Appendix E

NUCLEAR WASTE MANAGEMENT PROCEDURE Sandia National Laboratories	**Design Document Criteria**	**Form Number: NP 19-1-4** **Page 1 of 1**

1. **Software Name:** CUTTINGS_S
2. **Software Version:** 6.04
3. **Document Version:** 6.04
4. **ERMS #:** 574596

Prior to sign-off of the DD, all items shall be appropriately addressed by the code sponsor so that "Yes" may be checked. Include this form as part of the DD.

Are the following appropriately defined and documented in the DD?

5. Major Software Components — ☒ Yes
6. Technical description of the software with respect to: theoretical basis, embodied mathematical model, major control flow, control logic, and data structures — ☒ Yes
7. Functionalities and interfaces of object components, functions, and subroutines. — ☒ Yes
8. Allowable or prescribed ranges for inputs and outputs — ☒ Yes
9. Verifiability: Is the design verifiable through testing or other means? — ☒ Yes
10. Consistency and Traceability: Is the design consistent with and traceable to the software's requirements? — ☒ Yes
11. Technical Feasibility: Is the design technically feasible? — ☒ Yes
12. Implementation: Is the design presented in sufficient detail to allow for implementation as computer software? — ☒ Yes

13.	Dwayne Kicker **Code Team/Sponsor** (*print*)	*Signature on File* Signature	3/26/21 Date
14.	L. Michael Feng **Technical Reviewer** (*print*)	*Signature on File* Signature	4/1/2021 Date
15.	Shelly Nielsen **QA Reviewer** (*print*)	Shelly R. Nielsen Signature	4-21-2021 Date
16.	Steve Wagner **Responsible Manager** (*print*)	*Signature on File* Signature	3/26/21 Date
17.	Jennifer Long **SCM Coordinator** (*print*)	*Signature on File* Signature	3/26/21 Date

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Appendix G

NUCLEAR WASTE MANAGEMENT PROCEDURE Sandia National Laboratories	**User's Manual Criteria**	**Form Number: NP 19-1-6** **Page 1 of 1**

Does the User's Manual contain as appropriate:

1. **Software Name:** CUTTINGS_S
2. **Software Version:** 6.04
3. **Document Version:** 6.04
4. **ERMS #:** 574596

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)?	☒ 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	☒ N/A	

15.	Dwayne Kicker **Code Team/Sponsor** (*print*)	*Signature on File* Signature	3/26/2021 Date
16.	L. Michael Feng **Technical Reviewer** (*print*)	*Signature on File* Signature	4/1/2021 Date
17.	Shelly Nielsen **QA Reviewer** (*print*)	Shelly R. Nielsen Signature	4-21-2021 Date
18.	Steve Wagner **Responsible Manager** (*print*)	*Signature on File* Signature	3/26/2021 Date
19.	Jennifer Long **SCM Coordinator** (*print*)	*Signature on File* Signature	3/26/2021 Date

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WIPP PA

Design Document and User's Manual

for

CUTTINGS_S Version 6.04

Document Version 6.04

ERMS # 574596

April 2021

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1.0 INTRODUCTION AND SCOPE

This Design Document and User's Manual for CUTTINGS_S Version 6.04, describes the following major features of software design: software components, theoretical basis, mathematical model, control flow and logic, data structures, and functionality and the interfaces of subroutines. It also describes in detail the allowed or prescribed ranges for input data and user interface, in accordance with the Nuclear Waste Management Procedure NP 19-1 Software Requirements (Long, 2020). This code is used by the Sandia National Laboratories' Performance Assessment (PA) Department in support of the performance assessment calculations for the Waste Isolation Pilot Plant (WIPP). It is controlled under the software configuration management system Concurrent Versions System (CVS) on the Linux cluster.

1.1 Software Identification

Code Name:	CUTTINGS_S
Version:	6.04
CVS Repository:	/data/cvs/CVSLIB/WIPP_CODES/PA_CODES/CUTTINGS_S
Platform:	CentOS 7/Dell PowerEdge C6420
Host:	fwm.sandia.gov
Compiler:	Gfortran/GCC 8.2.0

1.2 Points of Contact

Code Sponsor:	Dwayne Kicker	dckicke@sandia.gov	(575) 620-0117

1.3 Code Overview

The CUTTINGS_S code was written to calculate the quantity of material (in m^3) 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. Additionally, the code calculates information about the pressure, saturation, porosity, and crushed panel height, which is used as initial conditions for DBR calculations.

2.0 REQUIREMENTS

The requirements for CUTTINGS_S are listed in the *Requirements Document, Verification and Validation Plan, and Validation Document for CUTTINGS_S Version 6.04* (Kicker, 2021a). The requirements are repeated here for the reader's convenience.

2.1 Functional Requirements

The functional requirements for CUTTINGS_S, Version 6.04 are listed below.

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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 volume of spalled material using a pressure threshold and a distribution of spallings volumes (spall model 3).

R.4 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).

R.5 CUTTINGS_S calculates volume-weighted averages of porosity, pressure, saturation and permeability over specified regions of the repository.

2.2 External Interface Requirements

The external interface requirements are listed below:

R.6 CUTTINGS_S requires one text input master control file identifying the scenarios, vectors, cavities, and intrusions that will be used in the analysis, and the other input files and output files.

R.7 CUTTINGS_S requires a text input control file identifying parameters that will be used in the analysis. The parameters may be values or may reference values on an input CAMDAT file.

R.8 CUTTINGS_S requires a set of input CAMDAT files containing values that will be referenced from the input control file. The CAMDAT file is normally generated by the GENMESH, MATSET, POSTLHS code sequence and contains values from the WIPP Parameter Database or sampled vector values. There should be one CAMDAT file for each vector.

R.9 CUTTINGS_S requires a set of input CAMDAT files from the BRAGFLO code containing element data for the volume-weighted averages. (This file is required for regulatory calculations, but is optional for functional testing.) There should be one BRAGFLO CAMDAT file for each scenario-vector pair.

R.10 If spall model 4 is used, CUTTINGS_S requires a text input spall data file with spall volume data.

R.11 CUTTINGS_S generates a set of output CAMDAT files. This file contains data that includes the amounts of repository material brought to the surface by drilling and the

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volume-weighted averages calculated by the code. There will be one CAMDAT file for each scenario-vector-cavity-intrusion combination. (In this document and subsequent CUTTINGS_S version 6.04 documents, cavity is defined as a region of the WIPP repository: for example, the intrusion panel, the south rest of repository, or the north rest of repository.) These CAMDAT files will normally be read by BRAGFLO for direct brine releases (DBR) in regulatory calculations.

R.12 CUTTINGS_S generates one text output data file suitable for use as input by the code PRECCDFGF. This file contains data that includes the amount of spalled material and the amount of repository material brought to the surface due to erosion of the borehole resulting from laminar or turbulent flow in the drilling fluid.

R.13 CUTTINGS_S generates one text debug file.

2.3 Other Requirements

There are no other requirements for CUTTINGS_S.

2.4 Functionality Not Tested

All code functionality is covered in the requirements and test cases.

3.0 MAJOR SOFTWARE COMPONENTS

The CUTTINGS_S code is written in FORTRAN 90. In addition to the main program, there are several subroutines and modules that comprise the CUTTINGS_S code. These software components include the following:

- *A1main_cuttings_s.f90* – The main CUTTINGS_S code, which was written to calculate the quantity of material (in m^3) 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 code ages the cuttings to the intrusion time.

- *brag_average_module.F90* – Contains information about the BRAGFLO CAMDAT averages. This includes the elements to be averaged for each zone, the names of the variables to be averaged, and the averaged values.

- *brag_sizing_module.F90* – Contains information from the BRAGFLO CAMDAT file needed to read the input control file and to check the file. This includes the names of the material, properties, attributes, and element variables, and the number of elements per block.

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- *bragflo_routines.f90* – Contains subroutines for processing the input BRAGFLO CAMDAT file.
    - SUBROUTINE PREPRO_BRAG (IBRAG) - Processes the input BRAGFLO CAMDAT file. Reads sizing and arrays that are needed for input file processing.
    - SUBROUTINE CHECK_BRAG (NUMCAVS, IERR) - Checks that the BRAGFLO CAMDAT file contains the items that will be read by READ_BRAG.
    - SUBROUTINE READ_BRAG (FIBRAG, IBRAG, IERRBRG) - Extracts information from the BRAGFLO CAMDAT file. The BRAGFLO element variables are processed for all cavities and all intrusions. The element variables are averaged over specified areas and may be weighted by volume.
    - SUBROUTINE READAVG (IBRAG, VARNAM, MAXZONES, MAXZNSETS, NUMCAVS, NZONES, IXZONES, NELSETS, IELBEG, IELEND, WTAVG, GRIDVOL, SUMAVG, VARVAL, EVAVG, IERR) - Reads variable and calculates average, which may be weighted by grid volume.
    - SUBROUTINE FINALPORO - Calculates final porosity and final height for all cavities and intrusions.
    - SUBROUTINE WRITE_CAMDATS (ICDB, FOCDB, OCDB) - Writes cuttings results and BRAGFLO averages for all cavities and intrusions to output CAMDAT files. One CAMDAT file for each cavity and intrusion.
    - SUBROUTINE WRITE_CDBHEAD (OCDB) - Writes the "header" section of CAMDAT to the output CAMDAT file. The CUTTINGS parameters are output as properties.
    - SUBROUTINE WRITE_CDBVARS (OCDB, FIRSTSTEP, ICAV, IHIT) -Writes analysis section of CAMDAT for a single timestep. Results are output as global variables. For the first step only, the variable names are written to the CAMDAT file.
- *cdb_props_module.F90* – Contains the input CAMDAT property values, and the material and property names.
- *constants_module.F90* – Contains mathematical constants.
- *controlfile_routines.f90* – Contains subroutines for scanning, reading, and processing the input control file.
    - SUBROUTINE SCAN_CONTROL (ITXT1) - Scans the CUTTINGS input control file for program array sizing parameters.

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- SUBROUTINE READ_CONTROL (FITXT1, ITXT1) - Reads the CUTTINGS input control file. Some commands are processed directly, but commands that set parameters that may be read from the input CAMDAT file (or the BRAGFLO CAMDAT file) save the CAMDAT property location only.

- SUBROUTINE CMDINTR (ODBG, CMD, MAXZNSETS, ICAV, NELSETS, IELBEG, IELEND, WTAVG, IERR) - Processes the INTR_n or REPPRES command from the input control file.

- SUBROUTINE GETLOCVAL (ODBG, CMD, ONCDB, ITYPE, VARVAL, VARSTR, LOCTXT, MATNAM, PRPNAM, XVAL, IERR) - Gets a value that may be input directly or read from a CAMDAT property. For a CAMDAT property, only the location (material, property) is returned.

- SUBROUTINE VECTOR_CONTROL (FICDB) - Sets the parameters that are read from the input CAMDAT file. The parameter locations, if any, are stored when the input control file is read. Writes the value and origin of each parameter to debug file.

- SUBROUTINE GETVECVAL (ODBG, WRT, CMD, LOCTXT, MATNAM, PRPNAM, XVAL, IERR) - Gets the value, if it is an input CAMDAT property (else value unchanged). Writes the value and its origin, if requested.

- *debug_module.F90* – Contains the unit number for the output debug file.

- *drill_internals_module.F90* – Contains internally-calculated information shared by the DRILL routines

- *drill_params_module.F90* – Contains parameters for the DRILL routines.

- *drill_routines.f90* – Contains subroutines for a variety of drill-related calculations.

  - SUBROUTINE DRILL (XDRILDIA, XCOLDIA, XAREAC) - Calculates new borehole area based on drilling and penetrating either:
    (1) WIPP repository containing CH or RH type transuranic waste, or
    (2) Hypothetical INEL/WINCO repository containing HLW/SNF waste.

  - SUBROUTINE SIMPSONS (TAURT, TAURZ) - Performs numerical integration of coefficients using Simpson's 1/3 rule.

  - SUBROUTINE INTERFACE (CC) - Calculates the multiplier CC of VBAR required to match the eroded radius at TREY=2100 for the turbulent and laminar solutions for non-zero DOMEGA. This process accounts for drillstring rotation in the turbulent flow regime.

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  - SUBROUTINE FXX (ALPHA, RHO, F11, F12, F13, F21, F22, F23, F31, F32, F33, EF1, EF2, EF3) - Computes the numerical integration parameters for Simpson's 1/3 rule. A11,A12,A13, A21,A22,A23, A31,A32,A33 integrals. F1, F3, F3 integrals.

  - DOUBLE PRECISION FUNCTION ETA (RHO) - Solves a cubic equation for the local value of viscosity ETA.

  - DOUBLE PRECISION FUNCTION FRICTION (TREY) - Calculates Fanning friction factor when flow is turbulent.

- *freefield_module.F90* – Contains free-field reader data needed by the FREEFIELD routines.

- *freefield_routines.f90* – These routines interact with CAMCON_LIB free-field reader to read a text file line-by-line and return fields, as requested.

  - SUBROUTINE NEXTLINE (IN0, ILOG0, IOSTAT) - Reads the next line with CAMSUPES_LIB free-field reader. NEXTLINE must be called before the routines that return individual fields (NEXTWORD, NEXT_C, etc.).

  - SUBROUTINE NEXTWORD (KTYPE, COUT, IOUT, ROUT) - Returns the next field from line read by NEXTLINE.

  - SUBROUTINE NEXT_C (COUT, IERR) - Returns the next field from line. If there is no field, an error results. (Any field type is returned as character.)

  - SUBROUTINE NEXT_I (IOUT, IERR) - Returns the next field from line. If it is not an integer field, an error results.

  - SUBROUTINE NEXT_R (ROUT, IERR) - Returns the next field from line. If it is not a real field, an error results.

- *model4_data_module.F90* – Contains data for model4.

- *model_params_module.F90* – Contains model type and model-specific parameters. Also contains repository height and collar diameter.

- *output_data_module.F90* – Contains the input parameters or calculated results available for output on the output data file.

- *param_locs_module.F90* – Contains CAMDAT material-property locations of all parameters that need to be read from the input CAMDAT file.

- *qa_module.F90* – Contains the name of the author and sponsor for QA prints.

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- *readwritemisc_routines.f90* – Contains a variety of subroutines for reading, writing, and processing input and output files.
    - SUBROUTINE WRITE_OUTPUT (FODAT, ODAT) - Writes cuttings results to output data file.
    - SUBROUTINE PREPRO (FIMASTER, ODBG) - Interacts with command line to determine input and output files. Opens the debug file.
    - SUBROUTINE READ_MASTER (FMASTER, IMASTER, FITXT1, FICDB, FIBRAG, FISPL4, FODAT, FOCDB) - Reads master control file, which describes the scenarios, vectors, cavities, and intrusions for this run. The master control file also contains the names (or templates for) the other input/output files.
    - SUBROUTINE READ_MODEL4_DATA (FISPL4, ISPL4, NUMVECS, IERR) - Read data for Model4 for solid blowout.
    - SUBROUTINE READ_CDB_PROPS (ICDB) - Processes the input CAMDAT file. Reads sizing and arrays that are needed for input file processing. Property values are read, along with the material and property names.
    - SUBROUTINE INIT_DEFAULTS - Sets defaults and computes mathematical and other constants. These values may be overwritten when the input control file is read.
    - SUBROUTINE HANDLE_MEMORY_ERROR (ISALLOC, ARYNAM, IERR) - Handles a dynamic memory allocation error. Write an error message only.
    - SUBROUTINE EXPAND_TEMPLATE (TEMPLA, ISINP, IDSCEN, IVEC, CAV, TIM, FILNAM) - Generates file name from the given file name template, given the scenario, the vector, the cavity, and the intrusion.
    - INTEGER FUNCTION IXCDBNAM (NAME, NCNAMES, CNAMES) - Returns the index of a name (material, property, variable) on a CAMDAT file (character length of 8). Returns 0 if name not found.
- *scen_info_module.F90* – Contains information about the scenarios, vectors, cavities, and intrusions.
- *spallmodel_routines.f90* – Contains routines for calculating the area resulting from cuttings and cavings removed from the intrusion borehole, the volume removed by spall, and the final blowout radius and waste volume.
    - SUBROUTINE CUTSPALL - Calculates area resulting from cuttings and cavings removed from the intrusion borehole and volume removed by spall. Spall

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calculations done for all cavities and intrusions; cuttings/cavings area is the same for all cavities and intrusions if the drill diameter is the same.

- SUBROUTINE MODEL3 (ODBGX, REPPRES, VOL) - New model3 for solid blowout. Calculates final blowout radius and waste volume.

- SUBROUTINE MODEL4 (ODBGX, REPPRES, VOL, IVEC) - New model4 for solid blowout. Calculates final blowout radius and waste volume.

CUTTINGS_S makes use of the WIPP PA libraries CAMCON_LIB, CAMDAT_LIB, and CAMSUPES_LIB to standardize common user interface and I/O functions (Gilkey, 1995a; Gilkey, 1995b; Gilkey, 1995c). These libraries are linked to the CUTTINGS_S executable during the build process as documented in the Implementation Document for CUTTINGS_S Version 6.04 (Kicker, 2021b):

- The CAMCON_LIB library provides a library of general-use functions, such as handling command line arguments, displaying standardized output, and parsing free-field input.

- The CAMDAT_LIB library is a set of routines that read and write information to a computational database (CAMDAT) file.

- The CAMSUPES_LIB library is a collection of machine dependent functions.

4.0 THEORETICAL OVERVIEW

Three separate release modes, cuttings, cavings, and spallings, are used to determine the quantity of solid waste brought to the ground surface as the result of a drilling intrusion through a waste panel. Cuttings designates the waste contained in the cylindrical volume created by the cutting action of the drill bit passing through the waste, cavings designates the waste that erodes from the borehole in response to the upward-flowing drilling fluid within the borehole, and spallings designates the waste introduced into the borehole by the release of waste-generated gas escaping to the lower-pressure borehole. The releases associated with these processes are computed within the CUTTINGS_S code. The mathematical representations are described in Section 5.2. Additionally, a brief description of how the volume weighted averages of porosity, pressure, saturation, and permeability are calculated for BRAGFLO PA calculations is given in Section 5.2.4.

5.0 MODELS AND METHODS

The discussion of the model and methods given below is an overview of the theory and methods employed by CUTTINGS_S. Additionally, a thorough, detailed treatment of the theory and numerics applied in CUTTINGS_S is given in the Compliance Certification Application (CCA) (U.S. DOE, 1996, Appendix CUTTINGS Appendix A - Reference Manual on the Theory and Numerical Methods Underlying the WIPP Code CUTTINGS).

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5.1 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, 1992). 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 into the repository, 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 area of repository material removed as cuttings is the portion of the 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.[1] 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 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

[1] In tightly matrixed or crystaline 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.

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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 CUTTINGS Appendix A of the CCA (U.S. DOE, 1996) for details).

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.[2] 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, CUTTINGS_S may return a spall volume of zero.

5.2 Mathematical Model

5.2.1 Cuttings

The uncompacted volume of cuttings removed and transported to the surface in the drilling mud, V_{cut}, is given by

$$V_{cut} = AH_i = \pi D^2 H_i / 4, \tag{5.1}$$

where H_i is the initial (i.e., uncompacted) repository height (m), A is the drill bit area (m^2), and D is the drillbit diameter (m). The size of the cuttings release is independent of the conditions that exist in the repository at the time of a drilling intrusion, with the result that the cuttings volume V_{cut} is a lower bound on the quantity of material removed by a drilling intrusion.

5.2.2 Cavings (adapted from Section 4.5.3 of Helton et al., 1998)

The cavings component of the direct surface release is caused by the shearing action of the drilling fluid (mud) on the waste as the mud flows up the borehole annulus. As is the case for the cuttings release, the cavings release is assumed to be independent of the conditions that exist in the repository at the time of a drilling intrusion.

The final diameter of the borehole will depend on the diameter of the drill-bit and on the extent to which the actual borehole diameter exceeds the drill-bit diameter. Although a number of

[2] 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 the independent BRAGFLO DBR calculations. The gas flow, although crucial to the overall deformational process, transports no radioisotopes and is therefore not assessed.

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factors affect erosion within a borehole (Broc, 1982), the most important factor is believed to be the fluid shear stress on the borehole wall (i.e., the shearing force per unit area, (kg m/s^2/m^2)) resulting from circulating drilling fluids (Darley, 1969; Walker and Holman, 1971). As a result, the WIPP PA estimates cavings removal with a model based on the effect of shear stress on the borehole diameter. In particular, the borehole diameter is assumed to grow until the shear stress on the borehole wall is equal to the shear strength of the waste (i.e., the limiting shear stress below which the erosion of the waste ceases).

The final eroded diameter, D_f (m), of the borehole through the waste determines the volume V (m^3) of uncompacted waste that will be removed to the surface by circulating drilling fluid. Specifically,

$$V = V_{cut} + V_{cav} = \pi D_f^2 H_i / 4, \tag{5.2}$$

where V_{cav} is the volume (m^3) of waste removed as cavings.

Most borehole erosion is believed to occur in the vicinity of the drill collar (Figure 1) (Rechard et al., 1990). An important determinant of the extent of this erosion is whether the flow of the drilling fluid in the vicinity of the collar is laminar or turbulent. The WIPP PA uses Reynolds numbers to distinguish between the occurrence of laminar flow and turbulent flow. The Reynolds number is the ratio between inertial and viscous (i.e., shear) forces in a fluid and can be expressed as

$$R_e = \frac{\rho_f \|\mathbf{v}\| D_e}{\eta}, \tag{5.3}$$

where R_e is the Reynolds number (dimensionless), ρ_f is the fluid density (kg m^{-3}), D_e is the equivalent diameter (m), $\mathbf{v}$ is the fluid velocity (m s^{-1}), and η is the fluid viscosity (kg m^{-1} s^{-1}).

Typically, ρ, $\mathbf{v}$ and η are averages over a control volume with an equivalent diameter of D_e, and $D_e = 2\,(R - R_i)$ as shown in Figure 1. The fluid velocity, $\|\mathbf{v}\|$, is calculated by dividing the drilling fluid flow rate (m^3 s^{-1}) by $\pi(R^2 - R_i^2)$. Reynolds numbers less than 2100 are assumed to be associated with laminar flow, while Reynolds numbers greater than 2100 are assumed to be associated with turbulent flow (Walker, 1976).

Drilling fluids are non-Newtonian fluids, which means that the viscosity η is a function of the shear rate within the fluid (i.e., the rate at which the fluid velocity changes normal to the flow direction, ((m/s)/m). The WIPP PA uses a model proposed by Oldroyd (1958) to estimate the viscosity of drilling fluids. As discussed by Broc (1982), this model leads to the following expression for the Reynolds number associated with the helical flow of a drilling fluid within an annulus:

$$R_e = 0.8165\, D_e \|\mathbf{v}\| \rho / \eta_\infty, \tag{5.4}$$

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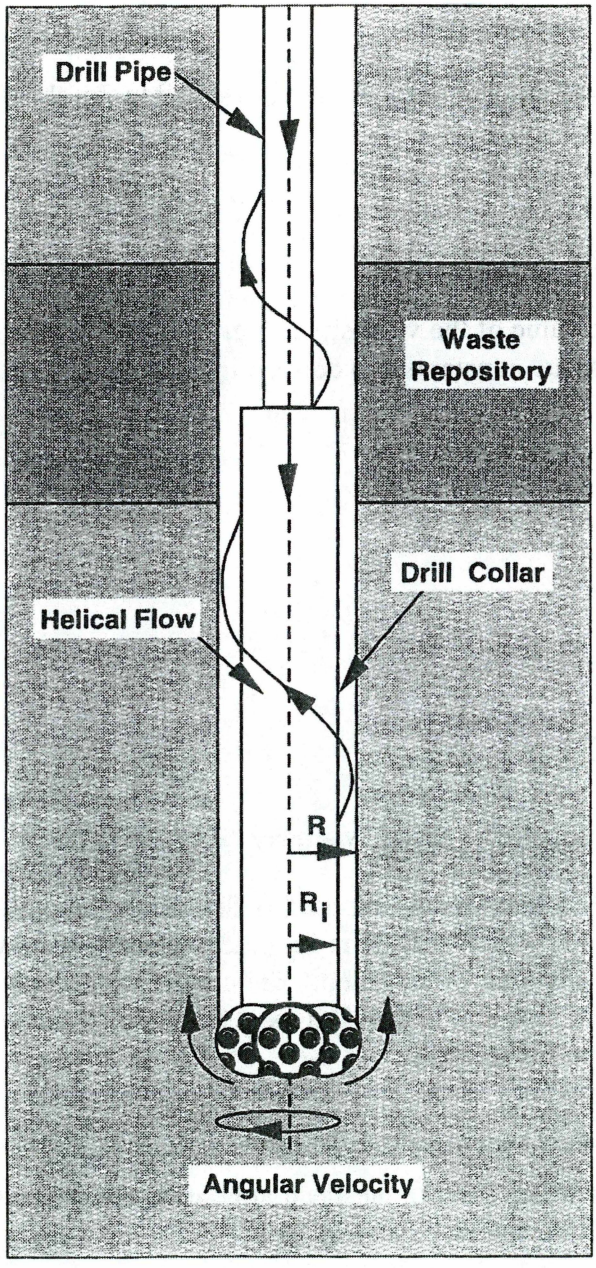


Figure 1 Detail of Rotary Drill String Adjacent to Drill-bit (Fig. 4.5.1 of Helton et al., 1998)

where De, $\|\mathbf{v}\|$ and ρ_f are defined in conjunction with Eq. (5.3), and η_∞ is the asymptotic value for the derivative of the shear stress (τ, kg m^{-1} s^{-2}) with respect to the shear rate (Γ, s^{-1}) obtained as the shear rate increases (i.e., $\eta_\infty = d\tau/d\Gamma$ as $\Gamma \rightarrow \infty$). The WIPP PA uses Eq. (5.4) to obtain the

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Reynolds numbers that are used to determine whether drilling fluids in the area of the drill collar are undergoing laminar or turbulent flow.

The Oldroyd model assumes that the shear stress τ is related to the shear rate Γ by the relationship

$$\tau = \eta_0 \left(\frac{1+\sigma_2 \Gamma^2}{1+\sigma_1 \Gamma^2} \right) \Gamma, \tag{5.5}$$

where η_0 is the asymptotic value of the viscosity (kg m^{-1} s^{-1}) that results as the shear rate Γ approaches zero, and σ_1, σ_2 are constants (s^2) defined in the following manner:

$$\sigma_2 = \frac{\eta_\infty \Gamma - y_p}{2\Gamma^2 y_p} \tag{5.6}$$

$$\sigma_1 = 2\sigma_2 \tag{5.7}$$

The expression leads to

$$\eta_\infty = \eta_0 \left(\frac{\sigma_2}{\sigma_1} \right). \tag{5.8}$$

The quantity η_∞ is comparable to the plastic viscosity of the fluid (Broc, 1982).

As previously indicated, different models are used to determine the eroded diameter of a borehole (i.e., $2R$ in Figure 1, with $R = D_f/2$ in Eq. (5.2)) depending on whether flow in the vicinity of the drill collar is laminar or turbulent. The model for borehole erosion in the presence of laminar flow is described next and is then followed by a description of the model for borehole erosion in the presence of turbulent flow.

5.2.2.1 Model of Borehole Erosion in the Presence of Laminar Flow

As shown by Savins and Wallick (1966), the shear stresses associated with the laminar helical flow of a non-Newtonian fluid can be expressed as

$$\tau(R,\rho) = \left\{ \left[\frac{C}{\rho^2} \right]^2 + \left[\frac{RJ}{2} \left(\frac{\rho^2 - \lambda^2}{\rho} \right) \right]^2 \right\}^{1/2} \tag{5.9}$$

for $R_i/R \le \rho \le 1$, where R_i and R are the inner and outer radii within which the flow occurs, as indicated in Figure 1; $\tau(R, \rho)$ is the shear stress (kg m^{-1} s^{-2}) at a radial distance ΔR beyond the inner boundary (i.e., at $\rho = (R_i + \Delta R)/R$). The quantities C, J, and λ must satisfy the following three conditions (Savins and Wallick, 1966) for the expression in Eq. (5.9) to be valid:

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$$0 = \int_{R_i/R}^{1} \left(\frac{\rho^2 - \lambda^2}{\rho\eta} \right) d\rho, \tag{5.10}$$

$$0 = C \int_{R_i/R}^{1} \left(\frac{1}{\rho^3 \eta} \right) d\rho - \Delta\Omega, \tag{5.11}$$

and

$$0 = \frac{4Q}{\pi R^3} + 2RJ \int_{R_i/R}^{1} \left[\frac{(R_i/R)^2 - \rho^2}{\eta} \right] \left[\frac{\rho^2 - \lambda^2}{\rho} \right] d\rho, \tag{5.12}$$

where η is the drilling fluid viscosity (kg m^{-1} s^{-1}) and is a function of R and ρ, $\Delta\Omega$ is the drill string angular velocity (rad s^{-1}), and Q is the drilling fluid flow rate (m^3 s^{-1}).

The shear stress at the outer boundary (i.e., R) is given by

$$\tau(R,1) = \left\{ C^2 + \left[\frac{RJ}{2} \left(1 - \lambda^2 \right) \right]^2 \right\}^{1/2}. \tag{5.13}$$

As previously indicated, the borehole radius R is assumed to increase as a result of erosional processes until a value of R is reached at which $\tau(R, 1)$ is equal to the shear strength of the waste. In the WIPP PA, the shear strength of the waste is treated as an uncertain input variable (see *WTAUFAIL* (BOREHOLE/TAUFAIL) in Section 5.2 Helton et al., 1998). Computationally, determination of the eroded borehole diameter R associated with a particular waste shear strength requires repeated evaluation of $\tau(R, 1)$, as indicated in Eq. (5.9), until a value of R is determined for which $\tau(R, 1)$ equals that shear strength.

The viscosity η in Eqs. (5.10) to (5.12) is introduced into the analysis through the assumption that the drilling fluid follows the Oldroyd model for shear stress in Eq. (5.5). Since viscosity is defined

$$\tau = \eta\Gamma, \tag{5.14}$$

a direct consequence of Eq. (5.5) is

$$\Gamma^2 = \frac{(\eta - \eta_0)}{(\eta_0\sigma_2 - \eta\sigma_1)}. \tag{5.15}$$

The expression in Eq. (5.7) can be reformulated as

$$\frac{\eta^2(\eta - \eta_0)}{(\eta_0\sigma_2 - \eta\sigma_1)} = \left[\frac{C}{\rho^2} \right]^2 + \left[\frac{RJ}{2} \left(\frac{\rho^2 - \lambda^2}{\rho} \right) \right]^2. \tag{5.16}$$

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As discussed by Savins and Wallick (1966) and also by Berglund (1992), the expressions in Eqs. (5.10) to (5.12) and (5.16) can be numerically evaluated to obtain C, J, and λ for use in Eqs. (5.9) and (5.13). The drilling fluid flow rate is related to the velocity of the drilling fluid by the following equation:

$$Q = \|\mathbf{v}\|\left(\pi R^2 - \pi R_i^2\right) \tag{5.17}$$

5.2.2.2 Model of Borehole Erosion in the Presence of Turbulent Flow

The model for borehole erosion in the presence of turbulent flow is now described. Unlike the theoretically derived relationship for erosion in the presence of laminar flow, the model for borehole erosion in the presence of turbulent flow is empirically based. In particular, pressure loss for axial flow in an annulus under turbulent flow conditions can be approximated by (Broc, 1982):

$$\Delta P = \frac{2fL\rho_f\|\mathbf{v}\|^2}{0.8165D_e}, \tag{5.18}$$

where ΔP is the pressure change (Pa), L is the distance (m) over which pressure change ΔP occurs, f is the Fanning friction factor (dimensionless), and ρ_f, $\|\mathbf{v}\|$, and D_e are defined in conjunction with Eq. (5.3).

For pipe flow, f is empirically related to the Reynolds number R_e and a roughness term ε by (Whittaker, 1985):

$$\frac{1}{f^{1/2}} = -4\log_{10}\left(\frac{\varepsilon}{3.72D} + \frac{1.255}{R_e f^{1/2}}\right), \tag{5.19}$$

where D is the inside diameter (m) of the pipe and ε is the average depth (m) of pipe wall irregularities. In the absence of a similar equation for flow in an annulus, Eq. (5.19) is used in the WIPP PA to define f for use in Eq. (5.18), with D replaced by the effective diameter $D_e = 2(R-R_i)$, ε equal to the average depth of irregularities in the waste-borehole interface, and R_e is the Reynolds number defined in Eq. (5.4).

The pressure change ΔP in Eq. (5.18) and the corresponding shear stress τ at the walls of the annulus are approximately related by

$$\Delta P\left[\pi\left(R^2 - R_i^2\right)\right] = \tau\left[2\pi L\left(R + R_i\right)\right], \tag{5.20}$$

where $\pi(R^2 - R_i^2)$ is the cross-sectional area of the annulus (see Figure 1) and $2\pi L(R + R_i)$ is the total (i.e., interior and exterior) surface area of the annulus. Rearrangement of Eq. (5.20) and use of the relationship in Eq. (5.18) yields

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$$\tau = \frac{f\rho_f \|\mathbf{v}\|^2}{2(0.8165)}, \tag{5.21}$$

the shear stress at the surface of a borehole of radius R. As a reminder, R enters into Eq. (5.21) through the use of $D = 2(R–R_i)$ in the definition of f in Eq. (5.19). As in the case for laminar flow, the borehole radius R is assumed to increase until a value of τ (actually, τ (R)) is reached that equals the shear strength of the waste. Computationally, the eroded borehole diameter is determined by solving Eq. (5.21) for R under the assumption that τ equals the assumed shear strength of the waste.

A slight modification to the definition of τ in Eq. (5.21) is made to account for drillstring rotation when fluid flow in the vicinity of the drill collars is turbulent (Abdul Khader and Rao, 1974; Bilgen et al., 1973). Specifically, an axial flow velocity correction factor (i.e., a rotation factor), F_r , was introduced into the definition of τ. The correction factor F_r is defined by

$$F_r = \|\mathbf{v}_{2100}\| / \|\mathbf{v}\|, \tag{5.22}$$

where $\|\mathbf{v}_{2100}\|$ is the norm of the flow velocity required for the eroded diameters to be the same for turbulent and laminar flow at a Reynolds number of 2100. $\|\mathbf{v}_{2100}\|$ can be obtained by solving

$$\tau_{fail} = \frac{f\rho_f \|\mathbf{v}_{2100}\|^2}{2(0.8165)} \tag{5.23}$$

for $\|\mathbf{v}_{2100}\|$, with D in Eq. (5.19) assigned the final diameter value that results for laminar flow at a Reynolds number of $R_e = 2100$ (i.e., the D in $D_e = 2(R–R_i) = D–2R_i$ obtained from Eq. (5.4) with $R_e = 2100$). The modified definition of τ is

$$\tau = \frac{f\rho_f (F_r \|\mathbf{v}\|)^2}{2(0.8165)} \tag{5.24}$$

and results in turbulent and laminar flow having the same eroded diameter at a Reynolds number of 2100, which is the Reynolds number at which a transition between turbulent and laminar flow is assumed to take place.

The following algorithm was used to determine the final eroded radius R_f of a borehole and incorporates the possible occurrence of a transition from turbulent to laminar fluid flow within a borehole:

Step 1. Use Eq. (5.4) to determine an initial Reynolds number R_e, with R set to the drill-bit radius (i.e., R_0).

Step 2. If $R_e < 2100$, then the flow is laminar and the procedures discussed in conjunction with Eqs. (5.9) and (5.13) are used to determine R_f. Because any increase in the borehole diameter will cause the Reynolds number to decrease, the flow will remain laminar, and there is no need

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to consider the possibility of turbulent flow as the borehole diameter increases. The final eroded radius of the borehole is the value of R_f that is calculated in this step.

Step 3. If $R_e \geq 2100$, then the flow is turbulent and the procedures discussed in conjunction with Eqs. (5.21) and (5.24) are used to determine R_f. Once R_f is determined, the associated Reynolds number R_e is calculated with Eq. (5.4) and $R = R_f$. If $R_e > 2100$, then a transition from turbulent to laminar flow cannot take place, and the final eroded radius is R_f, determined in this step.

Step 4. If the Reynolds number R_e determined in Step 3 satisfies the inequality $R_e \leq 2100$, then a transition from turbulent to laminar flow is assumed to have taken place. In this case, the calculation of R_f is redone for laminar flow, with the outer borehole radius R initially defined to be the radius at which the transition from turbulent to laminar flow occurs (i.e., the radius associated with $R_e = 2100$). In particular, the initial value for R is given by

$$R = R_i + \frac{2100\eta_\infty}{2(0.8165)\|\mathbf{v}\|\rho} \tag{5.25}$$

which is obtained from Eq. (5.4) by solving for R with $R_e = 2100$. A new value for R_f is then calculated with the procedures discussed in conjunction with Eqs. (5.8) and (5.9) for laminar flow, with this value of R_f replacing the value from step 3 as the final eroded diameter of the borehole.

Step 5. Once R_f is known, the amount of waste removed to the surface is determined by Eq. (5.2) with $D_f = 2R_f$.

5.2.3 Spallings

During the history of the WIPP PA, four different models have been used to calculate spallings releases. The current version of CUTTINGS_S (version 6.04) only supports models 3 and 4. Model 3 is an IF statement that checks to see if the repository pressure is above or below the blowout threshold value specified in the input control file. If pressure is above the threshold, the spall volume released is the value in the input control file. If pressure is below the threshold, the spall volume released is zero.

The spallings model 4 computes the spall volume using the data in the input spall data file. This file (described in Section 10.5)) contains a distribution of spall volumes for each of a set of reference values for repository pressure. These pressures, denoted by Pres(I), are ordered from I=1,2,..., NS, and PRES(I) < PRES(I+1). NS denotes the number of sets of pressures.

CUTTINGS_S obtains the repository pressure (P) at the time of intrusion from the CAMDAT file from BRAGFLO. A random number (R) sampled from a uniform (0,1) distribution is specified in the input control file. To determine spall volume, CUTTINGS_S uses the random number R to select one of the distribution elements, then interpolates the spall volume from the DRSPALL results for that element. Algorithmically,

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1. Let *NV* denote the number of vectors determined by the input control file. If *E* denotes an integer between 1 and *NV*, select distribution element *E* when processing vector number *E*.

2. Find scenarios which bracket the repository pressure
   a. If P < MinPres, set I=1 and P_{Spall}=Pres(1).
   b. If P > MaxPres, set I=NS-1 and P_{Spall}=Pres(NS).
   c. If MinPres < P < MaxPres, let I be such that Pres(I) ≤ P < Pres(I+1). Let P_{Spall}=P.

3. Volume = Vol(E,I) + (P_{Spall} – Pres(I))/(Pres(I+1) – Pres(I)) × (Vol(E,I+1) – Vol(E,I)).

5.2.4 Calculations for BRAGFLO

CUTTINGS_S does a series of calculations that result in a series of input files for BRAGFLO for PA calculations. CUTTINGS_S calculates the volume weighted averages of the waste room porosity, repository gas pressure, repository brine pressure, brine saturation, and permeability of rock to brine for certain user specified zones at time steps specified from the BRAGFLO input files. These user specified zones are composed of various BRAGFLO grid elements. This section only describes how these quantities are computed in CUTTINGS_S. For a detailed description of what these quantities represent and how they are utilized by BRAGFLO, see the User's Manual for BRAGFLO (King, 2020).

The volume weighted averages for gas pressure, brine pressure, gas saturation, permeability of rock to brine, and waste room porosity for each user specified zone of the repository can be calculated using the following equations:

$$A_{pg,i}(t_{BF}) = \frac{\sum_{j=1}^{N_i} PG_{i,j}(t_{BF}) \times V_{i,j}(t_{BF})}{\sum_{j=1}^{N_i} V_{i,j}(t_{BF})}, \quad A_{pb,i}(t_{BF}) = \frac{\sum_{j=1}^{N_i} PB_{i,j}(t_{BF}) \times V_{i,j}(t_{BF})}{\sum_{j=1}^{N_i} V_{i,j}(t_{BF})}$$

$$A_{k,i}(t_{BF}) = \frac{\sum_{j=1}^{N_i} k_{i,j}(t_{BF}) \times V_{i,j}(t_{BF})}{\sum_{j=1}^{N_i} V_{i,j}(t_{BF})}, \quad A_{S,i}(t_{BF}) = \frac{\sum_{j=1}^{N_i} S_{i,j}(t_{BF}) \times V_{i,j}(t_{BF})}{\sum_{j=1}^{N_i} V_{i,j}(t_{BF})}$$

$$A_{\phi,i}(t_{BF}) = \frac{\sum_{j=1}^{N_i} \phi_{i,j}(t_{BF}) \times V_{i,j}(t_{BF})}{\sum_{j=1}^{N_i} V_{i,j}(t_{BF})}$$

where

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- N_i is the number of grid elements in the i^{th} zone.
- $V_{i,j}(t_{BF})$ is the volume of the j^{th} grid element in the i^{th} zone at the BRAGFLO time step t_{BF}.
- $PG_{i,j}(t_{BF}), PB_{i,j}(t_{BF}), k_{i,j}(t_{BF}), S_{i,j}(t_{BF})$, and $\phi_{i,j}(t_{BF})$ are the gas pressure, brine pressure, permeability of rock to brine, gas saturation, and waste room porosity of the j^{th} grid element in the i^{th} zone at the BRAGFLO time step t_{BF}, respectively.
- $A_{pg,i}(t_{BF})$, $A_{pb,i}(t_{BF})$, $A_{k,i}(t_{BF})$, $A_{s,i}(t_{BF})$ and $A_{\phi,i}(t_{BF})$ are the volume weighted averages of gas pressure, brine pressure, permeability of rock to brine, gas saturation, and waste room porosity in the i^{th} zone at the BRAGFLO time step t_{BF}, respectively.

If an intrusion time does not correspond with a BRAGFLO time step, the values of the volume weighted averages at the intrusion time are calculated using linear interpolation.

Additionally, CUTTINGS_S uses a volume weighted average of waste porosity to compute a scaled porosity and the height for each zone. The following relationships are used to calculate these quantities:

$$\left(1-A_{\phi,i}(0)\right)H_i(0)=\left(1-\hat{\phi}_i(t)\right)H_i(t)$$

$$\hat{\phi}_i(t)H_i(t)=A_{\phi,i}(t)H_i(0)$$

where $\hat{\phi}_i(t)$ is the scaled waste room porosity of the ith zone at time t and $H_i(t)$ is the height of the i^{th} zone at time t. The following equations follow directly:

$$\hat{\phi}_i(t)=\frac{A_{\phi,i}(t)}{1-A_{\phi,i}(0)+A_{\phi,i}(t)}$$

$$H_i(t)=\left(\frac{1-A_{\phi,i}(0)}{1-\hat{\phi}_i(t)}\right)H_i(0)$$

5.3 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

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equations. They are discussed thoroughly in the CCA (U.S. DOE, 1996, Appendix CUTTINGS 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.

6.0 CONTROL FLOW AND LOGIC

CUTTINGS_S Version 6.04 processes multiple scenarios, vectors, cavities, and intrusions in a single execution, but previous versions of the code (prior to Version 6.00) required an execution for each scenario, vector, cavity, and intrusion combination. Thus, the control flow and logic is presented in the form of a pseudocode so that the looping procedures are highlighted. The names of the major subroutines that currently perform the functions described are provided in brackets ([]), and the requirements that they address follow in braces ({}).

CUTTINGS_S Version 6.04 control flow and logic:

- Define calculation (files, scenarios, etc.) [PREPRO, READ_MASTER] {R.6}
- DO for each scenario
    - Pre-process the input control file [INIT_DEFAULTS, SCAN_CONTROL] and allocate memory {R.7}
    - DO for each vector
        - IF first vector THEN
            - Process input control file [READ_CONTROL] {R.7}
            - Read Spall Model 4 data, if applicable [READ_MODEL4_DATA] {R.10}
        - END IF
        - Read parameters from input CAMDAT file [READ_CDB_PROPS, VECTOR_CONTROL] {R.8}
        - DO for each intrusion [READ_BRAG]
            - For lower-bounding time step, read BRAGFLO CAMDAT variables and calculate volume-weighted average for all "zones", cavities [READAVG] {R.5,R.9}
            - For upper-bounding time step, read variables and calculate volume-weighted average for all "zones", cavities [READAVG] {R.5,R.9}
            - Interpolate average to intrusion time for all variables, zones, cavities {R.5}
        - END DO
        - Calculate derived average variables (final porosity and height) [FINALPORO] {R.5}
        - Calculate the area of the footprint of the volume removed by cavings [DRILL, called from CUTSPALL] for each cavity and intrusion {R.1,R.2}
        - Calculate the volume removed by spallings [MODEL3 or MODEL4, called from CUTSPALL] for each cavity and intrusion {R.3,R.4}

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        - Write the BRAGFLO and cuttings output to the CAMDAT files (one file for each cavity and intrusion) [WRITE_CAMDATS] {R.11}
    - END DO
- END DO
- Write output data file [WRITE_OUTPUT] {R.12}.

6.1 Code Sequence for CUTTINGS_S within a Regulatory Calculation

Within regulatory calculations, 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 and DRSPALL. CUTTINGS_S output is normally transferred to codes PRECCDFGF and ALGEBRACDB (in the BRAGFLO (DBR) computational loop). To assist the reader, the code sequence is depicted in Figure 2. Note that codes LHS, CCDFGF, and BRAGFLO have pre- and post-processors, and that data on the CAMDAT file may be manipulated with the ALGEBRACDB or RELATE codes. These code sequences are compressed for brevity.

6.2 Data Structures

The files associated with running CUTTINGS_S are listed below. Additional details on input files are provided in Section 10. Addition details on output files are provided in Section 12.

Input Files:

- Text master control file identifying the scenarios, vectors, cavities, and intrusions that will be used in the analysis, and the other input and output files.

- Text input control file specifying drilling and intrusion parameters, either as direct values or as a reference to a CAMDAT file property.

- Set of binary input CAMDAT files (one file for each vector) containing values that will be referenced from the input control file. These files are normally generated by a GENMESH, MATSET, POSTLHS code sequence and contain values from the WIPP Parameter Database or sampled vector values.

- Set of binary input BRAGFLO CAMDAT files (one file for each scenario-vector pair) containing element data for the volume-weighted averages. (These files are required for regulatory runs, but are optional for test runs.)

- Text input spall data file for Spall Model 4 only specifying pressures and their volumes by vector.

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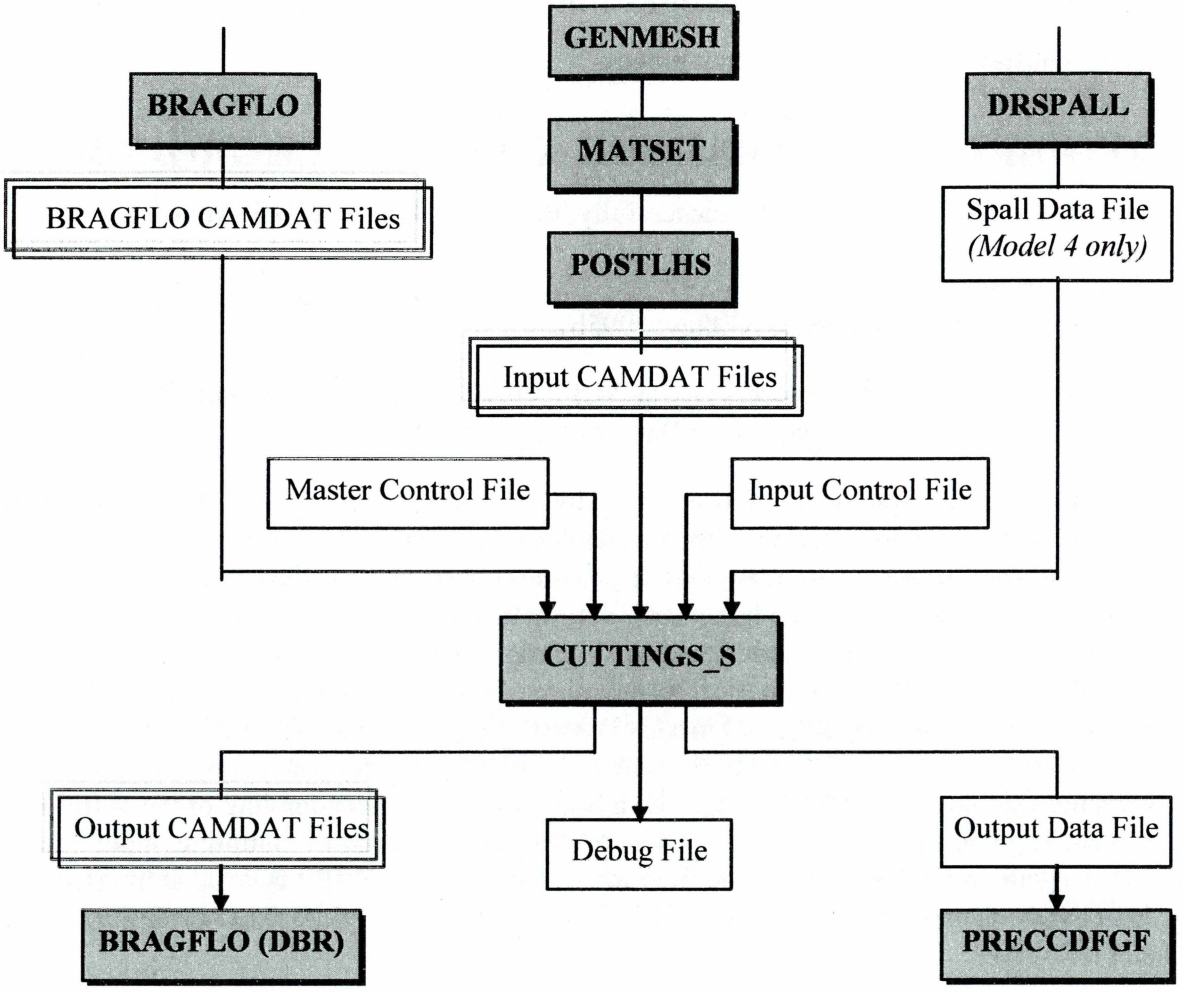


Figure 2 Data Flow Diagram for CUTTINGS_S

Output Files:

- Set of binary output CAMDAT files (one file for each scenario-vector-cavity-intrusion combination) containing CUTTINGS_S output. This file contains data that includes the amounts of repository material brought to the surface by drilling and the volume-weighted averages calculated by the code. These CAMDAT files will be read by BRAGFLO for direct brine releases in regulatory calculations.

- Text output data file containing data that includes the amount of spalled material and the amount of repository material brought to the surface due to erosion of the borehole resulting from laminar or turbulent flow in the drilling fluid.

- Text debug file.

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6.3 Allowable/Prescribed Ranges for Input and Output

There are no constraints on input or output ranges.

7.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the CUTTINGS_S code successfully, the user will need a basic knowledge of

- Linux operating system
- Sandia's CAMDAT database (Gilkey, 1995b).

In addition, users should also have access to the WIPP cluster of Dell PowerEdge C6420 with CentOS 7 and the WIPP PA database server bto.sandia.gov.

To manipulate and/or interpret the results of CUTTINGS_S as it is exercised in WIPP PAs, users should have (1) a basic understanding of 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, especially GENMESH, MATSET, POSTLHS, BRAGFLO (WIPP PA, 1992) and DRSPALL.

8.0 CAPABILITIES AND LIMITATIONS

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, BRAGFLO, and DRSPALL. 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.

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9.0 USER INTERACTIONS WITH THE SOFTWARE

CUTTINGS_S Version 6.04 executes on a Linux platform. To execute CUTTINGS_S, the program executable name (cuttings_s) must be in the user's current PATH or referenced by its path name.

CUTTINGS_S expects two command line arguments. The program arguments may either be positional (provided in order) or flagged (preceded by the appropriate flag). Flags always start with "-"; they may be abbreviated. All positional arguments must be listed before any flagged arguments.

Interactive users may request that the program prompt for any missing command line arguments by appending "?" to the command line.

CUTTINGS_S expects the following command line arguments (file extensions are examples):

1. -user Master control file (.inp) describing the scenarios, vectors, cavities, and intrusion times to run and identifying the other input files that CUTTINGS_S needs and the output files that will be generated. The master control file is described in Section 10.1.

2. -debug Output diagnostic file(.dbg). This text file is described in Section 12.3.

If the code executes without errors, CUTTINGS_S will run and issue a "normal completion" message. If errors are encountered, CUTTINGS_S will issue an error message and abort. See Section 11.0 for information on handling error messages.

10.0 DESCRIPTION OF INPUT FILES

The input files for CUTTINGS_S are described in this section.

10.1 Master Control File

The master control file is a text file that describes the scenarios, vectors, cavities, and intrusion times to run. It also identifies the input files that CUTTINGS_S needs and the output files that the code generates.

Most of these files are identified using a file name "template." The provided template is the base name that will be applied to a set of files. The template has "wildcard" characters that will be replaced with the appropriate characters to form a file name. The following wildcards are defined: *%* for scenario, *(* for cavity, ^ for vector (zero padded to three characters), *!* for intrusion time. Thus, the file name template *cusp_r1_s%_v^_(_t!.cdb* for scenario 2, vector 40, cavity U, intrusion time 100 would result in file name *cusp_r1_s2_v040_u_t100.cdb*. All wildcards are not appropriate for all templates. If a wildcard is missing, the same file name will be generated for all items of the missing category. For example, *lhs3_cusp_r1_v^.cdb* would generate a new

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file name for each vector, but have the same file name for vector *n* of all scenarios, cavities, and intrusion times.

The master control file is fixed format, with certain parameters expected on certain lines. Below is the list of items expected on each line, in order. Note that one bullet may encompass more than one line. Any number of blanks may precede, follow, or separate items on a line. Numeric values should be in any valid Fortran format.

- The number of scenarios, vectors, and cavities.

- The scenario identifier, the number of intrusions, and the intrusion times for each scenario, with one line for each scenario. The order the scenarios are listed in this section determines the order they will appear on the output data file.

- The abbreviation for each cavity (e.g., U, M, L), with one line for each cavity. (In this document, cavity is defined to be a region of the WIPP repository. For example, in recent calculations, the following cavities were defined: the intrusion panel, the south rest of repository, and the north rest of repository.)

- The file name template for the input control file. A wildcard is allowed for scenario only, but usually there will be just one input control file. These input control files specify drilling and intrusion parameters along with parameters specific to the spall model. These text files are described in Section 10.2.

- The file name template for the input CAMDAT file. A wildcard is allowed for scenario and vector only, but usually there will be one input CAMDAT file for each vector. The input CAMDAT files are created by the GENMESH, MATSET, POSTLHS sequence described in Section 6.1. These binary files are described in Section 10.3.

- The file name template for the input BRAGFLO CAMDAT file. A wildcard is allowed for scenario and vector only, and usually there will be one input BRAGFLO CAMDAT file for each scenario – vector pair. The binary input BRAGFLO CAMDAT file is described in Section 10.4. **This file is optional for test runs; it is required for regulatory runs.** If there is no BRAGFLO CAMDAT file for the test run, enter "CANCEL" for the file name template.

- The input spall data file for Spall Model 4 specifying pressures and their volumes by vector. A wildcard is allowed for scenario only, but usually there will be just one input spall data file. This text file is described in Section 10.5. **This file is required for Spall Model 4 only**; for all other models, enter "CANCEL" to specify that there is no file.

- The file name of the output text file containing the CUTTINGS_S output needed for the PRECCDFGF run described in Section 6.1. This text file is described in Section 12.1.

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- The file name template for the output CAMDAT files. All wildcards are allowed; the template must specify one CAMDAT file for each cavity – scenario – vector – intrusion combination. The output CAMDAT files contain the CUTTINGS_S output needed for the BRAGFLO runs described in Section 6.1. These binary files are described in Section 12.2.

Example master control files for regulatory runs and for test or debug runs are shown in Appendix A (Section 14).

10.2 Input Control File

The input control file is a text file that contains various drilling parameters and repository data required by CUTTINGS_S. This file also identifies which spall model will be used and specifies parameters appropriate for that spall model. In regulatory calculations, many of the parameters are read from the input CAMDAT file properties, where they were set with values from the QA-controlled WIPP Parameter Database by the MATSET code or with sampled values provided by the POSTLHS code. (Parameters DOMEGA, TAUFAIL, VOLSPALL, and RNDSPALL in Table 10-1 are normally sampled.)

Each statement in the input control file begins with a keyword, followed by parameters that apply. There is no required order for keywords. The generic format of a statement is explained in detail in Section 2.9.4 of the User's Reference Manual for CAMCON (Rechard, 1992). The following syntax rules apply:

- Either lowercase or uppercase letters are acceptable, but lowercase letters are converted to uppercase. The only exception is a quoted string in a command.
- Valid delimiters are a comma (,), an equal sign (=), and one or more blanks.
- An exclamation point (!) in any line starts a comment. The exclamation point (!) and any characters following it on the line are ignored.
- A statement can be continued over several lines with an ampersand (&). The ampersand (&) and any characters following it on the current line are ignored, and the next line is appended to the current line.

Table 10-1 lists the input control file keywords that are recognized by CUTTINGS_S with their expected parameters. In most cases, the parameter may either be a real number or a reference to a property on the input CAMDAT file. To reference a CAMDAT property, the parameter must have a colon (:) separating the CAMDAT material name on the left from the CAMDAT property name on the right, with no intervening blanks.

Example input control files for regulatory runs and for test or debug runs are shown in Appendix B (Section 15).

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Table 10-1– Input Control File Keywords and Parameters

Keyword	Parameter Type; Number	Parameter Description
The following keywords set parameters for drilling and general use. They are required, unless the listed default applies.		
PI	Real or Property	Mathematical constant π; default provided
YRSEC	Real or Property	Years-to-seconds conversion factor (i.e., the number of seconds in a year); default is 3.1556930E+7. The conversion factor may be specified with either YRSEC or SECYR; only one keyword should be present in the input control file.
SECYR	Real or Property	Seconds-to-years conversion factor; default is 1.0/3.1556930E+7. This conversion factor, if provided, will be converted into a years-to-seconds factor. Thus, the conversion factor may be specified with either YRSEC or SECYR; only one keyword should be present in the input control file.
DIAMMOD	Real or Property or BRAGFLO Property	Drill diameter for each intrusion time. Drill diameter is supplied by the BRAGFLO CAMDAT file if "BRAGFLO" precedes the property designator.
DNSFLUID	Real or Property	Density for drilling mud (kg/m^3)
DOMEGA	Real or Property	Angular velocity of drillstring (rad/s)
ABSROUGH	Real or Property	Absolute borehole roughness (m)
TAUFAIL	Real or Property	Effective shear strength of drilling fluid (Pa)
VISCO	Real or Property	Plastic viscosity of drilling fluid (Pa-s)
YLDSTRSS	Real or Property	Drilling fluid yield stress (Pa)
HREPO	Real or Property	Height of repository at burial time (m)
COLDIA	Real or Property	Collar diameter (m)
SHEARRT	Real or Property	Shear rate (/s); default is 1020
MUDFLWRT	Real or Property	Drilling mud flow rate ($m^3/(s*m)$); default is 0.09935
The following keywords select the spall model and set the parameters dependent on the spall model.		
NOMODEL	No parameter	No Spall Model is selected
Spall Model 3 requires the following keywords.		
MODEL3	No parameter	Select Spall Model 3
VOLSPALL	Real or Property	Sampled volume for spall model 3
PTHRESH	Real or Property	Pressure threshold for spall model 3
Spall Model 4 requires the following keywords.		
MODEL4	No parameter	Select Spall Model 4
RNDSPALL	Real or Property	(Optional) Random number for spall model 4 to map DRSPALL vectors to BRAGFLO vectors
The following keywords apply to the input BRAGFLO CAMDAT file variables and the output CAMDAT files. The keywords are required (if there is a BRAGFLO CAMDAT file) unless the listed default applies.		

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OUT_MAT	Character*8	Output CAMDAT material where properties are to be written; default is the last material
INTR_*n* where *n* is 0 to the number of averages requested, in order	Integers or CAMDAT material name; any number	The "zone" or elements to average over for BRAGFLO element variables, expressed as a series of integer element numbers or the material name. If NO_GRDVOL is included as a parameter, the average will be a simple average; otherwise the average will be weighted by grid volume.
NAME_GRIDVOL	Character*8	Name of the BRAGFLO CAMDAT attribute containing the grid volume; default is GRIDVOL
NAME_POROS	Character*8	Name of the BRAGFLO CAMDAT element variable (and output CAMDAT global variable) containing porosity; default is POROS
NAME_PRESGAS	Character*8	Name of the BRAGFLO CAMDAT element variable (and output CAMDAT global variable) containing pressure in gas; default is PRESGAS
NAME_PRESBRIN	Character*8	Name of the BRAGFLO CAMDAT element variable (and output CAMDAT global variable) containing pressure in brine; default is PRESBRIN
NAME_SATGAS	Character*8	Name of the BRAGFLO CAMDAT element variable (and output CAMDAT global variable) containing saturation in gas; default is SATGAS
NAME_SATBRIN	Character*8	Name of the output CAMDAT global variable containing saturation in brine; default is SATBRIN
NAME_PERMBRIN	Character*8	Name of the BRAGFLO CAMDAT element variable (and output CAMDAT global variable) containing permeability of brine; default is PERMBRX
NAME_BRAG	Character*8; any number	Names of additional BRAGFLO CAMDAT element variables to be averaged and written to the output CAMDAT file. Variables POROS, PRESGAS, PRESBRIN, SATGAS, SATBRIN (calculated from SATGAS), and PERMBRIN are always output. Multiple NAME_BRAG statements are allowed in the file.
NAME_REPPRES or REPPR_NM	Character*8	Name of the BRAGFLO CAMDAT element variable containing repository average pressure. If no NAME_REPPRES keyword is present, the name will default to the name of the variable containing pressure in gas (NAME_PRESGAS).

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REPPRES	Integers or CAMDAT material name; any number	Elements to average over for repository pressure, expressed as a series of integer element numbers or the material name. If NO_GRDVOL is included as a parameter, the average will be a simple average, otherwise it will be grid-volume averaged. If no REPPRES keyword is present, the repository pressure will default to the average pressure in gas for INTR_0 (PRESGAS0).
The following keywords set parameters that are normally read from the input BRAGFLO CAMDAT file. They are only valid if there is no BRAGFLO CAMDAT file. Thus, they are valid for TESTING ONLY.		
POROSITY	Real; 1+NHITS	The initial repository porosity (at time of decommissioning), followed by the porosity for each intrusion time
PRESSURE	Real; 1 or NHITS	Pressure in gas for each intrusion time

10.3 Input CAMDAT Files

A CAMDAT file is a binary, sequential file. A CAMDAT file may be referred to as a CDB or a CAMDAT database, but it is not a database in the traditional use of the word. A detailed description of the CAMDAT file format is given in Chapter 7 of the CAMDAT_LIB User's Manual (Gilkey, 1995b). The CAMDAT file may be examined with the GROPECDB program described in the GROPECDB User's Manual (Feng, 2021).

There is usually one input CAMDAT file for each vector. The input CAMDAT file serves two purposes: 1) input parameters are provided to CUTTINGS_S through references in the input control file to property values in the file (see Section 10.2) and 2) the contents of this file are the basis of the output CAMDAT file, to which CUTTINGS_S's results will be transferred. In regulatory runs, this file is normally provided by GENMESH, MATSET, POSTLHS code sequence illustrated in Figure 2. MATSET adds unsampled material and property values from the WIPP Parameter Database, and POSTLHS adds the sampled data. Note that POSTLHS creates *N* CAMDAT files, one for each of the *N* samples. These correspond to the *N* vectors.

As a convenience to users, an all-purpose input CAMDAT file for use with test or debug runs is stored with the test input files as *cusp_test_1.cdb*.

10.4 Input BRAGFLO CAMDAT Files

An input BRAGFLO CAMDAT file is the CAMDAT file output from BRAGFLO as it is exercised in the various scenarios. There is usually one input CAMDAT file for each scenario – vector pair. The CAMDAT values listed in

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Table 10-2 are extracted from this file.

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Table 10-2– Items Extracted from BRAGFLO CAMDAT File

CAMDAT Name	CAMDAT Type	Description
DIAMMOD	Property	The drill diameter, if specified with DIAMMOD BRAGFLO in the input control file
GRIDVOL	Attribute	The grid volume of each element; for grid-volume averaging
POROS	Element variable	The porosity for each element at each intrusion time. The porosity at time=0.0 is the initial porosity (at time of decommissioning).
PRESGAS	Element variable	The pressure in gas for each element at each intrusion time
PRESBRIN	Element variable	The pressure in brine for each element at each intrusion time
SATGAS	Element variable	The saturation of gas for each element at each intrusion time
PERMBRX	Element variable	The permeability of brine for each element at each intrusion time

The names of each CAMDAT item in

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Table 10-2 may be changed with the NAME_xxx commands in the input control file (see Table 10-1). Note that the variable name on the input BRAGFLO CAMDAT file is the variable name used on the output CAMDAT file (see Section 12.2). The time step time must be in seconds, and element values will be interpolated from the time steps straddling each intrusion time. All intrusion times must be in a single BRAGFLO CAMDAT file.

As a convenience to users, a BRAGFLO CAMDAT file for use with test or debug runs is stored with the test input files as *cusp_test_bf.cdb*.

10.5 Input Spall Model 4 Data File

The input spall model 4 data file is a text 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 spall data is normally provided by the DRSPALL code.

The input spall model 4 data file is fixed format, with certain parameters expected on certain lines. Below is the list of items expected on each line. Any number of blanks may precede, follow, or separate items on a line. Numeric values should be in any valid Fortran format.

- Line 1 of the file is the number of vectors in pressure data set. Note that the spall data file vectors are not necessarily the same as the vectors discussed elsewhere in this document.
- Line 2 is the number of pressure data sets.
- Line 3 lists the different pressures in increasing order for the number of data sets given in Line 2.
- The following lines list the data sets relating to each pressure. The first data set is for the first pressure given in Line 3, the second data set is for the second pressure in Line 3, etc. The data sets have three columns of data: column 1 is the vector number, column 2 is the time (not used), and column 3 is the volume. Each of the data sets must contain the number of vectors listed in Line 1 (one line per vector), in order. Each data set is followed by a blank line.

If RNDSPALL is not specified in the input control file, the first spallings vector volume in the input spall model 4 data file will be used for calculation of spallings releases for the first vector output, the second spallings vector volume will be used for calculation of spallings releases for the second vector output, and so on.

Computation of spallings in this manner requires that the number of vectors specified in the master control file is equal to (or less than) the number of spallings vectors in the input spall model 4 data file.

If RNDSPALL is specified, it will be used to map DRSPALL vectors to BRAGFLO vectors.

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An example spall model 4 data file for test or debug runs is shown in Appendix C (Section 16). This file is stored with the test input files as *cusp_test_10_spl4.dat*.

11.0 ERROR MESSAGES

CUTTINGS_S can generate three types of error messages: a warning, error, or fatal error. In general, a warning signals a condition about which the user should be aware; an error signals a serious problem; a fatal error causes the program to immediately abort. All error messages are written to the output debug file, if open. Fatal error messages are also written to the screen.

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.

When CUTTINGS_S reads the master control file, it writes the information read to the output debug file. If any errors are detected, CUTTINGS_S will write an error message and abort. The user should check the output debug file; any mismatch of information indicates missing or extra fields in the master control file. If the output debug file does not provide sufficient information to correct the file, the user should consult Section 10.1 for information about the file format, and check all file names.

When CUTTINGS_S processes the input control file, it echoes the file to the output debug file. If the code detects an error, it writes an error message directly below the statement that caused the error. If any errors are detected in the input control file, CUTTINGS_S will abort after the entire input control file is read.

For example, the following segment from the output debug file identifies several errors in the input control file.

```
Reading input control file
   U1:[TESTDIR]CUSP_ERROR.INP;6

! Spallings Model selection

MODEL4
NAME_REPPRES PRESGAS
REPPRES   CAVITY_1
*** ERROR - Expected cavity abbreviation or "*"
RNDSPALL  DUM5:RNDSPALL

! Properties

TAUFAIL   BOREHOLE:TAUFAIL
DNSFLUID  DRILLMUD:DENSITY
DOMEGA    BOREHOLE:DOMEGA
VISCO     DRILLMUD:VISCO
YLDSTRSS  DRILLMUD:YLDSTRSS
ABSROUGH  WAS_AREA:BAD_PROP
*** ERROR - Invalid ABSROUGH material:property WAS_AREA:BAD_PROP - property BAD_PROP is
not on input CAMDAT file
```

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```
BAD_KEY
*** ERROR - Unknown keyword BAD_KEY

! BRAGFLO zones

INTR_0  CAVITY_1
*** ERROR - Expected cavity abbreviation or "*"

INTR_1  *  CAVITY_1   NO_GRDVOL
>>> Simple average will be used; average will not be weighted by grid volume

INTR_2  *  457  458  459
```

%%% FATAL ERROR - Reading input control file

The following fatal error message would be written to the screen.

```
%%% FATAL ERROR - Reading input control file
%%%                (see output file for more information)
%%% Program is aborting %%%
%SYSTEM-?-ABORT, abort
```

If the error message does not provide sufficient information to correct the statement, the user should consult Section 10.2 for information about syntax or the appropriate keyword and parameters. If the error is an invalid CAMDAT property reference, the user should examine the input CAMDAT file described in Section 10.3 to determine the correct material and property name.

Once the input control file is read, CUTTINGS_S reads data from the BRAGFLO CAMDAT file. Errors may occur if the expected CAMDAT items (e.g., element variables) are not on the file. The user may need to examine the input BRAGFLO CAMDAT file described in Section 10.4.

To familiarize readers with CUTTINGS_S's error-message patterns, CUTTINGS_S's various fatal error messages are listed below.

```
%%% FATAL ERROR - Calling DBSETUP
%%% FATAL ERROR - Opening input control file
%%% FATAL ERROR - Opening input control file
%%% FATAL ERROR - Opening input CAMDAT file
%%% FATAL ERROR - Opening input BRAGFLO CAMDAT file
%%% FATAL ERROR - Opening Spall Model 4 data file
%%% FATAL ERROR - Invalid BRAGFLO CAMDAT file items requested
%%% FATAL ERROR - Reading BRAGFLO CAMDAT file

%%% FATAL ERROR - Reading input control file
%%% FATAL ERROR - Retrieving vector parameters from input CAMDAT file

%%% FATAL ERROR - Opening output data file
%%% FATAL ERROR - Cannot assign files
%%% FATAL ERROR - Reading Master Control File
%%% FATAL ERROR - Reading CAMDAT sizing info
```

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```
%%% FATAL ERROR - Reading CAMDAT material IDs and names
%%% FATAL ERROR - Reading CAMDAT property names
%%% FATAL ERROR - Reading CAMDAT property values

%%% FATAL ERROR - Reading BRAGFLO CAMDAT sizing parameters
%%% FATAL ERROR - Reading number of BRAGFLO CAMDAT variables
%%% FATAL ERROR - Reading BRAGFLO CAMDAT material names
%%% FATAL ERROR - Reading BRAGFLO CAMDAT number of elements per block
%%% FATAL ERROR - Reading BRAGFLO CAMDAT property names
%%% FATAL ERROR - Reading BRAGFLO CAMDAT attribute names
%%% FATAL ERROR - Reading BRAGFLO CAMDAT element variable names
%%% FATAL ERROR - Reading BRAGFLO CAMDAT sizing parameters
%%% FATAL ERROR - Reading BRAGFLO CAMDAT material names
%%% FATAL ERROR - Opening output CAMDAT file
%%% FATAL ERROR - Closing output CAMDAT file
%%% FATAL ERROR - Adding QA record to CAMDAT file
%%% FATAL ERROR - Writing CAMDAT property name
%%% FATAL ERROR - Writing "header" to the CAMDAT file
%%% FATAL ERROR - Adding CAMDAT global variable name name
%%% FATAL ERROR - Writing CAMDAT time step time
%%% FATAL ERROR - Writing CAMDAT global variable name
%%% FATAL ERROR - Writing time step (DBOSTEP)

%%% FATAL ERROR - Negative ROUTER in DRILL
```

12.0 DESCRIPTION OF OUTPUT FILES

The output files for CUTTINGS_S are described in this section.

12.1 Output Data File

The output data file is the principal CUTTINGS_S output file. It is a text file that contains the drill diameter and the amount of material removed by cuttings and cavings (as area) and spallings (as volume) for each scenario – vector – cavity – intrusion time combination.

The output data file is in a specific format expected by the PRECCDFGF code. The format is described below.

- The first line of the output data file is a header record with the following columns:
  1. the number of scenarios
  2. the number of vectors
  3. the number of cavities

- The second line lists the number of intrusion times for each scenario, in the order that the scenarios were defined on the master control file and are written on the output data file.

- The third line is a comment that describes the data columns for the data lines.

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- The data lines follow. The data lines are ordered by scenario, then cavity, then intrusion time, and finally vector. Thus, all the data for a particular scenario appears together, and the vector index increments each line. The scenario order is determined by the order they were defined on the master control file. Each data line has the following columns:
  1. the scenario number,
  2. the cavity abbreviation,
  3. the intrusion time,
  4. the vector number,
  5. the drill diameter,
  6. the footprint area of the material brought to the surface by cuttings and cavings, and
  7. the volume of the material brought to the surface by spallings.

An example output data file is shown in Appendix D (Section 17).

12.2 Output CAMDAT Files

A CAMDAT file is a binary file, as described under Section 10.3. It is not directly human readable, but may be read with programs that use the CAMDAT_LIB library routines.

One output CAMDAT file will be generated for each scenario – vector – cavity – intrusion time combination. Each output CAMDAT file contains the amount of material removed by cuttings, cavings, and spallings, along with volume-weighted averaged variables from the corresponding input BRAGFLO CAMDAT file.

All of the model information on the input CAMDAT file is copied to the output CAMDAT file. CUTTINGS_S parameters are added as CAMDAT properties of the material specified in the input control file with OUT_MAT. These parameters are DNSFLUID (as property DENSITY), DOMEGA, ABSROUGH (as property ABSRO), TAUFAIL, VISCO, and YLDSTRSS.

Each CAMDAT file has a single time step corresponding to the appropriate intrusion time (in seconds). CUTTINGS_S output is written to the CAMDAT file as global variables. Table 12-1 lists the global variables that are written to the CAMDAT file for a regulatory run.

Table 12-1– CAMDAT Global Variables Output by CUTTINGS_S

Global Variable Name	Description
AREA_C	Footprint area of the material brought to the surface by cuttings and cavings
AREA_S	Footprint area of the material brought to the surface by spallings (volume / initial repository height)
AREA_T	Area of all material brought to the surface (AREA_C + AREA_S)

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VOL_C	Volume of the material brought to the surface by cuttings and cavings (area * initial repository height)
VOL_S	Volume of the material brought to the surface by spallings
VOL_T	Volume of all material brought to the surface (VOL_C + VOL_S)
DRILDIAM	Drill diameter
NUM_INTR	Number of zones defined with INTR_*n* commands, with *n* starting at 0 (e.g., if NUM_INTR is 3, *n* ranges from 0 to 2)
POROS*n*	Final porosity for zone *n*, calculated from volume-weighted average POROS from BRAGFLO CAMDAT file
HFINAL_*n*	Final height for zone *n*, calculated from volume-weighted average POROS from BRAGFLO CAMDAT file
PRESGAS*n*	Volume-weighted average PRESGAS from BRAGFLO CAMDAT file for zone *n*
PRESBRI*n*	Volume-weighted average PRESBRIN from BRAGFLO CAMDAT file for zone *n*
SATGAS*n*	Volume-weighted average SATGAS from BRAGFLO CAMDAT file for zone *n*
SATBRIN*n*	1.0 - SATGAS*n*
PERMBRI*n*	Volume-weighted average PERMBRX from BRAGFLO CAMDAT file for zone *n*

The set of variables ending in *n* is output for each zone. Zone *n* is defined by the INTR_*n* keyword in the input control file. Note that with Version 6.04 of CUTTINGS_S these variable names have been shortened and given a two-digit *n* identifier, this is to accommodate more than 10 zone specifications. Most of these variables are from element variables from the input BRAGFLO CAMDAT file. The element variable values are interpolated from the BRAGFLO times straddling the intrusion time. The element variable values are weighted by grid volume and averaged, unless simple averaging is requested in the INTR_*n* command. The names of the variables from the BRAGFLO CAMDAT file may be changed with the NAME_xxx keywords in the input control file.

If there is no BRAGFLO CAMDAT file, the only *n*-type variables that will be output are POROSITY, HFINAL, and PRESGAS (without the *n*).

CUTTINGS_S attempts to define properties and time step variables on the output CAMDAT file in a reasonable order, but the user should not make assumptions about this ordering.

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12.3 Output Debug File

The text output debug file echoes the input control file (along with the values of any input CAMDAT properties referenced), and includes a summary of the calculated results. Error messages, if any, appear in this file.

An annotated example of the debug file is given in Appendix E (Section 18).

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Information Only

14.0 APPENDIX A: EXAMPLE MASTER CONTROL FILE

The master control file is discussed in Section 10.1. It describes the scenarios, vectors, cavities, and intrusion times to run, and identifies the input files that CUTTINGS_S needs and the output files that the code generates. Two examples are shown below. The first is designed for a regulatory calculation; the second is designed for a test run. The examples are annotated with explanatory comments (in italics) that are not part of the file.

Example Master Control File for Regulatory Run

```
5  100  3                                  5 scenarios, 100 vectors, 3 cavities
1 6   100   350  1000  3000  5000  10000   6 intrusion times for Scenario 1
2 5   550   750  2000  4000 10000          ... 5 for Scenario 2
4 5   550   750  2000  4000 10000          ... 5 for Scenario 4
3 5  1200  1400  3000  5000 10000          ... 5 for Scenario 3, and Scenario 5 (below)
5 5  1200  1400  3000  5000 10000          Scenario ordering is 1,2,4,3,5
L                                         Abbreviation for first cavity
M                                         ... second cavity
U                                         ... third cavity
CUSP_CRA1.INP                             Input control file
LHS3_CRA1_CUSP_A1_R^.CDB                  Input CAMDAT files (one for each vector)
BF3_CRA1_R1_S%_V^.CDB                     BRAGFLO CAMDAT files (one for each scen-vec pair)
SUM_DRS_SPLVOL2.TBL                       Spall model 4 data file
CUSP_CRA1_OUT.TBL                         Output data file
CUSP_CRA1_S%_V^_(_T!_OUT.CDB              Output CAMDAT files (one for each scen-vec-cav-intr)
```

Example Master Control File for Test Run

```
1  1  1                                   Single run
1  1  1000                              One intrusion time of 1000 for Scenario 1
-                                         "-" for no cavity abbreviation
CUSP_TEST_4.INP                           Input control file
CUSP_TEST_4.CDB                           Input CAMDAT file
CANCEL                                    No BRAGFLO CAMDAT file
CANCEL                                    No spall model 4 data file
CUSP_QA0600_TEST_4_OUT.TBL                Output data file
CUSP_QA0600_TEST_4_OUT.CDB                Output CAMDAT file
```

Information Only

15.0 APPENDIX B: EXAMPLE INPUT CONTROL FILE

The input control file is discussed in Section 10.2. It contains the drilling parameters and repository data. Two examples are shown below. The first is designed for a regulatory calculation; the second is designed for a test run. Note that the control file for the test run defines specific numerical values for the various parameters; the file for the regulatory run references properties from the input CAMDAT file.

Example Input Control File for Regulatory Run

```
! Input Control File for CUTTINGS_S
!
SECYR       REFCON:SECYR        ! Seconds-to-year conversion factor

HREPO       BLOWOUT:HREPO       ! Height of repository at burial time (m)

COLDIA      BOREHOLE:COLDIA     ! Collar diameter (m)
DIAMMOD     BOREHOLE:DIAMMOD    ! Borehole diameter

TAUFAIL     BOREHOLE:TAUFAIL    ! Effective shear strength of erosion
DOMEGA      BOREHOLE:DOMEGA     ! Angular velocity of drillstring
DNSFLUID    DRILLMUD:DNSFLUID   ! Density of the drilling fluid (mud)
VISCO       DRILLMUD:VISCO      ! Plastic viscosity
YLDSTRSS    DRILLMUD:YLDSTRSS   ! Yield stress of drilling fluid (mud)
ABSROUGH    WAS_AREA:ABSROUGH   ! Absolute borehole roughness
!
! Parameters for Spall Model 4
!
MODEL4
RNDSPALL    SPALLMOD:RNDSPALL
!
! Define "zones" for Bragflo averaged variables
! Intr_0 zone is defined for each cavity; all others defined for all cavities
!
INTR_0    L    CAVITY_1
INTR_0    M    CAVITY_1
INTR_0    U    CAVITY_2

INTR_1    *    1434 1435 1436 1437 1438 1439
INTR_2    *    1428 1429 1430 1431 1432 1433
INTR_3    *    2225
INTR_4    *    2244
INTR_5    *    1168
INTR_6    *    1417
INTR_7    *    DRZ_0
!
! Define zone for Bragflo averaged repository pressure (for spallings)
! Zone defined for each cavity
!
REPPRES   L   CAVITY_1
REPPRES   M   1428 1429 1430 1431 1432 1433
```

Information Only

```
REPPRES  U  1434 1435 1436 1437 1438 1439
!
! Define material on output CAMDAT file for CUTTINGS_S parameters
!
OUT_MAT  BOREHOLE
```

Substitute for Spall Model 3:

```
! Parameters for Spall Model 3

MODEL3
PTHRESH   WAS_AREA:PTHRESH
VOLSPALL  WAS_AREA:VOLSPALL
```

Example Input Control File for Test Run

```
! CUTTINGS_S TEST PROBLEM 4 checks laminar flow
!
!!! There is no BRAGFLO CAMDAT file for this test
!!! Note that no spall model is selected

! Parameters that normally come from BRAGFLO CAMDAT file
PRESSURE        15.0E6
POROSITY  0.88   0.606

! Parameters that normally come from input CAMDAT file
HREPO            3.96
COLDIA     0.2032004
DIAMMOD      0.26663
DNSFLUID      1200.0
DOMEGA           4.2
TAUFAIL        0.048
VISCO           0.06
YLDSTRSS         4.4
ABSROUGH    0.25E-01

OUT_MAT     BOREHOLE
```

16.0 APPENDIX C: EXAMPLE SPALL MODEL 4 DATA FILE

The data file required for spall model 4 is discussed in Section 10.5. It contains pressures and their corresponding data to determine the spall volume. An example spall model 4 data file suitable for a test run is shown below. The example contains two data sets of five vectors each. The example is annotated with explanatory comments (in italics) that are not part of the file.

```
5                       5 vectors in the pressure data set
2                       2 pressure data sets
10000000    20000000    Pressure for Set 1; pressure for Set 2
1    0    1             Set 1: Vector 1, unused, volume
```

Information Only

```
2     0     1.25          ... Vector 2 volume
3     0     1.5           ... Vector 3 volume
4     0     1.75          ... Vector 4 volume
5     0     2.00          ... Vector 5 volume
                          This line is ignored
1     0     10            Set 2: Vector 1, unused, volume
2     0     12.5          ... Vector 2 volume
3     0     15            ... Vector 3 volume
4     0     17.5          ... Vector 4 volume
5     0     20            ... Vector 5 volume
                          This line is ignored
```

17.0 APPENDIX D: SAMPLE OUTPUT DATA FILE

The output data file is discussed in Section 12.1. A sample file is shown below.

Line 1 of the file specifies that there are five scenarios, four vectors, and three cavities. Line 2 specifies that there are six intrusion times for Scenario 1, five times for Scenarios 2 and 4, and four times for Scenario 3 and 5. Note that the scenarios do not have the same intrusion times and the scenarios are not in numerical order. The intrusion times and the ordering of the scenarios are specified in the master control file. Line 3 of the file is a comment describing the contents of the data lines that follow. The file contains 288 data lines (4 vectors * 3 cavities * (6+5+5+4+4) intrusion times per scenario). Many of the data lines have been removed for brevity and replaced with "..." and a comment (in italics) explaining what data lines have been removed.

```
     5     4     3
     6     5     5     4     4
SCN CAV     TIME        VEC     DRILDIAM      AREA_C        VOL_S
  1 L    1.00000E+02     1   3.111500E-01  2.128595E-01  0.000000E+00
  1 L    1.00000E+02     2   3.111500E-01  1.131132E-01  0.000000E+00
  1 L    1.00000E+02     3   3.111500E-01  7.603780E-02  0.000000E+00
  1 L    1.00000E+02     4   3.111500E-01  1.309525E-01  0.000000E+00
  1 L    3.50000E+02     1   3.111500E-01  2.128595E-01  0.000000E+00
  1 L    3.50000E+02     2   3.111500E-01  1.131132E-01  0.000000E+00
  1 L    3.50000E+02     3   3.111500E-01  7.603780E-02  0.000000E+00
  1 L    3.50000E+02     4   3.111500E-01  1.309525E-01  2.410427E-02
  1 L    1.00000E+03     1   3.111500E-01  2.128595E-01  0.000000E+00
  1 L    1.00000E+03     2   3.111500E-01  1.131132E-01  4.980908E-01
  1 L    1.00000E+03     3   3.111500E-01  7.603780E-02  0.000000E+00
  1 L    1.00000E+03     4   3.111500E-01  1.309525E-01  3.760077E-01
  1 L    3.00000E+03     1   3.111500E-01  2.128595E-01  0.000000E+00
  1 L    3.00000E+03     2   3.111500E-01  1.131132E-01  5.401633E-01
  1 L    3.00000E+03     3   3.111500E-01  7.603780E-02  0.000000E+00
  1 L    3.00000E+03     4   3.111500E-01  1.309525E-01  2.590723E-01
  1 L    5.00000E+03     1   3.111500E-01  2.128595E-01  0.000000E+00
  1 L    5.00000E+03     2   3.111500E-01  1.131132E-01  5.332199E-01
  1 L    5.00000E+03     3   3.111500E-01  7.603780E-02  0.000000E+00
  1 L    5.00000E+03     4   3.111500E-01  1.309525E-01  2.110886E-01
  1 L    1.00000E+04     1   3.111500E-01  2.128595E-01  0.000000E+00
```

Information Only

```
  1 L     1.00000E+04     2  3.111500E-01  1.131132E-01  4.988766E-01
  1 L     1.00000E+04     3  3.111500E-01  7.603780E-02  0.000000E+00
  1 L     1.00000E+04     4  3.111500E-01  1.309525E-01  1.872676E-01
  1 M     1.00000E+02     1  3.111500E-01  2.128595E-01  0.000000E+00
  1 M     1.00000E+02     2  3.111500E-01  1.131132E-01  0.000000E+00
...     The 24 (6*4) data lines for Scenario 1, Cavity M, 6 intrusion times (100, 350, 1000, 3000,
        5000, 10000), Vectors 1-4 follow the same pattern as for Cavity L above.
  1 M     1.00000E+04     3  3.111500E-01  7.603780E-02  0.000000E+00
  1 M     1.00000E+04     4  3.111500E-01  1.309525E-01  1.864856E-01
  1 U     1.00000E+02     1  3.111500E-01  2.128595E-01  0.000000E+00
  1 U     1.00000E+02     2  3.111500E-01  1.131132E-01  0.000000E+00
...     The 24 data lines for Scenario 1, Cavity M, 6 intrusion times, Vectors 1-4.
  1 U     1.00000E+04     4  3.111500E-01  1.309525E-01  1.846775E-01
  2 L     5.50000E+02     1  3.111500E-01  2.128595E-01  3.135009E-02
  2 L     5.50000E+02     2  3.111500E-01  1.131132E-01  2.227808E-01
...     The 60 (3*5*4) data lines for Scenario 2, 3 cavities (L,U,M), 5 intrusion times, Vectors 1-
        4 follows the same pattern as for Scenario 1 above.
  2 U     1.00000E+04     4  3.111500E-01  1.309525E-01  0.000000E+00
  4 L     5.50000E+02     1  3.111500E-01  2.128595E-01  0.000000E+00
  4 L     5.50000E+02     2  3.111500E-01  1.131132E-01  2.248455E-01
...     The 60 data lines for Scenario 4, 3 cavities (L,U,M), 5 intrusion times, Vectors 1-4.
  4 U     1.00000E+04     4  3.111500E-01  1.309525E-01  0.000000E+00
  3 L     1.20000E+03     1  3.111500E-01  2.128595E-01  3.691427E-02
  3 L     1.20000E+03     2  3.111500E-01  1.131132E-01  3.954772E-01
...     The 48 (3*4*4) data lines for Scenario 3, 3 cavities (L,U,M), 4 intrusion times, Vectors 1-4.
  3 U     1.00000E+04     4  3.111500E-01  1.309525E-01  0.000000E+00
  5 L     1.20000E+03     1  3.111500E-01  2.128595E-01  0.000000E+00
  5 L     1.20000E+03     2  3.111500E-01  1.131132E-01  5.141423E-01
...     The 48 data lines for Scenario 5, 3 cavities (L,U,M), 4 intrusion times, Vectors 1-4.
  5 U     1.00000E+04     4  3.111500E-01  1.309525E-01  0.000000E+00
```

18.0 APPENDIX E: SAMPLE OUTPUT DEBUG FILE

The output debug file is discussed in Section 12.3. A portion of a sample file is shown below, annotated with explanatory comments (in italics) that describe the various sections.

Below is standard header information found on many WIPP output debug files. It includes the code version and the run date, and the names of the files input on the command line.

```
CUTTINGS_S 6.04 PRODUCTION 11/13/2020                    11/13/2020 09:18:42

  CCCCC  UU    UU TTTTTT  TTTTTT    IIII  N    NN  GGGGG   SSSSSS          SSSSSS
 CC   CC UU    UU   TT      TT       II   NN   NN GG   GG SS              SS
 CC       UU    UU   TT      TT       II   NNN  NN GG      SS              SS
 CC       UU    UU   TT      TT       II   NN N NN GG       SSSSS           SSSSS
```

Information Only

```
CC      UU    UU   TT      TT       II   NN  NNN GG  GGG      SS            SS
CC   CC UU    UU   TT      TT       II   NN   NN GG   GG      SS            SS
 CCCCC   UUUUU     TT      TT      IIII  NN    N  GGGGG  SSSSSS  _______ SSSSSS
```

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

CUTTINGS_S Version 6.04
PRODUCTION Built 11/13/2020
Written by Jerry W. Berglund (1995)

Run on 11/13/2020 at 09:18:42
Run on x86_64 cb001 Linux 3.10.0-957

****

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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****

****

FILE ASSIGNMENTS:

Master control file:

Information Only

```
    ./Input/cusp_v604_test_11_master.inp
       Written on 11/13/2020 09:19:23
 Output diagnostics file:
   CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11.dbg
```

The master control file is read once. Information from this file is written to the debug file as the file is read. If errors were detected when reading this file, error messages would appear in this section and the code would abort.

```
*******************************************************************************
 Reading master control file
    ./Input/cusp_v604_test_11_master.inp

 Process for each Scenario:      4 Vectors    3 Cavities
 Process Scenarios in the following order:
 Scenario 1 Intrusions:     100.
 Scenario 4 Intrusions:    2000.    4000.   10000.
 Scenario 3 Intrusions:    1200.   10000.
 Cavity Abbreviations:  L    M    U

 Input Control File:
    ./Input/cusp_test_11.inp
 Input CAMDAT File:
    ./Input/lhs3_cra1_cusp_a1_r^.cdb
 Input BRAGFLO CAMDAT File:
    ./Input/bf3_cra1_r1_s%_v^.cdb
 Input Spall Model 4 Data File:
    ./Input/cusp_test_11_spl4.dat
 Output Data File:
    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11.tbl
 Output CAMDAT File:
    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11_s%_v^_(_t!.cdb
```

Processing starts with Scenario 1, Vector 1. The input control file is read (and echoed) once for each scenario. If errors were detected when reading this file, error messages would appear in this section and the code would abort.

```
*******************************************************************************

                    *** SCENARIO 1 *** VECTOR    1 ***

 *******************************************************************************
 Reading input control file
    ./Input/cusp_test_11.inp

 ! Input Control File for CUTTINGS_S
 !
 SECYR       3.168876E-8          ! Seconds-to-year conversion factor
                                  ! (as listed in CUTTINGS_S 5.10 code)
 SHEARRT     1020
 MUDFLWRT    0.09935

 HREPO       3.960000E+00         ! Height of repository at burial time (m)
```

Information Only

```
COLDIA      2.032004E-01        ! Collar diameter (m)
DIAMMOD     BOREHOLE:DIAMMOD    ! Borehole diameter

TAUFAIL     BOREHOLE:TAUFAIL    ! Effective shear strength of erosion
DOMEGA      BOREHOLE:DOMEGA     ! Angular velocity of drillstring
DNSFLUID    DRILLMUD:DNSFLUID   ! Density of the drilling fluid (mud)
VISCO       DRILLMUD:VISCO      ! Plastic viscosity
YLDSTRSS    DRILLMUD:YLDSTRSS   ! Yield stress of drilling fluid (mud)
ABSROUGH    WAS_AREA:ABSROUGH   ! Absolute borehole roughness
!
! Properties for Spall Model 4
!
MODEL4
PTHRESH     WAS_AREA:PTHRESH     ! Not needed
*** WARNING - PTHRESH ignored if not MODEL3
!!! Delete  RNDSPALL   SPALLMOD:RNDSPALL  (use default spallings vector order)
!
! Define "zones" for Bragflo averaged variables
! Intr_0 zone is defined for each cavity; all others defined for all cavities
!
INTR_0    L    CAVITY_1
INTR_0    M    CAVITY_1
INTR_0    U    CAVITY_2

INTR_1    *    1434 1435 1436 1437 1438 1439
INTR_2    *    1428 1429 1430 1431 1432 1433
INTR_3    *    2225
INTR_4    *    2244
INTR_5    *    1168
INTR_6    *    1417
INTR_7    *    DRZ_0
!
! Define zone for Bragflo averaged repository pressure (for spallings)
! Zone defined for each cavity
!
REPPRES   L   CAVITY_1
REPPRES   M   1428 1429 1430 1431 1432 1433
REPPRES   U   1434 1435 1436 1437 1438 1439
!
! Define material on output CAMDAT file for CUTTINGS_S parameters
!
OUT_MAT   BOREHOLE
```

The spall model 4 data file, if any, is read once for each scenario. The spall data file information is written to the debug file after the entire file is read. Note that there are 4 vectors for the spall data, as opposed to the four scenario vectors.

```
*******************************************************************************
 Reading data from spall model 4 data file
    ./Input/cusp_test_11_spl4.dat

        Pressure     Pressure     Pressure     Pressure
 Vec   1.000E+07    1.200E+07    1.400E+07    1.480E+07
```

Information Only

```
  1      0.00000      0.00000      0.18940      0.34033
  2      0.00000      0.00000      0.60119      1.17003
  3      0.00000      0.00000      0.18940      0.34033
  4      0.00000      0.00000      0.09304      0.37601
```

Below starts the information that is included for each vector. The parameter values for this vector are listed. The parameters are defined in the input control file as values or as references to properties on the input CAMDAT file.

```
*******************************************************************************
 Retrieving vector parameters from input CAMDAT file
    ./Input/lhs3_cra1_cusp_a1_r001.cdb

 PI             3.141593E+00   Default
 SECYR          3.168876E-08   Value
 HREPO          3.960000E+00   Value
 COLDIA         2.032004E-01   Value
 DNSFLUID       1.210000E+03   CAMDAT material:property DRILLMUD:DNSFLUID
 DOMEGA         7.009000E+00   CAMDAT material:property BOREHOLE:DOMEGA
 ABSROUGH       2.500000E-02   CAMDAT material:property WAS_AREA:ABSROUGH
 TAUFAIL        1.025000E+00   CAMDAT material:property BOREHOLE:TAUFAIL
 VISCO          9.170000E-03   CAMDAT material:property DRILLMUD:VISCO
 YLDSTRSS       4.400000E+00   CAMDAT material:property DRILLMUD:YLDSTRSS
 SHEARRT        1.020000E+03   Value
 MUDFLWRT       9.935000E-02   Value
 DIAMMOD        3.111500E-01   CAMDAT material:property BOREHOLE:DIAMMOD
```

Information from the BRAGFLO CAMDAT file for all cavities and intrusion times for this scenario-vector is listed below. This section lists the BRAGFLO CAMDAT times straddling the intrusion times (for interpolation). It also lists the volume-weighted averages for the variables that will be written to the output CAMDAT file.

```
*******************************************************************************
 Reading BRAGFLO CAMDAT file
    ./Input/bf3_cra1_r1_s1_v001.cdb

 GRIDVOL read from BRAGFLO CAMDAT attribute GRIDVOL

 Intrusion Time =      0.    BRAGFLO Time                  0.00 years
 Intrusion Time =    100.    BRAGFLO Times      67.61     100.00 years

 Cav  Time   Zone    POROS         PRESGAS       PRESBRIN      SATGAS        PERMBRX

 L     100.    0  2.34896E-01  9.39054E+05  9.39054E+05  7.90089E-01  2.39990E-13
 L     100.    1  2.35074E-01  9.45601E+05  9.45601E+05  7.99190E-01  2.39990E-13
 L     100.    2  2.34999E-01  9.42836E+05  9.42836E+05  7.99303E-01  2.39990E-13
 L     100.    3  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
 L     100.    4  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
 L     100.    5  1.87235E-02  9.39028E+05  9.39028E+05  6.83386E-01  4.89778E-16
 L     100.    6  2.34896E-01  9.39054E+05  9.39054E+05  8.62339E-01  2.39990E-13
 L     100.    7  1.87134E-02  7.64854E+05  7.64854E+05  5.86296E-01  4.87412E-16

 M     100.    0  2.34896E-01  9.39054E+05  9.39054E+05  7.90089E-01  2.39990E-13
```

Information Only

```
M      100.    1  2.35074E-01  9.45601E+05  9.45601E+05  7.99190E-01  2.39990E-13
M      100.    2  2.34999E-01  9.42836E+05  9.42836E+05  7.99303E-01  2.39990E-13
M      100.    3  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
M      100.    4  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
M      100.    5  1.87235E-02  9.39028E+05  9.39028E+05  6.83386E-01  4.89778E-16
M      100.    6  2.34896E-01  9.39054E+05  9.39054E+05  8.62339E-01  2.39990E-13
M      100.    7  1.87134E-02  7.64854E+05  7.64854E+05  5.86296E-01  4.87412E-16
```

... This section lists the volume-weighted average BRAGFLO variables over the eight zones (0-7) for all intrusion times for Cavity L, M, and U.

```
U      100.    0  2.35041E-01  9.44372E+05  9.44372E+05  7.99240E-01  2.39990E-13
U      100.    1  2.35074E-01  9.45601E+05  9.45601E+05  7.99190E-01  2.39990E-13
U      100.    2  2.34999E-01  9.42836E+05  9.42836E+05  7.99303E-01  2.39990E-13
U      100.    3  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
U      100.    4  6.07459E-01  1.60658E+07  1.60600E+07  0.00000E+00  7.76248E-13
U      100.    5  1.87235E-02  9.39028E+05  9.39028E+05  6.83386E-01  4.89778E-16
U      100.    6  2.34896E-01  9.39054E+05  9.39054E+05  8.62339E-01  2.39990E-13
U      100.    7  1.87134E-02  7.64854E+05  7.64854E+05  5.86296E-01  4.87412E-16

From these two relationships:
   (1.0-Pi)*Hi = (1.0-Pf)*Hf
         Pf*Hf = Pb*Hi
Where:
   Pi = Initial porosity
   Hi = Initial height
   Pb = BRAGFLO porosity
   Pf =  Final  porosity
   Hf =  Final  height
Code will calculate:
   Pf = Pb/(1.0-Pi+Pb)
   Hf = (1.0-Pi)/(1.0-Pf)*Hi

HREPO (initial repository height) =  3.96000E+00

Cav  Time   Zone    InitPoro     BRAGPoro      POROF        HFINAL

L      100.    0  8.48350E-01  2.34896E-01  6.07679E-01  1.53072E+00
L      100.    1  8.48350E-01  2.35074E-01  6.07859E-01  1.53143E+00
L      100.    2  8.48350E-01  2.34999E-01  6.07783E-01  1.53113E+00
L      100.    3  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
L      100.    4  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
L      100.    5  1.82870E-02  1.87235E-02  1.87154E-02  3.96173E+00
L      100.    6  8.48350E-01  2.34896E-01  6.07679E-01  1.53072E+00
L      100.    7  1.83515E-02  1.87134E-02  1.87067E-02  3.96143E+00

M      100.    0  8.48350E-01  2.34896E-01  6.07679E-01  1.53072E+00
M      100.    1  8.48350E-01  2.35074E-01  6.07859E-01  1.53143E+00
M      100.    2  8.48350E-01  2.34999E-01  6.07783E-01  1.53113E+00
M      100.    3  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
M      100.    4  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
M      100.    5  1.82870E-02  1.87235E-02  1.87154E-02  3.96173E+00
M      100.    6  8.48350E-01  2.34896E-01  6.07679E-01  1.53072E+00
M      100.    7  1.83515E-02  1.87134E-02  1.87067E-02  3.96143E+00
```

Information Only

... This section lists the calculated values of final porosity and height over the eight zones for all intrusion times for Cavity L, M, and U.

```
U      100.    0  8.48350E-01  2.35041E-01  6.07825E-01  1.53130E+00
U      100.    1  8.48350E-01  2.35074E-01  6.07859E-01  1.53143E+00
U      100.    2  8.48350E-01  2.34999E-01  6.07783E-01  1.53113E+00
U      100.    3  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
U      100.    4  6.07459E-01  6.07459E-01  6.07459E-01  3.96000E+00
U      100.    5  1.82870E-02  1.87235E-02  1.87154E-02  3.96173E+00
U      100.    6  8.48350E-01  2.34896E-01  6.07679E-01  1.53072E+00
U      100.    7  1.83515E-02  1.87134E-02  1.87067E-02  3.96143E+00
```

The section below lists information from the cuttings and caving calculation for this scenario-vector. Cavity and intrusion time do not affect this calculation.

```
*******************************************************************************
 Calculating Cuttings and Cavings

 DOMEGA   =  7.0090E+00    DENSITY  =  1.2100E+03    TAUFAIL  =  1.0250E+00
 ABSRO    =  2.5000E-02    VISCO    =  9.1700E-03    YLDSTRSS =  4.4000E+00
 DRILDIA  =  3.1115E-01    COLDIA   =  2.0320E-01    FLOWRATE =  3.0913E-02
 ETA0     =  1.8340E-02    SIGMA1   =  1.0821E-06    SIGMA2   =  5.4103E-07

 Initial Reynolds Number =      8244., Flow is TURBULENT
    If >=2100 assumes TURBULENT AXIAL Flow; <2100 assumes LAMINAR HELICAL Flow

 VBAR Multiplier (CC) =  1.4295E+00

 Collar      Drill       Final       Critical    Final       Reynolds    Solution
 Radius      Radius      Radius      Radius      Area        Number      Algorithm
 ----------  ----------  ----------  ----------  ----------  ----------  ----------
 1.0160E-01  1.5558E-01  2.6030E-01  9.0803E-01  2.1286E-01  5.8587E+03  TURBULENT
```

The section below lists information from the spalling calculation for all cavities and intrusion times for this scenario-vector. It then lists the cavings and cuttings area and spall volume, which appear on the output data file.

```
*******************************************************************************
 Cuttings+Cavings and Spallings for Scenario 1  Vector   1

 Spall Model: MODEL4

 Cav  Time  Drill Diam (m)   Cut+Cav AREA  Rep Pres (pa)   Spall VOLUME

 L     100.   3.111500E-01   2.128608E-01   9.390539E+05   0.000000E+00

 M     100.   3.111500E-01   2.128608E-01   9.428356E+05   0.000000E+00

 U     100.   3.111500E-01   2.128608E-01   9.456009E+05   0.000000E+00
```

Information Only

The output CAMDAT files for all cavities and intrusion times for this scenario-vector are written at this point.

```
**********************************************************************
 Writing CAMDAT files

    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11_s1_v001_l_t100.cdb
    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11_s1_v001_m_t100.cdb
    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11_s1_v001_u_t100.cdb
```

The section below signals the start of processing for the next vector.

```
**********************************************************************

                    *** SCENARIO 1 *** VECTOR    2 ***

 **********************************************************************
 Retrieving vector parameters from input CAMDAT file
    ./Input/lhs3_cra1_cusp_a1_r002.cdb

 PI             3.141593E+00   Default
 SECYR          3.168876E-08   Value
 HREPO          3.960000E+00   Value
 COLDIA         2.032004E-01   Value
 DNSFLUID       1.210000E+03   CAMDAT material:property DRILLMUD:DNSFLUID
 DOMEGA         1.154000E+01   CAMDAT material:property BOREHOLE:DOMEGA
 ABSROUGH       2.500000E-02   CAMDAT material:property WAS_AREA:ABSROUGH
 TAUFAIL        1.092000E+01   CAMDAT material:property BOREHOLE:TAUFAIL
 VISCO          9.170000E-03   CAMDAT material:property DRILLMUD:VISCO
 YLDSTRSS       4.400000E+00   CAMDAT material:property DRILLMUD:YLDSTRSS
 SHEARRT        1.020000E+03   Value
 MUDFLWRT       9.935000E-02   Value
 DIAMMOD        3.111500E-01   CAMDAT material:property BOREHOLE:DIAMMOD
```

... The rest of the file has been removed for brevity. Similar information is listed for each scenario-vector. For the first vector of the scenario, the input control file and spall model 4 data file information will be repeated. The scenarios will be ordered as defined in the master control file.

The output data file is written at the end of the CUTTINGS_S run. The section below will be written if CUTTINGS_S runs to completion.

```
**********************************************************************
 Writing Output Data File
    CUTTINGS_S/Test/Output/Linux_604/cusp_604_test_11.tbl

 **********************************************************************


 CUTTINGS_S CPU time is 0:00 (minute:second)
```

Information Only

```
*** END OF CUTTINGS_S ***
CUTTINGS_S 6.04 PRODUCTION 11/13/2020                    11/13/2020 09:18:42
```

Information Only