Sandia National Laboratories

Operated for the U.S. Department
of Energy by
Sandia Corporation

4100 National Parks Highway
Carlsbad, NM 88220

Phone: (505) 234-0110
Fax: (505) 234-0061
Internet: tbkirch@sandia.gov

Date: June 12, 2006

To: David Kessel, 6820

From: Tom Kirchner, 6821
Eric Vugrin, 6821

Technical Review: Mike Gross, WRES

QA Review: Mario Chavez, 6820

Mgmt. Review: David Kessel, 6820

Subject: Uncertainty in Cellulose, Plastic, and Rubber Measurements for the Waste Isolation Pilot Plant Inventory

1.0 Executive Summary

On April 10, 2006, the U. S. Department of Energy (DOE) submitted a planned change request (PCR) to the U. S. Environmental Protection Agency (EPA) requesting approval to emplace "1.2 moles of magnesium oxide (MgO) for every mole of consumable carbon contained in the Waste Isolation Pilot Plant (WIPP)" (Moody 2006). This amount of MgO represents a reduction from the 1.67 moles of MgO per mole of organic carbon that the EPA currently requires. In response to the DOE's request, the EPA indicated that they would not approve the request without additional analyses addressing the "uncertainties related to MgO effectiveness" (Gitlin 2006). Gitlin (2006) states that

> *"DOE needs to address uncertainties related to MgO effectiveness, the size of the uncertainties, and the potential impact of the uncertainties on long-term performance. For example, EPA would like DOE to discuss how the presence of supercompacted waste, and the uncertainties in the amount of CPR* [cellulose, plastic, and rubber] *disposed of at the WIPP, affect the results of analyses like that done for the removal of mini-sacks."*

The purpose of this memo is to address the EPA's questions concerning uncertainties in CPR measurements and their impact upon long-term performance and the MgO safety factor. Section 2.0 reviews DOE's stance on uncertainty in CPR measurements, and

Section 3.0 discusses a previous performance assessment (PA) that assessed the impact of CPR quantities on repository performance. Section 4.0 details a new analysis that compares CPR estimates for individual containers from Real Time Radiography (RTR) and Visual Examination (VE) and quantifies the relative uncertainty in CPR measurements for a single room in a WIPP panel. The results of this analysis indicate that the relative uncertainty in CPR quantities in an individual room is insignificant and bounded above by 0.3 %. This quantity is so small that it will have no significant impact on the calculation of MgO safety factors. Hence, uncertainties in CPR quantities will not significantly impact long term performance of the repository.

2.0 Introduction

In response to EPA questions concerning uncertainties in waste inventory (Chavez 2005), DOE put forth the argument that the best estimate for the mass of the emplaced CPR material in the WIPP was the sum of the masses estimated using the Real Time Radiography (RTR) estimates (for those container examined with both RTR and Visual Examination (VE)) and the VE estimates (for those containers undergoing only VE methodologies) (Leigh 2006). This argument was based on the assumption that the estimates were unbiased estimates of the true value and, because of the large number of containers involved, that even potentially large errors in the mass estimates for single containers would have little impact on the uncertainty in the total mass of CPR in a room. The unbiased errors, or random errors, are simply statistical fluctuations in the measured values. In the case of RTR and VE measurements, such random errors are expected due to variability in the way people make estimates of the volume or mass of waste components, in the determination of density of waste components by these techniques, in the assignment of waste to the various CPR components, etc. Because of the large number of containers whose CPR masses are added to calculate the total CPR content in a room, random errors are expected, overall, to cancel out since overestimates of mass in some containers are compensated by underestimates of mass in other containers.

However, if there were systematic errors introduced by the RTR methodology, i.e. a bias in the RTR methodology, then there would be a tendency to consistently over- or under-estimate the CPR masses. In such a case the errors would not cancel out and the uncertainty on the total CPR estimated for a room could be significant. The assumption of random errors is a central part of the DOE’s argument, and this analysis provides data to support this assumption.

3.0 Previous Assessments: Dunagan et al. (2005)

The presence of MgO is not explicitly modeled in WIPP PAs. Rather, PA models assume that there is enough MgO in the repository to consume all of the CO_2 that is generated by microbial consumption of CPR materials. Under this assumption, Dunagan et al. (2005) compared the results of two PA calculations that differed only in the quantity of CPR in the inventory. One calculation, termed AMW2 in Dunagan et al. (2005), used the CPR quantity from the 2004 Compliance Recertification Application (CRA-2004) inventory, and the second calculation, termed AMW1, used a CPR quantity that was

250% of the CRA-2004 amount. Dunagan et al. (2005) concluded that "increasing CPR affects pressure, saturation and brine outflow; however, for most realizations, the effects of increasing CPR are minor." Dunagan et al. (2005) further state that the "increases in pressure and brine outflow are not sufficient to significantly affect releases from the repository…Because the excess CPR included in the AMW1 calculation is far larger than any omission or uncertainty in the current inventory, and because the releases remain well within the release limits, no further analysis is necessary to determine the effects of moderate increases in CPR."

In response to the EPA's queries about the impact of CPR materials in emplacement materials on repository performance, the DOE provided the Dunagan et al. (2005) results to the EPA during the EPA's review of the completeness of the CRA-2004.

4.0 CPR Measurements and Related Errors

Gitlin (2006) asked the DOE to quantify "uncertainties relating to the effectiveness of MgO," and this section details an analysis that quantifies the uncertainties in CPR measurements. The methods used to estimate CPR masses for individuals containers are described, and the analytical method used to propagate the uncertainty in container measurements to room scale quantities is described and performed. A Monte Carlo analysis was additionally performed to confirm the analytical results.

4.1 *Radiography and Visual Examination Process*

Radiography is a nondestructive qualitative and quantitative technique that involves x-ray scanning of waste containers to identify and verify waste container contents. Visual examination consists of either observing the filling of waste containers or opening full containers and physically examining their contents.

A radiography system (e.g., Real Time Radiography [RTR], digital radiography/computed tomography) normally consists of an x-ray-producing device, an imaging system, an enclosure for radiation protection, a waste container handling system, an audio/video recording system, and an operator control and data acquisition station. The imaging system typically utilizes either a fluorescent screen with a low-light television camera or x-ray detectors to generate the image.

To perform radiography, the waste container is scanned while the qualified operator views the television screen. An audio/videotape, or equivalently non-alterable media, is made of the waste container scan and is maintained as a non-permanent record. A radiography data form is also used to document the Waste Matrix Code and estimated waste material parameter weights of the waste. Twelve waste material parameters are required to be identified. They are: Iron-Based Metals/Alloys, Aluminum-Based Metals/Alloys, Other Metals, Other Inorganic Materials, Cellulosics, Rubber, Plastics (Waste Materials), Organic Matrix, Inorganic Matrix, Soils/Gravel, Steel (Packaging Materials), and Plastics (Packaging Materials). The estimated waste material parameter weights based on visual determination of the volume of the materials identified above are determined by compiling an inventory of waste items, residual materials, and packaging materials for each container. The items on this inventory are sorted by waste material parameter and combined with a standard weight look-up table to provide an estimate of waste material parameter weights in kilograms (kg).

The radiography system involves qualitative and semi-quantitative evaluations of visual displays. Therefore, RTR Operator training and experience are the most important considerations for assuring Quality Control (QC) in regard to the operation of the radiography system and for interpretation and disposition of radiography results. Only trained personnel are allowed to operate radiography equipment. In addition to formal training on Radiographic systems and techniques and hours of on-the-job training, these personnel are subject to regularly scheduled eye examinations, visual performance checks during batch processing, and tests using test drums prior to qualification.

As a QC check, or in lieu of radiography, the waste container contents are verified directly by visual examination (VE) of the waste container contents. Visual examination is conducted to describe all contents of a waste container, and the presence or absence of prohibited items in the waste. The description must clearly identify all noticeable waste items, residual materials, packaging materials, or waste material parameters. The masses of the items in the waste are measured or estimated. Estimated weights are established through the use of historically derived waste weight tables and an estimation of the waste volumes. It may not be possible to see through inner bags because of discoloration, dust, or because inner containers are sealed. In these instances, documented acceptable knowledge may be used to identify the Waste Matrix Code and estimated waste material parameter weights. All visual examination activities are documented on video/audio tape and the results of all visual examination are documented on visual examination data forms.

Visual examination is performed on a statistically determined portion of waste containers to verify the results of radiography. This verification includes a check on the Waste Matrix Code assigned and waste material parameter weights. The verification is performed through a comparison of radiography and visual examination results. The Waste Matrix Code is determined and waste material parameter weights are estimated to verify that the container is properly included in the appropriate waste stream. The VE mass estimates have been considered to be more accurate than the RTR estimates because RTR must rely on radiographic density characteristics to identify the type of CPR material as opposed to a visual inspection of each item. Furthermore, individual items can be weighed in VE.

4.1.1 Statistically Selecting Waste Containers for Visual Examination

As a Quality Control check on the radiographic examination of waste containers, a statistically selected portion of the certified waste containers must be opened and visually examined. The data obtained from the visual examination is also used to determine, with acceptable confidence, the percentage of miscertified waste containers from the radiographic examination. Miscertified containers are those that radiography indicates meet the Waste Isolation Pilot Plant Waste Acceptance Criteria and Transuranic Package Transporter-II Authorized Methods for Payload Control but that visual examination indicates do not meet these criteria. Over- or under-estimating the weight of the waste material parameters does not constitute a miscertified waste container and is not used to calculate the miscertification rate. Sites conservatively use an eleven-percent (11%) miscertification rate at start up to calculate the number of waste containers that shall be visually examined until a site-specific miscertification rate has been established. Sites may establish a site-specific miscertification rate by characterizing a lot of no less than fifty containers in a single Summary Category Group at the initial 11% miscertification rate. This site-specific miscertification rate is typically much lower than the initial 11% that is assumed at start up. The site-specific miscertification rate is reassessed annually. For further information on the RTR and VE process, see NMED (2005).

4.1.2 AMWTP Waste

The Advanced Mixed Waste Treatment Project (AMWTP) was developed to process contact-handled transuranic (CH-TRU) debris waste prior to shipment to the WIPP. The AMWTP retrieves, characterizes, repackages, and compacts 55-gallon drums of debris waste and places the compacted drums into 100-gallon drums prior to shipment. During the repackaging process, all of the supercompacted waste undergoes visual examination to assess its contents. Therefore, RTR is not done to assess the waste contents for containers of supercompacted waste. As described previously, all other waste streams assess waste contents via RTR and the VE process is used for Quality Control.

4.2 *Calculating the Variability of Sums of Random Variables*

The quantitative impact of systematic uncertainty can be seen by examining the formula for computing the variance of a sum or difference of random variables (Mood, Graybill and Boes, 1974):

$$Var\left[\sum_{i=1}^{n} X_i\right] = \sum_{i=1}^{n} Var\left[X_i\right] \pm 2\sum_{i=1}^{n}\sum_{j=i+1}^{n} Cov\left[X_i, X_j\right]$$

where the ± operator is + for sums and – for differences. If the variates being added or subtracted are independently distributed, then the covariance between them, $Cov[X_i,X_j]$, will be 0 and the variance of the sum or difference will simply be the sum of the variances:

$$Var\left[\sum_{i=1}^{n} X_i\right] = \sum_{i=1}^{n} Var\left[X_i\right] \qquad \textbf{(1)}$$

Covariance is a measure of the linear relationship between two random variables. The covariance between variables X_1 and X_2, denoted $Cov[X_1, X_2]$, will be positive when X_1-

μ and X_2-μ, where μ denotes the true mean, tend to have the same sign with high probability, (Mood et al. 1974), as would be the case if there is bias in the measurements.

Assuming that the X_i are elements of the same population having mean μ and standard deviation σ and that their measurement is free from bias, then:

$$X_{total} = \sum_{i=1}^{n} X_i = n\mu \tag{2}$$

and

$$\sigma_{total} = \sigma\left(X_{total}\right) = \sigma\sqrt{n}. \tag{3}$$

Thus the relative variability, or coefficient of variation (CV), for the total is

$$CV = \frac{\sigma_{total}}{X_{total}} = \frac{\sigma}{\mu\sqrt{n}}. \tag{4}$$

A single room contains approximately 11,000 55-gallon drums (or 55-gallon drum equivalents) [1]. Summing over this number of containers would produce a relative variability for the sum that was more than 100 times smaller than that observed for the containers.

4.3 *Methods*

On May 19, 2006, the Central Characterization Project (CCP) Data Center/Tracking Systems Portal was queried to determine which containers from Idaho National Laboratory (INL), Los Alamos National Laboratory (LANL), and the Savannah River Site (SRS) had both RTR and VE assessments reported. These sites were selected because no other sites are currently working with the CCP and shipping waste to the WIPP, and, thus, the CCP database did not contain data from other sites.

A total of 708 container identification numbers were obtained by a search of the database. The identified containers were those that underwent classification of the contents using both VE and RTR methods. The 708 identifiers were assigned at random without replacement an “order number” between 1 and 708. The mass estimates for plastic packaging materials, plastic waste materials, rubber waste materials, and cellulosic waste materials were obtained from 200 of the first 204 of the randomly ordered waste container data reports; data for four containers could not be found in the online records. The waste container data reports are stored as scanned images of the report forms in the (CCP) Data Center/Tracking Systems Portal, necessitating transcription of the data. A sample size of 200 is sufficient to quantify the bias and uncertainty in the CPR masses of

[1] (160-180 rows/room)*(3 stacks /row)*(3 7-pack equivalents/stack)*(7 55-gallon drums/7-pack equivalent)=10,080-11,340 55-gallon drums per room.

the containers; the standard error (standard deviation of the mean) will be more than a factor of 14 smaller than the standard deviation and the t-value (1.97, α=0.05) used in tests of significance is very near the asymptotic limit of 1.96. CPR mass estimates from both the VE and RTR methodologies were obtained from the reports and paired by container number. A multiplicative weighting factor of 1.7 was applied to the mass of plastics and plastic packaging materials to adjust for the difference in the proportion of carbon in plastics as compared to rubber and cellulosics (Wang and Brush 1996). The carbon-equivalent masses (CEMs) of the CPR materials were then summed by container. The difference (delta) between the VE and RTR mass estimates (RTR - VE) was computed for each container, along with an error ratio computed as the RTR estimate divided by the VE estimate. The error ratio is used to normalize the errors across containers because the containers have highly variable masses of CPR, i.e. it is the error relative to the mass of CPR in the container. The means and variances of the VE and RTR masses and the means and variances of the deltas and error ratios were computed.

As described in Section 4.1, the VE is a more thorough examination process, so it is reasonable to expect that the VE estimates are more accurate than the RTR estimates. Thus, in order to assess the types of errors associated with RTR CPR measurements, we assume that the VE estimates represent the true mass of the CPR which in turn implies that the mean error ratio would represent the best estimate of bias in the RTR methodology and its variance would represent the relative uncertainty expected in the mass estimates obtained from the RTR methodology.

In order to illustrate the distribution of total masses that would result from the measurement errors, the means and variances of the paired differences and error ratios were subsequently used in a Monte Carlo simulation. The total masses were generated using two models. The first model assumes that the true values are normally distributed and that the errors (ε_a) are normally distributed and additive:

$$Mass_{total} = \sum_{i=1}^{11,000} Container(i) + \varepsilon_a(i)$$

The true mass values are normally distributed with a mean and standard deviation that were determined by the mean and standard deviation of the VE values from the data. The additive error term, ε_a, was assumed to be normally distributed with a mean equal to the mean delta (RTR-VE) value and a standard deviation equal to the standard deviation of the delta values. The precise parameter values for the distribution are described in Section 4.4. The second model also assumes that the true values are normally distributed but that the errors (ε_p) are proportional to the mass of the containers:

$$Mass_{total} = \sum_{i=1}^{11,000} Container_i \times \varepsilon_p$$

The error factor, ε_p, was assumed to be lognormally distributed in order to account for positive skewness. The geometric mean and geometric standard deviation assigned to the distribution were computed from observed mean and standard deviation of the error ratios from the data.

The simulations were carried out in three steps. First, the "true" masses for 11,000 containers were generated to represent a collection of containers for which RTR estimates of CPR have been made. Second, 400 simulations of the additive model were run to create 400 sets of additive errors. (Each set consisted of 11,000 errors, one for each container). Finally, the additive error terms were added to the true values to generate 400 realizations of error across the 11,000 containers. Using the same set of "true" masses, the multiplicative model was carried out in an analogous manner.

All of the parameter values for the above distributions were derived from the VE and RTR data and are described in the following section.

4.4 *Results and Discussion*

Vugrin (2006a) contains the RTR and VE estimates for the 200 containers that were selected for this analysis. This data was loaded into a Microsoft Access Database®, and all calculations to analyze this data were performed within the database. The Monte Carlo simulation was performed using the commercial-off-the-shelf software Crystal Ball®. The calculations and Monte Carlo results for this analysis are archived in Kirchner (2006). Description of the calculations and validation of the database are detailed in Vugrin (2006b). The following sections discuss the results of this analysis.

4.4.1 Analysis of the Data Set

The results of this analysis (Table 1) show that the RTR methodology to estimate CPR masses is equivalent, on the average, to the VE methodology. The data of this sample show relatively high levels of variability in masses between containers (a standard deviation of about 17 compared to a mean of about 36). This variation is expected because the containers are selected from many different waste streams. Although the average difference (bias) between the VE and RTR estimates is small (0.334 kg of cellulosics equivalent or 0.9% relative bias) the variability is relatively high (standard deviation equals about 7.8 kg carbon-equivalent or 21% relative difference). The probability that the difference from 1 of the mean bias of 1.011 is attributable to random error is 0.968, based on a Student's-t test, and thus the bias is clearly not significant. Based on the standard deviations of the observed relative and additive errors, these conclusions would not change even if all 708 containers were used in the analysis.

Table 1 Uncertainties in container mass estimates and potential bias in the RTR methodology, based on 200 samples.

	Average Weighted Mass	***Standard Deviation***	***Standard Error***
RTR Mass Estimate	36.8	17.4	1.23
VE Mass Estimate	36.5	16.5	1.17
Paired Difference (delta)	0.334	7.83	.553
Error Ratio (bias)	1.011	.271	.019

Deleted: 17

Deleted: 23

The distribution of the RTR measurements (Figure 1), VE measurements (Figure 2) and the paired differences (Figure 3) are all approximately symmetric, although all show significant (p=0.95) kurtosis and skewness. Skewness represents deviation from

symmetry in the distribution and kurtosis represents the flatness or peakedness of the distribution. The significance of the skewness and kurtosis of the RTR and VE distribution is due the rightmost point in each case, container number 10003372.
If this single point was removed from the distribution of masses, the kurtosis and skewness would be reduced to insignificant levels. Regardless, we have included this point in all calculations and analyses.

The distribution of the paired differences is significantly leptokurtic, i.e. those values are more tightly clustered around the mean (0.334) than expected for a normal distribution. The distribution of error ratios (bias) is significantly positively skewed (Figure 4). Such skewness is expected since the error ratio is derived from the ratio of two distributions. The Central Limit Theorem of statistics shows that products and quotients of random variables tend to converge to lognormal distributions, which are positively skewed.

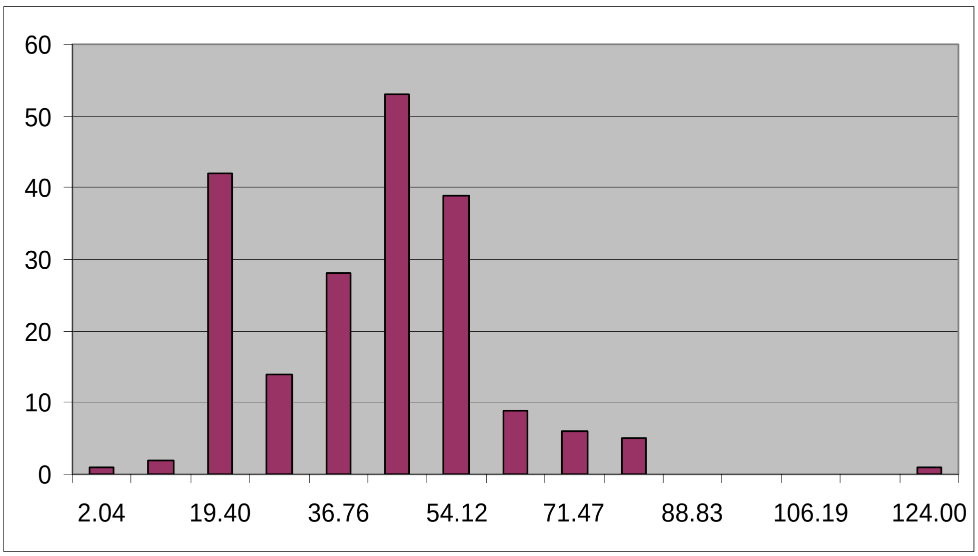

Figure 1. Distribution of RTR measurements. All measurements are in CEMs.

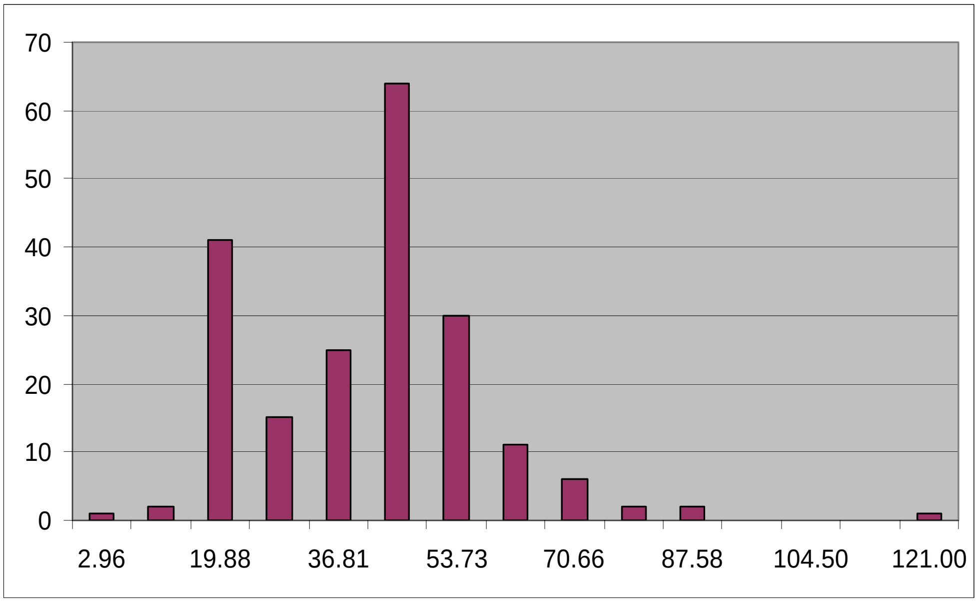

Figure 2. Distribution of VE measurements. All measurements are in CEMs.

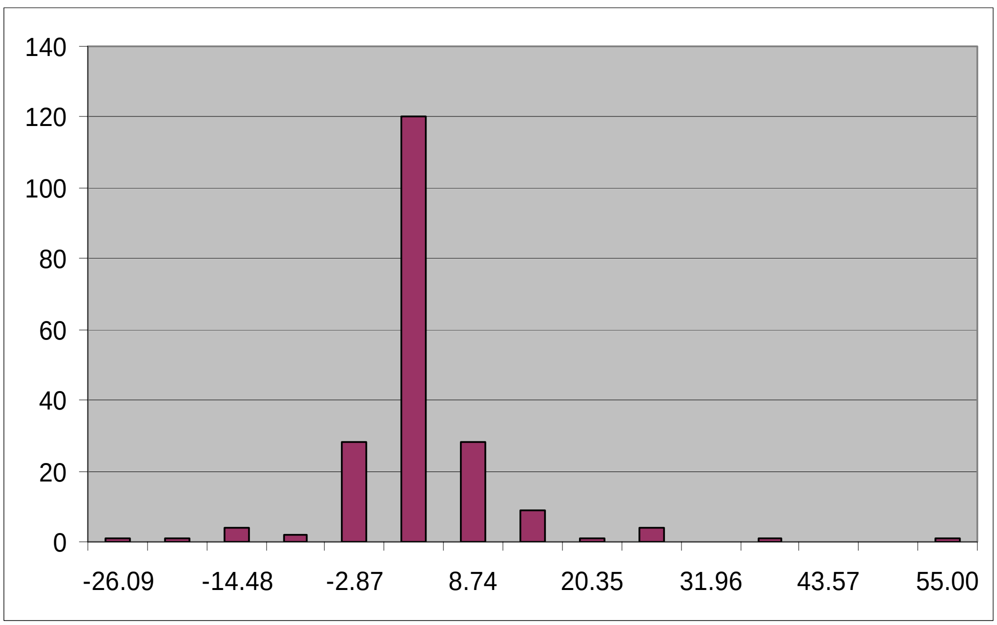

Figure 3. Distribution of errors (Delta) in RTR measurements. All measurements are in CEMs.

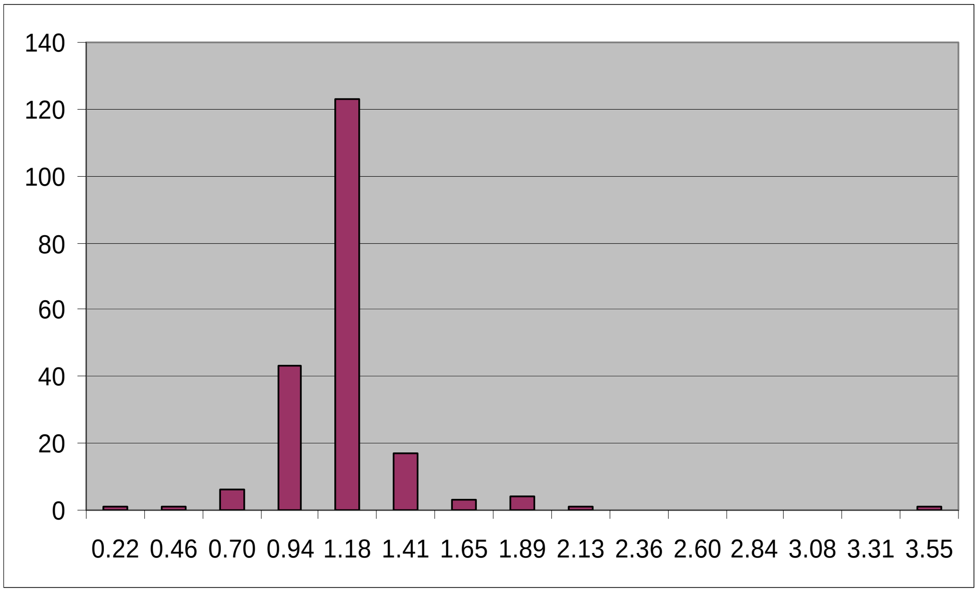

Figure 4. Distribution of Error Ratios in RTR measurements. All measurements are in CEMs.

4.4.2 Uncertainty in the Total CPR

Under the assumption that the VE estimates represent the true CPR masses, Table 1 identifies the variability in the container masses (VE Mass Estimate) and the uncertainty in the RTR mass estimate (delta). The RTR measurements combine both of these variabilities, i.e.,

$$RTR = VE + \varepsilon$$

where ε is a random variable representing the error in the RTR measurements. The distribution of ε is assumed to have a mean of 0.334 and a standard deviation of 7.83.

Assuming that there are 11,000 containers in a room, that there is no bias in the errors, and that the data used for this analysis are representative of all containers, the relative uncertainty ($\sigma_{total} / Mass_{total}$) of the mass of CPR waste in the room would be

$$\frac{1}{\sqrt{11,000}} \frac{7.83}{(36.5)} = 0.00204 ,$$

or about 0.2%. By Equation 2, the expected value of the total is

X_{total}= 36.5 *11,000 = 401500 CEM

and by Equation 3, its standard deviation is

σ_{total} = $7.83\sqrt{11000}$ = 821 CEM.

Note that it is the standard deviation of the errors that is considered, not the between-container variability. Because it is the total mass of CPR being considered, the between-container variability does not impact the uncertainty in the total mass.

Computing the expected standard deviation of masses for the proportional model

$$RTR = VE \times \varepsilon_p$$

requires approximating the standard deviation of the products of the true masses and the error term ε_p. Assuming that the true mass of each container is equal to the mean μ, the variance of the product is

$\sigma^2_p = \mu^2\sigma^2$ (Mood, Graybill and Boes 1974)

Thus, from Equation 2, the variance of the sum is expected to be approximately

$$\sigma_{Total} = \sqrt{n}\sigma_p = \sqrt{11000} \times 36.5 \times 0.271 = 1037.$$

It should be noted that Equation 1, from which this analysis derives, applies to random variables having any type of distribution. Departure from normality (i.e. significant skewness or kurtosis in the distributions of the errors) is not an issue in terms of the conclusions based on this analysis. Because it is the sum of a large number of containers that is of interest, the presence of “outliers” will have no significant impact on the uncertainty of that sum other than that due to their contribution to the variance in the errors.

4.4.3 Monte Carlo Simulations

The Monte Carlo simulation shows that the estimates of the uncertainty in the total mass for the additive model case are consistent with the theoretical result (Table 2). The distribution of the uncertainty due to additive error among the 400 simulated totals is similar to that predicted by the analytical solution. The results based on the proportional error model are also presented. Some of the differences between the predicted and observed results are undoubtedly due to the large variability in the container masses and the errors. These simulations confirm that the impact of relatively high levels of uncertainty in the mass of CPR in a single drum will nevertheless have little impact (<0.3%) on the uncertainty of the total mass of CPR in a room regardless of whether an additive or multiplicative model of error is considered.

Table 2 Results of Monte Carlo Simulation of Errors

Parameter	***Predicted***	***Observed***
Mean (True value)	401500	401606
Mean (Additive error)	405174	407701
Standard deviation (Additive error)	821	746
Coefficient of variation (Additive error)	0.00204	0.00187
Mean (Proportional error)	405916	407534
Standard deviation (Proportional error)	1037	892
Coefficient of variation (Proportional error)	0.00255	0.00222

4.4.4 An Alternative Method of Assessing the Uncertainty for RTR and VE Estimates

AMWTP waste is expected to fill about 36% of the total available volume for CH-TRU waste in the WIPP (Hansen et al. 2004), and as discussed in Section 4.1.2, CPR estimates for this waste are determined only by VE and not RTR. The previous discussion assumed that VE CPR estimates represented the true quantities of CPR. Thus the difference between the CPR and RTR estimates was assumed to represent error in the RTR measurement. Alternatively, we can consider that the RTR and VE estimates are both unbiased approximations of the true CPR quantities. These methods provide two independent estimates of CPR quantities, with neither method leading to consistently higher or lower estimates than the other for individual containers. Thus,

$$VE = X + \varepsilon_{VE}$$

and

$$RTR = X + \varepsilon_{RTR}$$

where X is the true value and ε_{VE} and ε_{RTR} are the errors in the VE and RTR estimates, respectively. The variance of (RTR-VE) would be, by Equation 1,

$$Var[RTR - VE] = Var[Delta] = Var[RTR] + Var[VE]$$

Or

$$\sigma^2_{Delta} = \sigma^2_{RTR} + \sigma^2_{VE}\,.$$

Thus,

$\sigma^2_{VE} \le \sigma^2_{Delta}$ and

$\sigma^2_{RTR} \le \sigma^2_{Delta}\,.$

The coefficient of variation for the total amount of CPR in a room of 11,000 containers would be

$$CV = \frac{\sigma_{VE}}{\mu\sqrt{n}} \le \frac{\sigma_{Delta}}{\mu\sqrt{n}} = \frac{7.83}{36.5\sqrt{11000}} = 0.00204\,.$$

This logic results in the conclusion that the variability in CPR quantities for a room is insignificant and is bounded above by the results (0.3%) of the previous section. This conclusion is applicable to both RTR and VE estimates.

5.0 Summary and Conclusions

A previous analysis (Dunagan et al. 2005) showed that under the assumption that if there is enough MgO in the repository to sequester any CO_2 that is generated by microbial consumption of CPR materials, large increases in the amount of CPR placed in the WIPP affect repository pressures, saturations, and brine outflows, but these increases are insufficient to significantly affect releases from the WIPP.

An examination of the potential errors in the CPR mass estimates made using RTR showed that the effect of errors in these measurements is unlikely to cause the uncertainty in the total mass of CPR for a room to be of any practical significance. The analysis was based on differences between the VE and RTR estimates of mass paired by container. In this analysis the VE estimates were assumed to be the more accurate value and were treated as the true values. Monte Carlo methods were used to simulate potential errors in the RTR measurements and to construct a distribution representing the uncertainty in the total CPR in a room. These results confirm that the uncertainty on the total mass of CPR in a room would be less that 0.3%. Because no significant bias was observed in the RTR measurements it is appropriate to assume that the total of the CPR measurements is the best estimate of the true value of the total.

Furthermore, an alternative method for examining potential errors in the CPR mass estimates from both the RTR and VE methods concluded that the uncertainty on the total mass of CPR in a room is bounded above by the 0.3%. In this methodology, the RTR and VE estimates are both assumed to be unbiased estimates of the true CPR mass. As a result the standard deviation of both the VE and the RTR estimates is less than that of the paired RTR-VE differences. Consequently, the uncertainty on the total mass of CPR in a room would be less than the uncertainty that resulted from assuming that the VE estimates represented the true masses of CPR.

As noted in the Introduction, Leigh (2006) argued that the best estimate for the mass of the emplaced CPR material in the WIPP was the sum of the masses estimated using a combination of the Real Time Radiography (RTR) and Visual Examination (VE) methodologies. The results of this analysis indicate that the relative uncertainty in CPR quantities in an individual room is expected to be less than 0.3 %. This uncertainty would have a negligible impact on the calculation of MgO safety factors.

6.0 References

Chavez, A. V. 2005. Technical Adequacy Comments. TRU Solutions, Carlsbad, NM. ERMS 542112.

Dunagan, S. C., C. W. Hansen, and W. P. Zelinski. 2005. Effect of Increasing Cellulosics, Plastics, and Rubbers on WIPP Performance Assessment, Revision 1. Sandia National Laboratories, Carlsbad, NM. ERMS 538445.

Gitlin, B. C. 2006. Letter to D. C. Moody Concerning the DOE's Request to Reduce the MgO Excess Factor from 1.67 to 1.2, dated April 28, 2006. ERMS 543319.

Hansen, C. W., L. H. Brush, M. B. Gross, F. D. Hansen, B.-Y. Park, J. S. Stein, and T. W. Thompson. 2004. Effects of Supercompacted Waste and Heterogeneous Waste Emplacement on Repository Performance. Sandia National Laboratories, Carlsbad, NM. ERMS 533551.

Kirchner, T. B. 2006. Machine Readable Media: Calculations to Assess Uncertainty in CPR Estimates for the WIPP. Sandia National Laboratories, Carlsbad, NM.

Leigh, C. D. 2006. Incorporation of Inventory Uncertainty in the CRA-2004 Performance Assessment Baseline Calculation. Sandia National Laboratories, Carlsbad, NM. ERMS 542308.

Mood, A. M., F. A. Graybill and D. C. Boes. 1974. Introduction to the Theory of Statistics. McGraw-Hill, New York.

Moody, D. C. 2006. Letter to E. A. Cotsworth Requesting a Reduction in the MgO Excess Factor from 1.67 to 1.2, dated April 10, 2006. ERMS 543262.

New Mexico Environment Department (NMED). 2005. *Waste Isolation Pilot Plant (WIPP) Hazardous Waste Facility Permit*, #NM4890139088, Module II, and Attachments B, B1 – B6. New Mexico Environment Department, New Mexico.

Vugrin, E. D. 2006a. Visual Examination (VE) and Real Time Radiography (RTR) Estimates of CPR Masses for 200 WIPP Waste Containers. Sandia National Laboratories, Carlsbad, NM.

Vugrin, E. D. 2006b. Description and Validation of Routine Calculations for "Uncertainty in Cellulose, Plastic, and Rubber Measurements for the Waste Isolation Pilot Plant Inventory. Sandia National Laboratories, Carlsbad, NM.

Wang, Y. and L. H. Brush. 1996. Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment. Sandia National Laboratories, Carlsbad, NM. ERMS 231943.