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Analysis Package for the Cuttings and Spalling Calculations (Tasks 5 and 6) of the Performance Assessment Analyses Supporting the Compliance Certification Application
(WPO# 40521)
WBS Number 1.2.07.4.1

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6	Charging Case Number	0517.207510

Note 1: At the time this Analysis Package was issued, no Activity Authorizations (AA) were in place. When the AA covering this work is issued, the requirements defined in this Analysis Package will be checked for consistency with the governing AA.

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1.0 Introduction

This analysis is concerned with a series of calculations performed to support the Cuttings and Spallings portions of the 1996 performance assessment (PA) of the WIPP repository site. The entire suite of these PA analyses are described in the Analysis Plan for the Performance Assessment Analyses Supporting the Compliance Certification Application (a.k.a., the CCA Analysis Plan) and their associated records packages. These PA analyses are performed to calculate the complementary cumulative distribution function (CCDF), the probability distribution of exceeding normalized cumulative radionuclide releases to the accessible environment, that will become part of the Compliance Certification Application (CCA). The Cuttings and Spallings calculations are designated as Tasks 5 and Task 6 in the CCA Analysis Plan. Analysis of these two tasks have been combined in this single document.

This analysis package is one of eight packages documenting analyses performed in support of the Compliance Certification Application (CCA) for the Waste Isolation Pilot Plant (WIPP). The following background and overview of the analyses is provided to assist the reader in understanding this analysis package and the overall strategy and framework of these analyses. The reader is also referred to the glossary for further information regarding terms used in this analysis package.

1.1 Background

The WIPP is a geologic repository operated by the U.S. Department of Energy (DOE) for disposal of transuranic radioactive wastes. The repository is located approximately 650 meters underground in the Salado Formation, and is connected to the surface by four shafts which will be sealed after waste emplacement is completed. The geologic formations immediately above and below the Salado are the Rustler and Castile Formations, respectively. The Rustler is considered important because it contains the most transmissive units above the repository; the most significant of these is considered to be the Culebra Dolomite Member. The Castile contains areas of pressurized brine (brine pockets); it is not known whether any such pockets are located under the repository. The area surrounding the shafts and surface facilities and the underlying subsurface are controlled by the DOE.

In October 1996, the DOE submitted the CCA to the U.S. Environmental Protection Agency (EPA) in accordance with the requirements of Title 40 of the Code of Federal Regulations (40 CFR) Parts 191 and 194. The containment requirements in 40 CFR 191.13(a) specify that the disposal system is to be designed to provide a reasonable expectation that radionuclide releases to the accessible environment during 10,000 years are not likely to exceed certain limits (the limits are based on the radionuclide inventory in the repository). The demonstration of having a reasonable expectation is to be based on a performance assessment. Performance assessment (PA) is defined in 40 CFR 191.12:

> *Performance assessment* means an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

The PA process used in the CCA fulfills these requirements through 6 major steps, listed below.

(1) Collecting data, characterizing the site and disposal system, and developing the modeling system.

(2) Constructing scenarios (combinations of possible future events), with and without human activities.

(3) Estimating the probability that various scenarios will occur.
(4) Analyzing the consequences of the various scenarios (deterministic futures) which have sufficiently high consequences and probability of occurrence. There are four basic scenarios considered: (1) undisturbed performance (the absence of human intrusion); (2) the E1 intrusion scenario (a borehole which penetrates both the repository and an underlying pressurized brine reservoir in the Castile Formation); (3) the E2 intrusion scenario (a borehole which penetrates the repository); and (4) multiple intrusions (for example, an E2 intrusion followed by an E1 intrusion - E2E1). Each of these scenarios is considered with and without the effects of mining potash located in the Salado within the controlled area.

(5) Calculating cumulative radionuclide releases and comparing them to regulatory standards in 40 CFR Part 191. The releases are calculated using the consequences of each scenario and their combinations in various (probabilistic) futures. The releases are expressed as complementary cumulative distribution functions (CCDFs), the probability distribution of exceeding normalized cumulative radionuclide releases.

(6) Performing sensitivity analyses to identify the most significant factors.

The PA calculations described in these analysis packages (and in this overview) complete the fourth and fifth steps: analysis of scenario consequences and calculation of CCDFs, respectively. The other steps are addressed elsewhere.

1.2 PA Calculation Strategy

Because of the large number of complex calculations that are required to produce CCDFs, it is not practical, nor is it necessary, to model the total system in a single calculation. Instead, disposal system components and subsystems are modeled (in six separate tasks) to calculate consequences for the undisturbed scenario and for the E1, E2, and E2E1 human intrusion scenarios (with and without mining). Each of these tasks is performed for a set of reference conditions, which include specific intrusion scenarios at certain times. The reference conditions are designed to allow the results of the first six tasks to be incorporated into the CCDF calculations in a seventh task.

To perform the first six tasks, several major computer codes are used to simulate relevant features of the disposal system and calculate scenario consequences. An additional computer code is used to construct the CCDFs in the seventh task. The seven tasks are described in the Analysis Plan for the Performance Assessment Analyses Supporting the Compliance Certification Application (AP-AAD), dated March 8, 1996. They are summarized here, together with their major computer codes. The computer codes and disposal system components addressed in the first six tasks are also shown schematically in Figure I-1.

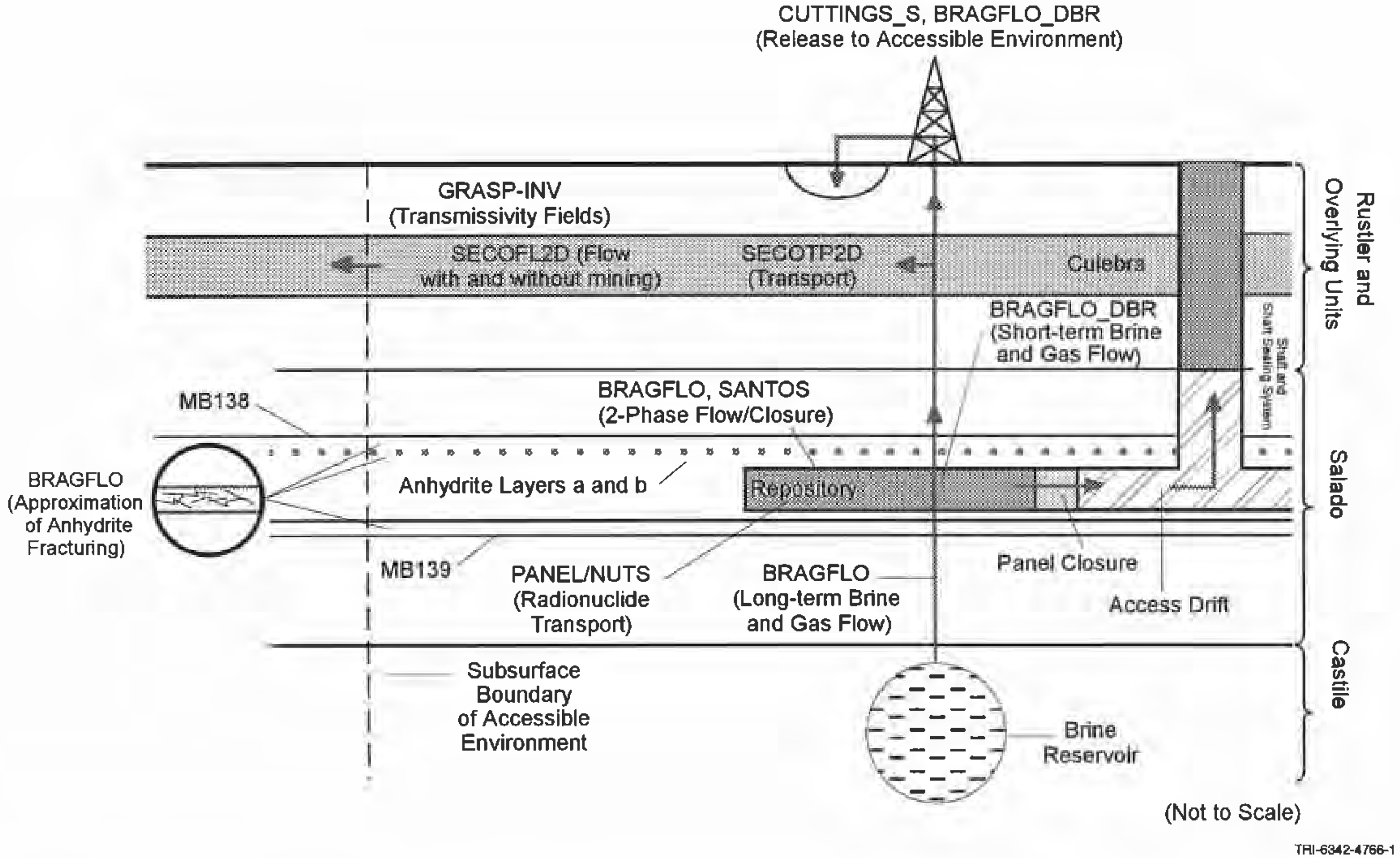


Figure I-1 Schematic Side View of the Disposal System Associating Performance Assessment Codes with the Components of the Disposal System Each Code Simulates

Task 1
In the first task, overall flow of brine and gas is calculated for undisturbed conditions and for human intrusion scenarios. The flow of brine and gas is calculated in the repository, in the sealed shafts, in the Salado Formation (where the repository is located), and in the human intrusion boreholes. Brine flow in other formations is also calculated (except for the Culebra, which is addressed separately in Task 3 because of its significance as a pathway for long-term releases). Processes which are coupled to brine and gas flow are also included in this task: gas generation in the repository, disposal room closure and consolidation, brine flow, and effects on the rock surrounding the repository. Creep closure within the waste regions in the repository is represented in this task using a porosity surface describing porosity as a function of time and pressure. These calculations are performed for the set of system reference conditions, and provide results that are used in subsequent disposal system models (Tasks 2 through 6) and also in CCDF construction (Task 7).

The brine and gas flow and coupled repository processes are modeled using version 4.00 of the computer code BRAGFLO. The porosity surface describing closure of the modeled disposal room is generated using the code SANTOS. The codes and disposal system components are shown in Figure I-1. There are two analysis packages associated with this task: *Analysis Package for the Salado Flow Calculations (Task 1) of the Performance Assessment Analyses Supporting the Compliance Certification Application* (WPO# 40514) and *Final Porosity Surface Data* (WPO# 35697).

Task 2
This task is calculation of the overall long-term transport and radioactive decay of radionuclides from the waste in brine in the Salado and in the overlying Rustler Formation (except for the Culebra, which is addressed in Task 3). The brine flow fields and disposal system model geometry are those calculated in Task 1, and the transport calculations are performed for undisturbed conditions and for human-intrusion scenarios. The radionuclide source concentrations in the brine (the actinide source term) in the repository are the modeled solubilities of the radionuclides contained in the waste. These calculations are performed for the system reference conditions.

The overall transport and decay are calculated using the computer code NUTS for the undisturbed, E1, and E2 scenarios. In simulations of the E1 scenario, NUTS also tracks brine originating in the underlying Castile brine reservoir, including the fraction of Castile brine that has flowed out from the human-intrusion borehole into the waste in the repository. The code PANEL calculates radionuclide concentrations in brine and also radionuclide transport to the Culebra for the E2E1 scenario. In all scenarios, the quantity of brine flowing up the shafts or a degraded exploratory borehole to the Culebra calculated by BRAGFLO (Task 1), together with the concentration of radionuclides in that brine calculated by NUTS or PANEL (Task 2), is used to determine the quantity of radionuclides released to the Culebra (the Culebra is addressed in Task 3). The radionuclide concentration in brine calculated by PANEL is also used to determine the quantity of radionuclides released to the surface in Task 4. The codes and disposal system components are shown in Figure I-1. The analysis package for this task is *Analysis Package for the Salado Transport Calculations (Task 2) of the Performance Assessment Analysis Supporting the Compliance Certification Application* (WPO# 40515).

Task 3
Detailed fluid flow and radionuclide transport in the Culebra for each scenario are modeled in Task 3. The fluid flow calculations use transmissivity fields that are generated for the Culebra to represent the spatial heterogeneity in flow characteristics which has been observed

experimentally. Each scenario may occur with or without potash mining in the Salado in the controlled area; this mining affects the transmissivity of the Culebra. Detailed movement of radionuclides is also calculated using a modeled double-porosity medium for the Culebra, accounting for flow in fractures, diffusion in the matrix, retardation, and radioactive decay. The transport is calculated using a unit source of radionuclides. These calculations are performed for the system reference conditions.

The computer code SECOFL2D calculates fluid flow in the Culebra, using transmissivity fields calculated by the code GRASP-INV (one field in each simulation). The code SECOTP2D calculates radionuclide transport in the Culebra. In Task 7, transport of the unit radionuclide source *in* the Culebra (from this task) is combined with the release *to* the Culebra (calculated in Task 2 using brine flows calculated in Task 1) to determine whether any radionuclides are actually released to the Culebra and subsequently transported through it for each scenario. The codes and disposal system components are shown in Figure I-1. There are two analysis packages associated with this task: *Analysis Package for the Culebra Flow and Transport Calculations (Task 3) of the Performance Assessment Analyses Supporting the Compliance Certification Application* (WPO# 40516) and *Analysis of the Generation of Transmissivity Fields for the Culebra Dolomite* (WPO# 40517).

Task 4
Drilling intrusions into the repository (the E1, E2, and E2E1 scenarios) have immediate consequences: they lead to direct releases of material containing radionuclides to the accessible environment at the surface. These consequences are calculated for the system reference conditions in Tasks 4, 5, and 6. The radionuclide content of the materials released is dependent on the time of intrusion and is calculated separately using the system reference conditions.

Task 4 addresses brine containing dissolved radionuclides in the repository that may reach the surface if it is sufficiently pressurized. Short-term flow in the repository is modeled on a scale which includes repository features such as panel closures to calculate brine and gas flow (gas released to the surface is addressed in Task 6). The radionuclide concentration in the brine is calculated in Task 2. The short-term flow in the repository is modeled using version 4.01 of the code BRAGFLO (also referred to as BRAGFLO_DBR to differentiate it from the BRAGFLO code used in Task 1). The modeled geometry in Task 4 is different from the geometry used in the BRAGFLO code in Task 1, to account for the repository features. The initial conditions for Task 4 are provided by the long-term repository conditions calculated in Task 1. The code and modeled system components are shown in Figure I-1. The analysis package for this task is *Analysis Package for the BRAGFLO Direct Release Calculations (Task 4) of the Performance Assessment Analysis Supporting the Compliance Certification Application* (WPO# 40520).

Task 5
Task 5 addresses cuttings and cavings - the second direct release pathway associated with drilling intrusions into the repository (the E1, E2, and E2E1 scenarios). Cuttings and cavings are solid material carried to the surface by the drilling fluid during the process of drilling the borehole: cuttings are materials removed directly by the drill bit, and cavings are materials eroded from the walls of the borehole by the circulating drilling fluid. The code CUTTINGS_S calculates the quantity of material transported to the surface as cuttings for the system reference conditions. The radionuclide content of the materials released is dependent on the time and location of the intrusion; the content is calculated separately (using the results from the reference conditions) during construction of the CCDFs in Task 7. The code and modeled system components are shown in Figure I-1. The analysis package for this task is *Analysis Package for the Cuttings and Spallings Calculations (Tasks 5 and 6) of the Performance Assessment Analysis Supporting the Compliance Certification Application* (WPO# 40521).

Task 6
Task 6 addresses spallings - the third direct release pathway associated with drilling intrusions into the repository (the E1, E2, and E2E1 scenarios). Spallings are solid materials carried up the borehole by pressurized gas which may be present in the repository at the time of intrusion. The repository pressure and conditions are calculated in Task 1. The code CUTTINGS_S calculates the quantity of material transported to the surface as spallings for the system reference conditions. The radionuclide content of the materials released is dependent on the time of intrusion and is calculated separately (using the results from the reference conditions) during construction of the CCDFs in Task 7. The code and modeled system components are shown in Figure I-1. This task is discussed together with Task 5 in *Analysis Package for the Cuttings and Spallings Calculations (Tasks 5 and 6) of the Performance Assessment Analysis Supporting the Compliance Certification Application* (WPO# 40521).

Task 7
The final task is construction of CCDFs representing futures of the repository and calculation of cumulative releases (this task represents Step 5 in the performance assessment process described in the previous section). There are three parts in this task: (1) determine futures (random sequences of future events that may occur over the next 10,000 years at the WIPP site); (2) estimate the radionuclide releases resulting from these random sequences of future events, using the results of the calculations for each scenario and the reference conditions; and (3) construct a CCDF for each future. In order to efficiently calculate the consequences of multiple futures without repeating Tasks 1 through 6 for each history, the radionuclide releases for each future are calculated by scaling the reference-condition results from the first six tasks.

The computer code CCDF_GF is used to perform the steps in this task, using the results from all the previous tasks and associated computer codes. Task 7 does not address a component of the disposal system, therefore the CCDF_GF code is not shown in Figure I-1. The analysis package for this task is *Analysis Package for the CCDF Construction (Task 7) of the Performance Assessment Analysis Supporting the Compliance Certification Application* (WPO# 40524).

1.3 PA Computer Calculations

The major computer codes used in the analyses (including CCDF_GF) and the flow of information among them are illustrated in Figure I-2. Combined, Figures I-1 and I-2 illustrate the flow of information through the codes and the relationship between the codes and the physical system being simulated. In the PA calculations, the codes shown in the figures are executed under the requirements of the software configuration management system (CMS or SCMS), which creates and maintains a complete record of the input data and results of each calculation, together with the exact codes and scripts (commands for executing the codes) used to create those results.

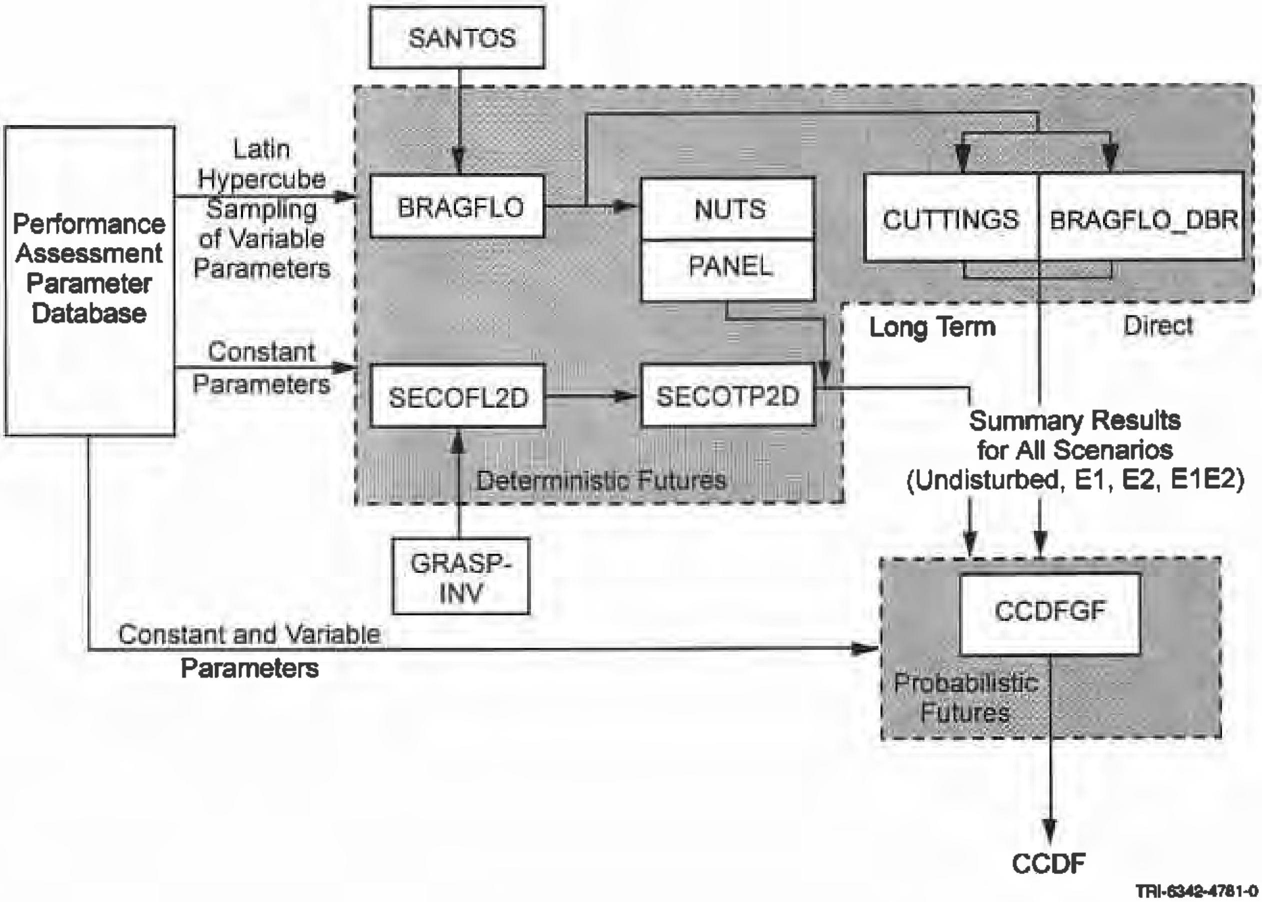


Figure I-2 Major codes, Code Linkages, and Flow of Numerical Information in WIPP Performance Assessment

Figures I-1 and I-2 show only those codes that perform the bulk of the computational effort related to simulating the significant physical processes occurring within the disposal system. In addition to these codes, a variety of additional codes are used in this performance assessment. These additional codes are used for the transfer of data between codes, preparation of input data and files, model output processing, and similar tasks. Many of these additional codes are also executed within the CMS, and all are qualified for use in these analyses under applicable SNL WIPP quality assurance procedures.

As shown in Figure I-2, there are three major calculation steps in analyzing the consequences of various scenarios (Tasks 1 through 6 in the previous section):

> Preparation of input from submodels (GRASP-INV and SANTOS),
>
> Latin hypercube sampling (LHS) of the variables in the parameter database that represent subjective uncertainty (such as spatial variability in a disposal system component property or processes), and
>
> Execution of the codes within the "deterministic futures" box indicated by dashed lines in Figure I-2.

The parameter database is the initial element in the calculation process. The database includes the values of parameters used in performance assessment codes that pertain to the technical aspects of disposal system performance. Parameters pertaining only to the execution of the computer codes (for example, convergence criteria for Newton-Raphson numerical solvers) are generally not included in the database but are recorded in input files and are traceable through the CMS. The parameters in the database fall into two categories: those that are assigned fixed values, and those that are uncertain and are therefore assigned a range of values according to a cumulative distribution function (CDF).

For the analyses of scenario consequences (Tasks 1 through 6), vectors (sets) of parameter values are created from the variable parameters representing subjective uncertainty by LHS of each variable for the set of simulations in the analyses. Each of the fixed parameter values from the database and a vector of sampled parameter values are combined to form a realization (a set of input parameters that are used in one or more of the codes). Each set of input parameters is then propagated through Tasks 1 through 6 (that is, the codes are executed) under four code sequence configurations, one each for the undisturbed performance scenario, the E1 scenario, the E2 scenario, and the E2E1 scenario. In each configuration, the codes are executed sequentially, as shown in Figure I-2.

In this performance assessment, subjective uncertainty is addressed using a LHS sample size no less than a third larger than the number of uncertain parameters: there are 57 sampled parameters (used in one or more of the codes) that represent subjective uncertainty, and they are sampled to create 100 vectors. The entire process (LHS of uncertain parameters, creation of vectors, and evaluation of scenario consequences through execution of the codes) is repeated three times (each time comprises a replicate which is independent of the other replicates) to achieve confidence in the results.

Once the consequences of various scenarios are calculated, there are two major steps in evaluating consequences of probabilistic futures (Task 7):

Random sampling of parameters which address stochastic uncertainty (such as location of an intrusion borehole), and

Execution of the code in the "probabilistic futures" box (CCDF_GF) in Figure I-2, in which the releases for the futures are calculated using the results of the calculations for each scenario and the reference conditions, and a CCDF is constructed for each future.

This sequence of two steps is repeated once for each of the 100 vectors of uncertain parameters (that is, all the random sequences of future events that may occur over the next 10,000 years at the WIPP site are considered for each of the vectors). This yields a group (family) of 100 CCDFs (one for each of the vectors). The family arises from the fact that fixed, but unknown, quantities are needed in the estimation of each CCDF (these quantities are the uncertain parameters in each vector).

Each individual CCDF displays the effects of stochastic uncertainty in that the stepwise shape of the CCDF reflects the fact that a number of different occurrences have a real possibility of taking place. The variations between the individual CCDFs in the family display the effects of subjective uncertainty. The distribution of CCDFs in the family thus provide a complete display of both stochastic and subjective uncertainty.

In the final step, the family of CCDFs for each replicate is compared to the regulatory standard in 40 CFR 191.13(a) to determine compliance.

2.0 Analysis Overview

2.1 Description of the Analysis

This analysis describes the computations performed by the CUTTINGS_S computer code which was written to calculate the quantity of solid radioactive material brought to the surface from WIPP as a consequence of an inadvertent drilling intrusion. The inadvertent penetration of a waste storage room by an exploratory drill bit causes an amount of solid radioactive material to be directly released to the ground surface and thus to the accessible environment. The code determines the amount of material removed by several release mechanisms, and passes this information to other codes where the activities are computed based on inventory and intrusion time. This activity information coupled with scenario probabilities is used to compute the contribution of direct releases to the complementary cumulative distribution function (CCDF).

2.1.1 Release Mechanisms

Three separate physical processes are assumed to influence the quantity of waste brought to the ground surface as the result of the inadvertent penetration of the repository by an exploratory drill bit. These are:

***Cuttings** - waste contained in the cylindrical volume created by the cutting action of the drill bit passing through the waste.

***Cavings** - waste that erodes from the borehole in response to the upward-flowing drilling fluid within the annulus, and

***Spallings** - waste introduced into the drilling fluid caused by the release of waste-generated gas escaping to the lower-pressure borehole. This requires a repository gas pressure that exceeds the hydrostatic pressure of the drilling mud.

Spallings can be further subdivided into three regimes that are dependent upon the state of waste permeability and gas pore pressure at the time of intrusion. These are:

**Blowout - the direct release of waste to the surface in waste decomposition gas that has cleared the borehole annulus of drilling mud and is flowing freely to the surface.

**Gas Erosion - low permeability waste that is pressed against the drillstring due to stresses from escaping decomposition gas and is eroded by the flowing drilling mud.

**Stuck Pipe - low permeability waste that is pressed against the drillstring sufficiently hard to prevent normal drilling. This occurs at high gas pressures.

The first two processes (Cuttings and Cavings) constitute the cuttings portion of the analysis (Task 5) while Task 6 is concerned with the analysis of the last process i.e. spallings.

The release processes and when they are active are depicted graphically in Figure 1.

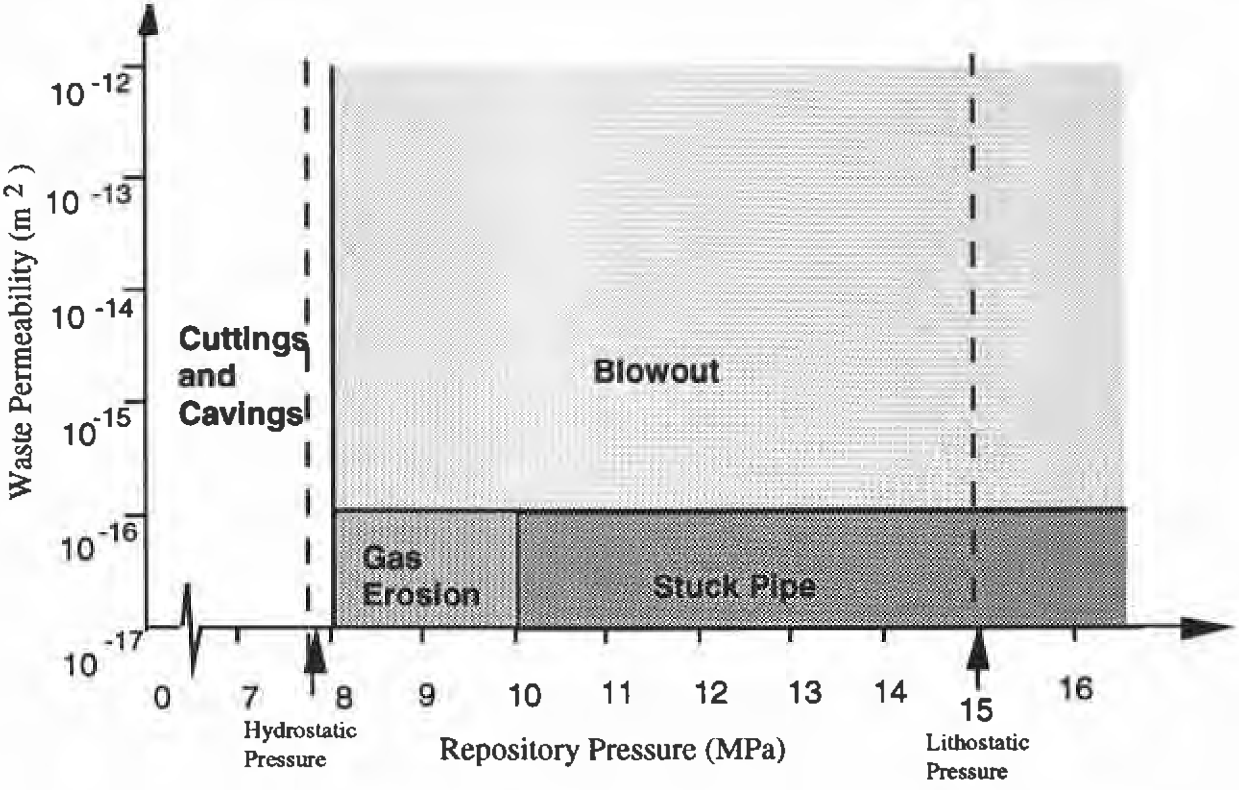


Figure 1. Release process zones

The release process zone boundaries are based on waste permeability and repository gas pressure at the time of intrusion and will be discussed in the model descriptions for the zones. Descriptions of the release process zones, their principal assumptions, and mathematical formulation will be discussed in the following sections.

2.1.2 Cuttings

This is the simplest component of the direct release model and is assumed to occur irrespective of repository pressure. For a gauge borehole, the volume of cuttings removed and transported to the surface is equal to the product of the drill bit area and the drill depth. Thus, to estimate the total solid volume of waste removed due to the cutting action of the drill bit , it is only necessary to know the compacted repository height (H), the porosity at the time of intrusion (φ), and the drill bit area (A).

$$Volume = AH(1-\varphi) \qquad (1)$$

The cuttings volume calculated in this manner is a lower bound to the total quantity of waste removed by drilling. In the CUTTINGS_S code the waste is assumed to be uniformly distributed throughout the disposal region. Thus the actual computation for release requires only the drill bit area and the waste curie content per unit area. The actual computation of cuttings release in the CUTTINGS_S code is computed within the module for cavings. This description follows.

2.1.3 Cavings

The cavings component of direct surface release consists of that quantity of waste material that is eroded from the borehole wall by the action of the flowing drilling fluid after a waste disposal room is penetrated. The erosion process is assumed to be driven solely by the shearing action of the drilling fluid (mud) on the waste as it moves up the borehole annulus.

In the annulus formed by the collars or drill pipe and the borehole wall, the flow of the drilling fluid has both a vertical and rotational component. Within this helical flow pattern, shear stresses are generated by the relative motion of adjacent fluid regions and by the action of the fluid on the borehole wall. In this model, it is assumed that if the fluid shear stress at the wall exceeds the effective shear resistance to erosion of the wall material (compacted repository wastes), erosion of the wall material will occur, increasing the diameter of the bored hole. The eroded material will then be passed to the surface in the flowing drilling fluid.

Flow in the annulus between the drillpipe and borehole wall is usually laminar (Darley and Gray, 1988, p243). Adjacent to the collars, however, the flow may be either laminar or turbulent as a consequence of the larger collar diameter and resulting higher mud velocities. For laminar flow, the analysis lends itself to classical solution methods. Turbulent flow, where the flow is assumed to be axial with a correction for the rotational component, requires a more approximate approach. A discussion of these two cases follows.

2.1.3.1 Laminar Flow

Below Reynolds numbers of about 2100 for Newtonian fluids and 2400 for some non-Newtonian fluids (Walker, 1976), experiments have shown that the flow of a fluid in a circular pipe or annulus is well behaved and can be described using a well-defined relationship between the velocity field and the fluid shear stress. This type of flow is called laminar. The laminar helical flow solution procedure outlined below and used in the CUTTINGS_S code is, for the most part, an adaptation of methods described in a paper by Savins and Wallick (1966).

One of the principal difficulties in solving for the shear stresses within a helically flowing drilling fluid is the shear rate dependence of the fluid viscosity. This non-Newtonian fluid behavior necessitates choosing a functional form for the variation of viscosity with shear rate for the fluid. There are several functional forms for the viscosity of drilling fluids that can be assumed. For example, in the oil and gas industry the Bingham and power law models are often used to approximate the shear rate dependence of the fluid viscosity. A less common function is a form chosen by Oldroyd (1958) and used in the analysis by Savins and Wallick (1966). Oldroyd assumed that the viscosity varied according to the functional relation

$$\eta = \eta_o \left[\frac{1+\sigma_2 \Gamma^2}{1+\sigma_1 \Gamma^2} \right] \qquad (2)$$

where σ_1 and σ_2 are constants, η_o is the limiting viscosity at zero rate of shear, η_∞ (defined as $\eta_o(\sigma_2/\sigma_1)$) is the limiting viscosity at infinite rate of shear, and Γ is the shear rate. The viscous shear stress is described by $\tau = \eta\Gamma$.

Using the Oldroyd viscosity, Equation (2), the viscous shear stress can be illustrated graphically as in Figure 2a and 2b.

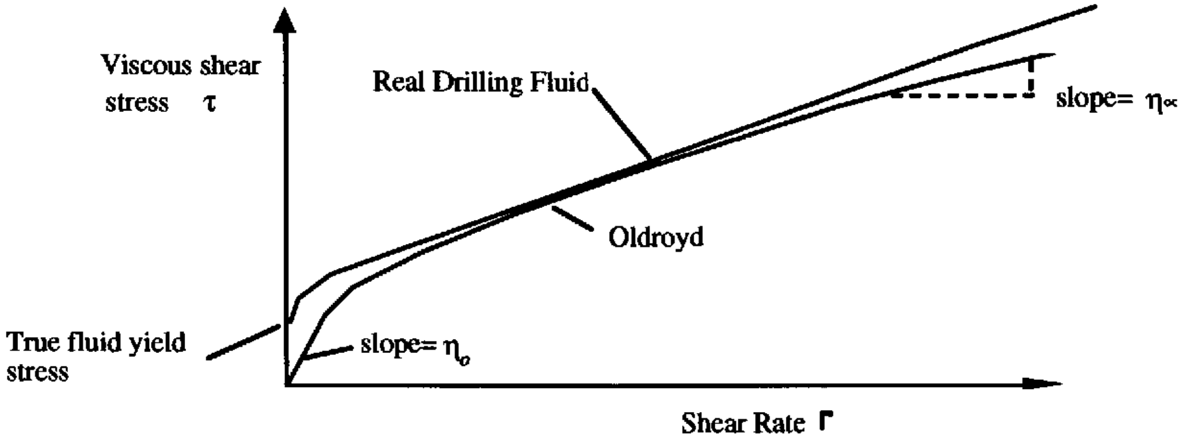


Figure 2a Oldroyd and real drilling fluid

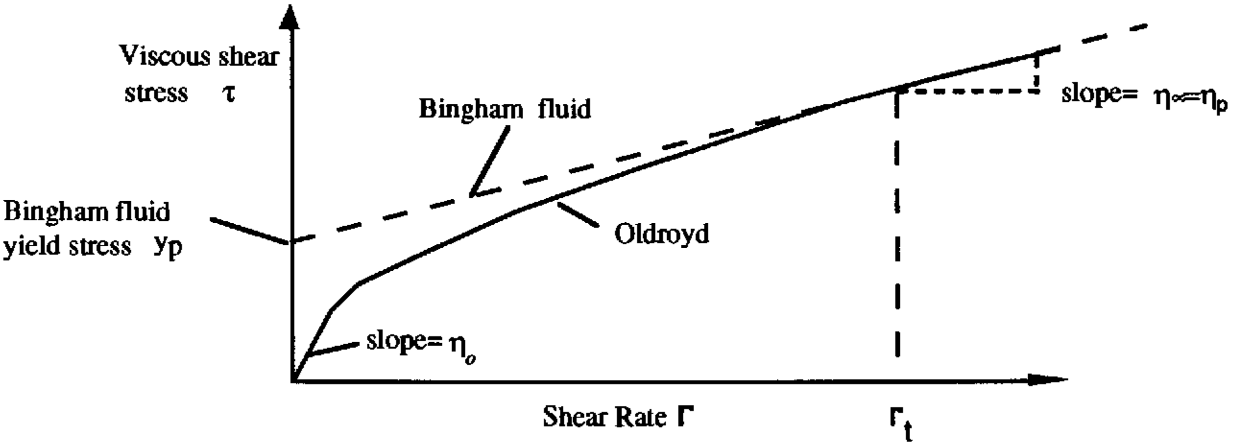


Figure 2b Oldroyd and Bingham fluid

This is a rate softening (pseudoplastic) model that has an initial slope of η_o and a limiting slope of η_∞ for large shear rates.

The Oldroyd model cannot account for drilling fluids that exhibit a yield stress. However, above a shear rate of zero, parameters can be chosen so that the model can be made to approximate the pseudoplastic rate response of many drilling fluids (see Figure 2).

Savins and Wallick (1966) showed that the solution for laminar helical flow of a non-Newtonian fluid in an annulus could be written in terms of three nonlinear integral equations.

$$
\begin{aligned}
F_1 &= \int_{\alpha}^{1}\left(\frac{\rho^2-\lambda^2}{\rho}\right)\frac{d\rho}{\eta}=0 \\
F_2 &= C\int_{\alpha}^{1}\frac{d\rho}{\rho^3\eta}-\Delta\Omega=0 \qquad (3)\\
F_3 &= \frac{4Q}{\pi R^3}+4\left(\frac{RJ}{2}\right)\int_{\alpha}^{1}\left(\frac{\alpha^2-\rho^2}{\eta}\right)\left(\frac{\rho^2-\lambda^2}{\rho}\right)d\rho=0
\end{aligned}
$$

where α is the ratio of the collar radius over the cutting radius (R_i/R) (Figure 3), $\Delta\Omega$ is the drill string angular velocity, Q is the drilling fluid (mud) flow rate, r is the radial coordinate, and ρ is the non-dimensional radial coordinate representing the ratio r/R.
The unknown parameters λ^2, $RJ/2$, and C are related to the fluid shear stresses through the relations

$$
\begin{aligned}
\tau_{r\theta} &= \frac{C}{\rho^2} \\
\tau_{rz} &= \frac{RJ}{2}\left(\frac{\rho^2-\lambda^2}{\rho}\right) \qquad (4)\\
\tau^2 &= \tau_{r\theta}^2+\tau_{rz}^2
\end{aligned}
$$

where r, θ, and z represent radial, tangential, and vertical coordinates associated with the cylindrical geometry of Figure 3.

The three nonlinear integral equations represented by (3) are solved numerically. The final eroded diameter is determined through an iterative process (Figure 4) that equates the fluid shear stress adjacent to the waste as computed by equations (3) to a measure of the erosion resistance of the waste. The erosion resistance is governed by the effective shear resistance to erosion.

The effective shear resistance for erosion (τ_{fail}), equals the threshold value of fluid shear stress required to sustain general erosion at the borehole wall. Parthenaides and Passwell (1970), in discussing investigations on the erosion of seabed sediments and in channels, has noted that this effective soil shear resistance is not related to the soil shear strength as normally determined from conventional soil tests. The effective shear resistance for erosion based on seabed data, as determined by Parthenaides and Passwell (1970), is on the order of a few Pa and is thus smaller by several orders of magnitude than the macroscopic soil shear strength.

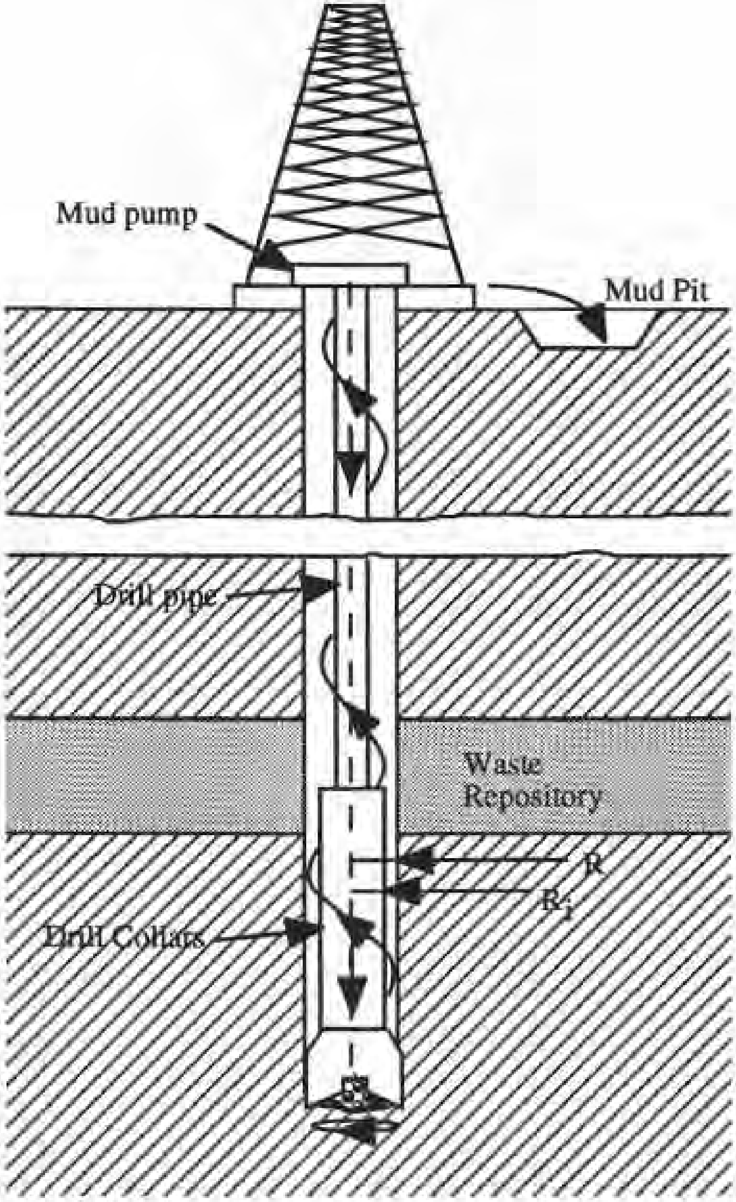


Figure 3. Detail of rotary drill string adjacent to repository.

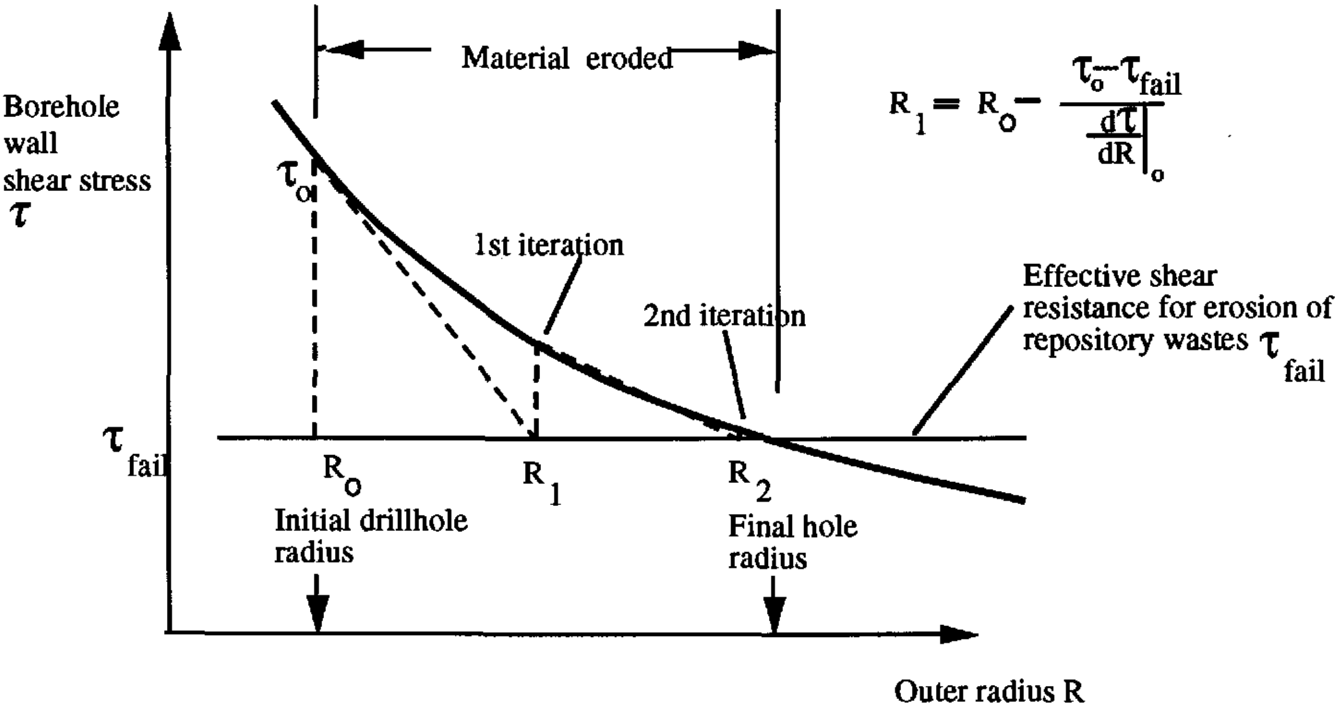


Figure 4. Iterate to find the final hole radius

2.1.3.2 Turbulent Flow

For Newtonian fluids with Reynolds numbers greater than about 2100, flow in a circular pipe or annulus starts to become more or less random in character, which makes orderly mathematical analysis of the flow difficult, if not impossible. With increasing Reynolds numbers, this random behavior increases until, at a Reynolds number of about 3000, the flow becomes fully turbulent. In fully turbulent flow, momentum effects dominate and the fluid viscosity is no longer important in characterizing pressure losses.

The Reynolds number (R_e) is defined as

$$R_e = \frac{\bar{\rho}\bar{V}D_e}{\bar{\eta}} \tag{5}$$

where D_e is the equivalent hydraulic diameter, $\bar{\rho}$ is the drilling fluid density, $\bar{V}$ is the average axial fluid velocity, and $\bar{\eta}$ is the average fluid viscosity.

For Newtonian fluids, the value to use for the viscosity is clear since the viscosity is constant for all rates of shear. Non-Newtonian fluids exhibit a changing viscosity with shear rate and present a special problem in calculating R_e. For fluids that exhibit a limiting viscosity at high rates of shear (such as the Bingham model and in our case the Oldroyd model), it has been suggested (Broc, 1982) that the limiting viscosity ($\bar{\eta} = \eta_\infty$) be used in calculating the Reynolds number.

The Reynolds number for an Oldroyd fluid in an annulus can then be written as (Broc, 1982)

$$R_e = \frac{0.8165 D_e \bar{V}\bar{\rho}}{\bar{\eta}} \tag{6}$$

where the equivalent hydraulic diameter is expressed as $D_e = 2(R - R_i)$ (see Figure 3).

The most important influence viscosity has on the calculation of pressure losses in fully turbulent flow of non-Newtonian fluids appears to be in the calculation of the Reynolds number. A far more important parameter is the surface roughness past which the fluid must flow. The Reynolds number, however, does have a role in determining the onset of turbulence. For Newtonian fluids this number is about 2100. For non-Newtonian, rate-thinning fluids, the critical value of R_e tends to be greater than 2100 but less than 2400 (Walker, 1976). For our purposes, a value of 2100 will be used to represent R_{e_c} (the critical Reynolds number) for the Oldroyd fluid model. Since turbulent flow is more effective in generating fluid shear stresses at the borehole wall, this assumption is conservative.

There is a transition region beyond R_{e_c} before the development of fully turbulent flow. In this regime the flow has the character of both laminar and turbulent flow. However, since pressure losses increase rapidly in turbulent flow and affect borehole shear stresses more severely, it will be assumed that beyond R_{e_c} the flow is fully turbulent.

Turbulent flow is very complex and, thus, to characterize the turbulent flow regime, the great bulk of analysis has concentrated on empirical procedures. For axial flow in an annulus, the pressure loss under turbulent conditions can be approximated by (Broc, 1982)

$$\Delta P = \frac{2fL\bar{\rho}\bar{V}^2}{(0.8165)D_e} \tag{7}$$

where f is the coefficient of pressure head loss (Fanning friction factor) and L is the borehole length.

If the shear stress due to the flowing fluid is assumed to be uniformly distributed on the inner and outer surfaces of the annulus, it can be easily shown using Equation (7) that the shear stress is related to the average fluid velocity through the relation

$$\tau = \frac{f\bar{\rho}\bar{V}^2}{2(0.8165)} \tag{8}$$

The Fanning friction factor is empirically related to the Reynolds number and relative roughness by the equation (Whittaker, 1985)

$$\frac{1}{\sqrt{f}} = -4\log_{10}\left[\frac{\varepsilon}{3.72D} + \frac{1.255}{R_e\sqrt{f}}\right] \tag{9}$$

where ε/D is the relative roughness. For circular pipes, D in this equation represents the inside diameter and ε is the absolute roughness or the average depth of pipe wall irregularities. In the absence of a similar equation for flow in an annulus, it is assumed that this equation also applies here, where D is the equivalent hydraulic diameter (D_e) as defined earlier and ε is the absolute roughness of the waste-borehole interface.

For laminar flow within the annulus both axial and rotational flow are modeled. Some of the available literature (Khader and Rao, 1974 ; Bilgen E., Boulos, R., and Akgungor A.C., 1973) indicates the importance of also accounting for drillstring rotation when the drilling mud flow within the annulus is turbulent. Consequently, to account for rotational flow in the turbulent regime, an axial flow velocity correction factor (rotation factor) is introduced into the above formulation that maintains eroded diameter compatibility across the laminar- turbulent flow transition. The rotation factor (F_r) is determined by increasing (or decreasing) the axial velocity $\bar{V}$ in equation 8 until the turbulent flow eroded diameter equals the laminar flow eroded diameter computed at the prescribed angular velocity at a Reynolds number of 2100. The rotation factor is defined as

$$F_r = \frac{\overline{V}_{2100}}{\overline{V}} \tag{10}$$

where $\overline{V}_{2100}$ is the axial velocity required for eroded diameters to be the same for turbulent and laminar flow. This rotation factor is then used to modify the axial turbulent flow velocity at all other turbulent flow Reynolds numbers. The rotation factor is not used when computing the Reynolds number. Equation 8 then can be rewritten

$$\tau = \frac{f\rho\left(F_r\overline{V}\right)^2}{2(0.8165)} \tag{11}$$

Using a relative roughness and a calculated Reynolds number based on $\overline{V}$, a Fanning friction factor can be determined by iteratively solving Equation (9). The value of the shear stress acting on the borehole wall can then be determined from Equation (11). Using an iterative procedure similar to that for the laminar flow problem, the fluid shear stress can be forced to equal the repository shear resistance to erosion (τ_{fail}) to obtain the final eroded borehole radius (see Figure 4).

2.1.4 Spallings

Spallings comprises that quantity of solid waste that reaches the ground surface as the result of the high pressure gas in the waste. If the repository gas pressure exceeds the hydrostatic pressure of the column of drilling fluid, solids releases can occur from blowout, stuck pipe or gas erosion. Contaminated brine can also be expelled during a blowout event, a process not considered in the CUTTINGS_S code. Brine releases to the surface resulting from blowout are computed using a separate set of BRAGFLO runs (Analysis Package for the BRAGFLO Direct Release Calculations (Task 4) of the Performance Assessment Analyses Supporting the Compliance Certification Application (WPO# 40520)).

2.1.4.1 Blowout (Solids Removal)

Blowout is assumed to occur when repository gas pressures exceed 8 MPa (~hydrostatic) and when waste permeabilities exceed 10^{-16} m^2 (see figure 1). For permeabilities that are lower than 10^{-16} m^2 the gas flow into the borehole is assumed to be too low to cause well blowout (Berglund 1994).

Results from steady state flow experiments through granular material in a cylindrical geometry (Lenke, et al. 1996) indicate that a porous pattern of channels is formed in the "waste" adjacent to the "borehole". Based on this channeling process a conceptual model for release model was devised. The conceptual model is based on a number of assumptions. These are:

1. After intrusion by a drillbit, the pressure gradients associated with the flow of gas toward the borehole fracture the porous (waste) material sufficiently to permit the escaping gas to flow within the fractures rather than through the porous matrix (Figure 5). Consequently, the intrinsic

permeability of the matrix no longer restricts gas flow and the gas pressure at the borehole entrance can be assumed to be the initial pore pressure.

2. The gas flow velocity up the borehole is governed by the isothermal flow of gas in a long tube of a given cross-sectional area, tube roughness, and gas pressure at the borehole entrance. (For sufficiently high borehole entrance pressures the flow velocity tends to choke or become self limiting.)

3. The mass flowrate of gas in the fractures at any radial cross-section away from the borehole is equal to the mass flowrate up the borehole.

4. Radial gas flow within the fractures of the waste matrix erode and widen the fractures. Erosion is assumed to occur if the fracture gas velocity exceeds a velocity v_e. (The higher gas velocities in fractures near the borehole create wider channels near the borehole.)

5. The fracture erosion velocity v_e is related to the terminal velocity of a waste particle at the fracture surface and to the cohesive strength afforded by moisture and cementation in the matrix. Experiments will determine the effectiveness of cohesive strength and gravity on erosion and will provide experimentally determined effectiveness factors F_{se} , F_{ge} , and F_{ce} which are related to these factors.

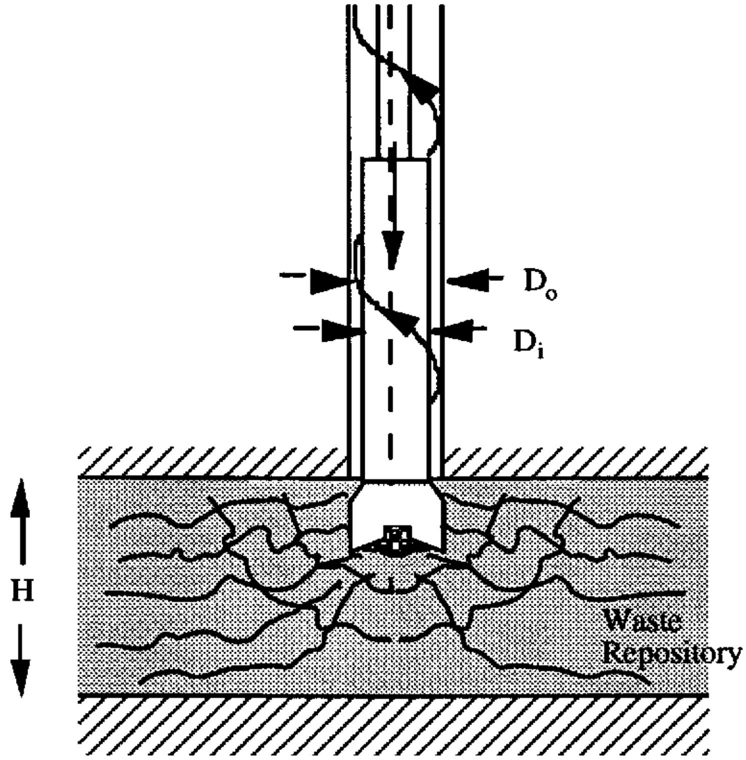


Figure 5 Fractured Waste Matrix after Penetration

2.1.4.1.1 Computation of Release Volume

Since the gas pressure is assumed to be constant throughout the fractured, porous matrix, conservation of mass flow requires (Figure 6)

$$2\pi rVH = A_{borehole}V_{borehole}$$

or

$$V = \frac{A_{borehole}V_{borehole}}{2\pi rH} \tag{12}$$

where V is the average gas velocity within the matrix at a radius r from the borehole and H is the height of a repository room at the time of intrusion. The borehole annulus area is denoted as $A_{borehole}$ and the average gas velocity up the borehole annulus is denoted $V_{borehole}$.

The local gas velocity within the fractures (Figure 6) can be written as $v = \dfrac{V}{\varphi_f}$ where φ_f is the fracture porosity. Thus the fracture porosity associated the erosion fracture velocity v_e is

$$\varphi_{fe} = \frac{V}{v_e} = \frac{A_{borehole}V_{borehole}}{2\pi rHv_e} \tag{13}$$

The solid volume eroded from the fractures is

$$V_{ol} = 2\pi H(1-\phi)\int_0^{r_o} \varphi_{fe} r\,dr = \frac{A_{borehole}V_{borehole}}{v_e}(1-\phi)\int_0^{r_o} dr \tag{14}$$

or

$$V_{ol} = \frac{A_{borehole}V_{borehole}r_o}{v_e}(1-\phi) \tag{15}$$

where ϕ is the matrix porosity at the time of intrusion

Equation (15) indicates that the solid volume of material removed (spalled) due to a borehole penetration is a function of the flowrate up the borehole, the physical extend of a repository room, the waste porosity, and a velocity above which erosion occurs in waste fractures. The gas velocity up the borehole is a known function of the gas pressure at the borehole entrance.

2.1.4.1.2 Erosion Velocity (within fractures)

The fracture erosion velocity v_e is the average threshold gas velocity in a fracture required to "erode" the fracture walls. It is assumed to be related to the terminal velocity of a waste particle and to the cohesive strength between particles caused by pore water and cementation.

The terminal velocity of a spherical particle can be found by equating the particle weight to the drag force acting on the particle when traveling at a velocity V_e. The relationship that results is (Cheremisinoff, 1984)

$$V_e^2 = \frac{4gd(\rho_s - \rho_g)}{3C_D\rho_g} \tag{16}$$

where g= acceleration of gravity, d= particle diameter, $\rho_s =$ particle density, $\rho_g =$ gas density, and C_D is the coefficient of drag. The coefficient of drag for a sphere is an empirical function of the particle Reynolds number R_{ed} (Fox et. al. 1973)

where $R_{ed} = \frac{\rho_g V_e d}{\mu}$ and μ is the gas viscosity

For $R_{ed} < 0.4$ $\quad C_D = \frac{24}{R_{ed}}$

For $0.4 < R_{ed} < 200000$ the data can be fit with the following function

$$C_D = 10^{\left(\bar{a}+\bar{b}x+\bar{c}x^2+\bar{d}x^3+\bar{e}x^4+\bar{f}x^5+\bar{g}x^6\right)} \tag{17}$$

where

$$\bar{a} = 1.3918$$
$$\bar{b} = -0.907723$$
$$\bar{c} = 0.136371$$
$$\bar{d} = 0.0165093$$
$$\bar{e} = -0.0285484$$
$$\bar{f} = 0.00933281$$
$$\bar{g} = -0.000897166$$

and

$$x = \log_{10} R_{ed}$$

These coefficients were determined using code GRAPHER, Version 1.23 from Golden Software Inc., Golden Colorado.

For $R_{ed} > 200000$ $\quad C_D = 0.2$

Equations (16) and (17) are solved simultaneously using an iterative process that converges to a value of V_e that satisfies both equations.

The downward force resisting the drag force caused by the flowing gas is the weight of the particle. If there are additional forces acting to resist lofting such as tensile strength an effective gravity force can be computed and used to replace the gravity force in the terminal velocity equation.

Consider a material that has a tensile strength σ . This parting stress on the particle level can be written

$$\sigma = \frac{\textit{Parting}\text{ force}}{\text{Particle projected area}} = \frac{mg_t}{\pi R^2} = \frac{\frac{4}{3}\pi R^3 \rho_s g_t}{\pi R^2} = \frac{4}{3}\rho_s g_t R \tag{18}$$

where m is the particle mass, R is the particle radius, ρ_s is the particle density and g_t is the effective acceleration of gravity necessary to generate a particle weight equal to the parting force.

Solving equation (18) for g_t obtains

$$g_t = \frac{3}{4}\frac{\sigma}{\rho_s R} \tag{19}$$

The effective acceleration of gravity that accounts for particle weight and strength can then be written

$$g_{eff} = (g + g_t) = g + \frac{3}{4}\frac{\sigma}{\rho_s R} \tag{20}$$

or

$$g_{eff} = (g + g_t) = g + \frac{3}{4}\frac{\sigma}{\rho_s R} = g + \frac{3}{4}\frac{\sigma_p}{\rho_s R} + \frac{3}{4}\frac{\sigma_c}{\rho_s R} \tag{21}$$

where the parting stress (equation 20) is assumed to have contributions resulting from pore water σ_p and intergranular cementation σ_c. For the channeling model, since particle erosion is occurring in the channels rather than lofting, correction factors are applied to the parting stresses and acceleration of gravity. Thus the effective gravity term becomes

$$g_{eff} = gF_{ge} + \frac{3}{4}\frac{\sigma_p}{\rho_s R}F_{se} + \frac{3}{4}\frac{\sigma_c}{\rho_s R}F_{ce} \tag{22}$$

where F_{ge} is the gravity effectiveness factor and F_{se} and F_{ce} are the stress effectiveness factors. These constants are determined by experiment (Lenke, et.al., 1996). Since the fracture erosion velocity v_e is dependent upon a coefficient of drag C_D which is in turn a function of v_e (see equation 17) an iterative solution process is used to converge to a solution for v_e.

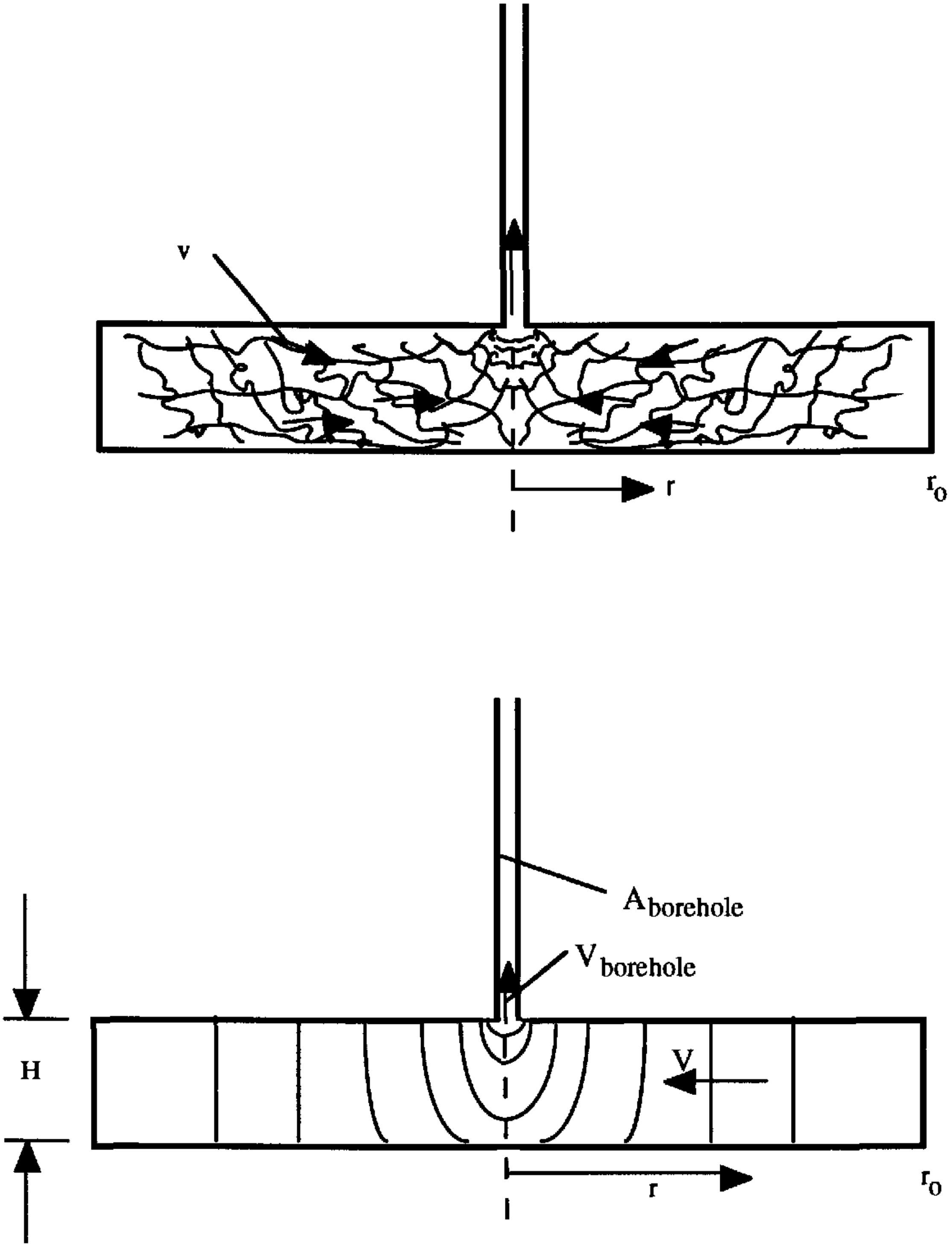


Figure 6 Flow Model

2.1.4.1.3 Solution Process for Solids Removal caused by Blowout

The solution to equation 15 requires 5 quantities. The value r_o is chosen as the equivalent radius of a repository room based on area. For a WIPP room $r_o \sim 17$ m. The borehole area $A_{borehole}$ is detemined by the annulus area or (Figure 5)

$$A_{borehole} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) \tag{23}$$

To determine $V_{borehole}$ requires the solution for the borehole entrance Mach number M_1. The borehole entrance Mach number is computed based on flow in the borehole annulus and assumes that the borehole is free of drilling mud and undergoing full blowout. Compressible, isothermal flow in a channel (the borehole annulus) with friction is governed by the equation (Binder, 1958)

$$\frac{fl}{D} = \frac{1}{KM_1^2}\left[1 - \frac{p_2^2}{p_1^2}\right] - 2\ln\frac{p_1}{p_2} \tag{24}$$

where f=friction factor, D=pipe diameter, l =pipe length, K=ratio of specific heats of the gas, p_1 and p_2= inlet and outlet gas pressures, and M_1= inlet Mach number. The pipe diameter to use for our purposes is the effective hydraulic diameter computed from the annular area. Actually there are two annular areas that are considered for flow up the borehole; one area is adjacent to the drill collars and the other is adjacent to the drill pipe and consequently equation (24) has to be solved over these two regions. The pressure ratio is based on the inlet and exit pressures for the two annuli with pressure compatibility maintained at the drillpipe / drill collar connection.

Utilizing conservation of mass, equation 24 can be divided into the two equations

$$\frac{fl_{coll}}{D_{coll}} = \frac{1}{KM_1^2}\left[1 - \frac{p_i^2}{p_1^2}\right] - 2\ln\frac{p_1}{p_i} \tag{25}$$

$$\frac{fl_{drill}}{D_{drill}} = \frac{1}{KM_1^2\left(\frac{p_1}{p_i}\right)^2\left(\frac{D_{coll}}{D_{drill}}\right)^4}\left[1 - \frac{p_{exit}^2}{p_i^2}\right] - 2\ln\frac{p_i}{p_{exit}} \tag{26}$$

where p_{exit}= exit pressure

l_{drill}= length of drillpipe
l_{coll}=collar length
D_{coll}=equivalent diameter for collar annulus (based on annulus area)
D_{drill}=equivalent diameter for drillpipe annulus (based on annulus area)
p_i=intermediate pressure

M_1=inlet Mach number

In addition to equations 25 and 26 the flow requires the additional constraint (Binder, 1958 p 64) that either $\frac{dp}{dl}$ becomes unbounded at the pipe exit or $p_{exit}= p_{atm}$. A recursive process based on Taylor series expansions are used to obtain the solution to the three governing equations. Seed values used as initial guesses to the solution are obtained by systematically scanning over possible values of p_i and p_{exit} for a fixed backpressure (p_1= waste gas pore pressure).

The borehole velocity is related to the inlet Mach number by the relation

$$V_{borehole} = CM_1$$

where $C = (KRT)^{\frac{1}{2}}$ is the local sound speed, T is the absolute temperature and K and R are gas constants. For hydrogen gas K =1.41 and $R = 4116. \frac{Nm}{kg.s}$ (Obert, 1948, p541)

2.1.5 Stuck Pipe

If the waste has a low permeability when penetrated by a drillbit, the gas flow into the drilling mud may cause waste failure adjacent to the borehole (Berglund, 1993) and jam the drillbit preventing further drilling. Prior to becoming completely stuck the driller will notice an increase in torque on the drillstring and a decrease in the rotational speed. When sticking occurs the driller will usually initiate a cleanout procedure wherein the drill bit is raised and lowered repeatedly into the sticking formation to clear the obstruction. This process can be continued for as much as 12-24 hours if it is shown to be effective. After this time the problem must be solved by weighting up the mud, spot sealing with cement or setting casing (Short,1982).

During the cleanout procedure waste will be transported to the surface with each thrust of the drillbit into the obstruction. The quantity of waste removed is related to the maximum carrying capacity of the drilling mud and can be estimated based on the observation that for drill cutting loadings above 5% in the drilling mud (Darley & Gray, 1988, p259) tight hole conditions or stuck drillpipe may occur when circulation is stopped for any reason. Thus the maximum solid waste removal rate would consist of 5% of the drilling mud flowrate. The total quantity of solid waste transported to the surface can thus be computed as the waste removal rate multiplied by the cleanout time. The range of releases possible is based on variations in drillbit diameter (10.5 to 17.5 inches), duration of the cleanout procedure (12 to 24 hours) and the drilling mud flowrate (30 to 50 gallons/minute/inch of drill diameter). The releases are based on

$$V_s= 0.05QD_oT \qquad (27)$$

where

V_s= Solid waste volume brought to ground surface
Q=Drilling mud flow rate/drillbit diameter
T=Cleanout duration
D_o= Drill bit diameter

and varies between 43 to 238 m^3 of solid waste. The range of drill bit diameters illustrated (10.5 to 17.5 inches) is for illustration only. In the current CCA database the drillbit diameter is fixed at a single value of 12.25 inches.

The lower limit of repository gas pressure at which sticking would occur (10MPa) is based on a drillstring power of 800hp and a coefficient of friction between the waste and drillcollars of 0.3. For these conditions the drill string angular velocity would decrease by more than 50% from the normal operating range alerting the driller to sticking conditions.

2.1.6 Gas Erosion

As with stuck pipe(section 2.1.5) this occurs when the waste has a low permeability and the gas flow to the borehole is very low and either is not detected by the driller or is allowed to trickle slowly along the drillstring and be released at the surface. The waste fails adjacent to the borehole perhaps causing some pipe sticking but the driller is able to continue and does not detect the unusual nature of the drill cuttings being brought to the surface. The flow of gas from the waste to the borehole generates a stress state in the waste adjacent to the borehole that depending on waste strength and the magnitude of the pressure gradient impresses the failed waste against the drillstring causing a continuous process of gas assisted erosion. As waste erodes more waste moves towards the drillstring in response to the gas pressure gradient and the process continues until sufficient gas has been released from the panel to preclude waste failure or until casing is set. Because the driller is either not aware of, or ignores the nature of the drill cuttings being removed in this case, the final volume of waste removed can be substantial.

For compacted waste with little or no strength waste failure will generally occur for all repository gas pressures that exceed the hydrostatic stress of the drilling mud. The failed waste is then transported to the accessible environment in the drilling mud. As with the sticking mode described above, the volume of waste removed can be computed based on the observation that above drill cutting loadings of 5% in the drilling mud (Darley & Gray, 1988, p259) tight hole conditions or stuck drillpipe may occur when circulation is stopped for any reason. Thus under these conditions the driller is not likely to remove waste to the surface at a rate faster than continuous drilling at the 5 percent limit.

The 5 percent cuttings loading will consist of both cuttings (from the hole bottom) and gas spallings. For a fixed mud flowrate the cuttings percentage will vary with the penetration rate. The penetration rate varies between 50 - 100 ft/hr. For high penetration rates the cuttings percentage will be high leaving only a small amount for spallings to add up to the assumed 5 percent limit. For low penetration rates the cuttings percentage will be small and the spallings percentage correspondingly greater. The quantity of waste removed to the surface will be equal to (spall percentage) X (mud flowrate) X (drilling time). The drilling time is governed by the time required to drill from the elevation of the repository to the elevation at which casing is set which is below the Castile formation at 4500 ft.

The solid volume of waste brought to the surface can by readily computed based on available drilling parameters utilizing the following equation.

$$V_S=[0.05QD_O-\pi(D_O^2/4.)R_p]\Delta/R_p \qquad (28)$$

where

V_S= Solid waste volume brought to ground surface
Q=Drilling mud flow rate/drillbit diameter

Do=Drill bit diameter
R_p=Penetration rate
Δ=Differential Drilling Depth (distance from repository depth to depth where casing is set)

Based on a differential drilling depth of 2350 ft, and placing the remaining variables at their extreme values the range of volumes of solid waste released to the surface ranges from 44 to 356 m^3. As with stuck pipe (section 2.1.5) the range of drill bit diameters used for the gas erosion estimate (10.5 to 17.5 inches) is for illustration only. In the current CCA database the drillbit diameter is fixed at a single value of 12.25 inches.

For the CCA calculations, since the waste permeability was fixed at 1.7×10^{-13} m^2, computations for stuck pipe and gas erosion were not performed (see figure 1).

2.1.7 CUTTINGS_S Calculations

Data on repository conditions at different times from the Salado Flow task (Task 1 in the CCA Analysis Plan) were used to compute the direct releases due to cuttings, cavings, and spallings. These computations were conducted within the CUTTINGS_S code. The CUTTINGS_S code was run for critical conditions, and releases for other conditions required in the CCDF generation were inferred from analysis of these results. Cuttings, cavings, and spallings were computed for the following conditions:

- 100, 350, 1000, 3000, 5000, and, 10000 years after closure for undisturbed conditions (Designated scenario S1)
- 550, 750, 2000, 4000, and, 10000 years after closure after an initial intrusion at 350 years after closure (Single E1 i.e. brine pocket intrusion designated scenario S2)
- 1200, 1400, 3000, 5000, and, 10000 years after closure after an initial intrusion at 1000 years after closure (Single E1 i.e. brine pocket intrusion designated scenario S3)
- 550, 750, 2000, 4000, and, 10000 years after closure after an initial intrusion at 350 years after closure (Single E2 i.e. non brine pocket intrusion designated scenario S4)
- 1200, 1400, 3000, 5000, and, 10000 years after closure after an initial intrusion at 1000 years after closure (Single E2 i.e.. non brine pocket intrusion designated scenario S5)

These calculations were replicated to achieve confidence in results. For a sample size of 100, 3 replications, and upper and lower repository intrusions, 15,600 computer runs were performed.

2.2 Software Requirements

The WIPP direct release code named CUTTINGS_S was used to model the direct releases due to cuttings cavings and spallings. CUTTINGS_S requires three input files for executing PA calculations for the CCA analyses. One of the input files is associated with the BRAGFLO code that is used to estimate the repository conditions at the time of intrusion (Task 1 in the CCA

Analysis Plan). For each BRAGFLO run, a unique ASCII input file containing initial and boundary conditions, material flow properties, and other information is required. A binary output file corresponding to each of these BRAGFLO input files is created by BRAGFLO and contains the resulting repository conditions. For each CUTTINGS_S run, a set of these BRAGFLO files is required as input. In addition, a CUTTINGS_S input file containing CUTTINGS_S run parameters is required as well as an binary input file that contains sampled data and additional input such as the waste inventory and drilling parameters. Each CUTTINGS_S run produces a unique binary output file corresponding to a particular set of

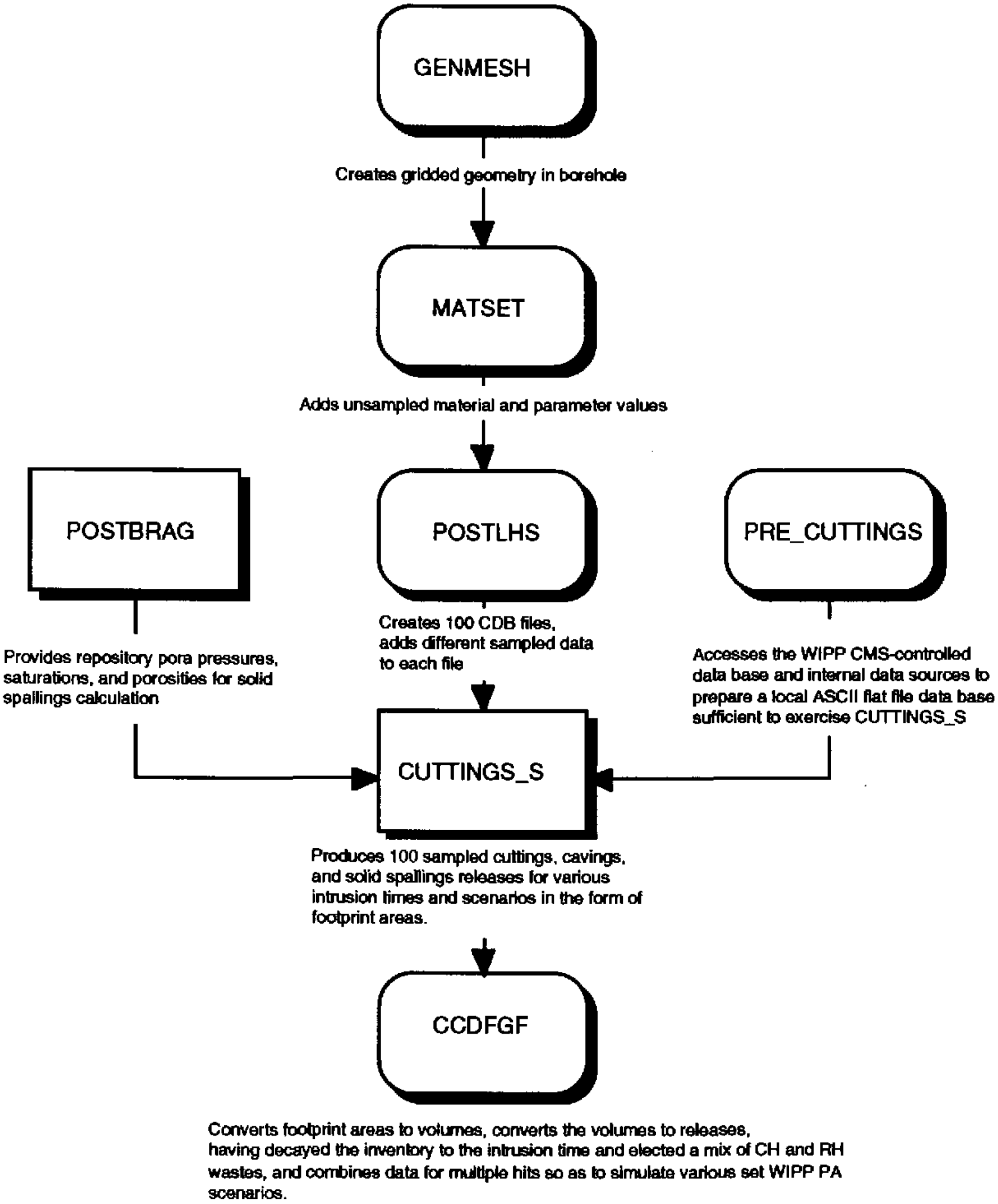
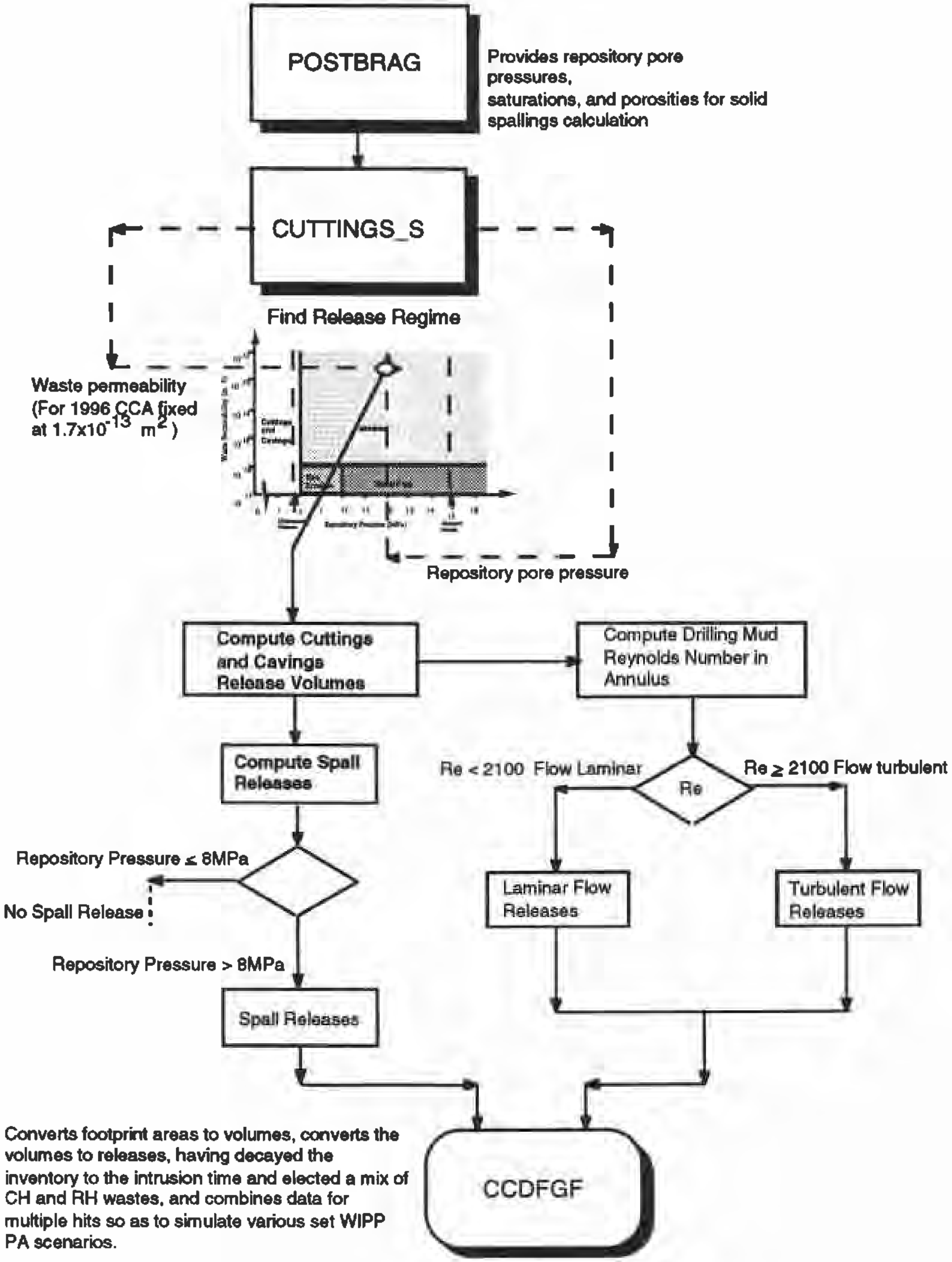


Figure 7 Code sequence for CUTTINGS_S in the 1996 CCA PA.

BRAGFLO files and CUTTINGS_S input files. This binary output file contains the cuttings, cavings, and spallings releases that will be used as part of the input for the calculation of the CCDF.

CUTTINGS_S is normally exercised as one of a sequence of codes that includes GENMESH (GM_PA96, Version 6.08), MATSET (MATSET_PA_96 Version 9), and POSTLHS (POSTLHS_96, Version 4.07), and requires input data files that originate with the code BRAGFLO (BRAGFLO_PA96, Version 4.0). The code sequence is depicted in figure 7, and examples of the input control files required by GENMESH and MATSET in preparation for a CUTTINGS_S run are given in the CUTTINGS_S users manual. POSTLHS requires an input file, but it is empty.

A more detailed flow chart for the running of CUTTINGS_S is shown in figure 8.



Provides repository pore pressures, saturations, and porosities for solid spallings calculation

Converts footprint areas to volumes, converts the volumes to releases, having decayed the inventory to the intrusion time and elected a mix of CH and RH wastes, and combines data for multiple hits so as to simulate various set WIPP PA scenarios.

Figure 8. CUTTINGS_S Flowchart

The specific version, or class, of CUTTINGS_S that was used for the CCA calculations is located in the WIPP Software Configuration Management System (SCMS) on the Alpha Cluster computers. The class of CUTTINGS_S currently available in the SCMS is the following:

Class:	PA96
Name:	CUSPPA96.EXE
Directory:	WP$PRODROOT:[CUSP.EXE]
Version no.:	5.03
Platform:	Fortran 77 for Open VMS AXP, ver 6.1, on a DEC Alpha

The CUTTINGS_S code is controlled by CMS as described in the description document (*Traceability/Reproducibility of the PA96 Calculations for the CCA*, WPO#40313)

This is an updated version of the CUTTINGS_S code. The analysis plans for Tasks 5 and 6 referred to a version number 5.00 for the CUTTINGS_S code. This new version (5.03) was qualified per QAP 19-1 and made available in the SCMS on 23 May 1996. The CUTTINGS_S code is documented in the following

WIPP PA User's Manual for CUTTINGS_S, Version 5.03 WPO#37765, May 22, 1996

WIPP PA Implementation Document for CUTTINGS_S, Version 5.03 WPO#37764, May 22, 1996

WIPP PA Requirements Document and Verification and Validation Plan (RD/VVP) for CUTTINGS_S, Version 5.03 WPO#37763, May 22, 1996

WIPP PA Validation Document for CUTTINGS_S, Version 5.03 WPO#36689 May 12, 1996

Pertinent data for analysis was extracted from the CUTTINGS_S output cdb files using the current camdat database examination program GROPE designated GROPECDB_PA96 version 2.12 built on 6/27/96. The input file for this code is shown in Appendix B along with a macro that extracts the desired data from the 100 output cdb files chosen for analysis. The results from the 100 GROPECDB runs are concateneated into a single file. Imbedded within the macro is an executable for the code EXTRACT (listing shown in Appendix C) that orders the data into columns for use by the plotting program. The input for EXTRACT is the concatenated GROPECDB output files an example of which is shown in Appendix D.

2.3 Assumptions, Data Sources, Initial and Boundary Conditions

The input parameters used for the CUTTINGS_S calculations come from three sources: the BRAGFLO input and output files, the WIPP database, and run parameters used for CUTTINGS_S.

- The initial flow conditions, which include the waste porosity, gas saturation, and room pressure at the time of intrusion, for the CUTTINGS_S calculations were defined by the BRAGFLO input and output files used for each CUTTINGS_S run. The locations of the BRAGFLO output files available for the CUTTINGS_S calculations are stored within the configuration management system (CMS) under directory names:

  WP$CMSROOT:[LIBBFR1S1]

```
WP$CMSROOT:[LIBBFR2S1]
WP$CMSROOT:[LIBBFR3S1]
WP$CMSROOT:[LIBBFR1S2]
...............................................
...............................................
WP$CMSROOT:[LIBBFR3S5]
```

where R1, R2, R3 represent the three replicates and S1, S2, S3, S4, S5 represent the five scenarios.

The output binary files from BRAGFLO are also repeated in subdirectories of the analysis directory:

```
CC1:[CUSP.DATA]
```

- The CUTTINGS_S input file includes several physical constants (e.g., brine surface tension); data from the controlled PA parameter database were used for these inputs. NOTE: If a required parameter is not contained in the PA parameter database, entry of that parameter was initiated in accordance with QAP 9-2.
- Several parameters are required for the running of the CUTTINGS_S code which are code-specific; the values of these parameters were reviewed as part of the overall documentation review required by QAP 9-2.

3.0 Scope of Work

3.1 Work Acceptance Criteria

The criteria for completion of this task are the completion of all assigned CUTTINGS_S calculations, the hand-off of the results of those calculations to those personnel performing CCDF calculations, and the technical review of the records package per QAP 6-3.

3.2 Subtask Descriptions

Subtask 1 -- QA Training for all personnel listed in Section 6.0: All personnel in Section 4.0 were trained according to the QA procedures in Section 5.0.

Subtask 2 -- Software QA: The class of CUTTINGS_S used for this analysis has been qualified for use in the SCMS per QAP 19-1.

Subtask 3 -- Technical review of analysis per QAPs 6-3 and 9-1: The results of the cuttings and cavings calculations are subject to a technical review per QAP 6-3. The scope of the technical review includes the assumptions on code-specific parameters in the CUTTINGS_S input files, the results obtained from the CUTTINGS_S output files, memos describing the results of the calculations and all other analysis and QA information regarding the work described in this AP.

4.0 Personnel Assignments

Jerry Berglund served as the Principal Investigator for this work. Jerry Berglund and Robert Cole provided the input files for the calculations described in this analysis.

5.0 QA Requirements and QA Records

The following SNL WIPP QA procedures were required for all work pertaining to this Work Agreement:

QAP 6-3	(Conducting and Documenting Reviews of Documents)
QAP 9-1	(Quality Assurance Requirements for Conducting Analyses)
QAP 9-2	(QA Requirements for Selection and Documentation of Parameter Values)
QAP 9-5	(Conducting and Documenting Routine Calculations)
QAP 17-1	(WIPP Quality Assurance Records Source Requirements)
QAP 19-1	(WIPP Computer Software Requirements)

6.0 Training Requirements

All personnel listed in Section 4.0 were trained to the QA procedures identified in Section 5.0, and used analysis plans AP016 and AP015 as the guides to perform the work.

7.0 Input Parameters and Sources

The use of the CUTTINGS_S code in the 1996 CCA performance assessment calculations utilized a number of parameters from the CMS controlled WIPP parameter database.

Values for some of these parameters are stated below. IDMTRL and IDPRAM names are also given.

BLOWOUT:SUFTEN $T=8.0E-2$ Surface tension of brine (N/m)

BLOWOUT:FGE $F_{ge}=18.1$ Gravity scaling factor (unitless)

BLOWOUT:FSE $F_{se}= 00.0$ Strength scaling factor (unitless)

BLOWOUT:KGAS $K=1.41$ Ratio of Specific Heats for Hydrogen (unitless)

BLOWOUT:RGAS $R=4116.0$ Gas Constant for Hydrogen (N·m/kg/°K)

After the completion of all the CUTTINGS_S computer simulations for the 1996 CCA it was determined that the gas constant used should have been R=4123 N·m/kg/°K rather than the value R=4116 N·m/kg/°K. The true value is different by less than 0.2% of the value used and computations with the CUTTINGS_S code show that there is an insignificant impact on the results.

BLOWOUT:VISC $\mu=0.92$ E-5 Hydrogen viscosity (Pa·s)

BLOWOUT:PSUF $p_{atm}=0.089465$ E6 Surface atmospheric pressure (Pa) at elevation 1039 m

BLOWOUT:TREPO $T=300.0$ Temperature of repository (°K)

BLOWOUT:INPORO $\phi_0=0.849$ Initial repository porosity, (unitless) normally read from the BRAGFLO CDB file

BLOWOUT:HREPO	$H = 3.96$	Height of repository at burial time (m)
BLOWOUT:RPANEL	$R_\infty = 60.87$	The equivalent radius of 1 panel (m)
BLOWOUT:ROOM	$r_0 = 17.1$	The equivalent radius of 1 room (m)
BLOWOUT:RHOS	$\rho_s = 2650.0$	Waste particle density (kg/m^3)
BLOWOUT:PARTDIA	$d = 0.000040 - 0.20$	Waste particle diameter (m) to be sampled (log uniform).
BLOWOUT:APORO	$k = 1.7E-13$	Waste permeability (m^2)
BOREHOLE:L1	$l_{coll} = 182.88$	Collar Length (m)
BOREHOLE:L2	$l_{drill} = 472.12$	Drill pipe length when repository penetrated (m)
BOREHOLE:DIAMMOD	$D_o = 0.31115$	Drill diameter (m)
BOREHOLE:COLDIA	$D_i = 0.2032004$	Collar diameter (m)
BOREHOLE:PIPED	0.1143002	Drill pipe diameter (m)
BOREHOLE:ROUGHP	$f = 0.08$	Friction factor (unitless) for very rough pipe
BOREHOLE:TAUFAIL	$\tau_{fail} = 0.05 - 10.$	Effective shear resistance to erosion (Pa) to be sampled (uniform)
BOREHOLE:INV_ARea	111520.	The area of the repository (m^2)
BOREHOLE:RHW_AR	15760.	The total area of the remote-handled waste (m^2)
BLOWOUT:CEMENT	$\sigma_c = 6895.$	Waste cementation strength (Pa)
BLOWOUT:FCE	$F_{ce} = 1.0$	Cementation scaling factor (unitless)
DRILLMUD:DNSFLUID	$\bar{\rho} = 1210.$	Drilling mud density (kg/m^3)
BOREHOLE:DOMEGA	$\Delta\Omega = 7.8$	Drilling string angular velocity (rad/s)
DRILLMUD:VISCO	$\eta_0 = 0.00917$	Drilling mud viscosity (Pa·s)
DRILLMUD:YLDSTRSS	$y_p = 4.4$	Drilling mud yield stress (Pa) Sandia WIPP Project. 1992 *Preliminary Performance Assessment for the Waste Isolation Pilot*
WAS_AREA:ABSROUGH	$\varepsilon = 0.025$	Absolute roughness (m)

The CUTTINGS_S code also requires data to compute the decay of radionuclides that are in the baseline waste inventory. The inventory and data to compute decay are read from the CMS controlled WIPP parameter database. The 9 decay chains assumed were

```
CHAIN1  PU242  U238  TH234  PA234M U234  TH230  RA226
     RN222  PO218  PB214  BI214  PO214  PB210  <

CHAIN2  PU238  U234  TH230  RA226  RN222  PO218
     PB214  BI214  PO214  PB210  <

CHAIN3  AM243  NP239  PU239  U235  TH231  PA231  AC227
     TH227  RA223  RN219  PO215  PB211  BI211  TL207  <

CHAIN4  CM243  PU239  U235  TH231  PA231  AC227  TH227
     RA223  RN219  PO215  PB211  BI211  TL207  PB209  <

CHAIN5  CF252  CM248  PU244  PU240  U236  TH232  RA228
     AC228  TH228  RA224  RN220  PO216  PB212  BI212
     PO212  <

CHAIN6  CM244  PU240  U236  TH232  RA228  AC228  TH228
     RA224  RN220  PO216  PB212  BI212  PO212  <

CHAIN7  CM245  PU241  AM241  NP237  PA233  U233  TH229
     RA225  AC225  FR221  AT217  BI213  PO213  <

CHAIN8  CS137  BA137M <

CHAIN9  PM147  SM147  ND143  <

CHAIN10  SR90  Y90  ZR90  <
```

The initial flow conditions, which include the waste porosity, gas saturation, and room pressure at the time of intrusion, for the CUTTINGS_S calculations were defined by the BRAGFLO input and output files used for each CUTTINGS_S run.

Several other hard wired parameters, which define the release zones covered by the CUTTINGS_S code, are listed below. Some of these are also shown in figure 9.

PCUT 8 MPa Boundary defining the repository pressure above which spall effects are possible. This is based on the hydrostatic pressure of the brine drilling mud used in a drilling operation. (Category Type 4B)

PR_MAX 15 MPa Anticipated greatest repository pore pressure based on the lithostatic pressure. Any computed BRAGFLO gas pressures above this pressure are set to this value in CUTTINGS_S. (Category Type 4B)

PE_MAX 1×10^{-12} m^2 Greatest waste permeability considered in CUTTINGS_S (Category Type 4B)

KCRIT $1\text{x}10^{-16}$ m^2 Waste permeability that separates blowout spall response from gas erosion and stuck pipe response. (PA User's Manual for CUTTINGS_S, Version 5.03 WPO#37765) (Category Type 4B)

PGAS 10 MPa Repository pore pressure that separates gas erosion and stuck pipe response in the CUTTINGS_S model. . (PA User's Manual for CUTTINGS_S, Version 5.03 WPO#37765) (Category Type 4B)

PI Defined as 4.0*ATAN(1.0) (Category Type 3)

GRAV 9.81 m/s^2 Acceleration of gravity (Category Type 3)

SPECKN $1.128169\text{x}10^{13}$ (curie's)/(gmole) Activity conversion factor (Category Type 3)

YRPSEC $3.168876\text{x}10^{-8}$ years/s Inverse of number of seconds/year (Category Type 3)

A	$\bar{a}$=1.3918	(unitless see equation 17)
B	$\bar{b}$=-0.907723	(unitless see equation 17)
C	$\bar{c}$=0.136371	(unitless see equation 17)
D	$\bar{d}$=0.0165093	(unitless see equation 17)
E	$\bar{e}$=-0.0285484	(unitless see equation 17)
F	$\bar{f}$=0.00933281	(unitless see equation 17)
G	$\bar{g}$=-0.000897166	(unitless see equation 17)

The parameters A through G are coefficients determined from the code GRAPHER, Version 1.23 from Golden Software Inc., Golden Colorado. They correspond to a fit of the curve of coefficient of drag for spherical particles described in Fox and McDonald 1973, p406. These coefficients were reviewed as part of the overall review of the CUTTINGS_S code as per the requirements of QAP 19-1 and are also verified in Appendix G.

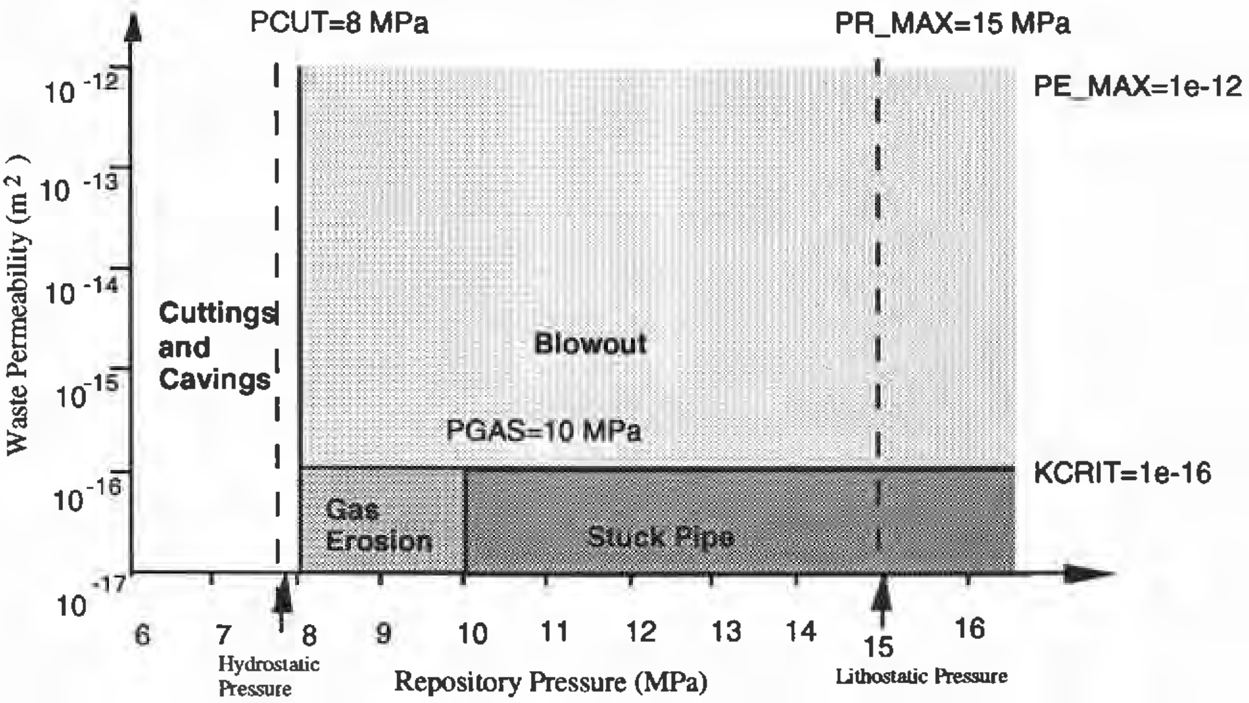


Figure 9 Release zone boundary values

Details of the implementation of CUTTINGS_S and its required input is described in WIPP PA User's Manual for CUTTINGS_S, Version 5.03 WPO#37765.

8.0 Analysis

8.1 Extraction of cuttings, cavings, and spall results from CUTTINGS_S results for analysis

Output cdb files for all the CUTTINGS_S runs were placed in an analysis directory designated disk$ike_cca2:[000000.cusp.data] that contained sub directories corresponding to the scenarios and replicates run for the CCA calculations. Each of the subdirectories contained cdb files for all the vectors corresponding to a particular scenario and replicate at all the chosen times of intrusion. To extract pertinent data for analysis, the GROPECDB code was used multiple times within a com file to generate a single output ascii file that could be used for plotting purposes. The input file for the GROPECDB runs (GROPIN.) is shown in Appendix B along with a com file that shows the repeated application of GROPECDB. This com file generated an intermediate file input.inp that was used in a code called EXTRACT (Appendix C) that placed the CUTTINGS_S results in an appropriate form for plotting. The ascii file generated by EXTRACT for the particular case shown in Appendix B was called out10000.out and this file is shown in Appendix E. A comparison of the input file for the code EXTRACT (Appendix D) with the output (Appendix E) verifies that the code is properly transferring the required data into the appropriate tabular form.

Since the analysis was controlled by CMS all input and output files can be obtained by using the software utilities described in *Traceability/Reproducibility of the PA96 Calculations for the CCA*, WPO#40313.

8.2 Plotting Software

Analysis of the CUTTINGS_S results was facilitated through data plots of the files generated by the code EXTRACT (Appendix C). The plotting package used was Cricket Graph Version 1.3.2 from Cricket Software, Inc., Philadelphia, Pa. GRAPHER, Version 1.23 from Golden Software Inc., Golden Colorado was also used to fit drag data.

8.3 Analysis Results

Releases to the accessible environment from cuttings and cavings, and spallings (in terms of intercepted areas) are shown in figures 10 through 15. Results for replicate 1 scenario 1 are shown for a drillbit intrusion at 10000 years and discussed. Results for other replicates and scenarios are similar in character.

The releases are depicted in terms of intercepted areas. The solid volume of waste released is defined as

$$Solid\ Volume = A_i H(1-\varphi)$$

where H is the compacted repository height, φ the porosity at the time of intrusion, and A_i the intercepted area. This equation is of the same form as for cuttings (equation 1). To be comparable, spallings releases are also shown in terms of intercepted areas.

The areas or volumes can be used in computing the activity (in curies) of the released waste due to an inadvertent intrusion for different waste streams. Although the CUTTINGS_S has the capability of providing the activity of the released waste by solving the Bateman equations for a baseline inventory at the time of intrusion, for the 1996 CCA only the physical volume of waste was passed on to other codes (see figures 7 and 8) where this computation was performed. This activity information coupled with scenario probabilities is used to compute the contribution of direct releases to the complementary cumulative distribution function (CCDF).

Cuttings and cavings correspond to those solids releases that are not influenced by the repository pressure at the time of intrusion. The minimum release area corresponds to the area of the drill bit which is $3.14159(0.3111)^2/4=0.0760\ m^2$. However, since the maximum sampled effective shear resistance to erosion (TAUFAIL) is only 10.0 Pa, some erosion (caving) of the waste surface will always occur to increase this area. Figure 10 shows a minimum release area in excess of 0.1 m^2 and no dependence on repository pressure for the 100 data points (vectors). For all 15,600 computer runs performed, erosion occurred in an initially turbulent annular flow field (see section 2.1.3.2)

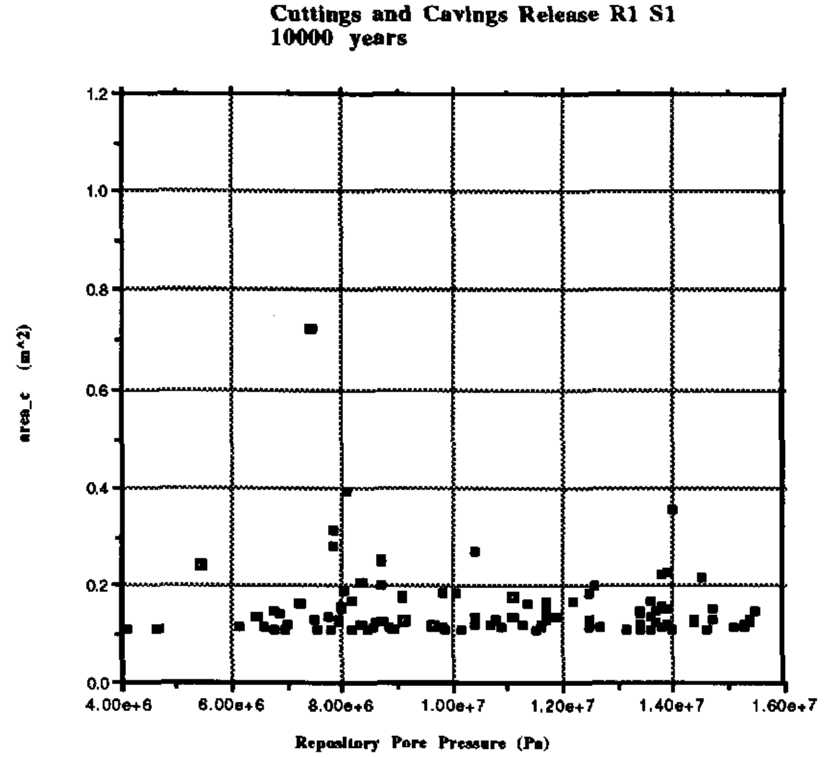


Figure 10. Cuttings and Cavings Release vs. Repository Pressure

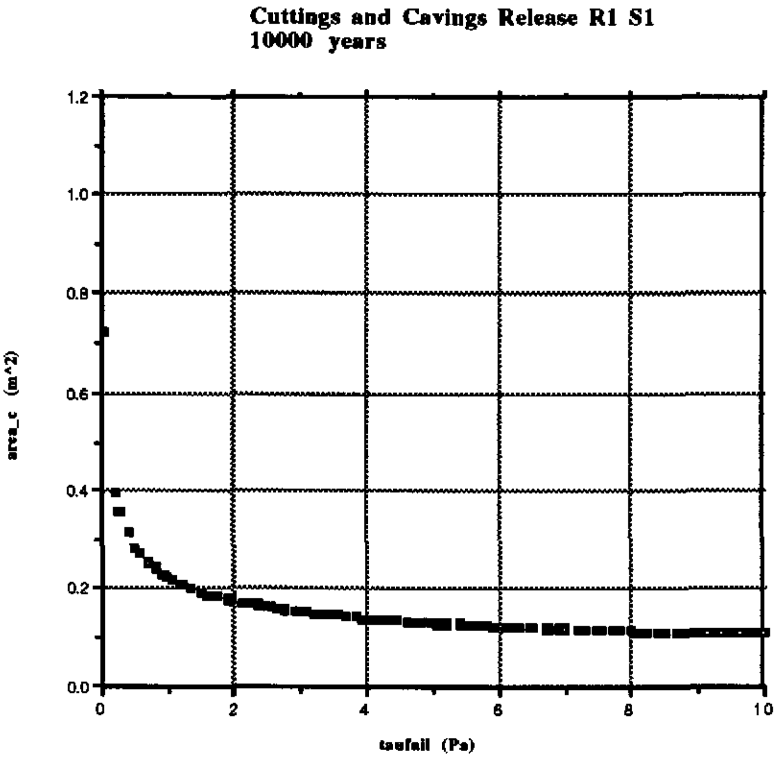


Figure 11. Cuttings and Cavings Release vs. Effective Shear Resistance to Erosion

The clear dependence of cuttings and cavings on TAUFAIL is shown in figure 11. For small sampled values of TAUFAIL the release area tends to be large and gradually decreases with increasing effective shear resistance until a value of approximately 0.1 m^2 is achieved at TAUFAIL=10. Pa.

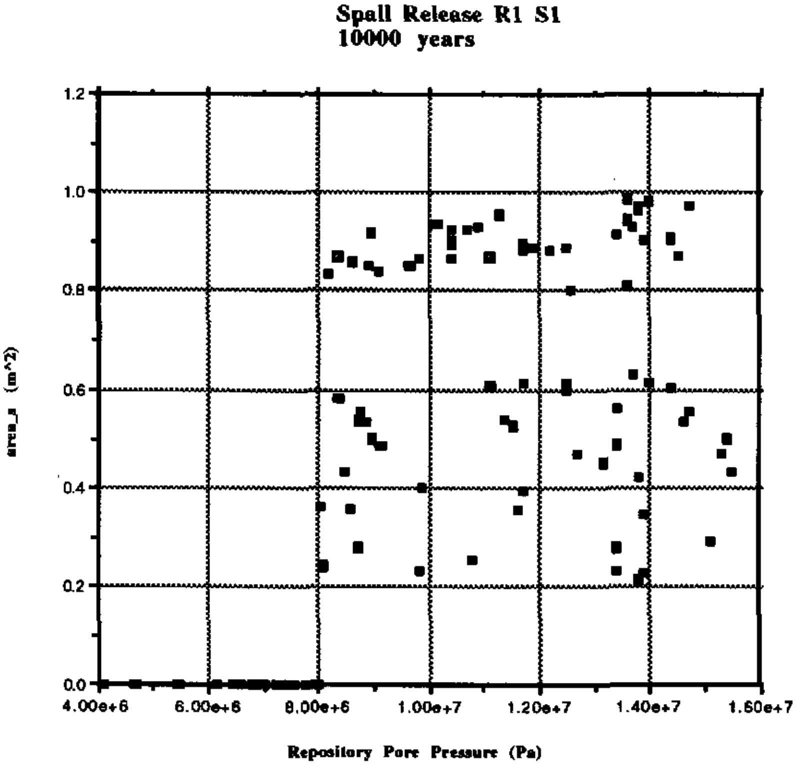


Figure 12. Spall Releases vs Repository Pressure

Spall releases occur only if the repository pressure exceeds the drilling mud hydrostatic pressure of 8 MPa. This is observed in figure 12 where the only non zero spall releases are found for pressures exceeding this value.

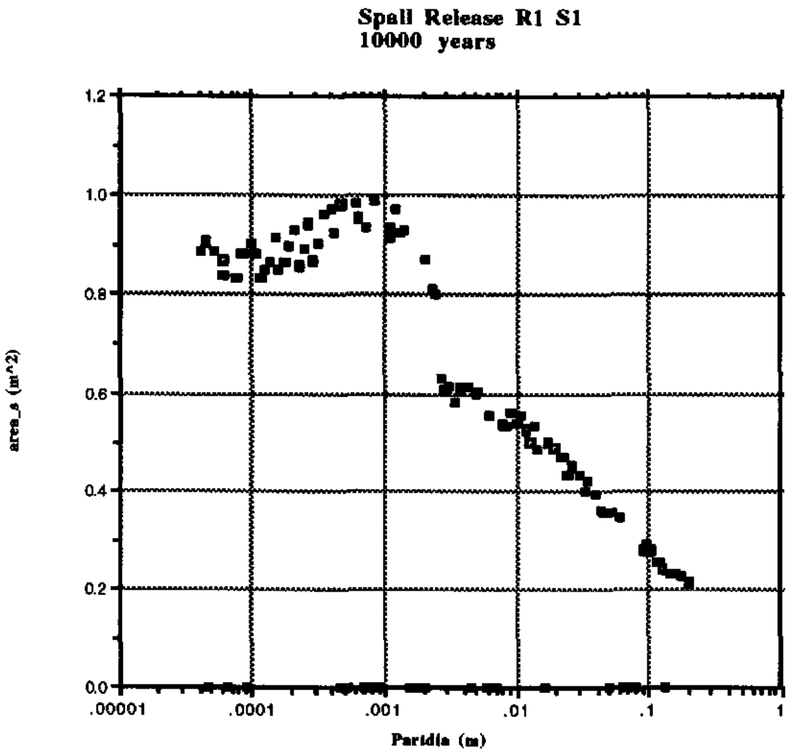


Figure 13. Spall Releases vs Waste Particle Diameter

Spall releases are strongly correlated to the waste particle diameter (PARTDIA) at the time of intrusion. Figure 13 shows this variation with waste particle diameter as well as those vectors for which the repository pressure was less than 8 MPa and for which there is no spall release. The vertical variation along the trend line is due to variations in repository porosity and pressure at the time of intrusion. The lack of releases in the gap around a particle diameter of 0.002 m is due to the abrupt change in the coefficient of drag of waste particles at Reynolds (Re) numbers of 200000. Above Re=200000 the boundary layer on the forward surface of smooth spheres changes from laminar to turbulent flow and tends to move the boundary layer point of separation downstream. This causes the size of the wake to decrease and reduces pressure drag (Fox, et.al. 1973). The data gap can also be seen in figure 12.

There is an additional data gap in spall releases around a particle diameter of 0.07 m. The lack of spall releases for these particle diameters is anomaly is caused by repository pressures less than 8 MPa for these vectors and the grouping is the result of pure chance.

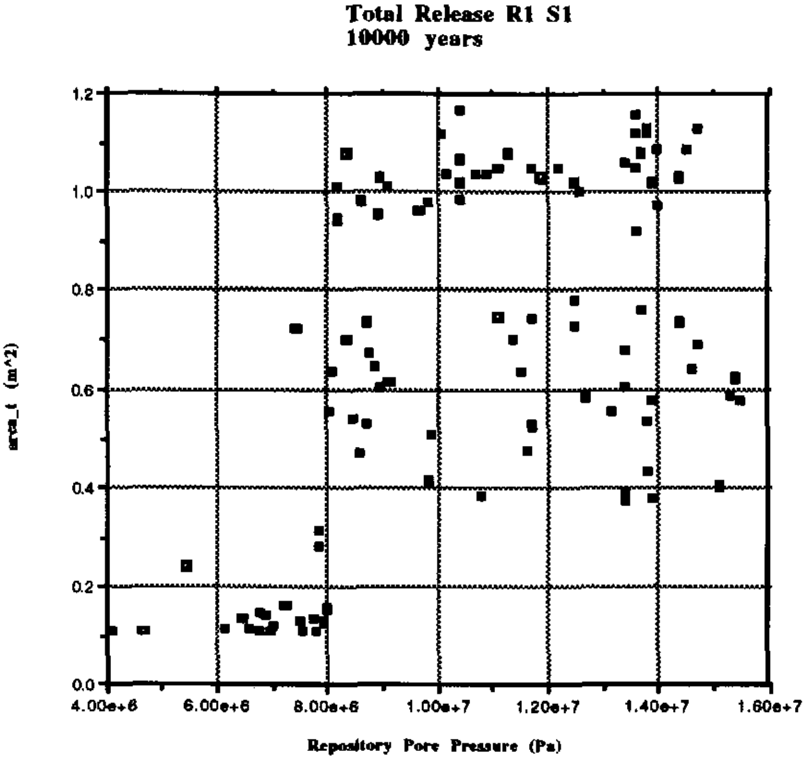


Figure 14. Combined Cuttings, Cavings and Spall Releases vs Repository Pressure

The combined effect of cuttings, cavings, and spallings is shown in figure 14. Spall effects become apparent for repository pressures above 8MPa. The minimum release in terms of area removed is approximately 0.1 m^2.

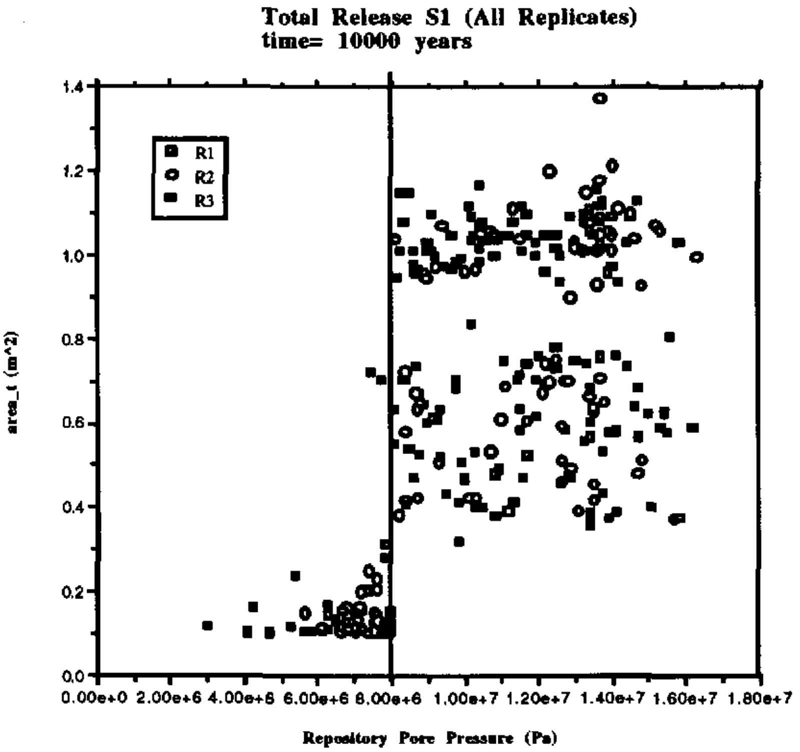


Figure 15. Combined Cuttings, Cavings and Spall Releases vs Repository Pressure for all Replicates (R1, R2, R3)

The qualitative similarity in results for the three replicates (R1, R2, R3) is shown in figure 15 where the results are overlaid. Each of the three replicates are based on a separate statistical sampling of data. The vertical line at 8 MPa denotes the pressure boundary between spall and no spall releases.

The data used for Figures 10 through 14 are shown in Appendix E

Appendix A Description of the Master CCA Run

The following is a discussion of how the CCA_MASTER calculations were done for CUTTINGS_S:

The actual runs of the CUTTINGS_S CCA calculations were done by the CCA_MASTERS. The code sponsor nor the code PI had any control over the direct running of the calculations. The code sponsor interacted with the CCA_MASTERS to facilitate the hows and whys of the code and how it was designed to be used. The master scripts for CUTTINGS_S are stored by the CCA_MASTERS. There are a lot of other issues addressed in these scripts for QA purposes and are best discussed by the CCA_MASTERS.

The preliminary phase of a master CCA run consists of 4 parts. The first part of the preliminary phase is GENMESH. The input file for GENMESH is shown in appendix (A1). CUTTINGS_S does not require a grid as such. The grid is a null or non-existing grid. CUTTINGS_S is a lumped parameter model. CUTTINGS_S does make use of the WIPP data base and these variables are associated through the IDMTRL and IDPARM identifiers of the WIPP data base. These in turn are brought into the code through the element properties name.

The second part is MATSET (MATSET_PA96 Version 9). The input file for MATSET is shown in appendix (A2). This phase identifies the element property name associated with the dummy grid.

The third part is the LHS phase. The LHS phase actually consists of three sub parts. A typical input file for the first sub part is shown in appendix (A3). There is a unique file for each replicate. They are stored under CMS for the LHS code. The third sub part of LHS also requires a dummy input file. There is nothing of significance in the file, appendix (A4). The net result of the third part of LHS is to produce the input CDB files for CUTTINGS_S. There are three replicates with 100 vectors each for a total of 300 files. These files have the sampled variables for the Latin hyper-cube sampling. These files are stored in the CMS portion of LHS. Additional information about the workings of LHS can be found under the appropriate users manuals for LHS.

The fourth phase is PRE_CUTTINGS. PRE_CUTTINGS is a special way to run CUTTINGS_S. This phase extracts the WIPP data base properties that are used over and over again. This is done once at the beginning so as not to access the WIPP data base over and over again, saving a lot of I/O time.

The actual calculations are then done for each vector, intrusion time, scenario and replicate. There were 100 vectors and 5 scenarios. For the first scenario, the intrusions times were 100, 350, 1000, 3000, 5000, and 10000 years. The second and fourth scenarios had intrusion times of 550, 750, 2000, 4000, and 10000 years. The third and fifth scenarios had intrusion times of 1200, 1400, 3000, 5000, and 10000 years. For all five scenarios, there is a total of 52 intrusion time. With 100 vectors, this is a total of 5200 calculations for one replicate or a total of 15600 calculations for all three replicates.

The following is a discussion of how any single run interfaces with the input files:

First there are 11 hard wired constants used in CUTTINGS_S. These are PI which is calculated from 4.0 * ATAN (1.0), the acceleration due to gravity GRAV, the number of years per second, YRPSEC, and the specific activity conversion factor, SPECKN. There are also seven coefficients, A, B, C, D, E, F, and G used in subroutine TERMV that define the curve of drag verses Reynolds number for a spherical particle. These are the only hard wired constants that reside in CUTTINGS_S

The rest of the constants, parameters, and variables enter CUTTINGS_S through one of three ways. The first way is through a input file, a known logical in the Digital Control Language (DCL) scripts as CUSP_INP$TXT0, which has the constants and parameters that are not sampled on. The second way relies on two input files, known in the DCL scripts as CUSP_INP$TXT1 and CUSP_INP$CDB, which tells CUTTINGS_S about the sampled input variables. In a normal CCA calculation the intrusion time, and the location of the drilling intrusion are inputted in the TXT1 file. The rest of the input in the TXT1 file has references to the IDMATL and IDPARM names to find the value in the input CDB file. These input CDB files where created in the LHS preliminary phase. Those variables in the input CDB file are the ones that are being sampled now or in the past for the Latin hypercube method scenario/replicate. (For testing purposes, it possible to input values in the TXT1 file directly). The family of input TXT1 files was created by the code sponsor. The only difference between any of these file is the intrusion time and the location in the BRAGFLO CDB file of the intrusion. Appendix (A5) shows examples of two of these files.

The third way values are inputted into CUTTINGS_S is through the BRAGFLO CDB file. For a given intrusion time, CUTTINGS_S interpolates the repository pressure, porosity, and saturation conditions at the appropriate place in the BRAGFLO grid. CUTTINGS_S can find these values for one particular element, several, or for the whole element group. It can calculate a simple average or a grid weighted volume average. CUTTINGS_S also calculates some additional information from the BRAGFLO file and passes this information on through the output CDB file for brine flow modeling.

Most of the constants, parameters, or variables are extracted from the WIPP data base for the first way (the TXT0 file) and all for the second way (the TXT1 & CDB files) in a CCA calculation.

Several parameters are required for the running of the CUTTINGS_S code which are code-specific; the values of these parameters were reviewed as part of the overall documentation review required by QAP 9-2. These 12 variables are not in the data base for the TXT0 file; They are in the PRE_CUTTINGS input file CUSP_CCA_TEMPLATE.INP and are the responsibility of the code sponsor (appendix A6). This file resides in the CUSP CMS library and is used in the DCL script for the CCA calculation for the PRE_CUTTINGS phase.

The extraction of WIPP data base variables for the TXT0 file takes place in the PRE_CUTTINGS phase of the master CCA calculation. This phase takes place once at the beginning for the master CCA run. In the CUSP_CCA_TEMPLATE.INP file, all WIPP data base variables are identified by the IDMATL name and IDPARM name separated by a colon. For example, the height of the repository at burial time is identified as BLOWOUT:HREPO. The PRE_CUTTINGS phase recognizes the colon and then queries the WIPP data base for the value of the constant or parameter. PRE_CUTTINGS writes a new flat file called CUSP_CCA_ASCII.INP which is an echo of the input file except the line with the WIPP data base entry is replaced with the IDPARM name followed by the value extracted from the WIPP data base, (i.e. HREPO 3.96). When PRE_CUTTINGS reads the radionuclide chains, it keeps track of the radionuclide found and then sorts the list alphabetically and discards duplicate entries. The code then extracts from the WIPP data base the half life, the atomic weight, the EPA release limits and the initial inventories of contact handled waste or remote handled waste.

It then calculates the specific conversion factor from the half life and atomic weight. The code then writes out to the new flat file in tabular form all this information for the radionuclides. This new flat file is shown in Appendix (A7). Appendix (A8) is a summary of the WIPP data base variables and the twelve non WIPP data base variables. This new flat file is also stored in the CUSP CMS library and is used by all the calculations. This file is under strict control of the CCA masters and is used over and over again in all the 15,600 CUSP calculations. This was done to avoid excessive IO time that would have been required to access the WIPP data base every time.

The input CDB files are part of the LHS phase. The variables that are sampled on are build into the input CDB according the sampling distribution in the WIPP data base. The present CCA calculations only sampled on two vectors, the shear strength of the repository (TAUFAIL) and particle diameter (PARTDIA). All other where set to be constant and were extracted from the data base as constants.

Appendix A1 The input file for GENMESH:
GM_CUSP_CCA.INP

```
!======================================================================
=========
!
! TITLE:    CUSP Input GENMESH file
! ANALYST:  Robert A. Cole
!
!======================================================================
=========
!
*SETup_grid
 DIMension=      3
 ORIgin= 0.0000E+00, 0.0000E+00, 0.0000E+00
 IJKmax=      2,      2,      2
!
*GRID_spacing
 DEL,COORD=X,DEL= 1.0000E+00,INRANGE=      1,      2
 DEL,COORD=Y,DEL= 1.0000E+00,INRANGE=      1,      2
 DEL,COORD=Z,DEL= 1.0000E+00,INRANGE=      1,      2
!
*REGion
 REGion=      1,IRANGE=      1,      2,JRANGE=      1,      2,KRANGE=      1,      2
!
*END
```

Appendix A2 The input file for MATSET: MS_CUSP_CCA.INP

```
!======================================================================
=====
!
!  FILETYPE:
!  ANALYSTS:
!  DATE:
!  PURPOSE:
!
!
!

!======================================================================
=====
!
*PRINT_ASSIGNED_VALUES
!
*HEADING
 TITLE, CUSP MATSET INPUT FILE
 SCALE, LOCAL
 SCENARIO, ALL
!
*UNITS=SI
!
*CREATE_blocks
 BLOCK_IDS=2,3,4
!
*RETRIEVE
 COORD, DIM=3, NAMES=X,Y,Z
!
! ...Define region names
 MATERIAL, 1=BLOWOUT, 2=BOREHOLE, 3=DRILLMUD, 4=WAS_AREA

!1...Define BLOWOUT  property names
 PROPERTY, MATerial=BLOWOUT, NAMES=PARTDIA

!2...Define BOREHOLE property names
 PROPERTY, MATerial=BOREHOLE, NAMES=DIAMMOD, DOMEGA, TAUFAIL
!
!3...Define DRILLMUD property names
 PROPERTY, MATerial=DRILLMUD, NAMES=DNSFLUID, VISCO, YLDSTRSS
!
!
!4...Define WAS_AREA property names
 PROPERTY, MATerial=WAS_AREA, NAMES=ABSROUGH
```

```
!
!
!*SET_VALUES
!
!#### Assign values to material property names not   ####
!#### found in the Secondary Database (PROPERTY.SDB) ####
!

!======================================================================
===
 *END
```

Appendix A3 Input file for the first phase of LHS, replicate 1

```
!
!=================================================================
=====
! TITLE:   1996 CCA Input File for Realization R1 for the PRELHS Code
! ANALYST:  Lanny Smith, May 3, 1996
!=================================================================
=====
!
! DESCRIPTION:
!
! WIPP 1996 CCA, Realization R1 PRELHS Input File
!
! This input file to PRELHS is used to generate, as an output file, an LHS
! input file containing all distribution information and execution options
! required to create a sample for Realization R1 for the WIPP 1996 CCA
! analysis.
!
!======== No Comments Allowed between *ECHO and *ENDECHO ==============
*ECHOLHS
TITLE 1996 CCA, Realization R1 Input File for the LHS Code
NOBS        100
RANDOM SEED   238766283
CORRELATION MATRIX
   3
   18  19 -0.99
   20  21 -0.99
   28  29 -0.75
OUTPUT CORR HIST DATA
*ENDECHO
!
!== PROPERTIES TO BE RETRIEVED FROM WIPP 1996 CCA DATABASE, 'CCA4' ==
!
*RETRIEVE
!
  MATERIALS,  STEEL
  PROPERTIES, CORRMCO2
!
  MATERIALS,  WAS_AREA
  PROPERTIES, PROBDEG
!
  MATERIALS,  WAS_AREA
  PROPERTIES, GRATMICI
!
  MATERIALS,  WAS_AREA
  PROPERTIES, GRATMICH
!
  MATERIALS,  CELLULS
```

```
 PROPERTIES, FBETA
!
 MATERIALS, WAS_AREA
 PROPERTIES, SAT_RGAS
!
 MATERIALS, WAS_AREA
 PROPERTIES, SAT_RBRN
!
 MATERIALS, WAS_AREA
 PROPERTIES, SAT_WICK
!
 MATERIALS, CL_L_T1
 PROPERTIES, PRMX_LOG
!
 MATERIALS, CONC_T1
 PROPERTIES, PRMX_LOG
!
 MATERIALS, ASPHALT
 PROPERTIES, PRMX_LOG
!
 MATERIALS, SHFT_DRZ
 PROPERTIES, PRMX_LOG
!
 MATERIALS, SALT_T1
 PROPERTIES, CUMPROB
!
 MATERIALS, SALT_T1
 PROPERTIES, SAT_RGAS
!
 MATERIALS, SALT_T1
 PROPERTIES, SAT_RBRN
!
 MATERIALS, SALT_T1
 PROPERTIES, PORE_DIS
!
 MATERIALS, S_HALITE
 PROPERTIES, POROSITY
!
 MATERIALS, S_HALITE
 PROPERTIES, PRMX_LOG
!
 MATERIALS, S_HALITE
 PROPERTIES, COMP_RCK
!
 MATERIALS, S_MB139
 PROPERTIES, PRMX_LOG
!
 MATERIALS, S_MB139
 PROPERTIES, COMP_RCK
!
 MATERIALS, S_MB139
 PROPERTIES, RELP_MOD
```

```
!
 MATERIALS, S_MB139
 PROPERTIES, SAT_RBRN
!
 MATERIALS, S_MB139
 PROPERTIES, SAT_RGAS
!
 MATERIALS, S_MB139
 PROPERTIES, PORE_DIS
!
 MATERIALS, S_HALITE
 PROPERTIES, PRESSURE
!
 MATERIALS, CASTILER
 PROPERTIES, PRESSURE
!
 MATERIALS, CASTILER
 PROPERTIES, PRMX_LOG
!
 MATERIALS, CASTILER
 PROPERTIES, COMP_RCK
!
 MATERIALS, BH_SAND
 PROPERTIES, PRMX_LOG
!
 MATERIALS, CASTILER
 PROPERTIES, GRIDFLO
!
 MATERIALS, BLOWOUT
 PROPERTIES, PARTDIA
!
 MATERIALS, BOREHOLE
 PROPERTIES, TAUFAIL
!
 MATERIALS, CULEBRA
 PROPERTIES, MINP_FAC
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
```

```
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
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 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
```

```
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
!
 MATERIALS, GLOBAL
 PROPERTIES, PRMTZIDX
```

```
!
  MATERIALS, GLOBAL
  PROPERTIES, PRMTZIDX
!
!=====================================================================
=====
!
*END
```

Appendix A4 Input file for third phase of LHS

```
C********************************************************
C LHS3_CUSP_CCA.INP
C PERFORMS NO FUNCTION OTHER THAN A FILE MUST EXIST
C IN ORDER TO RUN POSTLHS
C********************************************************
```

Appendix A5 Typical TXT1 file: CUSP_CCA_R1_S1_U_T8000.INP

```
!
! Intrusion
!
 TINTR      8000.0
 PARTDIA   BLOWOUT:PARTDIA

! Properties

 TAUFAIL   BOREHOLE:TAUFAIL

 DIAMMOD   BOREHOLE:DIAMMOD
 DOMEGA    BOREHOLE:DOMEGA
 DNSFLUID  DRILLMUD:DNSFLUID
 VISCO    DRILLMUD:VISCO
 YLDSTRSS  DRILLMUD:YLDSTRSS
 ABSROUGH   WAS_AREA:ABSROUGH

!
! Bragflo
!
! Multiple hits (max of 10, 0 thru 9)
!
! MHIT_0  is associated with the hit that
!        CUTTINGS used for BRAGFLO  properties
!

 INTR_0  CAVITY_2     <

 INTR_1  619  622  625  <

 INTR_2  618  621  624  <

 INTR_3  617  620  623  <
 INTR_4  1010  <

 INTR_5  1023  <

 INTR_6  471  <

 INTR_7  606  <
```

Appendix A6 The input template for PRE_CUTTINGS: CUSP_CCA_TEMPLATE.INP

```
!!
!! Template file for PRE_CUSP Ingres SDB interface
!!

  MODEL_DATA
!!
!! =wipp::my_database:calc_name
!!
=wipp::wipp_db:WIPP_CCA

!
!   The following input variables are hard wired are related to the
! Repository model J. W. Berglund paper
!
! PR_MAX  <>The maximum pressure allowed by model
 PR_MAX         15.0E6

! PR_MIN  <>The minimum pressure allowed by model
 PR_MIN          0.0E6

! PE_MAX  <>The maximum permeability allowed by model
 PE_MAX         1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
 PE_MIN        1.0E-17

! PCUT    <> Pressure (pa) which defines the border between the
!              erosion phase and the blowout phase
 PCUT           8.0E6

! PGAS    <> Pressure (Pa) which defines the border between the gas
!              erosion phase and the stuck pipe phase
 PGAS          10.0E6

! KCRIT   <> Permeability which defines the phase border the blowout
!             phase and the gas erosion/stuck pipe phase
 KCRIT          1.0E-16



!
! Properties relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<<
!
! DELTR   <>  Delta radius for derivative in stress calculation
```

```
 DELTR          0.00001

! ITER    <> Number of iterations to solve for Reynolds number
 ITER       1

! FGE     <>  Gravity  effectiveness factor
 BLOWOUT:FGE

! FSE     <>  Strength effectiveness factor
 BLOWOUT:FSE

! FCE     <>  Cementation  effectiveness factor
 BLOWOUT:FCE

! CEMCEM  <>  Cementation stress
 BLOWOUT:CEMENT

! SUFTEN  <> Surface tension (N/N)
 BLOWOUT:SUFTEN



! Properties of the gas (Hydrogen) the repository <<<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS    <> Ratio of Specific Heats
 BLOWOUT:KGAS

! RGAS    <> Gas Constant for Hydrogen
 BLOWOUT:RGAS

! VISC    <> Hydrogen viscosity
 BLOWOUT:VISC

! PSUF    <> Surface pressure (Pa)
 BLOWOUT:PSUF



! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO   <> Temperature of repository (K)
 BLOWOUT:TREPO

! DEPTH   <> Distance from repository depth to depth where casing
!              is set (m)
 BLOWOUT          716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!              mud (unitless)
 FLWCNST          0.05

! HREPO   <> Height of repository at burial time      (4m)
```

```
 BLOWOUT:HREPO

! RPANEL  <> The equivalent radius of 1 panels    (910.0m**2)
 BLOWOUT:RPANEL

! ROOM    <> The equivalent radius of 1 room     (11,640m**2)
 BLOWOUT:ROOM

! RHOS    <> Waste particle density (kg/m**3)
 BLOWOUT:RHOS

! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<<

! L1      <> Collar Length (m)
 BOREHOLE:L1

! L2      <> Drill pipe length (m)
 BOREHOLE:L2

! COLDIA  <> Collar diameter (m)
 BOREHOLE:COLDIA

! PIPED   <> Drill pipe diameter (m)
 BOREHOLE:PIPED

! ROUGHP  <> Friction factor (unitless)
 BOREHOLE:ROUGHP

!
! APORO   <> A constant in equation to determine permeability as a
!            function of porosity
 BLOWOUT:APORO

! NPORO   <> N constant in equation to determine permeability as a
!            function of porosity
 BLOWOUT          0.0
!
! END_OF_MODEL_INPUT
!


  RADIONUCLIDE_DATA


!GEOMETRY

 BOREHOLE:INV_AR

 BOREHOLE:RHW_AR
 BOREHOLE:WUF

!MATERIAL
```

```
 OUT_MAT     BOREHOLE

!REPOSITORY_TYPE

 REP_NAME    WIPP
 REP_GEOLogy HALITE

 RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
!  chain1/chain2 from U234  & down are the same:
!  (It is required that both chains are inputted)

!     V    V    V    V    V    V    V

 CHAIN1   PU242  U238   TH234  PA234M U234   TH230  RA226
      RN222  PO218  PB214  BI214  PO214  PB210  <

 CHAIN2   PU238  U234   TH230  RA226  RN222  PO218
      PB214  BI214  PO214  PB210  <

!  chain3/chain4 from PU239 & down are the same:

 CHAIN3   AM243  NP239  PU239  U235   TH231  PA231  AC227
      TH227  RA223  RN219  PO215  PB211  BI211  TL207  <

 CHAIN4   CM243  PU239  U235   TH231  PA231  AC227  TH227
      RA223  RN219  PO215  PB211  BI211  TL207  PB209  <

!  chain5/chain6 from U236  & down are the same:

 CHAIN5   CF252  CM248  PU244  PU240  U236   TH232  RA228
      AC228  TH228  RA224  RN220  PO216  PB212  BI212
      PO212  <

 CHAIN6   CM244  PU240  U236   TH232  RA228  AC228  TH228
      RA224  RN220  PO216  PB212  BI212  PO212  <


 CHAIN7   CM245  PU241  AM241  NP237  PA233  U233   TH229
      RA225  AC225  FR221  AT217  BI213  PO213   <

 CHAIN8   CS137  BA137M <

 CHAIN9   PM147  SM147  ND143  <

 CHAIN10  SR90   Y90    ZR90   <

!      ^    ^    ^    ^    ^    ^    ^
```

```
SAVE  AM241 AM243 CF252 CM243 CM244 CM245 CM248 CS137
    NP237 PA231 PB210 PM147 PU238 PU239 PU240 PU241
    PU242 PU244 RA226 RA228 SR90  TH229 TH230 TH232
    U233  U234  U235  U236  U238 <

 TABULAR_DATA

!
! Example of how the radioisotope data is inputted:
!
!...1st Line: Radionuclide (an asterisk in column 1 follow
!                by radionuclide name, ex; *AC225 )
!...2nd & 3rd line
!
!...Field#1 Atomic Weight      (Kg/Mole) AWT    [REAL] (3(11x,1pe14.6))
!...Field#2 Half-Life          (Years)  HALFY  [REAL]        "
!...Field#3 Activity Conversion (Ci/Kg) AWTCNV [REAL]        "
!...Field#4 EPA Release Limit   (Ci)    EPAREL [REAL]        "
!...Field#5 Inventory           (Ci)    INVCHD [REAL]        "
!...Field#6 Inventory           (Ci)    INVRHD [REAL]        "
!
!*PU241
!xxxaaaaaaaaeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeee
! AWT     2.410000E-01  HALFY    1.439900E+01  ACTCNV   1.030000E+05
! EPAREL  1.000000E+07  INVCHD   1.930000E+06  INVRHD   0.000000E+00
!
!
<TABLE_INPUTS
<GENERATE_RADIO>
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!
```

Appendix A7 Output flat file from PRE_CUTTINGS: CUSP_CCA_SDB.ASC

```
 MODEL_DATA

!
!   The following input variables are hard wired are related to the
! Repository model J. W. Berglund paper
!
! PR_MAX  <>The maximum pressure allowed by model
 PR_MAX          15.0E6

! PR_MIN  <>The minimum pressure allowed by model
 PR_MIN          0.0E6

! PE_MAX  <>The maximum permeability allowed by model
 PE_MAX          1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
 PE_MIN          1.0E-17

! PCUT    <> Pressure (pa) which defines the border between the
!             erosion phase and the blowout phase
 PCUT           8.0E6

! PGAS    <> Pressure (pa) which defines the border between the gas
!             erosion phase and the stuck pipe phase
 PGAS           10.0E6

! KCRIT   <> Permeability which defines the phase border the blowout
!             phase and the gas erosion/stuck pipe phase
 KCRIT          1.0E-16



!
! Properties relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<<
!
! DELTR   <>  Delta radius for derivative in stress calculation
 DELTR          0.00001

! ITER    <> Number of iterations to solve for Reynolds number
 ITER       1

! FGE     <>  Gravity  effectiveness factor
 FGE          1.810000E+01
```

```
! FSE    <> Strength effectiveness factor
 FSE        0.000000E+00

! FCE    <> Cementation  effectiveness factor
 FCE        1.000000E+00

! CEMCEM <> Cementation stress
 CEMENT     6.895000E+03

! SUFTEN <> Surface tension (N/N)
 SUFTEN     8.000000E-02


! Properties of the gas (Hydrogen) the repository <<<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS   <> Ratio of Specific Heats
 KGAS       1.410000E+00

! RGAS   <> Gas Constant for Hydrogen
 RGAS       4.116000E+03

! VISC   <> Hydrogen viscosity
 VISC       9.200000E-06

! PSUF   <> Surface pressure (Pa)
 PSUF       8.946500E+04


! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO  <> Temperature of repository (K)
 TREPO      3.000000E+02

! DEPTH  <> Distance from repository depth to depth where casing
!           is set (m)
 BLOWOUT       716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!           mud (unitless)
 FLWCNST       0.05

! HREPO  <> Height of repository at burial time      (4m)
 HREPO      3.960000E+00

! RPANEL <> The equivalent radius of 1 panels    (910.0m**2)
 RPANEL     6.087000E+01

! ROOM   <> The equivalent radius of 1 room     (11,640m**2)
 ROOM       1.710000E+01
```

```
! RHOS   <> Waste particle density (kg/m**3)
 RHOS         2.650000E+03


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<<

! L1     <> Collar Length (m)
 L1          1.828800E+02

! L2     <> Drill pipe length (m)
 L2          4.721200E+02
! COLDIA  <> Collar diameter (m)
 COLDIA        2.032004E-01

! PIPED   <> Drill pipe diameter (m)
 PIPED         1.143002E-01

! ROUGHP  <> Friction factor (unitless)
 ROUGHP        8.000000E-02

!
! APORO   <> A constant in equation to determine permeability as a
!           function of porosity
 APORO         1.700000E-13

! NPORO   <> N constant in equation to determine permeability as a
!           function of porosity
 BLOWOUT           0.0
!
! END_OF_MODEL_INPUT
!


  RADIONUCLIDE_DATA


!GEOMETRY

 INV_AR        1.115200E+05

 RHW_AR         1.576000E+04

 WUF          4.070000E+00

!MATERIAL
 OUT_MAT     BOREHOLE

!REPOSITORY_TYPE

 REP_NAME    WIPP
 REP_GEOLogy HALITE
```

```
RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
! chain1/chain2 from U234  & down are the same:
! (It is required that both chains are inputted)

!      V    V    V    V    V     V    V

CHAIN1   PU242  U238   TH234  PA234M  U234   TH230  RA226
      RN222  PO218  PB214  BI214  PO214  PB210  <

CHAIN2   PU238  U234   TH230  RA226  RN222  PO218
      PB214  BI214  PO214  PB210  <

! chain3/chain4 from PU239 & down are the same:

CHAIN3   AM243  NP239  PU239  U235   TH231  PA231  AC227
      TH227  RA223  RN219  PO215  PB211  BI211  TL207  <

CHAIN4   CM243  PU239  U235   TH231  PA231  AC227  TH227
      RA223  RN219  PO215  PB211  BI211  TL207  PB209  <

! chain5/chain6 from U236  & down are the same:

CHAIN5   CF252  CM248  PU244  PU240  U236   TH232  RA228
      AC228  TH228  RA224  RN220  PO216  PB212  BI212
      PO212  <

CHAIN6   CM244  PU240  U236   TH232  RA228  AC228  TH228
      RA224  RN220  PO216  PB212  BI212  PO212  <


CHAIN7   CM245  PU241  AM241  NP237  PA233  U233   TH229
      RA225  AC225  FR221  AT217  BI213  PO213   <

CHAIN8   CS137  BA137M  <

CHAIN9   PM147  SM147  ND143  <

CHAIN10  SR90   Y90    ZR90   <

!      ^    ^    ^    ^    ^    ^    ^


SAVE   AM241 AM243 CF252 CM243 CM244 CM245 CM248 CS137
    NP237 PA231 PB210 PM147 PU238 PU239 PU240 PU241
    PU242 PU244 RA226 RA228 SR90  TH229 TH230 TH232
    U233  U234  U235  U236  U238 <
```

```
TABULAR_DATA

!
! Example of how the radioisotope data is inputted:
!
!...1st Line: Radionuclide (an asterisk in column 1 follow
!                  by radionuclide name, ex; *AC225 )
!...2nd & 3rd line
!
!...Field#1 Atomic Weight      (Kg/Mole) AWT    [REAL] (3(11x,1pe14.6))
!...Field#2 Half-Life          (Years)  HALFY  [REAL]        "
!...Field#3 Activity Conversion  (Ci/Kg)  AWTCNV [REAL]        "
!...Field#4 EPA Release Limit    (Ci)    EPAREL [REAL]        "
!...Field#5 Inventory           (Ci)    INVCHD [REAL]        "
!...Field#6 Inventory           (Ci)    INVRHD [REAL]        "
!
!*PU241
!xxxaaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaaeeeeeeeeeeeeee
!  AWT     2.410000E--01  HALFY    1.439900E+01  ACTCNV    1.030000E+05
!  EPAREL   1.000000E+07  INVCHD    1.930000E+06  INVRHD    0.000000E+00
!
!
<TABLE_INPUTS
*AC225
  AWT      2.250230E-01  HALFY    2.737909E-02  ACTCNV   5.802745E+07
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*AC227
  AWT      2.270280E-01  HALFY    2.177335E+01  ACTCNV   7.232273E+04
  EPAREL   1.000000E+02  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*AC228
  AWT      2.280310E-01  HALFY    6.993709E-04  ACTCNV   2.241702E+09
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*AM241
  AWT      2.410570E-01  HALFY    4.322347E+02  ACTCNV   3.431153E+03
  EPAREL   1.000000E+02  INVCHD   4.420000E+05  INVRHD   5.960000E+03
*AM243
  AWT      2.430610E-01  HALFY    7.380313E+03  ACTCNV   1.992918E+02
  EPAREL   1.000000E+02  INVCHD   3.260000E+01  INVRHD   2.280000E-04
*AT217
  AWT      2.170050E-01  HALFY    1.023547E-09  ACTCNV   1.609540E+15
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*BA137M
  AWT      1.369070E-01  HALFY    4.851549E-06  ACTCNV   5.382367E+11
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*BI211
  AWT      2.109870E-01  HALFY    4.049823E-06  ACTCNV   4.183961E+11
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*BI212
  AWT      2.119910E-01  HALFY    1.151253E-04  ACTCNV   1.464844E+10
  EPAREL   0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*BI213
  AWT      2.129940E-01  HALFY    8.679552E-05  ACTCNV   1.933814E+10
```

```
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*BI214
 AWT    2.139990E-01  HALFY  3.783638E-05  ACTCNV  4.415278E+10
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*CF252
 AWT    2.520820E-01  HALFY  2.638089E+00  ACTCNV  5.375862E+05
 EPAREL  0.000000E+00  INVCHD  2.390000E+02  INVRHD  1.290000E+00
*CM243
 AWT    2.430610E-01  HALFY  2.850087E+01  ACTCNV  5.160669E+04
 EPAREL  1.000000E+02  INVCHD  2.720000E+00  INVRHD  4.950000E+01
*CM244
 AWT    2.440630E-01  HALFY  1.811013E+01  ACTCNV  8.088276E+04
 EPAREL  0.000000E+00  INVCHD  3.150000E+04  INVRHD  3.150000E+02
*CM245
 AWT    2.450650E-01  HALFY  8.498926E+03  ACTCNV  1.716462E+02
 EPAREL  1.000000E+02  INVCHD  1.150000E+02  INVRHD  1.460000E-06
*CM248
 AWT    2.480720E-01  HALFY  3.390697E+05  ACTCNV  4.250232E+00
 EPAREL  1.000000E+02  INVCHD  8.950000E-02  INVRHD  2.050000E-04
*CS137
 AWT    1.369070E-01  HALFY  2.999975E+01  ACTCNV  8.704346E+04
 EPAREL  1.000000E+03  INVCHD  8.060000E+03  INVRHD  2.160000E+05
*FR221
 AWT    2.210140E-01  HALFY  9.126363E-06  ACTCNV  1.772401E+11
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*ND143
 AWT    1.429100E-01  HALFY  3.168876E+30  ACTCNV  7.894262E-25
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*NP237
 AWT    2.370480E-01  HALFY  2.139942E+06  ACTCNV  7.047598E-01
 EPAREL  1.000000E+02  INVCHD  5.610000E+01  INVRHD  2.850000E+00
*NP239
 AWT    2.390530E-01  HALFY  6.448663E-03  ACTCNV  2.319079E+08
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PA231
 AWT    2.310360E-01  HALFY  3.276618E+04  ACTCNV  4.722522E+01
 EPAREL  1.000000E+02  INVCHD  4.510000E-01  INVRHD  1.910000E-03
*PA233
 AWT    2.330400E-01  HALFY  7.392988E-02  ACTCNV  2.075052E+07
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PA234M
 AWT    2.340430E-01  HALFY  2.224551E-06  ACTCNV  6.866595E+11
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PB209
 AWT    2.089810E-01  HALFY  3.764625E-04  ACTCNV  4.544132E+09
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PB210
 AWT    2.099840E-01  HALFY  2.229938E+01  ACTCNV  7.634848E+04
 EPAREL  1.000000E+02  INVCHD  2.550000E+00  INVRHD  7.160000E-06
*PB211
 AWT    2.109890E-01  HALFY  6.863786E-05  ACTCNV  2.468630E+10
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
```

```
*PB212
 AWT     2.119920E-01  HALFY   1.213680E-03  ACTCNV  1.389492E+09
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PB214
 AWT     2.140000E-01  HALFY   5.095552E-05  ACTCNV  3.278494E+10
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PM147
 AWT     1.469150E-01  HALFY   2.623513E+00  ACTCNV  9.275346E+05
 EPAREL  0.000000E+00  INVCHD  7.870000E+00  INVRHD  1.070000E+01
*PO212
 AWT     2.119890E-01  HALFY   9.506629E-15  ACTCNV  1.773943E+20
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PO213
 AWT     2.129930E-01  HALFY   1.330928E-13  ACTCNV  1.261129E+19
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PO214
 AWT     2.139950E-01  HALFY   5.206463E-12  ACTCNV  3.208728E+17
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PO215
 AWT     2.149990E-01  HALFY   5.640599E-11  ACTCNV  2.947934E+16
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PO216
 AWT     2.160020E-01  HALFY   4.753314E-09  ACTCNV  3.481971E+14
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PO218
 AWT     2.180090E-01  HALFY   5.799043E-06  ACTCNV  2.827800E+11
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*PU238
 AWT     2.380500E-01  HALFY   8.774618E+01  ACTCNV  1.711524E+04
 EPAREL  1.000000E+02  INVCHD  2.610000E+06  INVRHD  1.450000E+03
*PU239
 AWT     2.390520E-01  HALFY   2.406444E+04  ACTCNV  6.214572E+01
 EPAREL  1.000000E+02  INVCHD  7.850000E+05  INVRHD  1.030000E+04
*PU240
 AWT     2.400540E-01  HALFY   6.537391E+03  ACTCNV  2.278064E+02
 EPAREL  1.000000E+02  INVCHD  2.100000E+05  INVRHD  5.070000E+03
*PU241
 AWT     2.410570E-01  HALFY   1.439937E+01  ACTCNV  1.029950E+05
 EPAREL  0.000000E+00  INVCHD  2.310000E+06  INVRHD  1.420000E+05
*PU242
 AWT     2.420590E-01  HALFY   3.869198E+05  ACTCNV  3.817133E+00
 EPAREL  1.000000E+02  INVCHD  1.170000E+03  INVRHD  1.500000E-01
*PU244
 AWT     2.440640E-01  HALFY   8.261260E+07  ACTCNV  1.773084E-02
 EPAREL  1.000000E+02  INVCHD  1.500000E-06  INVRHD  2.210000E-11
*RA223
 AWT     2.230190E-01  HALFY   3.130532E-02  ACTCNV  5.120582E+07
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*RA224
 AWT     2.240200E-01  HALFY   1.001999E-02  ACTCNV  1.592669E+08
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*RA225
```

```
 AWT    2.250240E-01  HALFY   4.052993E-02  ACTCNV   3.919898E+07
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*RA226
 AWT    2.260250E-01  HALFY   1.599965E+03  ACTCNV   9.885812E+02
 EPAREL  1.000000E+02  INVCHD   1.160000E+01  INVRHD   3.580000E-05
*RA228
 AWT    2.280310E-01  HALFY   6.699955E+00  ACTCNV   2.339988E+05
 EPAREL  0.000000E+00  INVCHD   7.470000E-01  INVRHD   7.770000E-02
*RN219
 AWT    2.190090E-01  HALFY   1.254875E-07  ACTCNV   1.300819E+13
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*RN220
 AWT    2.200110E-01  HALFY   1.761895E-06  ACTCNV   9.222635E+11
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*RN222
 AWT    2.220180E-01  HALFY   1.046997E-02  ACTCNV   1.537963E+08
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*SM147
 AWT    1.469150E-01  HALFY   1.070129E+11  ACTCNV   2.273929E-05
 EPAREL  1.000000E+02  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*SR90
 AWT    8.990770E-02  HALFY   2.912197E+01  ACTCNV   1.365406E+05
 EPAREL  1.000000E+03  INVCHD   6.850000E+03  INVRHD   2.090000E+05
*TH227
 AWT    2.270280E-01  HALFY   5.124072E-02  ACTCNV   3.073157E+07
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*TH228
 AWT    2.280290E-01  HALFY   1.913050E+00  ACTCNV   8.195263E+05
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*TH229
 AWT    2.290320E-01  HALFY   7.339117E+03  ACTCNV   2.126863E+02
 EPAREL  1.000000E+02  INVCHD   2.880000E+00  INVRHD   1.170000E-01
*TH230
 AWT    2.300330E-01  HALFY   7.700369E+04  ACTCNV   2.018263E+01
 EPAREL  1.000000E+01  INVCHD   8.060000E-02  INVRHD   7.560000E-03
*TH231
 AWT    2.310360E-01  HALFY   2.911246E-03  ACTCNV   5.315214E+08
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*TH232
 AWT    2.320380E-01  HALFY   1.405080E+10  ACTCNV   1.096527E-04
 EPAREL  1.000000E+01  INVCHD   9.130000E-01  INVRHD   9.250000E-02
*TH234
 AWT    2.340440E-01  HALFY   6.597600E-02  ACTCNV   2.315240E+07
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*TL207
 AWT    2.069770E-01  HALFY   9.069324E-06  ACTCNV   1.904506E+11
 EPAREL  0.000000E+00  INVCHD   0.000000E+00  INVRHD   0.000000E+00
*U233
 AWT    2.330400E-01  HALFY   1.585072E+05  ACTCNV   9.678320E+00
 EPAREL  1.000000E+02  INVCHD   1.790000E+03  INVRHD   1.580000E+02
*U234
 AWT    2.340410E-01  HALFY   2.445105E+05  ACTCNV   6.247266E+00
```

```
 EPAREL  1.000000E+02  INVCHD  4.650000E+02  INVRHD  4.270000E+01
*U235
 AWT    2.350440E-01  HALFY  7.038074E+08  ACTCNV  2.161108E-03
 EPAREL  1.000000E+02  INVCHD  1.280000E+01  INVRHD  4.630000E+00
*U236
 AWT    2.360460E-01  HALFY  2.341482E+07  ACTCNV  6.468325E-02
 EPAREL  1.000000E+02  INVCHD  3.330000E-01  INVRHD  9.680000E-02
*U238
 AWT    2.380510E-01  HALFY  4.468115E+09  ACTCNV  3.361128E-04
 EPAREL  1.000000E+02  INVCHD  3.960000E+01  INVRHD  1.050000E+01
*Y90
 AWT    8.990700E-02  HALFY  7.301090E-03  ACTCNV  5.446258E+08
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
*ZR90
 AWT    8.990500E-02  HALFY  3.168876E+30  ACTCNV  1.254846E-24
 EPAREL  0.000000E+00  INVCHD  0.000000E+00  INVRHD  0.000000E+00
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!
```

Appendix A8 Constants/parameters not in WIPP data base

Constants/parameter not in WIPP data base

PR_MAX	<>The maximum pressure allowed by model	15.0E6
PR_MIN	<>The minimum pressure allowed by model	0.0E6
PE_MAX	<>The maximum permeability allowed by model	1.0E-12
PE_MIN	<>The minimum permeability allowed by model	1.0E-17
PCUT	<> Pressure (pa) which defines the border between the erosion phase and the blowout phase	8.0E6
PGAS	<> Pressure (pa) which defines the border between the gas erosion phase and the stuck pipe phase	10.0E6
KCRIT	<> Permeability which defines the phase border the blowout blowout phase and the gas erosion/stuck pipe phase	1.0E-16
DELTR	<> Delta radius for derivative in stress calculation	0.00001
ITER	<> Number of iterations to solve for Reynolds number	1
DEPTH	<> Distance from repository depth to depth where casing is set (m)	716.0
FLWCNST	<> Percent volume of material that is carried by Drilling mud (unitless)	0.05
NPORO	<> N constant in equation to determine permeability as a function of porosity	0.0

Constants/parameter in WIPP data base

FGE	<> Gravity effectiveness factor	BLOWOUT:FGE
FSE	<> Strength effectiveness factor	BLOWOUT:FSE
FCE	<> Cementation effectiveness factor	BLOWOUT:FCE
CEMCEM	<> Cementation stress	BLOWOUT:CEMENT
SUFTEN	<> Surface tension (N/N)	BLOWOUT:SUFTEN
KGAS	<> Ratio of Specific Heats	BLOWOUT:KGAS

RGAS <> Gas Constant for Hydrogen BLOWOUT:RGAS

VISC <> Hydrogen viscosity BLOWOUT:VISC

PSUF <> Surface pressure (Pa) BLOWOUT:PSUF

TREPO <> Temperature of repository (K) BLOWOUT:TREPO

HREPO <> Height of repository at burial time (4m) BLOWOUT:HREPO

RPANEL <> The equivalent radius of 1 panels (910.0m**2) BLOWOUT:RPANEL

ROOM <> The equivalent radius of 1 room (11,640m**2) BLOWOUT:ROOM

RHOS <> Waste particle density (kg/m**3) BLOWOUT:RHOS

L1 <> Collar Length (m) BOREHOLE:L1

L2 <> Drill pipe length (m) BOREHOLE:L2

COLDIA <> Collar diameter (m) BOREHOLE:COLDIA

PIPED <> Drill pipe diameter (m) BOREHOLE:PIPED

ROUGHP <> Friction factor (unitless) BOREHOLE:ROUGHP

APORO <> A constant in equation to determine permeability BLOWOUT:APORO
as a function of porosity

INV_AR <> Contact handled waste area BOREHOLE:INV_AR
RHW_RHW <> Remote handled waste area BOREHOLE:RHW_AR

WUF <> Waste Unit factor BOREHOLE:WUF

Appendix B Input File for GROPECDB_PA96 (GROPIN.)

```
!==================================================
    !
    ! GROPECDB input command file
    !
!==================================================
    !
    SELECT STEP 2
    SELECT BLOCK 1
    SELECT PROPERTY PARTDIA
    LIST PROPERTY
    PRINT PROPERTY
    SELECT BLOCK 2
    SELECT PROPERTY TAUFAIL
    LIST PROPERTY
    PRINT PROPERTY
    SELECT GVARS AREA_C AREA_S AREA_T POROS0 VOL_C VOL_S VOL_T PRESGAS0
    LIST GVARS
    PRINT GVARS
    SELECT GVARS HFINAL_0
    LIST GVARS
    PRINT GVARS
    !
    EXIT
    !
    !=====================================================
```

An example com file (CCA10000.COM) designed to extract data for replicate 1 scenario 1 for an intrusion at 10000 years into the lower part of the repository follows. The ascii file generated was called out10000.out and this file is shown in Appendix E The file uses a number of aliases for VMS commands .i.e. cat, destroy, cp, and pu. These aliases are defined in Appendix F.

CCA10000.COM

```
$define sys$output grope.log
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V001_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V002_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V003_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V004_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V005_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V006_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V007_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V008_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V009_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V010_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V011_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V012_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V013_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V014_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V015_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V016_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V017_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V018_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V019_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V020_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V021_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V022_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V023_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V024_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V025_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V026_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V027_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V028_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V029_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V030_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V031_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V032_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V033_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V034_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V035_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V036_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V037_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V038_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V039_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V040_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V041_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V042_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V043_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V044_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V045_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V046_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V047_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V048_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V049_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V050_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V051_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V052_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V053_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V054_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V055_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V056_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V057_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V058_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V059_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V060_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V061_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V062_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V063_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V064_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V065_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V066_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V067_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V068_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V069_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V070_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V071_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V072_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V073_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V074_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V075_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V076_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V077_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V078_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V079_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V080_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V081_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V082_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V083_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V084_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V085_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V086_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V087_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V088_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V089_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V090_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V091_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V092_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V093_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V094_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V095_L_T10000 -
GROPIN. -
```

```
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V096_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V097_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V098_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V099_L_T10000 -
GROPIN. -
g.lis
$grope -
disk$ike_cca2:[000000.cusp.data.r1s1]CUSP_CCA_r1_s1_V100_L_T10000 -
GROPIN. -
g.lis
$cat -
g.lis;1 -
g.lis;2 -
g.lis;3 -
g.lis;4 -
g.lis;5 -
g.lis;6 -
>all10000.dat
$cat -
g.lis;7 -
g.lis;8 -
g.lis;9 -
g.lis;10 -
g.lis;11 -
g.lis;12 -
>>all10000.dat
$cat -
g.lis;13 -
g.lis;14 -
g.lis;15 -
g.lis;16 -
g.lis;17 -
g.lis;18 -
>>all10000.dat
$cat -
g.lis;19 -
g.lis;20 -
g.lis;21 -
g.lis;22 -
g.lis;23 -
g.lis;24 -
```

```
>>all10000.dat
$cat -
g.lis;25 -
g.lis;26 -
g.lis;27 -
g.lis;28 -
g.lis;29 -
g.lis;30 -
>>all10000.dat
$cat -
g.lis;31 -
g.lis;32 -
g.lis;33 -
g.lis;34 -
g.lis;35 -
g.lis;36 -
>>all10000.dat
$cat -
g.lis;37 -
g.lis;38 -
g.lis;39 -
g.lis;40 -
g.lis;41 -
g.lis;42 -
>>all10000.dat
$cat -
g.lis;43 -
g.lis;44 -
g.lis;45 -
g.lis;46 -
g.lis;47 -
g.lis;48 -
>>all10000.dat
$cat -
g.lis;49 -
g.lis;50 -
g.lis;51 -
g.lis;52 -
g.lis;53 -
g.lis;54 -
>>all10000.dat
$cat -
g.lis;55 -
g.lis;56 -
g.lis;57 -
g.lis;58 -
g.lis;59 -
g.lis;60 -
>>all10000.dat
$cat -
g.lis;61 -
g.lis;62 -
```

```
g.lis;63 -
g.lis;64 -
g.lis;65 -
g.lis;66 -
>>all10000.dat
$cat -
g.lis;67 -
g.lis;68 -
g.lis;69 -
g.lis;70 -
g.lis;71 -
g.lis;72 -
>>all10000.dat
$cat -
g.lis;73 -
g.lis;74 -
g.lis;75 -
g.lis;76 -
g.lis;77 -
g.lis;78 -
>>all10000.dat
$cat -
g.lis;79 -
g.lis;80 -
g.lis;81 -
g.lis;82 -
g.lis;83 -
g.lis;84 -
>>all10000.dat
$cat -
g.lis;85 -
g.lis;86 -
g.lis;87 -
g.lis;88 -
g.lis;89 -
g.lis;90 -
>>all10000.dat
$cat -
g.lis;91 -
g.lis;92 -
g.lis;93 -
g.lis;94 -
g.lis;95 -
g.lis;96 -
>>all10000.dat
$cat -
g.lis;97 -
g.lis;98 -
g.lis;99 -
g.lis;100 -
>> all10000.dat
$deassign sys$output
```

```
$cp all10000.dat input.inp
$run EXTRACT.EXE
$cp out.out out10000.out
$pu
$destroy g.lis;*
$destroy GROPE.LOG;*
```

Appendix C Program Extract

```
program extract
c
c
c      reads data from all.dat files
c
c
      real time,area_c,area_s,area_t,poro,partdia,taufail
      real press,dummy
      integer i
      OPEN(UNIT=5,FILE='INPUT.INP',STATUS='OLD')
C     OPEN(UNIT=6,FILE='OUT.OUT',STATUS='NEW')
      write(6,76)
    1 read(5,33)partdia
      read(5,43)taufail
      read(5,44)dummy,time,area_c,area_s,area_t,poro
      read(5,54)dummy,dummy,dummy,dummy,dummy,press
      write(6,55)partdia,taufail,time,area_c,area_s,area_t,poro,press
      read(5,63)dummy
      go to 1
   33 format(////////////////////////////e14.5)
   43 format(//////e14.5)
   44 format(/////e8.4,5e14.5)
   54 format(e8.4,5e14.5)
   63 format(////e8.4)
   55 format(8e11.3)
   76 format(' partdia    taufail    time    area_c    area_s
     1  area_t    poro       press')
      end
```

Appendix D

Example input file for the analysis code EXTRACT
(First 3 of 100 concatenated GROPE output files for R1S1 at 10000 years)

```
                                 GROPECDB_PA96

  GGGGG  RRRRRR   OOOOO  PPPPPP  EEEEEEE  CCCCC  DDDDDD  BBBBBB          PPPPPP
 GG   GG RR   RR OO   OO PP   PP EE      CC   CC DD   DD BB   BB         PP   PP
 GG      RR   RR OO   OO PP   PP EE      CC      DD   DD BB   BB         PP   PP
 GG      RRRRRR  OO   OO PPPPPP  EEEEE   CC      DD   DD BBBBBB          PPPPPP
 GG  GGG RRRRR   OO   OO PP      EE      CC      DD   DD BB   BB         PP
 GG   GG RR  RR  OO   OO PP      EE      CC   CC DD   DD BB   BB         PP
  GGGGG  RR   RR  OOOOO  PP      EEEEEEE  CCCCC  DDDDDD  BBBBBB  ______  PP

                          GROPECDB_PA96 Version 2.12
                            PROD PA96 Built 06/27/96
                           Sponsored by Amy Gilkey

                          Run on 07/25/96 at 07:55:53
                        Run on ALPHA AXP TINA OpenVMS V6.1

Database:  DISK$IKE_CCA2:[000000.CUSP.DATA.R1S1]CUSP_CCA_R1_S1_V001_L_T10000.CDB;1
Written on:  05/23/96 14:26:24

CAMDAT Version:   1        (EXODUS Version:   1)

PROPERTIES

Element Block 1)    'BLOWOUT '     1=ID      1 elements (1..1)
     8-node      5 attributes     1 properties
   PARTDIA
  6.03400E-02

PROPERTIES

Element Block 2)    'BOREHOLE'     2=ID      0 elements
     0-node      0 attributes     7 properties
   TAUFAIL
  9.25800E-01

GLOBAL TIME STEP VARIABLES

   Step        Time       AREA_C        AREA_S        AREA_T        POROS0
                          VOL_C         VOL_S         VOL_T         PRESGAS0
      2    3.15569E+11   2.28458E-01   3.47681E-01   5.76139E-01   5.77394E-01
                         9.04692E-01   1.37682E+00   2.28151E+00   1.39208E+07

GLOBAL TIME STEP VARIABLES

   Step        Time       HFINAL_0
      2    3.15569E+11   1.42103E+00

                                 GROPECDB_PA96

  GGGGG  RRRRRR   OOOOO  PPPPPP  EEEEEEE  CCCCC  DDDDDD  BBBBBB          PPPPPP
 GG   GG RR   RR OO   OO PP   PP EE      CC   CC DD   DD BB   BB         PP   PP
 GG      RR   RR OO   OO PP   PP EE      CC      DD   DD BB   BB         PP   PP
 GG      RRRRRR  OO   OO PPPPPP  EEEEE   CC      DD   DD BBBBBB          PPPPPP
 GG  GGG RRRRR   OO   OO PP      EE      CC      DD   DD BB   BB         PP
 GG   GG RR  RR  OO   OO PP      EE      CC   CC DD   DD BB   BB         PP
  GGGGG  RR   RR  OOOOO  PP      EEEEEEE  CCCCC  DDDDDD  BBBBBB  ______  PP

                          GROPECDB_PA96 Version 2.12
                            PROD PA96 Built 06/27/96
                           Sponsored by Amy Gilkey

                          Run on 07/25/96 at 07:55:56
                        Run on ALPHA AXP TINA OpenVMS V6.1

Database:  DISK$IKE_CCA2:[000000.CUSP.DATA.R1S1]CUSP_CCA_R1_S1_V002_L_T10000.CDB;1
```

```
Written on:  05/23/96 14:29:54

CAMDAT Version:   1         (EXODUS Version:   1)

PROPERTIES

Element Block 1)     'BLOWOUT '     1=ID      1 elements (1..1)
      8-node      5 attributes     1 properties
   PARTDIA
  2.02400E-03

PROPERTIES

Element Block 2)     'BOREHOLE'     2=ID      0 elements
      0-node      0 attributes     7 properties
   TAUFAIL
  2.75300E+00

GLOBAL TIME STEP VARIABLES

   Step         Time          AREA_C         AREA_S         AREA_T         POROS0
                              VOL_C          VOL_S          VOL_T          PRESGAS0
      2    3.15569E+11    1.55709E-01    0.00000E+00    1.55709E-01    4.83922E-01
                          6.16606E-01    0.00000E+00    6.16606E-01    7.99865E+06

GLOBAL TIME STEP VARIABLES

   Step         Time        HFINAL_0
      2    3.15569E+11    1.16365E+00

                                  GROPECDB_PA96

 GGGGG  RRRRRR   OOOOO  PPPPPP  EEEEEEE  CCCCC  DDDDDD  BBBBBB          PPPPPP
GG   GG RR   RR OO   OO PP   PP EE      CC   CC DD   DD BB   BB         PP   PP
GG      RR   RR OO   OO PP   PP EE      CC      DD   DD BB   BB         PP   PP
GG      RRRRRR  OO   OO PPPPPP  EEEEE   CC      DD   DD BBBBBB          PPPPPP
GG  GGG RRRRR   OO   OO PP      EE      CC      DD   DD BB   BB         PP
GG   GG RR  RR  OO   OO PP      EE      CC   CC DD   DD BB   BB         PP
 GGGGG  RR   RR  OOOOO  PP      EEEEEEE  CCCCC  DDDDDD  BBBBBB  _______ PP

                         GROPECDB_PA96 Version 2.12
                          PROD PA96 Built 06/27/96
                          Sponsored by Amy Gilkey

                         Run on 07/25/96 at 07:55:58
                       Run on ALPHA AXP TINA OpenVMS V6.1

Database:  DISKSIKE_CCA2:[000000.CUSP.DATA.R1S1]CUSP_CCA_R1_S1_V003_L_T10000.CDB;1
Written on:  05/23/96 14:34:09

CAMDAT Version:   1         (EXODUS Version:   1)

PROPERTIES

Element Block 1)     'BLOWOUT '     1=ID      1 elements (1..1)
      8-node      5 attributes     1 properties
   PARTDIA
  1.58500E-01

PROPERTIES

Element Block 2)     'BOREHOLE'     2=ID      0 elements
      0-node      0 attributes     7 properties
   TAUFAIL
  3.82800E+00
```

```
GLOBAL TIME STEP VARIABLES

   Step        Time          AREA_C         AREA_S         AREA_T         POROS0
                             VOL_C          VOL_S          VOL_T          PRESGAS0
      2    3.15569E+11    1.39853E-01    2.33638E-01    3.73491E-01    5.71769E-01
                          5.53817E-01    9.25206E-01    1.47902E+00    1.34221E+07

GLOBAL TIME STEP VARIABLES

   Step        Time          HFINAL_0
      2    3.15569E+11    1.40236E+00
```

Appendix E Analysis Data R1S1 10000 years (100 Vectors)

```
$ cat out10000.out
   partdia    taufail      time       area_c     area_s     area_t      poro       press
 0.603E -01 0.926E+00 0.316E+12 0.228E+00 0.348E+00 0.576E+00 0.577E+00 0.139E+08
 0.202E -02 0.275E+01 0.316E+12 0.156E+00 0.000E+00 0.156E+00 0.484E+00 0.800E+07
 0.159E+00 0.383E+01 0.316E+12 0.140E+00 0.234E+00 0.373E+00 0.572E+00 0.134E+08
 0.186E -03 0.342E+01 0.316E+12 0.145E+00 0.901E+00 0.105E+01 0.551E+00 0.117E+08
 0.143E -02 0.783E+01 0.316E+12 0.112E+00 0.931E+00 0.104E+01 0.541E+00 0.109E+08
 0.677E -04 0.490E+01 0.316E+12 0.129E+00 0.000E+00 0.129E+00 0.469E+00 0.751E+07
 0.311E -02 0.476E+01 0.316E+12 0.131E+00 0.614E+00 0.744E+00 0.552E+00 0.117E+08
 0.485E -04 0.632E+01 0.316E+12 0.120E+00 0.000E+00 0.120E+00 0.454E+00 0.703E+07
 0.397E -03 0.308E+01 0.316E+12 0.150E+00 0.977E+00 0.113E+01 0.588E+00 0.147E+08
 0.295E -03 0.120E+01 0.316E+12 0.208E+00 0.871E+00 0.108E+01 0.495E+00 0.837E+07
 0.707E -03 0.523E+01 0.316E+12 0.127E+00 0.000E+00 0.127E+00 0.482E+00 0.794E+07
 0.835E -02 0.732E+01 0.316E+12 0.115E+00 0.532E+00 0.647E+00 0.508E+00 0.885E+07
 0.720E -01 0.951E+01 0.316E+12 0.106E+00 0.000E+00 0.106E+00 0.369E+00 0.468E+07
 0.192E -01 0.702E+01 0.316E+12 0.116E+00 0.489E+00 0.605E+00 0.572E+00 0.134E+08
 0.151E -03 0.355E+01 0.316E+12 0.143E+00 0.915E+00 0.106E+01 0.572E+00 0.134E+08
 0.380E -02 0.670E+01 0.316E+12 0.118E+00 0.612E+00 0.730E+00 0.561E+00 0.125E+08
 0.199E+00 0.101E+01 0.316E+12 0.221E+00 0.212E+00 0.433E+00 0.576E+00 0.138E+08
 0.111E -02 0.927E+01 0.316E+12 0.107E+00 0.937E+00 0.104E+01 0.531E+00 0.102E+08
 0.347E -01 0.720E+01 0.316E+12 0.115E+00 0.419E+00 0.534E+00 0.576E+00 0.138E+08
 0.244E -02 0.134E+01 0.316E+12 0.200E+00 0.804E+00 0.100E+01 0.563E+00 0.126E+08
 0.532E -04 0.505E+01 0.316E+12 0.128E+00 0.890E+00 0.102E+01 0.561E+00 0.125E+08
 0.695E -02 0.963E+01 0.316E+12 0.106E+00 0.000E+00 0.106E+00 0.348E+00 0.412E+07
 0.898E -01 0.715E+00 0.316E+12 0.252E+00 0.277E+00 0.529E+00 0.505E+00 0.874E+07
 0.702E -01 0.526E+00 0.316E+12 0.283E+00 0.000E+00 0.283E+00 0.480E+00 0.786E+07
 0.460E -03 0.401E+01 0.316E+12 0.138E+00 0.000E+00 0.138E+00 0.436E+00 0.648E+07
 0.600E -03 0.430E+01 0.316E+12 0.135E+00 0.986E+00 0.112E+01 0.574E+00 0.136E+08
 0.244E -01 0.840E+01 0.316E+12 0.110E+00 0.430E+00 0.540E+00 0.498E+00 0.849E+07
 0.339E -02 0.611E+01 0.316E+12 0.121E+00 0.581E+00 0.702E+00 0.494E+00 0.836E+07
 0.222E -01 0.699E+01 0.316E+12 0.116E+00 0.472E+00 0.588E+00 0.596E+00 0.153E+08
 0.918E -02 0.627E+01 0.316E+12 0.120E+00 0.562E+00 0.682E+00 0.571E+00 0.134E+08
 0.456E -02 0.800E+01 0.316E+12 0.112E+00 0.000E+00 0.112E+00 0.440E+00 0.661E+07
 0.126E -01 0.945E+01 0.316E+12 0.107E+00 0.499E+00 0.605E+00 0.510E+00 0.895E+07
 0.141E -03 0.652E+01 0.316E+12 0.119E+00 0.868E+00 0.986E+00 0.534E+00 0.104E+08
 0.528E -02 0.469E+01 0.316E+12 0.131E+00 0.606E+00 0.737E+00 0.583E+00 0.144E+08
 0.173E -01 0.540E+01 0.316E+12 0.126E+00 0.498E+00 0.624E+00 0.597E+00 0.154E+08
 0.616E -04 0.197E+01 0.316E+12 0.174E+00 0.840E+00 0.101E+01 0.514E+00 0.909E+07
 0.106E -01 0.461E+01 0.316E+12 0.132E+00 0.554E+00 0.686E+00 0.588E+00 0.147E+08
 0.118E -01 0.907E+01 0.316E+12 0.108E+00 0.527E+00 0.635E+00 0.549E+00 0.115E+08
 0.847E -04 0.217E+01 0.316E+12 0.169E+00 0.884E+00 0.105E+01 0.557E+00 0.122E+08
 0.134E -01 0.869E+01 0.316E+12 0.109E+00 0.532E+00 0.641E+00 0.586E+00 0.146E+08
 0.784E -04 0.812E+01 0.316E+12 0.111E+00 0.835E+00 0.946E+00 0.489E+00 0.818E+07
 0.160E -01 0.986E+01 0.316E+12 0.105E+00 0.000E+00 0.105E+00 0.471E+00 0.756E+07
 0.127E+00 0.227E+00 0.316E+12 0.396E+00 0.240E+00 0.635E+00 0.486E+00 0.808E+07
 0.623E -02 0.576E+01 0.316E+12 0.123E+00 0.552E+00 0.675E+00 0.505E+00 0.876E+07
 0.645E -03 0.592E+01 0.316E+12 0.122E+00 0.955E+00 0.108E+01 0.546E+00 0.113E+08
 0.859E -03 0.225E+01 0.316E+12 0.167E+00 0.990E+00 0.116E+01 0.574E+00 0.136E+08
 0.632E -01 0.321E+01 0.316E+12 0.148E+00 0.000E+00 0.148E+00 0.446E+00 0.678E+07
 0.134E+00 0.445E+01 0.316E+12 0.133E+00 0.000E+00 0.133E+00 0.476E+00 0.773E+07
 0.182E -02 0.556E -01 0.316E+12 0.722E+00 0.000E+00 0.722E+00 0.466E+00 0.742E+07
 0.200E -02 0.106E+01 0.316E+12 0.218E+00 0.875E+00 0.109E+01 0.584E+00 0.145E+08
 0.529E -03 0.369E+01 0.316E+12 0.141E+00 0.000E+00 0.141E+00 0.449E+00 0.688E+07
 0.728E -03 0.160E+01 0.316E+12 0.187E+00 0.936E+00 0.112E+01 0.530E+00 0.101E+08
```

```
0.968E -04  0.620E+01  0.316E+12  0.120E+00  0.904E+00  0.102E+01  0.577E+00  0.139E+08
0.477E -03  0.852E+01  0.316E+12  0.110E+00  0.982E+00  0.109E+01  0.579E+00  0.140E+08
0.261E -01  0.980E+01  0.316E+12  0.105E+00  0.451E+00  0.557E+00  0.569E+00  0.132E+08
0.144E -01  0.515E+01  0.316E+12  0.127E+00  0.486E+00  0.614E+00  0.515E+00  0.914E+07
0.431E -01  0.153E+01  0.316E+12  0.190E+00  0.362E+00  0.553E+00  0.485E+00  0.805E+07
0.332E -01  0.842E+01  0.316E+12  0.110E+00  0.400E+00  0.510E+00  0.527E+00  0.987E+07
0.394E -01  0.436E+01  0.316E+12  0.134E+00  0.392E+00  0.526E+00  0.551E+00  0.117E+08
0.156E -02  0.999E+01  0.316E+12  0.105E+00  0.000E+00  0.105E+00  0.478E+00  0.781E+07
0.941E -03  0.409E+00  0.316E+12  0.312E+00  0.000E+00  0.312E+00  0.479E+00  0.784E+07
0.957E -01  0.770E+01  0.316E+12  0.113E+00  0.291E+00  0.404E+00  0.593E+00  0.151E+08
0.794E -01  0.891E+01  0.316E+12  0.108E+00  0.000E+00  0.108E+00  0.446E+00  0.678E+07
0.207E -03  0.343E+01  0.316E+12  0.145E+00  0.932E+00  0.108E+01  0.574E+00  0.137E+08
0.425E -03  0.646E+01  0.316E+12  0.119E+00  0.926E+00  0.104E+01  0.538E+00  0.107E+08
0.262E -03  0.914E+01  0.316E+12  0.108E+00  0.944E+00  0.105E+01  0.573E+00  0.136E+08
0.512E -01  0.691E+01  0.316E+12  0.117E+00  0.358E+00  0.475E+00  0.550E+00  0.116E+08
0.177E -03  0.751E+01  0.316E+12  0.114E+00  0.865E+00  0.979E+00  0.526E+00  0.984E+07
0.302E -01  0.331E+01  0.316E+12  0.147E+00  0.431E+00  0.578E+00  0.598E+00  0.155E+08
0.356E -03  0.292E+01  0.316E+12  0.153E+00  0.965E+00  0.112E+01  0.576E+00  0.138E+08
0.101E -01  0.249E+01  0.316E+12  0.161E+00  0.540E+00  0.701E+00  0.548E+00  0.114E+08
0.908E -04  0.756E+01  0.316E+12  0.114E+00  0.000E+00  0.114E+00  0.425E+00  0.618E+07
0.230E -03  0.582E+01  0.316E+12  0.123E+00  0.861E+00  0.984E+00  0.501E+00  0.860E+07
0.427E -02  0.288E+00  0.316E+12  0.359E+00  0.616E+00  0.975E+00  0.578E+00  0.140E+08
0.418E -04  0.393E+01  0.316E+12  0.139E+00  0.891E+00  0.103E+01  0.554E+00  0.119E+08
0.267E -02  0.551E+01  0.316E+12  0.125E+00  0.634E+00  0.759E+00  0.574E+00  0.137E+08
0.453E -04  0.558E+01  0.316E+12  0.124E+00  0.909E+00  0.103E+01  0.582E+00  0.144E+08
0.216E -01  0.772E+01  0.316E+12  0.113E+00  0.472E+00  0.584E+00  0.563E+00  0.127E+08
0.124E -02  0.266E+01  0.316E+12  0.157E+00  0.973E+00  0.113E+01  0.576E+00  0.138E+08
0.612E -04  0.192E+01  0.316E+12  0.176E+00  0.870E+00  0.105E+01  0.544E+00  0.111E+08
0.451E -01  0.728E+01  0.316E+12  0.115E+00  0.357E+00  0.472E+00  0.500E+00  0.857E+07
0.254E -03  0.567E+01  0.316E+12  0.124E+00  0.893E+00  0.102E+01  0.534E+00  0.104E+08
0.123E -03  0.676E+01  0.316E+12  0.117E+00  0.850E+00  0.967E+00  0.524E+00  0.966E+07
0.118E+00  0.501E+01  0.316E+12  0.129E+00  0.256E+00  0.384E+00  0.539E+00  0.108E+08
0.290E -02  0.409E+01  0.316E+12  0.137E+00  0.610E+00  0.747E+00  0.544E+00  0.111E+08
0.493E -02  0.175E+01  0.316E+12  0.182E+00  0.598E+00  0.780E+00  0.560E+00  0.125E+08
0.118E -03  0.213E+01  0.316E+12  0.170E+00  0.837E+00  0.101E+01  0.490E+00  0.822E+07
0.495E -01  0.256E+01  0.316E+12  0.160E+00  0.000E+00  0.160E+00  0.461E+00  0.726E+07
0.146E+00  0.171E+01  0.316E+12  0.183E+00  0.229E+00  0.412E+00  0.526E+00  0.982E+07
0.134E -02  0.421E+01  0.316E+12  0.136E+00  0.929E+00  0.107E+01  0.534E+00  0.104E+08
0.235E -02  0.936E+01  0.316E+12  0.107E+00  0.815E+00  0.922E+00  0.574E+00  0.136E+08
0.172E+00  0.298E+01  0.316E+12  0.152E+00  0.227E+00  0.378E+00  0.578E+00  0.139E+08
0.768E -02  0.136E+01  0.316E+12  0.199E+00  0.538E+00  0.736E+00  0.503E+00  0.869E+07
0.315E -03  0.598E+00  0.316E+12  0.269E+00  0.904E+00  0.117E+01  0.534E+00  0.104E+08
0.113E -02  0.824E+01  0.316E+12  0.111E+00  0.918E+00  0.103E+01  0.511E+00  0.899E+07
0.801E -03  0.819E+00  0.316E+12  0.239E+00  0.000E+00  0.239E+00  0.399E+00  0.545E+07
0.105E+00  0.807E+01  0.316E+12  0.111E+00  0.278E+00  0.390E+00  0.571E+00  0.134E+08
0.159E -03  0.873E+01  0.316E+12  0.109E+00  0.848E+00  0.957E+00  0.510E+00  0.893E+07
0.601E -02  0.884E+01  0.316E+12  0.109E+00  0.000E+00  0.109E+00  0.453E+00  0.698E+07
0.108E -03  0.234E+01  0.316E+12  0.164E+00  0.882E+00  0.105E+01  0.552E+00  0.117E+08
```

Appendix F VMS Aliases used in CCA10000.com

Alias		VMS equivalent command(s)
CP	:==	COPY
DESTROY	:==	DELETE/NOCONFIRM
PU	:==	PURGE
CAT	:==	

```
$ ! CAT.COM   UNIX CAT Command     HJI.    2/16/88.
$ !
$ IF P1 .NES. "" .AND. P1 .NES."?"  THEN GOTO CTUE
$!    Explain usage:
$ TYPE SYS$INPUT

CAT displays/copies/appends a file or files to the terminal or another file

Usage: CAT inputfilelist              -- display inputfilelist
     CAT inputfilelist > outputfile  -- copy inputfilelist to outputfile
     CAT inputfilelist >> outputfile  -- append inputfilelist to outputfile
     CAT  > outputfile              -- copy terminal input to outputfile
     CAT  >> outputfile              -- append terminal input to outputfile

     inputfilelist can be a blank-separated list of files, but
     there can be at most 8 arguments counting > or >>.
     Terminate terminal input with ctrl-Z.

$ GOTO ENDCAT
$!
$CTUE:
$ IF P1 .EQS. ">" .OR. P1 .EQS. ">>" THEN GOTO CP_INP
$ P_STR="P0,P1,P2,P3,P4,P5,P6,P7,P8"
$ STRING="''P1'"+"''P2'"+"''P3'"+"''P4'"+"''P5'"+"''P6'"+"''P7'"+"''P8'"
$ STR_LEN=F$LENGTH(STRING)
$ OUTPUTFILE=F$ELEMENT(1,">",STRING)
$ IF OUTPUTFILE .EQS. ">" THEN GOTO COPY_TO_OUT
$ IF OUTPUTFILE .NES. "" THEN GOTO WR_OUT
$ OUTPUTFILE=F$ELEMENT(2,">",STRING)
$ IF OUTPUTFILE .EQS. "" THEN OUTPUTFILE=SYS$OUTPUT
$! Append:
$ GOTO APP_REST
$COPY_TO_OUT:
$ OUTPUTFILE="SYS$OUTPUT"
$WR_OUT:
$ CREATE 'OUTPUTFILE'
$ GOTO APP_REST
```

```
$!
$APP_REST:
$ N=0
$LOOP:
$ N=N+1
$ PARAM=F$ELEMENT(N, ",", P_STR)
$ IF 'PARAM' .EQS. "" .OR. 'PARAM' .EQS. ">" .OR. -
    'PARAM' .EQS. ">>" THEN GOTO ENDCAT
$ IN_FIL_PARAM='PARAM'
$ IN_FIL=F$SEARCH(IN_FIL_PARAM,N)
$NXT_WILD:
$ APPEND 'IN_FIL' 'OUTPUTFILE'
$ IN_FIL=F$SEARCH(IN_FIL_PARAM,N)
$ IF IN_FIL .NES. "" .AND. F$LOCATE("*",IN_FIL_PARAM) -
            .LT. F$LENGTH(IN_FIL_PARAM) THEN GOTO NXT_WILD
$ IF N .LT. 8 THEN GOTO LOOP
$ GOTO ENDCAT
$CP_INP:
$ IF P2 .EQS. "" THEN P2="SYS$OUTPUT"
$ CREATE 'P2'
$ GOTO ENDCAT
$!
$ENDCAT:
$!!
```

Appendix G Check of Curve Fit Parameters for Coefficient of Drag of Sphere

The coefficient of drag for a sphere is plotted as a function of Reynolds number in Fox, R. W., and McDonald, A. T., 1973. This curve has been fitted with the function

$$C_D = 10^{\left(\bar{a}+\bar{b}x+\bar{c}x^2+\bar{d}x^3+\bar{e}x^4+\bar{f}x^5+\bar{g}x^6\right)}$$

where

$\bar{a} = 1.3918$

$\bar{b} = -0.907723$

$\bar{c} = 0.136371$

$\bar{d} = 0.0165093$

$\bar{e} = -0.0285484$

$\bar{f} = 0.00933281$

$\bar{g} = -0.000897166$

and

$x = log_{10} R_{ed}$

In the above equation C_D represents the coefficient of drag and R_{ed} is the Reynold's number.

The coefficients were determined using code GRAPHER, Version 1.23 from Golden Software Inc., Golden Colorado. As a check of the fit this functional form was coded into a Fortran program called DRAG listed below.

```
      Program Drag
c     Verifies the curve fit for the coefficient of drag
c     of a sphere.  Curve is shown in Fox and McDonald 1973,
c     Introduction to Fluid Mechanics, J.Wiley, New York, p406
c
      write(6,12)
c
c     Coefficients
c
      a=1.3918
      b=-0.907723
      c=0.136371
      d=0.0165093
      e=-0.0285484
      f=0.00933281
      g=-0.000897166
c
c     Loop through Reynolds numbers
c     and compute coefficient of drag
      re=0.1
```

```
      do  14 i=1,5
      re=re*10.
      x=log10(re)
      exponent=a+b*x+c*x**2+d*x**3+e*x**4+f*x**5+g*x**6
      dragcoef=10.**exponent
      write(6,*)re,dragcoef
   14 continue
   12 format('  Reynolds #    Coefficient of drag')
      stop
      end
```

The output from the above code is

```
Reynolds #   Coefficient of drag
  1.000000     24.64904
  10.00000     4.138515
  100.0000     1.092369
  1000.000    0.4396828
  10000.00    0.3741568
```

These data have been plotted by hand directly on to a copy of the curve from Fox, R. W., and McDonald, A. T., 1973. (See attached figure)

Ref. Fox, R. W, and McDonald, A.T., Introduction to Fluid Mechanics,
J. Wiley + Sons, Inc., New York, 1973, p. 406.

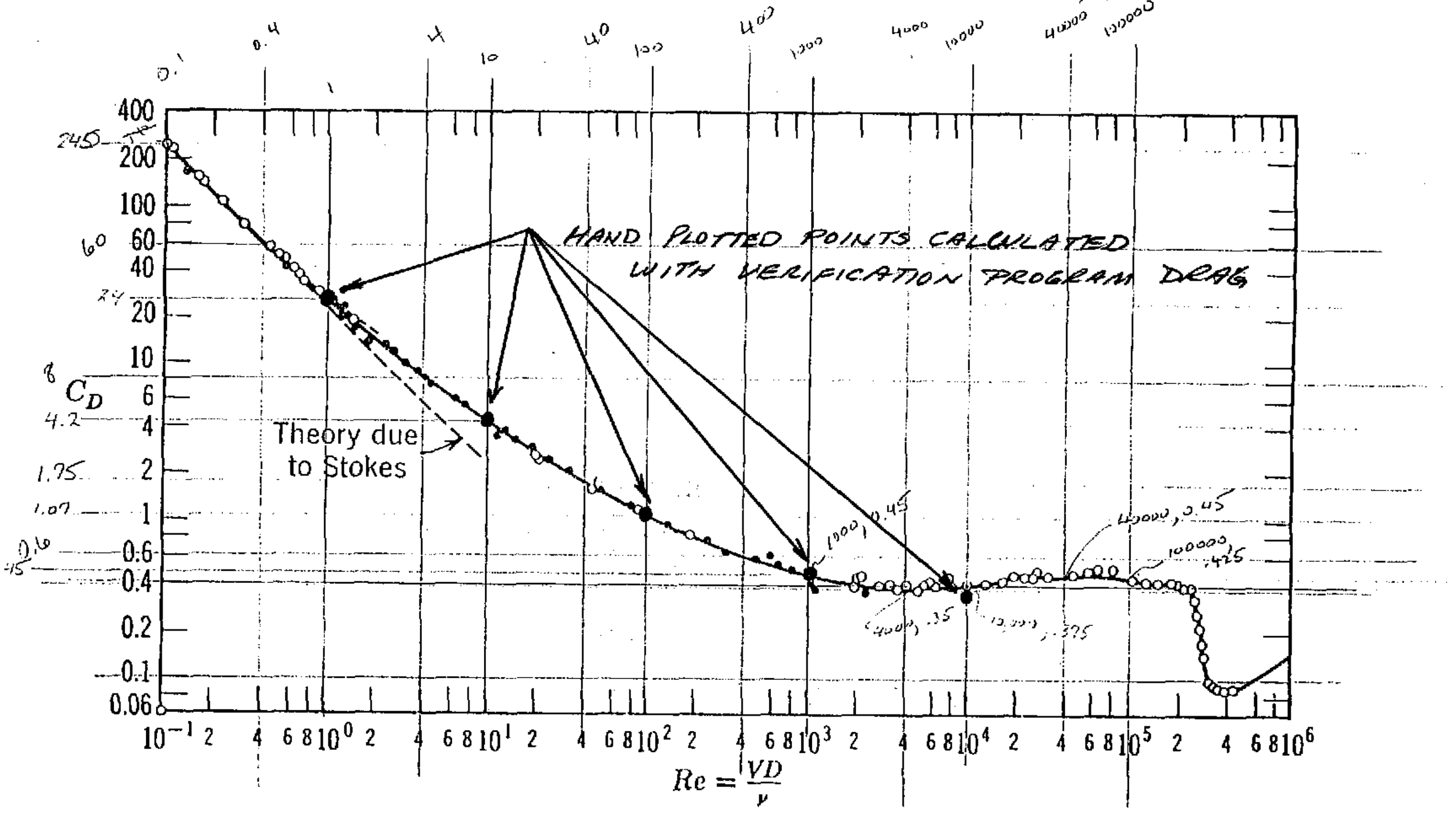

Fig. 8.32 *Drag coefficient of a sphere as a function of Reynolds number (data from Ref. 11).*

APPENDIX H Glossary

accessible environment. "(1) [T]he atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere that is beyond the controlled area." (40 CFR § 191.12[k])

CCA - Compliance Certification Application. The application submitted by the DOE to the EPA in October 1996 for certification that the WIPP meets the disposal standards in 40 CFR Part 191.

CCDF - complementary cumulative distribution function. Mathematically, a complementary cumulative distribution function is equal to one minus a cumulative distribution function. A cumulative distribution function is the sum (or integral) of the probability of those values or variables that are less than or equal to a specified value.

For the WIPP, a CCDF is the ordered set of points that span the cumulative normalized releases from the waste isolation system for all combinations of future histories of the repository over the 10,000-year regulatory period. The CCDF is a graphical display of the probability (the ordinate) that the value of the cumulative release will be greater than the normalized release (the abscissa). The points are ordered by normalized cumulative releases.

Radionuclide releases are normalized as stipulated in 40 CFR Part 191, Appendix A, and the complementary cumulative distribution function is compared to the quantitative release limits specified in 40 CFR § 191.13(a) to determine compliance.

CMS - Configuration Management System. The system used to provide traceability and reproducibility of the performance assessment calculations. Also referred to as SCMS - software configuration management system.

conceptual model. A statement of how important features, events, and processes are to be represented in performance assessment.

controlled area. The area within the withdrawal boundary (see land withdrawal boundary) and the underlying subsurface.

disposal system. "[A]ny combination of engineered and natural barriers that isolate ... radioactive waste after disposal" (40 CFR § 191.12[a]). For the purposes of the Waste Isolation Pilot Plant, this includes the combination of the repository/shaft system and the controlled area.

distribution. The statistical distribution of values of an entity over the range of expected values.

disturbed rock zone. That portion of the geologic barrier in which the physical and/or chemical properties are significantly altered by underground activities.

E1, E2. These are potential human-intrusion scenarios used in constructing the future histories of the disposal system for compliance purposes. E1 intrusions penetrate both the repository and an underlying brine reservoir in the Castile Formation. E2 intrusions penetrate the repository but do NOT penetrate an underlying brine reservoir.

E2E1. A scenario in which an E2 intrusion is followed by an E1 intrusion. The consequences of this particular intrusion were calculated in this performance assessment.

E1E2. Any multiple-human-intrusion scenario that includes at least one E1 intrusion (note that this also encompasses the E2E1 intrusion scenario described above).

event. A phenomenon that occurs instantaneously or within a short time interval relative to the time frame of interest.

FEPs - features, events, and processes. Features, events, and processes that are potentially important to long-term performance of the disposal system. A comprehensive set of features, events, and processes relevant to the WIPP was considered in applying a screening methodology to develop the conceptual model that is used to evaluate compliance with the numerical performance requirements provided in 40 CFR Part 191.

feature. An aspect or feature of the repository and its environment. For example, the mine shafts are a feature of the repository, and the stratigraphy is a feature of the repository environment.

human intrusion. (See Inadvertent Human Intrusion).

inadvertent human intrusion. The accidental violation of the disposal system through human activity such as mining or exploration drilling. Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario (40 CFR § 194.33[b][1]).

LWA - Land Withdrawal Act. Public Law 102-579, which withdraws the land at the WIPP site from "entry, appropriation, and disposal"; transfers jurisdiction of the land from the Secretary of the Interior to the Secretary of Energy; reserves the land for activities associated with the development and operation of the WIPP; and includes many other requirements and provisions pertaining to the protection of public health and the environment.

LWB - land withdrawal boundary, WIPP site boundary. The boundary of the 16-section land withdrawal area defined by the Land Withdrawal Act.

LHS - Latin hypercube sampling. A Monte Carlo sampling technique that divides the range of each variable into intervals of equal probability and samples from each interval. (See Monte Carlo Analysis/Technique).

marker bed. One of the well-defined anhydrite layers in the Salado. Four of these thin, horizontal layers are located near the repository and are considered in performance assessment because their properties differ from those of the Salado halite: Marker Bed 139 (below the repository), anhydrites a and b (located between the repository floor and roof and combined into a single layer in the CCA calculations), and Marker Bed 138 (located above the repository).

mean. The probabilistic expectation of a random variable.

median. The value for which the probability of sampling a value greater than the median is 0.5.

Monte Carlo Analysis/Technique. A technique that obtains the statistical distribution of outcomes of deterministic calculations by statistical sampling of the input and computer simulations of disposal system performance. For the WIPP performance assessment, the method is used to evaluate the distribution of the consequences and approximate the uncertainty in the results.

parameter. The quantities in the mathematical model that incorporate information about the features, events, and processes included in the conceptual model of disposal system performance. Parameters are underlying elements ($x = x_1, \ldots, x_n, \ldots, x_{nV}$) of a computational model. As x changes so does the model result. The individual parameters, x_n, may be vectors, tensors, higher order quantities, or even functions, but are usually scalar quantities.

PICs - passive institutional controls. "(1) [P]ermanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system." (40 CFR § 191.12[e])

PA - performance assessment. "[A]n analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable. (40 CFR § 191.12[q])

performance modeling. A process of building models of the factors affecting the containment of nuclear waste to project into the future how the WIPP facility will respond to probabilistic events and processes. Calculations of system performance using mathematical implementation of the conceptual models.

process. A natural or anthropogenic phenomenon that occurs continuously or over a significant portion of the time frame of interest; a "long-term" phenomenon; processes typically alter the physical state of material under consideration.

probabilistic analysis. Analysis through statistical investigations is referred to as probabilistic analysis. Monte Carlo analysis is used for probabilistic analysis in the WIPP PA. This analysis propagates uncertainties in the future, in the conceptual models, and in the parameters into the analytical results.

QA - quality assurance. The planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.

realization. One set of values for all uncertain parameters selected through LHS; synonymous with vector.

release. Movement of regulated substances into the accessible environment as defined in 40 CFR Part 191.

replicate. One complete set of probabilistic performance assessment calculations made using a single random number seed to initiate the LHS procedure for generating values of uncertain parameters at the beginning of the calculations. Three independent replicates were made in the CCA performance assessment to demonstrate statistical confidence. The replicates differ from each other only in the random number seed.

repository. The portion of the WIPP underground system within the Salado Formation, including the access drifts, waste panels, and experimental areas, but excluding the shafts.

risk. In the performance assessment analyses, risk is defined by the triplet {what could happen (scenarios), likelihood that it will happen (probability), and the consequences}.

sample. A value randomly drawn from a probabilistic distribution.

SWCF - Sandia WIPP Central Files. A records system containing documentation related to WIPP.

scenario. A combination of naturally occurring or human-induced events and processes that represent realistic future changes to the repository, geologic, and geohydrologic systems that could cause or promote the escape of radionuclides and/or hazardous constituents from the repository.

screening argument. Criteria used to eliminate from scenario and conceptual model development those events and processes that are not applicable to a specific disposal system or that do not have the potential of contributing significantly to performance. The three screening criteria used for the CCA are *Regulatory Guidance*, *Probability of Occurrence*, and *Consequence*.

sensitivity and uncertainty analyses. Analyses to determine the sensitivity of performance to changes in the values of uncertain parameters (those that were expressed as probability distributions). The distributions represent the range of known values for a parameter and the uncertainty in the actual value.

SO-C. Screened-Out on the basis of Consequence: elimination of FEPs on the basis of low consequence to system performance.

SO-P. Screened-Out on the basis of low Probability: elimination of FEPs on the basis of low probability of occurrence.

SO-R. Screened-Out on the basis of Regulations: elimination of FEPs on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

subjective uncertainty. Subjective uncertainty derives from a lack of knowledge about quantities, attributes, or properties believed to have a single or certain range of values.

transmissivity. "[T]he hydraulic conductivity integrated over the saturated thickness of an underground formation." (40 CFR § 191.12[l])

TRU - transuranic waste. "[W]aste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for: (1) high-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this Part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61" (40 CFR § 191.02[i]). The "Department" is DOE, the "Administrator" is the Administrator of the EPA, "this Part" is 40 CFR Part 191, and the "Commission" is the Nuclear Regulatory Commission.

uncertainty analysis. (1) An evaluation to determine the uncertainty in model predictions that results from imprecisely known input variables. (2) Determination of the degree of uncertainty in the results of a calculation based on uncertainties in the input parameters and underlying assumptions. Such an analysis requires definition of a system, description of the uncertainties in the factors that are to be investigated, and the characteristics of the system that are to be simulated, and the consequences of varying values on input parameters over their respective statistical distributions.

undisturbed performance. "[T]he predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." (40 CFR § 191.12[p])

vector. A mathematical construct that requires both a magnitude and direction. Many physical quantities such as force, velocity, acceleration, and fluxes are represented mathematically as vectors. In performance assessment, the term also means a vector over the real numbers and is therefore synonymous with realization (see realization).

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