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OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE

Description of a Full-Scale Experimental Voloxidizer Facility

B. B. Spencer
T. D. Welch
M. E. Whatley

CONSOLIDATED FUEL REPROCESSING PROGRAM

[redacted]

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Consolidated Fuel Reprocessing Program

DESCRIPTION OF A FULL-SCALE EXPERIMENTAL VOLOXIDIZER FACILITY

B. B. Spencer, T. D. Welch, and M. E. Whatley
Fuel Recycle Division

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OAK RIDGE NATIONAL LABORATORY
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GLOSSARY OF ACRONYMS

A/D	analog-to-digital
AD9	auto-data nine
AI	analog input
AO	analog output
ASCII	American National Standard Code for Information Interchange
CE	C. E. Raymond/Bartlett-Snow
CFRP	Consolidated Fuel Reprocessing Program
CPU	central processing unit
CRT	cathode ray tube
DI	discrete input
DO	discrete output
DP	Differential Pressure
FD	Floppy Disc (sometimes appears as F/D)
FM	Frequency Modulated
FMC	Food Machinery Corporation
FSEV	Full-Scale Experimental Voloxidizer
HEPA	high-efficiency particulate air (filter)
HVAC	heating, ventilation, and air conditioning
I/O	input/output
I&C	Instrumentation and Controls
IODP	integral orifice differential pressure (transmitter)
JCL	job control language
LED	light-emitting diode
MSA	Mine Safety Appliances
ORO	Oak Ridge Operations (Office of the Department of Energy)
ORNL	Oak Ridge National Laboratory
PID	proportional-integral-derivative
PMP	programmer maintenance panel
POP	process operators panel
PS	panel switch
RAM	random access memory
RTD	resistance temperature device
SLC	serial line clock
UPC	unit process controller

ABSTRACT

The voloxidation process has been under development as a dry head-end method for removing tritium from spent uranium reactor fuel prior to aqueous processing. Tritium is released from the fuel when the fuel changes in crystalline structure upon oxidation from UO_2 to U_3O_8. A rotary calciner was chosen as the reactor, since the oxidation reaction takes place in a temperature range of 720 to 920 K and since agitation is thought to be beneficial to the reaction.

A rotary calciner, called the Full-Scale Experimental Voloxidizer (FSEV), capable of processing fuel at a rate of 0.5 t/d of heavy metal, was designed and fabricated. It represented the state of the art in the development of hardware for the voloxidation process, providing the test-bed for further development and verification of the full-scale design.

This report describes the FSEV. Information is provided on (1) the project objectives, (2) design criteria, (3) physical and functional description of the machine and ancillary equipment, (4) the control systems and algorithms, (5) objectives of experimental programs, and (6) history of the machine itself. Although some aspects of both the operating experience and the experimental results are presented, detailed analyses of the data are not included herein. This report does describe the methods used to create a final, permanent data set, and it contains the necessary information to relate the data to the physical system as an aid to meaningful analysis.

1. INTRODUCTION

The voloxidation process was developed as a dry head-end method for removing tritium from spent uranium reactor fuel prior to aqueous processing. The process is based on the reaction of the oxide fuel with oxygen or air at a temperature range of 720 to 920 K, where the release of tritium and, to a lesser extent, some of the other fission products occurs when UO_2 is restructured to U_3O_8. The rationale for process development assumes that it is more desirable to remove tritium from the fuel and concentrate it into a relatively small volume than to dilute the tritium with water in subsequent aqueous processing steps. Additional benefits of voloxidation include oxidation of residual sodium in the fuel prior to dissolution, an increase in the rate of dissolution, and provision of a temperature-controlled surge capacity between shearing and dissolution.

1.1 Project Objectives

The Full-Scale Experimental Voloxidizer (FSEV) was used to:

1. establish certain characteristics and capabilities of commercial rotary calciner components for operation in reprocessing, such as operability and reliability;
2. study certain important process parameters;
3. confirm and develop data and mathematical models describing heat and mass transport in voloxidation systems;
4. address the problems of process control; and
5. provide a broad base of experience and information applicable to the voloxidation concept.

The size of the FSEV was chosen to be capable of processing 0.5 t/d of heavy metal. The process design calculations for the unit are presented in Appendix A.

1.2 Background

In December 1976, a bid package of specifications and criteria for the design and fabrication of the calciner was prepared and issued to candidate vendors. Two responses were received in February 1977, and C. E. Raymond/Bartlett-Snow (CE) was awarded the contract.

UCC-ND engineering began the design of the auxiliary equipment, and in September 1977, the design of the auxiliaries was completed and fabrication was begun.

In December 1977, a request for directive was submitted to Oak Ridge Operations Office (ORO) to proceed with installation. Rust Engineering prepared an installation time and cost estimate.

In January 1978, the calciner (Fig. 1.1) was delivered and inspected. The flight cartridge was not delivered because the vendor had unexpected problems in fabrication. All auxiliary components were onsite and ready for installation.

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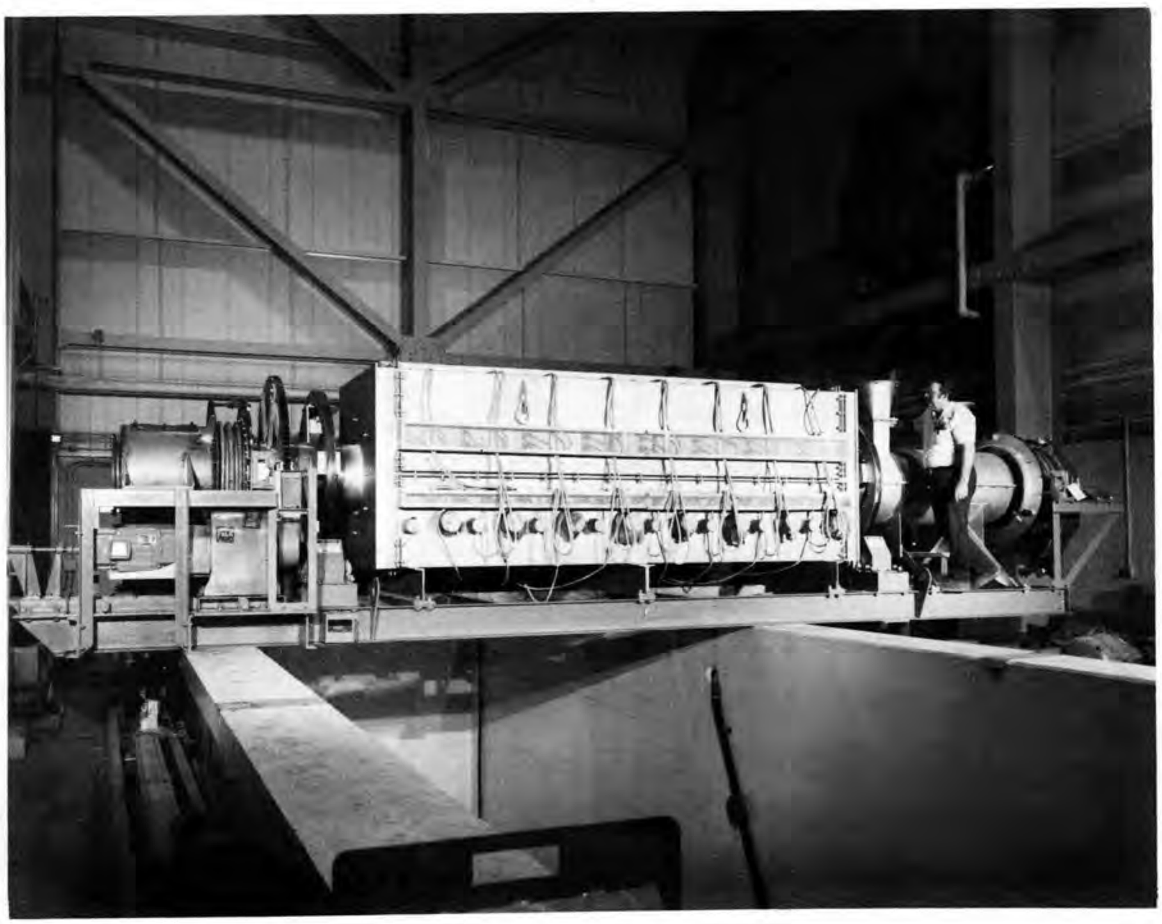

Fig. 1.1. Calciner as delivered by vendor.

In June, participation of Rust Engineering in the installation phase was completed. The following month the flight cartridge was received but inspection revealed defective welds.

During the remainder of 1978, the available systems were checked out, and additional instrumentation was installed. Attempts to rework the flight cartridge proved to be futile.

In January 1979, temporary flights were installed, and solids were fed to the systems for the first time. At this point, a decision had been made to purchase a new drum with built-in prototypical flights. During the remainder of the year, several experimental campaigns were completed. A temperature telemetry system was purchased, and work began on its installation in October. By January 1980, the telemetry system was installed. While this work was under way, special inlet flights, an inlet cone, and a dam were fabricated and welded into the front end of the drum. The systems were calibrated and brought up to operating readiness by March 1980, and experimentation again proceeded.

Meanwhile, in July 1979, a purchase order for the replacement drum was sent to CE. They responded in September 1979 that they would fabricate the drum, which was delivered in May 1980. However, the drum was rejected because of bad welds and because the flights in the furnace section were not straight. The drum was returned to CE, reworked, and subsequently accepted in September 1980.

Disassembly of the voloxidizer system to exchange drums began in October 1980. Included in this work was the fabrication and installation of special dam flights (see Appendix B) in the inlet section of the new drum by ORNL forces. An inlet chute collar was also fabricated and installed. By March 1981, all equipment and instrumentation were installed, and the drum replacement activity was completed. Experimentation resumed in April.

Near the end of April 1981, a solids recirculation system was fabricated and installed on the voloxidation system. The purpose of this apparatus was to recycle back into the drum any solids that would spill into the inlet breaching section.

1.3 System Components and Arrangement

The FSEV is located in Building 7603 of the Consolidated Fuel Reprocessing Facility. The location and arrangement of major components are shown in Fig. 1.2.

The high bay area houses the solids feed, off-gas, and furnace cooling subsystems. The rotary calciner and unit process controller, including man-to-machine interface equipment, are located on the next lower level. The basement level contains product collection and gas supply equipment. A hatch allows movement of materials (using the crane) between the basement and the high bay.

In the event of loss of power, a diesel generator provides the electrical power necessary for safe shutdown.

1.4 Brief History of Experimental Campaigns

It is not the purpose of this report to describe the details of experimental work performed with the FSEV or to present an analysis of the data obtained. However, it seems appropriate to briefly review the experimental campaigns which were performed. Table 1.1 lists

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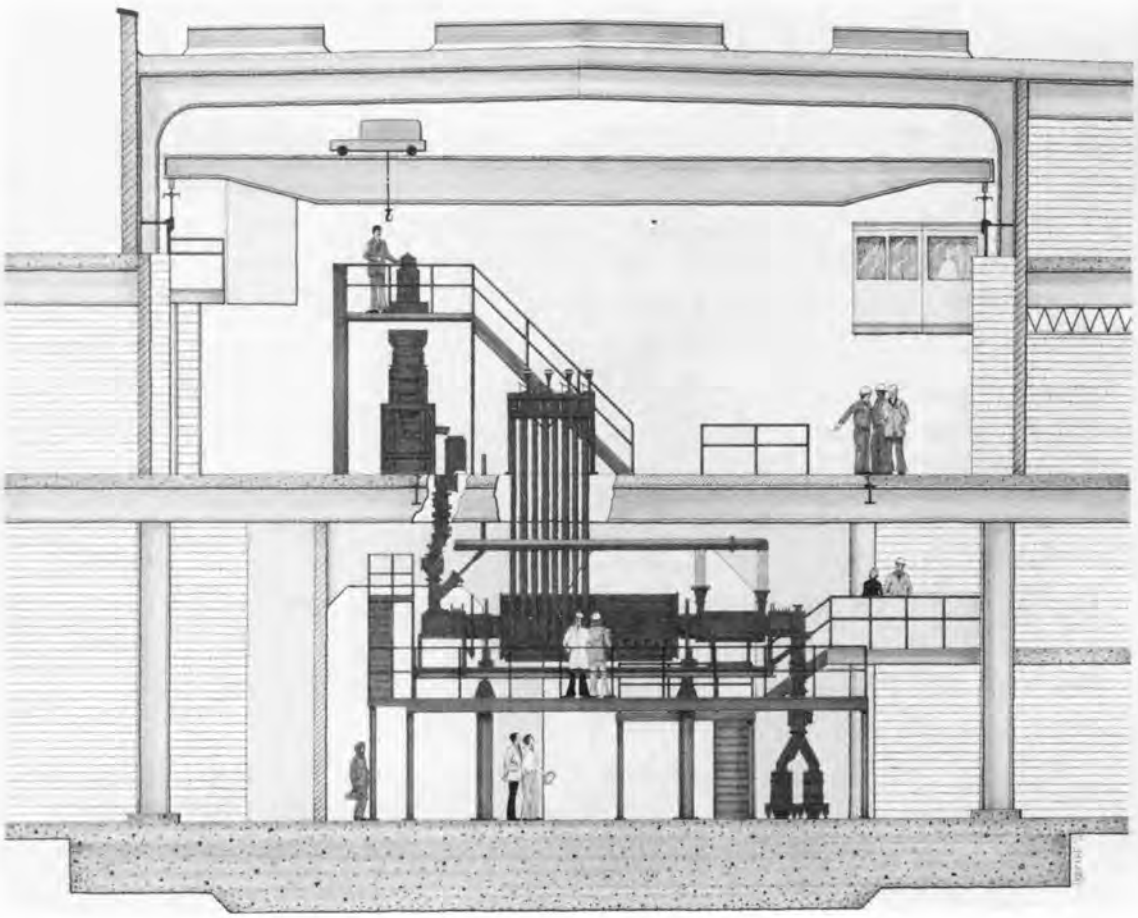

Fig. 1.2. Arrangement of voloxidizer system components.

the 21 runs performed, the duration of each run, when the run was performed, and a very short description of the major objectives of the run. Detailed instructions and other documents were available on the experimental site to ensure that the experimental campaigns were successfully executed. A list of these documents is given in Table 1.2. A log book was kept onsite for recording useful observations and data. The bulk of the data was recorded automatically by the programmable unit process controller on magnetic tape. For a complete discussion, see Sect. 3.

Table 1.1. Summary of Full-Scale Experimental Voloxidizer (FSEV) experimental campaigns

Run	Duration (h)	Date performed	Purpose of run
1	56	7/31/78 – 8/2/78	Dry out (cure) furnace insulating lining and check out the FSEV for operability
2	80	9/8/78 – 9/15/78	Test cooling stacks and new instrumentation (auto-data nine, remote set-point furnace controllers and data recorder)
3	30	10/17/78 – 10/18/78	Additional shakedown of FSEV components, as in run 2, including testing of the off-gas system
4	104	1/22/79 – 1/26/79	Operate FSEV with solids throughput; also test solids feeders and product collection apparatus
5	80	4/17/79 – 4/20/79	Demonstrate temperature profile control (furnace zones)
6	7	5/24/79	Obtain data concerning flow rate and pressure drop across off-gas filter and some study of solids spillage into breeching
7	8	8/2/79	Additional testing of off-gas filter
8	7	8/15/79	Off-gas filter test
9	5	8/23/79	Shakedown following adjustment of seals to reduce off-gas flow rate
10	70	3/18/80 – 3/21/80	Evaluate newly installed thermocouple telemetry system, special test thermocouples and effectiveness of inlet flights in reducing spillage
11	105.5	4/14/80 – 4/18/80	Further evaluation of telemetry system following modifications and testing of newly installed oxygen supply system and prototypical off-gas filter
12	107	6/23/80 – 6/27/80	Evaluate performance of inlet flights and study heat transfer characteristics
13	106	8/11/80 – 8/15/80	Characterize solids and gas flow behavior, including measuring solids spill rate, response of gas composition to step change in O_2 flow rate, and response of gas composition to oxygen getter (iron fillings)
14	107	9/8/80 – 9/12/80	General, with emphasis on measuring drum temperature with special "reflected" thermocouples and additional work with oxygen getters
15	107	10/6/80 – 10/10/80	Continued experimentation (at different operating parameters) with oxygen getter, parabolic reflected thermocouples, and inlet chute collar
16	106	4/6/81 – 4/10/81	Shakedown of FSEV following drum replacement activity, including measurements of general system behavior with emphasis on furnace zone coolers, ability of voltage transient suppressors to protect controller, and demonstration of inlet chute collar to prevent solids spillage
17	108	5/11/81 – 5/15/81	Second phase of shakedown of FSEV following drum replacement with emphasis on testing how prototypical flights enhance surge capacity, new solids recirculating system, oxygen control systems, and the temperature telemetry system

Table 1.1. (continued)

Run	Duration (h)	Date performed	Purpose of run
18	108	7/13/81 – 7/17/81	Demonstrate temperature profile control with emphasis on cooling stack performance and calciner drive performance at sustained high speed, including modified solids recirculation system and shroud feeder tests
19A	12	10/13/81	Test thermocouple telemetry system following extensive repair work
19B	12.5	11/3/81	Second test of telemetry system and shakedown of all hardware and software systems, particularly those items which required corrective actions
20	108	11/16/81 – 11/20/81	Demonstrate axial temperature profile control of rotary drum by manipulating furnace zone temperatures, and demonstrate the capacity of the FSEV to accept very high feed rates (rates far in excess of steady state)

Table 1.2. Documents on hand at the operating site

Document name	Information contained in document
Run instructions	Statement of run objectives (instructions different for each run), lists of nominal operating conditions and parameters to be manipulated, and a checklist of important items requiring monitoring
Problem safety summary	Process description and assessment of safety hazards. Minimum safety regulations are established, and description and locations of safety equipment are listed. Emergency shutdown procedures are also included
Operating procedures	Detailed instructions of how to operate the equipment and instrumentation with descriptions of the function of each item. Procedures for startup, operation, and shutdown are enumerated
Software cross-reference listing	Listing of source code from which controller software was generated, including a cross-reference listing so that software modules and signal names can be located and traced
Software summary	Description of the software in both prose and diagrammatic flow charts. (This document was written after the software evolution slowed and became available prior to run 16.)

2. MECHANICAL SYSTEMS

In a fuel reprocessing facility, the voloxidizer would accept sheared fuel from the shear and discharge "voloxidized" fuel to the dissolver. Since the shear and dissolver were also in the development stages, it was necessary to provide support equipment to simulate these items. The principal mechanical components of the Full-Scale Experimental Voloxidizer (FSEV) facility are solids feed equipment, off-gas system, rotary calciner, and product collection station. Support items include the solids feed equipment and product collection station; all other components are viewed as development items.

The arrangement of this section on mechanical components corresponds to the flow direction of solids through the facility. The reader should keep in mind that all items between the isolation valves on the feed chute and the isolation valves on the discharge chute are the critical development items. Items outside that sphere are support items. Detailed engineering drawings describing the system are listed in Appendixes C, D, E, and F for reference. The appendixes provide the drawing number, title, and a brief description of the information contained on the drawing so that intricate details can be easily found.

2.1 Solids Feed System

The FSEV is equipped with peripherals designed to simulate interfaces with connecting systems (shear and dissolver). It is fed with a mixture of sand, sheared steel rod (hulls), and formed steel strap (shroud) to simulate sheared fuel assemblies (Fig. 2.1).

Figure 2.2 is a schematic view of the feed system. The major feed system parameters are presented in Table 2.1.

The feed system, contained within the feed house in the high bay area, transfers materials to the kiln through two isolation valves and the inlet chute. Feed control is provided by the unit process controller, which processes signals from weigh cells and responds appropriately.

The principal components of the feed system – the feed system enclosure, vibratory screener, feeders (3), isolation valves (2), sampling station, and inlet (feed) chute – are described below.

2.1.1 Feed system enclosure

The feed house (Fig. 2.3), located in the high bay area, isolates the dusty environment of the feed system from the rest of the high bay. The feed house is constructed of steel

ORNL-PHOTO. 2631-82

Fig. 2.1. Photograph of (from left to right) sand, sheared steel rod, and formed steel strap.

panels and support beams and contains observation windows. The house is 4.88 m (16.0 ft) long, 2.74 m (9.0 ft) wide, and 3.35 m (11.0 ft) high. Personnel access doors are located on the north and east sides.

A feed drum is transferred to the top of the feed enclosure with a 1-t hoist attached to the bridge crane (Fig. 1.2). The drum is emptied through the unloading hatch, which is shown in Fig. 2.4.

The calciner is fed by the apparatus inside the feed house through an 8-in. pipe (inlet chute) which penetrates the feed house floor.

2.1.2 Vibratory screen

A charge of material drops from the feed unloading hatch onto a Food Machinery Corp. (FMC) vibratory screener which separates the feed into three different size fractions (Fig. 2.2). The first cut is <0.0725 cm (0.0285 in.), the second <1.91 cm (0.750 in.), and the remaining material is larger than 1.91 cm (0.750 in.). The screen has a variable slope – usually up for loading and down for screening.

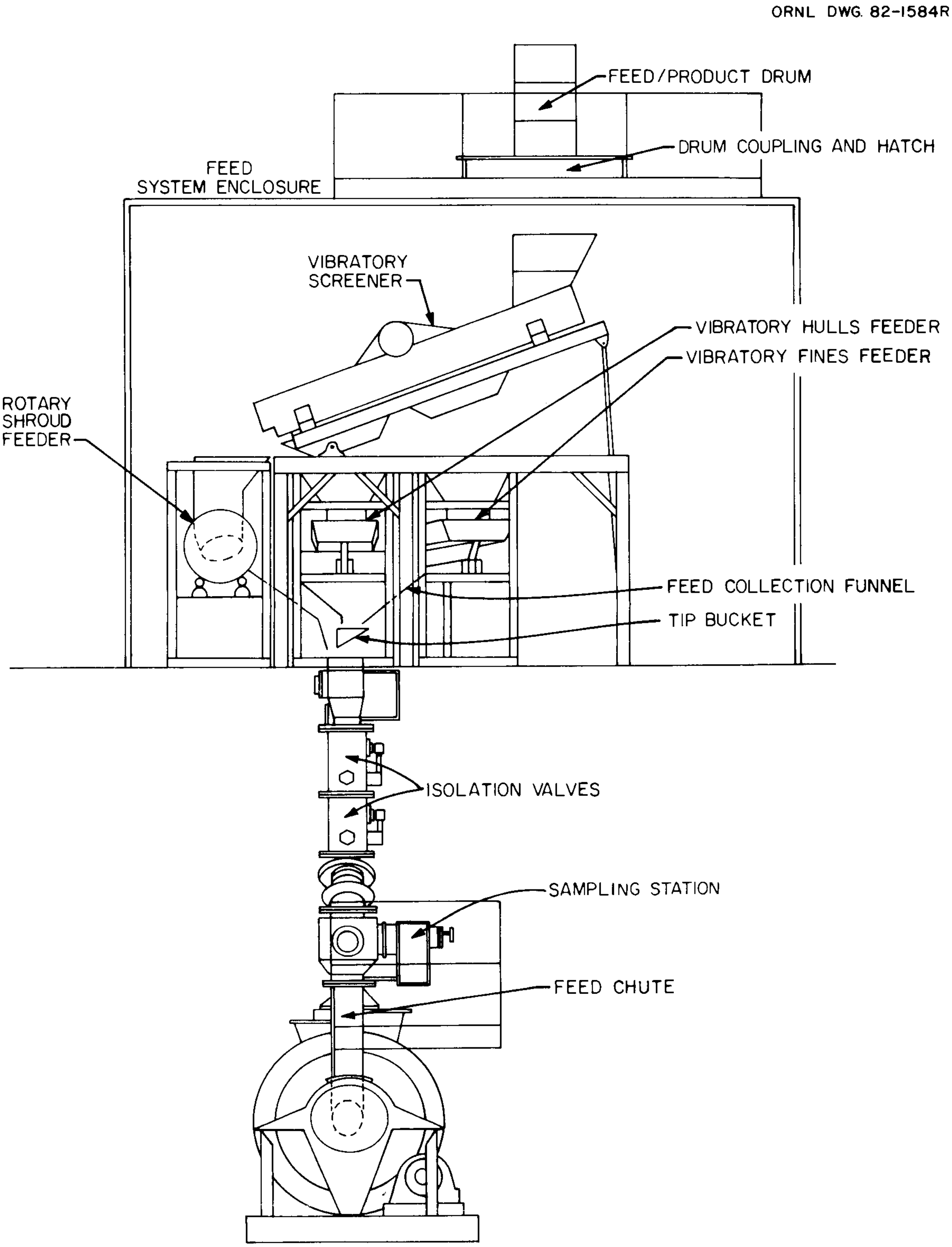

Fig. 2.2. Feed system.

Table 2.1. Solids feed system parameters

Parameters	Values
Nominal feed rate, kg/min	
Sand	0.6
Hulls	0.1
Shroud	0.1
Maximum throughput	
Shroud, kg/min	1.0
Sand and hulls per feed cycle, kg	0.9
Nominal feed cycle time, s	60
Minimum feed cycle time, s	20
Maximum weigh table capacity, kg	454
Maximum tip bucket capacity, g	1000
Maximum feed hopper capacity, kg	
Sand	227
Hulls	227
Shroud	114

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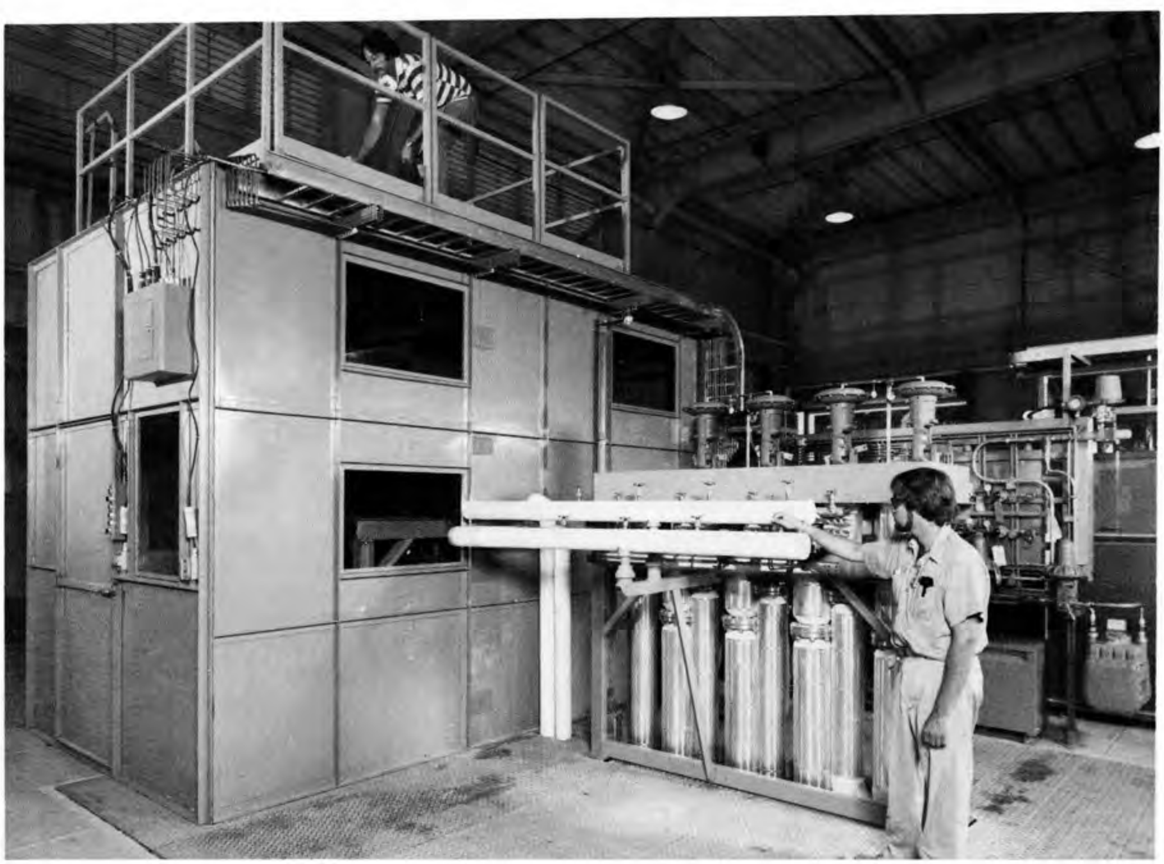

Fig. 2.3. Feed system enclosure.

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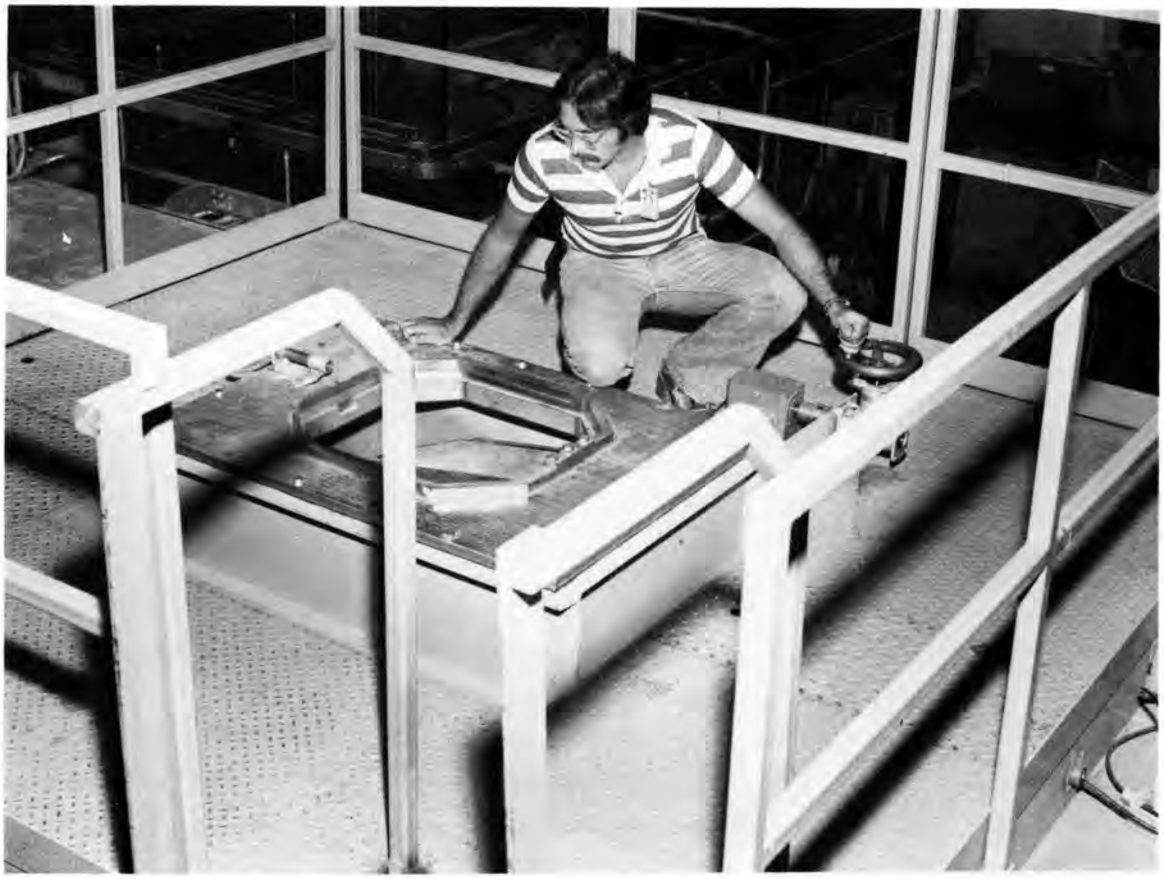

Fig. 2.4. Drum unloading hatch on top of feed house.

2.1.3 Feeders

From the screen, the sized feed collects in one of three hoppers. Each hopper empties into a feeder. The fine (sand) and medium (hulls) feeders are vibratory trays driven by air motors (Fig. 2.2). The shroud feeder is an electric motor-driven rotary feeder (Fig. 2.2).

Each feeder sits on a weigh table, each of which has a capacity of 454 kg (1000 lb). However, because of the weight of the feeders, the sand and hulls hoppers may contain only 227 kg (500 lb) of feed material. The shroud hopper has been spanned to measure up to 114 kg (250 lb) of shroud. Control is provided by the Bristol unit process controller (UPC). The vibratory feeders can be run fast or slow via solenoid valves, and can feed a Tridyne tip bucket (indicated in Fig. 2.2). The tip bucket, which has a capacity of 1000 g (2.2 lb), collects and weighs more precisely what is discharged from the vibratory feeders.

One solid type is fed at a time until the desired amount is obtained, then the contents of the tip bucket are emptied into the kiln inlet chute.

Sensing switches detect when a shroud piece has been discharged from the rotary feeder; the drum is then stopped and its contents weighed. If the desired amount has not been fed, according to weigh table measurements, the drum begins to rotate again.

2.1.4 Isolation valves

Two isolation valves separate the feed enclosure from the calciner. These valves (see Fig. 2.2) serve to isolate the feed house environment, which is at atmospheric pressure, from the calciner, which is maintained at $\leqslant$0.5 in. of water below atmospheric. The air actuated valves are controlled by the Bristol UPC to operate in sequence with the dumping of the tip bucket.

2.1.5 Sampling station

The solids sampling station (see Fig. 2.2) consists of a sampling spoon, which can be inserted into the solids flow stream and can be monitored at the viewing ports. This station is used for obtaining samples of the solids feed. It is of the same construction as the sampling station in the discharge line, described in Sect. 2.4.1.

2.1.6 Inlet chute

Feed material passes into the rotary drum through the inlet chute. The chute is fabricated from 8-in. sched-40 pipe and is curved on a 60.96-cm (2.0-ft) radius so that the minimum slope over which the solids slide is 0.52 rad (30°). This is a specific exception to the general requirement to maintain at least 45° with the horizontal for sliding solids. The vertical cross section of the chute is not circular, but somewhat elliptical, requiring that a collar be fastened around it to reduce the gap between the chute and the rotating drum (see Sect. 2.3.8).

2.2 Off-Gas System

Vacuum is provided to the calciner drum through the off-gas system. After passing through the calciner, the gas stream is filtered to remove particulates and the gas flow rate is measured. Vacuum is supplied by the building off-gas and a parallel air jet. Controi of the off-gas system is provided by the Bristol UPC.

Figure 2.5 is a schematic of the off-gas system. The major system parameters are presented in Table 2.2.

The off-gas line connects to the inlet chute above the inlet breeching. This line is an 8-in.-diam pipe. The filter, located near the feed house in the high bay, consists of a cylindrical structure containing filter elements. Each element is a smaller cylindrical shape, open only at the downstream end. Particulates collect on the inside surface of the elements. The clean gas stream then flows through a 4-in.-diam pipeline leading to the main building off-gas line. A 5.98×10^{-3} m^3 (0.211 ft^3) vessel above the filter supplies air for filter blowback.

A quick opening solenoid valve, operated from the Bristol UPC, releases air directly into the filter element and causes the filter cake to be blown free of the filter and to fall back through the off-gas line into the voloxidizer drum. When the filters become blinded, new filters are pushed into place and the old filters fall into the voloxidizer.

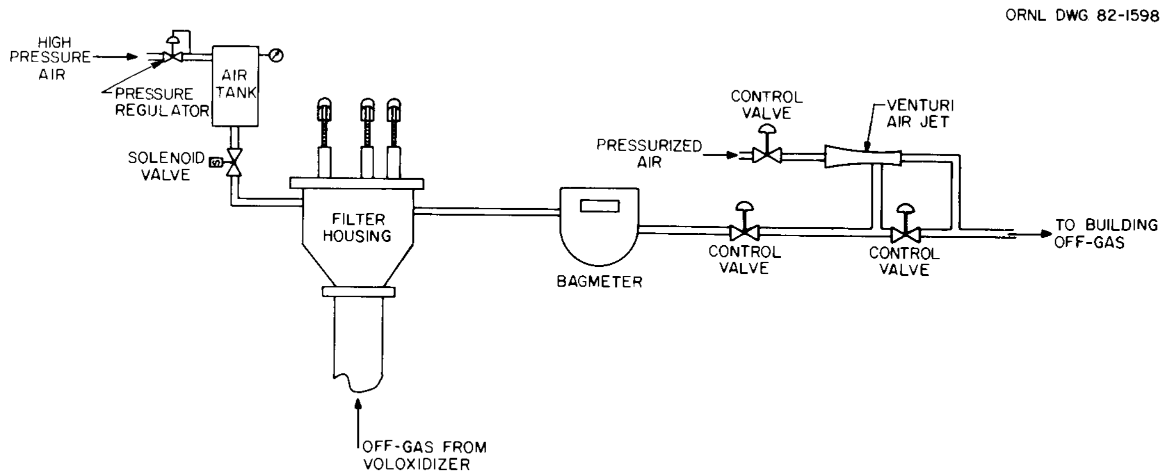

Fig. 2.5. Off-gas system.

Table 2.2. Off-gas system parameters

Parameters	Values
Nominal flow rate	9.44×10^{-4} std m^3/s (2 scfm)
Filter area	9.29×10^{-2} m^2 (1 ft^2)
Clean filter, ΔP	9.95×10^2 Pa (4 in. H_2O)
Blowback pressure, maximum	5.52×10^5 Pa (80 psig)
Volume of air tank	5.98×10^{-2} m^3 (0.211 ft^3)
Max building off-gas header vacuum	2.99×10^3 Pa (12 in. H_2O)
Max total header vacuum	6.22×10^3 Pa (25 in. H_2O)
Pipe diam to filter	8 in.
Pipe diam past filter	4 in.
Nominal filter opening size	
Felt metal	3 μ
Sintered metal[a]	3 μ
Woven metal	5 μ

[a]Judged to be best material and was used in system.

Downstream from the filter a Singer* bagmeter measures the gas volume in 2.83×10^{-2} m^3 (1.0 ft^3) increments. Flow rate is calculated from time elapsed between consecutive increments. Two air actuated valves control the flow rate and pressure. The first valve provides the main control; the second is a bypass valve for a parallel air jet. The bagmeter, air jet, and valves are shown in Fig. 2.5.

*Trademark.

2.3 Rotary Calciner

The principal components of the calciner (Fig. 2.6) are the drum, drive system, support structure, furnace, cooling stacks, product cooler, and seals. Figures 1.2, 2.7, and 2.8 are views from different angles showing the overall appearance of the machine; the major design parameters are presented in Table 2.3.

2.3.1 Drum

The drum functions as the reaction vessel where oxidation of the sheared fuel takes place. Attached to the inside surface of the drum are mixing flights that (1) motivate solids flow; (2) provide agitation, which helps dislodge fuel from sheared elements; (3) promote uniform solids bed temperature; and (4) cause good contact between the solids and gas as the drum rotates. Two riding rings are attached to the outside surface of the drum with spokes. These rings act as the wheels on which the drum can turn.

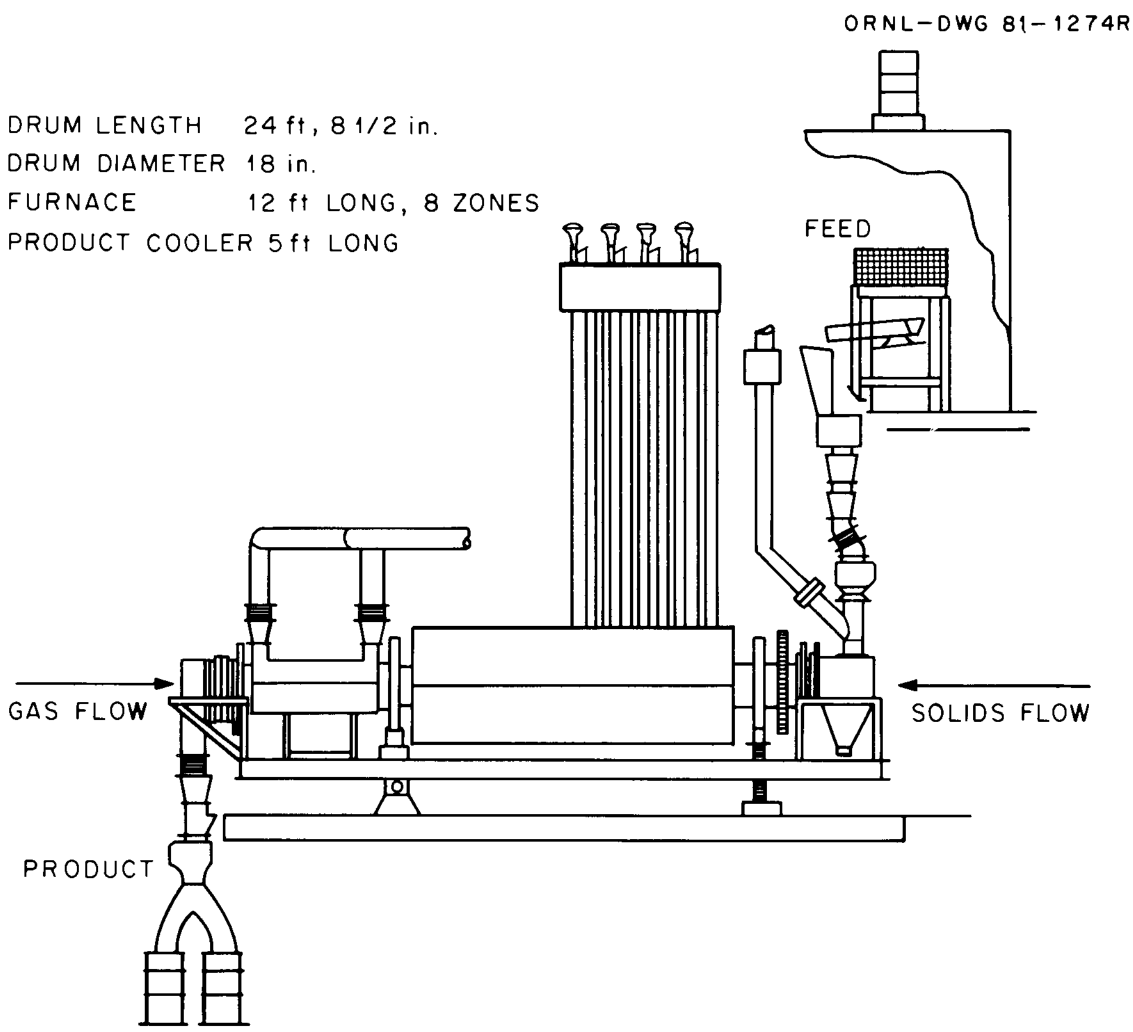

Fig. 2.6. Schematic view of calciner.

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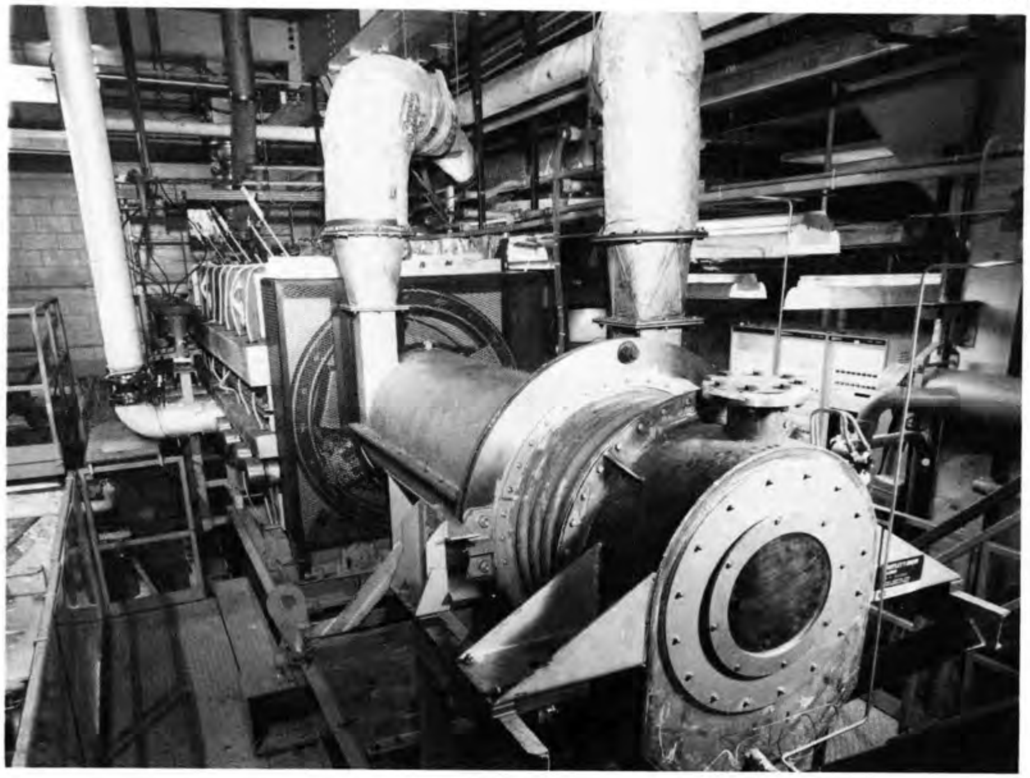

Fig. 2.7. Calciner with discharge breeching in foreground.

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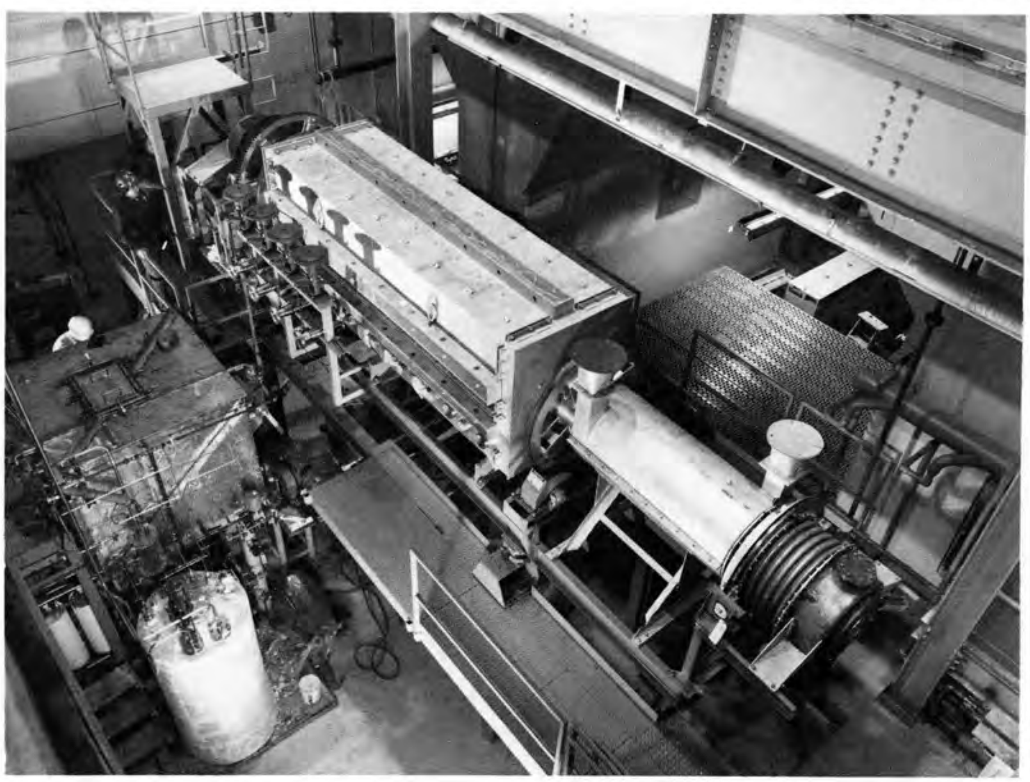

Fig. 2.8. View of calciner from high bay area during installation.

Table 2.3. Major design parameters of the FSEV

Parameter	Value
Drum (Incoloy 800H)	
Length	7.531 m (24.708 ft)
Inside diam	45.72 cm (18.0 in.)
Wall thickness	0.635 cm (0.25 in.)
Feed end dam	9.14 cm (3.60 in.)
Seal	
Leak rate at 2 in. of H_2O	2.36×10^{-4} m^3/s (0.5 cfm)
Max design temperature	800°C
Max drum rotation rate	5 rpm
Min drum rotation rate	0.5 rpm
Motor power	5.0 hp
Motor rotation rate	1750 rpm

Two drums have been tested in the FSEV. The first drum was a one-piece unit with a smooth inside surface to accommodate insertable flight cartridges. The idea was to provide a means for quick and economic changes in the type of flights used, making the unit a testing ground for different flight designs. Three flight cartridges were ordered from the calciner vendor. The three equiangularly spaced helical flights, constructed on a 1.44-m (4.71-ft) pitch, for the inlet section were 1.07 m (3.50 ft) long, 1.91 cm (3/4 in.) wide, and would protrude 5.08 cm (2 in.) from the drum wall toward the centerline of the drum. Another cartridge for the furnace section contained six equiangularly spaced straight flights and was 3.96 m (13.00 ft) long. The third cartridge was 2.50 m (8.21 ft) long and contained three helical flights, equally spaced one from the other, also having a pitch of 1.44 m (4.71 ft). These cartridges are presented schematically in Fig. 2.9. Because the helical flights could not be made within required specifications, they were abandoned and temporary cartridges with straight flights similar to those in the furnace section were fabricated and installed. The flights in the temporary cartridge were 0.64 cm (1/4 in.) wide. In February 1980, the straight flights in the inlet section were removed and replaced with special flights (shown in Fig. 2.10) that move material forward regardless of the direction of the drum rotation. The development effort that led to this design is summarized in Appendix B.

The replacement (second) drum was installed in the FSEV in March 1981. Flights in this drum were prototypical, being welded in place with no gaps between the flights and the drum wall. (A photograph of the drum appears in Fig. 2.11, and the flight arrangement is shown in Fig. 2.12.) The special flights were installed in the inlet section. In addition to moving solids forward for both directions of drum rotation, these flights induce a large solids velocity and thus low inventory. Flights in the furnace sections consist

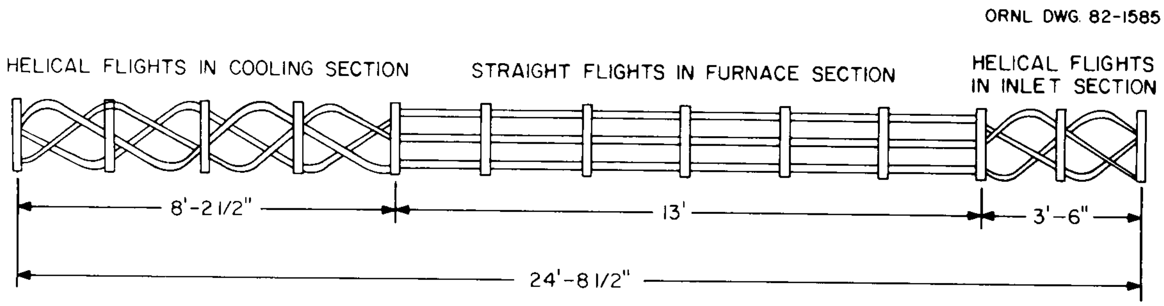

Fig. 2.9. Insertable flight cartridges made in three sections.

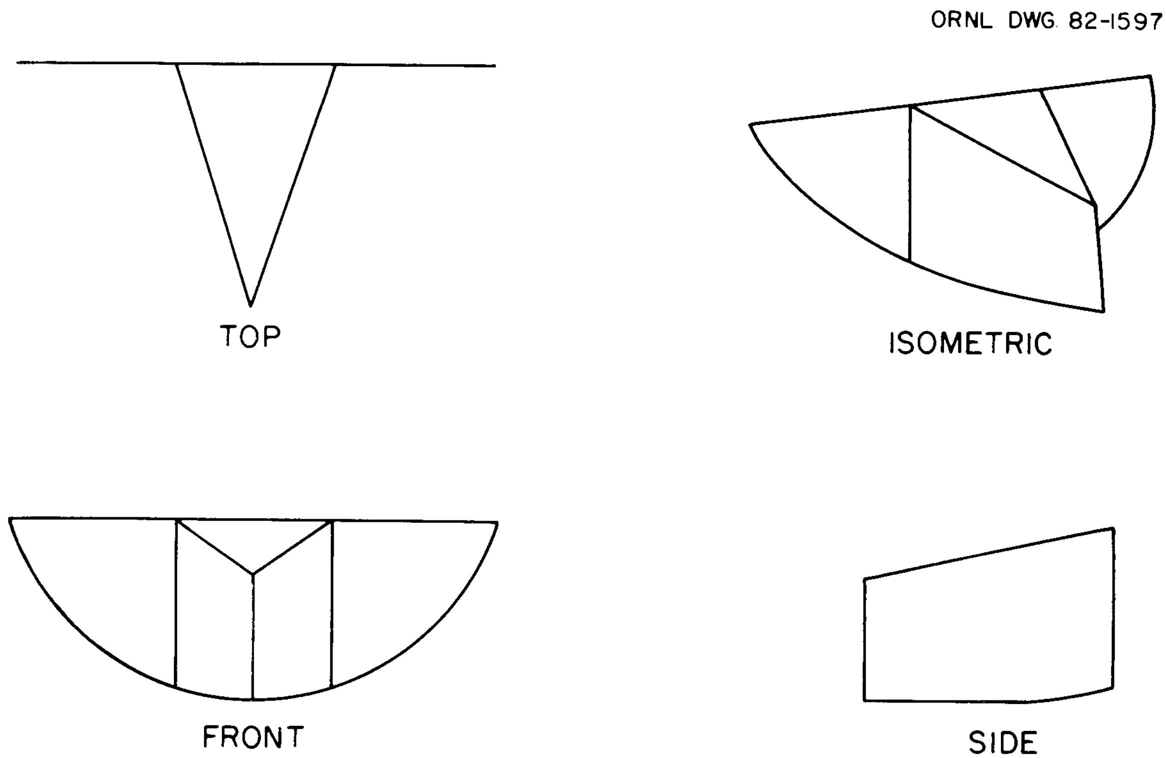

Fig. 2.10. Specially designed flights for the inlet section.

of six rows of linear flights that provide a low solids velocity. The rows are broken every 30.48 cm (12.0 in.) with a 2.54-cm (1.0-in.) gap. The flights protrude 2.54 cm (1 in.) from the drum wall and are 1.91 cm (1/4 in.) wide. The cooling section flights consist of three "rows" of flight sections 30.48 cm (12.0 in.) long and 1.91 cm (1/4 in.) wide, protruding 6.35 cm (2.5 in.) from the drum wall, arranged into a helical pattern. Although these flights provide a high solids velocity, the direction of flow is dependent on rotational direction. When the drum is rotated in a direction that is the reverse of normal operating direction, the drum can act as a surge tank for sheared fuel.

ORNL-PHOTO. 2600-80

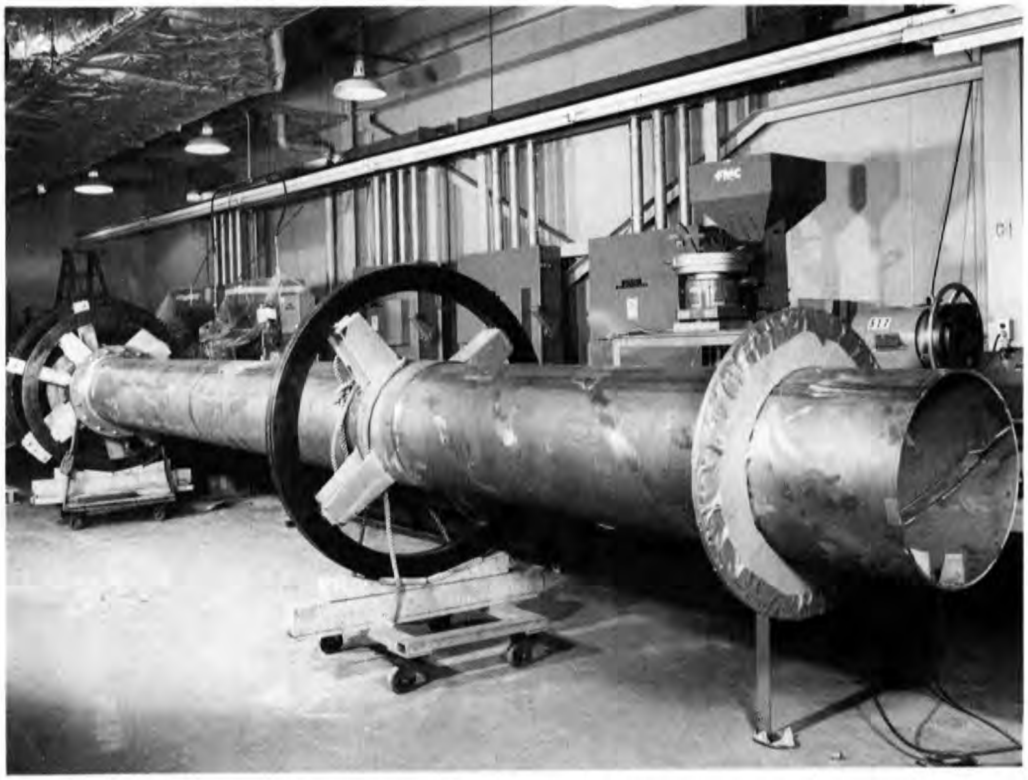

Fig. 2.11. Replacement drum.

2.3.2 Drive system

The mechanism for turning (rotating) the calciner drum is referred to as the drive system (Fig. 2.13). This system utilizes a 5-hp dc electric motor (Reliance motor 211DATCZ), which operates at a maximum speed of 1750 rpm. Maximum electrical rating is 23.5 A at 180 V. Motor speed can be controlled by varying the voltage of the current fed to the motor. The motor drives a gear reducer (Falk model 52-5EZ3-06A2) with an input-to-output ratio of 40.09-to-1. Attached to the output shaft of the reducer is a pinion gear, 16.9 cm (6.66 in.) in pitch diameter with 15 teeth. The pinion gear engages the bull gear that is 137.7 cm (54.22 in.) in pitch diameter and has 122 teeth and is an integral part of the drum. Thus, as the bull gear turns, so does the drum. Tests have shown that minimum drum speed is 0.4 rpm and maximum speed is 5.6 rpm.

2.3.3 Support structure

The support structure is that upon which the calciner components (drum, drive system, furnace, etc.) rest. Two pairs of trunnion rollers are bolted to the support frame. The riding rings roll on the trunnion rollers, 27.9 cm (11.0 in.) in diameter and 15.2 cm (6.0 in.) wide, and thus support the drum. Also bolted to the support frame are the thrust rollers, 12.7 cm

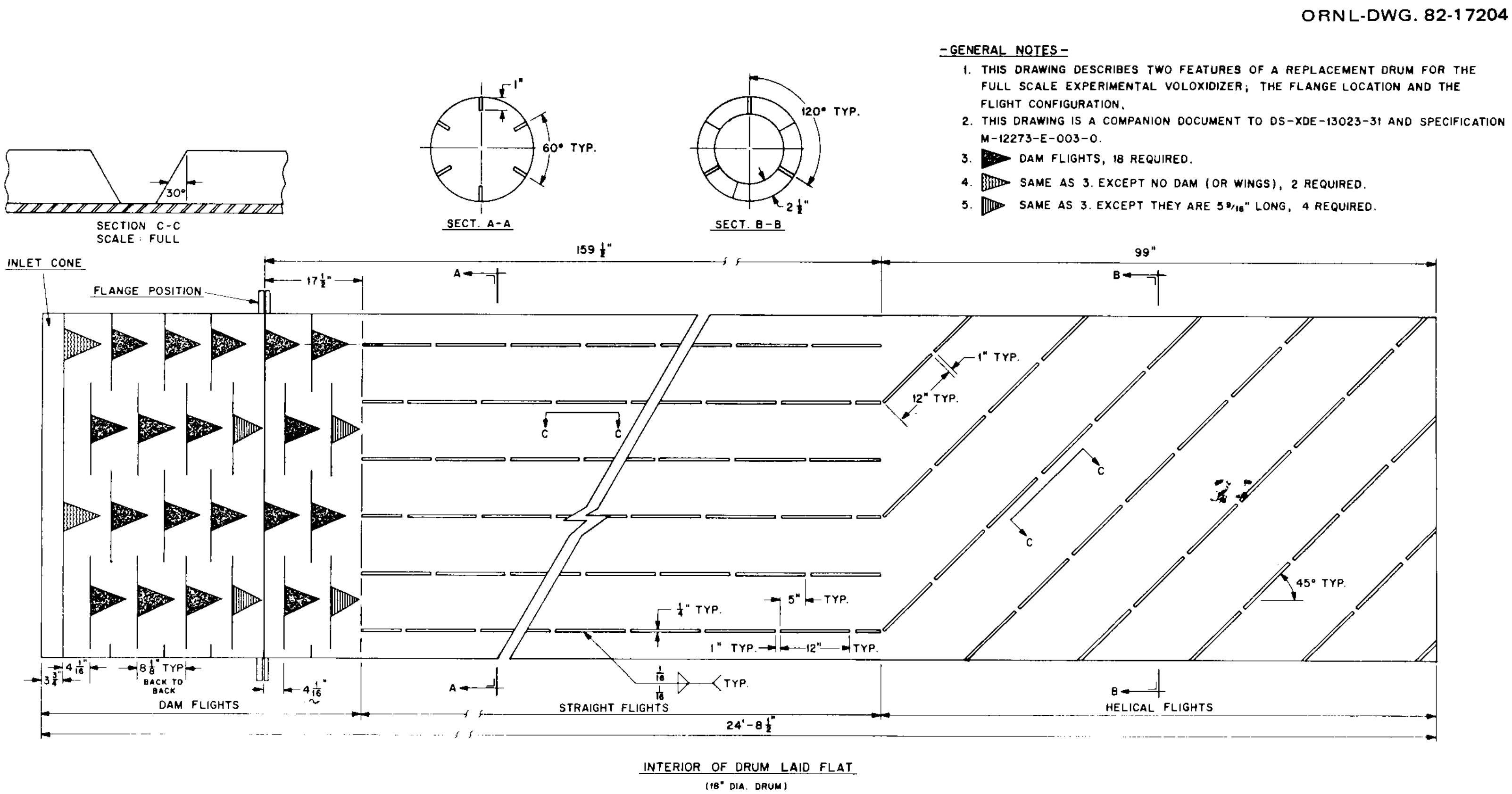

Fig. 2.12. Interior of drum laid flat.

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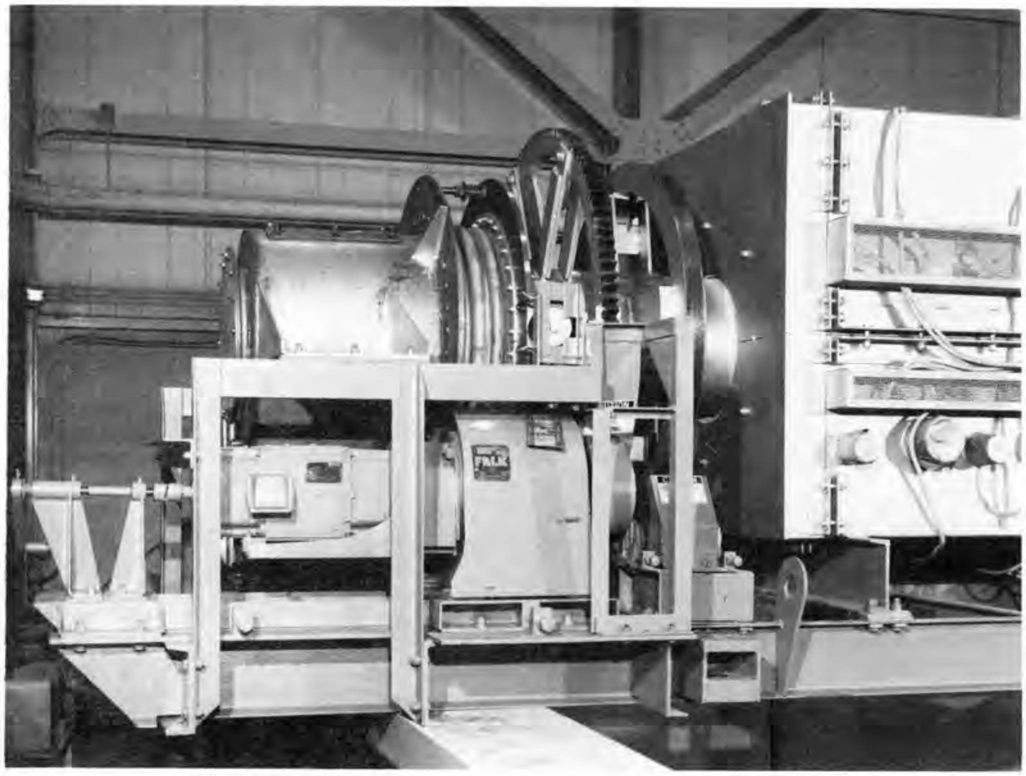

Fig. 2.13. Gear drive system.

(5.0 in.) in diameter and 6.4 cm (2.5 in.) wide, that bracket the riding ring nearest the bull gear to prevent the drum from traversing axially. (Refer to Fig. 2.14.)

As indicated in Sect. 3.1.1, the frame is hinged so that it may swing in the vertical plane with respect to the remainder of the support platform. Jack bolts are provided so that the slope of the frame and hence the slope of the drum may be adjusted.

2.3.4 Furnace

The furnace surrounds a 3.66-m (12-ft)-long section of the drum as shown in Fig. 2.8. The outside dimensions of the furnace are 1.23 m × 1.37 m × 3.96 m (4.03 ft × 4.51 ft × 13.0 ft). The inside surfaces of the furnace are lined with firebrick to act as insulation. The furnace is divided into eight 0.46-m (1.5-ft)-long zones separated by 2.54-cm (1.0-in)-thick insulating panels (see Figs. 2.15 and 2.16). Each zone is equipped with electrical heating elements that occupy part of the space between the firebrick lining and the enveloped drum. The heating elements can deliver a maximum of 15.0 kW (117 V at 128 A) of heat to each zone. These zones can be controlled independently to obtain a desired temperature profile through the furnace. The first four zones (i.e., the four closest to the feed end) are further equipped with natural convection cooling stacks as described in Sect. 2.3.5.

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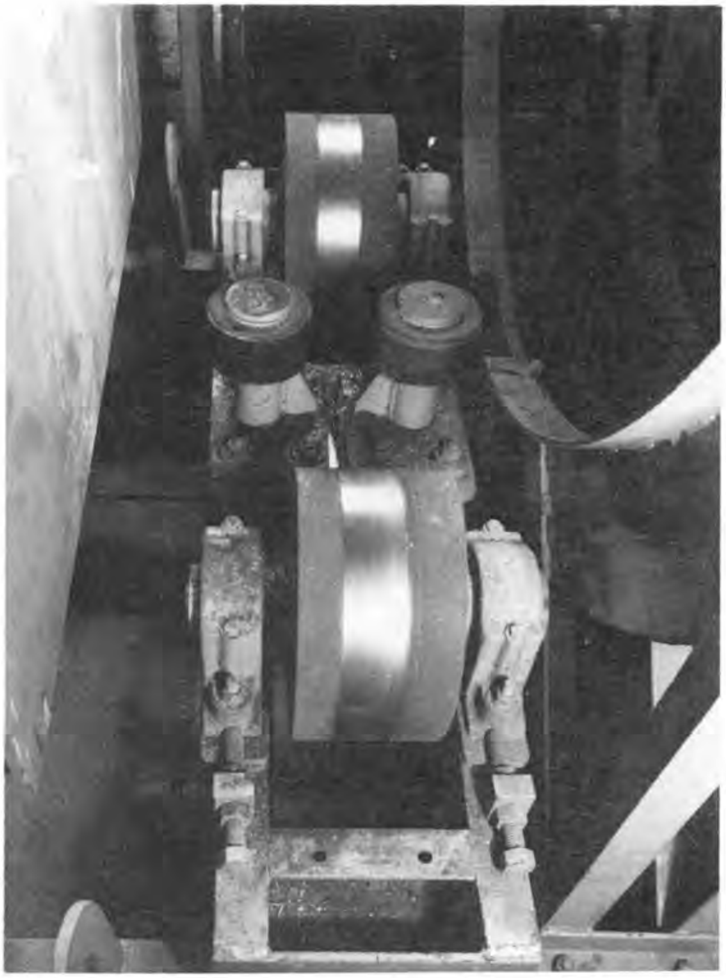

Fig. 2.14. Trunnion and thrust rollers located near feed end.

2.3.5 Cooling stacks

The first four furnace zones in the FSEV are equipped with natural convection cooling stacks to facilitate a programmed heating of the solids feed. Cold air is delivered to a furnace zone through a 3-in. sched-40 pipe serving as one leg of a closed-loop assembly. This cold air removes heat from the rotary drum and the internal surface of the furnace walls. The warmed air rises and enters a larger pipe (5-in. sched 40) where it is delivered to a water cooled heat exchanger. In passing through the exchanger, the air is cooled and then enters the opposite leg of the stack assembly and is again delivered to the furnace zone. By containing the cooling air within a closed system above the furnace zone the cross flow of air between furnace zones was avoided. Appropriate logic in the control system prevented simultaneous operation of the cooling stack and the furnace heater in a zone. A cutaway sketch of a furnace zone showing the flow path in the cooling circuit is presented in Fig. 2.17.

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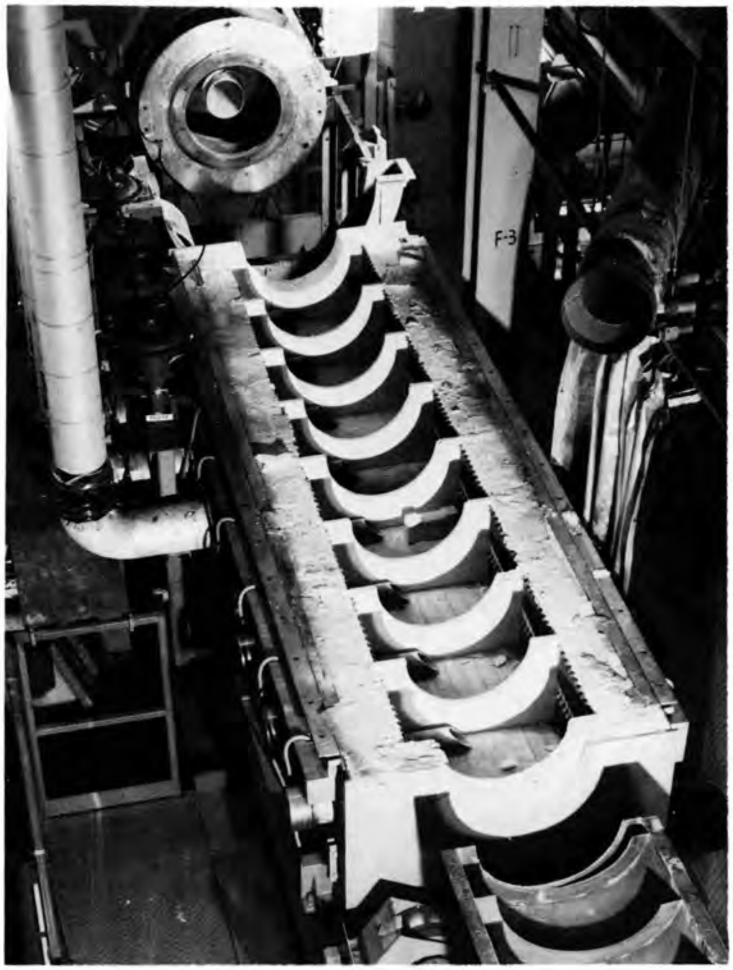

Fig. 2.15. View of furnace taken with furnace lid and drum removed.

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Fig. 2.16. Close-up of one furnace section showing heating elements and air pipes associated with cooling stacks.

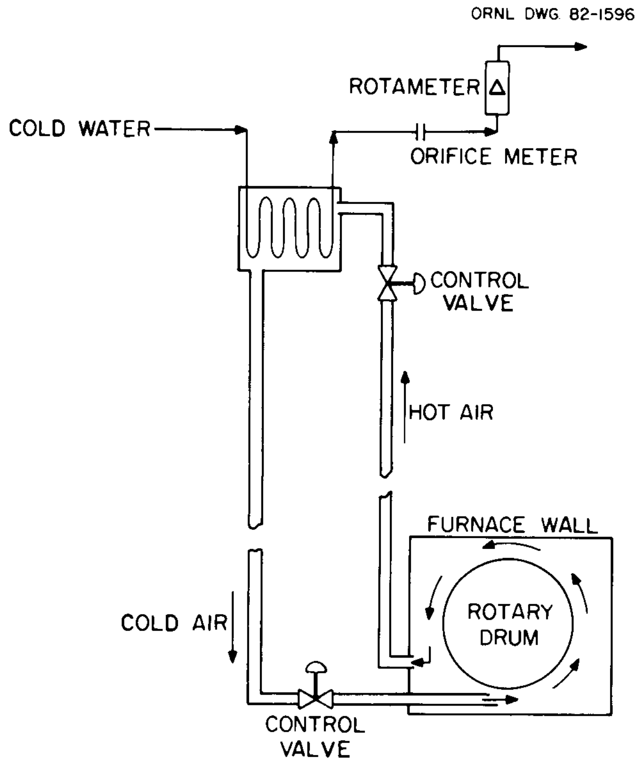

Fig. 2.17. Cooling circuit for a furnace zone.

2.3.6 Product cooler

The product is cooled by cooling a 1.52-m (5.0-ft) section of the drum with a flowing stream of air conducted about the drum by a loosely fitted sheet-metal enclosure called the product cooler (Fig. 2.18). The blower draws air through the product cooler so that all leakage will be into the product cooler. Most of the air flowing through the product cooler comes from outside of the building through a 25.4-cm (10.0-in.) duct and is discharged out of the building through a 30.5-cm (12.0-in.) duct. The temperature and velocity of the air in both the inlet and outlet ducts are measured, providing a means of computing the inleakage rate. The maximum capacity of the blower is 28.3 m^3/min (1000 cfm).

Cool air flow through the product cooler follows a helical pattern because the internal surface of the product cooler shell is fitted with helical baffles set on a 30.48-cm (12-in.) pitch (Fig. 2.19). Small gaps between the helical baffles and the drum are required to permit unrestricted rotation of the drum; however, the gaps do allow some bypass of the air. Flow of the air is countercurrent to the flow of solids within the drum. The circular component of the air flow path is directed opposite to the direction of drum rotation. The product cooler is designed to cool the solid material to 150°C or less before it is discharged from the rotary drum.

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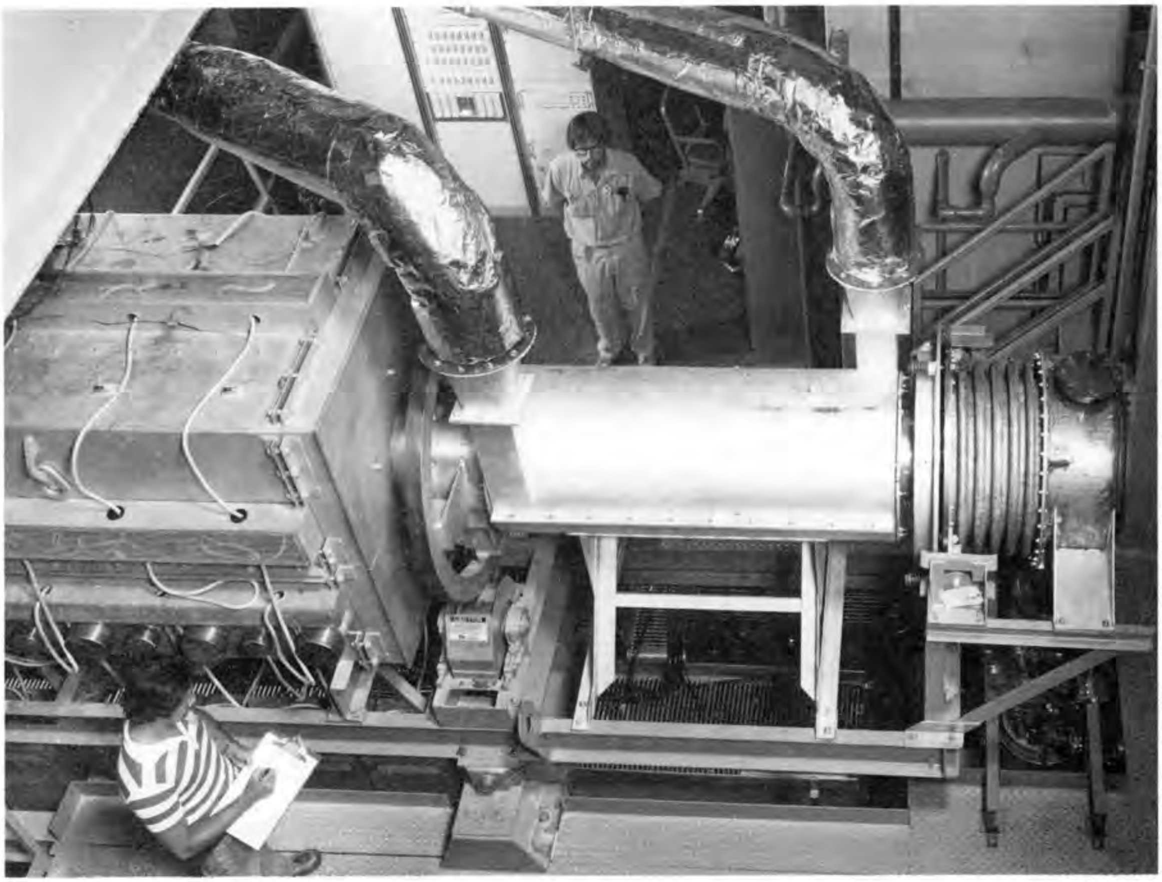

Fig. 2.18. Product cooler with air delivery and exhaust ducts.

2.3.7 Breeching sections and seals

At either end of the rotary drum, the calciner is equipped with a breeching section. The function of the breeching section is to act as an interface between the rotating drum and the stationary pipes and chutes. Furthermore, this interface must have the capability of isolating or sealing the process streams from the environment. Dry seals fabricated from graphite were chosen because of their resistance to damage by radiation. The seal assembly includes a graphite ring providing a sealing surface, which presses against the pressure plate welded to the outside surface of the drum; a bellows, which accommodates drum expansion and misalignment; and springs, cam rollers, and support plates, which maintain a constant pressure on the seal. All components except the drum pressure plate are attached to and supported by the breeching section (Fig. 2.20). Since such a sealing arrangement will leak, the voloxidizer is operated at a slight vacuum. Inleakage rates of 0.057 m^3/min (2 cfm) at 0.2-in. of water vacuum are typical.

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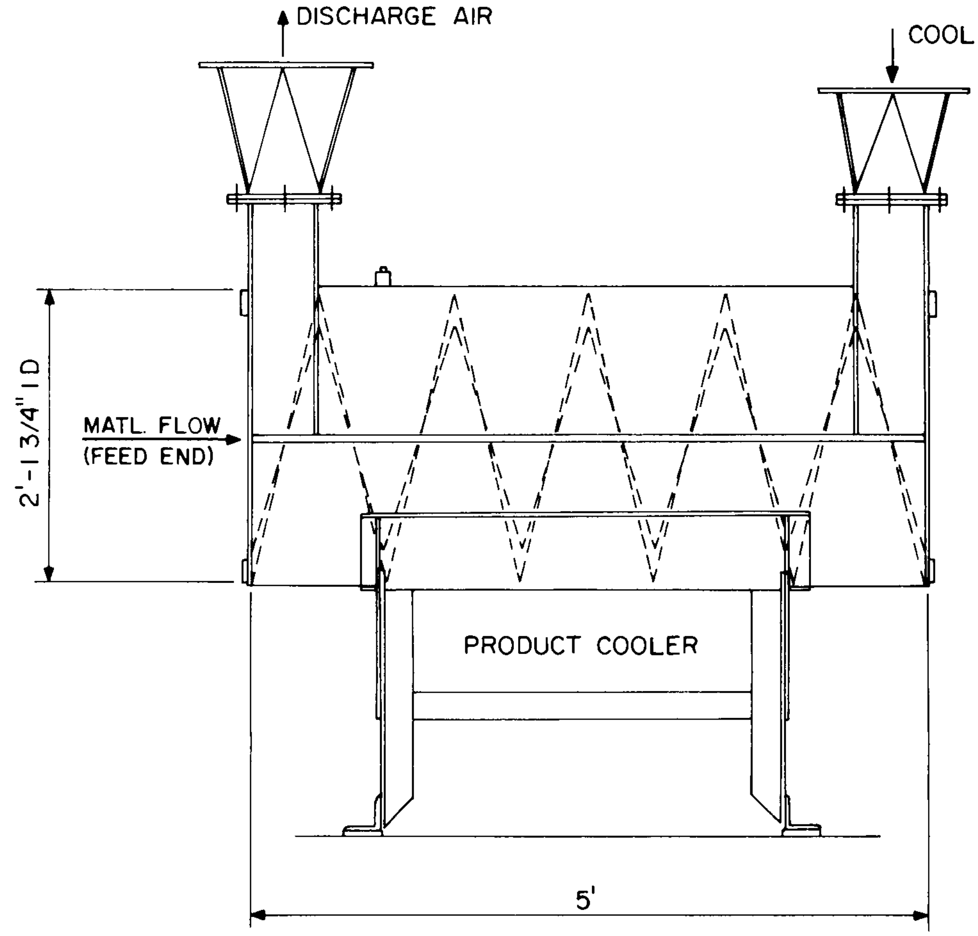

Fig. 2.19. The product cooler induces a helical flow pattern for air to follow.

2.3.8 Solids recirculation subsystem

Operating experience with the voloxidizer demonstrated that solid material, mostly fines, will spill from the gap between the rotary drum and the feed chute. By fabricating and installing a collar on the feed chute, the gap between the dam (part of the drum at the inlet) and the chute was reduced (Fig. 2.21); however, spillage of fines still occurred at a reduced rate. Any material spilled would collect in the inlet breeching section, eventually filling it.

A solids recirculation system was developed that would return spilled material to the feed chute from the breeching section. The apparatus was arranged (Fig. 2.22) so that the material would fall into the 2-in. sched-40 transfer line and come to rest in front of an air jet. On a predetermined schedule (e.g., every 2 h) the recycle pulse (a burst of air from the indicated tank) would be activated and the material transferred. One drawback is that additional air is added to the voloxidizer system.

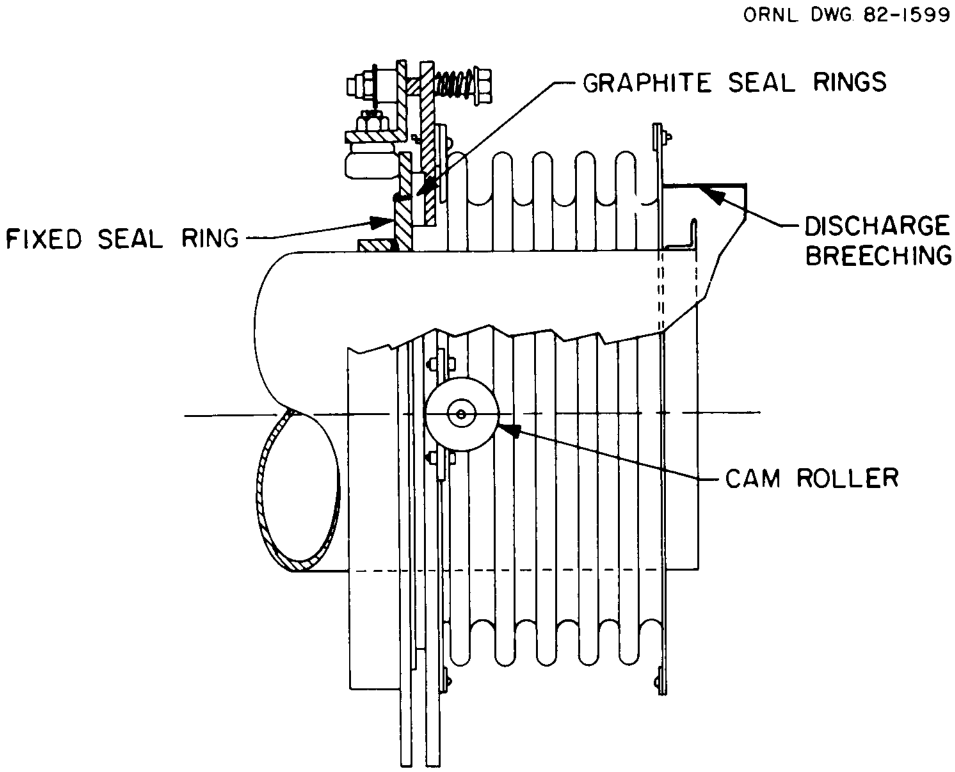

Fig. 2.20. Breeching sections support a bellows and rotary seal.

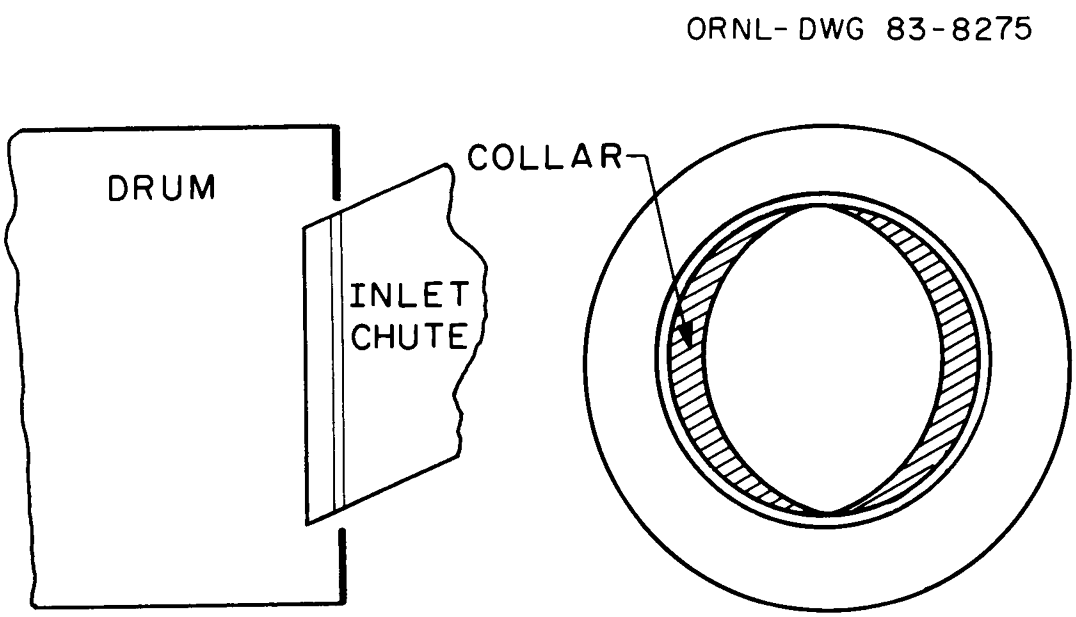

Fig. 2.21. Inlet chute fitted with collar.

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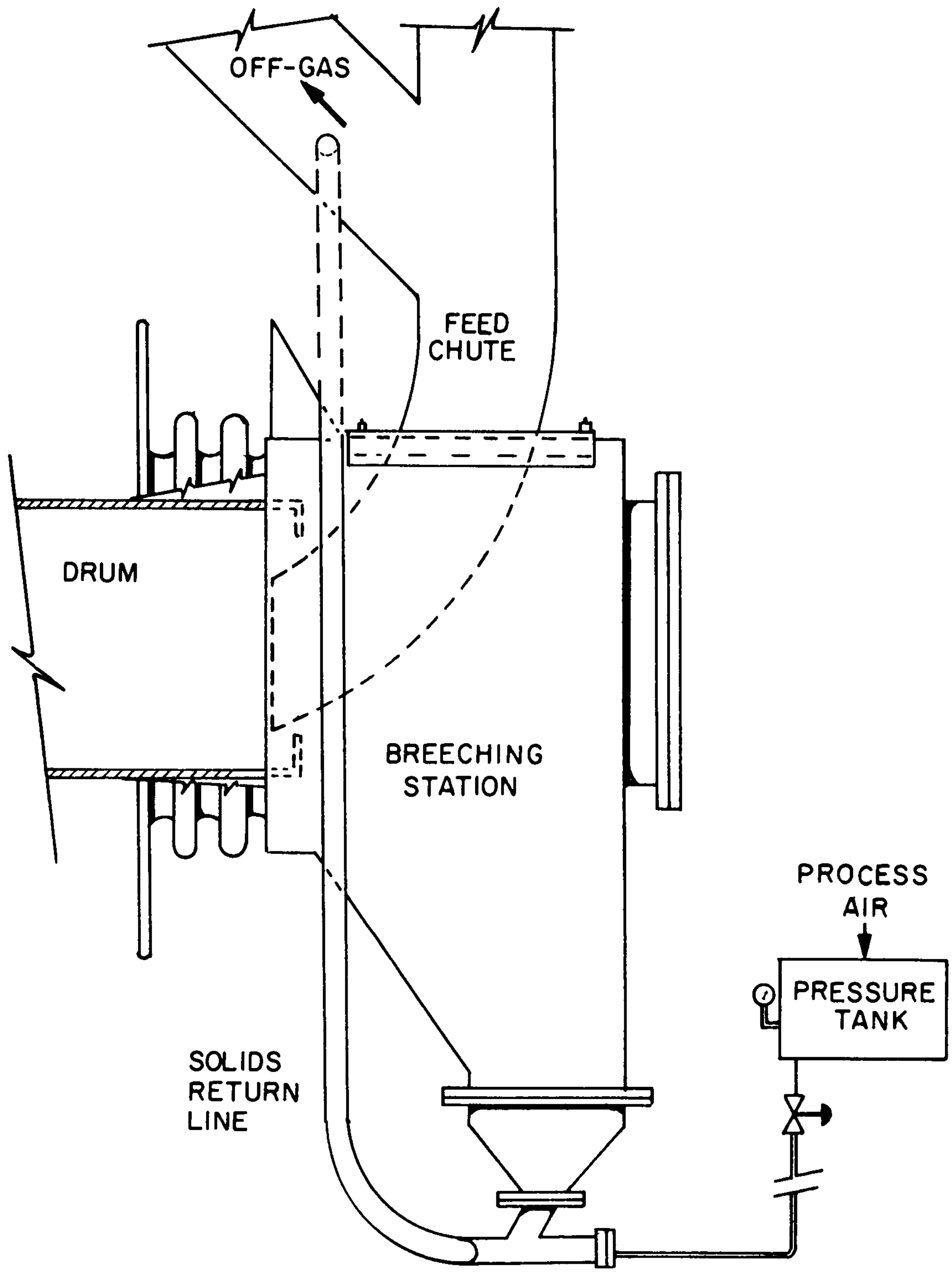

Fig. 2.22. Solids recirculating system.

2.4 Product Collection

A product collection facility has been provided as part of the FSEV. Solid product from the calciner must be collected into containers since a dissolver is not located downstream of this experimental unit. Because the solids used in the experimental program are inert stand-ins that simulate chopped fuel assemblies, the material is recycled to the feed house and used again.

2.4.1 Product flow path

Discharged solid product falls into the exit breeching section and is funneled into the exit chute. The product then falls past an expansion bellows (an 8-in.-diam bellows that accommodates movement of the breeching section relative to the stationary exit chute when the drum slope is changed), through a sampling station, and through two isolation valves (identical to those in the inlet chute described in Sect. 2.1.4); see Fig. 2.23.

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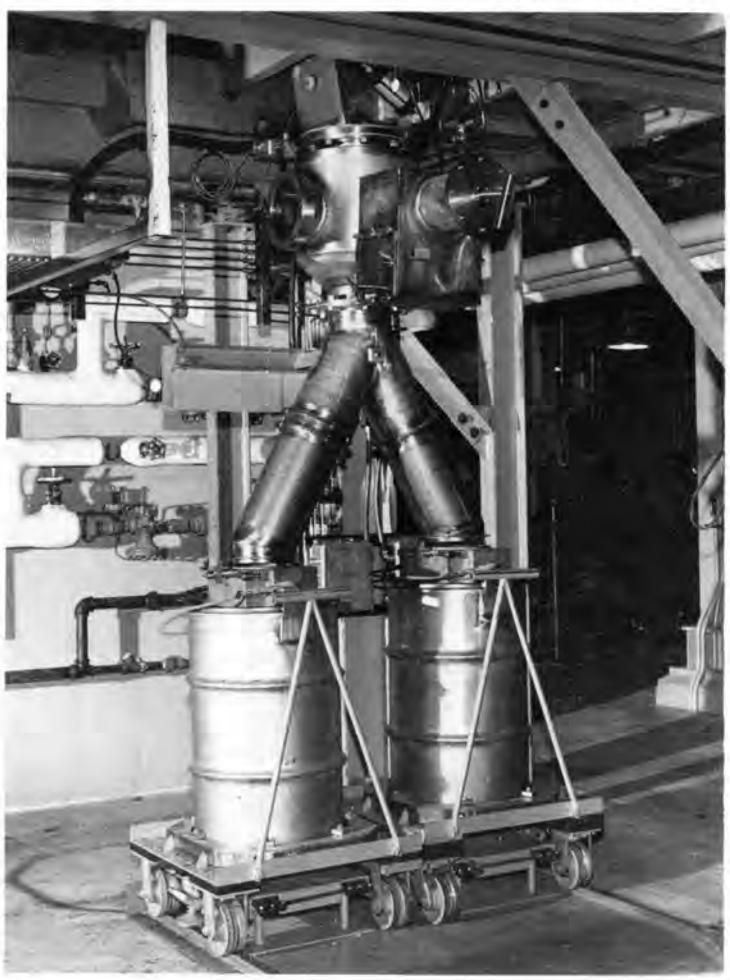

Fig. 2.23. Product collection station showing one isolation valve, sampling station, diverter valve, and receiving containers.

2.4.2 Diverter valve

Once past the isolation valves, the solids pass through a diverter valve (Fig. 2.23). The diverter valve is air operated and manually actuated. This valve permits the solids to flow in one of two directions and subsequently to be delivered to one of two product receivers. One receiver can be in service at all times even though the other receiver is being used to transfer material back to the feed house.

2.4.3 Product receivers

There are two identical product receivers, each resting upon its respective weigh cell. A receiver (see Fig. 2.23) is a drum fabricated with "trap" doors to provide for top filling and bottom discharge of solid material. Each drum has a capacity of 0.121 m^3 (4.28 ft^3).

The weigh cell upon which a receiver rests has a measurement range from 0 to 454 kg (1000 lb); however, because of the weight of the receiver and attached hardware, the net capacity (i.e., quantity of solids product that a receiver can accommodate) of a receiver is bounded to 272 kg (600 lb).

2.5 Gas Supply System

A compressed gas cylinder station (Fig. 2.24), located close to the calciner, provides feed gas for the FSEV. This gas is usually a mixture of oxygen and nitrogen used to enrich the atmosphere inside the rotary drum with oxygen. The gas is introduced at the exit breeching (i.e., the end of the calciner where solids are discharged) and flows countercurrent to the solids in the drum. Gas can be supplied at a rate of up to 1.7 std m^3/h (1.0 scfm).

2.6 Miscellaneous Equipment

Several other pieces of equipment are required for the operation of the FSEV. These manually operated devices are described below.

2.6.1 Overhead crane

The high bay area of Building 7603 is equipped with an overhead bridge crane. The capacity of the crane is 25 ton. During the installation of the FSEV and drum replacement activity, this crane (Fig. 2.25) was used extensively to move the heavy components into place.

2.6.2 One-ton hoist

A one-ton hoist was fitted to the trolley assembly of the overhead crane (Fig. 2.25) to provide for the transport of light materials. For example, this hoist was used during experimental campaigns to transport filled product receivers to the feed house where the feed material was recycled.

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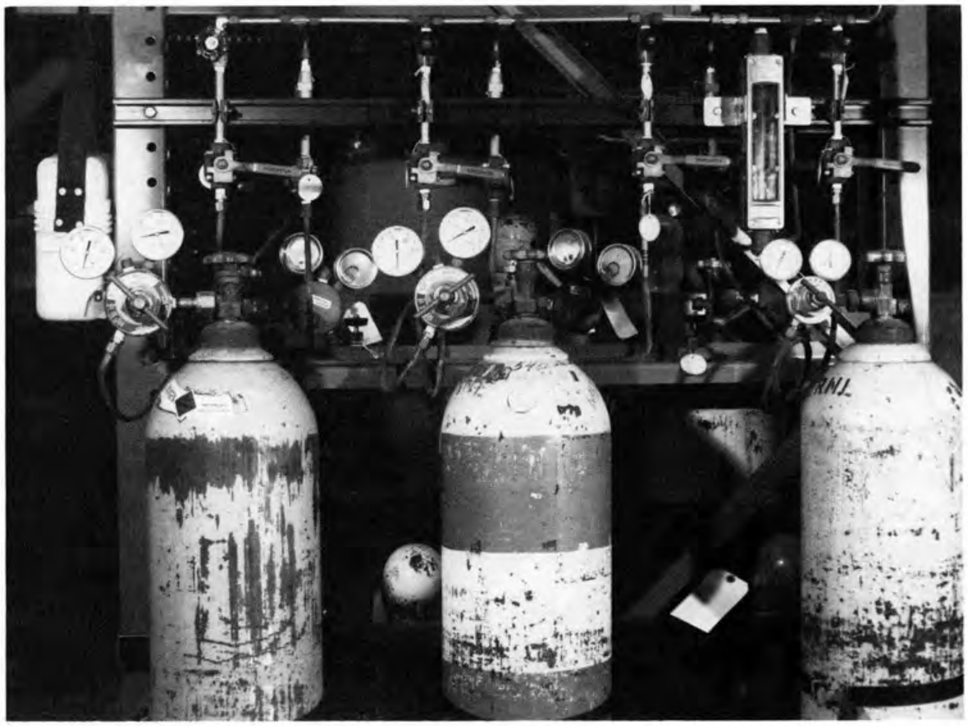

Fig. 2.24. Oxygen supply station.

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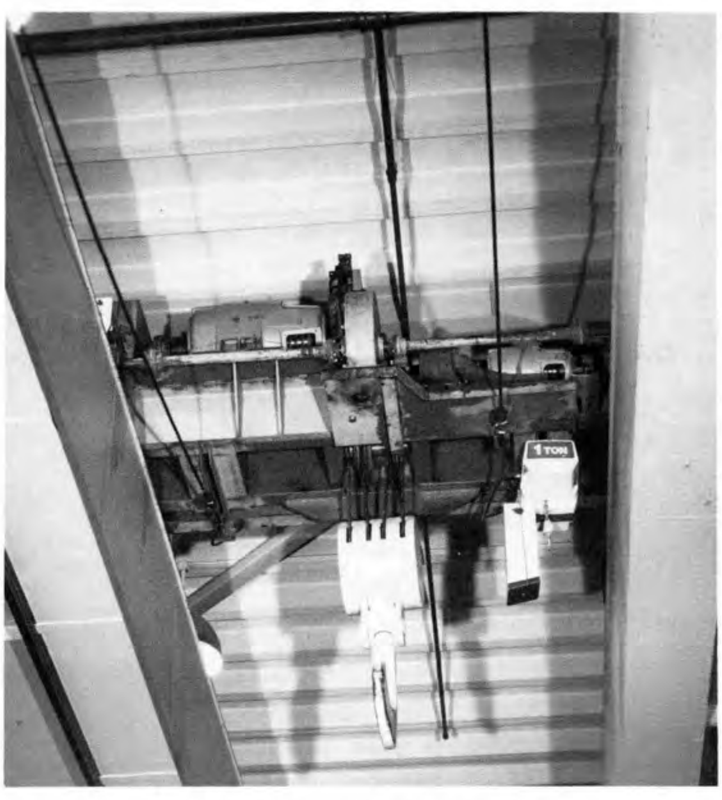

Fig. 2.25. Bridge crane with auxiliary hoist.

2.6.3 Auxiliary screener

An auxiliary screener (Fig. 2.26), located near the feed house, is used to separate the three feed components (sand, hulls, and shroud) in situations where one component is not to be recycled. The undesired component can then be replaced with fresh material prior to recycle to the feed house.

ORNL-PHOTO. 2630-82

Fig. 2.26. Auxiliary screener.

3. INSTRUMENTATION AND CONTROL HARDWARE

This section describes the instrumentation and controls (I&C) components used to obtain and condition signals from the appropriate field sensors and to provide control and data acquisition functions. Descriptions of the control system algorithms (software) appear in Sect. 4.

The instrumentation provides sensors and signal processing devices, controllers, field actuators, operation interface devices, and data recording equipment. A list of major components is provided in Table 3.1. Head-end data acquisition components, such as the thermocouple telemetry system and auto-data nine multiplexer, feed measured values of controlled (and noncontrolled) variables to the controller system. The control system, built around a programmable Bristol unit process controller (UPC), provides coordination of all operating logistics of the Full-Scale Experimental Voloxidizer (FSEV). Conditions of temperature, vacuum (pressure), solids feed rate, and oxygen supply rate for startup, steady operation, and shutdown are provided. The functional configuration of the automatic control system is shown in Fig. 3.1.

3.1 Field Sensors and Input Signal Processing

Field sensors are provided to measure temperature, pressure, weight, flow rate, electrical power, and gas composition. (Solids flow rates are inferred from weight measurements made at two different points in time, and fluid flow rates are inferred from differential pressure measurements across orifices, etc.) A list of measured quantities is provided in Table 3.2 along with information as to which section and table(s) to reference to trace specific measurements of interest.

3.1.1 Thermocouple telemetry

A TESDATA/INMET model 1910 temperature telemeter was provided to measure the temperature of the rotary drum in the FSEV. This device was chosen as the most reliable and accurate means to measure the temperature of the rotating drum using thermocouples as sensors.

The telemetry system consists of a transmitter mounted on the riding ring (nearest the solids discharge end) of the rotary drum, as shown in Figs. 3.2 and 3.3, and a receiver mounted in the instrument racks, as shown in Figs. 3.4 and 3.5. Power is provided to the transmitter through slip rings. Thirty-three type S thermocouples are connected to the 33

Table 3.1. List of major control system components

Item	Manufacturer	Model	Purpose of item
Thermocouple telemetry (1 ea)	Tesdata/Inmet Corporation	1910	Utilize 33 thermocouples to measure temperature of rotating drum at 33 locations
Auto-data nine (1 ea)	Accurex Corporation	AUTO-DATA NINE	Interrogate, digitize, and multiplex signals from many (~100) sensors, such as thermocouples and RTDs; transmit this data serially (ASCII) to the UPC
Power calculators (8 ea)	Scientific Columbus	6268-A7	Measure the power (kW) delivered to the furnace heating elements (one for each zone)
Oxygen analyzers (2 ea)	Mine Safety Appliances Company	MSA-803	Measure oxygen concentration at the inlet and discharge ends of the rotary drum
Bristol unit process controller (UPC) (1 ea)	The Bristol Company	UCS-3000	Overall control and data logging for the experimental voloxidizer
Serial line clock (1 ea)	Digital Pathways, Inc.	SLC-1	Provides time standard for all time-related functions; feeds directly to UPC
Furnace control panel (1 ea)	Bartlett-Snow Company		Houses the relay switches, recorder, and controller
12-pt. recorder (1 ea)	Honeywell	Electronik III 11170180-52020-00000-00-00010-102-18	Records furnace temperatures on strip chart from 0–1200°C
and controller (8 ea)	Honeywell	R7350J-1016-1	Controls individual furnace zones with on/off action as slave controllers with remote set point from UPC
Teletype (1 ea)	Digital Equipment Corporation	Decwriter II	Prints warnings, alarms, and instructions for operators
Data recorder (1 ea)	Techtran Industries, Inc.	8421	Records data logged by UPC on cassette tape (dual drive)
Cathode ray tube (CRT) (2 ea)	(1) Tektronix, Inc. (2) Lear Siegler, Inc.	4006-1 ADM-3A	Displays data being recorded. Spare CRT
System overview:	Intelligent Systems Corporation		Stores process data for retrieval on interrogation, and displays data in tabular and graphical form
disk drive (1 ea)		DUAL 8" F/D	
keyboard (1 ea)		KEYBOARD	
color CRT (1 ea)		8051	

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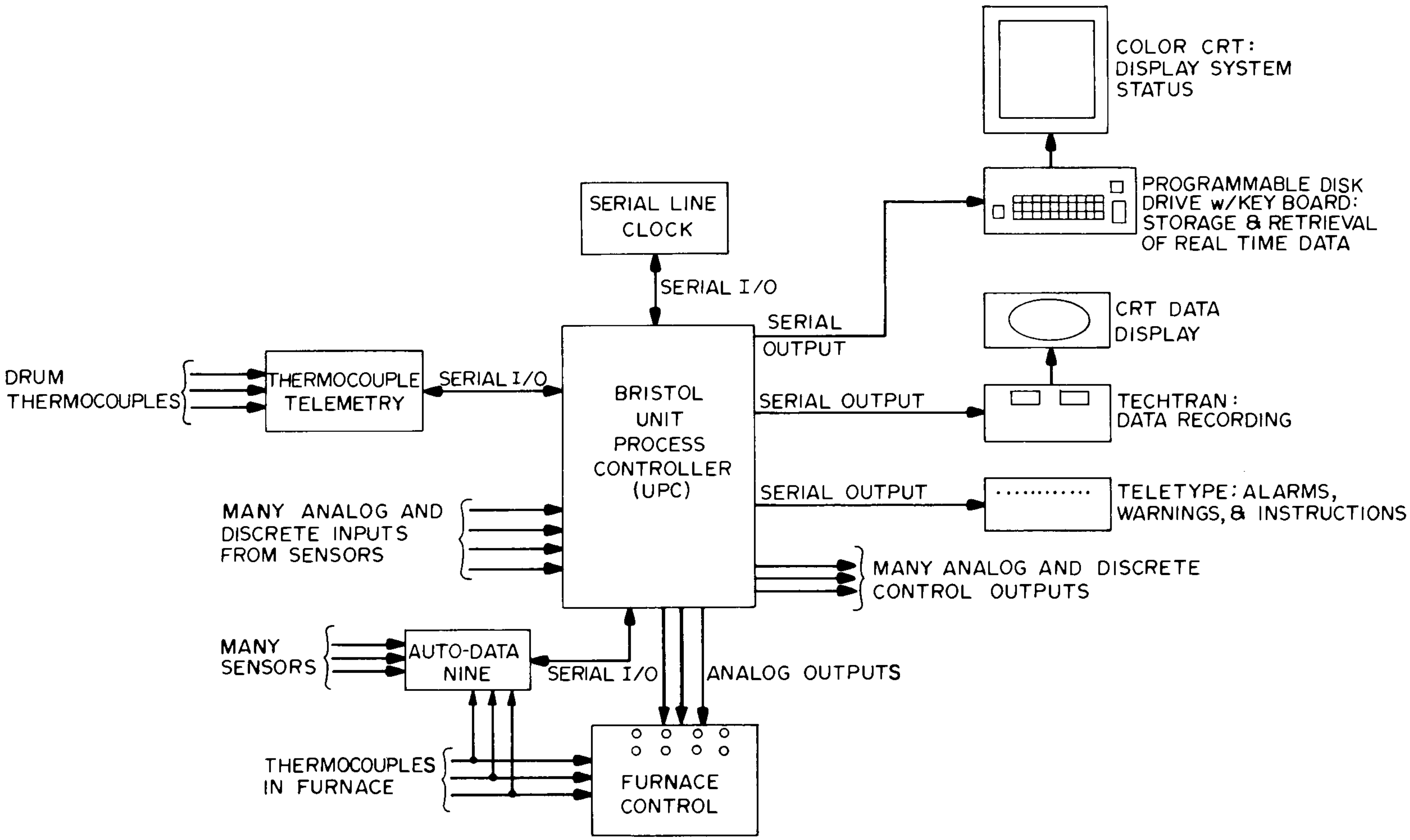

Fig. 3.1. Full-Scale Experimental Voloxidizer control system functional diagram.

Table 3.2. Quantities measured and types of sensors utilized

Quantity	Sensor(s)	Conditioning device	Applied to	Refer to
Temperature	Thermocouple, type K	Auto-data nine	All items except rotary drum and those associated with Honeywell controller	Tables 3.4 and 3.5
		Honeywell controller	Furnace zones	Sect. 3.3
	Thermocouple, type S	Telemetry system	Rotary drum	Table 3.3
		Auto-data nine	Test thermocouples in furnace zones	Tables 3.4 and 3.5
	Resistance temperature device	Auto-data nine	Cooling water for heat exchangers	Tables 3.4 and 3.6
Pressure	Differential pressure (DP) cells	Bristol	System pressure and pressure drop across orifices and pitot venturis	Table 3.7
	Integral orifice DP cells	Auto-data nine	Pressure drop resulting from water flow through orifice	Table 3.7
Flow	Rotameters	Operators	Water flow through heat exchangers	Table 3.7
	Bagmeter	Bristol	Off-gas flow	Table 3.7
Weight	Tridyne tip bucket	Schaevitz/Bristol	Solids feed material fed batchwise	Table 3.7
	Load cell	BLH/Bristol	Solids in feed trays and product receivers	Table 3.7
Power (electrical)	"Power calculators"	Scientific Columbus/ Bristol	Electrical power delivered to furnace heating elements	Sect. 3.1.3
Gas composition	Oxygen analyzers	MSA/Bristol	Oxygen concentration in voloxidizer	Sect. 3.1.4
Valve position, etc.	Micro-switches	Bristol	Isolation valves, diverter valve, etc.	Table 3.8

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Fig. 3.2. Telemetry system transmitter mounted on riding ring.

separate input ports on the transmitter. Reference junction compensation is built into the transmitter. Eleven "channels" are scaled to read temperatures in the range of 10 to 290°C, and the remaining 22 are scaled from 10 to 790°C. Each channel is scanned one time every second. The mV thermocouple signals are multiplexed, digitized, and transmitted via a frequency modulated (FM) link to the receiver. The receiver demodulates and demultiplexes the FM signal and performs error checking. Valid data are smoothed, linearized, and scaled to the desired range. Digitized data are then available to the Bristol UPC through an RS232-C serial link. At this point, the measurements are accurate to ±0.2% of full scale.

Thermocouples used with the telemetry system are type S (platinum vs platinum–10% rhodium) stainless steel sheathed ($^1/_{16}$-in.-diam). All tips of the sheaths (location of the actual thermocouple junctions) are imbedded in the drum to a depth of 0.476 cm ($^3/_{16}$ in.) except for thermocouples 3, 4, 5, 23, and 24, which were imbedded 1.429 cm ($^9/_{16}$ in.) to penetrate "sleeves" at those locations. Locations of the thermocouples on the drum are

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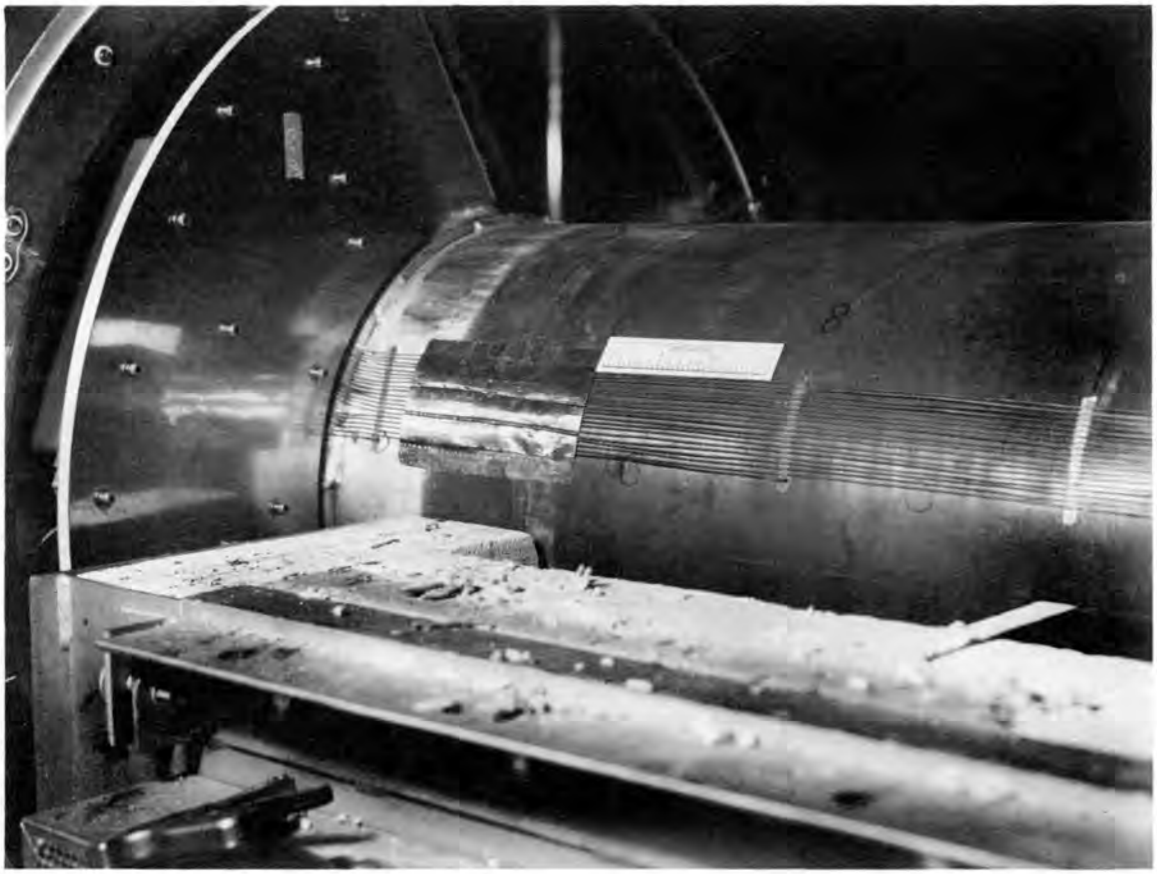

Fig. 3.3. Heat shield behind telemetry transmitter and thermocouples attached to drum.

illustrated in Fig. 3.6, and a tabulated key to those locations is given in Table 3.3. Each thermocouple was x-ray examined prior to installation to ensure quality junctions.

3.1.2 Auto-data nine

There are many temperature measurements important to the experimental program focused on studying the FSEV, other than those measurements of the drum temperature. Most of these measurements are made using thermocouples. An auto-data nine (AD9) system (Figs. 3.5 and 3.7), manufactured by Accurex Corp., was put into service to handle the more than 100 additional temperature measurements.

The AD9 is a microprocessor-controlled data acquisition system. It can be programmed at either standard or high resolutions to (1) interpret signals from a variety of thermocouple types (types J, K, T, E, R, and S, with ice-point compensation for each), (2) provide mV sources to, and interpret resulting signals from, resistance temperature devices (RTDs), and (3) provide for current conditioning measurements (e.g., 0–100 mV, 4–20 mA, or 10–50 mA). The AD9 scans "channels" at a rate of 24 channels per second, digitizes the signal

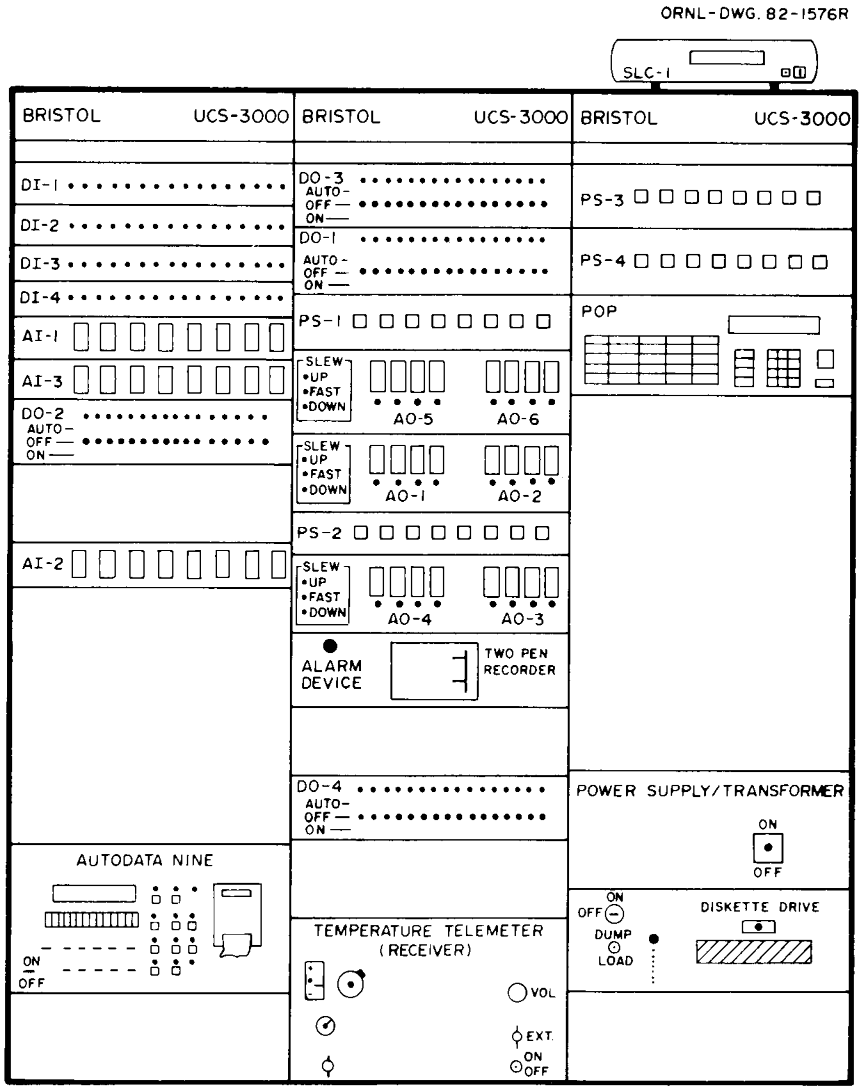

Fig. 3.4. Arrangement of module panels comprising Bristol Unit Process Controller.

in the units specified by the programmer, and multiplexes the data for serial output via an RS232-C link. Data are fed to the Bristol UPC through this link.

Table 3.4 shows the type of field sensors used and the units into which the respective signals are converted in the AD9. Either standard or high resolution is also indicated. High resolution is used for those items judged to have greater effect on equipment performance. Tables 3.5 and 3.6 give a terse description of sensor location by sensor number and by AD9 channel number. Tables 3.4, 3.5, or 3.6 may be cross-referenced to find the sensor type, conversion used, and signal resolution for any measured quantity using the AD9 channel number as an index.

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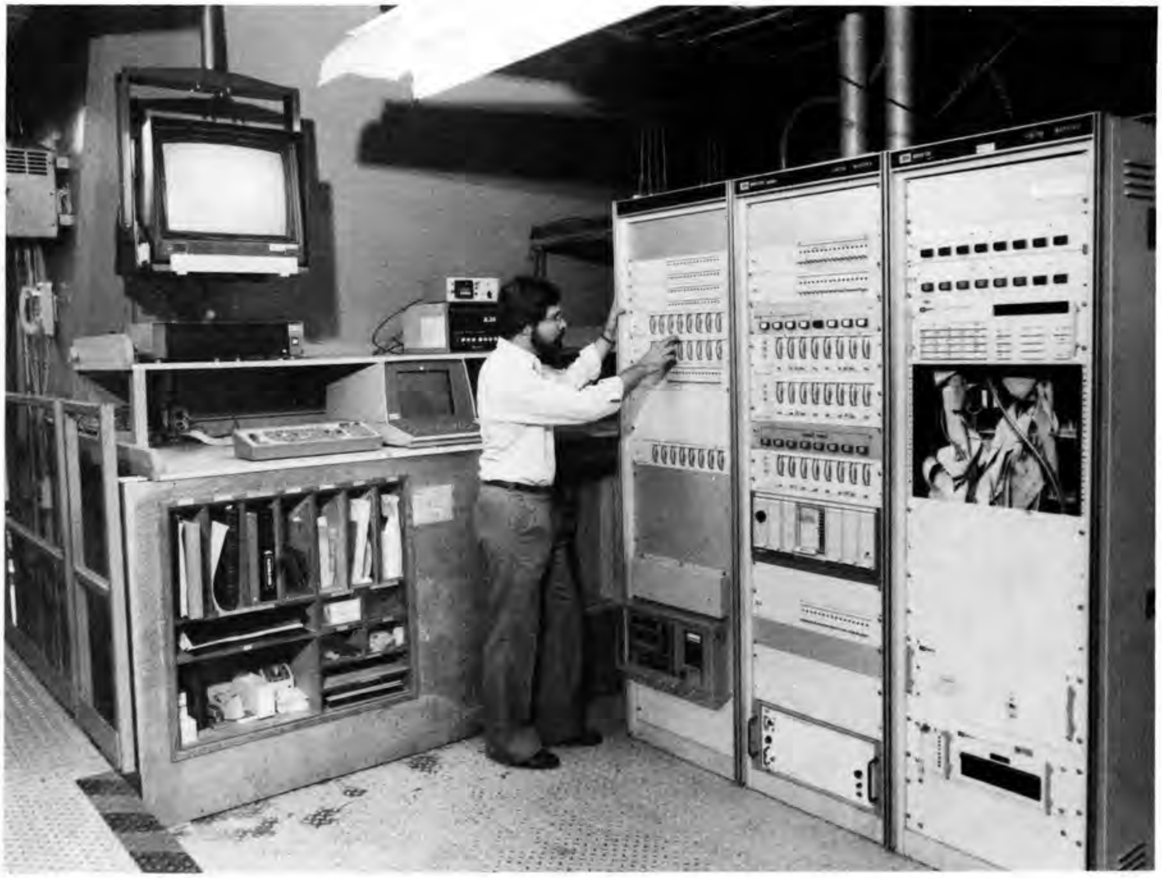

Fig. 3.5. Bristol UPC and some other instrumentation hardware.

3.1.3 Power calculators

Recall from Sect. 2.3.4 that the calciner furnace is divided into eight zones, each of which may be controlled (heated) individually so that desired temperature profiles can be maintained. For purposes of analysis, it was required that the power being supplied to each zone be measured. Each zone was equipped with a Scientific Columbus current watt transducer, model 6268-A7, so as to measure the power in kW delivered to the heating elements within. These instruments measure power in the range of 0 to 20.5 kW to within ±0.5% and generate a 4- to 20-mA signal to relay the information to an analog receiver. All eight instrument outputs were connected to analog input ports (8 ports, one for each signal) on the Bristol UPC.

3.1.4 Oxygen analyzers

Two oxygen analyzers are used with the FSEV to monitor oxygen concentration at the solids feed end of the drum and at the solids discharge. Control of oxygen concentration within the system is based on measurements at these two points.

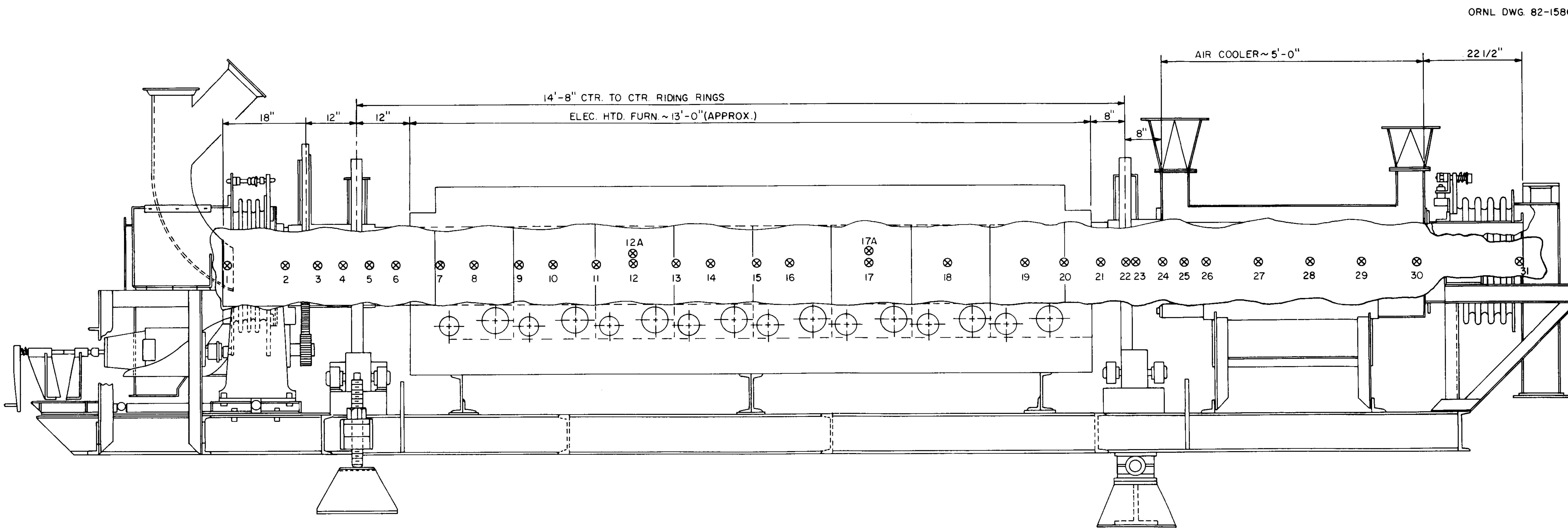

Fig. 3.6. Location of thermocouples on the rotary drum.

Table 3.3. Key to telemetry thermocouple locations

ITE[a]	Distance from feed end of drum (in.)	TC	Telemetry[b] channel
1	¼	1	1
2	14½	2	2
3	21	3	3
4	27	4	12
5	33	5	13
6	39	6	14
7	49	7	15
8	57	8	16
9	67	9	17
10	75	10	18
11	85	11	19
12	93	12	20
13	93	12A	21
14	103	13	22
15	111	14	23
16	121	15	24
17	129	16	25
18	147	17	26
19	147	17A	27
20	165	18	28
21	183	19	29
22	192	20	30
23	200	21	31
24	206	22	32
25	208	23	33
26	214	24	4
27	219	25	5
28	224	26	6
29	236	27	7
30	248	28	8
31	260	29	9
32	272	30	10
33	296¼	31	11

[a]The ITE number refers to the numbering system used in the controller; it is given here simply as a reference counter.

[b]Channels 1 through 11 are scaled from 10 to 290°C, and channels 12 through 33 are scaled from 10 to 790°C.

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Fig. 3.7. Auto-data nine.

Table 3.4. Auto-data nine programming by channel number

Channel(s)	Conversion[a]	Resolution[b]
000	K/°C	Hi
001–009	K/°C	Std
010	K/°C	Hi
011–019	K/°C	Std
020	K/°C	Hi
021–029	K/°C	Std
030	K/°C	Hi
031–039	K/°C	Std
040	K/°C	Hi
041–049	K/°C	Std
050	K/°C	Hi
051–059	K/°C	Std
060	K/°C	Hi
061–069	K/°C	Std
070	K/°C	Hi
071–079	K/°C	Std
080	S/°C	Hi
081–089	S/°C	Std
090–104	100 mV	Hi

[a]Conversion K/°C means that the signal from a type K thermocouple is converted to °C. The 100 mV implies conditioning for RTD's with output as mV.

[b]High (Hi) resolution is 0.001% of full scale; standard (Std) resolution is 0.01% of full scale.

Table 3.5. Location of thermocouples scanned by auto-data nine

Signal name and thermocouple number	Auto-data nine channel	Location of thermocouple
TE-1	00	Furnace zone 1, top of calciner between refractory and drum
TE-2	01	Furnace zone 2, top of calciner between refractory and drum
TE-3	02	Furnace zone 3, top of calciner between refractory and drum
TE-4	03	Furnace zone 4, top of calciner between refractory and drum
TE-5	04	Furnace zone 5, top of calciner between refractory and drum
TE-6	05	Furnace zone 6, top of calciner between refractory and drum
TE-7	06	Furnace zone 7, top of calciner between refractory and drum
TE-8	07	Furnace zone 8, top of calciner between refractory and drum
TE-9	08	None installed
TE-10	09	Surface of exit end breeching section below viewing port
TE-11	10	Cooling stack, zone 4, center of cold air leg at bottom of stack (temperature of cold air entering furnace zone)
TE-12	11	Cooling stack, zone 4, center of hot air leg at bottom of stack (temperature of hot air leaving furnace zone)
TE-13	12	Cooling stack, zone 3, center of cold air leg at bottom of stack
TE-14	13	Cooling stack, zone 3, center of hot air leg at bottom of stack
TE-15	14	Cooling stack, zone 2, center of cold air leg at bottom of stack
TE-16	15	Cooling stack, zone 2, center of hot air leg at bottom of stack
TE-17	16	Cooling stack, zone 1, center of cold air leg at bottom of stack
TE-18	17	Cooling stack, zone 1, center of hot air leg at bottom of stack
TE-19	18	Center of off-gas pipe at first connecting flange
TE-20	19	Inside surface of first flange of off-gas pipe
TE-21	20	Cooling stack, zone 4, center of hot air leg at top of stack (temperature of hot air entering heat exchanger)
TE-22	21	Cooling stack, zone 4, center of cold air leg at top of stack (temperature of air leaving heat exchanger)

Table 3.5 (continued)

Signal name and thermocouple number	Auto-data nine channel	Location of thermocouple
TE-23	22	Cooling stack, zone 3, center of hot air leg at top of stack
TE-24	23	Cooling stack, zone 3, center of cold air leg at top of stack
TE-25	24	Cooling stack, zone 2, center of hot air leg at top of stack
TE-26	25	Cooling stack, zone 2, center of cold air leg at top of stack
TE-27	26	Cooling stack, zone 1, center of hot air leg at top of stack
TE-28	27	Cooling stack, zone 1, center of cold air leg at top of stack
TE-29	28	Center of duct feeding air to product cooler
TE-30	29	Center of duct removing air from product cooler
TE-31	30	Heat exchangers, surface of water feed pipe
TE-32	31	Heat exchanger, zone 4, surface of water discharge pipe
TE-33	32	Heat exchanger, zone 3, surface of water discharge pipe
TE-34	33	Heat exchanger, zone 2, surface of water discharge pipe
TE-35	34	Heat exchanger, zone 1, surface of water discharge pipe
TE-36	35	Product cooler, in air stream near bottom of cooler, east side (temperature of air near air discharge of product cooler)
TE-37	36	Product cooler, in air stream near top center of cooler
TE-38	37	Product cooler, in air stream near bottom of cooler, west side (air feed to product cooler)
TE-39	38	Product cooler, center, bottom surface of cooler
TE-40	39	Below frame of calciner (ambient air temperature)
TE-41	40	Furnace zone 1, top north side of heater insulation
TE-42	41	Furnace zone 2, top north side of heater insulation
TE-43	42	Furnace zone 3, top north side of heater insulation
TE-44	43	Furnace zone 4, top north side of heater insulation

Table 3.5 (continued)

Signal name and thermocouple number	Auto-data nine channel	Location of thermocouple
TE-45	44	Furnace zone 5, top north side of heater insulation
TE-46	45	Furnace zone 6, top north side of heater insulation
TE-47	46	Furnace zone 7, top north side of heater insulation
TE-48	47	Furnace zone 8, top north side of heater insulation
TE-49	48	Product cooler, inlet duct, 2-in. penetration into duct and 1 in. from pitot venturi
TE-50	49	Product cooler, inside surface of discharge duct flange
TE-51	50	Cooling stack, zone 4, inside surface at bottom of hot air leg
TE-52	51	Cooling stack, zone 4, inside surface at bottom of cold air leg
TE-53	52	Cooling stack, zone 3, inside surface at bottom of hot air leg
TE-54	53	Cooling stack, zone 3, inside surface at bottom of cold air leg
TE-55	54	Cooling stack, zone 2, inside surface at bottom of hot air leg
TE-56	55	Cooling stack, zone 2, inside surface at bottom of cold air leg
TE-57	56	Cooling stack, zone 1, inside surface at bottom of hot air leg
TE-58	57	Cooling stack, zone 1, inside surface at bottom of cold air leg
TE-59	58	Product cooler, discharge duct, 2-in. penetration into duct and 1 in. from pitot venturi
TE-60	59	Off-gas pipe, center of pipe underneath filter
TE-61	60	Off-gas pipe, inside surface of pipe near lower flange
TE-62	61	Southeast roller (trunnion) bearing, surface mounted
TE-63	62	Northeast roller (trunnion) bearing, surface mounted
TE-64	63	Northwest roller (trunnion) bearing, surface mounted
TE-65	64	Southwest roller (trunnion) bearing, surface mounted
TE-66	65	Thrust roller, surface of roller nearest furnace

Table 3.5. (continued)

Signal name and thermocouple number	Auto-data nine channel	Location of thermocouple
TE-67	66	Drive motor, center, top surface
TE-68	67	Feed house, northwest corner of ceiling (ambient temperature in feedhouse)
TE-69	68	Furnace control panel, inside (temperature of air inside controller)
TE-70	69	Bristol UPC (inside air temperature)
TE-71	70	Flapper valve 1, outside surface
TE-72	71	Flapper valve 3, outside surface
TE-73	72	Furnace insulation, outside surface of west center top
TE-74	73	Furnace insulation, outside surface of south center top
TE-75	74	Product drum (either 1 or 2 according to whichever is in use), inside with collecting product
TE-76	75	Sand feeder, center of vibrating tray
TE-77	76	Sample station, discharge sample spoon
TE-78	77	Water operated heat exchanger, outside surface
TE-79	78	Bellows, discharge end, surface
TE-80	79	Bellows, feed end, surface
TE-81	80	Furnace zone 1 (test thermocouple, in 1-in. well in calcium silicate block); used to measure drum temperature
TE-82	81	Furnace zone 2 (test thermocouple, in 2-in. well in calcium silicate block)
TE-83	82	Furnace zone 4 (test thermocouple, in platinum cone at bottom of 3-in. well in calcium silicate)
TE-84	83	Furnace zone 5 (test thermocouple, in platinum cone at bottom of 3-in. well in calcium silicate)
TE-85	84	Furnace zone 7 (test thermocouple, in platinum cone at bottom of 3-in. well in calcium silicate)
TE-86	85	Furnace zone 8 (test thermocouple in platinum cone at bottom of 1-in. well in calcium silicate)
TE-87	86	Not used
TE-88	87	Not used
TE-89	88	Not used
TE-90	89	Not used

Table 3.6. Location of miscellaneous sensors scanned by auto-data nine

Signal name	Auto-data nine channel	Sensor	Location of sensor and purpose
TE-91 (RTD-1)	90	RTD[a]	Heat exchanger, zone 1, water discharge temperature
TE-92 (RTD-2)	91	RTD	Heat exchanger, zone 2, water discharge temperature
TE-93 (RTD-3)	92	RTD	Heat exchanger, zone 3, water discharge temperature
TE-94 (RTD-4)	93	RTD	Heat exchanger, zone 4, water discharge temperature
TE-95 (RTD-5)	94	RTD	Heat exchangers, common header to each exchanger, water inlet temperature
TE-96	95		Not used
TE-97	96		Not used
TE-98	97		Not used
TE-99	98		Not used
TE-100	99		Not used
FLW-1	100	IODP[b]	Heat exchanger, zone 1, water flow
FLW-2	101	IODP	Heat exchanger, zone 2, water flow
FLW-3	102	IODP	Heat exchanger, zone 3, water flow
FLW-4	103	IODP	Heat exchanger, zone 4, water flow
	104		Not used

[a]Resistance temperature device (RTD).
[b]Integral orifice differential pressure (IODP) transmitter.

The two oxygen analyzers, each MSA model 803, were purchased from the Mine Safety Appliances Company (MSA). Oxygen analysis is performed through the use of a "fuel cell" composed of a rare earth stabilized zirconium oxide solid electrolyte with platinum electrodes deposited on the inside and outside. Operating at ~750°C, the cell generates a logarithmic voltage output dependent on the ratio of the partial pressure of O_2 in a reference gas to the partial pressure of O_2 in the sample gas. Sample gas is continuously withdrawn at a rate of 0.47 L/min (1.0 cfh) from the process, and air is used as the reference gas. Concentrations of 1.0 to 100.0% oxygen can be measured to within ±2% of full scale. Measurements are scaled from 4- to 20-mA dc outputs, which are tied directly to analog inputs on the Bristol UPC.

3.1.5 Other instrumentation

Many other instruments are used in the FSEV to make measurements required for process control or for data logging (Table 3.7). Basically, these instruments measure pres-

Table 3.7. Instruments/sensors and physical quantity measured

Instrument/sensor	Manufacturer	Model	Quantity measured	Measurement range	Output signal/ range	Signal destination
Integral orifice differential pressure (DP) cell (4 ea)	Foxboro	E13DL	Pressure drop across orifice (implies water flow rate to each of the four cooling stack heat exchangers)	5–25-in. H_2O (0.55 – 5.50 L/min)	0–5 mV	Auto-data nine
Rotameters (4 ea)	Brooks Instrument Division	1110–08 H2B1B	Water flow rate to each of the four cooling stack heat exchangers	0.55–5.50 L/min	10–100% (visual reading)	Operator (for manual adjustment)
Rotameters (2 ea)	Fischer and Porter Company	7710A1164A1	Sample gas flow to each of the two oxygen analyzers	1–1.2 ft^3/h	1–1.2	Operator (for manual adjustment)
DP cell (1 ea)	Foxboro	E13DM	Voloxidizer system vacuum at feed chute	0–20-in. H_2O	4–20 mA	Bristol Unit Process Controller (UPC)
DP cell (1 ea)	Foxboro	E13DL	Voloxidizer system vacuum at feed end of drum	0–6-in. H_2O	4–20 mA	Bristol UPC
DP cell (1 ea)	Foxboro	E13DL	Voloxidizer system vacuum at product drums	0–6-in. H_2O	4–20 mA	Bristol UPC
Bagmeter (1 ea)	Singer/American Meter Division	AL-800	Off-gas flow rate	NA[a]	1 digital count/ft^3 of gas flow-through	Bristol UPC
DP cell (1 ea)	Foxboro	E13DL	Pressure drop across off-gas filter	0–10-in. H_2O	4–20 mA	Bristol UPC
DP cell (1 ea)	Foxboro	E13DM	Pressure drop across orifice (implies oxygen flow rate to voloxidizer)	0–100-in. H_2O	4–20 mA	Bristol UPC
DP cell (1 ea)	Foxboro	E13DL	Pressure generated by pitot venturi described second item below (implies inlet air flow rate to cooling section)	0–3-in. H_2O	4–20 mA	Bristol UPC
DP cell (1 ea)	Foxboro	E13DL	Pressure generated by pitot venturi described next item below (implies outlet air flow rate from cooling section)	0–5-in. H_2O	4–20 mA	Bristol UPC
Pitot-venturi (2 ea)			Flow, see above two items			DP cell, above
Tip bucket (1 ea)	Tridyne with Schaevitz signal conditioner	(Schaevitz) LPM-210	Mass per shot of feed material fed through tip bucket	0–1000 g	4–20 mA	Bristol UPC
Load cell platform (5 ea)	BLH Electronics	5200	Mass of feed or product as follows: (1) sand hopper, 0–227 kg (2) hulls hopper, 0–227 kg (3) shroud hopper, 0–114 kg (4) product receiver 1, 0–272 kg (5) product receiver 2, 0–272 kg	0–454 kg	4–20 mA	Bristol UPC

[a]Not applicable.

sures, flow rates, and weight. Limit switches are also used to monitor valve positions and operational readiness of some systems (detailed in Table 3.8).

Table 3.7 lists the instruments by name and gives manufacturer, model number, quantity measured, measurement range, output signal and range, and signal destination. As shown, most of these signals are linked directly to the Bristol UPC; all signals end up in the Bristol UPC although they may initially be processed through an instrument such as the AD9.

Table 3.8. Items monitored with limit switches[a]

Item	Meaning of discrete, on/off, signal(s)	Number of switches required
Isolation valve 1	Proper opening and closing of valve	2
Isolation valve 2	Proper opening and closing of valve	2
Isolation valve 3	Proper opening and closing of valve	2
Isolation valve 4	Proper opening and closing of valve	2
Product receiver 1	Receiver is raised into position	1
Product receiver 2	Receiver is raised into position	1
Diverter valve	Valve positioned to deliver product to receiver 1 or 2	2
Drum rotation[b]	Drum has made a full revolution	1

[a]All signals are connected to discrete input ports on the Bristol UPC.

[b]Switch is tripped by a wire, which is connected to drum, each time the drum completes one full revolution. Using the time elapsed between successive switch-trips, the Bristol UPC calculates the rotational speed; and if the time between trips is longer than a predetermined value, the Bristol UPC sounds an alarm indicating that the drum has stopped.

3.2 Unit Process Controller (UPC)

The UPC (Bristol, model UCS-3000) is a microprocessor based control system. It is essentially a computer programmed to operate in real time and to perform real-time control operations. This device provides continuous analog and discrete control functions and regulates the data acquisition functions. Since the UPC is programmable, control algorithms can easily be adapted to changing scope and objectives. Within the control framework devised, the UPC acts as both a prime controller and a master controller.

The Bristol UPC (Figs. 3.4 and 3.5) consists of rack mounted modules, housing such components as computer memory, central processing unit (CPU), serial input/output (I/O) cards, display panels, operators panel (keyboard), software maintenance panel, floppy disk drive, and power supply (transformer). The CPU is an 8080 microprocessor. Total random access memory (RAM) available for storage of control algorithms is 60K bytes.

3.2.1 Programming

Although the entire procedure of programming the Bristol UPC will not be presented in this report, it is appropriate to mention some functions of the controller that fall in the domain of programming.

The controller is a digital computer that can perform the functions of an analog controller using algorithms written in finite difference form. To facilitate programming, the vendor has developed 22 software modules that simulate all basic hardware functions [proportional-integral-derivative (PID) controller, comparator, peak detector, etc.]. Calculator modules with equations specified by the user allow for advanced digital control techniques. These modules can be linked together by the use of common variable names, referred to as "wires," to perform any control function that analog systems perform. The maximum number of wires allowed is 1500.

There are several methods and combinations of methods to program the Bristol UPC, ranging from programming in machine language through the programmer maintenance panel (PMP) to writing a source program in a high-level language (e.g., ACCOL F) and then using a main-frame computer to translate this information into the machine language object code; the latter is the preferred method. The executable code is stored on a floppy disk (a magnetic media) and can be copied into computer memory using the disk drive. Changes to the program can be made through the PMP, and limited changes (such as connecting software wires to other modules) can be made through the process operators panel (POP), shown in Fig. 3.8. To retain changes, the disk drive can record contents of the main memory on a floppy disk, using the disk drive illustrated in Fig. 3.9.

3.2.2 Field interface and signal connections

The controller software communicates to the outside world via serial I/O, analog, and discrete signals. Serial I/O will be discussed in the next section.

The Bristol UPC is factory equipped to handle both analog input (AI) and analog output (AO) signals. Sensors in the field are hard-wired to AI ports on the controller. An electrical signal coming from such a sensor is scaled, digitized with a 12-bit hardware analog-to-digital (A/D) converter, and read by the CPU. Each AI port is fitted with a dial gage (see Fig. 3.10), providing a visual indication of signal magnitude on a scale of 0 to 100%

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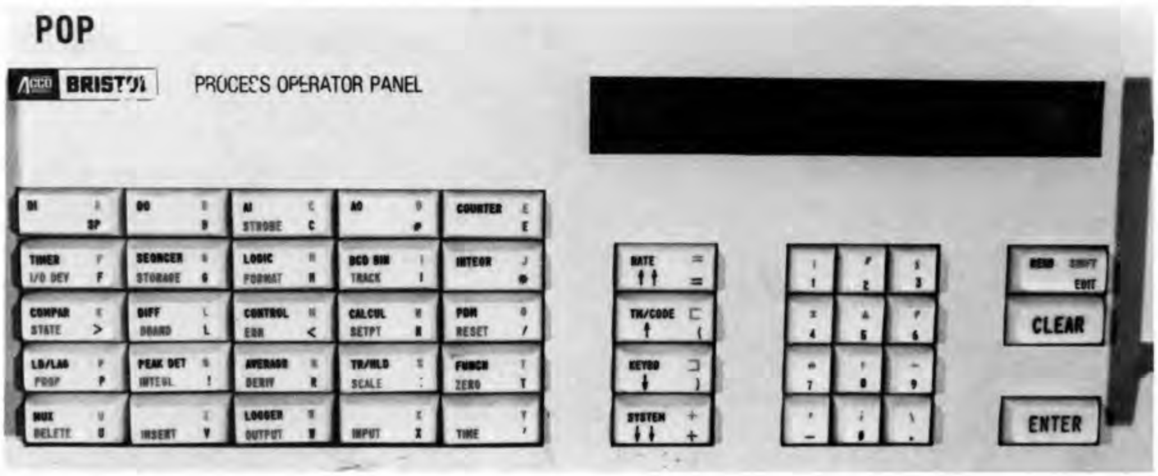

Fig. 3.8. Process operator panel.

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FLOPPY DISK PANEL

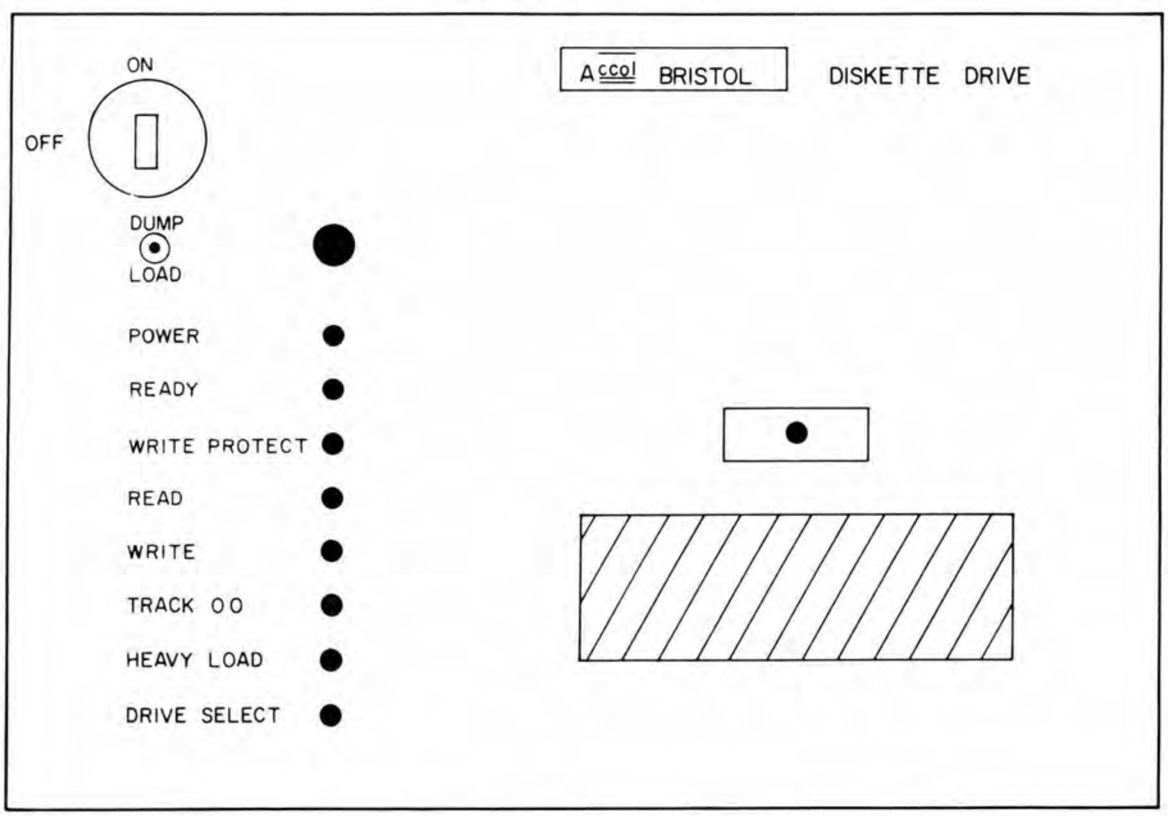

Fig. 3.9. Disk drive unit.

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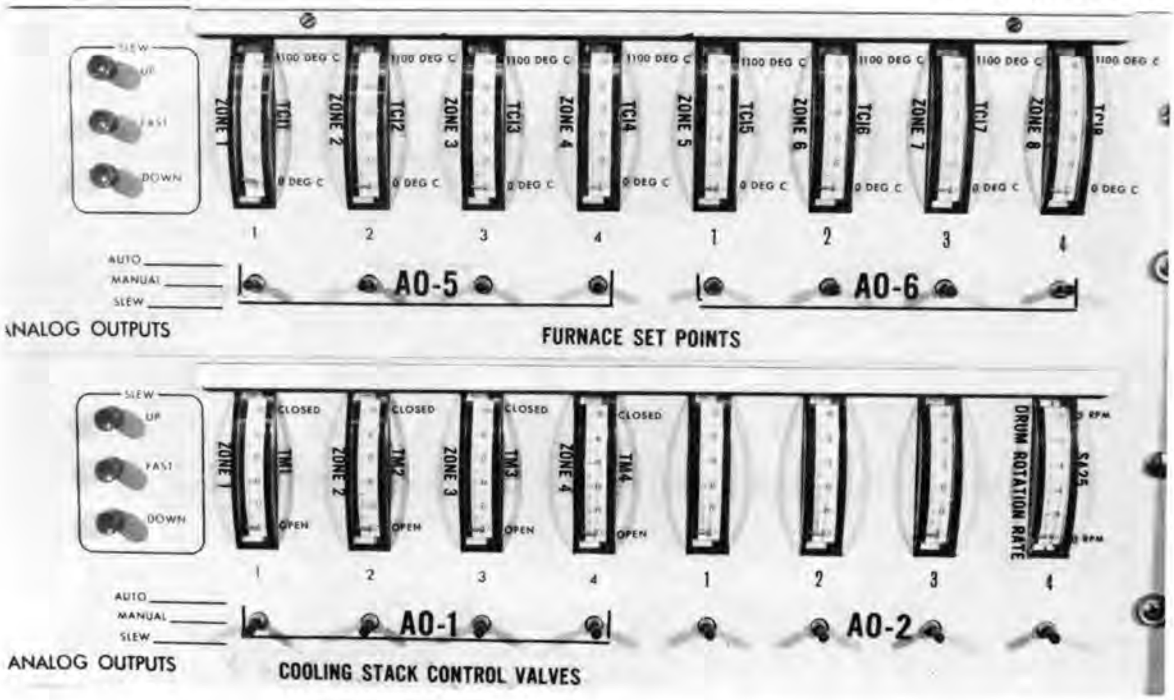

Fig. 3.10. Analog output panel.

of full scale. An AO works in the reverse order with a digital signal originating in the CPU, resulting in an analog signal to drive a field actuator. A dial gage is also provided for each AO so that the control output can be read (0–100% of full scale) at a glance. Analog outputs are further equipped with a manual override switch and can be adjusted manually to a desired output level. Bumpless, balanceless transfer switching between control modes (i.e., automatic and manual) is provided. Analog inputs are read only and cannot be changed manually.

Discrete inputs (DI) and discrete outputs (DO) are other features of the controller. A DI may originate as an on/off signal from a trip-switch in the field and is interpreted by the machine as an on/off signal which the CPU may read. Similarly a DO turns components, in the field, on or off as instructed by the CPU. All DI and DO have light-emitting diodes (LED) to indicate signal status; DI has read only capability, whereas DO has a manual on/off control.

The controller has been configured with 24 AI, 48 DI, 24 AO, 48 DO, and 32 panel switches (PS) which act as DI. (PS units allow operators to turn on specific control algorithms through the CPU.) Photographs of the AO and DO panels are given in Figs. 3.10 and 3.11 respectively. A DI panel looks like a DO panel without the manual override controls, and an AI panel looks like an AO panel without override controls.

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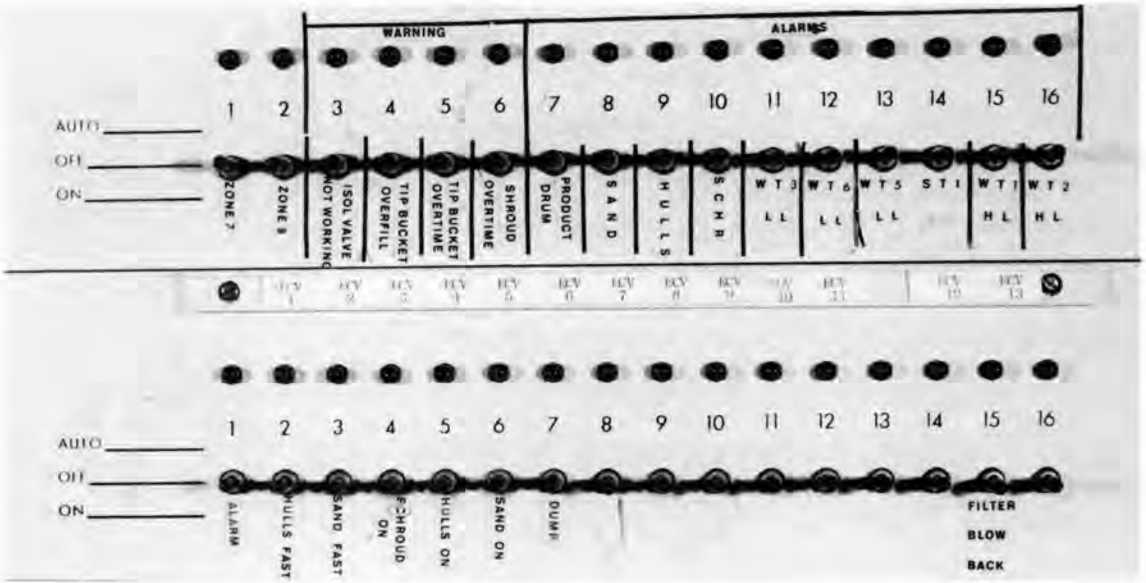

Fig. 3.11. Discrete output panel.

Input signals, to either the DI or AI, originate from instrumentation described in Sects. 3.1.3 through 3.1.5. Field actuators are described in detail in Sect. 3.4.

3.2.3 Serial I/O interfaces

The bulk of the information exchanged between the Bristol UPC and other apparatuses is through serial I/O. There are six RS-232-C links provided for serial communication. The auto-data nine and the thermocouple telemetry systems (described in Sects. 3.1.1 and 3.1.2) transmit information on request from the Bristol UPC. The system status display, data recorder, and teletype are driven via serial I/O, and the serial line clock (SLC) provides constant time data to the UPC through a serial port (see Fig. 3.1).

Each serial I/O operates at a speed designated by the programmer so that the transmission and/or reception speed will match that of the peripheral device. Transmission speed can be either 60, 120, 300, 600, 1200, 2400, 4800, or 9600 baud (e.g., 300 baud means 300 bits/s).

3.2.4 Serial line clock

A serial line clock (Digital Pathways, Inc., model SLC-1) is provided as the time standard for the experimental system. The clock is a programmable device that provides both serial (digital) output and visual output (light-emitting diode display) of the day of the year, day of the week, week, month, year, and time of day (h, min, and s). The SLC is located atop the Bristol UPC, as shown in Fig. 3.6.

Even though the Bristol UPC has its own internal clock, the serial-line clock was installed for dedicated use with the UPC. The primary reason for clock installation was that whenever the UPC was reloaded (i.e., software restored to memory) from the disk, time functions would reset to whatever time the disk was recorded. Some intervention was therefore necessary to set the clocks to the proper time. The most reliable method was to use the serial line clock, comparing its time to the Bristol's time, and resetting the Bristol time to the time indicated by the SLC when the two times were different by more than 20 s. All clock resetting was done automatically by the software.

3.2.5 Operator interface with control algorithms

Operators can interface with the control system by a variety of means. The light emitting diodes (LED) and dial gages associated with discrete and analog inputs and outputs (as discussed in Sect. 3.2.2) provide a direct means to check system parameters. A two-pen chart recorder is also included in the rack to monitor oxygen concentration. Manual overrides on the outputs have already been addressed.

More profound interaction with the control software can be obtained through the process operator panel (POP). By use of this device (Fig. 3.8), the operator can access any wire in the computer memory and have its value and engineering units displayed on the LED area of the POP. The value carried by the wire can be cleared and a new value input through the keyboard; however, driven signals will quickly return to their original state, whereas read only signals maintain the new value. This property of the control system allows for a fast means to change system set points, etc.

The POP also provides a powerful means to change the control system configuration. Wires can be reassigned to different software modules, modules can be activated or deactivated (i.e., put on an executable or nonexecutable rate table), and new control algorithms can be created when given sufficient numbers and types of spare modules (modules created during a main-frame compilation and designated as spare).

3.2.6 Safety features

The Bristol UPC has several safety features that maintain controlled variables in the event of loss of power or some other catastrophe. When power is lost, computer processing of the control loops ceases; however, battery backup keeps the memory "refreshed" so that when power is restored, operation resumes. Furthermore, the output signals (either analog or discrete) may be maintained or allowed to fail to a safe condition. Analog and discrete inputs may still be monitored on the panel, but the POP will be inoperative.

Security of the system is maintained through three access levels. An access code is entered via the POP and must be verified against an internal list of valid codes before any access to the software is allowed. Each valid combination code will fall into one of three categories allowing (1) read only, (2) read and change set points, and (3) read, change set points, and reprogram privileges on a module by module or wire by wire basis. Access levels required for each module, wire, etc. are determined when the software is compiled. By this method, all but authorized personnel are prohibited from interfering with the operations of the process.

3.3 Furnace Controller

Control of the calciner drum temperature is accomplished by regulating the heat added with the electrical resistance heaters in the furnace and the heat removed with the natural convection cooling stacks. The cooling stacks are controlled by the Bristol UPC and will be discussed further in Sect. 3.4. The heating elements in the furnace are controlled by the furnace controller (Fig. 3.12). Basically, the furnace controller console houses eight controllers, a multipoint strip-chart recorder, and relay switches. Master switches are located on the front of the console so that all controllers and power may be turned off in an emergency.

3.3.1 Controllers

Eight controllers (Honeywell model R7350 J-1016-1) are utilized to control the temperature of the eight furnace zones; one controller is associated with each zone. These con-

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Fig. 3.12. Control area showing furnace controller console (right hand side of photo).

trollers have on/off and time proportioning potentiometric control capability with relay output. Either local (manual) or remote set point switching has been provided. Thermocouples are used as the temperature sensing devices.

In application to control of the FSEV, the controllers are used in the remote set point mode. The set point is received from the Bristol UPC as a scaled 4–20 mA signal. The controller reacts in such a way as to drive the zone temperature to the set point. A type K thermocouple installed in the zone provides feedback to the controller. The Bristol UPC monitors the zone temperature by a different means (i.e., another thermocouple, located in the zone, connected through the AD9) and changes the set point appropriately so as to attain the target temperature set by the operator (illustrated in Fig. 3.13). By ramping the set point temperature up (or down) in this manner, the equipment is protected from damage by too rapid a rise (or fall) in temperature. The ramp rate was programmed so that temperature changes would not exceed 25°C/15 min. Furthermore, the control algorithm in the Bristol UPC (which acts as a master controller in this arrangement) adjusts the set point fed to the furnace controller in such a way that there is no offset between the measured temperature (i.e., measured by the Bristol's sensor) and the target.

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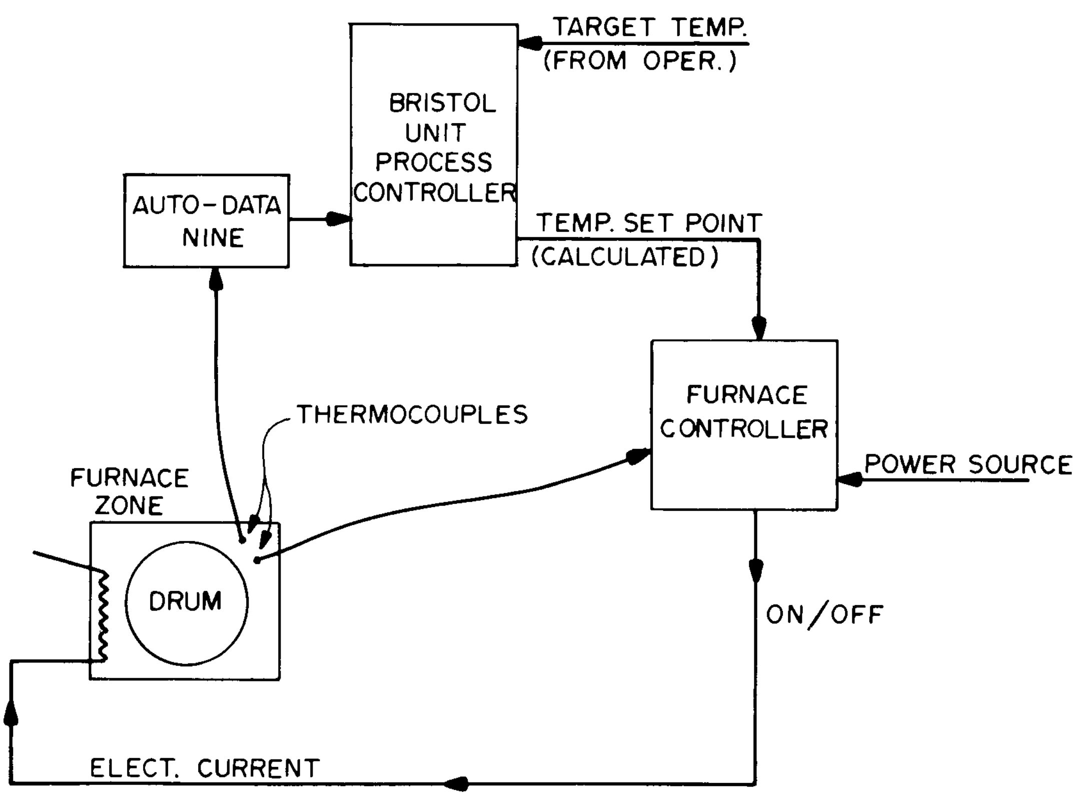

Fig. 3.13. Furnace control scheme.

3.3.2 Multipoint recorder

The furnace control console is equipped with a multipoint strip-chart recorder (Honeywell model 11170180-52020-00000-00-00010-102-18), which can be seen in Fig. 3.12. Eight of its twelve channels are used to record the temperature of the eight furnace zones. Type K thermocouples located in each zone, redundant with respect to those already discussed, are wired to the recorder. A printed temperature history is thus provided to the operator for consultation at any time.

3.4 Field Actuators

All automatically controlled variables in the FSEV are controlled either directly or indirectly by the Bristol UPC. The furnace heating elements are controlled indirectly through remote furnace controllers by the Bristol, as discussed in Sect. 3.3. Many other field actuators are operated directly by output from the Bristol; the three types of actuators being proportional values, solenoid valves, and relay switches. A list of all such actuators along with a description of their respective functions is given in Table 3.9; also listed are all manually operated actuators. The changes made to manually operated systems are sensed by the Bristol via limit switches (for valve position), flow meters, etc., so that the related data may also be recorded. (An exception is the solids recycle system which is activated on a regular schedule.)

3.5 Operator Interfaces

Two-way communication between the operator and the process/control system has been effected by both hardware and software components. Both discrete and analog incoming and outgoing signals can be monitored on the Bristol UPC panel boards, as discussed in Sects. 3.2.2 and 3.2.5. Access to the software through the POP is also discussed.

The communication functions can be grouped into three sets. Each set is ascribable to one of three hardware groups: alarm enunciators, a hardcopy printer, and a colorgraphics display system.

3.5.1 Alarm enunciators

The main audio alarm enunciator is located in the center rack of the Bristol UPC (Fig. 3.5). This horn is wired so that it can be sounded by output from any of several discrete outputs (DO) from the Bristol. Software used in the Bristol recognizes upset conditions when they occur and turns on a DO which in turn sounds the alarm. Each DO is equipped with a LED which lights when the DO is on, and the DO is labeled so that the operator can easily determine the source of the problem. Also, when the alarm sounds, a logger module in the software is activated resulting in printed messages on the hardcopy printer. These messages aid in determining the cause of the upset condition, and when the

Table 3.9. Field actuators and controlled variables

Actuator	Manufacturer	Model	Controlled variable	Control signal	Signal source
Proportional valve (8 ea)	Honeywell	113889/01-11SLO	Air flow through cooling stacks; each of the four stacks uses two valves, one at the top of the hot air leg and one at the bottom of the cold air leg	3–15 psi	Bristol UPC
Proportional valve (2 ea)	Foxboro	P50/77N-49039	Off-gas flow rate; one valve regulates flow resulting from off-gas system vacuum and one valve regulates jet assisted flow	3–15 psi	Bristol UPC
Proportional valve (1 ea)	Research Control Valve Company	78S	Oxygen flow rate into voloxidizer	3–15 psi	Bristol UPC
Solenoid valve (1 ea)	Valcor	84C18HC2	Air blowback across off-gas filter	115 Vac[b]	Bristol UPC
Solenoid valve (1 ea)	ASCO	8210B82	Air recirculation pulse in solids recirculation system	120 Vac	Manual (operator flips switch)
Potentiometer	Reliance Electric Company	(V*S drive)	Drum rotational speed	NA[a]	Manual
Switch (1 ea)	Allen-Bradley	NA	Air flow through product cooler	NA	Manual
Solenoid valve (4 ea)	ASCO	8344A70	Opening and closing of the four isolation flapper valves	120 Vac	Bristol UPC
Solenoid valve (1 ea)	ASCO	8344C25	Diverter valve position	120 Vac	Manual
Solenoid valve (2 ea)	ASCO	83D0661F	Air operated vibratory feeders	120 Vac	Birstol UPC
Solenoid valve (2 ea)	ASCO	8300C610	Also used with vibratory feeders, giving two-speed capability	120 Vac	Bristol UPC
Relay switch (1 ea)	Allen-Bradley	NA	Motor that drives rotary shroud feeder	NA	Bristol UPC
Solenoid valve (1 ea)	ASCO	8300C610	Tip bucket trap door	120 Vac	Bristol UPC
Solenoid valve (2 ea)	ASCO	8300C61U	Pneumatic lift	120 Vac	Bristol UPC

[a]Not applicable.
[b]Vac – volts of alternating current.

condition is rectified, the alarm is automatically turned off. Improper operation of isolation valves, full product receiver, overfilling of tipbucket, low inventory of solids in any feeder, and stalling of the rotating drum are examples of some of the upset conditions that will trigger the alarm.

Another audio alarm was installed for dedicated use with the data recorder. (The recorder is described in more detail in Sect. 3.6.1.) This alarm sounds when a tape has been filled or when the data recorder fails to receive information from the Bristol UPC in 15-min periods.

3.5.2 Hardcopy printer

A teletype (Digital Equipment Corp., model DECWRITER II) has been utilized to make printed (on paper) alarm messages and other data requested by the operator. The advantage of using such a hardcopy unit is that once printed, the record is permanent, as compared to information displayed on a CRT which will be overwritten when the screen is filled.

Messages printed in response to upset conditions were discussed in Sect. 3.5.1. Other information can be requested by the operator. Because the teletype is not interactive (it acts strictly as a printer) with the Bristol, the request is not entered through the teletype keyboard, but rather through the panel switches mounted in the Bristol console. These switches act as discrete inputs (DI) that turn on specific software loggers connected to the serial output port which feeds the teletype. The five switches, located on PS-3, and their functions are:

1. All temperatures – prints current value of all temperature readings, TE1 through TE100.
2. Auto-data nine clues – prints a score for each of the 11 data blocks indicating the success rate for data transfer from the auto-data nine to the Bristol.
3. Furnace status – prints a table giving the target temperature, current remote set point, and current temperature for each of the eight furnace zones; also prints other process set points.
4. Drum temperature – prints the temperature readings corresponding to each of the 33 thermocouples mounted on the rotary drum.
5. Miscellaneous data – prints data considered to be of importance to the objectives of an experimental run; programming of the involved logger(s) varied from run to run.

Additional loggers were programmed to print regularly. These loggers listed the operating personnel on duty and the temperature, feed rate, and system pressure set points.

3.5.3 Colorgraphics display system

The colorgraphics display system is used to retrieve and display data in tabular and graphical form. (The unit appears on the left hand side of the photograph in Fig. 3.5.) It is used for presenting trend and historical displays and for routine system status surveillance. Three major components make up the system: a disk drive, keyboard with a full ASCII character set, and a color CRT (Intelligent Systems Corp., models DUAL 8-in. F/D, KEYBOARD and 8051 respectively).

The system is programmed to accept serial data from the Bristol UPC. Data representing 1 h of real time process states are stored in memory on a first-in/first-out basis. Programs to interpret the data and generate the displays are stored on disk. With proper commands entered through the keyboard, any one of several possible displays can be generated for viewing on the CRT. For example, the solids feed rate for the previous hour can be plotted as a histogram.

3.6 Data Recorders

Three mechanical data recording devices are used to produce permanent records of measured and calculated quantities. Two of these recorders are strip-chart recorders, already described in Sects. 3.2.5 and 3.3.2.

The primary recorder is a digital cassette tape recorder (Techtran Industries, Inc., model 8421) referred to as a Techtran. All information pertinent to the operation and analysis of the FSEV, including the same information recorded on the strip charts, is fed from the Bristol UPC through a serial output port to the Techtran and is recorded on magnetic tape. (The Techtran shows up in the photograph just behind the operator's head in Fig. 3.5.) Seventeen separate software loggers in the Bristol are used to transfer the data. Organization of these loggers is discussed in detail in Sect. 5.1.

During the recording process, the Techtran shares the incoming data with a CRT. The CRT displays the data in alphanumeric form so that the operator may verify that the recording function is being executed properly. Since the Techtran is the primary (practically only) data recorder, it is very important that operation is correct to avoid loss of data. As an additional measure to ensure that the recording operation is functioning properly, an alarm device has been fitted to the Techtran. This device sounds an alarm when no data has been received by the Techtran over a 15-min period or when the magnetic tape has been filled. Operator action is then required to correct the malfunction or to renew the tape. Both the Techtran and the alarm device are shown in Fig. 3.14.

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Fig. 3.14. Log monitor/alarm (top) and Techtran (bottom).

4. CONTROL FUNCTIONS

The basic function of the voloxidizer is that of a chemical reactor where UO_2 in nuclear fuel is further oxidized to release tritium. Control of the reaction is best effected by control of the reactant temperature and control of oxygen (one of the reactants) concentration. Since it is required that the tritium evolved during reaction be contained, it is further necessary to implement an off-gas control system that maintains a slight vacuum within the voloxidizer under conditions of sporadic inleakage. The Full-Scale Experimental Voloxidizer (FSEV) was equipped and instrumented to control these three conditions that would be common to a voloxidizer operating in an actual reprocessing facility. In the experimental facility, control of three feeders to meter three feed materials in the correct proportions were required to simulate a shear operating at various rates. And finally, a control system was implemented with the purpose of monitoring important operating variables and issuing alarms and warnings whenever upset conditions occurred. The five control systems mentioned above are discussed in Sects. 4.1 through 4.5.

4.1 Furnace Control

Since rapid temperature changes could damage the ceramic liner of the furnace, provision was made in the control to restrict increases and decreases to 25°C/15 min. The furnace zones were directly controlled by a set of Honeywell controllers whose set points were generated by the Bristol UPC (see Sect. 2.3.4). Changes in furnace temperature were made by setting target temperatures in the Bristol UPC, which initiated a ramp change from the existing set point to the target at the desired rate. The control scheme for most of the work did not use a feedback control loop involving the Bristol UPC, and accuracy was limited to how well the Honeywell controllers brought the zones to the set point temperatures. Since the system response was generally much faster than the ramp rate and the Honeywell controllers were responsive, this scheme worked well. There was a persistent small offset, however, between the set point and the thermocouple that read the temperature for the Bristol UPC. In later runs, an integral mode was employed that eliminated this offset. This mode involved an inherent danger that a failure of a thermocouple could drive the set point to unacceptably high values; therefore, rigorous operator surveillance was used during operation.

Protection was provided from an inadvertent step change imposed by a system reload. When reloading the UPC (or several other upsets), a # POWER UP software switch was activated. The state of this switch was used in the logic to set the set points to the measured zone temperatures. When these set points were different from the target temperatures, the ramping process brought them into line. This process could also be artificially induced by pushing the "Furnace Set Point Reset" switch on the operator panel.

4.2 Off-Gas Control

The off-gas system involved several elements most of which were interrelated. The voloxidizer pressure was measured (PT5) at the feed chute, which is the point at which the gas leaves the rotating drum. Since the size of the system and the relatively small gas flow rate precluded any significant local pressure variations, the pressure at the feed chute was taken as the pressure of the voloxidizer from the product end flapper valves, to the feed end flapper valves, to the off-gas filter. The off-gas line leading to the filter was the same diameter as the feed chute. The gas proceeded through the filter, through a bag-type flowmeter, through a control valve (PCV5) to a point where the suction pressure (IPT2) was controlled by an air ejector and a control valve (PCV6) before the gas was released to the building off-gas system. The pressure drop across the filter was measured (PDT3), and when the buildup of accumulated powder caused it to exceed an input set point, a blowback system was activated through a quick acting solenoid valve which discharged the contents of a 5.98×10^{-3} m^3 (0.211 ft^3) gas accumulator at $\sim 3.45 \times 10^5$ Pa (50 psig) as a pulse to the discharge side of the filter. This discharge knocked off the cake which fell down the 8-in.-diam line into the feed chute. The process equipment for this system is described in Sect. 2.2.

The automatic blowback system worked well for set points which varied from 5 to 10 in. of water, depending on the dust loading and the gas flow rate. The Bristol UPC logic was programmed to allow the blowback discharge valve to be opened for a time interval which was usually 0.8 s. The accumulator was filled through a pressure regulator from a 5.52×10^5 Pa (80 psig) air supply. To satisfy interest in the effect of blowback on system pressure, logic was established to record the filter pressure drop at 1-s intervals for a total of 18 readings after blowback. This record showed that pressure high enough to cause back flow persisted for 3 or 4 s, and after 6 to 8 s the system was back to normal.

The system was designed so that the voloxidizer pressure (PT5) would be controlled to a set point by the valve (PCV5). This control scheme was rather ambitious because the pressure drop across the filter varied and the system was subject to various spurious gas flow disturbances. Efforts to test this system were frustrated in the early runs by the many leaks in the system which made it impossible, with reasonable gas flows, to draw the voloxidizer pressure to a measurable vacuum. When the leaks were found and plugged, limiting the inleakage to that through the flapper valves, it was possible to routinely achieve $<$0.2-in. water vacuum, and the control scheme was found to work well.

4.3 Oxygen Concentration Control

Several control algorithms were used to control the concentration of oxygen in the voloxidizer drum. The system that seemed to perform best was the triple cascade control scheme, shown diagrammatically in Fig. 4.1. This system was implemented in an effort to overcome control problems caused by (1) a delay in changes in concentration at the feed end following changes in the manipulated variable (i.e., oxygen flow rate) and (2) dilution of oxygen admitted at the product end, with gases inleaking at both the feed- and product-end seals. (The identifications "feed end" and "product end" are associated with solids flow. Since gas flows countercurrent to the solids, the gas discharges at the feed end and is fed at the product end.) Oxygen concentration at the product end is kept from getting too high while the concentration at the feed end is forced to reach the desired set point.

As shown in Fig. 4.1, the scheme utilizes two proportional controllers and one proportional/integral controller. Software modules in the Bristol UPC are used to implement the control loops. The four tuning parameters, namely three proportional gains and one integral time, were determined by on-line tuning of the control system.

4.4 Feeder Room Control

Although the system that fed the voloxidizer was not related to voloxidation, per se, in any fundamental sense, the experimental program to study voloxidation required an accurate, reliable feeding system for its success. This system eventually performed to satisfy our most demanding need, and evolved into perhaps the most elaborate and sophisticated of the subsystems. The hardware of the feed system is described in Sect. 2.1. This objective was to meter three materials (sand, hulls, and shroud pieces) steadily and accurately in proportions that could be adjusted to simulate sheared fuel elements. The signals available to the Bristol included the weights from the three weigh tables (the sand, hulls, and shroud) and the tip-bucket reading, which could be sampled as desired. An accelerometer was located on the chute that received shroud feed which would detect the delivery of individual pieces.

The software is best considered in three parts: one that controlled the sequence of steps for the sand and hulls feed; one that kept account of the materials fed and calculated the targets for sand and hulls; and one that controlled the feeding of the shroud. Shroud was, in the original plan, treated by the same method as sand and hulls, but problems with the relatively large contorted pieces forming bridges and tight aggregate clumps required a different physical approach.

When the sequence to feed the sand and hulls was initiated by a timer, the first operation was to record a tare weight for the tip-bucket. This recorded weight was adjusted to include the target weight for hulls minus 30 g, and then the fast feed for the hulls vibratory feeder was activated. The weight of the tip-bucket was compared to this value and when it was exceeded, the 30 g was added back and the slow feed was operated until this value was

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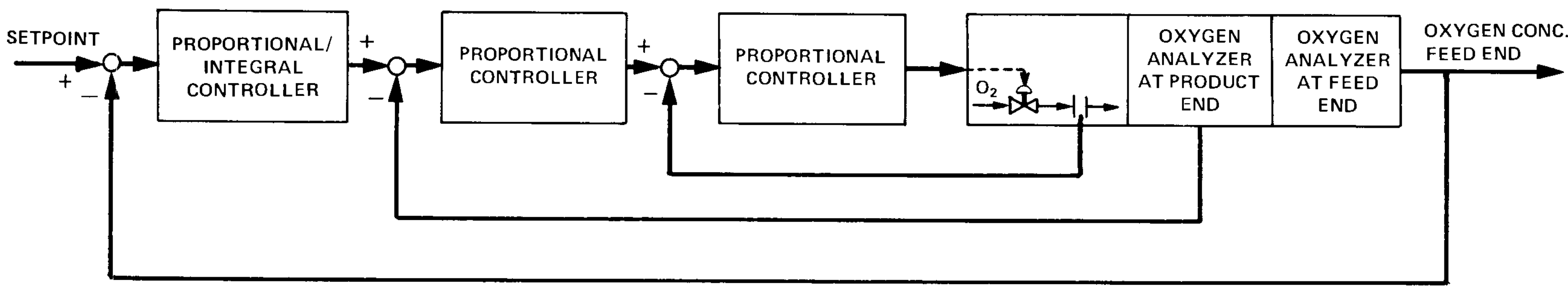

Fig. 4.1. Oxygen control system.

exceeded. The system was allowed to settle down for a couple of seconds and this weight was recorded. Again, this recorded weight was adjusted to include the target weight for sand minus 30 g, and the fast feed for sand was activated. When the tip-bucket weight exceeded this value, the 30 g was added back and the slow feed for the sand was operated until this value was exceeded. The system was again allowed a couple of seconds settling time and the reading was made. The contents of the tip-bucket were then dumped.

The sand/hulls system was programmed to truncate the operations if the target values were not going to be reached in the time allowed by the feeding cycle time interval and to activate a warning light. If the calculation called for more than a total of 1 kg to be fed to the tip-bucket (its maximum for accurate readings), the operation was truncated and a warning light was lit. The status of these lights was sampled by the data logger.

The flapper valves on the feed and discharge chutes were also activated by the feed system timer such that the contents of the tip-bucket were stopped by the first flapper valve. Shortly thereafter, the valve opened and the material passed to the second valve. The second, third, and fourth flapper valves were activated in sequence by their own separate logic, with provisions for detecting failure to open or failure to close. When a flapper valve failed to close (as detected by microswitches), it was presumed that an object had been caught between the flapper and the seat and the valve was made to cycle several times. When any flapper valve failed to operate properly for more than a reasonable time interval, an alarm would sound. The other valves would not operate while any valve was open.

Because of several inherent inaccuracies in the tip-bucket weight, it could not be used as a valid indicator of the amount of material fed. The most serious deficiency of the tip-bucket was its inadequate closure which permitted sand to leak out during filling. The tip-bucket was used successfully, however, as a flow measuring device. The sand and hulls were treated identically, so only one system need be described.

The vibratory feeders that fill the tip-bucket reset on weigh tables. When the weigh table reading for a particular component increased by more than 1 kg, it was assumed that the hopper had been refilled and readings were zeroed. From zero time, three quantities were accumulated: (1) the time integral of the set point rate, (2) the total amount of the component fed according to the tip-bucket readings, and (3) the differences between the initial weigh table reading and the current weigh table reading, which was taken as the most accurate measurement after a few kilograms had been fed. The ratio of the amount that the tip-bucket indicated to the amount that the weigh table indicated became a factor which was multiplied by the amount that should have been fed to convert it to a tip-bucket basis. The target for the next time increment was obtained by subtracting from this the amount that the tip-bucket indicated was fed. Since this algorithm involved the difference between large numbers, the targets were subject to a high noise level; therefore, the signal was processed through a lead-lag module to give a smoothing effect. This algorithm was found to give quite good feed control over extended periods of operation.

The shroud feeding system operated more or less independently. Shroud was fed from a rotary drum feeder which was, itself, fed from a hopper. This whole assembly, including the electric drive motor, was mounted on a weigh table. From an initialization upon filling the hopper, the set point rate was integrated over time giving an amount that should have been fed. From the weigh table, the amount that had been fed was obtained. When less than required had been fed, the feeder was started. When a piece of shroud fell into the feed chute, it was detected by an accelerometer, causing the drum to stop rotating so that a weighing could be made. The drum would then either start or not start based on the new values. During normal operation, the feeder drum was required to rotate less than half of the time. The rotation was also interrupted during the operation of the first flapper valve to avoid catching a falling shroud piece in a closing flapper.

Alarms were available to be activated when the feed rate of any component fell behind that intended by more than a designated amount (about a kilogram). Alarms also flagged (1) low weights on each of the weigh tables and (2) the attainment of a target value for the product collection receiver.

4.5 Alarms and Warnings

In order to assist the operators in identifying problems, the Bristol UPC was programmed to generate several alarms and warnings, which were displayed on a panel on the POP. These alarms did three other things: (1) an audio signal was activated for about 5 s, (2) the Decwriter was activated to print a summary of the alarms for short-term reference, and (3) the logger DISCRETE was output to the data logger for permanent record. Many of the alarms have been discussed elsewhere in the text, but all are summarized in Table 4.1.

Warnings caused lights to be lit on the operating panel and were available as data on logger DISCRETE, but did not sound the audio alarm nor cause DISCRETE to be immediately recorded. These warnings included: TIPBKOFL, which indicated an attempt to overfill the tip-bucket; TIPBKTOTM, which indicated that the cycle time ran out before the target weights had been delivered to the tip-bucket; and SHRDSLOW, which indicated that the shroud feeder had not been able to catch up with demand for more than a designated time (but was not necessarily enough behind to sound the alarm).

In addition to these warnings, signals that were not displayed but presented as digital information on DISCRETE included: which personnel were on duty, which furnace zones were on, which isolation valve (if any) was not working, and information as to which operational switches were on, as well as the state of the components of the product receiving station. The organization of this logger is presented in Appendix G.

Table 4.1. Alarms

Name of alarm	Significance
ISOVXM	At least one of the flapper valves is not operating
NORECEIVER	The product diverter valve does not route product material to a properly installed receiver
SANDALARM	The feeder system is more than 1 kg behind in feeding sand
HULLALARM	The feeder system is more than 1 kg behind in feeding hulls
SHROUDALARM	The feeder system is more than 5 kg behind in feeding shroud
WT3LLVL	The sand in its feed hopper has dropped below 20 kg
WT6LLVL	The hulls in their feed hopper have dropped below 20 kg
WT5LLVL	The shroud in its feed hopper has dropped below 20 kg
ST1ALRM	The voloxidizer drum has stopped
WT1HLVL	Product receiver 1 is full
WT2HLVL	Product receiver 2 is full

5. DATA ACQUISITION AND MANAGEMENT

Since the Full-Scale Experimental Voloxidizer (FSEV) was a facility used for performing experiments where many subsystems operated simultaneously, provisions for taking, recording, and handling large amounts of data were necessary. The hardware related to data acquisition is described in Sect. 3.6. This section describes data collected and how these data were organized for convenient use, storage, and retrieval. Methods for editing and interpreting the data are discussed, but the analysis of the data is beyond the scope of this report.

5.1 Organization of Loggers

It is pointed out in Sect. 3 that all data are taken and recorded by the automatic control system. The Bristol UPC is programmed with software modules called loggers (in addition to the control modules, etc.), which generate serial output when activated. These loggers can output either the signal name, the value of the signal, other literal fields of alphanumeric characters, or any combination of these three items depending on how the logger is programmed (i.e., formats used).

Fourteen loggers are utilized in the data-taking process, and each is set up to generate records (a line of "printed" data) in a standardized format. Each record consists of the logger name followed by the run time (i.e., the time, in hours, at which the logger was activated) and 18 other numbers which represent the value of 18 signals. The order in which the numbers appear depends on the order in which the signal wires were connected to the logger. The loggers can be activated again and again throughout a run so that the value of a measurement may be tracked through time during the data analysis.

The signals connected to the loggers are organized such that related measurements appear on the same logger and will therefore be synchronized in time. Table 5.1 gives a list of the loggers and a definition of how the variables are grouped. A listing of all variable names, their definitions, and their engineering units by logger name are given in Appendix G for reference. (Of course, this listing includes those variables discussed and listed in Sect. 3.1.2.)

5.2 Transient Detector

Most of the time, in systems such as the FSEV, most of the measured variables remain unchanged for hours of operation. Occasionally something happens, either in response to a

Table 5.1. Grouping of variables by logger name

Logger name	Variable group type
ZONEONE	Measurements associated with furnace zone 1 and its cooling stack
ZONETWO	Measurements associated with furnace zone 2 and its cooling stacks
ZONETHRE	Measurements associated with furnace zone 3 and its cooling stacks
ZONEFOUR	Measurements associated with furnace zone 4 and its cooling stacks
OTHERZNS	Measurements associated with furnace zones 5 through 8
PRODCOOL	Measurements associated with product cooler
GASSTOPH	Measurements associated with oxygen feed and off-gas system including filter
PROCDATA	Process data related to clock functions, feed set-points and general operating information, and miscellaneous measurements
FEEDMETR	Measurements and calculations associated with feed and product collection systems
COUNCE	Continuation of PROCDATA
JUBIN	Continuation of PROCDATA
LEWIS	Continuation of PROCDATA
DISCRETE	Condition of 54 on/off (on or off is coded as 0 or 1, respectively, and are put together in groups of 6 digits to make 9 numbers)
RECOVERY	Differential pressure across off-gas filter

deliberate change in operating conditions or from an unanticipated perturbation, and values for measured variables in part of the system change rather rapidly. [Were the recording of data infrequent, an interesting event could be entirely missed. Were all of the data recorded rapidly enough to catch all possible interesting events, the volume of data (mostly of unchanging variables) would be overwhelming and intractable.] Therefore, a detector was provided which would accelerate the data recording rate when variables were changing.

Relevant information was contained in ~90 variables, organized into 11 loggers, and driven by 8 strobes (4 of the loggers were fired by a single strobe). Throughout the system, 16 variables (2 pressures, 1 concentration and 13 temperatures) were identified as adequate to indicate a transient condition. The software was constructed such that these variables were sent to a multiplexer. To another multiplexer, in corresponding ports, values were sent for rates which, if exceeded, would indicate a transient. To a third multiplexer, a code was sent indexing which of the loggers contained the variables. The cycle provided sampling about once a minute for each variable, and when a transient was detected, the appropriate logger was recorded and continued to be recorded each minute as long as the transient persisted. In the absence of a detected transient, these loggers were recorded on a 10- or 15-min cycle.

5.3 Editing of Data

Data recorded on small cassette tapes must be transferred (copied) onto a medium compatible with and accessible to the computer where the data will be analyzed. Editing of the new data to create a final, permanent data set is necessary for two reasons. First, some small percentage of data recorded will contain format errors (caused by faulty transmission to the recorder, a flaw on the cassette tape, or whatever) and therefore be unrecognizable to the computer. Second, some quantities are accumulated during operation and are reset to zero whenever the Bristol UPC is reloaded from disk (as in a recovery from a WATCH-DOG) or if the time of day clock is reset manually. These accumulated quantities are:

RNTM	run time
FS7	counts (represent ft^3) of off-gas
HULLSTOTAL	total hulls fed via tip-bucket
SANDTOTAL	total sand fed via tip-bucket
PWRZ1	integrated power fed to heater zone 1
PWRZ2	integrated power fed to heater zone 2
PWRZ3	integrated power fed to heater zone 3
PWRZ4	integrated power fed to heater zone 4
PWRZ5	integrated power fed to heater zone 5
PWRZ6	integrated power fed to heater zone 6
PWRZ7	integrated power fed to heater zone 7
PWRZ8	integrated power fed to heater zone 8

(see also Appendix G). The function of the editor is to delete records in the wrong format and to track and correct the accumulated variables so they will be monotonically increasing functions of time. Correction to run time is possible because the time of day and day of week are recorded on the PROCDATA logger and these times are always correct (i.e., read from the SLC-1 and immediately written). A test of the run time is made to determine if the run time has been upset (e.g., became smaller). If an upset is detected, the correction algorithms are called on to calculate correction terms, which remain in effect until another upset occurs which will again require new correction terms to be calculated. The logic of how the data editor (written in FORTRAN) works is most easily understood in terms of the flow chart given in Fig. 5.1. A listing of the program (editor) is given in Appendix H. The program can correct for any number of system resets that occur in the data set.

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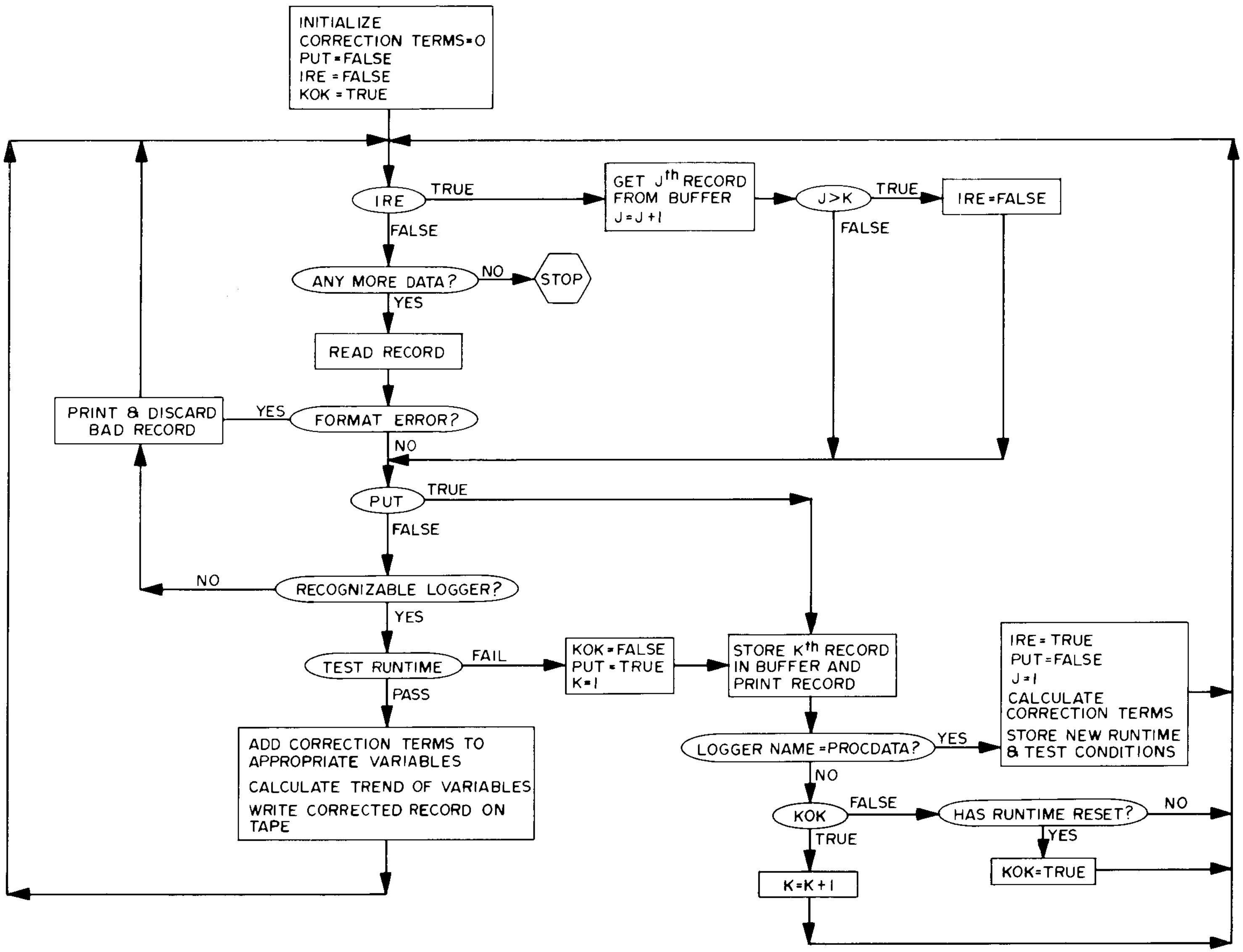

Fig. 5.1. Logic flow chart of data editing program.

Corrected data sets are stored on a very reliable nine-track, computer compatible, magnetic tape for access by analysis programs. To ensure that loss of data does not occur, each tape is duplicated so that a backup is available.

5.4 Post-Operation Examination of Data

The nature of the experimental runs with the FSEV was such that attention of involved personnel was required for the execution of the experiment. It was not until the run was completed that there was time to look seriously at the results. The data, then on nine-track computer tapes stored at the ORNL computer center, could be accessed *only* by the computer system.

To make the most of this situation, a computer program called CRUNCH was developed which made access, scrutiny, and processing of the data convenient. By invoking a packaged job control language (JCL) file and providing an input of instructions in a simplified language, it was possible, in a matter of hours, to have any set of variables (limited to eight per submission), over any interval of run time, (1) retrieved from the tape, (2) manipulated in a wide variety of ways, and (3) the results presented in tabular form or in plots of any variables or calculated results (up to six) against any result or variable, including run time.

The CRUNCH computer program used a dictionary of variable names and remembered where and on which loggers each variable was to be found. Some variables were on more than one logger. From an input list of variables, it read through the magnetic tape extracting values for each of the variables along with the run time at which the variable was measured, building a matrix in core. To get calculated quantities as a function of time, the matrix could be modified by instruction to interpolate, making all readings consistent with the times at which the first named variable was read.

Arithmetic operations could be performed by instructions taken from a short catalog of operational strings, which included provisions for taking roots, taking logarithms, exponentiation, differentiation, and integration. Calculated results became new columns in the matrix and were labeled for further manipulation. Instructions were available for smoothing the data and for detecting bad points and discarding or truncating them. A limit of 15 data columns were available plus run time, but provision was made to delete columns that were used as scratch to develop a desired result and no longer needed.

Special options included regression fits of a variable (or calculated quantity) against one or two variables (or calculated quantities) and a run history generated from the DISCRETE logger. The output from this instruction presented all of the digital signals in the form of an operating log, noting (1) when switches were turned on or off, (2) when alarms or warnings were turned on and off, and (3) when operating individuals reported for duty and when they were relieved, all in English and journal form. The concise nature and informative format of this output was achieved by an algorithm that simply ignored switches that had not changed with successive records and noted only those that had.

Operations that were always required or that presented difficulties to the standard format of CRUNCH were programmed into special subroutines and invoked by a single instruction. These subroutines included calculations on the feeder system to yield calculated drum inventories, as well as instantaneous rates, and an analysis of the filter system with its pressure buildup and automatic blowback.

A package distinctly different in nature would, on instruction, draw a sketch of the FSEV and plot the system temperatures on the sketch. This computer action required, as input, only the interval of run times over which the plotted temperatures were to be averaged.

After some experience with CRUNCH, calculations compatible with the standard format and often needed were reduced to standard instruction sets, or MACROs, and kept on file for repeated use.

6. SERVICES AND UTILITIES

This section describes services and utilities that are primarily provided in Building 7603 for general use, but which are useful or essential for the safe and reliable operation of the Full-Scale Experimental Voloxidizer (FSEV). These include the following: water, electricity, compressed air and other compressed gases, a vessel off-gas system, ventilation, and transportation equipment.

6.1 Water

Plant water is supplied to the Building 7600 area from a 16-in. water main running from the Building 7000 area. The small amount of water used in the FSEV ($\leqslant$4 L/min) is provided to the tube side of the cooling stack heat exchangers. The water was supplied at pressure of 4.83×10^5 Pa (70 psig), and the temperature ranged from 18 to 22°C. A pressure reducer (set at 4 psig) was installed in the supply line to damp out pressure surges.

6.2 Compressed Air

Three Joy compressors, located in the basement of Building 7603, compress air which is made available at 1.01×10^3 Pa (14.7 psig) via pressure reducers to actuate a number of control elements (control valves, isolation valves, etc.). Compressed air is also supplied to an air-jet to provide additional vacuum to the building off-gas system, and it is periodically used by the solids recirculation system (see Sect. 3.4).

6.3 Other Compressed Gases

Various other compressed gases are supplied in standard gas cylinders. An oxygen supply station is located at the basement level and provides gaseous oxygen feed into the solids-exit breeching. Various mixtures of nitrogen-oxygen were supplied by cylinders located at a station on the basement level under the FSEV control platform. These gases are also used to calibrate the oxygen analyzers (see Sect. 3.1.4).

6.4 Vessel Off-Gas

A vacuum (up to 10 in.) of water was provided by the Building 7603 vessel off-gas system, which consists of a 2.360-m^3/s (5000-cfm) fan and high-efficiency particulate air

(HEPA) filters. The nominal contribution of gas flow to this system from the FSEV is 0.001 m^3/s (2 cfm).

6.5 Ventilation

Ventilation is provided by the facility's heating, ventilation, and air conditioning (HVAC) system. Additional ventilation is provided to the feed house via the vessel off-gas system to facilitate dust removal from this area.

6.6 Electricity

Electrical power to the Building 7600 area is furnished through two transformers which deliver 3500 kVA to safety switches located in the switch gear room and to the main power distribution center located in the basement of Building 7603. All the electrical services for the FSEV are routed through motor control center 5. Electrical service is required for the calciner's furnace heaters, the drum drive, the Bristol UPC, the solids feeders, product screen, and various other instruments and controls. The electrical circuits are shown in Fig. 6.1.

Emergency power is provided to the drum drive by a diesel-engine-driven electrical power generator.

6.7 Transport

Normal operation requires the transport of product collection drums from the basement to the top of the feed house. A 23-ton bridge crane with a 1-ton chain hoist mounted on the trolley are available for this purpose (see Sect. 2.6.1). A freight elevator is also available for transporting materials between levels.

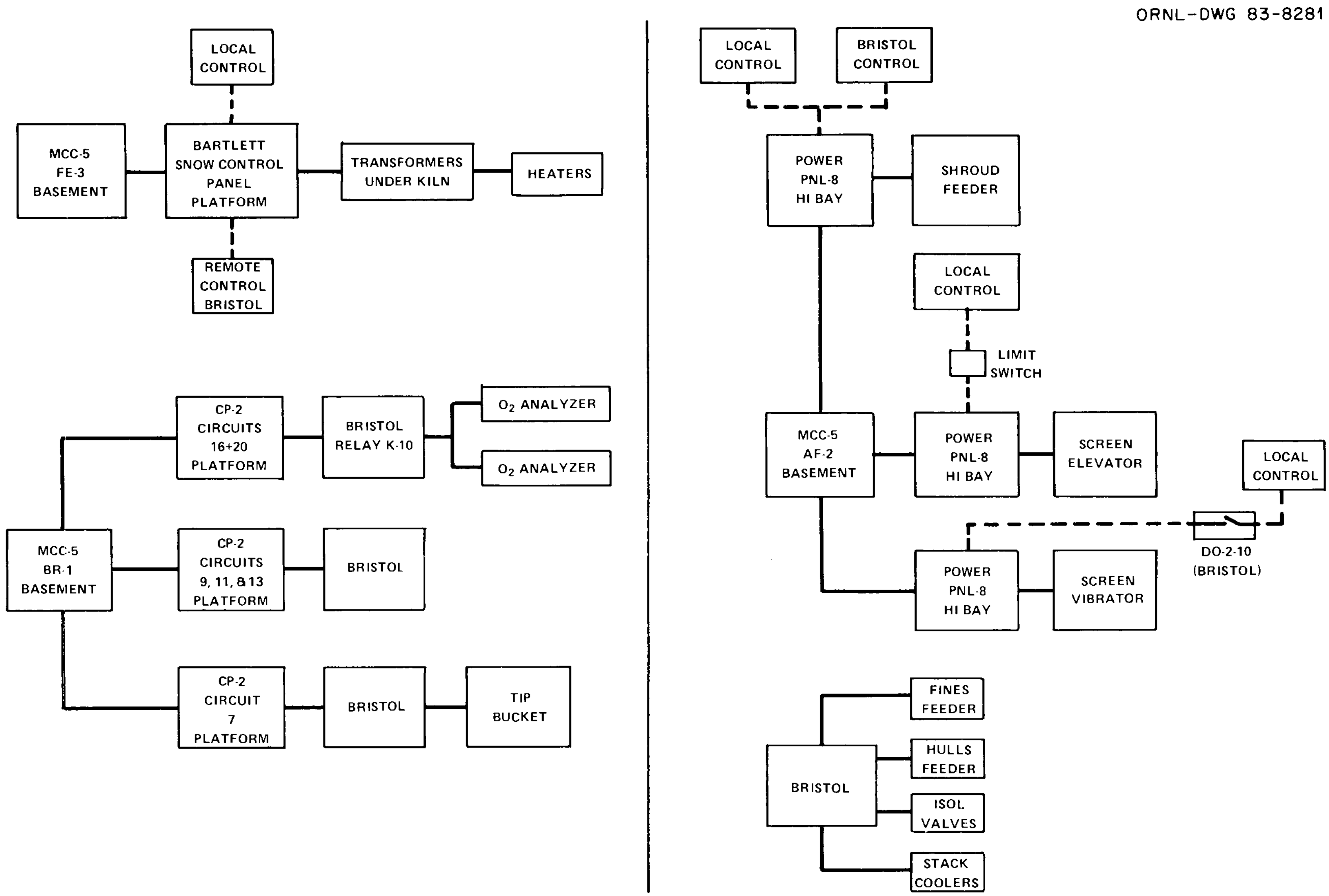

Fig. 6.1. Electrical circuit for the Full-Scale Experimental Voloxidizer.

7. ACKNOWLEDGMENTS

The Full-Scale Experimental Voloxidizer (FSEV) facility described in this report was the result of the work of many individuals from several organizations at ORNL, and specific recognition of major contributions is appropriate.

Mechanical design, construction, and modifications were handled primarily through the efforts of M. J. Rennich with assistance from B. H. Singletary, T. W. Semple, and K. W. Tidwell of UCC-ND Engineering.

Instrumentation and control systems of the FSEV were assembled and brought to operational status with the aid of members of the Instrumentation and Controls Division, particularly W. F. Johnson, G. R. Wetherington, S. S. Gould, and J. K. Yarbrough.

The specialized crafts required to maintain, repair, and modify the system were coordinated by E. F. Roy of the Plant and Equipment Division.

Operation of the FSEV system during the experimental phase of the program was conducted by D. E. Spangler, W. T. Bostic, and S. A. Richardson of the Technical Support Group of the Consolidated Fuel Reprocessing Program. Their talents as lead technicians proved to be invaluable.

The secretarial assistance of Janice Allgood in preparing the manuscript is especially appreciated. Thanks also to J. E. Van Cleve, Jr., G. R. Wetherington, W. S. Groenier, and S. M. Babcock for their reviews of the manuscript.

APPENDIX A

PROCESS DESIGN CALCULATIONS

The process design of the Full-Scale Experimental Voloxidizer (FSEV) represented the state of understanding at the time (1976). Since then, virtually all important assumptions have been substantiated, and the process design for the prototypic voloxidizer (completed toward the end of the experimental program with the FSEV in 1981) made no significant change in the design.

A.1. Criteria

Because the anticipated revisions to the standards for tritium release have not been forthcoming, there are no firm process criteria for voloxidation. To prepare for stringent regulation, the development program assumed that a voloxidizer would be expected to do the following:

1. remove in excess of 99% of the available tritium from sheared light-water reactor (LWR) fuel [95% for liquid-metal fast breeder reactor (LMFBR) fuel] by reacting the UO_2 content of the fuel with oxygen to form U_3O_8;
2. confine the tritium in a contained gas stream which could be withdrawn to a tritium collection point; this gas stream is also the source of oxygen for the reaction and, for various reasons, must not be excessive;
3. heat the material gradually to 650°C while accommodating the reaction heat and any heat from radioactive decay;
4. cool material to less than 150°C before discharge; and
5. reduce material inventory as much as consistent with overall objectives.

The eventual requirement for remote operation and maintenance dictated several features, such as the selection of a bull gear rather than a chain drive, parallel alignment of the trunnion rolls rather than in-field training, graphite rather than grease lubricated rotating seals, and others. These features are better treated in other documents and will not be further discussed here.

A.2 History

The program inherited several ideas regarding the physical geometrics of a voloxidizer. Most of these items were helpful and were used; some, after a more careful analysis, were discarded. In 1974, Murbach, Carr, and Gray[1] completed a study which evaluated the potential application of krypton retention, voloxidation, and Iodox to the Barnwell Nuclear Fuel Plant. Their voloxidizer was 3.5 ft in diam by 7 ft long, heated by 150 kW to temperatures up to 750°C, rotated at speeds from 0 to 20 rpm, and had a 5-t/d capacity. The internals were not specified, but the residence time was about 3 h.

Irvine and Nicholson,[2] in evaluating options for a 5-t/d commercial plant in 1974, described a 4-ft-diam by 12-ft-long voloxidizer that ran at 550°C. With about 8% of the volume full of solids, it provided 4 h of residence time. This unit was compartmentalized in a manner similar to the continuous dissolver and had separate inlet and cooling sections. This compartmentalized concept formed the basis for subsequent studies and proposals by both Boeing and Exxon companies, but problems with thermal stresses in such a complex structure and anticipated difficulties with the movement of dry irregular solids through intercompartment ports discouraged its pursuit. Irvine and Nicholson also discussed the alternative of a smaller diameter and longer calciner of a more conventional design which, of course, became the basis of development.

A.3. Reactor Design Approach

The original design was based on less accurate and less optimistic numbers than are available as this report is being written, and it involved some trial and error calculations and some arbitrary decisions. Rather than retrace the original thinking, the design reconstructed in this report will be developed more directly and calculations will be made to illustrate its adequacy.

For purposes of process design for tritium release, the voloxidizer can be considered a continuous, one-dimensional flow-through reactor, with axial dispersion. (There are classical techniques for analyzing this system.[3]) Further, our data do not justify assumptions more complicated than first-order reaction rate kinetics and steady-flow with a constant dispersion coefficient, rendering the calculation straightforward when the parameters are known. First we address the reaction rate constants.

A.4 Reaction Kinetics

The kinetics of tritium release from the fuel under oxidation involve three steps: (1) the oxygen must diffuse to the surface of the solids; (2) as the UO_2 reacts to form U_3O_8, a restructuring of the crystallite occurs which is accompanied by particle crumbling, increasing the available surface for reaction; and (3) the tritium, which may be present in elemental form, diffuses to the surface where it reacts with oxygen to form water, which then enters the gas stream. The limited amount of data available and the conditions under which they were taken preclude analysis which could separate these effects. Laboratory studies used a small apparatus designed to simulate the physical agitation of a voloxidizer in which samples of fuel were brought through a batch-wise voloxidation.[4–9] While being tumbled and exposed to a gas stream containing oxygen, the sample was heated to a reference reaction temperature and held there as the off-gas was sampled for analysis. One aspect of the technique that tends to obscure the results was that the reaction rate, for a period which consumed as much as half of the UO_2 in the sample, was high enough to deplete the oxygen in the reacting chamber usually to less than half its original value and sometimes to <10% of the original value.

Studies were made with both clad and unclad fuel. With LWR fuel it was found that the initial tritium release was delayed only slightly, the fuel quickly crumbling and falling out of the hulls to give a rate comparable to the unclad fuel. For the purpose of design it was necessary to have a release rate constant. By examining the available data, making allowances for oxygen depletion and gross simplification, a first-order reaction rate constant of ~1.53/h might be inferred, with the rate dependent on oxygen concentration. This predicts that 99% recovery of the tritium can be achieved under batch conditions in 3 h, run in air at 480°C, which compares conservatively with the data.

Similar examination of the data with high plutonium fuels (LMFBR), run in air at 650°C, gave a rate constant of 1.0/h. This rate is considerably less reliable since large differences in behavior are found depending on the manufacturing technique used and the irradiation history of the fuel. This rate constant predicts that under batch conditions, 95% of the tritium will be released in about 3 h. In our voloxidizer application, the reaction would not proceed batch-wise but would be continuous with the solids moving countercurrent to the gas flow such that as the tritium content in the solids decreased they would encounter higher temperatures and higher concentrations of oxygen in the gas phase. The gas would leave at the point where the solids enter, and sufficient oxygen would be used to ensure that the oxygen concentration at this point was at least 20%. Although this mode of operation would improve the kinetics, credit for the improvement was omitted in the analysis. The solids would also be subject to axial dispersion as they moved through the calciner which was included in the analysis.

A.5 Tube Diameter

The diameter of the tube was the first dimension to be fixed and was the result of rather circuitous reasoning. It was known from engineering studies that axial dispersion in rotating drums was significant and that dispersion increased with increasing diameter. To most effectively use the holdup time of the fuel, the axial dispersion and hence the diameter should be small. Conditions imposed on the feed chute to the voloxidizer from the shear were that it be at least 8 in. in diameter and that at no point it be <45° with the horizontal.

Were the outside diameter of the chute 8.5 in., the intersection of a 45° plane sets an absolute minimum at 12.02 in. for the drum diameter. It is necessary, however, to have a dam at the feed end to retain the solids. Experience with mock-ups impressed the need for an adequate dam. In an 18-in. diam drum at 8% full, the dam must be 2.5 in. to accommodate a flat surface of settled solids. The final compromise called for an 18-in. inside diameter drum with a 3-in. dam and a curved feed chute that terminated at a 22° angle with the horizontal, violating the original feed chute criterion, allowing the chute to enter the 12-in. opening with adequate tolerance. In subsequent work with the FSEV it was found that a small amount of powder did reside on the 4 in. of feed chute that were <45° with the horizontal, but the vibration of the system and the introduction of new feed kept it constantly refreshed. It is further noted that only through special effort could the spillage of material over the 3-in. dam and into the inlet breeching section be reduced to an acceptable level. It is, therefore, concluded that 18 in. represent a practical minimum of acceptable voloxidizer diameters. It is comforting that as these units are scaled up, the feed-end problems diminish.

A.6. Reaction Zone

Establishing the length of the reaction zone was a matter of accommodating the design volumetric throughput to the filled cross-section of the bed of solids. The calculations are given in Table A.1. Calciner tubes are designed to be operated from a few percent full to 15% and rarely 20% full. Typical values range around 8%. A voloxidizer is a nontypical calciner because of the extremely low forward velocity of the solids. A design value of 7% full was used. Although the reaction kinetics predicted a 95% tritium removal in 3 h for a batch reaction, the design basis was a 5-h hold-up time to make ample allowance for uncertainty and axial dispersion. These assumptions yield a heated length (reaction zone) of 12 ft.

A dimensionless number developed in our studies of rotating tubes with small slopes is

$$\text{UNUM} = \frac{V}{2\pi \times s \times \text{rpm} \times D} ,$$

where:

V = the forward velocity of the solids,

rpm = the rotation rate of the tube,

D = the diameter of the tube,

s = the slope of the tube.

It was found that for conditions in the general range around the voloxidizer design, UNUM was quite constant with a value of 0.80. Selecting a rotation rate of 1 rpm gave a design slope of $^1/_{16}$ in./ft, which is very much smaller than slopes used in conventional calciners.

Table A.1. Calciner holdup calculation

Component	Flow rates	
	kg/d	g/min
Design feed requirements for voloxidizer[a]		
UO_2	408.0	283.5
PuO_2	102.0	70.6
Stainless steel	610.0	423.4
Fission products	50.0	34.6
T_2O	2×10^{-4}	1.4×10^{-4}
Total	1170.0	812.1
Bulk volume	6.97 ft^3/day	0.0048 ft^3/min (0.29 ft^3/h)

Voloxidizer length requirement

At 7% full, an 18-in. diam tube holds 0.123 ft^3/ft. Desired velocity is

$$\frac{0.29\ \mathrm{ft^3/h}}{0.123\ \mathrm{ft^3/ft}} = 2.36\ \mathrm{ft/h}\ .$$

A residence time of 6 h requires 5 × 2.36 = 11.8 ft.

Chosen length of heated zone = 12 ft.

Voloxidizer slope requirement

Typical value for

$$\mathrm{UNUM} = \frac{V}{2\pi(\mathrm{slope})(\mathrm{rpm})(\mathrm{diam})} = 0.8\ .$$

At 1 rpm

$$\mathrm{slope} = \frac{2.36\ \mathrm{ft/h}}{2\pi(1\ \mathrm{rpm})(1.5\ \mathrm{ft})(0.8)(60\ \mathrm{min/h})} = 0.00522\ \mathrm{ft/ft}\ .$$

Slope = 0.0626 in./ft ≅ 1/16 in./ft .

[a]0.5 t/d of heavy metal average LMFBR fuel at 10% burnup.

The selection of 1 rpm for rotation rate is loosely developed by general criteria. The minimum rotation rate to stir the solids enough to effect necessary heat transfer and allow contact with the bulk gas is much less than 1 rpm. Mass transfer, in particular, is limited by the diffusion of gases through the solid phase. Mechanical equipment is subject to wear at rates proportional to rotational speed, but in our system little wear is anticipated until rates exceed perhaps 5 rpm. The design was found to be quite insensitive to rotational speed, and the selection represented a convenient point in the acceptable range.

A.7. Product Cooler

One design criterion imposed on the voloxidizer stipulated that the solid product be discharged at a temperature no greater than 150°C (302°F). To accomplish this, a jacket would be placed around a sectional length of the voloxidizer drum, and outside air, at about 25°C (77°F), would be circulated between the jacket and outer drum surface and would flow countercurrent to the solids. Solids would enter the product cooling section at a nominal rate of 108 lb/h at ~550°C (1022°F). The heat capacity of the solid mixture and the air is 0.10 Btu lb^{-1}-$°F^{-1}$ and 0.25 Btu lb^{-1}-$°F^{-1}$ respectively. Were the cooling air flow rate 1000 cfm (~75 lb/h), a heat balance over the cooler indicates that the air temperature would rise only 7°F. Thus, the cooling air temperature is nearly constant.

Assuming that the gas-to-drum wall heat-transfer coefficient is sufficiently large that the drum wall temperature is constant at the cooling air temperature, a simplified model describing the temperature of the solid material within the product cooler can be developed. Thus,

$$- \frac{dT}{(T-T_w)} = \frac{\alpha h_{ws}}{\dot{m} C_s} \, dx \quad , \tag{A.1}$$

where:

T = the solids temperature,
T_w = the drum wall temperature (77°F),
α = the arc length of solids to inside drum wall contact,
$\dot{m}$ = the mass flow rate of solids,
C_s = the heat capacity of the solids,
x = the longitudinal distance,
h_{ws} = the solids-to-wall heat-transfer coefficient.

The helical flights in the section of the drum, which passes through the product, maintain high solids velocity and low solids inventory. In an 18-in. diam drum, the fraction of the cross-section filled with solids would range from 0.001 to 0.01, and the corresponding values of α would be 0.26 ft and 0.54 ft respectively. Integrating Eq. (A.1), with appropriate boundary conditions, yields

$$- \ln \, (T-T_w) \Big|_{T_{in}}^{T_{out}} = \frac{\alpha h_{ws}}{\dot{m} C_s} \, x \quad . \tag{A.2}$$

Were the length of the product cooler 5 ft and the α taken to be 0.26 ft, substitution of the above data into Eq. (A.2) shows that h_{ws} = 12 Btu-h^{-1}-ft^{-2}-$°F^{-1}$. That is, a solids-to-wall heat-transfer coefficient in the magnitude of 12 $Btu\text{-}h^{-1}\text{-}ft^{-2}\text{-}°F^{-1}$ would be needed to obtain the required solids discharge temperature. The literature[10] presents data showing that h_{ws} is in the range of 8.8 to 52.8 $Btu\text{-}h^{-1}\text{-}ft^{-2}\text{-}°F^{-1}$. Therefore, a cooler length of 5 ft seemed plausible.

A check is now made to determine if the air side heat-transfer coefficient is limiting. If the actual heat load on the cooler were five times the load caused by the sensible heat of the solids as above (i.e., q = 39 000 Btu/h), the rise in the cooling air temperature would be 35°F. A heat balance on the air yields

$$q = h_{wg} A \Delta T_{\ell m} \quad , \tag{A.3}$$

where:

h_{wg} = the gas-to-drum wall heat-transfer coefficient,
A = the outside surface area of the drum/cooling section,
$\Delta T_{\ell m}$ = the log-mean difference in the air and wall temperatures.

Assuming that the drum-wall temperature in the cooling section is constant at 150°C (302°F), the log-mean temperatures difference will be given by

$$\Delta T_{\ell m} = \frac{(T_w - T_i) - (T_w - T_o)}{\ln \dfrac{(T_w - T_i)}{(T_w - T_o)}} \quad , \tag{A.4}$$

where:

T_i = the temperature of the inlet air,
T_o = the temperature of the air at the outlet.

With a 5-ft-long cooling section, the necessary gas-to-wall heat-transfer coefficient, given by Eq. (A.3), would be 8.0 $Btu\text{-}h^{-1}\text{-}ft^{-2}\text{-}°F^{-1}$. This coefficient is of the magnitude expected for forced convection.

It is apparent that the length of the cooling section should be 5 ft. Together with the length of heated reactor, the length of the voloxidizer is a minimum of 17 ft. However, additional drum length is required to accommodate the two riding rings, the two bellows/seal assemblies, and the bull gear bringing the total voloxidizer drum length to 25 ft.

A.8. Gas Balance

The voloxidation process is based on the oxidation reaction whereby UO_2 fuel is converted into U_3O_8, causing the fuel to restructure, pulverize, and release tritium. A voloxidizer processing 0.5 t/d of heavy metal, assuming that all the metal is present as UO_2, requires oxygen fed at 0.371 scfm to meet stoichiometric requirements. An equivalent amount of oxygen could be supplied by feeding 1.767 scfm of air. Because the voloxidizer operates at a slight vacuum and because the seals are required to be dry seals (because of radiation), gas will leak into the voloxidizer through the seals. The design limit was that the seals leak at a rate of no more than 0.5 scfm, a criterion that can easily be met. In a reprocessing facility, the voloxidizer would be placed in a cell where the atmosphere is nitrogen. Were the seals operating at the maximum allowable leak rate and twice the stoichiometric amount of oxygen used, the approximate gas balance would be as given in Table A.2. As shown, the total gas demand of the system is low. In an 18-in.-diam drum operating at a maximum temperature of 650°C (1200°F) with oxygen feed, as in Table A.2, the maximum gas velocity would be 0.055 ft/s, which is very low. The gas would therefore move through the voloxidizer in mixed or dispersed flow.

Table A.2. Approximate average gas balance for 0.5-t/d voloxidizer, dry basis

Species	Rate with oxygen feed (scfm)		Rate with air feed (scfm)	
	Inlet	Effluent	Inlet	Effluent
N_2	1.000[a]	1.000	3.792[a]	3.792
O_2[b]	0.742	0.371	0.742	0.371
T_2O	0	Negligible	0	Negligible
Total	1.742	1.371	4.543	4.163

[a]Inleakage through both seals total 1.0 scfm.
[b]Twice stoichiometric quantity.

A.9. Heat Balance

The reaction zone of the voloxidizer is required to provide both heating and cooling in order to maintain the solid fuel temperature within the rather narrow limits necessary to obtain the desired product. The solids and gas must be heated to the reaction temperature. It was feared that the subsequent release of reaction and decay heats could cause a catastrophic temperature excursion. Given that the heat of reaction for the conversion of UO_2 to U_3O_8 is 167 Btu/lb of UO_2, that the decay heat for 100-d cooled fuel after 100 000 MWd/t burnup is estimated to be 180 800 Btu/t, and that the holdup in the reaction zone is 5 h, the magnitude of heat sources can be easily calculated. The results of the calculation are summarized in Table A.3. Should the reaction go to completion in a 1-ft length of the reaction zone, the quantity of heat that would be released in that section would be 10 300 Btu/h or 3.0 kW. The accommodation of heat loads of this magnitude is quite tractable.

Table A.3. Voloxidizer heat balance

	Quantity (Btu/h, kW)
Heat sources	
Decay heat[a]	18.8×10^3 (5.5)
Reaction heat	8.7×10^3 (2.6)
Total	27.5×10^3 (8.1)
Sensible heat requirements[b]	
Solids	11.7×10^3 (3.4)
Gas	5.5×10^3 (1.6)
Total	17.2×10^3 (5.0)

[a]For 100-d cooled fuel; total heat generated in reactor section, which is 12 ft long.

[b]For a 600°C (1080°F) rise in temperature.

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APPENDIX B

MIXING-FLIGHT DEVELOPMENT

The mixing flights in each section of the drum served to meet different requirements, supported the central objective of voloxidation and provided a congruous interface between the voloxidizer, shear, and dissolver during both normal and abnormal operation. The cooling section flights provided a rapid solids flow rate to meet the requirement of a low inventory and a reversible-flow-direction, controlled by the rotation direction, to prevent undesirable feeding of the dissolver. The heating section flights provided a low solids flow rate to meet reaction-kinetics controlled residence-time requirements. The inlet-section flights needed to provide rotation-direction-independent, rapid, and effective solids movement. These characteristics were desirable to prevent accumulation of solids at the inlet with subsequent leakage into the inlet breeching and to prevent backmixing of material already in the heating section. This task needed to be performed both at normal and rapid shear rates for both drum rotation directions. The requirements for the inlet section performance were met by (1) a combination of modifications to the inlet chute to reduce the gap available for leakage (see Sect. 2.3.8), (2) the addition of an inlet cone to the inlet section, and (3) the flight design. The purpose of this appendix is to describe the inlet-flight development work.

The original FSEV inlet-flight design consisted of a helical cartridge. These flights were designed to meet the rapid velocity requirement, but not the drum rotation-direction-independent requirement. A linear flight cartridge, similar to the heating section design, was installed initially because of difficulties in fabrication and subsequent installation of the helical unit. Although these flights could not meet either of the primary inlet-flight requirements, they permitted the experimental effort to proceed and an ongoing flight development effort was expedited.

Meeting the requirements of the inlet section was first addressed experimentally in 1977 in a scoping test performed during solids residence-time-distribution characterizations. These flights were designated *triangular protrusions* and are illustrated in Fig. B.1. These flights provided a mean velocity for hulls of ~0.15 m/min, an order-of-magnitude higher than the mean velocity obtainable by linear flights, 0.015 m/min, under similar conditions* but nearly a quarter of the mean velocity obtainable by helical flights, 0.55 m/min. The concentration time distribution obtained using the *triangular protrusions* was bimodal, and

*The conditions were as follows: A hulls feed rate of 900 g/min, a rotation rate of 1.0 rpm, and a slope of 0.005 m/m (1/16 in./ft).

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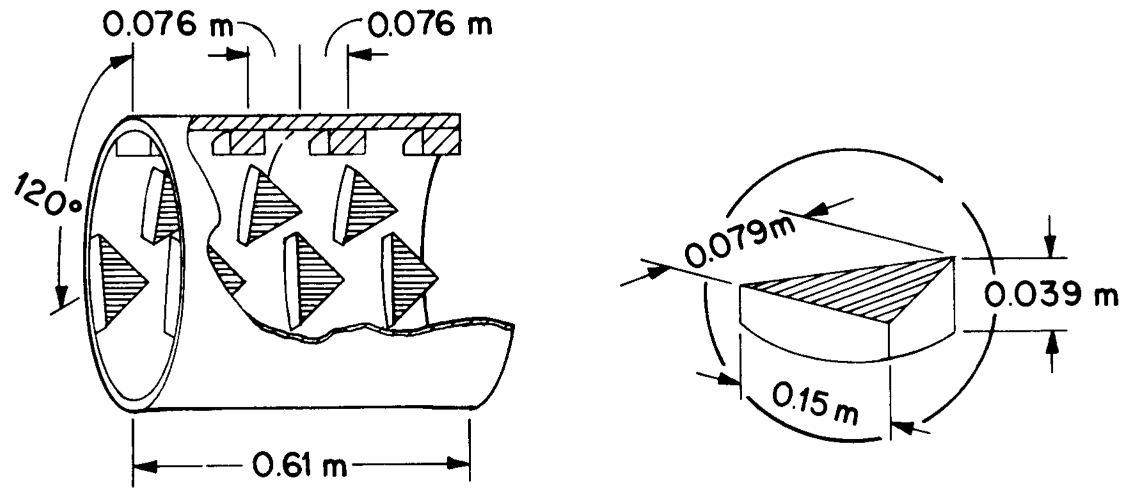


TRIANGULAR PROTRUSIONS

Fig. B.1. Early inlet-flight concept.

the material velocity ranged from 0.009 to 0.3 m/min. The objective of the development work that followed was to drive the solids velocity toward the higher value and to increase the flights effectiveness which could be measured by the degree of backmixing.

B.1. Experimental Procedures and Measures of Performance

The flight development effort included testing of nine different flight designs which were characterized in 76 runs. The tests were performed using a 0.46-m (18-in.) ID, 1.14-m (45-in.) long steel drum. The flights were constructed of stainless steel and were bolted into place through the drum wall with the flight-wall gap sealed using silicone rubber. The drum was mounted on an electric motor-driven roller assembly with controllable speed. Feed was introduced via an inlet chute which protruded through a replaceable dam. The exit was either (1) open, in which case the product was collected by a product collection chute, (2) partially blocked by an interchangeable dam to simulate solids inventory in the voloxidizer heating section, or (3) blocked off completelv.

The parameters that were investigated included the flight design, the distance between flights at the same radial positions and between flights at different axial positions, the flight density (i.e., number of flights through the cross-section), the feed rate, the inventory, and the feed type (sand, hulls, shroud, or a mixture of all three). In addition, the influence of the inlet's geometry, specifically the dam height and the internal dam surface angle, was investigated.

The experiments were designed to characterize the flights performance under normal conditions and to test their limit under abnormal conditions. The tests fell into four different categories which are described below:

1. *Continuous-feed, tracer-response tests.* Material was fed until steady-state was reached. Then a tracer was added, the output was sampled, and the output tracer concentration was determined. This procedure resulted in a residence-time-distribution from which the mean time and the variance (a measure of the degree of mixing) were determined.
2. *Exit-flow, batch-feed tests.* An initial inventory was loaded into the drum and the output was sampled. Although, by definition, this system was never at steady-state, an estimate of the mean time and the variance could be obtained. In addition, the procedure provided a good measure of the flights performance at high loading that could occur during rapid shearing.
3. *Inventory profile.* The exit was either dammed to obtain a desired percent-full or blanked off. The drum was loaded and rotated to obtain a steady-state profile. The height and the width of the solids bed was measured at various axial locations and an inventory profile was calculated. The shape of this profile provided a measure of the flight's effectiveness.
4. *Inlet-spillage rate.* The inlet was prepared as in Item 3 and the drum was continuously fed solids. The amount of material spilling from the inlet was then determined. A variation of this procedure was to continuously increase the feed rate until spill was observed, thus determining that design's maximum capacity.

B.2. Flight Designs

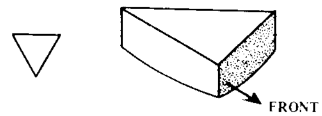
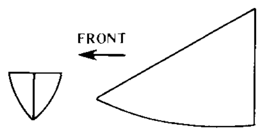
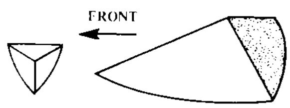
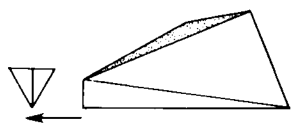
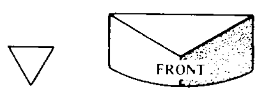
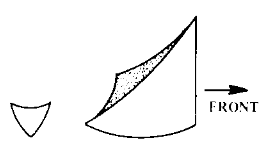
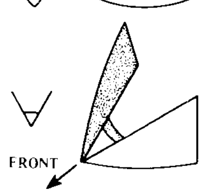
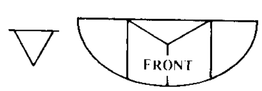
The evolution of the flight design is traced in Table B.1. Designs 4 and 5 are sketched in Figs. B.2 and B.3, respectively, and designs 4 and 5 are shown in Fig. B.4. All designs are symmetric, thus effective for both directions of rotation.

B.3. Data

A complete presentation and analysis of data collected is beyond the scope of this summary. Instead, a representative sample of the results is presented. The initial experiments were primarily *continuous-feed, tracer response* (procedure 1) and *exit-flow, batch-feed* (procedure 2) tests.

Figure B.5 shows the exit-flow rate vs time obtained by procedure 2 with sand and hulls feed using flight design 2 (straight-back) flights. Several observations are noteworthy. First, the time to empty sand is nearly three times the time to empty hulls. Second, the mean velocity for the hulls is ~0.25 m/min, a significant improvement over that obtained

Table B.1. Characteristics of flight design

Design	Designation	Illustration	Features
1	Triangular protrusions		Top perpendicular to diameter
2	Straight-back pyramidal		Back parallel to diameter
3	Slanted-back pyramidal		Back at 30° angle
4	Modified pyramidal		Combines 1 and 2
5	Modified triangular		Top slanted toward front
6	Double helical		Top is a cylindrical section; sides are helical (see Fig. B.2)
7	Triangular conical		High front, top and back is a conical section
8	Flying wings		No top or back
9	Dam		Combines design 5 with dams on back edge (see Fig. B.2)

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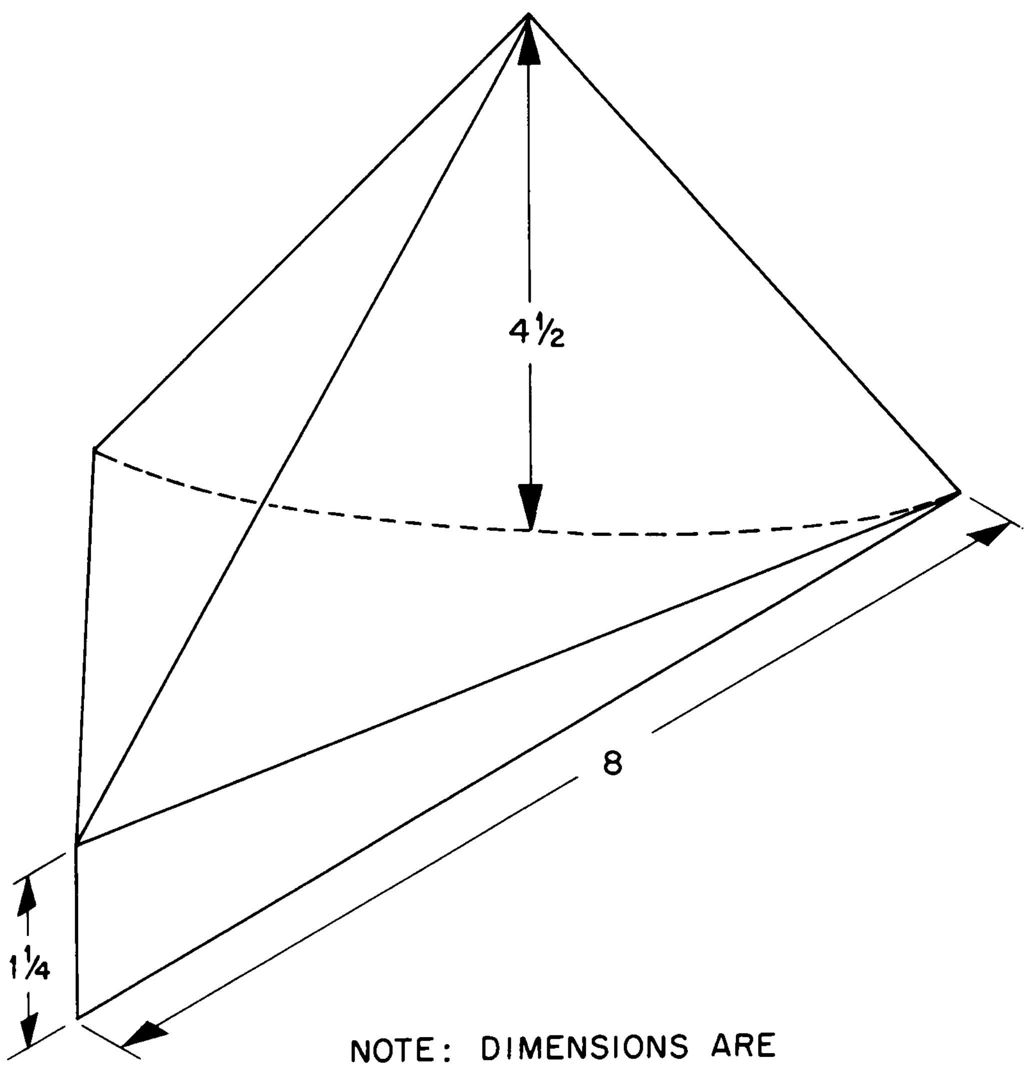

Fig. B.2. Modified pyramid flight (design 4).

with design 1 (~0.15 m/min), especially considering the high loading in this case. Finally, the output rate has an oscillatory character. Two hypotheses were proposed to explain this behavior.

It was conjectured that a systematic experimental bias could be present if the sampling time interval was out of phase with the rotation rate caused either by an inaccurate rotation rate setting or by speed drift resulting from a constantly decreasing load. Procedures were modified to eliminate this bias by sampling based on rotational intervals rather than on time intervals. However, this did not eliminate the cyclic behavior indicating that another mechanism was at work.

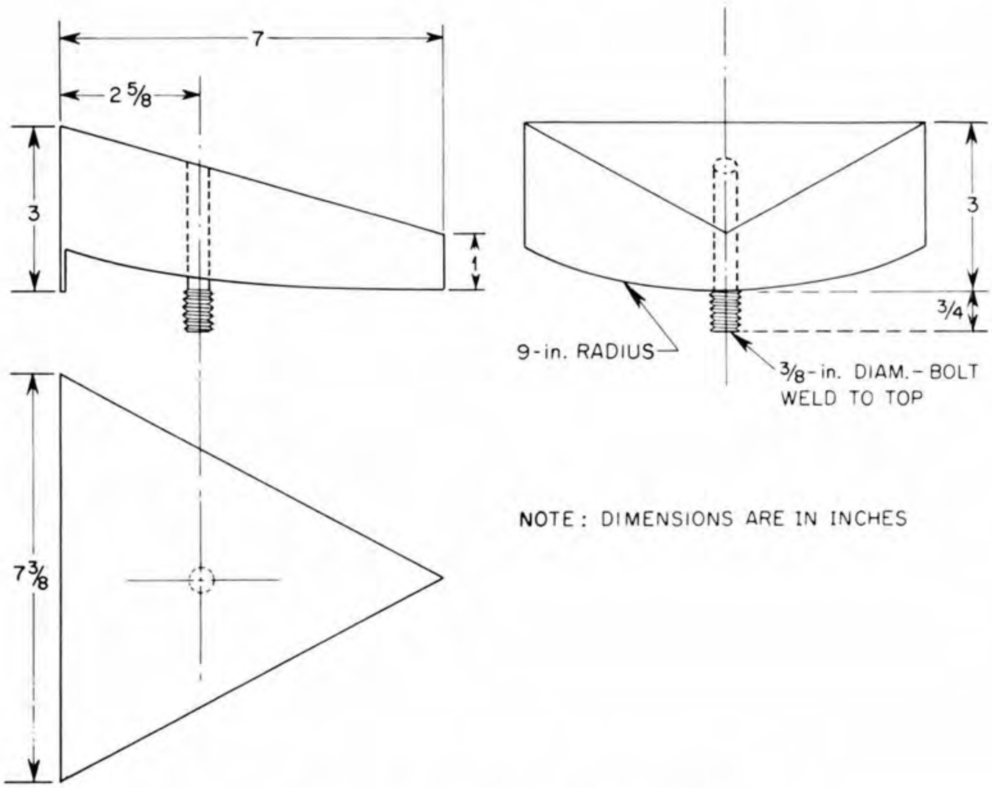

Fig. B.3. Modified triangular flights (design 5).

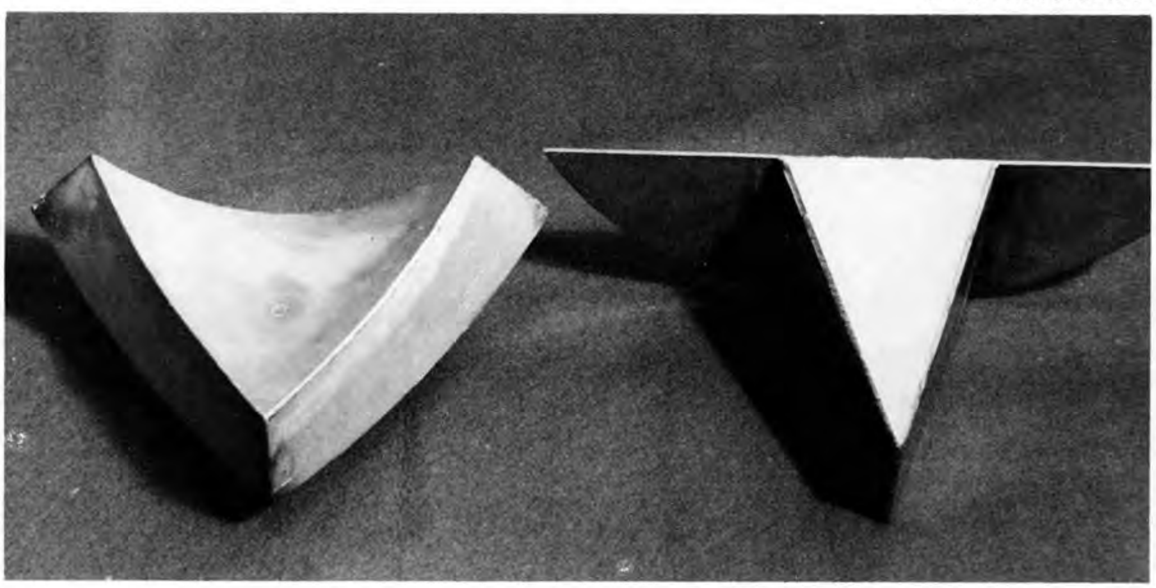

Fig. B.4. The *dam* (design 9) and *double helical* (design 6) flights.

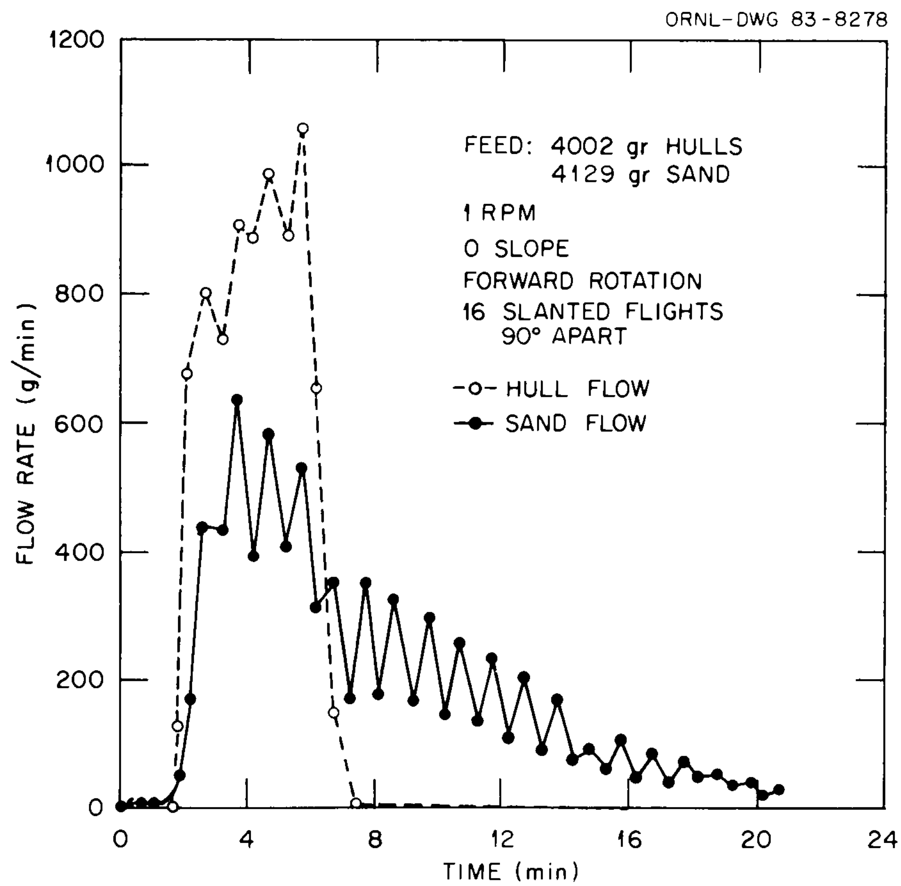

Fig. B.5. Representative output obtained using the batch feed procedure.

Another possibility is that the cyclic response results from an internal material recycle. The observed tracer signal for systems with relatively rapidly recirculation compared to throughflow exhibits this behavior. If this is the case, then the degree of cycling can be considered a measure of the backmixing and stagnation (a measure of effectiveness.)

Figure B.6 shows the steady-state inventory profile, as measured by the cross-sectional area filled with solids, with the exit blanked off. These results were obtained using design 4 with sand. Note that no accumulation at the entrance is present.

Figure B.7 presents spill rate data for three flight designs. The exit was blocked with a dam to simulate a 15% full heating section, and the drum rotated an equivalent number of times for each design. It is clear that the *dam* flights give superior performance.

B.4. Conclusions

The *dam* flights (design 9) provide an effective means for meeting the materials flow requirements imposed on the FSEV inlet section. The primary contributor to their effectiveness is the dam attached to the back edge which substantially reduces backmixing.

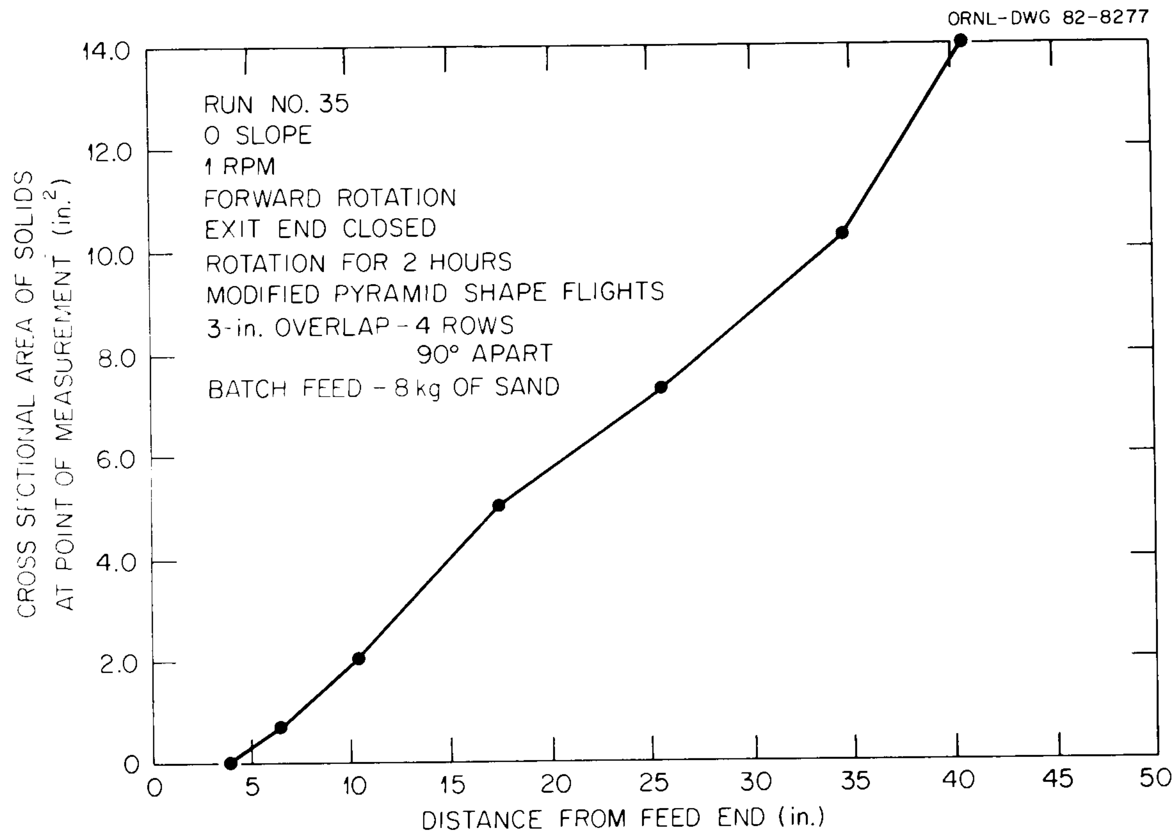

Fig. B.6. Inventory profile.

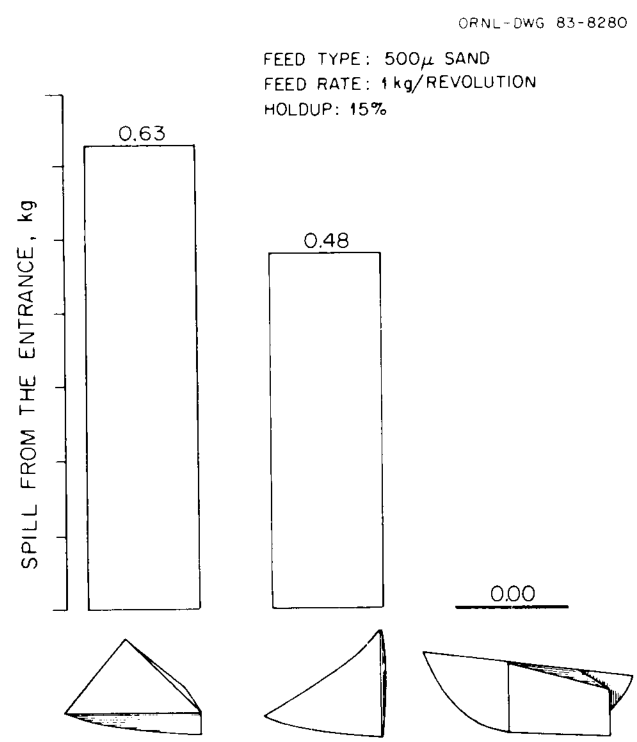

Fig. B.7. Cumulative spill for three flight designs from the feed-end test drum after an extended period of operation.

The other flight designs all performed well with respect to mean velocity, but permitted backmixing. A flight density (measured at a flights back edge) of 4 was found to be satisfactory. The smallest front-to-back distance that did not permit shroud lodging was determined to be ~1¼ in.

APPENDIX C

LIST OF DRAWINGS DETAILING FSEV MECHANICAL COMPONENTS

Drawing	Title	Description
X3E-13023-100-A	Voloxidizer general arrangement	Overview drawing of FSEV showing arrangement and elevation of major components in Building 7602
X3E-13023-105-0	Feed metering station voloxidizer – assembly	Drawing of tip-bucket and surrounding support hardware needed for metering solids feed (sheet 1 of 3)
X3E-13023-106-0	Feed metering station voloxidizer – details	Part-by-part detail of brackets, etc., used in fabricating metering station (sheet 2 of 3)
X3E-13023-107-0	Feed metering station voloxidizer – details	Additional details of solids metering station (sheet 3 of 3) – obsolete
X3E-13023-109-0	Voloxidizer sample station – assembly	Assembly drawing of solids sampling station showing sampling spoon; station is in line with the feed and discharge chutes – two required (sheet 1 of 5)
X3E-13023-110-0	Voloxidizer sample station – detail (sheet 1)	Details of sampler housing, receiving section (sheet 2 of 5)
X3E-13023-111-0	Voloxidizer sample station – detail (sheet 2)	Details of sampler housing, dumping section (sheet 3 of 5)
X3E-13023-112-0	Voloxidizer sample station – detail (sheet 3)	Details of sampling "spoon" and necessary gaskets (sheet 4 of 5)
X3E-13023-113-0	Voloxidizer sample station – detail (sheet 4)	More details of gaskets and details of viewing window and handles (sheet 5 of 5)
X3E-13023-114-A	Voloxidizer shroud metering station – assembly	Vibratory shroud feed (sheet 1 of 3) – obsolete
X3E-13023-115-A	Voloxidizer shroud metering station – assembly detail (sheet 1)	Details of frame for shroud feeder (sheet 2 of 3)
X3E-13023-116-A	Voloxidizer shroud metering station – assembly detail (sheet 2)	Details of vibrating tray and hopper (sheet 3 of 3)
X3E-13023-117-A	Voloxidizer hulls and powder metering station – assembly	Vibratory feeder used for metering both hulls and powder feed materials
X3E-13023-118-0	Voloxidizer hulls and powder metering station – assembly detail (sheet 1)	Details of frame for hulls and powder feeders

Drawing	Title	Description
X3E-13023-119-A	Voloxidizer hulls and powder metering station – assembly detail (sheet 2)	Details of vibrating trays and hoppers (sheet 1 of 1)
X3D-13023-120-A	Voloxidizer vibrating screen – assembly	Assembly drawing of the vibratory screener used in the feed house to separate the feed material into three size fractions (sheet 1 of 3)
X3E-13023-121-A	Voloxidizer vibrating screen – detail (sheet 1)	Supporting framework and braces
X3E-13023-122-0	Voloxidizer vibrating screen – detail (sheet 2)	Details of hopper and feed funnel
X3E-13023-123-A	Voloxidizer feed system enclosure – assembly	Drawing of feed house (sheet 1 of 6)
X3E-13023-124-A	Voloxidizer feed system enclosure – detail (sheet 1)	Details of front panel and door (sheet 2 of 6)
X3E-13023-125-A	Voloxidizer feed system enclosure – detail (sheet 2)	Details of floor, including connection funnel to chute (sheet 3 of 6)
X3E-13023-126-0	Voloxidizer feed system enclosure – detail (sheet 3)	Window frame, side panels, and trap door crank (sheet 4 of 6)
X3E-13023-127-0	Voloxidizer feed system enclosure – detail (sheet 4)	Top panel – roof (sheet 5 of 6)
X3E-13023-128-A	Voloxidizer feed system enclosure – detail (sheet 5)	Rear panel and brackets (sheet 6 of 6)
X3E-13023-129-0	Voloxidizer feed system enclosure; service platform – assembly	Assembly drawing showing deck, safety railing, ladder, and access panel (sheet 1 of 2)
X3E-13023-130-A	Voloxidizer feed system enclosure – service platform – details	Details for fabrication of deck, railing, and ladder (sheet 2 of 2)
X3E-13023-131-0	Voloxidizer – Voloxidizer modification	Corrections indicating proper flanges to be installed in the inlet and product chutes
X3E-13023-132-0	Alternate shroud feed trays	Improved design of vibrating trays to be used in shroud feeder (refer to dwg. X3E-13023-114-A)
X3E-13023-134-0	Expansion bellows for voloxidizer inlets and outlets	Bellows in the fixed feed (inlet) chute and discharge (outlet) chute to accommodate changes made to slope of voloxidizer
X3E-13023-135-0	Section cooling heat exchanger – assembly for voloxidizer	Water cooled heat exchanger used to cool air in natural convection cooling stack circuit; assembly drawing shows exchangers and valves for exchangers associated with all four furnace zones so equipped (sheet 1 of 4)
X3E-13023-136-0	Section cooling heat exchanger – details for voloxidizer	Details of support frame top and bottom covers and separator panels (sheet 2 of 4)
X3E-13023-137-0	Lower section cooling heat exchanger for voloxidizer	Assembly drawing showing cooling stacks and their connections with the furnace zones; valves and actuating linkage also shown (sheet 1 of 2)

Drawing	Title	Description
X3E-13023-138-0	Lower section cooling heat exchanger – details for voloxidizer	Support frame for stacks, connecting flanges, and expansion bellows (sheet 2 of 2)
M3D-13023-139-0	LMFBR fuel recycle rotary kiln voloxidizer	Conceptual design of voloxidizer showing essential features and approximate size – obsolete
X3D-13023-140-0	Voloxidizer component development system flowsheet	Flow network for gas and solids in the FSEV
X3D-13023-141-0	Vibratory feeder tray experiment tray – assembly and details	Second generation improvement to shroud feeder tray
X3D-13023-142-0	Vibratory feeder experiment feed hopper	Alternate and improved design of hopper for shroud feeder that reduces frequency of blockages
X3D-13023-143-0	Rotary kiln voloxidizer	Revised conceptual design of voloxidizer showing prototypic dimensions; supercedes M3D-13023-139-0
X3D-13023-144-0	Voloxidizer component development system flowsheet	Revised drawing of flow network of gas and solids in the FSEV; supercedes X3D-13023-140-0
X3E-13023-146-0	Feed/product container – assembly	Product drum (feed container) design showing valve assembly (lid) and closure assembly (sheet 1 of 6)
X3E-13023-147-0	Feed/product container – valve subassembly and details	Details of valve assembly, gaskets and latch assembly (sheet 2 of 6)
X3E-13023-148-0	Feed/product container – container subassembly	Details of drum body including adapter and cap assemblies on which valve is attached (sheet 3 of 6)
X3E-13023-149-0	Feed/product container – container details	Details of adapter (mates with feed hatch on feed house), gate type valve (trap door on bottom of container), and gate latch (sheet 4 of 6)
X3E-13023-150-0	Feed/product container – cell closure subassembly and details	Mating items on feed house that work with product drums for opening and closing bottom gate on drum (sheet 5 of 6)
X3E-13023-151-0	Feed/product container cell closure details	Detailed design of drum closing apparatus (sheet 6 of 6)
X3E-13023-153-C	Feed/product container dolly and weigher assembly and details	Wheeled product drum dolly and track on which it runs; drawing also shows placement of containers underneath diverter valve assembly (sheet 1 of 5)
X3E-13023-154-A	Weigher assembly and details	Weigh platform, with load cells, built on air operated "elevator" so that weight of product container is taken from dolly wheels and transferred to weigh platform (sheet 2 of 5)

Drawing	Title	Description
X3E-13023-155-B	Weigh platform/product container platform and container valve parts details	Details of load platform weldment, supporting plates, and latch assembly (sheet 3 of 5)
X3E-13023-156-A	Product container dolly, dolly frame assembly, and details	Details of dolly (sheet 4 of 5)
X3E-13023-157-A	Dolly track and weigher base assembly and details	Details of installation of dolly track in Building 7602 (sheet 5 of 5)
X3E-13023-158-0	Voloxidizer first floor hatch modification	Modification of hatch on first floor of Building 7602 allowing easier access to mezzanine level for delivery and removal of large pieces of equipment
X3E-13023-159-A	Voloxidizer cooling section installation – support details	Miscellaneous support structures
X3E-13023-160-0	Voloxidizer filter assembly	Off-gas filter and housing assembly
X3E-13023-161-0	Voloxidizer filter assembly – detail (sheet 1)	Details of filter housing body and cover flange
X3E-13023-162-0	Voloxidizer filter assembly – detail (sheet 2)	Details of filter elements, cover cap, and filter replacement driver; driver pushes new filter in place forcing old filter out and old filter falls into voloxidizer
X3E-13023-163-B	Voloxidizer platform	Supporting platforms and walkways; drawing gives on-site placement instructions (sheet 1 of 10)
X3E-13023-164-B	Voloxidizer platform	Erection plan (sheet 2 of 10)
X3E-13023-165-A	Voloxidizer platform	Bill of material (BM) and section sketches (sheet 3 of 10)
X3E-13023-166-B	Voloxidizer platform – details	BM (sheet 4 of 10)
X3E-13023-167-B	Voloxidizer platform – details	BM (sheet 5 of 10)
X3E-13023-168-B	Voloxidizer platform – details	BM (sheet 6 of 10)
X3E-13023-169-B	Voloxidizer platform – details	BM (sheet 7 of 10)
X3E-13023-170-B	Voloxidizer platform – details	BM (sheet 8 of 10)
X3E-13023-171-B	Voloxidizer platform – details	BM (sheet 9 of 10)
X3E-13023-172-A	Voloxidizer platform – details	BM (sheet 10 of 10)
X3D-13023-173	18-in. ID × 24-ft 8½-in. long electric heated calciner with cooler	As-built assembly drawing of FSEV [Combustion Engineering (CE) dwg. L-8543-1112-B]
X3D-13023-174	Trunnion roll base assembly for 18-in. ID × 24-ft 8½-in.-long rotary calciner	As-built details of trunnion roller assembly that supports rotating drum (CE dwg. L-110-8-32-0)
X3D-13023-175	Cartridge assembly	As-built drawing of the insertable flight cartridges for FSEV (CE dwg. L-110-1-177-B)
X3D-13023-176	Cylinder assembly for 18-in. ID electric heated calciner with cooler	As-built drawing of the rotary drum in the FSEV showing riding rings and bull gear (CE dwg. L-110-1-171-B)

Drawing	Title	Description
X3D-13023-177	Foundation and anchor bolt layout	As-built drawing of foundation for FSEV (CE dwg. L-77-41-70-0)
X3D-13023-178	Thrust roll and bracket assembly with 5-in. diam × 2½-in. face thrust roll and Graphalloy bushing	As-built drawing of thrust roller assembly (CE dwg. L-082-167-0)
X3D-13023-179	Discharge end assembly for 18-in. ID × 24-ft 8½-in long electric heated rotary calciner	As-built drawing of discharge breeching section (CE dwg. L-110-3-87-A)
X3D-13023-180	Feed end assembly for 18-in. ID × 24-ft 8½-in. long electric heated rotary calciner	As-built drawing of feed-end breeching section (CE dwg. L-110-2-94-A)
X3D-13023-181	Girt and pinion gear guard assembly	As-built drawing of safety guard surrounding bull (girt) gear and pinion gear (CE dwg. L-77-24-450-A)
X3C-13023-182	Feed end seal assembly for 18-in.-ID rotary calciner	As-built drawing of graphite seal assembly and expansion bellows at feed end of FSEV (CE dwg. H-110-22-192-0)
X3C-13023-183	Camrol discharge seal assembly for 18-in. ID rotary calciner	As-built drawing of graphite seal assembly, cam rollers, and expansion bellows at discharge end of FSEV (CE dwg. H-110-22-196-0)
X3C-13023-184	Air cooler assembly for 18-in.-ID calciner	As-built drawing of product cooler (CE dwg. H-110-25-73-0)
X3C-13023-185	Cylinder drive assembly for 18-in. ID × 24-ft 8½-in. long rotary calciner	As-built drawing of drum drive system; gear reducer, emergency hand crank, pinion and girt gears (CE dwg. H-110-30-63-A)
X3D-13023-186-1	Full-Scale Experimental Voloxidizer replacement drum	Design of replacement drum having prototypic internal mixing flights
X3E-13023-188-0	Experimental voloxidizer shroud feeder assembly	Rotary shroud feeder designed to replace vibratory tray models (sheet 1 of 3)
X3E-13023-189-0	Experimental voloxidizer shroud feeder drum – details	Details of support frame, rotating drum, and weigh platform (sheet 2 of 3)
X3E-13023-190-0	Experimental voloxidizer shroud feeder – details	Details of base, hopper, and chute (sheet 3 of 3)
X3E-13023-191-A	Filtering system assembly	Off-gas piping drawing showing details of off-gas line from voloxidizer to filter (sheet 1 of 2)
X3E-13023-192-A	Details for filter system assembly	Off-gas piping drawing (sheet 2 of 2)
X3D-13023-193-0	Full-Scale Experimental Voloxidizer replacement seal ring	Design of nonsegmented (i.e., solid, one piece) graphite seal ring
X3D-13023-195-0	Full-Scale Experimental Voloxidizer temporary furnace lid support	Frame used to support upper half of furnace (lid) at an elevation of 20 in. higher than the installed position so that work can be done on the rotary drum without removing that part of the furnace from the mezzanine level

Drawing	Title	Description
X3E-13023-200-0	Voloxidizer prototypical off-gas filter assembly	Prototypic filter housing and parts list
X3E-13023-201-0	Voloxidizer filter assembly – detail (sheet 3)	Flanges and seals for filter assembly
X3E-13023-202-A	Voloxidizer filter assembly – detail (sheet 2)	Flanges and seals
X3E-13023-203-0	Voloxidizer filter assembly – detail (sheet 2)	Flanges, seals, and pipework
X3D-13023-204	Cylinder assembly	Prototypic replacement drum (CE dwg. L-110-1-203-B)
X3D-13023-205-0	Full-Scale Experimental Voloxidizer powder recycle system	Drawing showing installation of recycle system on FSEV inlet breeching section (sheet 1 of 3)
X3E-13023-206-0	Full-Scale Experimental Voloxidizer powder recycle system – detail (sheet 1)	Detail of funnel attached to bottom of breeching section and lower pipework (sheet 2 of 3)
X3E-13023-207-0	Full-Scale Experimental Voloxidizer powder recycle system – detail (sheet 2)	Detail of connection flanges, gaskets, and air jet (sheet 3 of 3)
M3D-13054-R001-0	Full-Scale Experimental Voloxidizer inlet chute – detail	Detailed design of collar fitted around inlet chute
M3D-13023-R001	Full-Scale Experimental Voloxidizer replacement drum (as built)	Shows internal arrangement of mixing flights
M3C-13023-R002	Experimental voloxidizer drum flight – isometric and detail	Details of dam type mixing flight

APPENDIX D

LIST OF INSTRUMENTATION AND CONTROL DRAWINGS

Drawing	Title	Description
I3D-13023-Q001-0	Voloxidizer system instrumentation flowsheet	Overview sketch of FSEV system indicating required control valves, limit switches, field sensors, and instrument air supply
I3D-13023-Q002-D-0	Voloxidizer feed system instrumentation flowsheet	Isometric sketch of vibratory screener; all three feeders and tip-bucket showing control valves feeding air to pneumatic vibrators, and sensor signals and control signals communicating with control modules
I3D-13023-Q003-D-0	Voloxidizer unit process controller typical inter-connections	Diagrams of unit process controller showing location of power supply, disk drive, battery backup, CPU card cage, operators panel, analog inputs and outputs, discrete inputs and outputs and multiplexers
I3D-13023-Q004-D-0	Voloxidizer unit process controller and process interconnections	Block diagram showing signals being brought into controller and signals being driven by controller; wires connecting controller to devices are numbered
I3D-13023-Q005-D-0	Voloxidizer electrical interconnections tabulations – terminal board 1	Tabulation of wiring connections giving wire number and associated terminal number; also gives field device and function performed for terminal board 1
I3D-13023-Q006-D-0	Voloxidizer electrical interconnections tabulations – terminal boards 2 and 3	Tabulation of wiring connections and devices associated with terminal boards 2 and 3
I3D-13023-Q007	Auto-data nine/sensor electrical connections	Tabulation of thermocouples and resistance temperature devices; connected to auto-data nine giving sensor number, channel number, card number, and location of sensor in the field
I3D-13023-Q008	Auto-data nine/scanner electrical connections	Continuation of I3D-13023-Q007

APPENDIX E

LIST OF ELECTRICAL DRAWINGS

Drawing	Title	Description
E3E-13023-D001-0	AFR component development voloxidizer facility – elementary diagrams	Overall electrical diagram showing power requirements for each piece of equipment including instrumentation power requirements
E3E-13023-D002-0	AFR component development voloxidizer facility – feeder enclosure, plan, sections, and details	Detailed wiring plan for feed house and list of parts required (such as receptacles, etc.)
E3E-13023-D003-0	AFR component development voloxidizer facility – cable tray (partial), basement plan sections	Detailed installation plan for cable trays in basement area including control platform area
E3E-13023-D004-0	AFR component development voloxidizer facility – cabling interconnection diagram	Wiring diagram featuring furnace and controller interconnections
E3E-13023-D005-0	AFR component development voloxidizer facility – miscellaneous electrical details	(Same as title)

APPENDIX F

LIST OF PIPING DRAWINGS

Drawing	Title	Description
P3D-13023-C001-0	Voloxidizer service piping plan – basement	Diagrams of oxygen supply system and instrument air lines
P3D-13023-C002-0	Voloxidizer service piping plan – ground floor	Cooling stack connections and air actuated control valve interconnections; also shows solids inlet chute, off-gas line, and product cooler connections
P3D-13023-C003-0	Voloxidizer service piping sections	Details of sections called out in dwg. P3D-13023-C001-0
P3D-13023-C004-0	Voloxidizer ground floor instrument rack	Detailed interconnections of control and solenoid valves, showing tubing connections at controller
P3D-13023-C005-0	Voloxidizer basement instrument rack and miscellaneous details	(Same as title)
P3D-13023-C900-1	Voloxidizer sprinkler piping plan	Overview of sprinkler system, including general installation instructions
P3D-13023-C901-1	Voloxidizer sprinkler piping sections and details	(Same as title)

APPENDIX G

LISTING OF LOGGERS, VARIABLE NAMES, AND DEFINITIONS

The variable (signal) names of all recorded data are grouped according to logger name and listed on the following pages. The logger name, run-time, and 18 other variables on each logger (except DISCRETE) comprise the 20 items printed on each record. The actual logger name is printed, but only the values of the other variables are printed thus:

ZONEONE, ±X.XXXXXE±XX, ±X.XXXXXE±XX, ...

where ±X.XXXXXE±XX refers to a floating point number, and 19 such numbers appear after the logger name. Each logger output is coded in like manner except for DISCRETE, which is coded such that six on/off (1 or 0) signals comprise a single floating point number of the form +X.XXXXXE±05. For example, items 21 through 26 result in +1.01000E+05 when zones 1 and 3 heater switches are on and the other zone switches are off. The analysis program can decode this.

UPDATED 3-1-82

1	ZONEONE	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SPC1	DEGC	TEMPERATURE SETPOINT FOR ZONE 1
4	TE1	DEGC	TEMPERATURE OF FURNACE ZONE 1, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
5	TE41	DEGC	TEMPERATURE OF FURNACE ZONE 1, TOP NORTH SIDE OF HEATER INSULATION
6	TE18	DEGC	COOLING STACK, ZONE 1, TEMPERATURE OF HOT AIR DISCHARGED FROM FURNACE
7	TE58	DEGC	COOLING STACK, ZONE 1, INSIDE SURFACE TEMPERATURE OF COLD AIR LEG NEAR FURNACE
8	TE17	DEGC	COOLING STACK, ZONE 1, TEMPERATURE OF COLD AIR FED TO FURNACE
9	TE57	DEGC	COOLING STACK, ZONE 1, INSIDE SURFACE TEMPERATURE OF HOT AIR LEG NEAR FURNACE
10	TE28	DEGC	COOLING STACK, ZONE 1, TEMPERATURE OF COLD AIR DISCHARGED FROM HEAT EXCHANGER
11	TE27	DEGC	COOLING STACK, ZONE 1, TEMPERATURE OF HOT AIR FED TO HEAT EXCHANGER
12	TE35	DEGC	HEAT EXCHANGER, ZONE 1, SURFACE TEMPERATURE OF WATER DISCHARGE PIPE
13	FLW1	L/MIN	HEAT EXCHANGER, ZONE 1, WATER FLOW RATE THROUGH EXCHANGER
14	TM1	PCNT	OUTPUT OF CONTROLLER TO VALVES IN COOLING ST.
15	PWPZ1	KW	POWER TO ZONE 1 OF HEATING SECTION
16	RTD1	MV	HEAT EXCHANGER, ZONE 1, OUTLET WATER TEMPERATURE
17	TE91	DEGC	RTD1 CONVERTED TO DEGC
18	TE81	DEGC	TEST THERMOCOUPLE FOR ZONE 1,TYPE S,IN CALCIUM SILICATE BLOCK WITH 1 IN. WELL FOR DRUM TEMP.
19	ITE15	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 111.0 IN. FROM FEED END,CENTER ZONE 4
20	ITE16	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 121.0 IN. FROM FEED END,,BETWEEN ZONE 4 AND 5

END

1	ZONETWO	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SPC2	DEGC	TEMPERATURE SETPOINT FOR ZONE 2
4	TE2	DEGC	TEMPERATURE OF FURNACE ZONE 2, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
5	TE42	DEGC	TEMPERATURE OF FURNACE ZONE 2, TOP NORTH SIDE OF HEATER INSULATION
6	TE16	DEGC	COOLING STACK, ZONE 2, TEMPERATURE OF HOT AIR DISCHARGED FROM FURNACE
7	TE56	DEGC	COOLING STACK, ZONE 2, INSIDE SURFACE TEMPERATURE OF COLD AIR LEG NEAR FURNACE
8	TE15	DEGC	COOLING STACK, ZONE 2, TEMPERATURE OF COLD AIR FED TO FURNACE
9	TE55	DEGC	COOLING STACK, ZONE 2, INSIDE SURFACE TEMPERATURE OF HOT AIR LEG NEAR FURNACE
10	TE26	DEGC	COOLING STACK, ZONE 2, TEMPERATURE OF COLD AIR DISCHARGED FROM HEAT EXCHANGER
11	TE25	DEGC	COOLING STACK, ZONE 2, TEMPERATURE OF HOT AIR FED TO HEAT EXCHANGER
12	TE34	DEGC	HEAT EXCHANGER, ZONE 2, SURFACE TEMPERATURE OF WATER DISCHARGE PIPE
13	FLW2	L/MIN	HEAT EXCHANGER, ZONE 2, WATER FLOW RATE THROUGH EXCHANGER
14	TM2	PCNT	OUTPUT OF CONTROLLER TO VALVES IN COOLING ST
15	PWRZ2	KW	POWER TO ZONE 2 OF HEATING SECTION
16	RTD2	MV	HEAT EXCHANGER, ZONE 2, OUTLET WATER TEMPERATURE
17	TE92	DEGC	RTD2 CONVERTED TO DEGC
18	TE82	DEGC	TEST THERMOCOUPLE,2 IN. DEEP WELL IN CALCIUM SILICATE FOR DRUM TEMP. MEASUREMENT
19	ITE17	DEGC	THERMOCOUPLE MEASURING'DRUM TEMP.(TELEMETRY), 129.0 IN. FROM FEED END,CENTER OF ZONE 5
20	ITE18	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 147.0 IN. FROM FEED END,CENTER OF ZONE 6

END

1	ZONETHRE	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SPC3	DEGC	TEMPERATURE SETPOINT FOR ZONE 3
4	TE3	DEGC	TEMPERATURE OF FURNACE ZONE 3, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
5	TE43	DEGC	TEMPERATURE OF FURNACE ZONE 3, TOP NORTH SIDE OF HEATER INSULATION
6	TE14	DEGC	COOLING STACK, ZONE 3, TEMPERATURE OF HOT AIR DISCHARGED FROM FURNACE
7	TE54	DEGC	COOLING STACK, ZONE 3, INSIDE SURFACE TEMPERATURE OF COLD AIR LEG NEAR FURNACE
8	TE13	DEGC	COOLING STACK, ZONE 3, TEMPERATURE OF COLD AIR FED TO FURNACE
9	TE53	DEGC	COOLING STACK, ZONE 3, INSIDE SURFACE TEMPERATURE OF HOT AIR LEG NEAR FURNACE
10	TE24	DEGC	COOLING STACK, ZONE 3, TEMPERATURE OF COLD AIR DISCHARGED FROM HEAT EXCHANGER
11	TE23	DEGC	COOLING STACK, ZONE 3, TEMPERATURE OF HOT AIR FED TO HEAT EXCHANGER
12	TE33	DEGC	HEAT EXCHANGER, ZONE 3, SURFACE TEMPERATURE OF WATER DISCHARGE PIPE
13	FLW3	L/MIN	HEAT EXCHANGER, ZONE 3, WATER FLOW RATE THROUGH EXCHANGER
14	TM3	PCNT	OUTPUT OF CONTROLLER TO VALVES IN COOLING ST
15	PWRZ3	KW	POWER TO ZONE 3 OF HEATING SECTION
16	RTD3	MV	HEAT EXCHANGER, ZONE 3, OUTLET WATER TEMPERATURE
17	TE93	DEGC	RTD3 CONVERTED TO DEGC
18	ITE19	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 147.0 IN. FROM FEED END,CENTER OF ZONE 6
19	ITE20	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 165.0 IN. FROM FEED END,CENTER OF ZONE 7
20	ITE21	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 183.0 IN. FROM FEED END,CENTER OF ZONE 8

END

1	ZONEFOUR	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SPC4	DEGC	TEMPERATURE SETPOINT FOR ZONE 4
4	TE4	DEGC	TEMPERATURE OF FURNACE ZONE 4, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
5	TE44	DEGC	TEMPERATURE OF FURNACE ZONE 4, TOP NORTH SIDE OF HEATER INSULATION
6	TE12	DEGC	COOLING STACK, ZONE 4, TEMPERATURE OF HOT AIR DISCHARGED FROM FURNACE
7	TE52	DEGC	COOLING STACK, ZONE 4, INSIDE SURFACE TEMPERATURE OF COLD AIR LEG NEAR FURNACE
8	TE11	DEGC	COOLING STACK, ZONE 4, TEMPERATURE OF COLD AIR FED TO FURNACE
9	TE51	DEGC	COOLING STACK, ZONE 4, INSIDE SURFACE TEMPERATURE OF HOT AIR LEG NEAR FURNACE
10	TE22	DEGC	COOLING STACK, ZONE 4, TEMPERATURE OF COLD AIR DISCHARGED FROM HEAT EXCHANGER
11	TE21	DEGC	COOLING STACK, ZONE 4, TEMPERATURE OF HOT AIR FED TO HEAT EXCHANGER
12	TE32	DEGC	HEAT EXCHANGER, ZONE 4, SURFACE TEMPERATURE OF WATER DISCHARGE PIPE
13	FLW4	L/MIN	HEAT EXCHANGER, ZONE 4, WATER FLOW RATE THROUGH EXCHANGER
14	TM4	PCNT	OUTPUT OF CONTROLLER TO VALVES IN COOLING ST
15	PWRZ4	KW	POWER TO ZONE 4 OF HEATING SECTION
16	RTD4	MV	HEAT EXCHANGER, ZONE 4, OUTLET WATER TEMPERATURE
17	TE94	DEGC	RTD4 CONVERTED TO DEGC
18	TE83	DEGC	TEST THERMOCOUPLE FOR ZONE 4,1 IN. WELL IN CALCIUM SILICATE WITH PT. CONE FOR DRUM TEMP
19	ITE22	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 192.0 IN. FROM FEED END,TRAILING EDGE OF ZN 8
20	ITE23	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 200.0 IN. FROM FEED END,BETWEEN FURNACE & 2ND RIDING RING

END

1	OTHERZNS	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SPC5	DEGC	TEMPERATURE SETPOINT FOR ZONE 5
4	TE5	DEGC	TEMPERATURE OF FURNACE ZONE 5, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
5	TE45	DEGC	TEMPERATURE OF FURNACE ZONE 5, TOP NORTH SIDE OF HEATER INSULATION
6	PWRZ5	KW	POWER TO ZONE 5 OF HEATING SECTION
7	SPC6	DEGC	TEMPERATURE SETPOINT FOR ZONE 6
8	TE6	DEGC	TEMPERATURE OF FURNACE ZONE 6, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
9	TE46	DEGC	TEMPERATURE OF FURNACE ZONE 6, TOP NORTH SIDE OF HEATER INSULATION
10	PWRZ6	KW	POWER TO ZONE 6 OF HEATING SECTION
11	SPC7	DEGC	TEMPERATURE SETPOINT FOR ZONE 7
12	TE7	DEGC	TEMPERATURE OF FURNACE ZONE 7, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
13	TE47	DEGC	TEMPERATURE OF FURNACE ZONE 7, TOP NORTH SIDE OF HEATER INSULATION
14	PWRZ7	KW	POWER TO ZONE 7 OF HEATING SECTION
15	SPC8	DEGC	TEMPERATURE SETPOINT FOR ZONE 8
16	TE8	DEGC	TEMPERATURE OF FURNACE ZONE 8, TOP OF CALCINER BETWEEN REFRACTORY AND DRUM
17	TE48	DEGC	TEMPERATURE OF FURNACE ZONE 8, TOP NORTH SIDE OF HEATER INSULATION
18	PWRZ8	KW	POWER TO ZONE 8 OF HEATING SECTION
19	TE31	DEGC	HEAT EXCHANGER, TEMPERATURE OF SURFACE OF WATER FEED PIPE
20	TE95	DEGC	HEAT EXCHANGERS, INLET WATER TEMPERATURE (FROM RTD5)

END

1	PRODCOOL	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	TE49	DEGC	PRODUCT COOLER, TEMPERATURE OF COOL AIR FEED NEAR PITOT-VENTURI
4	TE29	DEGC	PRODUCT COOLER, TEMPERATURE OF COOL AIR ENTERING COOLER
5	TE36	DEGC	PRODUCT COOLER, TEMPERATURE OF AIR AT BOTTOM EXIT END OF COOLING SECTION
6	TE37	DEGC	PRODUCT COOLER, TEMPERATURE OF AIR AT TOP-CENTER OF COOLING SECTION
7	TE38	DEGC	PRODUCT COOLER, TEMPERATURE OF AIR AT BOTTOM OF COOLING SECTION, AIR INLET END OF SECTION
8	TE39	DEGC	PRODUCT COOLER, SURFACE TEMPERATURE OF BOTTOM CENTER OF COOLING SECTION
9	TE30	DEGC	PRODUCT COOLER, TEMPERATURE OF AIR DISCHARGED FROM COOLER
10	TE50	DEGC	PRODUCT COOLER, SURFACE TEMPERATURE OF DISCHARGE DUCT FLANGE (INSIDE)
11	TE59	DEGC	PRODUCT COOLER, TEMPERATURE OF AIR IN DISCHARGE DUCT NEAR PITOT VENTURI
12	ITE33	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 296.25 IN. FROM FEED END,@EXIT END
13	ITE4	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 27.0 IN. FRM FD END,BTWN RIDE RING&GIRTH GEAR
14	ITE5	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 33.0 IN. FROM FEED END,BTWN FURNACE&RIDE RING
15	ITE6	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 39.0 IN. FROM FEED END,BTWN FURNACE&RIDE RING
16	ITE7	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 49.0 IN. FROM FEED END,LEAD EDGE OF ZN 1
17	ITE8	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 57.0 IN. FROM FEED END,CENTER OF ZN 1
18	ITE9	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 67.0 IN. FROM FEED END,BETWEEN ZN 1 & 2
19	ITE10	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 75.0 IN. FROM FEED END,CENTER ZN 2
20	ITE11	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 85.0 IN. FROM FEED END,BETWEEN ZN 2 & 3

END

1	GASSTOPH	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	TE10	DEGC	SURFACE TEMPERATURE OF EXIT END BREECHING SECTION BELOW VIEWING PORT
4	TE9	DEGC	(NOT INSTALLED YET)
5	TE19	DEGC	OFF-GAS PIPE, TEMPERATURE OF GAS AT FIRST CONNECTING FLANGE
6	TE20	DEGC	OFF-GAS PIPE, INSIDE SURFACE TEMPERATURE OF FIRST FLANGE
7	TE60	DEGC	OFF-GAS PIPE, TEMPERATURE OF GAS BEFORE ENTERING FILTER
8	PT2	INS	PRESSURE TRANSMITTER FOR OFF-GAS ABOVE PVC5
9	PT5	INS	PRESSURE TRANSMITTER FOR OFF-GAS AT KILN FRONT
10	PT6	INS	PRESSURE TRANSMITR FOR OFF-GAS AT PRODUCT DRUMS
11	PT2M	PCNT	OUTPUT FROM CONTROLLER TO PCV6 IN OFF-GAS
12	PT5M	PCNT	OUTPUT FROM CONTROLLER TO PCV5 IN OFF-GAS
13	FS7	CNTS	FLOW INDICATOR FOR OFF-GAS
14	SPC12	DEGC	CONNECTED TO LOGGER ONLY (MEANS NOTHING)
15	SPC13	INS	SETPOINT FOR CONTROLLER FOR HEADER PRESSURE, VACUUM SUPPLY
16	PDT3	INS	FILTER DIFFERENTIAL PRESSURE (DP)
17	BLOWBKS	CNTS	NUMBER OF FILTER BLOW-BACKS SINCE A RELOAD
18	FILTRUN	SECS	NO. OF SECS SINCE THE LAST FILTER BLOWBACK
19	O2FLOW	CFM	FLOW RATE OF OXYGEN FED TO VOLOXIDIZER
20	O2I1	PCNT	CONCENTRATION OF OXYGEN AT SOLIDS DISCHARGE END OF VOLOXIDIZER

END

1	PROCDATA	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	##DY		DAY
4	##MN		MONTH
5	##YR		YEAR
6	#TIME:HRS	HRS	HOURS
7	#TIME:MIN	MINS	MINUTES
8	#TIME:SEC	SECS	SECONDS
9	RNTMPST	HRS	LAST VALUE OF OLD RUNTIME
10	FEEDCYCLE	SECS	SET TIME BETWEEN SHOTS OF FEED
11	DUSTSETPT	GRMS	MASS OF DUST TO BE FED PER SHOT
12	HULLSSETPT	GRMS	MASS OF HULLS TO BE FED PER SHOT
13	SHROUDSETPT	GRMS	MASS OF SHROUD TO BE FED PER SHOT
14	PDT3	INS	FILTER DIFFERENTIAL PRESSURE (DP)
15	PDT4	INS	DIFFERENTIAL PRESSURE ACROSS PITOT-VENTURI IN AIR STREAM ENTERING COOLING SECTION
16	PDT5	INS	DIFFERENTIAL PRESSURE ACROSS PITOT-VENTURI IN AIR STREAM LEAVING COOLING SECTION
17	AT102	PCNT	AI ON OXYGEN ANALYZER,INLET
18	AT202	PCNT	AI ON OXYGEN ANALYZER,OUTLET
19	RTD5	MV	HEAT EXCHANGERS, TEMPERATURE OF WATER FED TO EXCHANGERS
20	TE95	DEGC	(RTD5 CONVERTED TO DEG C)

END

1	FEEDMETR	LOGGER NAME	
2	RNTM	HRS	RUN TIME
3	SANDTOTAL	GRMS	ACCUMULATED AMOUNT OF SAND FED THROUGH TIP-BUCKET SINCE RUNTIME RESET
4	WTC3	KGS	SAND WEIGH TABLE READING,CURRENT
5	WSANDF		RATIO OF TIP BUCKET READINGS TO WEIGH TABLE READINGS
6	SANDTARGET	GRMS	CURRENT TARGET FOR SHOT OF SAND
7	HULLSTOTAL	GRMS	ACCUMULATED AMOUNT OF HULLS FED THROUGH TIP BUCKET SINCE RUNTIME RESET
8	WT6C	KGS	HULLS WEIGH TABLE READING,CURRENT
9	WHULLF		RATIO OF TIP BUCKET READINGS TO WEIGH TABLE READINGS
10	HULLSTARGET	GRMS	CURRENT TARGET FOR SHOT OF HULLS
11	WT5C	KGS	SHROUD WEIGH TABLE READING
12	SHDEF	KGS	DEFICIT IN AMOUNT OF SHROUD FED
13	FTMUSE	PCNT	PERCENT OF FEED CYCLE TIME ACTUALLY USED
14	BLANK		
15	WT1	KGS	WEIGHT OF PRODUCT DRUM #1
16	WT2	KGS	WEIGHT OF PRODUCT DRUM #2
17	SANDRATE	KG/H	AVERAGE FEED RATE OF SAND SINCE FEED WAS STARTED OR HOPPER REFILLED
18	HULLRATE	KG/H	AVERAGE FEED RATE OF HULLS SINCE FEED WAS STARTED OR HOPPER REFILLED
19	SHROUDRATE	KG/H	AVERAGE FEED RATE OF SHROUD SINCE FEED WAS STARTED OR HOPPER REFILLED
20	BLANK		

END

1	COUNCE	LOGGER NAME (CREATED FROM PROCDATA)	
2	RNTM	HRS	RUN TIME
3	SPC13	INS	SETPOINT FOR VACUUM HEADER CONTROLLER
4	SPC14	INS	SETPOINT PRESSURE FOR OFF-GAS CONTROL AT INLET OF CALCINER
5	SPC16	INS	SPARE SET PT.
6	ST1	RPM	ROTATIONAL SPEED OF DRUM
7	TE31	DEGC	HEAT EXCHANGER, SURFACE TEMPERATURE OF WATER INLET PIPE
8	TE40	DEGC	AMBIENT TEMPERATURE BELOW CALCINER FRAME
9	TE61	DEGC	OFF-GAS PIPE, INSIDE SURFACE TEMPERATURE OF FIRST FLANGE
10	TE62	DEGC	SURFACE TEMPERATURE OF SOUTHEAST ROLLER(TRUNION) BEARING
11	TE63	DEGC	SURFACE TEMPERATURE OF NORTHEAST ROLLER(TRUNION) BEARING
12	TE64	DEGC	SURFACE TEMPERATURE OF NORTHWEST ROLLER(TRUNION) BEARING
13	TE65	DEGC	SURFACE TEMPERATURE OF SOUTHWEST ROLLER(TRUNION) BEARING
14	TE66	DEGC	SURFACE TEMPERATURE OF WEST THRUST ROLLER (ROLLER NEAREST FURNACE)
15	TE67	DEGC	DRIVE MOTOR, SURFACE TEMPERATURE AT TOP-CENTER
16	TE68	DEGC	FEED HOUSE, AMBIENT TEMPERATURE
17	TE69	DEGC	FURNACE CONTROL PANEL, INSIDE TEMPERATURE
18	TE70	DEGC	BRISTOL UCS3000, TEMPERATURE INSIDE P.O.P.
19	TE71	DEGC	FLAPPER VALVE #1, OUTSIDE SURFACE TEMPERATURE
20	TE72	DEGC	FLAPPER VALVE #3, OUTSIDE SURFACE TEMPERATURE

END

1	JUBIN	LOGGER NAME (CREATED FROM PROCDATA)	
2	RNTM	HRS	RUN TIME
3	TE73	DEGC	FURNACE INSULATION, OUTSIDE SURFACE TEMPERATURE AT WEST CENTER TOP
4	TE74	DEGC	FURNACE INSULATION, OUTSIDE SURFACE TEMPERATURE AT SOUTH CENTER TOP
5	TE75	DEGC	PRODUCT DRUM, TEMPERATURE OF PRODUCT (EITHER DRUM #1 OR #2)
6	TE76	DEGC	SAND FEEDER, TEMPERATURE OF SAND IN TRAY
7	TE77	DEGC	SAMPLE STATION, TEMPERATURE OF SAMPLE SPOON
8	TE78	DEGC	AMBIENT TEMPERATURE NEAR HEAT EXCHANGERS
9	TE79	DEGC	BELLOWS, DISCHARGE END, SURFACE TEMPERATURE
10	TE80	DEGC	BELLOWS, FEED END, SURFACE TEMPERATURE
11	ITE1	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 0.25 IN. FROM FEED END,@ FEED END
12	ITE2	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 13.5 IN. FROM FEED END,BTWN GIRTH GEAR&SEAL
13	ITE3	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 21.0 IN. FROM FD END,BTWN GIRTH GEAR&RIDE RING
14	TE84	DEGC	FURNACE ZONE 5, TEMPERATURE(TEST THERMOCOUPLE IN PT. CONE WITHIN CALCIUM SILICATE BLOCK)
15	TE85	DEGC	FURNACE ZONE 7, TEMPERATURE(TEST THERMOCOUPLE IN PT. CONE WITHIN CALCIUM SILICATE BLOCK)
16	TE86	DEGC	FURNACE ZONE 8, TEMPERATURE(TEST THERMOCOUPLE IN PT. CONE WITHIN CALCIUM SILICATE BLOCK)
17	TE87	DEGC	NOT USED
18	TE88	DEGC	NOT USED
19	TE89	DEGC	NOT USED
20	TE90	DEGC	NOT USED

END

1	LEWIS	LOGGER NAME (CREATED FROM PROCDATA)	
2	RNTM	HRS	RUN TIME
3	TE96	DEGC	NOT USED
4	TE97	DEGC	NOT USED
5	TE98	DEGC	NOT USED
6	TE100	DEGC	NOT USED
7	VELI	FT/S	PRODUCT COOLER, VELOCITY OF AIR ENTERING COOLER
8	VELO	FT/S	PRODUCT COOLER, VELOCITY OF AIR DISCHARGED FROM COOLER
9	ITE12	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 93.0 IN. FROM FEED END,CENTER OF ZN 3
10	ITE13	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 93.0 IN. FROM FEED END,CENTER OF ZN 3
11	ITE14	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 103.0 IN. FROM FEED END,BTWN ZN 3 & 4
12	ITE24	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 206.0 IN. FROM FEED END,UNDER 2ND RIDE RING
13	ITE25	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 208.0 IN. FRM FD END,BTWN RIDE RING&PROD COOLER
14	ITE26	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 214.0 IN. FROM FD END,@ LEAD EDGE OF PROD COOL
15	ITE27	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 219.0 IN. FROM FEED END,IN PROD COOLER
16	ITE28	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 224.0 IN. FROM FEED END,IN PROD COOLER
17	ITE29	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 236.0 IN. FROM FEED END,IN PROD COOLER
18	ITE30	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 248.0 IN. FROM FEED END,IN PROD COOLER
19	ITE31	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 260.0 IN. FROM FEED END,IN PROD COOLER
20	ITE32	DEGC	THERMOCOUPLE MEASURING DRUM TEMP.(TELEMETRY), 272.0 IN. FROM FEED END,IN PROD COOLER

END

1	DISCRETE	LOGGER	NAME
2	RNTM	HRS	RUNTIME
3	BOSTIC	X.	ON DUTY
4	TROTTER	X	ON DUTY
5	KINGTON	X	ON DUTY
6	WELCH	X	ON DUTY
7	WETHERINGTON	X	ON DUTY
8	SHANNON	X	ON DUTY
		E+05	
9	METZ	X.	ON DUTY
10	THOMPSON	X	ON DUTY
11	RICHARDSON	X	ON DUTY
12	BALDWIN	X	ON DUTY
13	WHATLEY	X	ON DUTY
14	YARBROUGH	X	ON DUTY
		E+05	
15	RANDOLPH	X.	ON DUTY
16	TECHNICIAN#3	X	ON DUTY
17	COOP#1	X	ON DUTY
18	SPENCER	X	ON DUTY
19	RENNICH	X	ON DUTY
20	VANCLEVE	X	ON DUTY
		E+05	
21	HEAT1	X.	ZONE 1 HEATER SWITCH ON
22	HEAT2	X	ZONE 2 HEATER SWITCH ON
23	HEAT3	X	ZONE 3 HEATER SWITCH ON
24	HEAT4	X	ZONE 4 HEATER SWITCH ON
25	HEAT5	X	ZONE 5 HEATER SWITCH ON
26	HEAT6	X	ZONE 6 HEATER SWITCH ON
		E+05	
27	HEAT7	X.	ZONE 7 HEATER SWITCH ON
28	HEAT8	X.	ZONE 8 HEATER SWITCH ON
29	ISOV1M	X	ISOLATION VALVE 1 NOT WORKING
30	ISOV2M	X	ISOLATION VALVE 2 NOT WORKING
31	ISOV3M	X	ISOLATION VALVE 3 NOT WORKING
32	ISOV4M	X	ISOLATION VALVE 4 NOT WORKING
		E+05	
33	SANDALARM	X.	SAND FEED FAILURE
34	HULLALARM	X	HULLS FEED FAILURE
35	SHROUDALARM	X	SHROUD FEED FAILURE
36	TIPBKTOFL	X	TIPBUCKET OVERFILL WARNING
37	TIPBKTOTM	X	TIPBUCKET OVERTIME WARNING
38	SHRDSLOW	X	SHROUD OVERTIME WARNING
		E+05	
39	NORECEIVER	X.	PRODUCT STATION NOT READY
40	WT1HLVL	X	PRODUCT RECEIVER 1 OVERFULL
41	WT2HLVL	X	PRODUCT RECEIVER 2 OVERFULL
42	WT3LLVL	X	SAND HOPPER LOW
43	WT6LLVL	X	HULLS HOPPER LOW
44	WT5LLVL	X	SHROUD HOPPER LOW
		E+05	
45	PR2PUT	X.	PRODUCT RECEIVER 2 IN PLACE
46	PR1PUT	X	PRODUCT RECEIVER 1 IN PLACE
47	PR1GO	X	DIVERTER VALVE TO 1
48	PR2GO	X	DIVERTER VALVE TO 2

```
49 PRP2UP        X        PRODUCT RECEIVER 2 IS UP
50 PRP1UP        X        PRODUCT RECEIVER 1 IS UP
                 E+05
51 ST1ALRM       X.       DRUM ROTATION STOPPED
52 ISORUN        X        ISOVALVE OPERATION ON
53 FEED          X        FEED CYCLE SWITCH ON
54 SANDHULL      X        SAND AND HULLS SWITCH ON
55 SHROUD        X        SHROUD FEED SWITCH ON
56 SL03          X        CLOCK RESET
                 E+05


   END
```

1	RECOVERY	LOGGER	NAME
2	RNTM	HRS	RUN TIME
3	PDT301	INS	FILTER DP 1 SECS AFTER BLOWBACK
4	PDT302	INS	FILTER DP 2 SECS AFTER BLOWBACK
5	PDT303	INS	FILTER DP 3 SECS AFTER BLOWBACK
6	PDT304	INS	FILTER DP 4 SECS AFTER BLOWBACK
7	PDT305	INS	FILTER DP 5 SECS AFTER BLOWBACK
8	PDT306	INS	FILTER DP 6 SECS AFTER BLOWBACK
9	PDT307	INS	FILTER DP 7 SECS AFTER BLOWBACK
10	PDT308	INS	FILTER DP 8 SECS AFTER BLOWBACK
11	PDT309	INS	FILTER DP 9 SECS AFTER BLOWBACK
12	PDT3010	INS	FILTER DP 10 SECS AFTER BLOWBACK
13	PDT3011	INS	FILTER DP 11 SECS AFTER BLOWBACK
14	PDT3012	INS	FILTER DP 12 SECS AFTER BLOWBACK
15	PDT3013	INS	FILTER DP 13 SECS AFTER BLOWBACK
16	PDT3014	INS	FILTER DP 14 SECS AFTER BLOWBACK
17	PDT3015	INS	FILTER DP 15 SECS AFTER BLOWBACK
18	PDT3016	INS	FILTER DP 16 SECS AFTER BLOWBACK
19	PDT3017	INS	FILTER DP 17 SECS AFTER BLOWBACK
20	PDT3018	INS	FILTER DP 18 SECS AFTER BLOWBACK

END

APPENDIX H

LISTING OF DATA EDITING PROGRAM

The data editing program has been written to operate in an interactive mode. It reads in the raw data set and prints the data on magnetic media in final form. Bad records that must be deleted are deleted after printing on the interactive terminal so that the user may verify the error. Based on predetermined reference limits, the program detects errors in run time and displays them to the user. The user has the final decision as to whether an error has really occurred and can either instruct the computer to proceed or change the reference limits before proceeding. The computer will then continue the editing process using the user's input, if any, to generate the final data set. A listing of the program, written in FORTRAN, follows.

```
C-----FIXEMA.SPC
C       FIXES RUN TIME AND OTHER ACCUMULATED VALUES IN FSEV DATA
C        4-07-81
        DIMENSION VBUF(20,20),VLST(2,11),V(20),RNBUF(20),GBAR(11),
       1CFAC(11),ELJUNK(52),KPUT(14),KPUTN(14),KWD(14)
        REAL*8 A(14),ZONBUF(20),ZONE,MESSAG(8)
        LOGICAL*1 PUTM,BANG,SAV,IRE,KOK,TJAN,JANONE,RECONE
        DATA(A(K),K=1,14)/'ZONEONE   ','ZONETWO   ','ZONETHREE ','ZONEFOUR
       1  ','OTHERZNS  ','PRODCOOL  ','GASSTOPH  ','PROCDATA  ','FEEDMETR
       2 ','DISCRETE  ','COUNCE    ','JUBIN     ','LEWIS     ',
       3'RECOVERY  '/
        DATA KPUT/1,1,1,1,4,0,1,0,2,0,0,0,0,0/
        DATA KPUTN/1,2,3,4,5,9,9,10,10,0,0,0,0,0/
        DATA KWD/13,13,13,13,4,8,12,16,11,1,5,0,0,0/
        DATA ANSWER/'Y'/
        IFOR24=24
        ITAPE=1
        IUNIT=IFOR24+ITAPE
        DO 111 I=1,11
        GBAR(I)=0.
        VLST(1,I)=0.
        VLST(2,I)=0.
        CFAC(I)=0.
  111   CONTINUE
        DIFF=0.
        DIFF2=0.
        X=0.
        Y=0.
        RNN=0.
        PUTM=.FALSE.
        IRE=.FALSE.
        KOK=.TRUE.
        READ(IUNIT,999)MESSAG
  999   FORMAT(8A10)
        WRITE(18,999)MESSAG
        WRITE(5,998)MESSAG
  998   FORMAT(' ',8A10)
        DO 1 LOOP=1,50000
C       WHEN IRE IS TRUE READ FROM BUFFER
        IF(IRE)GO TO 2
        READ(IUNIT,100,ERR=902,END=908)ZONE,RN,(V(JUNE),JUNE=1,18)
  100   FORMAT(A10,2X,19(X,1PE12.5))
  10    IF(PUTM)GO TO 8
        DO 4 K2=1,14
        IF(A(K2).EQ.ZONE)GO TO 22
   4    CONTINUE
        GO TO 903
   22   Z=RN-Y
C        GO  TO 3 IF RNTM IS OK
        IF(RN.GE.Y .AND. ABS(Z).LE. 0.5 .OR. LOOP.EQ.1)GO TO 3
C-----BEGIN CORRECTIONS;FOUND A RNTM DISCONTINUITY
        IF(RN.LT.0.0)GO TO 904
        WRITE(5,300)Y,RN
  300   FORMAT(' RNTM CHANGED FROM ',1PE12.5,' TO',1PE12.5,/,
       1' IS THIS REAL? (Y)ES OR (N)O',5X,$)
        READ(5,301)REPLY
```

```
 301  FORMAT(A5)
      IF(REPLY.EQ.ANSWER)GO TO 3
      DELOLM=.04
      WRITE(5,202)DELOLM
 202  FORMAT(' STARTING WITH A RUNTIME LESS THAN ',1PE12.5,
     1/,' DATA WILL BE CORRECTED BY PUSHING THE RETURN KEY OR',
     2/,' IF THIS NUMBER IS NOT SATISFACTORY INPUT A NEW VALUE',
     3/,' AND PUSH RETURN',$)
      READ(5,203)FIXXX
  203 FORMAT(E10.4)
      IF(FIXXX.LE.0.0)GO TO 11
      DELOLM=FIXXX
 11   KOK=.FALSE.
      PUTM=.TRUE.
      KONT=1
C     FILL BUFFER
  8   ZONBUF(KONT)=ZONE
      RNBUF(KONT)=RN
      DO 9 ISAV=1,18
      VBUF(KONT,ISAV)=V(ISAV)
    9 CONTINUE
      IF(RN.LT. DELOLM)KOK=.TRUE.
      IF(KOK .AND. KONT.EQ.1)YOLD=RN
      IF(.NOT.KOK)WRITE(5,200)
 200  FORMAT(' DELETING:',$)
      M=KONT
   7  WRITE(5,103)M,ZONBUF(KONT),RNBUF(KONT),(VBUF(KONT,JUDY),JUDY=1,18)
 103  FORMAT(' ',I2,X,A10,2X,19(',',1PE12.5))
      IF(ZONE.EQ.A(8).AND.KOK)GO TO 6
      IF(KOK)KONT=KONT+1
      GO TO 1
C-----GENERATE CFAC TERMS AND RNN CORRECTIONS;FOUND PROCDATA
   6  PUTM=.FALSE.
      IRE=.TRUE.
      WRITE(5,501)V(4),V(5),V(6),V(2),V(1),V(3)
 501  FORMAT(' TIME:',3(F3.0),' DATE:',3(F3.0))
      JANICE=1
      JANONE=.TRUE.
      KINK=KONT
      Y=YOLD
      DIFF2=VBUF(KONT,4)+VBUF(KONT,5)/60.+VBUF(KONT,6)/3600.
      DIFF2=DIFF2-RNBUF(KONT)
      IDAY2=VBUF(KONT,1)
      DIFDAY=IDAY2-IDAY
      IF(DIFDAY.LT.0.0  .AND.  DIFDAY.GE.-20.)GO TO 777
      IF(DIFDAY.LT.-20.)DIFDAY=1.0
      GO TO 778
 777  DIFDAY=0.0
 778  RNN=DIFF+DIFF2+24.*DIFDAY
      DO 76 JIL=1,11
      CFAC(JIL)=VLST(1,JIL)+GBAR(JIL)*(RNN-VLST(2,JIL))
  76  CONTINUE
C-----
      GO TO 1
   2  RN=RNBUF(JANICE)
      ZONE=ZONBUF(JANICE)
```

```
      DO 75 NINA=1,18
      V(NINA)=VBUF(JANICE,NINA)
   75 CONTINUE
      JANICE=JANICE+1
      IF(JANICE.GT.KINK)IRE=.FALSE.
      GO TO 10
C     ENTER HERE TO DO ROUTINE CORRECTIONS
    3 Y=RN
      RN=RN+RNN
      RNSAV=RN
C     SKIP CORRECTIONS WHEN THERE IS NOTHING TO CORRECT
      IF(KPUT(K2).EQ.0) GO TO 77
C     JJ=NUMBER OF THINGS TO CORRECT
      JJ=KPUT(K2)
      DO 77 J=1,JJ
      JK=KPUTN(K2)+J-1
      V(KWD(JK))=V(KWD(JK))+CFAC(JK)
      GBAR(JK)=.1*(V(KWD(JK))-VLST(1,JK))/(RN-VLST(2,JK))+.9*GBAR(JK)
      VLST(1,JK)=V(KWD(JK))
      VLST(2,JK)=RN
   77 CONTINUE
      IF(K2.NE.8)GO TO 19
      DIFF=RN-(V(4)+V(5)/60.+V(6)/3600.)
      IDAY=V(1)
   19 WRITE(18,104)ZONE,RN,(V(JANE),JANE=1,18)
  104 FORMAT(A10,2X,19(',',1PE12.5))
      TJAN=JANICE.EQ.2
      IF(JANONE .AND. TJAN) WRITE(5,400) RN
  400 FORMAT(' *****RUNTIME=',1PE12.5,' NOW*****')
      IF(TJAN) JANONE=.FALSE.
      IF(RECONE) WRITE(5,500) RN
  500 FORMAT('    BEGINNING FIRST GOOD RECORD ON TAPE',/,
     1' ****RUNTIME=',1PE12.5,'****')
      RECONE=.FALSE.
      GO TO 1
C     ENTER HERE FOR BAD RECORD
  902 READ(IUNIT,101)ELJUNK
  101 FORMAT(52A5)
      WRITE(5,102)ELJUNK
  102 FORMAT(' ***FORMAT ERROR:BAD LINE FOLLOWS***',/,' ',52A5,/)
      GO TO 1
  904 WRITE(5,106)ZONE,RN
  106 FORMAT(/,' ***IGNORING LOGGER WITH NEGATIVE RUNTIME:',A10,X,
     11PE12.5)
      GO TO 1
  903 WRITE(5,105)ZONE
  105 FORMAT(/,' ***IGNORING INVALID LOGGER:',A10,'***',/)
      GO TO 1
  908 CLOSE(UNIT=IUNIT)
      RECONE=.TRUE.
      WRITE(5,201)ITAPE,RNSAV
  201 FORMAT(' END OF TAPE ',I2,' RUNTIME=',1PE12.5,/,
     1' ANY MORE TAPES?(YES) OR (N)O',5X,$)
      READ(5,301)REPLY
      ITAPE=ITAPE+1
      IUNIT=IFOR24+ITAPE
```

```
      IF(REPLY.EQ.ANSWER)GO TO 1
      GO TO 901
    1 CONTINUE
  901 CONTINUE
      STOP
      END
```

APPENDIX I

LIST OF MANUFACTURERS LITERATURE

Operation and maintenance manuals for each piece of equipment in the FSEV facility are kept in the FSEV file. These documents are listed below.

Manufacturer	Manufacturers document number	Number of copies	Description
ASCO	8262, 8263	1	Installation and maintenance instructions for two-way direct acting solenoid valves – normally open and normally closed
	8300, 8302, 8315	2	Installation and maintenance instructions for three-way direct acting solenoid valves – normally closed, normally open, and universal operation ($\frac{1}{8}$-, $\frac{1}{4}$-, $\frac{3}{8}$-, and $\frac{1}{2}$-in. N.P.T.)
	N/A[a]	1	Stroke chart; alternating current service
	V-5192 AR4	2	Spare parts, kits, replacement coils, and accessories for ASCO solenoid valves
ACUREX	N/A	1	The auto-data nine monitor/alarm/control system
Bristol	B-280C	1	UCS-3000; the process controller
	SP-462-004	1	Composite instruction book
Burgess & Associates, Inc.	N/A	1	Instructions for use and maintenance of Vibron vibratory feeders
CE Raymond/ Bartlett-Snow	N/A	2	Assembly and maintenance instructions for calciner
Digital	LA36/LA35	1	Decwriter-II user's manual
Duff-Norton Company	N/A	3	2800 series ball-screw jactuator maintenance manual, with spare parts breakdown
	ED-680-2	4	Coffing electric chain hoists operating and maintenance instructions and parts list for EC series hoists
	N/A	4	Coil chain electric hoists, parts list for EC series ECP-10-2
	ECMT-680-1	1	Motorized trolley operating and maintenance instructions for MT series trolleys, used with EC series electric chain hoists
	ECMT-10-1	4	Motorized trolley ECMT series parts list
	MT-680-2	4	Motorized trolley MT series parts list
Electro Sensors	ES-125-0875	2	Rotach-digital tachometer instruction manual

Manufacturer	Manufacturers document number	Number of copies	Description
Falk	128-010	3	Service manual – enclosed gear drives; typical lubricants meeting Falk specifications
	333-134	2	Parts guide – motoreducers, speed reducers (types EZ, EF, EZX, EFX, and C), and triple reduction units
	128-050	3	Service manual – instructions for installation and maintenance, speed reducers, and motoreducers
	428-110	1	Service manual – instructions for installation and maintenance; Steelflex couplings
	3510-03	2	Dimensions for motoreducers (type EZ); concentric shaft
Fischer & Porter	N/A	1	Instruction bulletin for series 10A1700 flowrator meters
	N/A	1	Parts list for series 10A1700 flowrator meters
Foxboro	PL-5230	1	Parts list for models P25, P50, and P110 pneumatic diaphragm actuators
	PL-5265	1	Parts list for model V9000 ball valves ½- to 4-in. sizes
FMC	LB-3175A	1	Instruction manual for linkbelt model 65 UP and NRM vibrating screens
GTE Sylvania	T85-001-10(1)	2	Installation, operating, and maintenance instructions for dry type transformers
Honeywell	810-98	2	Operator's manual for type 01 air-o-motor actuator
	N/A	2	Operator's manual for electronik one-eleven mechanically programmed multipoint 1117.
	N/A	2	Instructions for Dial-a-Trol on/off or time proportioning controllers with relay output
	95-8210-1	2	Instructions for Dial-a-Trol controllers remote set point operation
	N/A	2	Replacement parts for Dial-a-Trol
Lindberg	N/A	2	Installation, operation, and maintenance instructions for type 44-RO-18144-185 tube furnace
Reliance	C-3060-6	1	Instruction manual for reliance power matched/RPM D-C motors
	A-3611-7	1	Instruction manual for grease lubrication of antifriction bearings in reliance motors
	D-3684-4	1	Instruction manual for single-phase, ¾–5-HP dc V*S drives
Singer	PL-314.3	1	Parts list for American AL-800 aluminum case meter
Techtran	8420/8421	1	Data cassette operating instructions

[a]N/A – not applicable.

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37–38. Laboratory Records
39. Laboratory Records, ORNL-RC
40. ORNL Patent Office

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41–42. K. O. Laughon, Jr., Director, Office of Spent Fuel Management and Reprocessing Systems, U.S. Department of Energy, Washington, DC 20545
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