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MATHEMATICAL MODELING OF TWO-STAGE CLASSIFICATION
TECHNOLOGY TRANSFER SUMMARY & USER'S GUIDE

By
L. K. Baltich

August 1987

Work Performed Under Contract No. FC07-83ID12440

For
U. S. Department of Energy
Office of Industrial Programs
Washington, D.C.

By
AMAX Research & Development Center
Golden, Colorado

MASTER

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Prepared for
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Idaho Operations Office, Idaho Falls, Idaho
Office of the Assistant Secretary for
Conservation and Renewable Energy
Office of Industrial Programs
Washington, DC

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ABSTRACT

CIRCUIT is a computer program developed for use in designing optimum two-stage classification configurations and operating conditions for energy conservation. It was developed in a cooperative effort between AMAX Research & Development Center and the United States Department of Energy, Conservation Technologies Division. This document contains the final summary report for the technology phase of the project and the User's Guide for CIRCUIT.

CIRCUIT is now available for use with IBM compatible personal computers. Copies of the program in disk form may be requested from the following:

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TECHNOLOGY TRANSFER SUMMARY

L. K. Baltich

**Based on Work Performed
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TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
PROJECT BACKGROUND	2
TECHNOLOGY TRANSFER	4
METHODS	4
Improving Software Accessibility	4
Developing Documentation	4
Technology Transfer Workshops	5
RESULTS	5
LIST OF PARTICIPANTS	8

INTRODUCTION

Energy conservation and cost benefits may be realized for some comminution circuits with the application of two-stage classification. Increasing throughput and maintaining or even improving grinding-product quality in an existing operation may require relatively minor flowsheet alterations if the appropriate classification flowsheet can be determined. Mathematical modeling of two-stage classification circuits provides a means of evaluating promising arrangements before actual plant trials. A computer simulation program for use in designing optimum two-stage classification configurations and operating conditions has been developed in a cooperative effort between AMAX Research & Development Center (AMAX R&D) and the U. S. Department of Energy's Idaho Falls Office.

The Mathematical Modeling of Two-Stage Classification project was initiated in 1983. The objective of the project was to develop and verify computer simulation models of particle size classification technology that will enable users to design the optimum configurations and operating conditions of two-stage classifiers for energy conservation. Work on this project was completed in 1986 and a final report was issued.¹ In that document, a recommendation was made by AMAX R&D to transfer the technology developed to interested industry users. The technology transfer phase of the project was initiated in 1986. This report and the attached Two-Stage Classification Modeling Program User's Guide represents the completion of this effort.

Successful application of the computer simulation program depends on program distribution and use. The approach followed to achieve this goal was to improve the accessibility of the two-stage classification simulation program, develop documentation for the application of the software, and hold technology transfer workshops for industry users.

The results of the technology transfer activities include an IBM-compatible version of the computer software and a User's Guide providing information for executing the program. Seven technology transfer workshops were also held throughout the country to acquaint users with the program and documentation. Fifty-nine participants attended these sessions, and feedback was solicited as to the usefulness of the program and its strengths and weaknesses for application to grinding-classification circuit modeling. The impact of the computer simulation program, User's Guide, and workshops on the possible implementation of two-stage classification are discussed in this report.

¹ Baltich, L. K., "Mathematical Modeling of Two-Stage Classification", Final Report for Contract No. DE-FC07-83ID12440 (DOE/ID/12440-2), March 1986.

PROJECT BACKGROUND

A cooperative agreement between the Department of Energy (DOE) and AMAX Research & Development Center was initiated in April 1983. The objectives of the Mathematical Modeling of Two-Stage Classification contract were to develop and verify computer simulation models of particle size classification technology that will enable users to design the optimum configurations and operating conditions of two-stage classifiers for energy conservation.

The project was carried out in two phases. The first phase included collection of data from commercial and pilot-plant operations, development of classification models, and two-stage classification simulation and evaluation. In the second phase of the program, results of the simulation studies were verified, and necessary modifications to the models were incorporated. The results of these investigations have been previously reported in detail.¹

A major result of the project was the development of a computer simulation program for use as a tool in the design and study of two-stage classification circuits. The program allows simulation of five basic grinding-classification circuits, including one single-stage and four two-stage classification arrangements. Hydrocyclones, spiral classifiers, and sieve bend screens can be simulated using the program, and the user may choose the combination of devices to be used in the flowsheet simulation.

An additional feature of the program lets the user select from four classification modeling methods in order to achieve the goals of a simulation project using the most familiar concepts. Flexibility is also offered by the ability of the program to model circuit performance based on classification parameters or equipment operating conditions. A modular approach was taken in designing the program, which allows future addition of other models with relatively minor change to the overall program.

Other results of the Mathematical Modeling of Two-Stage Classification project included a comparison of simulation results and pilot-plant operating data. This study indicated that application of the program leads to acceptable predictions of circuit performance in terms of product-size distribution and energy efficiency when appropriate data are available.

Pilot-plant operation demonstrated that two-stage classification can be used to reduce unit energy consumption while increasing throughput and maintaining or improving circuit product-size distribution. In the pilot plant, grinding circuit capacity was increased by 10 to 30 percent by the use of two-stage rather than single-stage classification. This corresponds to a 12 to 20 percent reduction in unit mill-energy consumption. The addition of water to the grinding circuit was confirmed as an important factor in the implementation of two-stage classification.

The four basic two-stage classification flowsheets studied during the project were rank ordered in terms of energy conservation potential, and projections of national

energy savings resulting from two-stage classification were also made. It was determined that actual energy savings would depend on the type of flowsheet used and on the portion of comminution operations implementing two-stage classification.

TECHNOLOGY TRANSFER

The computer simulation program is a tool developed for the use of engineers involved in the study of comminution circuit performance. Therefore, the successful application of the technology depends on program distribution and use. A recommendation was made in the final report of the Mathematical Modeling of Two-Stage Classification project to transfer the technology developed to industry users.¹

METHODS

AMAX Research & Development Center proposed a contract modification to achieve this goal by improving the accessibility of the two-stage classification simulation program, developing documentation for the application of the software, and holding technology transfer workshops for industry users. This proposal was accepted by the Department of Energy, and the technology transfer activities for the project began in April 1986.

Improving Software Accessibility

CIRCUIT, the two-stage classification simulation program, was developed on a VAX 11/785 mainframe computer using a VMS operating system. The program is written in FORTRAN-77. General application of the program was, therefore, restricted to industry users with access to a compatible mainframe computer. Software accessibility was enhanced by modification of the program source code to operate on an IBM-compatible personal computer (PC) with an MS-DOS operating system. This type of system is widely used for engineering applications, and availability of a PC version of the software increases the range of application, as well as the portability of the program.

Software accessibility was also improved through the upgrading of input and output subroutines. Modifications were made to allow users to enter data interactively or by using a data file. Another result of the modification allows the user to change input data files through the program instead of a system editor. All input data were organized into categories for ease in making changes through a system of menu presentations and user selections. An additional improvement was made to increase the speed of operation of the program on a PC system.

Developing Documentation

The Two-Stage Classification Modeling Program User's Guide was written to provide users with the information necessary to apply the program to grinding-classification circuit studies. The User's Guide is attached to this report and contains instructions for loading and running CIRCUIT on a PC system, step-by-step instructions for data entry, a description of the program's structure, an overview of its capabilities, application strategies and examples, and instructions for modifying source code or adding process blocks. A checklist is provided to help the user coordinate data collection with application of CIRCUIT.

The documentation was developed for people who have minimal experience in operating IBM-compatible PC's. A person with experience in mass balance calculations and assessment of grinding circuit performance should be able to run CIRCUIT with the help of the User's Guide. No programming experience is necessary unless a user wishes to make modifications to the FORTRAN code.

Technology Transfer Workshops

Potential users of the simulation program were identified through contacts by mail and telephone throughout the country. A handout describing the workshop sessions was available at the annual meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) in Denver during February 1987 at the AMAX exhibit. Efforts were made to schedule workshops at the convenience of interested participants.

Seven technology transfer workshops were held between May and August 1987. A total of 59 participants attended these sessions. Each workshop provided an overview of the program and its present range of applications. Demonstrations were given and feedback from the participants was noted as to the usefulness of the program and its advantages and disadvantages for possible applications. Based on the comments and suggestions made by workshop attenders, minor software and documentation changes were made following the sessions.

A list of workshop participants is provided at the end of this report. The following is a list of the dates and locations of the technology transfer workshops:

May 27, 1987	Florida Institute of Phosphate Research, Bartow, Florida
July 8, 1987	AMAX Research & Development Center, Golden, Colorado
July 10, 1987	U. S. Bureau of Mines, Tuscaloosa, Alabama
July 21, 1987	AMAX Research & Development Center, Golden, Colorado
July 31, 1987	U. S. Bureau of Mines, Salt Lake City, Utah
August 12, 1987	AMAX Henderson Mill, Parshall, Colorado
August 17, 1987	Natural Resources Research Institute, Coleraine, Minnesota

A survey was sent to each participant to be returned after trying the program in-house. Participants were asked to express their level of interest in applying two-stage classification and the usefulness of the program in planning such applications.

RESULTS

The results of the technology transfer phase of the Mathematical Modeling of Two-Stage Classification project included the IBM-compatible PC computer simulation program, CIRCUIT. Participant surveys solicited a variety of comments about the usefulness of the program and its advantages and disadvantages.

Nearly all participants responding indicated that CIRCUIT includes the grinding and classification models of most interest to them. Numerous advantages of the program were mentioned including the ability of the program to study several flowsheet possibilities before committing to plant trials. This approach was praised for saving energy, time, and money. Other participants cited flexibility, simplicity, and speed of operation as advantages. Several additions to the software were recommended by different participants including vibrating screen, rod mill, semi-autogenous mill, and crusher models.

CIRCUIT disadvantages mentioned by participants included the caution that the program may be too easy to use and could "make instant experts out of ignorance". Other comments indicated that a few participants felt the program required the user to know too many details that might not be available for some modeling problems.

Another result of the technology transfer phase was the Two-Stage Classification Modeling Program User's Guide. A majority of the participants responding to the survey indicated that the User's Guide was easy or not difficult to understand and use. Nearly all respondents said the guide covered everything they would like to have included. These responses suggest that the User's Guide meets the objective of providing users with the information necessary to apply the program to grinding-classification circuit studies.

The goals of the technology transfer workshops were to demonstrate the usefulness of mathematical modeling as a tool in design and performance estimation of two-stage classifiers and to encourage the use of the software for studying grinding-classification circuits. The workshop method increased each person's understanding of the program's capabilities and gave the participants a chance to get familiar with program execution. Survey responses indicated that nearly all participants found the workshops helpful and most felt ready to use the program after the session. The technology transfer workshops have increased the probability that participants will make use of the simulation program to study grinding-classification circuit performance and to consider the use of two-stage classification for improving energy efficiency.

Several comments indicated an even more extensive workshop, including basic grinding and classification modeling concepts, would be welcome by some participants. Although this was beyond the scope of the present effort, it seems to indicate that this form of communication could be extended to include other topics as they are identified.

An additional result of the technology transfer phase is the impact of the computer simulation program, its documentation, and the workshops on the application of two-stage classification in grinding-classification circuits. This impact is not expected to be immediately measurable. However, responses to the surveys indicate a favorable outlook in several areas.

A few participants indicated that they are currently using multiple-stage classification in their grinding circuits. Over half of the respondents said they are

considering the use of multiple-stage classification and that CIRCUIT will be an aid in evaluation of this option. Several respondents indicated that they are not currently considering the use of multiple-stage classification, but the availability of CIRCUIT will influence them to re-evaluate this position. Most respondents indicated that the program, documentation, and workshop were valuable to themselves and their organizations.

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TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
1.1. HARDWARE REQUIREMENTS	2
1.2. SOFTWARE REQUIREMENTS	3
1.3. USING THIS GUIDE	3
2. GETTING STARTED	4
2.1. FLOPPY DISK SYSTEM	4
2.1.1. Making a Back-up Copy of CIRCUIT	4
2.1.2. Loading CIRCUIT	4
2.2. HARD DISK SYSTEM	5
2.2.1. Creating a CIRCUIT Sub-directory	5
2.2.2. Installing CIRCUIT	6
3. DATA ENTRY	7
3.1. DATA ENTRY OVERVIEW	7
3.2. INTERACTIVE DATA ENTRY	8
3.2.1. Set-up Information	8
3.2.2. Circuit Feed Data	16
3.2.3. Classifier Recycle Stream Data	17
3.2.4. Mill Data	18
3.2.5. Classifier Data	19
3.3. DATA FILE ENTRY	21
3.4. DATA CHECKLIST	22
4. CIRCUIT OVERVIEW	24
4.1. PROGRAM ORGANIZATION	24
4.1.1. INDATA	24
4.1.2. OUTDATA	27
4.1.3. SUMP	27
4.1.4. MILL	28
4.1.5. CLASS	28
4.1.6. STRMCAL	28
4.1.7. CONV	29
4.2. MODEL DESCRIPTIONS	29
4.2.1. Grinding Model	30
4.2.2. Classification Models	32
4.2.3. Equipment Models	37

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
4.3. PROGRAM CAPABILITIES	44
4.3.1. Flowsheet Selection	45
4.3.2. Classification Calculation Models	45
4.3.3. Classification Equipment Models	45
4.3.4. Grinding Mill Model	46
4.3.5. Unit Energy Consumption Calculation	46
4.3.6. Data Entry	46
4.3.7. Results Reporting	46
4.3.8. Expansion	47
4.4. FUTURE DEVELOPMENT	47
 5. APPLICATION STRATEGY	 48
5.1. DEFINING THE PROBLEM	48
5.2. IDENTIFYING SOLUTIONS	49
5.3. COLLECTING DATA	49
5.4. USING CIRCUIT	50
5.5. ANALYZING RESULTS	50
 APPENDIX A	
APPLICATION EXAMPLES	51
 APPENDIX B	
MODIFYING CIRCUIT	93

LIST OF FIGURES

		<u>Page</u>
Figure 1.	Representation of the order in which process subroutines are called during simulation of Flowsheet 1 (single-stage classification).	10
Figure 2.	Representation of the order in which process subroutines are called during simulation of Flowsheet 2 (two-stage classification).	11
Figure 3.	Representation of the order in which process subroutines are called during simulation of Flowsheet 3 (two-stage classification).	12
Figure 4.	Representation of the order in which process subroutines are called during simulation of Flowsheet 4 (two-stage classification).	13
Figure 5.	Representation of the order in which process subroutines are called during simulation of Flowsheet 5 (two-stage classification).	14
Figure 6.	Schematic representation of the computer simulation program, CIRCUIT.	26

1. INTRODUCTION

Two-stage classification is the operation of two stages of classification in one of several circuit configurations to improve process efficiency. Prior emphasis in the operation of two-stage classification systems has usually been toward improving the size-separation efficiency; this tends to increase selectivity and recovery by downstream mineral-recovery processes such as flotation and gravity separation. However, it has been estimated that a 25-percent increase in circuit capacity corresponding to a 20-percent reduction in energy consumption may result in a conventional grinding circuit when two-stage classification is used.¹ For example, a grinding circuit processing 10 million tons of ore annually while consuming 130 million kWh is effectively using 13 kWh of energy per ton of new feed. A 25-percent increase in circuit capacity would cause this effective energy requirement to drop to 10.4 kWh per ton of new feed with a corresponding energy savings of 26.0 million kWh when 10 million tons of ore are processed. This is a 20-percent reduction in energy consumption which amounts to \$1.3 million at \$0.05/kWh. If a 10-percent capacity increase were realized, energy savings for processing 10 million tons of ore would be 11.8 million kWh, a 9-percent reduction in consumption which would save \$590,000 at \$0.05/kWh.

This method of reducing unit energy consumption by increasing throughput and maintaining or even improving the grinding-circuit product quality can be used to modify existing operations through relatively minor flowsheet alterations. Additional energy savings are possible if new circuits are designed for lower energy consumption using two-stage classification. A further benefit of the design of new circuits is the decrease in capital cost possible through selection of a smaller grinding mill than would be necessary with traditional classification.

In order to evaluate possible two-stage classification circuit performance, an engineer must perform numerous mass balance calculations. The purpose of these calculations is to predict what the circuit might do under different feed or operating conditions, to determine flow rates for sizing new equipment, or to compare classification flowsheet options. A computer program that carries out the calculations necessary to balance the circuit is a tool that helps the engineer determine what is happening and allows him to envision what should happen under different conditions.

CIRCUIT is a computer program to mechanize the calculation of grinding-classification circuit mass balances. It performs this job by starting its calculations at the beginning of the circuit and proceeding through grinding and classification unit operations until all process stream variables have been calculated. CIRCUIT requires information about the circuit feed and parameters for the ball mill and classifiers.

¹ Committee on Comminution and Energy Consumption, Comminution and Energy Consumption, National Materials Advisory Board, Commission on Sociotechnical Systems, NMAB-364, May 1981.

Streams recycled to the ball mill cause CIRCUIT to repeat the calculations until convergence is realized. The program allows the engineer to spend his time assessing the results of the calculations and examining the effects of changes to the flowsheet or processing assumptions.

CIRCUIT can be used to simulate five basic grinding-classification flowsheets, including one single-stage and four two-stage classification arrangements. For single-stage classification, one classification step follows ball-mill grinding and the coarse-particle stream is returned to the mill, while the fine-particle stream is the circuit product. In two of the four two-stage classification flowsheets, the coarse-particle stream from the first classifier is fed to the second classifier. The fine-particle streams are combined as circuit product for one option; the second-stage fine-particle stream is recycled to the first stage in the other flowsheet.

In the remaining two flowsheets, the fine-particle stream from the first classifier is sent to the second stage. The second-stage fine-particle stream is the circuit product in both of these flowsheets. In one case, both coarse-particle streams are returned to the mill. For the other case, the second-stage coarse-particle stream is recycled to the first-stage classifier.

CIRCUIT consists of an executive program and seven primary subroutines for data input and output, grinding, classification, and sump modeling, stream inventory, and convergence calculations. A modular approach was taken in designing the program in order to allow future addition of other models with relatively minor changes to the overall package.

The package offers a selection of semi-empirical and empirical classification models to the user. The classification subroutine has been developed to allow modeling based on known classification parameters or equipment and operating variables. Calculation of coarse and fine product stream data may be made by four methods if the appropriate classification parameters are known. If these parameters are not available, they may be predicted based on equipment and operating variables for hydrocyclones, spiral classifiers, and sieve bend screens.

CIRCUIT was developed on the VAX 11/785, VMS v.4.2 system used by AMAX R&D. The program was written and compiled in FORTRAN-77. The IBM-compatible personal computer (PC) version of the program was subsequently developed. This User's Guide is intended to describe program capabilities and provide operating instructions for this PC version.

1.1. HARDWARE REQUIREMENTS

CIRCUIT will run on an IBM-compatible personal computer (PC) with 640 kilobytes (K) of random access memory (RAM). In order to increase speed of operation, a math coprocessor computer chip is desirable. In most cases, access to a printer is desirable for printing output data. Data output can be printed on 8-1/2 by 11-inch paper.

1.2. SOFTWARE REQUIREMENTS

In order to execute CIRCUIT, you will need a copy of Disk 1, Program Disk. This disk contains the current executable version of CIRCUIT and some example input and output data files. Disk 2, Source Disk, contains the FORTRAN source code and compiler files. Disk 2 is provided for your use when making program modifications (see Appendix B).

1.3. USING THIS GUIDE

This guide is written for people who have minimal experience in operating IBM compatible personal computers (PC's) with an MS DOS operating system. A person with experience in mass balance calculations and assessment of grinding circuit performance should be able to run CIRCUIT with the help of this User's Guide. No programming experience is necessary to run CIRCUIT. Users who want to modify the program or add subroutines will need some FORTRAN programming experience (see Appendix B).

This guide provides:

- Instructions for loading CIRCUIT on a PC.
- Instructions for running CIRCUIT and entering data.
- A description of the program's structure.
- An overview of the program's capabilities.
- Application strategies and examples.
- Instructions for making program modifications or adding new process blocks.

It is not necessary to read the entire User's Guide before running CIRCUIT. You will need to read Chapter 2, Getting Started, the first time you use CIRCUIT, and it may be very helpful to review Chapter 3, Data Entry, before you attempt to use the program, since it describes the data you will need. Otherwise, this guide is a reference manual, and you may wish to consult only specific sections to find the answers to your questions. For instance, you may want to check Section 3.4, Data Entry Checklist, prior to collecting data for use with the program.

2. GETTING STARTED

This chapter will get you ready to use CIRCUIT on an IBM-compatible personal computer (PC) with 640 kilobytes of memory and two floppy disks or a hard disk.

2.1. FLOPPY DISK SYSTEM

The following instructions will help you make a back-up copy of CIRCUIT and load the program onto your floppy disk system.

2.1.1. Making a Back-up Copy of CIRCUIT

If you will be working with a floppy disk system, you should make a back-up copy of CIRCUIT. To make a back-up copy you will need:

1. Your DOS disk.
2. Your original copy of the CIRCUIT program disk.
3. A blank, formatted disk that you should date and label as your back-up copy of CIRCUIT.

To make the copy, follow this procedure:

1. Boot your system using your DOS disk in Drive A.
2. When the A> prompter appears, type:

DISKCOPY A: B:
and press RETURN

3. When the system prompts you, insert the CIRCUIT program disk in Drive A and your blank back-up disk in Drive B.
4. When copying has finished, you will be prompted to answer if you wish to copy another disk. Since only the program disk is required to run CIRCUIT, you do not need to make back-up copies of the other disk.

2.1.2. Loading CIRCUIT

In order to load CIRCUIT on your floppy disk system, you will need:

1. Your DOS disk.
2. Your back-up copy of the CIRCUIT program disk.

3. A blank, formatted disk that you should date and label as your CIRCUIT data disk.

When you are ready to run CIRCUIT:

1. Boot your system using your DOS disk in Drive A.
2. When the A> prompter appears, type:

B:
and press RETURN

3. When the B> prompter appears, insert the CIRCUIT program disk in Drive A and your data disk in Drive B.
4. Then type:

A:CIRCUIT
and press RETURN.

The program will begin execution, and the data files that you create will be stored on your data disk in Drive B.

2.2. HARD DISK SYSTEM

The following instructions will help you make a sub-directory on your hard disk system and install CIRCUIT in that sub-directory.

2.2.1. Creating a CIRCUIT Sub-directory

If you will be using CIRCUIT on a hard disk system, it is suggested that you make a sub-directory that will include the program and the data files you will create. To create a sub-directory:

1. Boot your system.
2. When the C> prompter appears, type:

MD C: CIRCUIT
and press RETURN.

3. Then type:

CD CIRCUIT
and press RETURN.

4. When the C: CIRCUIT> prompter appears, you are working in your new sub-directory and may proceed to install CIRCUIT on your hard disk (see Step 3 below).

2.2.2. Installing CIRCUIT

Before you install CIRCUIT on your hard disk system, please read the previous instructions for creating a sub-directory. To install CIRCUIT, you will need:

1. Your CIRCUIT program disk.

When you are ready to install CIRCUIT:

1. Boot your system.
2. When the C> prompter appears, type:

CD CIRCUIT
and press RETURN.

3. When the C: CIRCUIT> prompter appears, insert the CIRCUIT program disk in Drive A.
4. Then type:

COPY A:*. *
and press RETURN.

5. When copying is complete, CIRCUIT is installed on your hard disk.

If you plan to modify the program, you can install all files from the source and compiler disks to your hard disk using the same procedure. Before attempting to modify the source code, please read Appendix B.

3. DATA ENTRY

CIRCUIT is a computer program that performs the mass balance calculations necessary to evaluate grinding-classification circuit performance. The program is a tool to help you determine what is happening in a circuit or to predict what should happen under different conditions. CIRCUIT starts its calculations at the beginning of the circuit and proceeds through grinding and classification unit operations until all process stream variables have been calculated. CIRCUIT requires information about the circuit feed and parameters for the ball mill and classifiers. Streams recycled to the ball mill cause CIRCUIT to repeat the calculations until convergence is realized.

In order to use CIRCUIT effectively, you will need to collect data for the grinding-classification circuit that you want to study. You will need to collect slurry samples and gather information on the operating conditions for the sampling period.

It is recommended that you use the program first to simulate the grinding-classification circuit as it is presently operated. This exercise will allow you to assess the accuracy of model predictions against the actual operating performance. If you have data collected under different operating conditions, you can also determine the ability of the program to simulate different conditions.

Another helpful practice is to use a material balance program to adjust your raw data before proceeding to the simulation studies. Samples taken from circuit streams may not be truly representative, and some amount of analytical error is also possible. CIRCUIT results will be more reliable if this sampling error is adjusted prior to using the program.

This chapter provides instructions for entering data during operation of CIRCUIT and should familiarize you with the questions to be asked and answered while running the program. A checklist is also included at the end of this chapter to help you plan your data collection.

3.1. DATA ENTRY OVERVIEW

All data required by CIRCUIT are entered in response to requests made by the program. Program options are offered in menu form. You may enter information without regard to format style, and it will automatically be converted to the correct format within the program. Data are checked upon entry for obvious errors such as improper negative values or weight-percent solids over 100. Size analyses are also checked to determine that total weight percent does not exceed 100. If you enter incorrect data, you will be notified by a message and asked to re-enter the data correctly.

The program allows you to enter data interactively or by using a data file. You should select interactive data entry for the first simulation of a flowsheet. A new data file will automatically be created by the program. Data entry for subsequent simulations of the flowsheet can then be made using the data file.

Data files may be changed through the simulation program. All input data have been organized into categories for ease in making changes. When you choose to enter data using a file, CIRCUIT will give you the option to edit the file. If you choose to edit the data file, a series of menus will allow you to make changes in the set-up information, circuit feed data, classifier recycle stream data, mill data, and classifier data. This capability is useful for changing circuit operating parameters or correcting mistakes. Data files can also be modified using any system editor.

3.2. INTERACTIVE DATA ENTRY

The first time you study a flowsheet, you will enter the input data by responding to a series of questions from CIRCUIT. To enter information, type the data and then press the RETURN key. You may enter numbers with or without decimal places; data will be automatically converted to the correct format within the program. For instance, it is permissible to enter 10 or 10. or 10.0 . Likewise, you may enter 0.1 or .1 . When more than one value is requested, you may enter each separately or you may type in all values, separated by commas, before entering. For instance, you may type 125 and press RETURN, followed by 56.3 and press RETURN, or you may type 125,56.3 and press RETURN.

It is recommended that you use the data given in one of the application examples presented in Appendix A for your first simulation using CIRCUIT. You can then use the following sections to clarify entry options as you go along.

The first information CIRCUIT will request is the name of a file in which to store the output data. File names can begin only with a letter but may contain up to eight letters and numbers. No symbols (i.e., %, -, #) are allowed in file names. It is usually helpful to select a file name with a one to three letter extension, such as FILE.DAT, TEST1A.OUT, or MILL1.IN.

After entering an output file name, CIRCUIT will ask if you wish to enter data from the terminal or from a file. If you want to use a data file, refer to Section 3.3. Otherwise, enter 1 for interactive data entry. A new data file will automatically be created by the program. A name for the input data file is requested. Follow the rules in the preceding paragraph for naming files and select a file name. The input file name or its extension should be different than the name of the output file (for example, MILLIN.DAT and MILLOUT.DAT or MILL.IN and MILL.OUT). The program will now begin requesting your data. The data you are required to enter is described in detail below.

3.2.1. Set-up Information

The set-up information required includes a title for the circuit and a description of the run. You must select a circuit flowsheet which will determine the order in which the equipment simulation subroutines are called. The convergence tolerance and the maximum number of flowsheet calculation iterations are requested. An output print option must be entered. Size fractions selection is also part of the set-up information.

3.2.1a. Circuit Title

Enter an identification title for your circuit. You may use up to 40 characters. Capital and small letters, numbers, and symbols are allowed.

Example: SINGLE-STAGE CYCLONES: Mill #5

This entry is optional. If you do not want to title the circuit, press RETURN.

3.2.1b. Data Description

Enter an additional identifying comment. You may use up to 40 characters. Capital and small letters, numbers, and symbols are allowed.

Example: 123 TPH, Mill Feed = 70% solids, 10/1/87

This entry is optional. If you do not want to enter a description, press RETURN.

3.2.1c. Flowsheet Selection

Five flowsheets are available for modeling using CIRCUIT. Figures 1 through 5 show the order in which the process subroutines are called for the five flowsheets and stream number designations. The process streams where convergence is determined have also been indicated for your information. Flowsheet 1 is used for single-stage classification; flowsheets 2 through 5 are two-stage classification flowsheets. Determine which flowsheet you want to model and enter 1, 2, 3, 4, or 5.

3.2.1d. Convergence Tolerance

A convergence check is performed by the program after each full iteration of flowsheet calculations. The present convergence stream size distribution is compared to that calculated for the previous iteration. The convergence tolerance determines how closely these distributions must match. Typically, a value of 0.1 or 0.01 is sufficient.

3.2.1e. Maximum Iterations

A convergence check is performed by the program after each full iteration of flowsheet calculations. The present convergence stream size distribution is compared to that calculated for the previous iteration. If the maximum number of iterations is reached before the convergence tolerance is met, the program run will be terminated and the current results sent to the output data file. Typically 20 iterations are sufficient.

Figure 1. Representation of the order in which process subroutines are called during simulation of Flowsheet 1 (single-stage classification).

Figure 2. Representation of the order in which process subroutines are called during simulation of Flowsheet 2 (two-stage classification).

Figure 3. Representation of the order in which process subroutines are called during simulation of Flowsheet 3 (two-stage classification).

Figure 4. Representation of the order in which process subroutines are called during simulation of Flowsheet 4 (two-stage classification).

Figure 5. Representation of the order in which process subroutines are called during simulation of Flowsheet 5 (two-stage classification).

3.2.1f. Output Print Option

Six output print options are offered by CIRCUIT. Selection of an option determines the type of report that will be printed to the output data file. Option 1 is a long form report which writes percent solids, flow rates, and size distributions for each stream in the circuit and also writes the values of all input data for review. Option 3 is a brief output form that writes results for the ball mill and classifier feed and product streams. The values of the input data are also included. Option 5 is a circuit summary form that lists the results for all streams using a tabular format and also writes the values of all the input data. Options 2, 4, and 6 are identical to Options 1, 3, and 5, respectively, except that input data values are not reported. Enter your selection of 1, 2, 3, 4, 5, or 6.

3.2.1g. Size Fraction Selection

The size fractions you select when planning your data collection will be used numerous times in CIRCUIT. There are three rules to keep in mind when determining these fractions.

1. Only one set of size fractions is allowed per simulation. This means the same deck of screens should be used for all stream samples taken. For instance, if a 1-inch screen is used for sizing the circuit feed, CIRCUIT will report percent of material retained on the 1-inch screen for the classifier fine product, even if that value is 0.
2. Size fractions must be consistently separated by the same interval such as the square root of 2 progression: 65, 100, 150, 200, 270, 400 mesh or some multiple of that interval. For instance, 65, 150, and 270 mesh is an allowable sequence, but 65, 150, and 400 mesh is not. The program allows you to enter your own size fractions, and it is possible to enter an incorrect series. However, some of the ball-mill model calculations depend on consistent separation, and erroneous results may occur if this rule is violated.
3. When selecting size fractions from those offered by CIRCUIT, the program will assume your finest size fraction is a passing (or minus) fraction. For instance, if you designate 400 mesh as your finest screen, CIRCUIT will assume you have both plus 400 and minus 400-mesh size fractions. Therefore, remember to include the finest size in the number of size fractions you select. For example, the series 65, 150, 270, -270 has 4 size fractions.

CIRCUIT will first display a list of size fractions you may select from:

400 mesh	270 mesh	200 mesh
150 mesh	100 mesh	65 mesh
48 mesh	35 mesh	28 mesh
20 mesh	14 mesh	10 mesh
8 mesh	6 mesh	4 mesh
3 mesh		
0.375 inch	0.500 inch	0.750 inch
1.000 inch	1.500 inch	2.000 inch
3.000 inch	4.000 inch	5.000 inch

Next, you will be given the choice of selecting your size fractions from among those given or specifying your own. If the size fractions you want to select are listed, enter a 1. If the size fractions you want to select are not listed or if you want to use a size interval other than a square root of 2 or double square root of 2, enter a 2.

If you selected 1 (select from listed size fractions), the program will ask for the number of size fractions you need. This can be a number from 1 to 25. Then you will be asked which is the finest size fraction for which you have a size distribution value. Enter the appropriate mesh size. For example, if you have minus 400-mesh material in the classifier product, enter 400. Finally, you will be requested to enter a 1 to choose a square root of 2 screen series or a 2 to choose a double square root of 2 series.

If you selected 2 (specify your own size fractions), the program will ask you for the number of size fractions you need. This can be a number from 1 to 25. Then you will be asked to designate your size fractions in inches or mesh and micrometers or in micrometers only. For instance, if you want a size fraction labeled as 400 mesh, 38 micrometers, enter 1. If you want a size fraction labeled 38 micrometers, enter 2.

If you selected 1 (inches or mesh and micrometers), you will be asked to designate mesh (1) or inches (2) for each size fraction. Then you will enter the mesh or inches and the corresponding micrometers. You may enter a negative number to indicate the finest (or passing) size fraction. Example: -400 mesh, -38 micrometers.

If you selected 2 (micrometers only), you will be asked to enter the size fraction micrometers designation. You may enter a negative number to indicate the finest (or passing) size fraction. Example: -38 micrometers.

When all size fractions have been selected, they will be displayed. If you made a mistake, you can go through the selection process again before proceeding.

3.2.2. Circuit Feed Data

In order to run a circuit simulation, the feed to the circuit must be characterized. The required circuit feed information includes the weight percent solids, solids flow rate, ore specific gravity, and size distribution. The water flow rate

to the ball-mill feed sump or the weight percent solids in the ball-mill feed must also be specified.

3.2.2a. Weight Percent Solids

Enter the fresh circuit feed weight percent solids. For circuit feed with 8 percent moisture by weight, enter 92.

3.2.2b. Solids Flow Rate

Enter the total solids flow rate in short tons per hour in the circuit feed stream. If the circuit feed is 100 tons per hour of rock with 3 percent moisture by weight, enter 97.

3.2.2c. Ore Specific Gravity

Enter the specific gravity of the solids in gm/cc. For ore with a specific gravity of 2.7 gm/cc, enter 2.7.

3.2.2d. Size Distribution

CIRCUIT will prompt you for the weight percent retained on each of the screens designated by the size fractions you selected previously. Enter each value for the circuit feed as you are prompted.

3.2.2e. Water Flow Rate To the Feed Sump

Enter the total water flow rate in short tons per hour to the ball-mill feed sump. If 40 tons per hour of water are added to the ball-mill feed, enter 40. The program offers you the option of specifying the weight percent solids for the ball-mill feed stream instead of the water flow rate to the sump. If you choose to enter the weight percent solids, refer to the following paragraph.

3.2.2f. Ball-Mill Feed Weight Percent Solids

Enter the ball-mill feed weight percent solids. To fix ball-mill feed at 65 percent solids by weight, enter 65. The program offers you the option of specifying the water flow rate to the feed sump instead of the weight percent solids for the ball-mill feed stream. If you choose to enter the water flow rate, refer to the previous paragraph.

3.2.3. Classifier Recycle Stream Data

Weight percent solids, solids flow rate, and size distribution of the classifier recycle stream must all be estimated. While these estimates are not fixed in the overall circuit flowsheet calculations, they are used during the first iteration in

combination with the circuit feed stream information to calculate the ball-mill feed characteristics. The ball-mill feed size distribution and volume flow rate are used to determine the selection function values if none are supplied. In this case, the recycle stream estimates have some effect on the selection function values determined.

3.2.3a. Weight Percent Solids

Enter an estimate of the weight percent solids for the classifier recycle stream. For a recycle stream that is 76 percent solids by weight, enter 76.

3.2.3b. Solids Flow Rate

Enter the total solids flow rate in short tons per hour for the classifier recycle stream. If the classifier recycle is 100 tons per hour of slurry, 73.5 percent solids by weight, enter 73.5.

3.2.3c. Size Distribution

CIRCUIT will prompt you for the estimated weight percent retained on each of the screens designated by the size fractions you selected previously. Enter each value for the classifier recycle stream as you are prompted.

3.2.4. Mill Data

Information concerning ball-mill operation is required in order to simulate ball-mill performance. The program will use the mill power draw to calculate estimated ball-mill unit energy consumption in kWh/ton, based on the total circuit feed. This will enable you to quickly compare estimated energy consumption of alternative circuits and operating conditions.

The ball-mill model calculates the ball-mill discharge size distribution and flow rates. These calculations are based on the size distributions and flow rates of the circuit feed and classifier recycle streams. Mill data entry requires you to supply either a set of selection function values and some related parameters or the ball-mill discharge size distribution.

In practice, the selection function values are not known the first time a particular ball mill is simulated. Therefore, the ball-mill discharge size distribution is required as input in an initial simulation and selection function values are calculated. These values can then be used to simulate ball-mill performance under other conditions. For more information about the ball-mill model and its function, please read Sections 4.1.4 and 4.2.1.

3.2.4a. Mill Power Draw

The program offers you the option of entering the mill power in units of horsepower or kilowatts. If you choose to enter mill power in horsepower, select 1,

then enter the mill power draw in horsepower. If ball-mill power draw is 1,000 HP, enter 1,000. If you choose to enter mill power in kilowatts, select 2, then enter the mill power draw in kilowatts.

3.2.4b. Discharge Size Distribution

CIRCUIT will ask if you have a selection matrix for the ball-mill model. If you do have selection function values, refer to the following paragraph. Otherwise, answer N and CIRCUIT will then prompt you for the estimated weight percent retained on each of the screens designated by the size fractions you selected previously. Enter each value for the ball-mill discharge as you are prompted.

3.2.4c. Selection Function Values

CIRCUIT will ask if you have a selection matrix for the ball-mill model. If you do not have selection function values, refer to the previous paragraph. Otherwise, answer Y and CIRCUIT will prompt you for the number of breakage stages at which the selection matrix was calculated. If CIRCUIT was used to calculate your selection function values and 10 breakage stages were used, you should enter 10.

Next, you will be prompted for the total volume flow rate in gallons/minute at which the selection matrix was calculated. If the selection function values were calculated at 900.5 gallons/minute, enter 900.5.

Then, CIRCUIT will prompt you for the selection function values. You may keep the current value or enter a new value for each size fraction.

3.2.5 Classifier Data

The classification model calculates the classifier fine and coarse product size distributions and flow rates for each stage of classification. These calculations are based on the size distributions and flow rates of the classifier feed streams. The split between products is determined by the application of the classification calculation methods available. Classifier data entry requires you to choose one of these calculation methods for each stage. You may then enter the appropriate classification parameters or equipment operating parameters for the device(s) you are modeling. You may use different calculation methods and different equipment models for each stage of classification. For more information about the classification models, please see Sections 4.1.5, 4.2.2, and 4.2.3.

3.2.5a Water Flow Rate to the Classifier Sump

Enter the total water flow rate in short tons per hour to the classifier feed sump. The program will prompt you for each stage of classification. If 10 tons per hour of water are added to the classifier feed, enter 10. The program offers you the option of specifying the weight percent solids for the classifier feed stream instead of the

water flow rate to the sump. If you choose to enter the weight percent solids, refer to the following paragraph.

3.2.5b. Weight Percent Solids in the Classifier Feed

Enter the classifier feed weight percent solids. The program will prompt you for each stage of classification. To fix classifier feed at 50 percent solids by weight, enter 50. The program offers you the option of specifying the water flow rate to the sump instead of the weight percent solids for the classifier feed stream. If you choose to enter the water flow rate, refer to the previous paragraph.

3.2.5c. Number of Classification Devices

Enter the number of equal size classification devices to be used. If you are using 6 hydrocyclones, enter 6. If you are using 2 spiral classifiers, enter 2. The program will prompt you for each stage of classification.

3.2.5d. Classification Device Model

A menu offers classification models for several devices. Choices from 1 to 9 indicate hydrocyclone models, 10 to 19 indicate spiral classifier models, and 20 to 29 indicate sieve bend screen models. Only the choices listed in the menu are available. Information about the development of the models and the model mathematics is provided in Section 4.2. Other models may be added during future development (see Section 4.4).

Even if you intend to model using classification parameters, you must indicate one of the devices listed in the menu. You may indicate different devices for each stage of classification.

3.2.5e. Classification Calculation Method

A menu offers classification calculation methods and lists the classification parameters required for each method. The exponential sum, logistic, double exponential, and simple logarithmic methods are included at present. You may use a different calculation method for each classification stage. These calculation methods are explained in detail in Section 4.2.2. If you want to use the double exponential calculation method, enter 3. To select the logistic method, enter 2.

3.2.5f. Classification Parameters

CIRCUIT displays a list of the classification parameters required for each calculation method and asks if you know the values of these parameters. If you do not have values for these parameters, refer to the following paragraph. Otherwise, enter Y and CIRCUIT will prompt you for the classification parameters. For example, if you are using the logistic calculation method, you will be prompted to enter d_{50} , SI, a, and

C (the program refers to C as CRATIO). These values are the equiprobable size in micrometers, sharpness index, apparent percent bypass, and circulation ratio, respectively, and are described in Section 4.2.2b. You should enter the appropriate values, for instance, 250,.49,15.4,1.6.

You will be prompted for each stage of classification and may indicate classification parameters for one stage and none for the other stage.

3.2.5g. Equipment Operating Parameters

CIRCUIT displays a list of the classification parameters required for each calculation method and asks if you know the values of these parameters. If you do have these parameter values and you want to use them for your simulation, refer to the previous paragraph. Otherwise, enter N and CIRCUIT will prompt you for the equipment operating parameters for the classification device chosen earlier. Note the units required for each parameter. Read this information and determine if you have the necessary parameter values. You will be prompted separately for each stage of classification.

CIRCUIT will ask if you want to continue with the program. If you do not have the necessary parameter values, you will need to collect more data before proceeding. In this case, enter N and the program will create a data file and terminate without running a simulation. If you have the necessary parameter values, enter Y and CIRCUIT will prompt you for these equipment operating parameters.

For example, to use the hydrocyclone mathematical model initially developed at the Julius Kruttschnitt Mineral Research Center (JKMRC), you will be prompted to enter the cyclone diameter in inches, the vortex finder diameter in inches, the inlet pressure in psi, and the spigot or apex diameter in inches. For a 6-inch hydrocyclone, you might enter 6,.25,20,.5. Three other equipment parameters are required, the diameter of a circle having the same area as the inlet in inches, the cyclone length in inches, and the hydrocyclone angle in degrees. Typical values of these parameters for the hydrocyclone size you have chosen will be displayed. CIRCUIT will prompt you, and you may enter changes to these values if you desire. Next, you will be required to enter the modeling constants K_v , K_w , and K_d and the curve-fitting parameter, α . For more information on these model parameters, please see Section 4.2.3a.

3.3. DATA FILE ENTRY

Once you have used interactive data entry to establish a data file, you will be able to re-enter that data as is or change it for another CIRCUIT computation.

The first information CIRCUIT will request is the name of a file in which to store the output data. File names can begin only with a letter but may contain up to eight letters and numbers. No symbols (i.e., %, -, #) are allowed in file names. It is usually helpful to select a file name with a one to three letter extension such as FILE.DAT, TEST1A.OUT, or MILL1.IN.

After entering an output file name, CIRCUIT will ask if you wish to enter data from the terminal or from a file. If you want to enter data interactively, refer to Section 3.2. Otherwise, enter 2 for data file entry. A data file name will be requested by the program. Enter the data file name (e.g., MILL2.DAT).

Next, CIRCUIT will ask if you want to edit your data. If you do not want to edit the data, enter N and the program will begin execution. Otherwise, enter Y and CIRCUIT will display a main menu allowing changes in the set-up information, circuit feed data, classifier recycle stream data, mill data, and classifier data. Enter 1, 2, 3, 4, or 5 respectively to select these options. Upon selection of any of these categories, a secondary menu allows you to specify which data are to be changed. Every menu offers the option to exit the menu. You may make as many changes as you wish by selecting various categories and specific data. When you exit the main menu, CIRCUIT will save the new data file and begin execution.

For example, if you want to change the output print option to 5, enter 1 from the main menu, and the secondary menu will allow changes in the circuit title and data description, flowsheet selection, convergence tolerance and maximum iterations, output print option, and size fraction selection. Select 4 for output print option and CIRCUIT will request the output print option. Enter 5 and the secondary menu will be displayed. Enter 6 to exit this menu and the main menu will be displayed. Enter 6 to exit this menu and the program will save the new file and begin execution.

Instructions on entry of specific data are the same as those provided in Sections 3.2.1 to 3.2.5.

3.4. DATA CHECKLIST

The following checklist may be useful when planning to collect data for studying a grinding-classification circuit. This checklist is a summary of the information contained in the preceding sections.

Circuit Feed Data

Weight Percent Solids, percent
Total Solids Flow Rate, tph
Ore Specific Gravity, gm/cc
Size Distribution, percent retained
Water Flow Rate to the Feed Sump, tph or
Weight Percent Solids of Ball-Mill Feed

Classifier Recycle Stream Data

Estimated Weight Percent Solids, percent
Estimated Total Solids Flow Rate, tph
Estimated Size Distribution, percent retained

Mill Data

Mill Power Draw, hp

Selection Function Values or

Ball-Mill Discharge Size Distribution, percent retained

Classifier Data

For each stage of classification,

Water Flow Rate to the Classifier Sump, tph or

Weight Percent Solids of Classifier Feed

Number of Classification Devices

Type of Classification Device

Classification Calculation Method

Classification Parameters or

Equipment Operating Variables

In addition to the collected data, you should also be ready to provide the following information to CIRCUIT:

Name of Output Data File

Name of Input Data File

Set-up Information

Circuit Title

Data Description

Flowsheet Number

Convergence Tolerance

Maximum Number of Iterations

Output Print Option

Size Fraction Selection

4. CIRCUIT OVERVIEW

This chapter will provide a description of the organization and capabilities of CIRCUIT. The structure of the program and the functions of the various subroutines will be explained, as well as the capabilities of the program. Possibilities for future development will also be discussed. For a more complete description of the entire Mathematical Modeling of Two-Stage Classification project, please read the project final report No. DOE/ID/12440-2, March 1986, prepared for the U. S. Department of Energy by AMAX Research & Development Center.

4.1 PROGRAM ORGANIZATION

CIRCUIT consists of an executive program and seven primary subroutines, INDATA, OUTDATA, SUMP, MILL, CLASS, STRMCAL, and CONV (see Figure 6). Input and output information for the package is handled by the INDATA and OUTDATA subroutines, respectively. The process simulation subroutines for modeling a sump (SUMP), ball mill (MILL), and classifier (CLASS) are called by the executive program in the order required to simulate the grinding-classification circuit selected by the user. Calculations of slurry density and solids, water, mass, and volume flow rates are made by the STRMCAL subroutine. A convergence subroutine (CONV) is called following each iteration of flowsheet calculations to determine when the results are balanced throughout the circuit. The following sections describe the functions of the primary subroutines.

4.1.1. INDATA

INDATA is the first subroutine called by the executive program. All data and information required by the executive and other subroutines are entered by the user in response to requests made by INDATA and its secondary subroutines. Program options are offered in menu form. The user may enter information without regard to format style, and it will automatically be converted to the correct format within the program. Data are checked upon entry for obvious errors such as improper negative values or weight percent solids over 100. Size analyses are also checked to determine that total weight percent does not exceed 100. If incorrect data are entered, the user is notified by a message and asked to re-enter the data correctly.

INDATA allows the user to enter data interactively or by using a data file. When interactive data entry is chosen, INDATA calls a series of subroutines to collect the required information from the user. These subroutines include SETUP, EDSIZE, FEED, RECYC, MILLIN, and CLASIN. When all the data have been entered, INDATA automatically creates a new data file.

When the user chooses to enter data using a file, INDATA will offer the option to edit the file. If this option is chosen, subroutine EDIT is called to determine if changes

are to be made in the set-up information, circuit feed data, classifier recycle stream data, mill data, or classifier data. Based on the user's selection, EDIT calls one of several editing subroutines. These subroutines are EDSETUP, EDFEED, EDRECY, EDMILL, and EDCLASS, respectively. When the modified data have been entered, INDATA automatically creates a new data file.

The calling structure for the data entry and editing subroutines of INDATA is shown in Figure 6.

Three support subroutines are also used by INDATA. ANSWER, FREAD, and SIZPIX perform routine data input tasks. The data entry and editing subroutines also call these support subroutines as necessary.

4.1.1a. Data Entry Subroutines

The name and purpose of each data entry subroutine is listed below. For additional information and instructions on entering data, please read Chapter 3.

SETUP	Requests the problem set-up information.
EDSIZE	Requests selection of size fractions to be used.
FEED	Requests the circuit feed data.
RECYC	Requests the classifier recycle stream data.
MILLIN	Requests the information required by the ball mill model and calculates the breakage function.
CLASIN	Requests the data used to model the first- and second-stage classifiers. Allows selection of a classification modeling method and requests the classification parameters required. If the user does not have classification parameters, CLASIN will call subroutine CLASPAR.

CLASPAR Requests equipment operating parameters.

4.1.1b. Editing Subroutines

Each of the editing subroutines prints a menu to prompt the user to specify which data are to be changed and then calls the corresponding data entry subroutine to request the information. The name and purpose of each editing subroutine is listed below. For additional information and instruction on editing data files, please read Section 3.3.

EDSETUP Prompts for editing of problem set-up information.

Figure 6. Schematic representation of the computer simulation program, CIRCUIT.

EDFEED Prompts for editing of circuit feed data.

EDRECY Prompts for editing of classifier recycle data.

EDMILL Prompts for editing of ball mill operating information.

EDCLASS Prompts for editing of first- and second-stage classifier data.

4.1.1c. Support Subroutines

The name and purpose of each of the support subroutines are listed below.

ANSWER Determines if a yes or no response has been entered and translates it to an integer value (yes = 1, no = 2).

FREAD Converts data entered to the format style required by the calling subroutine. Requires subroutine LENCHAR to check for the end of an entry response.

LENCHAR Determines the length of a character string.

SIZPIX Requests size distribution information.

4.1.2. OUTDATA

The OUTDATA subroutine is called after completion of a circuit simulation. OUTDATA writes the simulation results to a data file which can then be printed or stored. Six output file options are offered to the user, including a long form which writes percent solids, flow rates, and size distributions for each stream in the circuit. A brief output form is also available for writing results for the ball-mill and classifier feed and product streams. A circuit summary form lists the results for all streams using a tabular format. Each of these forms may be written with or without a summary of the input data included.

4.1.3. SUMP

This subroutine simulates a sump or mixing tank where needed in the circuit flowsheet. SUMP adds the flow rates of water and solids in up to five feed streams to produce one product stream. The size distribution of the product stream is also calculated based on the feed-size distributions. SUMP is used to combine process streams and/or to add or remove water from the circuit. An option exists in this subroutine for the user to specify the weight percent solids in the product stream. If this option is selected, SUMP will calculate the water addition or removal required to meet the specified percent solids.

4.1.4. MILL

The grinding process is simulated by the MILL subroutine which contains ball-mill mathematical model equations. MILL calculates the ball-mill discharge size distribution and flow rates, given the feed-size distribution and flow rates, the breakage and selection matrices, and the number of breakage stages. In practice, the breakage and selection matrices and the number of breakage stages are not known the first time a particular ball mill is simulated. Therefore, a breakage matrix is calculated by MILLIN based on the number of size fractions and screen series represented in the feed size distribution. This breakage matrix is supplied to MILL. The ball-mill discharge size distribution is required as input in an initial simulation. MILL will then assume 10 stages of breakage and calculate a selection matrix based on this information. Breakage and selection matrices developed in this manner can then be used to simulate ball-mill performance under other conditions.

Two secondary subroutines are called by MILL. STAGE calculates the ball-mill discharge size distribution, given the feed-size distribution for one breakage stage. MULT is a subroutine used to multiply a matrix by a vector.

4.1.5 CLASS

The classification process is simulated by the CLASS subroutine, which predicts solids and water flow rates and size distribution of the classifier coarse and fine product streams when given the appropriate classification parameters, solids and water flow rates, and size distribution of the classifier feed. CLASS allows calculation of coarse and fine product stream data by the exponential sum, logistic, double exponential, or simple logarithmic methods. The user selects the classification method and enters the appropriate classification parameters. Equiprobable size (d_{50}), curve fitting constant (α), recovery of water to the coarse stream (R_f), and recovery of solids to the coarse stream (R_s) are entered for the exponential sum method. Equiprobable size (d_{50}), sharpness index (SI), apparent bypass (a), and circulation ratio (C) are entered for the logistic, double exponential, and simple logarithmic methods.

If the appropriate classification parameters are unknown, the secondary subroutine DEVICE will be called. DEVICE predicts classification parameters listed above based on equipment and operating variables for hydrocyclones, spiral classifiers, and sieve bend screens.

4.1.6. STRMCAL

The STRMCAL subroutine is called following INDATA and also each time the contents of a stream are altered by a simulated process. STRMCAL calculates percent solids, total solids flow rate, total water flow rate, total mass flow rate, and total volume flow rate for any stream, given any two of these values for that stream. The executive program signals to STRMCAL the stream number and the two stream values on which to perform the calculations. For example, if the circuit feed is 100 tons per hour of ore with a specific gravity of 2.7 at 100 weight percent solids, STRMCAL will

calculate the total water flow rate (0.0 tons per hour), total mass flow rate (100 tons per hour), and total volume flow rate (148 gallons per minute) in the feed stream. STRMCAL performs a bookkeeping function and is called frequently by the executive. The user is not required to supply any information directing its usage.

4.1.7. CONV

Convergence of circuit simulation calculations is determined by the CONV subroutine. The subroutine is called after the completion of each full iteration of flowsheet calculations to compare the ball-mill feed-size distribution just calculated to the previously calculated distribution. If the difference observed for all size fractions is less than a user-specified tolerance value, CONV will signal to the executive program that the simulation is complete. If the difference observed for any size fraction is greater than the tolerance, CONV will generate a new stream size distribution based on distributions stored in the subroutine during the last two iterations. If the user-specified maximum number of iterations is reached without convergence, the program run will be terminated and the current results printed by OUTDATA.

4.2. MODEL DESCRIPTIONS

Complexity currently prevents modeling of mineral processes from fundamental parameters such as chemical and thermodynamic constants, atomic or molecular properties, or other basic physical parameters. Semi-empirical models (also called phenomenological models) are the usual alternative. These models are based on general theories but contain adjustable coefficients that must be calibrated by experiments on the process itself. When no theory exists, empirical relationships between process variables are obtained by numerical regression.

Each type of model has its own merits. Development of fundamental parameter models is a long-term objective, representing a complete understanding of process behavior from fundamental principles. Semi-empirical models represent a step toward understanding relationships between process variables and responses. Empirical models provide a convenient numerical match between observations in a given process. This may be sufficient for some applications such as automatic control of a single process.

The models incorporated into the computer simulation package developed for the Mathematical Modeling of Two-Stage Classification project are either semi-empirical or empirical. Development of the package has been based on a philosophy of offering a selection of classification models to the user. The classification subroutine has been developed to allow modeling based on known classification parameters or equipment and operating variables. Process simulation must be used sensibly to produce reasonable results. This principle requires the user to provide the best information available for the simulation and to select the models based on assumptions that most accurately describe the specific process under investigation.

The following sections describe the mathematical models developed during this project or by other investigators that have been included in the computer simulation

package. A grinding model is reviewed, as well as three models for predicting classifier performance based on known classification parameters. Model equations for calculating classification performance parameters from hydrocyclone, spiral classifier, and sieve bend screen equipment and operating variables are also presented.

4.2.1. Grinding Model

The mathematical ball-mill model used in the computer simulation program has been described in detail by Lynch.² The following description is a brief review of the model mathematics.

The ball-mill discharge size distribution can be considered the product of a breakage process acting on the ball-mill feed size distribution.

$$\mathbf{p} = (\mathbf{X}_k)^v * \mathbf{f} \quad (1)$$

where: $\mathbf{p}$ = Size distribution of the ball-mill discharge expressed as a vector of weight percent retained values with n elements (n = number of size fractions).

$\mathbf{X}_k$ = $n \times n$ matrix describing the breakage process for the k^{th} breakage stage.

v = Number of breakage stages.

$\mathbf{f}$ = Size distribution of the ball-mill feed expressed as a vector of weight percent retained values with n elements.

A stage of breakage in a ball mill is defined as the interval in which all particles in the maximum size range in the feed to that stage have a 100-percent probability of being broken. The breakage process for the k^{th} stage, $\mathbf{X}_k$, does not change during any other stage and can be defined as a combination of a selection function and a breakage function.

$$\mathbf{X}_k = (\mathbf{B} * \mathbf{S}) + (\mathbf{I} - \mathbf{S}) \quad (2)$$

where: $\mathbf{B}$ = $n \times n$ lower triangular matrix describing the breakage function in a ball mill.

$\mathbf{S}$ = $n \times n$ diagonal matrix describing the selection or probability of breakage for each size fraction.

$\mathbf{I}$ = Identity matrix.

² Lynch, A. J., Mineral Crushing and Grinding Circuits, Elsevier Scientific Publishing Company, Amsterdam, 1977.

The fundamental principle underlying the grinding model is the description of a single breakage event. Any technique which involves physical breakage must rely on mineral and machine characteristics, making it very difficult to define an experimental procedure to determine only the inherent breakage properties of mineral particles. The selection function is also at work whenever physical breakage occurs. It is, therefore, necessary to assume the form of the breakage function, **B**, and to determine the elements of the selection function, **S**, based on a knowledge of the ball-mill discharge size distribution. The breakage function assumed for the current project is:

$$B_{i,j} = b_1 * [1 - b_2 * \exp(-r_s^{(i-j+1)})] + b_3 \quad (3)$$

where: $B_{i,j}$ = Breakage function value for particles initially in size fraction j which appear in size fraction i after breakage.

b_1, b_2, b_3 = Constants of the breakage function.

r_s = Ratio between successive size fractions.

The constants of the breakage function can be calculated for any distribution by recognizing three practical conditions which the distribution should meet:

- 1) When the ratio between successive size fractions is 1, all particles are monosize and the breakage function is 0.

$$B_{i,j} = 0 \text{ when } r_s = 1 \quad (4)$$

- 2) The fraction of material appearing in the finest size fraction can be calculated by difference.

$$p_n = 1 - \sum_{i=1}^{n-1} p_i \quad (5)$$

Therefore, the breakage function, **B**, and selection function, **S**, require only $n - 1 \times n - 1$ elements to determine a unique product size distribution. A breakage function value of 0 can be assumed for the $B_{n,j}$ elements.

$$B_{i,j} = 0 \text{ when } i = n \quad (6)$$

- 3) The sum of the fractions of all particles initially in size j that appear in sizes j through $n - 1$ must equal unity.

$$\sum_{i=j}^{n-1} B_{i,j} = 1 \quad (7)$$

By solving Equation 3 for these conditions, values for the constants b_1 , b_2 , and b_3 can be calculated. The computer simulation program assumes these conditions and automatically determines a breakage function for the simulation.

Two other assumptions are made in the application of the ball-mill model.² All particles in the first breakage stage in the maximum size fraction of the feed have a 100-percent probability of being broken; therefore, $S_{1,1}$ has a value of 1. The final assumption is that ball-mill feed rate multiplied by the number of breakage stages is a constant product.

The ball-mill discharge size distribution is required as input in an initial simulation. The MILL subroutine will then use a least-squares fitting technique to calculate a selection matrix based on the mill feed and product-size distributions, mill feed rate, the assumed breakage function, and 10 stages of breakage. All information is then available to calculate the ball-mill discharge for any change in feed rate or feed-size distribution within a reasonable range of operation.

4.2.2. Classification Models

Various mathematical models may be chosen to describe the classification function. The exponential sum, logistic, and double exponential methods can be selected by the user to predict classifier behavior with the computer simulation package developed for the current project.

4.2.2a. Exponential Sum Method

Lynch has proposed an exponential sum equation as the basis for classification modeling carried out at the Julius Kruttschnitt Mineral Research Center (JKMRC).²

$$c(d_i) = \frac{\exp [\alpha * (d_i/d_{50})] - 1}{\exp [\alpha * (d_i/d_{50})] + \exp [\alpha] - 2} * 100 \quad (8)$$

where: $c(d_i)$ = Value of the classification function at particle size d_i , percent.

d_{50} = Equiprobable size or size of particles having a classification number of 50, micrometers.

α = A classification parameter obtained by curve fitting techniques.

Classification parameters d_{50} and α must be supplied to the CLASS subroutine if a user has selected the exponential sum modeling method. Recovery of water to the coarse product must also be entered. This parameter is used to calculate the classifier selectivity.

$$s(d_i) = \left[\frac{c(d_i)}{100} * (100 - R_f) \right] + R_f \quad (9)$$

where: $s(d_i)$ = Value of the selectivity function at particle size d_i , percent.

R_f = Recovery of water to the coarse-particle stream, percent.

Recovery of solids to the coarse product must be entered in order to calculate the coarse-particle stream size distribution.

$$t(d_i) = \frac{s(d_i) * p(d_i)}{R_s} \quad (10)$$

where: $t(d_i)$ = Percent of solids of size d_i in the classifier coarse-particle stream.

$p(d_i)$ = Percent of solids of size d_i in the classifier feed stream.

R_s = Recovery of solids to the coarse-particle stream, percent.

The feed and coarse-particle stream size distributions are used to calculate the fine-particle stream size distribution.

$$q(d_i) = \frac{(100 * p(d_i)) - (R_s * t(d_i))}{(100 - R_s)} \quad (11)$$

where: $q(d_i)$ = Percent of solids of size d_i in the classifier fine-particle stream.

The solids flow rate to the coarse product stream is calculated from the feed solids flow rate and the recovery of solids to the coarse product.

$$T = \frac{P * R_s}{100} \quad (12)$$

where: T = Solids flow rate of the coarse-particle stream.

P = Solids flow rate of the classifier feed stream.

The solids flow rate of the fine-particle stream, Q , is calculated by difference.

$$Q = P - T \quad (13)$$

Water flow rates to both product streams are similarly calculated:

$$T_w = \frac{P_w * R_f}{100} \quad (14)$$

and

$$Q_w = P_w - T_w \quad (15)$$

where P_w , T_w , and Q_w are the water flow rates of the feed, coarse-particle, and fine-particle streams, respectively.

4.2.2b. Logistic Method

The logistic equation is the basis for another classification modeling method described by Austin, et al.³

$$c(d_i) = \frac{100}{1 + (d_i/d_{50})^{-h}} \quad (16)$$

where h is a classification parameter defined by:

$$h = \frac{-2.1972}{\ln(SI)} \quad (17)$$

and SI is the sharpness index.

³ Austin, L. G., Klimpel, R. R., and Luckie, P. T., The Process Engineering of Size Reduction, Volume 1, Ball Milling, Pennsylvania State University, University Park, Pennsylvania, September 1978.

Classification parameters d_{50} and SI must be supplied to the CLASS subroutine if a user has selected the logistic modeling method. Apparent bypass must also be entered. This parameter is used to calculate the classifier selectivity.

$$s(d_i) = \left[\frac{c(d_i)}{100} * (100 - a) \right] + a \quad (18)$$

where: a = Apparent bypass, percent.

Another parameter, the circulation ratio, C , must be entered in order to calculate the coarse-particle stream size distribution.

$$t(d_i) = \frac{s(d_i) * p(d_i) * (1 + C)}{100 * C} \quad (19)$$

The feed and coarse-particle stream size distributions are used to calculate the fine-particle stream size distribution.

$$q(d_i) = [(1 + C) * p(d_i)] - [C * t(d_i)] \quad (20)$$

The solids flow rate to the coarse product stream is calculated from the feed solids flow rate and the circulation ratio.

$$T = \frac{P * C}{1 + C} \quad (21)$$

The solids flow rate of the fine-particle stream, Q , is calculated by difference.

$$Q = P - T \quad (13)$$

Finally, water flow rates to both product streams are calculated.

$$T_w = \frac{P_w * a}{100} \quad (22)$$

and

$$Q_w = P_w - T_w \quad (15)$$

4.2.2c. Double Exponential Method

The third classification functional form available in the computer simulation package is the double exponential equation. Plitt has described the use of this equation in classification analysis.⁴

$$c(d_i) = 100 - 100 * \exp [-(d_i/X_o)^g] \quad (23)$$

where g and X_o are classification parameters defined by:

$$g = \frac{-1.5725}{\ln (SI)} \quad (24)$$

and

$$X_o = \frac{d_{50}}{(0.693)^{1/g}} \quad (25)$$

Selectivity, size distribution, and flow rate calculations for the double exponential method are identical to those carried out for the logistic method.

4.2.2d. Simple Logarithmic Method

Another classification functional form is available in the computer simulation package. The simple logarithmic method can be used when the shape of the selectivity function resembles a straight line rather than the more typical curve. When this type of data is encountered, it is usually recommended that new data be collected, including size fraction information for a wider range of sizes. When this is not possible, you may wish to attempt a simulation using the simple logarithmic calculation method. It is important to note that this method should be used sparingly when alternatives are not available and the results should be viewed accordingly.

$$c(d_i) = 100 * (X_o + [g * \ln (d_i)]) \quad (26)$$

where g and X_o are classification parameters defined by:

$$g = \frac{-0.5}{\ln (SI)} \quad (27)$$

⁴ Plitt, L. R., "The Analysis of Solid-Solid Separations in Classifiers", CIM Bulletin, April 1971, Volume 64, No. 708, p. 42.

and

$$X_o = 0.5 - [g * \ln (d_{50})] \quad (28)$$

Selectivity, size distribution, and flow rate calculations for the simple logarithmic method are identical to those carried for the logistic method.

4.2.3. Equipment Models

Development of the computer simulation package for the Mathematical Modeling of Two-Stage Classification project has been based on a philosophy of offering a selection of classification models to the user. Classification modeling can be based on known classification parameters or equipment and operating variables. The hydrocyclone, spiral classifier, and sieve bend screen equipment models reviewed in this section predict the classification parameters required for the classification models described in the previous section. These empirical equipment models were developed during the Mathematical Modeling of Two-Stage Classification Project or by other investigators as indicated and are contained in the computer simulation program.

4.2.3a. Hydrocyclone Model

Krebs hydrocyclones were used in the test work to develop the hydrocyclone equipment model equations which are written in metric units. Data entry to the simulation program is in units commonly used in the United States mineral-processing industry. Conversion to the appropriate units for use of the hydrocyclone equipment model is made automatically if this model is selected by the user. Two important assumptions form the basis for the hydrocyclone equipment model:^{2,5}

- 1) Shape of the classification function, $c(d_i)$, given in Equation 8, is dependent only on material characteristics such as composition and specific gravity of the feed solids and is independent of hydrocyclone geometry.
- 2) The classification function determined from experimental data collected in tests carried out with one size hydrocyclone will have the same shape as any other hydrocyclone treating the same feed.

The user should keep these principles in mind when selecting this model.

Equiprobable size of classification, d_{50} , is related to equipment and operating variables by the following equations:

$$d_{50} = K_{d2} * D_c * R_1^{0.52} * R_2^{-0.47} * \lambda^{0.93} * \gamma^{-0.22} \quad (29)$$

⁵ Kavetsky, A., "A Report on Hydrocyclone Modeling and Scaling (Based on Thesis by Nageswararao)", AMIRA, December 7, 1979.

$$R_1 = \frac{D_o}{D_c} \quad (30)$$

$$R_2 = \frac{D_u}{D_c} \quad (31)$$

where d_c , D_o , and D_u are the diameters of the hydrocyclone, vortex-finder, and apex expressed in meters and K_{d2} is an equipment design constant. The slurry parameter, λ , and pressure factor, γ , are defined by:

$$\lambda = \frac{\omega}{(1 - \omega)^3} \quad (32)$$

and

$$\gamma = \frac{P}{\rho * g * D_c} \quad (33)$$

where: ω = Volumetric fraction of solids in the hydrocyclone feed stream.
 P = Inlet pressure, kilopascals
 ρ = Feed slurry density, metric tons per cubic meter.
 g = Gravitational constant.

The design constant, K_{d2} , is calculated using the following relationships:

$$K_{d2} = K_{d1} * R_3^{-0.5} * R_4^{0.2} * \theta^{0.15} \quad (34)$$

$$R_3 = \frac{D_i}{D_c} \quad (35)$$

$$R_4 = \frac{L_c}{D_c} \quad (36)$$

$$K_{d1} = K_d * D_c^{-0.65} \quad (37)$$

where D_i is the diameter in meters of a circle with the same area as the hydrocyclone inlet and L_c is the length of the hydrocyclone cylindrical section in meters. The

hydrocyclone angle in degrees is designated by θ , and K_d is a feed characteristics constant that must be determined from experimental data.

Recovery of water to the coarse product, R_f , is calculated using the following equations:

$$R_f = K_{w1} * R_1^{-1.19} * R_2^{2.40} * \gamma^{-0.53} * \lambda^{0.27} \quad (38)$$

$$K_{w1} = K_w * R_3^{-0.50} * \theta^{-0.24} * R_4^{0.22} \quad (39)$$

where K_w is a feed characteristics constant that must be determined from experimental data.

Volumetric recovery of feed slurry to the coarse product, R_v , is determined as follows:

$$R_v = K_{v1} * R_1^{-0.94} * R_2^{1.83} * \gamma^{-0.31} \quad (40)$$

$$K_{v1} = K_v * R_3^{-0.25} * \theta^{-0.24} * R_4^{0.22} \quad (41)$$

where K_v is a feed characteristics constant that must be determined from experimental data.

Finally, the recovery of solids to the coarse product, R_s , is calculated.

$$R_s = R_v + (R_v - R_f) * \sigma \quad (42)$$

$$\sigma = \left[\frac{100}{\kappa} - 1 \right] * sg \quad (43)$$

where: κ = Weight percent solids of the classifier feed stream.
 sg = Specific gravity of the classifier feed solids.

Data from at least one classification test are required to determine the necessary model constants. The classification parameters, equiprobable size (d_{50}), recovery of water to the coarse product (R_f), and recovery of solids to the coarse product (R_s) should be determined from the experimental data as well as α , the curve-fitting parameter. Equations 8 through 15 can be used in reverse order to calculate these parameters. The material-dependent constants, K_d , K_w , and K_v can then be found using Equations 29 through 43 in reverse order. Once these constants are known, the classification performance parameters may be calculated for different sizes of hydrocyclones under a variety of operating conditions by following Equations 29 through 43.

The computer simulation program prompts the user to enter K_d , K_w , K_v , all the equipment and operating variables, and α , the curve fitting parameter. Classification performance parameters are then calculated using Equations 29 through 43.

4.2.3b. Spiral Classifier Models

A 12-inch Hazen Quinn spiral classifier was used in the test work to develop the spiral classifier equipment model equations. Test conditions are described in detail in the Review of Data Collected section of the main body of this report.

When the spiral classifier is operated in open circuit with a 3 x 3-foot ball mill, equiprobable size of classification is related to equipment and operating variables by the following equation:

$$d_{50} = K_1 + (K_2 * \text{RPM}) + (K_3 * \text{SLP}) + (K_4 * \text{WHGT}) + (K_5 * \text{LBPH}) + (K_6 * \text{OFS}) + (K_7 * \text{RPM} * \text{SLP}) + (K_8 * \text{LBPH} * \text{OFS}) + (K_9 * \text{SLP}^2) \quad (44)$$

where: RPM = Spiral speed, revolutions per minute.
SLP = Classifier slope, inches/foot.
WHGT = Weir height, inches.
LBPH = Circuit throughput, pounds per hour.
OFS = Overflow percent solids, weight percent.

and the K_n values used in this and the following equations are empirical constants derived from experimental test series.

The following equation can be used to calculate the sharpness index, SI:

$$\text{SI} = K_{10} + (K_{11} * \text{LBPH}) + (K_{12} * \text{OFS}) + (K_{13} * \text{LBPH} * \text{OFS}) + (K_{14} * \text{SLP}^2) + (K_{15} * \text{OFS}^2) \quad (45)$$

Apparent bypass fraction, a , can be calculated as follows:

$$a = K_{16} + (K_{17} * \text{SLP}) + (K_{18} * \text{WHGT}) + (K_{19} * \text{OFS}) + (K_{20} * \text{RPM} * \text{WHGT}) + (K_{21} * \text{RPM} * \text{LBPH}) + (K_{22} * \text{RPM} * \text{OFS}) + (K_{23} * \text{SLP} * \text{WHGT}) + (K_{24} * \text{SLP} * \text{OFS}) + (K_{25} * \text{WHGT} * \text{LBPH}) + (K_{26} * \text{WHGT} * \text{OFS}) + (K_{27} * \text{LBPH} * \text{OFS}) \quad (46)$$

Circulation ratio, C , can be calculated by using the following equation:

$$C = K_{28} + (K_{29} * \text{SLP}) + (K_{30} * \text{WHGT}) + (K_{31} * \text{OFS}) + (K_{32} * \text{RPM} * \text{SLP}) + (K_{33} * \text{RPM} * \text{OFS}) + (K_{34} * \text{WHGT} * \text{OFS}) + (K_{35} * \text{LBPH} * \text{OFS}) \quad (47)$$

When the spiral classifier is operated in closed circuit with a 3 x 3-foot ball mill, equiprobable size of classification is related to equipment and operating variables by the following equation:

$$d_{50} = K_1 + (K_2 * RPM) + (K_3 * SLP) + (K_4 * WHGT) + (K_5 * LBPH) + (K_6 * OFS) + (K_7 * RPM * SLP) + (K_8 * RPM * LBPH) + (K_9 * SLP * WHGT) + (K_{10} * SLP * LBPH) + (K_{11} * SLP * OFS) + (K_{12} * WHGT * LBPH) + (K_{13} * WHGT * OFS) + (K_{14} * LBPH * OFS) + (K_{15} * RPM^2) + (K_{16} * SLP^2) + (K_{17} * WHGT^2) + (K_{18} * LBPH^2) + (K_{19} * OFS^2) \quad (48)$$

where the K_n values used in this and the following equations are empirical constants derived from experimental test series.

The following equation can be used to calculate the sharpness index, SI:

$$SI = K_{20} + (K_{21} * RPM) + (K_{22} * SLP) + (K_{23} * WHGT) + (K_{24} * LBPH) + (K_{25} * OFS) + (K_{26} * RPM * LBPH) + (K_{27} * WHGT * LBPH) + (K_{28} * WHGT * OFS) + (K_{29} * LBPH * OFS) + (K_{30} * SLP^2) + (K_{31} * LBPH^2) + (K_{32} * OFS^2) \quad (49)$$

Apparent bypass fraction, a , can be calculated as follows:

$$a = K_{33} + (K_{34} * RPM) + (K_{35} * SLP) + (K_{36} * WHGT) + (K_{37} * RPM * WHGT) + (K_{38} * RPM * LBPH) + (K_{39} * RPM * OFS) + (K_{40} * SLP * WHGT) + (K_{41} * WHGT * LBPH) + (K_{42} * WHGT * OFS) + (K_{43} * LBPH * OFS) + (K_{44} * WHGT^2) + (K_{45} * OFS^2) \quad (50)$$

Circulation ratio, C , can be calculated by using the following equation:

$$C = K_{46} + (K_{47} * SLP) + (K_{48} * WHGT) + (K_{49} * OFS) + (K_{50} * RPM * SLP) + (K_{51} * RPM * WHGT) + (K_{52} * RPM * LBPH) + (K_{53} * RPM * OFS) + (K_{54} * SLP * WHGT) + (K_{55} * SLP * OFS) + (K_{56} * WHGT * OFS) + (K_{57} * LBPH * OFS) + (K_{58} * WHGT^2) + (K_{59} * OFS^2) \quad (51)$$

Data from experimental classification tests are required to determine the necessary model constants. In some cases, selected variables will be fixed due to operational constraints. For example, the spiral speed may not be adjustable. Under these conditions, terms of the equation involving the fixed variable may be dropped.

The classification parameters, equiprobable size (d_{50}), sharpness index (SI), apparent bypass fraction (a), and circulation ratio (C) should be determined from the experimental data. Equations 16 through 22 can be used in reverse order to calculate these parameters. The K_n empirical constants can then be found by regression analysis using equations 44 through 47 or equations 48 through 51. Once these constants are known, the classification performance parameters may be calculated for spiral classifiers under a variety of operating conditions using equations 44 through 47 for open circuit operation or equations 48 through 51 for closed circuit operation.

The computer simulation program prompts the user to enter the type of circuit, the spiral speed classifier slope, weir height, circuit throughput, and overflow percent solids. Classification performance parameters are then calculated using equations 44 through 51 as required.

4.2.3c. Sieve Bend Screen Models

Sieve bend screen model equations have been developed using data from tests with a lead-zinc ore.² Screens of three slot widths (0.25, 0.50, and 1.0 mm) were used in the study. Equations were developed by using a multiple linear regression technique.

Equiprobable size of classification is related to equipment and operating variables by the following equation:

$$d_{50} = 10^y \quad (52)$$

where:

$$y = [K_1 * \log(SW)] + [K_2 * Q_w] + [K_3 * \kappa] + K_4 \quad (53)$$

The screen slot width, SW, must be expressed in millimeters, Q_w is the water flow rate of the fine-particle stream, and the K_n values in this and the following equations are empirical constants derived from experimental test series.

The following equation can be used to calculate Q_w :

$$Q_w = [K_5 * SW^{K_6} * P_w] + [K_7 * \kappa] + [K_8 * SW] \quad (54)$$

where P_w is the water flow rate of the classifier feed stream.

Recovery of water to the coarse product can be calculated as follows:

$$R_f = 100 - \frac{Q_w * 100}{P_w} \quad (55)$$

Recovery of solids to the coarse product stream was not estimated in the development of this model; however, one possible form of the required equation is given below.

$$R_s = [K_9 * SW^{K_{10}} * P] + [K_{11} * \kappa] + [K_{12} * SW] \quad (56)$$

where P is the solids flow rate of the classifier feed stream.

Data from experimental classification tests are required to determine the necessary model constants. The classification parameters, equiprobable size (d_{50}), recovery of water to the coarse product (R_p), and recovery of solids to the coarse product (R_s) should be determined from the experimental data, as well as α , the curve-fitting parameter. Equations 8 through 15 can be used in reverse order to calculate these parameters. The K_n empirical constants can then be found by regression analysis using Equations 52 through 56. Once these constants are known, the classification performance parameters may be calculated for sieve bend screens with different slot width under a variety of operating conditions using Equations 52 through 56.

The computer simulation program prompts the user to enter the empirical constants, all the equipment and operating variables, and α , the curve fitting parameter. Classification performance parameters are then calculated using Equations 52 through 56.

A 1-foot wide sieve bend screen was used in the test work to develop another set of model equations during the Mathematical Modeling of Two-Stage Classification project. Test conditions are described in the Review of Data Collected section of the main body of this report.

Equiprobable size of classification is related to equipment and operating variables by the following equation:

$$d_{50} = K_1 + (K_2 * TPH) + (K_3 * FS) + (K_4 * SW) + (K_5 * TPH * FS) + (K_6 * TPH * SW) + (K_7 * FS * SW) + (K_8 * TPH^2) + (K_9 * FS^2) \quad (57)$$

where: TPH = Solids flow rate of the screen feed stream.
FS = Screen feed percent solids, weight percent.

and the K_n values used in this and the following equations are empirical constants derived from experimental test series.

The following equation can be used to calculate the sharpness index, SI:

$$SI = K_{10} + (K_{11} * TPH) + (K_{12} * FS) + (K_{13} * SW) + (K_{14} * TPH * FS) + (K_{15} * TPH * SW) + (K_{16} * FS * SW) + (K_{17} * TPH^2) + (K_{18} * FS^2) \quad (58)$$

Apparent bypass fraction, a , can be calculated as follows:

$$a = K_{19} + (K_{20} * TPH) + (K_{21} * FS) + (K_{22} * SW) + (K_{23} * TPH * FS) + (K_{24} * TPH * SW) + (K_{25} * FS * SW) + (K_{26} * TPH^2) + (K_{27} * FS^2) \quad (59)$$

Circulation ration, C , can be calculated by using the following equation:

$$C = K_{28} + (K_{29} * TPH) + (K_{30} * FS) + (K_{31} * SW) + (K_{32} * TPH * FS) + (K_{33} * TPH * SW) + (K_{34} * FS * SW) + (K_{35} * TPH^2) + (K_{36} * FS^2) \quad (60)$$

Data from experimental classification tests are required to determine the necessary model constants. The classification parameters, equiprobable size (d_{50}), sharpness index (SI), apparent bypass fraction (a), and circulation ratio (C) should be determined from the experimental data. Equations 16 through 22 can be used in reverse order to calculate these parameters. The K_n empirical constants can then be found by regression analysis using Equations 57 through 60. Once these constants are known, the classification performance parameters may be calculated for these screens under a variety of operating conditions using equations 57 through 60.

The computer simulation program prompts the user to enter the estimated solids flow rate to the screen, the screen feed percent solids, and the slot width. Classification performance parameters are then calculated using Equations 57 through 60.

4.3. PROGRAM CAPABILITIES

CIRCUIT is a computer program developed for use in designing optimum two-stage classification configurations and operating conditions for energy conservation. In order to evaluate possible two-stage classification circuit performance, an engineer must perform numerous mass balance calculations. The purpose of these calculations is to predict what the circuit might do under different feed or operating conditions, to determine flow rates for sizing new equipment, or to compare classification flowsheet options. CIRCUIT carries out the calculations necessary to balance the circuit. It is a tool that helps the engineer examine numerous circuits and compare predicted performance under various operating conditions and flowsheets. The program allows the engineer to spend his time assessing the results of calculations instead of performing calculations.

It has been an important goal of program development to make it easier to evaluate two-stage classification as a grinding energy conservation alternative. However, such evaluations can be very complex. Process simulation must be used sensibly to produce reasonable results. This principle requires you to provide the best information available for the simulation and to select the models based on assumptions that most accurately describe the specific process under investigation. Several important features of CIRCUIT are described in the following paragraphs.

4.3.1. Flowsheet Selection

Five basic grinding-classification flowsheets can be simulated using CIRCUIT. These flowsheets are shown in Figures 1 through 5 and include one single-stage and four two-stage classification arrangements. CIRCUIT mechanizes the calculation of mass balances around these grinding-classification circuits. It performs this job by starting its calculations at the beginning of the circuit and proceeding through grinding and classification unit operations until all process stream variables have been calculated. CIRCUIT requires information about the circuit feed and parameters for the ball mill and classifiers. Streams recycled to the ball mill cause CIRCUIT to repeat the calculations until convergence is realized.

4.3.2. Classification Calculation Models

The goal of classification modeling is to predict how the classifier feed stream will split into coarse and fine particle streams. Most classification models are based on the assumption that a selectivity or efficiency factor can be calculated for each size fraction that determines the split of material in that fraction. In addition, it is also assumed that the values of these factors can be predicted by a mathematical function. To use a classification model, you must use data from at least one classification test to determine constants for the model or calculate these model constants based on equipment and operating parameters.

For the two-stage classification modeling program, you can select from four classification modeling methods to calculate product split. These methods are the exponential sum, logistic, double exponential, and simple logarithmic. The model parameters are called classification parameters. You can use a different method and different classification parameters for each classification stage. Mathematical equations for each calculation method and definitions of the classification parameters are described in detail in Section 4.2.2.

4.3.3. Classification Equipment Models

In some cases, you may not have correct classification parameters to use in modeling studies. You may want to change equipment operating conditions and predict the effects on the classification parameters and subsequent circuit performance. Flexibility was an important objective in developing CIRCUIT and is offered by the ability of the program to allow modeling based on known classification parameters or on equipment and operating variables.

Three types of classification devices can be modeled using CIRCUIT. These include hydrocyclones, spiral classifiers, and sieve bend screens. Equipment models and the required equipment and operating variables are described in Section 4.2.3. In general, any of the four classification modeling methods may be used in conjunction with each of the classification devices. The hydrocyclone model is an exception. If you choose to model hydrocyclone classification based on equipment operating conditions,

you must use the exponential sum calculation method. Another exception is the JKMRC sieve bend screen model. If you choose this model, you must also use the exponential sum calculation method.

You may use different devices for the first and second stage of classification. For example, you may compare a circuit operating with two stages of hydrocyclones, modeled with the exponential sum method, to a circuit having hydrocyclones for the first stage, modeled by the exponential sum method, and sieve bend screens for the second stage, modeled by the logistic method.

4.3.4. Grinding Mill Model

The grinding mill model applied in CIRCUIT is described in Section 4.2.1. This model is for a ball mill. Models for rod mills and other types of grinding devices are not included in the package at this time.

4.3.5. Unit Energy Consumption Calculation

CIRCUIT uses the mill power draw to calculate estimated ball-mill unit energy consumption in kWh/ton, based on the total circuit feed. This will enable you to quickly compare estimated energy consumption of alternative circuits and operating conditions.

4.3.6. Data Entry

All data required by CIRCUIT are entered in response to requests made by the program. You may enter data interactively or by using a data file. If you select interactive data entry, program options are offered in menu form. There is no need to type out a data file in correct format and style; CIRCUIT will do that automatically. You may enter information without regard to format style, and it will be converted within the program. Data are checked upon entry for obvious errors. If you enter incorrect data, you will be notified by a message and asked to re-enter the data correctly.

When you choose to enter data using a file, CIRCUIT will give you the option to edit the file. All input data have been organized into categories, and a series of menus will allow you to make changes. This capability is useful for changing circuit operating parameters or correcting mistakes. Data files can also be modified using any system editor.

4.3.7. Results Reporting

Six output file options are offered by CIRCUIT, including a long form report which writes percent solids, flow rates, and size distributions for each stream in the circuit. A brief output form is also available for writing results for the ball mill and classifier feed and product streams. A circuit summary form lists the results for all streams using a tabular format. Each of these forms may be written with or without a summary of the input data included.

Upon completion of a simulation run, CIRCUIT prints the results in the selected form to the output data file designated by you. These results may then be printed for review. All data output is printed in 8-1/2 by 11-inch page format.

4.3.8. Expansion

A modular approach was taken in designing CIRCUIT to allow future addition of other models with relatively minor changes to the overall package. Should you find that the classification model you prefer to use is not supplied by the program, you may add it to the appropriate subroutine. If the circuit you are studying includes a rod mill, you may add another grinding mill subroutine. If you have already developed an empirical grinding model for your operation, that could also be added to CIRCUIT. Most changes to CIRCUIT can be made by changing only the executive, the input subroutine, and the affected subroutine. Of course, you may want to change the output subroutine in order to reflect your alterations.

Your Source Disk contains the FORTRAN code and compiler files for CIRCUIT. Appendix B offers some helpful information on modifying the program.

4.4. FUTURE DEVELOPMENT

In order to enhance the application of the simulation package in designing optimum configurations and operating conditions of comminution circuits for energy conservation, several areas of future development have been suggested. These include improvements to input and output capabilities, improvements in modeling capabilities, and inclusion of other models and other flowsheets. It has been suggested that model enhancement efforts should include the addition of other classifiers such as vibrating screens. Other grinding methods such as rod mill, autogenous, and semi-autogenous grinding could be included. Inclusion of crusher models could result in a program for use in projecting optimum energy savings for entire comminution circuits under a variety of circumstances.

As a user of the program, you are encouraged to recommend areas of future development to AMAX Research & Development Center (AMAX R&D) at the address provided at the beginning of this User's Guide. If you are interested in a joint effort to make some of these modifications or to apply two-stage classification in a grinding circuit, please feel free to contact AMAX R&D to discuss your ideas.

5. APPLICATION STRATEGY

CIRCUIT has a wide variety of applications. In order to use the program effectively, you should follow the same steps you normally would take when comparing flowsheet alternatives: define the problem, identify possible solutions, and collect data. Instead of performing lengthy material balance calculations, you can use CIRCUIT to perform these calculations for you. Then, you can spend your time analyzing the results.

5.1. DEFINING THE PROBLEM

When applying CIRCUIT in the study of grinding-classification circuits, it is important to decide the purpose of your investigation. Some problems which may be studied using CIRCUIT include the following:

- Can grinding energy costs be decreased?
- A new grinding-classification circuit must be designed.
- One grinding mill must be shut down; can the dormant circuit classifiers be added to another circuit to improve separation performance?
- What change in circulating load will be experienced if the throughput is increased?
- Hydrocyclones are currently used for single-stage classification. Would second-stage classification with hydrocyclones be practical?
- Determine the amount of water required for a proposed two-stage classification circuit.
- What operating conditions will be required to produce the required product split with two-stage classification?
- If two-stage classification is applied, will circuit control requirements change?
- Will savings in energy costs offset capital investment if two-stage classification is used?

These are just a few instances in which you may find CIRCUIT a useful tool. Many times the problem is a combination of these questions. However, these are not complete definitions of the problem. For instance, if the problem is how to reduce grinding energy costs, you must determine the constraints. What must the product size be? Must the existing grinding mill be used? What is the capital budget for any modifications? Does the ore have any characteristics that eliminate some solutions from consideration? While considering the constraints, you will also want to apply your experience. Is it possible that grinding energy could be reduced by changing some operating conditions in the single-stage circuit?

Remember that CIRCUIT won't directly answer your problems; it is only a tool to make it easier for you to answer questions, so that you will have time to assess a wider variety of possibilities.

5.2. IDENTIFYING SOLUTIONS

Once you have defined the problem, you will begin to propose possible solutions. Usually, defining the constraints of the problem eliminates many possible solutions from consideration. You may determine that you want to look at changing hydrocyclone operating variables in the single-stage circuit and compare your results to a two-stage hydrocyclone classification circuit. You can then decide which circuit best reduces the energy consumption within the constraints of your operation and even simulate a range of operating conditions to try to optimize the selected circuit. Since you will have to perform numerous mass balance calculations in order to examine these circuits, CIRCUIT can help you examine more possible solutions.

5.3. COLLECTING DATA

Since process simulation must be used carefully to produce reasonable conclusions, the collection of appropriate data is extremely important to achieving accurate simulation results. You should provide the best information available for the simulation. Section 3.4 is a data checklist that outlines the information you need to run a CIRCUIT simulation. These data should be collected in the plant under the current operating conditions. It is not within the scope of this guide to discuss good sampling practice. However, sampling is always a critical factor in simulation studies and should be performed carefully.

When considering two-stage classification, you may make some assumptions about the performance of the second classification stage and run some simulations. However, for more reliable information, it is recommended that you collect pilot-scale data for single- and two-stage classification operation. Since the feed to the second-stage classifier is the coarse or fine product from the first stage, it has a much coarser or finer size distribution than the first classifier feed. This difference in feed size distribution greatly alters the classification performance in the second stage, even if the same classification device is used for both stages.

If it is not possible to examine entire pilot-scale circuits, it is especially recommended that samples be taken of the single-stage classifier product that is to be reclassified (usually the coarse product). These samples should be classified using pilot-scale equipment to determine the characteristics of the product split.

Please read Section 3.2.1g about the selection of size fractions before collecting your data. Only one set of size fractions is allowed per simulation for all streams. These fractions must be consistently separated by the same size interval and a passing (or minus) fraction is required for the finest size.

Size distribution analyses are required for the circuit feed, the ball mill discharge, and the classifier recycle stream when performing a simulation. Generally, a sampling campaign will include the classifier fine product stream which can then be used for purposes of comparison between actual and predicted product size. Adjustment of the raw data using a material balance method is a good practice. One useful method is described elsewhere.² Samples cut from circuit streams may not be truly representative, and some amount of analytical error is also possible. CIRCUIT results will be more reliable if this sampling error is adjusted prior to using the program.

5.4. USING CIRCUIT

After defining the problem, identifying possible solutions, and collecting data, you are ready to run CIRCUIT. Notice that up to this point you have taken the steps normally required to investigate a circuit design or modification. Without CIRCUIT, you would proceed to the numerous mass balance calculations necessary before you could compare alternatives. With CIRCUIT, you start the program, supply information in response to requests from the program, and wait for the program to complete its computation. Next, you print and examine the results. You can then modify the data file and examine additional cases as desired.

5.5. ANALYZING RESULTS

The analysis of your simulation results should help you answer the questions you posed when defining your problem. You may determine you want to gather other information. One important objective of this stage is to look at your solutions in comparison to one another. Is it likely that unit energy consumption will be reduced if two-stage classification is used in this circuit? Will the reduction justify the expense of a plant trial? Which two-stage classification circuit should be tried in the plant?

If you decide to run plant trials based on your simulation results, you will have some information with which to prepare for the trials. What kind of water flows can be expected? Approximately what circulating load can be expected?

Please remember that the simulation results are no guarantee of actual circuit performance. However, sensible use of CIRCUIT together with the experience at your operation should allow evaluation of more grinding-classification circuit modification options.

APPENDIX A
APPLICATION EXAMPLES

EXAMPLE A1

INTERACTIVE DATA ENTRY FOR A SINGLE-
STAGE CLASSIFICATION FLOWSHEET SIMULATION
(Figure 1, page 10)

CIRCUIT

Enter name of output data file

>TEST1.OUT

Enter file code as follows:

1 for interactive data input

2 for data input from file

>1

Input data will be stored in a file.

Enter file name.

>TEST1.IN

Enter circuit title (up to 40 characters).

>SINGLE-STAGE PILOT-SCALE SPIRAL CLASS

Enter data description (up to 40 characters).

>HENDERSON ORE TSA-38

Five flowsheets are available for circuit modeling

and are described in the Users Guide.

Enter flowsheet number 1,2,3,4, or 5.

>1

Enter the convergence tolerance and the maximum
number of iterations allowed for convergence.

>.1,20

Enter the output print option:

1 Flow rates and size distributions reported for each stream
- input values reported

2 Flow rates and size distributions reported for each stream
- input not reported

3 Feed and product stream values reported for mill and classifier(s)
- input values reported

4 Feed and product stream values reported for mill and classifier(s)
- input not reported

5 Circuit Summary - input values reported

6 Circuit Summary - input not reported

>5

Size fractions may be selected from the following:

400.Mesh 270.Mesh 200.Mesh

150.Mesh 100.Mesh 65.Mesh

48.Mesh 35.Mesh 28.Mesh

20.Mesh 14.Mesh 10.Mesh

8.Mesh 6.Mesh 4.Mesh

3.Mesh

.375Inch .500Inch .750Inch

1.000Inch 1.500Inch 2.000Inch

3.000Inch 4.000Inch 5.000Inch

If you do not want to select any of the size fractions
listed you may specify your own

1 Select from listed size fractions

2 Specify your own size fractions

Enter 1 or 2

>1

Enter number of size fractions
>16
Enter the finest size fraction for which you have
weight data--enter as mesh size
>400
Enter the appropriate screen series:
1 Square Root of 2
2 2 * Square Root of 2
>1
The following size fractions have been selected:

1	4.Mesh	4750.Micrometers
2	6.Mesh	3350.Micrometers
3	8.Mesh	2360.Micrometers
4	10.Mesh	1700.Micrometers
5	14.Mesh	1180.Micrometers
6	20.Mesh	850.Micrometers
7	28.Mesh	600.Micrometers
8	35.Mesh	425.Micrometers
9	48.Mesh	300.Micrometers
10	65.Mesh	212.Micrometers
11	100.Mesh	150.Micrometers
12	150.Mesh	106.Micrometers
13	200.Mesh	75.Micrometers
14	270.Mesh	53.Micrometers
15	400.Mesh	38.Micrometers
16	-400.Mesh	-38.Micrometers

Do you wish to make corrections?

>N

Enter fresh circuit feed percent solids and
total solids flowrate (TPH)

>100

>.705

Enter the specific gravity of the ore (gm/cc)

>2.7

Enter the weight percent retained on the following screens
for the circuit feed

4. MESH (4750.MICROMETERS)
>35.68

6. MESH (3350.MICROMETERS)
>12.76

8. MESH (2360.MICROMETERS)
>8.67

10. MESH (1700.MICROMETERS)
>6.88

14. MESH (1180.MICROMETERS)
>5.88

20. MESH (850.MICROMETERS)
>4.49

28. MESH (600.MICROMETERS)
 >3.49
 35. MESH (425.MICROMETERS)
 >3.34
 48. MESH (300.MICROMETERS)
 >2.89
 65. MESH (212.MICROMETERS)
 >2.59
 100. MESH (150.MICROMETERS)
 >1.89
 150. MESH (106.MICROMETERS)
 >1.98
 200. MESH (75.MICROMETERS)
 >1.66
 270. MESH (53.MICROMETERS)
 >1.42
 400. MESH (38.MICROMETERS)
 >.99

-400. MESH (-38.MICROMETERS)
 >5.4

You may specify either the water flowrate to the
 feed sump or the weight percent solids in the ball-mill feed.

Enter:

- 1 to specify water flowrate to the sump
- 2 to specify percent solids in the ball-mill feed

>1
 Enter the total water flowrate to the feed sump (TPH)
 >1.733
 Supply an initial guess of the following CLASSIFIER RECYCLE values.
 Enter Classifier recycle percent solids and
 total solids flowrate (TPH)

>75
 >1

Enter the weight percent retained on the following screens
 for the classifier recycle

4. MESH (4750.MICROMETERS)
 >0
 6. MESH (3350.MICROMETERS)
 >0
 8. MESH (2360.MICROMETERS)
 >0
 10. MESH (1700.MICROMETERS)
 >0

14. MESH (1180.MICROMETERS)

>0

20. MESH (850.MICROMETERS)

>0

28. MESH (600.MICROMETERS)

>0

35. MESH (425.MICROMETERS)

>29.33

48. MESH (300.MICROMETERS)

>26.43

65. MESH (212.MICROMETERS)

>17.84

100. MESH (150.MICROMETERS)

>10.22

150. MESH (106.MICROMETERS)

>6.75

200. MESH (75.MICROMETERS)

>3.88

270. MESH (53.MICROMETERS)

>1.88

400. MESH (38.MICROMETERS)

>.85

-400. MESH (-38.MICROMETERS)

>2.83

Mill power draw may be entered in:

1 Horsepower (HP)

2 Kilowatts (kW)

>1

Enter the mill power draw (HP)

>8.7

Do you have a selection matrix for the ball mill model?

>N

Enter the weight percent retained on the following screens
for the mill discharge

4. MESH (4750.MICROMETERS)

>0

6. MESH (3350.MICROMETERS)

>0

8. MESH (2360.MICROMETERS)

>0

10. MESH (1700.MICROMETERS)

>0


```

14. MESH ( 1180.MICROMETERS)
>0
20. MESH ( 850.MICROMETERS)
>0
28. MESH ( 600.MICROMETERS)
>0
35. MESH ( 425.MICROMETERS)
>20.77
48. MESH ( 300.MICROMETERS)
>16.24
65. MESH ( 212.MICROMETERS)
>16.76
100. MESH ( 150.MICROMETERS)
>11.13
150. MESH ( 106.MICROMETERS)
>8.8
200. MESH ( 75.MICROMETERS)
>5.59
270. MESH ( 53.MICROMETERS)
>3.99
400. MESH ( 38.MICROMETERS)
>2.63
-400. MESH ( -38.MICROMETERS)
>14.1

```

You may specify either the water flowrate to the sump or the weight percent solids in the 1st-stage classifier feed.

Enter:

1 to specify water flowrate to the sump

2 to specify percent solids in the 1st-stageclassifier feed

```

>1
Enter the total water flowrate to the first stage classifier sump (TPH)
>.47
Enter the number of classification devices at stage 1 .
>1

```

Classification device models are listed by description of their development. If you will be modeling based on classification parameters rather than equipment operating variables, please select 9, 19, or 29.

Specify classification device:

- 1 JKMRC Hydrocyclone
- 9 Hydrocyclone
- 10 12-inch Spiral Classifier: open circuit - Climax ore
- 11 closed circuit - Climax ore
- 12 closed circuit - Henderson ore
- 19 Spiral Classifier
- 20 1-foot wide Sieve Bend Screen
- 21 .7 mm Slot Width Only
- 22 JKMRC Sieve Bend Screen
- 29 Screen

>12

Four classification calculation methods may be used in this simulation. The following parameters are required for each method:

- 1 Exponential Sum Method: D50, ALPHA, RF, RS
- 2 Logistic Method: D50, SI, A, CRATIO
- 3 Double Exponential Method: D50, SI, A, CRATIO
- 4 Simple Logarithmic Method: D50, SI, A, CRATIO

(Please refer to the Users Guide for definitions of these parameters.)

Which method do you wish to use for stage 1?

>3

Do you have the parameters required?

>Y

For the first stage of classification,
Enter D50,SI,A,CRATIO

>240,.28,14.79

>1.46

Do you want to change any data for this simulation? (Y/N).

>N

Writing data to file...

Are you ready to execute program? (Y/N).

>Y

Calculating...

Program Execution Completed Normally

Stop - Program terminated.

EXAMPLE A2

INPUT DATA FILE FOR A SINGLE-STAGE
CLASSIFICATION FLOWSHEET SIMULATION
(Figure 1, page 10)

SINGLE-STAGE PILOT-SCALE SPIRAL CLASS

HENDERSON ORE TSA-38

NUMFLO=1 NSIZE=16 ISERES=1

FRACTION	MESH/IN	SIZE	MICROMETERS	FEED	PCT	RET
1	1	4.000	4750.		35.68	
2	1	6.000	3350.		12.76	
3	1	8.000	2360.		8.67	
4	1	10.000	1700.		6.88	
5	1	14.000	1180.		5.88	
6	1	20.000	850.		4.49	
7	1	28.000	600.		3.49	
8	1	35.000	425.		3.34	
9	1	48.000	300.		2.89	
10	1	65.000	212.		2.59	
11	1	100.000	150.		1.89	
12	1	150.000	106.		1.98	
13	1	200.000	75.		1.66	
14	1	270.000	53.		1.42	
15	1	400.000	38.		.99	
16	1	-400.000	-38.		5.40	

FEED PCT SOLIDS= 100.00 FEED TOT SOLIDS(TPH)= .705

ORE SPECIFIC GRAVITY= 2.7

ISW1=1

FEED SUMP WATER (TPH)= 1.733

BALL-MILL FEED PCT SOLIDS= .00

CLASSIFIER RECYCLE STREAM NUMBER= 7

RECYCLE PCT SOLIDS= 75.00 RECYCLE TOT SOLIDS(TPH)= 1.000

FRACTION	MESH/IN	SIZE	MICROMETERS	CLASS	RECYCLE	PCT	RET
1	1	4.000	4750.		.00		
2	1	6.000	3350.		.00		
3	1	8.000	2360.		.00		
4	1	10.000	1700.		.00		
5	1	14.000	1180.		.00		
6	1	20.000	850.		.00		
7	1	28.000	600.		.00		
8	1	35.000	425.		29.33		
9	1	48.000	300.		26.43		
10	1	65.000	212.		17.84		
11	1	100.000	150.		10.22		
12	1	150.000	106.		6.75		
13	1	200.000	75.		3.88		
14	1	270.000	53.		1.88		
15	1	400.000	38.		.85		
16	1	-400.000	-38.		2.83		

MILL POWER (HP)= 8.7

MANS=2 BREAKAGE STAGES= 0 TOT VOL FLOW= .00

I BREAKAGE(I,1) SELECTION(I,I) MILL PROD,PCT RET(I)

1	.000000	1.000	.00
2	.281821	1.000	.00
3	.202765	1.000	.00
4	.152977	1.000	.00
5	.113102	1.000	.00
6	.082307	1.000	.00
7	.059129	1.000	.00
8	.042001	1.000	20.77
9	.029505	.100	16.24
10	.020472	.100	16.76
11	.013984	.100	11.13

12	.009346	.100	8.80
13	.006040	.100	5.59
14	.003690	.100	3.99
15	.002021	.100	2.63
16	.000838	.100	14.10

ISW2=1

1ST STAGE CLASSIFIER SUMP WATER (TPH)= .470

1ST-STAGE CLASSIFIER FEED PCT SOLIDS= .00

STAGE=1 NO. OF CLASSIFIERS=1 DEVICE=12 METHOD=3 JANS=1 D50= 240.0

ALPHA= .00 RF= .00 RS= .00

SI= .28 A= 14.79 CRATIO= 1.46

VF= .000000E+00 P= .000000E+00 SPIG= .000000E+00

CYCDIAM= .0 INDIAM= .00 CYCLGT= .0 THETA= .0

KV= .000000E+00 KW= .000000E+00 KD= .000000E+00

RPM= .0 SLP= .00 WH= .00

LBPH= 0. OFS= .00

TPH= .000 FS= .00 SW= .00

K1= .00000 K2= .00000 K3= .00000 K4= .00000

K5= .00000 K6= .00000 K7= .00000 K8= .00000

K9= .00000 K10= .00000 K11= .00000 K12= .00000

CONROL= .10000 MAXIT= 20

IPRINT=5

EXAMPLE A3

OUTPUT DATA FILE FOR A SINGLE-STAGE
CLASSIFICATION FLOWSHEET SIMULATION
(Figure 1, page 10)

INPUT DATA

Flowsheet Number: 1

Ore Specific Gravity= 2.7

Convergence tolerance= .10000
 Maximum Iterations for Convergence= 20

Output Print Option: 5

BALL-MILL PARAMETERS

No. of Breakage Stages used to
 calculate selection matrix= 10

Mill Feed Volume Flowrate (gal/min) at which
 selection matrix was determined= 10.79

No. of Breakage Stages this case= 9.79

I	BREAKAGE(I,1)	SELECTION(I,I)
---	-----	-----
1	.00000	1.000
2	.26182	1.000
3	.20277	1.000
4	.15298	1.000
5	.11310	1.000
6	.08231	1.000
7	.05913	1.000
8	.04200	1.000
9	.02951	.045
10	.02047	.070
11	.01398	.034
12	.00935	.046
13	.00604	.045
14	.00369	.078
15	.00202	.097
16	.00084	.146

MILL POWER = 8.7 HP = 6.5 kW

Input: Page 2 of 3
SINGLE-STAGE PILOT-SCALE SPIRAL CLASS
HENDERSON ORE TSA-38

CLASSIFIER PARAMETERS

Classification Stage No. 1

No. of Classifiers at this stage= 1

Type of Classifier: SPIRAL CLASSIFIER

Calculation method used: DOUBLE EXPONENTIAL METHOD

d50= 240.0 SI= .28 a= 14.79 C= 1.46

SINGLE-STAGE PILOT-SCALE SPIRAL CLASS
 HENDERSON ORE TSA-38

INPUT SIZE DISTRIBUTIONS

SIZE FRACTION			WEIGHT PERCENT RETAINED		
NO.	MESH	MICROMETERS	CIRCUIT FEED	1ST STAGE COARSE RECYCLE	MILL DISCHARGE
1	4.000	4750.	35.7	.0	.0
2	6.000	3350.	12.8	.0	.0
3	8.000	2360.	8.7	.0	.0
4	10.000	1700.	6.9	.0	.0
5	14.000	1180.	5.9	.0	.0
6	20.000	850.	4.5	.0	.0
7	28.000	600.	3.5	.0	.0
8	35.000	425.	3.3	29.3	20.8
9	48.000	300.	2.9	26.4	16.2
10	65.000	212.	2.6	17.8	16.8
11	100.000	150.	1.9	10.2	11.1
12	150.000	106.	2.0	6.8	8.8
13	200.000	75.	1.7	3.9	5.6
14	270.000	53.	1.4	1.9	4.0
15	400.000	38.	1.0	.9	2.6
16	-400.000	-38.	5.4	2.8	14.1

FRESH CIRCUIT FEED

Percent Solids: 100.0
 Total Solids Flowrate (TPH): .70

1ST STAGE CLASS COARSE

Percent Solids: 75.0
 Total Solids Flowrate (TPH): 1.00

FEED SUMP H2O

Total water Flowrate (TPH): 1.73

1ST CLASS SUMP H2O

Total water Flowrate (TPH): .47

SINGLE-STAGE PILOT-SCALE SPIRAL CLASS
 HENDERSON ORE TSA-38

CIRCUIT SUMMARY

STREAM NO.	STREAM NAME	STREAM NO.	STREAM NAME
1	FRESH CIRCUIT FEED	5	1ST CLASS SUMP H2O
2	FEED SUMP H2O	6	1ST STAGE CLASS FEED
3	BALL-MILL FEED	7	1ST STAGE CLASS COARSE
4	BALL-MILL DISCHARGE	8	1ST STAGE CLASS FINE

SIZE FRACTION			WEIGHT PERCENT RETAINED					
NO.	MESH	MICROMETERS	1	3	4	6	7	8
1	4.000	4750.	35.7	14.5	.0	.0	.0	.0
2	6.000	3350.	12.8	5.2	.0	.0	.0	.0
3	8.000	2360.	8.7	3.5	.0	.0	.0	.0
4	10.000	1700.	6.9	2.8	.0	.0	.0	.0
5	14.000	1180.	5.9	2.4	.0	.0	.0	.0
6	20.000	850.	4.5	1.8	.0	.0	.0	.0
7	28.000	600.	3.5	1.5	.0	.0	.1	.0
8	35.000	425.	3.3	22.9	23.3	23.3	35.4	5.7
9	48.000	300.	2.9	12.0	13.8	13.8	18.4	7.1
10	65.000	212.	2.6	12.2	17.0	17.0	18.8	14.3
11	100.000	150.	1.9	6.4	10.7	10.7	9.5	12.3
12	150.000	106.	2.0	4.3	8.2	8.2	5.8	11.7
13	200.000	75.	1.7	2.4	5.1	5.1	2.9	8.3
14	270.000	53.	1.4	1.6	3.8	3.8	1.8	6.7
15	400.000	38.	1.0	1.0	2.5	2.5	1.0	4.7
16	-400.000	-38.	5.4	5.5	15.5	15.5	6.3	29.1

SINGLE-STAGE PILOT-SCALE SPIRAL CLASS
 HENDERSON ORE TSA-38

CIRCUIT SUMMARY

STREAM NO.	STREAM NAME	STREAM NO.	STREAM NAME
-----	-----	-----	-----
1	FRESH CIRCUIT FEED	5	1ST CLASS SUMP H2O
2	FEED SUMP H2O	6	1ST STAGE CLASS FEED
3	BALL-MILL FEED	7	1ST STAGE CLASS COARSE
4	BALL-MILL DISCHARGE	8	1ST STAGE CLASS FINE

STREAM NO.	PERCENT SOLIDS	TOTAL SOLIDS FLOWRATE (TPH)	TOTAL H2O FLOWRATE (TPH)	TOTAL MASS FLOWRATE (TPH)	TOTAL VOLUME FLOWRATE (GAL/MIN)
-----	-----	-----	-----	-----	-----
1	100.0	.70	.00	.70	1.04
2	.0	.00	1.73	1.73	6.93
3	45.0	1.73	2.12	3.85	11.03
4	45.0	1.73	2.12	3.85	11.03
5	.0	.00	.47	.47	1.88
6	40.1	1.73	2.59	4.32	12.91
7	72.9	1.03	.38	1.41	3.05
8	24.2	.70	2.20	2.91	9.85

BALL MILL UNIT ENERGY CONSUMPTION = 9.2 kWh/t
 (Based on Circuit Throughput)

EXAMPLE A4

DATA FILE ENTRY FOR A SINGLE-
STAGE CLASSIFICATION FLOWSHEET SIMULATION .
(Figure 1, page 10)

CIRCUIT

Enter name of output data file

>TEST1A.OUT

Enter file code as follows:

1 for interactive data input

2 for data input from file

>2

Enter name of input data file

>TEST1.IN

Do you want to edit this data? (Y/N). Y

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

- 1-----Setup Information
- 2-----Circuit Feed Data
- 3-----Classifier Recycle Stream Data
- 4-----Mill Data
- 5-----Classifier(s) Data
- 6-----EXIT THIS MENU

EDIT>1

EDIT SETUP INFORMATION MENU

- 1-----Circuit Title and Data Description
- 2-----Flowsheet Selection
- 3-----Convergence Tolerance, Max. Iterations
- 4-----Output Print Options
- 5-----Size Fraction Selection
- 6-----EXIT THIS MENU

EDSETUP>1

Enter circuit title (up to 40 characters).

>SINGLE-STAGE SPIRAL CLASSIFIER

Enter data description (up to 40 characters).

>PILOT RUN, HENDERSON ORE TBA-38

EDIT SETUP INFORMATION MENU

- 1-----Circuit Title and Data Description
- 2-----Flowsheet Selection
- 3-----Convergence Tolerance, Max. Iterations
- 4-----Output Print Options
- 5-----Size Fraction Selection
- 6-----EXIT THIS MENU

EDSETUP>6

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

- 1-----Setup Information
- 2-----Circuit Feed Data
- 3-----Classifier Recycle Stream Data
- 4-----Mill Data
- 5-----Classifier(s) Data
- 6-----EXIT THIS MENU

EDIT>5

EDIT CLASSIFIER DATA MENU

- 1-----Water Flowrate to Sump/Weight % Solids
in the Classification Feed
- 2-----Number of Classification Devices
- 3-----Classification Device Model
- 4-----Classification Calculation Method
- 5-----Edit Calculation Method Parameters
- 6-----Calculate New Calculation Parameters
- 7-----EXIT THIS MENU

EDCLASS>4

Four classification calculation methods may be used in this simulation.
The following parameters are required for each method:

- 1 Exponential Sum Method: D50, ALPHA, RF, RS
- 2 Logistic Method: D50, SI, A, CRATIO
- 3 Double Exponential Method: D50, SI, A, CRATIO
- 4 Simple Logarithmic Method: D50, SI, A, CRATIO

(Please refer to the Users Guide for definitions of these parameters.)

Which method do you wish to use for stage 1?

>2

EDIT CLASSIFIER DATA MENU

- 1-----Water Flowrate to Sump/Weight % Solids
in the Classification Feed
- 2-----Number of Classification Devices
- 3-----Classification Device Model
- 4-----Classification Calculation Method
- 5-----Edit Calculation Method Parameters
- 6-----Calculate New Calculation Parameters
- 7-----EXIT THIS MENU

EDCLASS>7

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

- 1-----Setup Information
- 2-----Circuit Feed Data
- 3-----Classifier Recycle Stream Data
- 4-----Mill Data
- 5-----Classifier(s) Data
- 6-----EXIT THIS MENU

EDIT>6

Writing data to file...

Are you ready to execute program? (Y/N).

>Y

Calculating...

EXAMPLE A5

INTERACTIVE DATA ENTRY FOR A TWO-
STAGE CLASSIFICATION FLOWSHEET SIMULATION
(Figure 2, page 11)

CIRCUIT

Enter name of output data file

>TEST2.OUT

Enter file code as follows:

1 for interactive data input

2 for data input from file

>1

Input data will be stored in a file.

Enter file name.

>TEST2.IN

Enter circuit title (up to 40 characters).

>FLOWSHEET A-1, SPIRAL CLASSIFIER/SCREEN

Enter data description (up to 40 characters).

>HENDERSON ORE, TSA-48 (BASED ON TSA-38)

Five flowsheets are available for circuit modeling
and are described in the Users Guide.

Enter flowsheet number 1,2,3,4, or 5.

>2

Enter the convergence tolerance and the maximum
number of iterations allowed for convergence.

>.1,20

Enter the output print option:

- 1 Flow rates and size distributions reported for each stream
- input values reported
- 2 Flow rates and size distributions reported for each stream
- input not reported
- 3 Feed and product stream values reported for mill and classifier(s)
- input values reported
- 4 Feed and product stream values reported for mill and classifier(s)
- input not reported
- 5 Circuit Summary - input values reported
- 6 Circuit Summary - input not reported

>5

Size fractions may be selected from the following:

400.Mesh	270.Mesh	200.Mesh
150.Mesh	100.Mesh	65.Mesh
48.Mesh	35.Mesh	28.Mesh
20.Mesh	14.Mesh	10.Mesh
8.Mesh	6.Mesh	4.Mesh
3.Mesh		
.375Inch	.500Inch	.750Inch
1.000Inch	1.500Inch	2.000Inch
3.000Inch	4.000Inch	5.000Inch

If you do not want to select any of the size fractions
listed you may specify your own

- 1 Select from listed size fractions
- 2 Specify your own size fractions

Enter 1 or 2

>1

```

Enter number of size fractions
>16
Enter the finest size fraction for which you have
weight data--enter as mesh size
>400
Enter the appropriate screen series:
  1 Square Root of 2
  2 2 * Square Root of 2
>1
The following size fractions have been selected:
  1  4.Mesh      4750.Micrometers
  2  6.Mesh      3350.Micrometers
  3  8.Mesh      2360.Micrometers
  4 10.Mesh      1700.Micrometers
  5 14.Mesh      1180.Micrometers
  6 20.Mesh      850.Micrometers
  7 28.Mesh      600.Micrometers
  8 35.Mesh      425.Micrometers
  9 48.Mesh      300.Micrometers
10 65.Mesh      212.Micrometers
11 100.Mesh     150.Micrometers
12 150.Mesh     106.Micrometers
13 200.Mesh      75.Micrometers
14 270.Mesh      53.Micrometers
15 400.Mesh      38.Micrometers
16 -400.Mesh     -38.Micrometers

```

Do you wish to make corrections?

>N

Enter fresh circuit feed percent solids and
total solids flowrate (TPH)

>100,.887

Enter the specific gravity of the ore (gm/cc)

>2.7

Enter the weight percent retained on the following screens
for the circuit feed

4. MESH (4750.MICROMETERS)
>35.58

6. MESH (3350.MICROMETERS)
>12.76

8. MESH (2360.MICROMETERS)
>8.67

10. MESH (1700.MICROMETERS)
>6.88

14. MESH (1180.MICROMETERS)
>5.88

20. MESH (850.MICROMETERS)
>4.49

28. MESH (600.MICROMETERS)
>3.49

35. MESH (425.MICROMETERS)
 >3.34

48. MESH (300.MICROMETERS)
 >2.89

65. MESH (212.MICROMETERS)
 >2.59

100. MESH (150.MICROMETERS)
 >1.89

150. MESH (106.MICROMETERS)
 >1.98

200. MESH (75.MICROMETERS)
 >1.66

270. MESH (53.MICROMETERS)
 >1.42

400. MESH (38.MICROMETERS)
 >.99

-400. MESH (-38.MICROMETERS)
 >5.4

You may specify either the water flowrate to the
 feed sump or the weight percent solids in the ball-mill feed.

Enter:

1 to specify water flowrate to the sump
 2 to specify percent solids in the ball-mill feed
 >2
 Enter the weight percent solids in the ball-mill feed
 >50

Supply an initial guess of the following CLASSIFIER RECYCLE values.
 Enter Classifier recycle percent solids and
 total solids flowrate (TPH)
 >39,1.7

Enter the weight percent retained on the following screens
 for the classifier recycle

4. MESH (4750.MICROMETERS)
 >0

6. MESH (3350.MICROMETERS)
 >0

8. MESH (2360.MICROMETERS)
 >0

10. MESH (1700.MICROMETERS)
 >0

14. MESH (1180.MICROMETERS)
 >0

```

20. MESH ( 850.MICROMETERS)
>0

28. MESH ( 600.MICROMETERS)
>0

35. MESH ( 425.MICROMETERS)
>29.33

48. MESH ( 300.MICROMETERS)
>26.43

65. MESH ( 212.MICROMETERS)
>17.84

100. MESH ( 150.MICROMETERS)
>10.22

150. MESH ( 106 MICROMETERS)
>6.75

200. MESH ( 75.MICROMETERS)
>3.88

270. MESH ( 53.MICROMETERS)
>1.88

400. MESH ( 38.MICROMETERS)
>.85

-400. MESH ( -38.MICROMETERS)
>2.83
Mill power draw may be entered in:
  1 Horsepower (HP)
  2 Kilowatts (kW)
>1
Enter the mill power draw (HP)
>8.7
Do you have a selection matrix for the ball mill model?
>Y
Enter the Number of Breakage Stages at which the
selection matrix was calculated.
Current Value = 0 Change it? (Y or N) >Y

>10
Enter the Total Volume Flowrate (gal/min) at which
the selection matrix was calculated.
Current Value = .00 Change it? (Y or N) >Y

>10.79
Enter the selection function value, S( 1, 1)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S( 2, 2)
Current Value = .0000 Change it? (Y or N) >Y

>1

```

Enter the selection function value, S(3, 3)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(4, 4)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(5, 5)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(6, 6)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(7, 7)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(8, 8)
Current Value = .0000 Change it? (Y or N) >Y

>1
Enter the selection function value, S(9, 9)
Current Value = .0000 Change it? (Y or N) >Y

>.045
Enter the selection function value, S(10,10)
Current Value = .0000 Change it? (Y or N) >Y

>.070
Enter the selection function value, S(11,11)
Current Value = .0000 Change it? (Y or N) >Y

>.034
Enter the selection function value, S(12,12)
Current Value = .0000 Change it? (Y or N) >Y

>.046
Enter the selection function value, S(13,13)
Current Value = .0000 Change it? (Y or N) >Y

>.045
Enter the selection function value, S(14,14)
Current Value = .0000 Change it? (Y or N) >Y

>.078
Enter the selection function value, S(15,15)
Current Value = .0000 Change it? (Y or N) >Y

>.097
Enter the selection function value, S(16,16)
Current Value = .0000 Change it? (Y or N) >Y

>.146

You may specify either the water flowrate to the sump or the weight percent solids in the 1st-stage classifier feed.

Enter:

- 1 to specify water flowrate to the sump
- 2 to specify percent solids in the 1st-stage classifier feed

>2

Enter the weight percent solids in the 1st-stage classifier feed

>45

You may specify either the water flowrate to the sump or the weight percent solids in the 2nd-stage classifier feed.

Enter:

- 1 to specify water flowrate to the sump
- 2 to specify percent solids in the 2nd-stage classifier feed

>2

Enter the weight percent solids in the 2nd-stage classifier feed

>30

Enter the number of classification devices at stage 1 .

>1

Enter the number of classification devices at stage 2 .

>1

Classification device models are listed by description of their development. If you will be modeling based on classification parameters rather than equipment operating variables, please select 9, 19, or 29.

Specify classification device model for the first stage

- 1 JKMRC Hydrocyclone
- 9 Hydrocyclone
- 10 12-inch Spiral Classifier: open circuit - Climax ore
- 11 closed circuit - Climax ore
- 12 closed circuit - Henderson ore
- 19 Spiral Classifier
- 20 1-foot wide Sieve Bend Screen
- 21 .7 mm Slot Width Only
- 22 JKMRC Sieve Bend Screen
- 29 Screen

>19

Specify classification device model for the second stage:

- 1 JKMRC Hydrocyclone
- 9 Hydrocyclone
- 10 12-inch Spiral Classifier: open circuit - Climax ore
- 11 closed circuit - Climax ore
- 12 closed circuit - Henderson ore
- 19 Spiral Classifier
- 20 1-foot wide Sieve Bend Screen
- 21 .7 mm Slot Width Only
- 22 JKMRC Sieve Bend Screen
- 29 Screen

>20

Four classification calculation methods may be used in this simulation.
The following parameters are required for each method:

- 1 Exponential Sum Method: D50, ALPHA, RF, RS
- 2 Logistic Method: D50, SI, A, CRATIO
- 3 Double Exponential Method: D50, SI, A, CRATIO
- 4 Simple Logarithmic Method: D50, SI, A, CRATIO

(Please refer to the Users Guide for definitions of these parameters.)

Which method do you wish to use for stage 1?

>2

Do you have the parameters required?

>Y

Which method do you wish to use for stage 2?

>2

Do you have the parameters required?

>N

For the first stage of classification,
Enter D50,SI,A,CRATIO

>240,.28,14.79,1.46

For the second stage of classification,
Parameters may be calculated using the models described
in the Users Guide. To obtain parameters, the following
information must be supplied:

Screen: Throughput (t/hr), Feed Solids (weight percent),
Slot Width (mm)

Do you want to continue?

>Y

Enter the following screen operating variables:

TPH,FS,SW

>1.8,30,.35

Do you want to change any data for this simulation? (Y/N).

>N

Writing data to file...

Are you ready to execute program? (Y/N).

>Y

Calculating...

Program Execution Completed Normally

Stop - Program terminated.

EXAMPLE A6

INPUT DATA FILE FOR A TWO-STAGE
CLASSIFICATION FLOWSHEET SIMULATION
(Figure 2, page 11)

FLWSHEET A-1, SPIRAL CLASSIFIER/SCREEN

HENDERSON ORE, TSA-48 (BASED ON TSA-38)

NUMFLO=2 NSIZE=16 ISERES=1

FRACTION	MESH/IN	SIZE	MICROMETERS	FEED	PCT	RET
1	1	4.000	4750.		35.58	
2	1	6.000	3350.		12.76	
3	1	8.000	2360.		8.00	
4	1	10.000	1700.		6.88	
5	1	14.000	1180.		5.88	
6	1	20.000	850.		4.49	
7	1	28.000	600.		3.49	
8	1	35.000	425.		3.34	
9	1	48.000	300.		2.89	
10	1	65.000	212.		2.59	
11	1	100.000	150.		1.89	
12	1	150.000	106.		1.98	
13	1	200.000	75.		1.66	
14	1	270.000	53.		1.42	
15	1	400.000	38.		.99	
16	1	-400.000	-38.		5.40	

FEED PCT SOLIDS= 100.00 FEED TOT SOLIDS(TPH)= .887

ORE SPECIFIC GRAVITY= 2.7

ISW1=2

FEED SUMP WATER (TPH)= .000

BALL-MILL FEED PCT SOLIDS= 50.00

CLASSIFIER RECYCLE STREAM NUMBER=11

RECYCLE PCT SOLIDS= 39.00 RECYCLE TOT SOLIDS(TPH)= 1.700

FRACTION	MESH/IN	SIZE	MICROMETERS	CLASS	RECYCLE	PCT	RET
1	1	4.000	4750.		.00		
2	1	6.000	3350.		.00		
3	1	8.000	2360.		.00		
4	1	10.000	1700.		.00		
5	1	14.000	1180.		.00		
6	1	20.000	850.		.00		
7	1	28.000	600.		.00		
8	1	35.000	425.		29.33		
9	1	48.000	300.		26.43		
10	1	65.000	212.		17.84		
11	1	100.000	150.		10.22		
12	1	150.000	106.		6.75		
13	1	200.000	75.		3.88		
14	1	270.000	53.		1.88		
15	1	400.000	38.		.85		
16	1	-400.000	-38.		2.83		

MILL POWER (HP)= 8.7

MANS=1 BREAKAGE STAGES= 10 TOT VOL FLOW= 10.79

I BREAKAGE(I,1) SELECTION(I,I) MILL PROD,PCT RET(I)

I	BREAKAGE(I,1)	SELECTION(I,I)	MILL PROD,PCT	RET(I)
1	.000000	1.000	.00	
2	.261821	1.000	.00	
3	.202765	1.000	.00	
4	.152977	1.000	.00	
5	.113102	1.000	.00	
6	.082307	1.000	.00	
7	.059129	1.000	.00	
8	.042001	1.000	.00	
9	.029505	.045	.00	
10	.020472	.070	.00	
11	.013984	.034	.00	

```

12      .009346      .046      .00
13      .006040      .045      .00
14      .003690      .078      .00
15      .002021      .097      .00
16      .000838      .146      .00
ISW2=2
1ST STAGE CLASSIFIER SUMP WATER (TPH)= .000
1ST-STAGE CLASSIFIER FEED PCT SOLIDS= 45.00
ISW3=2
2ND STAGE CLASSIFIER SUMP WATER (TPH)= .000
2ND-STAGE CLASSIFIER FEED PCT SOLIDS= 30.00
STAGE=1 NO. OF CLASSIFIERS=1 DEVICE=19 METHOD=2 JANS=1 D50= 240.0
ALPHA= .00 RF= .00 RS= .00
SI= .28 A= 14.79 CRATIO= 1.46
VF= .000000E+00 P= .000000E+00 SPIG= .000000E+00
CYCDIAM= .0 INDIAM= .00 CYCLGT= .0 THETA= .0
KV= .000000E+00 KW= .000000E+00 KD= .000000E+00
RPM= .0 SLP= .00 WH= .00
LBPH= 0. OFS= .00
TPH= .000 FS= .00 SW= .00
K1= .00000 K2= .00000 K3= .00000 K4= .00000
K5= .00000 K6= .00000 K7= .00000 K8= .00000
K9= .00000 K10= .00000 K11= .00000 K12= .00000
STAGE=2 NO. OF CLASSIFIERS=1 DEVICE=20 METHOD=2 JANS=2 D50= .0
ALPHA= .00 RF= .00 RS= .00
SI= .00 A= .00 CRATIO= .00
VF= .000000E+00 P= .000000E+00 SPIG= .000000E+00
CYCDIAM= .0 INDIAM= .00 CYCLGT= .0 THETA= .0
KV= .000000E+00 KW= .000000E+00 KD= .000000E+00
RPM= .0 SLP= .00 WH= .00
LBPH= 0. OFS= .00
TPH= 1.800 FS= 30.00 SW= .35
K1= .00000 K2= .00000 K3= .00000 K4= .00000
K5= .00000 K6= .00000 K7= .00000 K8= .00000
K9= .00000 K10= .00000 K11= .00000 K12= .00000
CONTOL= .10000 MAXIT= 20
IPRINT=5

```

EXAMPLE A7

OUTPUT DATA FILE FOR A TWO-STAGE
CLASSIFICATION FLOWSHEET SIMULATION
(Figure 2, page 11)

INPUT DATA

Flowsheet Number: 2

Ore Specific Gravity= 2.7

Convergence tolerance= .10000
 Maximum Iterations for Convergence= 20

Output Print Option: 5

BALL-MILL PARAMETERS

No. of Breakage Stages used to
 calculate selection matrix= 10

Mill Feed Volume Flowrate (gal/min) at which
 selection matrix was determined= 10.79

No. of Breakage Stages this case= 9.29

I	BREAKAGE(I,1)	SELECTION(I,I)
1	.00000	1.000
2	.26182	1.000
3	.20277	1.000
4	.15298	1.000
5	.11310	1.000
6	.08231	1.000
7	.05913	1.000
8	.04200	1.000
9	.02951	.045
10	.02047	.070
11	.01398	.034
12	.00935	.046
13	.00604	.045
14	.00369	.078
15	.00202	.097
16	.00084	.146

MILL POWER = 8.7 HP = 6.5 kW

CLASSIFIER PARAMETERS

Classification Stage No. 1

No. of Classifiers at this stage= 1

Type of Classifier: SPIRAL CLASSIFIER

Calculation method used: LOGISTIC METHOD

d50= 240.0 SI= .28 a= 14.79 C= 1.46

Classification Stage No. 2

No. of Classifiers at this stage= 1

Type of Classifier: SCREEN

Calculation method used: LOGISTIC METHOD

d50= 97.2 SI= .53 a= 48.96 C= 37.29

TPH= 1.800 FS= 30.00 SW= .35

INPUT SIZE DISTRIBUTIONS

SIZE FRACTION			WEIGHT PERCENT RETAINED	
NO.	MESH	MICROMETERS	CIRCUIT FEED	2ND STAGE COARSE RECYCLE
1	4.000	4750.	35.6	.0
2	6.000	3350.	12.8	.0
3	8.000	2360.	8.0	.0
4	10.000	1700.	6.9	.0
5	14.000	1180.	5.9	.0
6	20.000	850.	4.5	.0
7	28.000	600.	3.5	.0
8	35.000	425.	3.3	29.3
9	48.000	300.	2.9	26.4
10	65.000	212.	2.6	17.8
11	100.000	150.	1.9	10.2
12	150.000	108.	2.0	6.8
13	200.000	75.	1.7	3.9
14	270.000	53.	1.4	1.9
15	400.000	38.	1.0	.9
16	-400.000	-38.	5.4	2.8

FRESH CIRCUIT FEED

Percent Solids: 100.0
 Total Solids Flowrate (TPH): .89

2ND STAGE CLASS COARSE

Percent Solids: 39.0
 Total Solids Flowrate (TPH): 1.70

BALL-MILL FEED

Percent Solids: 50.0

1ST STAGE CLASS FEED

Percent Solids: 45.0

2ND STAGE CLASS FEED

Percent Solids: 30.0

FLWSHEET A-1, SPIRAL CLASSIFIER/SCREEN
 HENDERSON ORE, TSA-48 (BASED ON TSA-38)

CIRCUIT SUMMARY

STREAM NO.	STREAM NAME	STREAM NO.	STREAM NAME
1	FRESH CIRCUIT FEED	7	1ST STAGE CLASS COARSE
2	FEED SUMP H2O	8	1ST STAGE CLASS FINE
3	BALL-MILL FEED	9	2ND CLASS SUMP H2O
4	BALL-MILL DISCHARGE	10	2ND STAGE CLASS FEED
5	1ST CLASS SUMP H2O	11	2ND STAGE CLASS COARSE
6	1ST STAGE CLASS FEED	12	2ND STAGE CLASS FINE
		13	CIRCUIT PRODUCT

SIZE FRACTION			WEIGHT PERCENT RETAINED				
NO.	MESH	MICROMETERS	1	3	4	6	7
1	4.000	4750.	35.6	15.0	.0	.0	.0
2	6.000	3350.	12.8	5.4	.0	.0	.0
3	8.000	2360.	8.0	3.4	.0	.0	.0
4	10.000	1700.	6.9	2.9	.0	.0	.0
5	14.000	1180.	5.9	2.5	.0	.0	.0
6	20.000	850.	4.5	1.9	.0	.0	.0
7	28.000	600.	3.5	1.5	.1	.1	.1
8	35.000	425.	3.3	18.7	23.7	23.7	34.1
9	48.000	300.	2.9	11.9	14.2	14.2	18.4
10	65.000	212.	2.6	11.9	17.3	17.3	19.1
11	100.000	150.	1.9	6.2	10.6	10.6	9.5
12	150.000	106.	2.0	3.7	7.9	7.9	5.4
13	200.000	75.	1.7	1.9	4.8	4.8	2.5
14	270.000	53.	1.4	1.1	3.5	3.5	1.5
15	400.000	38.	1.0	.7	2.3	2.3	.8
16	-400.000	-38.	5.4	11.2	15.6	15.6	8.5

SIZE FRACTION			WEIGHT PERCENT RETAINED				
NO.	MESH	MICROMETERS	8	10	11	12	13
1	4.000	4750.	.0	.0	.0	.0	.0
2	6.000	3350.	.0	.0	.0	.0	.0
3	8.000	2360.	.0	.0	.0	.0	.0
4	10.000	1700.	.0	.0	.0	.0	.0
5	14.000	1180.	.0	.0	.0	.0	.0
6	20.000	850.	.0	.0	.1	.0	.0
7	28.000	600.	.0	.1	.1	.0	.0
8	35.000	425.	8.5	34.1	35.0	1.3	8.2
9	48.000	300.	8.1	18.4	18.9	2.2	7.9
10	65.000	212.	14.7	19.1	19.4	7.5	14.4
11	100.000	150.	12.3	9.5	9.4	11.8	12.3
12	150.000	106.	11.4	5.4	5.1	19.4	11.7
13	200.000	75.	8.0	2.5	2.0	21.1	8.5
14	270.000	53.	6.4	1.5	1.0	20.1	6.9
15	400.000	38.	4.5	.8	.5	14.0	4.9
16	-400.000	-38.	26.0	8.5	8.7	2.5	25.1

FLWSHEET A-1, SPIRAL CLASSIFIER/SCREEN
 HENDERSON ORE, TSA-48 (BASED ON TSA-38)

CIRCUIT SUMMARY

STREAM NO.	STREAM NAME	STREAM NO.	STREAM NAME
1	FRESH CIRCUIT FEED	7	1ST STAGE CLASS COARSE
2	FEED SUMP H2O	8	1ST STAGE CLASS FINE
3	BALL-MILL FEED	9	2ND CLASS SUMP H2O
4	BALL-MILL DISCHARGE	10	2ND STAGE CLASS FEED
5	1ST CLASS SUMP H2O	11	2ND STAGE CLASS COARSE
6	1ST STAGE CLASS FEED	12	2ND STAGE CLASS FINE
		13	CIRCUIT PRODUCT

STREAM NO.	PERCENT SOLIDS	TOTAL SOLIDS FLOWRATE (TPH)	TOTAL H2O FLOWRATE (TPH)	TOTAL MASS FLOWRATE (TPH)	TOTAL VOLUME FLOWRATE (GAL/MIN)
1	100.0	.89	.00	.89	1.31
2	.0	.00	.67	.67	2.70
3	50.0	2.12	2.12	4.24	11.62
4	50.0	2.12	2.12	4.24	11.62
5	.0	.00	.47	.47	1.88
6	45.0	2.12	2.59	4.71	13.50
7	76.7	1.26	.38	1.64	3.40
8	28.1	.86	2.21	3.07	10.11
9	.0	.00	2.55	2.55	10.21
10	30.0	1.26	2.94	4.19	13.61
11	46.0	1.23	1.44	2.66	7.56
12	2.1	.03	1.50	1.53	6.04
13	19.4	.89	3.71	4.60	16.15

BALL MILL UNIT ENERGY CONSUMPTION = 7.3 kWh/t
 (Based on Circuit Throughput)

EXAMPLE A8

DATA FILE ENTRY FOR A TWO-
STAGE CLASSIFICATION FLOWSHEET SIMULATION
(Figure 2, page 11)

C:\TWOSTG >CIRCUIT

Enter name of output data file

>TEST2A.OUT

Enter file code as follows:

1 for interactive data input

2 for data input from file

>2

Enter name of input data file

>TEST2.IN

Do you want to edit this data? (Y/N). Y

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

1-----Setup Information

2-----Circuit Feed Data

3-----Classifier Recycle Stream Data

4-----Mill Data

5-----Classifier(s) Data

6-----EXIT THIS MENU

EDIT>2

EDIT CIRCUIT FEED DATA MENU

1-----Circuit Feed % Solids and Total
 Solids Flowrate

2-----Ore Specific Gravity

3-----Circuit Feed Size Fraction Data

4-----Water Flowrate to the Feed Sump or
 Ball Mill Feed Percent Solids

5-----EXIT THIS MENU

EDFEED>4

You may specify either the water flowrate to the
feed sump or the weight percent solids in the ball-mill feed.

Enter:

1 to specify water flowrate to the sump

2 to specify percent solids in the ball-mill feed

>2

Enter the weight percent solids in the ball-mill feed

>55

EDIT CIRCUIT FEED DATA MENU

- 1-----Circuit Feed % Solids and Total Solids Flowrate
- 2-----Ore Specific Gravity
- 3-----Circuit Feed Size Fraction Data
- 4-----Water Flowrate to the Feed Sump or Ball Mill Feed Percent Solids
- 5-----EXIT THIS MENU

EDFEED>5

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

- 1-----Setup Information
- 2-----Circuit Feed Data
- 3-----Classifier Recycle Stream Data
- 4-----Mill Data
- 5-----Classifier(s) Data
- 6-----EXIT THIS MENU

EDIT>4

EDIT MILL DATA MENU

- 1-----Mill Power Draw
- 2-----Selection Matrix for Mill Model
- 3-----EXIT THIS MENU

EDMILL>1

Mill power draw may be entered in:

- 1 Horsepower (HP)
- 2 Kilowatts (kW)

>1

Enter the mill power draw (HP)

>8.4

EDIT MILL DATA MENU

- 1-----Mill Power Draw
- 2-----Selection Matrix for Mill Model
- 3-----EXIT THIS MENU

EDMILL>3

MAIN MENU--EDIT INPUT DATA FILE FUNCTION

- 1-----Setup Information
- 2-----Circuit Feed Data
- 3-----Classifier Recycle Stream Data
- 4-----Mill Data
- 5-----Classifier(s) Data
- 6-----EXIT THIS MENU

EDIT>6

Writing data to file...

Are you ready to execute program? (Y/N).

>Y

Calculating...

APPENDIX B
MODIFYING CIRCUIT

B. MODIFYING CIRCUIT

CIRCUIT mechanizes the calculation of grinding-classification circuit mass balances. It performs this job by starting its calculations at the beginning of the circuit and proceeding through grinding and classification unit operations until all process stream variables have been calculated. CIRCUIT requires information about the circuit feed and parameters for the ball mill and classifiers. Streams recycled to the ball mill cause CIRCUIT to repeat the calculations until convergence is realized.

A modular approach was taken in designing CIRCUIT to allow the future addition of other models with relatively minor changes to the overall package. Should you find that the classification model you prefer to use is not supplied by the program, you may add it to the appropriate subroutine. If the circuit you are studying includes a rod mill, you may add another grinding mill subroutine. If you have already developed an empirical grinding model for your operation, that could also be added to CIRCUIT. This appendix will provide you with helpful information if you decide to make some of these changes.

B.1. SOFTWARE REQUIREMENTS

In order to modify CIRCUIT, you will need a copy of Disk 2, Source Disk. This disk contains the FORTRAN source code and compiler files. You will also need an editor and PC FORTRAN compiler software. The current version of CIRCUIT was compiled and linked using Microsoft FORTRAN Compiler, Version 3.3, on an IBM-compatible personal computer with MS DOS Version 3.10.

B.2. USING THIS APPENDIX

This appendix is written for people who have experience in operating IBM-compatible PC's with an MS DOS operating system. A good understanding of FORTRAN is also necessary for modifying CIRCUIT. You should be able to write, compile, and link a FORTRAN program on a PC. It is beyond the scope of this guide to provide instructions for these operations.

B.3. EDITING CIRCUIT

Before editing the CIRCUIT source code, it is a good idea to make a back-up copy of Disk 2, Source Disk, if you are using a floppy disk system. Instructions for making back-up copies are given in Section 2.1.1. If you are using a hard disk system, you will want to install all the source and compiler files in your CIRCUIT sub-directory (see Section 2.2.2).

To edit CIRCUIT and its subroutines, you will want to call the appropriate .FOR files with your editor. For example, to change the source code for CLASS, you will edit the file CLASS.FOR.

B.4. PROGRAM ORGANIZATION

CIRCUIT consists of an executive program and seven primary subroutines, INDATA, OUTDATA, SUMP, MILL, CLASS, STRMCAL, and CONV (see Section 4.1 and Figure 6). Input and output information for the package is handled by the INDATA and OUTDATA subroutines, respectively. The process simulation subroutines for modeling a sump (SUMP), ball mill (MILL), and classifier (CLASS) are called by the executive program in the order required to simulate the grinding-classification circuit selected by the user. Calculations of slurry density and solids, water, mass, and volume flow rates are made by the STRMCAL subroutine. A convergence subroutine (CONV) is called following each iteration of flowsheet calculations to determine when the results are balanced throughout the circuit. Sections 4.1.1 to 4.1.7 describe the functions of the primary subroutines. You should read all of Section 4.1 before proceeding to modify CIRCUIT.

A step-by-step explanation of all the logic and variables used in CIRCUIT is beyond the scope of this guide. However, an attempt has been made to provide sufficient labeling within the FORTRAN source code to give the user a working understanding of the program. Section 4.2 of this guide provides the model equations used in the program. An attempt was made to keep the variables used in the FORTRAN coordinated with the variables used in these equations.

B.5. MODIFYING A SUBROUTINE

CIRCUIT allows selection of several classification equipment models to simulate classification in a hydrocyclone, spiral classifier, or sieve bend screen. The addition of another equipment model may be one type of modification you might make to CIRCUIT. This example will be used to explain the steps in modifying a subroutine.

The first step in modifying CIRCUIT is to determine which subroutines must be affected by the change. In this case, by reading Section 4.1.5, it is determined that a change to the classifier equipment modeling subroutine DEVICE is necessary. By examining Figure 6, it is apparent that subroutine CLASS may also be affected by the change. Since a new set of equipment operating variables will be required from the user, the CLASIN and CLASPAR subroutines must also be changed. Inclusion of the name of the new equipment and its parameters in the input and output data files necessitates changes in INDATA and OUTDATA.

To edit DEVICE, you will edit the file DEVICE.FOR. Write the block of FORTRAN code required for the equipment model and insert it into DEVICE.FOR. Be sure to familiarize yourself with the variable names in the subroutine in order to avoid conflict between the old and new code. You will notice that comment statements indicate where to insert "other" hydrocyclone, spiral classifier, and screen models. You will also notice that IDEV is a variable that indicates the classification device to be used and tells the program which model equations to employ. IDEV for hydrocyclones is between 1 and 9, for spiral classifiers, between 10 and 19, and for screens, IDEV is

between 20 and 29. It is also important to remember that the operating variables in your model equations should be dimensioned to allow for two-stages of classification.

Once you have entered your new code in DEVICE.FOR, you should check that you have included all new variables in the DIMENSION, COMMON, DATA, REAL, and INTEGER statements at the beginning of the program as required. Be sure to note the variables that must be passed to CLASS.FOR. You can use the other equipment models in DEVICE.FOR to guide you.

Now you will want to edit the file CLASS.FOR to include any DIMENSION and COMMON statements required. You should also check that the changes you have made in DEVICE.FOR are compatible with the way it is called from CLASS.FOR. After editing CLASS.FOR, you will proceed to make the necessary changes in CLASIN.FOR and CLASPAR.FOR to assure that the operating variables required for the new model are prompted for during data entry. Change INDATA.FOR by including a WRITE statement for writing the new variables to the input data file and a READ statement for reading them from the data file. OUTDATA.FOR should be edited to include WRITE statements for displaying the operating variables with the input data. In each of these cases, do not forget to include appropriate COMMON and DIMENSION statements for any new variables.

Finally, you should determine if any variables will be passed through CIRCUIT.FOR, the executive program. You will want to include any COMMON and DIMENSION statements necessary in this case.

B.6. ADDING A SUBROUTINE

CIRCUIT includes only a grinding model for a ball mill. The addition of another mill model could follow the same logic used to add a selection of classifier models. Subroutine ADMILL could be used to determine which mill will be used and contains the model equations for both. However, because of the complexity of most grinding mill models and the number of variables usually required, it may be easier to simply add another subroutine. In this case, CIRCUIT will call the appropriate mill calculations based on a variable switch added to the program. This example will be used to explain the steps in adding a subroutine.

The first step is to determine what other subroutines will be affected by the change. In this case, by examining Figure 6, it is apparent that the executive program and the input and output subroutines will be affected. Since a new set of equipment operating variables will be required from the user, the MILLIN subroutine must also be changed. Inclusion of the name of the new equipment and its parameters in the input and output data files necessitates changes in INDATA and OUTDATA. A selection in the menu provided by EDMILL may also be in order to allow the user to switch from one mill to another using an old data file.

To add the new subroutine, you will create a new file, say NUMILL.FOR, using the editor. You must write a FORTRAN program to perform all the necessary mill

calculations. The main function of the subroutine is to calculate the mill discharge size distribution, given the feed size distribution. You may wish to use ADMILL.FOR as a guide in determining the information to be returned to CIRCUIT from NUMILL.

Next, you must edit the file CIRCUIT.FOR to include a switch check before the mill subroutine is called. For instance, if MILSW is 1, CIRCUIT calls ADMILL, if MILSW is 2, CIRCUIT calls NUMILL. You must include this switch in a COMMON statement.

Now you will edit MILLIN.FOR to assure that the operating variables required for the new model and the switch variable are prompted for during data entry. Change INDATA.FOR by including WRITE statements for writing the new variables and the switch variable to the input data file and a READ statement for reading them from the data file. OUTDATA.FOR should be edited to include WRITE statements for displaying the new mill variables with the input data. In each of these cases, do not forget to include appropriate COMMON and DIMENSION statements for the new variables.

Finally, add appropriate menu selections to EDCLASS.FOR to allow changing the switching variable and to call the appropriate sections of MILLIN.FOR, depending on which type of mill data will be required.

B.7. CALLING SUPPORT SUBROUTINES

Three support subroutines, ANSWER, FREAD, and SIZPIX are frequently called by INDATA and its subroutines. You may want to use these subroutines for routine data input tasks. ANSWER is used following a WRITE statement that poses a yes or no question. ANSWER determines if a yes or no response has been entered and translates it to an integer value (yes = 1, no = 2). FREAD is called following a WRITE statement that requests a numerical answer. FREAD converts data entered to the format style required by the calling subroutine. SIZPIX requests size distribution information. Each of these support subroutines contains comment statements explaining its use.

B.8. COMPILING SOURCE FILES

You must compile each of the new or modified source code files upon completion of the editing process. You should follow instructions given with the FORTRAN compiler you are using. A batch file (COMPILE.BAT) has been added to the Source Disk to aid in compiling if you are using the Microsoft FORTRAN Compiler Version 3.3. All the required compiler files are also included on the Source Disk. Therefore, if you are using the same compiler, you will only need to compile the modified and/or new files. Compiled files have the extension .OBJ.

If you are using a different compiler or version number, you must compile all the source code files the first time you make modifications to the program. In subsequent editing sessions, you will need to compile only the modified and new files.

B.9. LINKING COMPILER FILES

Once you have compiled all files, you will need to link them and create an executable version of CIRCUIT. You should follow the linking instructions given with the FORTRAN compiler you are using. A batch file (LINKCIRC.BAT) has been added to the Source Disk to link all the compiler files for you if you are using the Microsoft FORTRAN Compiler Version 3.3. Type out LINKCIRC.BAT to review the list of files to be linked. You will notice that some of the file names have been shortened. You must rename your compiler files to match if you intend to use this batch file. For example, rename CLASIN.OBJ to CLSI.OBJ and rename EDIT.OBJ to ED.OBJ. You must add the names of compiler files for newly added subroutines.

If you are using a different compiler or version number, you must link all the source code files following the compiler software instructions. Be sure to include any newly created subroutines. You may find it helpful to create a batch file to do the linking for you.

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MATHEMATICAL MODELING OF TWO-STAGE CLASSIFICATION
TECHNOLOGY TRANSFER SUMMARY & USER'S GUIDE

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