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*Risk-Based Analysis for Prioritization and
Processing in the Los Alamos National
Laboratory 94-1 Program*

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Processing in the Los Alamos National
Laboratory 94-1 Program*

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RISK-BASED ANALYSIS FOR PRIORITIZATION AND PROCESSING IN THE LOS ALAMOS NATIONAL LABORATORY 94-1 PROGRAM

by

Stephen T. Boerigter, Nelson S. DeMuth, and Gary Tietjen

Abstract

A previous report, "Analysis of LANL Options for Processing Plutonium Legacy Materials," LA-UR-95-4301, summarized the development of a risk-based prioritization methodology for the Los Alamos National Laboratory (LANL) Plutonium Facility at Technical Area-55 (TA-55). The methodology described in that report was developed not only to assist processing personnel in prioritizing the remediation of legacy materials but also to evaluate the risk impacts of schedule modifications and changes. Several key activities were undertaken in the development of that methodology. The most notable was that the risk assessments were based on statistically developed data from sampling containers in the vault and evaluating their condition; the data from the vault sampling programs were used as the basis for risk estimates. Also, the time-dependent behavior of the legacy materials was explicitly modeled and included in the risk analysis. The results indicated that significant reductions in program risk can be achieved by proper prioritization of the materials for processing.

This report summarizes the further development of the methodology, focusing on more rigorous statistical treatment of the data. It also summarizes the application of the methodology for updating the risk estimates based on additional data and for identifying subpopulations of residues that affect risk in a manner disproportionate to their numbers. As such, it may serve as an example for other DOE sites in the development of their sampling and surveillance plans.

Finally, the methodology and data are used to compute risk metrics in the future as a function of programmatic decisions. In particular, comparisons between the present Los Alamos 94-1 processing schedule, a delayed-action schedule and the no-action alternative are computed. The results show that the processing of Los Alamos legacy materials increases overall risk to workers as compared to the no-action alternative for the near term. However, the overall integrated worker risk becomes significantly reduced by the year 2010. A hypothetical 5-year delayed schedule increases overall risk compared to the present schedule by a factor of about 2.

1. INTRODUCTION

This report described the application of a risk-based methodology for prioritizing the processing or remediation of legacy materials stored in the plutonium facility (TA-55) at the Los Alamos National Laboratory (LANL). The development of this methodology was described in a previous report, "Analysis of LANL Options for Processing Plutonium Legacy Materials," LA-UR-95-4301, written by Stephen T. Boerigter and Nelson S. DeMuth

In 1994 the Department of Energy (DOE) undertook the Plutonium Vulnerability Assessment (PVA) to identify environment, safety, and health vulnerabilities arising from storage of plutonium. Risks to workers were established in a very qualitative way. In February 1995 DOE issued their 94-1 Implementation Plan (94-1 IP), which calls for DOE sites to complete the remediation of plutonium-bearing materials by 2002. The part of the plan pertaining to LANL is referred to as Los Alamos 94-1. In March 1995 Los Alamos conducted an exercise using a statistically based process to select and examine a number of containers stored in the plutonium vault at TA-55. The purpose of this sampling was to obtain information from which estimates of the risk of container failure could be developed. Failure of containers in the vault or during their movement can result in radioactive contamination of workers or the workplace. Additional inspections of statistically selected containers were performed in August 1995 and in July 1996. In addition to the body of information obtained from these inspections, the condition of containers removed from the vault for processing was recorded and included in the database of information used to calculate risk. This report extends the original work using the additional data collected as well as improved statistical analysis algorithms to evaluate the risk of container failure.

2. BACKGROUND

The original Los Alamos 94-1 schedule for processing was based on the assumed capacities of the various residue processing lines and qualitative information on the risk behavior of the many types of residue materials. Thus, processing experience and plant capacity factored greatly into the original schedule. Data from the March and August container inspections served principally to quantify the risk levels associated with storing the materials to be processed as part of the Los Alamos 94-1 program. During the Spring of 1996, our analysis showed that relatively little useful information could be obtained from sampling the vault inventory in the same manner as in the past. We wished for information that would either reduce the uncertainty in risk estimates or identify subpopulations of residue materials for which the risk was disproportionately high compared to the number of items in storage. Thus, the July 1996 inspection was designed to obtain more data on specific subpopulations.

Items in the TA-55 vault containing residues are being processed or "worked-off" continuously, and new items are constantly being added to the vault. Items stored in the vault thus constitute a dynamic population. However, the 94-1 recommendation and the 94-1 IP requires the work-off of legacy items in the vault on May 1, 1994; although there is no programmatic need for these materials, they must be processed by May 2002. Even though the vault inventory is dynamic, this

analysis focuses on that inventory of legacy materials and the work-off of that inventory. Table 1 lists the original inventory of the Los Alamos 94-1 program by number of items.

Table 1. Los Alamos 94-1 IP Inventory by Detailed Material Category

Impure Metal: 1548		Combustibles: 185		Pure Metal: 612
<100 grams of >50% metal 1158		cellulose rags 113		>100 grams 612
Other Impure Metal 132		paper/wood 27		
Am, Np, etc. metals 258		other 45		
High-Priority Residues: 1242		Process Residues: 1274		Oxides: 672
calcium metal 3		calcium salt 39		>100 grams 672
evaporator bottoms 6		CaO 1		
hydrogenous salt 3		cement powder 1		
filter residue 261		cemented in drum 7		
hydroxide precipitate 313		incinerator ash 149		
sweepings/screenings 351		salt 1024		
oxalate precipitate 5		sample residue 1		
Sand, Slag, and Crucible (salts) 300		silica 52		
Noncombustibles: 918		High-Priority Compounds: 126		Compounds: 1540
asbestos 1		acetate 6		<100 grams
cemented in drum 1		chloride 38		PuO ₂ 721
filter media 4		fluoride 1		Oxide items 231
fire brick 1		hydride 3		U ₃ O ₈ 41
glass 55		nitrate 5		carbide 112
graphite 95		phosphate 2		nitride 31
heating mantle 2		sulfate 4		dioxide 404
HEPA filters 20		tetrafluoride 62		
lead gloves 9		trichloride 5		
MgO 279				
nonactinide metal 249				
plastic/Kimwipes® 113				
ion exchange resin 4				
rubber 9				
other 76				
				Totals = 8611

Table 2 lists the remaining inventory under the Los Alamos 94-1 program. This inventory listing has had all of the redundant items, such as duplicate entries for a single item arising from multiple material types in that item, removed. For example, a single item may be identified by both a material type for plutonium content and a material type for uranium content. Also, we have removed from this listing materials required for use in DOE programs. Thus, the differences between Table 1 and Table 2 do not necessarily represent the total number of items that have been processed.

Table 2. Remaining Los Alamos 94-1 IP Inventory by Detailed Material Category

Impure Metal:	453	Combustibles:	95	Pure Metal:	322
Other Impure Metal	386	cellulose rags	67	>100 grams	322
Spec Alloy	67	paper/wood	21		
		other	7		
High-Priority Residues:	777	Process Residues:	983	Oxides:	529
calcium metal	3	calcium salt	13	>100 grams	529
evaporator bottoms	3	CaO	1		
hydrogenous salt	3	cement powder	1		
filter residue	234	cemented in drum	2		
hydroxide precipitate	132	incinerator ash	117		
sweepings/screenings	294	salt	849		
oxalate precipitate	1	sample residue	0		
Sand, Slag, and Crucible	75				
silica	32				
Noncombustibles:	575	High-Priority Compounds:	58	Compounds:	840
asbestos	1	acetate	0	<100 grams	
filter media	1	chloride	15	PuO ₂	680
fire brick	1	fluoride	0	Oxide items	2
glass	10	hydride	3	U ₃ O ₈	54
graphite	60	nitrate	2	carbide	99
heating mantle	2	phosphate	0	nitride	5
HEPA filters	14	sulfate	3		
leaded gloves	4	tetrafluoride	26		
MgO	209	trichloride	2		
nonactinide metal	199	other	7		
plastic/Kimwipes®	51				
ion exchange resin	4				
rubber	4				
other	15				
				Sample Returns	149
				Totals =	4781

A more accurate version of the "original" Los Alamos 94-1 inventory was created using the items worked off in each category, listed in Table 3, together with the remaining inventory to get the corrected inventory listed in Table 4. Table 2 has been modified to reflect a new subpopulation (category) of material, which was identified through the inspection and analysis process. These higher-risk materials, denoted "Sample Returns," contain residues from analytical chemistry operations. Since this category is not based upon a particular material matrix, but instead on the origin of the residue, we do not have an accurate count of the original number of items in this category. This category was not identified in the original 94-1 IP, nor has the program, until recently, tracked these items as a separate subpopulation. Thus, we have approximated the number of items in this category that have been processed and the number in the original inventory identified as sample returns. Also, the particular subpopulation "silica" has been moved from the category of "Process Residues" in Table 1 to the category "High-Priority Residues" in Tables 2 and 4.

Table 3. Total Items Worked Off After Two Years on the Los Alamos 94-1 Program

Category	FY95		FY96		Totals	
	Projected	Completed	Projected	Completed	Projected	Completed
High-priority compounds	45	20	0	0	45	20
Compounds	13	58	0	135	13	193
Gases	0	0	1	1	1	1
Combustibles	10	113	0	84	10	197
Solutions	0	66	250	286	250	352
Metal	265	372	200	233	465	605
Noncombustibles	13	26	0	63	13	89
High-priority residues	224	111	250	340	474	451
Process residues	20	94	0	37	20	131
Totals	590	860	701	1179	1291	2039

Table 4. Corrected Original Los Alamos 94-1 IP Inventory by Material Category

Impure Metal:	896	Combustibles:	292	Pure Metal:	459
High-Priority Residues:	1228	Process Residues:	1114	Oxides:	529
Noncombustibles:	664	High-Priority Compounds:	78	Compounds:	1033
				Sample Returns:	311
					Totals = 6604

3. INSPECTION DATA ANALYSIS

3.1. CONTEXT OF RISK METHODOLOGY

The goal of this study is to identify the legacy items stored in the vault and to devise a processing schedule that mitigates the risk posed by the legacy items in the most expedient manner. The focus of the analysis is not to determine the actual risk levels associated with the Los Alamos 94-1 program, but to assign relative risk levels associated with the different categories of materials that are to be remediated as part of the program. Critical to the analysis is a direct link between observed characteristics of stored items and the risk posed by these items.

During the nearly 20 years of vault operations at TA-55, no containers of fissile material have failed in an uncontrolled environment. The primary storage facility at TA-55 is a cold vault and, as such, a failed container would induce substantial costs of cleanup as well as a potential for worker health risks. Almost all fissile material is stored in containers with at least three barriers. The typical container configuration is an inner can (which is contaminated from the glovebox environment), a bagout bag (which is contaminated on the inside but is clean on the outside), and an outer can (which is clean on both the inside and outside.) Although the inner can is contaminated, it confines the bulk of the residue material, and its failure is coupled to failure of the bagout bag, which cannot continue to confine the residue for very long after failure of the inner container. Thus, the inner container and the bagout bag function are characterized as a single confinement barrier in our analyses. While many variables affect the ability of the inner container/bagout bag combination to contain the fissile material, only two strong discriminators have been identified: matrix material and origin of the item.

Physical processes in the inner container/bagout bag dominate the degradation mechanisms. These processes are, in turn, governed principally by the matrix material contained. This was one of the reasons for maintaining a database that included matrix material as an entry. For the original study, six matrix material categories were identified and separated: oxides, pure metal, compounds and noncombustibles, impure metal, process residues, and high-priority materials. Since that time, a seventh category has been identified, not by matrix material but by item origin as sample returns. Items that originated from the facility performing many of the chemical analyses, in general, were packaged with a different bagout bag procedure. Also, these items tended to be smaller, less stable for a given matrix material, and were generally packaged with thinner bagout bags. These items demonstrated a significantly higher probability of failure of the inner container/bagout bag than the bulk of items in the TA-55 vault.

Through an event-tree analysis, we found that the risks of accidental contamination to workers in the facility could be characterized by the probability of loss of confinement of the inner container and/or bagout bag.¹ The container configuration, event trees, and the coupling between events and the sampling are described in Ref. 1. To determine this link, event trees were constructed to explicitly include events that could be observed by a sampling program. In March 1995 Los Alamos began the effort to collect information on the integrity of stored, plutonium-bearing legacy materials by inspecting a statistical sample of the items stored in the vault. A second inspection was conducted in August 1995, and a third in July 1996. In addition to information from these inspections, items introduced into the processing line as part of the work-off program were also inspected for contamination of the inside of the outer container.

3.2. NATURE OF INSPECTION DATA

The inspection data used in this analysis are from one of three separate sampling exercises or from the processing of items. Shortly after the March 1995 sampling program, an inspection program was instituted requiring all processed items to undergo the same inspection as those items in the sampling program. This inspection program has generated a large amount of data that complements the data from the sampling exercises. Since many of the items being processed are in the high-risk category, much of the inspection data acquired applies to residues in this category.

Plutonium is packaged in several ways, but most of the items considered here are placed in an inner container or "can," then the can is placed inside of a plastic bagout bag, which is twisted shut and tied or taped. There may be two of these bags. Finally, the bagged item is placed inside an outer container or can. When items are inspected, they are first screened visually for damage to the outer container. Then the inside surface of the outer container is "wiped" to detect contamination. If the inner surface of the outer container is contaminated, the bagout bags or inner container are characterized as "failed" (failed to provide a contamination barrier) and further information on the mode of failure is sought. The inner and outer cans may fail from corrosion. The bagout bags may fail by becoming untaped, worn from the weight of the inner can, torn from sharp edges, or degraded from radiolytic damage. In the latter case, they become blackened and brittle.

In the original inspection program and in the event trees, the failure of a container to pass a screening criterion is used in the risk calculations. This screening criterion is measurable contamination on the inside of the outer container. Failure to pass this criterion implies that the inner container/bagout bag have failed to provide an effective contamination barrier. Thus, the only remaining barrier to contamination is the outer container. Failure of the outer container is not thought to be a function of material matrix or point of origin, so it is treated as a statistical event. A more detailed discussion of the other events associated with the risk calculation, including discussion of the outer container failure calculations, is given in Ref. 1.

When a container fails the screening criterion (denoted as a "failed container"), the date the container failed is not known; we know only that it failed some time after the packaging (or "creation") date and before the inspection date. Similarly, for items that pass the screening criterion, we know only that they survived from the date of creation to the date of inspection. In most reliability studies, the actual lifetimes of the failed units are available for analysis. In our case, we have only "interval" data, which introduces a much larger uncertainty into the results. The unfailed units are said to be "censored on the right," meaning that their lifetimes are not known.

3.3. REVIEW OF INSPECTION DATA

The sources of data for analysis of failure probability of the inner container/bagout bag are the two sampling exercises conducted in 1995, the sampling exercise conducted in July 1996, and the ongoing program to process residues stored in the working vault. The motivation and mechanisms behind the sampling exercises of 1995 are described in Ref. 1. When this information was used, our analysis led to a somewhat different plan and strategy for selecting containers to be inspected in July 1996.

3.3.1. March 1995 Sampling Exercise

In March 1995, the material in the vault had been classified into five categories: corrosives, reactive metals, powders, bulk items, and pure metal. At that time there was speculation based on the PVA that some failure rates would depend on the matrix material and that they might worsen with time after packaging, but there were no quantitative estimates of failure rates. Starting with this speculation and the experience of technologists familiar with vault operations and residue

characteristics, we developed a broad-based sampling plan consisting of five categories of material and two age groups. Within each category and age group we sampled 16 units at random for a total of 32 items per material category. While some technologists experienced in processing plutonium suggested that container degradation would be better represented using different material categories, our analysis also indicated that development of a processing plan would require different categorization. After reclassifying the inventory into the following categories, "Oxides," "Pure Metal," "Compounds and Noncombustibles," "Impure Metal," "Low-Priority Process Residues," "High-Priority Process Residues," and "Compounds and Combustibles," the sample sizes were 22, 20, 33, 44, 24, and 17, respectively. A graphical representation of the results of the March sampling is provided in Fig. 1. A review of the qualitative results of the March sampling is available in Ref. 2.

Figure 1. Graphical results of March random sampling.

3.3.2. August 1995 Sampling Exercise

Results from the 160 units inspected in March raised a number of issues that could only be resolved through additional inspections. Failure rates in the various categories were in the 1%–5% range, which usually gave 0 or 1 failures per category. The estimates were thus very uncertain. (At the time, the Los Alamos 94-1 program was on a 15-year schedule to complete remediation of all materials identified in the 94-1 IP by May 2009; this longer schedule was very sensitive to the aging performance of materials scheduled for processing in the later years.) For these reasons, a second sampling, in which the containers to be inspected were randomly selected from two age groups and seven material categories, was conducted in August 1995. The purpose of this sampling was to obtain information leading to a reduction in the uncertainties in failure rates caused by the small number of samples that failed the screening criteria. At that time, a total of 220 items were inspected. Older items were targeted to obtain a larger number of failures of the inner barrier and to maximize information on aging behavior. This inspection provided a second source of data for the risk analysis and significantly reduced the uncertainty on the estimated failure rates for the inner barriers. A graphical representation of the results of the August sampling is provided in Fig. 2. A review of the qualitative results of this sampling is available in Ref. 3

Figure 2. Graphical results of August random sampling.

3.3.3. Ongoing Operations

A third source of data on the failure of the inner barriers to pass the screening criteria was developed during the calendar year 1995. After the March sampling exercise, the data sheets used to record pass/fail data for the screening criterion were used for all items that were processed. The data were not censored with respect to material category, so from the perspective of our analysis the data are assumed to be randomly sampled within each age group. Through this mechanism, inspection results were obtained for another 219 items and included in the database.

3.3.4. July 1996 Sampling Exercise

The final source of inspection data is from the sampling exercise conducted in July 1996. By the time this exercise was conducted, the total number of inspected items had become relatively large, and the uncertainty in the overall performance of the material categories was relatively small. We designed the July sampling exercise to focus on obtaining inspection results on specific subgroups that might not be representative of the larger material categories in which they were included. The recommended approach to this inspection is described in Ref. 4, and the technical basis for the sampling plan is included as Appendix A. Reference 5 contains a review of the qualitative results of the July 1996 sampling exercise.

3.4. OVERALL INSPECTION RESULTS

With the larger database and the more thorough statistical analysis, we have identified one particular subpopulation that was not identified in the original analysis. These are the items that originate from analytical chemistry operations and are identified with a particular "Lot ID." These items may have a variety of matrix materials. We have also identified one subpopulation whose failure characteristics imply they should be included in a different material category, "silica solids." Previous analyses were conducted with the substrata "silica solids" included in the "Process Residues" (PR) material category. However, the results of the July sampling program clearly demonstrated that these solids have a higher probability of inner barrier failure

than the other PR subpopulations and should assigned a higher priority for processing. Thus, they were transferred for analyses in this report to the "High-Priority Materials" category.

Even though the July sampling exercise was focused on gathering information on specific, potentially problematic subpopulations, no other subpopulations have been identified that require further major category refinement. With all of the inspection data aggregated into these material category definitions, analysis of the overall material categories can be completed. Table 5 lists the average fraction of items in these categories that were found to fail the screening criteria as well as the 90% confidence bound on that fraction. The 90% confidence bound reflects the expected upper limit of the failed fraction if the entire inspection database were to be collected 10 independent times. (More precisely, if the entire database were to be collected a very large number of times, the 90% confidence bound represents the upper limit on 10% of those collections.) Table 5 is critical to our analysis in that it completely describes the state of the legacy items as they exist at the time of the inspection. With the large number of items presently in the inspection database, the fraction of remaining items that are likely to have an inner barrier that fails the screening criteria in the near future is well understood.

Table 5. Average Fraction of Items that Failed the Screening Criteria and the Estimated Failed Fraction at 90% Confidence

Material Category	Fraction of items that are expected to have an inner barrier failure	90% confidence limit on the fraction of items that are expected to have an inner barrier failure
Oxides	1.0%	3.9%
Pure Metal	1.9%	3.5%
Sample Returns	18.0%	20.0%
Compounds and Noncombustibles	1.7%	3.3%
Impure Metal	1.7%	3.2%
Process Residues	2.6%	3.1%
High-Priority Materials	7.0%	9.6%

A graphical representation of the inspection results is useful in interpreting overall inner barrier failure rates as well as age-specific analysis. In Figs. 3-9, the overall inspection data results are shown in a similar format to the March 1995 and August 1995 results shown in Figs. 1 and 2, respectively.

Figure 3. Results of all inspection data for the oxide items.

Figure 4. Results of all inspection data for the metal items.

Figure 5. Results of all inspection data for the sample return items.

Figure 6. Results of all inspection data for the "Compounds and Noncombustibles" items.

Figure 7. Results of all inspection data for the impure metal items.

Figure 8. Results of all inspection data for the process residue items.

Figure 9. Results of all inspection data for the high-priority items.

3.5. MODELING LIFETIMES OF CONTAINERS

The actual time after packaging and before inner barrier failure is unknown. Since we have used reliability methods to describe the performance of these containers, we were originally very constrained in our ability to statistically correlate this data. A weakness in the original analysis as it applied to the Los Alamos inventory was the technique used to correlate the observed sampling data to lifetime estimation functions. This was a weakness not so much in approach, but in lack of appropriate data. With the collection of a much larger database containing the inspection data from the July 1996 sampling and from 18 months of inventory processing, more robust techniques could be applied.

Using the lifetimes (or approximate lifetimes in our case) of inspected units, we would like to predict the lifetimes of the units that were not inspected. This predictive ability allows us to calculate risk of container failure (as a function of age and category of material of the units) and to relate that risk to the risk of contaminating workers or the workplace. Prediction requires a model for lifetimes. We chose a flexible and widely used model, the two-parameter Weibull Distribution, which includes, as a special case, the exponential distribution. The density function of the Weibull is

$$f(y) = (\beta / \alpha^\beta) y^{\beta-1} \exp(-(y/\alpha)^\beta), \text{ where } y > 0. \quad (1)$$

The parameter α is the *scale* parameter, and β is the *shape* parameter. (Note that the notation is reversed from our first report, Ref. 1, to better conform with convention.) The parameter α represents the spread of the distribution; in particular, it is the 63rd percentile of any Weibull. The parameter β represents the shape of the distribution: for $\beta = 1$, the distribution drops off exponentially; for values of β between 1 and 3, the distribution is unimodal and skewed to the right; for values between 3 and 4, the shape resembles the normal distribution. More importantly, the Weibull hazard function (which represents the instantaneous failure rate at age y) is constant for $\beta = 1$ (not a function of age) and is an increasing function of age for higher values of β . When $\beta = 2$, the hazard function is linearly increasing, and the distribution becomes the Rayleigh distribution. As described in Section 4.2.4 of Ref. 1, it is quite likely that a material category containing items with a strong aging phenomena behaves in a manner that is modeled by this

Rayleigh distribution. The behavior of a mixed-set population with higher-order shape parameters, but with distributed scale parameters can, in the limit, be described by a Rayleigh distribution.

The items in the vault were created or packaged at various times. (Most items are "created" when the material is packaged into a new container, but this may not be the case in all instances.) To analyze the lifetimes, we consider that all the items are created at time zero and subtract the creation date from inspection date. The "new" inspection date of the i -th unit then becomes $d_i =$ (actual inspection date – creation date). In our sample, m of the items fail the screening criteria before inspection (have lifetimes less than d_i), and the others are "censored" (have lifetimes longer than d_i).

To apply the maximum-likelihood technique, we will assume that the lifetimes of all items have a Weibull distribution. The probability that the lifetime is less than or equal to d_i is the cumulative Weibull,

$$F(y) = 1 - e^{-(d_i/\alpha)^\beta}, \quad (2)$$

and the probability that the lifetime exceeds d_i is

$$1 - F(y) = e^{-(d_i/\alpha)^\beta}. \quad (3)$$

The likelihood is thus

$$L = \prod_{i=1}^m (1 - e^{-(d_i/\alpha)^\beta}) \prod_{i=m+1}^n (1 - e^{-(d_i/\alpha)^\beta}). \quad (4)$$

A simplex (Nelder-Mead) search routine was used to find the values of α and β that maximize the likelihood function; these values are called the "maximum-likelihood estimates" (MLEs). There is no need to take derivatives, but taking the log of the likelihood function simplifies the numerical problems (getting out of bounds). We obtain parameter estimates for each of the seven categories of material packages. There may be numerical problems here: the parameters are highly correlated, and likelihood function can be very flat so that one parameter can be changed significantly (if the other is adjusted accordingly) without making much change in the likelihood.

We now address the issue of uncertainty in the maximum-likelihood estimates of the parameters. Although there are several ways to approach this, we chose to use the likelihood ratio λ . Theoretically, $(-2 \ln \lambda)$ has a chi-square distribution with 2 degrees of freedom; that is, the 90th percentile or "critical value" is 4.605. We used a grid search to find values of α and β for which the absolute value of $\{(-2 \ln \lambda) - 4.605\}$ is small. This produces a confidence region that tends to have a long "banana" shape as shown in Fig. 10 and a corresponding vector of values of α and β .

Figure 10. Ninety percent (90%) confidence region of the scale and shape parameters for the material category High-Priority Materials.

To facilitate modeling, a transformation of the parameters to $1/\alpha$ versus β gives a more ellipsoidal shape. Asymptotically, the parameter estimates are normally distributed. Next the means, standard deviation, and correlation coefficient of the vectors were obtained. We then generated observations from a bivariate normal with these means and correlation coefficients (ρ). This was done by generating two random normal numbers, y_1 and y_2 , with mean of zero and unit standard deviation. The simulated values are then

$$1/\alpha = y_1\sigma_1 + \mu_1 \quad (5)$$

and

$$\beta = (y_1\rho + (1 - \rho^2)^{1/2}y_2)\sigma_2 + \mu_2. \quad (6)$$

The means and variances were adjusted so that the bivariate normal ellipse would fit within the confidence region. For each item in the database, we generated a pair of parameters from the bivariate ellipse and used them to generate a random lifetime for that unit (that is, we calculated a lifetime = $\alpha[-\ln(1 - u)]^{1/\beta}$, where u is a random number from a uniform distribution). Where the expected value of β was closer to 1 but with larger uncertainty, as for oxides, pure metal, compounds and noncombustibles, and impure metal, we drew the random variables, y_1 and y_2 , from the gamma distribution instead of the normal distribution. This facilitates the elimination of subzero values for $1/\alpha$. Finally, we added the simulated lifetime to the actual creation date to obtain a simulated failure date for each item. This new database is called the simulated inventory database. Using the simulated inventory database, the number of failed containers and the probability of failure can be calculated at any time. Figures 11–13 show the transformed confidence regions with a 100-point simulated database generated using this technique for three material categories.

Figure 11. Confidence region (90%) for the distribution parameters for the sample-returns category. Also plotted are 100 simulated data points and curves showing 20-, 50-, and 100-year mean-times-to-failure.

Figure 12. Confidence region (90%) for the distribution parameters for the process residue category. Also plotted are 100 simulated data points and curves showing 20-, 50-, and 100-year mean-times-to-failure.

In the original analysis, relatively few data points were available to develop a quantitative method for fitting the probability of inner barrier failure to the parameters of the Weibull distribution. Because of the paucity of data, we employed a method of fitting the inspection data using "engineering judgment" coupled with a simple ratio analysis to obtain the necessary parameters for the distribution. While the MLE technique provides for an analytic solution to the reliability parameters as a function of material category, the parameter estimates have very large uncertainties when few failures exist per category. This leads to a situation that grossly overestimates the uncertainties in performance of the material category.

Figure 13. Confidence region (90%) for the distribution parameters for the high-priority category. Also plotted are 100 simulated data points and curves showing 20-, 50-, and 100-year mean-times-to-failure.

Another approach to evaluating the parameters of the distributions for the various material categories is to examine the failed fraction of items as a function of item age. In Figs. 14–20, we present the fraction of items that were observed to have inner barrier failure as a function of material category and item age. This is not an annual failure rate but is the integral of the failure rate accumulated over several years. Dividing by the average age of the items gives an approximate annual failure rate. For the Weibull distribution the age-specific failure rate is given by the hazard function:

$$h(y) = (\beta / \alpha^\beta) y^{\beta-1}. \quad (7)$$

We have used a nonlinear least-squares (NLS) fitting algorithm with binomial weighting to fit the hazard function to the failure data. The results from the maximum-likelihood fit and the least-squares fit are shown in Table 6. For the maximum likelihood there is a range of values with nearly identical likelihood. We have chosen values nearest the least-squares values provided that the likelihoods were within 0.1 of the converged values.

Figure 14. Failed fraction of inner barrier plotted against age of item for oxides category.

Figure 15. Failed fraction of inner barrier plotted against age of item for pure metal category.

Figure 16. Failed fraction of inner barrier plotted against age of item for sample returns category.

Figure 17. Failed fraction of inner barrier plotted against age of item for "Compounds and Noncombustibles" category.

Figure 18. Failed fraction of inner barrier plotted against age of item for impure metal category.

Figure 19. Failed fraction of inner barrier plotted against age of item for process residues category.

Figure 20. Failed fraction of inner barrier plotted against age of item for high-priority materials category.

Physical considerations can add information to the total picture. For oxides, the two failures were items packaged on the same day and with adjacent "Lot ID" numbers. This means they were not independent failures, but represent a single failure, perhaps due to improper packaging technique, but not likely an age-related or a materials-related failure. Thus, with only a single failure point

we cannot analytically compute the age-related behavior for this material category. In terms of the parameters for the Weibull distribution used to characterize failure of oxide item, we must return to the "engineering approach" that suggested that a constant failure rate, $\beta = 1$, is the most likely.

For pure metals, the situation is similar. We have two failures at four and five years and only one at late times. The bulk of the metals are young in age, however. While the MLE and NLS techniques generate parameters for the distribution, they have very broad confidence bounds. This general problem also exists with the materials categories of "Compounds and Noncombustibles" and "Impure Metal." In each case, we have very few failures and mixed results with regard to aging phenomena. Because of these issues, the shape parameter for these categories is assumed to be near 1 (constant failure rate). The actual parameters used in the failure prediction calculations are generated by coupling this engineering approach to the results from the two analytical techniques.

Three of the material categories provide sufficient failure data to make use of the analytical techniques without reservation: sample returns, process residues, and high-priority materials. For the high-priority materials category, the failure rate appears constant until age 14. There are 5 failures out of 12 samples there, but 3 of the failures are silica solids, and 2 are rags. The July sampling uncovered the fact that these two subcategories had high failure rates. If we neglect these two small subpopulations, the failure rate appears to be quite constant. For the sample returns category, 4 of 17 failures are graphite crucibles, and exclusion of this small subpopulation would leave us with what appears to be a constant failure rate. We conclude then, that there is less of an aging effect than first appears; i.e., β may be closer to 1 than shown in Table 6. In order to provide a more conservative estimate on the future number of items that may fail the inner barrier, we maintain the higher β for the analysis.

Table 6. Summary of Weibull Parameters Estimated by Various Techniques and the Original Estimates

Material category	Weibull parameters from Ref. 1		Nonlinear Weighted Least-squares Fit on Hazard Function.		Maximum-Likelihood Technique	
	Scale (α)	Shape (β)	Scale (α)	Shape (β)	Scale (α)	Shape (β)
Oxides	NA	NA	NA	NA	NA	NA
Metal	36.9	2	454	1.10	150.	1.29
Sample Returns	NA	NA	48.9	1.61	50.1	1.02
Compounds and Noncombustibles	310	1	79.8	2.24	36.5	3.12
Impure Metal	44.5	2	5140	0.3	1400	0.80
Process Residues	42.5	2	94.9	1.77	94.9	1.65
High-Priority Materials	15.2	3	44.8	1.76	51.1	1.57

Review of the above figures demonstrates a weakness in the maximum-likelihood technique for estimating the parameters of the Weibull distribution when only a few failures are observed and when the data are interval data as in this case. In short, the technique does not appear to utilize the large amount of information available from the number of passes in a given category (as opposed to the number and date of failures). As shown in Table 5, the uncertainty in the *present* configuration in the vault as described by the hypergeometric distribution is quite small for most of the material categories. Further, these numerically based techniques (either the maximum-likelihood, or the weighted least-squares fit on the hazard function) do not make use of the engineering perspective on physical mechanisms for failure. Finally, they are not constrained to fit the categories recognizing the mixed-set limit that tends to force the β parameter towards 2. Thus, we arrive at a situation where some subset of the material categories is still best estimated by use of physical arguments for the β parameter and a fit to the α parameter.

In Table 7, we show the actual parameters used for the material category's expected performance of the inner barrier and the results of using these parameters for both the best estimate case and the 90% uncertainty bounded case. For all material categories, the uncertainty bounded case was generated by the creation of the parameter ellipse (as shown in Figs. 11-13). The bounds of the ellipses were modified so that the 90% confidence bounds on the expected inspection data were similar to the actual inspection data. In this way, we compensated for the lack in measured time to failure (since we have only interval data) by recognizing the information inherent in the number of items that *pass* the inspection criteria.

Table 7. Material Category Parameters Used to Estimate Performance of the Inner Barrier

Material Category	Weibull Parameters		Calculated Inspection Results	
	Shape (α)	Scale (β)	Mean	90% Confidence Limit
Oxides	1.0	380	0.9%	4.0%
Pure Metal	1.1	210	1.8%	3.6%
Sample Returns	1.1	53.	18.6%	23.0%
Compounds and Noncombustibles	1.0	420	1.8%	3.4%
Impure Metal	1.2	280	1.6%	2.9%
Process Residues	2.3	50.	2.8%	4.5%
High-Priority Materials	1.6	48.	7.2%	10.2%

The simulated database can be used in various ways. Random numbers can be assigned to each item, and the items can be sorted by the random number to simulate items being processed in random order. If we sort on the creation date, we simulate processing the items in order of elapsed time after creation. It is usually advantageous to process according to age if the

parameter β is greater than 1. The overall estimated impact of such a processing strategy can be evaluated with the database. Finally we can develop a processing schedule for each material category and then process (remove from the database) the items from each material category as a function of time and determine the number of items handled in such a processing schedule that have a failed inner barrier.

3.6. ROLE OF FURTHER PROGRAM SAMPLING EFFORTS

Before defining additional inspections for the July 1996 sampling, the initial approach was found to provide diminishing returns from sampling. Calculations showed that randomly inspecting an additional 220 items would not add significantly to the 613 observations already taken, and the confidence interval on the failure rates would be reduced by only 1% on each end of the interval. Precise estimates of these very low failure rates would require much larger sample sizes, but that was not feasible and would seriously interfere with the task of processing. Moreover, a processing schedule for remediation had already been developed based on the observed failure rates, the capability of the processing operation, and the judgment of experienced processing personnel. The schedule provided for the highest-risk items to be processed first. We found that precise estimation of failure rates was not only costly, but it generally would not affect the processing schedule, since the high-risk items were already being processed as rapidly as possible.

We have now demonstrated that the oxides, pure metals, and impure metals have failure rates in the range of 1%–2%. The failure rate for the sample returns is about 18% and has the top priority for processing. The high-priority materials category has a failure rate of about 10% or less overall. Because the processing schedule provides for some inspection data from each category (with a concentration from the higher-priority categories), we believe these data will be adequate for identifying subpopulations with high failure rates and that further sampling will not be necessary.

4. RISK ANALYSIS

Two characteristics distinguish this methodology for analysis of risk-based performance and processing prioritization for plutonium legacy materials from previous work in this field: (1) direct coupling between statistically treated observed data and container performance models, and (2) direct coupling between the performance model and worker risk. We considered the first characteristic in the previous section, and now develop the worker risk model in the context of the performance models established for inner barrier failure.

The event trees used for the risk calculation are presented and discussed in Ref. 1. For this study, we have not developed additional event trees, but focused on further analysis of the time- and material category-dependent frequencies that affect the risk model. Many other events can be postulated and probabilities assigned; these events and corresponding probabilities are poorly characterized. In general, these other probabilities, such as probability of operator mitigation, are neither time-dependent or material-category-dependent. Thus, even though the overall magnitude

of the risk values (for example, the estimated frequency of a contamination event) is poorly known, the relative risk associated with various processing strategies can be well characterized.

In the previous report describing the Los Alamos 94-1 risk-based performance analysis, we concluded that obtaining a bounding estimate of the probability of container failure per year sufficed as an indicator of risk performance. This is because of the large uncertainties in other events on the event tree. Some of the critical event probabilities, such as probability of operator intervention, cannot easily be estimated or evaluated due to the lack of data. Furthermore, we expect that these probabilities are independent of the material matrix. Thus, changes in these probabilities will not effect the relative risk differences computed between various processing schedules. We feel that the results of this model represent a valuable measure or "risk indicator" because it is

1. linear to the extent practical with actual imposed worker risk, and
2. reflects the overall context in which operational decisions are made.

In Fig. 21, we estimate the number of items in the 94-1 inventory that would have failed the inner barrier had no remediation been used. We see that the number of container failures would go up almost linearly with time for most categories. This graph represents the relative gain in net risk for vault workers if the Los Alamos 94-1 program were not undertaken.

Figure 21. Estimated number of items in Los Alamos holdings that have a failed inner barrier for the unremediated case.

In Fig. 22, we present the current processing. The present processing schedule includes the actual numbers of items worked off through the end of FY96. The out-years of the processing schedule were computed by evaluating the present Los Alamos 94-1 schedule against the remaining 94-1 inventory (Table 2).

Figure 22. Schedule of the Los Alamos 94-1 program (1995 and 1996 are actual).

4.1. SCHEDULE COUPLING TO RISK MODEL

Because the interaction between integrated program risk and other factors (such as likelihood of inner barrier failure, remaining inventory, and the processing schedule) is complicated, we developed a large calculational model. Figure 23 shows how the estimated number of items in the vault with inner barrier failure decline over time as the categories are worked off. This calculation takes into account the time-dependent behavior of legacy items. In Fig. 24, we show the time-dependent probability of a risk event as defined by a vault or worker surface contamination. Note that the curves go up initially as the work-off program ramps up. This is due to the increased risk associated with the number of vault operations. We show in Fig. 25 the integrated probability of risk event per unit item. This calculation serves to describe the material categories which, over the life of the program, contribute most significantly to worker risk.

Figure 23. Estimated number of items in the Los Alamos 94-1 holdings (all legacy items) that have a failed inner barrier.

Figure 24. Estimated annual frequency of a surface contamination event for the unremediated case and for the present processing schedule.

Figure 25. Integrated probability of surface contamination event per unit item for the present processing schedule.

4.2. UNCERTAINTY ANALYSIS

As we discussed in Section 4, the calculation of absolute risk is difficult and contains large uncertainties. Many other probabilities on the risk-event tree affect the overall estimation of probability of contamination event. Since we believe that these other factors are neither time-dependent nor substantially dependent on matrix material, we expect that any differences in processing strategies can be attributed to the probabilities of inner barrier failure.

Figures 26 and 27 show the results of a Monte Carlo calculation in which the present processing schedule was computed against the performance of the material categories 200 times. From these calculations, the 10% percentile, mean case (50% percentile) and 90% percentile are computed.

As expected, the time-dependent risk behavior does not change very much. At the 90% case, the overall risk curve increases some, but over the entire range of time.

Figure 26. Monte Carlo calculation results of the annual frequency of a surface contamination event.

A more interesting result is noticed when we evaluate the normalized risk behavior. Figure 27 presents the normalized risk per unit item for the three cases evaluated in the Monte Carlo calculation. We can see the effect of the larger uncertainties on the material categories with fewer failures. In shifting from the 90% case (largest number of failures) to the 10% case (fewest number of failures) we observe that the fraction of failures for the sample returns, process residues, and high-priority materials increases. This indicates the relatively lower level of uncertainty for these categories where we have more information. Likewise, the very high level of uncertainty for the oxides category is shown by having essentially no risk in the 10% case, while a larger level of risk is computed for the 90% case.

Figure 27. Monte Carlo calculation results of the normalized probability of surface contamination event per unit item for the present processing schedule.

5. RESULTS

5.1. ESTIMATING THE RISK IMPACT OF DELAYS

With the calculational model developed, we can now evaluate risk-based impacts of programmatic decisions on this Los Alamos 94-1 program. Of particular concern is the relationship between program delays and overall program risk. In Fig. 28, we show the present processing schedule, but with a start-up delay of 5 years. This is an entirely hypothetical schedule, but it represents a comparison with the present schedule that we find useful. Overlaying this schedule with the risk model, we develop the estimated number of items with inner barrier failure as shown in Fig. 29 and the time-dependent program risk in Fig 30.

Figure 30 shows that delaying the start of processing yields a lower probability of a surface contamination event in the near term. In fact, the delayed portion of the schedule is identical to the unremediated case because the only contribution to vault worker risk is from materials control and accountability (MC&A) requirements. These requirements necessitate the routine removal and measurement of the plutonium legacy items. Once processing begins on the 5-year delayed schedule, the worker risk is larger than for the present case because of the larger number of items that have a failed inner barrier due to inner container degradation.

Figure 28. Hypothetical schedule if the Los Alamos 94-1 program were to have been delayed by 5 years.

Figure 29. Estimated number of items in the vault with a failed inner barrier for the 5-year delayed schedule case.

Figure 30. Estimated annual frequency of surface contamination event; comparing the present schedule to a 5-year delayed schedule.

5.2. COMPARING PROGRAMMATIC ALTERNATIVES

Finally, a particular critical viewpoint can be established with this risk-based program performance model. Since Fig. 30 represents the annual frequency of a surface contamination event, we can integrate the area under a given curve to evaluate the overall program risk. Comparing the area under the present schedule curve with the unremediated case, we find that the area under the unremediated case curve is equal to the area under the present schedule curve at about the year 2004. Another way to view these data is to compute the change in risk brought about by the present schedule using the unremediated case as a baseline. This we call

comparative change in risk associated with the Los Alamos 94-1 program, and it is shown in Fig. 31. It is the normalized difference in the area under the curves shown in Fig. 30. Since the unremediated case exists without a Los Alamos 94-1 program (or with complete program stagnation), we call this the “no-action alternative.”

Figure 31 provides the *change* in risk between two programmatic decisions regarding the Los Alamos legacy inventory. It is immediately clear that the overall worker risk goes up upon implementation of the 94-1 program. This is because the nuclear materials workers are doing something more than inventory and surveillance operations required for MC&A purposes. Processing operations require workers to enter the vault much more frequently than these MC&A operations would alone. This greater level of material handling results in increased worker risk compared to the no-action alternative. As noted above in the context of the area under the curves in Fig. 30, the break-even point is realized in about 2004. After 2004, the integrated worker risk begins to shrink dramatically as a result of the 94-1 efforts.

Figure 31. Percentage change in integrated worker risk, comparing the present Los Alamos 94-1 schedule to the no-action alternative.

The critical point made in Fig. 31 is that the probability of a risk event went *up* during the initial stages of the Los Alamos 94-1 program when compared to the no-action alternative. In other words, the workers at TA-55 increased their likelihood of a surface contamination event by engaging in the effort to remediate the plutonium legacy items. In doing so, however, they mitigated a significantly greater future hazard before it became unmanageable.

Figure 32 shows the percentage change in integrated worker risk between the present Los Alamos 94-1 schedule and the hypothetical 5-year delayed schedule. We observe that the 5-year delayed schedule reduces worker risk compared to the present schedule up until the year 2001. At that point, however, the effect of the reduced number of degraded items processed on the present schedule (items processed before they “failed”) dominates. By the completion of the 5-year delayed schedule in 2007, the integrated worker risk associated with the present schedule is nearly 100% less than it would have been on the 5-year delayed schedule. In summary, while a delayed-action approach may induce a minor reduction worker risk within the immediate time

horizon, we observe that delayed action on the processing of these types of age-dependent materials can substantially raise the overall time-integrated worker risk.

Figure 32. Percentage change in integrated worker risk, comparing the present Los Alamos 94-1 schedule to the hypothetical 5-year delayed schedule.

6. CONCLUSIONS

We have developed a powerful methodology for modeling the time-dependent behavior of plutonium legacy materials. The results, however, are no better than the quality of the data collected from inspections. In the past 18 months, a large body of data has been collected as part of the Los Alamos 94-1 program. For the more problematic materials, we have good confidence in understanding the fraction of items that may have a failed inner barrier.

We have been able to provide for age differences within our models, but we cannot account for other variables, such as the techniques used in packaging. The packaging techniques vary with time and location. One set of practices, associated with items returned from analytical chemistry operations, was found to have a significant impact on the stability of the residue. These sample returns were placed into a separate category, since the item source showed a far stronger indication of performance degradation than the matrix material. There are differences in contribution to risk as derived from the probability of inner barrier failure associated with different matrix materials. For example, a significant difference was found between high-priority materials and the process residues. Also, as sufficient data became available, the relative performance of certain subpopulations within the high-priority materials category was noted. In general, we have good confidence in our estimates of the present condition of legacy items as a function of the categories created; however, our ability to model the future time-dependent behavior is still limited for those categories with low failure probabilities because of the lack of data on item failures.

Several broad conclusions for the Los Alamos plutonium legacy materials can be drawn:

1. No evidence of strong aging effects was found. However, mild aging effects occur in several material categories. Owing to the nature of the data, it is not clear whether these effects are time-related (that is, older items were not packed as well) or are age degradation phenomena. For future risk calculations, we use the conservative assumption that these effects are degradation.
2. We have reached a point of diminishing returns in random inspections, and additional sampling will not improve our understanding of inner barrier failure rates. However, knowledge of failure rates of particular subpopulations within the high-priority materials category may allow for improved risk-based performance of the overall program should container processing be delayed. Otherwise, this material category will be eliminated in such a short period of time that any potential net gain cannot be observed.
3. In the Los Alamos 94-1 remediation program, as with any remediation program, the additional handling associated with processing will raise the risk of contamination events when compared to a program without remediation. This occurs because worker risk is minimized in the near term by minimizing all handling of these materials. If, however, remediation of these materials will be required in the future, then the sooner remediation begins and can be completed, the lower the overall program risk. While it may appear from these analyses that maximum acceleration of this and similar remediation programs would minimize the overall program risk, this is not the case. Because these activities take place within a risk management regime, proceeding at too rapid a pace can jeopardize that regime and raise the risk to unacceptable levels by effecting other nodes of the risk event tree.

Many contemporary approaches to risk management minimize the potential risk by eliminating or significantly stretching out programs. Such approaches are based on static methods for estimating risk that use information elicited from experts and are inherently incapable of forecasting risk behavior. These methods cannot dynamically adapt to data accumulated during processing, systematically compute risk reductions due to processing, or be used for risk-based determination of surveillance or sampling programs. Some have speculated that the life cycle costs for plutonium legacy remediation may become unnecessarily large as significant fractions of this material remain in an unstable state at other sites as a result of delayed implementation of remediation programs.⁶ This lack of action may result from the inherent limitations of current risk management techniques, which lead to a failure to appreciate long-term risks from postponing remediation activities.

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APPENDIX A: TECHNICAL BASIS FOR JULY 1996 SAMPLING EXERCISE

Los Alamos

NATIONAL LABORATORY

memorandum

Technology Modeling and Analysis

To/MS: Ken Chidester, NMT-9
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Phone/FAX: (505)665-1334/FAX 667-2960
Symbol: TSA-7:96-26
Date: May 30, 1996

Subject: Technical Basis for 94-1 Sampling Plan

Refer to: TSA-7:96-22

This memo describes the goals and objectives of the sampling plan (Table 1) described in our previous memo, TSA-7:96-22. It also serves to document the criteria used in developing that sampling plan and expediting its issuance.

The goal of the LANL 94-1 sampling exercises is to reduce the program integrated risk through the collection of more information on legacy item performance. In general, as more information becomes available, the program risk can be minimized through the risk-prioritized remediation efforts or, if necessary, through short-term mitigation activities. As with all sampling efforts, a balance exists between the collection of more information, the resources required, and the risk incurred in collecting additional information.

To help provide the basis for the present sampling requirements, we need to review the requirements of the two 94-1 sampling exercises that were conducted last year. In each case, the objective was somewhat different. Near the beginning of the 94-1 remediation program at LANL, very little quantitative information was available by which to characterize the risk of the program and from which the materials in the program could be prioritized for work-off. Qualitative information led to the original processing plans, but quantitative information was needed to support the judgments that were based upon processing experience. Thus, the March 1995 sampling exercise was a "shotgun" approach in that a similar number of samples was taken from each category of materials in the vault. The vault items were separated into two age groups, and a similar number of samples were taken from each age group.

By the time of the August 1995 sampling exercise, a quantitative technical basis was being developed for the risk assessments carried out in support of the program. However, the risk assessment calculations were highly uncertain with respect to information on inner-barrier performance. The August sampling plan was specifically designed to optimize the information return for estimating integrated risk of the overall program. In particular, the assessment was sensitive to the aging performance and present behavior of the two material categories that are processed in the out-years of the program: Compounds and Non-combustibles, and Low-priority Process Residues. Because of this sensitivity, the sampling exercise focused heavily on these material categories.

During the past year, the 94-1 program has generated a great deal of data supporting the risk-based prioritization and sampling model. Further, as items are being processed, information is continually being collected and analyzed. Thus, we have reached a point of diminishing returns in terms of random sampling of the vault inventory. (A more detailed report that computes the risk/benefit characteristics of a random sampling exercise will be released at a later date.) The compression associated with the 8-year schedule compared to the baseline 15-year schedule significantly reduces the impact of aging factors on the out-year items. In short, the objective of the present sampling plan is not to confirm present average failure probabilities estimated for the categories or to reduce confidence bounds since these are already relatively well known.

More specific information on particular subsets of materials is now necessary for the vault sampling to benefit the program in a way that can be translated into risk reductions. The objective of the present sampling plan is to investigate certain subpopulations that may uncharacteristically contribute to overall program risk and that are not presently the highest priority. More specifically, we define the following detailed objectives:

- 1) to "fine-tune" the processing strategy with respect to particular subpopulations that may contribute disproportionately to the overall system risk,
- 2) to acquire more information on failure modes for the legacy items, and
- 3) to identify specific subpopulations that may require immediate remediation.

We identified several potential subpopulations of interest based on information from processing personnel (principally Keith Fife), our own analysis, and DOE-EH consultants. These potential subpopulations are shown in Table 1. The following criteria were used to identify the subpopulations:

- 1) processing experience,
- 2) analysis of the present sampling database,
- 3) current schedule for processing,
- 4) potential for significantly higher consequences from an accident, and
- 5) relative absence of information on the material.

If a particular subpopulation is presently of highest priority (for example, Sand Slag, and Crucible residues within the High-Priority Items category) and is being processed in the most expedient manner, then

- 1) information is presently being received from the processing operation and
- 2) the process could not be increased in priority.

Because of these conditions, there appears to be no reason to identify a particular subpopulation for sampling that already is of highest priority. Another reason for sampling specified subpopulations to maximize the number of observed failures is that short-term remediation in the

form of repackaging takes place during the sampling exercise. Also, the samples will be analyzed for root cause mechanisms to identify any systematic failure mechanisms that are present.

Two criteria were established to guide computation of the required number of samples. These criteria were used because of the variety of issues that need to be balanced with regard to collection of data on the performance of the items. One of the critical factors is that we learn a great deal about failure modes when we do an "autopsy" on a failure. Thus, an important criterion for the sampling plan is to obtain a large number of failures in the sample. Since we have developed a modeling approach that makes use of time-dependent reliability mechanisms to predict the expected failure rates, we must balance the need to collect information on failure modes with the need to develop a random database across a broad time-horizon so that the aging analysis is simplified. The two general criteria applied to subpopulations for calculating the number of items sampled are

- 1) to sample enough items so that the expected number of failures in the subpopulation is 4 items, and
- 2) to sample enough items so that we have 90% confidence that the subpopulation has an inner-barrier failure rate less than 25%.

Other considerations in developing the sampling plan include the need to recognize that certain lots of items may be as large as 20 or more items. Thus, even though we may want the 25 oldest items in a subpopulation, this would be imprudent because all 25 may come from a particular lot that may not be representative. Taking this into consideration, we choose a "stratified-random" sample population for the actual sampling. Also, it seemed imprudent to identify fewer than 5 items from a given sup-population to minimize the effect of an "outlier".

Pyrochemical salts that contain calcium chloride were also identified as a potential subpopulation that may have a higher than average impact on risk. These materials are more hygroscopic than salts that do not contain calcium chloride. However, these salts constitute a significant fraction of the LANL salt holdings. Thus, the present database is substantial enough to suggest that these materials do not present an undo hazard.

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Appendix A

Table 1 Subpopulations Assessed as Potentially Requiring More Information

Subpopulation	Subpopula- tion Size	Sample Size and Subpopulation Criteria	Basis
Filter Residues	261	24 (oldest 25%)	Possible higher failure probability due to moisture intrusion (2 out of 12 items in sample database have failed).
Sweepings/screenings	351	24 (oldest 25%)	Possible higher failure probability due to high surface content and mixture of materials (3 out of 18 items in sample database have failed).
Cellulose rags	113	20 (oldest 50%)	Possible higher failure probability due to moisture intrusion (1 out of 5 items in sample database has failed).
Incinerator ash	149	5 (oldest 25%)	This subpopulation has shown problems at other sites.
Plastic/Kim wipes	113	5 (oldest 25%)	Questionable classification as a noncombustible and sensitivity of plutonium in direct contact with plastic.
Silica	53	18 (oldest 50%)	From previous data, 2 out of 2 containers failed screening criteria. Need to determine if material should be moved to high priority.
Residue salts and ash received from other sites (slip-lid cans)	? (small)	all	Lack of knowledge of packaging leads to concern. The precise number of these items will be identified, and will be evaluated.
Livermore Metals and residue items from other sites (food-pack cans)	? (small)	none	Will be evaluated using radiography in the near future.
Non-Actinide Metals	249	none	While these items appear to be more susceptible to bagout bag tears, only 1 out of 35 items in sample database have failed. Not a concern.
Calcium-bearing Pyrochemical Salts	~500	none	Not easily separated from salt inventory, they presently compose a significant fraction of the sample database. Thus, they are well represented.