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**SPENT FUEL REPROCESSING SYSTEM
AVAILABILITY DEFINITION
BY PROCESS SIMULATION**

MASTER

by
N. HOLDER, B. B. HALDY, and M. JONZEN

**Prepared Under
Contract EY-76-C-03-0167
Project Agreement No. 53
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Department of Energy**

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ABSTRACT

To examine nuclear fuel reprocessing plant operating parameters such as maintainability, reliability, availability, equipment redundancy, and surge storage requirements and their effect on plant throughput, a computer simulation model of integrated HTGR fuel reprocessing plant operations is being developed at General Atomic Company (GA).

This is an interim report on the simulation methodology and the status of the computer programming completed to date on reprocessing head end systems.



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1. INTRODUCTION

The required availability of systems is of concern to equipment development activities so that the latitude in tradeoffs between reliability, maintainability, and other equipment operating parameters can be considered and applied in equipment design.

Total plant and individual system availability aspects under actual integrated operating conditions consist of more than mean time to failure and mean time to repair since other down time, idle time, and operation at reduced throughput all affect availability and production rates. It is necessary to examine all of the availability aspects under integrated operating conditions to determine the total inherent system availability envelope within which the equipment developer/designer must work.

In a non-remote production operation, availability can be greatly enhanced by the provision of surge storage and redundant equipment, thus giving greater latitude in equipment design for reliability and maintainability. In remote operations such as spent fuel reprocessing, space is at a premium, and equipment and piping complexity within the operating cell complicates both operation and maintenance activities as well as increasing failure risks.

In summary, the goal for the spent fuel reprocessing plant should be to minimize equipment redundancy and surge storage while maximizing system availability under integrated operating conditions. Computer simulation of process operations is an inexpensive and efficient method of examining integrated operating conditions under a variety of constraints to provide equipment design and development guidance at an early stage.

Careful definition of availability terminology is required, as there is little standardization in industry. An availability "number" in itself is meaningless unless the components of the calculation are well defined and described. The definition suggested for reprocessing systems is:

$$\text{Availability} \equiv \frac{\text{Operating Time} + \text{Ready Time}}{\text{Operating Time} + \text{Ready Time} + \text{Down Time}} ,$$

where

Operating Time = any time that equipment is producing product within acceptable limits (to be defined),

Ready Time = (a) any time that equipment could produce within acceptable limits but is not required to be in service,

(b) any time that equipment is operable but cannot operate because product surge storage is unavailable or feed is unavailable because of some upstream failure,

Down Time = (a) active corrective maintenance time (diagnostic time plus active repair time plus checkout and logging time),

(b) active preventive maintenance time,

(c) logistics time (obtaining of spares and administrative decision time),

(d) accountability and quality control release time, including any time spent waiting for analytical results or administrative decisions before releasing a batch from equipment or storage, and any

time spent in sweeping down equipment to gather material for accountability or quality control (QC) data.

The total plant availability calculation can be derived from the system availability definitions. This total plant availability definition is an end result of system availabilities under conditions that will produce a given quantity of product in a given time period. Use of computer simulation of operating conditions allows parametric iterations to determine acceptable combinations of major equipment redundancy, surge storage, and maintainability/reliability parameters that will meet plant throughput requirements. The method for determining system availability by simulation is presented in this report along with descriptions of work completed on an HTGR spent fuel reprocessing head-end simulation model.

2. SIMULATION MODEL DESCRIPTION

A GASP IV Simulation Language Package (Ref. 1) has been selected for use as a basis for Monte Carlo simulation of reprocessing plant operations. One of the uses of the simulation model is to collect statistics on down time, operating time, and ready time in order to define system availability.

The GASP IV Simulation Package consists of an executive routine that organizes and controls program execution, subroutines for data storage and retrieval and data collection, subroutines for computing and reporting statistics, and subroutines for random deviate generation. The user must define the operating characteristics of his systems in a series of Fortran subroutines.

Fortran subroutines modeling HTGR spent fuel reprocessing system operations are being programmed and added to the GASP IV Simulation Package. The head-end systems and product handling subsystems to be modeled are shown in Fig. 2-1. Appendix A gives detailed descriptions and flow charts of subroutines written to March 1978. Brief descriptions of the subroutines and their purpose in the simulation follows.

An initialization subroutine defines the characteristics of the spent fuel arriving for processing. Basic information such as the number of fuel elements of various types in various customer batches, characteristics such as weight and volume of fuel particles, and burnable carbon, uranium, and thorium content for each type of fuel element are read from cards. This constitutes data to be used in process calculations. Since the reprocessing plant feed characteristics are defined outside the model (card input), fuel characteristics can easily be changed as new design information develops. Appendix B contains user instructions for fuel data card input.

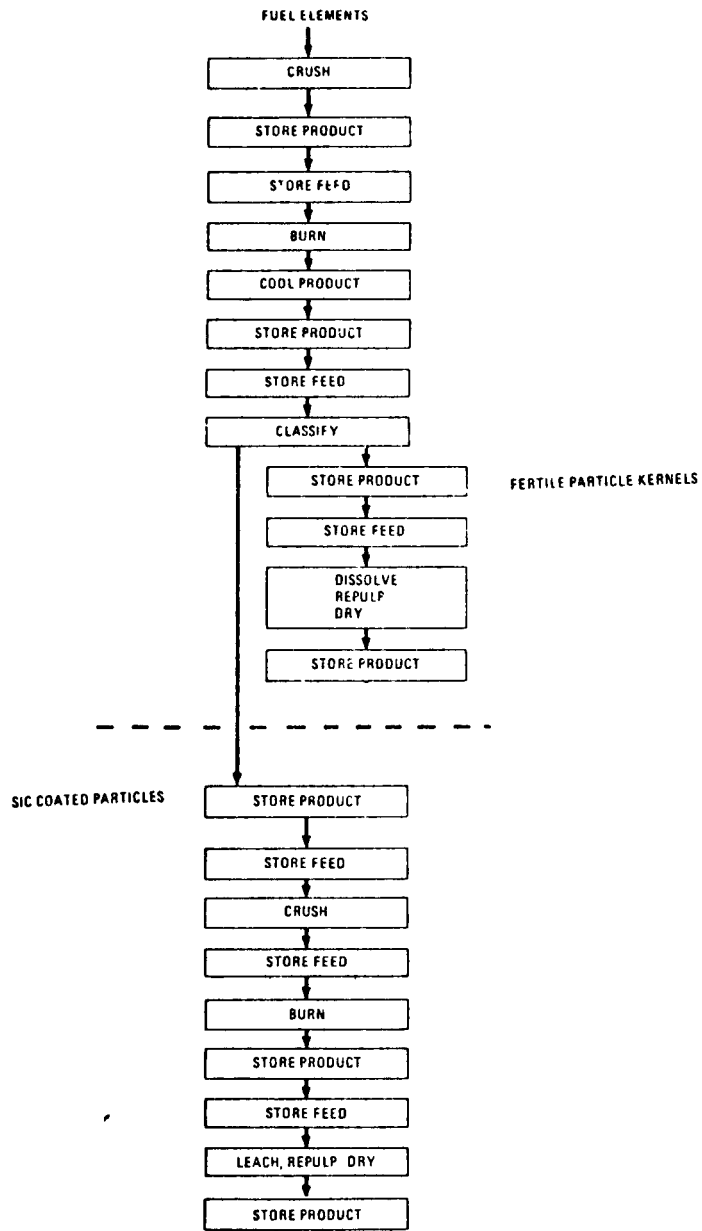


Fig. 2-1. Head-end systems and subsystems, HTGR spent fuel reprocessing

A separate subroutine is being programmed for the operating description of each major process system and for service subsystems such as feed and weigh hoppers and surge storage hoppers, as shown in Fig. 2-1. This separation will facilitate modifying the model for any future design changes. For example, if a different type of process is considered, the appropriate subroutine can be deleted and a new subroutine substituted without reprogramming of product handling subsystems.

Each system operation is programmed at the most basic level that will reasonably approximate real operation. For example, the fuel element crushing subroutine only considers the arrival of fuel elements and departure of sized product at random times chosen from a distribution of process times. The fuel element burner model is more complex, reflecting a waiting period from initial loading to ignition, a reduction of burnable carbon at an average full operation burn rate, and an alternative reduced burn rate for final bed carbon removal or for small batches that create abnormal operating conditions. (See Appendix C for equipment and system descriptions.)

Passage of material through the systems and subsystems is monitored by a series of GASP IV file entries (Fig. 2-2) as a simulation of integrated operation. Each file represents either a piece of major equipment, a feed hopper, a product receiving hopper, or a surge storage hopper. The fuel elements are treated as individual entries in each file. Each fuel element initially defined receives a customer identification number. The identification numbers are then monitored throughout the head-end systems so that customer lots can be kept together and completion of each customer batch can be signaled for accountability of special nuclear material. A print-out of the files at any time indicates the location of all the fuel material in the system. Limits are placed on the number of entries in each file to simulate equipment and surge storage size limitations. When a file reaches its entry limit, the preceding equipment subroutines are flagged to stop operation until space again becomes available. Statistics are collected on all stop and go operations so that operating time, ready time, and down time for each system can be distinguished.

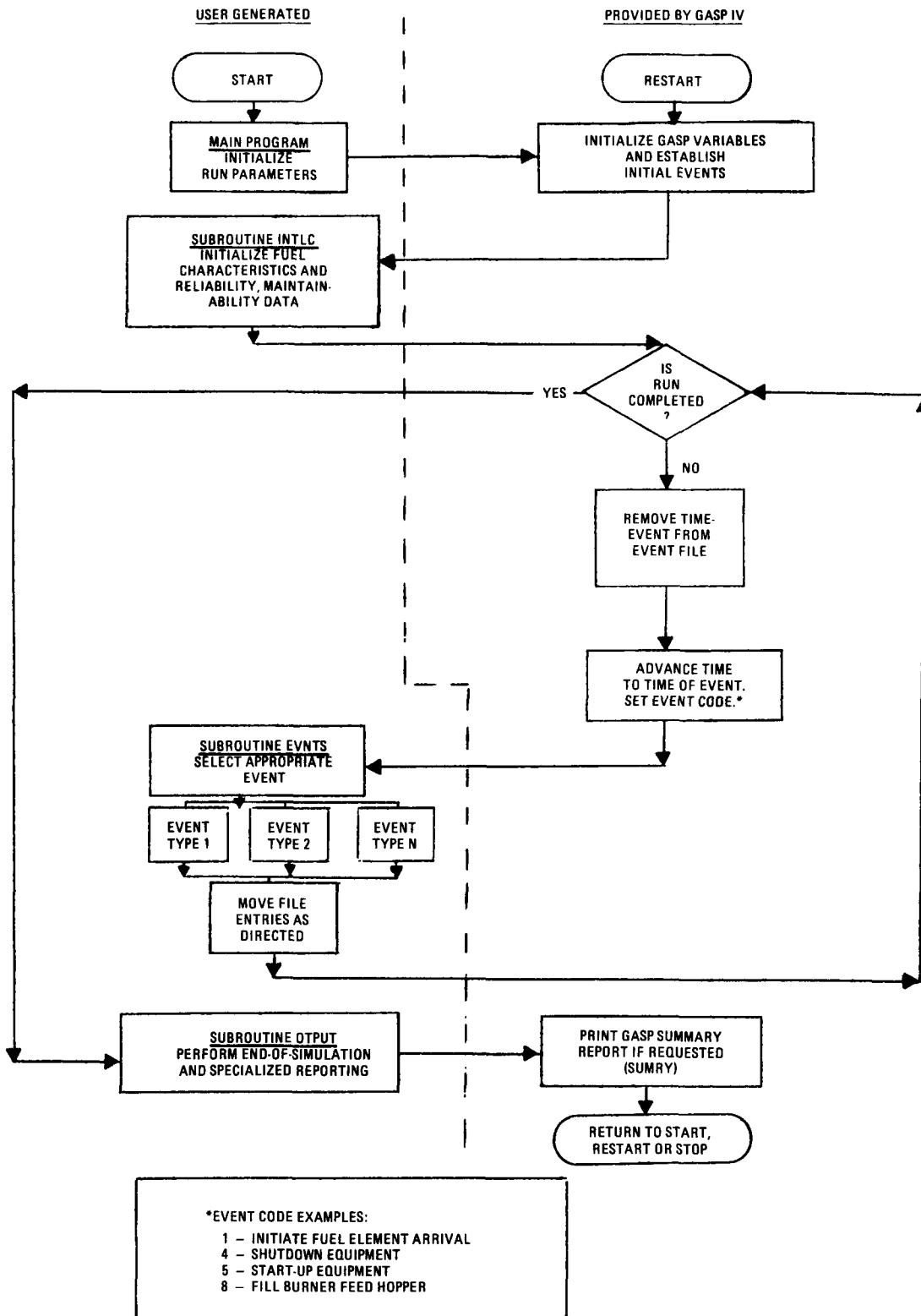
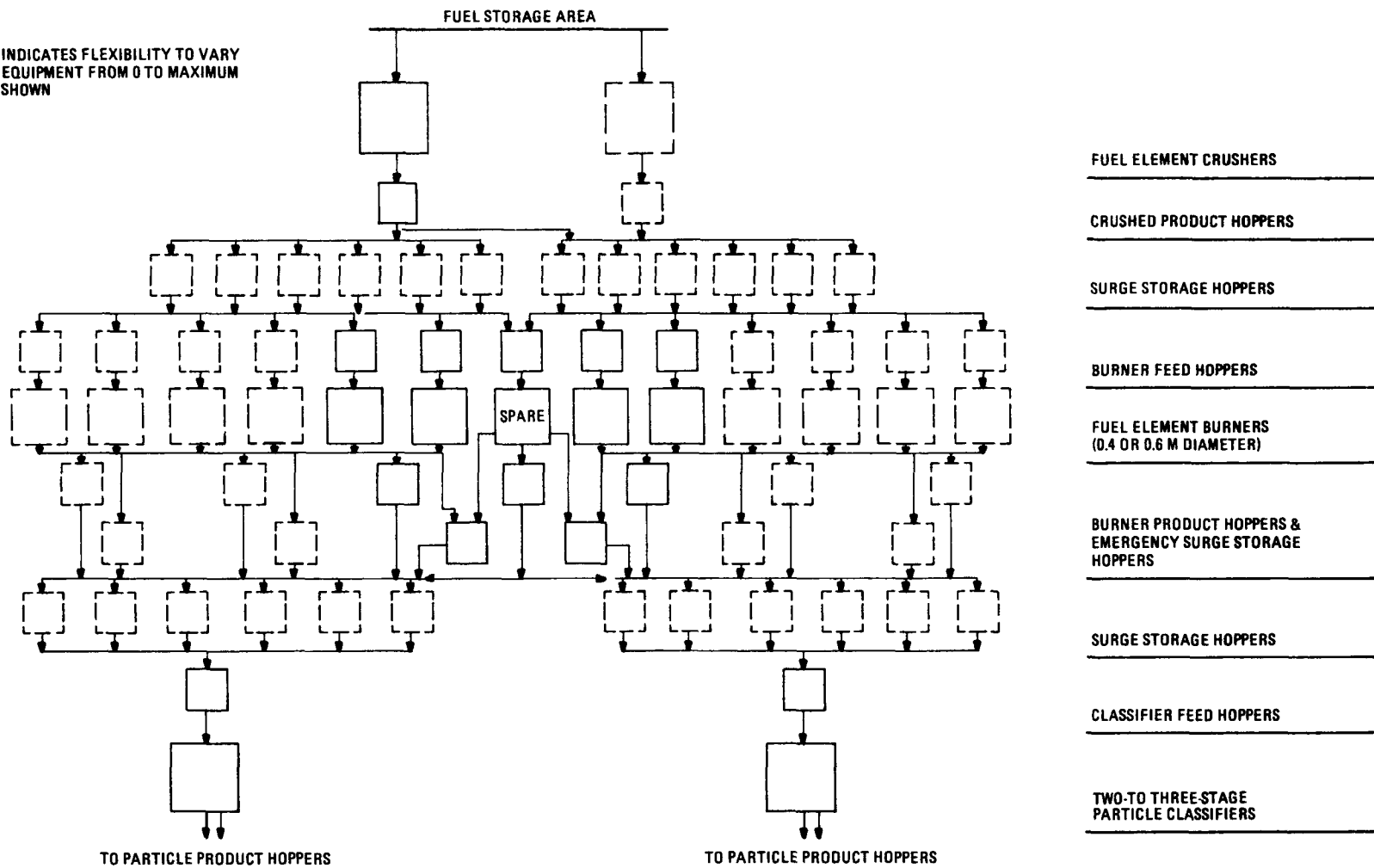


Fig. 2-2. Functional flow chart of a GASP IV program (adapted from Ref. 2-2)

In order to perform parametric studies, a certain degree of flexibility is being included in the user-written subroutines. Figure 2-3 indicates the model configuration defined to March 1978. The equipment shown by dashed lines can be reduced to zero in the model, or any number of pieces up to the maximum shown can be included. In addition, the burner size can be varied. Specifications for any given problem run are by card input so that variations will be as simple as possible. (See Appendix B for card input instructions.)

□ INDICATES FLEXIBILITY TO VARY EQUIPMENT FROM 0 TO MAXIMUM SHOWN



2-6

Fig. 2-3. Reprocessing simulation model equipment relationships

3. AVAILABILITY ALLOCATION METHODOLOGY

Additional card input to the initialization subroutine includes equipment failure rate and maintenance time distributions such as those developed in General Atomic Report GA-A14678 (Ref. 3). An example of the data from GA-A14678 is shown in Table 3-1. The information used from the maintainability data is determined by the parameters required by GASP IV to simulate the distributions. Several types of functions are available in GASP, including Uniform, Triangular, Normal, Lognormal, Erlang, Poisson, Gamma, Beta, and Weibull. All of the GASP IV functions require input of parameters such as mean or standard deviation that are not readily available from the data in GA-A14678. In this early unsophisticated stage of data and model development, the triangular distribution is being used to approximate the generally lognormally distributed data shown in Table 3-1. A separate availability study is currently refining the data shown in GA-A14678 and calculating the necessary parameters so that a more representative distribution function can be used. Since the distribution parameters are card input, the model can be easily changed.

Only the corrective maintenance data and failure rates for the equipment items shown in Appendix V of GA-A14678 are currently being included in the model. It is recognized that considerably more failure and maintenance data are required to approach a realistic plant operation simulation. Future refinements of the simulation model should include the addition of operational support system and process instrumentation and control failure rates, the consideration of secondary failure maintenance in the maintenance time distributions, and the addition of logistics time to maintenance times. Again, the card input method has been used, so future refinements in the reliability and maintainability data can be easily implemented in the model. Card input also allows simple data changes for

TABLE 3-1
 SIZE REDUCTION SYSTEM MAINTENANCE ACTIVITIES SUMMARY ^(a)

Equipment	Corrective Maintenance Required	Expected Failure Rate (per Stream Yr)			Expected Downtime (Hr/Failure)		
		Min.	Median	Max.	Min.	Median	Max.
Primary crusher	Replace pitman assembly ^(b)	<0.15	0.3	>0.6	8.7	22	56
Secondary crusher	Replace pitman assembly ^(b)	<0.15	0.3	>0.6	8.7	22	56
Tertiary crusher	Replace roll module	<0.05	0.1	>0.2	9.5	22	50
Screener	Clear blinded holes	<50	100	>350	7.8	16.9	48
Screener	Replace motor assembly	<0.5	1	>4	9.6	20.1	55.7
Oversize crusher	Replace roll module	<0.03	0.05	>0.1	10.5	25.5	56

^(a) Adapted from GA-A14678 (Ref. 3). Data are interim and currently under revision.

^(b) Includes replacement for failed pitman bearings and failed pin joint bearings.

parametric examination of reliability and maintainability effects on system availability.

Each time a simulation model run is made, the GASP IV random deviate generator chooses a random value for the number of failures for the time period considered and the maintenance time per failure from the input distributions. The random deviate generator then chooses random times during the problem run for the chosen failures to occur. All of the above actions are included in the user-written initialization subroutine; GASP IV provides a random number generator, distribution characteristics, and plotting routines. For convenience, the initialization subroutine has been programmed to print out the random values chosen as documentation for each run. Alternatively, fixed failure times can be used by card input.

The GASP IV executive routine arranges in sequence all material (file entry) movements according to instructions provided by the user in the process simulation subroutines. The random failure interruptions, calculated as described above, are included in this sequencing so that material flow is interrupted at the chosen random times and not allowed to resume until the chosen maintenance time has passed. Other types of down time such as preventive maintenance, accountability sweepdown, or waiting for analytical results can be included either in the user-written subroutines or as card input. With appropriate instructions from the user, the GASP IV data collection subroutines collect information separately on the different types of down time, on ready time, and on useful operating time. With these statistics in hand for each system, the availability can be calculated as:

$$\text{Availability} = \frac{\text{Operating Time} + \text{Ready Time}}{\text{Operating Time} + \text{Ready Time} + \text{Down Time}}$$

With this basic availability information for each system, total plant availability calculations can be made according to methods to be defined in a separate availability study currently in progress. Inclusion of the final total plant calculation in the model at some future time would be desirable.

In addition to availability data, other statistics such as mean material residence time in the systems can be obtained from the simulation model. This should be useful for material balance calculations where decay time is pertinent (such as for radon).

4. STATUS OF MODEL (MARCH 1978)

The model is currently being run on short term problems because of computer storage limitations. Programming to overcome these limitations will be added at a future date so that simulated operations of up to a one year duration can be run. Fuel element crushing maintainability and reliability data have already been included in the model so that the random failure generation technique can be validated as being reasonably representative of input information. The near term goal (FY-1978) is to complete modeling of the head-end processes and perform parametric studies to establish a first cut at head-end system availability goals. The continuous flow of feed requirement to the solvent extraction system from wet head-end can serve as an acceptable throughput criterion in lieu of total plant output until the entire reprocessing plant model is complete. The crushing, burning, and product handling subroutines are well along in development. Wet head-end maintainability and reliability data have been developed for use as wet head-end subroutine programming is initiated.

A longer term parametric study suggested for the completed reprocessing model is illustrated in Fig. 4-1. A basic plant structure such as that illustrated in Fig. 2-3 would be used along with reliability and maintainability data such as those illustrated in Table 3-1. Several simulation runs would be made to determine average operating, ready, and down times. If the plant throughput proved acceptable in all the runs, parametric runs would be made to separately identify the minimum surge storage, minimum redundant equipment, and upper reliability and maintainability limits to meet minimum throughput requirements. Economic analyses should be performed to determine whether meeting reliability and maintainability goals (and the attendant development costs) is more cost effective than adding surge storage and/or redundant equipment to the plant design.

4-2

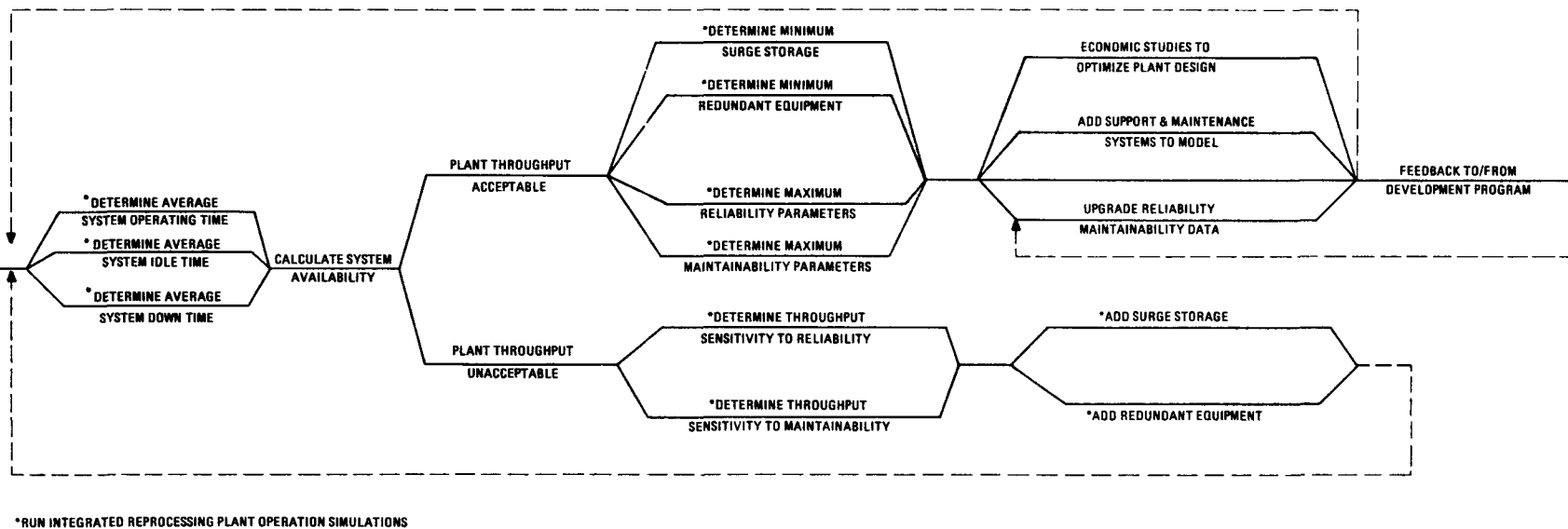


Fig. 4-1. System availability determination by simulation

If the throughput should prove unacceptable under the initial assumptions, sensitivity studies would be made to determine which systems are most critical in meeting plant throughput. Since the initial reliability/maintainability data represent a minimum case (many contributing items not yet identified), the technique recommended for adjustment is to add surge storage and/or redundant equipment until throughput is acceptable and then pursue the plant throughput acceptable path, shown in Fig. 4-1.

5. REFERENCES

1. Pritsker, A. Alan B., The GASP IV Simulation Language, John Wiley & Sons, New York, 1974.
2. Pritsker, A. Alan B., The GASP IV User's Manual, Pritsker and Associates, Inc., Lafayette, Indiana, January 1976.
3. Rode, J. S., and J. B. Strand, "A Preliminary Maintainability Analysis of the HTGR Dry Head-End Reprocessing Systems," DOE Report GA-A14678, General Atomic Company, November 1977.

APPENDIX A
SUBROUTINE DESCRIPTIONS AND FLOWCHARTS FOR
HTGR SPENT FUEL REPROCESSING SIMULATION
(MARCH 1978)



Appendix A

SUBROUTINE DESCRIPTIONS AND FLOWCHARTS FOR HTGR SPENT FUEL REPROCESSING SIMULATION (March 1978)

A.1 GASP IV SIMULATION LANGUAGE - HTGR FUEL REPROCESSING MODEL

For discrete events, the components are as follows (see Fig. 2-2 for generalized flow chart):

MAIN - User-written subroutine to initialize variables and call GASP.

GASP - Executive subroutine that:

1. Reads user data by calling INTLC.
2. Advances time using instruction in FILE 1 or in user-written EVNTS subroutines.
3. Stops simulation at the user-specified time.
4. Calls the subroutine OTPUT written by the user to specify any end-processing or data printing.

EVNTS - User-written directory to subroutines describing the desired events in the simulation. Types of events (as of March 1978) are:

1. Arrival of fuel elements (FEs) at one or two crushers.
2. End of service for one crusher.
3. End of service for second crusher.

4. Shutdown of either crusher or transport line.
5. Restart of either crusher or transport line.
6. Transfer of crushed FE to product surge storage.
7. Transfer of crushed FE to second crusher product surge storage.
8. Transfer of crushed FE to burner feed hoppers.
9. Transfer of crushed FE to first primary burner line.
10. Transfer of crushed FE to second primary burner line.

INTLC - User-written subroutine to initialize:

1. For U-235 makeup, U-233 recycle, and U-235 recycle spent fuel elements:
 - a. FE weight.
 - b. Crushed FE volume.
 - c. FE burnable carbon weight.
 - d. FE burnable carbon volume.
 - e. Burned back fissile particle weight.
 - f. Burned-back fissile particle volume.
 - g. Burned-back fertile particle weight.
 - h. Burned-back fertile particle volume.
 - i. SiC hulls weight.
 - j. SiC hulls volume.
 - k. Fissile kernel weight.
 - l. Fissile kernel volume.
 - m. Fissile particle uranium weight.

- n. Fertile particle uranium weight.
- o. Fissile particle plutonium weight.
- p. Fertile particle plutonium weight.
- q. Fertile particle thorium weight.

2. Fertile and fissile particle breakage data for:

- a. Irradiation damage in core.
- b. FE crushing.
- c. Transport from crushing to burning.
- d. FE burning.
- e. Transport from burning to classifying.
- f. Particle classification.

3. Particle crossover data for:

- a. Broken fertile particles.
- b. Broken fissile particles.
- c. Whole fertile particles.
- d. Whole fissile particles.

4. Failure and repair data:

- a. Primary crusher failure rate.
- b. Primary crusher repair time.
- c. Secondary crusher failure rate.
- d. Secondary crusher repair time.
- e. Tertiary crusher failure rate.
- f. Tertiary crusher repair time.
- g. Screener blind rate.
- h. Screener clearing time.
- i. Screener failure rate.
- j. Screener repair time.
- k. Oversize crusher failure rate.
- l. Oversize crusher repair time.

- m. Bunker module failure rate.
 - n. Bunker module repair time.
 - o. Bunker blower failure rate.
 - p. Bunker blower repair time.
 - q. Others to be added.
- 5. Equipment sweepdown times for accountability.
 - 6. Preventive maintenance data (to be added).

A.2 CRUSHER AND PRODUCT TRANSPORT MODEL

ARRVL - User-written discrete event subroutine called by EVNTS to:

- 1. Calculate relevant characteristics of sequential customer core segments from data initialized in INTLC. (Number and types of FE in segment, weight and volume of FE, contained particles, contained burnable carbon, and contained fissile and fertile material.)
- 2. File arriving FEs in first crusher queue.
- 3. Test to see if second crusher and product transport are available (not down for maintenance or not included in problem). If available, fill second queue.
- 4. If a crusher and its transport are free, remove file entry (fuel element) from the appropriate queue, set crusher status to busy, and establish check to be used for identifying batch.
- 5. If one crusher is down, check to see if the other crusher or transport line is down. If not, remove a file entry from the

other queue, set the crusher to busy status, and establish check to be used for identification.

Note: (4) and (5) are only done at time 0 to start crushers initially.

ENDSV - User-written event subroutine that:

1. Schedules next end of service for each crusher.
2. Checks to see if crusher is down and if not, checks to see if transport line is down. If not, checks to see if crusher is busy; if crusher is idle checks the crusher feed queue.
3. If feed queue empty, schedules next set of arrivals and files FEs in crusher feed storage file.
4. If crushers queue is not empty, removes FE from queue and checks to see if it is the same type of FE as last one processed. If type is same, sets crusher status to busy and collects statistics on it.
5. If queue contains different type of FE from the one last processed, sets check equal to new FE type so when it comes back again will be recognized as different type of FE. Meanwhile, sends this FE back to the file it came from and calls shutdown for cleanup. (Crusher is cleaned out after each customer batch of FE.)
6. If the FE is the same type as the last one processed, sets crusher to busy status. Collects statistics.
7. If crusher is busy, sets it to idle and collects statistics. Checks to see which crusher processed this FE and files it

in proper storage weigh hopper. Collects statistics on FE time in the system and time between departures.

CPHOP - User-written event subroutine that:

1. Checks to see if crusher product receiving weigh hopper is full (addition of last FE signifies completion of process control check on crusher product of first element into the hopper).
2. If receiving/weigh hopper is full, transfers five FEs to available surge hoppers. If room for five is not found stops crusher operation until space is available.
3. If customer batch is complete and crusher is down for clean-out, shuts hoppers down for cleanout as soon as they are empty.

Note: This subroutine can be bypassed by setting NHOP=0. Burner feed hoppers then interface directly with crusher product receiving weigh hoppers. NHOP can also be varied from 1 to 6 to evaluate the amount of surge required. (See Appendix C for hopper capacity descriptions.)

SHUT - User-written event subroutine to:

1. Shut down appropriate crusher, transport line, or product hopper as directed by event card entry or as called for cleanout.
2. Check to see if crusher is busy. If busy, set it to idle and collect statistics on it.
3. File the FE that has not finished crushing process in the temporary storage file.

4. Initialize time of start-ups based on a code for type of down-time.
5. If crusher is idle, initialize the start-up time based on code for type of down time.

START - User-written subroutine that restarts crusher transport line or hopper as scheduled in SHUT and:

1. Checks nature of shutdown (equipment or transport line).
2. Restarts crusher or transport line and collects statistics on it.
3. If crusher idle, checks to see if there are any FEs that did not finish processing because of shutdown.
4. If there are unfinished FEs, checks to see that FE batch is correct one and sets crusher to busy and collects statistics.

OUTPUT - User-written subroutine to show:

1. Mean service time for crusher.
2. Total fuel elements arriving for service.

SUMMARY - GASP IV report generator to show statistics collected from user-written subroutines such as:

Maximum, minimum, mean, standard deviation, and number of observations for:

1. Time FEs are in the crushing system.
2. Random failures.
3. Number of FEs in the system.

Maximum, minimum, mean, standard deviation, and time interval for:

1. Crusher operating time.
2. Crusher down time for repair.
3. Product hopper use time.
4. Product hopper down time for repair.
5. Crusher down time for cleanout between batches.
6. Product hopper down time for cleanout between batches.
7. Surge storage down time for repair.
8. Surge storage down time for cleanout between batches.
9. Crusher down time for product storage unavailable.
10. Others to be added for burner model.

A.3 BURNER MODEL

BFEED - User-written event subroutine that:

1. Sequentially checks all burner feed hoppers to find those needing additional material.
2. Finds crusher product hopper with material in it. Tests to see if material matches burner batch.
3. If material is part of current batch, fills burner feed hoppers.
4. If no matching material is found, resets next check of material.
5. If crusher product hoppers are empty and crusher is down for accountability cleanout, prepares for burner cleanout.

PBURN - User-written event subroutine that:

1. Checks for burners that are free and ready to operate.

2. If burner(s) is available checks to see if there is sufficient crusher product to start a burner batch.
3. If there is insufficient crusher product and product is the end of a customer batch, switches to small spare burner when available.
4. If sufficient crusher product is available to start up a large burner, transfers feed to burner and starts heatup.
5. Checks operating burners for ignition; if sufficient time for ignition has passed, feeds crushed fuel elements at burner approximate burn rate.
6. If burner(s) is in steady state feed/burn mode, monitors burned-back particle volume in burner until maximum bed volume is reached.
7. If maximum bed volume has been reached for burner(s), starts tailburning to reduce carbon.
8. If tailburning is complete for burner(s), initiates partial bed dump to receiving/weigh hopper.
9. If burner(s) is processing last of a customer lot, initiates total bed dump.
10. Initiates burner(s) cleanout when customer lot is completed.
11. Failure and maintenance logistics to be added.

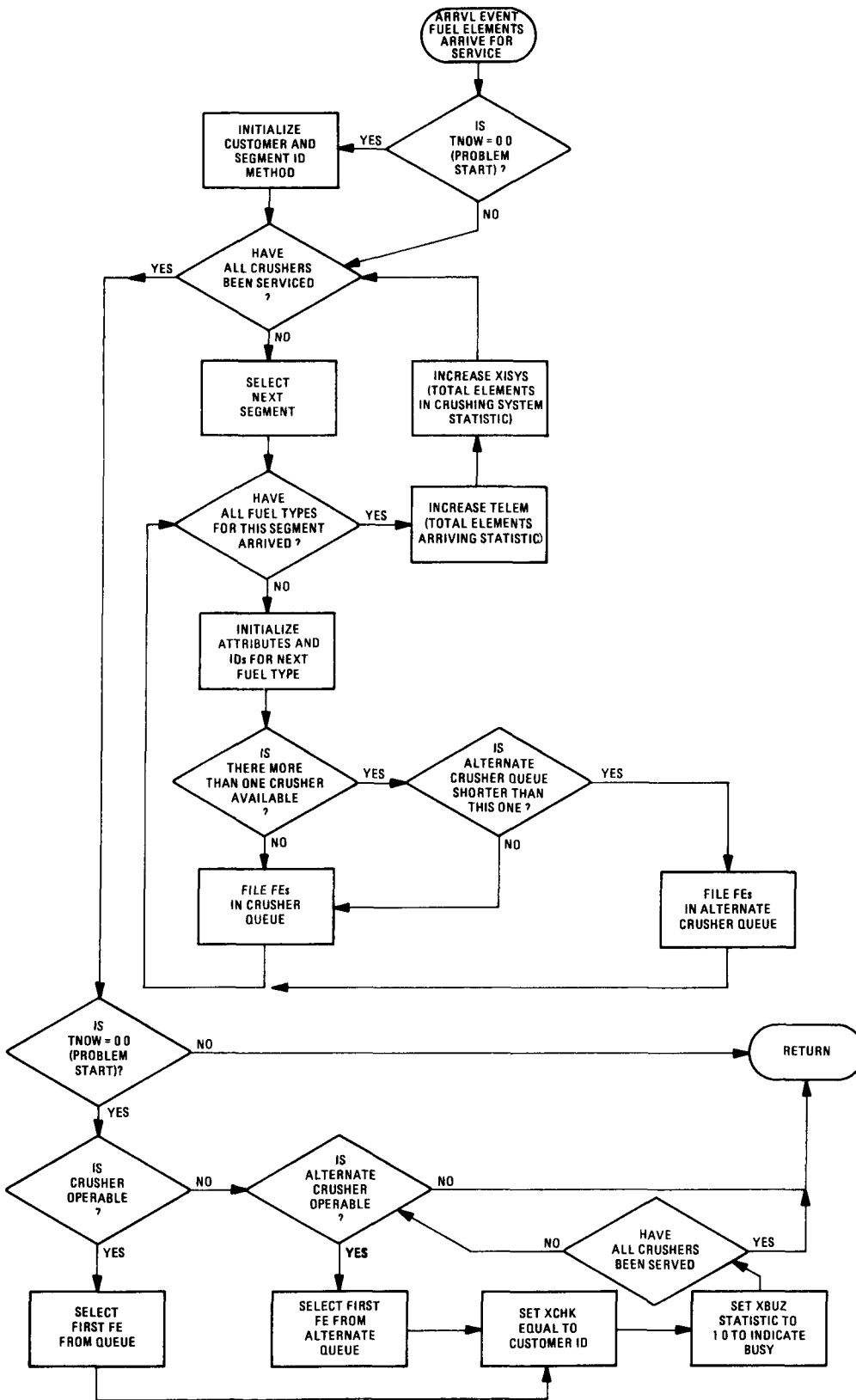


Fig. A-1. ARRVL flowchart (initialize fuel element arrival at crusher)

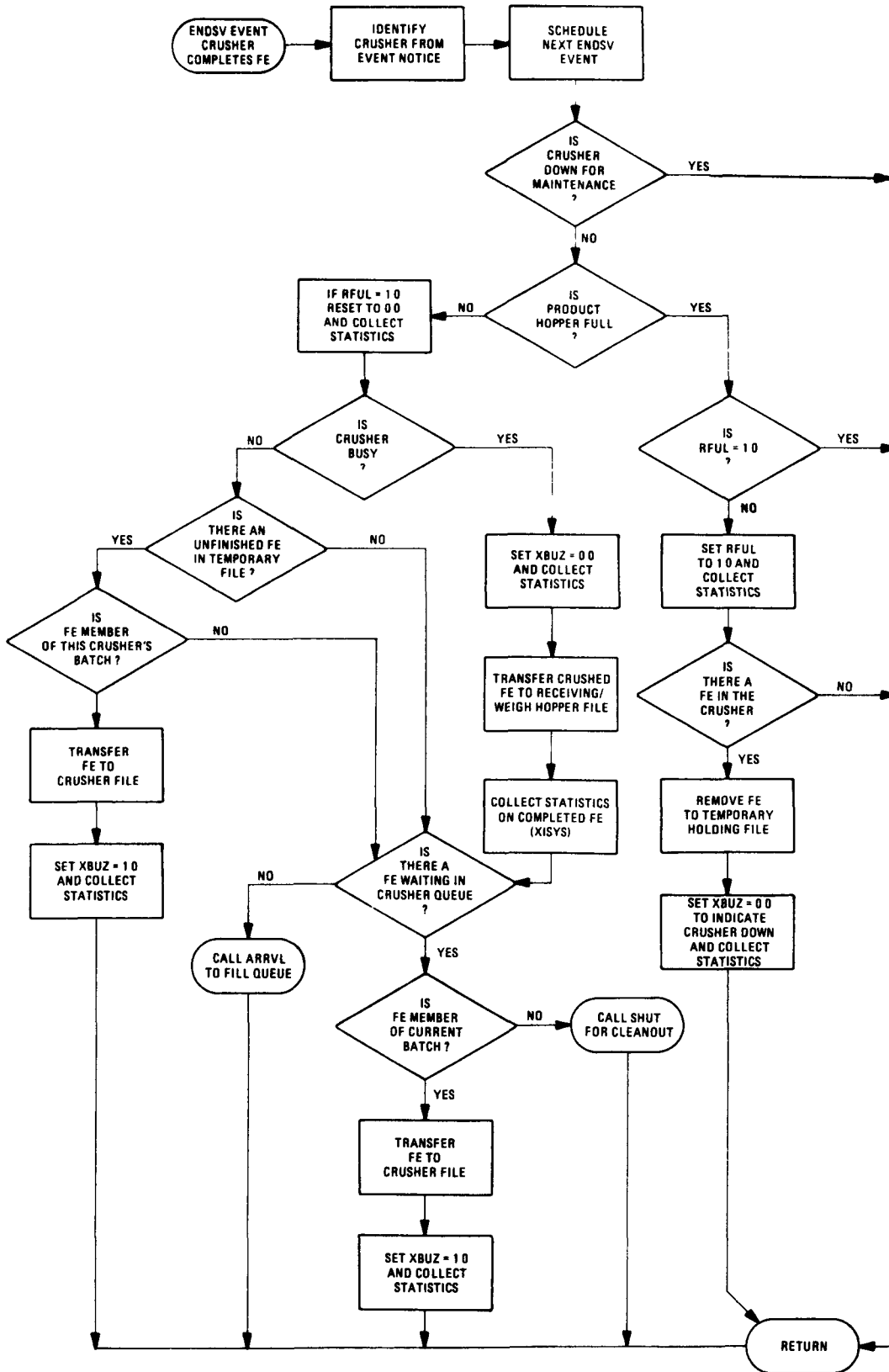


Fig. A-2. ENDSV flowchart (finishes crusher batch and starts new batch)

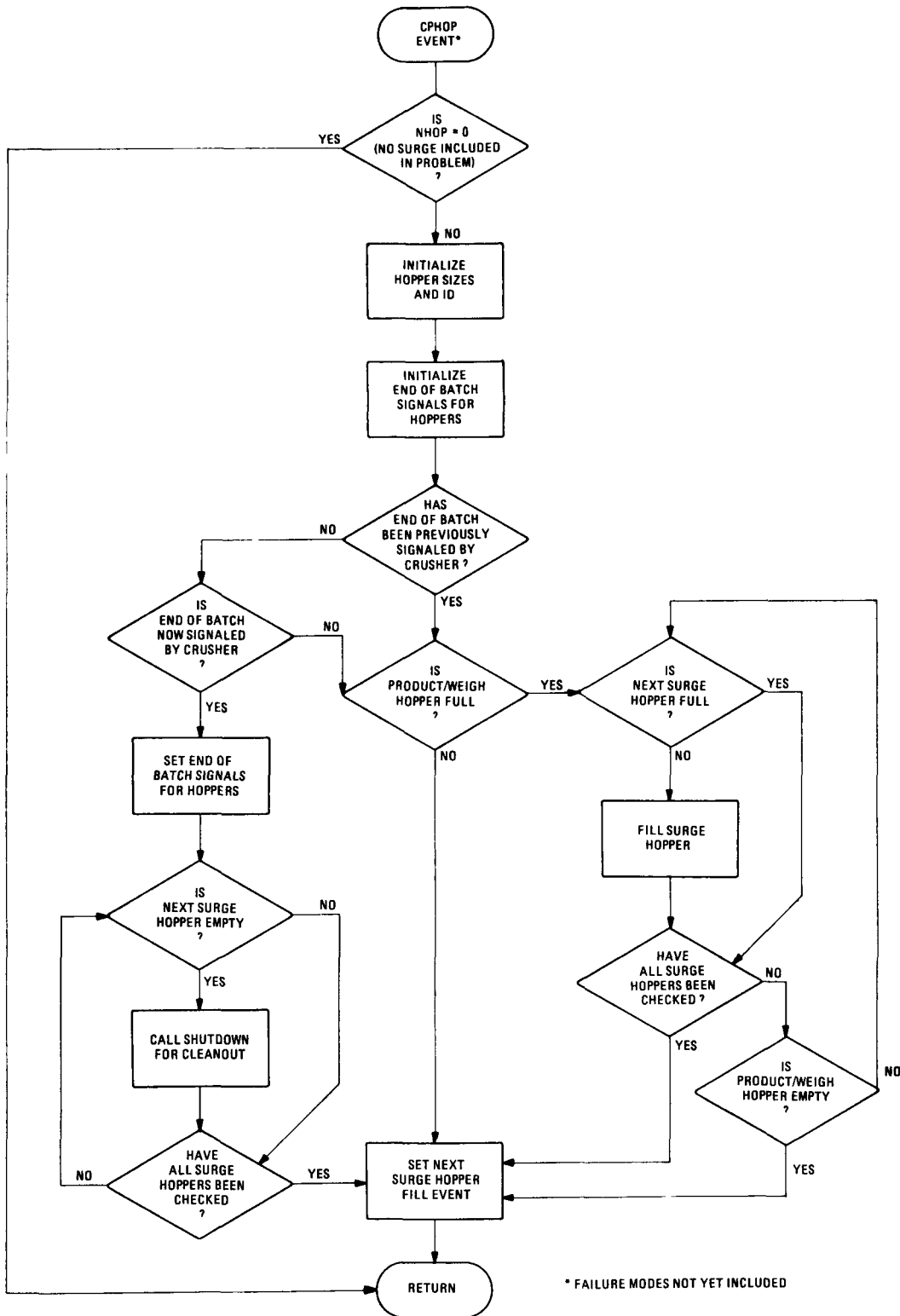


Fig. A-3. CPHOP flowchart (crusher product surge storage fill)

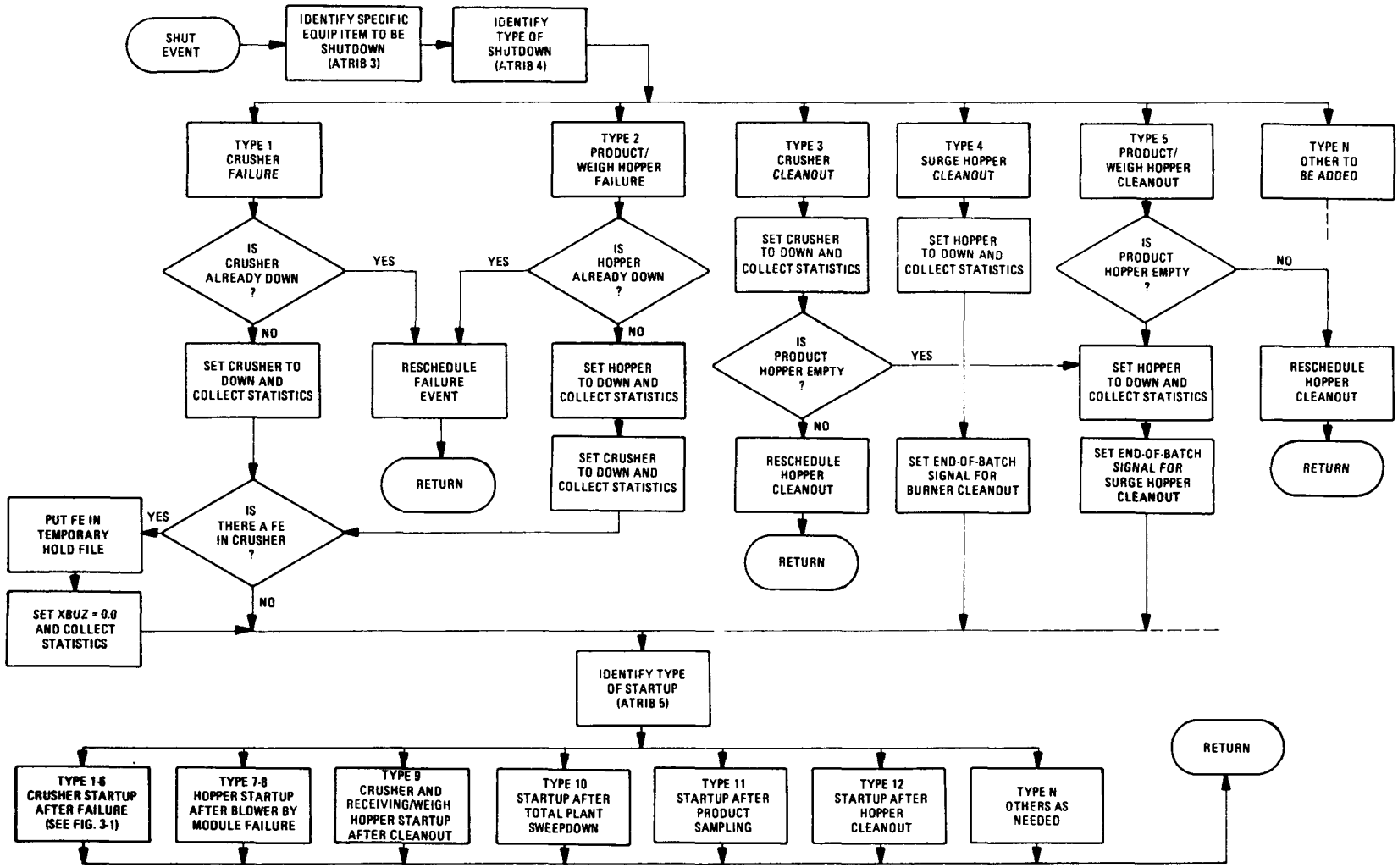


Fig. A-4. SHUT flowchart (shut down equipment for failure or cleanout)

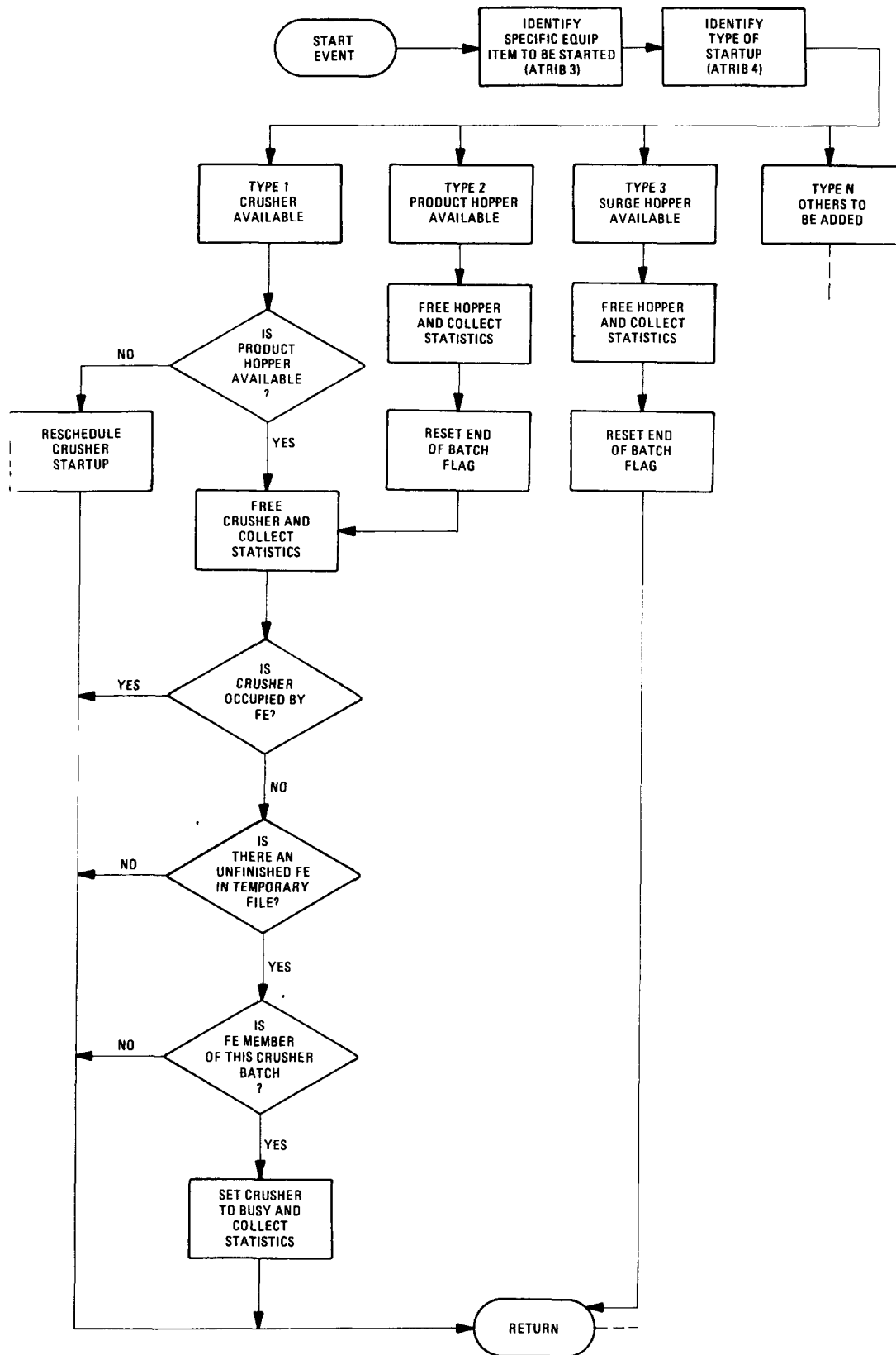


Fig. A-5. START flowchart (start up equipment after repair or cleanout)

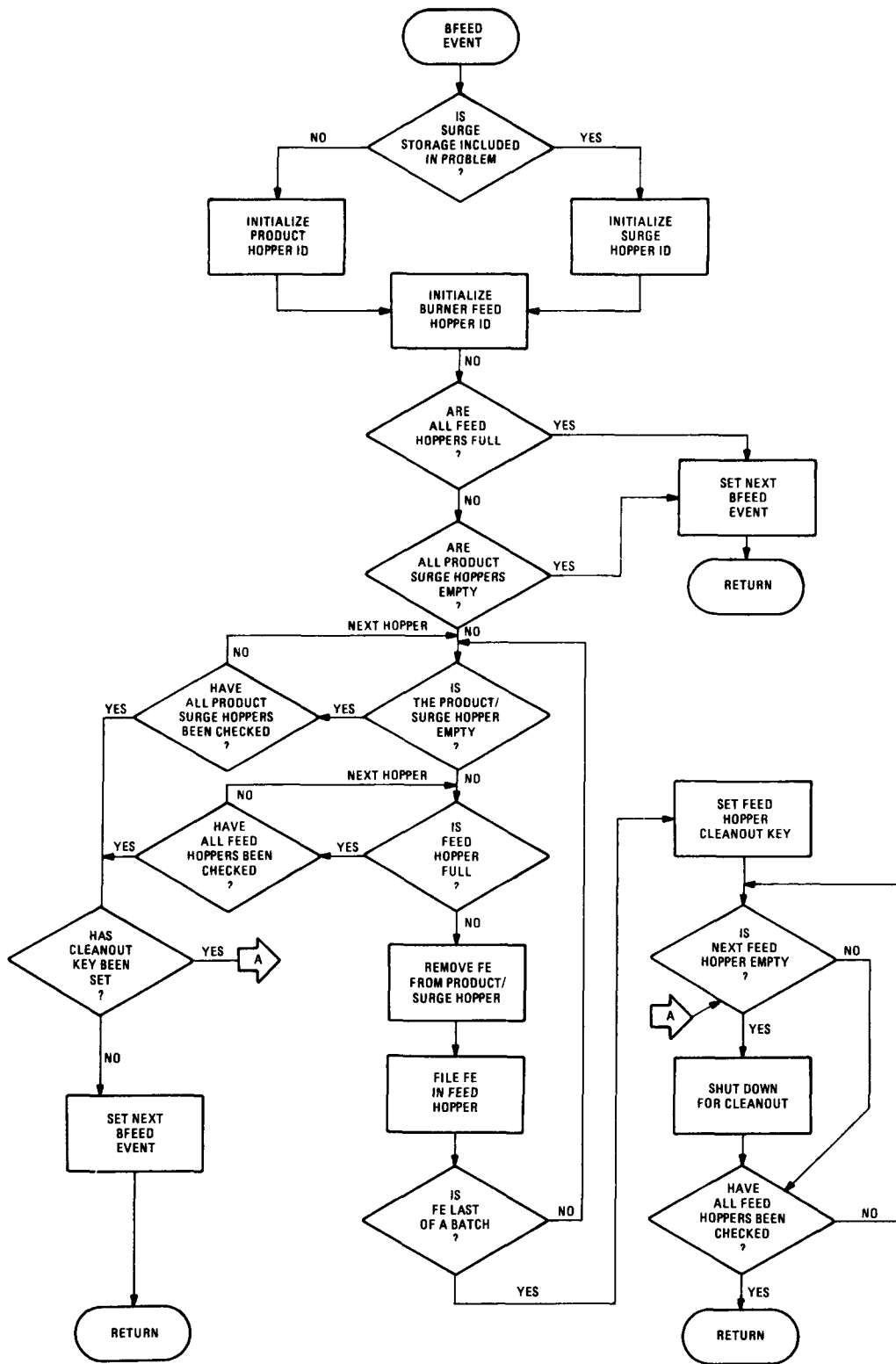


Fig. A-6. BFEED flowchart (burner feed hopper fill)

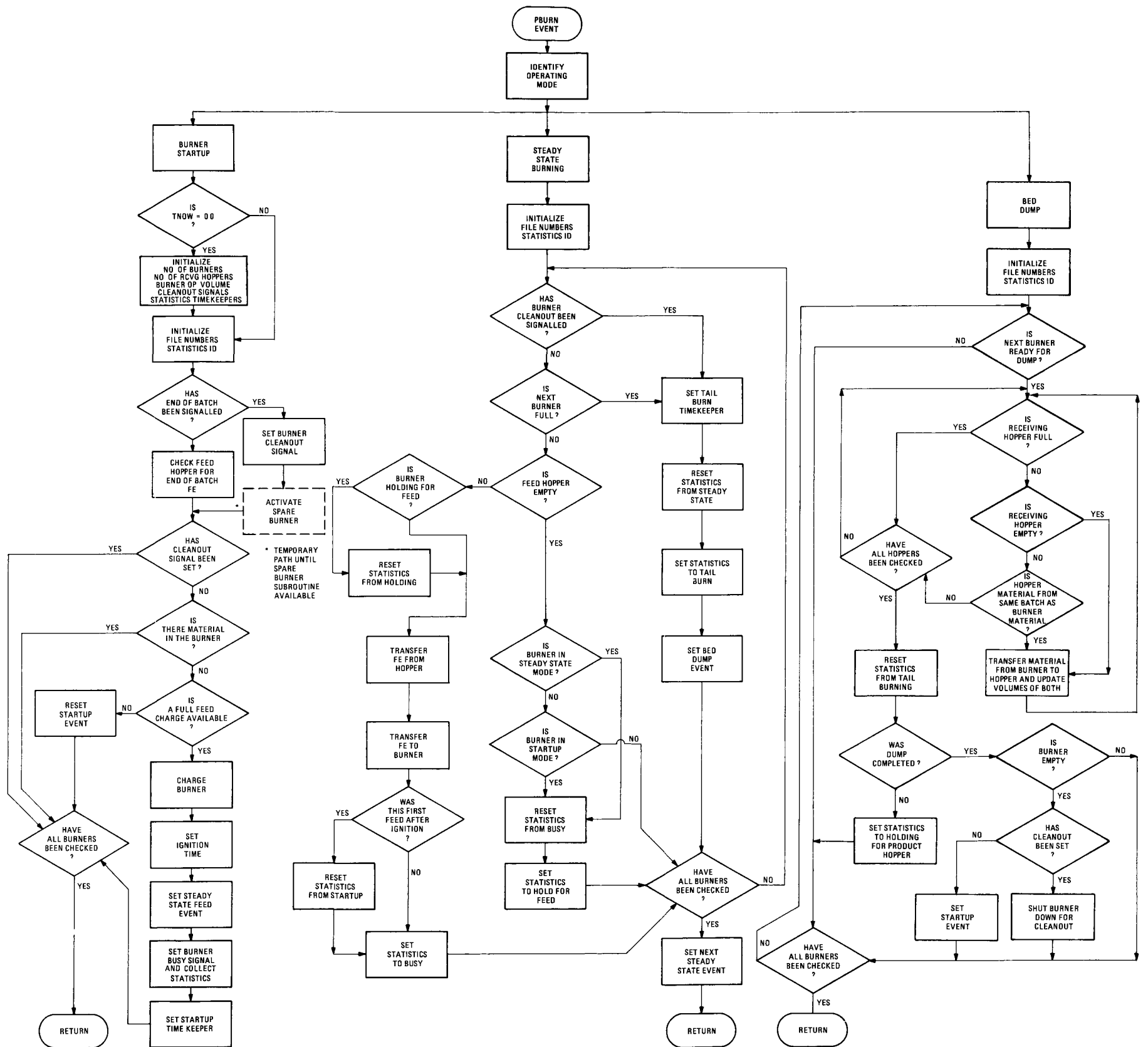


Fig. A-7. PBURN flowchart (primary burner operations)

APPENDIX B
USER CARD INPUT INSTRUCTIONS FOR SIMULATION MODEL



Execute card - @XQT

MAIN

Data cards

DATA SET 1

(see descriptions attached)

GASP DATA SET (SET 2)

DATA SET 3

B.2 PROBLEM DESCRIPTION CARDS (FIRST DATA SET - READ BY MAIN SUBROUTINE)

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
1	6	Number of crushers in problem (1 or 2).	I1
1	7-12	Number of fuel elements in system at beginning of problem (initialize at 0.0).	F6.3
1	13-18	(Not used - enter 0.0.)	F6.3
1	19-24	Processing status of first crusher at start of problem (initialize at 0.0).	F6.3
1	25-30	Processing status of second crusher at start of problem (initialize at 0.0).	F6.3
1	31-36	Down time for crusher at which other crusher switches over to using both burner lines. (Tentatively set at 1 week, 168.0 hr.)	F6.1
1	37-80	Any desired alpha numeric description (not read by computer).	Free
2	1-6	Down/up status of first crusher at start of problem (initialize at 0.0).	F6.3
2	7-12	Down/up status of second crusher at start of problem (initialize at 0.0 for a 1-crusher problem).	F6.3

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
2	13-18	Cleanout status of first crusher (initialize at 0.0).	F6.3
2	19-24	Cleanout status of second crusher (initialize at 0.0 for a 2-crusher problem, at 1.0 for a 1-crusher problem).	F6.3
2	25-30	Down/up status of first transport line and receiver/weigh hopper (initialize at 0.0).	F6.3
2	31-36	Down/up status of second transport line and receiver/weigh hopper (initialize at 0.0 for a 2-crusher problem, at 1.0 for a 1-crusher problem).	F6.3
2	37-42	Cleanout status of first transport line and receiver/weigh hopper (initialize at 0.0).	F6.3
2	43-48	Cleanout status of second transport line and receiver/weigh hopper (initialize at 0.0 for a 2-crusher problem, at 1.0 for a 1-crusher problem).	F6.3
3	1-3	Number of product surge storage hoppers serving first crusher (maximum of 6).	I3
3	4-6	Number of product surge storage hoppers serving second crusher (maximum of 6, 0 if 1-crusher problem).	I3
3	7-9	Number of burners served by first crusher	I3

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
3	10-12	Number of burners served by second crusher (0 if a 1-crusher problem).	I3
3	13-15	Number of burner product receiving hoppers for first burner line.	I3
3	16-18	Number of burner product receiving hoppers for second burner line.	I3
3	19-21	Number of spare burners.	I3
3	23-24	Maximum number of equivalent fuel elements in burner feed hoppers.	I3
3	25-30	Burner diameter (in meters).	F6.2
3	31-36	Maximum operating L/D for burner.	F6.2
3	37-42	Minimum operating L/D for burner.	F6.2
3	43-48	Spare burner diameter (in meters).	F6.2
3	49-54	Number of hours in burner feed and startup	F6.2
3	55-60	Number of hours in normal tailburn.	F6.2
3	61-66	Approximate time to burn one fuel element.	F6.2

B.3 GASP INPUT CARDS (CARD DATA SET 2)

1. Cards are free format which are uniquely identified by a 3 character identification (ID) (first 3 letters of card type) specified in the first field of the card.

2. An asterisk (*) must end data on each card.
3. Commas are used to separate fields.
4. Default values are indicated by a comma in appropriate field.
If there are only a few values on the beginning of the card and the rest are defaulted, place an asterisk after the last value.

B.3.1. Card Type #1 - General

B.3.1.1. Field Description

1. GEN
2. User name
3. Project number - up to 3 digits (any ID number)
4. Month
5. Day
6. Year
7. Number of runs
8. *

B.3.2 Card Type #2 - Statistics

B.3.2.1. Field Description

1. STA
2. Number of variables (statistics) of which COLLECT keeps track.
Must agree with total number of variables shown on card type #4.
3. Number of variables (statistics) being collected by TIMST.
Must agree with total number of variables shown on card type #5.

4. Number of histograms requested. Must agree with total number of histograms shown on card type #6.

5. *

B.3.3 Card Type #3 - Limits

B.3.3.1. Field Description

1. LIM
2. Number of parameter sets (number of PPARM variables initialized). Parameter sets are initialized by card type #11 and in INTLC subroutine.
3. Number of random number streams (set to 1 or largest stream number for which a seed (card type #13) is supplied).
4. Number of entries in NSET. (Must be large enough to accommodate all pointers to file entries.)
5. Number of attributes per entry in QSET. (25 is limit set by storage capability at present.)
6. Number of files in NSET.
7. Dimension of NSET; used to compute amount of storage available in NSET. (If dimension of NSET is changed, must change common QSET to the same value.) (Number of attributes times number of entries plus two pointers per entry.)

B.3.4. Card Type #4 - Collect Statistics

B.3.4.1. Field Description

1. COL
2. Index (sequential number assigned to Ith variable on which statistics are collected).
3. Label associated with the Ith variable used in COLECT.
4. *

Repeat card type #4 as many times as the indication in STA card type #2, field #2.

B.3.5. Card Type #5 - Time Statistics

B.3.5.1. Field Description

1. TIM
2. Index (sequential number assigned to Ith variable on which statistics are collected).
3. Label associated with Ith variable used in TIMST or TIMSA.
4. Initial value of time persistent variable I.
5. *

Repeat card Type #5 as many times as indicated on STA card type #2, field #3.

B.3.6. Card Type #6 - Histograms

B.3.6.1. Field Description

1. HIS

2. Index (sequential number assigned to Ith histogram).
3. Label associated with Ith histogram.
4. Number of cells in Ith histogram.
5. Upper limit of first cell of Ith histogram.
6. Width of a cell for Ith histogram.
7. *

Repeat card type #6 as many times as indicated on STA card type #2, field #4.

B.3.7. Card Types #7 and #8 (not used at this time)

B.3.8. Card Type #9 - Priority

B.3.8.1. Field Description

1. PRI
2. File index number of Ith file that is to be ranked as follows.
3. Key for priority system to be used in File I; values are:
LVF, HVF, FIFO, LIFO.
4. Attribute number by which file I is to be ranked.
5. *

Repeat card type #9 as many times as the number of different kinds of rankings required; if priority not specified for a file, the assumption will be that the values should be ranked on the first in first out (FIFO) basis.

B.3.9. Card Type #10 (not used at this time)

B.3.10. Card Type #11 - Parameters[†]

B.3.10.1. Field Description

1. PAR
2. Parameter set number (only #1 used at the current time. Other parameter sets are established in INTLC. See card data set 3).
3. Parameter values -- mean.[†]
4. Parameter values -- low.[†]
5. Parameter values -- high.[†]
6. *

Repeat card type #11 depending on number of parameters (use next sequential number after last parameter set number used in INTLC).

B.3.11. Card Type #12 - Initialization

B.3.11.1. Field Description

1. INI
2. Method of stopping (a) 0 → user to stop simulation by resetting MSTOP = -1, (b) 1 → stop at TTFIN. (Uses 1 at present time.)
3. Key to specifying if statistic array should be cleared during initialization (a) 0 → do not clear, (b) 1 → clear

[†]Note: Parameter values used vary with the type of functional distribution. Mean, low, and high represent a normal distribution. See Ref. 2-1 for additional distribution types and parameters.

(uses default at present time).

4. Key for initializing DRAND, TNOW; state variables and initial conditions set in INTLC.
 - a. 0 → do not initialize.
 - b. 1 or Y → initialize (uses Y at present time).
5. Initial value of TNOW (uses default at present time).
6. Ending time of simulation. ("1" = 1 hour; example: "1000" would stop simulation at 1000 hours.)
7. *

B.3.12. Card Type #13 - Seeds

Seed values for the random number generators are read as integers, but both real and integer seeds are made available. A zero seed value causes GASP to use an internal seed.

B.3.12.1. Field Description

1. SEE
- 2-7. Any desired seed numbers. (Difference between seed numbers must be greater than 5 to result in a new set of random numbers. Random number sets are repeatable by using identical seed numbers.)
8. *

B.3.13. Card Type #14 - Entry

B.3.13.1. Field Description

1. ENT.
2. The file storage area is initialized by reading this data field. (Uses "1" for all type #14 cards at present as all of the attributes are put in FILE 1.
- 3-9. Enter attributes 1 to 7 as described in Attribute Description below (B.4). (Balance of attributes are read in INTLC - data card set 3.)
10. *

The number of type #14 data cards to be read is limited only by the storage availability.

B.3.14. Card Type #15 - Simulate

1. SIM. (Only included if there are cards for next run; if SIM card is used, return to card type #1.)
2. *

B.3.15. Card Type #16 - Finish

1. FIN. (must be present in every run.)
2. *

B.4. ATTRIBUTE DESCRIPTION

1 EVENT TIME

2 EVENT CODE

- 1=INITIATES FUEL ELEMENT ARRIVAL AT TIME 0 (1 CARD ONLY)
- 2=END OF SERVICE EVENT FOR CRUSHER 1 (1 CARD ONLY)
- 3=END OF SERVICE EVENT FOR CRUSHER 2 (1 CARD ONLY)
- 4=SHUTDOWN (USE WITH ATRIB 3,4,5)
- 5=STARTUP (USED WITH ATRIB 3,4,5)
- 6=CALL CRUSHER STORAGE HOPPER FILL (1ST CRUSHER)
- 7=CALL CRUSHER STORAGE HOPPER FILL (2ND CRUSHER)
- 8=CALL BURNER FEED HOPPER FILL (1 CARD ONLY)
- 9=CALL PRIMARY BURNER LINE 1
- 10=CALL PRIMARY BURNER LINE 2

** 3 STATISTICS CODE

USED WITH ATRIB 4 TO INDICATE CORRECT SET OF STATISTICS

- 1= CRUSHER 1 BUSY
- 2=CRUSHER 2 BUSY
- 3=NUMBER IN CRUSHER SYSTEM
- 4=CRUSHER 1 FAILURE
- 5=CRUSHER 2 FAILURE
- 6=CRUSHER TRANSPORT 1 FAILURE
- 7=CRUSHER TRANSPORT 2 FAILURE
- 8=CRUSHER 1 ACCOUNTABILITY
- 9=CRUSHER 2 ACCOUNTABILITY
- 10=CRUSHER 1 TRANSPORT ACCOUNTABILITY
- 11=CRUSHER 2 TRANSPORT ACCOUNTABILITY
- 12-17 CRUSHER 1 PRODUCT HOPPER FAILURE
- 18-19 CRUSHER RECEIVER/WEIGH HOPPERS FULL
- 20-25 PRIMARY BURNER LINE 1 BUSY
- 26=NUMBER IN PRIMARY BURNER SYSTEM

** 4 SHUTDOWN CODE

USE WITH ATRIBS 3 AND 5
INDICATES TYPE OF SHUTDOWN (1 CARD FOR EACH FAILURE)

- 1=CRUSHER EQUIPMENT FAILURE
- 2=TRANSPORT LINE FAILURE
- 3=CRUSHER AND RECEIVING WEIGHT HOPPER CLEANOUT (IF HOPPER EMPTY)
- 4=CRUSHER PRODUCT STORAGE HOPPER CLEANOUT
- 5=RECEIVING WEIGH HOPPER CLEANOUT

5 STARTUP CODE

INDICATES TYPE OF STARTUP (I.E. MAINTENANCE TIME)
USE WITH ATRIBS 3 AND 4

- 1=REPLACE PRIMARY JAW CRUSHER PITMAN ASSEMBLY
- 2=REPLACE SECNDRY JAW CRUSHER PITMAN ASSEMBLY
- 3=REPLACE TERTIARY CRUSHER ROLL MODULE

- 4-CLEAN BLINDED HOLES
- 5-REPLACE SCREENER MOTOR ASSEMBLY
- 6-REPLACE OVERSIZE CRUSHER ROLL MODULE
- 7-REPLACE SOLIDS HANDLING BUNKER MODULE
- 8-REPLACE SOLIDS HANDLING BLOWER
- * 9-CRUSHER CLEANOUT
- 10-STARTUP AFTER ACCOUNTABILITY
- 11-PARTICLE SIZE SAMPLING (NOT ACTIVE-MEMO NUMBER 3)

- 6 FUEL ELEMENT WEIGHT AND ID
INCLUDES TOTAL KGS IN FE XXX,XX PLUS SEGMENT ID
000.00XX (INITIAL INPUT ON END OF SERVICE EVENTS)
USED FOR ID OF CUSTOMER BATCH
- 7 CRUSHER QUEUE ID
IDENTIFIES CRUSHER QUEUE TO BE FILLED WITH FES.
- 8 FUEL ELEMENT VOLUME
CRUSHED FUEL VOLUME IN CUBIC METERS
(0.6 PACKING FRACTION)
- 9 BURNABLE CARBON WEIGHT
TOTAL KGS IN FE EXTERIOR TO
ALL SIC COATINGS
- 10 BURNABLE CARBON VOLUME
CRUSHED FUEL CARBON VOLUME IN CUBIC
METERS (0.6 PACKING FRACTION)
- 11 BURNED BACK FISSILE PARTICLE WEIGHT
TOTAL KGS IN FUEL ELEMENT
- 12 BURNED BACK FISSILE PARTICLE VOLUME
TOTAL CUBIC METERS PER FE
(0.6 PACKING FRACTION)
- 13 BURNED BACK FERTILE PARTICLE WEIGHT
TOTAL KGS IN FE
- 14 BURNED BACK FERTILE PARTICLE VOLUME
TOTAL CUBIC METERS PER FE
(0.6 PACKING FRACTION)
- 15 SIC HULLS WEIGHT
TOTAL KGS PER FE
- 16 SIC HULLS VOLUME
TOTAL CUBIC METERS PER FE
(0.6 PACKING FRACTION)

- 17 FISSILE KERNEL WEIGHT
TOTAL KGS PER FE
- 18 FISSILE KERNEL VOLUME
TOTAL CUBIC METERS PER FE
(0.6 PACKING FRACTION)
- 19 FISSILE URANIUM WEIGHT
TOTAL KGS PER FE
- 20 FERTILE URANIUM WEIGHT
TOTAL KGS PER FE
- 21 FISSILE PLUTONIUM WEIGHT
TOTAL KGS PER FE
- 22 FERTILE PLUTONIUM WEIGHT
TOTAL KGS PER FE
- 23 THORIUM WEIGHT
TOTAL KGS PER FE

- * CLEANOUT
- ** NOTE 1 ATRIB 3 AND 4 ARE USED IN GASP TO SET TIME FE
ENTERED SYSTEM AND TIME ENTERED QUEUE

B.5 DATA CARDS (THIRD DATA SET - READ BY SUBROUTINE INTLC)

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
1	1-6	Number of initial/makeup fuel elements in first segment.	I6
1	7-12	Number of 23R fuel elements in first segment.	I6
1	13-18	Number of 25R fuel elements in first segment.	I6
1	19-24	Number of initial/makeup fuel elements in second segment.	I6
1	25-30	Number of 23R fuel elements in second segment.	I6
1	31-36	Number of 25R fuel elements in second segment.	I6
1	37-42	Number of initial/makeup fuel elements in third segment.	I6
1	43-48	Number of 23R fuel elements in third segment.	I6
1	49-54	Number of 25R fuel elements in third segment.	I6
1	60-80	Any desired identification (not read by computer).	Free
2	1-6	Number of initial/makeup fuel elements in fourth segment.	I6
2	7-12	Number of 23R fuel elements in fourth segment.	I6
2	13-18	Number of 25R fuel elements in fourth segment.	I6
2	19-24	Number of initial/makeup fuel elements in fifth segment.	I6
2	25-30	Number of 23R fuel elements in fifth segment.	I6
2	31-36	Number of 25R fuel elements in fifth segment.	I6

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
2	37-42	Number of initial/makeup fuel elements in sixth segment.	I6
2	43-48	Number of 23R fuel elements in sixth segment.	I6
2	49-54	Number of 25R fuel elements in sixth segment.	I6
2	60-80	Any desired identification (not read by computer).	Free
3	1-6	Number of initial/makeup fuel elements in seventh segment.	I6
3	7-12	Number of 23R fuel elements in seventh segment.	I6
3	13-18	Number of 25R fuel elements in seventh segment.	I6
3	19-24	Number of initial/makeup fuel elements in eighth segment.	I6
3	25-30	Number of 23R fuel elements in eighth segment.	I6
3	31-36	Number of 25R fuel elements in eighth segment.	I6
3	37-42	Number of initial/makeup fuel elements in ninth segment.	I6
3	43-48	Number of 23R fuel elements in ninth segment.	I6
3	49-54	Number of 25R fuel elements in ninth segment.	I6
3	60-80	Any desired identification (not read by computer).	Free
4	1-6	Number of initial/makeup fuel elements in tenth segment.	I6
4	7-12	Number of 23R fuel elements in tenth segment.	I6

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
4	13-18	Number of 25R fuel elements in tenth segment.	I6
4	61-80	Any desired identification (not read by computer).	Free
5	1-6	Weight (kg) of initial/makeup fuel element.	F6.2
5	7-12	Weight (kg) of 23R fuel element.	F6.2
5	13-18	Weight (kg) of 25R fuel element.	F6.2
5	19-24	Volume (m ³) of initial/makeup fuel element.	F6.4
5	25-30	Volume (m ³) of 23R fuel element.	F6.4
5	31-36	Volume (m ³) of 25R fuel element.	F6.4
5	61-80	Any desired identification (not read by computer).	Free
6	1-6	Weight (kg) of burnable carbon in crushed initial/makeup fuel element.	F6.2
6	7-12	Weight (kg) of burnable carbon in crushed 23R fuel element.	F6.2
6	13-18	Weight (kg) of burnable carbon in crushed 25R fuel element.	F6.2
6	19-24	Volume (m ³) of burnable carbon in initial/makeup fuel element.	F6.4
6	25-30	Volume (m ³) of burnable carbon in 23R fuel element.	F6.4
6	31-36	Volume (m ³) of burnable carbon in 25R fuel element.	F6.4
6	61-80	Any desired identification (not read by computer).	Free
7	1-6	Weight (kg) of burned-back fissile particles in initial/makeup fuel elements.	F6.2

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
7	7-12	Weight (kg) of burned-back fissile particles in 23R fuel elements.	F6.2
7	13-18	Weight (kg) of burned-back fissile particles in 25R fuel elements.	F6.2
7	19-24	Volume (m ³) of burned-back fissile particles in initial/makeup fuel elements.	F6.4
7	25-30	Volume (m ³) of burned-back fissile particles in 23R fuel elements.	F6.4
7	31-36	Volume (m ³) of burned-back fissile particles in 25R fuel elements.	F6.4
7	61-80	Any desired identification (not read by computer).	Free
8	1-6	Weight (kg) of silicon carbide hulls in initial/makeup fuel elements.	F6.2
8	7-12	Weight (kg) of silicon carbide hulls in 23R fuel elements.	F6.2
8	13-18	Weight (kg) of silicon carbide hulls in 25R fuel elements.	F6.2
8	19-24	Volume (m ³) of silicon carbide hulls in initial/makeup fuel elements.	F6.4
8	25-30	Volume (m ³) of silicon carbide hulls in 23R fuel elements.	F6.4
8	31-36	Volume (m ³) of silicon carbide hulls in 25R fuel elements.	F6.4
8	61-80	Any desired identification (not read by computer).	Free
9	1-6	Weight (kg) of fissile kernels in initial/makeup fuel elements.	F6.2

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
9	7-12	Weight (kg) of fissile kernels in 23R fuel elements.	F6.2
9	13-18	Weight (kg) of fissile kernels in 25R fuel elements	F6.2
9	19-24	Volume (m ³) of fissile kernels in initial/makeup fuel elements.	F6.4
9	25-30	Volume (m ³) of fissile kernels in 23R fuel elements.	F6.4
9	31-36	Volume (m ³) of fissile kernels in 25R fuel elements.	F6.4
9	61-80	Any desired identification (not read by computer).	Free
10	1-6	Weight (kg) of uranium in initial/makeup spent fissile particle.	F6.2
10	7-12	Weight (kg) of uranium in 23R spend fissile particle.	F6.2
10	13-18	Weight (kg) of uranium in 25R spend fissile particle.	F6.2
10	19-24	Weight (kg) of uranium in initial/makeup spent fertile particle.	F6.2
10	25-30	Weight (kg) of uranium in 23R spent fertile particle.	F6.2
10	31-36	Weight (kg) of uranium in 25R spent fertile particle.	F6.2
10	61-80	Any desired identification (not read by computer).	Free
11	1-6	Weight (kg) of plutonium in initial/makeup spent fissile particle.	F6.2
11	7-12	Weight (kg) of plutonium in 23R spent fissile particle.	F6.2
11	13-18	Weight (kg) of plutonium in 25R spent fissile particle.	F6.2

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
11	19-24	Weight (kg) of plutonium in initial/makeup spent fertile particle.	F6.2
11	25-30	Weight (kg) of plutonium in 23R spent fertile particle.	F6.2
11	31-36	Weight (kg) of plutonium in 25R spent fertile particle.	F6.2
11	61-80	Any desired identification (not read by computer).	Free
12	1-6	Weight (kg) of thorium in initial/makeup spent fertile particle.	F6.2
12	7-12	Weight (kg) of thorium in 23R spent fertile particle.	F6.2
12	13-18	Weight (kg) of thorium in 25R spent fertile particle.	F6.2
12	61-80	Any desired identification (not read by computer).	Free
13	1-6	Percent broken fertile particles due to irradiation damage.	F6.3
13	19-24	Percent broken fissile particles due to irradiation damage.	F6.3
13	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
14	1-6	Percent broken fertile particles due to fuel element crushing.	F6.3
14	19-24	Percent broken fissile particles due to fuel element crushing.	F6.3
14	7-18 25-36 61-80	Any desired identification (not read by computer).	Free

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
15	1-6	Percent broken fertile particles due to transport from crusher to primary burner.	F6.3
15	19-24	Percent broken fissile particles due to transport from crusher to primary burner.	F6.3
15	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
16	1-6	Percent broken fertile particles due to primary burning (including fines recycle).	F6.3
16	19-24	Percent broken fissile particles due to primary burning (including fines recycle).	F6.3
16	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
17	1-6	Percent broken fertile particles due to transport from primary burner to classifier	F6.3
17	19-24	Percent broken fissile particles due to transport from primary burner to classifier.	F6.3
17	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
18	1-6	Percent broken fertile particles due to particle classification (all stages).	F6.3
18	19-24	Percent broken fissile particles due to particle classification (all stages).	F6.3

<u>Card</u>	<u>Space</u>	<u>Description</u>	<u>Format</u>
18	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
19	1-6	Percent broken fertile particles crossing to fissile stream.	F6.3
19	19-24	Percent broken fissile particles crossing to fertile stream.	F6.3
19	7-18 25-36 61-80	Any desired identification (not read by computer).	Free
20	1-6	Percent whole fertile particles crossing to fissile stream.	F6.3
20	7-12	Percent whole fissile particles crossing to fertile stream.	F6.3
20	7-18 25-36 61-80	Any desired identification (not read by computer).	Free

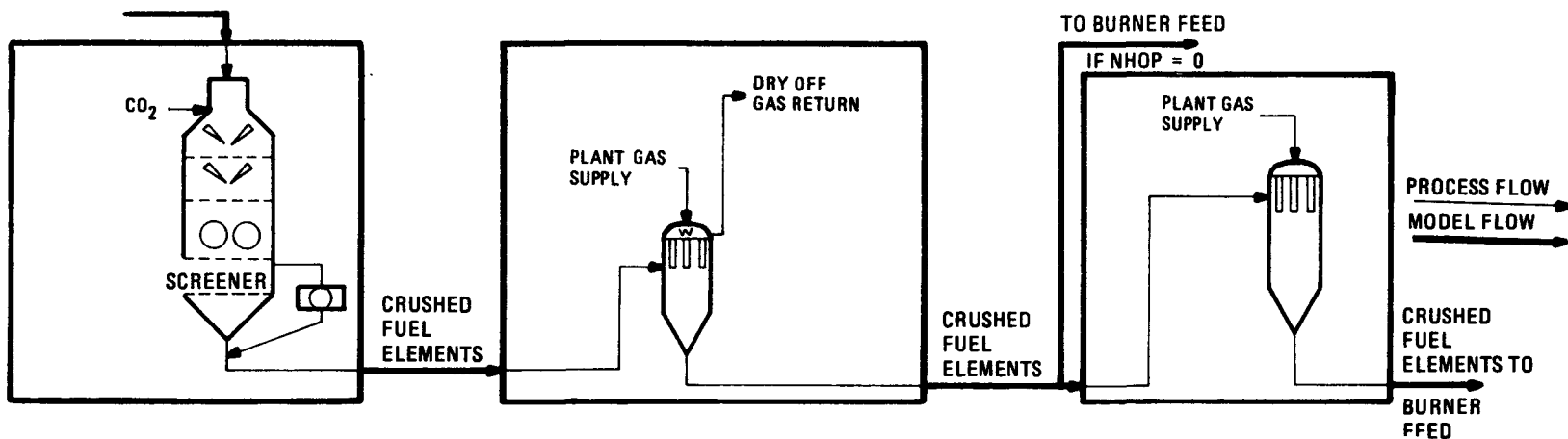
The following card formats may change as different distribution functions are used in the code. The current input assumes a triangular distribution of the data in Table 3-1, formatted as below.

21-	1-6	Median failure rate	F6.2
26	7-12	Low failure rate	
	13-18	High failure rate	
	19-24	Median repair time	
	25-30	Low failure rate	
	31-36	High failure rate	

Appendix C

HTGR REPROCESSING HEAD-END EQUIPMENT DESCRIPTIONS
FOR SIMULATION MODEL





ITEM: UNIFRAME CRUSHER

QUANTITY: Maximum 2

VARIABLES: NCRUSH = 1 or 2

COMMENTS: Model can be run with one or two crushers to evaluate number needed to meet availability requirements.

CRUSHER PRODUCT RECEIVING/WEIGH HOPPER

Maximum 2
(1 per crusher)

NCRUSH = 1 or 2

0.7 m³ volume (~25% freeboard, 60% packing fraction). Each holds five fuel elements. This allows 1 hr for first of five fuel element batch to be checked for product acceptability before releasing five fuel element batch to product surge storage.

CRUSHER PRODUCT SURGE STORAGE HOPPER

Maximum 12
(6 per crusher)

NHOP(1) = 0 to 6
NHOP(2) = 0 to 6

1.2 m³ volume (25% freeboard, 60%* packing fraction): Requires maximum of 30 deg angle with vertical for gravity flow feed from receiving/weigh hopper. Each holds eight fuel elements. Maximum considered is about one day's surge. Minimum needed will be determined from simulation study.

*60% has generally been used as a spherical particle packing fraction. It is recognized that the crushed fuel element material packing fraction could be <60%; however, to simplify fuel element burning calculations in the model as the material content changes to a high particle percent, the 60% packing factor is used here and 25% freeboard is allowed.

Fig. C-1. Fuel element crushing simulation model equipment description

ITEM: Primary Burner Feed/Weigh Hopper

QUANTITY: 1 per Burner

VARIABLES: NBURN (1) = 2 to 6
NBURN (2) = 2 to 6

COMMENTS: 0.7 m³ volume (25% freeboard, 60% packing fraction. Five fuel element batch for initial burner feed (0.6-m burner L/D of 3 = 4.4 FE).
or,
0.3 m³ volume (25% freeboard, 60% packing fraction). Two fuel element batch for initial burner feed (0.4-m burner L/D of 3 = 1.3 FE).

ITEM: Primary Burner System

QUANTITY: Maximum 12

VARIABLES: NBURN (1) = 2 to 6
NBURN (2) = 2 to 6
BDIAM = 0.4 or 0.6
XMXLD = 5.0
XMNLD = 3.0

COMMENTS: Diameter of burners can be varied in the model. Approximately ten 0.4-m burners should handle HRRF throughput. The number can be increased to 12 if needed. Lesser numbers of 0.6-m burners will be used. Burners operate from a minimum bed height of L/D = 3 to a maximum bed height of L/D = 5 (see Appendix D, Primary Burner Operating Description). For modeling purposes primary burner discharge hoppers and the Fines recycle systems will be assumed to be an integral part of the burners.

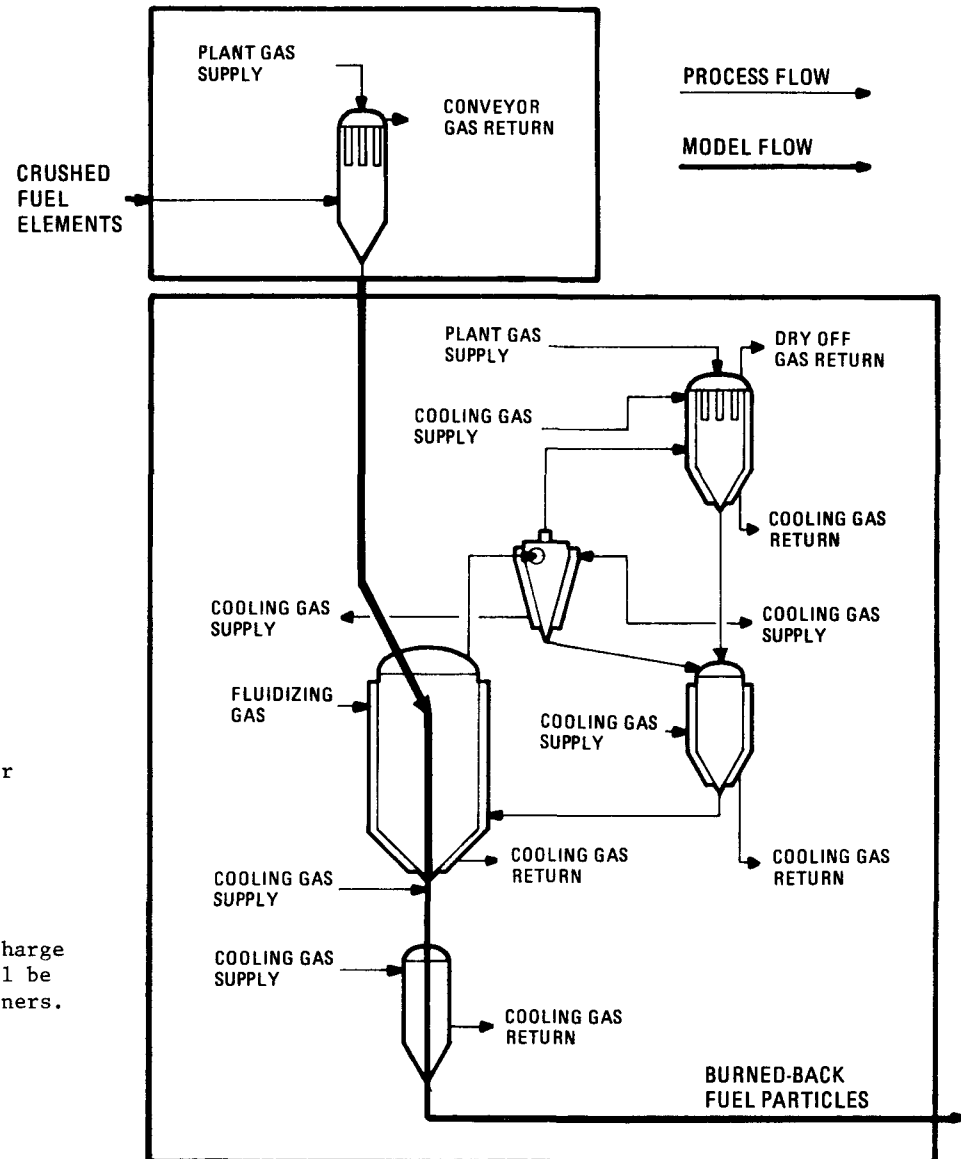
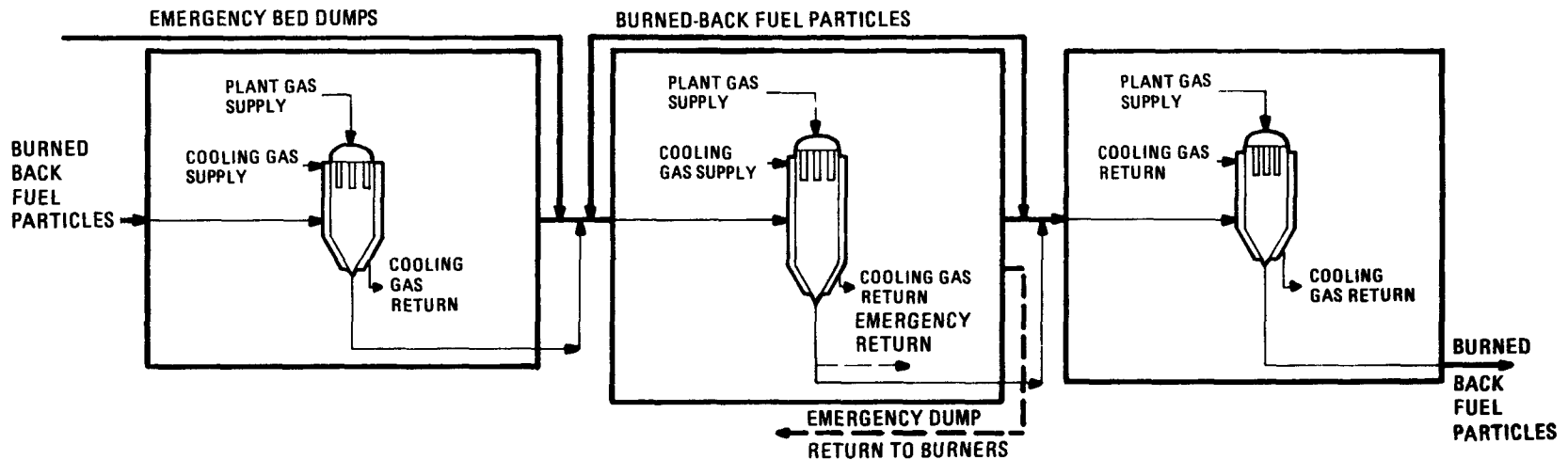


Fig. C-2. Primary burner simulation model equipment description (sheet 1 of 2)



ITEM:	Primary Burner Product Receiving/Weigh Hopper	Primary Burner Emergency Surge Storage Hopper	Primary Burner Product / Classifier Feed Surge Storage Hopper
QUANTITY:	1 per each two 0.6-m burners, or 2 per each five 0.4-m burners	1 per each two 0.6-m burners, or 2 per each five 0.4-m burners	1 per burner maximum
VARIABLES:	NBHOP(1) = 1 to 3 NBHOP(2) = 1 to 3 XMXLD-XMNLD (basis for calc.)	NEHOP(1) = 1 to 3 NEHOP(2) = 1 to 3 XMXLD (basis for calc.)	NSHOP(1) = 0 to NBURN(1) NSHOP(2) = 0 to NBURN(2) XMXLD-XMNLD (basis for calc.)
COMMENTS:	0.4-m ³ volume (equivalent to burner L/D = 2 + 25% freeboard for 0.6-m burners). Used directly for partial bed dumps. Final bed is dispatched in batches through receiving/ weigh hopper while holding fluidization. 0.1-m ³ volume (equivalent to burner L/D = 2 + 25% freeboard for 0.4-m burners). Used as described above.	Used for burner bed dump when necessary to remove material for burner maintenance after a failure. Hopper(s) size will accommodate a full burner load. (0.84 m ³ + 25% for 0.6-m burners or 0.25 m ³ + 25% for 0.4-m burners). These hoppers will also feed receiving/ weigh hoppers so they can be used for temporary surge if the receiving/ weigh hopper or other downstream equipment is out of service. Unburned material can be transferred to the spare burner or to the feed hopper of any burner working on the same customer batch.	0.4-m ³ volume for 0.6-m burners; 0.1-m ³ volume for each 0.4-m burners (each holds one receiving weigh hopper batch).

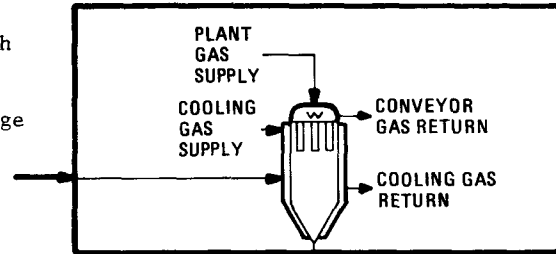
Fig. C-2. Primary burner simulation model equipment description (sheet 2 of 2)

ITEM: Classifier Feed/Weigh Hopper

QUANTITY: 1 per each first stage classifier

VARIABLE: NCLASS = 1 or 2

COMMENTS: 0.4-m³ volume if burners are 0.6-m;
0.2-m³ volume if burners are 0.4-m
(each holds one surge storage hopper batch).



ITEM: Classifiers

QUANTITY: Maximum-
2 sets of two
to three (TBD)
stages

VARIABLES: NCLASS = 1 or 2

COMMENTS: Model will treat classifier stages as
a single unit (i.e. two classifying
units in total model).

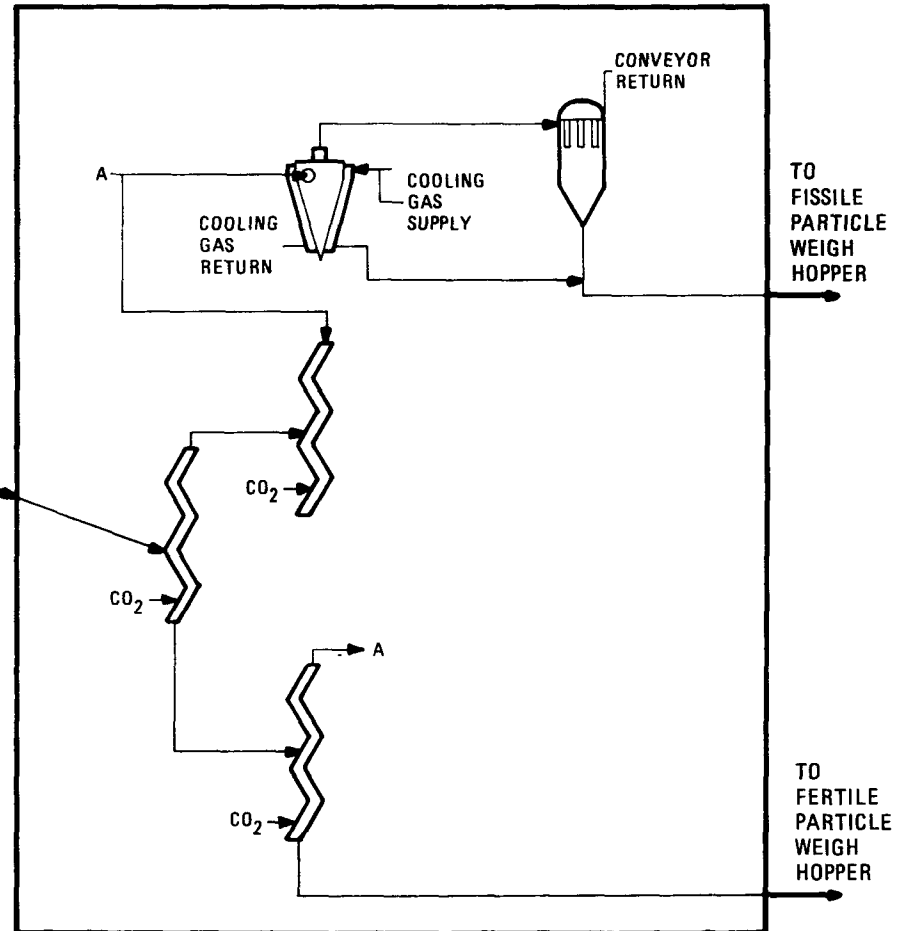


Fig. C-3. Classifier simulation model equipment description

APPENDIX D
PRIMARY BURNER OPERATIONS IN THE
HTGR RECYCLE REFERENCE FACILITY (HRRF)



Appendix D
PRIMARY BURNER OPERATIONS IN THE
HTGR RECYCLE REFERENCE FACILITY (HRRF)

D.1. INTRODUCTION

This appendix is an update to GA-C13596 (Ref. D-1), "Burner Cyclical Operations in a Commercial HTGR Reprocessing Facility," and it documents assumptions included in the reprocessing operations simulation work being performed under the HTGR Fuel Recycle Development Program Subtask 140.

Fluidized bed burners are the reference design for burning graphite from crushed HTGR fuel elements and outer carbon coatings from fuel particles in the head-end system of a HTGR fuel recycle facility. Cold pilot plant operations of 0.2- and 0.4-m crushed element (primary) burners have indicated the desirability of minimizing thermal cycling of the burners to reduce maintenance, repair, and replacement requirements in the burner system. Excessive maintenance, repair, and replacement downtime in the HRRF will detract from the burner system availability and reduce plant throughput by its effect on overall plant availability.

Major thermal cycles occur during sweepdown for accountability, when crusher product (burner feed) is not available during certain parts of the burner cycle, and during burner downtime for repair. Minor fluctuations occur when hot product ash is removed or when short-term feed unavailability occurs.

D.2. DISCUSSION

D.2.1. Accountability

Because of reactor customer accountability requirements, spent fuel elements are processed through the head-end system in customer lots. As a maximum, each customer lot may contain a full reactor segment if it contains only initial core fuel or fuel from a non-recycle mode of reactor operation. If the reactor is in a recycle mode of operation, a segment may consist of MS (spent makeup), 23 RS (spent U-233 recycle), or 25 RS (spent U-235 recycle) elements (for the HEU fuel cycle). Within a customer lot, the different types of fuel elements must be separately processed because the fissile particle materials from the three types follow different process paths. A typical equilibrium processing of a customer lot will thus consist of a maximum of three accountability cleanouts of each burner, each requiring complete tailburning of the last lot of fuel, complete emptying of equipment, and a build up to appropriate operating bed height for the next lot in queue. In addition, operations may be shut down an additional two or more times per year for recycle plant total accountability sweepdown.

D.2.2. Normal Operating Cycle

The following cycle description presupposes the use of 0.6-m burners in the HRRF. Head-end operations analysis and criticality studies may indicate the use of smaller burners; however, the general operating philosophy should remain the same.

Operation is started by loading each burner with five crushed fuel elements (bed L/D approximately 3). The crushed fuel is heated to a combustion temperature of about 850°C, loading and heating requiring approximately 4 hr. During the burning cycle, crushed fuel elements are fed to the burner at a rate of approximately one fuel element per hour. Feeding and burning continues until the burned-back particle bed height reaches a bed L/D of approximately 5. Feed is then stopped and burning is continued for about 4 hr to remove a maximum amount of carbon (to <1 wt %), and a partial bed dump to a bed L/D of approximately 3 is made. Feeding and burning again commences until a bed L/D of 5 is reached, at which point tailburning and partial bed dump occurs. When the available spent fuel elements from a

customer lot are exhausted, the bed is burned out and a total bed dump is made preparatory to cleanout for accountability. Figure D-1 schematically illustrates the cycle.

Smaller burners would follow approximately the same cycle. Fewer elements may be fed initially, and the burn/feed rate will be reduced (~ 0.4 FE/hr for a 0.4-m burner, ~ 0.1 FE/hr for a 0.2-m burner). If a possibility of small customer lots exists (such as the HEU cycle producing about 30-60 25RS elements per segment), a 0.4-m burner might be installed along with the 0.6-m burners to handle the small lots.

D.2.3. Operating Cycle Interruptions

Burner and support equipment failures may result in operating cycle interruptions. Depending on the nature and extent of the failure, burning may be interrupted and material may have to be removed from the burner. If the batch is near the end of tailburning (< 9 wt % carbon), it may be possible to send the batch on to the classifier so that fissile particles and free graphite can be introduced into the secondary burner for final burnout. If the carbon specifically associated with the classified fertile kernels is < 1 wt % carbon, they may not need to be returned to the burning operation. Again, a spare 0.4-m burner could be useful for completing small batches of material resulting from burner system failures at low bed heights.

Normal cycle operation may also be interrupted by failures in the crushing and crusher product transport and storage system. The bulk of the crushed fuel elements makes a large surge storage unattractive. Tentatively, a maximum of about one day's surge is being included in the simulation model. Since many crusher system failures require more than 24 hr to restart, the burner feed supply may often be cut off. Several burner operating options exist. If the bed height is above the critical level of the induction heater (60% of the coil height), the burner can continue to use the induction heater to assist the tailburn; if the bed height falls below the initial

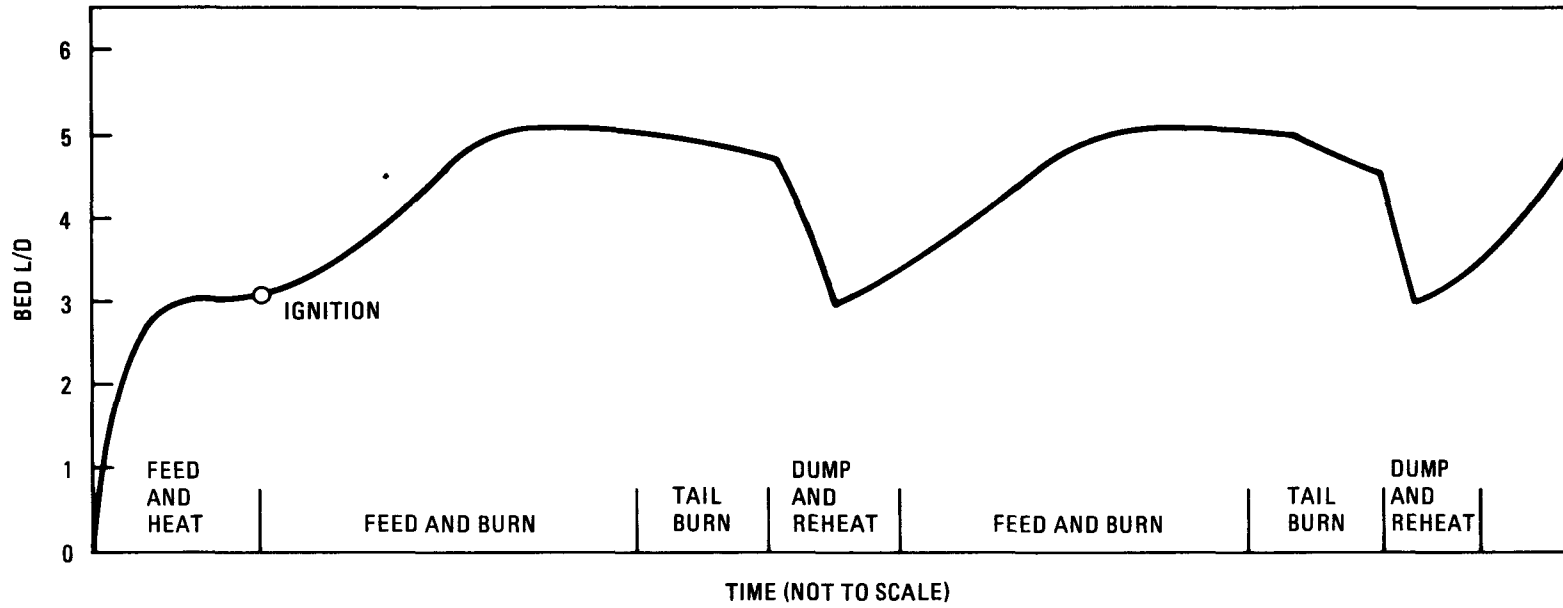


Fig. D-1. Burner operating cycle

induction heater level as burning proceeds, the hot gas preheater (if one is provided) can be used to assist the tailburn at a reduced rate. If new feed is available before the bed is completely burned out, feeding and burning could commence until normal operating conditions are restored. If feed is not available, the bed could be reduced to a minimum carbon content without the induction heater and a full bed dump could be made; then the burner would be idle until the crushing system is restarted and sufficient feed for burner restart is available. The partially burned-back bed will be recycled to the primary burner if its carbon content is $\gg 9\%$ and if additional feed of the same batch is available. If the bed should be the end of a customer batch, fissile particles could be burned in the secondary burner at a reduced rate, or a smaller size primary burner could be included in the plant design.

D.3. CONCLUSIONS

Semi-continuous operation of the primary burners with a partial bed dump to L/D of 3 when the burned out particle bed reaches L/D of 5 is recommended. If a burner system failure interruption occurs, material could be recycled back to the burner or the batch could be completed in a spare burner. The spare burner may be a smaller burner to handle odd lots of material that might not be efficiently handled in a large burner. If crusher or transport system failures result in loss of burner feed supply, tailburning can commence; the induction heater can assist tailburning if the bed level is above the critical coil level (if not, the bed can be tailburned to minimum carbon content without induction heating); finally, if burning is complete before more feed is available, the entire bed can be dumped. A hot gas preheater could be used to continue tailburning assist below the critical level of the induction coil (ability to restart with the preheater to be verified in pilot plant).

Criticality studies are necessary to verify the allowable burner size for this operating cycle because of the large quantities of fissile material in the final bed.

REFERENCES

- D.1. Carney, H. C., and V. H. Pierce, "Burner Cyclical Operations in a Commercial HTGR Reprocessing Facility," General Atomic Company, unpublished data.