



Department of Energy

Washington, DC 20585

January 30, 2006

The Honorable A.J. Eggenberger
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Ave, NW, Suite 700
Washington, DC 20004-2901

Dear Mr. Chairman:

On August 17, 2005, the Secretary of Energy approved the DOE Implementation Plan (IP) that addresses Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2005-1, Nuclear Materials Packaging. One of the deliverables in the IP is the draft repackaging prioritization methodology.

Per the implementation plan the 2005-1 working group has developed the enclosed draft repackaging prioritization methodology for your review.

Sincerely,

A handwritten signature in black ink that reads "Richard M. Stark".

Richard M. Stark
DNFSB 2005-1 Implementation Plan
Responsible Manager

Enclosure

cc:
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1
2 **DRAFT**

3 **Rev 2 1-30-06 F**

4
5 **Methodology for Determining Repackaging Needs and Prioritization of**
6 **Repackaging Nuclear Materials**

7
8 **Abstract**

9 Safe handling and storage of nuclear material at U. S. Department of Energy facilities
10 relies on the use of adequate containers to prevent worker contamination and uptake of
11 radioactive material. The U. S. Department of Energy is establishing requirements for
12 packaging and storage of nuclear materials other than: those declared excess, those
13 packaged to DOE-STD-3013-20004 and U-233 packaged to DOE-STD 3028-2000. This
14 report describes a methodology to assist managers in prioritizing the current inventory of
15 nuclear material containers deemed to need repackaging. The prioritization methodology
16 establishes worker hazards for managers to prioritize the repackaging of Nuclear Material
17 packages based upon worker risk. A risk factor is developed for each nuclear material
18 package based on a calculated potential accident dose to a worker due to a failed
19 container barrier and an estimated probability of container failure. This risk-based
20 methodology uses all accessible information to prioritize the repackaging effort. All
21 packages that exceed the threshold and appear on the attached dose vs. failure chart are
22 deemed to need repackaging. (See attached Chart in Appendix C) This risk methodology
23 determines which packages need to be repackaged and which of these should be
24 repackaged first. This methodology is NOT a safety analysis and cannot be used for
25 Documented Safety Analysis (DSA), Safety Analysis Report (SAR), or Authorization
26 Basis (AB) purposes. It is *a tool that management can use* to establish the priority of
27 necessary repackaging of nuclear material.

28
29 This methodology is generic for application at all DOE sites. It recognizes that each
30 DOE site has a different level of package information.

1 List of Acronyms

ALARA	As Low As Reasonably Achievable
ARF	Airborne Release Fraction – the fraction material aerosolized by the event
C	Vulnerability Index
C₁	Corrosion Vulnerability Index
C₂	Pressure Vulnerability Index
C₃	Pyrophoricity Vulnerability Index
C₄	Oxidative Expansion Vulnerability Index
C₅	Radiolysis Vulnerability Index
DSA	Documented Safety Analysis
DCF	Dose Conversion Factor
DOE	U. S. Department of Energy
DR	Damage Ratio – the fraction of the MAR impacted by the actual accident
F	Failure Probability of a Package
I	Overall Reactivity Index
I₁	Corrosion Reactivity Index
I₂	Pressure Reactivity Index
I₃	Pyrophoricity Reactivity Index
I₄	Oxidative Expansion Reactivity Index
I₅	Radiolysis Reactivity Index
IDES	Item Description
IP	Implementation Plan
LANL	Los Alamos National Laboratory
LPF	Leak Path Factor – the fraction of airborne material transported from containment
MAR	Material-At-Risk – amount of material available for release (Usually the contents of the container)
MASS	Material Accountability and Safeguards System
MRR	Materials Recycle and Recovery
MT	Material Type
R	Risk
CEDE	Committed Effective Dose Equivalent, in rem
RF	Respirable Fraction – the fraction of aerosolized material that is respirable
RRF	Respirable Release Fraction – $RRF = DR \times ARF \times RF$
S	Source Term, in g
SAR	Safety Analysis Report
SMT	Summary Material Type
SNM	Special Nuclear Material
T	Age of the Package
W	CEDE lung clearance class W, in rem/g
Y	CEDE lung clearance class Y, in rem/g

1
2 **Introduction**

3
4 Several incidents have occurred within the DOE/NNSA complex that have resulted in
5 personnel contaminations and/or exposures due to container failures. The container
6 failures were caused by container degradation over time or by handling mishaps.
7 Numerous types of materials and container configurations exist within the complex. The
8 combinations of material and container configurations were adequate for the originally
9 anticipated period of storage or for a particular use, but some are no longer adequate
10 because of a longer than anticipated storage condition caused by a change in mission.

11
12 This document outlines the methodology for DOE Managers to determine the Nuclear
13 Material packages that need to be repackaged and for the prioritization of existing
14 packaging configurations deemed to need repackaging across the DOE complex.
15 Additionally, this document meets a DNFSB 2005-1 commitment to develop a
16 prioritization methodology for implementing the repackaging criteria based on the
17 hazards and risks posed by the existing nuclear material.

18
19 The methodology uses the relevant physical, reactive, and radiological properties of the
20 stored material as well as their interactions with the containment barriers of the
21 packaging system. The methodology is generic and covers a wide range of materials,
22 forms, and hazards. The evaluation techniques acknowledge the variety of packaging
23 systems available and provide a means to evaluate existing packages. The prioritization
24 provides a means to focus on the most hazardous items as well as providing a means to
25 develop an implementation plan for repackaging that employs a graded approach based
26 on an objective measure of relative risk to the facility workers.

27
28 **Approach**

29
30 The purpose of the prioritization methodology is to provide a means of evaluating the
31 packaging of stored nuclear material across the complex that results in a measure of the
32 relative risk posed by the item. The risk is an estimate of the potential consequences of a
33 container breach that results in a release of the material and the probability of that
34 occurring. The receptors are the facility workers who may be impacted by such a release.

35
36 With this prioritization methodology, the sites and the complex can focus resources on
37 corrective actions, such as repackaging of the material, to reduce or minimize the
38 potential risks posed by the containers. In many cases, the material may be suitably
39 packaged and this methodology provides a measure of the adequacy of the packaging.

40
41 The methodology is based on an understanding of the properties of the nuclear material
42 and those characteristics that could increase the consequences or probability of a release.
43 With a clear understanding of the material characteristics, one can estimate the challenges
44 the containment system must endure to adequately contain the material. Material with a
45 high specific radioactivity and/or a particular physical state can pose an increased risk to
46 the worker. For example, a finely divided powder presents a greater dispersion

1 consequence than a solid metallic object. Other material characteristics of interest are
2 those that would promote, or increase the probability of a container breach, such as
3 corrosivity or radiolytic decomposition of organic polymers

4
5 The characteristics of the containment system (packaging) can be evaluated. Various
6 materials of construction, sealing/venting systems, and design issues must be considered.
7 Often multiple layers of containment are employed to adequately address the multiple
8 challenges posed by the material. Likewise, additional containment may be employed for
9 handling and transfer during the packaging process to enable attainment of ALARA goals
10 at the facility level.

11
12 Dose Consequence Model (Y Axis of Chart in Appendix C)

13 A dose consequence model is used to address the potential hazard source term (S) that the
14 material in the container poses to the local workers. This is done by calculating a value
15 that incorporates the material at risk (MAR), i.e. the radioactive material in the container,
16 the respirable release fraction (RRF), and a leak path factor (LPF) which is a measure of
17 the fraction of the container that is spilled. The relationship is as follows:

18
19 (1) $S = \text{MAR} \times \text{RRF} \times \text{LPF}$

20
21 (2) Where $\text{RRF} = \text{DR} \times \text{ARF} \times \text{RF}$

22
23 The Respirable Release Fraction (RRF) is composed of the Damage Ratio (DR), which is
24 the fraction of the MAR that can be released, the Airborne Release Fraction (ARF), how
25 much gets into the air and the Respirable Fraction (RF), what fraction of the airborne
26 release is small enough particles to enter and stay in a persons lungs.

27
28 The Acronyms used above are listed on a previous page. They are based upon the
29 discussion and calculations which may be found in LA-UR-05-3864. A more detailed
30 discussion of the 5 factor formula, its basis, use and acronyms used for release
31 calculations can be found in DOE-HDBK-3010-94.

32
33 For example, a solid metallic object with no fines or dust associated with the object
34 would have an ARF and RF of zero and therefore, an RRF of zero. As a result, the object
35 presents an essentially zero source term for a containment breach scenario. On the other
36 hand, a gas would be effectively released by a containment breach such that the RRF for
37 a gas would approach unity (1.0). Powdered materials and liquids lie somewhere in
38 between depending on the specific characteristics of the material.

39
40 A useful way of grouping the materials is necessary to avoid the necessity of evaluating
41 all of the individual items in a large inventory. The recommended grouping is by the
42 descriptor used in the Item Description Implementation Plan (IDES). This permits the
43 source term calculation to be performed on classes of materials, thus simplifying the
44 prioritization exercise. Assumptions on the maximum quantity available or permitted in
45 a given container are applied to derive the maximum source terms for the classes of

1 materials. Values for DR, ARF, RF and RRF are listed in Appendix A, by IDES, using
2 example data.

3
4 The source term (S) has units of grams. The consequence of releasing a particular
5 material is also driven by the specific activity of the radioactive material. This is
6 recognized by applying a dose conversion factor (DCF) to the source term. Appendix B
7 has DCFs for selected materials. The DCF has the units of rem CEDE/g. From this
8 information, a dose consequence can be calculated for each container or class of
9 materials. This can be plotted on the Y Axis.

10 Container Failure Probability Model (X Axis of Chart in Appendix C) (Option 1)

11
12
13 The failure probability of a package is a function of its mechanical robustness, the
14 chemical reactivity of its contents, and the compatibility of its contents with the
15 packaging barriers. Age of the container is a driver in the ability of the package to
16 maintain the initial barrier characteristics. Evaluation of the relative failure risks of the
17 packages (X Axis) is based on the expert judgment of the packaging experts, and the
18 limited failure data that is available, and results in a more qualitative result than the dose
19 consequence model (Y Axis).

20
21 Several packaging characteristics are important to ensure the maintenance of a suitable
22 containment barrier, such as resistance to corrosion by the contents, resistance to or
23 venting of pressure buildup within the container, temperature effects, and the potential for
24 the material to physically expand due to oxidation. This last phenomenon is termed
25 “oxidative expansion” and can lead to internal forces by the material on the container that
26 could cause the container to stretch, break, tear or otherwise be breached. Each package
27 is therefore evaluated against the following indices: corrosion, pressure, pyrophoricity,
28 and oxidative expansion. Each of these indices is assigned a relative value ranging from
29 zero for very low potential for the index to three for a very high potential for the index.

30
31 The relative probability of failure per year is then computed using the following
32 relationship:

$$33 \quad (3) \quad F = I \cdot C$$

34
35
36 where: F is the Failure Probability of a Package

37 I is called the Reactivity Index and

38 C is called the Vulnerability Index.

39 Reactivity Index (I)

40
41
42 The Reactivity Index (I) describes the characteristics of a given packaged material having
43 four components,

44
45 I = (I1, I2, I3, I4, I5) corresponding to the characteristics of

46 I = (I1 = corrosivity, I2 = pressure, I3 = pyrophoricity, I4 = oxidative expansion)

1 I5 is a placeholder = 1 (so that we aren't trying to multiply by 0)

2
3 Each value (i.e., I1, I2, I3, I4) can range from 0, 1, 2, 3 corresponding to very low, low,
4 medium, or high. I5, as a placeholder, will always be equal to 1.

5
6 For example, a very fine, plutonium metal powder might have an index of

7
8 $I = (0, 1, 2, 3, 1)$

9
10 indicating that it is not very corrosive, it may generate some gas because of the potential
11 of having water adsorbed on the surface, it is fairly pyrophoric, and its potential for
12 oxidative expansion is great. Each of the reactivity indices is generated from the IDES
13 database at a given site, as determined by subject matter experts (personnel who are
14 familiar with the processes, packaging and material at the site).

15
16 Vulnerability Index (C)

17
18 The Vulnerability Index (C) describes how a given package configuration matches to the
19 Reactivity Index of the contents. It contains the four characteristics for the Reactivity
20 Index, plus a fifth one for radiolysis.

21
22 $C = (C1, C2, C3, C4, C5)$ corresponding to the vulnerability of a given package
23 configuration.

24 $C = (C1 = \text{corrosivity}, C2 = \text{pressure}, C3 = \text{pyrophoricity}, C4 = \text{oxidative}$
25 $\text{expansion}, C5 = \text{radiolysis})$

26
27 For example, given the metal powder above (with its $I = (0,1,2,3)$) packaged in a stainless
28 steel, cross-taped slip lid can, it might have a Vulnerability Index (C) of:

29
30 $C = (0, 0, 2, 3, 0)$, where

31
32 $C1=0$, the powder will not corrode the can;

33 $C2=0$, the cross-tape will allow the inside of the can to "breathe";

34 $C3=2$, depending on how fine the powder, and how passivated, it might be fairly
35 pyrophoric;

36 $C4=3$, the powder will very likely convert to oxide over time, resulting in a huge
37 expansion of the can contents;

38 $C5=0$, the can will not suffer radiolysis.

39
40 The Failure Probability (F) is then the "dot product" of I and C, the product of
41 multiplying each of the first indices together, then the second, then the third, etc, and then
42 summing all five products together. Using the above example:

43
44 $F = I \cdot C$

45 $F = (0, 1, 2, 3, 1) \cdot (0, 0, 2, 3, 0)$

46 $F = (0 \times 0 + 1 \times 0 + 2 \times 2 + 3 \times 3 + 1 \times 0)$

1 $F = (0 + 0 + 4 + 9 + 0)$
 2 $F = 13$

3
 4 For a multiple packaging configuration,

5 C then becomes, the total Vulnerability Index (C_T) of all packages, and that is calculated
 6 as a product which is simply the product of each of the indices of each of the containers.

7
 8 For example, two packages, package i inside of package o, each have vulnerability
 9 indices of C_i and C_o , respectively,

10
 11 $C_i = (0,1,0,2,3)$
 12 $C_o = (1,2,0,0,1)$

13
 14 Then,

15 $C_T = C_i \times C_o$
 16 $C_T = (0,1,0,2,3) \times (1,2,0,0,1)$
 17 $C_T = (0 \times 1, 1 \times 2, 0 \times 0, 2 \times 0, 3 \times 1)$
 18 $C_T = (0 , 2 , 0 , 0 , 3)$

19
 20 Thus, C_T would be the C that would be dotted with I in the above equation, $F = I \cdot C$:

21
 22 $F = I \cdot C_T$
 23 $F = (0, 1, 2, 3, 1) \cdot (0, 2, 0, 0, 3)$
 24 $F = (0 \times 0 + 1 \times 2 + 2 \times 0 + 3 \times 0 + 1 \times 3)$
 25 $F = (0 + 2 + 0 + 0 + 3)$
 26 $F = 5$

27
 28 The age of the package is taken into account by multiplying by a factor, T, which has the
 29 units of years.

30
 31 The risk to the worker is then the product of the deterministic dose result and the
 32 qualitative failure probability as follows:

33
 34 (4) Risk (R) = Dose x F x T

35
 36 Ideally, perfect knowledge of packaging would allow relevant assignment of values for F,
 37 because relevant values for C would be known (as drawn from equation $F = I \cdot C$ and to the
 38 extent that can be accurately determined). However, with imperfect, or no knowledge of
 39 packaging status, a default value for C of (1,1,1,1,1) can be assigned until the knowledge
 40 of packaging details is determined through appropriate surveillance or repackaging
 41 activities. With the assignment of $C = (1,1,1,1,1)$, F will equal I. Therefore, in the
 42 following analysis, C is assumed to be 1, and I is substituted for F.

43
 44 The sum of the Reactivity Indices (I_{total}) determined for selected packages ranged from 0
 45 to about 7.52 (in the LANL risk prioritization model). In order to normalize the range

1 from 0 to 1, each Reactivity Index sum (I_{total}) was divided by 7.52 (i.e., I_{max}), yielding, in
2 general, the normalized I (I_{norm}).

3
4 (5) $I_{norm} = I_{total} / I_{max}$
5

6 Also, it was assumed that the age of the package would play a greater role in potential
7 package failure for those packages that had higher reactivity indices (i.e., age would be
8 much more detrimental to a package with a total reactivity index of, say, 7 versus of one
9 with a 2). Furthermore, it was determined that a simple linear scaling would be
10 inadequate to capture the effect (i.e., For a given reactivity index, a ten-year-old package
11 was much more than two-times likely to fail than a five-year-old package). Therefore,
12 package age (time in years) was scaled by a factor I_{norm}

13
14 (6) $R = \text{Dose} \times (I_{norm}) \times T$ (standard equation)
15

16 (7) $R = \text{Dose} \times (I_{norm} \times (I_{norm} \times T))$ (equation modified to reflect compounding
17 effect of time and reactivity index)
18

19 (8) $R = \text{Dose} \times (I_{norm})^2 \times T$
20

21 A scatter-plot of Dose vs. $(I_{norm})^2 \times T$ for a representative set of package provides a
22 visualization of the relative risks of all packages in Fig. 1 below. Each point represents a
23 container of nuclear material in an inventory, and the packages in the upper right portion
24 are determined by the model to have the highest failure risk. The packages are plotted on
25 a log-log plot to accommodate the broad range of risk values of packages in the
26 inventory.

27
28 It is noteworthy that the items that have failed in recent incidents are found to have
29 among the highest failure risk of all packages in study populations. In general, packages
30 with the highest source term, the highest Reactivity Indices, and longest shelf life fall into
31 the highest risk percentiles

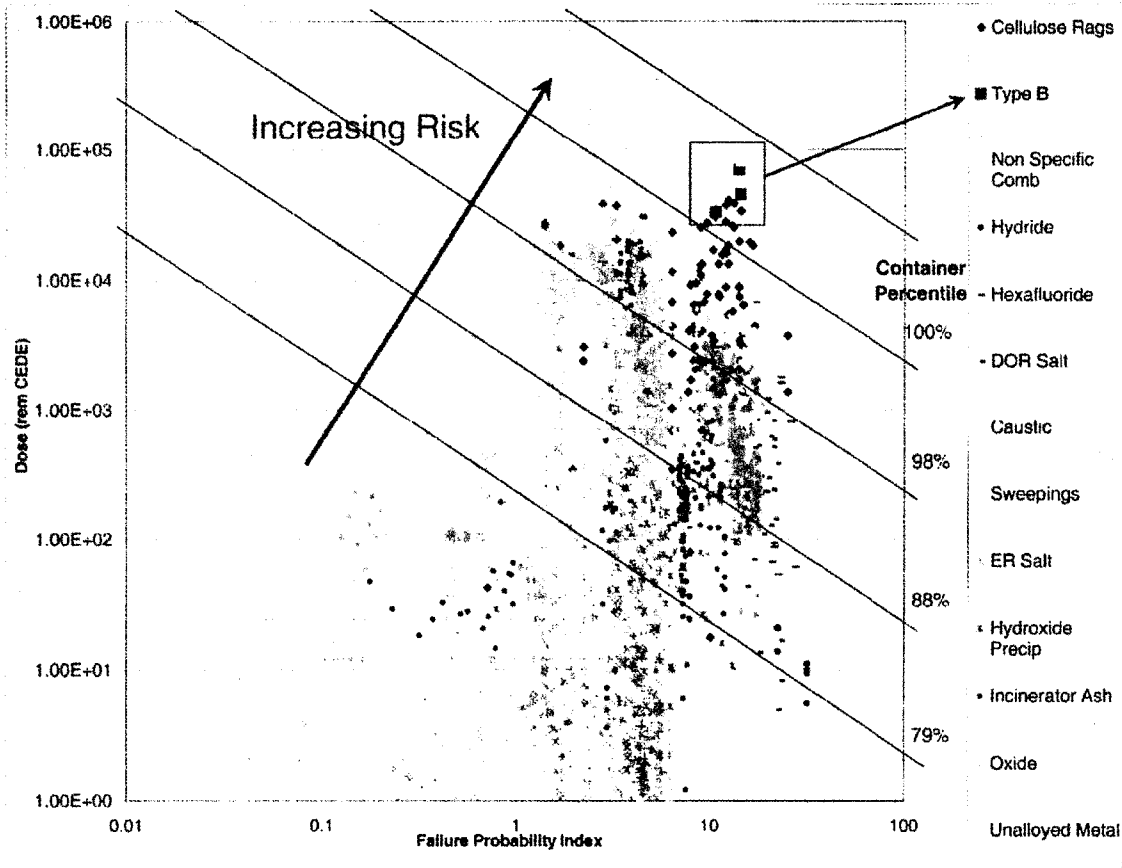
32
33 Further details and specific examples of materials and the calculations may be found in
34 LA-UR-05-3864.
35

36 Therefore, on a plot such as the one depicted in Figure 1, the items in the upper right
37 quadrant pose the highest risk, whereas the items in the lower left quadrant pose the
38 lowest risk. Funds and efforts should be focused on the items in the upper right quadrant
39 before items in the lower left quadrant. This provides a means to prioritize the corrective
40 actions for specific containers or classes of containers to effectively utilize limited
41 available resources to address this concern.
42

43 Discussion and Model Evaluation 44

45 In general, it is recognized that the model is based upon quantitative calculations for the
46 dose, and experience from surveillance data and engineering knowledge for the failure

1 probability. Its value lies in its ability to systematize and automate the ranking of
 2 thousands of containers in order to prioritize the repackaging campaign, a task that would
 3 otherwise be extremely tedious. Furthermore, the model is flexible and can easily
 4 accommodate insights derived from package inspections and surveillance. Another key
 5 benefit of an automated nature of this methodology is that it provides a tool to examine
 6 the relative importance of various input parameters and thus provides for expedient
 7 sensitivity analyses.



9
 10 Figure 1. Container Failure Probability

11
 12 Container Failure Probability Model (X Axis of Chart in Appendix C)(Option 2)

13
 14 This is another model, which management can use, to provide a relatively simple method
 15 using available information (or defaults where it isn't available) to determine the failure
 16 probability index factor for prioritization of repackaging nuclear material that is in
 17 interim storage. This model for the X Axis, along with the potential dose associated with
 18 a package failure calculated using the Dose Consequence Model for the Y Axis, can be
 19 used to create a chart similar to Figure 1 and estimate the repackaging priority.

20
 21 (9) $RP = 1/CR \times T$

22
 23 Where: RP = Repackaging Priority

24 T = time package has been in storage, in years

1 CR = Container robustness

2 And:

3 (10) $CR = A + B + C + D + E + F + G + H + I$

4

5 If the package consists of more than one container, evaluate the most robust container,
6 using the following parameters:

7

8 Where: A = Type of Material of Container

9 10 Stainless Steel

10 8 Aluminum

11 6 Tinned Steel

12 4 Plastic

13 2 Glass

14 0 Other

15

16 B = Type of Container Closure

17 10 Welded Top

18 9 Bolted top with gasket

19 8 Screw top with gasket

20 7 Swaged top (food pack can)

21 5 Slip lid top, taped

22 0 No top

23

24 C = Container Venting Mechanisms

25 10 Vented and Filtered

26 5 Sealed

27 5 Vented without filter

28 0 No top

29

30 D = Number of Containers

31 10 Three or More

32 8 Double

33 5 Single

34

35 E = Material State/ Form of the Smallest Items/ Particles

36 10 Monolithic metal/solid

37 8 Large Chunks, no powder

38 5 Large Particle size powder

39 3 Fine powder

40 2 Liquid

41 0 Unknown

42

43 F = Other materials in container

44 10 No

45 8 Yes – non- combustible

46 5 Yes – plastic or other material than can generate gas

1 3 Yes – potentially combustible
2 0 Unknown

3
4 G = Challenges
5 10 Non – corrosive
6 8 Slightly corrosive
7 5 Corrosive
8 5 Pyrophoric Material
9 0 Unknown

10
11 H = Conditions when material packaged (for sealed packages only)
12 10 Dry/ inert atmosphere
13 5 Ambient Conditions
14 3 Unknown
15 0 Wet atmosphere or wet material

16
17 I = Potential for Radiolytic Damage
18 10 Low
19 5 Medium
20 3 Unknown
21 0 High

22
23 The container robustness (CR) is the sum of the numbers. The higher the CR number, the
24 safer the package. Therefore, 1/CR, which equals the Repackaging Priority, is lower and
25 there is a lower priority to repackage the material.

26
27 As an example, if we had a solid metallic piece of U-235 with no fines, oiled to prevent
28 corrosion, stored in a cross-taped stainless steel slip lid can for 10 years, using the simple
29 model in option 2 the following calculation might result:

30
31 A = 10 Type of container material is stainless steel
32 B = 5 Type of container closure is slip lid top, taped
33 C = 5 Vented without filter - slip lid top, taped
34 D = 5 Single container
35 E = 10 Monolithic Metal/ solid
36 F = 10 Other Material – none
37 G = 10 Non-corrosive since it is oiled
38 H = N/A Since container not sealed
39 I = 10 Potential for radiolytic damage is low

40
41 CR = 65
42 RP = 1/CR x T
43 = 1/65 x 10
44 = 0.015 x 10
45 RP = 0.15
46

1 Assuming the Repackaging Priority (RP) is approximately equal to the Failure
2 Probability Index as shown on the Scatter Plot in Figure 1, then:

3
4 (11) Failure Probability $F \sim RP = 1/CR \times T$
5

6 Assuming the Source Term (S) in the above example is essentially zero, since the activity
7 involved with the U-235 is not readily respirable, the result with equation 11 would fall
8 on the X Axis at 0.15 on Figure 1.
9

10 **Conclusions**

11
12 The methods outlined in this report estimate the relative risks of individual, or classes, of
13 packaged Nuclear Materials. The methodologies consider both characteristics of the
14 material and the package. The relative risk determination is a useful management tool to
15 prioritize repackaging or disposition activities based on the potential exposure dose and
16 failure probability of the package. A consistent approach also permits evaluation and
17 prioritization across the DOE sites and acknowledges various site-specific packaging
18 approaches. Either option is used with the Appendix C to determine which packages are
19 excluded from repackaging and which packages are in scope and assist in determining the
20 priority for repackaging, based upon worker risk.
21

1 **Appendix A. Physical Characteristics and Release Parameters for a Spill –**
 2 **by IDES – Example data**
 3

IDES	Description	Physical Characteristic	DR	ARF	RF	RRF
TBD	Metal Monolith – ²³⁵ U	large pieces, <0.1% fines, passivated	0.001	1.0E-04	0.1	1.0E-08
A11	Sub-assembly	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
A75	Hemi	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
A95	RTG	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
A99	Pit	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
B52	Non-Weap Nitrate Assembly	large pieces, < 10% fines in bottom	0.1	2.0E-03	0.3	6.0E-05
C02	Acetate	small chunks/powder	0.1	2.0E-03	0.3	6.0E-05
C13	Carbide	non-disp. mat. (ceramic pellet)	0	0	0	0
C19	Chloride	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C21	Dioxide	loose, free-flowing powder	1	2.0E-03	0.3	6.0E-04
C21	Dioxide - ²³⁸ Pu	loose, free-flowing powder	1	2.0E-03	1	2.0E-03
C28	Fluoride	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C40	Hydride	loose, free-flowing powder	1	2.0E-03	0.3	6.0E-04
C40	Hydride - ²³⁸ Pu	loose, free-flowing powder	1	2.0E-03	0.3	6.0E-04
C52	Nitrate	small chunks/powder	0.1	2.0E-03	0.3	6.0E-05
C54	Nitride	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
C66	Phosphate/Phosphoric	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C77	Sulfate	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C80	Tetrafluoride	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C82	Trichloride	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
C86	Trioxide	loose, free-flowing powder	1	2.0E-03	0.3	6.0E-04
C88	U308	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
E54	Nitride - Reactor Element	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
G00	Non-Specific Gas	gas	1	1	1	1
G00	Non-Specific Gas - ²³⁸ Pu	gas	1	1	1	1
G36	Hexafluoride	gas	1	1	1	1
G36	Hexafluoride - ²³⁸ Pu	gas	1	1	1	1
K00	Non-specific Comb.	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
K00	Non-specific Comb. - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
K15	Cellulose Rags	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
K15	Cellulose Rags - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
K30	Wooden HEPA Filter	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
K60	Paper/Wood	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
K60	Paper / Wood - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
L14	Caustic	liquid	1	2.0E-04	0.5	1.0E-04
L19	Chloride Solution	liquid	1	2.0E-04	0.5	1.0E-04
L19	Chloride Solution - ²³⁸ Pu	liquid	1	2.0E-04	0.5	1.0E-04
L52	Nitrate	liquid	1	2.0E-04	0.5	1.0E-04
L52	Nitrate - ²³⁸ Pu	liquid	1	2.0E-04	0.5	1.0E-04
L58	Organic Solution	liquid	1	2.0E-04	0.5	1.0E-04
L61	Perchlorate	liquid	1	2.0E-04	0.5	1.0E-04
L77	Sulfate	liquid	1	2.0E-04	0.5	1.0E-04
L90	Water	liquid	1	2.0E-04	0.5	1.0E-04
M32	Beryllide	non-disp. mat. (encaps. neut. source)	0	0	0	0
M32	Beryllide - ²³⁸ Pu	non-disp. mat. (encaps. neut. source)	0	0	0	0
M44	Unalloyed Metal	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
M44	Unalloyed Metal - ²³⁸ Pu	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
M74	Alloyed Metal	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06

IDES	Description	Physical Characteristic	DR	ARF	RF	RRF
M74	Alloyed Metal - ²³⁸ Pu	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
M76	Alloyed Turnings	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N00	Non-spec. Noncombustibles	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N00	Non-spec. Noncomb. - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N05	Asbestos	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N24	Filter Media	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N24	Filter Media - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N27	Fire Brick	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N29	Glass	contamination on flexible substrate	0.01	2.0E-03	0.3	6.0E-06
N29	Glass - ²³⁸ Pu	contamination on flexible substrate	0.01	2.0E-03	1	2.0E-05
N31	Graphite	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
N33	Heating Mantles	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N35	HEPA Filters	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N35	HEPA Filters - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N48	Leaded Gloves	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N48	Leaded Gloves - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N50	MgO	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N55	Non-actinide Metals	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N55	Non-actinide Metals - ²³⁸ Pu	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
N67	Plastic / Kim Wipes	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N67	Plastic/Kim Wipes - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N69	Resin	non-disp. mat. (large resin beads)	0	0	0	0
N70	Rubber	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N70	Rubber - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
N89	Unleaded Gloves	contamination on flexible substrate	1	1.0E-03	0.1	1.0E-04
N89	Unleaded Gloves - ²³⁸ Pu	contamination on flexible substrate	1	1.0E-03	1	1.0E-03
R03	Hydrogenous Salt	small chunks/powder	0.1	2.0E-03	0.3	6.0E-05
R04	Al ₂ O ₃ crucible pieces	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
R09	Calcium Salt	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R09	Calcium Salt - ²³⁸ Pu	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R10	CaO	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R12	Calcium Metal	large pieces, < 10% fines in bottom	0.01	2.0E-03	0.3	6.0E-06
R18	Cemented Residue	non-disp. mat. (cemented piece)	0	0	0	0
R22	Evaporator Bottom	liquid	1	2.0E-04	0.5	1.0E-04
R26	Filter Residue	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R26	Filter Residue - ²³⁸ Pu	small chunks and powder	0.1	2.0E-03	1	2.0E-04
R41	Hydroxide Precip.	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R41	Hydroxide Precip - ²³⁸ Pu	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R42	DOR Salt	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R47	Incinerator Ash	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R47	Incinerator Ash - ²³⁸ Pu	small chunks and powder	0.1	2.0E-03	1	2.0E-04
R59	Oxalate Precip.	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R65	ER Salt	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R71	Misc. Salt	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R73	Silica	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05
R78	Sweepings	loose, free-flowing powder	1	2.0E-03	0.3	6.0E-04
R78	Sweepings - ²³⁸ Pu	loose, free-flowing powder	1	2.0E-03	1	2.0E-03
R83	MSE Salt	small chunks and powder	0.1	2.0E-03	0.3	6.0E-05

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2 The MASS accountability system is used to track special nuclear material (SNM) inventory by material
3 type (MT) and summary material type (SMT), two groupings that bin commonly associated radioisotopes
4 found in materials of interest at DOE sites. Using the LANL standard isotopic compositions of MT's and

1 SMT's and specific activities of the isotopes from the Federal Guidance Report #11 ¹ the association ² of
2 rem CEDE per inhaled gram of the material shown in Table 2 can be developed: (DOE sites may find it
3 necessary to augment this table with material specific to their facilities.)

¹ DE89-011065, Limiting Values of the Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, Keith F. Eckerman, Anthony B. Wolbast, and Allan C.B. Richardson, 1988.

² LA-UR-04-6820, Consequence Calculations for Safety Analysis at TA-55 and the CMR Facility, Hans Jordan and Gregory D. Smith, September 2004.

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Appendix B Dose Conversion Factors (DCF) for Various Material Types

SMT	MT	Description	rem CEDE/g	
			W	Y
10		Depleted uranium	2.36	39.8
20		Enriched uranium	5.15E+02	8.66E+03
40	42*	Pu-242	1.46E+08	1.14E+08
44		Am-241	1.52E+09	NA
45		Am-243	8.76E+07	NA
46		curium	1.39E+08	NA
47		berkelium	2.32E+09	NA
48		californium	7.37E+10	8.44E+10
50		plutonium	3.74E+07	2.75E+07
	51		3.09E+07	2.24E+07
	52		3.58E+07	2.62E+07
	53		4.22E+07	3.12E+07
	54		5.43E+07	4.10E+07
	55		6.23E+07	4.73E+07
	56		6.65E+07	5.07E+07
	57		1.23E+08	9.51E+07
60		enriched lithium		<i>Stable</i>
70		uranium enr. U-233	7.74E+04	1.31E+06
81		natural uranium	2.36	39.8
82		Np-237	3.82E+05	NA
83		heat source Pu	5.99E+09	4.42E+09
86		deuterium		<i>Stable</i>
87		tritium	6.14E+05	NA
88		thorium	1.80E+02	1.27E+02

* SMT consists of MT-41 and MT-42. Only MT-42 is present at LANL in appreciable amounts.

3 In this table, the inhalation dose is the 50-year Committed Effective Dose Equivalent or rem CEDE. It is
4 shown for both lung clearance classes W and Y. For this analysis, salts and solutions were assigned class
5 W; all other physico-chemical forms were assigned class Y.

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Appendix C

Definition of “In-scope” Packages for DNFSB 2005-1 Repackaging Effort

↑ Higher Risk Packages	Higher Risk Packages	100
↓	Lower Risk Packages	5
Excluded from Repackaging Requirement Meets STD 3013, 3028 or HDBK-1129	Excluded from Repackaging Requirement (low exposure)	100
Dose (rem CEDE)	Failure Probability Index	100
.01		