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,

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

Enclosure

cc:
R. Hardwick, EH-2
R. Rosen, DNFSB
R. McMorland
M. Whitaker, DR-1
G. Roberson

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
C_1	CorrosionVulnerability Index
C_2	PressureVulnerability Index
C_3	Pyrophoricity Vulnerability Index
C_4	Oxidative Expansion Vulnerability Index
C_5	RadiolysisVulnerability 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
I_1	Corrosion Reactivity Index
I_2	Pressure Reactivity Index
I_3	Pyrophoricity Reactivity Index
I_4	Oxidative Expansion Reactivity Index
I_5	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 x ARF x 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   <u>Dose Consequence Model (Y Axis of Chart in Appendix C)</u>
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) $S = MAR \times RRF \times LPF$
20

21   (2)   Where $RRF = DR \times ARF \times RF$
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
11   Container Failure Probability Model (X Axis of Chart in Appendix C) (**Option 1**)
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
34   (3) $F = I \cdot C$
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
40   Reactivity Index (I)
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           $I = (I1 = \text{corrosivity}, I2 = \text{pressure}, I3 = \text{pyrophoricity}, I4 = \text{oxidative expansion})$

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

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

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

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

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

Vulnerability Index (C)

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

$C = (C1, C2, C3, C4, C5)$ corresponding to the vulnerability of a given package configuration.
$C = (C1 = \text{corrosivity}, C2 = \text{pressure}, C3 = \text{pyrophoricity}, C4 = \text{oxidative expansion}, C5 = \text{radiolysis})$

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

$$C = (0, 0, 2, 3, 0), \quad \text{where}$$

C1=0, the powder will not corrode the can;
C2=0, the cross-tape will allow the inside of the can to "breathe";
C3=2, depending on how fine the powder, and how passivated, it might be fairly pyrophoric;
C4=3, the powder will very likely convert to oxide over time, resulting in a huge expansion of the can contents;
C5=0, the can will not suffer radiolysis.

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

$$F = I \bullet C$$
$$F = (0, 1, 2, 3, 1) \bullet (0, 0, 2, 3, 0)$$
$$F = (0x0 + 1x0 + 2x2 + 3x3 + 1x0)$$

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

2    $F = 13$

3

4   <u>For a multiple packaging configuration,</u>

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 Ci and Co, respectively,

10

11       $Ci = (0,1,0,2,3)$

12       $Co = (1,2,0,0,1)$

13

14   Then,

15       $C_T = Ci \times Co$

16       $C_T = (0,1,0,2,3) \times (1,2,0,0,1)$

17       $C_T = (0x1, 1x2, 0x0, 2x0, 3x1)$

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       $F = (0x0 + 1x2 + 2x0 + 3x0 + 1x3)$

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•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 = Dose x (I_{norm}) x T (standard equation)
15
16   (7)   R = Dose x (I_{norm} x (I_{norm} x T)) (equation modified to reflect compounding
17   effect of time and reactivity index)
18
19   (8)   R = Dose x $(I_{norm})^2$ x 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   <u>Discussion and Model Evaluation</u>
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.
8
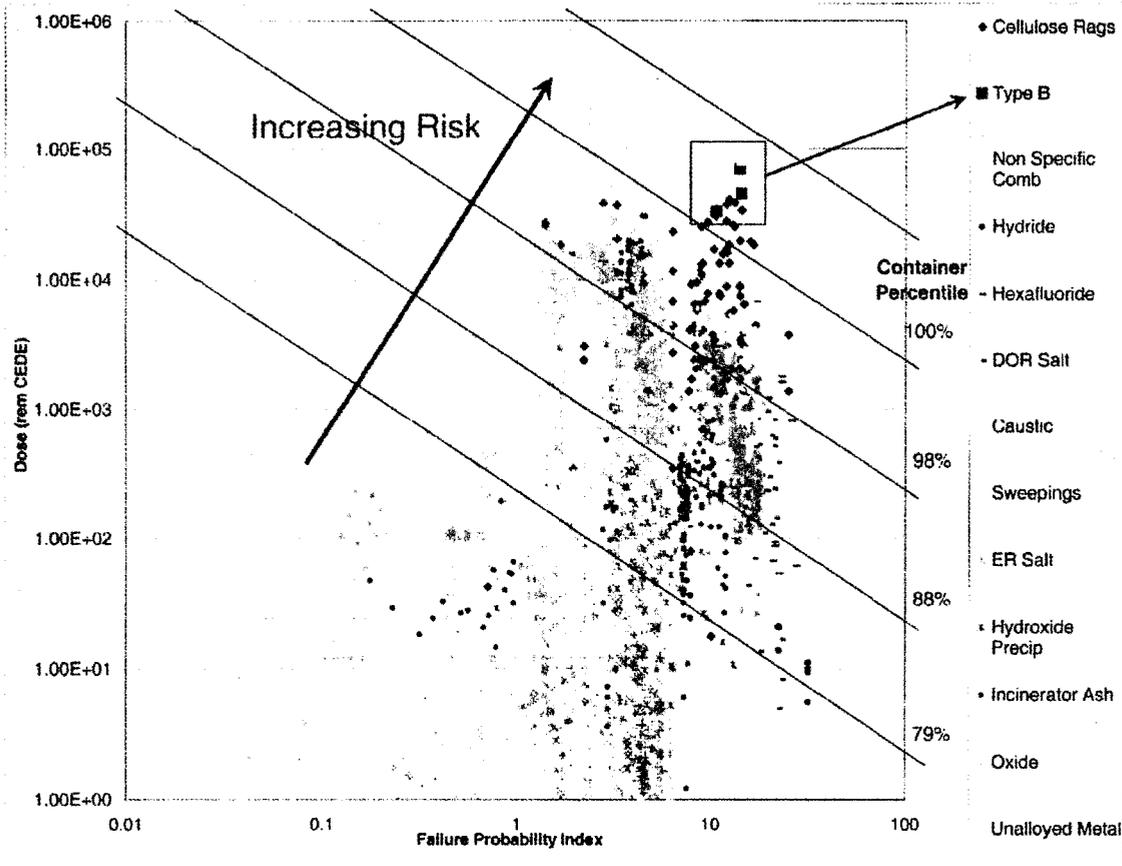
9
10 Figure 1. Container Failure Probability
11
12 <u>Container Failure Probability Model (X Axis of Chart in Appendix C)(Option 2)</u>
13
14 This is another model, which management can use, to provide a relatively simple method
15 using available information (or defaults where it isn't available) to 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 x T
22
23   Where: RP = Repackaging Priority
24   T = time package has been in storage, in years

9

CR = Container robustness

And:

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

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

Where: A = Type of Material of Container
- 10   Stainless Steel
- 8   Aluminum
- 6   Tinned Steel
- 4   Plastic
- 2   Glass
- 0   Other

B = Type of Container Closure
- 10   Welded Top
- 9   Bolted top with gasket
- 8   Screw top with gasket
- 7   Swaged top (food pack can)
- 5   Slip lid top, taped
- 0   No top

C = Container Venting Mechanisms
- 10   Vented and Filtered
- 5   Sealed
- 5   Vented without filter
- 0   No top

D = Number of Containers
- 10   Three or More
- 8   Double
- 5   Single

E = Material State/ Form of the Smallest Items/ Particles
- 10   Monolithic metal/solid
- 8   Large Chunks, no powder
- 5   Large Particle size powder
- 3   Fine powder
- 2   Liquid
- 0   Unknown

F = Other materials in container
- 10   No
- 8   Yes – non- combustible
- 5   Yes – plastic or other material than can generate gas

3   Yes – potentially combustible

0   Unknown

G = Challenges

      10   Non – corrosive

      8   Slightly corrosive

      5   Corrosive

      5   Pyrophoric Material

      0   Unknown

H = Conditions when material packaged (for sealed packages only)

      10   Dry/ inert atmosphere

      5   Ambient Conditions

      3   Unknown

      0   Wet atmosphere or wet material

I = Potential for Radiolytic Damage

      10   Low

      5   Medium

      3   Unknown

      0   High

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

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

A = 10   Type of container material is stainless steel

B = 5   Type of container closure is slip lid top, taped

C = 5   Vented without filter - slip lid top, taped

D = 5   Single container

E = 10   Monolithic Metal/ solid

F = 10   Other Material – none

G = 10   Non-corrosive since it is oiled

H = N/A   Since container not sealed

I = 10   Potential for radiolytic damage is low

CR = 65

RP = 1/CR x T

      = 1/65 x 10

      = 0.015 x 10

RP = 0.15

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

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

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	Al2O3 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

1
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.)

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[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.

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

| | | | rem CEDE/g | |
SMT	MT	Description	*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		*Stable*
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		*Stable*
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