

Appendix G

<b>NUCLEAR WASTE MANAGEMENT PROGRAM</b>  Sandia National Laboratories	<h2 style="margin: 0;">User's Manual Criteria Form</h2>	Form Number: <b>NP 19-1-6</b>  Page 1 of 1
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**Does the user's manual contain as appropriate:**

1. **Software Name:** CUTTINGS\_S
2. **Software Version:** 5.10
3. **Document Version:** 1.00
4. **ERMS #:** 532340

Prior to sign-off of the User's Manual, all items shall be appropriately addressed by the code sponsor so that "Yes" or "N/A" may be checked. Include this form as part of the User's Manual.

5. A statement(s) of functional requirements (consistent with those in the RD) and system limitations?  Yes
6. An explanation of the mathematical model and numerical models, where applicable as based on code functionality?  Yes  N/A
7. Physical and mathematical assumptions, where applicable as based on code functionality?  Yes  N/A
8. The capabilities and limitations inherent in the software?  Yes
9. Instructions that describe the user's interaction with the software?  Yes
10. The identification of input parameters, formats, and valid ranges?  Yes
11. Messages initiated as a result of improper input and how the user can respond?  Yes
12. The identification and description of output specifications and formats?  Yes
13. A description of any required training necessary to use the software?  Yes
14. The identification of components of the code that were not tested?  Yes

15. <u>Cliff Hansen</u>	<u><i>Cliff Hansen</i></u> Signature	<u>10/22/03</u> Date
Code Team/Sponsor (print)		
16. <u>James Garner</u>	<u><i>James Garner</i></u> Signature	<u>10/22/03</u> Date
Technical Reviewer (print)		
17. <u>David Kessel</u>	<u><i>David Kessel</i></u> Signature	<u>10/22/03</u> Date
Responsible Manager (print)		
18. <u>Jennifer Long</u>	<u><i>Jennifer Long</i></u> Signature	<u>10/22/03</u> Date
SCM Coordinator (print)		

**Key for check boxes above:**

Check <b>Yes</b> for each item reviewed and found acceptable
Check <b>N/A</b> for items not applicable, where applicable as based on code functionality

Information Only

**Dunagan, Sean**

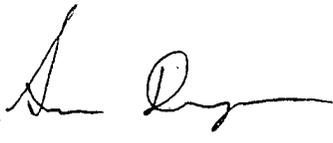
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**From:** Hansen, Clifford W  
**Sent:** Monday, October 20, 2003 10:26 AM  
**To:** Dunagan, Sean; Chavez, Mario Joseph  
**Subject:** Sig. authority for CUTTINGS documents

Sean,

In my absence, you have permission to sign CUTTINGS documents as the code sponsor. You may sign the RD, VVP, VD, the ID, the I&C, and the criteria forms for the RD, VVP, VD and the ID.

Cliff Hansen  
Sandia National Labs Dept 6821  
505-234-0103 (Carlsbad)  
505-845-0285 (Albuquerque)

 10/21/2003

Information Only

**WIPP PA**  
**User's Manual**

**for**

**CUTTINGS\_S, Version 5.10**

**DOCUMENT VERSION 1.00**

**ERMS # 532340**

**OCTOBER 2003**

**Information Only**

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## 1.0 INTRODUCTION

This document is the User's Manual for the WIPP code called CUTTINGS\_S, Version 5.10. Using repository-height data from SANTOS via BRAGFLO, CUTTINGS\_S estimates the volume of wastes brought to the surface as a result of an inadvertent borehole drilled directly over the WIPP repository so as to penetrate a waste panel. The manual identifies the code, its authors and expert consultants (Section 1). It describes the code's WIPP-PA purposes and functions (Section 2), provides recommended user training (Section 3), outlines the code's theoretical basis and numerical methods (Section 4), its inherent capabilities and limitations (Section 5), describes user interactions (Section 6), input files (Section 7), error messages (Section 8), output files (Section 9), and useful reference materials (Section 10). It provides examples of relevant input, output, and debug files in its Appendices as well as a set of sample test problems to familiarize the user with the run sequence.

It is useful to remember that the present version of CUTTINGS\_S's evolved in time through a sequence of WIPP PAs. Design criteria for each PA differed slightly from the set before, and careful readers will detect, especially in the appendices, terminology, test cases, and parameter values such as radioisotope decay data, that serve no apparent purpose in the *present* version of the code. Outdated but working subroutines were normally retained within the code so as to provide versatility.

### 1.1 Software Identifier:

**Code Name:** CUTTINGS\_S, a borehole waste-removal code for cuttings, cavings, and spallings.

**WIPP Prefix:** CUSP

**Version Number:** 5.10

**Date:** October 2003

**Platform:** FORTRAN 77 for Open VMS 7.3-1, ES40.

## 1.2 Points of Contact:

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Carlsbad, NM 88220  
E-mail: [cwhanse@sandia.gov](mailto:cwhanse@sandia.gov)

## 1.3 Code Overview

The CUSP code was written to calculate the quantity of material (in m<sup>3</sup>) brought to the surface from a radioactive waste disposal repository as a consequence of an inadvertent human intrusion through drilling. The code determines the amount of material removed from the repository by several release mechanisms, including cuttings, cavings and spallings. The CUSP code includes functionality to compute the radioactivity in the released material, including decay of the material to the time of intrusion.

## 2.0 FUNCTIONAL REQUIREMENTS

### 2.1 Functional Requirements

- R.1 CUTTINGS\_S calculates the amount of repository material brought to the surface due to erosion of the borehole resulting from laminar flow in the drilling fluid.
- R.2 CUTTINGS\_S calculates the amount of repository material brought to the surface due to erosion of the borehole resulting from turbulent flow in the drilling fluid.
- R.3 CUTTINGS\_S calculates the amount of repository material brought to the surface due to blowout of the borehole.
- R.4 CUTTINGS\_S calculates the amount of repository material brought to the surface due to gas erosion of the borehole.
- R.5 CUTTINGS\_S calculates the amount of repository material brought to the surface due to a stuckpipe.
- R.6 CUTTINGS\_S calculates model specific parameter values based on experimental data.
- R.7 CUTTINGS\_S calculates the volume of spalled material using a pressure threshold and a distribution of spallings volumes (spall model 3).
- R.8 CUTTINGS\_S determines the volume of spalled material using a set of distributions of spalled volumes, calculated for a set of reference repository pressures, by interpolating between distributions to account for current repository pressure (spall model 4).

## 2.2 Performance Requirements

There are no performance requirements for the CUTTINGS\_S code.

## 2.3 Attribute Requirements

There are no attribute requirements for CUTTINGS\_S code.

## 2.4 External Interface Requirements

- R.9 CUTTINGS\_S utilizes routines from CAMDAT\_LIB, CAMCON\_LIB, SDBREAD\_LIB, and CAMSUPES\_LIB. Consequently it must be linked with these libraries.
- R.10 CUTTINGS\_S requires one CDB input file from the BRAGFLO code, CUSP\_INP\$BRAGCDB.
- R.11 CUTTINGS\_S requires one input file containing preliminary data base information, CUSP\_INP\$CDB.
- R.12 CUTTINGS\_S requires one input file containing model and site dependent parameters and radionuclide properties, inventories, drilling procedures, and characteristics of the drilling fluid, CUSP\_INP\$TXT0.
- R.13 CUTTINGS\_S requires one input file identifying input sample vector values that will be used in the analysis, CUSP\_INP\$TXT1.
- R.14 CUTTINGS\_S generates one output file CUSP\_OUT\$DBG, which contains information that is used for comparing with acceptance criteria, and is used only for testing purposes.
- R.15 CUTTINGS\_S generates one output file CUSP\_OUT\$NVERIFY, which contains information that is used in the functional testing for hand calculations, and is not used in production runs.
- R.16 CUTTINGS\_S generates one output CDB (binary) file, CUSP\_OUT\$CDB, containing output generated by the code. This output must conform to the format specified in the WIPP PA User's Manual for CAMDAT\_LIB (4).
- R.17 If spall model 4 is used, CUTTINGS\_S reads spall volume data from a text input file, CUSP\_SPL4\$DAT.

## 2.5 Other Requirements

There are no other requirements for CUSP that require verification.

### 3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

To exercise CUTTINGS\_S, users should have (1) basic knowledge of open VMS, (2) basic facility with Digital Command Language, and (3) an overall understanding of Sandia's CAMDAT database, which is used in virtually every WIPP code (Rechard, 1992; and Rechard et al., 1993). User's should also have (4) access to the WIPP cluster of Compaq Alpha microcomputers with an open VMS 7.3-1 operating system or their functional equivalents.

To manipulate and/or interpret the results of CUTTINGS\_S as it is exercised in WIPP PAs, user's should have (1) a basic understanding of the physics of radioactive decay, the mechanics of laminar and turbulent flow of non-Newtonian fluid suspensions in annular conduits, erosion scouring of matrixed materials, flow through permeable media, and of the large-scale deformation and failure of elastic, plastic, and viscoelastic materials (2) a basic understanding of partial-differential equations and integral calculus, as they apply in the mathematical formulation of physical principles and especially of conservation of momentum, energy, and mass\*, (3) a generalist's conceptual understanding of numerical methods as they are applied to the numerical solution of the boundary-value problems of mathematical physics and chemistry, and (4) a basic overview understanding of the WIPP PA process, including conceptual models, scenarios, inventories, uncertainty sampling, input-data vectors, and a general familiarity with the files and functions of the WIPP codes that interface with CUTTINGS\_S and especially GENMESH, MATSET, POSTLHS, and BRAGFLO (WIPP PA Dept [5 Volumes], 1992).

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\* Strictly speaking, the decay of radioisotopes is not mass conserving. It requires loss of mass, although the amounts are insignificant for present purposes. Fluid and gas flows associated with CUTTINGS\_S are mass conserving.

## 4.0 DESCRIPTION OF THE MODEL AND METHODS

The discussion of the model and methods given below is but a brief overview of the theory and methods employed by CUTTINGS\_S. It is intended for users who have only a cursory interest in the mathematical and fluid dynamical details. A thorough, detailed treatment of the theory and numerics applied in CUTTINGS\_S is given in Appendix A of this manual.

### 4.1 Description of the Model

CUTTINGS\_S is a multi-faceted computational procedure to assess the effects of *direct removal* of wastes buried in a WIPP-like nuclear-waste repository. Direct removal is hypothesized to occur as the result of inadvertent penetration of the repository by a borehole drilled in connection with oil or gas exploration at some unknown time in the future (Berglund, 1993). The word "direct" refers to the fact that CUTTINGS\_S removals from the repository to the surface occur *at the time* of drilling. Since drilling operations are normally completed on the time scale of weeks, removal of drilled wastes from the repository to the surface (i.e., the accessible environment) takes place entirely within a single timestep of the much-longer-term groundwater transport codes. Hence, the word "direct" should be taken to mean "from the repository to the surface within a single timestep of a typical WIPP groundwater code."

Removal is subdivided according to process, which results in three principal categories, cuttings, cavings, and spallings.

First, the borehole is assumed to penetrate directly through waste containers stored within the repository. The drill bit cuts directly through the waste containers, allowing those repository wastes located on a collision course with the drill bit (called cuttings) to be transported directly and immediately to the surface via the cooling fluid (muddy brine) that is circulated through the borehole during drilling. The volume of repository material removed as cuttings is the portion of the deformed repository cut by the borehole.

Wastes that originally bordered the borehole on its exterior are permitted to erode into the cooling fluid as a result of the fluid's frictional effects on the outer cylindrical surface of the borehole. If shear stresses in the cooling fluid at the wall exceed the shear strength of the matrixed materials located at the wall, erosion will occur and wall material (cavings) will be removed\*. As a result, the borehole diameter may increase locally at the level of the repository. Because of that action, the volume of wastes removed from the repository can actually be larger than the volume of the borehole originally cut through the wastes. As the diameter of the borehole increases, the fluid shear stresses at the outer boundary decrease. If they decrease enough that the failure stress of the wall material equals or exceeds the fluid shear stress at the outer boundary of the flow region, then the caving process will terminate. CUTTINGS\_S allows for both laminar and turbulent shear flow in the circulating fluids, which, in turn, leads to two

\* In tightly matrixed or crystalline media such as the WIPP-site halite formation, exploratory boreholes are usually unlined. Rather, the drilling fluid is changed to saturated salt solution to minimize dissolution at the walls, and the borehole is permitted to support itself until the drill bit reaches granular strata below the halite horizon.

different models to assess the effects of material removal due to erosion. If the cooling-fluid flow is laminar, CUTTINGS\_S employs an analytical solution of the modeling equations to evaluate wall stresses and other flow parameters. The analytical solution takes the form of non-linear integral equations, which CUTTINGS\_S evaluates via an iterative numerical procedure. If the flow is turbulent, CUTTINGS\_S turns to a simpler empirical model to evaluate the turbulent shear stresses. Transition to turbulence is assumed to occur at a Reynolds number greater than 2100. In nature, the transition to turbulence actually occurs over a range of Reynolds numbers and is not an abrupt process. Normally there is a transitional regime during which the flow is partly laminar and partly turbulent with active and chaotic transitions between the two states. CUTTINGS\_S does not attempt to model the transition regime. Rather, it assumes the flow becomes fully and abruptly turbulent when the Reynolds exceeds 2100. CUTTINGS\_S employs a corrective procedure to compensate for the effects of that assumption (see Appendix A for details). To date, all WIPP-like runs have required turbulent cooling-fluid flow.

The cuttings/cavings model described thus far is functionally similar to the CUTTINGS model used in previous WIPP PAs (WIPP PA Dept, 1992, Vol 1). However, an important new element has been added to the newer CUTTINGS\_S code, namely, the inclusion of a third material-removal mechanism, removal in the form of spallings, which is discussed below.

If the repository is pressurized at the time of penetration, and if the pressure within the repository is high enough (i.e., above the hydrostatic pressure in the cooling-fluid column), repository materials originally surrounding the borehole, but interior to the repository-fluid interface, can be forced to deform inward toward the borehole so as to replace the materials already removed by action of the cutting bit and the erosive brine. The solid fraction of these materials are called spallings\*. Depending on the parameters of the problem, spalling deformations can be rapid, or they can be a sluggish, more like a large-amplitude, viscoelastic flow. If repository materials are relatively impermeable, the spalled materials can deform slowly inward so as to press against the rotating drill string. If repository pressures are high enough, frictional forces against the drill string may be high enough to stop the drill from turning. In that event, drillers normally withdraw the drill (vertically) and redrill downward through the spalled materials that clog the borehole. On occasion, that procedure must be repeated more than once. If repository materials are more permeable, the pressurized gas may simply seep through the matrix carrying loose particles with it. Alternatively, if repository pressures are too low, the spallings part of CUTTINGS\_S may do nothing at all. CUTTINGS\_S may have to be applied more than once during an assessment run, at more than one intrusion time, since multiple borehole intrusions are permissible in WIPP PAs.

The total volume of repository material removed by CUTTINGS\_S is the sum over all intrusions of cuttings, cavings, and spallings. Options cuttings and cavings are assumed to operate

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\* If the repository is wet with brine at time of penetration, which possibility is allowed in WIPP PAs, three phases of material could, in principle, flow toward the borehole, namely: pressurized gases, pressurized brine, and solid wastes. CUTTINGS\_S estimates only the amount of solids that are moved into the borehole. Pressurized brine that may be released into the borehole is treated by an independent WIPP code named DBR\_BRAGFLO. The gas flow, although crucial to the overall deformational process, transports no radioisotopes and is therefore not assessed.

continuously, whereas spallings operates only when repository pressure conditions permit it (the cut off being 8MPa.). The amount of material removed by each process, during each hypothesized drilling intrusion is reported in CUTTINGS\_S's output in terms of an equivalent area. Downstream WIPP codes, namely CCDFGF, use BRAGFLO's repository-height data to convert the equivalent areas to volumes of repository material, and then assign various sampled aged repository contents to convert these material volumes to releases. Thus, CCDFGF evaluates the release effects of striking contact-handled versus remote-handled wastes. The reader is referred to Appendix A for details.

The fluid-flow portion of CUTTINGS\_S is based on a non-linear analytical integral solution for laminar helical flow of a non-Newtonian (Oldroyd-type) fluid in an annular pipe, and on empirical equations for turbulent flow in the same geometrical configuration. CUTTINGS\_S acquires its parameter data from (i) the input CDB files provided by the WIPP codes MATSET and BRAGFLO, (ii) a user-supplied input text file, and (iii) the carefully controlled and QAed WIPP property database. Discrete values of sampled data are provided by the WIPP sampling code POSTLHS in cases where parameter uncertainty is judged to impact assessments of the repository's performance. CUTTINGS\_S input includes the rotational speed of the drill string, cutting-bit diameter, the shear-rate-dependent viscosity and density parameters for the drilling mud, borehole roughness, the compacted repository thickness and porosity, and the effective failure shear strength of the compacted repository material. A few required parameters, namely drilling-mud flow rate and drill-collar diameter, are calculated internally by the code, based on present-day oil-drilling industry guidelines.

## 4.2 Description of the Modeling Methods

CUTTINGS\_S does not endeavor to integrate conservation equations characterizing the flow on a point-for-point, time-for-time basis in search of a detailed space-time history of the removal process. Rather, removal is treated as instantaneous, that is, within a single timestep of the longer-term groundwater codes. Thus, numerical methods are used primarily to determine the limiting values of the physical parameters that represent the final configurations of the various (sampled) drilled systems, which is all that is required to assess radioactive waste removal due to the cuttings, cavings, and spallings that arise during drilling operations. These methods are fairly straightforward, iterative, recursive approximation techniques that involve systems of algebraic equations. They are discussed thoroughly in Appendix A (Sections 2.2.1.1, 2.2.2.1, and 2.4.1.2.1), which is highly recommended to readers who aim to understand this code.

## **5.0 INHERENT CAPABILITIES AND LIMITATIONS OF THE SOFTWARE**

CUTTINGS\_S is not presently put forward as a general borehole-mechanics code. Rather, it was developed with WIPP-like conditions and applications firmly in mind. To function properly, it requires inputs from other WIPP PA codes, specifically GENMESH, MATSET, POSTLHS, and BRAGFLO. Thus, although CUTTINGS\_S is quite likely to be fully applicable to other kinds of boreholes, other geologies, and other parameter ranges, it is not presently recommended for applications outside the presently-conceived boundaries that define the WIPP, primarily because such applications have not yet been tested. Consequently, no claims are made that CUTTINGS\_S should give reasonable results for parameter ranges that are atypical of the WIPP and its immediate environs.

All aspects of CUTTINGS\_S are based on the present-day drilling methods and technologies that would apply at a WIPP-like site. CUTTINGS\_S has been tested under those conditions and those conditions only. Hence, applications beyond the limits of those assumptions are not recommended at this time.

## 6.0 USER INTERACTIONS WITH THE SOFTWARE

Before launching into the exercising of CUTTINGS\_S, the reader is reminded that CUTTINGS\_S is normally exercised as one of a sequence of codes that includes GENMESH, MATSET, and POSTLHS, and requires input data files that originate with the code BRAGFLO. To assist the reader, the code sequence is depicted in figure 1, and examples of the input control files required by GENMESH and MATSET in preparation for a CUTTINGS\_S run are given in Appendix B. POSTLHS requires an input control file, but it is empty.

### 6.1 Exercising CUTTINGS\_S Interactively

CUTTINGS\_S has been modified in comparison with its parent code, CUTTINGS, so as to remove the possibility of user-interactive runs.

The following is an example of how to execute the CUTTINGS\_S code. The following example is the executable that was used in the 1996 CCA PA. To execute CUTTINGS\_S from a command line, it is necessary to define a logical symbol that invokes its executable, by typing either of the following two lines at the VMS \$ prompt:

```
$CUSP ::= "$WP$PRODROOT:[CUSP.EXE]CUSPPA96.EXE" <CR>*
```

or

```
$CUSP ::= "$WP$TESTROOT:[CUSP.EXE]CUSP_TEST_NODBG.EXE"
```

No matter which definition is used, typing "\$CUSP" and striking the carriage-return key will result in invoking CUTTINGS\_S's executable.

Like all WIPP codes, CUTTINGS\_S must be made aware of the names of and paths to the suite of input files it requires in order to exercise. It must also be given user-selected names for the files to which it will write its output. In command-line execution mode, CUTTINGS\_S will search for files by reviewing its internal list of logical symbols associated with input/output files. Thus, the user must inform CUTTINGS\_S which of its list of internal logical symbols corresponds to which input or output file for that specific run. That information is normally transferred by typing (at the VMS \$ prompt that will appear after defining the executable logical) a line such as the following:

```
$DEFINE CUSP_INP$CDB XY:[ABC.DEF.GHI]JKL.MNO ,
```

---

\* In this user's manual, VMS commands will always be entered by striking the carriage-return key. That instruction will not be repeated hereafter.

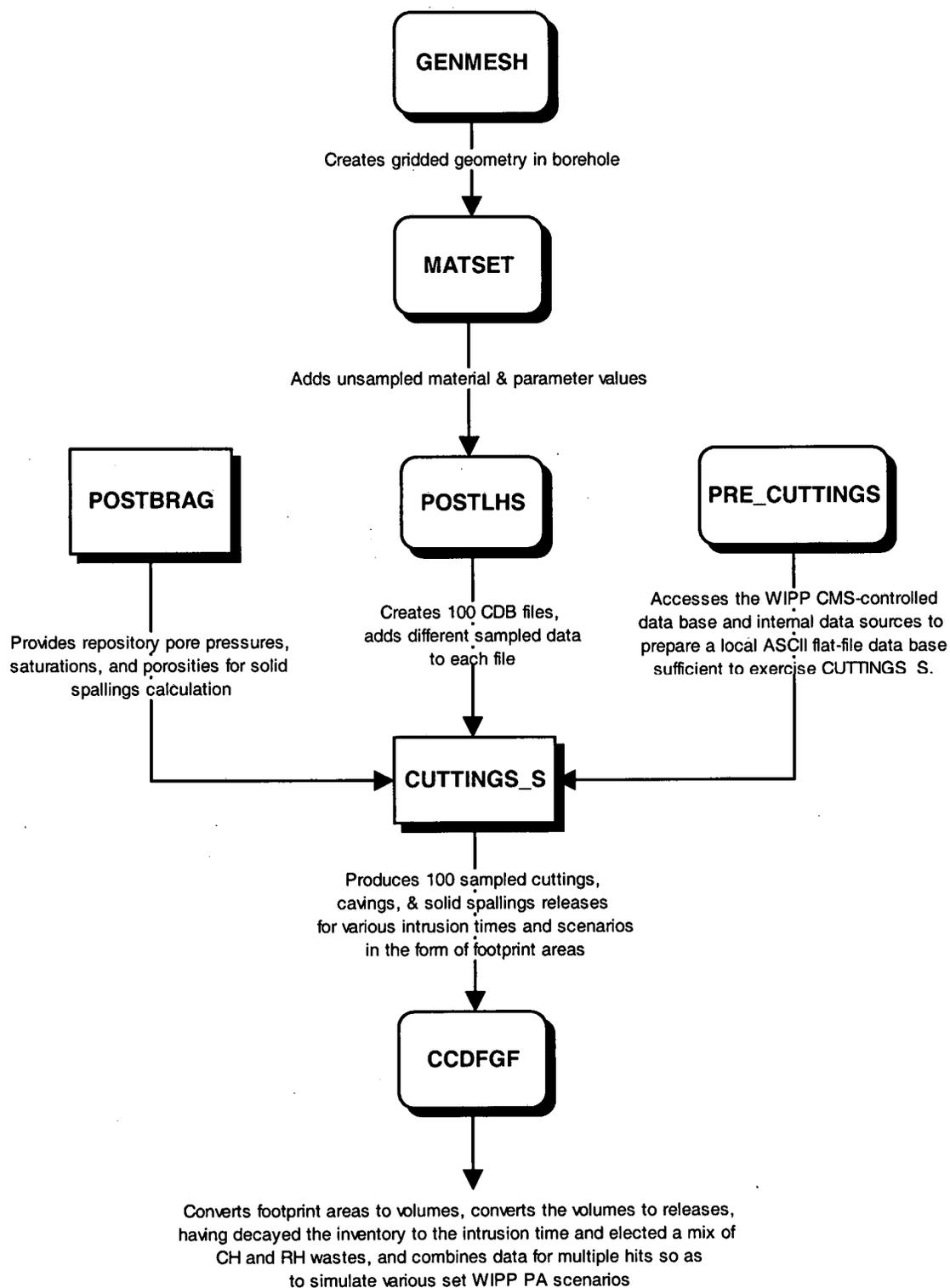


Figure 1: The code sequence for CUTTINGS\_S in the 1996 CCA PA.

where XY:[ABC.DEF.GHI]JKL.MNO represents the specific input file the user wishes to associate with the input logical CUSP\_INP\$CDB . The path need be included only if the file resides other then in the local working-level directory.

## 6.2 CUTTINGS\_S's Input/Output File Structure

Up to 12 logical symbols may be associated with CUTTINGS\_S's various input/output files. Of them, 6 are required and 5 are optional in regulatory runs. Before discussing the nature and function of the 12 possible input/output files, we first list them one-by-one, for ready reference, together with their corresponding logical symbols. They are:

File ID No.	Input/Output File Names	Associated Logical Symbol	Is the file Required or Not?
1.	Binary input CAMDAT file (from MATSET)	CUSP_INP\$CDB	Yes
2.	Input control file (text) specifying repository/model parameters, initial inventories, generic radioisotope database.	CUSP_INP\$TXT0	Yes
3.	Input control file (text) specifying drilling and intrusion parameters	CUSP_INP\$TXT1	Yes
4.	BRAGFLO binary output .CDB file. Regulatory runs Test runs	CUSP_INP\$BRAGCDB	Yes No
5.	Input control file for Spall Model 4 specifying pressures and their volumes by vector	CUSP_SPL4\$DAT	Yes (spall model 4 only)
6.	CUTTINGS_S's binary output .CDB file	CUSP_OUT\$CDB	Yes
7.	CUTTINGS_S's output debug text file	CUSP_OUT\$DBG	Yes
8.	Text file for verification testing	CUSP_OUT\$NVERIFY	No
9.	Radioisotope inventory history (in CURIES) output text file	CUSP_OUT\$IHISTO	No
10.	Normalized-release-history output text file (EPA 40CFR191, Subpt B) file in ASCII format	CUSP_OUT\$NHISTO	No
11.	Time-history plotting text file for: Long half-life radioisotope decay Medium half-life radioisotope decay Short half-life radioisotope decay	CUSP_OUT\$PLT1 CUSP_OUT\$PLT2 CUSP_OUT\$PLT3	No No No
12.	Output text file for transfer to	CUSP_OUT\$ICTRN	No

the WIPP code CCDFPERM

The first five files of the above list are CUTTINGS\_S's input data and control files. They are described briefly in Section 7.0 of this user's manual. The text-format input files include specific examples printed out in full in the appendices of this user's manual. Appendix C is included to assist the user in understanding the format used in CUTTINGS\_S's input control files (file numbers 1 and 2).

The last seven files of the above list are CUTTINGS\_S's output files. They are described briefly in Section 9.0 of this user's manual. Of the required output files, only the debug file is created in text format. One example of a CUTTINGS\_S output file is included in Appendix D. It is a debug file. It is annotated with italicized remarks that identify and explain the various groups of data that are reported therein.

### 6.3 Exercising CUTTINGS\_S

Once the logical symbol CUSP has been defined (see Section 6.1), and the necessary input and output files have been properly assigned (see Sections 6.1 and 6.2), CUTTINGS\_S may be exercised simply by typing the logical symbol:

\$CUSP

followed by a carriage return. If all goes well, CUTTINGS\_S will run and issue a "normal completion" message. If errors are encountered, CUTTINGS\_S will abort and issue an error message(s). See Section 8.0 for a listing of the possible error messages CUTTINGS\_S can produce.

### 6.4 Using CUTTINGS\_S's PRE\_CUTTINGS Mode

Because interactions with the controlled WIPP database require large and unnecessary expenditures of input/output time during production runs, CUTTINGS\_S includes a special operational mode designed to expedite data acquisitions during production runs. It is called PRE\_CUTTINGS, and in it, the WIPP QAed property database is accessed but once during an entire production run. PRE\_CUTTINGS reads a template file that interfaces the WIPP property database, extracting the required values and writing them to an ASCII file that can be read time and again by CUTTINGS\_S without subsequent reference to the property database. The ASCII data file thus produced is under strict CMS control.

PRE\_CUTTINGS's template file, which is shown in Appendix E, treats three data types. The first type is exemplified by CUTTINGS\_S's code parameters, which are discussed in the theoretical Manual (see Appendix A). These values are essential to exercising CUTTINGS\_S, but were not entered as part of the WIPP's CCA controlled database. They are discussed in detail in Appendix A. The second type are common property values as taken from the WIPP's CCA controlled database. For example, the datum BOREHOLE:L1 is called. In this example, the colon at mid word identifies the form as a WIPP controlled database property. BOREHOLE

is the material identifier and L1 is the parameter identifier. Using these two keywords, the WIPP property database is scanned until the numerical value associated with that specific parameter is located. CUTTINGS\_S then writes to the new template the parameter identifier L1 and the corresponding numerical value that was found in the database.

The third data type in the input template file includes the 10 radioisotope decay chains and the 29 specific radioisotopes that have initial inventories, which are denoted by the word "SAVE." CUTTINGS\_S tracks selected data for all of these radioisotopes. When CUTTINGS\_S encounters the key word "GENERATE\_RADIO", it sorts the list alphabetically and for each unique radioisotope, it queries the property database for atomic weight, half life, EPA release limit, initial contact-handled inventories, and initial remote-handled inventories. The code converts the half life in seconds to half life in years and calculates the specific activation energy, which is a function of atomic weight and half life. The code then writes all the necessary radioisotopic properties in tabular form. Appendix F is an example of the output ASCII text file from PRE\_CUTTINGS. Appendix G is a sampled "COM" file to test this portion of the code. Because this functionality of the code is basically data in / data out, it was not assigned a specific test problem.

## 6.5 Using CUTTINGS\_S's CHECK\_OUT Mode

CUTTINGS\_S has a special mode, called "CUSP\$CHECK\_OUT," designed to check the agreement between Model 2's blowout calculation and corresponding experimental results. CHECK\_OUT was added so the blowout model could be used for confirmation of experiential results. The CHECK\_OUT mode is set by specifying "CUSP\$CHECK\_OUT" as TRUE in DEC's Digital Command Language (DCL). Appendix H provides a listing of the DCL nomenclature required to exercise this operational mode. The CUTTINGS\_S input file CUSP\_INP\$TXT0 provides data for the experimental input, the geometry of the test fixture, and the properties of air. It is also shown in Appendix H. In CHECK\_OUT mode, three functions can be performed, as follows:

1. The "EXPERIMENT" function is set by including the keyword EXPERIMENT in the CUSP\_INP\$TXT1 text file. It allows CUTTINGS\_S to be run as though data is being gathered from an experimental run.
2. The "VALIDATE" function is set by including the keyword VALIDATE in the CUSP\_INP\$TXT1 text file. It allows CUTTINGS\_S to be run over the total range of possible inputs and thereby checks the code for numerical instabilities.
3. The "CALIBRATE" function is set by including this keyword CALIBRATE in the CUSP\_INP\$TXT1 text file. This function searches for the optimum values of FSE & FGE (see Appendix A) to minimize the error between the experiential results and the computer model. The CALIBRATE function is illustrated as a test problem #6 in the Validation Document.

The input files for these three functions are also shown in Appendix H.

## 7.0 DESCRIPTION OF CUTTINGS\_S'S INPUT FILES

CUTTINGS\_S's input files are listed in Section 6.2 together with their corresponding CUTTINGS\_S logical symbols. They are file numbers 1 through 4 in that listing.

**File 1. CUSP\_INP\$CDB** is the principal input CDB file and is absolutely required by CUTTINGS\_S. It is the file to which CUTTINGS\_S's results will be transferred and it is normally provided by an upstream code such as MATSET. In production runs, sampled data from POSTLHS would be fed to this input file. In that case, there would be N input CDB files, one for each of the sampled values where N is the number of samples employed. In test-case mode or debug mode, it is inconvenient to open the editor and hand build an input CDB file for specific input values. However, even in test or debug mode, CUTTINGS\_S expects to receive an input CDB file. As a convenience to users, an all-purpose, input CDB file for use with test problems and in debug runs is stored in the configuration-management-system (CMS) portion of the WIPP Alpha cluster. It is named: CUSP\_TEST\_1.CDB and can be called by typing:

```
$LIBCUSP
```

```
$CFE CUSP_TEST_1.CDB
```

**File 2. CUSP\_INP\$TXT0** is an ASCII input control file that contains various repository, drill geometry, and material input parameters required by CUTTINGS\_S. File 2 also contains the required radioisotope inventory data for the scenario currently under study. In regulatory calculations, these data are taken directly from the controlled WIPP property database. File 2 also provides radioisotope data essential for (1) the Bateman (1910) decay calculation, for (2) calculation of radioactive release values in Curies, and for (3) normalizing calculated releases in terms of the Environmental Protection Agency's (EPA's) 40CFR191 release limits (WIPP PA Dept [Vol 1], 1992). A sample CUSP\_INP\$TXT0 file usable for QA test and/or debug problems is available in the CMS portion of the WIPP Alpha cluster. It is named: CUSP\_TEST\_REPOSITORY.DAT, and it is printed in full in Appendix I of this user's manual. Most of its parameters are specific to the CUTTINGS\_S model and to individual radioisotopic properties.

**File 3. CUSP\_INP\$TXT1** is an ASCII input control file that contains various drilling and intrusion input parameters required by CUTTINGS\_S. A sample CUSP\_INP\$TXT1 file usable for test and/or debug runs is available in the CMS portion of the WIPP Alpha cluster. It is named CUSP\_TEST\_#.INP where # is the QA test problem number and varies from 1 through 5. In a normal production run, this file would contain no specific input data other than an intrusion time. Instead, only character variables would appear, identifying the element property name on the input CDB file. Values would then be assigned from the secondary database (see item 4, below). Appendix J is sample printout of a typical production input file. For specific testing or

debugging, this file would have fixed specific numerical values. Appendix K is a listing of CUSP\_TEST\_2.INP.

This file also identifies which spall model will be used. At the end of the file the model is determined by entering MODEL3 or MODEL4, depending on which model will be used. This is followed by the parameters that are needed for the model. If model three is selected then three parameters will be needed. Model four uses three parameters and one dummy parameter. The parameter PTHRESH is not used in model four. An example of how to call each model and the parameters it requires is below.

```
MODEL3
PTHRESH WAS_AREA: PTHRESH
VOLSPALL WAS_AREA: VOLSPALL
REPPRES CAVITY_1 <
```

```
MODEL4
REPPR_NM PRES GAS
REPPRES CAVITY_1 <
RNDSPALL DUM5: RNDSPALL
PTHRESH DUM5: PTH
```

**File 4. CUSP\_INP\$BRAGCDB** is the output CDB file from BRAGFLO as it is exercised in the undisturbed or disturbed scenarios. CUTTINGS\_S extracts from it (1) the repository porosity at time of decommissioning, and (2) the repository porosity and (3) repository pressure at the specified intrusion time. In regulatory calculations, these data would be provided by a regulatory BRAGFLO run. For QA testing and debug purposes, a fixed BRAGFLO output CDB file has been stored in the CMS portion of the WIPP Alpha cluster. It is named CUSP\_TEST\_INP\_BF.CDB , and it is the BRAGFLO output file used for test problem 1.

**File 5. CUSP\_SPL4\$DAT** is a data file that contains information pertinent to spall model 4. The file supplies the code with pressures and their corresponding data to determine the spall volume. The first line of the file lists the number of vectors in pressure data set. The second line is the number of pressure data sets. The third line lists the different pressures in increasing order separated by blank spaces. The following lines list data relating to each pressure. The first data set is for the first pressure given in line three, the second data set is for the second pressure in line three, and so on. The data sets have three columns of data that are separated by blank spaces. The first column is the vector numbers, the second column is the time (not used), and the third column is the volume. Each of the data sets is followed by a blank line. Each data set must contain the same number of vectors and be in the same order. An example data file is shown below.

```
5
2
10000000    20000000
1    0    1
2    0    1.25
3    0    1.5
4    0    1.75
```

```
5    0    2.00
blank
1    0    10
2    0    12.5
3    0    15
4    0    17.5
5    0    20
blank
```

## 8.0 ERROR MESSAGES

Numerous procedural errors can cause CUTTINGS\_S to abort. In general, these errors relate to the improper input of data. By noting where the code was when the abort occurred, and what the code was trying to read at the time, these problems can generally be resolved. However, there is not specific advice that can be offered to users in resolving errors beyond the general statement: locate the error and repair it. However, Appendix L, which was extracted primarily from the source code, contains useful operating notes and tips to the user. They are included purely because the code sponsor felt they might be useful to novice users.

To familiarize readers with CUTTINGS\_S's error-message patterns, CUTTINGS\_S's various error messages are listed below, section for section within the code.

---

### SUBROUTINE ADDMEM( MORMEMR, MORMEMC )

```
CALL QAABORT(
$ '(ADDMEM) - REAL array size errors detected ***')
CALL QAABORT(
$ '(ADDMEM) - REAL array memory errors detected ***')
CALL QAABORT(
$ '(ADDMEM) - CHARACTER array size errors detected ***')
CALL QAABORT(
$ '(ADDMEM) - CHARACTER array memory errors detected ***')
CALL QAABORT('(ADDMEM1) - REAL array size errors detected ***')
CALL QAABORT('(ADDMEM1) - REAL memory errors detected ***')
CALL QAABORT(
$ '(ADDMEM1) - CHARACTER array size errors detected ***')
CALL QAABORT(
$ '(ADDMEM1) - CHARACTER array memory errors detected ***')
CALL QAABORT('(ADDMEM2) - REAL array size errors detected ***')
CALL QAABORT('(ADDMEM2) - REAL memory errors detected ***')
CALL QAABORT(
$ '(ADDMEM2) - CHARACTER array size errors detected ***')
CALL QAABORT(
$ '(ADDMEM2) - CHARACTER array memory errors detected ***')
```

```
CALL QAABORT('(ADDMEM3) - REAL array size errors detected ***)  
CALL QAABORT('(ADDMEM3) - REAL memory errors detected ***)  
CALL QAABORT(  
$ '(ADDMEM3) - CHARACTER array size errors detected ***)  
CALL QAABORT(  
$ '(ADDMEM3) - CHARACTER array memory errors detected ***)
```

---

**SUBROUTINE BRGCDB( MAXC, MAXQ, IQ, LQ, Q, C, IERRDB )**

```
IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading input CAMDAT '//  
$ 'sizing parameters ***)  
IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading input CAMDAT '//  
$ 'TITLE ***)  
IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading number of input//  
$ 'CAMDAT analysis variables ***)
```

---

**SUBROUTINE DRILL( IWASFLG, IHIT, XTINT, DBDIAM, TUNITS, XNEWAREA)**

```
CALL QAABORT('(DRILL) - Negative ROUTER %%%')
```

---

**SUBROUTINE GETVAL( NOUTFL, NUQPRP, NELBLK, VARNAM, IASPRP,  
\$ XMATPR, NAMELB, NMATPR, XVAL )**

```
CALL QAABORT('(GETVAL) - ILLEGAL I.C. interpolation '//  
+ 'variable value range name ***)
```

---

**INTEGER FUNCTION GINDX( RADNAM, IDMTRL )**

```
CALL QAABORT('(GINDX) - cannot locate nuclide index in '//  
$ 'generic radioisotope data base (GRDB) ***)
```

---

**INTEGER FUNCTION GJNDX( RADNAM, NUCNAM )**

```
CALL QAABORT('(GJNDX) - cannot locate nuclide index in '//  
$ 'unique radioisotope names array (NCUNAM(*)) ***)
```

---

**SUBROUTINE GSDBQA( FSDB, NQAREC, QAINFO )**

```
CALL QAABORT('(GSDBQA) - Error reading SDB version number '//  
$ 'using SDBREAD_LIB routine: SDBQERRY ***)  
CALL QAABORT('(GSDBQA) - Error reading SDB geology name/t//
```

---

\$           'type using SDBREAD\_LIB routine: SDBQERRY \*\*\*)

---

**Information Only**

## PROGRAM CUSP\_MAIN

```
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Setting up DYNAMIC'//
$      'base arrays ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening input '//
$      'CAMDAT ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Setting up DYNAMIC'//
$      'base arrays ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening input '//
$      'CAMDAT ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$      'input text file 1 ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$      'input parameter text file ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$      'input parameter binary file ****')
IF(IERRDB.NE.0) CALL QAABORT ('(BRGCDB) - Check BRAG CDB ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening output'//
$      'CAMDAT and SCRATCH files ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Closing input '//
$      'CAMDAT ****')
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Trouble closing'//
$      'output cdb-scratch & CAMDAT files, etc... ****')
```

---

## SUBROUTINE MEMADJ( MORMEM, MNUSED, Q )

```
CALL QAABORT('(MEMADJ) - Invalid REAL dynamic array '//
+      'indices detected ****')
CALL QAABORT('(MEMADJ) - REAL DYNAMIC MEMORY '//
+      'ALLOCATION ERRORS ****')
CALL QAABORT('(MEMADJ2) - Invalid REAL dynamic array '//
+      'indices detected ****')
CALL QAABORT('(MEMADJ2) - REAL '//
$      'DYNAMIC MEMORY ALLOCATION ERRORS ****')
CALL QAABORT('(MEMADJ3) - REAL '//
$      'DYNAMIC MEMORY ALLOCATION ERRORS ****')
```

---

---

**SUBROUTINE MEMADJC( MORMEMC, MNUSED, C )**

```
CALL QAABORT('(MEMADJ) - Invalid CHARACTER dynamic array '//  
+ 'indices detected ***)  
CALL QAABORT('(MEMADJC) - CHARACTER DYNAMIC MEMORY '//  
+ 'ALLOCATION ERRORS ***)  
CALL QAABORT('(MEMADJC2) - Invalid CHARACTER dynamic array '//  
+ 'indices detected ***)  
CALL QAABORT('(MEMADJC2) - CHARACTER '//  
$ 'DYNAMIC MEMORY ALLOCATION ERRORS ***)  
CALL QAABORT('(MEMADJC3) - ### CHARACTER ### '//  
$ 'DYNAMIC MEMORY ALLOCATION ERRORS ***)
```

---

**SUBROUTINE PARBIN0**

```
CALL QAABORT('( PARBIN0) - PARBIN0 error input parameters ***)
```

---

**SUBROUTINE PARTXT0**

```
IF (IERR .GT. 0) CALL QAABORT(  
$ ' (PARTXT0) - PARTXT0 error input parameters ***)
```

---

**SUBROUTINE PREPRO( FIDB, FTXT0, FBIN0, FTXT1, FODB, FBRG )**

```
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS//  
$ ' input template file ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS//  
$ ' input desc_0500 file ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS//  
$ ' input text file 1 ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' output ascii SDB file ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' output binary SDB file ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' input text file 0 ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' input text file 1 ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' output verify file ***)  
IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS//  
$ ' output plot file ***)
```

---

**SUBROUTINE PROCDB( MAXC, MAXQ, IQ, LQ, Q, C )**

```
IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading input CAMDAT '//  
$      'sizing parameters ****')  
IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading input CAMDAT '//  
$      'TITLE ****')  
IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading number of input '//  
$      'CAMDAT analysis variables ****')
```

---

**SUBROUTINE PROSDB( MAXC, MAXQ, IQ, LQ, Q, C , IWASFLG, QAINFO )**

```
IF (IABORT .NE. 0)  
& CALL QAABORT('(CUSP_PROSDB) - finding data in the INGRES SDB '//  
&      ' database ****')
```

---

**REAL\*4 FUNCTION QUANKG( DT, LPOINT, NRILC, NLEFT, RADCHN,  
\$ NGRAD, IDMTRL, HALFY, AWT, XMOLES )**

```
CALL QAABORT('(QUANKG) - cannot find all radioisotopes in '//  
$      'local chain in GRDB rad. names array ****')
```

---

**SUBROUTINE REABIN0( NNIC, RADCHN, IDMTRL, NUCNAM,  
\$ MAPSAV, SAVNAM, HALFS, HALFY, AWT,  
\$ ACTCNV, EPAREL, CIPMSQ, MAPINV, IWASFLG )**

```
CALL QAABORT(' (PARBIN0) - PARBIN0 error input parameters ****')
```

---

**SUBROUTINE REASDB( DBNAME, CALC\_NAME, IDMTRL, IDPRAM, MEDIAN,  
& IABORT)**

```
CALL QAABORT('(CUSP_PROSDB) - extracting '//  
$      ' idmtrl, idpram ****')
```

---

**SUBROUTINE REATXT0( NNIC, RADCHN, IDMTRL, NUCNAM,  
\$ MAPSAV, SAVNAM, HALFS, HALFY, AWT,  
\$ ACTCNV, EPAREL, CIPMSQ, MAPINV, IWASFLG )**

```
IF (ICHECK .GT. 11111)  
& CALL QAABORT('(REATXT0) - read errors radionuclide input****')
```

```
IF(IERR.GT.0)CALL QAABORT('(REATXT0) - read errors ****')
      CALL QAABORT('(REATXT0) - Repeating/Duplicate radio//
$       'isotope names in chain ****')
      CALL QAABORT('(REATXT0) - Illegal names in "SAVE" '//
$       'radionuclides list %%%')
```

```
-----
SUBROUTINE REATXT1( IASPRP, NAMELB, NMATPR, XMATPR, TINT,      1
&                 DIAMMOD, TUNITS, PORO, TCLOUT, PRESSR,
&                 PARTDIA, SATGASX, CEMSIG, FGE, FSE,
&                 FCE )
```

```
      CALL QAABORT('(REATXT1) - ILLEGAL drilling bit diamet'//
&                 'er specified (<=0) ****')
IF(IERR.GT.0)CALL QAABORT('(REATXT1) - read errors ****')
```

```
-----
SUBROUTINE RECHEA( Q, C, IDEBLK, NUMPRP, IASPRP,      1
$                 XMATPR, QAINFO, NAMELB, NMATPR )
```

```
      IF(IERR.NE.0)
$      CALL QAABORT('(RECHEA) - reading material ID and names array ****')
      IF(IERR.NE.0)
$      CALL QAABORT('(RECHEA) - reading PROPERTY NAMES array ****')
      IF(IERR.NE.0)
$      CALL QAABORT('(RECHEA) - reading PROPERTY values ****')
      IF(IERR.NE.0)CALL QAABORT('(RECHEA) - reading QA array ****')
      IF(IERR.NE.0)CALL QAABORT('(RECHEA) - obtaining input CAMDAT'//
$      'no. of time steps ****')
```

```
-----
SUBROUTINE RGRDB( IDMTRL, HALFS, HALFY, AWT, ACTCNV, EPANORM ) 1
```

```
      CALL QAABORT('(RGRDB) - read errors ****')
      CALL QAABORT('(RGRDB) - counting entries in GRDB ****')
```

```
-----
SUBROUTINE SCASDB( FSDB, NENTRY, ID1, ID2, ID3,      1
$                 ID4, ID5, ID6, ID7, IDENT )
```

```
      CALL QAABORT('(SCASDB) - Bad SDB initialization ****')
      CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine'//
$      ': SDBCASES ****')
      CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine'//
$      ': SDBINFO ****')
```

```
CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine '//  
$      ': SDBNINFO ***)  
CALL QAABORT('(SCASDB) - keyword IDMTRL missing on SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword IDPRAM missing in SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword IDSCAL missing in SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword MEDIAN missing in SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword LOWRNG missing in SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword HIRNGE missing in SDB '//  
$      'header description ***)  
CALL QAABORT('(SCASDB) - keyword UNITS missing in SDB '//  
$      'header description ***)
```

---

```
SUBROUTINE SCATXT0( IWASFLG, NAMELB, KOMAT, OUTMAT, IDMTRL, 1  
$      QAINFO, ISETUP )
```

```
IF(N.NE.NGRAD)CALL QAABORT(  
$ (SCATXT0) - SCATXT0 input text for generic sizing ***)  
IF(IERR.GT.0)CALL QAABORT(  
$ (SCATXT0) - SCATXT0 input text for sizing parameters ***)
```

---

```
SUBROUTINE SCATXT1( IWASFLG, IASPRP, XMATPR, NAMELB, NMATPR, 1  
&      IDMTRL, OUTMAT )
```

```
IF (MULTP .NE. JULTP) CALL QAABORT(  
& ' (SCATXT1) - SCATXT1 MULTP gt NULTP ***)  
IF (MULTP .GT. NULTP) CALL QAABORT(  
& ' (SCATXT1) - SCATXT1 order of multiple hits wrong ***)  
IF (INUM .GT. NRMS) CALL QAABORT(  
& ' (SCATXT1) - SCATXT1 INUM gt NRMS ***)  
999 IF(IERR.GT.0)CALL QAABORT(  
& ' (SCATXT1) - SCATXT1 input text for sizing parameters ***)
```

---

```
SUBROUTINE SGRDB
```

1

```
CALL QAABORT('(SGRDB) - Illegal GRDB format ***)  
666 IF(IERR.GT.0)CALL QAABORT('(SGRDB) - read errors ***)
```

---

**SUBROUTINE WRCHEA( IWASFLG, Q, CH, IASPRP, NMATPR, 1**  
**\$ QAINFO, LDUMP, RDUMP, KOMAT, NUCNAM,**  
**\$ SAVNAM, MAPSAV )**

```
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "DENSITY" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "DOMEGA" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "ABSRO" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "TAUFAIL" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "VISCO" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT(  
$ '(WRCHEA) - ADDING "YLDSTRSS" as a CAMDAT property ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Trouble writing '//  
$'CUTTINGS SDB QA record to CDB-scratch file ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Trouble writing '//  
$'CUTTINGS QA record to CDB-scratch file ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Writing "HEADER" '//  
$'section to the final output CAMDAT file ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (AREA_C) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (AREA_S) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (AREA_T) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (VOL_C) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (VOL_S) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (VOL_T) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (DRILDIA) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (NUM_INTR) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (POROSITY) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (HFINAL) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//  
$ ' NEW GLOBAL variable names (PRESGAS) to CDB ****)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
```

```
$ ' NEW GLOBAL variable names (PRESBRIN) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (SATGAS) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (SATBRIN) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (POROSITY) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (HFINAL) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (PRESGAS) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (SATBRIN) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (NUCNAM C_) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (NUCNAM S_) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'  
$ ' NEW GLOBAL variable names (NUCNAM T_) to CDB ***)
```

---

```
SUBROUTINE WRPLFIL( IWASFLG, MAPSAV, HALFY, NUCNAM, RADHIS, 1  
$ TINT, XRAD1, XRAD2, XRAD3, TMPNM1,  
$ TMPNM2, TMPNM3 )
```

```
CALL QAABORT('(WRPLFIL) - Exceeded maximum history plott'  
$ 'ing file "width" ***)
```

---

```
SUBROUTINE WRTANA( IWASFLG, Q, C, TIME, HIFLAG, 1  
$ AINTC, DRILDIA, NUCNAM, MAPSAV, SUMCI,  
$ XPORO, XPRGS, XPRBR, XSATG, KULTP, KH )
```

```
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (AINTC(1,KH)) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (AINTC(2,KH)) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (AINTC(3,KH)) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (VOL_C) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (VOL_S) to CDB ***)  
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'  
$ ' NEW GLOBAL variable values (VOL_T) to CDB ***)
```

```
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (DRILDIA) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (NUM_INTR) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (POROF) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (HFINAL) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (PRESGAS) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (PRESBRIN) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (SATGAS) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (SATBRIN) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (POROF) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (HFINAL) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (PRESGAS) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (SATBRIN) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$ ' NEW GLOBAL variable values (SUMCI) to CDB ***)
IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing a completed'//
$' time-step and advancing to next step /DBOSTEP ***)
```

-----

INTEGER FUNCTION INEXT(INDEX)

```
WRITE (6,(' INCORRECT WORD TYPE WAS FOUND, INEXT'))
WRITE (6,(' WORD CMD ",A,
&      " INTEGER ",I20,
&      " RNUMBER ",E16.8')) C18, NUM1, RNUM1
STOP ' ERROR INEXT'
```

-----

REAL\*4 FUNCTION RNEXT(INDEX)

```
WRITE (6,(' INCORRECT WORD TYPE WAS FOUND, RNEXT'))  
WRITE (6,(' WORD CMD ",A,  
&      " INTEGER ",I20,  
&      " RNUMBER ",E16.8')) C18, NUM1, RNUM1  
STOP ' ERROR RNEXT'
```

---

SUBROUTINE ANEXT (INDEX, AVALUE, NP)

```
WRITE (6,100)  
100  FORMAT(" NONE REAL NUMBER WAS FOUND, ANEXT")  
STOP ' ERROR ANEXT'
```

```
WRITE (6,130)  
130  FORMAT(" NO END OF ARRAY, ANEXT")  
STOP ' ERROR ANEXT'
```

---

SUBROUTINE SOLID\_OUT (DIA, SATBRIN, HF, PG, PARTDIA, PORO,

```
C  
IF (PG .LT. PSUF) THEN  
  WRITE(NOUTFL,  
&      '(/" **** REPOSITORY PRESSURE LESS THAN ATMOSPHERIC"))  
  STOP  
ENDIF  
C
```

## 9.0 DESCRIPTION OF CUTTINGS\_S'S OUTPUT FILES

CUTTINGS\_S's output files are listed above in Section 6.2, together with their identification numbers and the logical symbols CUTTINGS\_S associates with them. The output files are file numbers 7 through 13. Each of them is briefly described below. Of the required files, the only user-readable output appears in the debug file, an annotated example of which is given in Appendix D.

**File 7. CUSP\_OUT\$CDB** is the principal CUTTINGS\_S output CDB file. It contains the calculated total volume (in terms of an areal footprint) of all radioactive materials, isotope by isotope, brought to the surface by the combined actions of cuttings, cavings, and spillings. Being a CDB file, it is binary and therefore not directly human readable.

**File 8. CUSP\_OUT\$DBG** is an ASCII output file that echoes the various input files, the input parameter values, and includes a summary of the output calculations given in file 7.

NOTE: There are three run-time debug flags that cause changes in the amount of output written to the DBG output file. They are defined as follows:

DEBUG = <LOGICAL> for debugging dynamic memory allocation.  
DBRAG = <LOGICAL> for debugging the BRAGFLO CDB file  
NOECHO = <LOGICAL> to cancel echoing of input data to the DBG file

These run-time flags may be invoked and set by typing the variable, for example: DBSPALL on the command line. Alternatively, the user may type the line: \$DEFINE CUSP\$DPSPALL TRUE prior to the execution of CUTTINGS\_S.

**File 9. CUSP\_OUT\$NVERIFY** is an optional ASCII output file of intermediate results that is used during developmental phases to verify CUTTINGS\_S's calculations against other independent calculations, normally performed by hand.

**Files 10 through 11** are optional output files that are normally forwarded to system plotting packages for diagnostic and developmental purposes. See the summary table above for a listing of their logical symbols. Their use in regulatory calculations is not contemplated. Hence, these logicals will either remain undefined or will be defined as NULL or CANCEL, in which case the code will not write to them.

## 10.0 REFERENCES

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## **APPENDIX A: A REFERENCE MANUAL ON THE THEORY AND NUMERICAL METHODS UNDERLYING THE WIPP CODE CUTTINGS\_S (BY J. W. BERGLUND)**

This appendix describes the theoretical basis of the CUTTINGS\_S computer code which was written to calculate the quantity of solid radioactive material (in curies) brought to the surface from a radioactive waste disposal facility as a consequence of an inadvertent drilling intrusion. The code determines the amount of material removed by several release mechanisms, and decays the releases to the intrusion time. The report describes the background, assumptions, equations, and variables governing the releases and the methods used to solve them. The code was written specifically for the computations required for the Performance Assessment of the Waste Isolation Pilot Project (WIPP) but with due care can be used for other radioactive waste repositories.

### 1.0 Introduction

The Waste Isolation Pilot Plant (WIPP), located in southern New Mexico, is the first planned, mined geologic repository for transuranic wastes generated by U.S. defense programs. WIPP is currently being evaluated to assess compliance with the requirements of EPA 40 CFR 191 Subpart B. Briefly, this requirement, promulgated by the Environmental Protection Agency, limits the amount of radioactive material that can be released to the accessible environment over a 10,000-year regulatory period.

Of the possible pathways for release during this period, one of the most important is that caused by the inadvertent penetration of a waste storage room by an exploratory drill bit. The current performance assessment model relies on the assumption that future drilling techniques will be similar to those in use today. The validity of this assumption is unknown but is necessary to provide a basis on which predictions of release can be estimated. Assuming that current, standard drilling practices for gas and oil are used, mechanisms governing the direct removal of radioactive waste can be identified and governing equations developed and solved. The following report summarizes the current understanding of the processes related to the direct removal of wastes, presents the governing mechanisms, and describes the solution of the model equations.

### 1.1 Background

The WIPP repository will consist of a number of excavated waste disposal rooms located in bedded halite (salt) approximately 650m below the ground surface in southeast New Mexico. Most excavated rooms will be approximately 91 m long, 10 m wide and 4 m high. Transuranic waste packaged in 55-gallon drums or standard waste boxes will be placed in each room and backfilled primarily with crushed salt.

After the WIPP repository is filled with waste and sealed, the waste is expected to be slowly compacted vertically by salt creep from an original waste room height of 4 m to a compacted height of 0.5 to 2 m within 100 to 200 years. The overburden (vertical) stress acting on the waste will also increase to the lithostatic stress (~14.8 MPa) during this period. The waste in its unmodified form will consist of a mixture of contaminated organic (e.g., cloth, wood, rubber,

plastics) and inorganic (e.g. metals, glass) materials. After placement in the mined (salt) repository, the waste will be compacted by creep closure of the surrounding salt and in addition may become exposed to brine. The exposure of the metallic waste to brine is expected to cause corrosion of the metals and as a by-product will generate gas ( $H_2$ ). Additional gas will be generated by the biodegradation of the organic materials in the waste inventory. The gas volumes generated by corrosion and biodegradation are expected to increase continuously for hundreds of years and the pore pressure may reach and possibly exceed the lithostatic overburden stress. During this time the repository is also expected to expand under the influence of the elevated gas pressure.

At some time within the 10,000-year regulatory period, it is probable that one or more exploration boreholes will be drilled into and through the vertically compacted waste and some of the waste will be carried to the surface as a direct result of the drilling process. The volume of waste removed to the ground surface will depend upon the physical properties of the compacted, decomposed wastes, the drilling procedures used, and the pore pressures encountered. Because of radioactive decay, the radioactivity of nuclides in the removed waste (in curies) will also depend upon the time of intrusion.

### 1.2 Current Drilling Practices

In considering the problem of the direct releases caused by drilling it is important to understand the procedures currently utilized in drilling a gas or oil well. The following description is tailored to practices in use near the WIPP site. Typically, independent drilling companies respond to requests for fixed price bids from oil companies to provide drilled and cased holes of a specified diameter to a specified depth at a location leased by the oil company. The bids are competitive and generally the low bidder is selected. As a result of this bidding process, profit margins for the winning driller are governed by the effectiveness of the driller in maintaining efficient drilling parameters and by solving unforeseen difficulties that may arise quickly and safely. The principal goal of the driller is to "make hole" and meet contract requirements. If this is accomplished the drilling operation will be profitable.

Within the Delaware Basin near the WIPP site, gas and oil wells are started by clearing the site, and drilling a shallow hole (~40') to house a conductor pipe. The conductor pipe is set in cement and serves to prevent surface sands from sloughing into the wellbore during later drilling. Below the conductor, drilling is continued to 300 - 600 feet (to top of salt section) using a large diameter (17-26") drill bit and another steel casing is set. This "surface" casing is cement grouted into the hole and a blowout preventer tree is attached to the casing at the surface. Drilling below the surface casing (in the salt section) uses a drilling mud that consists of a saturated brine solution to prevent dissolution of the salt. Drilling through the salt section proceeds at rates from 50 to 100 feet/hour depending on bit diameter. If higher rates are attempted by increasing the weight on bit (WOB) there is the danger of producing a crooked hole. While in the salt section, drilling mud (brine) is supplied from a large plastic lined reserve pit dug in the ground with a surface area of approximately 4000 ft<sup>2</sup>. Drilling mud is pumped from the reserve pit down through the drillpipe and drillbit and up the annulus formed by the drillstring and drilled hole. The drilling mud and drill cuttings are returned directly to the reserve pit where the cuttings settle out. While drilling in the salt section no formal attempt is made to monitor the character of the cuttings or the fluid volume of the reserve pit. A gas analyzer is not attached to the returns until the hole is much deeper than the depth of the WIPP repository. The drillstring generally consists of a drillbit attached to approximately 20, 30 foot long drill collars followed by multiple sections of 30 foot long 4 1/2 " diameter drillpipe. One to four drillbit changes may be necessary when drilling through the salt section. This process requires the removal of the entire drillstring (tripping). Once the drill has passed the salt section (~4500 ft) the hole is again cased and set with cement. At this point, if the repository had been penetrated no further contact would occur between the drilling mud and the exposed WIPP waste.

## 2.0 Release Processes

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.

In the above and in the following it is understood that usage of the word "waste" also includes any backfill or other materials that may have been added to the actual waste material.

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.

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

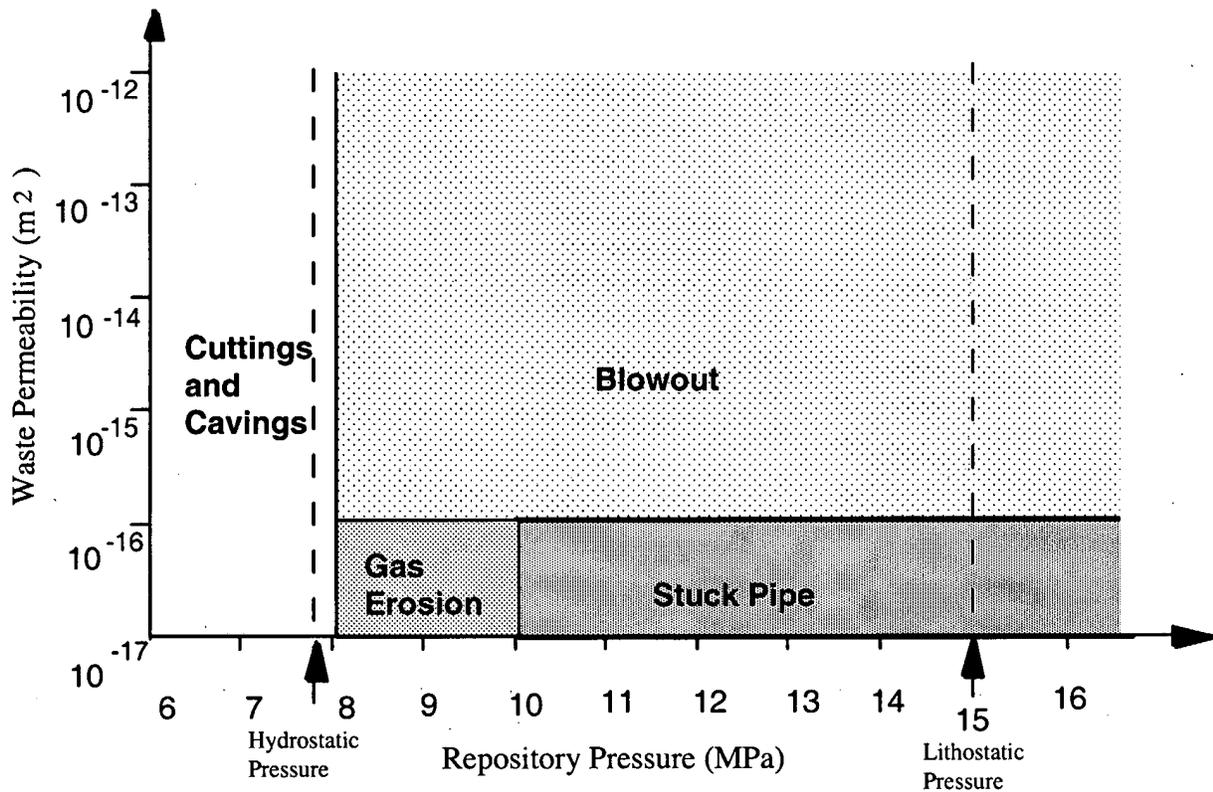


Figure 1. Release process zones

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

### 2.1 Cuttings

This is the simplest component of the direct release model and is assumed to occur for repository pressures less than the hydrostatic pressure of the drilling mud. This pressure is approximately 8 Mpa (Figure 1). 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 ( $\phi$ ), and the drill bit area (A).

$$Volume = AH(1 - \phi) \tag{1}$$

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.

## 2.2 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. For cavings it is further assumed that the repository is not pressurized by either brine or gas, i.e. the repository pressure is less than the hydrostatic pressure caused by a brine column to the surface (Figure 1). Gas pressurization effects are included in other release processes (spall) and will be discussed later.

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.

### 2.2.1 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.

Some of the early work on laminar helical flow of a non-Newtonian fluid in an annulus was performed by Coleman and Noll (1959), and Fredrickson (1960). 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

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

where  $\sigma_1$  and  $\sigma_2$  are constants,  $\eta_o$  is the limiting viscosity at zero rate of shear,  $\eta_\infty$  (defined as  $\eta_o(\sigma_2/\sigma_1)$ ) is the limiting viscosity at infinite rate of shear, and  $\Gamma$  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.

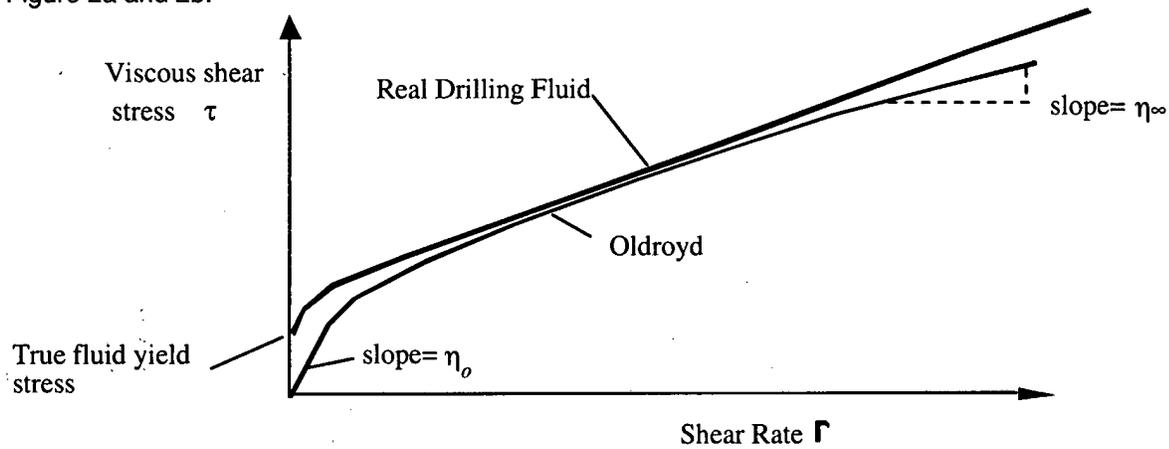


Figure 2a Oldroyd and real drilling fluid

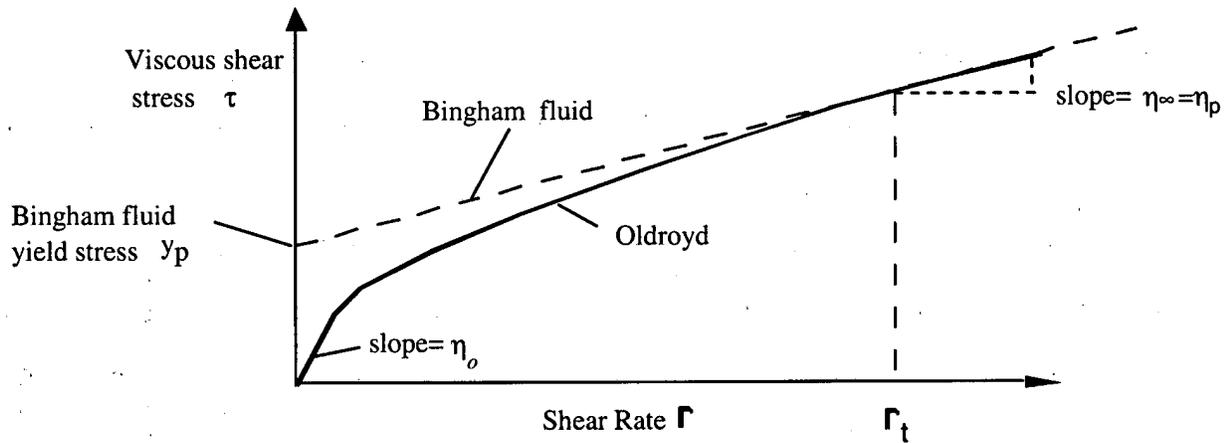


Figure 2b Oldroyd and Bingham fluid

This is a rate softening (pseudoplastic) model that has an initial slope of  $\eta_o$  and a limiting slope of  $\eta_\infty$  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), expanding on the work of Coleman and Noll (1959) and Fredrickson (1960), 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.

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

where  $\alpha$  is the ratio of the collar radius over the cutting radius ( $R_c/R$ ) (Figure 3),  $\Delta\Omega$  is the drill string angular velocity,  $Q$  is the drilling fluid (mud) flow rate,  $r$  is the radial coordinate, and  $\rho$  is the non-dimensional radial coordinate representing the ratio  $r/R$ .

The unknown parameters  $\lambda^2$ ,  $RJ/2$ , and  $C$  are related to the fluid shear stresses through the relations

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

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

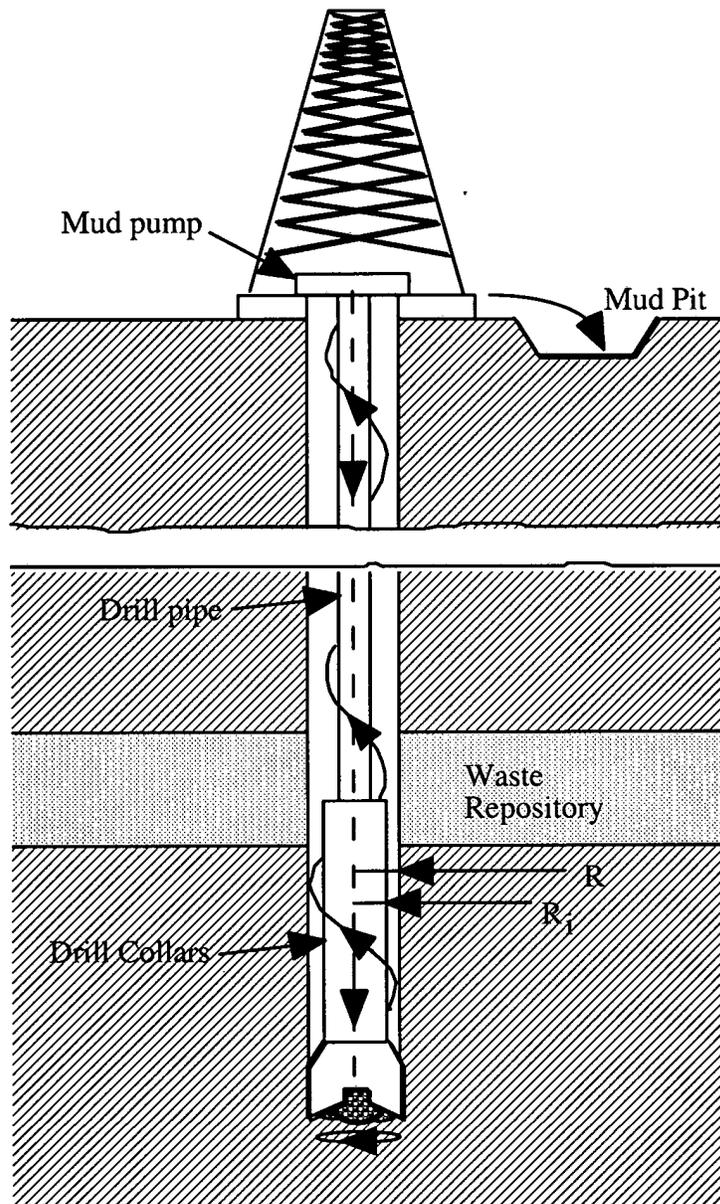


Figure 3. Detail of rotary drill string adjacent to repository.

The three nonlinear integral equations represented by (3) in general must be solved numerically. By expanding each of the integral equations into a Taylor series and retaining only the linear terms, a recursive solution procedure can be used (see Appendix AA) to find the solution for the unknowns  $\delta\lambda^2$ ,  $\delta\left(\frac{RJ}{2}\right)$ , and  $\delta C$ . The three linear equations are

$$\begin{aligned} \frac{\partial F_1}{\partial \lambda^2} \delta \lambda^2 + \frac{\partial F_1}{\partial C} \delta C + \frac{\partial F_1}{\partial \left(\frac{RJ}{2}\right)} \delta \left(\frac{RJ}{2}\right) &= -F_1 \\ \frac{\partial F_2}{\partial \lambda^2} \delta \lambda^2 + \frac{\partial F_2}{\partial C} \delta C + \frac{\partial F_2}{\partial \left(\frac{RJ}{2}\right)} \delta \left(\frac{RJ}{2}\right) &= -F_2 \\ \frac{\partial F_3}{\partial \lambda^2} \delta \lambda^2 + \frac{\partial F_3}{\partial C} \delta C + \frac{\partial F_3}{\partial \left(\frac{RJ}{2}\right)} \delta \left(\frac{RJ}{2}\right) &= -F_3 \end{aligned} \tag{5}$$

The solution procedure consists of assuming initial values for  $\lambda^2$ ,  $\left(\frac{RJ}{2}\right)$ , and C and solving the three linear equations in (5) for the corrections  $\delta \lambda^2$ ,  $\delta \left(\frac{RJ}{2}\right)$ , and  $\delta C$ . The unknowns  $\lambda^2$ ,  $\left(\frac{RJ}{2}\right)$ , and C are then replaced by  $\lambda^2 + \delta \lambda^2$ ,  $\left(\frac{RJ}{2}\right) + \delta \left(\frac{RJ}{2}\right)$ , and  $C + \delta C$ . This recursive solution procedure is repeated until  $|\delta \lambda^2|$ ,  $\left| \delta \left(\frac{RJ}{2}\right) \right|$ , and  $|\delta C|$  are all less than some specified limit.

The coefficients of the unknowns  $\delta \lambda^2$ ,  $\delta \left(\frac{RJ}{2}\right)$ , and  $\delta C$  in equations (5) are determined by differentiating equations (3). These derivatives are:

$$\begin{aligned} \frac{\partial F_1}{\partial \lambda^2} &= -\int_{\alpha}^1 \frac{1}{\eta \rho} \left[ 1 + \frac{(\rho^2 - \lambda^2)}{\eta} \frac{\partial \eta}{\partial \lambda^2} \right] d\rho \\ \frac{\partial F_1}{\partial C} &= -\int_{\alpha}^1 \frac{1}{\eta \rho} \frac{(\rho^2 - \lambda^2)}{\eta} \frac{\partial \eta}{\partial C} d\rho \\ \frac{\partial F_1}{\partial \left(\frac{RJ}{2}\right)} &= -\int_{\alpha}^1 \frac{1}{\eta \rho} \frac{(\rho^2 - \lambda^2)}{\eta} \frac{\partial \eta}{\partial \left(\frac{RJ}{2}\right)} d\rho \\ \frac{\partial F_2}{\partial \lambda^2} &= -C \int_{\alpha}^1 \frac{1}{\eta^2 \rho^3} \frac{\partial \eta}{\partial \lambda^2} d\rho \\ \frac{\partial F_2}{\partial C} &= \int_{\alpha}^1 \frac{1}{\eta \rho^3} \left[ 1 - \frac{C}{\eta} \frac{\partial \eta}{\partial C} \right] d\rho \tag{6} \\ \frac{\partial F_2}{\partial \left(\frac{RJ}{2}\right)} &= -C \int_{\alpha}^1 \frac{1}{\eta^2 \rho^3} \frac{\partial \eta}{\partial \left(\frac{RJ}{2}\right)} d\rho \\ \frac{\partial F_3}{\partial \lambda^2} &= -4 \left(\frac{RJ}{2}\right) \int_{\alpha}^1 \frac{\alpha^2 - \rho^2}{\eta \rho} \left[ 1 + \frac{(\rho^2 - \lambda^2)}{\eta} \frac{\partial \eta}{\partial \lambda^2} \right] d\rho \\ \frac{\partial F_3}{\partial C} &= -4 \left(\frac{RJ}{2}\right) \int_{\alpha}^1 \frac{(\alpha^2 - \rho^2)(\rho^2 - \lambda^2)}{\eta \rho} \frac{\partial \eta}{\partial C} d\rho \\ \frac{\partial F_3}{\partial \left(\frac{RJ}{2}\right)} &= 4 \int_{\alpha}^1 \frac{(\alpha^2 - \rho^2)}{\eta \rho} (\rho^2 - \lambda^2) d\rho - 4 \left(\frac{RJ}{2}\right) \int_{\alpha}^1 \frac{(\alpha^2 - \rho^2)(\rho^2 - \lambda^2)}{\eta \rho} \frac{\partial \eta}{\partial \left(\frac{RJ}{2}\right)} d\rho \end{aligned}$$

From equations (4) and using the relation  $\tau = \eta I$  the viscosity can be related to the shear rate function  $Y(I)$  by the equation

$$\eta^2 Y = 2 \left[ \left(\frac{RJ}{2}\right)^2 \left(\frac{\rho^2 - \lambda^2}{\rho}\right)^2 + \frac{C^2}{\rho^4} \right] \tag{7}$$

where

$$Y = 2I^2 \tag{8}$$

For the Oldroyd viscosity function, equation (2), the unknown derivatives of the viscosity in equations (6) can be determined by using the chain rule of differentiation and equation (7).

$$\frac{\partial \eta}{\partial \lambda^2} = \frac{\partial(\eta^2 Y)}{\partial \lambda^2} \frac{\partial \eta}{\partial(\eta^2 Y)} = -4 \left( \frac{RJ}{2} \right)^2 \left( \frac{\rho^2 - \lambda^2}{\rho^2} \right) \frac{\partial \eta}{\partial(\eta^2 Y)}$$

$$\frac{\partial \eta}{\partial C} = \frac{\partial(\eta^2 Y)}{\partial C} \frac{\partial \eta}{\partial(\eta^2 Y)} = \frac{4C}{\rho^4} \frac{\partial \eta}{\partial(\eta^2 Y)} \tag{9}$$

$$\frac{\partial \eta}{\partial \left( \frac{RJ}{2} \right)} = \frac{\partial(\eta^2 Y)}{\partial \left( \frac{RJ}{2} \right)} \frac{\partial \eta}{\partial(\eta^2 Y)} = 4 \left( \frac{RJ}{2} \right) \left( \frac{\rho^2 - \lambda^2}{\rho} \right)^2 \frac{\partial \eta}{\partial(\eta^2 Y)}$$

The derivative  $\frac{\partial \eta}{\partial(\eta^2 Y)}$  can be determined by combining equations (2) and (8) and differentiating to obtain

$$\frac{\partial \eta}{\partial(\eta^2 Y)} = \frac{\left( \frac{\sigma_2}{2} \eta_o - \frac{\sigma_1}{2} \eta \right)^2}{\left( \frac{\sigma_2}{2} \eta_o - \frac{\sigma_1}{2} \eta \right) [\eta^2 + 2(\eta - \eta_o)\eta] + (\eta - \eta_o)\eta^2 \frac{\sigma_1}{2}} \tag{10}$$

A cubic equation for  $\eta$  in terms of the unknown parameters  $\lambda^2$ ,  $RJ/2$ , and  $C$  can be written by combining equations (2), (7) and (8)

$$\eta^3 - \eta_o \eta^2 + \sigma_1 \left[ \left( \frac{RJ}{2} \right)^2 \left( \frac{\rho^2 - \lambda^2}{\rho} \right)^2 + \frac{C^2}{\rho^4} \right] \eta - \sigma_2 \left[ \left( \frac{RJ}{2} \right)^2 \left( \frac{\rho^2 - \lambda^2}{\rho} \right)^2 + \frac{C^2}{\rho^4} \right] \eta_o = 0 \tag{11}$$

### 2.2.1.1 Solution Process for Laminar Flow

Laminar helical flow of an Oldroyd fluid in an annulus of a given size with a rotating inner core is based on the solution to the three integral equations (3) which have three unknown parameters  $\lambda^2$ ,  $RJ/2$ , and  $C$ . A recursive process for computing the unknowns based on a Taylor series expansion (equation 5) requires the evaluation of the coefficients of the three linear equations. These coefficients (equations 6 combined with 9, 10, and 11) involve integrals across the radius of the annulus which must be integrated numerically. Simpson's 1/3 rule (Salvadori, et al 1962) is used to perform these integrations by dividing the annular radius into ten equal intervals. The initial solution obtained from the recursive process assumes no erosion has occurred and thus corresponds to an annulus with an outer radius equal to one half the borehole diameter. For the specific case of borehole erosion, once a solution to the unknowns ( $\lambda^2$ ,  $RJ/2$ , and  $C$ ) in the three integral equations in (3) is found, the shear stress in the fluid  $\tau$  at the wall can be calculated by setting  $\rho = 1$  in the equations in (4). By changing the outer radius of the hole and repeating the above process a new shear stress in the fluid at the wall can be calculated. By adjusting the outer radius appropriately the fluid shear stress can be forced to equal the repository effective shear resistance to erosion. That radius corresponds to the final eroded radius. The required outer hole radius is determined by iteration as shown in Figure 4. The derivatives required for the iteration  $\left( \frac{d\tau}{dR} \right)$  are found numerically by determining the change in shear stress for a small assumed change in outer radius R.

Based upon the preceding equations a Fortran computer code was written to perform the necessary computations for a solution to the problem of laminar helical flow in an annulus. This code was partially verified by comparing its results against those published by Savins and Wallick (1966).

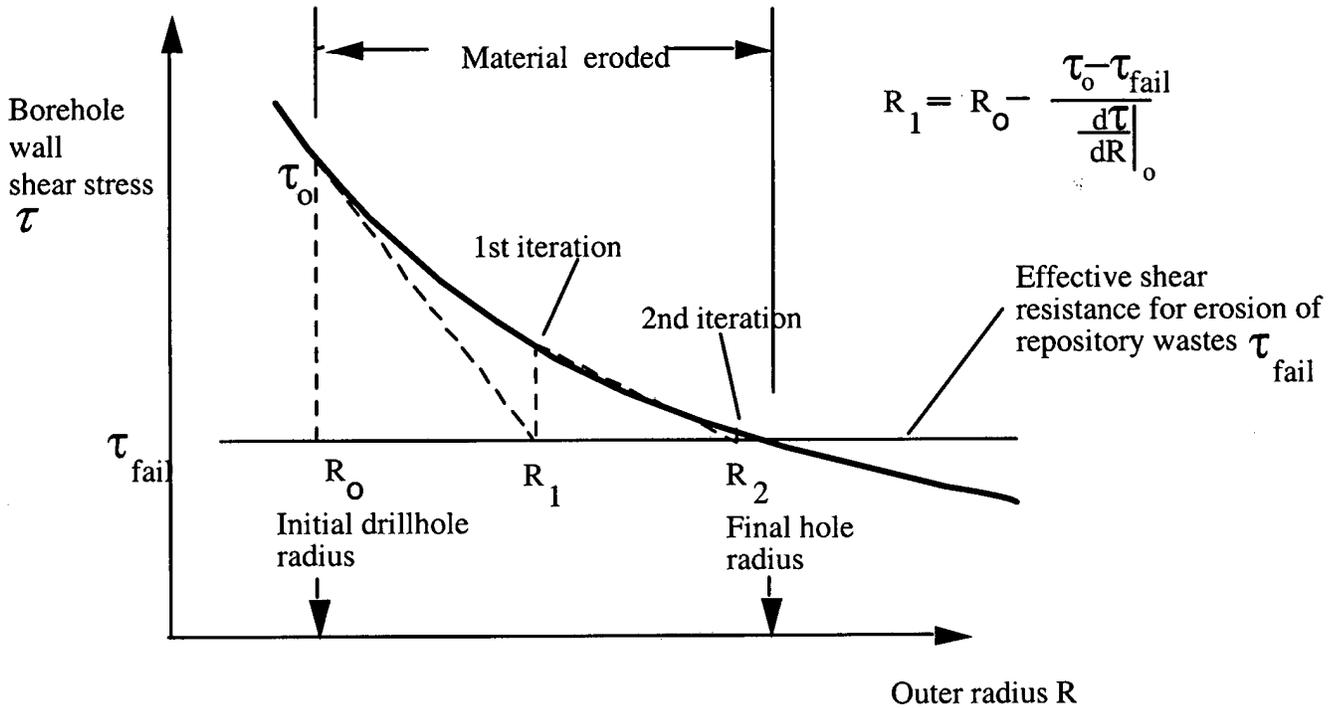


Figure 4. Iterate to find the final hole radius

The final eroded diameter is determined through an iterative process that equates the fluid shear stress adjacent to the waste to a measure of the erosion resistance of the waste. The erosion resistance is governed by the effective shear resistance to erosion, a parameter not directly related to the shear strength as normally determined for granular materials using conventional soil tests.

The effective shear resistance for erosion ( $\tau_{fail}$ ), 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.

### 2.2.2 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

$$R_e = \frac{\bar{\rho} \bar{V} D_e}{\bar{\eta}} \quad (12)$$

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)

$$R_e = \frac{0.8165 D_e \bar{V} \bar{\rho}}{\bar{\eta}} \quad (13)$$

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  $R_{ec}$  (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  $R_{ec}$  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  $R_{ec}$  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)

$$\Delta P = \frac{2 f L \bar{\rho} \bar{V}^2}{(0.8165) D_e} \quad (14)$$

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 (14) that the shear stress is related to the average fluid velocity through the relation

$$\tau = \frac{f \bar{\rho} \bar{V}^2}{2(0.8165)} \quad (15)$$

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

$$\frac{1}{\sqrt{f}} = -4 \log_{10} \left[ \frac{\epsilon}{3.72D} + \frac{1.255}{R_e \sqrt{f}} \right] \quad (16)$$

where  $\epsilon/D$  is the relative roughness. For circular pipes,  $D$  in this equation represents the inside diameter and  $\epsilon$  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  $\epsilon$  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 15 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

$$F_r = \frac{\bar{V}_{2100}}{\bar{V}}$$

where  $\bar{V}_{2100}$  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 15 then can be rewritten

$$\tau = \frac{f \bar{\rho} (F_r \bar{V})^2}{2(0.8165)} \quad (17)$$

#### 2.2.2.1 Solution process for turbulent flow

Using a relative roughness and a calculated Reynolds number based on  $\bar{V}$ , a Fanning friction factor can be determined by iteratively solving Equation (16). The value of the shear stress acting on the borehole wall can then be determined from Equation (17). 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 ( $\tau_{fail}$ ) to obtain the final eroded borehole radius (see Figure 4).

The equations governing cavings (and cuttings) based on laminar and turbulent flow form a portion of the Fortran computer code CUTTINGS\_S (see figure 1). Using appropriately selected input based on the physical properties of the waste and other drilling parameters, this section of the code calculates the final eroded diameter of the borehole that passes through the waste. In the actual solution sequence employed in the fortran code the Reynolds number is calculated first to determine which solution regime (laminar or turbulent) should first be initiated. For Reynolds numbers initially less than  $R_{ec}$  the code calculates the flow as laminar. Any increase in diameter of the borehole calculated during the laminar calculation will

cause the Reynolds number to decrease ensuring that the calculation remains laminar. If the initial Reynolds number is greater than or equal to  $R_{ec}$  the turbulent formulation is used to calculate borehole erosion. When the turbulent calculation is complete, a check is again made to determine if the Reynolds number still exceeds  $R_{ec}$ . If it does not, the laminar calculation is performed starting with a "critical" borehole radius. The critical borehole radius corresponds to a Reynolds number of  $R_{ec}$  and is given by

$$R_{crit} = \frac{\bar{\rho}Q}{1286\pi\eta_{\infty}} - R_i \tag{18}$$

### 2.3 Drilling parameters for cuttings and cavings

The drilling parameters chosen must reflect data typical of that valid near the WIPP repository. For drilling operations through salt in the Delaware basin, the drilling mud most likely to be used is a brine (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)), with the density cut somewhat with an emulsified oil. The mud density and viscosity parameters required in the laminar and turbulent regime erosion calculations can be estimated based on the assumption of the use of such a brine-based drilling mud. For the 1992 PA the drilling mud properties used were (Sandia WIPP Project 1992, Table 4.4-1):

Parameter	Median	Range	Units	Distribution Type
Density	1211	1139 - 1378	kg/m <sup>3</sup>	Constructed
Bingham Plastic				
Viscosity $\eta_p$	0.00917	0.005 - 0.03	Pa·s	Constructed
Bingham				
Yield Stress $y_p$	4	2.4 - 19.2	Pa	Constructed

The values for plastic viscosity and yield stress correspond to parameters for a Bingham plastic fluid (Darley and Grey 1988, p188) from which the Oldroyd parameters are derived.

If in equation (2) it is assumed that  $\eta_{\infty} = \eta_o \left( \frac{\sigma_2}{\sigma_1} \right) = \eta_p$  where  $\eta_p$  is the Bingham plastic viscosity, and if  $\eta_o = 2\eta_{\infty}$  (a trend based on other drilling muds (Darley and Grey 1988, p242)) the following relationship can be derived.

$$\sigma_2 = \frac{\eta_p I_t - y_p}{2I_t^2 y_p} \tag{19}$$

where  $I_t$  is the shear rate at which the Oldroyd model and Bingham model coincide (Figure 2b). This shear rate is chosen to be 1020 1/s which corresponds to a reading at 600 rpm on a direct reading viscometer (Darley and Grey 1988, p214).

For drilling through salt, the drilling speeds can vary from 40 to 220 rpm (Austin, 1983 and Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)). The most probable speed is about 70 rpm (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)).

Mud flow rates are usually selected to be from 30 to 50 gallons/minute per inch of drill bit diameter (Austin, 1983) and usually result in flow velocities in the annulus between the drill collars and the borehole wall at or near the critical flow state (laminar-turbulent transition) (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)).

The drill bit diameter is related to the total planned depth of the hole to be drilled. For gas wells in the 4000- to 10,000-foot range, it is likely that the drill bit used that passes through a waste room would have a diameter of 10.5 to 17.5 inches. The most probable drill diameter is 12.25 inches. The collar diameter is assumed to be 8 inches, a value consistent with current drilling practice in the Delaware Basin (Marquis, 1995). For the 1992 PA these parameters are presented in table 4.2-1 (Sandia WIPP Project 1992)

Parameter	Median	Range		Units	Distribution Type
Drill bit diameter	0.355	0.267	- 0.444	m	Uniform
Drill string angular velocity	7.7	4.2	- 23	rad/s	Constructed
Drilling mud flowrate	0.09935	0.0745	- 0.124	m <sup>3</sup> /(s·m)	Uniform

For turbulent flow, the shear stress acting at the borehole at the repository is dependent on the absolute surface roughness. The value chosen for the calculations exceeds that of very rough concrete or riveted steel piping (Streeter, 1958).

The amount of material eroded from the borehole wall is dependent upon the magnitude of the fluid-generated shear stress acting on the wall and the effective shear resistance to erosion of the compacted, decomposed waste. In the absence of experimental data, the effective shear resistance to erosion of the repository material is assumed to be similar to that of a ocean bay mud (Parthenaides and Passwell, 1970), or a montmorillonite clay, (Sargunam et al., 1973). These values are on the order of a fraction to several Pa.

For the 1992 PA, the roughness and shear resistance parameters were given in table 3.4-1 (Sandia WIPP Project 1992).

Parameter	Median	Range		Units	Distribution Type
Absolute roughness	0.025	0.01	- 0.04	m	Uniform
Erosion shear resistance	1	0.05	- 10	Pa	Constructed

The lower bound to erosion resistance shown above is lower than that used in the 1992 PA and is based on the availability of additional data (Parthenaides and Passwell, 1970).

The hydrostatic pressure at the repository depth resulting from 1211 kg/m<sup>3</sup> drilling mud corresponds to 7.78 MPa. In the CUTTINGS\_S code repository pressures below 8 MPa are assumed to cause surface releases from cuttings and cavings. Above 8 MPa releases are caused by spall (see figure 1).

## 2.4 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 code.

### 2.4.1 Blowout (Solids Removal)

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

Two alternative computational models are used to compute the solid waste released to the surface resulting from the sudden penetration of a pressurized WIPP panel. The models assume waste strength based on brine saturation and are self limiting ie. neither model relies on driller response. Of the two models described below, model 2 is more consistent with data obtained from experiment.

#### 2.4.1.2 Solids Removal Caused by Blowout (Model 1)

A borehole penetration of a WIPP panel saturated by decomposition gases at pressures above hydrostatic and with a waste permeability greater than  $10^{-16} \text{ m}^2$  is likely to initiate a blowout of the well. The initial flow of gas into the borehole will be restricted somewhat by the presence of drilling mud and a backpressure may develop that could be greater than hydrostatic. As the gas flows into the borehole and rises due to buoyancy, the backpressure will diminish as the weight of the mud column decreases. With a decreasing backpressure the gas flowrate into the borehole will increase. It will also increase as the result of the removal of waste material and the generation of a larger surface through which the gas can flow. Eventually the borehole will be cleared of drilling mud and the backpressure will drop to a value governed by the rate of flow of a compressible fluid in the drillstring annulus.

In the development of a bounding model for waste release due to a blowout it is important to note that the blowout process occurs over a finite time (minutes) and consequently it is not necessary to consider the high transient gas flow rates that occur from the assumption of instantaneous pressures drops. This is especially true for waste with high permeability where pressure profiles in the waste change rapidly. After these initial transients the gas flowrates out of an exposed waste surface become relatively constant for volumes comparable to a WIPP panel. It is this relative constancy of flow that allows for the development of the bounding model described below.

During blowout and after the decay of initial flow transients the gas velocity ( $V$ ) at an exposed waste surface remains relatively constant for long periods of time. If the gas velocity is great enough and there is little cohesive strength between waste grains, the waste grains at this free surface will be lofted into the flow of gas (entrained) and be carried into the borehole and to the ground surface. As the waste is removed and the exposed waste surface area increases, the resistance to flow up the borehole annulus increases causing a backpressure to develop in the evacuated volume. Consequently, the velocity of gas at this interface will decrease, eventually reaching a condition where waste is no longer entrained into the flowing gas at the waste surface. At this point an equilibrium condition will have been achieved and the volume associated with the dimensions of the exposed surface will be equal to a bounding waste release due to blowout.

The volume released is dependent on the shape of the void produced near the borehole. The shape is dependent on the waste properties and the character of the release process. A possible shape may be similar to the relatively flat ellipsoidal form shown in Figure 5.

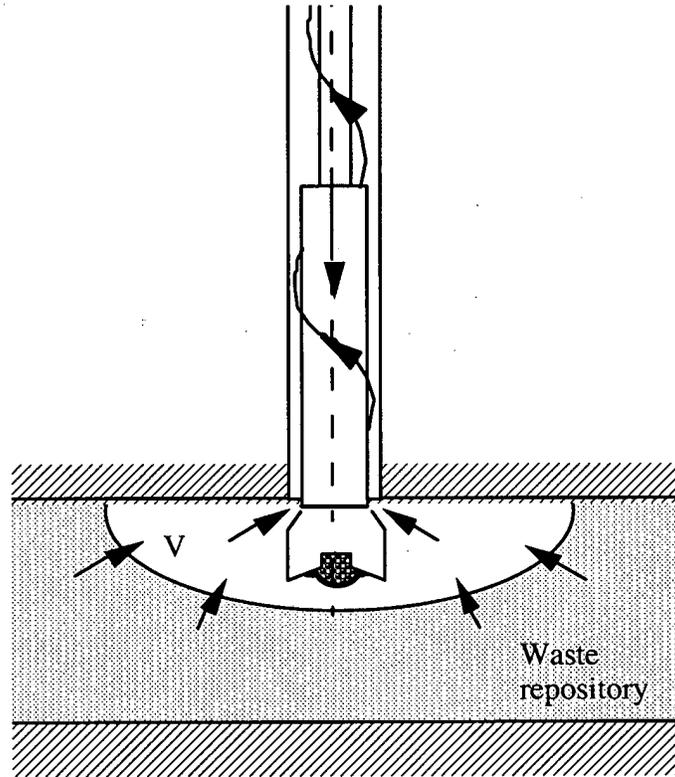


Figure 5 Potential Final Release Volume Configuration

A shape that provides a larger volume for the given exposed surface and one that is easy to calculate is the cylindrical volume shown in Figure 6.

The bounding blowout radius  $R_b$  (Figure 6) can then be written

$$R_b = \left[ \left( \frac{D_o}{2} \right)^2 - \left( \frac{D_i}{2} \right)^2 \right] \frac{M_1 c}{2 H V_e} \quad (20)$$

where

- $D_o$  and  $D_i$  are the borehole and collar diameters
- $M_1$  = the mach number for gas flow into the borehole entrance
- $c$  = the gas sound speed at the borehole entrance
- $H$  = the panel height at time of intrusion
- $V_e$  = the entrainment velocity

In this equilibrium condition the gas velocity  $V$  is equal to the entrainment velocity  $V_e$  and the solid waste volume released to the surface is

$$Volume = \pi R_b^2 H(1 - \varphi) \tag{21}$$

where  $\varphi$  is the waste porosity at the time of intrusion. For the "actual" void shape (Figure 5),  $V_e$  is the gas velocity required to loft a waste particle vertically in a gravity field. This velocity is also used in the computational model where the void shape is assumed to be cylindrical.

As with cuttings (section 2.1), since the waste is assumed to be uniformly distributed throughout the disposal region, the actual computation for release requires only the area associated with  $R_b$  and the waste curie content per unit area. The panel height at the time of intrusion is related to the original height and waste porosity, and to the porosity at the time of intrusion.

$$H = \text{Initial height} \left( \frac{1 - \text{intial porosity}}{1 - \varphi} \right)$$

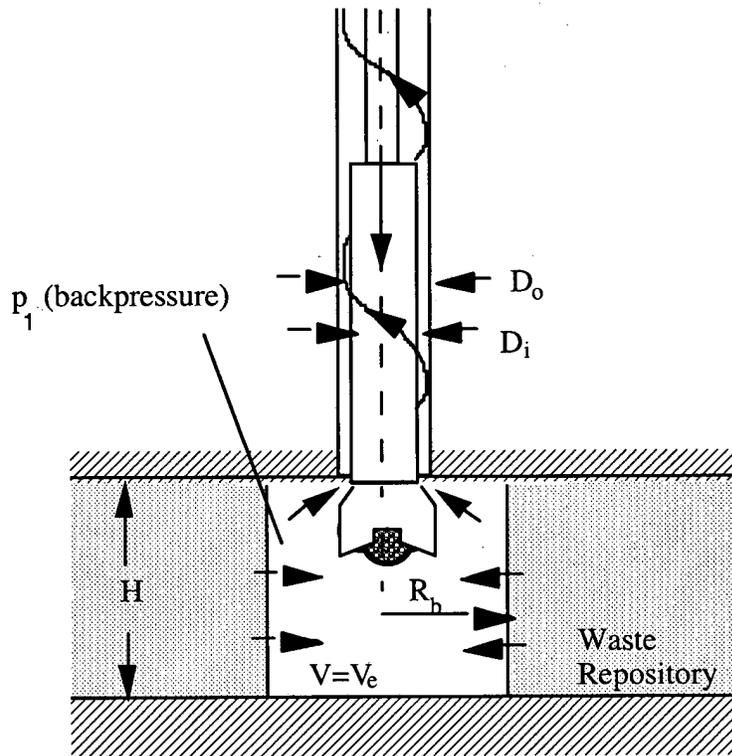


Figure 6 Idealized Cylindrical Final Volume Release Configuration

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)

$$\frac{fl}{D} = \frac{1}{KM_1^2} \left[ 1 - \frac{p_2^2}{p_1^2} \right] - 2 \ln \frac{p_1}{p_2} \quad (22)$$

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 (22) has to be solved over these two regions. The pressure ratio is based on the exit pressure at the ground surface ( $p_2 \geq$  atmospheric) and the borehole entrance pressure  $p_1$  (backpressure).

The entrainment velocity  $V_e$  is the magnitude of the gas velocity at the exposed waste surface that will cause waste particles to be removed from the surface and transported in the gas to the borehole. For a horizontal waste surface this velocity is assumed to be the terminal velocity of the particle. The terminal velocity is the speed at which a particle will fall in a motionless gas of density  $\rho_g$ . For the present model, choosing this value to represent  $V_e$  is conservative since the terminal velocity is less than the surface normal gas velocity required to vertically support the particle if the surface is inclined.

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)

$$V_e^2 = \frac{4gd(\rho_s - \rho_g)}{3C_D\rho_g} \quad (23)$$

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  $\mu$  is the gas viscosity

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

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

$$C_D = 10^{(a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6)} \quad (24)$$

where

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

and

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

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

Equations (23) and (24) are solved simultaneously using an iterative process that converges to a value of  $V_o$  that satisfies both equations.

The velocity of gas flow ( $V$ ) out of the cylindrical waste surface can be computed for various waste permeabilities and repository gas pressures using the equation

$$\frac{k}{2\mu} \nabla^2 p^2 = \phi \frac{\partial p}{\partial t} \quad (25)$$

where  $k$  is the permeability,  $\mu$  is the gas viscosity,  $\phi$  is the waste porosity,  $\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r} \frac{\partial}{\partial r}$ ,  $p$  is the gas pressure, and  $r$  is the radial coordinate. The rate is dependent on the pressure boundary condition ( $p_1$ ) (Figure 6) assumed in the evacuated volume. The gas velocity in the waste at any radius  $r$  and time  $t$  is a function of the pressure gradient

$$v(r, t) = \frac{k}{\mu} \frac{\partial p(r, t)}{\partial r} \quad (26)$$

and the gas velocity at the free surface is  $V = v(R_b, t)$  (27)

Solving equations (20), and (22-27) simultaneously and using stabilized flowrates out of the waste the bounding volumes of waste removed due to blowout can be obtained.

As observed earlier, the blowout process occurs over a finite time and the gas flowrate out of the free surface ( $r=R_b$ ) tends to stabilize and remain constant for long periods of time. The time chosen to measure this "stable" flow condition has been chosen to be 700s after penetration. This is the minimum time necessary to replace the drilling mud in the annulus volume at the maximum expected drilling mud flowrate (50 gal/minute/inch of borehole diameter). This time is a measure of the minimum time necessary to generate full blowout.

The nonlinear partial differential equation for pressure in the waste (equation 25) can only be solved using numerical approximations (this is done in a code called GASFLOW) but the resulting solution is time consuming since it must be solved many times using different boundary conditions ( $p_1$  and  $R_b$ ). This process can be simplified by analytically solving the steady state form of equation 25 and by using a set of correction factors (calculated in GASFLOW) to obtain the free surface gas velocity at 700s. The steady state form of equation 25 is

$$\nabla^2 p^2 = 0 \tag{28}$$

The general solution to equation 28 is

$$p^2 = C_1 + C_2 \ln(r)$$

where

$$C_2 = \frac{p_1^2 - p_\infty^2}{\ln \frac{R_b}{R_\infty}} \tag{29}$$

$$C_1 = p_1^2 - C_2 \ln(R_b)$$

In these equations  $R_\infty$  is assumed to be the radius of an equivalent WIPP panel (~61m) and  $p_\infty$  is the far field gas pressure (ie. the initial pressure in the panel).  
 The steady state gas velocity at the free surface is

$$V(R_b) = \frac{k}{\mu} \frac{dp(R_b)}{dr} = \frac{k}{\mu} \frac{C_2}{2R_b(C_1 + C_2 \ln R_b)^{0.5}} \tag{30}$$

Equation 30 generally gives velocities lower than those that would be calculated from equation 26 using the GASFLOW code and setting the time to 700s. To be conservative in computing waste releases, the results from equation 30 should be at least as great as the velocities computed by GASFLOW at 700s. This is accomplished by multiplying the velocity calculated by equation 30 by a factor obtained from specific GASFLOW computations. For example, assuming the repository is pressurized with hydrogen gas ( $\mu=9.3 \times 10^{-6}$  Pa-s) the following velocity ratios

$$V_R = \text{velocity ratio} = \frac{\text{Velocity from GASFLOW @ 700s}}{\text{Steadystate velocity from equation 30}} \tag{31}$$

are obtained for different radii  $R_b$  and waste permeabilities  $k$ .

let  $p_\infty = 8 \times 10^6$  Pa,  $p_1 = 1 \times 10^6$  Pa,  $\phi_0 = 0.19$ ,  $R_\infty = 61$ m,  
 then

k (m <sup>2</sup> )	velocity ratio $V_R$				$R_b=8\text{m}$ $R_b=3\text{m}$ $R_b=1\text{m}$	
	$R_b=0.3\text{m}$	$R_b=0.1\text{m}$				
$1 \times 10^{-12}$	0.558	0.734	0.836	0.897	0.92	
$1 \times 10^{-13}$	1.46	1.38	1.29	1.23	1.18	
$1 \times 10^{-14}$	2.75	2.19	1.78	1.53	1.12	
$1 \times 10^{-15}$	6.98	4.64	3.08	2.25	1.87	

1x10<sup>-16</sup> 20.5                      12.23                      6.68                      3.90                      2.79

equation 30 thus becomes

$$V(R_b) = \frac{k}{\mu} \frac{V_R C_2}{2R_b (C_1 + C_2 \ln R_b)^{0.5}} \quad (32)$$

A more complete set of tables for the velocity ratio data is shown in appendix AB. Data from these tables can be used to generate an equation for  $V_R$  as a function of the waste permeability. The fit corresponds to data values which produce the largest velocity ratio for a particular permeability. This process is conservative. See appendix AB. The resulting relationship for the velocity ratio is

$$V_R = -12593 - 5040\xi - 806.18\xi^2 - 64.455\xi^3 - 2.5771\xi^4 - 0.04125\xi^5 \quad (33)$$

where

$$\xi = \log_{10} k$$

The terminal velocity described above (equations 23 and 24) is based on no cohesive strength between waste particles. Strength can be included in the model by changing the gravity term to that of an effective acceleration of gravity.

#### 2.4.1.2.1 Effect of Strength on Solids Removal caused by Blowout

The model for solids removal during blowout is based on the lofting of particles from a horizontal surface of the waste as the result of the flow of escaping gas from the interior of the waste. Waste is lofted into the flowing gas if the velocity of the gas is equal to the terminal velocity of the waste particle. The equation for terminal velocity (equation 23) can again be written as

$$V_e^2 = \frac{4gd(\rho_s - \rho_g)}{3C_D\rho_g} \quad (34)$$

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 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  $\sigma$ . This parting stress on the particle level can be written

$$\sigma = \frac{\text{Parting force}}{\text{Particle projected area}} = \frac{mg_i}{\pi R^2} = \frac{\frac{4}{3}\pi R^3 \rho_s g_i}{\pi R^2} = \frac{4}{3}\rho_s g_i R \quad (35)$$

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

Solving equation (35) for  $g_t$  obtains

$$g_t = \frac{3 \sigma}{4 \rho_s R} \quad (36)$$

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

$$g_{eff} = (g + g_t) = g + \frac{3 \sigma}{4 \rho_s R} \quad (37)$$

This effective acceleration of gravity can be used in the equation that computes the particle terminal velocity (equation 23) thus accounting for strength. A model for computing the parting stress based on waste saturation and particle size is presented in appendix AD. Additional contributions to strength, such as from cementation between particles, can also be included in the parting stress  $\sigma$ .

#### 2.4.1.2.2 Solution Process for Solids Removal caused by Blowout (Model 1)

Utilizing Boyles Law which relates gas pressure to gas density it is possible to reduce equations 20, 22, 23, 24, and 32 to two simultaneous nonlinear equations in the unknowns  $R_b$  and the backpressure  $p_1$ . A solution process similar to that described in appendix AA was used to solve this system but it often failed to converge to the solution and was therefore considered unsuitable for use in a code where the input parameters were to vary over considerable ranges. To create a more robust solution to the system of equations, they are solved sequentially starting with equation 22.

As indicated earlier, flow in the borehole annulus is assumed to occur adjacent to both the drill collars and the drillpipe. Consequently, there are two annular areas that must be considered for flow up the borehole and equation (22) 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 22 can be divided into the two equations

$$\frac{f_{coll}}{D_{coll}} = \frac{1}{KM_1^2} \left[ 1 - \frac{p_1^2}{p_i^2} \right] - 2 \ln \frac{p_1}{p_i} \quad (38)$$

$$\frac{f_{drill}}{D_{drill}} = \frac{1}{KM_1^2 \left( \frac{p_1}{p_i} \right)^2 \left( \frac{D_{coll}}{D_{drill}} \right)^4} \left[ 1 - \frac{p_{exit}^2}{p_i^2} \right] - 2 \ln \frac{p_i}{P_{exit}} \quad (39)$$

where  $p_{exit}$  = exit pressure

$l_{drill}$  = length of drillpipe

$l_{coll}$  = collar length

$D_{coll}$ =equivalent diameter of annulus opposite collars (based on annulus area)  
 $D_{drill}$ =equivalent diameter of annulus opposite drillpipe (based on annulus area)  
 $p_i$ =intermediate pressure

Eliminating  $M_1^2$  from equations 38 and 39 results in a single nonlinear equation in the dependent variables  $p_i$  and  $p_{exit}$ .

$$F(p_i, p_{exit})=0 \quad (40)$$

A sequence of solutions to equation 40 for various backpressures  $p_1$  are obtained by systematically scanning over possible values of  $p_i$  and  $p_{exit}$  and using the additional constraint (Binder, 1958 p 64) that either  $\frac{dp}{dl}$  becomes unbounded at the pipe exit or  $p_{exit}=p_{atm}$ . Using this method results in a discrete set of  $p_1, M_1$  pairs that satisfy equations 38 and 39.

Three equations remain to be satisfied; equations 20, 23 and 32.

For each  $p_1$ , the gas density can be determined from Boyles law and the terminal velocity  $V_e$  computed from equations 23 and 24 again using an iterative process. For the corresponding mach number in the  $p_1, M_1$  pair it is now possible to compute  $R_b$  utilizing equation 20. The velocity  $V$  at the waste surface is then obtained from equation 32 using  $p_1$  and  $R_b$ . For a valid solution the waste surface velocity  $V$  must equal the terminal velocity  $V_e$ . New  $p_1, M_1$  pairs are selected sequentially until the  $V, V_e$  solutions approach equality and then linear interpolation is used for the final adjustment.

#### 2.4.1.3 Solids Removal Caused by Blowout (Model 2)

Results from steady state flow experiments through granular material in a cylindrical geometry (Lary R. Lenke, et al. 1996) indicate that a porous pattern of channels is formed adjacent to the "borehole". This channeling process does not conform to conceptual model 1 as described above. As a consequence of these experiments a new conceptual model has been defined (model 2) which more closely corresponds to the physical processes that appear to be occurring. The new conceptual model is described below.

Conceptual model 2 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 7). 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.

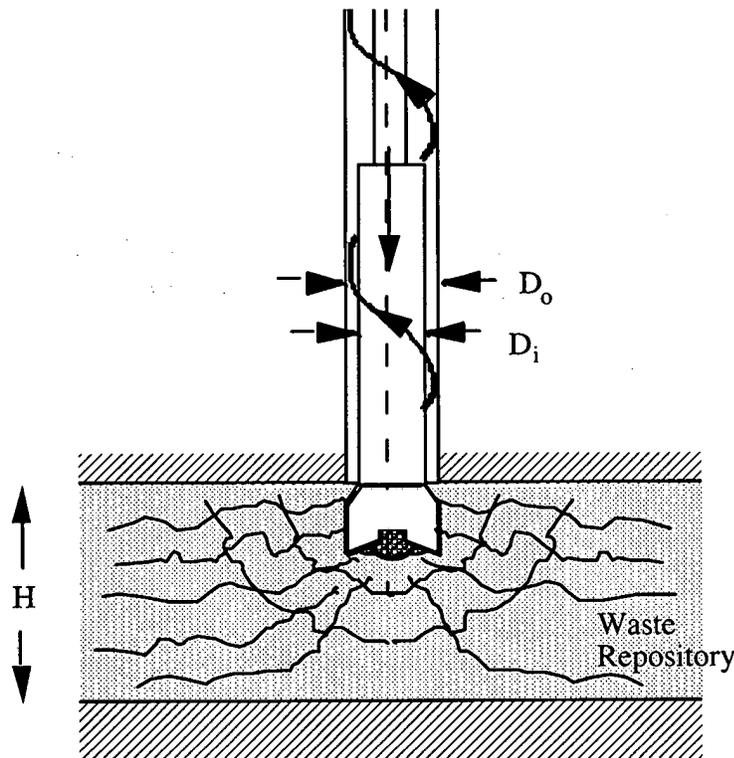


Figure 7 Fractured Waste Matrix after Penetration

#### 2.4.1.3.1 Computation of Release Volume (Model 2)

Since the gas pressure is assumed to be constant throughout the fractured, porous matrix, conservation of mass flow requires (Figure 8)

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

or

$$V = \frac{A_{\text{borehole}} V_{\text{borehole}}}{2\pi rH} \quad (41)$$

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  $A_{\text{borehole}}$  and the average gas velocity up the borehole annulus is denoted  $V_{\text{borehole}}$ .

The local gas velocity within the fractures (Figure 8) can be written as  $v = \frac{V}{\phi_f}$  where  $\phi_f$  is the fracture porosity. Thus the fracture porosity associated the erosion fracture velocity  $v_e$  is

$$\phi_{fe} = \frac{V}{v_e} = \frac{A_{\text{borehole}} V_{\text{borehole}}}{2\pi rH v_e} \quad (42)$$

The solid volume eroded from the fractures is

$$V_{ol} = 2\pi H(1 - \phi) \int_0^{r_o} \phi_{fe} r dr = \frac{A_{\text{borehole}} V_{\text{borehole}}}{v_e} (1 - \phi) \int_0^{r_o} dr \quad (43)$$

or

$$V_{ol} = \frac{A_{\text{borehole}} V_{\text{borehole}} r_o}{v_e} (1 - \phi) \quad (44)$$

where  $\phi$  is the matrix porosity at the time of intrusion

Equation (44) 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.

#### 2.4.1.3.2 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.

Equations 23 and 37 relate the gas velocity required to loft a waste particle to the weight of the particle and to the tensile strength required to separate two particles that are bonded by pore water and cementation. The resulting equation

$$v_e^2 = \frac{4g_{\text{eff}}d(\rho_s - \rho_g)}{3C_D\rho_g} \quad \text{depends on an effective gravity term}$$

$$g_{eff} = (g + g_t) = g + \frac{3 \sigma}{4 \rho_s R} = g + \frac{3 \sigma_p}{4 \rho_s R} + \frac{3 \sigma_c}{4 \rho_s R}$$
 where the parting stress (equation

37) is assumed to have contributions resulting from pore water  $\sigma_p$  and intergranular cementation  $\sigma_c$ . 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

$$g_{eff} = g F_{ge} + \frac{3 \sigma_p}{4 \rho_s R} F_{se} + \frac{3 \sigma_c}{4 \rho_s R} F_{ce} \quad (45)$$

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. 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 24) an iterative solution process is used to converge to a solution for  $v_e$ .

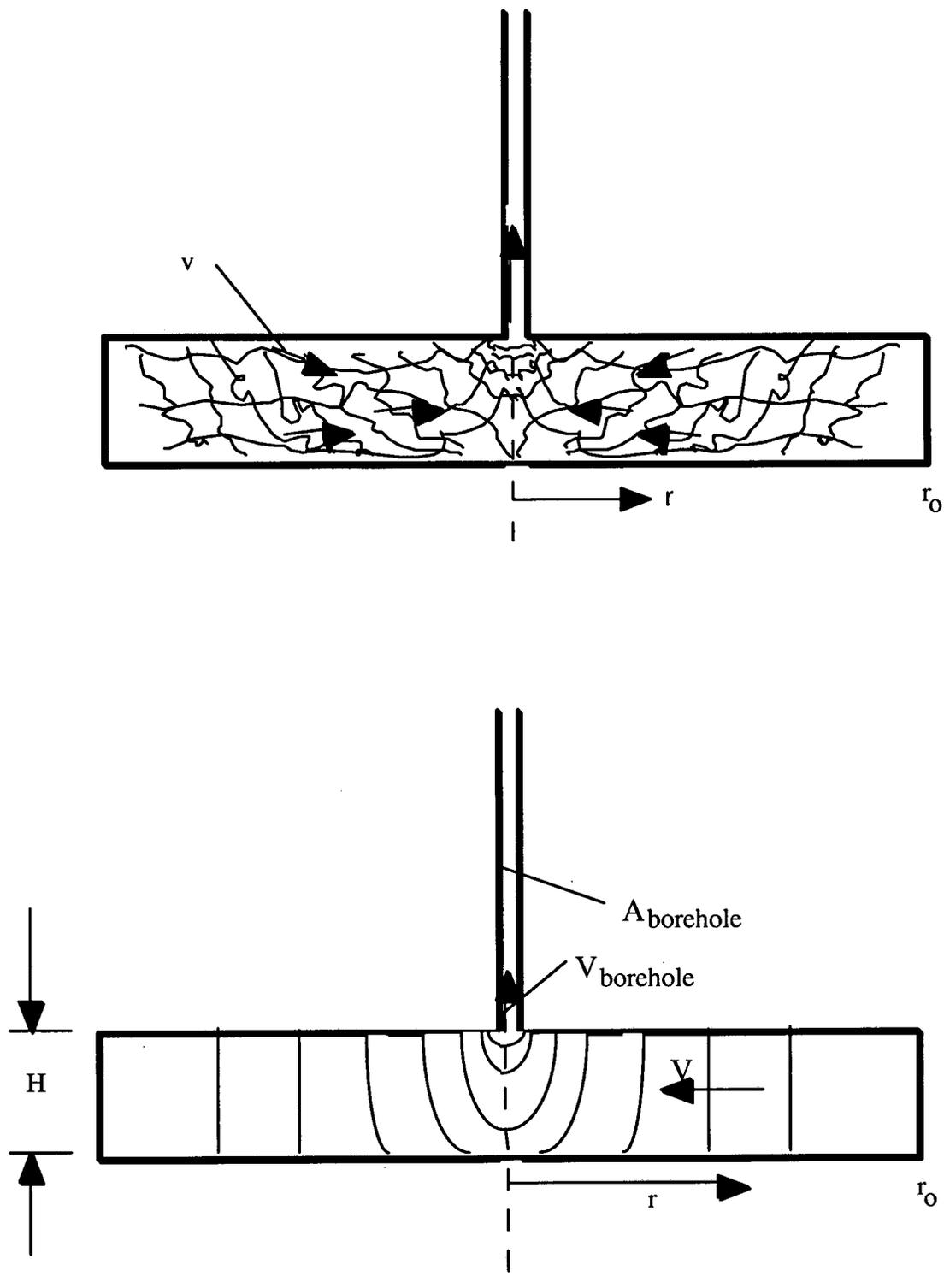


Figure 8 Flow Model

Information Only

2.4.1.3.3 Solution Process for Solids Removal caused by Blowout (Model 2)

The solution to equation 44 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 determined by the annulus area or (Figure 7)

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

To determine  $V_{borehole}$  requires the solution of equation 22. As indicated earlier, flow in the borehole annulus is assumed to occur adjacent to both the drill collars and the drillpipe. Consequently, there are two annular areas that must be considered for flow up the borehole and equation (22) 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 22 can be divided into the two equations

$$\frac{f_{coll}}{D_{coll}} = \frac{1}{KM_I^2} \left[ 1 - \frac{p_i^2}{p_I^2} \right] - 2 \ln \frac{p_I}{p_i} \tag{46}$$

$$\frac{f_{drill}}{D_{drill}} = \frac{1}{KM_I^2 \left( \frac{p_I}{p_i} \right)^2 \left( \frac{D_{coll}}{D_{drill}} \right)^4} \left[ 1 - \frac{p_{exit}^2}{p_i^2} \right] - 2 \ln \frac{p_i}{p_{exit}} \tag{47}$$

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
- $M_I$  = inlet Mach number

In addition to equations 46 and 47 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 (appendix AA) is 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)

#### 2.4.1.3.4 Determination of the factors $F_{go}$ and $F_{so}$

The gravity effectiveness factor  $F_{go}$  and the stress effectiveness factors  $F_{so}$  and  $F_{co}$  are required in equation (45) to compute an effective gravity term for use in model 2 ( Section 2.4.1.3.1). Laboratory scale blowout experiments (SNL Contract AL 7022) have been performed which produce data on the volume of material ejected under various conditions of borehole diameter, gas pressure, waste particle size, etc. For arbitrarily selected values of the parameters  $F_{go}$ ,  $F_{so}$  and  $F_{co}$  various degrees of fit to the data can be achieved. This process is conducted within the CUTTINGS\_S code prior to performing any predictions of full scale response. In the present analysis a best fit is achieved when the sum of the squares of the differences in computed volumes and experimental volumes is a minimum for all data points.

Defining the error as  $E$

$$E = \sum_i^n [V_{ei} - V_{mi}(F_{se}, F_{ge}, F_{ce})]^2 \tag{48}$$

where  $V_{ei}$  is the volume of waste simulant ejected in experiment  $i$   
 $V_{mi}(F_{se}, F_{ge}, F_{ce})$  is the computed volume of waste simulant ejected (calculated by CUTTINGS\_S computer code)  
 $n$  is the number of experiments

A best fit is achieved when  $F_{go}$ ,  $F_{so}$ , and  $F_{co}$  are chosen such that  $E$  is a minimum.

For the set of  $n$  data points the computations defined by equation (48) are made within a module of the CUTTINGS\_S computer code by scanning over a range of possible values of  $F_{go}$ ,  $F_{so}$ , and  $F_{co}$ .

#### 2.4.2 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

$$V_S = 0.05QD_oT \quad (49)$$

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<sup>3</sup> of solid waste.

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.

#### 2.4.3 Gas Erosion

This again 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 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 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 spillings to add up to the assumed 5 percent limit. For low penetration rates the cuttings percentage will be small and the spillings 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 be readily computed based on available drilling parameters utilizing the following equation.

$$V_s = [0.05QD_o - \pi(D_o^2/4.)R_p]\Delta/R_p \quad (50)$$

where

- $V_s$  = Solid waste volume brought to ground surface
- $Q$  = Drilling mud flow rate/drillbit diameter
- $D_o$  = Drill bit diameter
- $R_p$  = Penetration rate
- $\Delta$  = 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<sup>3</sup>.

### 3.0 Radionuclide Chains and Decay

The radionuclide inventory contained in the waste decays with time and follows several decay pathways or chains until stable elements are attained. The number of atoms of each radioactive waste constituent thus varies with time and the activity of waste brought to the surface as the result of human intrusion must account for the initial radionuclide inventory, the decay pathways, the mass of waste released, and the time of intrusion.

The radioactive decay of a chain of radionuclides is governed by the Bateman equations and is described in Kaplan, 1962.

Consider a chain of n radionuclides where  $N_1, N_2, N_3, N_d, \dots, N_n$  represent the number of atoms of each of the radionuclides in the repository and where  $N_n$  is stable. The differential equations that govern the decay and growth are

$$\begin{aligned} \frac{dN_1}{dt} &= -\lambda_1 N_1 \\ \frac{dN_2}{dt} &= \lambda_1 N_1 - \lambda_2 N_2 \\ \frac{dN_3}{dt} &= \lambda_2 N_2 - \lambda_3 N_3 \\ &\dots\dots\dots \\ &\dots\dots\dots \end{aligned} \quad (51)$$

$$\frac{dN_n}{dt} = \lambda_{n-1}N_{n-1}$$

It will be assumed that the initial number of atoms of radionuclide 1 in the repository is  $N_1^0$  and the initial number of atoms of the daughter atoms are  $N_2^0, N_3^0, N_4^0, \dots, N_n^0$ . The disintegration constants are  $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \dots, \lambda_{n-1}$ . The half lives of the radionuclides are related to the disintegration constants through the relation,  $t_{\frac{1}{2}} = \text{half life} = \frac{\ln 2}{\lambda}$ . Solving the differential equations (7) sequentially

obtains 
$$N_n = \sum_{j=1}^n N_j^0 \prod_{i=j}^{n-1} \lambda_i \sum_{i=j}^n \left( \prod_{l=j+1}^n \frac{1}{\lambda_l - \lambda_i} \right) e^{-\lambda_i t} \quad (52)$$

where t is the decay time at the time of intrusion.

Additional details of this derivation are shown in Appendix AC.

The activity (in curies) of each radionuclide is related to the number of atoms through the relation (Sandia

WIPP Project. 1992, Table 15) 
$$A_i = \frac{1.128 \times 10^{16} N_i}{t_{\frac{1}{2}} M_i} \quad \text{where } M_i \text{ is the gram molecular weight}$$

of the ith radionuclide. The activity in curies of the ith radionuclide released to the surface resulting from a human intrusion ( $a_i$ ) is determined by multiplying the repository activity  $A_i$  by the percent of waste removed or

$$a_i = A_i \left( \frac{\text{Volume Released}}{\text{Repository Volume}} \right) = A_i \left( \frac{\text{Projected Area Removed}}{\text{Repository Area}} \right)$$

### Appendix AA

Recursive process for solving a system of non-linear equations (Salvadori, et al 1962)

Given a system of non-linear equations (in our case 3 equations) in the unknowns x,y,z of the form

$$\begin{aligned} F_1(x, y, z) &= 0 \\ F_2(x, y, z) &= 0 \\ F_3(x, y, z) &= 0 \end{aligned} \quad (A1)$$

A recursive solution procedure can be developed by expanding the equations in Taylor series about an initial guess  $(x_0, y_0, z_0)$  for the solution.

$$\begin{aligned}
 F_1(x, y, z) &= F_1(x_0, y_0, z_0) + \frac{\partial F_1(x_0, y_0, z_0)}{\partial x}(x - x_0) + \frac{\partial F_1(x_0, y_0, z_0)}{\partial y}(y - y_0) + \frac{\partial F_1(x_0, y_0, z_0)}{\partial z}(z - z_0) + \dots = 0 \\
 F_2(x, y, z) &= F_2(x_0, y_0, z_0) + \frac{\partial F_2(x_0, y_0, z_0)}{\partial x}(x - x_0) + \frac{\partial F_2(x_0, y_0, z_0)}{\partial y}(y - y_0) + \frac{\partial F_2(x_0, y_0, z_0)}{\partial z}(z - z_0) + \dots = 0 \\
 F_3(x, y, z) &= F_3(x_0, y_0, z_0) + \frac{\partial F_3(x_0, y_0, z_0)}{\partial x}(x - x_0) + \frac{\partial F_3(x_0, y_0, z_0)}{\partial y}(y - y_0) + \frac{\partial F_3(x_0, y_0, z_0)}{\partial z}(z - z_0) + \dots = 0
 \end{aligned}
 \tag{A2}$$

Retaining only the linear terms of the Taylor series and defining

$$\begin{aligned}
 \delta x &= x - x_0 \\
 \delta y &= y - y_0 \\
 \delta z &= z - z_0
 \end{aligned}
 \tag{A3}$$

three linear simultaneous equations result

$$\begin{aligned}
 \frac{\partial F_1(x_0, y_0, z_0)}{\partial x} \delta x + \frac{\partial F_1(x_0, y_0, z_0)}{\partial y} \delta y + \frac{\partial F_1(x_0, y_0, z_0)}{\partial z} \delta z + F_1(x_0, y_0, z_0) &= 0 \\
 \frac{\partial F_2(x_0, y_0, z_0)}{\partial x} \delta x + \frac{\partial F_2(x_0, y_0, z_0)}{\partial y} \delta y + \frac{\partial F_2(x_0, y_0, z_0)}{\partial z} \delta z + F_2(x_0, y_0, z_0) &= 0 \\
 \frac{\partial F_3(x_0, y_0, z_0)}{\partial x} \delta x + \frac{\partial F_3(x_0, y_0, z_0)}{\partial y} \delta y + \frac{\partial F_3(x_0, y_0, z_0)}{\partial z} \delta z + F_3(x_0, y_0, z_0) &= 0
 \end{aligned}
 \tag{A4}$$

Based on an initial trial solution  $(x_0, y_0, z_0)$  sufficiently "close" to the actual solution, the three linear equations (A4) can be solved for the increments  $\delta x$ ,  $\delta y$ , and  $\delta z$  and new values for  $x$ ,  $y$ , and  $z$  can be determined from equations (A3). This process can be repeated until  $|\delta x|$ ,  $|\delta y|$ , and  $|\delta z|$  are less than a specified limit.

#### Appendix AB Velocity ratio factors

Calculation of blowout releases using the model of section 2.4.1 requires the value of the gas velocity escaping from a cylindrical waste surface 700s after the drill bit has breached the repository. Since the solution process for the final blowout radius is iterative, the required gas velocity has to be determined many times using a large number of blowout radii. Although this velocity can be computed using the finite difference code GASFLOW, the code is slow and the total computation time necessary would be prohibitive. Therefore rather than using the results of the GASFLOW directly in the computational model a corrected steady state model is used which can be solved quickly in closed form. To calculate conservative blowout releases the steady state model should generate releases at least as great as those that would be predicted using the computationally intensive GASFLOW code. The correction factors

required for this are determined by running both GASFLOW and the steady state model over a range of boundary and initial conditions and by computing the velocity ratios given by

$$V_R = \text{velocity ratio} = \frac{\text{Velocity from GASFLOW @ 700s}}{\text{Steadystate velocity from equation 28}}$$

Tabulated values for  $V_R$  are given below for a number of cases which cover a wide variable range. By choosing the largest  $V_R$  value for a given permeability (indicated in each table) a fit to the data using permeability as the independent variable can be made.

$k=10^{-16}m^2$	$p_{\infty}=8 \text{ MPa}$ $p_1=1\text{Mpa}$			$p_{\infty}=15 \text{ MPa}$ $p_1=1\text{Mpa}$		
	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$
$R_b$ (m)						
0.1	2.41	2.79	3.04	2.17	2.47	2.68
0.3	3.20	3.90	4.40	2.76	3.30	3.69
1.0	5.09	6.68	7.87	4.13	5.31	6.2
3.0	8.82	12.23	14.8	6.81	9.32	11.2
8.0	14.4	20.5	25.1	10.8	15.3	18.7
13.0	17.4	24.9	30.6	12.9	18.5	22.7
20.0	19.0	27.4	33.7	14.1	20.3	24.9

$k=10^{-15}m^2$	$p_{\infty}=8 \text{ MPa}$ $p_1=1\text{Mpa}$			$p_{\infty}=15 \text{ MPa}$ $p_1=1\text{Mpa}$		
	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$
$R_b$ (m)						
0.1	1.69	1.87	1.99	1.56	1.71	1.82
0.3	1.96	2.25	2.45	1.76	2.00	2.16
1.0	2.52	3.08	3.48	2.17	2.6	2.91
3.0	3.55	4.64	5.46	2.89	3.71	4.31
8.0	5.07	6.98	8.42	3.94	5.35	6.41
13.0	5.86	8.21	9.99	4.47	6.21	7.51
20.0	6.25	8.85	10.8	4.71	6.62	8.07

$k=10^{-14}m^2$	$p_{\infty}=8 \text{ MPa}$ $p_1=1\text{Mpa}$			$p_{\infty}=15 \text{ MPa}$ $p_1=1\text{Mpa}$		
	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$	$\phi = 0.09$	$\phi = 0.19$	$\phi = 0.29$
$R_b$ (m)						
0.1	1.29	1.12	1.46	1.21	1.3	1.36
0.3	1.38	1.53	1.63	1.28	1.40	1.49
1.0	1.54	1.78	1.94	1.40	1.58	1.70
3.0	1.80	2.19	2.47	1.56	1.85	2.07
8.0	2.13	2.75	3.22	1.77	2.22	2.57
13.0	2.28	3.03	3.60	1.86	2.39	2.80
20.0	2.3	3.12	3.74	1.87	2.42	2.87

k=10 <sup>-13</sup> m <sup>2</sup>	p <sub>∞</sub> =8 MPa p <sub>1</sub> =1Mpa			p <sub>∞</sub> =15 MPa p <sub>1</sub> =1Mpa		
	R <sub>b</sub> (m)	φ = 0.09	φ = 0.19	φ = 0.29	φ = 0.09	φ = 0.19
0.1	1.17	1.18	1.19	1.11	1.18	1.19
0.3	1.20	1.23	1.24	1.12	1.20	1.22
1.0	1.22	1.29	1.32	1.11	1.24	1.28
3.0	1.25	1.38	1.44	1.09	1.28	1.35
8.0	1.24	1.46	1.58	1.00	1.28	1.41
13.0	1.18	1.48	1.63	0.881	1.23	1.40
20.0	1.03	1.40	1.60	0.677	1.09	1.31

k=10 <sup>-12</sup> m <sup>2</sup>	p <sub>∞</sub> =8 MPa p <sub>1</sub> =1Mpa			p <sub>∞</sub> =15 MPa p <sub>1</sub> =1Mpa		
	R <sub>b</sub> (m)	φ = 0.09	φ = 0.19	φ = 0.29	φ = 0.09	φ = 0.19
0.1	0.692	0.929	1.03	0.460	0.735	0.872
0.3	0.631	0.897	1.01	0.394	0.678	0.831
1.0	0.537	0.836	0.980	0.305	0.587	0.758
3.0	0.414	0.734	0.911	0.208	0.464	0.645
8.0	0.257	0.558	0.762	0.111	0.301	0.467
13.0	0.164	0.416	0.617	0.0646	0.200	0.337
20.0	0.0816	0.253	0.419	0.0292	0.106	0.198

The values of V<sub>R</sub> and permeability k are thus

V <sub>R</sub>	k
33.7	10 <sup>-16</sup>
10.8	10 <sup>-15</sup>
3.74	10 <sup>-14</sup>
1.63	10 <sup>-13</sup>
1.03	10 <sup>-12</sup>

These can be fit with the function

$$V_R = -12593 - 5040\xi - 806.18\xi^2 - 64.455\xi^3 - 2.5771\xi^4 - 0.04125\xi^5$$

where

$$\xi = \log_{10} k$$

### Appendix AC

#### Solution of the Bateman Equations

Consider a chain of n radionuclides where N<sub>1</sub>, N<sub>2</sub>, N<sub>3</sub>, N<sub>d</sub> .....N<sub>n</sub> represent the number of atoms of each of the radionuclides in the repository and where N<sub>n</sub> is stable. The differential equations that govern the decay and growth are

$$\begin{aligned} \frac{dN_1}{dt} &= -\lambda_1 N_1 \\ \frac{dN_2}{dt} &= \lambda_1 N_1 - \lambda_2 N_2 \\ \frac{dN_3}{dt} &= \lambda_2 N_2 - \lambda_3 N_3 \\ &\dots\dots\dots \\ \frac{dN_n}{dt} &= \lambda_{n-1} N_{n-1} \end{aligned} \tag{C1}$$

The initial number of atoms of radionuclide 1 in the repository is  $N_1^0$  and the initial number of atoms of the daughter atoms are  $N_2^0, N_3^0, N_4^0 \dots\dots\dots N_n^0$ . The disintegration constants are  $\lambda_1, \lambda_2, \lambda_3, \lambda_4 \dots\dots\dots \lambda_{n-1}$ . The half lives of the radionuclides are related to the disintegration constants through the relation,  $t_{1/2} = \text{half life} = \frac{\ln 2}{\lambda}$ .

The Laplace transform of  $N_i$  and  $\frac{dN_i}{dt}$  will be defined by the notation (Hildebrand, 1962)

$$\begin{aligned} L\{N_i\} &= f_i(s) \text{ and} \\ L\left\{\frac{dN_i}{dt}\right\} &= sf_i(s) - N_i^0 \end{aligned}$$

Taking the Laplace transform of both sides of equations C1 results in

$$\begin{aligned} sf_1(s) - N_1^0 &= -\lambda_1 f_1(s) \\ sf_2(s) - N_2^0 &= \lambda_1 f_1(s) - \lambda_2 f_2(s) \\ sf_3(s) - N_3^0 &= \lambda_2 f_2(s) - \lambda_3 f_3(s) \\ &\dots\dots\dots \\ &\dots\dots\dots \\ sf_n(s) - N_n^0 &= \lambda_{n-1} f_{n-1}(s) \end{aligned} \tag{C2}$$

or solving for  $f_1(s) \dots\dots\dots f_n(s)$

$$\begin{aligned}
 f_1(s) &= \frac{N_1^0}{s + \lambda_1} \\
 f_2(s) &= \frac{N_2^0 + \lambda_1 f_1(s)}{s + \lambda_2} = \frac{N_2^0}{s + \lambda_2} + \frac{\lambda_1 N_1^0}{(s + \lambda_1)(s + \lambda_2)} \\
 f_3(s) &= \frac{N_3^0 + \lambda_2 f_2(s)}{s + \lambda_3} = \frac{N_3^0}{s + \lambda_3} + \frac{\lambda_2 N_2^0}{(s + \lambda_2)(s + \lambda_3)} + \frac{\lambda_2 \lambda_1 N_1^0}{(s + \lambda_1)(s + \lambda_2)(s + \lambda_3)} \\
 &\dots\dots\dots \\
 &\dots\dots\dots
 \end{aligned}
 \tag{C3}$$

$$\begin{aligned}
 f_n(s) &= \frac{N_n^0}{s + \lambda_n} + \frac{\lambda_{n-1} N_{n-1}^0}{(s + \lambda_n)(s + \lambda_{n-1})} + \frac{\lambda_{n-1} \lambda_{n-2} N_{n-2}^0}{(s + \lambda_n)(s + \lambda_{n-1})(s + \lambda_{n-2})} + \dots \\
 &\quad + \frac{\lambda_{n-1} \lambda_{n-2} \dots \lambda_1 N_1^0}{(s + \lambda_n)(s + \lambda_{n-1}) \dots (s + \lambda_1)}
 \end{aligned}$$

The terms of equations (C3) can be rewritten in terms of partial fractions as

$$\begin{aligned}
 f_1(s) &= \frac{N_1^0}{s + \lambda_1} \\
 f_2(s) &= \frac{N_2^0}{s + \lambda_2} + \frac{\lambda_1 N_1^0}{(s + \lambda_1)(\lambda_2 - \lambda_1)} + \frac{\lambda_1 N_1^0}{(s + \lambda_2)(\lambda_1 - \lambda_2)} \\
 f_3(s) &= \frac{N_3^0}{s + \lambda_3} + \frac{\lambda_2 N_2^0}{(s + \lambda_2)(\lambda_3 - \lambda_2)} + \frac{\lambda_2 N_2^0}{(s + \lambda_3)(\lambda_2 - \lambda_3)} + \\
 &\quad + \frac{\lambda_1 \lambda_2 N_1^0}{(s + \lambda_1)(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{\lambda_1 \lambda_2 N_1^0}{(s + \lambda_2)(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} \\
 &\quad + \frac{\lambda_1 \lambda_2 N_1^0}{(s + \lambda_3)(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)} \\
 &\dots\dots\dots \\
 &\dots\dots\dots
 \end{aligned}
 \tag{C4}$$

$$f_n(s) = \sum_{j=1}^n \frac{N_j}{(s + \lambda_n)^{n-1}} \prod_{i=j}^{n-1} \left( \frac{\lambda_i}{s + \lambda_i} \right)$$

Inverting equations (C4) back into the time domain obtains

$$N_1 = N_1^0 e^{-\lambda_1 t}$$

$$N_2 = N_2^0 e^{-\lambda_1 t} + \lambda_1 N_1^0 \left[ \frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)} \right]$$

$$N_3 = N_3^0 e^{-\lambda_1 t} + \lambda_2 N_2^0 \left[ \frac{e^{-\lambda_2 t}}{(\lambda_3 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_2 - \lambda_3)} \right] \\ + \lambda_1 \lambda_2 N_1^0 \left[ \frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)} \right]$$

.....  
 .....

$$N_n = \sum_{j=1}^n N_j^0 \prod_{i=j}^{n-1} \lambda_i \sum_{i=j}^n \left( \prod_{l=j+1}^n \frac{1}{\lambda_l - \lambda_i} \right) e^{-\lambda_i t}$$

Appendix AD  
 Parting Stress Based on Pore Water

Consider two spherical particles in contact with a small volume of liquid surrounding the point of contact (Figure D1). Assume that the surface tension is  $T$  and the pressure within the liquid is  $P_c$  and outside the liquid is  $P_o$ . For static equilibrium of a small element of the liquid surface

$$(P_c - P_o)ds' ds'' + 2T \sin\left(\frac{d\theta'}{2}\right) ds'' - 2T \sin\left(\frac{d\theta''}{2}\right) ds' = 0 \quad (D1)$$

or

$$(P_c - P_o)ds' ds'' + 2T\left(\frac{d\theta'}{2}\right) ds'' - 2T\left(\frac{d\theta''}{2}\right) ds' = 0 \quad (D2)$$

thus

$$(P_c - P_o)ds' ds'' + Td\theta' ds'' - Td\theta'' ds' = 0 \quad (D3)$$

but

$$ds' = r' d\theta' \quad \text{and} \quad ds'' = r'' d\theta''$$

Therefore

$$P_c - P_o = T\left(\frac{1}{r''} - \frac{1}{r'}\right) \quad (D4)$$

The quantity  $P_c - P_o$  represents the capillary pressure in the liquid volume. To physically separate the two spherical particles requires a force  $F$

$$F = 2\pi r'' T - (P_c - P_o)\pi r''^2 \quad (D5)$$

The parting stress is based on the projected area of a particle and the force  $F$ . It can be written

$$\sigma_p = \frac{F}{\pi R^2} = \frac{2\pi r'' T - (P_c - P_o)\pi r''^2}{\pi R^2} = \frac{2r'' T - T\left(\frac{1}{r''} - \frac{1}{r'}\right)r''^2}{R^2} \quad (D6)$$

where from geometry (Figure D2)

$$r'' = -r' + \sqrt{r'^2 + 2r'R} \quad (D7)$$

The above analysis assumes that only one fluid contact point is involved in the determination of the parting stress. For more densely packed material as many as three fluid contact points should be considered resulting in a greater stress. However to be conservative only one fluid contact point is assumed.

Waste Saturation

The volume of liquid associated with each particle contact is

$$V_w = 2\pi w^2 h - 2V_R - V_c \quad (D8)$$

Where  $V_R$  is the volume associated with a portion of the particle formed by a plane passing through the particle a distance  $h$  from the particle surface, and  $V_c$  is the toroidal volume defined by an area  $A$  rotated around axis  $a'$ . The area of the latter is delineated by the straight line  $2h$  and a portion of the circle of radius  $r'$  (Figure D3).

$$V_R = \frac{1}{3} \pi h^2 (3R - h) \quad (D9)$$

$$V_c = 2\pi A \left[ r'' + r' - \frac{2r'}{3} \left( \frac{\sin^3 \theta}{\theta - \sin \theta \cos \theta} \right) \right] \quad (D10)$$

where

$$A = \frac{r'^2}{2} (2\theta - \sin 2\theta) \quad (D11)$$

The liquid saturation is defined as the ratio of the liquid volume to the total void volume in a sample of material. Void volume is a function of particle shape, particle size distribution, and packing density. For spherical particles of a single diameter the maximum percent voids (void ratio) is 37.5% (Katz; HS, et al 1978). The number of single size particles ( $N$ ) within a volume ( $V$ ) of material at maximum packing density is

$$N = \frac{(1 - 0.375)V}{\frac{4}{3} \pi R^3} \quad (D12)$$

Within the volume  $V$  each particle is in contact with 12 surrounding particles. Thus the volume of liquid associated with  $N$  particles is

$$V_{wt} = 6 V_w N \quad (D13)$$

And the saturation ( $S$ ) is

$$S = \frac{V_{wf}}{0.375V} \quad (D14)$$

or

$$S = 2.39 \frac{V_w}{R^3} \quad (D15)$$

For a known saturation S and particle radius R it is possible to back solve for r' and the parting stress  $\sigma_p$ . This must be done numerically because of the complexity of the governing equations. Using equation (D8) and (D15) a variable Q can be defined thus

$$Q = V_w - \frac{SR^3}{2.39} = 2\pi w^2 h - 2V_R - V_c - \frac{SR^3}{2.39} = 0 \quad (D16)$$

The iterative numerical procedure used to determine the value of r' that satisfies equation (D16) is illustrated in Figure D4. The value of r' from the solution of equation (D16) can then be used to determine the parting stress using equations (D6) and (D7). The parting stress can then be used to compute the effective acceleration of gravity utilizing equation (37a).

Strength effects arising from moisture content of the waste can thus be included in the blowout model utilizing the waste saturation at the time of intrusion and the assumed waste particle radius. The waste particle radius is an unknown quantity which will have to be sampled.

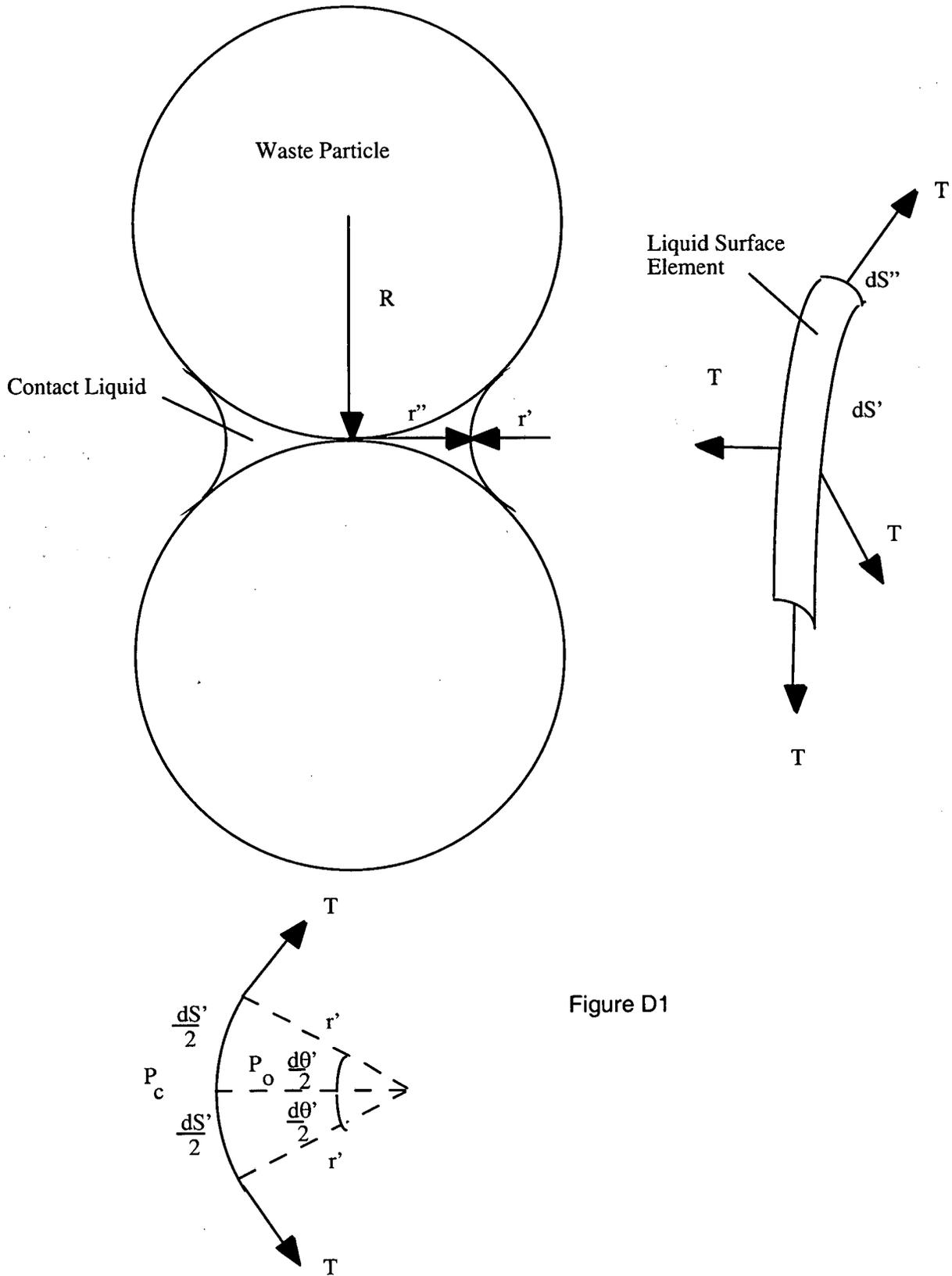


Figure D1

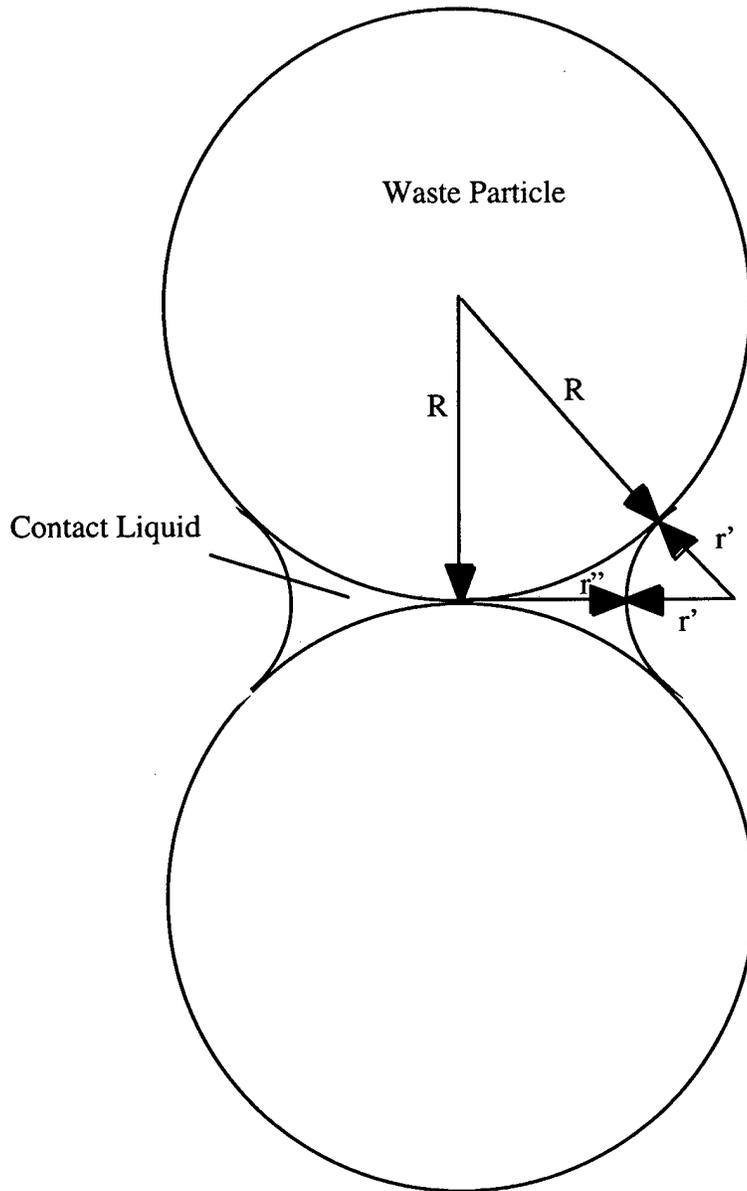


Figure D2

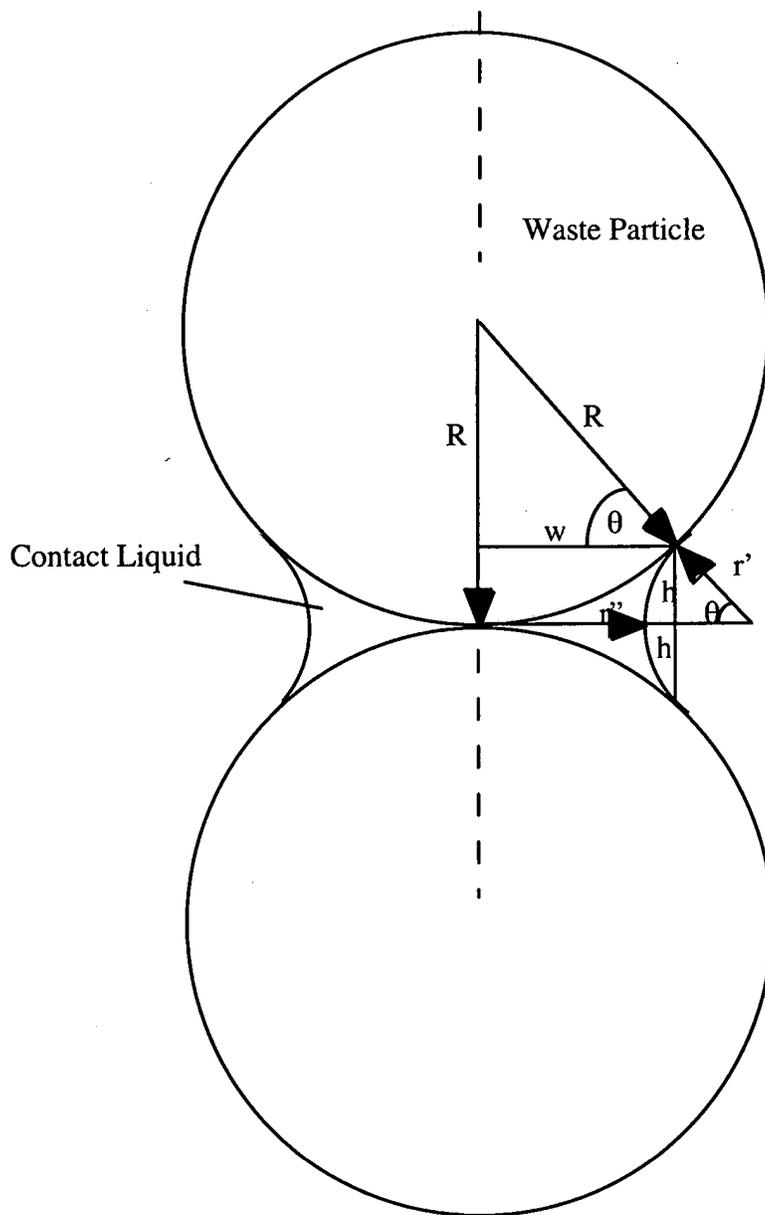


Figure D3

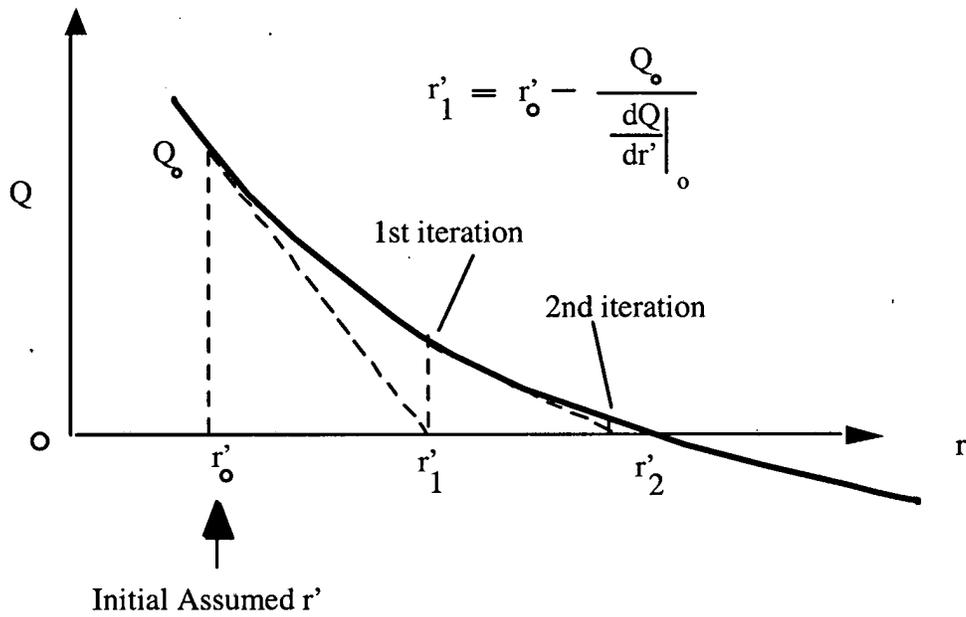


Figure D4

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Information Only

## APPENDIX B: SAMPLES OF INPUT FILES REQUIRED TO RUN GENMESH, MATSET, AND POSTLHS IN PREPARATION TO EXERCISING CUTTINGS\_S

This appendix includes brief command files that exercise GENMESH, MATSET, and POSTLHS, as well as the actual input control files necessary to exercise the specific runs required prior to exercising CUTTINGS\_S (see Figure 1 in Section 6).

### CUSP\_GENMESH.COM

```
$! -----  
$! MODULE:  
$! PURPOSE:  
$! DATE:  
$! AUTHOR:  
$! -----  
$!  
$ SET NOON  
$ EXE_SRC   ::= $WP$PRODROOT:[GM.EXE]GM_PA96.EXE  
$!  
$ DEFINE GM_UIF$INPUT  GM_CUSP_CCA.INP  
$ DEFINE GM_CDB$OUTPUT GM_CUSP_CCA.CDB  
$ DEFINE GM_DBG$OUTPUT GM_CUSP_CCA.DBG  
$!  
$ EXE_SRC GM_UIF$INPUT GM_CDB$OUTPUT GM_DBG$OUTPUT  
$! -----  
$ EXIT
```

### 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
```

## CUSP\_MATSET.COM

```
$!=====
$!
$ EXE_SRC   ::= $WP$PRODROOT:[MS.EXE]MATSET_PA96.EXE
$!
$ DEFINE MS_CDB$INPUT   GM_CUSP_CCA.CDB
$ DEFINE MS_UIF$INPUT   MS_CUSP_CCA.INP
$ DEFINE MS_SDB$INPUT   WIPP::WIPP_DB
$ DEFINE MS_SDB_CALC$INPUT CCA4
$ DEFINE MS_CDB$OUTPUT  MS_CUSP_CCA.CDB
$ DEFINE MS_DBG$OUTPUT  MS_CUSP_CCA.DBG
$!
$ EXE_SRC MS_CDB$INPUT MS_UIF$INPUT MS_SDB$INPUT MS_SDB_CALC$INPUT -
          MS_CDB$OUTPUT MS_DBG$OUTPUT
$!
$ EXIT
```

## 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
```

The file that follows is an input control file to exercise POSTLHS in preparation to exercising CUTTINGS\_S.

**PLHS\_CUSP\_CCA.INP** -----

```
!
!=====
! 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, CORRMC02
!
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  
! MATERIALS, GLOBAL  
! PROPERTIES, PRMTZIDX  
! MATERIALS, GLOBAL  
! PROPERTIES, PRMTZIDX  
! MATERIALS, GLOBAL  
! PROPERTIES, PRMTZIDX

! =====

!  
!\*END

**END OF APPENDIX B**

**Information Only**

## APPENDIX C: GRAMMATICAL STRUCTURE OF CUTTINGS\_S'S INPUT FILES NOS. 1 & 2

The grammatical structure of CUTTINGS\_S's input control files (file numbers 1 and 2) follows the four rules stated below. In Section 6.2, these files are associated with the logical symbols: CUSP\_INPT\$TXT0 \$ , and CUSP\_INPT\$TXT0TXT1 .

- (1) Text files consist of keywords followed by (i) a real number, (ii) an integer, or (iii) a character variable. There is no required order for keywords.
- (2) Text following an exclamation point (!) is treated as a comment. That is, it is printed out with the file and normally provides the user with useful explanatory information regarding the file, but it is ignored by the code when the file is read.
- (3) Arrays can span more than one line of an input file. Arrays of numbers are terminated by any non-numeric character. Character arrays are terminated by any non-numeric, non-alphabetical character. These include the symbols: <>?:[]-+&%\$#@!.
- (4) If input is specified as a character data field, numerical values will be extracted from the upstream (MATSET or POSTLHS) input CDB file. The character data field must have a colon, (:), separating the CAMDAT material name on the left from the CAMDAT property name on the right. No intervening blanks are permitted. Material and property names are restricted to a maximum of 8 characters.

END OF APPENDIX C

Information Only

## APPENDIX D: SAMPLE CUTTINGS\_S DEBUG FILE FROM TEST - RUN PROBLEM #1

This file is taken from QA test problem number 1 (see Section 6.4) The file itself is annotated here and there with explanatory comments that describe the various collections of data. Explanatory comments are printed in italics to offset them from the normal content of the Debug file. The Debug file itself is described in Section 6.1 as file number 8.

*Explanatory Comment: The data below are the standard WIPP title page and disclaimer, followed by dynamic memory allocation data. End comment.*

-----  
CUSP\_PA96 5.03 PROD PA96 05/23/96 06/04/96 09:52:46

CCCCC	UU	UU	SSSSSS	PPPPPP	PPPPPP	AAAAA	9999	6666			
CC	CC	UU	UU	SS	PP	PP	AA	AA	9	9	6
CC		UU	UU	SS	PP	PP	AA	AA	9	9	6
CC		UU	UU	SSSSS	PPPPPP	PPPPPP	AAAAAAA	99999	66666		
CC		UU	UU	SS	PP	PP	AA	AA	9	6	6
CC	CC	UU	UU	SS	PP	PP	AA	AA	9	6	6
CCCCC		UUUUU	SSSSSS	PP	PP	AA	AA	9999	6666		

Program for computing the quantity of radioactive material (in Curies) brought to the surface as cuttings/spall generated by a drilling operation that penetrates a rad-waste repository.

CUSP\_PA96 Version 5.03  
PROD PA96 Built 05/23/96  
Written by Jerry W. Berglund  
Sponsored by Robert A. Cole & (J. S. Rath)

Run on 06/04/96 at 09:52:46  
Run on ALPHA AXP BEATLE OpenVMS V6.1

\*\*\*\*\*

Prepared for  
Sandia National Laboratories  
Albuquerque, New Mexico 87185-5800  
for the United States Department of Energy  
under Contract DE-AC04-76DP00789

\*\*\*\*\*

### Disclaimer

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```

! COLDIA <> Collar diameter (m)
COLDIA      0.2032004

! PIPED <> Drill pipe diameter (m)
PIPED      0.1143002

! ROUGHF <> Friction factor (unitless)
ROUGHF     0.08

!
! APORO <> A constant in equation to determine permeability as a
! function of porosity
APORO      1.0E-11

! NPORO <> N constant in equation to determine permeability as a
! function of porosity
NPORO      4.6

!
! END_OF_MODEL_INPUT
!
  
```

RADIONUCLIDE\_DATA

!GEOMETRY

```

INV_AR      1.11520E+05
RHW_AR      1.11520E+05
WUF         5.25
  
```

!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:
! (Both chains are required input)
  
```

```

!          \/\      \/\      \/\      \/\      \/\      \/\      \/\
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   <
  
```

```

! 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  PB209  <

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 radioisotope data are entered:

! ...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
!xxxxaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
!  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   5.802700E+07
  EPAREL   0.000000E+00  INVCHD   0.000000E+00
*AC227
  AWT      2.270280E-01  HALFY    2.177335E+01  ACTCNV   7.232300E+04
  EPAREL   1.000000E+02  INVCHD   0.000000E+00
*AC228
  AWT      2.280310E-01  HALFY    6.993710E-04  ACTCNV   2.241700E+09
  EPAREL   0.000000E+00  INVCHD   0.000000E+00
*AM241
  AWT      2.410570E-01  HALFY    4.322347E+02  ACTCNV   3.431200E+03
  EPAREL   1.000000E+02  INVCHD   2.400000E+05
*AM243
  AWT      2.430610E-01  HALFY    7.380313E+03  ACTCNV   1.992900E+02
  EPAREL   1.000000E+02  INVCHD   0.000000E+00
*AT217
  AWT      2.170050E-01  HALFY    1.023547E-09  ACTCNV   1.609500E+15
  EPAREL   0.000000E+00  INVCHD   0.000000E+00
*BA137M
  AWT      1.369070E-01  HALFY    4.851550E-06  ACTCNV   5.382400E+11
  EPAREL   0.000000E+00  INVCHD   0.000000E+00
*BI211
  AWT      2.109870E-01  HALFY    4.049824E-06  ACTCNV   4.184000E+11

```

EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*BI212					
AWT	2.119910E-01	HALFY	1.151253E-04	ACTCNV	1.464800E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*BI213					
AWT	2.129940E-01	HALFY	8.679553E-05	ACTCNV	1.933800E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*BI214					
AWT	2.139990E-01	HALFY	3.783638E-05	ACTCNV	4.415300E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*CF252					
AWT	2.520820E-01	HALFY	2.638090E+00	ACTCNV	5.375899E+05
EPAREL	0.000000E+00	INVCHD	2.960000E+03		
*CM243					
AWT	2.430610E-01	HALFY	2.850088E+01	ACTCNV	5.160700E+04
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*CM244					
AWT	2.440630E-01	HALFY	1.811013E+01	ACTCNV	8.088299E+04
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*CM245					
AWT	2.450650E-01	HALFY	8.498927E+03	ACTCNV	1.716500E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*CM248					
AWT	2.480720E-01	HALFY	3.390698E+05	ACTCNV	4.250200E+00
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*CS137					
AWT	1.369070E-01	HALFY	2.999975E+01	ACTCNV	8.704300E+04
EPAREL	1.000000E+03	INVCHD	2.070000E+04		
*FR221					
AWT	2.210140E-01	HALFY	9.126364E-06	ACTCNV	1.772400E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*ND143					
AWT	1.430000E-01	HALFY	3.168876E+30	ACTCNV	0.000000E+00
EPAREL	1.000000E+03	INVCHD	0.000000E+00		
*NP237					
AWT	2.370480E-01	HALFY	2.139942E+06	ACTCNV	7.047600E-01
EPAREL	1.000000E+02	INVCHD	6.670000E+01		
*NP239					
AWT	2.390530E-01	HALFY	6.448664E-03	ACTCNV	2.319100E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA231					
AWT	2.310360E-01	HALFY	3.276618E+04	ACTCNV	4.722500E+01
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PA233					
AWT	2.330400E-01	HALFY	7.392988E-02	ACTCNV	2.075100E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA234M					
AWT	2.340430E-01	HALFY	2.224551E-06	ACTCNV	6.866600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB209					
AWT	2.089810E-01	HALFY	3.764625E-04	ACTCNV	4.544100E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB210					
AWT	2.099840E-01	HALFY	2.229938E+01	ACTCNV	7.634800E+04
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PB211					
AWT	2.109890E-01	HALFY	6.863786E-05	ACTCNV	2.468600E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB212					
AWT	2.119920E-01	HALFY	1.213680E-03	ACTCNV	1.389500E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB214					
AWT	2.140000E-01	HALFY	5.095553E-05	ACTCNV	3.278500E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PM147					
AWT	1.469150E-01	HALFY	2.623513E+00	ACTCNV	9.275300E+05
EPAREL	0.000000E+00	INVCHD	5.250000E+02		
*PO212					
AWT	2.119890E-01	HALFY	9.506629E-15	ACTCNV	1.773900E+20
EPAREL	0.000000E+00	INVCHD	0.000000E+00		

*PO213					
AWT	2.129930E-01	HALFY	1.330928E-13	ACTCNV	1.261100E+19
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO214					
AWT	2.139950E-01	HALFY	5.206464E-12	ACTCNV	3.208700E+17
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO215					
AWT	2.149990E-01	HALFY	5.640600E-11	ACTCNV	2.947900E+16
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO216					
AWT	2.160020E-01	HALFY	4.753314E-09	ACTCNV	3.482000E+14
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO218					
AWT	2.180090E-01	HALFY	5.799044E-06	ACTCNV	2.827800E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PU238					
AWT	2.380500E-01	HALFY	8.774619E+01	ACTCNV	1.711500E+04
EPAREL	1.000000E+02	INVCHD	4.240000E+06		
*PU239					
AWT	2.390520E-01	HALFY	2.406445E+04	ACTCNV	6.214600E+01
EPAREL	1.000000E+02	INVCHD	3.920000E+05		
*PU240					
AWT	2.400540E-01	HALFY	6.537392E+03	ACTCNV	2.278100E+02
EPAREL	1.000000E+02	INVCHD	6.930000E+04		
*PU241					
AWT	2.410570E-01	HALFY	1.439937E+01	ACTCNV	1.030000E+05
EPAREL	0.000000E+00	INVCHD	1.930000E+06		
*PU242					
AWT	2.420590E-01	HALFY	3.869198E+05	ACTCNV	3.817100E+00
EPAREL	1.000000E+02	INVCHD	4.910000E+04		
*PU244					
AWT	2.440640E-01	HALFY	8.261261E+07	ACTCNV	1.773100E-02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA223					
AWT	2.230190E-01	HALFY	3.130533E-02	ACTCNV	5.120600E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA224					
AWT	2.240200E-01	HALFY	1.001999E-02	ACTCNV	1.592700E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA225					
AWT	2.250240E-01	HALFY	4.052993E-02	ACTCNV	3.919900E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA226					
AWT	2.260250E-01	HALFY	1.599966E+03	ACTCNV	9.885801E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA228					
AWT	2.280310E-01	HALFY	6.699955E+00	ACTCNV	2.340000E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN219					
AWT	2.190090E-01	HALFY	1.254875E-07	ACTCNV	1.300800E+13
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN220					
AWT	2.200110E-01	HALFY	1.761895E-06	ACTCNV	9.222600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN222					
AWT	2.220180E-01	HALFY	1.046997E-02	ACTCNV	1.538000E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*SM147					
AWT	1.470000E-01	HALFY	1.059355E+11	ACTCNV	2.295400E-05
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*SR90					
AWT	8.990801E-02	HALFY	2.912197E+01	ACTCNV	1.365400E+05
EPAREL	1.000000E+03	INVCHD	9.850002E+03		
*TH227					
AWT	2.270280E-01	HALFY	5.124073E-02	ACTCNV	3.073200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH228					
AWT	2.280290E-01	HALFY	1.913051E+00	ACTCNV	8.195301E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH229					

AWT	2.290320E-01	HALFY	7.339118E+03	ACTCNV	2.126900E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*TH230					
AWT	2.300330E-01	HALFY	7.700370E+04	ACTCNV	2.018300E+01
EPAREL	1.000000E+01	INVCHD	0.000000E+00		
*TH231					
AWT	2.310360E-01	HALFY	2.911247E-03	ACTCNV	5.315200E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH232					
AWT	2.320380E-01	HALFY	1.405080E+10	ACTCNV	1.096500E-04
EPAREL	1.000000E+01	INVCHD	6.110000E-01		
*TH234					
AWT	2.340440E-01	HALFY	6.597601E-02	ACTCNV	2.315200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TL207					
AWT	2.069770E-01	HALFY	9.069325E-06	ACTCNV	1.904500E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*U233					
AWT	2.330400E-01	HALFY	1.585072E+05	ACTCNV	9.678300E+00
EPAREL	1.000000E+02	INVCHD	1.310000E+03		
*U234					
AWT	2.340410E-01	HALFY	2.445105E+05	ACTCNV	6.247300E+00
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*U235					
AWT	2.350440E-01	HALFY	7.038074E+08	ACTCNV	2.161100E-03
EPAREL	1.000000E+02	INVCHD	1.150000E+00		
*U236					
AWT	2.360460E-01	HALFY	2.341483E+07	ACTCNV	6.468300E-02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*U238					
AWT	2.380510E-01	HALFY	4.468115E+09	ACTCNV	3.361100E-04
EPAREL	1.000000E+02	INVCHD	2.010000E-01		
*Y90					
AWT	8.990701E-02	HALFY	7.301091E-03	ACTCNV	5.446300E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*ZR90					
AWT	9.000000E-02	HALFY	3.168876E+30	ACTCNV	0.000000E+00
EPAREL	1.000000E+03	INVCHD	0.000000E+00		

END\_TABLES>  
!  
! END\_OF\_RADIOISOTOPE\_INPUT  
!

\*\*\*\*\*  
(SCATXT1)

Explanatory Comment: This ends the listing of data read from the repository/model input control file and begins the echo of drilling/intrusion data read from the (input control) file whose logical symbol is CUSP\_INP\$TXT1. End of Comment.

!  
!  
! INTRUSION

TINTR 100.0  
TAUFAIL BOREHOLE:TAUFAIL  
\*\*\* CUTTINGS variable: TAUFAIL value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = BOREHOLE:TAUFAIL : 8.11200E+00)

TCLOUT WAS\_AREA:TCLOUT  
\*\*\* CUTTINGS variable: TCLOUT(\*) value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = WAS\_AREA:TCLOUT : 6.48000E+04)

PARTDIA 0.006

!PROPERTIES

DNSFLUID DRILLMUD:DENSITY  
\*\*\* CUTTINGS variable: DENSITY value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:DENSITY : 1.21000E+03)

DOMEGA BOREHOLE:DOMEGA  
\*\*\* CUTTINGS variable: DOMEGA value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = BOREHOLE:DOMEGA : 7.80000E+00)

VISCO DRILLMUD:VISCO  
\*\*\* CUTTINGS variable: VISCO value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:VISCO : 9.17000E-03)

YLDSTRSS DRILLMUD:YLDSTRSS  
\*\*\* CUTTINGS variable: YLDSTRSS value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:YLDSTRSS : 4.40000E+00)

ABSROUGH WAS\_AREA:ROUGH  
\*\*\* CUTTINGS variable: ABSRO value extracted from CAMDAT \*\*\*  
(CAMDAT MATERIAL:PROPERTY:VALUE = WAS\_AREA:ROUGH : 2.50000E-02)

!  
! BRAGFLOW  
!  
! Multiple hits (max of 10, 0 thru 9) must be entered in order  
!  
! MHIT\_0 is associated with the hit that CUTTINGS used for BRAG flow  
! properties  
!

INTR\_0 CAVITY\_1 <  
INTR\_1 CAVITY\_1 NO\_GRDVOL <  
SIMPLE AVERAGE WILL BE USED INSTEAD OF WEIGHTED AVERAGE VOLUME  
INTR\_2 457 458 459 <  
INTR\_3 460 461 462 <  
INTR\_4 463 464 465 <

*Explanatory Comment: The following is a summary of the data CUTTINGS\_S read from the BRAGFLO output CDB file. Note that block number 7, which contains 21 elements, is the location of the repository. End of Comment.*

element block names found

block name,	block id
S_HALITE	1
DRZ_0	2
TRANS_0	3
S_MB139	4
S_ANH_AB	5
S_MB138	6
CAVITY_1	7
CAVITY_2	8
CAVITY_3	9
CAVITY_4	10
IMPERM_Z	11
CASTILER	12
WAS_AREA	13
REPOSIT	14
DRZ_1	15
UNNAMED	16
CULEBRA	17
TAMARISK	18
MAGENTA	19
FORTYNIN	20
DEWYLAKE	21
SANTAROS	22
BACKFILL	23
EXP_AREA	24
SHFT_B_1	25

Information Only

SHFT_B_2	26
SHFT_L_1	27
SHFT_L_2	28
SHFT_U_1	29
SHFT_U_2	30
SHFT_LS1	31
SHFT_LS2	32
SHFT_US1	33
SHFT_US2	34
PAN_S_1	35
PAN_S_2	36
BOREHOLE	37
BRINESAL	38
H2	39
PB210	40
RA226	41
RA228	42
TH229	43
TH230	44
TH232	45
PA231	46
U233	47
U234	48
U235	49
U236	50
U238	51
NP237	52
PU238	53
PU239	54
PU240	55
PU241	56
PU242	57
PU244	58
AM241	59
CM244	60
CM248	61
CF252	62
PB	63
RA	64
TH	65
PA	66
U	67
NP	68
PU	69
AM	70
CM	71
CF	72
TRANS_1	73

number of elements per block

block number, number of elements

1	297
2	64
3	16
4	14
5	14
6	30
7	21
8	9
9	12
10	27
11	275
12	27
13	0
14	0
15	0
16	0
17	0

18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
32	0
33	0
34	0
35	0
36	0
37	0
38	0
39	0
40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	0
59	0
60	0
61	0
62	0
63	0
64	0
65	0
66	0
67	0
68	0
69	0
70	0
71	0
72	0
73	0

attribute names found

i,	name
1	THICK
2	ELEVAT
3	DEL_X
4	DEL_Y
5	DEL_Z
6	GRIDVOL

---

element #	attribute value
1	1.2799E+11
2	1.4830E+10
3	1.9030E+09
4	2.3061E+08
5	2.9423E+07
6	1.0210E+07
7	2.4135E+06
8	1.8411E+06
9	9.8849E+06
10	1.9705E+06
11	5.5664E+04
12	7.6922E+05
13	4.0078E+04
14	1336.
15	10.96
16	1336.
17	4.0078E+04
18	7.6922E+05
19	2.1041E+05
20	7.4433E+05
21	1.3151E+05
22	1.3220E+04
23	1.7117E+05
24	3.6947E+06
25	1.7519E+06
26	8.1208E+06
27	2.8095E+07
28	2.7331E+08
29	2.0035E+09
30	1.5118E+10
31	1.2885E+11
32	4.5986E+10
33	5.3286E+09
34	6.8375E+08
35	8.2858E+07
36	1.0572E+07
37	3.6686E+06
38	8.6715E+05
39	6.6150E+05
40	3.5516E+06
41	7.0800E+05
42	2.0000E+04
43	2.7638E+05
44	1.4400E+04
45	480.0
46	3.936
47	480.0
48	1.4400E+04
49	2.7638E+05
50	7.5600E+04
51	2.6744E+05
52	4.7250E+04
53	4750.
54	6.1500E+04
55	1.3275E+06
56	6.2945E+05
57	2.9178E+06
58	1.0095E+07
59	9.8200E+07
60	7.1985E+08
61	5.4317E+09
62	4.6295E+10
63	1.0117E+10
64	1.1723E+09
65	1.5043E+08
66	1.8229E+07
67	2.3257E+06
68	8.0709E+05
69	1.9077E+05

70	1.4553E+05
71	7.8136E+05
72	1.5576E+05
73	4400.
74	6.0803E+04
75	3168.
76	105.6
77	0.8660
78	105.6
79	3168.
80	6.0803E+04
81	1.6632E+04
82	5.8836E+04
83	1.0395E+04
84	1045.
85	1.3530E+04
86	2.9205E+05
87	1.3848E+05
88	6.4192E+05
89	2.2208E+06
90	2.1604E+07
91	1.5837E+08
92	1.1950E+09
93	1.0185E+10
94	1.2692E+09
95	1.4707E+08
96	1.8872E+07
97	2.2869E+06
98	2.9177E+05
99	1.0125E+05
100	2.3933E+04
101	1.2148E+09
102	1.4076E+08
103	1.8062E+07
104	2.1888E+06
105	2.7926E+05
106	9.6910E+04
107	2.2907E+04
108	1.2148E+09
109	1.4076E+08
110	1.8062E+07
111	2.1888E+06
112	2.7926E+05
113	9.6910E+04
114	2.2907E+04
115	1.2148E+09
116	1.4076E+08
117	1.8062E+07
118	2.1888E+06
119	2.7926E+05
120	9.6910E+04
121	2.2907E+04
122	2.4074E+09
123	2.7896E+08
124	3.5796E+07
125	4.3378E+06
126	5.5344E+05
127	1.9206E+05
128	4.5397E+04
129	1.7373E+04
130	8.0531E+04
131	2.7861E+05
132	2.7103E+06
133	1.9868E+07
134	1.4992E+08
135	1.2777E+09
136	1.6628E+04
137	7.7077E+04
138	2.6666E+05
139	2.5941E+06

Information Only

140	1.9016E+07
141	1.4348E+08
142	1.2229E+09
143	1.6628E+04
144	7.7077E+04
145	2.6666E+05
146	2.5941E+06
147	1.9016E+07
148	1.4348E+08
149	1.2229E+09
150	1.6628E+04
151	7.7077E+04
152	2.6666E+05
153	2.5941E+06
154	1.9016E+07
155	1.4348E+08
156	1.2229E+09
157	3.2953E+04
158	1.5275E+05
159	5.2847E+05
160	5.1410E+06
161	3.7686E+07
162	2.8436E+08
163	2.4236E+09
164	8.3326E+09
165	9.6554E+08
166	1.2390E+08
167	1.5014E+07
168	1.9156E+06
169	6.6475E+05
170	1.5713E+05
171	1.1406E+05
172	5.2871E+05
173	1.8291E+06
174	1.7794E+07
175	1.3044E+08
176	9.8423E+08
177	8.3887E+09
178	5.6084E+10
179	6.4987E+09
180	8.3390E+08
181	1.0105E+08
182	1.2893E+07
183	4.4742E+06
184	1.0576E+06
185	8.0677E+05
186	4.3316E+05
187	8.6348E+05
188	2.4392E+04
189	3.3707E+05
190	1.7562E+04
191	585.4
192	4.801
193	585.4
194	1.7562E+04
195	3.3707E+05
196	9.2202E+04
197	3.2616E+05
198	5.7626E+04
199	1.4580E+11
200	1.6895E+10
201	2.1679E+09
202	2.6271E+08
203	3.3518E+07
204	1.1632E+07
205	2.7494E+06
206	2.0974E+06
207	1.1261E+07
208	2.2448E+06
209	6.3412E+04

210	8.7628E+05
211	4.5657E+04
212	1522.
213	12.48
214	1522.
215	4.5657E+04
216	8.7628E+05
217	2.3970E+05
218	8.4793E+05
219	1.4981E+05
220	1.4580E+11
221	1.6895E+10
222	2.1679E+09
223	2.6271E+08
224	3.3518E+07
225	1.1632E+07
226	2.7494E+06
227	2.0974E+06
228	1.1261E+07
229	2.2448E+06
230	6.3412E+04
231	8.7628E+05
232	4.5657E+04
233	1522.
234	12.48
235	1522.
236	4.5657E+04
237	8.7628E+05
238	2.3970E+05
239	8.4793E+05
240	1.4981E+05
241	4.6721E+09
242	5.4138E+08
243	6.9469E+07
244	8.4183E+06
245	1.0741E+06
246	3.7273E+05
247	8.8102E+04
248	6.7208E+04
249	3.6085E+05
250	7.1933E+04
251	2032.
252	2.8080E+04
253	1463.
254	48.77
255	0.3999
256	48.77
257	1463.
258	2.8080E+04
259	7681.
260	2.7171E+04
261	4801.
262	7.5005E+04
263	1.6190E+06
264	7.6768E+05
265	3.5585E+06
266	1.2311E+07
267	1.1976E+08
268	8.7793E+08
269	6.6245E+09
270	5.6462E+10
271	1.9499E+05
272	4.2090E+06
273	1.9957E+06
274	9.2512E+06
275	3.2006E+07
276	3.1135E+08
277	2.2824E+09
278	1.7222E+10
279	1.4678E+11

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280	1.9499E+05
281	4.2090E+06
282	1.9957E+06
283	9.2512E+06
284	3.2006E+07
285	3.1135E+08
286	2.2824E+09
287	1.7222E+10
288	1.4678E+11
289	6248.
290	1.3487E+05
291	6.3952E+04
292	2.9645E+05
293	1.0256E+06
294	9.9771E+06
295	7.3137E+07
296	5.5186E+08
297	4.7036E+09
298	1.1246E+04
299	6.0378E+04
300	1.2036E+04
301	340.0
302	4698.
303	244.8
304	8.160
305	6.6916E-02
306	8.160
307	244.8
308	4698.
309	1285.
310	4546.
311	803.3
312	1.8257E+04
313	9.8025E+04
314	1.9541E+04
315	552.0
316	7628.
317	397.4
318	13.25
319	0.1086
320	13.25
321	397.4
322	7628.
323	2087.
324	7381.
325	1304.
326	1046.
327	2.2568E+04
328	1697.
329	3.6639E+04
330	3.4631E+04
331	1.8593E+05
332	3.7065E+04
333	1047.
334	1.4469E+04
335	753.9
336	25.13
337	0.2061
338	25.13
339	753.9
340	1.4469E+04
341	3958.
342	1.4001E+04
343	2474.
344	3572.
345	1.9179E+04
346	3823.
347	108.0
348	1492.
349	77.76

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350	2.592
351	2.1256E-02
352	2.592
353	77.76
354	1492.
355	408.2
356	1444.
357	255.1
358	3220.
359	6.9497E+04
360	332.1
361	7169.
362	1.1986E+05
363	6.4355E+05
364	1.2829E+05
365	3624.
366	5.0080E+04
367	2609.
368	86.98
369	0.7132
370	86.98
371	2609.
372	5.0080E+04
373	1.3699E+04
374	4.8459E+04
375	8562.
376	1.1144E+04
377	2.4054E+05
378	7.8176E+08
379	9.0586E+07
380	1.1624E+07
381	1.4086E+06
382	1.7972E+05
383	6.2366E+04
384	1.4742E+04
385	1.0701E+04
386	4.9603E+04
387	1.7161E+05
388	1.6694E+06
389	1.2238E+07
390	9.2339E+07
391	7.8702E+08
392	2.4832E+08
393	2.8774E+07
394	3.6923E+06
395	4.4743E+05
396	5.7086E+04
397	1.9810E+04
398	4683.
399	3399.
400	1.5756E+04
401	5.4510E+04
402	5.3028E+05
403	3.8872E+06
404	2.9331E+07
405	2.4999E+08
406	1.6555E+08
407	1.9183E+07
408	2.4615E+06
409	2.9829E+05
410	3.8057E+04
411	1.3207E+04
412	3122.
413	2381.
414	1.2786E+04
415	2549.
416	72.00
417	995.0
418	51.84
419	1.728

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420	1.4170E-02
421	1.728
422	51.84
423	995.0
424	272.2
425	962.8
426	170.1
427	221.4
428	4779.
429	2266.
430	1.0504E+04
431	3.6340E+04
432	3.5352E+05
433	2.5915E+06
434	1.9554E+07
435	1.6666E+08
436	7301.
437	380.4
438	12.68
439	0.1040
440	12.68
441	380.4
442	7301.
443	7301.
444	380.4
445	12.68
446	0.1040
447	12.68
448	380.4
449	7301.
450	7301.
451	380.4
452	12.68
453	0.1040
454	12.68
455	380.4
456	7301.
457	1.7474E+04
458	9.3820E+04
459	1.8703E+04
460	1.7474E+04
461	9.3820E+04
462	1.8703E+04
463	1.7474E+04
464	9.3820E+04
465	1.8703E+04
466	7065.
467	1248.
468	7065.
469	1248.
470	7065.
471	1248.
472	1625.
473	3.5067E+04
474	1625.
475	3.5067E+04
476	1625.
477	3.5067E+04
478	528.3
479	528.3
480	528.3
481	1997.
482	1997.
483	1997.
484	80.75
485	131.1
486	125.5
487	125.5
488	125.5
489	248.7

Information Only

490	25.65
491	860.7
492	17.10
493	5793.
494	1.5060E+04
495	1.5060E+04
496	482.6
497	3420.
498	731.5
499	2356.
500	807.5
501	1644.
502	1.0070E+04
503	4114.
504	1497.
505	3.3110E+10
506	3.8366E+09
507	4.9230E+08
508	5.9657E+07
509	7.6115E+06
510	2.6414E+06
511	6.2435E+05
512	4.7628E+05
513	2.5572E+06
514	5.0976E+05
515	1.4400E+04
516	1.9899E+05
517	1.0368E+04
518	345.6
519	2.834
520	345.6
521	1.0368E+04
522	1.9899E+05
523	5.4432E+04
524	1.9255E+05
525	3.4020E+04
526	4.4280E+04
527	9.5580E+05
528	4.5320E+05
529	2.1008E+06
530	7.2680E+06
531	7.0704E+07
532	5.1829E+08
533	3.9108E+09
534	3.3333E+10
535	7.0818E+09
536	8.2060E+08
537	1.0530E+08
538	1.2760E+07
539	1.6280E+06
540	5.6496E+05
541	1.3354E+05
542	1.0187E+05
543	5.4695E+05
544	1.0903E+05
545	3080.
546	4.2562E+04
547	2218.
548	73.92
549	0.6062
550	73.92
551	2218.
552	4.2562E+04
553	1.1642E+04
554	4.1185E+04
555	7277.
556	9471.
557	2.0444E+05
558	9.6935E+04
559	4.4934E+05

Information Only

560	1.5546E+06
561	1.5123E+07
562	1.1086E+08
563	8.3649E+08
564	7.1295E+09
565	2.2809E+10
566	2.6430E+09
567	3.3914E+08
568	4.1097E+07
569	5.2435E+06
570	1.8196E+06
571	4.3011E+05
572	3.2810E+05
573	1.7616E+06
574	3.5117E+05
575	9920.
576	1.3708E+05
577	7142.
578	238.1
579	1.952
580	238.1
581	7142.
582	1.3708E+05
583	3.7498E+04
584	1.3265E+05
585	2.3436E+04
586	3.0504E+04
587	6.5844E+05
588	3.1221E+05
589	1.4472E+06
590	5.0069E+06
591	4.8707E+07
592	3.5705E+08
593	2.6941E+09
594	2.2962E+10
595	7.8176E+09
596	9.0586E+08
597	1.1624E+08
598	1.4086E+07
599	1.7972E+06
600	6.2366E+05
601	1.4742E+05
602	1.1246E+05
603	6.0378E+05
604	1.2036E+05
605	3400.
606	4.6984E+04
607	2448.
608	81.60
609	0.6692
610	81.60
611	2448.
612	4.6984E+04
613	1.2852E+04
614	4.5464E+04
615	8033.
616	1.0455E+04
617	2.2568E+05
618	1.0701E+05
619	4.9603E+05
620	1.7161E+06
621	1.6694E+07
622	1.2238E+08
623	9.2339E+08
624	7.8702E+09
625	1.5911E+10
626	1.8437E+09
627	2.3658E+08
628	2.8669E+07
629	3.6577E+06

Information Only

630	1.2693E+06
631	3.0003E+05
632	2.2888E+05
633	1.2289E+06
634	2.4497E+05
635	6920.
636	9.5627E+04
637	4982.
638	166.1
639	1.362
640	166.1
641	4982.
642	9.5627E+04
643	2.6158E+04
644	9.2533E+04
645	1.6349E+04
646	2.1279E+04
647	4.5932E+05
648	2.1779E+05
649	1.0096E+06
650	3.4927E+06
651	3.3977E+07
652	2.4907E+08
653	1.8794E+09
654	1.6018E+10
655	9.7490E+10
656	1.1297E+10
657	1.4496E+09
658	1.7566E+08
659	2.2412E+07
660	7.7774E+06
661	1.8384E+06
662	1.4024E+06
663	7.5294E+06
664	1.5010E+06
665	4.2400E+04
666	5.8592E+05
667	3.0528E+04
668	1018.
669	8.345
670	1018.
671	3.0528E+04
672	5.8592E+05
673	1.6027E+05
674	5.6696E+05
675	1.0017E+05
676	3.9824E+10
677	4.6145E+09
678	5.9213E+08
679	7.1755E+07
680	9.1549E+06
681	3.1770E+06
682	7.5095E+05
683	5.7286E+05
684	3.0757E+06
685	6.1313E+05
686	1.7320E+04
687	2.3934E+05
688	1.2470E+04
689	415.7
690	3.409
691	415.7
692	1.2470E+04
693	2.3934E+05
694	6.5470E+04
695	2.3160E+05
696	4.0919E+04
697	1.3038E+05
698	2.8143E+06
699	1.3344E+06

700	6.1857E+06
701	2.1400E+07
702	2.0818E+08
703	1.5261E+09
704	1.1515E+10
705	9.8146E+10
706	5.3259E+04
707	1.1496E+06
708	5.4510E+05
709	2.5268E+06
710	8.7418E+06
711	8.5041E+07
712	6.2339E+08
713	4.7039E+09
714	4.0092E+10
715	1.4495E+10
716	1.6796E+09
717	2.1552E+08
718	2.6117E+07
719	3.3321E+06
720	1.1563E+06
721	2.7333E+05
722	2.0850E+05
723	1.1195E+06
724	2.2316E+05
725	6304.
726	8.7114E+04
727	4539.
728	151.3
729	1.241
730	151.3
731	4539.
732	8.7114E+04
733	2.3829E+04
734	8.4296E+04
735	1.4893E+04
736	1.9385E+04
737	4.1843E+05
738	1.9840E+05
739	9.1969E+05
740	3.1818E+06
741	3.0953E+07
742	2.2690E+08
743	1.7121E+09
744	1.4592E+10
745	2.5090E+09
746	2.9073E+08
747	2.9635E+08
748	2.5259E+09
749	4.3569E+10
750	5.0485E+09
751	6.4781E+08
752	7.8503E+07
753	1.0016E+07
754	3.4758E+06
755	8.2157E+05
756	6.2673E+05
757	3.3650E+06
758	6.7079E+05
759	1.8949E+04
760	2.6185E+05
761	1.3643E+04
762	454.8
763	3.729
764	454.8
765	1.3643E+04
766	2.6185E+05
767	7.1626E+04
768	2.5338E+05
769	4.4767E+04

Information Only

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770	4500.
771	5.8268E+04
772	1.2577E+06
773	5.9637E+05
774	2.7644E+06
775	9.5639E+06
776	9.3039E+07
777	6.8202E+08
778	5.1462E+09
779	4.3862E+10
780	3.7305E+07
781	4.5207E+06
782	5.7678E+05
783	2.0016E+05
784	4.7312E+04
785	3.6091E+04
786	1.9378E+05
787	3.8628E+04
788	1091.
789	1.5079E+04
790	785.7
791	26.19
792	0.2148
793	26.19
794	785.7
795	1.5079E+04
796	4125.
797	1.4591E+04
798	2578.
799	259.2
800	3355.
801	7.2428E+04
802	3.4343E+04
803	1.5920E+05
804	5.5076E+05
805	5.3578E+06
806	3.9275E+07
1	297
2	64
3	16
4	14
5	14
6	30
7	21
8	9
9	12
10	27
11	275
12	27

number of elements to average over 21

number of elements to average over 21

number of elements to average over 3

number of elements to average over 3

number of element to average over 3

unique property names

Information Only

---

property number	property name
1	PRMX_LOG
2	POROSITY
3	SP_S_LOG
4	REL_P_MOD
5	CAP_MOD
6	PC_MAX
7	SAT_RBRN
8	SAT_RGAS
9	PORE_DIS
10	COMP_RCK
11	SB_MIN
12	PO_MIN
13	PCT_A
14	PCT_EXP
15	PCT_FLAG
16	PTINDEX
17	GRID_ID
18	REF_PRES
19	PTHRESH
20	PRESSURE
21	PERM_EXP
22	PHIMAX
23	DPHIMAX
24	PI_DELTA
25	PF_DELTA
26	P_LITHO
27	FRAC_PMX
28	FRAC_PMY
29	FRAC_PMZ
30	KMAXLOG
31	DELTA_PF
32	CG_NF
33	CG_F
34	CB
35	SAT_IBRN
36	SAT_PUD
37	GRATCORI
38	GRATCORH
39	GRATMICI
40	GRATMICH
41	STOICOR
42	STOIMIC
43	DCELLCHW
44	DCELLRHW
45	DIRONCHW
46	DIRONRHW
47	DPLASCHW
48	DPLASRHW
49	DRUBBCHW
50	DRUBBRHW
51	DIRNCCHW
52	DIRNCRHW
53	DPLSCCHW
54	VOLCHW
55	VOLRHW
56	DRH_METL
57	DCH_METL
58	DRH_BIO
59	DCH_BIO
60	FRAC_PR
61	PRMX
62	STORAGEC
63	DIAMMOD
64	DNSFLUID
65	WTF
66	COMPRES
67	RSOD0
68	RSOD1

69	BSLOPE
70	RSLOPE
71	VSLOPE
72	VISCO
73	REF_TEMP
74	INVCHD
75	INVRHD
76	HALFLIFE
77	ATWEIGHT
78	DIS_ENGY
79	LOGSOLM
80	PERM_X
81	PERM_Y
82	PERM_Z
83	SOLUB
84	PAVE
85	COMP

*Explanatory Comment: The data below represent CUTTINGS\_S's search (through BRAGFLO's output CDB file) for the time of intrusion. End of Comment.*

```
element block 37 3.16599995E-01
TIME-years 0.00000000E+00
TIME-years 5.34747819E-08
TIME-years 2.22228164E-06
TIME-years 1.09104358E-05
TIME-years 7.41431795E-05
TIME-years 2.42588285E-04
TIME-years 2.23672390E-03
TIME-years 2.98848525E-02
TIME-years 6.96178913E-01
TIME-years 3.18654060E+00
TIME-years 1.78978786E+01
TIME-years 2.58163357E+01
TIME-years 3.57182579E+01
TIME-years 5.97380142E+01
TIME-years 6.10059128E+01
TIME-years 6.26197319E+01
TIME-years 7.07265167E+01
TIME-years 7.27253571E+01
TIME-years 7.28040161E+01
TIME-years 7.83843460E+01
TIME-years 8.09984283E+01
TIME-years 8.67234039E+01
TIME-years 1.00000221E+02
```

```
Interpolation xval 9.99983311E-01
for TINT(KINT) 1.00000000E+02
```

*Explanatory Comment: The listing below represents all the data CUTTINGS\_S extracted from the BRAGFLO output CDB file. End of Comment.*

RESULTS from BRAGFLOW file: CUSP\_INP\$BRAGCDB

Unaltered output follows here:

Diameter of borehole 3.16599995E-01

Initial porosity 8.81034851E-01

Intrusion time (yrs)	element porosity	average value
Multiple hits_0 0.00	POROS	8.81034851E-01

	PRESGAS	6.80242750E+06
	PRESBRIN	1.01325008E+05
	SATGAS	9.95905936E-01
Multiple hits_1		
0.00	POROS	8.81034970E-01
	PRESGAS	6.80243050E+06
	PRESBRIN	1.01325000E+05
	SATGAS	9.95906115E-01
Multiple hits_2		
0.00	POROS	8.81034911E-01
	PRESGAS	6.80242850E+06
	PRESBRIN	1.01324992E+05
	SATGAS	9.95905936E-01
Multiple hits_3		
0.00	POROS	8.81034911E-01
	PRESGAS	6.80242850E+06
	PRESBRIN	1.01324992E+05
	SATGAS	9.95905936E-01
Multiple hits_4		
0.00	POROS	8.81034911E-01
	PRESGAS	6.80242850E+06
	PRESBRIN	1.01324992E+05
	SATGAS	9.95905936E-01
Multiple hits_0		
100.00	POROS	3.00751239E-01
	PRESGAS	1.65183310E+07
	PRESBRIN	9.81722700E+06
	SATGAS	9.83161747E-01
Multiple hits_1		
100.00	POROS	3.00751239E-01
	PRESGAS	1.65183330E+07
	PRESBRIN	9.81722900E+06
	SATGAS	9.83178914E-01
Multiple hits_2		
100.00	POROS	3.00751209E-01
	PRESGAS	1.65185040E+07
	PRESBRIN	9.81740000E+06
	SATGAS	9.77457225E-01
Multiple hits_3		
100.00	POROS	3.00751209E-01
	PRESGAS	1.65183470E+07
	PRESBRIN	9.81724400E+06
	SATGAS	9.89357471E-01
Multiple hits_4		
100.00	POROS	3.00751209E-01
	PRESGAS	1.65181900E+07
	PRESBRIN	9.81708600E+06
	SATGAS	9.82479930E-01

From these two relationships:

$$(1.0-P_i)*H_i = (1.0-P_f)*H_f \cdot$$

$$\&$$

$$P_f*H_f=P_b*H_i$$

Where:

P<sub>i</sub> = Initial porosity  
 H<sub>i</sub> = Initial height  
 P<sub>f</sub> = Final porosity  
 H<sub>f</sub> = Final height  
 P<sub>b</sub> = Brag porosity

Code will calculate porosity as:

$$P_f=P_b/(1.0-P_i+P_b)$$

$$H_f=(1.0-P_i)/(1.0-P_f)*H_i$$

& output these transformed values  
 to the output cuttings CDB

after max, min

Information Only



porosity, initial  
    (unitless) 0.8810  
porosity (bragflow) 0.3008  
porosity (unitless) 0.7166  
permeability (m\*\*2) 1.0000E-12  
particle dia (m) 6.0000E-03

FINAL RESULTS: Type: SOLID\_BLOWOUT  
AREA (spall) 1.206  
AREA (erosion) 0.1125  
AREA (total) 1.319

\*\*\*\*\*  
(WRIOUT)

*Explanatory Comment: The data below are the results of dividing the initial inventory (CMS-controlled data) by INV.AREA, whose numerical value is 1.11520e5 m<sup>2</sup>.  
End of Comment.*

INITIAL radioisotope LOADING (CI) with an inventory  
area of 1.11520E+05 M\*\*2 FOR WIPP TRU CH WASTE)

-----  
AM241 2.4000E+05  
AM243 0.0000E+00  
CF252 2.9600E+03  
CM243 0.0000E+00  
CM244 0.0000E+00  
CM245 0.0000E+00  
CM248 0.0000E+00  
CS137 2.0700E+04  
NP237 6.6700E+01  
PA231 0.0000E+00  
PB210 0.0000E+00  
PM147 5.2500E+02  
PU238 4.2400E+06  
PU239 3.9200E+05  
PU240 6.9300E+04  
PU241 1.9300E+06  
PU242 4.9100E+04  
PU244 0.0000E+00  
RA226 0.0000E+00  
RA228 0.0000E+00  
SR90 9.8500E+03  
TH229 0.0000E+00  
TH230 0.0000E+00  
TH232 6.1100E-01  
U233 1.3100E+03  
U234 0.0000E+00  
U235 1.1500E+00  
U236 0.0000E+00  
U238 2.0100E-01

*Explanatory Comment: The data below represent the principal results of CUTTINGS\_S's calculations, namely, releases to the surface (in Curies) at the time of intrusion. These data are also printed in the (binary) output CDB file.  
End of Comment.*

radioisotope RELEASE (CI) for 1 hit  
\*\*\* CUTTINGS & CAVING ONLY \*\*\*

-----  
AM241 2.6296E-01  
AM243 0.0000E+00  
CF252 1.1598E-14  
CM243 0.0000E+00  
CM244 0.0000E+00  
CM245 0.0000E+00

CM248	2.3237E-08
CS137	2.0726E-03
NP237	7.6122E-05
PA231	2.4936E-09
PB210	3.0864E-09
PM147	1.7776E-15
PU238	1.9421E+00
PU239	3.9448E-01
PU240	6.9201E-02
PU241	1.5811E-02
PU242	4.9544E-02
PU244	1.8757E-14
RA226	6.4693E-09
RA228	6.1663E-07
SR90	9.1989E-04
TH229	1.2425E-05
TH230	4.2647E-07
TH232	6.1663E-07
U233	1.3215E-03
U234	8.3853E-04
U235	1.1995E-06
U236	2.0594E-07
U238	2.0362E-07

radioisotope RELEASE (CI) for 1 hit  
\*\*\* SPALL ONLY \*\*\*

AM241	2.8188E+00
AM243	0.0000E+00
CF252	1.2432E-13
CM243	0.0000E+00
CM244	0.0000E+00
CM245	0.0000E+00
CM248	2.4910E-07
CS137	2.2217E-02
NP237	8.1600E-04
PA231	2.6731E-08
PB210	3.3085E-08
PM147	1.9055E-14
PU238	2.0819E+01
PU239	4.2286E+00
PU240	7.4181E-01
PU241	1.6949E-01
PU242	5.3109E-01
PU244	2.0107E-13
RA226	6.9349E-08
RA228	6.6101E-06
SR90	9.8609E-03
TH229	1.3320E-04
TH230	4.5716E-06
TH232	6.6101E-06
U233	1.4166E-02
U234	8.9887E-03
U235	1.2858E-05
U236	2.2076E-06
U238	2.1828E-06

radioisotope RELEASE (CI) for 1 hit  
\*\*\* TOTAL CUTTINGS & SPALL \*\*\*  
ratio of spall area  
to cuttings area 10.72  
type of blow out: SOLID\_BLOWOUT

AM241	3.0818E+00
AM243	0.0000E+00
CF252	1.3592E-13
CM243	0.0000E+00
CM244	0.0000E+00
CM245	0.0000E+00
CM248	2.7233E-07

Information Only

CS137 2.4290E-02  
NP237 8.9212E-04  
PA231 2.9224E-08  
PB210 3.6172E-08  
PM147 2.0833E-14  
PU238 2.2761E+01  
PU239 4.6231E+00  
PU240 8.1101E-01  
PU241 1.8530E-01  
PU242 5.8064E-01  
PU244 2.1983E-13  
RA226 7.5818E-08  
RA228 7.2267E-06  
SR90 1.0781E-02  
TH229 1.4562E-04  
TH230 4.9981E-06  
TH232 7.2267E-06  
U233 1.5488E-02  
U234 9.8272E-03  
U235 1.4058E-05  
U236 2.4136E-06  
U238 2.3864E-06

\*\*\*\*\*  
(CUSP\_MAIN)

J.W. BERGLUND: SPM2 MAR 95

DIS\_01 LOCAL 00000000

CAMDAT Version 1

QA Records (6):

GENNET C-2.03ZO 03/22/95 14:03:42  
WIPPSLT X-4.00VV 02/24/95 10:37:00  
MATSET C-8.07ZO 03/22/95 14:37:07  
POSTLHS C-4.04VV 03/22/95 14:38:39

CUSP\_PA9 5.03 06/04/96 09:52:46

Number of coordinates per node = 1  
Number of nodes = 7  
Number of element blocks = 6  
Number of elements = 6  
Number of nodes per element = 2  
Number of properties = 14  
Number of attributes = 1  
Number of node sets = 0  
Number of side sets = 0

CUSP\_PA96 CPU time is 0:06 (minute:second)

\*\*\* END OF CUSP\_PA96 \*\*\*  
CUSP\_PA96 5.03 PROD PA96 05/23/96

06/04/96 09:52:46

END OF APPENDIX D

Information Only





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:  
! (Both chains are required input)

!	\\	\\	\\	\\	\\	\\	\\
CHAIN1	PU242 RN222	U238 PO218	TH234 PB214	PA234M BI214	U234 PO214	TH230 PB210	RA226 <
CHAIN2	PU238 PB214	U234 BI214	TH230 PO214	RA226 PB210	RN222 <	PO218	

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

CHAIN3	AM243 TH227	NP239 RA223	PU239 RN219	U235 PO215	TH231 PB211	PA231 BI211	AC227 TL207	<
CHAIN4	CM243 RA223	PU239 RN219	U235 PO215	TH231 PB211	PA231 BI211	AC227 TL207	TH227 PB209	<

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

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

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

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

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 radioisotope data are input:
!
! ...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
!xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
!  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
!
```

**END OF APPENDIX E**

Information Only





!  
 ! ! END\_OF\_MODEL\_INPUT

**RADIONUCLIDE\_DATA**

!GEOMETRY

INV\_AR 1.11520E+05  
 RHW\_AR 1.11520E+05  
 WUF 5.25

!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:  
 ! (Both chains are input)

!	\\	\\	\\	\\	\\	\\	\\
CHAIN1	PU242 RN222	U238 PO218	TH234 PB214	PA234M BI214	U234 PO214	TH230 PB210	RA226 <
CHAIN2	PU238 PB214	U234 BI214	TH230 PO214	RA226 PB210	RN222 <	PO218	

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

CHAIN3	AM243 TH227	NP239 RA223	PU239 RN219	U235 PO215	TH231 PB211	PA231 BI211	AC227 TL207	<
CHAIN4	CM243 RA223	PU239 RN219	U235 PO215	TH231 PB211	PA231 BI211	AC227 TL207	TH227 <	

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

CHAIN5	CF252 AC228 PO212	CM248 TH228 <	PU244 RA224	PU240 RN220	U236 PO216	TH232 PB212	RA228 BI212	
CHAIN6	CM244 RA224	PU240 RN220	U236 PO216	TH232 PB212	RA228 BI212	AC228 PO212	TH228 <	

CHAIN7	CM245 RA225	PU241 AC225	AM241 FR221	NP237 AT217	PA233 BI213	U233 PO213	TH229 PB209	<
--------	----------------	----------------	----------------	----------------	----------------	---------------	----------------	---

CHAIN8 CS137 BA137M <

CHAIN9 PM147 SM147 ND143 <

CHAIN10 SR90 Y90 ZR90 <

! ^ ^ ^ ^ ^ ^ ^



AWT	2.440630E-01	HALFY	1.811013E+01	ACTCNV	8.088299E+04
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*CM245					
AWT	2.450650E-01	HALFY	8.498927E+03	ACTCNV	1.716500E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*CM248					
AWT	2.480720E-01	HALFY	3.390698E+05	ACTCNV	4.250200E+00
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*CS137					
AWT	1.369070E-01	HALFY	2.999975E+01	ACTCNV	8.704300E+04
EPAREL	1.000000E+03	INVCHD	2.070000E+04		
*FR221					
AWT	2.210140E-01	HALFY	9.126364E-06	ACTCNV	1.772400E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*ND143					
AWT	1.430000E-01	HALFY	3.168876E+30	ACTCNV	0.000000E+00
EPAREL	1.000000E+03	INVCHD	0.000000E+00		
*NP237					
AWT	2.370480E-01	HALFY	2.139942E+06	ACTCNV	7.047600E-01
EPAREL	1.000000E+02	INVCHD	6.670000E+01		
*NP239					
AWT	2.390530E-01	HALFY	6.448664E-03	ACTCNV	2.319100E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA231					
AWT	2.310360E-01	HALFY	3.276618E+04	ACTCNV	4.722500E+01
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PA233					
AWT	2.330400E-01	HALFY	7.392988E-02	ACTCNV	2.075100E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA234M					
AWT	2.340430E-01	HALFY	2.224551E-06	ACTCNV	6.866600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB209					
AWT	2.089810E-01	HALFY	3.764625E-04	ACTCNV	4.544100E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB210					
AWT	2.099840E-01	HALFY	2.229938E+01	ACTCNV	7.634800E+04
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PB211					
AWT	2.109890E-01	HALFY	6.863786E-05	ACTCNV	2.468600E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB212					
AWT	2.119920E-01	HALFY	1.213680E-03	ACTCNV	1.389500E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB214					
AWT	2.140000E-01	HALFY	5.095553E-05	ACTCNV	3.278500E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PM147					
AWT	1.469150E-01	HALFY	2.623513E+00	ACTCNV	9.275300E+05
EPAREL	0.000000E+00	INVCHD	5.250000E+02		
*PO212					
AWT	2.119890E-01	HALFY	9.506629E-15	ACTCNV	1.773900E+20
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO213					
AWT	2.129930E-01	HALFY	1.330928E-13	ACTCNV	1.261100E+19
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO214					
AWT	2.139950E-01	HALFY	5.206464E-12	ACTCNV	3.208700E+17
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO215					
AWT	2.149990E-01	HALFY	5.640600E-11	ACTCNV	2.947900E+16
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO216					
AWT	2.160020E-01	HALFY	4.753314E-09	ACTCNV	3.482000E+14
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO218					
AWT	2.180090E-01	HALFY	5.799044E-06	ACTCNV	2.827800E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PU238					
AWT	2.380500E-01	HALFY	8.774619E+01	ACTCNV	1.711500E+04

EPAREL	1.000000E+02	INVCHD	4.240000E+06		
*PU239					
AWT	2.390520E-01	HALFY	2.406445E+04	ACTCNV	6.214600E+01
EPAREL	1.000000E+02	INVCHD	3.920000E+05		
*PU240					
AWT	2.400540E-01	HALFY	6.537392E+03	ACTCNV	2.278100E+02
EPAREL	1.000000E+02	INVCHD	6.930000E+04		
*PU241					
AWT	2.410570E-01	HALFY	1.439937E+01	ACTCNV	1.030000E+05
EPAREL	0.000000E+00	INVCHD	1.930000E+06		
*PU242					
AWT	2.420590E-01	HALFY	3.869198E+05	ACTCNV	3.817100E+00
EPAREL	1.000000E+02	INVCHD	4.910000E+04		
*PU244					
AWT	2.440640E-01	HALFY	8.261261E+07	ACTCNV	1.773100E-02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA223					
AWT	2.230190E-01	HALFY	3.130533E-02	ACTCNV	5.120600E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA224					
AWT	2.240200E-01	HALFY	1.001999E-02	ACTCNV	1.592700E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA225					
AWT	2.250240E-01	HALFY	4.052993E-02	ACTCNV	3.919900E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA226					
AWT	2.260250E-01	HALFY	1.599966E+03	ACTCNV	9.885801E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA228					
AWT	2.280310E-01	HALFY	6.699955E+00	ACTCNV	2.340000E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN219					
AWT	2.190090E-01	HALFY	1.254875E-07	ACTCNV	1.300800E+13
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN220					
AWT	2.200110E-01	HALFY	1.761895E-06	ACTCNV	9.222600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN222					
AWT	2.220180E-01	HALFY	1.046997E-02	ACTCNV	1.538000E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*SM147					
AWT	1.470000E-01	HALFY	1.059355E+11	ACTCNV	2.295400E-05
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*SR90					
AWT	8.990801E-02	HALFY	2.912197E+01	ACTCNV	1.365400E+05
EPAREL	1.000000E+03	INVCHD	9.850002E+03		
*TH227					
AWT	2.270280E-01	HALFY	5.124073E-02	ACTCNV	3.073200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH228					
AWT	2.280290E-01	HALFY	1.913051E+00	ACTCNV	8.195301E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH229					
AWT	2.290320E-01	HALFY	7.339118E+03	ACTCNV	2.126900E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*TH230					
AWT	2.300330E-01	HALFY	7.700370E+04	ACTCNV	2.018300E+01
EPAREL	1.000000E+01	INVCHD	0.000000E+00		
*TH231					
AWT	2.310360E-01	HALFY	2.911247E-03	ACTCNV	5.315200E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH232					
AWT	2.320380E-01	HALFY	1.405080E+10	ACTCNV	1.096500E-04
EPAREL	1.000000E+01	INVCHD	6.110000E-01		
*TH234					
AWT	2.340440E-01	HALFY	6.597601E-02	ACTCNV	2.315200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TL207					
AWT	2.069770E-01	HALFY	9.069325E-06	ACTCNV	1.904500E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		

```
*U233
  AWT      2.330400E-01  HALFY      1.585072E+05  ACTCNV      9.678300E+00
  EPAREL    1.000000E+02  INVCHD      1.310000E+03
*U234
  AWT      2.340410E-01  HALFY      2.445105E+05  ACTCNV      6.247300E+00
  EPAREL    1.000000E+02  INVCHD      0.000000E+00
*U235
  AWT      2.350440E-01  HALFY      7.038074E+08  ACTCNV      2.161100E-03
  EPAREL    1.000000E+02  INVCHD      1.150000E+00
*U236
  AWT      2.360460E-01  HALFY      2.341483E+07  ACTCNV      6.468300E-02
  EPAREL    1.000000E+02  INVCHD      0.000000E+00
*U238
  AWT      2.380510E-01  HALFY      4.468115E+09  ACTCNV      3.361100E-04
  EPAREL    1.000000E+02  INVCHD      2.010000E-01
*Y90
  AWT      8.990701E-02  HALFY      7.301091E-03  ACTCNV      5.446300E+08
  EPAREL    0.000000E+00  INVCHD      0.000000E+00
*ZR90
  AWT      9.000000E-02  HALFY      3.168876E+30  ACTCNV      0.000000E+00
  EPAREL    1.000000E+03  INVCHD      0.000000E+00
END_TABLES>
!
!  END_OF_RADIOISOTOPE_INPUT
!
```

END OF APPENDIX F

Information Only

## APPENDIX G: SAMPLE COMMAND FILE FOR PRE\_CUTTINGS

This command file exercises PRE\_CUTTINGS.

```
$!@CUSP_RUN_PRE_CUTTINGS.COM
$!
$ ON control_y THEN goto TERMINATE
$ ON control_c THEN goto TERMINATE
$ ON error THEN goto TERMINATE
$!
$!
$! The production executable
$!
$! DEFINE CUSP$EXE WP$PRODROOT:[CUSP.EXE]CUSP_PA96.EXE
$!
$!
$! This sets CUSP into the pre_cuttings mode
$!
$! DEFINE CUSP$PRE_CUTTINGS TRUE
$!
$!
$! Input files required by PRE_CUTTINGS
$!
$! This file is a template to reference the WIPP CMS-controlled Data Base
$! It will have the chains and some hardwired numbers which
$! can be found in the theoretical manual.
$! The file will be placed into CMS CUSP
$!
$! DEFINE/NOLOG CUSP_INP$CDB CUSP_TEST_1.CDB
$!
$! DEFINE/NOLOG CUSP_INP$TXT1 CUSP_TEST_1.INP
$!
$! DEFINE/NOLOG CUSP_INP$SDB CUSP_CCA_TEMPLATE.INP
$!
$! DEFINE/NOLOG CUSP_INP$DESC CUSP_CCA.SDB
$!
$!
$! A summary of the results of the pre_cuttings
$!
$! DEFINE/NOLOG CUSP_OUT$DBG PRE_CUSP_OUTPUT.DBG
$!
$!
$! The output ASCII file that is read by all production runs
$!
$! DEFINE/NOLOG CUSP_OUT$DB_ASC CUSP_CCA_SDB.ASC
$!
$!
$! The output BINARY file that could be read by all the production runs
$! ^^^^^
$!
$! DEFINE/NOLOG CUSP_OUT$DB_BIN -
$! CUSP_INPUT.BINARY
$!
$!
$! CUSP := $CUSP$EXE
$!
$!
$! CUSP
$!
$!
$! TERMINATE:
$!
$! Turn off pre_cuttings mode
$!
$! DEASSIGN CUSP$PRE_CUTTINGS
$!
$! DEASSIGN CUSP_INP$CDB
```

```
$ DEASSIGN      CUSP_INP$TXT1  
$ DEASSIGN      CUSP_INP$SDB  
$ DEASSIGN      CUSP_OUT$DB_ASC  
$ DEASSIGN      CUSP_OUT$DB_BIN  
$!  
$TERMINATE:  
$ EXIT
```

**END OF APPENDIX G**

**Information Only**

## APPENDIX H: SAMPLE CHECK\_OUT PROBLEMS

This file includes a command file that exercises CHECK\_OUT and a sequence of actual input control files associated with selected applications of interest.

### General Purpose ".COM" file to run CHECK\_OUT modes

```
!@CUSP_CHECK_OUT.COM "p1"
$!
$! 'p1' > Check_Out Type
$!
$! Where 'p1': CALIBRATE
$!             EXPERIMENT
$!             VALIDATE
$!
$!
$! ON control_y THEN goto TERMINATE
$! ON control_c THEN goto TERMINATE
$! ON error     THEN goto TERMINATE
$!
$!
$! LIBCUSP
$!
$! Clea up any preexisting logicals
$!
$! IF F$SEARCH("CUSP_DEASSIGN.COM") .eqs. "" -
$!     THEN CFE CUSP_DEASSIGN.COM ""
$!
$! @CUSP_DEASSIGN
$!
$! IF F$SEARCH("CUSP$EXE") .eqs. ""
$! THEN
$!
$!     IF F$SEARCH("CUSP_TEST_SETUP_CUSP.COM") .eqs. "" -
$!         THEN CFE CUSP_TEST_SETUP_CUSP.COM ""
$!
$! @CUSP_TEST_SETUP_CUSP
$!
$! ENDIF
$!
$! DEFINE CUSP$CHECK_OUT TRUE
$!
$! Input files required by CUSP$CHECK_OUT
$!
$! DEFINE/NOLOG CUSP_INP$TXT0 CUSP_CHECK_OUT.DAT
$! DEFINE/NOLOG CUSP_INP$TXT1 CUSP_'p1'.INP
$!
$! Output files required by CUSP$CHECK_OUT
$!
$! DEFINE/NOLOG CUSP_OUT$NVERIFY CUSP_'p1'.VER
$! DEFINE/NOLOG CUSP_OUT$PLT1 CUSP_'p1'.PLT
$!
$!
$! CUSP := $CUSP$EXE
$!
$! CUSP
$!
$! DEASSIGN CUSP$CHECK_OUT
$!
$! DEASSIGN CUSP_INP$TXT0
$! DEASSIGN CUSP_INP$TXT1
```

```
$ DEASSIGN CUSP_OUT$NVERIFY  
$ DEASSIGN CUSP_OUT$PLT1  
$!  
$!  
$TERMINATE:  
$!  
$ EXIT
```

**Input file for: CALIBRATE**

```
!  
! TEST_FUNCT  
!  
CALIBRATE  
  
FSEMIN      10.0  
  
DELFS      5.0  
  
IFSE        3  
  
FGEMIN      10.0  
  
DELFG      10.0  
  
JFGE        3  
  
FCEMIN      0.0  
  
DELFC      0.0  
  
KFCE        0  
  
ITMAX       200  
  
DELERR      0.01  
  
POROST      0.40  
  
START_SEARCH  
.000151 .01021 2.133 394379. .0007221 .261 295. 85151. #28  
.000151 .01021 2.133 290958. .0005760 .261 295. 85151. #28  
.000151 .01021 2.133 290958. .0005057 .262 295. 84805. #29  
.000151 .01021 2.133 290958. .0006104 .279 296. 84048. #30  
.000151 .01021 2.133 222010. .0004148 .262 295. 84805. #29  
.000151 .01021 2.133 222010. .0004817 .261 295. 85151. #28  
.000151 .01021 2.133 222010. .0004800 .279 296. 84048. #30  
.000151 .01021 2.133 153064. .0003005 .262 295. 84805. #29  
.000151 .01021 2.133 153064. .0003642 .261 295. 85151. #28  
.000151 .01021 2.133 153064. .0003444 .279 296. 84048. #30  
.000151 .01021 2.133 118590. .0001261 .262 295. 84805. #29  
.000151 .01021 2.133 118590. .0000663 .261 295. 85151. #28  
.000151 .01021 2.133 118590. .0001740 .279 296. 84048. #30
```

**Input file for: EXPERIMENT**

```
!  
! TEST_FUNCT  
!  
EXPERIMENT  
  
DIA 0.3110  
  
PARTMIN 0.0002 PARTMAX 0.2 PARTMUL 1.5  
  
SAT 0.3
```











! chain1/chain2 from U234 & down are the same:  
 ! (Both chains are required input)

!		\/	\/	\/	\/	\/	\/	\/
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	<	

! 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	PB209	<

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 are input:  
 !  
 ! ...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
!xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
!  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      5.802700E+07
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*AC227
  AWT      2.270280E-01  HALFY      2.177335E+01  ACTCNV      7.232300E+04
  EPAREL   1.000000E+02  INVCHD     0.000000E+00
*AC228
  AWT      2.280310E-01  HALFY      6.993710E-04  ACTCNV      2.241700E+09
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*AM241
  AWT      2.410570E-01  HALFY      4.322347E+02  ACTCNV      3.431200E+03
  EPAREL   1.000000E+02  INVCHD     2.400000E+05
*AM243
  AWT      2.430610E-01  HALFY      7.380313E+03  ACTCNV      1.992900E+02
  EPAREL   1.000000E+02  INVCHD     0.000000E+00
*AT217
  AWT      2.170050E-01  HALFY      1.023547E-09  ACTCNV      1.609500E+15
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*BA137M
  AWT      1.369070E-01  HALFY      4.851550E-06  ACTCNV      5.382400E+11
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*BI211
  AWT      2.109870E-01  HALFY      4.049824E-06  ACTCNV      4.184000E+11
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*BI212
  AWT      2.119910E-01  HALFY      1.151253E-04  ACTCNV      1.464800E+10
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*BI213
  AWT      2.129940E-01  HALFY      8.679553E-05  ACTCNV      1.933800E+10
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*BI214
  AWT      2.139990E-01  HALFY      3.783638E-05  ACTCNV      4.415300E+10
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*CF252
  AWT      2.520820E-01  HALFY      2.638090E+00  ACTCNV      5.375899E+05
  EPAREL   0.000000E+00  INVCHD     2.960000E+03
*CM243
  AWT      2.430610E-01  HALFY      2.850088E+01  ACTCNV      5.160700E+04
  EPAREL   1.000000E+02  INVCHD     0.000000E+00
*CM244
  AWT      2.440630E-01  HALFY      1.811013E+01  ACTCNV      8.088299E+04
  EPAREL   0.000000E+00  INVCHD     0.000000E+00
*CM245
  AWT      2.450650E-01  HALFY      8.498927E+03  ACTCNV      1.716500E+02
  EPAREL   1.000000E+02  INVCHD     0.000000E+00
*CM248
  AWT      2.480720E-01  HALFY      3.390698E+05  ACTCNV      4.250200E+00
  EPAREL   1.000000E+02  INVCHD     0.000000E+00
*CS137
  
```

AWT	1.369070E-01	HALFY	2.999975E+01	ACTCNV	8.704300E+04
EPAREL	1.000000E+03	INVCHD	2.070000E+04		
*FR221					
AWT	2.210140E-01	HALFY	9.126364E-06	ACTCNV	1.772400E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*ND143					
AWT	1.430000E-01	HALFY	3.168876E+30	ACTCNV	0.000000E+00
EPAREL	1.000000E+03	INVCHD	0.000000E+00		
*NP237					
AWT	2.370480E-01	HALFY	2.139942E+06	ACTCNV	7.047600E-01
EPAREL	1.000000E+02	INVCHD	6.670000E+01		
*NP239					
AWT	2.390530E-01	HALFY	6.448664E-03	ACTCNV	2.319100E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA231					
AWT	2.310360E-01	HALFY	3.276618E+04	ACTCNV	4.722500E+01
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PA233					
AWT	2.330400E-01	HALFY	7.392988E-02	ACTCNV	2.075100E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PA234M					
AWT	2.340430E-01	HALFY	2.224551E-06	ACTCNV	6.866600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB209					
AWT	2.089810E-01	HALFY	3.764625E-04	ACTCNV	4.544100E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB210					
AWT	2.099840E-01	HALFY	2.229938E+01	ACTCNV	7.634800E+04
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*PB211					
AWT	2.109890E-01	HALFY	6.863786E-05	ACTCNV	2.468600E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB212					
AWT	2.119920E-01	HALFY	1.213680E-03	ACTCNV	1.389500E+09
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PB214					
AWT	2.140000E-01	HALFY	5.095553E-05	ACTCNV	3.278500E+10
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PM147					
AWT	1.469150E-01	HALFY	2.623513E+00	ACTCNV	9.275300E+05
EPAREL	0.000000E+00	INVCHD	5.250000E+02		
*PO212					
AWT	2.119890E-01	HALFY	9.506629E-15	ACTCNV	1.773900E+20
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO213					
AWT	2.129930E-01	HALFY	1.330928E-13	ACTCNV	1.261100E+19
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO214					
AWT	2.139950E-01	HALFY	5.206464E-12	ACTCNV	3.208700E+17
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO215					
AWT	2.149990E-01	HALFY	5.640600E-11	ACTCNV	2.947900E+16
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO216					
AWT	2.160020E-01	HALFY	4.753314E-09	ACTCNV	3.482000E+14
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PO218					
AWT	2.180090E-01	HALFY	5.799044E-06	ACTCNV	2.827800E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*PU238					

AWT	2.380500E-01	HALFY	8.774619E+01	ACTCNV	1.711500E+04
EPAREL	1.000000E+02	INVCHD	4.240000E+06		
*PU239					
AWT	2.390520E-01	HALFY	2.406445E+04	ACTCNV	6.214600E+01
EPAREL	1.000000E+02	INVCHD	3.920000E+05		
*PU240					
AWT	2.400540E-01	HALFY	6.537392E+03	ACTCNV	2.278100E+02
EPAREL	1.000000E+02	INVCHD	6.930000E+04		
*PU241					
AWT	2.410570E-01	HALFY	1.439937E+01	ACTCNV	1.030000E+05
EPAREL	0.000000E+00	INVCHD	1.930000E+06		
*PU242					
AWT	2.420590E-01	HALFY	3.869198E+05	ACTCNV	3.817100E+00
EPAREL	1.000000E+02	INVCHD	4.910000E+04		
*PU244					
AWT	2.440640E-01	HALFY	8.261261E+07	ACTCNV	1.773100E-02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA223					
AWT	2.230190E-01	HALFY	3.130533E-02	ACTCNV	5.120600E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA224					
AWT	2.240200E-01	HALFY	1.001999E-02	ACTCNV	1.592700E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA225					
AWT	2.250240E-01	HALFY	4.052993E-02	ACTCNV	3.919900E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RA226					
AWT	2.260250E-01	HALFY	1.599966E+03	ACTCNV	9.885801E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*RA228					
AWT	2.280310E-01	HALFY	6.699955E+00	ACTCNV	2.340000E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN219					
AWT	2.190090E-01	HALFY	1.254875E-07	ACTCNV	1.300800E+13
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN220					
AWT	2.200110E-01	HALFY	1.761895E-06	ACTCNV	9.222600E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*RN222					
AWT	2.220180E-01	HALFY	1.046997E-02	ACTCNV	1.538000E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*SM147					
AWT	1.470000E-01	HALFY	1.059355E+11	ACTCNV	2.295400E-05
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*SR90					
AWT	8.990801E-02	HALFY	2.912197E+01	ACTCNV	1.365400E+05
EPAREL	1.000000E+03	INVCHD	9.850002E+03		
*TH227					
AWT	2.270280E-01	HALFY	5.124073E-02	ACTCNV	3.073200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH228					
AWT	2.280290E-01	HALFY	1.913051E+00	ACTCNV	8.195301E+05
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH229					
AWT	2.290320E-01	HALFY	7.339118E+03	ACTCNV	2.126900E+02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*TH230					
AWT	2.300330E-01	HALFY	7.700370E+04	ACTCNV	2.018300E+01
EPAREL	1.000000E+01	INVCHD	0.000000E+00		
*TH231					

AWT	2.310360E-01	HALFY	2.911247E-03	ACTCNV	5.315200E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TH232					
AWT	2.320380E-01	HALFY	1.405080E+10	ACTCNV	1.096500E-04
EPAREL	1.000000E+01	INVCHD	6.110000E-01		
*TH234					
AWT	2.340440E-01	HALFY	6.597601E-02	ACTCNV	2.315200E+07
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*TL207					
AWT	2.069770E-01	HALFY	9.069325E-06	ACTCNV	1.904500E+11
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*U233					
AWT	2.330400E-01	HALFY	1.585072E+05	ACTCNV	9.678300E+00
EPAREL	1.000000E+02	INVCHD	1.310000E+03		
*U234					
AWT	2.340410E-01	HALFY	2.445105E+05	ACTCNV	6.247300E+00
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*U235					
AWT	2.350440E-01	HALFY	7.038074E+08	ACTCNV	2.161100E-03
EPAREL	1.000000E+02	INVCHD	1.150000E+00		
*U236					
AWT	2.360460E-01	HALFY	2.341483E+07	ACTCNV	6.468300E-02
EPAREL	1.000000E+02	INVCHD	0.000000E+00		
*U238					
AWT	2.380510E-01	HALFY	4.468115E+09	ACTCNV	3.361100E-04
EPAREL	1.000000E+02	INVCHD	2.010000E-01		
*Y90					
AWT	8.990701E-02	HALFY	7.301091E-03	ACTCNV	5.446300E+08
EPAREL	0.000000E+00	INVCHD	0.000000E+00		
*ZR90					
AWT	9.000000E-02	HALFY	3.168876E+30	ACTCNV	0.000000E+00
EPAREL	1.000000E+03	INVCHD	0.000000E+00		

END\_TABLES>

!

! END\_OF\_RADIOISOTOPE\_INPUT

!

!

!

-----  
END OF CUSP\_TEST\_INP\_CH\_REPOSITORY.DAT  
-----

\*\*\*\*\*

The input file listed above was designed specifically to apply to WIPP-site calculations. In principle, CUTTINGS\_S could be applied to other sites, although no such applications are foreseen for regulatory calculations. As a convenience to users, the list below specifies those parameters that could be changed to reflect sites other than the WIPP. It is not to be regarded as part of the code's QA documentation.

!Repository Geometry

VARIABLE\_name <default value> Only capitalized portion of name is  
or required  
VARI MATERIAL\_NAME:PROPERITY\_NAME fetch input from CDB file

!Repository Data/Input

INV\_Area <no default> - Area of repository according to the  
WIPP TRU waste type (CH or RH)  
[REAL].

INV\_AR MATERIAL\_NAME:PROPERITY\_NAME fetch input from CDB file

OUT\_MAT <no default> - The CAMDAT material region to  
which CUTTINGS\_S output variables  
are written (CHARACTER\*8).

RADWAS <CONTACT\_handled> - Type of radioisotope waste form (CHARACTER). Valid  
reposes are:

REMOte\_handled; WIPP Remote-Handled (RH) TRU waste,  
CONtact\_handled; WIPP Contact-Handled (CH) TRU waste,

or

INEL\_wincO; INEL/WINCO HLW/SNF waste(s).

CHAIN <no default> rad\_name\_1, rad\_name\_2, rad\_name\_3, ... <

A list of all the radioisotope names in a decay chain. The order of the list is from parent to daughter, ..., terminating at a stable element. Repeat the CHAIN keyword and list of radioisotopes for as many chains as desired. The half-lives, atomic weights, activity conversions, EPA release limits, and waste-unit information will be retrieved from the generic radioisotope data base. The inventory (in Curies) of each radioisotope will be extracted from the secondary database (CHARACTER).

SAVE <all unique radioisotopes> rad\_name\_1, rad\_name\_2, rad\_name\_3, ... <

A list of all unique radioisotope names for which values are to be written to the output CAMDAT and to the debug/diagnostics file. As a default, all unique radioisotope values will be stored/saved to the output CAMDAT and the debug/diagnostics file.

REP\_NAME <WIPP> - Name of the repository (CHARACTER). Other valid  
responses are: INEL/WINCO.

REP\_GEOLOGY <SALT> - Repository geologic medium (CHARACTER). Other  
valid responses are: HALITE, or GRANITE.

DISPOSAL\_group <1> - Waste Disposal Group number (INTEGER). Valid  
waste-disposal group numbers are from 1 to 5. If NAME=WIPP, and GEOLOGY=SALT, the  
waste-disposal group number is not used. By specifying a WDG number, radioisotope  
inventory data is accessed from the Secondary Database according to the WDG number.

Do not specify PACKAge\_id !!

PACKAge\_id <1> - Waste Package ID (INTEGER). Valid waste package  
(WP) IDs are from 1 to 26. If NAME=WIPP, and GEOLOGY=SALT, the waste package ID is

Information Only

not used. By specifying a WP ID, Radioisotope inventory data is accessed from the Secondary Database according to the WP ID.

Do not specify DISPOSal\_group !!

**END OF APPENDIX I**

**Information Only**

## APPENDIX J: EXAMPLE OF THE INPUT FILE: CUSP\_INP\$TXT1

This input file provides various data relevant to the drilling equations and the intrusion time. Because it is designed for a regulatory-type calculation, it does not list specific numerical values for the various parameters. Rather, it identifies them by name (see Appendix C, item 4, for an explanation of input-file formats). Numerical values are then copied over from the input CDB files. This file is discussed in Section 6.1 above as file number 3.

Definitions of the various parameters used in this input file are given at the end of Appendix J.

```
-----  
                BEGINNING      OF      A      PRODUCTION - LIKE      INPUT      FILE  
-----  
!  
!   Intrusion  
!  
TINTR          100.0  
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  
  
!  
!   Bragflow  
!  
!   Multiple hits (max of 10, 0 thru 9)  
!  
!   MHIT_0      is associated with the hit that  
!               CUTTINGS used for BRAG flow properties  
!  
  
INTR_0  CAVITY_1  <  
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  <  
  
!  
!   Spallings  
!  
MODEL3  
  
!   Properties for Model 3  
  
PTHRESH  WAS_AREA:PTHRESH  
VOLSPALL WAS_AREA:VOLSPALL  
REPPRES  CAVITY_1  <  
  
OR (MODEL 4)  
  
MODEL4
```

REPPR\_NM PRES GAS  
REPPRES CAVITY\_1 <  
RNDSPALL DUM5 : RNDSPALL  
PTHRESH DUM5 : PTH

---

END OF PRODUCTION - LIKE INPUT FILE

---

END OF APPENDIX J

Information Only

## APPENDIX K: EXAMPLE OF THE INPUT FILE: CUSP\_INP\$TXT1 FOR A TEST RUN

This input file provides various data relevant to the drilling equations and the intrusion time. Because it is designed for a test run, specific numerical values are defined for each of the various parameters. The file is stored in the CMS portion of the WIPP Alpha cluster under the name: CUSP\_TEST\_2.INP. Corresponding input files for the other test problems may be found by replacing the number 2 in the file's name by the problem number of interest. This file is discussed in Section 6.1 above as file number 3.

Definitions of the various parameters used in this input file are given at the end of this appendix.

```
-----  
                BEGINNING      OF      A      TEST - LIKE      INPUT      FILE  
-----  
!  
! TEST PROBLEM 2, STUCK PIPE  
!  
! INTRUSION  
  
TINTR          2000.0  
DIAMMOD        0.3556  
PRESSURE       12.5E6  
TCLOUT         6.40E4  
  
!  
! Initial porosity is required, hence two entries  
!  
POROSITY       0.88          0.070405  
  
! PROPERTIES  
  
DNSFLUID       0.1210E+04  
DOMEGA         0.7800E+01  
VISCO          0.9170E-02  
YLDSTRSS      0.4400E+01  
ABSROUGH       0.2500E-01  
TAUFAIL       8.1120E+00  
  
-----  
                END            OF            A            TEST - LIKE            INPUT            FILE  
-----
```

Explanation of Input Parameters Used in Appendices J and K

In the list that follows, two entries are made for each listing. The first applies to a test-like input file such as the one given in Appendix E. The second applies to a regulatory-calculation-like input file such as the one given in Appendix D. Both pertain to drilling and intrusion parameters.

VARIABLE\_name <default values> Only capitalized portion of name is  
or required  
VARI MATERIAL\_NAME:PROPERITY\_NAME fetch input from CDB file

Drilling Parameters

DENSITY <1.210E+03> - Density of the drilling fluid (mud) in kg/m<sup>3</sup>.  
or  
DENS MATERIAL\_NAME:PROPERITY\_NAME

DOMEGA <0.7800E+01> - Angular velocity of the drill string in rad/s.  
or  
DOME MATERIAL\_NAME:PROPERITY\_NAME

ROUGH <.0250> - Absolute borehole roughness (m)  
or  
ROUGH MATERIAL\_NAME:PROPERITY\_NAME

TAUFail <0.1000E+03> - Effective shear resistance to erosion (Pa).  
or  
TAUF MATERIAL\_NAME:PROPERITY\_NAME

VISCO <0.9170E-02> - Plastic viscosity of drilling mud  
or associated with an Oldroyd type fluid model (Pa-s)  
(zero shear-rate viscosity).  
VISC MATERIAL\_NAME:PROPERITY\_NAME

YLDStrss <0.4400E+01> - Yield Stress of the drilling fluid (mud) (Pa).  
or  
YLDS MATERIAL\_NAME:PROPERITY\_NAME

Intrusion Parameters

VARIABLE\_name <default value> Only capitalized portion of name is  
or required  
VARI MATERIAL\_NAME:PROPERITY\_NAME fetch input from CDB file  
or if nhits .gt. 1 (testing mode), then  
VARI variable(1) variable(2) ... variable(nhits)

UNITS <SEC> - Type of time units that  
UNITS the times of intrusions  
are specified [CHARACTER].  
Valid responses are:  
YEARS or SECONDS.

NHITS <1> - Number of intrusions [REAL]\*.  
NHITS

\* [REAL] signifies a real, floating-point number.

DBDIAM <0.5080E+00> - Drilling bit diameter (m); (outside diameter of drill-string annulus) corresponding to the first intrusion time [REAL].  
or  
DBDIAM MATERIAL\_NAME:PROPERITY\_NAME  
or  
DBDIAM(nhits)

TINTR <> - First intrusion time (m) [REAL].  
or  
TINTR MATERIAL\_NAME:PROPERITY\_NAME  
or  
TINTR(nhits)

TCLOUT <> - Clean-out time\*\* (s) [REAL].  
or  
TCLOUT MATERIAL\_NAME:PROPERITY\_NAME  
or  
TCLOUT(nhits)

PARTDIA <> - Particle diameter (m) [REAL].  
or  
PARTDIA(nhits)

Note!!! The following two parameters are NOT required if a BRAGFLO CDB file is attached.

POROSITY <> - Porosity at time of intrusion (unitless) [REAL].  
or  
POROSITY MATERIAL\_NAME:PROPERITY\_NAME  
or  
POROSITY(nhits)

PRESSure <> - Repository pressure at time of intrusion (Pa) [REAL].  
or  
PRESS MATERIAL\_NAME:PROPERITY\_NAME  
or  
PRESS(nhits)

Note!!! The preceding two parameters are NOT required if a BRAGFLO CDB file is attached.

## END OF APPENDIX K

---

\*\* Clean-out time is the time required to replace all of the borehole drilling fluid at the present pumping rate.

534000



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**Jennifer Long**  
SCM Coordinator

Date: February 25, 2004

To: SNL WIPP Records Center  
Carlsbad Programs Group

From: Jennifer Long  
SCM Coordinator

A handwritten signature in cursive script that reads "Jennifer Long".

Subject: Record Correction to User's Manual Criteria Form and Cover Sheet for CUTTINGS\_S Version 5.10

Please disregard the User's Manual Criteria Form and Cover Page for CUTTINGS\_S Version 5.10 and replace with the attached User's Manual Criteria Form and Cover Page. The originals incorrectly listed the Document Version as 1.00. The correct Document Version is 5.10.

Cc: C. Hansen

WIPP:1.5.1:SFT:QA-L:532334

Appendix G

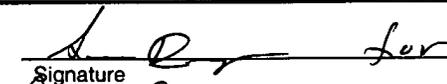
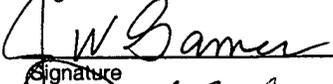
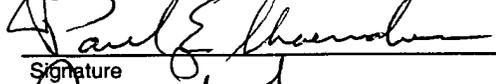
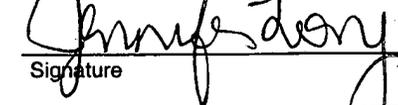
<b>NUCLEAR WASTE MANAGEMENT PROGRAM</b>  Sandia National Laboratories	<h2 style="margin: 0;">User's Manual Criteria Form</h2>	Form Number: <b>NP 19-1-6</b>  Page 1 of 1
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**Does the user's manual contain as appropriate:**

1. <b>Software Name:</b>	<u>CUTTINGS_S</u>	
2. <b>Software Version:</b>	<u>5.10</u>	
3. <b>Document Version:</b>	<u><del>1.00</del> 5.10 2/25/04</u>	
4. <b>ERMS #:</b>	<u>532340</u>	

Prior to sign-off of the User's Manual, all items shall be appropriately addressed by the code sponsor so that "Yes" or "N/A" may be checked. Include this form as part of the User's Manual.

5. A statement(s) of functional requirements (consistent with those in the RD) and system limitations?	<input checked="" type="checkbox"/>	Yes
6. An explanation of the mathematical model and numerical models, where applicable as based on code functionality?	<input checked="" type="checkbox"/>	Yes <input type="checkbox"/> N/A
7. Physical and mathematical assumptions, where applicable as based on code functionality?	<input checked="" type="checkbox"/>	Yes <input type="checkbox"/> N/A
8. The capabilities and limitations inherent in the software?	<input checked="" type="checkbox"/>	Yes
9. Instructions that describe the user's interaction with the software?	<input checked="" type="checkbox"/>	Yes
10. The identification of input parameters, formats, and valid ranges?	<input checked="" type="checkbox"/>	Yes
11. Messages initiated as a result of improper input and how the user can respond?	<input checked="" type="checkbox"/>	Yes
12. The identification and description of output specifications and formats?	<input checked="" type="checkbox"/>	Yes
13. A description of any required training necessary to use the software?	<input checked="" type="checkbox"/>	Yes
14. The identification of components of the code that were not tested?	<input checked="" type="checkbox"/>	Yes

15. <u>Cliff Hansen</u> <b>Code Team/Sponsor</b> (print)	<u></u> Signature	<u>10/22/03</u> Date
16. <u>James Garner</u> <b>Technical Reviewer</b> (print)	<u></u> Signature	<u>10/22/03</u> Date
17. <u>David Kessel</u> <b>Responsible Manager</b> (print)	<u></u> Signature	<u>10/22/03</u> Date
18. <u>Jennifer Long</u> <b>SCM Coordinator</b> (print)	<u></u> Signature	<u>10/22/03</u> Date

**Key for check boxes above:**

Check <b>Yes</b> for each item reviewed and found acceptable
Check <b>N/A</b> for items not applicable, where applicable as based on code functionality

Information Only

**WIPP PA**

**User's Manual**

**for**

**CUTTINGS\_S, Version 5.10**

**DOCUMENT VERSION 5.10**

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**OCTOBER 2003**

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**Janis Trone**  
Member of Technical Staff

Date: May 27, 2004

To: SNL WIPP Records Center  
Carlsbad Programs Group

A handwritten signature in cursive script that reads "Janis Trone".

From: Janis Trone  
Member of Technical Staff

Subject: Record Correction to User's Manual for CUTTINGS\_S Version 5.10

Please replace pages 8-10, 14-15, 17 – 19 and 152- 153 of the User's Manual for CUTTINGS\_S Version 5.10 with the attached pages. The attached pages contain change bars beside text which was revised, rather than the hand edits in red ink found in the original pages.

This page change correction is in response to Finding 1 of the February 24-26, 2004 EPA Audit of SNL.

Cc: C. Hansen  
J. Long

WIPP:1.5.1:SFT:QA-L:532334

## 4.0 DESCRIPTION OF THE MODEL AND METHODS

The discussion of the model and methods given below is but a brief overview of the theory and methods employed by CUTTINGS\_S. It is intended for users who have only a cursory interest in the mathematical and fluid dynamical details. A thorough, detailed treatment of the theory and numerics applied in CUTTINGS\_S is given in Appendix A of this manual.

### 4.1 Description of the Model

CUTTINGS\_S is a multi-faceted computational procedure to assess the effects of direct removal of wastes buried in a WIPP-like nuclear-waste repository. Direct removal is hypothesized to occur as the result of inadvertent penetration of the repository by a borehole drilled in connection with oil or gas exploration at some unknown time in the future (Berglund, 1993). The word "direct" refers to the fact that CUTTINGS\_S removals from the repository to the surface occur at the time of drilling. Since drilling operations are normally completed on the time scale of weeks, removal of drilled wastes from the repository to the surface (i.e., the accessible environment) takes place entirely within a single timestep of the much-longer-term groundwater transport codes. Hence, the word "direct" should be taken to mean "from the repository to the surface within a single timestep of a typical WIPP groundwater code."

Removal is subdivided according to process, which results in three principal categories, cuttings, cavings, and spallings.

First, the borehole is assumed to penetrate directly through waste containers stored within the repository. The drill bit cuts directly through the waste containers, allowing those repository wastes located on a collision course with the drill bit (called cuttings) to be transported directly and immediately to the surface via the cooling fluid (muddy brine) that is circulated through the borehole during drilling. The volume of repository material removed as cuttings is the portion of the deformed repository cut by the borehole.

Wastes that originally bordered the borehole on its exterior are permitted to erode into the cooling fluid as a result of the fluid's frictional effects on the outer cylindrical surface of the borehole. If shear stresses in the cooling fluid at the wall exceed the shear strength of the matrixed materials located at the wall, erosion will occur and wall material (cavings) will be removed\*. As a result, the borehole diameter may increase locally at the level of the repository. Because of that action, the volume of wastes removed from the repository can actually be larger than the volume of the borehole originally cut through the wastes. As the diameter of the borehole increases, the fluid shear stresses at the outer boundary decrease. If they decrease enough that the failure stress of the wall material equals or exceeds the fluid shear stress at the outer boundary of the flow region, then the caving process will terminate. CUTTINGS\_S allows for both laminar and turbulent shear flow in the circulating fluids, which, in turn, leads to two

\* In tightly matrixed or crystalline media such as the WIPP-site halite formation, exploratory boreholes are usually unlined. Rather, the drilling fluid is changed to saturated salt solution to minimize dissolution at the walls, and the borehole is permitted to support itself until the drill bit reaches granular strata below the halite horizon.

different models to assess the effects of material removal due to erosion. If the cooling-fluid flow is laminar, CUTTINGS S employs an analytical solution of the modeling equations to evaluate wall stresses and other flow parameters. The analytical solution takes the form of non-linear integral equations, which CUTTINGS S evaluates via an iterative numerical procedure. If the flow is turbulent, CUTTINGS S turns to a simpler empirical model to evaluate the turbulent shear stresses. Transition to turbulence is assumed to occur at a Reynolds number greater than 2100. In nature, the transition to turbulence actually occurs over a range of Reynolds numbers and is not an abrupt process. Normally there is a transitional regime during which the flow is partly laminar and partly turbulent with active and chaotic transitions between the two states. CUTTINGS S does not attempt to model the transition regime. Rather, it assumes the flow becomes fully and abruptly turbulent when the Reynolds exceeds 2100. CUTTINGS S employs a corrective procedure to compensate for the effects of that assumption (see Appendix A for details). To date, all WIPP-like runs have required turbulent cooling-fluid flow.

The cuttings/cavings model described thus far is functionally similar to the CUTTINGS model used in previous WIPP PAs (WIPP PA Dept, 1992, Vol 1). However, an important new element has been added to the newer CUTTINGS S code, namely, the inclusion of a third material-removal mechanism, removal in the form of spallings, which is discussed below.

If the repository is pressurized at the time of penetration, and if the pressure within the repository is high enough (i.e., above the hydrostatic pressure in the cooling-fluid column), repository materials originally surrounding the borehole, but interior to the repository-fluid interface, can be forced to deform inward toward the borehole so as to replace the materials already removed by action of the cutting bit and the erosive brine. The solid fraction of these materials are called spallings\*. Depending on the parameters of the problem, spalling deformations can be rapid, or they can be a sluggish, more like a large-amplitude, viscoelastic flow. If repository materials are relatively impermeable, the spalled materials can deform slowly inward so as to press against the rotating drill string. If repository pressures are high enough, frictional forces against the drill string may be high enough to stop the drill from turning. In that event, drillers normally withdraw the drill (vertically) and re-drill downward through the spalled materials that clog the borehole. On occasion, that procedure must be repeated more than once. If repository materials are more permeable, the pressurized gas may simply seep through the matrix carrying loose particles with it. Alternatively, if repository pressures are too low, the spallings part of CUTTINGS S may do nothing at all. CUTTINGS S may have to be applied more than once during an assessment run, at more than one intrusion time, since multiple borehole intrusions are permissible in WIPP PAs.

The total volume of repository material removed by CUTTINGS S is the sum over all intrusions of cuttings, cavings, and spallings. Options cuttings and cavings are assumed to operate

\* If the repository is wet with brine at time of penetration, which possibility is allowed in WIPP PAs, three phases of material could, in principle, flow toward the borehole, namely: pressurized gases, pressurized brine, and solid wastes. CUTTINGS\_S estimates only the amount of solids that are moved into the borehole. Pressurized brine that may be released into the borehole is treated by an independent WIPP code named DBR\_BRACFLO. The gas flow, although crucial to the overall deformational process, transports no radioisotopes and is therefore not assessed.

continuously, whereas spallings operates only when repository pressure conditions permit it (the cut off being 8MPa.). The amount of material removed by each process, during each hypothesized drilling intrusion is reported in CUTTINGS S's output in terms of an equivalent area. Downstream WIPP codes, namely CCDFGF, use BRAGFLO's repository-height data to convert the equivalent areas to volumes of repository material, and then assign various sampled aged repository contents to convert these material volumes to releases. Thus, CCDFGF evaluates the release effects of striking contact-handled versus remote-handled wastes. The reader is referred to Appendix A for details.

The fluid-flow portion of CUTTINGS S is based on a non-linear analytical integral solution for laminar helical flow of a non-Newtonian (Oldroyd-type) fluid in an annular pipe, and on empirical equations for turbulent flow in the same geometrical configuration. CUTTINGS S acquires its parameter data from (i) the input CDB files provided by the WIPP codes MATSET and BRAGFLO, (ii) a user-supplied input text file, and (iii) the carefully controlled and QAed WIPP property database. Discrete values of sampled data are provided by the WIPP sampling code POSTLHS in cases where parameter uncertainty is judged to impact assessments of the repository's performance. CUTTINGS S input includes the rotational speed of the drill string, cutting-bit diameter, the shear-rate-dependent viscosity and density parameters for the drilling mud, borehole roughness, the compacted repository thickness and porosity, and the effective failure shear strength of the compacted repository material. A few required parameters, namely drilling-mud flow rate and drill-collar diameter, are calculated internally by the code, based on present-day oil-drilling industry guidelines.

## **4.2 Description of the Modeling Methods**

CUTTINGS\_S does not endeavor to integrate conservation equations characterizing the flow on a point-for-point, time-for-time basis in search of a detailed space-time history of the removal process. Rather, removal is treated as instantaneous, that is, within a single timestep of the longer-term groundwater codes. Thus, numerical methods are used primarily to determine the limiting values of the physical parameters that represent the final configurations of the various (sampled) drilled systems, which is all that is required to assess radioactive waste removal due to the cuttings, cavings, and spallings that arise during drilling operations. These methods are fairly straightforward, iterative, recursive approximation techniques that involve systems of algebraic equations. They are discussed thoroughly in Appendix A (Sections 2.2.1.1, 2.2.2.1, and 2.4.1.2.1), which is highly recommended to readers who aim to understand this code.

where XY:[ABC.DEF.GHI]JKL.MNO represents the specific input file the user wishes to associate with the input logical CUSP\_INP\$CDB. The path need be included only if the file resides other then in the local working-level directory.

## 6.2 CUTTINGS S's Input/Output File Structure

Up to 12 logical symbols may be associated with CUTTINGS S's various input/output files. Of them, 6 are required and 5 are optional in regulatory runs. Before discussing the nature and function of the 12 possible input/output files, we first list them one-by-one, for ready reference, together with their corresponding logical symbols. They are:

File ID No.	Input/Output File Names	Associated Logical Symbol	Is the file Required or Not?
1.	Binary input CAMDAT file (from MATSET)	CUSP_INP\$CDB	Yes
2.	Input control file (text) specifying repository/model parameters, initial inventories, generic radioisotope database.	CUSP_INP\$TXT0	Yes
3.	Input control file (text) specifying drilling and intrusion parameters	CUSP_INP\$TXT1	Yes
4.	BRAGFLO binary output .CDB file.	CUSP_INP\$BRAGCDB	Yes
	Regulatory runs		No
	Test runs		No
5.	Input control file for Spall Model 4 specifying pressures and their volumes by vector	CUSP_SPL4\$DAT	Yes (spall model 4 only)
6.	CUTTINGS S's binary output .CDB file	CUSP_OUT\$CDB	Yes
7.	CUTTINGS S's output debug text file	CUSP_OUT\$DBG	Yes
8.	Text file for verification testing	CUSP_OUT\$NVERIFY	No
9.	Radioisotope inventory history (in CURIES) output text file	CUSP_OUT\$IHISTO	No
10.	Normalized-release-history output text file (EPA 40CFR191, Subpt B) file in ASCII format	CUSP_OUT\$NHISTO	No
11.	Time-history plotting text file for:		
	Long half-life radioisotope decay	CUSP_OUT\$PLT1	No
	Medium half-life radioisotope decay	CUSP_OUT\$PLT2	No
	Short half-life radioisotope decay	CUSP_OUT\$PLT3	No
12.	Output text file for transfer to the WIPP code CCDFPERM	CUSP_OUT\$ICTRN	No

The first five files of the above list are CUTTINGS\_S's input data and control files. They are described briefly in Section 7.0 of this user's manual. The text-format input files include specific examples printed out in full in the appendices of this user's manual. Appendix C is included to assist the user in understanding the format used in CUTTINGS\_S's input control files (file numbers 1 and 2).

The last seven files of the above list are CUTTINGS\_S's output files. They are described briefly in Section 9.0 of this user's manual. Of the required output files, only the debug file is created in text format. One example of a CUTTINGS\_S output file is included in Appendix D. It is a debug file. It is annotated with italicized remarks that identify and explain the various groups of data that are reported therein.

### 6.3 Exercising CUTTINGS\_S

Once the logical symbol CUSP has been defined (see Section 6.1), and the necessary input and output files have been properly assigned (see Sections 6.1 and 6.2), CUTTINGS\_S may be exercised simply by typing the logical symbol:

\$CUSP

followed by a carriage return. If all goes well, CUTTINGS\_S will run and issue a "normal completion" message. If errors are encountered, CUTTINGS\_S will abort and issue an error message(s). See Section 8.0 for a listing of the possible error messages CUTTINGS\_S can produce.

### 6.4 Using CUTTINGS\_S's PRE\_CUTTINGS Mode

Because interactions with the controlled WIPP database require large and unnecessary expenditures of input/output time during production runs, CUTTINGS\_S includes a special operational mode designed to expedite data acquisitions during production runs. It is called PRE\_CUTTINGS, and in it, the WIPP QAed property database is accessed but once during an entire production run. PRE\_CUTTINGS reads a template file that interfaces the WIPP property database, extracting the required values and writing them to an ASCII file that can be read time and again by CUTTINGS\_S without subsequent reference to the property database. The ASCII data file thus produced is under strict CMS control.

PRE\_CUTTINGS's template file, which is shown in Appendix E, treats three data types. The first type is exemplified by CUTTINGS\_S's code parameters, which are discussed in the theoretical Manual (see Appendix A). These values are essential to exercising CUTTINGS\_S, but were not entered as part of the WIPP's CCA controlled database. They are discussed in detail in Appendix A. The second type are common property values as taken from the WIPP's CCA controlled database. For example, the datum BOREHOLE:L1 is called. In this example, the colon at mid word identifies the form as a WIPP controlled database property. BOREHOLE is the material identifier and L1 is the parameter identifier. Using these two keywords, the WIPP

## 7.0 DESCRIPTION OF CUTTINGS\_S'S INPUT FILES

CUTTINGS\_S's input files are listed in Section 6.2 together with their corresponding CUTTINGS\_S logical symbols. They are file numbers 1 through 4 in that listing.

**File 1. CUSP\_INP\$CDB** is the principal input CDB file and is absolutely required by CUTTINGS\_S. It is the file to which CUTTINGS\_S's results will be transferred and it is normally provided by an upstream code such as MATSET. In production runs, sampled data from POSTLHS would be fed to this input file. In that case, there would be N input CDB files, one for each of the sampled values where N is the number of samples employed. In test-case mode or debug mode, it is inconvenient to open the editor and hand build an input CDB file for specific input values. However, even in test or debug mode, CUTTINGS\_S expects to receive an input CDB file. As a convenience to users, an all-purpose, input CDB file for use with test problems and in debug runs is stored in the configuration-management-system (CMS) portion of the WIPP Alpha cluster. It is named: CUSP\_TEST\_1.CDB and can be called by typing:

```
SLIBCUSP
```

```
$CFE CUSP_TEST_1.CDB
```

**File 2. CUSP\_INP\$TXT0** is an ASCII input control file that contains various repository, drill geometry, and material input parameters required by CUTTINGS\_S. File 2 also contains the required radioisotope inventory data for the scenario currently under study. In regulatory calculations, these data are taken directly from the controlled WIPP property database. File 2 also provides radioisotope data essential for (1) the Bateman (1910) decay calculation, for (2) calculation of radioactive release values in Curies, and for (3) normalizing calculated releases in terms of the Environmental Protection Agency's (EPA's) 40CFR191 release limits (WIPP PA Dept [Vol 1], 1992). A sample CUSP\_INP\$TXT0 file usable for QA test and/or debug problems is available in the CMS portion of the WIPP Alpha cluster. It is named: CUSP\_TEST\_REPOSITORY.DAT, and it is printed in full in Appendix I of this user's manual. Most of its parameters are specific to the CUTTINGS\_S model and to individual radioisotopic properties.

**File 3. CUSP\_INP\$TXT1** is an ASCII input control file that contains various drilling and intrusion input parameters required by CUTTINGS\_S. A sample CUSP\_INP\$TXT1 file usable for test and/or debug runs is available in the CMS portion of the WIPP Alpha cluster. It is named CUSP\_TEST\_#.INP where # is the QA test problem number and varies from 1 through 5. In a normal production run, this file would contain no specific input data other than an intrusion time. Instead, only character variables would appear, identifying the element property name on the input CDB file. Values would then be assigned from the secondary database (see item 4, below). Appendix J is sample printout of a typical production input file. For specific testing or debugging, this file would have fixed specific numerical values. Appendix K is a listing of CUSP\_TEST\_2.INP.

This file also identifies which spall model will be used. At the end of the file the model is determined by entering MODEL3 or MODEL4, depending on which model will be used. This is followed by the parameters that are needed for the model. If model three is selected then three parameters will be needed. Model four uses three parameters and one dummy parameter. The parameter PTHRESH is not used in model four. An example of how to call each model and the parameters it requires is below.

```
MODEL3
PTHRESH WAS AREA:PTHRESH
VOLSPALL WAS AREA:VOLSPALL
REPPRES CAVITY 1 <
```

```
MODEL4
REPPR NM PRES GAS
REPPRES CAVITY 1 <
RNDSPALL DUM5:RNDSPALL
PTHRESH DUM5:PTH
```

**File 4. CUSP\_INP\$BRAGCDB** is the output CDB file from BRAGFLO as it is exercised in the undisturbed or disturbed scenarios. CUTTINGS\_S extracts from it (1) the repository porosity at time of decommissioning, and (2) the repository porosity and (3) repository pressure at the specified intrusion time. In regulatory calculations, these data would be provided by a regulatory BRAGFLO run. For QA testing and debug purposes, a fixed BRAGFLO output CDB file has been stored in the CMS portion of the WIPP Alpha cluster. It is named CUSP\_TEST\_INP\_BF.CDB, and it is the BRAGFLO output file used for test problem 1.

**File 5. CUSP\_SPL4\$DAT** is a data file that contains information pertinent to spall model 4. The file supplies the code with pressures and their corresponding data to determine the spall volume. The first line of the file lists the number of vectors in pressure data set. The second line is the number of pressure data sets. The third line lists the different pressures in increasing order separated by blank spaces. The following lines list data relating to each pressure. The first data set is for the first pressure given in line three, the second data set is for the second pressure in line three, and so on. The data sets have three columns of data that are separated by blank spaces. The first column is the vector numbers, the second column is the time (not used), and the third column is the volume. Each of the data sets is followed by a blank line. Each data set must contain the same number of vectors and be in the same order. An example data file is shown below.

```
5
2
10000000 20000000
1 0 1
2 0 1.25
3 0 1.5
4 0 1.75
5 0 2.00
blank
1 0 10
2 0 12.5
```

3	0	15
4	0	17.5
5	0	20
<u>blank</u>		

## 8.0 ERROR MESSAGES

Numerous procedural errors can cause CUTTINGS\_S to abort. In general, these errors relate to the improper input of data. By noting where the code was when the abort occurred, and what the code was trying to read at the time, these problems can generally be resolved. However, there is not specific advice that can be offered to users in resolving errors beyond the general statement: locate the error and repair it. However, Appendix L, which was extracted primarily from the source code, contains useful operating notes and tips to the user. They are included purely because the code sponsor felt they might be useful to novice users.

To familiarize readers with CUTTINGS\_S's error-message patterns, CUTTINGS\_S's various error messages are listed below, section for section within the code.

---

### SUBROUTINE ADDMEM( MORMEMR, MORMEMC )

```
CALL QAABORT(
$ '(ADDMEM) - REAL array size errors detected ****')
CALL QAABORT(
$ '(ADDMEM) - REAL array memory errors detected ****')
CALL QAABORT(
$ '(ADDMEM) - CHARACTER array size errors detected ****')
CALL QAABORT(
$ '(ADDMEM) - CHARACTER array memory errors detected ****')
CALL QAABORT('(ADDMEM1) - REAL array size errors detected ****')
CALL QAABORT('(ADDMEM1) - REAL memory errors detected ****')
CALL QAABORT(
$ '(ADDMEM1) - CHARACTER array size errors detected ****')
CALL QAABORT(
$ '(ADDMEM1) - CHARACTER array memory errors detected ****')
CALL QAABORT('(ADDMEM2) - REAL array size errors detected ****')
CALL QAABORT('(ADDMEM2) - REAL memory errors detected ****')
CALL QAABORT(
$ '(ADDMEM2) - CHARACTER array size errors detected ****')
CALL QAABORT(
$ '(ADDMEM2) - CHARACTER array memory errors detected ****')
CALL QAABORT('(ADDMEM3) - REAL array size errors detected ****')
CALL QAABORT('(ADDMEM3) - REAL memory errors detected ****')
CALL QAABORT(
```

## APPENDIX J: EXAMPLE OF THE INPUT FILE: CUSP\_INP\$TXT1

This input file provides various data relevant to the drilling equations and the intrusion time. Because it is designed for a regulatory-type calculation, it does not list specific numerical values for the various parameters. Rather, it identifies them by name (see Appendix C, item 4, for an explanation of input-file formats). Numerical values are then copied over from the input CDB files. This file is discussed in Section 6.1 above as file number 3.

Definitions of the various parameters used in this input file are given at the end of Appendix J.

```
-----  
          BEGINNING      OF      A      PRODUCTION - LIKE      INPUT      FILE  
-----  
!  
!  Intrusion  
!  
TINTR      100.0  
PARTDIA    BLOWOUT:PARTDIA  
  
!  Properties  
  
TAUFAIL    BOREHOLE:TAUFAIL  
  
DIAMMOD    BOREHOLE:DIAMMOD  
DOMEGA     BOREHOLE:DOMEGA  
DNSFLUID   DRILLMUD:DNSFLUID  
VISCO      DRILLMUD:VISCO  
YLDSTRSS   DRILLMUD:YLDSTRSS  
ABSTROUGH  WAS_AREA:ABSTROUGH  
  
!  
!  Bragflow  
!  
!  Multiple hits (max of 10, 0 thru 9)  
!  
!  MHIT_0 is associated with the hit that  
!  CUTTINGS used for BRAG flow properties  
!  
  
INTR_0    CAVITY_1    <  
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 <  
  
!  
!  Spallings  
!  
  
MODEL3  
  
! Properties for Model 3  
  
PTHRESH   WAS AREA:PTHRESH  
VOLSPALL  WAS AREA:VOLSPALL  
REPPRES   CAVITY_1 <  
  
OR (MODEL 4)
```

MODEL4  
REPPR NM PRESAS  
REPPRES CAVITY 1 <  
RNDSPALL DUM5:RNDSPALL  
PTHRESH DUM5:PTH

-----  
END OF PRODUCTION - LIKE INPUT FILE

**END OF APPENDIX J**

**Information Only**