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Sandia National Laboratories
Waste Isolation Pilot Plant

Analysis Package for DRSPALL: CRA-2004 Performance Assessment Baseline Calculation

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1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is a deep geologic repository developed by the U.S. Department of Energy (DOE) for the disposal of transuranic (TRU) radioactive waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Parts 191 (EPA 1985) and 194 (EPA 1996). In March of 2004, Sandia National Laboratories (SNL) completed a Performance Assessment (PA) of the WIPP. This PA was part of the Compliance Recertification Application (CRA-2004) (DOE 2004) submitted by the DOE to the EPA to demonstrate compliance with the radiation protection regulations of 40 CFR 191 (EPA 1985) and 40 CFR 194 (EPA, 1996). The EPA has begun both a completeness review and a technical adequacy review of the CRA-2004. EPA has since required that DOE and SNL complete another PA to incorporate technical changes to the CRA (Cotsworth 2005). This PA will replace the CRA-2004 and "will establish the baseline against which future changes at WIPP are evaluated" (Cotsworth 2005). This new analysis has been termed the 2004 CRA Performance Assessment Baseline Calculation (CRA-2004 PABC).

Analysis plan AP-122 (Kanney and Leigh 2005) presents the full set of PA calculations required for the CRA-2004 PABC and details the changes that were made for the CRA-2004 PABC. This report presents the analysis of the spallings calculations performed by the code DRSPALL included as part of the CRA-2004 PABC.

2.0 Background

A WIPP spallings event is a special case of drilling intrusion in which the repository contains gas at high (> 8 MPa) pressure. This highly pressurized gas can cause localized mechanical failure and entrainment of solid WIPP waste into and up the borehole, resulting in transport to the land surface. Under the direction of the DOE, SNL developed a spallings model and the computer code DRSPALL to calculate the spallings volume from a single borehole intrusion (Lord et al. 2004, WIPP-PA 2004b). The first PA for which this model and code were utilized was the CRA- 2004.

In order for a WIPP spallings event to occur, two processes must take place:

1) Repository waste contents experience material failure due to near surface tension. This phenomenon happens when the pressure difference between the repository and the wellbore is large enough to cause tensile failure of the waste material.
2) The failed material is transported to the surface.

This document assumes that the reader has a basic understanding of the code DRSPALL and how the spallings process occurs, and, thus, this document does not discuss in detail the complex physical processes that lead to spallings in the WIPP PA spallings model. These details and the mathematical systems of equations that are used for calculating spallings releases are discussed in great detail in Lord et al. (2003, 2004, 2005) and WIPP PA (2004b).

3.0 Approach

This work was conducted in accordance with Analysis Plan AP-122 (Kanney and Leigh 2005). Calculation of spallings releases followed the same procedure outlined in (Lord 2002) with 4 significant procedural changes. First, the sampling of uncertain DRSPALL parameters was done in the same Latin hypercube sample as the uncertain parameters for other WIPP PA codes (Kirchner 2005). This change ensured that no spurious correlations exist between the DRSPALL parameters and the other sampled parameters because the Latin hypercube sampling code LHS enforces zero correlations between parameters unless a correlation is specified (WIPP PA 2005a, 2005c).

Secondly, whereas the CRA-2004 consisted of one replicate of fifty DRSPALL vectors and four DRSPALL pressure scenarios per vector, a larger set of DRSPALL calculations were performed for the CRA-2004 PABC: three replicates consisting of 100 vectors each and four DRSPALL pressure scenarios were calculated for each vector. The end result was a set of 1,200 DRSPALL calculations. This change was mandated for the CRA-2004 PABC by the EPA (Cotsworth 2005).

Third, a new procedure was established to create the file containing the DRSPALL calculation data for the code CUTTINGS_S (WIPP PA 2005b). The utility MERGESPALL was written, tested, and utilized in combination with SUMMARIZE runs to create the spallings input file for CUTTINGS_S. This procedure adds traceability to the spallings calculation procedure and run control, documented in Long and Kanney (2005). Use of this utility is a deviation from AP-122 (Kanney and Leigh 2005) because this utility was not discussed in AP-122 (Kanney and Leigh 2005).

Finally, since CRA-2004 used only 50 DRSPALL vectors for all three replicates of the CRA-2004 PA, the parameter SPALLMOD:RNDSPALL was used by CUTTINGS_S version 5.10 (WIPP PA 2005b) to map the 50 DRSPALL vectors to the 300 PA vectors (Lord et al 2005). Use of this parameter was unnecessary for the CRA-2004 PABC since this analysis consisted of 300 DRSPALL vectors. The parameter SPALLMOD:RNDSPALL was not sampled (Kirchner 2005), and DRSPALL vector 1 of replicate 1 was mapped to PA vector 1 of replicate 1, vector 2 was mapped to vector 2, and so forth.

4.0 Methodology

Calculation of spallings release for the CRA-2004 PABC and the CRA-2004 is divided into four steps (Lord et al. 2003): (1) characterization of subjective uncertainty in calculation of spall volumes; (2) calculation of spall volumes using DRSPALL accounting for subjective uncertainty in waste properties; (3) interpolation of DRSPALL results in the code CUTTINGS_S to calculate spall volumes in the scenarios for drilling intrusions; and (4) calculation of spall releases accounting for stochastic uncertainty in the future of the repository using the code CCDFGF (WIPP PA 2003). This section discusses the first two calculation steps.

4.1 Characterization of Subjective Uncertainty

Lord et al. (2003, 2004) identifies five uncertain input parameters that largely determine the variability of spall volumes calculated by DRSPALL. Higher initial repository pressures generally result in larger spallings release volumes. This parameter is treated by DRSPALL as an initial condition and discussed in further detail in Section 4.2. Additionally, the permeability of the waste (SPALLMOD:REPIPERM), the porosity of the waste (SPALLMOD:REPIPOR), the tensile strength of the waste (SPALLMOD:TENSLSTR), and the particle diameter of the waste after tensile failure (SPALLMOD:PARTDIAM) affect spall volumes. These four parameters were sampled to comprise the DRSPALL Latin hypercube sample for the CRA-2004 (Table 1).

Table 1. Uncertain Sampled Parameters for DRSPALL.

Parameter	Material: Property	Description	Distribution	Range
Repository Permeability	SPALLMOD: REPIPERM	Permeability of waste (m^2)	Loguniform	2.4×10^{-14} to 2.4×10^{-12}
Repository Porosity	SPALLMOD: REPIPOR	Porosity of waste (dimensionless)	Uniform	0.35 to 0.66
Particle Diameter	SPALLMOD: PARTDIAM	Particle diameter of waste after tensile failure (m)	Loguniform	0.001 to 0.1
Tensile Strength	SPALLMOD: TENSLSTR	Tensile strength of waste (Pa)	Uniform	12×10^{4} to 17×10^{4}

These same DRSPALL parameters, distributions, and ranges were used for the CRA-2004 PABC. One Latin hypercube sample of 100 vectors was created by the code LHS (WIPP PA 2005c) for each of the three replicates. As discussed in Section 3.0, the DRSPALL parameters were included in the CRA-2004 PABC Latin hypercube sample for all WIPP PA uncertain parameters. A total of fifty-six uncertain parameters were sampled for the CRA-2004 PABC. (In this document, a DRSPALL vector consists of four sampled values, one of each of the four uncertain parameters).

4.2 Calculation of Spall Volumes by DRSPALL

Four initial repository pressures were considered for the CRA-2004 PABC DRSPALL calculations. These pressures correspond to what are referred to as DRSPALL pressure scenarios (DPSs). DPS 1 has an initial repository pressure of 10.0 MPa, DPS 2 has an initial repository pressure of 12.0 MPa, DPS 3 has an initial repository pressure of 14.0 MPa, and DPS 4 has an initial repository pressure of 14.8 MPa. For both the CRA-2004 PABC and the CRA-2004, DRSPALL was executed once for each vector and scenario combination, resulting in 1200 separate runs for CRA-2004 PABC. Only 200 DRSPALL calculations were required for the CRA-2004 DRSPALL calculations.

4.2.1 Output Variables

A complete list of DRSPALL variables and their definitions is given in WIPP PA (2004b, 2004c). The discussion of the following variables is required for comprehension of this document:

- Drilled radius (DRILLRAD) - this variable represents the contribution of the cavity radius in the repository that is due to drill cuttings. This variable is a function of time and is bounded by the variable CUTRAD, the maximum equivalent cuttings radius.
- Maximum equivalent cuttings radius (CUTRAD) - this variable represents the length of the radius of the hemisphere (or cylinder, depending on choice of geometric model) with the same amount of surface area as the lateral surface area of a cylinder with height equal to the repository height and diameter equal to the drill bit diameter. This variable is constant with respect to time.
- Cavity radius (CAVRAD) - this variable represents the length of the radius of the cavity and includes contributions from drill cuttings and spallings. This variable is a function of time.
- Repository thickness (REPOSTCK) - this variable represents the thickness of the repository. This variable is constant with respect to time.
- SPLVOL2 – this variable represents the accumulated uncompacted spall volumes. This variable is a function of time and is the major variable of interest.

4.2.2 Exception Runs- Increased Run Time

The DRSPALL input control file allows the user to specify the length of time of the drilling intrusion (WIPP PA 2004c). For the CRA-2004 PABC, all DRSPALL calculations were run for a 600 second drilling intrusion time which is generally long enough to capture all drilling and spalling activity.

CAVRAD is a non-decreasing quantity, and two processes can occur that result in an increase of CAVRAD. The first process that causes CAVRAD to increase is the passage of the drillbit through the repository, and as drilling occurs, the radius of the equivalent cavity increases. Secondly, if spalling is occurring, the cavity radius will increase, and the quantity CAVRAD increases. When the drill bit reaches the bottom of the repository and spallings have ceased, CAVRAD does not increase.

CAVRAD is used as an indicator to determine when the system has stabilized and the spallings process has ceased. If CAVRAD has increased at a time close to the end of the simulation, the spallings process may not have finished, and the run time for the simulation needs to be increased to ensure that all of the spallings volume has been calculated. This situation was observed for several CRA-2004 PABC DRSPALL runs. All runs that had an increase in CAVRAD in the final 100 seconds of the DRSPALL simulation were rerun with an increased "maximum run time" and "stop drilling time" of 1500 seconds. When run times were extended for the CRA-2004, the maximum run time was extended only to 1000 seconds.

4.2.3 Repository- Spherical and Cylindrical Geometries

The spallings model domain is divided into two regions that are coupled. The first is the wellbore domain, and this document does not discuss the details associated with flow in the wellbore. For a thorough discussion of the wellbore domain, see Lord et al. (2004) and WIPP PA (2004b). This section briefly discusses the geometries associated with the repository domain.

DRSPALL has the capability to model the repository two different ways. When the user specifies the cylindrical model, the repository and cavity are modeled as a cylinder of constant height equal to the constant REPOSTCK. (Calculation of REPOSTCK is discussed in section 4.2.4). The radius of the cylindrical cavity, CAVRAD, increases with drilling time and as spalling occurs. When the user specifies the spherical model, the repository and cavity are hemispherical where the cavity radius, CAVRAD, is also a function of time and increases for the same reasons.

All spallings executions for the CRA-2004 PABC were begun using the spherical model. Certain exception runs required restarting the code with the cylindrical model. These exception runs are discussed in further detail in the following section.

4.2.4 Exception Runs

The repository thickness at the time of intrusion, represented by the variable REPOSTCK, is determined from the repository porosity ϕ (the sampled parameter SPALLMOD:REPIPOR), the height of the repository at burial time, H_o, and porosity ϕ_o of a waste-filled room prior to closure:

$$REPOSTCK = \frac{(1-\phi_0)H_0}{1-\varphi}.$$

WIPP PA assigns the values of H_o=3.96 m (BLOWOUT:HREPO) and ϕ_o=0.85 (BLOWOUT:INPORO). By the end of some CRA-2004 PABC DRSPALL simulations, the cavity radius exceeded the height of the repository. This occurrence was also observed in the CRA-2004 calculations (Lord et al. 2003). In an actual intrusion, this would correspond to spalling occurring into the disturbed rock zone (DRZ) below the repository. Lord et al. (2003) state that "the unsteady porous flow and stress equations that describe the repository in hemispherical geometry do not address the presence of the lower DRZ." Thus, for a hemispherical simulation in which the cavity radius exceeded the height of the repository, DRSPALL cylindrical exception runs were made. They were run by restarting the DRSPALL calculation in cylindrical mode. An initial radius for the cylindrical cavity was specified to be the height of the repository. This initial radius was specified to account for the cavity calculated when DRSPALL was executed in spherical mode. The initial radius is set equal to the repository thickness so that the initial cylindrical cavity has lateral surface area equivalent to the surface area of the hemispherical cavity at the time when the hemispherical cavity reaches the base of the repository. The volume of spalled material (SPLVOL2) from the cylindrical run was added to the volume of spalled material (SPLVOL2) at the time step when CAVRAD first exceeded the repository height during the spherical run, and this total volume is used by CUTTINGS_S and recorded in Table 14, Table 15, and Table 16 in Appendix D.

The procedure for implementing each exception run was as follows:

1) DRSPALL was run for all vectors and DPSs with a maximum run time of 600 seconds.

2) All DRSPALL runs were examined to determine in which runs CAVRAD exceeded REPOSTCK.

3) For each run in which CAVRAD exceeded REPOSTCK, a new DRSPALL input control file was created. This control file differed from the control file that was used for the initial run in the following ways (Figure 1):

    a. The flag indicating use of the spherical model was changed from "S" to "C" to indicate that the cylindrical model is used.

    b. "INITIAL CAVITY RADIUS" is specified to a length equal to the height of the repository.

    c. To assist in establishing "true" initial conditions from the inputted approximate initial conditions for restarting the run in cylindrical mode, the drill bit is started 0.15 m above the repository with a velocity of 0.00444 m/s. At 33.78 seconds, the drill bit is at the top of the repository. "STOP DRILLING TIME" was changed from "1.0000E+03" to "33.78."

At this point, sufficient initial conditions have been re-established and the code proceeds with the normal coupled wellbore/repository calculations without drilling. Since the drilled volume was already determined in the spherical run, the drill bit is stopped before penetration, and spalling proceeds as determined by the model.

d. "RADIUS, GROWTH RATE" was changed from "0.5, 1.01" to "1.5, 1.01." "RADIUS" separates the region in the repository where zone size is constant from the region where zone size grows at "GROWTH RATE." The value specified for "RADIUS" in the cylindrical runs results in about 0.5 m (1.5 - 1) outside the initial cavity radius where zone size remains constant. This assumes a repository height of ~1.0 m. The value of 0.5 m (from the original spherical DRSPALL control file) would be inside the initial cylindrical cavity and would have resulted in relatively large zones sizes in the region of interest.

4) DRSPALL was run using the new input control file.

5) SPLVOL2 at time 600 seconds from the cylindrical run was added to the spherical SPLVOL2 value at the first time when CAVRAD exceeded REPOSTCK. This procedure is discussed in greater detail in Section 4.2.5. Note that for all cylindrical DRSPALL runs, CAVRAD attained a steady state value within 500 seconds.

The code does not have the capability to start with an arbitrary pressure profile within the repository or fluid/solid distribution in the wellbore, and, therefore, a uniform pressure distribution and mud-filled column are used for the initial conditions at the beginning of the cylindrical run (end of the run in spherical geometry). Thus, the cylindrical calculations start with a similar initial pressure difference between the wellbore and repository as the spherical calculations.

```
.............................................................
Stop Pump Exit Vol Rate       (m^3/s):  SPALLMOD STPPVOLR
Stop Drilling Time                (s):  33.78

COMPUTATIONAL
Spherical/Cylindrical           (S/C): C
Allow Fluidization              (Y/N): Y
Max Run Time                      (s):  600.
Respository Cell Length           (m):  0.004
radius, Growth rate             (m,-):  1.5, 1.01
Wellbore Cell Length              (m):  2.0
wellbore Zone Growth Rate         (-):  1.0
First wellbore Zone               (-):  10
Well Stability factor             (-):  0.05
Repository Stability factor       (-):  5.0
Mass Diffusion factor             (-):  0.0001
Momentum Diffusion factor         (-):  0.01

INITIAL CAVITY RADIUS             (m): 0.939427
```

Figure 1. Excerpt of Modified DRSPALL Control File for Cylindrical Runs. Lines in bold differ from control files for spherical runs.

4.2.5 Creation of the Spallings Data File for CUTTINGS_S

As discussed in Lord et al. (2005) and the *Design Document for CUTTINGS_S version 6.00* (WIPP PA 2004a), the code CUTTINGS_S calculates spall volumes for the PA drilling intrusion scenarios from the DRSPALL calculated spall volumes. A spall volume is calculated for each PA vector and at each of a set of discrete times and locations (unique pressure) within the repository for each drilling intrusion scenario.

CUTTINGS_S requires an input file that contains the spallings volumes calculated by DRSPALL for each vector and DPS for one replicate (WIPP PA 2004a, 2004b). The procedure implemented in the CRA-2004 PABC for creating this file differed from the method used in the CRA-2004, which was a manual process. This section details how this spallings data file was created for the CRA-2004 PABC.

The first step involved a series of SUMMARIZE runs. The code SUMMARIZE was run using the DRSPALL data from the spherical runs, once per DPS and replicate combination. Figure 21 in Appendix B displays the SUMMARIZE input file for replicate 1, DPS 1 as an example. A fragment of the corresponding output table is shown in Figure 2. The entire file, SUM_DRS_CRA1BC_SPHERE_R1_P1.TBL, is stored in the SCMS library PACMS2:[CMS_CRA1BC.CRA1BC_DRS] in the CRA1BC-0 class.

```
vector,time REPOSTCK CAVRAD   SPLVOL2
 ,[P:9],[H],[H]
      .
      .
      .
 9.500000E+01  0.000000E+00  1.143407E+00  0.000000E+00  0.000000E+00
 9.600000E+01  0.000000E+00  1.326485E+00  0.000000E+00  0.000000E+00
 9.700000E+01  0.000000E+00  1.035926E+00  0.000000E+00  0.000000E+00
 9.800000E+01  0.000000E+00  1.232365E+00  0.000000E+00  0.000000E+00
 9.900000E+01  0.000000E+00  1.728251E+00  0.000000E+00  0.000000E+00
 1.000000E+02  0.000000E+00  1.010548E+00  0.000000E+00  0.000000E+00

 1.000000E+00  2.000000E+00  1.520348E+00  1.100081E-01  0.000000E+00
 2.000000E+00  2.000000E+00  1.071428E+00  1.100081E-01  0.000000E+00
 3.000000E+00  2.000000E+00  1.092112E+00  1.100081E-01  0.000000E+00
 4.000000E+00  2.000000E+00  9.151131E-01  1.100081E-01  0.000000E+00
 5.000000E+00  2.000000E+00  1.242678E+00  1.100081E-01  0.000000E+00
      .
```

Figure 2. Fragment of SUMMARIZE Output File for Spherical DRSPALL Run - Replicate 1, DPS 1.

The resulting output file (Figure 2) contains data for the variables REPOSTCK, CAVRAD, and SPLVOL2 at a set of discrete set of times for each vector of a DPS. The output contains two header lines followed by a blank line. The first header line lists the CAMDAT variable names of the data contained in the file: vector, time, REPOSTCK, CAVRAD, and SPLVOL2. The second header line contains information pertaining to the type of CAMDAT variable listed in line 1. The data following the header lines are grouped in sections containing 100 lines and five columns. The first column contains the vector number of the DRSPALL run, the second column contains a time (multiples of 2 seconds), the third column contains the repository height for each vector (constant for all times), the fourth column contains the value of CAVRAD calculated by DRSPALL at the time in the second column for the vector in the first column, and the fifth column contains the value of SPLVOL2 calculated by DRSPALL for the same time and vector. Each group of 100 lines has the same time value.

A second set of SUMMARIZE runs was performed using the output from the DRSPALL cylindrical exception runs. SUMMARIZE was run an additional six times, once each for DPSs 3 and 4 of replicates 1, 2, and 3. The output from these runs contained the accumulated spall volume, SPLVOL2, calculated at 600 seconds for the cylindrical exception DRSPALL runs. Figure 22 in Appendix B lists the SUMMARIZE input file for Replicate 1, DPS 3 as an example, and Figure 3 shows the output resulting from this input file.

```
vector,time SPLVOL2
 ,[H]
 5.100000E+01  6.000000E+02  6.046141E-
01
 5.900000E+01  6.000000E+02  5.950286E-
```

Figure 3. SUMMARIZE Output file for DRSPALL Cylindrical Run - Replicate 1, DPS 3.

The final step in the creation of the spallings data files (one for each DPS) was execution of the utility MERGESPALL to combine the "summarized" results from the spherical and cylindrical runs. This utility was developed for the CRA-2004 PABC, and Appendix C documents its qualification under NP 9-1, *Analyses* (Chavez 2001). MERGESPALL works in the following manner:

1) MERGESPALL reads a SUMMARIZE output file containing the DRSPALL data from the *spherical* calculations for a single DPS. For each vector, MERGESPALL reads through all the times and finds the first time where CAVRAD exceeds REPOSTCK and writes the value of SPLVOL2 at that time to an intermediate text file. IF CAVRAD does not exceed REPOSTCK, MERGESPALL records the value of SPLVOL2 at the final time. For all vectors, MERGESPALL also writes the final time listed in the SUMMARIZE output file.

2) MERGESPALL reads the SUMMARIZE output file containing SPLVOL2 quantities from the *cylindrical* exception runs for the same DPS (if the file exists). For all of the vectors whose CAVRAD value exceeded its REPOSTCK value, MERGESPALL adds the SPLVOL2 quantity from the cylindrical run to the corresponding spherical SPLVOL2 quantity. If MERGESPALL does not find an SPLVOL2 value for a vector that requires one, an error message is logged in the log output file.

3) MERGESPALL checks the output directory to see if a file already exists with the user specified output file name. If one does exist, it appends the data to the end of that file. MERGESPALL writes 3 columns: the vector number, a time, and the spall volume for the vector. Otherwise, MERGESPALL creates a new text output file with a three line header. The first line contains the number of vectors, the second line contains the number of DPSs, and the third line contains the initial repository pressures used for each DPS. MERGESPALL assumes four pressure scenarios with initial pressures of 10, 12, 14, and 14.8 MPa. After writing the header, MERGESPALL writes the spall data to the new output text file.

For the CRA-2004 PABC MERGESPALL was executed four times per replicate (data for the 4 DPS are merged) for a total of three separate spallings data files (one for each replicate). Note that the CRA-2004 used the same spallings data file for all three replicates and that the procedure for creation of the spallings data file for CUTTINGS_S detailed in this section is unique to the CRA-2004 PABC.

4.3 Run Control

Run control for this analysis is documented in Long and Kanney (2005).

5.0 DRSPALL Results

The final spallings volumes calculated by DRSPALL and MERGESPALL for the CRA-2004 PABC are listed in Table 14, Table 15, and Table 16 of Appendix D – DRSPALL Calculated Spall Volumes The tables correspond to the spallings data files MERGESPALL_DRS_CRA1BC_R1.OUT, MERGESPALL_DRS_CRA1BC_R2.OUT, and MERGESPALL_DRS_CRA1BC_R3.OUT, respectively, which are stored in the SCMS library PACMS2:[CMS_CRA1BC.CRA1BC_DRS] in the class CRA1BC-0. These volumes were calculated by the procedures outlined in Section 4.2.4 and Section 4.2.5. All spallings volumes statistics presented in the following sections were calculated using these volumes which represent the volumes after processing by MERGESPALL and not the volumes listed in the DRSPALL output files.

5.1 DPS 1 Results

For DPS 1, the initial repository pressure was set to 10 MPa. All DPS 1 DRSPALL calculations resulted in no spalling. These results are identical to what was observed in the CRA-2004, and Lord et al. (2003) explain this phenomenon by noting that the initial pressure difference between the repository and the wellbore (hydrostatic pressure of approximately 7.8 MPa) is not large enough to cause tensile failure of the waste material. As a result, no spalling can occur.

5.2 DPS 2 Results

For DPS 2 the initial repository pressure was set to 12 MPa. Table 2 lists the DRSPALL volume statistics from the CRA-2004 PABC. They are separated by replicate, but the pooled (combined replicates 1, 2 and 3) statistics are presented, as well. For the sake of comparison, the statistics from the CRA-2004 are also included. Of the CRA-2004 PABC replicates, replicate 1 had the largest individual spall volume (7.71 m^3) and largest mean volume (0.196 m^3). All three replicates yielded similar percentages of nonzero spall volume vectors (~21 %) and large (>1 m^3) spall volume vectors (~4 %).

The largest CRA-2004 PABC spall volume was approximately 10 % larger than the maximum spall volume calculated by DRSPALL for the CRA-2004 (7.00 m^3). However, the CRA-2004 DRSPALL calculations had a mean spall volume more than 40% larger than the CRA-2004 PABC mean and a slightly higher percentage of nonzero and large spall volumes (26 % and 6 %, respectively). Note that the 40% increase only amounts to 0.07 m^3.

Table 2. Statistics for DRSPALL Volumes: DPS 2.

Replicate	Maximum Volume (m^3)	Mean Volume (m^3)	Median Volume (m^3)	% of Vectors with Volumes > 0 m^3	% of Vectors with Volumes > 1 m^3
CRA-2004	7.00	0.244	0.00	26	6
PABC-POOLED	7.71	0.172	0.00	21	4
PABC-R1	7.71	0.196	0.00	21	4
PABC-R2	6.27	0.163	0.00	21	3
PABC-R3	6.86	0.157	0.00	20	4

5.2.1 Exception Runs- Increased Run Time

As discussed in Section 4.2.5, the cavity radius (CAVRAD) is the key indicator for determining when the spallings process has ceased. Table 3 lists the vectors that had CAVRAD values that increased during the final 100 seconds of the DRSPALL simulation, and Figure 4, Figure 5 and Figure 6 plot the DPS 2 cavity radii for all vectors versus time for the CRA-2004 PABC. These vectors were rerun with a drilling time of 1500 seconds. Figure 7 indicates that CAVRAD did not increase after 1000 seconds for the vectors that were rerun.

Table 3. Vectors with Increasing CAVRAD Values after 500 s- DPS 2.

Replicate 1 Vectors	Replicate 2 Vectors	Replicate 3 Vectors
V032	V041	V021
V037	V058	V025

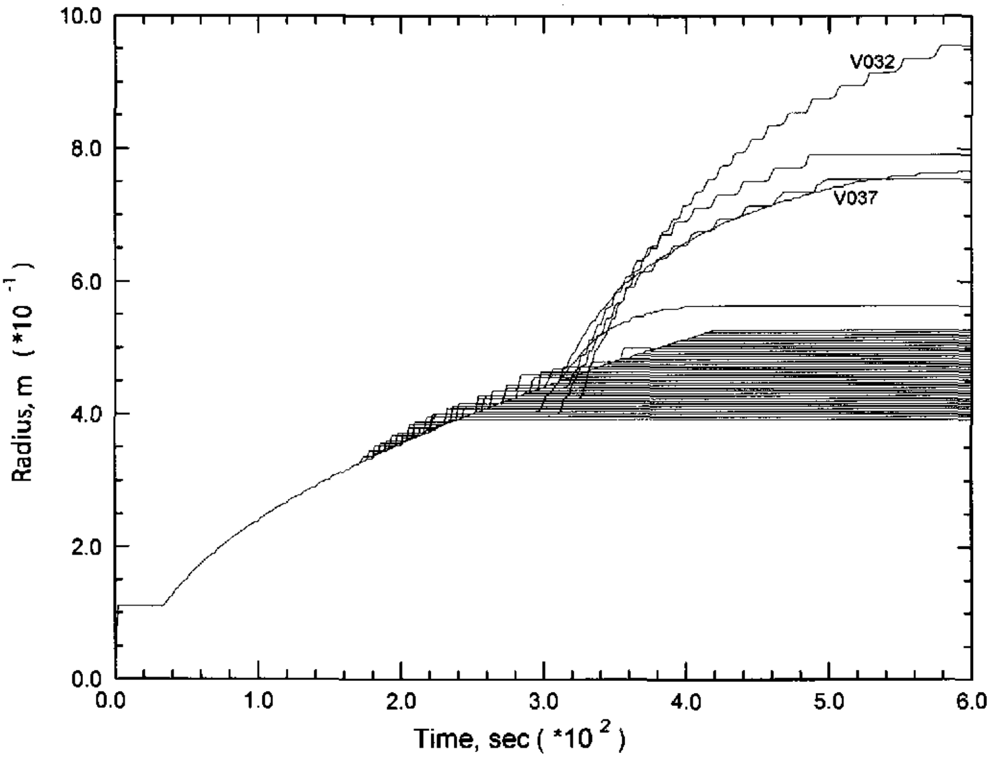

Figure 4. Cavity Radius Versus Time: Replicate 1 DPS 2.

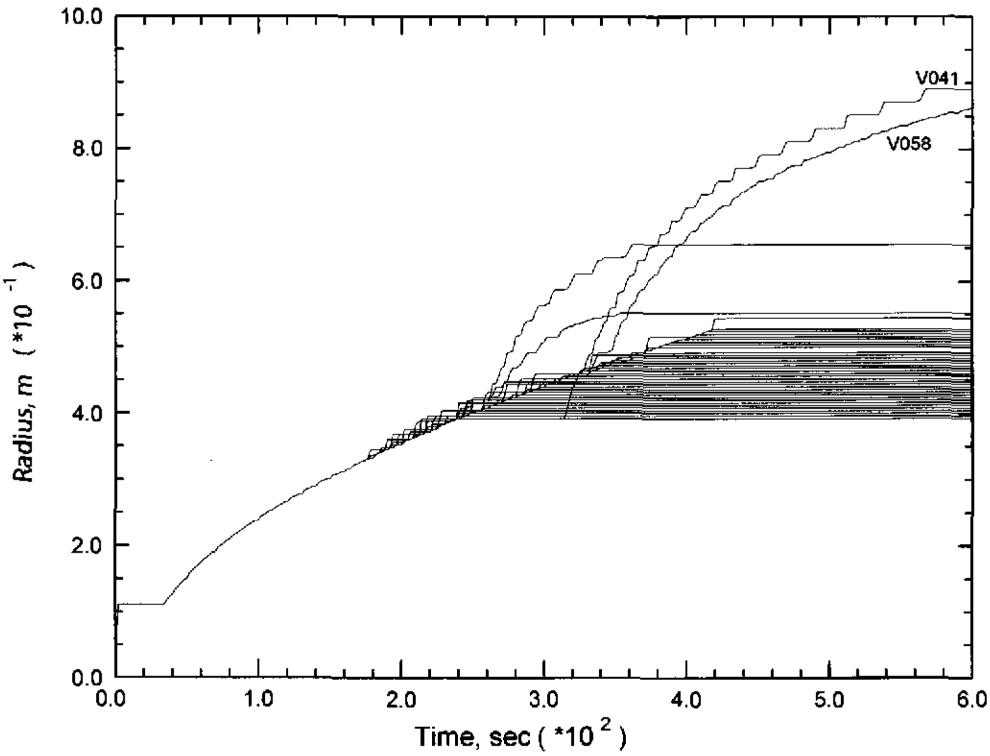

Figure 5. Cavity Radius Versus Time: Replicate 2 DPS 2.

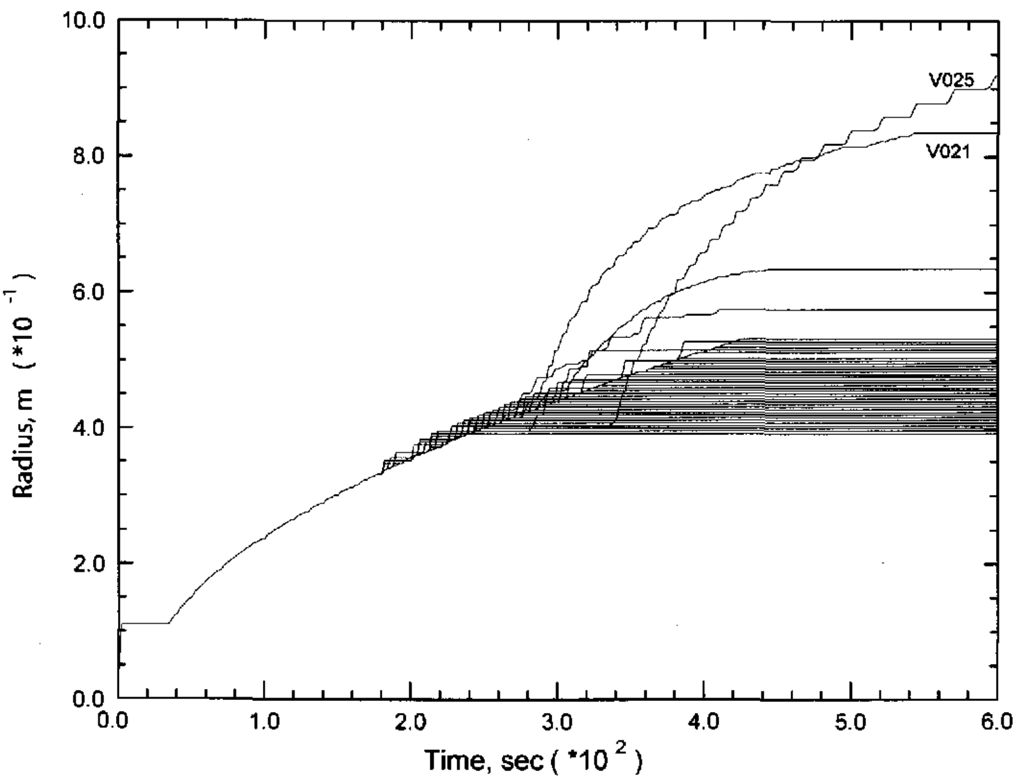

Figure 6. Cavity Radius Versus Time: Replicate 3 DPS 2.

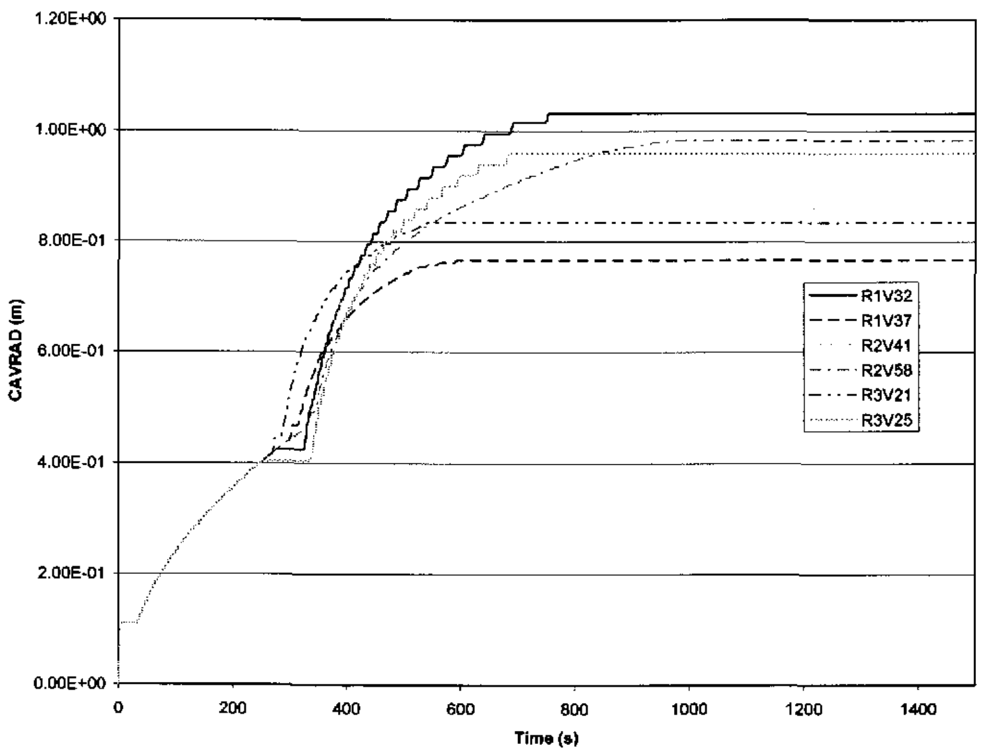

Figure 7. Cavity Radius Versus Time: Extended Time Runs for DPS 2.

5.2.2 Exception Runs- Cylindrical Model Restarts

For the CRA-2004 PABC, CAVRAD did not exceed REPOSTCK for any of the DPS 2 runs, so no DPS 2 runs were restarted using the cylindrical model.

5.3 DPS 3 Results

For DPS 3 the initial repository pressure was set to 14 MPa. Table 4 lists the DRSPALL volume statistics from the CRA-2004 PABC. They are separated by replicate, and the pooled statistics are presented, as well. For the sake of comparison, the statistics from the CRA-2004 are also included. Of the CRA-2004 PABC replicates, replicate 1 had the largest individual spall volume (11.8 m^3) and largest mean volume (0.745 m^3). All three replicates yielded similar percentages of nonzero spall volume vectors (~76 %), and the percentages of large spall volume vectors ranged from 11% to 16%.

The CRA-2004 mean spall volume exceeds the CRA-2004 PABC mean spall volume by approximately 20 % (0.13 m^3). The largest DPS 3 spall volume from the CRA-2004 is 9.45 m^3, and the largest DPS 3 spall volume from the CRA-2004 PABC is 11.8 m^3. The CRA-2004 had a slightly higher percentage on nonzero spall vectors (82% versus 76%), and 18% of the CRA-2004 vectors yielded spall volumes greater than 1 m^3, whereas 13% of the CRA-2004 PABC vectors resulted in spall volumes exceeding 1 m^3.

Table 4. Statistics for DRSPALL Volumes: DPS 3.

Replicate	Maximum Volume (m^3)	Mean Volume (m^3)	Median Volume (m^3)	% of Vectors with Volumes > 0 m^3	% of Vectors with Volumes > 1 m^3
CRA-2004	9.45	0.793	0.200	82	18
PABC-POOLED	11.8	0.665	0.160	76	13
PABC-R1	11.8	0.745	0.162	76	13
PABC-R2	7.72	0.530	0.156	77	11
PABC-R3	8.86	0.721	0.166	76	16

5.3.1 Exception Runs- Increased Run Times

Table 5 lists the vectors that had CAVRAD values that increased during the final 100 seconds of the DRSPALL simulation, and Figure 8, Figure 9, and Figure 10 plot the DPS 3 cavity radii for all vectors versus time for the CRA-2004 PABC. Of these vectors, only vector 37 of replicate 1, vector 58 of replicate 2, and vector 21 of replicate 3 were rerun with a drilling time of 1500 seconds. The other vectors listed in Table 5 were not rerun because their respective CAVRAD values exceeded their respective repository height (REPOSTCK) values within the first 600 seconds of the simulation, hence requiring restarting them using the cylindrical model. These vectors are addressed in Section 5.3.2.

Figure 11 indicates that CAVRAD did not increase after 1000 seconds for the vectors that were rerun with increased run time.

Table 5. Vectors with Increasing CAVRAD Values after 500 s- DPS 3.

Replicate 1 Vectors	Replicate 2 Vectors	Replicate 3 Vectors
V032	V041	V021+
V036	V058+	V025
V037+		
V042		

+Rerun with increased run time.

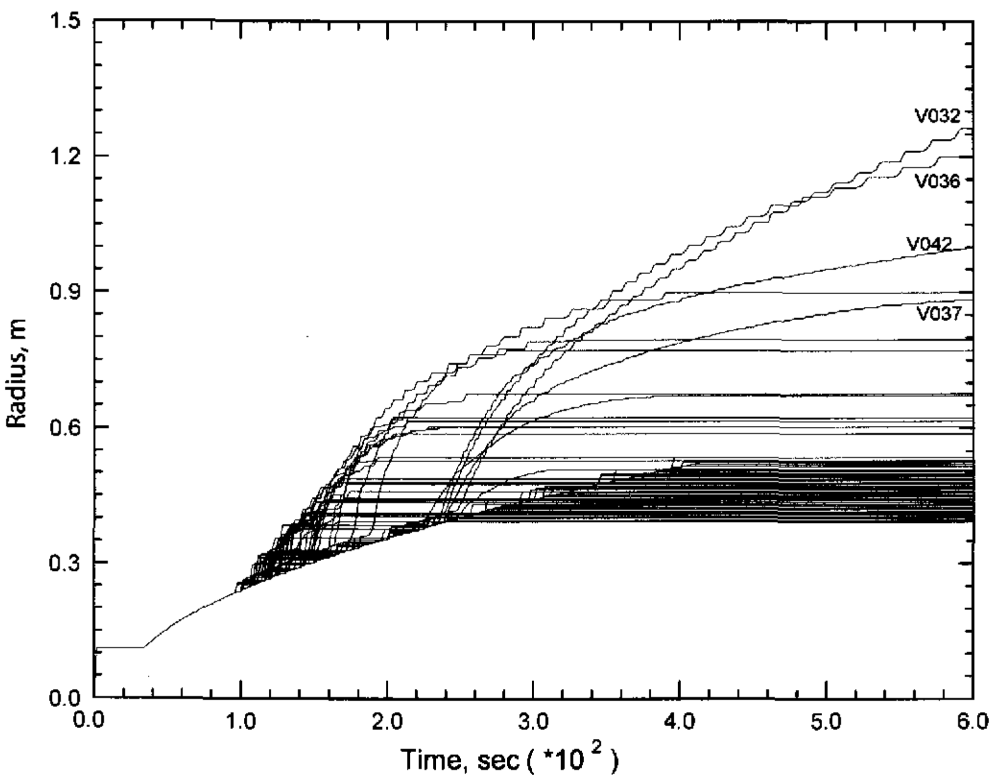

Figure 8. Cavity Radius Versus Time: Replicate 1 DPS 3.

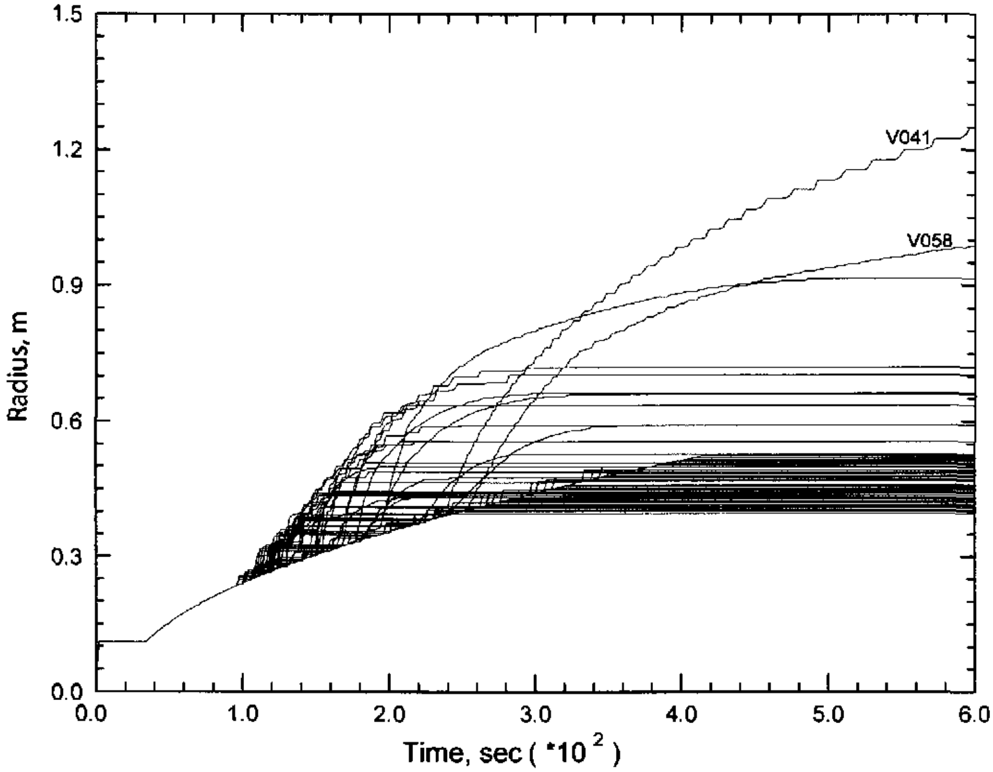

Figure 9. Cavity Radius Versus Time: Replicate 2 DPS 3.

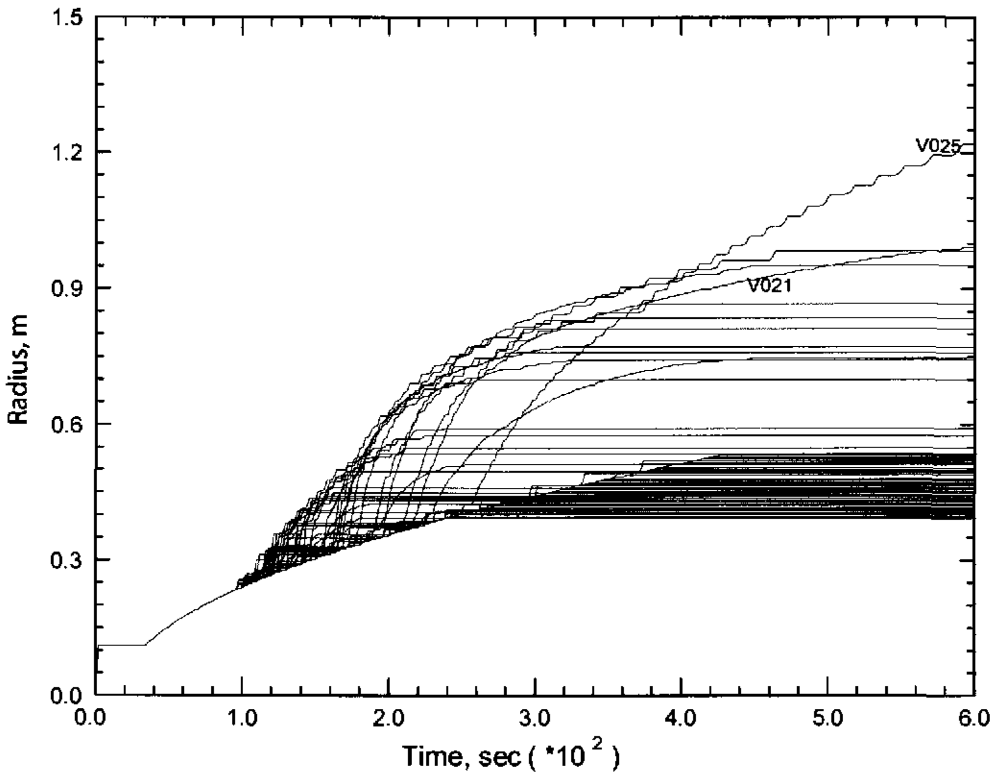

Figure 10. Cavity Radius Versus Time: Replicate 3 DPS 3.

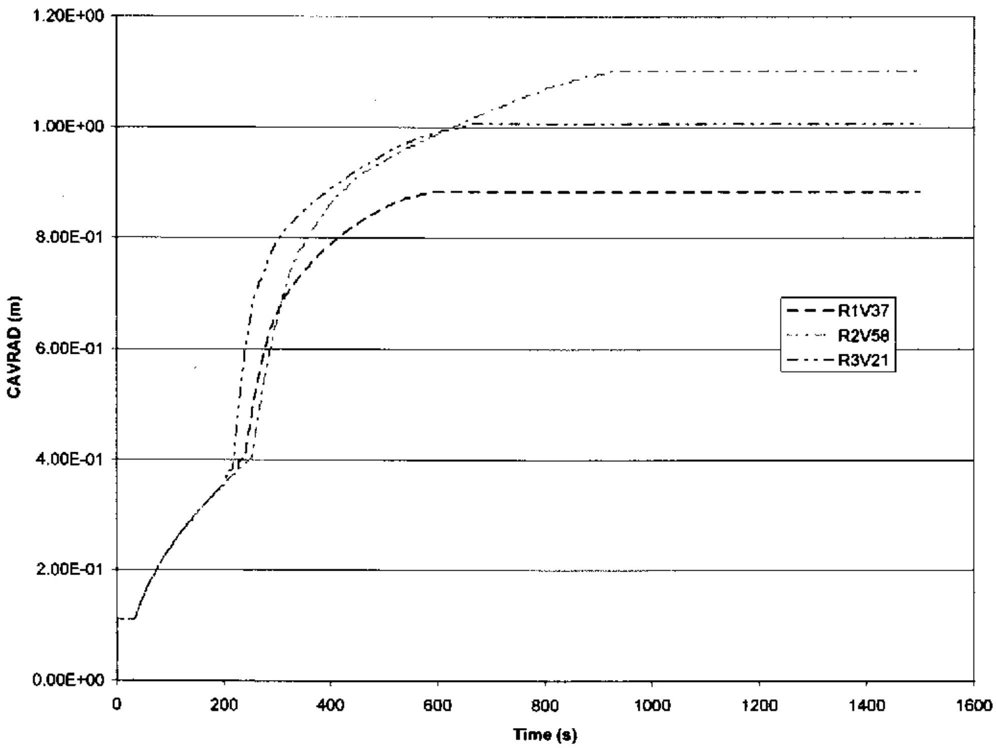

Figure 11. Cavity Radius Versus Time: Extended Run times for DPS 3.

5.3.2 Exception Runs- Cylindrical Model Restarts

Table 6 lists the vectors that were restarted using the cylindrical model and the values of REPOSTCK and CAVRAD after 600 seconds using the spherical model. Additionally, the final spall volume calculated for each vector is broken down into the contributions from the spherical model run and the cylindrical model restart.

Table 6. DPS 3 Cylindrical Model Restarts.

Replicate-Vector	REPOSTCK (m)	Final CAVRAD (m)	Spherical Volume (m^3)	Cylindrical Volume (m^3)	Total Volume (m^3)
R1- V032	1.10	1.26	9.63	1.92	11.5
R1- V036	1.17	1.20	11.2	0.662	11.8
R1- V042	0.958	0.999	7.16	0.00	7.16
R2- V041	0.920	1.25	6.58	0.530	7.11
R3- V025	0.987	1.22	7.72	1.14	8.86
R3- V036	0.950	0.983	7.29	0.00	7.29

5.4 DPS 4 Results

For DPS 4 the initial repository pressure was set to 14.8 MPa. Table 7 lists the DRSPALL volume statistics from the CRA-2004 PABC. For the sake of comparison, the statistics from the CRA-2004 are also included. Of the CRA-2004 PABC replicates, replicate 1 had the largest individual spall volume (14.5 m^3) and largest mean volume (1.08 m^3), and replicate 3's mean volume was only slightly smaller at 1.07 m^3. All three replicates yielded similar percentages of nonzero spall volume vectors (~79 %), and the percentages of large spall volume vectors ranged from 16% to 23%.

The CRA-2004 mean spall volume exceeded the CRA-2004 PABC mean spall volume by approximately 10 % (0.1 m^3). The largest DPS 4 spall volume from the CRA-2004 was 12.1 m^3, and the largest DPS 4 spall volume from the CRA-2004 PABC was 14.5 m^3. For both analyses, approximately 80% of the runs result in nonzero spall volumes, but 26% of the CRA-2004 vectors yielded spall volumes larger than 1 m^3, as compared to 20% of the CRA-2004 PABC vectors.

Table 7. Statistics for DRSPALL Volumes: DPS 4.

Replicate	Maximum Volume (m^3)	Mean Volume (m^3)	Median Volume (m^3)	% of Vectors with Volumes > 0 m^3	% of Vectors with Volumes > 1 m^3
CRA-2004	12.1	1.09	0.343	82	26
PABC-POOLED	14.5	0.978	0.318	79	20
PABC-R1	14.5	1.08	0.320	79	22
PABC-R2	9.89	0.789	0.327	79	16
PABC-R3	11.9	1.07	0.312	78	23

5.4.1 Exception Runs- Increased Run Times

Table 8 lists the vectors that had CAVRAD values that increased during the final 100 seconds of the DRSPALL simulation, and Figure 12, Figure 13, and Figure 14 plot the DPS 4 cavity radii for all vectors versus time for the CRA-2004 PABC. Of these vectors, only vector 37 of replicate 1, vector 58 of replicate 2, and vectors 21 and 22 of replicate 3 were rerun with a drilling time of 1500 seconds. The other vectors listed in Table 8 were not rerun because their respective CAVRAD values exceeded their respective repository height (REPOSTCK) values within the first 600 seconds of the simulation. These vectors were restarted with the cylindrical model and are addressed in Section 5.4.2. Figure 15 indicates that CAVRAD did not increase after 1000 seconds for the vectors that were rerun.

Table 8. Vectors with Increasing CAVRAD Values after *500* s- DPS 4.

Replicate 1 Vectors	Replicate 2 Vectors	Replicate 3 Vectors
V032	V041	V021[+]
V036	V058[+]	V022[+]
V037[+]		V025
V042		V036
V059		

[+]rerun with increased run time.

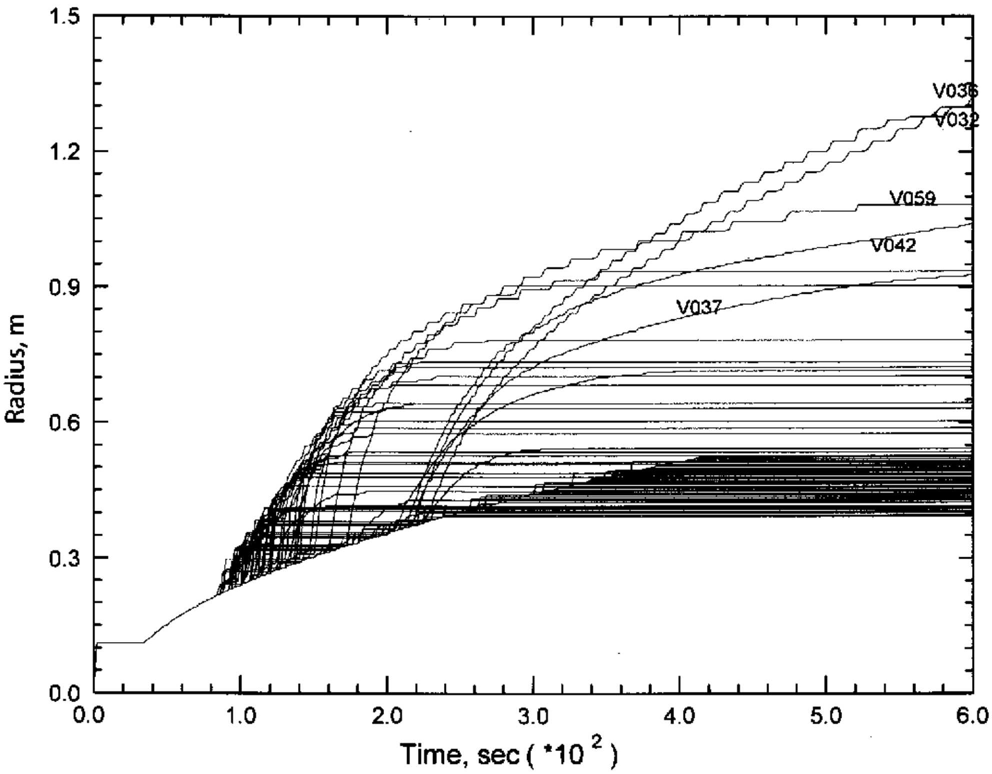

Figure 12. Cavity Radius Versus Time: Replicate 1 DPS 4.

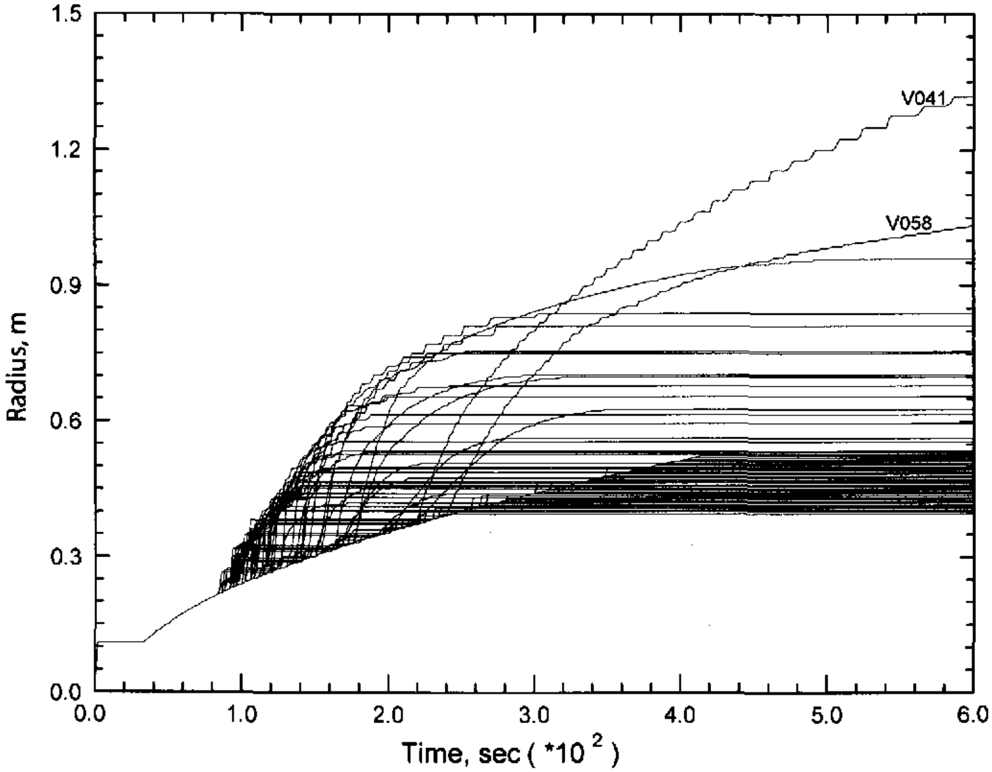

Figure 13. Cavity Radius Versus Time: Replicate 2 DPS 4.

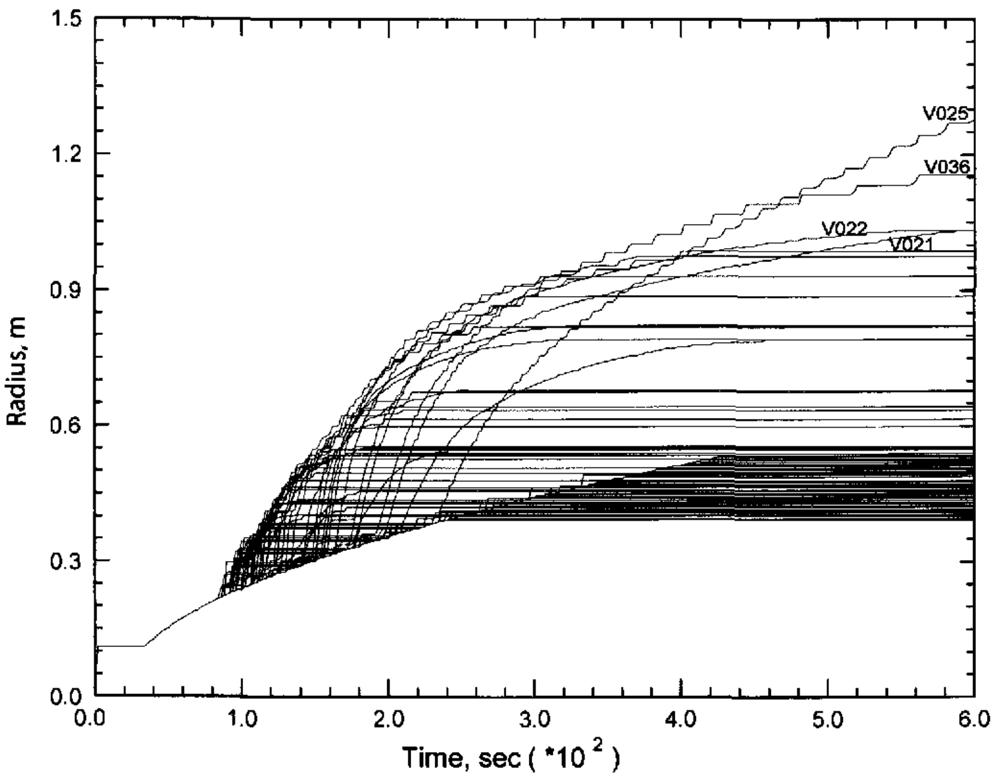

Figure 14. Cavity Radius Versus Time: Replicate 3 DPS 4.

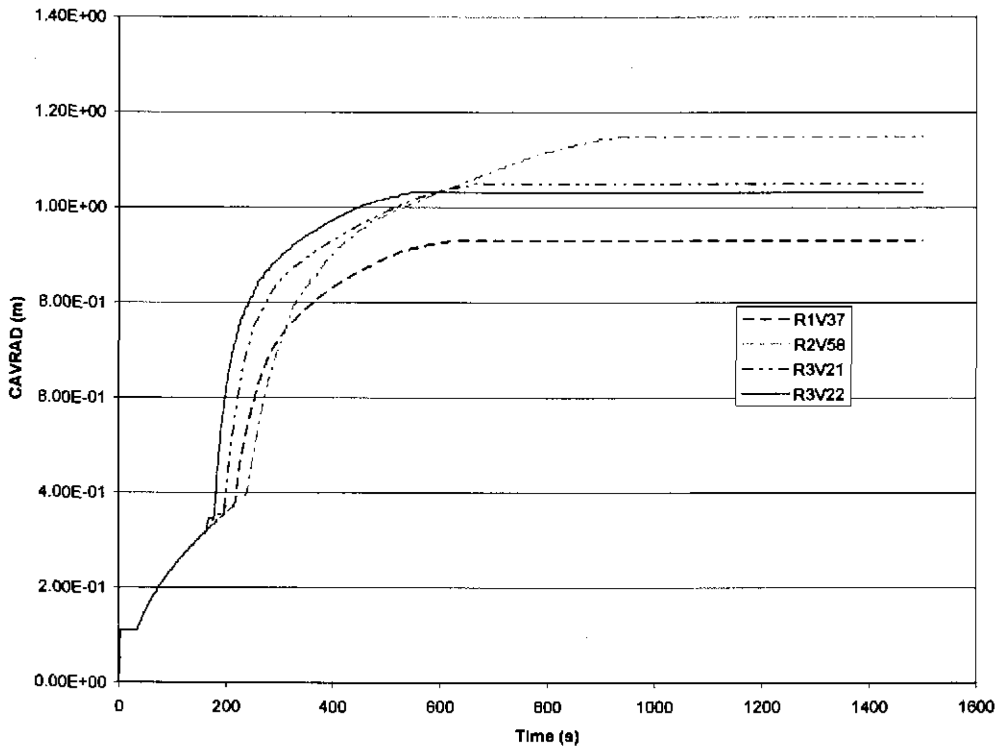

Figure 15. Cavity Radius Versus Time: Extended Run times for DPS 4.

5.4.2 Exception Runs- Cylindrical Model Restarts

Table 9 lists the DPS 4 vectors that were restarted using the cylindrical model and the values of REPOSTCK and CAVRAD at the end of each of these runs using the spherical model. Additionally, the spall volume for each vector is broken down into the contributions from the spherical model run and the cylindrical model restart.

Table 9. DPS 4 Cylindrical Model Restarts.

Replicate - Vector	REPOSTCK (m)	Final CAVRAD (m)	Spherical Volume (m^3)	Cylindrical Volume (m^3)	Total Volume (m^3)
R1- V032	1.10	1.30	9.89	4.65	14.5
R1- V036	1.17	1.32	11.3	0.662	11.9
R1- V042	0.958	1.04	7.24	0.00	7.24
R1- V059	1.06	1.08	9.28	0.605	9.89
R2- V041	0.920	1.32	6.62	3.27	9.89
R3- V001	0.935	0.987	7.25	0.538	7.79
R3- V025	0.987	1.28	7.67	4.23	11.9
R3- V036	0.950	1.16	7.46	0.546	8.01

It should be noted that vectors 32, 36, and 42 of replicate 1, vector 41 of replicate 2, and vectors 25 and 36 of replicate 3 were restarted with the cylindrical model for both DPSs 3 and 4. If DRSPALL recorded SPLVOL2 values at the precise time that CAVRAD equaled REPOSTCK, the spherical volumes in Table 6 and Table 9 for corresponding vectors should be equal because the hemispherical cavities that contribute to the spalling calculations would have the same radii (REPOSTOCK) for DPS 3 and DPS 4. However, SPLVOL2 was recorded only at discrete times, so the spherical volumes are not precisely equal. This analysis has chosen to handle this limitation in a conservative manner. When determining the volume contribution from the spherical run, MERGESPALL selected the SPLVOL2 value at the first time when CAVRAD *exceeded* REPOSTCK and then added the volume contribution from the cylindrical run. Thus, the SPLVOL2 volumes reported are actually slightly larger than the volume of the cavity when CAVRAD equals REPOSTCK.

5.4.3 Scenario 4 Scatter Plots

This section presents scatter plots of DPS 4 spall volumes calculated by DRSPALL versus the uncertain sampled parameters, waste porosity, waste permeability, waste particle diameter, and waste tensile strength. The final SPLVOL2 values have been pooled and are plotted against each input variable on a vector by vector basis. The final SPLVOL2 numbers correspond to numbers given in Table 14, Table 15, and Table 16, in Appendix D and the sampled parameters match the values given in Table 11, Table 12, and Table 13 in Appendix A. Scatter plots can give a rough visual indication of how these parameters affect the resulting spall volumes. DPS 4 plots are shown because the high pressure results in fewer zero spallings vectors than the lower pressures. Scatter plots for DPS 2 and 3 yield similar conclusions.

Figure 16 indicates that the largest spall volumes occur when waste permeability is less than 1.00E-13 m^2, but larger permeability values result in a higher frequency of nonzero spall volumes. This observation can be explained as follows: the higher permeability values that were sampled result in less tensile stresses and less tensile failure but promote fluidization. Lower permeability leads to greater tensile stresses and tensile failure, but failed material may not be able to fluidize at this low permeability. Smaller particle diameter values (see Figure 17) tend to result in larger spall volumes and higher frequency of nonzero spall volumes. This can be explained by the particle diameter's impact on fluidization velocities: smaller particle diameters lead to lower minimum fluidization velocities (see Lord et al. 2004). No obvious correlations could be established between waste tensile strength and spall volume over the small sampled range of tensile strengths (Figure 18); Lord et al. (2003) reached this same conclusion. Lord et al. (2003) concluded that lower waste porosity values tended to correlate with larger spallings volumes for the CRA-2004. For the CRA-2004 PABC results, such a correlation is not obvious (Figure 19), but these results neither confirm nor refute the conclusion made in Lord et al. (2003). With the possible exception of the waste porosity, the conclusions in this section are consistent with those made in Lord et al. (2003).

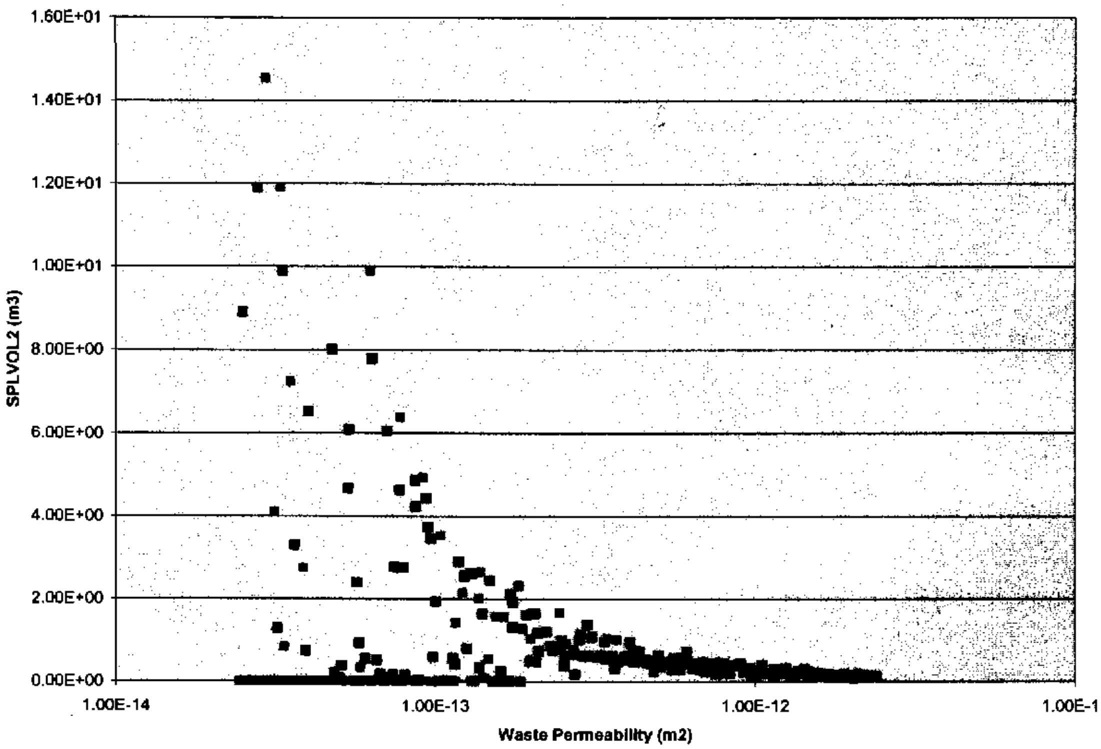

Figure 16. Scatter Plot of Pooled Vectors: Waste Permeability vs SPLVOL2.

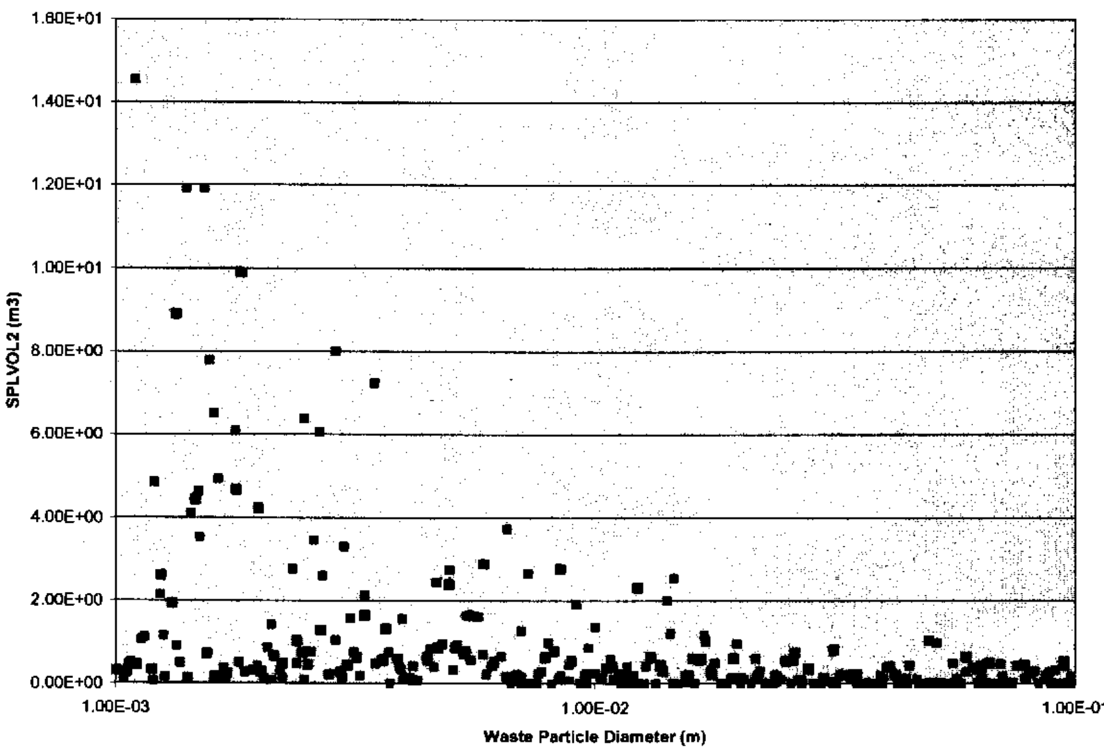

Figure 17. Scatter Plot of Pooled Vectors: Waste Particle Diameter vs. SPLVOL2.

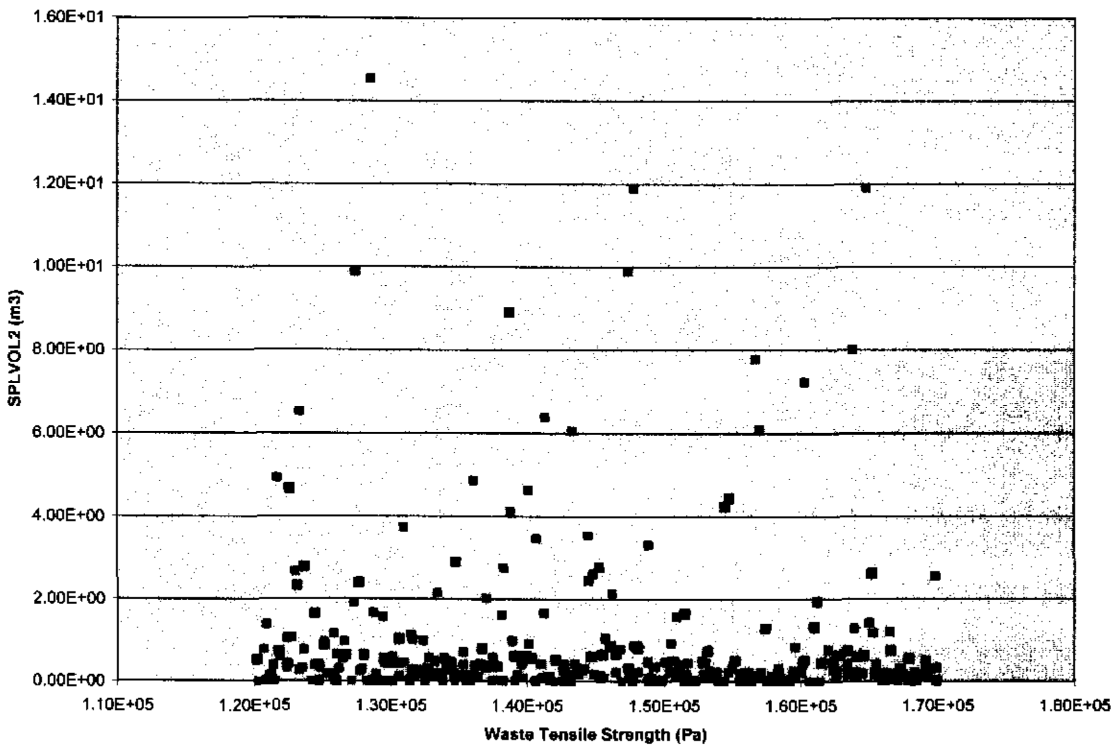

Figure 18. Scatter Plot of Pooled Vectors: Waste Tensile Strength vs. SPLVOL2.

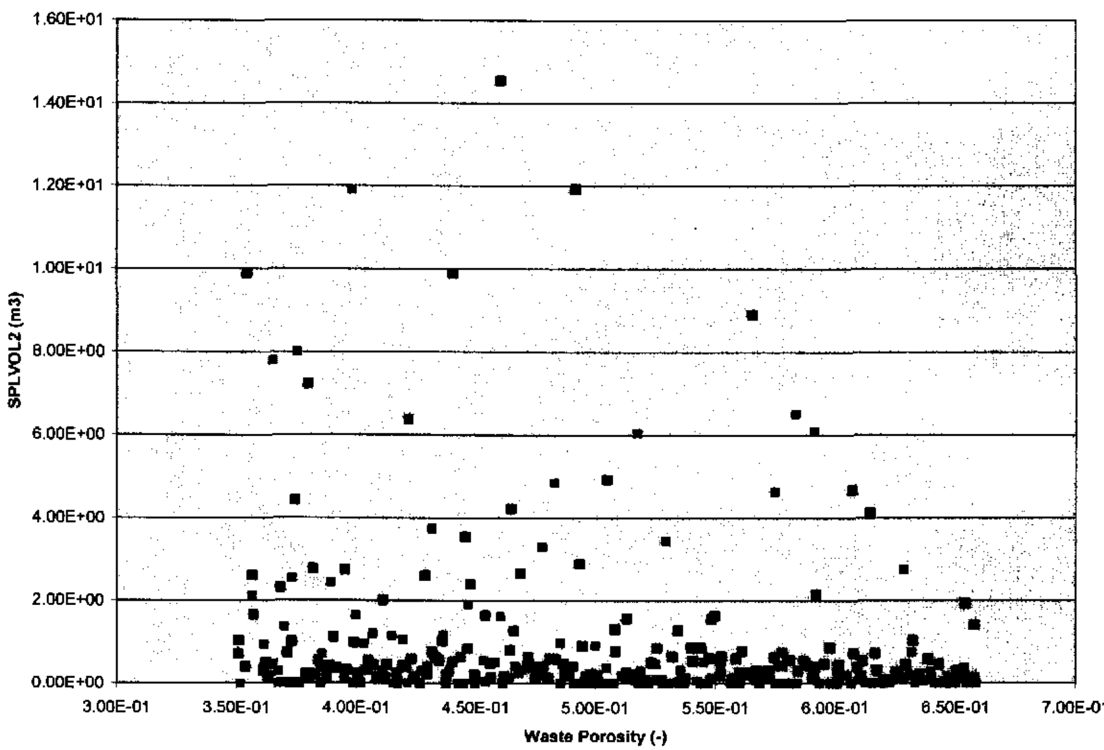

Figure 19. Scatter Plot of Pooled Vectors: Waste Porosity vs. SPLVOL2.

6.0 Summary

The CRA-2004 PABC introduced four procedural changes from CRA-2004 for calculating spallings releases (see Section 3.0): (1) the number of spallings vectors was increased from one replicate of fifty vectors to three replicates of 100 vectors each; (2) spallings parameters were sampled in the same Latin hypercube samples as the rest of the sampled parameters for the CRA-2004 PABC codes; (3) use of the utility MERGESPALL was added; and (4) use of the parameter SPALLMOD:RNDSPALL was eliminated. Of these changes, the number of spallings calculations had the greatest impact on the DRSPALL calculations and this impact was procedural – results did not change signficantly. Whereas the CRA-2004 consisted of one replicate of fifty DRSPALL vectors and four DRSPALL pressure scenarios per vector, a larger set of DRSPALL calculations were performed for the CRA-2004 PABC: three replicates consisting of 100 vectors each and four DRSPALL pressure scenarios were calculated for each vector. The end result was a set of 1,200 DRSPALL calculations.

The maximum CRA-2004 PABC spallings volumes for all DPS were slightly larger than the respective CRA-2004 maximum spallings volumes (Table 10). Since the CRA-2004 PABC had a larger sample size, there is an increased probability of observing large spallings volumes. That is, the likelihood of coupling parameters that lead to material failure, fluidization, and, ultimately, large spall volumes increased for the CRA-2004 PABC because of the larger set of vectors and a greater number of extreme parameter values. Despite these differences in extreme values, the shape of the spallings volume distributions remains similar (Figure 20).

In general, the spallings volumes calculated by DRSPALL for the CRA-2004 PABC were slightly smaller than the spallings volumes from the CRA-2004 (see Table 10). All DPSs had vectors with no spalling in both analyses, but CRA-2004 mean spallings volumes were approximately 40% larger for DPS 2, 20% larger for DPS 3, and 10% larger for DPS 4. The authors hypothesize that it was simply the stochastic nature of sampling that lead to mean spall volumes for the CRA-2004 that were larger than those of the CRA-2004 PABC.

Table 10. Summary Spallings Statistics.

Pressure Scenario	CRA-2004		CRA-2004 PABC	
	Mean Spall Volume (m^3)	Max. Spall Volume (m^3)	Mean Spall Volume (m^3)	Max. Spall Volume (m^3)
DPS 2- 12 MPa	0.244	7.00	0.172	7.71
DPS 3- 14 MPa	0.793	9.45	0.665	11.8
DPS 4- 14.8 MPa	1.09	12.1	0.978	14.5

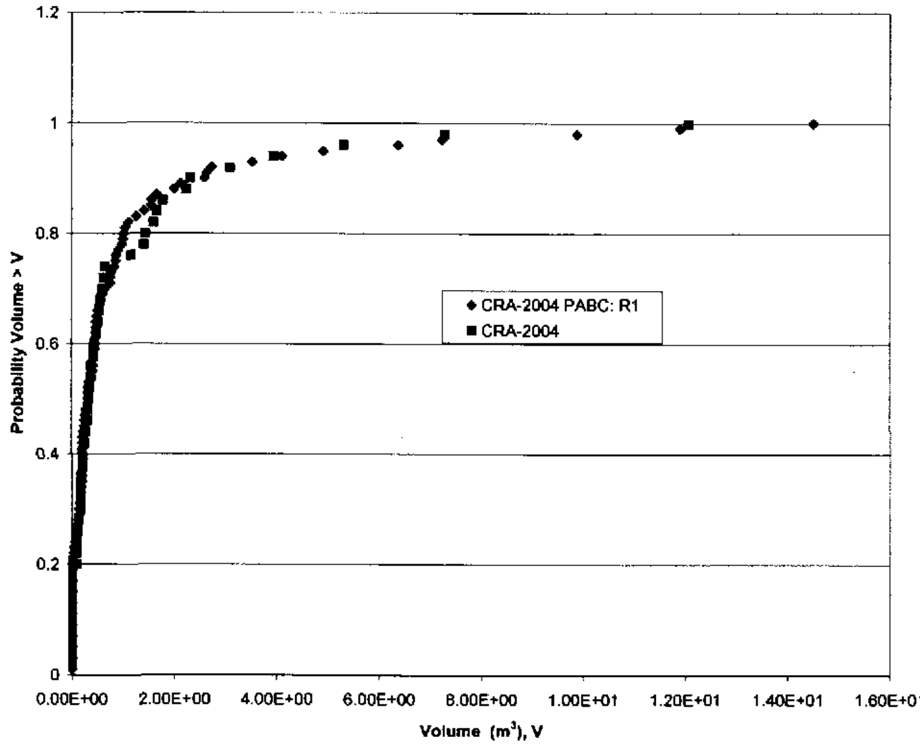

Figure 20. Distribution of Spallings Volumes vs. Cumulative Probability for DPS 4

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8.0 Appendix A - Sampled Parameters

Table 11, Table 12, and Table 13 list the DRSPALL sampled parameters from the Latin hypercube samples for the CRA-2004 PABC.

Table 11. DRSPALL Sampled Parameters from Replicate 1 of the CRA-2004 PABC.

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
1	5.12E-13	1.35E+05	4.63E-03	6.09E-01
2	1.04E-13	1.45E+05	1.50E-03	4.46E-01
3	6.20E-13	1.34E+05	1.78E-02	4.56E-01
4	3.44E-13	1.46E+05	4.96E-02	3.51E-01
5	4.70E-14	1.54E+05	7.33E-02	5.22E-01
6	1.08E-13	1.59E+05	3.09E-02	4.54E-01
7	6.92E-14	1.43E+05	2.86E-02	5.47E-01
8	5.84E-13	1.70E+05	1.94E-03	5.67E-01
9	1.92E-12	1.56E+05	2.69E-02	5.27E-01
10	6.56E-14	1.69E+05	3.64E-02	3.76E-01
11	3.93E-13	1.69E+05	1.81E-03	5.88E-01
12	1.76E-13	1.27E+05	9.30E-02	5.57E-01
13	5.67E-13	1.53E+05	6.37E-02	4.07E-01
14	1.99E-13	1.22E+05	2.88E-03	6.33E-01
15	2.24E-12	1.45E+05	4.29E-03	6.37E-01
16	7.81E-13	1.51E+05	5.92E-02	5.65E-01
17	6.94E-13	1.41E+05	6.10E-03	4.20E-01
18	2.32E-12	1.49E+05	2.05E-02	5.26E-01
19	9.73E-13	1.63E+05	1.93E-02	6.53E-01
20	8.93E-14	1.30E+05	1.34E-02	6.07E-01
21	2.08E-13	1.50E+05	6.98E-02	3.65E-01
22	4.81E-14	1.63E+05	6.88E-03	4.77E-01
23	1.05E-12	1.58E+05	1.01E-03	4.04E-01
24	1.58E-12	1.55E+05	1.58E-02	3.83E-01
25	1.38E-12	1.35E+05	1.21E-02	5.01E-01
26	1.22E-12	1.55E+05	9.09E-02	3.62E-01
27	2.81E-13	1.32E+05	5.15E-02	3.99E-01
28	2.46E-13	1.29E+05	3.31E-03	3.57E-01
29	2.28E-13	1.48E+05	2.07E-03	5.44E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
30	1.87E-12	1.36E+05	4.45E-02	5.37E-01
31	3.52E-13	1.33E+05	5.51E-03	5.81E-01
32	2.94E-14	1.29E+05	1.10E-03	4.60E-01
33	7.81E-14	1.41E+05	2.47E-03	4.22E-01
34	3.11E-13	1.32E+05	1.15E-03	3.91E-01
35	4.26E-13	1.21E+05	2.56E-03	4.32E-01
36	3.28E-14	1.65E+05	1.53E-03	4.92E-01
37	3.14E-14	1.39E+05	1.43E-03	6.15E-01
38	7.59E-13	1.64E+05	2.38E-02	6.26E-01
39	9.57E-14	1.37E+05	2.26E-02	5.35E-01
40	1.88E-13	1.64E+05	7.02E-03	4.66E-01
41	6.33E-13	1.66E+05	1.28E-02	4.78E-01
42	3.51E-14	1.60E+05	3.47E-03	3.80E-01
43	6.62E-13	1.24E+05	2.20E-03	6.18E-01
44	5.28E-13	1.53E+05	2.39E-03	4.87E-01
45	1.64E-13	1.29E+05	3.98E-03	5.49E-01
46	1.69E-13	1.38E+05	2.40E-02	6.50E-01
47	2.57E-13	1.40E+05	1.34E-03	4.95E-01
48	9.52E-13	1.23E+05	1.00E-02	5.60E-01
49	8.52E-14	1.26E+05	1.62E-02	6.01E-01
50	1.07E-12	1.44E+05	3.46E-02	6.11E-01
51	5.84E-14	1.25E+05	5.08E-03	5.72E-01
52	1.18E-12	1.60E+05	7.63E-03	4.17E-01
53	8.72E-13	1.40E+05	3.92E-03	3.54E-01
54	1.31E-12	1.68E+05	9.52E-03	4.50E-01
55	1.37E-13	1.37E+05	1.41E-02	4.11E-01
56	1.16E-13	1.65E+05	2.11E-03	6.58E-01
57	8.43E-13	1.21E+05	6.10E-02	4.73E-01
58	5.58E-14	1.61E+05	4.30E-02	4.86E-01
59	6.27E-14	1.47E+05	1.84E-03	4.41E-01
60	2.65E-14	1.42E+05	5.60E-02	5.84E-01
61	3.65E-14	1.66E+05	1.49E-02	3.85E-01
62	5.43E-14	1.34E+05	9.66E-02	6.41E-01
63	8.00E-14	1.52E+05	3.99E-02	5.75E-01
64	3.29E-13	1.26E+05	6.39E-03	5.32E-01
65	1.31E-13	1.45E+05	2.71E-03	4.29E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
66	2.72E-13	1.47E+05	5.40E-03	5.08E-01
67	3.86E-14	1.38E+05	4.99E-03	3.95E-01
68	4.46E-14	1.54E+05	1.14E-02	6.46E-01
69	2.77E-14	1.67E+05	8.13E-03	6.20E-01
70	1.12E-13	1.58E+05	8.39E-02	5.06E-01
71	2.01E-12	1.43E+05	1.27E-03	3.88E-01
72	3.36E-14	1.60E+05	4.55E-03	4.47E-01
73	5.06E-14	1.42E+05	6.83E-02	3.68E-01
74	4.17E-13	1.62E+05	1.07E-03	6.02E-01
75	2.90E-13	1.30E+05	1.08E-02	6.39E-01
76	1.22E-13	1.33E+05	1.24E-03	5.92E-01
77	4.42E-13	1.49E+05	3.49E-03	5.95E-01
78	1.48E-12	1.28E+05	1.71E-03	4.01E-01
79	9.18E-14	1.22E+05	1.64E-03	5.05E-01
80	2.10E-13	1.62E+05	3.73E-03	5.78E-01
81	1.12E-12	1.47E+05	5.95E-03	5.17E-01
82	1.41E-12	1.52E+05	3.95E-02	4.96E-01
83	1.72E-12	1.25E+05	1.15E-02	4.62E-01
84	2.62E-14	1.50E+05	3.58E-02	3.72E-01
85	1.38E-13	1.23E+05	7.26E-03	4.69E-01
86	2.30E-13	1.48E+05	9.71E-03	5.40E-01
87	1.55E-13	1.51E+05	3.09E-03	5.13E-01
88	7.96E-13	1.56E+05	3.25E-02	5.91E-01
89	4.58E-13	1.31E+05	8.83E-03	6.29E-01
90	2.42E-14	1.61E+05	2.12E-02	4.38E-01
91	1.59E-12	1.68E+05	4.69E-02	6.24E-01
92	3.68E-13	1.32E+05	1.71E-02	3.73E-01
93	1.47E-13	1.27E+05	2.60E-02	4.35E-01
94	4.83E-13	1.57E+05	7.99E-02	5.61E-01
95	1.80E-12	1.39E+05	7.92E-02	4.81E-01
96	7.38E-14	1.67E+05	8.50E-03	5.52E-01
97	3.99E-14	1.21E+05	5.42E-02	4.27E-01
98	7.09E-14	1.36E+05	1.84E-02	5.18E-01
99	4.20E-14	1.24E+05	2.96E-02	6.56E-01
100	2.11E-12	1.57E+05	2.97E-03	4.12E-01

Table 12. DRSPALL Sampled Parameters from Replicate 2 of the CRA-2004 PABC.

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
1	2.06E-13	1.24E+05	5.51E-03	4.54E-01
2	8.36E-13	1.44E+05	1.55E-02	6.31E-01
3	1.26E-13	1.37E+05	8.24E-03	5.61E-01
4	2.95E-13	1.39E+05	1.60E-02	5.59E-01
5	7.74E-13	1.62E+05	7.84E-02	3.89E-01
6	6.13E-13	1.22E+05	1.55E-03	3.51E-01
7	3.14E-14	1.68E+05	7.13E-02	4.02E-01
8	3.20E-14	1.57E+05	2.68E-03	5.34E-01
9	5.35E-14	1.23E+05	1.78E-03	6.07E-01
10	1.51E-13	1.52E+05	8.91E-02	4.50E-01
11	2.72E-13	1.47E+05	2.14E-03	5.53E-01
12	3.94E-14	1.63E+05	2.46E-03	6.08E-01
13	9.87E-14	1.64E+05	1.67E-02	4.23E-01
14	8.83E-14	1.25E+05	5.28E-02	5.80E-01
15	2.86E-14	1.26E+05	2.71E-02	4.99E-01
16	5.59E-13	1.40E+05	8.95E-03	4.05E-01
17	4.16E-13	1.67E+05	2.61E-02	3.71E-01
18	1.99E-13	1.55E+05	6.63E-02	3.62E-01
19	1.63E-13	1.31E+05	7.38E-02	5.44E-01
20	7.66E-14	1.48E+05	6.28E-02	5.93E-01
21	1.71E-13	1.36E+05	9.76E-02	5.30E-01
22	2.29E-13	1.25E+05	5.13E-03	5.98E-01
23	6.57E-14	1.20E+05	6.18E-03	5.23E-01
24	8.16E-13	1.58E+05	2.80E-03	6.02E-01
25	8.70E-14	1.55E+05	1.99E-03	4.65E-01
26	4.60E-13	1.62E+05	1.11E-03	5.88E-01
27	2.85E-13	1.31E+05	2.39E-03	4.36E-01
28	2.52E-14	1.41E+05	3.67E-02	6.15E-01
29	2.63E-14	1.52E+05	7.34E-03	4.61E-01
30	1.05E-12	1.37E+05	1.19E-03	3.96E-01
31	6.73E-14	1.64E+05	2.18E-02	3.63E-01
32	7.30E-13	1.30E+05	3.05E-03	3.85E-01
33	6.77E-13	1.33E+05	2.01E-03	6.25E-01
34	1.01E-13	1.61E+05	1.31E-03	6.54E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
35	6.41E-13	1.47E+05	1.00E-03	5.85E-01
36	5.70E-14	1.28E+05	4.97E-03	4.48E-01
37	5.10E-14	1.36E+05	1.06E-02	3.92E-01
38	4.58E-14	1.56E+05	1.46E-02	3.99E-01
39	9.26E-13	1.69E+05	1.06E-03	4.68E-01
40	2.11E-12	1.33E+05	2.40E-02	4.09E-01
41	3.33E-14	1.27E+05	1.82E-03	3.54E-01
42	7.45E-14	1.24E+05	8.48E-03	3.82E-01
43	3.42E-13	1.68E+05	2.51E-02	5.41E-01
44	2.01E-12	1.41E+05	6.91E-03	6.35E-01
45	2.38E-13	1.46E+05	4.72E-03	5.26E-01
46	1.75E-13	1.61E+05	3.67E-03	5.08E-01
47	4.22E-13	1.46E+05	1.31E-02	4.44E-01
48	4.15E-14	1.29E+05	6.44E-02	6.46E-01
49	5.82E-14	1.50E+05	1.19E-02	5.03E-01
50	3.59E-13	1.40E+05	1.94E-02	4.81E-01
51	3.01E-14	1.59E+05	1.89E-02	5.20E-01
52	1.15E-13	1.21E+05	4.74E-02	5.28E-01
53	1.55E-13	1.70E+05	4.46E-02	5.68E-01
54	1.29E-12	1.45E+05	3.00E-02	6.29E-01
55	6.93E-13	1.30E+05	2.53E-03	4.13E-01
56	1.38E-12	1.51E+05	1.75E-02	4.30E-01
57	5.01E-14	1.59E+05	4.18E-03	6.36E-01
58	2.49E-14	1.39E+05	1.34E-03	5.65E-01
59	2.37E-12	1.21E+05	4.12E-03	4.75E-01
60	1.89E-12	1.34E+05	1.62E-03	4.24E-01
61	4.57E-13	1.42E+05	9.48E-02	4.40E-01
62	3.72E-13	1.60E+05	2.23E-03	6.43E-01
63	5.09E-13	1.38E+05	2.79E-02	6.54E-01
64	1.06E-13	1.49E+05	4.99E-02	5.98E-01
65	4.99E-13	1.27E+05	5.93E-02	4.33E-01
66	2.24E-12	1.68E+05	1.41E-03	3.80E-01
67	1.19E-12	1.32E+05	9.63E-03	4.98E-01
68	5.85E-13	1.44E+05	1.39E-02	6.50E-01
69	8.03E-14	1.53E+05	6.57E-03	6.40E-01
70	1.41E-13	1.52E+05	3.31E-03	5.50E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
71	1.29E-13	1.65E+05	1.24E-03	3.57E-01
72	7.18E-14	1.60E+05	1.10E-02	5.17E-01
73	4.56E-14	1.58E+05	2.29E-02	3.75E-01
74	1.83E-13	1.23E+05	1.23E-02	3.68E-01
75	1.02E-12	1.43E+05	2.95E-03	4.87E-01
76	1.14E-12	1.26E+05	1.70E-03	6.58E-01
77	3.29E-13	1.63E+05	4.49E-03	4.72E-01
78	2.11E-13	1.53E+05	5.34E-03	6.17E-01
79	1.80E-12	1.42E+05	3.98E-02	5.57E-01
80	1.71E-12	1.51E+05	8.71E-02	5.91E-01
81	1.60E-12	1.66E+05	3.40E-02	4.11E-01
82	3.50E-14	1.49E+05	9.35E-03	4.17E-01
83	3.91E-13	1.45E+05	3.89E-03	4.83E-01
84	1.40E-12	1.66E+05	4.24E-02	4.38E-01
85	8.87E-13	1.22E+05	4.12E-02	4.21E-01
86	9.39E-14	1.55E+05	1.47E-03	3.74E-01
87	6.03E-14	1.30E+05	3.62E-03	6.11E-01
88	1.23E-12	1.54E+05	3.52E-02	4.78E-01
89	2.46E-13	1.48E+05	3.15E-02	4.64E-01
90	4.23E-14	1.56E+05	3.17E-02	5.37E-01
91	1.93E-12	1.35E+05	1.03E-02	4.56E-01
92	1.19E-13	1.35E+05	5.88E-03	4.93E-01
93	5.33E-13	1.34E+05	1.37E-02	5.78E-01
94	1.52E-12	1.57E+05	2.01E-02	5.73E-01
95	2.55E-13	1.65E+05	3.19E-03	5.47E-01
96	1.47E-12	1.69E+05	5.68E-02	6.20E-01
97	3.03E-13	1.28E+05	7.89E-03	5.75E-01
98	1.33E-13	1.38E+05	5.06E-02	4.91E-01
99	9.68E-13	1.32E+05	8.09E-02	5.13E-01
100	3.75E-14	1.43E+05	7.04E-03	5.07E-01

Table 13. DRSPALL Sampled Parameters from Replicate 2 of the CRA-2004 PABC.

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
1	6.36E-14	1.57E+05	1.57E-03	3.65E-01
2	2.86E-13	1.26E+05	1.26E-03	4.15E-01
3	2.14E-12	1.40E+05	8.85E-03	5.71E-01
4	2.04E-12	1.64E+05	1.20E-03	6.22E-01
5	7.75E-14	1.40E+05	1.49E-03	5.75E-01
6	3.26E-13	1.38E+05	3.59E-03	5.87E-01
7	1.06E-13	1.42E+05	1.83E-02	6.48E-01
8	1.75E-13	1.27E+05	9.15E-03	4.47E-01
9	3.09E-13	1.23E+05	1.13E-03	4.20E-01
10	2.45E-14	1.52E+05	1.27E-02	4.97E-01
11	2.49E-13	1.39E+05	8.01E-03	4.85E-01
12	1.43E-12	1.28E+05	8.24E-02	3.67E-01
13	2.99E-13	1.21E+05	1.00E-02	3.70E-01
14	2.10E-13	1.65E+05	1.69E-02	4.37E-01
15	7.07E-14	1.43E+05	2.67E-03	5.17E-01
16	6.98E-13	1.53E+05	1.12E-02	6.35E-01
17	1.67E-12	1.33E+05	3.01E-02	5.37E-01
18	5.12E-14	1.66E+05	2.37E-02	5.60E-01
19	6.91E-13	1.44E+05	7.55E-02	4.71E-01
20	1.85E-12	1.32E+05	2.43E-02	6.02E-01
21	4.01E-14	1.23E+05	1.60E-03	5.83E-01
22	5.38E-14	1.57E+05	1.78E-03	5.91E-01
23	2.54E-13	1.37E+05	4.06E-02	5.05E-01
24	1.42E-13	1.48E+05	2.65E-02	5.42E-01
25	2.78E-14	1.48E+05	1.40E-03	3.98E-01
26	6.31E-14	1.28E+05	3.73E-02	4.15E-01
27	2.58E-14	1.56E+05	7.58E-03	4.45E-01
28	9.71E-14	1.41E+05	2.60E-03	5.29E-01
29	1.54E-12	1.69E+05	9.82E-02	4.64E-01
30	3.49E-13	1.22E+05	2.17E-02	5.49E-01
31	3.35E-14	1.30E+05	3.50E-02	4.50E-01
32	1.15E-12	1.34E+05	8.88E-02	4.39E-01
33	7.68E-13	1.60E+05	3.29E-02	6.05E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
34	3.64E-14	1.39E+05	9.63E-03	5.08E-01
35	6.92E-14	1.50E+05	3.13E-02	4.93E-01
36	4.77E-14	1.64E+05	2.88E-03	3.75E-01
37	2.34E-13	1.24E+05	3.14E-03	6.32E-01
38	9.01E-13	1.62E+05	6.12E-03	3.54E-01
39	1.95E-12	1.31E+05	2.04E-03	5.13E-01
40	1.26E-12	1.26E+05	2.21E-02	4.11E-01
41	1.30E-13	1.61E+05	2.57E-02	6.42E-01
42	7.98E-13	1.25E+05	4.18E-03	4.67E-01
43	3.39E-13	1.27E+05	1.98E-02	4.03E-01
44	4.97E-14	1.22E+05	2.01E-02	6.12E-01
45	1.03E-12	1.29E+05	7.04E-03	6.47E-01
46	1.48E-12	1.36E+05	2.23E-03	5.58E-01
47	4.85E-13	1.53E+05	1.37E-02	5.77E-01
48	1.55E-13	1.29E+05	4.92E-02	6.01E-01
49	5.51E-13	1.62E+05	1.86E-03	6.40E-01
50	3.07E-14	1.59E+05	3.74E-03	6.54E-01
51	1.49E-13	1.45E+05	4.67E-03	3.89E-01
52	1.03E-13	1.68E+05	5.16E-02	6.15E-01
53	5.87E-13	1.34E+05	4.47E-03	3.84E-01
54	7.55E-13	1.65E+05	3.23E-03	6.51E-01
55	2.22E-12	1.59E+05	2.48E-03	5.21E-01
56	8.35E-13	1.49E+05	3.95E-03	4.69E-01
57	7.98E-14	1.45E+05	2.34E-03	6.29E-01
58	6.49E-13	1.52E+05	4.52E-02	4.76E-01
59	9.66E-13	1.55E+05	7.74E-03	4.27E-01
60	4.44E-14	1.20E+05	5.79E-02	6.59E-01
61	2.05E-13	1.41E+05	5.41E-03	4.00E-01
62	2.40E-12	1.54E+05	3.99E-03	3.95E-01
63	1.31E-12	1.69E+05	1.04E-03	5.69E-01
64	3.64E-13	1.67E+05	6.25E-02	5.19E-01
65	4.37E-13	1.33E+05	5.56E-02	5.25E-01
66	4.20E-14	1.42E+05	4.75E-02	5.82E-01
67	8.69E-14	1.36E+05	1.20E-03	4.83E-01
68	1.73E-13	1.46E+05	3.31E-03	3.57E-01
69	4.08E-13	1.25E+05	4.82E-03	3.61E-01

Vector	REPIPERM (m^2)	TENSLSTR (Pa)	PARTDIAM (m)	REPIPOR (-)
70	1.85E-13	1.35E+05	6.66E-02	6.17E-01
71	5.58E-14	1.61E+05	6.69E-03	6.33E-01
72	3.63E-14	1.49E+05	3.00E-03	4.78E-01
73	3.23E-14	1.47E+05	5.39E-02	4.42E-01
74	2.23E-13	1.67E+05	1.44E-02	4.07E-01
75	1.23E-13	1.70E+05	1.46E-02	3.73E-01
76	2.74E-13	1.45E+05	7.05E-02	4.89E-01
77	1.34E-12	1.58E+05	8.44E-03	5.66E-01
78	6.15E-13	1.63E+05	1.98E-03	4.30E-01
79	5.17E-13	1.43E+05	1.09E-02	5.92E-01
80	8.87E-14	1.67E+05	1.55E-02	5.33E-01
81	5.26E-13	1.37E+05	9.53E-02	4.91E-01
82	9.51E-14	1.31E+05	6.57E-03	4.32E-01
83	1.63E-12	1.58E+05	7.87E-02	5.48E-01
84	2.67E-14	1.54E+05	4.27E-02	3.52E-01
85	1.38E-13	1.22E+05	1.75E-02	5.35E-01
86	1.16E-12	1.56E+05	8.69E-02	5.11E-01
87	3.85E-13	1.60E+05	1.08E-03	5.45E-01
88	1.61E-13	1.63E+05	6.38E-02	3.79E-01
89	2.89E-14	1.68E+05	2.88E-02	4.21E-01
90	5.79E-14	1.51E+05	5.17E-03	5.00E-01
91	9.24E-13	1.48E+05	3.44E-02	5.63E-01
92	7.57E-14	1.56E+05	3.86E-02	5.98E-01
93	4.78E-13	1.51E+05	1.36E-03	4.58E-01
94	1.06E-12	1.24E+05	1.68E-03	3.91E-01
95	1.15E-13	1.51E+05	1.17E-02	5.52E-01
96	1.93E-13	1.38E+05	5.73E-03	4.60E-01
97	1.14E-13	1.30E+05	1.65E-02	4.53E-01
98	3.98E-14	1.33E+05	1.25E-02	6.23E-01
99	1.81E-12	1.46E+05	2.12E-03	6.09E-01
100	4.35E-13	1.35E+05	5.85E-03	3.86E-01

9.0 Appendix B - SUMMARIZE Input Files

The utility MERGESPALL requires a set of input files for execution. These files are output from SUMMARIZE, and this appendix lists examples of the input files used to create the MERGESPALL input files (see Section 4.2.5). One input file is used to create a table of volumes from the spherical runs (Figure 21), and the other file is used for the cylindrical runs (Figure 22).

```
*input files
        template=DRS_CRA1BC_R1_P1_V###
type=CDB

*vector
        id= #
        vector= 1 to 100

*times
        read=   seconds
        input=  seconds
        output= seconds
        time=0. to 1000. by 2.

*items
        type= PROPERTY
        number= 9
        name= REPOSTCK

        type= HISTORY
        name= CAVRAD, SPLVOL2


*output
```

Figure 21 SUMMARIZE Input File for Spherical DRSPALL Runs - Replicate 1, DPS 1.

Figure 22 SUMMARIZE Input File for Cylindrical DRSPALL Runs - Replicate 1, DPS 3.

10.0 Appendix C - MERGESPALL

This appendix describes the utility MERGESPALL. This utility was qualified for this analysis under Chavez (2001).

10.1 Description and Requirements

A new procedure was implemented in the calculation of spallings releases for the CRA-2004 PABC (see Section 4.2.5). This new procedure included the use of the utility MERGESPALL. MERGESPALL was used to read a set of SUMMARIZE tables to create an input file for the code CUTTINGS_S. MERGESPALL has the following set of requirements:

1) MERGESPALL reads a SUMMARIZE output file containing the DRSPALL data for multiple times from the *spherical* calculations for a single DPS.

2) MERGESPALL reads a SUMMARIZE output file containing the DRSPALL data for a single time from the *cylindrical* calculations for a single DPS (if necessary).

3) For each vector, MERGESPALL adds the spall volume from the spherical run file at the first time that that CAVRAD exceed REPOSTCK to the spall volume from the cylindrical SUMMARIZE output file for the same DPS. If CAVRAD does not exceed REPOSTCK for a vector, MERGESPALL selects the spall volume at the final time from the spherical run and no cylindrical SUMMARIZE file is required.

4) If MERGESPALL does not find a spall volume for a vector that requires one, an error message is logged in the optional log output file.

5) MERGESPALL checks the output directory to see if a file already exists with the user specified output file name. If one does exist, it appends the data to the end of that file. Otherwise, MERGESPALL creates a new text output file with a three line header and the calculated spall volumes.

10.2 Platform and Source Code Description

The MERGESPALL source code was written in FORTRAN 90 and executed on OpenVMS Version 7.3-1 operating system.

10.3 Usage

Files

Two input files are used by MERGESPALL: one contains the DRSPALL data for multiple times from the spherical calculations for a single DPS, and one contains the DRSPALL data for a single time from the cylindrical calculations for a single DPS. The first two lines of the spherical file consist of a header, followed by a blank line. Five columns of data follow. The first column contains the vector number, the second column lists the times the time, the third lists the REPOSTCK values for each vector, the fourth column contains a CAVRAD value for the vector, and the fifth column contains a SPLVOL2 value for the vector. REPOSTCK values are constant for all times but vary by vector. CAVRAD and SPLVOL2 vary by vector and increase with time. The first two lines of the cylindrical file consist of a header, followed by a blank line. Three columns of data follow. The first column contains the vector number, the second column lists a time, and the third column contains a SPLVOL2 value for the vector. See Figure 23 and Figure 26 for examples of these files.

MERGESPALL checks the output directory to see if a file already exists with the user specified output file name. If one does exist, it appends the data to the end of that file. Otherwise, MERGESPALL creates a new text output file with a three line header and the calculated spall volumes.

The first line of the header contains the number of vectors, the second line contains the number of DPSs, and the third line contains the initial repository pressures used for each DPS. MERGESPALL assumes four pressure scenarios with initial pressures of 10, 12, 14, and 14.8 MPa . After writing the header, MERGESPALL writes the spall data to the new output text file. Figure 24 contains an example of an output file.

The input files for MERGESPALL are identified by VMS logicals which is an alias or pointer to the actual file. The logical SUM_SPHERICAL$TBL identifies the input file with the spherical model spallings results, and the logical SUM_CYLINDRICAL$TBL identifies the input file with the cylindrical run spallings data, if necessary. The text output file is identified by the logical SPALL$OUT.

Execution

If the executable MERGESPALL.EXE is found in the directory DRIVE:[EXE_DIR], MERGESPALL is run with the following execution with input files SPHER_FILE.TBL and CYL_FILE.TBL:

```
$ DEFINE SUM_SPHERICAL$TBL SPHER_FILE.TBL
$ DEFINE SUM_CYLINDRICAL$TBL CYL_FILE.TBL
$ DEFINE SPALL$OUT OUT.OUT
$ MERGESPALL == "$DRIVE:[EXE_DIR]MERGESPALL"
$ MERGESPALL
```

To output an optional logfile named LOG.LOG, use the following syntax:

```
$ MERGESPALL == "$DRIVE:[EXE_DIR]MERGESPALL"
$ MERGESPALL /OUTPUT=LOG.LOG
```

10.4 Testing of MERGESPALL

Test Procedure

All test cases were run using the WIPP PA run control system. The command script used to execute all test cases, MERGESPALL_TEST.COM and all input and output files are available in the MERGESPALL_V1.0 class of the SCMS library PACMS2:[CMS_CRA1BC.CRA1BC_DRS] (VMS symbol LIBCRA1BC_DRS). The log file for all tests, MERGESPALL_TEST.LOG, is also stored in the MERGESPALL_V1.0 class of the library SCMS PACMS2:[CMS_CRA1BC.CRA1BC_DRS] (VMS symbol LIBCRA1BC_DRS).

10.4.1 Test Case #1

The purpose of this Test Case #1 is to evaluate the MERGESPALL calculations when CAVRAD does not exceed REPOSTCK for any time or vector. MERGESPALL should simply return the final SPLVOL2 values for all vectors. No cylindrical run input files are needed for this test case.

Additionally, Test Case #1 verifies that MERGESPALL formats the output file properly.

Test Files

The following test files are associated with this test case:

MERGESPALL Input Files:
SUM_TEST_P1.TBL (Figure 23)

MERGESPALL Output Files:
TEST1.OUT (Figure 24)
TEST1.LOG

The input file SUM_TEST_P1.TBL contains data for 3 vectors: 51, 74, and 97.

```
vector,time REPOSTCK CAVRAD   SPLVOL2
 ,[P:9],[H],[H]

 5.100000E+01  0.000000E+00  1.060335E+00  0.000000E+00  0.000000E+00
 7.400000E+01  0.000000E+00  9.540635E-01  0.000000E+00  0.000000E+00
 9.700000E+01  0.000000E+00  9.394274E-01  0.000000E+00  0.000000E+00

 5.100000E+01  1.200000E+02  1.060335E+00  2.651143E-01  0.000000E+00
 7.400000E+01  1.200000E+02  9.540635E-01  2.651143E-01  0.000000E+00
 9.700000E+01  1.200000E+02  9.394274E-01  2.651143E-01  0.000000E+00

 5.100000E+01  2.400000E+02  1.060335E+00  3.923810E-01  0.000000E+00
 7.400000E+01  2.400000E+02  9.540635E-01  3.923810E-01  0.000000E+00
 9.700000E+01  2.400000E+02  9.394274E-01  4.122663E-01  1.013220E-01

 5.100000E+01  3.600000E+02  1.060335E+00  6.470975E-01  1.571354E+00
 7.400000E+01  3.600000E+02  9.540635E-01  5.514642E-01  9.001429E-01
 9.700000E+01  3.600000E+02  9.394274E-01  4.122663E-01  1.013220E-01

 5.100000E+01  4.800000E+02  1.060335E+00  6.910975E-01  2.033756E+00
 7.400000E+01  4.800000E+02  9.540635E-01  5.673726E-01  1.029988E+00
 9.700000E+01  4.800000E+02  9.394274E-01  4.122663E-01  1.013220E-01

 5.100000E+01  6.000000E+02  1.060335E+00  6.910975E-01  2.033756E+00
 7.400000E+01  6.000000E+02  9.540635E-01  5.673726E-01  1.029988E+00
 9.700000E+01  6.000000E+02  9.394274E-01  4.122663E-01  1.013220E-01
```

Figure 23. Test Case #1 Input File SUM_TEST_P1.TBL Showing Final SPLVOL2 for Spherical Runs. CAVRAD < REPOSTCK for All Vectors.

Acceptance Criteria

The acceptance criteria for Test Case #1 is as follows:

1) MERGESPALL creates two output files: TEST1.OUT and TEST1.LOG.
2) TEST1.OUT contains a three line header followed by three rows of spall data. There should be three rows of data, each containing the vector number, followed by a time, followed by a spall volume. The required header is pictured below.

```
           3
           4
    10000000      12000000      14000000      14800000
```

3) TEST1.OUT lists the following spall volumes for each vector:

   Vector 51 2.033756
   Vector 74 1.029988
   Vector 97 0.1013220

Evaluation

Visual inspection was used to evaluate Test Case #1. MERGESPALL created the output files TEST1.OUT and TEST1.LOG. This satisfies the first acceptance criteria. The file TEST1.OUT is shown in Figure 24. Visual inspection confirms that the second and third acceptance criteria are met. Therefore, the acceptance criteria for Test Case 1 are met.

```
          3
          4
  10000000     12000000     14000000     14800000
 51.0000000000000          600.000000000000          2.03375600000000
 74.0000000000000          600.000000000000          1.02998800000000
 97.0000000000000          600.000000000000          0.101322000000000
```

Figure 24. Test Case #1 Output File TEST1.OUT Showing Final SPLVOL2 for Spherical Runs. CAVRAD < REPOSTCK for All Vectors.

10.4.2 Test Case #2

The purpose of this test case is to evaluate the MERGESPALL calculations when CAVRAD exceeds REPOSTCK for multiple vectors. MERGESPALL will identify in which vectors CAVRAD exceeds REPOSTCK and add spall volumes from the cylindrical spall data input file to the spall volumes from the spherical spall data file. Additionally, this test case verifies that MERGESPALL appends the spall data to a preexisiting file.

Test Procedure

Test Case #2 is run using the WIPP PA run control system using command script described previously.

Test Files

The following test files are associated with this test case: MERGESPALL Input Files:

SUM_TEST_P2.TBL	(Figure 25)
SUM_CYL_TEST_P2.TBL	(Figure 26)
TEST1.OUT (used by MERGESPALL_TEST.COM)	(Figure 24)

MERGESPALL Output Files:

TEST2.OUT	(Figure 27)
TEST2.LOG	

Figure 25 shows that at a time of 360 s, CAVRAD exceeds REPOSTCK for vector 97, and at a time of 480 s, CAVRAD exceeds REPOSTCK for vector 51. The input file SUM_CYL_TEST_P2.TBL (Figure 26) contains the spall data from the cylindrical restarts.

The script MERGESPALL_TEST.COM copies the file TEST1.OUT to a file named TEST2.OUT. The reason for this procedure is that this test case verifies that MERGESPALL will append data to the end of this file since it shares the name with the user specified output file.

```
vector,time REPOSTCK CAVRAD   SPLVOL2
 ,[P:9],[H],[H]

 5.100000E+01  0.000000E+00  1.060335E+00  0.000000E+00  0.000000E+00
 7.400000E+01  0.000000E+00  9.540635E-01  0.000000E+00  0.000000E+00
 9.700000E+01  0.000000E+00  9.394274E-01  0.000000E+00  0.000000E+00

 5.100000E+01  1.200000E+02  1.060335E+00  2.651143E-01  0.000000E+00
 7.400000E+01  1.200000E+02  9.540635E-01  2.651143E-01  0.000000E+00
 9.700000E+01  1.200000E+02  9.394274E-01  2.651143E-01  0.000000E+00

 5.100000E+01  2.400000E+02  1.060335E+00  7.350975E-01  2.829125E+00
 7.400000E+01  2.400000E+02  9.540635E-01  6.390975E-01  1.971441E+00
 9.700000E+01  2.400000E+02  9.394274E-01  7.830975E-01  3.969426E+00

 5.100000E+01  3.600000E+02  1.060335E+00  1.058887E+00  9.008760E+00
 7.400000E+01  3.600000E+02  9.540635E-01  7.550975E-01  3.444920E+00
 9.700000E+01  3.600000E+02  9.394274E-01  9.430975E-01  7.135302E+00

 5.100000E+01  4.800000E+02  1.060335E+00  1.218825E+00  1.388441E+01
 7.400000E+01  4.800000E+02  9.540635E-01  7.630975E-01  3.565143E+00
 9.700000E+01  4.800000E+02  9.394274E-01  9.630975E-01  7.616509E+00

 5.100000E+01  6.000000E+02  1.060335E+00  1.290507E+00  1.653304E+01
 7.400000E+01  6.000000E+02  9.540635E-01  7.630975E-01  3.565143E+00
 9.700000E+01  6.000000E+02  9.394274E-01  9.630975E-01  7.616509E+00
```

Figure 25. Test Case #2 Input File SUM_TEST_P2.TBL Highlighting Vectors Where CAVRAD Exceeded REPOSTCK.

```
vector,time SPLVOL2
 ,[H]
 5.100000E+01  6.000000E+02  6.046141E-01
 9.700000E+01  6.000000E+02  5.400164E-01
```

Figure 26. Test Case #2 Input File SUM_CYL_TEST_P2.TBL Showing Data From Cylindrical Restarts.

Acceptance Criteria

The acceptance criteria for Test Case #2 is as follows:

1) MERGESPALL lists the following spall volumes for each vector:

Vector 51 14.4890241 (13.88441 + 0.6046141)

Vector 74	3.565143	(spherical at 600s)
Vector 97	7.6753184	(7.135302 + 0.5499164)

2) MERGESPALL appends the above spall data to the file TEST1.OUT.

Evaluation

Figure 27 lists the output file TEST2.OUT from Test Case #2. Visual inspection indicates that the acceptance criteria for Test Case #2 are met.

```
        3
        4
  10000000     12000000     14000000     14800000
  51.0000000000000         600.000000000000         2.03375600000000
  74.0000000000000         600.000000000000         1.02998800000000
  97.0000000000000         600.000000000000        0.101322000000000
appended
  51.0000000000000         600.000000000000         14.4890241000000
  74.0000000000000         600.000000000000         3.56514300000000
  97.0000000000000         600.000000000000         7.67531840000000
```

Figure 27. Test Case #2 Output File TEST2.OUT.
Note that '*appended*' was added to file for figure readability.

10.4.3 Test Case #3

If CAVRAD exceeds REPOSTCK for a vector, MERGESPALL adds a spall quantity from the cylindrical model input file to a spall quantity from the spherical spall data file.
The purpose of this unit test is to verify that MERGESPALL logs an error message when it does not find a cylindrical spall volume in this situation.

Test Procedure

Test Case #3 is run using the WIPP PA run control system using the command script described previously.

Test Files

The following test files are associated with this test case:

MERGESPALL Input Files:
SUM_TEST_P2.TBL (Figure 25)
SUM_CYL_TEST_P2_NO97.TBL (
Figure 28)

MERGESPALL Output Files:

TEST3.OUT (Figure 29)
TEST3.LOG

This test case uses the same spherical spall data input file from Test Case #2. As discussed in Section 10.4.2, CAVRAD exceeds REPOSTCK for vector 97 at 360 seconds, and the code is required to add a cylindrical spall quantity to a spherical spall quantity for this vector. The input file SUM_CYL_TEST_P2_NO97.TBL (

Figure 28) does not contain such a quantity.

```
vector,time SPLVOL2
 , [H]

 5.100000E+01  6.000000E+02  6.046141E-01
```

Figure 28. Test Case #3 Input File SUM_CYL_TEST_P2_NO97.TBL Showing Data for Vector 51 Only

Acceptance Criteria

The acceptance criteria for Test Case #3 is as follows:

1) The following error message is logged in the Vector 97 portion of the file TEST3.LOG.

```
ERROR: No cylindrical volume was input
```

Evaluation

Figure 29 lists the log file TEST3.LOG from Test Case 3. Visual inspection indicates that the acceptance criteria for Test Case 3 are met.

```
Number of vectors =           3
 Input file (spherical): SUM_TEST_P2.TBL
 Input file (cylindrical): SUM_CYL_TEST_P2_NO97.TBL
 Radius exceeds repository height in vector          97
 Time=   360.000000000000      CAVRAD=  0.943097500000000      Repostck=
  0.939427400000000        7.13530200000000
 ERROR: No cylindrical volume was input
 Spherical Input
File=PAWORK:[CRA1BC.DRS.STEP5.MERGESPALL_TEST]SUM_TEST_P2.TBL;1
 Cylindrical Input File =SUM_CYL_TEST_P2_NO97.TBL
 Radius exceeds repository height in vector          51
 Time=   480.000000000000      CAVRAD=  1.21882500000000      Repostck=
   1.06033500000000        13.8844100000000
  0.604614100000000       added from cylindrical coordinate results to
yield
   14.4890241000000
```

Qualification

MERGESPALL passed the acceptance criteria for all test cases and is therefore qualified for this analysis under Chavez (2001).

10.5 MERGESPALL Source Code

The source code for MERGESPALL can be found in the file MERGESPALL.FOR in the SCMS library PACMS2:[CMS_CRA1BC.CRA1BC_DRS] (LIBCRA1BC_DRS) in the MERGESPALL_V1.0 class. The executable MERGESPALL.EXE is found in the same library and class. The source code is reproduced below.

```
      Program MergeSpall
!.......Read summarize tables and extract the spall volumes. Unit 1 is
!       assigned to the tables of results assuming spherical coordinates.
!       Unit 2 is the table of results assuming cylindrical coordinates, used
!       if the radius of the hemisphere exceeds the repository height. In that
!       case the final spall volume is computed as the sum of the spallings at
!       that time plus the spallings from the cylindrical simulation. Unit 3
!       receives the final spallings data. If the file assigned to Unit 3
!      through a logical does not exist it is created and a header written to
!      it. Otherwise data are appended to the file. The logicals used are:
!      Unit 1:      SUM_Spherical$TBL
!      Unit 2:      SUM_Cylindrical$TBL
!      Unit 3:      spall$out
!      Unit 4: log$file
!      NOTE: MergeSpall must be installed as a "foreign" command in order to
!      be able to use the command line option of /OUTPUT=log_file_name
!      This requires the following command:
```

```
!           MergeSpall == "$drive:[directory_where_exe_is]MergeSpall"
! e.g.
!           MergeSpall == "$U1:[tbkirch.bin]MergeSpall"
!       MergeSpall is then run like a regular command, i.e.
!           MergeSpall /OUTPUT=file_name
!       NOTE:The command line argument /OUTPUT must be in upper case

        Double Precision Vector(100),Time(100),CavRad(100),SplVol2(100)
        Double Precision ReposTck(100),FinalSpallVol(100)
        Double Precision CylSpallVol(100)
       Logical CylData(100)
       Integer Log
       Common/Spalldata/Vector,Time,CavRad,SplVol2,CylData,CylSpallVol,
     &                 ReposTck,FinalSpallVol,Log,CylindricalFile
       Double Precision v,t,c,s,r
       Character*80 dum
       Character*10 FileAccess
        Logical fileExists   !Set to true if the output file already exists
        Character*100 CmdLine, LogFile, SphericalFile, CylindricalFile
        Character*100 OutputFile
       Character*100 fName   !file name returned from Inquire
        Integer nVectors     !Number of vectors

        FinalSpallVol=0.0     !Set array to 0
        Cyldata=.False.         !Set to FALSE as flag
        CylSpallVol=0.0         !Set array to 0

!.......Get the command line
        If (IArgC().LT.4) Then
            Write(*,*) "Insufficient number of arguments specified"
            stop "Too few arguments"
        Else
            Call GetArg(1,CmdLine)
            write(*,*) "Output file=",Trim(CmdLine)
            OutputFile=Trim(CmdLine)
            Call GetArg(2,CmdLine)
            write(*,*) "Log file=",Trim(CmdLine)
            LogFile = Trim(CmdLine)
            Open(4,file=trim(LogFile),ACCESS='APPEND')
            Log=4
            Call GetArg(3,CmdLine)
            SphericalFile=Trim(CmdLine)
            Call GetArg(4,CmdLine)
            CylindricalFile=Trim(CmdLine)
        End If

        nVectors=nVecs(SphericalFile)
        write(4,*) "Number of vectors =",nVectors

       Inquire(file=Trim(OutputFile),exist=fileExists)
       If (.not.fileExists) then
            FileAccess='Sequential'
            Open(3,file=Trim(OutputFile),ACCESS=FileAccess,
     &          FORM='FORMATTED')
!...........Write the header
            Write(3,*) nVectors    !number of vectors
          Write(3,*) 4    !Number of pressures
          Write(3,*) 10000000,12000000,14000000,14800000    !Pressures
        Else
```

```
          FileAccess='Append'
          Open(3,file=Trim(OutputFile),ACCESS=FileAccess,
     &             FORM='FORMATTED')
      End If

      Open(1,file=Trim(SphericalFile),STATUS='OLD', FORM='FORMATTED',
     &        READONLY)
      Write(Log,*) "Input file (spherical): ",Trim(SphericalFile)

        If (trim(CylindricalFile).NE."NONE") Then
           Inquire(file=Trim(CylindricalFile),exist=fileExists)
          If (FileExists) Then
              Open(2,file=Trim(CylindricalFile),STATUS='OLD',
     &            FORM='FORMATTED', READONLY)
              Write(Log,*) "Input file (cylindrical): ",
     &            Trim(CylindricalFile)
!.............Read header records
              Do i=1,2
                  Read(2,*) dum
              End Do
!..............Read the cylindrical volumes for specific vectors
    5         Continue
                  Read(2,*,End=6) v,t,s
                  i = int(v)
                  CylData(i)=.TRUE.
                  CylSpallVol(i)=s
              Go To 5
    6         Close(2)
          Else
              Write(*,*) "WARNING:Cylindrical file ",
     &            trim(CylindricalFile)," not found."
              Write(Log,*) "WARNING:Cylindrical file ",
     &            trim(CylindricalFile)," not found."
          End If
        Else
           Write(Log,*) "No cylindrical file was specified"
      End If

!......Read header records
        Do i=1,2
            Read(1,*) dum
        End Do

   10   Read(1,*,end=100) v,t,r,c,s
!.......EOF not found, so save the data and procede
        Vector(1)=v
        j=v
        Time(j)=t
        CavRad(j)=c
        SplVol2(j)=s
        REPOSTCK(j)=r
        Call Checkradius(j)

        Do i=2,nVectors    !read all vectors
           Read(1,*) v,t,r,c,s
            j=v
            Vector(i)=v
            Time(j)=t
            ReposTck(j)=r
```

```
            CavRad(j)=c
            SplVol2(j)=s
            Call CheckRadius(j)
        End Do

        Go to 10
  100   Continue

        Do i=1,nVectors    !Write all vectors
            j=Vector(i)
            If (FinalSpallVol(j).EQ.0.0) Then
                FinalSpallVol(j)=SplVol2(j)
            End If
            Write(3,*) Vector(i),Time(j),FinalSpallVol(j)
        End Do
!.......Write a blank line
        Write(3,*) " "
       Close(1)
        Close(3)
        End

       Subroutine CheckRadius(i)
!.......Check the cavity radius against the repository height and add
!       the cylindrical spallings results if it does
        Integer i
        Double Precision Vector(100),Time(100),CavRad(100),SplVol2(100)
        Double Precision ReposTck(100),FinalSpallVol(100)
        Double Precision CylSpallVol(100)
        Logical CylData(100)
       Integer Log
        Common/Spalldata/Vector,Time,CavRad,SplVol2,CylData,CylSpallVol,
     &                  ReposTck,FinalSpallVol,Log,CylindricalFile

       Character*100 fName, CylindricalFile

        If (CavRad(i).gt.ReposTck(i).AND.FinalSpallVol(i).eq.0.0)
     &      Then
            Write(Log,*)"Radius exceeds repository height in vector ",i
            Write(Log,*) "Time=",Time(i),"CAVRAD=",Cavrad(i),
     &                "Repostck=",REPOSTCK(i),SPLVOL2(i)
            FinalSpallVol(i)=SPLVOL2(i)   !preserve this value
            If (CylData(i)) Then
                FinalSpallVol(i)=FinalSpallVol(i)+CylSpallVol(i)
             Write(Log,*) CylSpallVol(i)," added from cylindrical ",
     &         "coordinate results to yield ",FinalSpallVol(i)
            Else
                Write(Log,*) "ERROR: No cylindrical volume was input"
                Inquire(1,NAME=fName)
                Write(Log,*) "Spherical Input File=",Trim(fName)
                Write(Log,*) "Cylindrical Input File =",
     &              Trim(CylindricalFile)
                If (Log.NE.6) Then
                   Write(6,*) "Time=",Time(i),"CAVRAD=",Cavrad(i),
     &                 "Repostck=",REPOSTCK(i),SPLVOL2(i)
                   Write(6,*) "ERROR: No cylindrical volume was input"
                   Write(6,*) "Spherical Input File=",Trim(fName)
                   Write(6,*) "Cylindrical Input File=",
     &                 Trim(CylindricalFile)
                End If
```

```
            End If
        End If

       Return
       End
C=================================================================
        Integer Function NArgs()
!.......Return the number of command line arguments, including the program name
        Integer N
        Call GetArgInfo(iArg,buffer,N,.FALSE.)
        NArgs = N+1 ! +1 for the program name
        Return
        End

        Integer Function IArgC()
!.......Return the index of the last command line argument
        Integer N
        Call GetArgInfo(iArg,buffer,N,.FALSE.)
        IArgC = N
        Return
        End

        Subroutine GetArg(iArg, buffer)
        Integer N
        Call GetArgInfo(iArg,buffer,N,.TRUE.)

        Return
        End

        Subroutine GetArgInfo(iArg, buffer,N, ReturnArg)
!.......Return the number of arguments on the command line or a specific
!       argument (if ReturnArg is TRUE)
        Integer iArg
        Character*(*) buffer
        Logical ReturnArg
        INTEGER LIB$GET_FOREIGN

        INTEGER ISTATUS
        INTEGER*2 I2
        INTEGER IDUMGT
        INCLUDE '($JPIDEF)'
        Character*128 Line     !Storage for command line
        Integer i,j,L,Start
        Character*1 C
!       Get the command line
        INTEGER LIB$GETJPI

        If (ReturnArg .AND. iArg.EQ.0) Then
!...........Get the name of the current executable
            ISTATUS = LIB$GETJPI (JPI$_IMAGNAME, , , IDUMGT, LINE)
            IF (MOD (ISTATUS, 2) .NE. 1) RETURN
            buffer = LINE
        End If

        IDUMGT = 0
        ISTATUS = LIB$GET_FOREIGN (LINE, , I2, IDUMGT)
!           write(*,*) 'cl=',line
        Line = Trim(Line)
        L = Len_Trim(Line)                !Length of line
```

```
      If (L.EQ.0) Then
          buffer=""
          Return
      End If
      i = 1
      N=0
      Do While (i.le.L)
          C = Line(i:i)
          If (C.EQ.'"') Then
              start = i
              i=i+1
              C=Line(i:i)
              Do While (C.NE.'"'.AND.i.LT.L)
                   i=i+1
                   C = Line(i:i)
              End Do
              N=N+1
              if (ReturnArg.AND. n.EQ.iArg) then
                  buffer=line(start:i)
                  return
              End If
              i=i+1
              C=Line(i:i)
          End If
          If (C.EQ." ") Then
               Do While (C.EQ." ".AND.i.LT.L)
                   i=i+1
                   C = Line(i:i)
               End Do
          End If
          start=i
          Do While (C.NE." ".AND. i.LT.L)
              i=i+1
              C=Line(i:i)
          End Do
          N=N+1
          if (ReturnArg .AND. N.EQ.iArg) then
               buffer=line(start:i)
               return
           End If
          i=i+1
      End Do
      Return
      End

      Integer Function nVecs(fName)
      Character*(*) fName
      Character*5 txt
      Integer n,i

      Open(unit=9,file=trim(fName),status='OLD')
      do i=1,3  !Read header records
           Read(9,'(a5)') txt
      end do
      n=0
10    Read(9,'(a5)',END=100) txt
      if (txt.eq.'     ') Then
          nVecs=n
          close(9)
```

```
          return
      end if
      n=n+1
      goto 10
      Write(*,*) "EOF on input, nVectors = ",n
100   nVecs=n
      close(9)
      return
      end
```

11.0 Appendix D – DRSPALL Calculated Spall Volumes

Table 14, Table 15, and Table 16 lists the spall volumes calculated by DRSPALL for all four pressure scenarios in the CRA-2004 PABC for replicates 1, 2 and 3, respectively.

Table 14. CRA-2004 PABC Spall Volumes- Replicate 1.

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
1	0.00E+00	0.00E+00	2.33E-01	4.10E-01
2	0.00E+00	2.29E-01	2.15E+00	3.53E+00
3	0.00E+00	0.00E+00	2.85E-01	4.97E-01
4	0.00E+00	0.00E+00	4.48E-01	1.05E+00
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00	3.89E-02
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	1.71E-01	3.25E-01
9	0.00E+00	0.00E+00	1.44E-02	9.54E-02
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	0.00E+00	2.82E-01	5.16E-01
12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	0.00E+00	0.00E+00	3.46E-01	4.47E-01
14	0.00E+00	4.52E-02	6.49E-01	1.03E+00
15	0.00E+00	0.00E+00	0.00E+00	7.19E-02
16	0.00E+00	0.00E+00	1.25E-01	2.77E-01
17	0.00E+00	0.00E+00	2.73E-01	4.27E-01
18	0.00E+00	0.00E+00	9.66E-03	8.98E-02
19	0.00E+00	0.00E+00	5.21E-02	1.38E-01
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	0.00E+00	3.81E-02	3.56E-01	4.74E-01
22	0.00E+00	0.00E+00	1.13E-01	2.28E-01
23	0.00E+00	0.00E+00	1.45E-01	3.19E-01
24	0.00E+00	0.00E+00	7.75E-02	2.21E-01
25	0.00E+00	0.00E+00	7.86E-02	1.98E-01
26	0.00E+00	0.00E+00	1.33E-01	3.14E-01
27	0.00E+00	0.00E+00	6.53E-01	9.88E-01
28	0.00E+00	5.07E-02	8.51E-01	1.67E+00
29	0.00E+00	0.00E+00	5.08E-01	8.65E-01
30	0.00E+00	0.00E+00	3.04E-02	1.24E-01

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
31	0.00E+00	0.00E+00	4.22E-01	5.78E-01
32	0.00E+00	7.71E+00	1.15E+01	1.45E+01
33	0.00E+00	1.87E-01	3.78E+00	6.38E+00
34	0.00E+00	0.00E+00	5.40E-01	1.12E+00
35	0.00E+00	0.00E+00	4.76E-01	7.65E-01
36	0.00E+00	2.91E+00	1.18E+01	1.19E+01
37	0.00E+00	1.96E+00	3.41E+00	4.11E+00
38	0.00E+00	0.00E+00	8.59E-02	2.07E-01
39	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	2.16E-02	6.31E-01	1.27E+00
41	0.00E+00	0.00E+00	2.23E-01	4.18E-01
42	0.00E+00	3.17E+00	7.16E+00	7.24E+00
43	0.00E+00	0.00E+00	1.67E-01	3.22E-01
44	0.00E+00	0.00E+00	2.89E-01	4.80E-01
45	0.00E+00	1.63E-01	8.22E-01	1.56E+00
46	0.00E+00	0.00E+00	0.00E+00	3.22E-02
47	0.00E+00	0.00E+00	5.51E-01	9.16E-01
48	0.00E+00	0.00E+00	1.26E-01	2.61E-01
49	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	7.29E-02	1.70E-01
51	0.00E+00	0.00E+00	2.12E-01	3.37E-01
52	0.00E+00	0.00E+00	1.12E-01	2.48E-01
53	0.00E+00	0.00E+00	2.69E-01	4.15E-01
54	0.00E+00	0.00E+00	6.46E-02	2.11E-01
55	0.00E+00	2.28E-01	1.59E+00	2.01E+00
56	0.00E+00	2.34E-01	8.37E-01	1.42E+00
57	0.00E+00	0.00E+00	2.13E-01	3.87E-01
58	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	0.00E+00	2.87E-01	5.38E+00	9.89E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	0.00E+00	0.00E+00	4.92E-01	6.58E-01
65	0.00E+00	2.27E-01	1.53E+00	2.60E+00
66	0.00E+00	0.00E+00	5.40E-01	7.82E-01

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
67	0.00E+00	9.52E-01	2.12E+00	2.74E+00
68	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	0.00E+00	0.00E+00	5.46E-02	1.70E-01
72	0.00E+00	0.00E+00	5.44E-01	8.41E-01
73	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	0.00E+00	0.00E+00	2.49E-01	4.67E-01
75	0.00E+00	0.00E+00	4.95E-01	5.99E-01
76	0.00E+00	3.73E-01	1.23E+00	2.14E+00
77	0.00E+00	0.00E+00	2.57E-01	4.80E-01
78	0.00E+00	0.00E+00	1.12E-01	2.48E-01
79	0.00E+00	3.25E-01	2.96E+00	4.92E+00
80	0.00E+00	0.00E+00	5.80E-01	7.60E-01
81	0.00E+00	0.00E+00	9.02E-02	2.23E-01
82	0.00E+00	0.00E+00	5.74E-02	1.81E-01
83	0.00E+00	0.00E+00	6.13E-02	1.88E-01
84	0.00E+00	0.00E+00	0.00E+00	0.00E+00
85	0.00E+00	2.84E-01	1.54E+00	2.65E+00
86	0.00E+00	0.00E+00	5.12E-01	8.72E-01
87	0.00E+00	1.51E-01	8.34E-01	1.57E+00
88	0.00E+00	0.00E+00	1.07E-01	2.21E-01
89	0.00E+00	0.00E+00	2.47E-01	4.54E-01
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91	0.00E+00	0.00E+00	1.15E-02	9.37E-02
92	0.00E+00	0.00E+00	4.23E-01	1.01E+00
93	0.00E+00	7.44E-02	3.71E-01	5.49E-01
94	0.00E+00	0.00E+00	1.57E-01	2.23E-01
95	0.00E+00	0.00E+00	4.63E-02	1.52E-01
96	0.00E+00	0.00E+00	8.04E-02	1.91E-01
97	0.00E+00	0.00E+00	0.00E+00	0.00E+00
98	0.00E+00	0.00E+00	0.00E+00	0.00E+00
99	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	2.43E-02	1.39E-01

Table 15. CRA-2004 PABC Spall Volumes- Replicate 2.

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
1	0.00E+00	8.02E-02	8.28E-01	1.64E+00
2	0.00E+00	0.00E+00	8.29E-02	1.97E-01
3	0.00E+00	2.42E-01	6.04E-01	7.90E-01
4	0.00E+00	0.00E+00	4.78E-01	6.15E-01
5	0.00E+00	0.00E+00	2.41E-01	4.37E-01
6	0.00E+00	0.00E+00	4.09E-01	7.16E-01
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	1.73E-01	9.63E-01	1.28E+00
9	0.00E+00	1.20E+00	3.99E+00	4.67E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	0.00E+00	4.91E-01	6.60E-01
12	0.00E+00	1.28E-01	5.30E-01	7.39E-01
13	0.00E+00	5.51E-02	4.03E-01	5.81E-01
14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	0.00E+00	0.00E+00	3.73E-01	5.54E-01
17	0.00E+00	0.00E+00	4.30E-01	7.41E-01
18	0.00E+00	3.92E-02	3.48E-01	4.95E-01
19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	0.00E+00	7.50E-03	5.39E-01	8.67E-01
23	0.00E+00	0.00E+00	3.54E-01	5.14E-01
24	0.00E+00	0.00E+00	9.06E-02	2.15E-01
25	0.00E+00	2.51E-01	2.53E+00	4.22E+00
26	0.00E+00	0.00E+00	2.32E-01	4.46E-01
27	0.00E+00	0.00E+00	5.00E-01	1.03E+00
28	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	1.87E-01	3.36E-01
31	0.00E+00	0.00E+00	7.44E-02	1.68E-01
32	0.00E+00	0.00E+00	2.98E-01	4.42E-01

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
33	0.00E+00	0.00E+00	1.44E-01	2.87E-01
34	0.00E+00	4.28E-01	1.09E+00	1.93E+00
35	0.00E+00	0.00E+00	1.59E-01	3.18E-01
36	0.00E+00	8.13E-01	1.90E+00	2.39E+00
37	0.00E+00	0.00E+00	1.53E-01	3.76E-01
38	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	0.00E+00	0.00E+00	1.22E-01	2.76E-01
40	0.00E+00	0.00E+00	5.27E-02	1.66E-01
41	0.00E+00	6.27E+00	7.11E+00	9.89E+00
42	0.00E+00	3.00E-01	2.21E+00	2.76E+00
43	0.00E+00	0.00E+00	3.85E-01	5.43E-01
44	0.00E+00	0.00E+00	7.32E-03	7.07E-02
45	0.00E+00	0.00E+00	5.28E-01	8.60E-01
46	0.00E+00	5.25E-02	6.38E-01	1.31E+00
47	0.00E+00	0.00E+00	4.55E-01	6.41E-01
48	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	4.45E-01	6.11E-01
51	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	0.00E+00	0.00E+00	4.23E-02	1.31E-01
55	0.00E+00	0.00E+00	3.00E-01	4.54E-01
56	0.00E+00	0.00E+00	9.84E-02	2.26E-01
57	0.00E+00	0.00E+00	0.00E+00	7.11E-02
58	0.00E+00	5.15E+00	7.72E+00	8.90E+00
59	0.00E+00	0.00E+00	2.10E-02	1.20E-01
60	0.00E+00	0.00E+00	5.84E-02	1.68E-01
61	0.00E+00	0.00E+00	3.74E-01	5.15E-01
62	0.00E+00	0.00E+00	2.73E-01	4.72E-01
63	0.00E+00	0.00E+00	1.90E-01	3.55E-01
64	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	0.00E+00	0.00E+00	4.37E-01	6.39E-01
66	0.00E+00	0.00E+00	1.89E-02	1.29E-01

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
67	0.00E+00	0.00E+00	1.01E-01	2.42E-01
68	0.00E+00	0.00E+00	1.49E-01	2.94E-01
69	0.00E+00	0.00E+00	6.19E-02	1.56E-01
70	0.00E+00	1.96E-01	9.19E-01	1.63E+00
71	0.00E+00	1.35E-01	1.60E+00	2.61E+00
72	0.00E+00	0.00E+00	0.00E+00	9.42E-02
73	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	0.00E+00	1.68E-01	1.31E+00	2.32E+00
75	0.00E+00	0.00E+00	1.15E-01	2.66E-01
76	0.00E+00	0.00E+00	5.90E-02	1.46E-01
77	0.00E+00	0.00E+00	4.63E-01	6.36E-01
78	0.00E+00	0.00E+00	5.27E-01	7.27E-01
79	0.00E+00	0.00E+00	2.91E-02	1.11E-01
80	0.00E+00	0.00E+00	1.65E-02	1.03E-01
81	0.00E+00	0.00E+00	6.20E-02	1.79E-01
82	0.00E+00	0.00E+00	0.00E+00	0.00E+00
83	0.00E+00	0.00E+00	4.23E-01	5.96E-01
84	0.00E+00	0.00E+00	6.60E-02	2.04E-01
85	0.00E+00	0.00E+00	2.35E-01	4.08E-01
86	0.00E+00	1.95E-01	2.76E+00	4.43E+00
87	0.00E+00	7.94E-02	4.24E-01	5.44E-01
88	0.00E+00	0.00E+00	9.03E-02	2.07E-01
89	0.00E+00	0.00E+00	4.85E-01	8.06E-01
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91	0.00E+00	0.00E+00	4.84E-02	1.50E-01
92	0.00E+00	3.13E-01	1.62E+00	2.89E+00
93	0.00E+00	0.00E+00	2.41E-01	4.43E-01
94	0.00E+00	0.00E+00	3.84E-02	1.20E-01
95	0.00E+00	0.00E+00	5.12E-01	6.26E-01
96	0.00E+00	0.00E+00	2.08E-02	1.01E-01
97	0.00E+00	0.00E+00	5.39E-01	6.32E-01
98	0.00E+00	0.00E+00	0.00E+00	0.00E+00
99	0.00E+00	0.00E+00	1.36E-01	2.61E-01
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 16. CRA-2004 PABC Spall Volumes- Replicate 3.

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
1	0.00E+00	2.20E-01	5.43E+00	7.79E+00
2	0.00E+00	0.00E+00	6.36E-01	1.15E+00
3	0.00E+00	0.00E+00	1.31E-02	8.30E-02
4	0.00E+00	0.00E+00	0.00E+00	6.24E-02
5	0.00E+00	3.10E-01	2.97E+00	4.63E+00
6	0.00E+00	0.00E+00	4.58E-01	5.82E-01
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	1.66E-01	1.09E+00	1.91E+00
9	0.00E+00	0.00E+00	5.03E-01	1.06E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	0.00E+00	4.66E-01	9.82E-01
12	0.00E+00	0.00E+00	1.28E-01	3.03E-01
13	0.00E+00	0.00E+00	6.85E-01	1.37E+00
14	0.00E+00	0.00E+00	5.33E-01	1.17E+00
15	0.00E+00	2.56E-01	3.68E+00	6.06E+00
16	0.00E+00	0.00E+00	1.11E-01	2.47E-01
17	0.00E+00	0.00E+00	4.73E-02	1.36E-01
18	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	0.00E+00	0.00E+00	2.31E-01	4.29E-01
20	0.00E+00	0.00E+00	1.60E-02	1.02E-01
21	0.00E+00	2.96E+00	5.67E+00	6.52E+00
22	0.00E+00	4.16E-01	4.68E+00	6.09E+00
23	0.00E+00	0.00E+00	2.80E-01	3.84E-01
24	0.00E+00	0.00E+00	2.33E-02	7.80E-02
25	0.00E+00	6.86E+00	8.86E+00	1.19E+01
26	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	0.00E+00	3.25E-01	2.05E+00	3.45E+00
29	0.00E+00	0.00E+00	4.92E-02	1.54E-01
30	0.00E+00	0.00E+00	4.64E-01	6.03E-01
31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	0.00E+00	0.00E+00	1.32E-01	2.92E-01
33	0.00E+00	0.00E+00	9.09E-02	2.19E-01
34	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
35	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	0.00E+00	1.12E+00	7.29E+00	8.01E+00
37	0.00E+00	0.00E+00	5.81E-01	7.56E-01
38	0.00E+00	0.00E+00	2.17E-01	4.35E-01
39	0.00E+00	0.00E+00	3.80E-02	1.31E-01
40	0.00E+00	0.00E+00	1.40E-01	3.07E-01
41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	0.00E+00	0.00E+00	2.27E-01	4.18E-01
43	0.00E+00	0.00E+00	5.17E-01	9.62E-01
44	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	0.00E+00	0.00E+00	6.57E-02	1.77E-01
46	0.00E+00	0.00E+00	5.04E-02	1.55E-01
47	0.00E+00	0.00E+00	2.38E-01	4.44E-01
48	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	0.00E+00	0.00E+00	1.50E-01	2.80E-01
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	0.00E+00	2.24E-01	1.41E+00	2.44E+00
52	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	0.00E+00	0.00E+00	3.87E-01	5.60E-01
54	0.00E+00	0.00E+00	7.46E-02	1.89E-01
55	0.00E+00	0.00E+00	9.91E-03	9.76E-02
56	0.00E+00	0.00E+00	1.72E-01	3.46E-01
57	0.00E+00	4.40E-01	2.21E+00	2.76E+00
58	0.00E+00	0.00E+00	2.35E-01	4.36E-01
59	0.00E+00	0.00E+00	1.60E-01	3.06E-01
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	0.00E+00	7.64E-02	8.35E-01	1.65E+00
62	0.00E+00	0.00E+00	1.85E-02	1.22E-01
63	0.00E+00	0.00E+00	3.96E-02	1.26E-01
64	0.00E+00	0.00E+00	2.30E-01	3.16E-01
65	0.00E+00	0.00E+00	3.53E-01	4.89E-01
66	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	0.00E+00	2.59E-01	2.93E+00	4.86E+00
68	0.00E+00	1.27E-01	1.16E+00	2.13E+00
69	0.00E+00	0.00E+00	4.31E-01	9.55E-01
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Vector	Scenario 1 10 MPa	Scenario 2 12.0 MPa	Scenario 3 14.0 MPa	Scenario 4 14.8 MPa
71	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	0.00E+00	1.28E+00	2.65E+00	3.30E+00
73	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	0.00E+00	0.00E+00	5.61E-01	1.20E+00
75	0.00E+00	1.67E-01	1.56E+00	2.54E+00
76	0.00E+00	0.00E+00	1.08E-01	1.73E-01
77	0.00E+00	0.00E+00	4.38E-02	1.48E-01
78	0.00E+00	0.00E+00	2.68E-01	4.22E-01
79	0.00E+00	0.00E+00	2.24E-01	4.18E-01
80	0.00E+00	0.00E+00	0.00E+00	3.57E-02
81	0.00E+00	0.00E+00	2.90E-01	4.19E-01
82	0.00E+00	2.57E-01	3.01E+00	3.74E+00
83	0.00E+00	0.00E+00	2.95E-02	1.27E-01
84	0.00E+00	0.00E+00	0.00E+00	0.00E+00
85	0.00E+00	0.00E+00	2.32E-01	3.32E-01
86	0.00E+00	0.00E+00	8.69E-02	1.94E-01
87	0.00E+00	0.00E+00	3.53E-01	5.26E-01
88	0.00E+00	0.00E+00	1.22E-01	2.45E-01
89	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	1.03E-01	6.59E-01	9.24E-01
91	0.00E+00	0.00E+00	9.08E-02	2.27E-01
92	0.00E+00	0.00E+00	0.00E+00	0.00E+00
93	0.00E+00	0.00E+00	3.73E-01	5.04E-01
94	0.00E+00	0.00E+00	1.96E-01	3.84E-01
95	0.00E+00	0.00E+00	2.86E-01	4.14E-01
96	0.00E+00	8.11E-02	7.51E-01	1.61E+00
97	0.00E+00	7.67E-02	3.66E-01	5.54E-01
98	0.00E+00	0.00E+00	0.00E+00	0.00E+00
99	0.00E+00	0.00E+00	1.17E-02	8.56E-02
100	0.00E+00	0.00E+00	4.06E-01	7.08E-01

Vugrin, Eric D Eric D Vugrin 7/7/05

From: Rudeen, David K
Sent: Tuesday, July 05, 2005 9:28 AM
To: Vugrin, Eric D
Subject: RE: DRSPALL Analysis Package

Eric,

I have completed the review of the 2004 PABC DRSPALL Analysis Package and all comments have been resolved.

I, hereby, give you signature authority for the document and any associated QA forms.

David Rudeen
GRAM, Inc,
(505)998-0046