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CO-COMBUSTION OF REFUSE-DERIVED FUEL
AND COAL IN A CYCLONE FURNACE
AT THE BALTIMORE GAS AND ELECTRIC COMPANY,
C. P. CRANE STATION

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Sections of this report, as noted in the text, were taken directly from Baltimore Gas & Electric Company, Fossil Power Department, Report #80-28 entitled, C.P. Crane No. 2 Coal Burning tests by J. D. Warner, Service Engineer. Other parts of the BG&E report are included as an appendices to this report.

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ABSTRACT

A co-combustion demonstration burn of coal and fluff refuse-derived fuel (RDF) was conducted by Teledyne National and Baltimore Gas and Electric Company (BG&E) from July to September 1980 at the BG&E, C. P. Crane Station utility at rates of 15 to 100 ton/day. This utility, located approximately 25 miles from the Baltimore County Resource Recovery Facility, has two B&W cyclone furnaces capable of generating 400 MW. The facility is under a prohibition order to convert from #6 oil to coal; as a result, it was desirable to demonstrate that RDF, which has a low sulphur content, can be burned in combination with coals containing up to 2% sulphur, thus reducing overall sulphur emissions without deleterious effects. The program was partially funded by a grant awarded to the Maryland Environmental Service (MES) by the U.S. Department of Energy (DOE). Tests were conducted in accordance with an agreement between MES and BG&E.

Each furnace consists of four cyclones capable of generating 1,360,000 pounds per hour steam. The tertiary air inlet of one of the cyclones was modified with an adapter to permit fluff RDF to be pneumatically blown into the cyclone. At the same time, coal was fed into the cyclone furnace through the normal coal feeding duct, where it entered the burning chamber tangentially and mixed with the RDF during the burning process.

Secondary shredded fluff RDF prepared by the Baltimore County Resource Recovery Facility was delivered to the boiler site in Heil compactor trailers containing 10 to 16 tons of RDF. The RDF was discharged into a receiving station consisting of a belt conveyor discharging into a lump breaker, which in turn, fed the RDF into a pneumatic line through an air-lock feeder. A total of 2316 tons were burned at an average rate of 5.6 tons per hour. The average heat replacement by RDF for the cyclone was 25%, based on Btu input for a period of forty days. The range of RDF burned was from 3 to 10 tons per hour, or 7 to 63 percent heat replacement.

The average analysis of the RDF (39 samples) was:

Moisture	18.9%
Ash	13.4%
Heat Content (HHV)	6296 Btu/lb
Sulphur (5 samples)	0.26%

RDF used in the test was secondary shredded through $1\frac{1}{2}$ inch grates producing the following particle size distribution:

<u>Screen Size</u> (Inch)	<u>Weight %</u>	
	Through	On
2.0	100	0
1.0	95	5
.5	51	44
.187	17	—

Findings to date after inspection of the boiler and superheater indicate satisfactory results with no deleterious effects from the RDF. Current plans call for a long-term demonstration burn. This would be initiated after installation of a baghouse filter, which is required to meet current Maryland Air Quality Standards when burning coal.

SECTION 1

INTRODUCTION

Tests conducted by the Baltimore Gas and Electric Company (BG&E) in cooperation with Teledyne National, on co-combustion of coal and RDF in cyclone furnaces at the 400-MW C.P. Crane Station are described. The tests were sponsored by the Maryland Environmental Service (MES), and partially funded by the U.S. Department of Energy (DOE). A total of 2316 tons were burned at an average RDF replacement of 5.6 tons per hour or 25%, based on Btu input for a period of forty days. The range of RDF burned was from 3 to 10 tons per hour, or 7 to 63 percent of heat input for the test cyclone unit.

The report provides background information, a description of the facilities involved, a description of test operations, and results and conclusions.

SECTION 2

BACKGROUND2.1 The Baltimore County Resource Recovery Facility (BCRRF)

A major step in the development of resource recovery in Maryland (and the United States as a whole) was the formation of a partnership between MES and Baltimore County to build a solid waste resource recovery facility to provide services to the northern sector of Baltimore County. The objectives in the implementation of the project were:

1. to provide Baltimore County with a full-scale facility to shred refuse for compaction and transfer to a remote landfill, and to recover ferrous metals
2. to demonstrate technology and equipment for the recovery of the cellulosic fraction of the refuse, glass, and aluminum
3. to develop markets for the recovered materials, especially the cellulosic fraction.

These objectives have been met by the BCRRF which began operation in 1976. The facility is located in north-central Baltimore County at the site of the old Texas landfill in Cockeysville, Maryland.

Baltimore County has become one of the most successful resource recovery operations in the nation through operational reliability. Since startup in 1976, the facility has been down only four working days.

On a typical operating day, 110 local collection vehicles and 14 transfer trailers from the Southwest Transfer Station bring in an average of 685 tons of residential trash. Trucks are weighed and emptied into one of four push pits or an overflow pit. Trash is fed from here into two 1000-hp shredders. The shredded waste (95% of which has been reduced to 4 in. or less) moves up an inclined conveyor where ferrous metals are magnetically removed and discharged into waiting trailers for bailing and delivery to a local steel company. The remaining waste is sent to a secondary recovery area for further processing or loaded into compactor trailers for removal to the Parkton Landfill (Figures 1 and 2).

In the secondary separation/recovery area material is processed to recover refuse-derived fuel (fluff RDF) as well as densified or pelletized RDF (Figure 3). Presently approximately 250 ton-day of fluff RDF can be produced.

One of the principal difficulties encountered with the BCRRF was that, despite considerable effort, no firm long-term markets for the fuel fraction (RDF) of the processed solid waste could be found.

1. AUTOMATED WEIGH STATION	9. FUEL PROCESSING INPUT SYSTEM
2. STAGING AREA	10. FUEL PROCESSING AREA
3. OVERFLOW PIT	11. SECONDARY SEPARATION AND RECOVERY AREA
4. SHREDDER INPUT SYSTEM	12. PRODUCT MANUFACTURE - FUTURE
5. SHREDDER	
6. SHREDDER OUTPUT SYSTEMS	
7. FERROUS SEPARATOR	
8. LOADING TOWER	

TELEDYNE NATIONAL

Figure 1. Plan View of Processing Facility

Figure 2. Layout of Processing Equipment

Figure 3. Layout of Processing Equipment

2.2 Search for Energy Markets

It was recognized early in the development of the Baltimore County resource recovery system that the conversion of processed solid waste to energy represents the best ultimate disposal option.

The BG&E, the principal energy user in the Baltimore region, was contacted early by MES and Teledyne with the request to consider combustion of RDF in its own furnaces. Although the company expressed interest in assisting MES and Baltimore County, and cooperated by negotiating a contract to purchase electricity generated by burning RDF in a dedicated boiler, direct combustion of RDF in its own boiler was not possible, since candidate boilers were burning oil.

2.3 Co-Combustion Demonstration

Under order of the U.S. Department of Energy (DOE), BG&E is actively planning to convert the boilers at the C.P. Crane Station to coal by 1983. A significant step in accomplishing this conversion was a test burn in the spring and summer of 1980 under a variance from air quality requirements issued by the State of Maryland Bureau of Air Quality Control. The purpose of the test was to experiment with various types of coal, especially the high sulphur coals typically found in Western Maryland, which could be obtained at minimal transport cost. MES and BG&E agreed that this was an opportunity they could not pass up: the testing of co-combustion of coal and RDF. A significant advantage could result for the utility company if the tests were successful. RDF contains only an insignificant amount of sulphur. Therefore, co-firing this fuel could reduce sulphur emissions from the C.P. Crane Station. Furthermore, since the co-combustion of coal and fluff RDF (the type of product at the BCRRF) in a cyclone furnace had never been attempted, this represented a unique opportunity to make a substantial contribution to the state-of-the art.

RDF fluff could supply up to 20% of the energy requirements at the C.P. Crane Station, furthering the national goal of independence from foreign oil. Furthermore, co-combustion in existing boilers could result in a substantial reduction of the capital cost requirements for the BCRRF and energy conversion system by eliminating the need to construct a dedicated boiler for burning RDF at the plant site. At the same time, the application of this technology would fulfill the goal of minimizing the reliance on landfills for disposal of Baltimore County waste.

A successful co-combustion demonstration would help pave the way for increased utilization of RDF, locally and nationally, by utility companies supporting the national goal of energy independence. Fuel costs reductions and air quality benefits also could result. Since RDF is low in sulphur content, it would make a valuable additive to the nation's vast supply of relatively high sulphur content coal.

As a result of the interest expressed by BG&E, MES submitted an unsolicited proposal to DOE on December 28, 1979, requesting \$129,101.50 for support of co-combustion demonstration of coal and RDF in a cyclone furnace at the BG&E C.P. Crane Station. DOE awarded Grant 80CS24320. on March 20, 1980, before initiating their tests with coal, BG&E agreed with MES to incorporate tests of RDF into the testing schedule.

MES engaged Teledyne National to arrange for the handling and feeding of RDF at the plant site, with fuel supplied by the BCRRF in Texas, Maryland. BG&E installed the RDF feed line at the cyclone under the supervision of Teledyne. A goal was established to replace as much as 20% of the coal with RDF on the basis of replaced energy for one cyclone burner, or 5% of the total furnace heat input.

2.4 Objectives¹

The specific objectives of the test burns were selected and defined after the major phases of the test, evaluating coal and Refuse Derived Fuel, were scheduled. The objectives were intended to provide information for three main goals:

1. To determine if coal with 2% sulfur can be burned in this boiler continuously within specified environmental limits.
2. To determine if there is a benefit to partial substitution with Refuse Derived Fuel.
3. To test the fabric filter bag material under plant operating conditions.

Five test objectives were selected, and are discussed below:

1. Selection of Suitable Coals - Using a premise that the coal characteristics will dominate the burn performance, rather than the operation or condition of the boiler, the coals were targeted for sampling and analysis both as delivered and as fed. High load and low load test conditions were applied to span actual operating conditions with eventual long term coal firing of the Unit.
2. Feasibility of burning Refuse Derived Fuel - Similar to above, a fuel consisting of 20% (based on energy content, i.e. Btu/lb) Refuse Derived Fuel and 80% preferred coal was planned to provide not only performance data against ambient environmental limits, but also for comparison to coal.
3. Sulfur and Ash Distribution - The sulfur distribution was intended to identify the species and amount of sulfur compounds that enter and exit the boiler to better predict the stack emissions for a fuel of a given sulfur content. The sulfur content of fuel as fed, gaseous stack emissions, fly ash, and slag, was monitored. The ash

¹Section 2.4 was retyped from BG&E report #80-28, p. 8.

distribution (slag versus fly ash), was intended to be used for ash removal information particularly since the trend in disposal regulations has been toward specific identification of each.

4. Evaluation of Fabric Filter Bag and Material - Sample squares of the fabric intended to be used (Teflon & Glass) were provided, and a test rig was assembled to simulate the flow of stack gas through the material. The test point was designed to monitor any deterioration of the fabric, visually compare the solids - contact side with the opposite side - to judge solids retention, and supply additional fly ash for analysis.
5. Measurement of Ambient Environmental Effects - In addition to local stack emission measurements, monitoring stations were placed in positions nearby the plant to determine regional environmental effects and to assist modeling efforts for environmental planning.

2.5 Long-term Implications

BG&E indicated to MES that if the test program were successful, it would consider a long-term commitment for fluff RDF firing after installation and testing of new dust collection equipment.

Operating and maintenance costs, fuel costs, and air quality requirements would be major considerations in any such long-term commitment.

2.6 Cost Sharing

DOE awarded Grant DE-FG01-80-CS24320 to MES for 50% of the project, which cost \$246,673. DOE provided \$123,336.50, with the balance divided as follows:

BG&E	-	\$63,173.00
Baltimore County	-	\$34,243.99
MES	-	\$25,919.51

SECTION 3

FACILITIES3.1 Remote RDF Feed Station

The RDF fluff feeding equipment, which was used successfully in several previous tests at other locations, consisted of the following principal components (Figure 4):

1. Hydraulic System - Hydraulic supply system for Heil Compactor Trailers with one, 60-hp, motor-driven, 37 gal/min, 3000-psi pump.
2. Loading Conveyor - 14-ft-long x 10-ft-wide flatbed belt conveyor with 5-hp motor and dynamatic electric clutch drive - speed range 2 to 20 ft/min.
3. Feed Conveyor - 36-ft-long x 4-ft-high x 4-ft-wide pan-type conveyor with 5-hp motor, dynamatic electric clutch drive, and speed range of 2 to 20 ft/min. Conveyor is fitted with lump-breaking and load-leveling devices to allow smooth, even feed of material.
4. Rotary Air Lock - motor-driven, Radar Model ESL, 36-in.-drain x 41 $\frac{1}{2}$ -in.-long, four blades with motor-driven gear reducer 28-rpm modified to increase capacity.
5. Blower - Radar Pneumatics, Inc. - electric-motor-driven, 100-hp, 4661-ft³/min, 6 psig, pneumatic blower series 3100.
6. Electrical Motor Control Center - two electrical motor control cabinets containing all 440/120 Vac motor starters, breakers, fuses, etc., for operation.

3.2 Process Flow

RDF is delivered to the site compacted in Heil compactor trailers holding 10 to 16 tons per trailer (13 tons average) and discharged into the loading conveyor by using the hydraulic system to supply pressure to the trailer push blade. Material is discharged from the trailer to the inclined loading conveyor by free fall into the conveyor bed. The inclined conveyor feeds the pan feed conveyor by moving the RDF at a variable speed of 0 to 20 ft/min. Four sets of rotating lump breakers break large lumps of RDF as they are discharged onto the pan conveyor. Feed conveyor speed was set by the boiler room operator depending on power generation levels required. A set of load levelers in the feed conveyors assured a uniform burden depth and constant rate of RDF flow.

Material is charged from the feed conveyor by vertical free fall through an opening 21 x 34 $\frac{3}{4}$ in. a surge chute feeding the Radar rotary air lock feeder. The air lock feeder has a rotary drum with four 12-in.-deep x

Figure 4. Burn Test Equipment Layout at the BG&E Crane Station

The Rader pneumatic blower (4661 ft³ /min, 6-psig maximum) conveys the RDF into the boiler feed line at a controlled pressure varying from 0 to 6 psi depending on the feed rate. Since the cyclone operates at 40 to 50 in. of water (1.44 to 1.8 psig), the blower pressure was maintained at an average of 2.5 psig for 20% RDF replacement of coal on a heat basis. Blower pressure is steady with dry and fluff RDF, but varies when the RDF is wet and lumpy; making it difficult to control the feed rate. Since feed conveyor speed was set by the boiler operator, it was Teledyne's responsibility to maintain a constant volume of RDF flow into the boiler.

As the RDF entered the boiler house, it discharged from the feed pipe into the tertiary air line. The 10 $\frac{3}{4}$ in.-o.d. RDF feed line was connected to the tertiary air duct of one of the four cyclones (No. 22 B. cyclone in No. 2 boiler). In addition, a new scroll piece was fabricated and installed at the tertiary air inlet, which allowed the RDF to be fed directly through the tertiary air duct, thus eliminating erosion of the duct. A series of slide valves was installed in the RDF lines which permitted one to change from the tertiary air duct feed point to the new scroll feed point without interrupting boiler operation.

3.3 Cyclone Furnaces

Cyclone furnaces were developed in the last 30 to 40 years and provide all the benefits derived from pulverized coal firing plus the following:

1. ability to burn a wide variety of fuels
2. reduction in fly ash content in the flue gas
3. savings in the cost of fuel preparation
4. reduction in furnace size
5. slag can be used as construction material or as sand-blasting grit.

A major advantage of the cyclone furnace is its ability to burn a large variety of fuels (from low volatility bituminous lignite) often in combination with supplemental fuels such as wood bark, coal chars, and petroleum coke. This characteristic makes the cyclone furnace uniquely qualified to burn RDF along with coal.

In addition, cyclone furnaces appear to be suited for RDF combustion because of their ability to receive relatively high ash content fuels with slagging points close to those typically exhibited by RDF.

The C.P. Crane Station has two boilers rated at 192 mw each, consisting of four cyclones per boiler. The cyclone furnace is a water-cooled, horizontal cylinder that is 10 ft in diameter with walls formed by hundreds of small tubes containing water flowing through the boiler circuit.

All combustion takes place in a cyclone at very high intensities, such that the walls of this pre-combustion chamber are coated with molten slag. Crushed coal ($\frac{1}{4}$ in. particle size) is fed into this chamber with primary air in vortex motion and thoroughly mixed with heated combustion air (secondary air) which enters the top of the cylinder tangentially (Figure 5). At the same time, the tertiary air enters tangentially at the center of the burner creating vortex motion. At the C.P. Crane

Figure 5. Arrangement of Cyclone Furnace Direct-Fired System for Pressure Furnace

Station, RDF is fed into one of the four cyclones by introducing the fuel into the tertiary air duct. The release of heat in the cyclone furnace is very high, at temperatures exceeding 3000°F. Moreover, any heat transferring refractory surface is partially insulated by the covering slag layer. This combination of high heat release and low heat absorption ensures the high temperatures necessary to complete combustion and melt the ash into a liquid-slag that forms a layer on the walls of the cyclone. The gaseous products of combustion are discharged through a water-cooled throat into a water-walled furnace, where the bulk of the heat transfer takes place.

Molten slag, in excess of the thin layer retained on the walls, continually drains away from the cyclone and discharges from a slag tap opening in the boiler floor, where it is tapped into a slag tank, solidified, and crushed for transport and disposal.

3.4 Slagging Requirements of Fuels

While the operation of other furnace designs may depend on particle size more than any other fuel parameter to burn successfully, a cyclone furnace requires a low melting point ash below some maximum temperature to form a liquid slag for removal from the furnace.

An ash fusion temperature of 2500°F generally is accepted from experience as the maximum. While there may be a theoretical basis for specifying a minimum ash fusion temperature to ensure a coating on the cyclone walls, no serious firing problems are reported with low melting point fuels.

Ash fusion temperature is a major parameter for successfully burning fuels in this furnace. The suitability of coals for the cyclone furnace is dependent on the moisture, ash, and volatile content of the coal, and the chemical composition of the ash. The combination of coal characteristics must result in a fuel causing a slagging viscosity at the temperatures developed in the cyclone and primary furnaces which will permit fluid flow, the major means by which the combustion products are removed from the furnace. The molten slag is required to flow through the cyclone into the bottom of the furnace, where it exists through a tap hole into the bottom ash hopper. The suitability of supplemental fuels then is highly dependent on their effect on the fluidity of the slag. This effect was closely monitored during the co-combustion test. In laboratory tests the slagging temperature of RDF fluff has been determined to be in the admissible temperature range.

3.5 Sulphur Content of Fuels

In the past, coals high in sulphur content have been shown to have properties well suited for cyclone furnaces. Western Maryland coal typically is high in sulphur and available at low transport costs. RDF fluff contains virtually no sulphur and its co-combustion with high sulphur coal has the potential for reducing sulphur emissions, thus reducing the cost of air pollution control equipment.

3.6 Controls

The feed control circuit was electrically interlocked with the boiler plant feed controls to prevent discharge of RDF into the pipeline except as required by the boiler operator. All equipment is electrically sequenced for orderly startup and shutdown.

SECTION 4

BURN TEST PROGRAM - PHASE I²4.1 Candidate Coals

The coals supplied for testing were from three geographical areas selected by prior knowledge of broad quality characteristics. Specifically, coal was purchased to satisfy the low sulfur content and low ash fusion temperature specifications, with the awareness that the iron content might exceed acceptable limits. The coals tested were:

<u>Pennsylvania</u>	<u>West Virginia</u>	<u>Western Maryland</u>
Clarion	Pepper	Jones
Vipond	Blacksville No. 1	Moran
Medix	Blacksville No. 2	Phillips
R.E.M.		
Cooper		
Militant		
Bullskin		
N. Cambria		
Glenn		
Apollo		

It became apparent that observation of subjective differences in coal performance was the most important criteria available for eventual ranking of coals. Using viewing ports in each cyclone and in the slag tank, a comparative experience was developed by plant personnel. Such items as fluidity of slag entering the slag tank, cyclone slag buildup, and furnace slag buildup were included with more obvious results such as flame trip in a cyclone or plugged rotary seals due to wet coal.

These performance differences were not inconsequential; more often than not the Unit had to be brought down to clean slag from the cyclones and furnace or to clear a rotary seal. Of seven outages due to tube leaks, two were considered traceable to fuel characteristics.

With slag flow control essential to maintaining the test, coal fluxing was applied when the coal analysis or burning performance dictated it. The response of a coal to limestone flux, and the optimum dosage, must be determined experimentally as mentioned in the Discussion of this report [this refers to Report #80-28]. The preparation of the coal sample and the technique involved generate analytical lag time which taxes the available storage time in the coal yard. With extended use of given coal, such as in Phase II, ash fusion temperature vs. flux dosage curves were more valuable. However, it was yet to be shown that a given type of coal followed the curve over multiple deliveries.

² Section 4 was retyped from BG&E Report #80-28, P. 9-11

When slag buildup in the furnace floor tap or a cyclone was noted, a proprietary fluxing agent was fed directly into a cyclone to clear it. However the particle size of this material was such that it was blown throughout the furnace rather than the localized area of buildup. Mixing with coal on a feeder belt was ineffective. Overall, limestone is considered superior to this product in reducing slag buildup.

It was apparent that it was better to prevent than correct ash fusion temperature problems, so limestone flux yard feed was applied when its need was implied by analysis or performance. As mentioned in the Discussion section, the most accurate description of this operation is that some limestone was fed, but at an estimated rate. When more was needed or when fluxing was seen necessary after the coal had been sent to the storage silos, limestone was added to the feeder belts, but with great difficulty in moving the limestone to the belt elevation and in applying it at a measurable rate.

An interesting difference was seen between the fly ash analysis at the filter bag location and the fly ash sample point in the upper hoppers; the filter bag sample was often several times higher in sulfur but about half as high in combustible material. A case could be made for the decrease in sulfur in the fly ash as it travels up the stack as the release of absorbed sulfur dioxide to a gas, but the increase in combustible material is not readily apparent [of Report #80-28]..

Some comparative observations between Phase I and Phase II are included in the Phase II section [of report # 80-28].

4.2 Ranking

As outlined above, ranking of the coals is subjective, but perhaps only as subjective as the ranking applied by coal suppliers, and possibly only a reflection of it. It is intended to be a relative comparison.

Three catagories of test experience were recognized:

Acceptable - A minimum of handling problems, consistent burning, and good slag tapping in both cyclones and furnace whether or not assisted by flux.

Marginally Acceptable - Some problems with handling or burning, but primarily based on observed slag tapping.

Unacceptable - Inconsistent performance which could affect continuous generation, for any reason.

COAL RANKINGAcceptable

Pepper (W. VA)
 Clarion (PA)
 Vipond (PA)
 Medix (PA)
 Blacksville No. 1 (W.VA)

Marginally Acceptable

Blacksville No. 2 (W.VA)
 R.E.M. (PA)
 Jones No. 1 (MD)
 Cooper (PA)
 Moran (Royal (MD)

Unacceptable

Militant (PA)
 Bullskin (PA)
 Cambria (PA)
 Glenn (PA)
 Apollo (PA)
 Phillips (MD)

After consulting with Purchasing and Stores Department, Vipond coal was selected as the best balance of acceptable performance and adequate supply to use in Phase II of the tests. Other than supply and price, the other coals listed in th acceptable rank can be considered interchangeable when considering alternate fuels.

Table 1. Analytical Summary of Coals ^{a/}

	<u>Sulphur, %</u>	<u>Ash, %</u>	<u>Btu/lb</u>	<u>Fluid Melting Point, °F</u>
Blacksville No. 1	2.01 ± 0.08	7.3 ± 0.4	14928 ± 395	2367 ± 43
Militant	2.13 ± 0.22	10.2 ± 0.8	13114 ± 239	2427 ± 69
Bullskin	2.15 ± 0.07	10.1 ± 1.2	13080 ± 653	2339 ± 37
N. Cambria	1.90 ± 0.15	11.0 ± 1.5	12776 ± 279	2548 ± 73
Clarion	1.98 ± 0.17	7.0 ± 0.4	13313 ± 160	2454 ± 60
Glenn	2.32 ± 0.41	10.4 ± 1.2	12496 ± 421	2368 ± 103
Vipond	2.05 ± 0.16	11.0 ± 0.7	12560 ± 197	2473 ± 46
Pepper	2.39 ± 0.87	9.1 ± 1.9	13077 ± 249	2201 ± 150
Apollo	2.26 ± 0.33	10.3 ± 2.2	12563 ± 505	2394 ± 79
Jones	2.28 ± 0.14	11.8 ± 2.3	12932 ± 836	2431 ± 55
R.E.M.	2.09 ± 0.13	8.0 ± 0.5	13224 ± 83	2443 ± 63
Phillips	1.93 ± 0.35	13.0 ± 2.4	12905 ± 348	2576 ± 62
Cooper	2.16 ± 0.15	11.9 ± 0.4	12407 ± 252	2448 ± 121
Medix	1.97 ± 0.24	10.9 ± 0.9	12350 ± 360	2525 ± 57
Moran	2.13 ± 0.46	14.5 ± 4.3	12149 ± 904	2432 ± 41
Blacksville No. 2	2.30 ± 0.06	6.6 ± 0.3	13740 ± 204	2279 ± 136

^{a/} From BG&E Report #80-28, Data Volume.

SECTION 5

BURN TEST PROGRAM - PHASE II5.1 RDF

RDF co-combustion with Vipond coal was initiated on July 7, 1980, and tests were completed by September 15, 1980. RDF was burned on 40 days in this time period, usually for 10 hours per day between 7:30 am and 11 pm.

The RDF feed rate was proportioned to the coal feed rate by ratio to the appropriate coal feeder belt speed. When all four belt speeds were equal, and when the RDF represented 20% of the energy to cyclone 22B, it represented about 5% of the overall fuel energy input. Since the RDF density varied, instantaneous feed rates were difficult to establish, but confident estimates were possible using truck weights and coal scales. Handling problems were rare to nonexistent.

A total of 2316 tons were burned at an average RDF replacement of 5.6 tons per hour or 25% heat replacement, based on Btu input for a period of forty test days. The range of RDF burned was from 3 to 10 tons per hour, or 7 to 63%.

Table 2 summarizes RDF consumption on a daily basis. A more complete listing of the RDF usage along with heat input for RDF and coal for each load of RDF is presented as Appendix A.

All aspects of the test were monitored closely including RDF quantities and analysis, bottom and fly ash composition, stack emissions, and ambient air quality impact.

Overall, the RDF was remarkably consistent in texture, energy content, and absence of large-sized impurities such as glass, metal, etc. The average analysis of the RDF (39 samples) was:

Ash	-	13.4%
Moisture	-	18.9%
Heat Content (HHV)	-	6296 Btu/lb
Sulphur (5 samples)	-	0.26

Sample-to-sample variations are shown in Table 3.

The RDF coal mixture burned well. After familiarity with equipment and feed stability was established, and in conjunction with steady operation with Vipond coal, generation was continuous.

Table 2. RDF Daily Consumption

Date	Weight Lbs.	Tons	Total Hours	Ton/h, average	Total Heat 10 ⁶ Btu
7-07-80	27,850	(13.93)	3:28	4.02	209.49
7-08-80	80,166	(40.08)	11:15	3.56	516.99
7-09-80	98,567	(49.28)	13:08	3.75	540.15
7-10-80	41,912	(20.96)	6:27	3.25	272.89
7-11-80	31,939	(15.97)	5:27	2.93	208.98
7-14-80	48,786	(24.39)	6:00	4.07	303.64
7-15-80	117,110	(58.56)	12:20	4.75	852.44
7-21-80	135,855	(67.93)	12:00	5.66	831.30
7-22-80	66,427	(33.21)	7:40	4.33	477.74
7-23-80	68,828	(34.41)	6:12	5.55	394.52
7-24-80	91,550	(45.78)	8:55	5.13	495.56
7-25-80	103,010	(51.51)	9:45	5.28	600.24
7-28-80	127,718	(63.86)	14:50	4.31	694.66
7-29-80	161,710	(80.86)	13:40	5.92	1,007.00
7-30-80	168,717	(84.36)	14:30	5.82	987.50
7-31-80	127,020	(63.51)	11:52	5.35	790.95
8-01-80	103,515	(51.76)	13:17	3.90	747.79
8-04-80	144,030	(72.02)	12:45	5.65	1,077.90
8-08-80	134,170	(67.09)	10:10	6.60	691.78
8-09-80	104,970	(52.49)	7:21	7.14	592.87
8-11-80	160,672	(80.34)	11:10	7.19	1,006.00
8-12-80	161,148	(80.57)	12:25	6.49	910.97
8-13-80	66,080	(33.04)	3:02 + 5:00 ^{a/}	6.51	359.81
8-14-80	188,310	(94.16)	15:07	6.23	1,157.40
8-15-80	165,890	(82.95)	13:00	6.38	1,068.20
8-18-80	166,310	(83.16)	13:35	6.12	999.19
8-19-80	152,780	(76.39)	12:45	5.99	945.40
8-20-80	145,500	(72.75)	11:25	6.37	910.25
8-21-80	139,960	(69.98)	11:35	6.04	1,006.30
8-22-80	65,045	(32.52)	5:10	6.29	374.59
8-25-80	11,060	(5.53)	0:50	6.64	63.69
9-02-80	125,340	(62.67)	14:57	4.19	876.75
9-03-80	132,060	(66.03)	11:41	5.65	866.98
9-04-80	109,145	(54.57)	14:03	3.55	714.90
9-05-80	112,710	(56.36)	11:22	4.96	706.47
9-08-80	211,110	(105.56)	15:13	6.94	1,103.30
9-09-80	45,940	(22.97)	6:20	3.63	303.07
9-10-80	195,570	(97.79)	14:25	6.78	1,334.00
9-13-80	97,940	(48.97)	6:10	7.94	692.34
9-15-80	195,670	(97.84)	12:40	7.72	1,285.60
Total					
40 days	4,632,090	= 2,316.05	416:30	5.56 Ave.	289,779.60

^{a/} Special test run with premixed RDF and coal fed through coal handling system.

Table 3. RDF Analysis

<u>Date</u>	<u>Moisture, %</u>	<u>Ash, %</u>	<u>Btu/lb</u>	<u>Sulfur, %</u>	<u>Chloride, %</u>
7-07-80	8.7	11.1	7,522	--	--
7-08-80	19.1	16.3	6,449	--	--
7-09-80	9.2	10.6	5,480	--	--
7-10-80	19.8	13.1	6,511	--	--
7-11-80	18.5	15.3	6,543	--	--
7-14-80	19.3	13.1	6,224	--	--
7-15-80	13.0	9.6	7,279	--	--
7-21-80	19.1	17.7	6,119	--	--
7-22-80	13.5	11.0	7,192	--	--
7-23-80	23.2	11.7	5,732	--	--
7-24-80	26.4	14.3	5,413	--	--
7-25-80	22.7	11.6	5,827	--	--
7-28-80	18.9	12.4	5,439	--	--
7-29-80	18.3	11.0	6,227	--	--
7-30-80	21.4	14.6	5,853	--	--
7-31-80	18.2	14.3	6,227	--	--
8-01-80	9.1	13.4	7,224	--	--
8-04-80	20.8	14.6	7,484	--	--
8-08-80	26.6	15.6	5,156	--	--
8-09-80	26.3	14.0	5,648	--	--
8-11-80	17.2	12.8	6,261	--	--
8-12-80	25.7	15.2	5,653	--	--
8-13-80	27.6	14.2	5,445	--	--
8-14-80	15.5	13.3	6,146	--	--
8-15-80	33.6	13.1	6,439	--	--
8-18-80	21.6	17.4	6,008	--	--
8-19-80	14.9	15.3	6,188	--	--
8-20-80	23.5	11.4	6,256	--	--
8-21-80	25.1	11.1	7,190	--	--
8-22&25 80	25.5	14.2	5,759	--	--
9-02-80	12.3	13.5	6,995	--	--
9-03-80	17.3	12.0	6,565	--	--
9-04-80	18.0	11.7	6,550	--	--
9-05-80	21.8	12.5	6,268	--	--
9-08-80	13.8	15.6	5,226	0.25	0.81
9-09-80	14.6	12.6	6,597	0.31	0.86
9-10-80	14.6	13.5	6,821	0.27	1.02
9-13-80	10.6	13.1	7,069	0.24	0.039
9-15-80	13.3	12.9	6,570	0.23	0.25
	738.6/39	520.7/39	245,555/39		
	=18.9	=13.4	=6,296.3		

5.2 Comparisons of Analytical Data for RDF and Vipond Coal

The average analysis of Vipond coal was:

Ash	11	±	0.7%
S	2.05	±	0.16%
Heat Content (HHV)	12560	±	197 Btu/lb
Fusion Temp.	2473	±	45°F fluid melting pt

Properties of RDF are presented in Table 3.

With a heat content ratio of 12,560/6296 or 2 to 1, it requires two tons of RDF to replace one ton of coal. Therefore, 25% RDF by energy content would be equivalent to 40% RDF by weight.

Most of the data for RDF are typical except for volatiles, which was high.

The proximate analysis of a composite of 13 samples of fluff RDF, similar to that burned in the BG&E tests, analyzed in March, 1979, is given below for comparison purposes. These results show a volatile content of 69.4%, which is considerably below the figure of 87.8% for a single sample shown in Table 3.

Proximate Analysis on Composite of Thirteen samples of RDF

	<u>As Received</u>	<u>Dry Basis</u>
% Volatile Matter	69.4	77.6
% Moisture	10.6	—
% Fixed Carbon	12.4	13.9
% Ash	7.6	8.5
Btu/pound	7692	8602
Total Sulfur	0.19	0.21

RDF used in the test was secondary shredded through $1\frac{1}{2}$ inch grates producing the following particle size distribution.

<u>Screen Size</u> (Inch)	<u>Weight %</u>	
	<u>Through</u>	<u>On</u>
2.0	100	0
1.0	95	5
.5	51	44
187	17	—

5.3 Heat Contribution of RDF

The heat contribution of the RDF is shown in Appendix A for each trailer load of RDF. As previously stated, the contribution ranged from 7 to 63%, with an average of 25% for the test cyclone unit.

Calculation of the heat contribution of RDF is based on the assumption (per discussions with BG&E personnel) that approximately 16 ton/h of Vipond coal at 12,560 Btu/lb per cyclone was required to generate 192 MW (full load for four cyclones). Although test plans called for 20% heat substitution of RDF on a continuing basis, wide variations in the power load, ranging from 35 to 192 MW, during the test period resulted in associated variations in RDF heat substitution at constant RDF feed rate. An additional problem was caused by changes in wind direction. The variance granted to BG&E for conducting the test stipulated that power generation be reduced whenever the wind shifted toward the residential area and boat yard adjacent to the plant. Power generation at the plant is summarized by day and hour in Appendix B.

When power was reduced to 100 MW or less, one or more cyclones had to be shut down. In order to reduce combustibles in the fly ash, it was necessary to inject fly ash into three coal-burning cyclones (the cyclone burning coal plus RDF had no provision for fly ash injection). BG&E personnel made every effort to inject fly ash during the night shift so that the cyclone burning RDF could be used during the day shifts. However, if fly ash had to be injected into three cyclones during the day - at reduced loads - it then became necessary to shut down the cyclone burning RDF. Shutdowns also were required when the Air Quality Board declared air stagnation warnings in the Baltimore region, such as from August 25 to August 31, 1980.

5.4 Ash and Fly Ash

An analysis of coal and RDF ash is given in Table 4 (reported by BG&E). Particle size distribution of the fly ash also is shown indicating an unexpectedly large size of fly ash particles as a result of RDF firing.

5.5 Ash Distribution³

The ash distribution uses a material balance based on ash from the fuel into the boiler versus the stack outlet particulate concentration and the slag to the slag tank. The ash from the fuel is available from coal as burned values, and the stack values were measured during the stack tests. The slag is wet when available for sampling at the dewatering bin and truck weights are difficult to interpret in terms of slag generated over the same time that stack values were taken. Bottom ash (slag), then, is calculated by difference.

In this particular case, since the precipitator performance was poor, the calculated ash distribution can roughly serve as a measure of loading to the eventual baghouse operation.

Using Vipond coal values of 12,576 Btu/lb and 11.0% and RDF values of 6570 Btu/lb and 12.7% ash, the ash distribution is as follows:

³Sections 5.5 and 5.6 were retyped from BG&E Report #80-28, p. 17-19.

Table 4. Comparison of Analytical Data for Vipond coal and RDF

1) Proximate Analysis (typical)

	<u>Vipond</u>	<u>RDF</u>
Moisture =	6.3%	15.4%
Volatiles =	25.2%	87.8%
Ash =	11.1%	12.7%
Sulphur =	2.22%	0.19%
Btu/lb =	12,576	6570
Fluid Ash Fusion Temp. =	2514°F	2010°F

2) Ash Analysis (from fuel burned in the laboratory)

	<u>Vipond</u>	<u>RDF</u>
% SiO ₂ =	46.3	57.0
% AL ₂ O ₃ =	25.5	17.8
% Fe ₂ O ₃ =	22.5	2.5
% TiO ₂ =	1.0	1.8
% C _A O =	1.3	10.7
% MgO =	0.5	1.7
% NA ₂ O =	0.4	2.2
% K ₂ O =	1.3	2.2
% SO ₃ =	<u>1.5</u>	<u>2.2</u>
TOTAL =	100.3%	98.1%

3) Fly Ash Particle-Size Distribution

	<u>Vipond</u>	<u>Vipond plus RDF</u>
Under 20	58%	18%
Under 10	30%	6%
Under 5	9%	1%
Under 3	3%	0.1%

a/ Moisture - free basis.

<u>Stack Test</u>	<u>Ash In (lb)</u>	<u>Fly Ash Out (lb)</u>	<u>Fly Ash (%)</u>	<u>Bottom Ash (%)</u>
A	8.75	3.74	43	57
B	8.75	2.19	25	75
1	10.87	4.73	43	57
2	10.87	4.46	41	59
3	10.87	6.15	56	44
4	10.87	5.94	55	45
5	8.75	5.47	62	38
6	8.75	4.85	55	45
7	8.75	4.77	55	45

The results are not considered accurate, but a distribution roughly consistent with predictions for a cyclone boiler, about 50% flyash and 50% bottom ash, are noted.

5.6 Sampling for Sulfur Content

The attempt at determining the sulfur distribution through the boiler was based on a simple mass balance of sulfur in the fuel as burned versus the sulfur exiting the boiler as sulfur oxides in stack gas, sulfur in fly ash, and sulfur in the slag. Two factors complicated the effort: leakage in the air heaters which diluted the stack gas before sulfur oxides were measured, and suspected sluice water leaching of sulfur salts in the slag before sampling.

Initially, slag samples were sampled for sulfur and little or none was detected. With sluice water leaching suspected, sulfur analyses were discontinued. Additional spot samples verified that very little sulfur remained in the ash. For example:

Clarion slag	= 0.02% sulfur
Medix slag	= 0.06% sulfur
Phase II, Test ' slag	= 0.25% sulfur
Cyclone slag, 9/17/80	= 0.16% sulfur ⁴
Upper precipitator ash, 9/18/80	= 0.67% sulfur
Lower precipitator ash, 9/18/80	= 1.18% sulfur

The heater leakage is estimated to be 20%, introducing sulfur - free air to the stack, diluting, and producing an erroneously low reading.

For each of the seven stack tests, the sulfur in the fuel as burned was compared to the total of:

- 1) Sulfur Dioxide measured, as SO₂
- 2) Sulfur Trioxide measured, as SO₂
- 3) Sulfur remaining in ash, as SO₂

⁴Before contact with sluice water. Compare with slag samples above.

The total was corrected for dilution by dividing by 0.80 from an assumed leakage of 20%. The sulfur dioxide measurements are from the SO₂ monitor and stack tests results, and are compared below. The heating value of the fuel is used to express the results in pounds of sulfur dioxide per million Btu of fuel.

The overall equations are:

$$1. [(SO_2 \text{ measured}) + (SO_3 \text{ correction} + (SO_2 \text{ in fly ash})] = SO_2 \text{ detected, million Btu.}$$

$$1a. SO_3 \text{ correction} = (SO_3, \text{ million Btu}) \left(\frac{M.W. SO_2}{M.W. SO_3} \right)$$

M.W. = Molecular weight

$$1b. SO_2 \text{ in fly ash/million Btu} = \left(\frac{\% \text{ Sulfur in Ash}}{100} \right) \left(\frac{\% \text{ Ash in Fuel}}{100} \right) \left(\frac{\text{Fuel}}{\text{million Btu}} \right) \left(\frac{M.W. SO_2}{M.W. \text{ sulfur}} \right)$$

$$2. \left(\frac{SO_2 \text{ detected, million Btu}}{M.W. SO_2} \right) \div 0.80 = \text{Per cent sulfur accounted for.}$$

To the degree that the per cent sulfur accounted for approaches 100% an accurate sulfur distribution will be implied. A summary of results follows.

Summary of Per Cent Sulfur Accounted for

<u>Stack Test</u>	<u>SO₂ from probe</u>	<u>SO₂ from meter</u>
A	-	73.3%
B	-	108.3%
1	133.4%	95.2%
2	103.3%	96.0%
3	88.8%	95.5%
4	84.6%	84.6%
5	69.5%	101.3%
6	110.8%	93.6%
7	99.8%	84.4%

Apparently the SO₂ meter produced a better accounting than the probe, and the average accounted² for is 92.5%, which is quite good considering the inaccuracy of the assumed air heater leakage. Unfortunately, the SO₂ monitor operational history was poor. While accurate when reading, the meter required adjustments and calibrations which were aggravated by its plant environment, and was offline quite often.

Using the best (closest to 100%) per cent sulfur accounted for from the SO_2 meter series, test No. 5, a selected sulfur distribution is calculated:

SO_2 as SO_2 in stack gas	= 92.7%
SO_2 as SO_3 in stack gas	= 4.0%
SO_2 in fly ash	= <u>3.3%</u>

Total sulfur as SO_2 = 100 %

5.7 Alternative Feed Methods

Alternative feed points were explored for information on future use. RDF was shoveled onto a coal feeder belt, but the mixture plugged the rotary seals. Evidently, materials-handling equipment that presents a close-tolerance, rubbing environment, as opposed to those that fluidize the material, is not appropriate for RDF. An attempt was made to mix RDF with coal in the coal yard to the 80% coal by energy blend. The proportions were estimated by scoopfuls using a front-end loader, with layering into empty coal cars. The cars were rotated and the blend forwarded by belts. The RDF light density presented problems in the yard. The free fall from the bulldozer scoop and the coal crane allowed drifting losses of RDF even with a light wind. The vibrating feeder clogged, and the volume increase of the RDF and coal limited the rate of fuel supplied to the boiler on the basis of energy content. The RDF was found to have clung to the gridwork under the car dumper before contact with the first conveyor belt. The blend did not plug the Bradford Breaker, but later inspection showed that it selectively bridged in the coal silo and eventually would have interfered with gravity flow to the feeder belt.

Designs that maintain the segregation of RDF and coal until they reach the cyclone furnace are preferable.

5.8 Burn Test Observations

During the RDF test period, Vipond (Pa.) coal, with an average heating value of 12,560 Btu/lb, was burned most of the time. Inspection of the cyclone furnaces during combustion of coal and RDF, even at average RDF heat contribution rates of 55%. There were some slagging problems with the coal that were corrected by additives or fluxing agents such as limestone.

During the test period, the following minor problems were observed:

1. dust problems around the receiving area when the RDF was very dry
2. failure of hydraulic parts and fittings - did not interrupt operation. Spare parts were on hand
3. lost lump breaker arms - wet and heavy loads create large, dense lumps of RDF. Material that was a few days old was hard and there

was a problem in breaking the lumps

4. dense lumps caused the special-lined elbow of the RDF feed duct to jam when the feed conveyor speed control malfunctioned
5. wear on the tertiary air scroll - abrasive material caused wear on the scroll piece after several weeks in operation. It worked fine after relining the scroll piece.
6. slide gate in the duct line - packing materials loosened up when the slide gate was opened and closed. A new slide gate was fabricated, which worked well
7. rotary airlock leakage caused dust in the feed conveyor and control platform area.

BG&E personnel were concerned with possible clinker buildup on the boiler wall and superheater area. After the test run, a Teledyne representative inspected the boiler and superheater area and found no clinker buildup in those areas. A final inspection was conducted with BG&E personnel and others after completing the RDF burn test. The bottom of the boiler and cyclones appeared normal, even though RDF was fed at 63% heat substitution on the last day of the test. All four cyclones looked alike and the boiler looked normal, as did the superheater areas and economizer. Although air heater fans were plugged with small clinkers, the cause could not be determined.

5.9 Comments on Performance of RDF

As a fuel complement, RDF performed exceptionally well at an average fuel substitution of 25% (heat basis), with excursions up to 63%.

The RDF-coal mixture burned well. After familiarity with equipment and feed stability was established, and in conjunction with steady operation with Vipond coal, generation was continuous. The slagging qualities of the RDF appeared to be satisfactory when burned with Vipond coal.

Overall, the RDF produced by air classifying, trommeling and secondary shredding) was remarkably consistent in texture, energy content, and absence of large sized impurities such as glass, metal, etc.

Post-test inspection showed no damage or deterioration of the furnace due to RDF. A glassy coating on precipitator surfaces, reported during similar tests at other utilities, was not seen.

The only equipment deterioration during testing was erosion of the cyclone scroll wall at the point of tangential impact of incoming RDF, eventually wearing through and allowing some burning fuel to exit the boiler. An external wear plate was welded on, and a sluice gate arrangement was installed in the RDF feed line as a safety measure. Since this area normally is used for air, this does not indicate inherent erosive properties of RDF; appropriate material selection at this point

should eliminate the problem.

Unit shutdowns during Phase II were due to tube leaks, air stagnation advisories, etc., as outlined in the test chronology. Generation was not interrupted for any reason traceable to the fuel.

The RDF receiving station and pneumatic feeding equipment worked well. The design, with some modifications to permit immediate unloading of RDF trailers plus surge storage capacity, could be used as the basis for a permanent station feeding four cyclones.

Burning of RDF with coal did not appear to adversely affect air quality. However, insufficient data were available to enable a valid conclusion.

5.10 Evaluation of Environmental Effects

BG&E reported that ambient monitoring indicated no sulfur dioxide or total suspended particulate concentrations in excess of National Ambient Air Quality Standards.

Before these tests it was known the electrostatic precipitation, which was quite old, could not meet current air quality standards for particulates. However, eventual substitution of a baghouse would obviate this problem.

Details on particulate and sulfur emission testing are presented in Appendix D — a report by KVB, prepared for BG&E.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS⁵

Conclusions and recommendations are directed to each of the five objectives selected for the tests.

Evaluation of Suitable Coals

While purchasing specifications for a class of coal will avoid broad quality mayontrol problems, it must be expected that the coal actually delivered may require fluxing to allow continuous use. The flux required will be empirical, and the coal yard limestone feed system should be replaced with one that will offer known, steady feed rates. After a familiarization period with a given fuel, the judgment of plant personnel will be a major factor in fuel properties adjustment. As a class, fuels rated acceptable in this test series can be burned successfully.

Evaluation of Refuse Derived Fuel

As a fuel complement, this material performed exceptionally well. No deterioration of equipment or interruption of normal generation occurred with localized fuel substitution of 20%, with excursions to 30%. Future use should incorporate corrosion studies of affected surfaces to establish the long term operation of its use.

Sulfur and Ash Distribution

As expected, approximately 95% of the sulfur in the incoming fuel leaves the boiler as sulfur oxides in the stack gas. While a small amount was detected in the fly ash, the value was less than the statistical variation of sulfur in the fuel, so a deduction of this sulfur for credit in stack emission predictions is not mathematically logical, beyond what is currently allowed.

The ash distribution approaches 50% fly ash and 50% bottom ash, although the results are not consistent.

Evaluation of Filter Bag Material

The filter bag material specified for the future baghouse appears appropriate, since plant simulation tests showed no problems with filtering performance or material wear. The unexpectedly large size of fly ash particles as a result of RDF firing should be incorporated into considerations of bag loading and pressure drop through the filter cake before removal.

⁵ From BG&E ' Report #80-28, p. 21

Evaluation of Environmental Effects

The precipitator efficiency was low during the stack tests, but eventual substitution of a baghouse should improve the emissions level.

Ambient monitoring reported no sulfur dioxide or total suspended particulate concentrations in excess of National Ambient Air Quality Standards.

REFERENCES

1. Baltimore Gas & Electric Company,
"C.P. Crane No. 2 - Coal Burning Tests,"
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2. Maryland Environmental Service,
"Proposal for Co-Combustion of Refuse-Derived Fuel & Coal in a
Cyclone Furnacer at the Baltimore Gas & Electric Company,
C.P. Crane Station," made to the U.S. Department of Energy
(December 28, 1979).
3. Contract between Maryland Environmental Service and
Baltimore Gas & Electric Company for the
"Co-Combustion of Coal and RDF at the
C.P. Crane Station" (March 20, 1980).

APPENDIX A

Summary of RDF and Coal Consumption and Heat Input during
BG&E Crane Station Test
July 7 through September 15, 1980

APPENDIX A
SUMMARY OF RDF AND COAL CONSUMPTION
AND HEAT INPUT DURING BG&E CRANE STATION TEST
July 7 through September 15, 1980

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution RDF %
7-07-80	315	9,390	1:38	2.87	43.18	335.04	11.40
	324	18,460	1:50	5.03	75.67	322.06	19.03
7-08-80	521	23,940	2:45	4.35	56.11	341.62	14.11
	331	22,590	2:30	4.52	58.30	326.87	15.14
	321	20,870	4:25	2.36	30.44	358.92	7.82
	326	27,310	3:23	4.03	51.98	345.75	13.07
7-09-80	"	"					
	330	26,250	2:38	4.98	54.58	313.85	14.81
	335	28,310	3:25	4.14	45.37	352.36	11.41
	319	27,010	4:57	2.73	29.92	367.81	7.52
	326	26,610	3:17	4.05	52.74	298.94	15.0
7-10-80	"	"					
	331	21,960	3:55	2.80	36.46	352.90	9.36
7-11-80	"	"					
	335	21,520	2:37	4.11	53.78	346.05	13.45
	330	24,680					
7-14-80	"	"	6:05	4.14	53.91	343.82	13.55
	308	25,720					
	316	20,120	2:55	3.45	43.00	358.92	10.70
7-15-80	"	"					
	320	20,410	3:03	3.35	48.80	353.12	12.14
	321	26,610	3:07	4.27	62.16	335.57	15.63
	306	29,860	2:20	6.40	93.17	302.47	23.55
	327	24,710	1:35	7.80	113.60	279.95	28.87
7-21-80	335	29,630	2:25	6.13	75.02	310.15	19.48
	325	28,700	2:50	5.06	61.92	300.23	17.10
		26,270	2:15	5.84	71.47	296.96	19.40
	327	25,740	2:15	5.72	70.00	298.43	19.00
	317	30,240	2:40	5.67	69.40	311.59	18.22
7-22-80	"	"					
	321	22,750	3:15	3.50	50.34	326.46	13.36
	313	21,330	2:10	4.92	70.80	322.75	18.00
	332	32,360	3:22	4.81	69.20	324.35	17.58
7-23-80	"	"					

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution	RDF %
7-23-80	319	22,270	2:10	5.14	58.90	334.65	14.97	
	321	31,820	2:30	6.36	72.90	322.74	18.43	
7-24-80	315	(38,780) 12,750	2:23	2.67	28.90	266.26	9.79	
	308	26,700	2:37	5.10	55.20	237.87	18.84	
	321	25,320	2:00	6.33	68.50	222.47	23.50	
	327	26,780	1:55	6.99	75.70	215.27	26.02	
7-25-80	306	27,140	3:07	4.35	50.70	336.57	13.09	
	308	26,930	3:18	4.08	47.55	348.09	12.02	
	311	22,550	1:43	6.57	76.57	319.07	19.35	
	522	26,390	1:37	8.16	95.10	302.63	23.91	
7-28-80	521	23,910	3:10	3.78	41.12	243.57	14.44	
	305	21,890	2:50	3.86	41.99	221.77	15.92	
	324	26,710	3:05	4.33	47.10	199.91	19.07	
	330	31,640	3:10	5.00	54.39	311.94	14.85	
	324	28,130>	3:05	4.56	49.60	320.92	13.39	
7-29-80	"	"						
	325	25,720	3:05	4.17	51.93	197.18	20.85	
	326	27,120	2:20	5.81	72.36	289.79	19.98	
	324	23,330	1:35	7.37	91.79	310.13	22.84	
	333	32,050	1:45	9.16	114.08	287.84	28.38	
	315	26,480	2:10	6.11	76.09	325.83	18.93	
	322	35,750>	3:35	4.99	62.15	323.02	16.14	
7-30-80	"	"						
	306	33,850	2:05	8.12	95.05	290.12	24.68	
	315	26,730	1:45	7.64	89.43	241.32	27.04	
	333	27,100	1:55	7.07	82.76	157.97	34.38	
	314	27,220	2:50	4.80	56.19	228.50	19.74	
	309	27,530	3:20	4.13	48.35	322.17	13.05	
	327	29,780>	2:52	5.19	60.75	265.81	18.60	
7-31-80	"	"						
	308	27,880	2:00	6.97	86.80	264.88	24.68	
	314	25,880	1:40	7.76	96.64	278.07	25.79	
	321	27,120	3:13	4.22	52.56	294.93	15.13	

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution	RDF %
7-31-80	309	26,710	3:02	4.40	54.80	319.91	14.62	
	326	27,280 >	3:27	3.95	49.19	312.96	13.58	
8-01-80	"	"						
	311	24,310	3:45	3.24	46.81	250.44	15.75	
	321	29,050	3:15	4.47	64.58	278.73	18.81	
	308	25,510	3:10	4.03	58.23	306.01	16.07	
8-04-80	312	26,400	3:10	4.17	62.42	310.19	16.75	
	309	26,420	3:25	3.87	57.93	318.87	15.37	
	3521	28,400	1:40	8.52	127.53	242.99	34.42	
	326	31,880	1:50	8.69	130.10	238.33	35.31	
	330	30,930	2:40	5.79	86.70	281.73	23.53	
8-08-80	318	27,330	3:21	4.07	42.96	172.65	19.92	
	308	22,630	2:18	4.92	50.74	236.05	17.69	
	314	27,510	1:20	10.06	103.74	268.87	27.84	
	310	30,640	1:34	9.78	100.65	242.66	29.32	
	330	26,090	1:35	8.24	85.00	153.64	35.62	
8-09-80	327	22,080	1:46	6.25	70.60	147.11	32.43	
	321	26,820	1:49	7.38	83.36	134.35	38.29	
	314	28,280	1:50	7.71	87.09	128.51	40.39	
	310	27,790	1:56	7.19	81.22	132.30	38.04	
8-11-80	330	29,360	2:18	6.38	79.90	269.69	22.86	
	309	30,870	2:05	7.41	92.80	250.51	27.03	
	329	28,720	1:35	9.07	113.60	181.56	38.49	
	330	33,060	2:12	7.51	94.04	138.32	40.47	
	314	25,870	2:00	6.47	81.02	170.18	32.25	
	306	26,650 >	2:05	6.40	80.14	168.97	32.17	
8-12-80	"	"						
	318	31,890	2:25	6.60	74.62	235.19	24.09	
	310	27,600	2:10	6.37	72.02	237.79	23.25	
	307	31,310	2:25	6.48	73.26	263.77	21.74	
	312	28,570	2:10	6.59	74.51	304.38	19.66	
	317	27,920	2:10	6.44	72.81	301.90	19.43	
8-13-80	318	26,110	Test run with premixed RDF & coal					
	326	28,400	2:07	6.70	73.00	270.31	21.26	
	314	27,140 >	2:09	6.31	68.72	247.37	21.74	
8-14-80	"	"						

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution	RDF %
8-14-80	307	29,010	2:16	6.40	78.70	277.17	22.11	
	358	28,600	2:12	6.50	79.90	278.06	22.32	
	318	28,720	2:40	5.39	66.30	293.75	18.41	
	312	26,340	2:25	5.45	67.00	303.52	18.08	
	320	30,180	2:15	6.70	82.40	298.59	21.63	
	322	29,890	2:05	7.17	88.13	290.76	23.26	
8-15-80	321	27,620	2:30	5.52	71.10	295.23	19.41	
	310	30,250	2:24	6.30	81.13	283.11	22.27	
	328	30,190	2:11	6.91	89.00	273.15	24.58	
	318	26,430	1:48	7.34	94.52	271.81	25.80	
	326	26,630	2:07	6.29	81.00	291.61	21.74	
	311	28,900 >	2:20	6.19	79.71	292.90	21.39	
8-18-80	"	"						
	314	30,360	2:40	5.70	68.50	306.21	18.28	
	331	28,000	2:05	6.72	80.80	296.00	21.44	
	317	27,130	2:30	5.43	65.30	313.59	17.23	
	332	33,720	2:40	6.32	75.94	302.95	20.04	
	313	28,240	2:15	6.28	75.50	278.27	21.34	
8-19-80	331	29,460 >	2:10	6.80	81.71	240.66	25.35	
	"	"						
	317	30,500	3:25	4.46	55.20	323.69	14.57	
	332	29,960	2:15	6.66	82.42	290.19	22.12	
	313	26,770	2:00	6.70	82.92	291.79	22.13	
	308	27,600	2:10	6.37	78.84	297.96	20.92	
8-20-80	307	28,060 >	2:15	6.24	77.23	299.57	20.50	
	"	"						
	332	29,390	2:16	6.48	81.16	211.97	27.67	
	315	26,880	2:09	6.25	78.20	206.49	27.47	
	322	30,260	2:27	6.18	77.32	217.84	26.20	
	307	25,870	1:58	6.58	82.33	214.92	27.70	
8-21-80	332	28,260	2:10	6.52	81.60	201.00	28.87	
	312	28,540	2:15	6.34	91.20	128.60	41.49	
	322	26,410	2:05	6.34	91.20	124.41	42.30	
	317	29,260	2:10	6.75	97.10	118.51	45.04	
	311	25,610	2:25	5.30	76.21	141.50	35.01	

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution	RDF %
8-21-80	307	30,140	2:40	5.65	81.30	140.59	36.64	
8-22-80	312	28,640	2:15	6.36	73.30	146.50	33.35	
	317	26,450	2:10	6.10	70.30	147.41	32.29	
	322	25,440						
8-25-80	"	"	1:55	6.64	76.48	145.41	34.47	
9-02-80	"	"						
	318	24,690	2:52	4.31	60.30	208.13	16.37	
	3522	26,380	2:28	5.35	74.90	297.71	20.19	
	306	17,700	2:52	3.09	42.23	328.29	11.40	
	325	18,730	2:35	3.62	50.64	319.88	13.67	
	318	21,380	2:20	4.58	64.10	308.51	17.20	
	334	24,070	3:00	4.01	56.10	295.58	15.95	
9-03-80	"	"						
	316	24,790	2:21	5.27	69.20	280.39	19.79	
	3521	29,630	2:15	6.58	86.40	269.47	24.28	
	309	29,740	2:10	6.86	90.10	274.14	24.74	
	330	26,330	2:15	5.85	76.81	287.43	21.09	
	312	24,930	3:03	4.09	53.70	241.46	18.19	
9-04-80	"	"						
	322	29,060	3:50	3.79	49.70	170.10	22.61	
	314	25,290	3:20	3.79	49.70	268.49	15.62	
	311	14,300	2:00	3.58	46.90	311.06	13.10	
	317	25,100	3:00	4.18	54.80	307.35	15.13	
9-05-80	332	25,320	2:20	5.43	68.10	285.67	19.25	
	330	23,610	1:52	6.32	79.23	272.45	22.53	
	314	25,950	2:50	4.58	57.41	287.99	16.62	
	317	27,620	2:40	5.18	64.94	284.65	18.58	
	321	10,210	1:40	3.06	38.40	300.72	11.32	
9-08-80	312	29,510	2:01	7.32	76.51	254.24	23.13	
	330	24,970	1:12	10.30	108.70	242.98	30.91	
	321	28,110	1:35	8.88	92.81	227.47	28.98	
	521	28,640	2:20	6.14	64.20	161.88	28.40	
	322	25,280	2:00	6.32	66.10	174.64	27.46	

Date	Trailer Number	Weight	Hours ^{a/}	Ton/h	RDF Input/h (10 ⁶ Btu)	Coal Input/h (10 ⁶ Btu)	Heat Contribution	RDF %
9-08-80	327	26,280	1:45	7.51	78.50	191.54	29.07	
	310	23,820	2:05	5.72	59.80	247.92	19.43	
	333	24,500	2:15	5.44	56.90	296.87	16.08	
9-09-80	322	19,660	3:15	3.02	39.90	309.69	11.41	
	311	26,280	3:05	4.26	56.21	293.38	16.08	
9-10-80	330	24,370	1:45	6.96	95.00	272.52	25.64	
	321	27,810	1:40	8.34	113.80	252.53	31.06	
	305	25,970	3:05	4.21	57.43	311.00	15.59	
	322	28,640	2:20	6.14	83.80	284.63	22.75	
	327	27,920	2:10	6.44	87.90	253.31	25.76	
	328	29,650	1:30	9.88	134.80	162.45	45.35	
	319	25,650	1:30	8.55	116.64	163.87	41.58	
	330	24,450	1:50	6.67	91.00	212.53	29.98	
	"	"						
	335	27,810	1:45	7.95	112.40	266.49	29.67	
9-13-80	327	26,640	1:30	8.88	125.60	257.48	32.79	
	310	24,600	1:30	8.20	115.93	267.15	30.26	
	321	26,140	1:42	7.69	101.05	108.28	48.27	
	318	23,880	1:58	6.07	79.80	125.35	38.90	
	314	26,270	2:12	5.97	78.50	126.65	38.26	
	319	32,320	2:05	7.76	102.00	98.96	50.76	
	328	31,540	1:38	9.66	126.93	74.03	63.18	
	332	29,770	1:35	9.40	123.52	77.44	61.46	
	317	25,750	1:30	8.58	112.74	88.22	56.10	

Note:

40 days 174 4,632,090 416.5
 = 2316.05 tons

4,632,090/174 = 26621.21 lb/trailer

4,632,090 lb /416.5 h = 11121.5 lb/h
 = 5.56 ton/h

416.5 h/40 days = 10.4 h/day

^{a/} Hours to minutes.

APPENDIX B

Power Generation at
C.P. Crane Station during Test Period

DATE

HOUR OF DAY

TOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
3/28/80																						3	11	22	36
3/29/80	28	25	26	28	26	26	25	25	28	33	33	47	72	67	102	102	101	149	151	152	145	144	143	138	1816
3/30/80	135	126	127	126	124	124	123	122	124	124	123	123	127	124	121	121	129	122	124	118	118	116	116	117	2956
3/31/80	117	115	117	116	115	114	115	111	110	111	107	22													1270
4/1/80																									0
4/2/80										9	43	46	80	126	132	134	152	145	139	131	130	128	126	124	1645
4/3/80	127	125	126	137	159	165	168	165	160	172	167	166	174	181	190	191	190	192	192	190	154	147	168	164	3970
4/4/80	141	141	143	142	126	129	129	79	41	37	46	63	53	74	99	153	187	190	188	182	167	166	128	39	2837
4/5/80																									0
4/6/80																									0
4/7/80																									0
4/8/80																									0
4/9/80																									0
4/10/80																									0
4/11/80										22	58	94	148	189	171	143	163	191	190	192	192	193	193	193	2332
4/12/80	175	143	98	97	95	97	97	96	130	162	177	174	171	170	164	153	171	168	166	163	165	165	163	120	3480
4/13/80	113	98	96	97	97	97	99	104	120	155	131	144	123	107	105	94	111	102		48	118	121	100	85	2465
4/14/80	45	80	82	83	85	85	57	17	28		5	3													570
4/15/80																									0
4/16/80																									0
4/17/80	178	180	179	181	173	161	133	156	136	143	146	145	144	143	141	141	19	55	76	163	175	185	182	179	1034
4/18/80	74	34	98	120	10												138	138	137	135	136	129	127	122	3542
4/19/80																									336
4/20/80																									0
4/21/80																									0
4/22/80																									0
4/23/80																									0
4/24/80											1	10	51	75	93	118	118	119	117	137	140	146	139	140	1404
4/25/80	141	144	144	151	151	149	144	144	143	146	139	128	138	150	136	138	150	151	153	152	159	155	148	147	3501
4/26/80	145	146	145	140	140	150	147	145	147	146	156	158	172	176	156	166	173	168	69						2845
4/27/80																									0
4/28/80																									0
4/29/80				5	41		21	40	60	93	138	181	191	189	158	191	191	192	175	186	192	191	161	17	2567
																									46

TOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
4/30/80																	27	40	73	106	160	163	182	188	939	
5/1/80	134	100	96	95	94	122	172	131	165	181	170	167	178	142	140	119	123	120	131	131	125	160	176	175	3347	
5/2/80	124	114	114	114	112	121	150	122	127	119	131	127	129	143	134	123	130	106							2248	
5/3/80																									0	
5/4/80																									0	
5/5/80			13	42	57	68	65	48	65	58	55	85	80	75	120	117	127	114	120	111	112	110	113	106	1861	
5/6/80	115	105	111	98	108	81	92	121	136	124	149	97	105	133	147	145	143	127	117	118	124	63			2559	
5/7/80																									0	
5/8/80														14	42	39	98	124	134	141	142	142	120	120	1116	
5/9/80	124	111	116	122	144	140	138	142	157	139	102	129	138	174	188	190	171	78							2503	
5/10/80																									0	
5/11/80																									0	
5/12/80				1	20	63	86	103	119	175	192	191	195	192	192	191	192	192	192	192	179	190	136	131	121	3053
5/13/80	101	98	100	101	99	105	37																		641	
5/14/80																	32	48	78	160	192	189	134	101	934	
5/15/80	100	99	96	96	95	97	109	179	190	192	192	188	194	184	172	191	192	191	192	192	192	192	193	150	3868	
5/16/80	100	101	98	100	104	99	137	185	191	192	191	194	191	190	191	188	152	121	92	91	92	91	92	90	3268	
5/17/80		94	91	92	91	92	91	109	176	190	192	191	192	191	191	146	160	174	161	190	191	192	182	165	3635	
5/18/80	167	134	91	89	91	91	92	115	162	190	188	192	191	188	172	172	179	188	179	191	192	192	192	163	3801	
5/19/80	143	143	141	126	98	130	171	189	190	192	192	192	191	192	192	191	192	192	192	192	191	192	167	122	4113	
5/20/80		95	95	93	94	93	102	146	187	190	192	192	192	191	192	192	191	192	192	187	192	192	177	164	3925	
5/21/80	124	92	94	98	94	97	163	191	192	191	190	191	190	190	192	191	192	191	191	192	192	136	19		3593	
5/22/80			3	37	63	66	67	67	68	69	70														511	
5/23/80																									0	
5/24/80						6	38	64	116	142	123	108	107	153	156	149	123	101	103	102	103	103	103	103	2003	
5/25/80	103	105	105	120	118	102	102	103	114	130	141	142	140	131	101	103	100	101	115	98	98	99	99	36	2606	
5/26/80	8	58	98	113	112	109	128	142	149	150	181	157	83	92	99	97	98	98	100	98	99	98	99	99	2565	
5/27/80	100	98	100	98	99	120	177	176	162	172	162	170	182	184	190	184	180	171	177	156	145	170	115	82	3552	
5/28/80	85	85	84	83	85	83	84	90	82	85	139	181	189	186	178	165	145	162	172	158	155	169	145	85	3075	
5/29/80	83	84	85	86	85	83	113	148	110	113	94	102	166	186	177	162	186	175	176	119	104	107	102	103	2949	
5/30/80	104	103	134	183	49	2																			575	
5/31/80																									0	
6/1/80																									0	

DATEHOUR OF DAYTOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
6/2/80						4	29	81	131	132	176	180	188	185	187	187	183	184	185	183	184	187	186	185	2957
6/3/80	169	97	95	94	97	138	171	173	169	105	132	135	128	120	63	107	119	100	128	129	116	79	45		2709
6/4/80																									0
6/5/80																									0
6/6/80															19	34	64	118	121	124	114	152	155		901
6/7/80	155	155	157	146	119	117	115	117	146	174	140	181	159	165	177	156	167	172	164	160	150	151	150	150	3643
6/8/80	151	153	157	155	154	154	154	154	159	164	165	160	140	143	144	140	142	145	63	70	67	74	14		3022
6/9/80																									0
6/10/80																									0
6/11/80												3	20	60	79	93	128	162	185	182	174	124	110	111	1431
6/12/80	109	108	108	109	109	111	109	110	124	124	104	104	103	113	132	132	121	111	130	123	141	136	128	128	2828
6/13/80	128	132	131	128	129	128	129	133	133	139	162	143	145	155	174	176	178	170	138	144	145	144	143	144	3470
6/14/80	144	144	144	146	146	115	98	100	99	99	101	132	178	163	118	104	124	126	111	100	100	97	98	116	2903
6/15/80	143	141	144	140	142	140	142	141	142	144	138	142	175	176	171	167	170	169	170	108	98	99	101	100	3403
6/16/80	100	101	101	119	99	98	115	95	99	105	80														1112
6/17/80																									0
6/18/80																									0
6/19/80						7	28	58	94	122	48			65	140	183	184	184	136	21				14	1304
6/20/80	56	76	76	76	75	76	77	77	76	119	136	136	147	180	190	186	156	112	129	142	154	109	89	96	2746
6/21/80	95	77	61	75	77	77	108	118	117	110	108	107	106	111	138	140	140	108	105	133	132	120	121	116	2600
6/22/80	115	116	116	117	116	118	116	119	118	113	118	121	125	139	143	143	142	141	141	142	141	139	139	131	3069
6/23/80	120	133	132	132	116	115	114	158	186	188	186	186	187	188	187	187	187	186	186	187	188	186	178	149	3962
6/24/80	128	118	114	111	110	111	109	113	170	183	184	183	184	182	183	166	179	183	184	168	138	136	112	106	3555
6/25/80	100	101	102	100	100	100	102	124	175	180	159	171	184	184	185	183	186	182	158	153	151	116			3196
6/26/80																									0
6/27/80																									0
6/28/80																									0
6/29/80											13	35	54	109	169	174	177	155	145	142	105	95	8		1381
6/30/80							32	60	82	54	81	83	83	85	83	85	82	183	163	138	106	108	106	95	2504
7/1/80	92	90	92	90	91	109	180	189	191	190	192	191	191	192	193	192	189	192	180	158	191	192	135	99	3801
7/2/80	97	98	95	96	94	113	187	191	192	192	192	192	192	162											2093
7/3/80																									0
7/4/80								20	45	58	115	165	173	173	171	176	179	180	179	178	178	176	179	90	2435

DATEHOUR OF DAYTOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
7/5/80																									0
7/6/80																									0
7/7/80							6	42	69	156	180	181	181	180	183	184	188	186	190	191	186	191	190	192	2876
7/8/80	178	132	104	101	101	103	145	178	190	161	190	190	189	166	190	189	190	191	172	187	192	191	189	189	4008
7/9/80	184	137	101	100	97	97	124	177	190	189	191	150	149	188	188	190	192	189	188	191	192	191	191	189	3977
7/10/80	190	190	190	190	142	140	190	184	94	111	185	190	191	134	187	189	187	190	186	186	185	187	185	189	4192
7/11/80	191	188	190	148	156	155	186	189	191	192	191	189	118	89	90	94	78	42	35	29	86	93	93	93	3106
7/12/80	92	93	92	93	93	92	93	108	166	190	191	191	191	192	190	187	186	185	185	186	185	182	186	171	3721
7/13/80	92	94	93	87	85	85	84	91	94	94	94	94	95	95	94	96	151	184	188	185	188	190	191	189	2933
7/14/80	191	140	92	87	85	86	85	67	83	88	91	93	111	186	189	192	191	192	191	192	193	191	192	191	3399
7/15/80	191	130	83	77	98	144	162	190	192	192	191	192	191	192	191	189	190	190	189	189	188	188	190	186	4115
7/16/80	189	191	179	107	128	146	182	187	188	190	190	190	191	191	188	183	183	183	177	185	186	192	191	187	4304
7/17/80	188	164	100	138	103	98	130	188	189	148	92	92	102	190	190	189	187	183	184	183	184	182	187	179	3770
7/18/80	140	106	87	78	80	76	82	101	111	153	123	92	93	119	190	187	187	184	187	185	185	186	179	77	3188
7/19/80																									0
7/20/80																1	41	67	136	175	175	179	183	164	1121
7/21/80	101	166	173	173	172	175	176	174	176	181	184	183	186	185	184	176	177	175	177	177	179	189	189	189	4277
7/22/80	188	167	148	66							8	30	52	91	173	180	181	185	190	187	187	186	185	184	2588
7/23/80	165	121	113	115	140	128	134	177	186	190	185	190	191	189	187	184	182	182	183	183	183	170	176	178	4032
7/24/80	158	152	146	148	153	152	155	176	183	183	178	137	145	140	140	140	138	138	138	140	138	140	139	139	3596
7/25/80	149	99	87	118	142	143	136	177	186	188	188	188	189	188	189	189	190	191	191	189	192	191	189	188	4077
7/26/80	185	179	178	180	109	107	108	148	180	145	110	107	108	116	113	113	142	186	185	189	186	188	186	188	3581
7/27/80	176	178	179	179	171	140	141	140	136	136	135	155	190	188	191	192	192	191	192	192	192	192	143	144	4065
7/28/80	148	140	140	120	102	103	103	180	126	102	100	100	174	168	86	84	128	190	192	191	192	192	189	185	3430
7/29/80	159	111	106	107	107	105	107	106	133	132	102	106	173	192	191	192	191	192	192	191	192	191	188	185	3651
7/30/80	178	174	172	154	126	109	128	171	182	186	184	166	125	102	133	136	136	138	187	192	191	192	188	182	3827
7/31/80	179	178	175	174	179	122	102	102	100	101	104	137	186	180	181	175	181	180	175	180	178	180	178	180	3807
8/1/80	100	170	178	180	158	135	155	175	175	170	172	118	108	141	170	149	174	163	179	178	174	80			3491
8/2/80																									0
8/3/80																									0
8/4/80						16	45	104	170	182	179	180	182	182	176	176	177	174	177	175	175	176	174	177	2997
8/5/80	176	177	180	141	105	106	180	179	179	179	179	178	179	179	177	177	176	177	176	161	173	179	175	176	4064
8/6/80	181	114	91	124	124	147	181	180	180	150	161	178	178	178	108	103	101	152	175	177	176	176	178	177	3690

DATEHOURLY OF DAYTOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
8/7/80	155	115	111	111	111	116	182	172	127	100	103	102	102	101	100	100	99	101	99	101	99	99	99	101	2706
8/8/80	99	100	100	100	101	101	100	101	102	101	102	101	102	102	131	178	179	178	135	103	102	104	102	103	2722
8/9/80	103	102	103	103	103	103	103	102	103	102	103	103	101	102	100	100	101	101	100	101	101	101	98	100	2439
8/10/80	98	100	100	100	101	101	102	101	102	102	102	104	102	102	102	101	102	102	100	102	101	101	101	102	2431
8/11/80	100	101	101	102	101	132	166	167	166	167	165	160	163	104	100	98	99	98	132	126	116	102	103	105	2974
8/12/80	104	106	104	104	111	127	125	147	136	148	148	147	149	148	148	154	181	180	181	178	180	178	178	178	3535
8/13/80	178	178	180	150	115	137	175	175	170	138	138	143	134	131	139	141	141	141	138	162	178	177	141	94	3594
8/14/80	92	91	93	92	93	91	120	167	171	172	171	171	172	172	173	170	177	184	181	181	181	179	183	176	3653
8/15/80	170	169	152	158	171	172	173	171	174	178	174	173	174	174	173	172	174	175	177	181	179	179	177	178	4143
8/16/80	168	122	120	92	91	89	91	90	112	176	176	178	177	174	174	174	176	178	180	118	181	124	115	97	3268
8/17/80	94	91	91	90	91	90	92	88	91	92	92	94	101	170	177	176	177	177	167	126	156	168	110	98	2894
8/18/80	91	91	90	90	91	90	153	174	174	180	179	181	180	180	182	180	181	181	180	165	163	145	127	96	3555
8/19/80	93	90	91	90	90	92	106	158	181	182	183	182	181	176	178	177	180	180	179	180	181	180	180	165	3675
8/20/80	98	89	98	98	98	98	96	96	94	150	142	129	140	140	141	136	145	140	140	136	128	140	137	131	2935
8/21/80	104	99	100	95	92	89	92	93	93	100	104	104	104	103	100	103	103	101	103	104	105	105	104	104	2404
8/22/80	103	103	105	103	104	104	103	105	103	103	103	103	105	103	100	102	102	102	103	102	102	90			2203
8/23/80																									0
8/24/80																									0
8/25/80								20	47	78	95	108	101												449
8/26/80																									0
8/27/80																									0
8/28/80																									0
8/29/80																									0
8/30/80																									0
8/31/80																									0
9/1/80	85	87	85	76	73	76	75	74	99	154	181	178	180	178	177	174	177	180	176	177	177	179	177	177	3383
9/2/80	102	103	161	145	119	114	166	170	177	177	178	179	178	177	178	176	176	178	179	177	178	178	176	177	4039
9/3/80	178	144	114	99	94	98	124	123	151	162	165	166	167	169	172	173	174	174	175	173	173	158	171	159	3656
9/4/80	102	95	105	110	97	98	111	132	118	96	92	92	94	145	172	174	173	170	169	175	173	173	172	133	3182
9/5/80	115	102	104	94	93	101	145	167	169	169	169	168	172	164	164	167	167	169	165	167	153	190	114	117	3435
9/6/80	122	124	102	89	90	89	91	117	136	133	98	98	105	146	162	164	159	161	162	160	161	159	162	156	3146
9/7/80	122	130	129	113	99	103	115	96	95	125	167	173	175	172	174	176	174	172	168	155	168	150	108	104	3363

DATEHOOR OF DAYTOTAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
9/8/80	104	102	104	101	102	103	127	168	168	168	169	122	101	102	102	119	131	137	137	166	174	178	159	149	3193
9/9/80	95	92	91	93	92	92	94	122	165	169	166	168	167	166	167	167	166	168	168	167	168	168	168	154	3433
9/10/80	114	98	126	128	131	140	179	177	176	175	175	178	171	178	178	172	171	170	139	116	146	139	114	116	3587
9/11/80	113	115	113	127	132	126	130	138	173	176	175	176	178	176	177	178	172	173	177	174	175	172	126	118	3690
9/12/80	122	136	137	137	133	128	102	101	103	103	101	103	102	101	130	169	176	177	176	179	176	177	178	177	3324
9/13/80	177	178	176	118	104	102	102	118	178	182	183	183	183	183	182	188	182	182	183	183	183	183	186	182	3991
9/14/80	148	102	98	96	98	98	100	107	145	181	180	181	181	181	179	180	179	179	181	178	180	179	182	179	3692
9/15/80	181	149	102	100	100	98	99	100	99	98	97	97	98	97	94	94	96	94	96	94	95	94	95	94	2463
9/16/80	95	94	95	93	95	94	94	96	95	121	108	93	91	92	92	83	84	84	82	86	85	84	87	87	2210
9/17/80	87	87	89	88	88	88	87	94	109	120	129	139	139	137	135	128	125	131	134	65	39	45	28		2312

APPENDIX C

Selected Sections of BG&E Report #80-28

Note

Portions of Report #80-28 were retyped and included in the main text of this report for easier review.

This Appendix contains additional parts of the main BG&E report. Data and irreproducible figures and photographs have not been included.

Appendix D contains a report to BG&E that also was part of Report #80-28.

C. P. CRANE NO. 2

COAL BURNING TESTS

REPORT NO. 80-28

FOSSIL POWER DEPARTMENT

BALTIMORE GAS AND ELECTRIC COMPANY

Test Period = March 28, 1980 - September 17, 1980

Date of Report October 31, 1980

Prepared By: J. D. Warner, Senior Engineer

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APPENDIX

- A. TEST CHRONOLOGY
- B. MELTING POINT VS. FLUX CURVES
- C. PLANT PHOTOGRAPHS

INTRODUCTION

This report describes the objectives, experiences, measurements and conclusions of coal burning tests at the Baltimore Gas & Electric Company C. P. Crane Generating Plant from March 28, 1980 to September 17, 1980.

The tests involved coals from Pennsylvania, Western Maryland, and West Virginia with a sulfur content of approximately 2%. Earlier tests were unsuccessful in attempting to burn coal with a lower sulfur content.

The test schedule was developed to complete two phases:

Phase I : Short term tests - Evaluation and ranking of candidate coals (2-3 days).

Phase II: Long term tests - Evaluation of preferred coal partially substituted with Refuse Derived Fuel (R.D.F.) (weeks).

Specific objectives were:

- 1) Determination of acceptable coal(s).
- 2) Evaluation of Refuse Derived Fuel.
- 3) Estimation of sulfur and ash distribution.
- 4) Evaluation of fabric filter bag material.
- 5) Monitoring ambient environmental levels to assess impact.

Test limitations were specified as operation with sulfur dioxide emission concentration of less than 3.5 pounds per million B.T.U. heat input, particle emission concentration of less than 0.6 pounds per million B.T.U. heat input, and termination of operation during an Air Stagnation Advisory during the 60 day extension period.

The boiler has four Cyclone Furnaces designed by Babcock and Wilcox to provide the benefits of pulverized coal firing, although only crushing of the fuel is required. Features include reduction in the fly ash content, fuel preparation cost, and furnace size. Its performance is based on maintaining combustion in turbulent, very high temperature cyclones where combustion is completed and the combustion gases exiting the cyclones are cooled by the main boiler surfaces. Temperatures exceeding 3000°F are developed, sufficient to melt the ash into a liquid slag which forms a layer on the walls of the cyclone.

The incoming coal is thrown to the walls by centrifugal force where it is held in the slag, and scrubbed by secondary air, which completes combustion and removes combustion products. Molten slag, in excess of the thin layer retained on the walls continually drains away from the cyclone and discharges from a slag tap opening in the boiler floor, where it is tapped into a slag tank, solidified, and crushed for transport and disposal.

While the operation of other designs may depend on particle size more than any other fuel parameter to burn successfully, a Cyclone Furnace requires a low melting point of the ash to be below some maximum temperature in order to form a liquid slag for removal.

An ash fusion temperature of 2500°F is generally accepted from experience as the maximum. While there may be a theoretical basis for specifying a minimum ash fusion temperature to ensure a coating on the cyclone walls, no serious firing problems are reported with low melting point fuels.

Ash fusion temperature is a major parameter on the successful burning of fuels in this furnace. Its measurement and adjustment with fluxing materials is discussed in detail in the report. Successful burning, as reflected in the ranking of the fuels, presumes ash fusion temperature control as a minimum standard of acceptability.

DISCUSSION

Data Selection

Data was gathered in the following manner:

- 1) Specialized Instrumentation - Ambient air monitors for SO_x, particulates, and NO_x, and a stack monitor for SO₂ measurements of flue gas.
- 2) Observation (Plant and Test Personnel) - Used for slag flow of test coals with and without Refuse Derived Fuel, handling and transport problems, and fabric filter bag performance.
- 3) Grab Sampling and Analysis - Used for fuel characterization, sulfur balance, and ash balance.

A discussion of existing fuel specifications and plant operations follows to explain the data selected for these tests.

Fuel Specifications

Suppliers were requested to provide shipments of coal with the following specifications:

Sulfur:	Equiv. to 3.5 pounds Sulfur Dioxide per million B.T.U.
Ash:	10% maximum
Moisture:	8% maximum
B.T.U./LB:	12,000 minimum
Volatile Matter:	40% maximum
Grindability:	45 minimum
Ash Fe ₂ O ₃ :	26.0%
Size:	2 inches maximum
Ash Fusion Temp., Softening:	2300°F maximum
Ash Fusion Temp., Fluid:	2500°F maximum

It became apparent that slag tapping performance, a consequence of ash fusion temperature, dictated whether or not a test of a coal could proceed, so the other specifications were secondary to the melting point.

Coal Analysis

To predict or verify the melting point or any other physical or chemical property of coal, its non-homogeneous nature must be recognized. Coals are differentiated by rank, which refers to their degree of metamorphism during formation and is reflected by the fixed carbon content. Coal properties merge among the several ranks. Even on the semi-macro scale, small lumps of coal will exhibit internal laminae from distinct ingredients which affect properties. Elaborate methods have been proposed to minimize the sampling error for coal, dwelling on standardized procedures, quantities, and equipment, which admits the difficulties involved. Applying these methods is complicated by size classification during shipment (additional non-homogeneity), weathering of coal piles (selective leaching of soluble constituents), and normally large ratios of massive storage pile quantities

to convenient laboratory samples. The method itself normally used for melting point determination allows variation, not only in instrument reproducibility but also in the analyst's judgement; the determination is based on reading the temperature when a bead of coal ash deforms to where the height equals the width, or other arbitrarily selected geometry.

One approach to bypassing problems with melting point determination is the prediction of slag viscosity from the elemental analysis of the coal ash. With a value of 250 poise accepted as a maximum, correlations have been developed using the "silica ratio"* and/or the "base-to-acid ratio"*** to predict the temperature above which slag flow will be adequate. This temperature is compared to a recommended minimum of 2500°F for cyclone boilers. Unfortunately, these results are greatly influenced by the amount of iron present and the fraction of iron in each of its oxidation states, which is quite difficult to determine.

The primary objection to using this approach is that if the calculated temperature (T_{250}) is below 2500°F and melting point adjustment is being considered, the sampling errors are again confronted, whether a melting point vs. flux curve or an adjusted silica ratio for flux constituents are used for flux feed.

Coal Fluxing

With the problem of melting point prediction and its importance to coal performance recognized, arrangements were made to flux coal when necessary.

Coal fluxing is a technology used to improve the tapping of coal slag by introducing inorganic chemicals to the fuel before combustion, to lower the melting point. Dolomitic limestone (Calcium and Magnesium Carbonate) is often used. The phenomenon is similar to salting roads to lower the freezing point of water during winter.

The mechanism involved is only partially traceable to physical or chemical properties. Both Calcium and Magnesium Carbonate will decompose to their respective Oxides at cyclone temperatures (decomposition points of 1517°F and 662°F respectively). The melting points of Calcium and Magnesium Oxide are 4982°F and 5072°F. With a typical melting point of coal slag of 2500°F, flux might be expected to elevate the average melting point of coal slag as a common mixture. The fact that it lowers the melting point is best explained in terms of crystal deformation as slag melts. A distinct geometry of slag crystals has been formed after combustion, and energy is absorbed deforming the crystal structure showing a hesitation in temperature rise which we refer to as melting point.

When selected impurities such as limestone are added, they interfere with the geometry and produce an alternate crystal structure which is asymmetric and easier to deform, so a lower temperature is adequate and a lower melting point is noted. If the impurities are added excessively, other crystal geometries become possible and may result in forms more stable than those in coal slag, which would elevate the melting point. Unfortunately, the number of possible crystal configurations and the problems detecting them are extensive, so flux requirements and type cannot be predicted from coal analyses.

$$* \text{ Silica Ratio} = (\text{SiO}_2 \times 100) / (\text{SiO}_2 + \text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO})$$

$$**\text{Base-to-acid ratio} = (\text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{K}_2\text{O}) / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2)$$

However, curves of coal slag melting point versus flux percentage offer some benefit even with the admitted problem of sampling and melting point accuracy. With flux material as finely divided as the fuel and homogeneous mixing for optimum fuel-flux contact, the curve will indicate in which direction the melting point is being altered and/or no effect is produced. Melting point versus flux curves were generated for each coal tested (See Appendix), and Figure I-2.1 illustrates their use.

Figure I - 2.1

1. Melting Point Lowering
2. Little or no effect
3. Melting Point Elevation

Proprietary fluxing additives of the Borax - Dolomite type were used during the coal tests, although Dolomitic Limestone was considered the primary fluxing agent. The major advantage of this product was that it was supplied with a particle size small enough to be blown in the cyclone directly when a local problem occurred.

The options on flux injection points are limited. The plant coal feeding equipment configuration is such that coal is moved from yard storage, to storage silos, to feeder belts, through rotary seals, to the cyclones. Since there is no convenient way to return coal in the storage silos to yard storage, a coal that has had flux added while being transported to the silos represents a committed mixture to be burned. If too little flux has been added, additional flux can be shoveled onto the feeder belts, but any hope of knowing the overall flux content for yard feed adjustment is lost. If too much flux has been added, the melting point may be elevated as shown by the curve.

The existing flux feeding equipment is shown in photographs in the Appendices. The limestone flow depended on gravity flow through a vertical sluice gate from a hopper with a tilted floor. Limestone is hygroscopic and will not flow freely after a rainy day (even if covered) or lengthy open storage. An attempt was

made to calibrate the flow versus sluice gate opening, but steady flow was only occasional. Fortunately, a typical curve shows a range where inaccurate flow has little effect, but considering the continuity of fuel combustion necessary, the modification of the flux feeder to a positive displacement design that won't depend on limestone texture appears warranted.

Finally, it must be mentioned that the consequences of insufficient flux feed are heavy. Once solidified, slag removal through the tap to the slag tank was slowed and sometimes stopped. Further additions of Limestone was seen to reduce or eliminate the problem, but only after up to several days. The dead weight of the slag on the furnace floor must be monitored to prevent structural damage to the Unit. If the solidified slag did not respond quickly enough to additional Limestone, the Unit was brought down and the slag was jackhammered loose and removed.

Plant Operating Data

Initially, selected plant operating data was monitored to maintain equivalent conditions between various fuels and to document them for repeatability at a later date. However, it became apparent that the coal performance was independent of operating stability. The only correlation distinguishable was slag flow problems vs. load (M.W.), which was often cause and effect, and was more of a vicious cycle than a control parameter. Again, ash fusion temperature dominated the performance criteria.

Selected plant data for most of Phase I of the tests is included in the Appendix.

Typical Sample Set

With an appreciation of coal handling and preparation procedures and the plant data selected, additional sampling and readings formed a typical set:

- 1) Coal as delivered - Analyzed for sulfur and moisture content to compare to purchasing specifications to insure at least broad compliance before in-plant transport. Also, melting point vs. flux curves were generated for each coal.
- 2) Coal as burned - Analyzed for sulfur and moisture content to provide a comparative base for sulfur detection at the boiler outlets and to indicate rain retention of a coal. Also, ash content for an ash balance.
- 3) Fly ash - Analyzed for sulfur content and loss on ignition (percent combustible material) to give one component of sulfur out of the boiler, and to give an indication of combustion efficiency and potential for fly ash ignition.
- 4) Fabric filter bag sample - Analyzed for sulfur content and loss on ignition to compare to the fly ash sample, and to test the filter fabric.
- 5) Slag - Analyzed for sulfur content and loss on ignition for the same purpose as fly ash. However, sampling was discontinued after preliminary results showed that little or none of these materials were present.
- 6) SO₂ monitor - A reading of pounds sulfur dioxide per million B.T.U. was given for comparison against the 3.5 standard for the tests.

7) Ambient Air Tests - Monitors were installed at four locations near the plant and data was recorded continuously.

Data Rejection

Samples and readings were not taken when some doubt existed as to which type of coal was being burned; in a given silo, the point at which one coal was depleted and another was being fed was not apparent and could only be estimated by the burning rate at that time.

Several hours were allotted after a startup to establish stability at a load before resuming data collection.

Test Scheduling

Although originally planned and approved for a 120 day period beginning on March 28, 1980, an extension was sought and granted for 60 additional days to evaluate Refuse Derived Fuel in combination with coal.

In conjunction with data collected and anticipation of this extension, the following test schedule resulted.

- 1) March 28, 1980 to June 25, 1980 - Testing of individual coals; review of performance and selection of preferred coals.
- 2) June 25, 1980 to July 6, 1980 - Establish steady burn of preferred coal.
- 3) July 7, 1980 to September 17, 1980 - Testing of R.D.F./coal combinations.

The stack tests were attempted during the period between the test phases, but were interrupted by a boiler tube leak. They were resumed during Phase II, with R.D.F. feed discontinued to give comparative data for coal only.

PHASE II

Background

Prior to the coal tests, Baltimore Gas and Electric Co. entered into an agreement with Maryland Environmental Services to incorporate tests of Refuse Derived Fuel (R.D.F.) into the testing schedule. Maryland Environmental Services (M.E.S.) is a governmental corporation and a unit of the Maryland Department of Natural Resources. M.E.S. engaged Teledyne National to arrange for the handling and feeding of R.D.F. at the plant site, with the fuel supplied by the Baltimore County Resource Recovery Facility in Texas, Maryland. A goal was established to replace as much as 20 per cent of the coal with R.D.F. on the basis of replaced energy for one cyclone burner, or five per cent of the total furnace heat input.

Physical Characteristics

While R.D.F. was not available in the pellet form, fluff was supplied for these tests. Photographs of R.D.F. and its handling are in the Appendix.

The heating value averaged well over the minimum of 5000 BTU/LB guaranteed. Statistical averages of the fuel properties are:

$$\begin{aligned}\text{BTU/LB} &= 6289 \pm 304 \text{ BTU/LB} \\ \% \text{ Ash} &= 17.7 \pm 2.9\% \\ \% \text{ Moisture} &= 14.4 \pm 1.8\% \\ \% \text{ Sulfur} &= 0.26 \pm 0.04\%\end{aligned}$$

The R.D.F. density was much less than coal, of course, and the proportions of a blend by energy content were markedly different by weight or volume.

For example, a fuel blend representing 20 per cent R.D.F. by energy content (one part in five) would be about 33 per cent by weight (one part in three), and might be 80 per cent by volume (four parts in five) depending on how compressed it is.

Overall, the R.D.F. was remarkably consistent in texture, energy content, and absence of large sized impurities such as glass, metal, etc.

Delivery and Handling

The delivery and handling operations are illustrated in plant photographs in the Appendix. A delivery and consumption schedule is enclosed in this section. Tractor trailer rigs equipped with hydraulic rams to discharge the R.D.F. onto wide conveyor belts were used. Approximately 12 tons of R.D.F. per truck was typical. The only other preparation applied was a "chopping" motion of rotating bars to loosen and separate R.D.F. lumps. The fuel was then forwarded pneumatically to cyclone 22B, entering through the line normally used for tertiary air.

The R.D.F. feed rate was proportioned to the coal feed rate by ratio to the appropriate coal feeder belt speed. When all four belt speeds were equal, R.D.F. which represented 20 per cent of the energy to cyclone 22B represented about 5 per cent of the overall fuel energy input. Since the R.D.F. density varied, instantaneous feed rates were difficult to establish but confident estimates were possible using truck weights and coal scales. Handling problems were rare to non-existent.

Performance

The R.D.F. - coal mixture burned well. After familiarity with equipment and feed stability was established, and in conjunction with steady operation with Vipond coal, generation was continuous.

The physical characteristics of R.D.F. which will warrant improved handling are its odor and texture when wet. The odor is mild in degree, but objectionable and persistent. Long term usage and storage can be expected to result in a wider radius of detection with respect to the generating plant neighborhood. The unloading terminal must be protected from precipitation, since the pneumatic forwarding equipment requires a fuel of appropriate bulk density to operate successfully. Also, microbiological growth in larger storage piles should be investigated to avoid any potential health hazards.

The only equipment deterioration during testing was erosion of the cyclone scroll wall at the point of tangential impact of incoming R.D.F., eventually wearing through and allowing some burning fuel to exit the boiler. An external wear plate was welded on, and a sluice gate arrangement was installed in the R.D.F. feed line as a safety measure. Since this area is normally used for air, this does not indicate inherent erosive properties of R.D.F.; appropriate material selection at this point should eliminate the problem.

Unit shutdowns during Phase II were due to tube leaks, air stagnation advisories, etc., as outlined in the test chronology. Generation was not interrupted for any reason traceable to the fuel.

Post test inspection showed no damage or deterioration of the furnace or auxiliary equipment due to R.D.F. A glassy coating on precipitator surfaces, reported during similar tests at other utilities, was not seen.

Alternate feed points were explored for information toward future use. R.D.F. was shoveled onto a coal feeder belt, but the mixture plugged the rotary seals. Evidently, materials handling equipment that presents a close tolerance, rubbing environment, as opposed to those which fluidize the material, is not appropriate for R.D.F. An attempt was made to mix R.D.F. with coal in the coal yard to the 80 per cent coal by energy blend. The proportions were estimated by scoops using a front end loader, with layering into empty coal cars. The cars were rotated and the blend forwarded by belts. The R.D.F. light density presented problems in the yard. The free fall from the bulldozer scoop and the coal crane allowed drifting losses of R.D.F. even with a light wind. The vibrating feeder was clogged, and the volume increase of the blend of R.D.F. and coal limited

the rate of fuel supplied to the boiler on the basis of energy content. The R.D.F. was found to have clung to the gridwork under the car dumper before contact with the first conveyor belt. The blend did not plug the Bradford Breaker, but later inspection showed that it selectively bridged in the coal silo and eventually would have interferred with gravity flow to the feeder belt.

Evidently, designs which maintain the segregation of R.D.F. and coal until they reach the cyclone are preferred.

APPENDIX D

Report on Particulate and Sulfur Emission Tests
by KVB, Inc.
Part of BG&E Report #80-28, Data Volume

COAL/RDF COMBUSTION

C.P. CRANE - UNIT 2

PREPARED FOR

BALTIMORE GAS & ELECTRIC CO.

OCTOBER 1980

PREPARED BY

BRIAN DOYLE & JAMES ORCUTT

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1.0 Introduction

KVB, Inc. was retained by the Baltimore Gas & Electric Company to perform particulate and sulfur emissions testing on Unit 2 at its Charles P. Crane generating station. The test program was split into three phases. The first phase was performed on Vipond coal fired July 1 - 3, 1980. The second phase tested the same coal mixed with refuse derived fuel (RDF). The RDF constituted 5% of the total Btu firing rate with one cyclone burning 80% coal - 20% RDF. This testing was conducted from July 29 - 31 and on August 4. The third phase of testing was performed on August 5 - 6 while firing 100% of a second type of coal.

All testing was done at maximum load conditions ranging from 185 to 200 MW (depending on forced draft fan limitations) at approximately 10% excess air with gas recirculation.

2.0 Summary

The test program was carried out in two increments between July 1, 1980 and August 6, 1980. RDF was fired in addition to the coal during late July and the first few days of August. The test data do not show any significant effect of the RDF firing on the emissions of particulate matter or sulfur oxides. However, the test results do provide an indication of emissions performance and some of the factors which influence this performance.

Particulate emissions were relatively high, and this was caused by at least three phenomena. During the testing the station experienced operational difficulties with the precipitators which caused collection efficiencies to be low. Ash retention by the cyclones was somewhat lower than normal which caused flue gas ash loadings to be 30% to 100% above those usually associated with cyclones. In addition carbon burnout was incomplete (incompletely burned coal was leaving the furnace) which raised flue gas particulate loadings by as much as 80%. These last two phenomena are caused either by some adjustment in the cyclone (possibly structural) which is not optimal or by unusual coal behavior during firing (i.e., a change to another coal might inexplicably reduce the problem).

Sulfur oxides measurements by wet chemistry showed SO₂ levels in general agreement with continuous analyzer readings and with fuel sulfur content. Disparities in the data are believed to be primarily due to the imprecision of the wet chemical technique. Measurements of SO₃ were compromised by low stack temperatures and interference by particulate matter. These problems can be avoided through custom engineering of the test procedure to match the source.

3.0 Boiler Description

C.P. Crane Unit 2 is a coal fired steam generator rated at about 200MW. The unit has a cyclone fired boiler using four cyclones in an opposed firing configuration. The flue gases pass through an air heater, then through "piggy-back" precipitators above the air heater and then into a short stack above. Figure 1 is a schematic of this configuration. Test ports are located in the ductwork leading to and from the precipitators. Neither location is ideal in terms of generating uniform velocity or particulate concentration distributions. Note that the inlet ducting from the air heater will probably push heavier particles toward the outside of the duct (left side as drawn) and then into the upper precipitator.

The unit is equipped with gas recirculation fans for steam temperature control and a recirculation rate of about 10% of the gas flow was utilized during the testing. During each test the boiler was run at steady operating conditions.

FIGURE 1

DUST COLLECTORS AND SAMPLING LOCATIONS

4.0 Test Program & Results

Testing was conducted during two general time periods including the beginning of July and the beginning of August. Table 1 summarizes the test effort. The testing included periods when the boiler was firing all coal and a period when 5% of the thermal input was from RDF. The measured parameters were flue gas concentrations of SO_2 , SO_3 (including its hydrated forms) and particulate matter. In addition a limited chemical analysis of the particulate matter has been performed. During all the tests, boiler operational data was recorded (Appendix C) and a number of fuel samples were submitted for ultimate analysis. The average results and calculated composite analysis are tabulated in Table 2. Individual fuel analyses are listed in Appendix E.

4.1 Particulate Tests

Particulate emission tests were conducted at both the inlet and outlet to the electrostatic precipitator at locations which were common to both precipitators. (See Figure 1). All testing utilized out of stack filtration and methodology identical to EPA Method 5 except for the sampling location. For Tests 1 and 2 the inlet sampling utilized 48 sample points (using 6 ports in each duct) and for the remaining tests the traverse was reduced to 24 sample points (using 3 ports in each duct). All outlet testing utilized 48 sample points (6 ports in each duct). On both inlet and outlet the total sampling time for each test was maintained at 144 minutes. Table 3 summarizes the emission rates measured for each test. The actual field data sheets are reproduced in Appendix A and D.

Several samples of particulate matter were submitted for chemical analysis of carbon and sulfate, and results are summarized in Table 4. Inlet and outlet samples were taken from particulate emission test filters. Precipitator hopper samples were obtained during the outage on August 2 - 3. The actual source of the bottom ash sample is uncertain. Physical examination of the particulate revealed that larger sized particles accumulated preferentially in the upper precipitator. This and other discussion items are presented in Section 5.0.

4.2 Sulfur Oxides Measurements

During each of the particulate tests, SO_2 was measured by wet chemical methods at either the precipitator inlet or outlet. These measurements were independent of the readings from the SO_2 continuous analyzer which was in operation during this period. Measurements of SO_3 were also performed at the precipitator inlet during several of the particulate tests. Table 5 summarizes the results of the sulfur oxides measurements. Note that several different techniques were employed as described below. Section 5.0 discusses some of the reasons for the variations in measured results, particularly in regard to the SO_3 levels. Results of the SO_2 measurements were in reasonable agreement with the continuous analyzer as summarized in Table 6.

SO_3 was measured using both the controlled condensation method and a method similar to EPA Method 8. SO_2 was measured by techniques similar to EPA Methods 6 and 8 with the sample train connected either directly to the sampling probe, or to the downstream end of the SO_3 train or to the downstream end of the particulate sampling train. In all cases a filter was located upstream of the first SO_x analysis train. The various combinations are summarized in Table 5.

The controlled condensation method of measuring SO_3 (using the so-called Goksyor-Ross coil) relies on a glass coil maintained below the minimum acid dewpoint of about 220°F , but above the maximum water dew point of about 130°F . Acid is rinsed from the coil after the test with an isopropyl alcohol solution and the solution is titrated with NaOH for hydrogen on (acid species). Tests have shown that acids other than sulfuric do not significantly contribute to the results and the technique has been widely accepted as the most reliable way to measure acid species in flue gases from fossil fired facilities. During these tests the quartz wool filter located at the probe inlet was not included in the analysis. Given the low temperature of the flue gases, it is quite possible that much or most of the acid in the flue gas was trapped in condensed form on this filter.

EPA Methods 6 and 8 rely on bubbling the flue gas sample through solutions of isopropyl alcohol and hydrogen peroxide which selectively trap SO_3 and SO_2 . Method 6 as written is used for SO_2 and the solution which traps SO_3 is discarded. Either method can, with appropriate modification, be integrated with a Method 5 particulate train. During tests 3, 4, and 7, SO_3 was collected in a train similar to that of Method 6. The procedure was modified in that larger (not midget) impingers were used, a quartz wool filter was used at the probe inlet and the contents of the first impinger was titrated for sulfate (not hydrogen) rather than being discarded. In contrast to the controlled condensation test procedure, the quartz wool plug was included in the titration so that soluble solid or condensed sulfate species are included in the analysis and reported as SO_3 .

SO_2 is analyzed (in either Method 6 or 8) by bubbling the flue gas through a peroxide solution and titrating the solution for sulfate. In the cases where this was part of a Method 5 (particulate) train the total gas sample was about 80 ft³. Otherwise the sample was only about 5 ft³. It is significant to note that despite variations in the SO_2 measurements methodology, all results gave reasonable comparison to the continuous monitor results.

TABLE 1

C. P. CRANE #2 TEST EFFORT

DATE	TEST No.	BOILER OPERATION	TEST MEASUREMENTS
7-1	1	Coal	SO ₂ , SO ₃ , Particulate
7-2	2	Coal	SO ₂ , SO ₃ , Particulate
7-29	3	Coal and RDF	SO ₂ , SO ₃ , Particulate
7-30	4	Coal and RDF	SO ₂ , SO ₃ , Particulate
7-31	5	Coal and RDF	SO ₂ , Particulate
8-4	6	Coal and RDF	SO ₂ , Particulate
8-5	7	Coal	SO ₂ , SO ₃ , Particulate
8-5	8	Coal	SO ₂ , Particulate
8-6	9	Coal	SO ₂ , Particulate

TABLE 2

AVERAGE FUEL ANALYSIS

	COAL (5 SAMPLES)	RDF (3 SAMPLES)	COMBINATION * (5% RDF + 95% COAL)
Btu/lb	12874	4824	11930
Water	5.17	27.98	7.83
C	72.68	30.26	67.70
H	4.27	4.28	4.28
N	1.27	.50	1.18
S	1.70	.38	1.55
O	5.86	24.39	8.04
Ash %	9.05	12.21	9.42
Ash $\frac{\text{lb}}{\text{MBtu}}$	7.03	25.31	7.90

* (.133 lb RDF per lb coal)

TABLE 3

PARTICULATE TEST SUMMARY
(Baltimore Gas & Electric - Crane - Unit 2)

TEST NO.	DATE	INLET (lbs/10 ⁶ Btu)	OUTLET (lbs/10 ⁶ Btu)	COMMENTS
1	7-1-80	5.07	3.74	Coal
2	7-2-80	2.82	2.19	Coal
3	7-29-80	4.82	4.73	5% RDF in Coal
4	7-30-80	5.97	4.46	5% RDF; abbrev- iated due to cyclone loss;
5	7-31-80	5.63	6.15	5% RDF in Coal
6	8-4-80	5.89	5.94	5% RDF in Coal
7	8-5-80	5.44	5.47	Coal
8	8-5-80	5.53	4.85	Coal
9	8-6-80	4.94	4.77	Coal

TABLE 4

CHEMICAL ANALYSIS OF FLY ASH

SOURCE	CARBON %	SULFATE %
Precipitator Inlet (2 Samples)	44	1.8
Precipitator Outlet (2 Samples)	40	2.0
Lower Precipitator Hopper	9.6	3.6
Upper Precipitator Hopper	74	0.2
Furnace Bottom Ash (?) (Slag)	73	0.3

TABLE 5

SO_x TESTING
(Baltimore Gas & Electric - C. P. Crane Unit #2)

TEST NO.	DATE	LOCATION	SO ₂ (4) (ppm)	SO ₃ (4) (ppm)	O ₂ (%)	
1	7-1-80	Inlet	1,660	0	8.9	Controlled condensation for SO ₃ in series with Method 6 train for SO ₂ (1)
2	7-2-80	Inlet	1,540	0	7.0	Same as Test 1
3	7-29-80	Inlet	1,400	57.6	6.0	EPA Method used for both SO ₃ and SO ₂ (2)
4	7-30-80	Inlet	1,076	29.6	6.4	Same as above
5	7-31-80	Outlet	905	--	7.8	EPA Method 6 used for SO ₂
6	8-4-80	Outlet	805	--	8.1	EPA Method 6 integrated with Method 5 for SO ₂ and particulates (3)
7	8-5-80	Inlet	648	53	7.7	Same as 3
8	8-5-80	Outlet	1,121	--	8.1	Same as 6
9	8-6-80	Outlet	1,006	--	7.9	Same as 6

- Notes:
1. Probe inlet filter not included in SO₃ analysis
 2. Probe inlet filter included in SO₃ analysis
 3. Very large gas sample volume (80 cubic feet)
 4. Concentrations are not corrected to constant oxygen level

TABLE 6 COMPARISON OF KVB SO_x TESTING VS SO₂ ANALYZER
(Baltimore Gas & Electric - Crane - Unit #2)
(SO₂ is Corrected to 2% O₂ in Flue Gas)

TEST NO.	DATE	TEST LOCATION	SO ₂ TESTED (ppm)	SO ₂ ANALYZER (ppm)	FUEL
3	7-29	Inlet	1,770	1,550	5% RDF Plus Coal
4	7-30	Inlet	1,400	1,520	5% RDF Plus Coal
5	7-31	Outlet	1,303	1,304	5% RDF Plus Coal
6	8-4	Outlet	1,252	1,218	5% RDF Plus Coal
7	8-5	Inlet	926	1,411	Coal
8	8-5	Outlet	1,651	1,351	Coal
9	8-6	Outlet	1,459	1,218	Coal

5.0 Discussion of Results

5.1 Particulates

The design concept of the cyclone fired boiler is to fire crushed coal without the need for pulverization, and to retain most of the coal ash in the furnace in liquid form for disposal as coarse slag. One of the limitations of this concept is that the coal ash melting point must be below the operating temperature of the cyclone, which thus limits the choice of fuel.

Cyclone furnaces use high air velocities and the resulting intense mixing usually results in essentially complete combustion with little carbon carry over. Ash and coal particles are retained in the cyclone by centrifugal forces so that only very small particles (in which aerodynamic drag forces exceed inertial forces) leave the cyclone, under optimum operating conditions.

The samples of stack particulate matter which were analyzed from this test series showed carbon contents exceeding 40% which is high for a coal fired boiler of any design. It implies that about 2% boiler thermal input was leaving the stack as unburned fuel. It also means that the particulate mass loading to the precipitator was increased by about 80% over the complete combustion case. It appears that most of the carbon carryover from this furnace is in the form of large (millimeter size) particles which resemble incompletely burned pieces of coal. The carbon content of the very fine particulate normally associated with cyclone furnaces is relatively low in carbon. This is illustrated by the different composition of the ash in the two precipitators.

As shown in Figure 1, the flow division preceeding the precipitators occurs just downstream of a bend in the duct. This bend in the flow causes an inertial movement of larger particulate across gas stream lines toward the outside wall. As a result most of the larger particulate is fed to the upper precipitator while the fine particulate remains distributed between both

Precipitator collection efficiency during the test program appears to be low. However, the plant was experiencing operational difficulties with the units at that time, which resulted in sections being removed from service or operated at reduced power. Some of the measurements show negative collection which is unlikely to have occurred (but is temporarily possible). Since neither the inlet nor the outlet sampling plane is ideally configured it is entirely possible that some systematic bias occurred in the particulate sampling. It is unlikely that this error was very large.

5.2 Sulfur Oxides

Essentially all fuel sulfur is oxidized to SO_2 in the combustion zone. A very small amount of this gas will be further oxidized to SO_3 which may combine with water and possibly other matter to form various sulfates. For practical purposes it is valid to assume that all the fuel sulfur will appear in the stack as SO_2 so that measureable changes in SO_2 levels (when corrected for air dilution) reflect changes in fuel sulfur content.

Typically flue gas SO_3 (including H_2SO_4) levels from utility boilers are in the range of 5 to 20 ppm which represents less than 2% of the fuel sulfur. A roughly equivalent amount may appear as solid (non acid) sulfates combined with various ash constituents.

Sulfuric acid (SO_3 and its hydrates) has a typical dew point above 230°F for fossil fuel fired systems. Figure 2 shows the theoretical dew point concentration relationship as well as some experimental data trends. This shows that at the precipitator inlet temperatures (245°F) encountered, gas phase acid concentrations from 1.0 to 5 ppm might have been expected. Any additional acid would have been in condensed phase as a mist or combined with particulate matter. Thus the filter at the inlet to the sampling apparatus probably collected most or all of the acid. Unfortunately, these filters were not analyzed for the first two tests, which utilized the controlled condensation measurement technique. During the subsequent tests, the filters were included in the analysis. This analysis (Method 6 and 9) is specific to soluble sulfates, so that soluble sulfate salts present on the filter would contribute and would be reported as SO_3 . The extent to which this problem tainted the SO_3 figures is not known.

FIGURE 2 RELATIONSHIP OF ACID DEWPOINT AND SO_3 CONCENTRATIONS

Reese, J. T., et al, "Prevention of Residual Oil Combustion Problems by Use of Low Excess Air and Magnesium Additives" Trans. ASME. J. Engrg. Power V 87A, p 229, 1965

Methods 6 and 8 have some fundamental problems which always plague these measurements. In order to obtain a valid figure for acid mist, all of the SO_2 must be removed from the first (isopropyl alcohol) impinger. Experience has shown that this generally requires substantially longer purge times than the 15 minutes specified by the methods. There is also the possibility of SO_2 being oxidized in the sample train. Practical experience with these difficulties has lead to a general preference for the controlled condensation technique. However, any methodology must deal with the particulate matter in the gas stream and the effect which it or the filter will have on the operation of the sampling train.

Sulfur Dioxide and Total Suspended Particulate Ambient
Monitoring during the C.P. Crane Unit 2 Test Burn (1980).

Table of Contents

I	Introduction
II	Monitoring Network
III	Monitoring Results
IV	Conclusion

Appendix A - Sulfur Dioxide Monitoring Data

Appendix B - Total Suspended Particulate Data

I. Introduction

Ambient air quality monitoring was conducted to determine the impact of the increased sulfur dioxide and particulate matter emissions resulting from the test burning of coal and refuse-derived fuel. A network of four stations was established which consisted of one existing station and three new stations. The new stations were installed for the duration of the test burn. Each monitoring site included instrumentation for measuring sulfur dioxide and total suspended particulate concentrations in the ambient air.

II. Monitoring Network

The monitoring network consisted of the following four stations: Crane, Bengies, Carroll Island and Matthew Church. Their locations are shown in Figure 1. The Crane monitoring station, which is operated by the Company, has been in existence for over 10 years. The Company added a second station at the Bengies Sub-Station just prior to the commencement of the test burn.

Two additional stations, Carroll Island and Matthew Church, were added in early April. They were operated under contract by Enviroplan, Inc. Their locations were based on recommendations made by Enviroplan, Inc. after their review of prediction modeling performed by Power Plant Siting Programs (Air Quality Impact of Converting the C.P. Crane Power Plant to Higher Sulfur Content Fuels, Brower, 1979) and the Company. The maximum impact was predicted by the models to occur in the area of these two monitoring sites.

Each station consisted of a Hi-Vol particulate sampler which operated on a six day cycle and sulfur dioxide monitors which operated continuously. The monitors used at each station are listed in Table 1.

The Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD), May 1978 and the US EPA regulation Air Programs; Ambient Air Quality Monitoring Data Reporting and Surveillance Provisions (44 FR 27558, May 10, 1979) were used as primary references concerning all operation and quality assurance procedures.

III. Monitoring Results

The sulfur dioxide and total suspended particulate data which was collected from the beginning of the test burn on March 28, 1980 thru the end of September 1980 are shown in the attached appendices. Table 2 summarizes the highest values recorded for each of the stations. It should be noted that none of the values exceeded any of the National Ambient Air Quality Standards which are listed in Table 3.

The highest recorded daily average sulfur dioxide concentration was $108 \mu\text{g}/\text{m}^3$ which is well below the $365 \mu\text{g}/\text{m}^3$ daily sulfur dioxide standard. Likewise, the maximum three hour average sulfur dioxide concentration of $286 \mu\text{g}/\text{m}^3$ is far below the three hour sulfur dioxide standard of $1300 \mu\text{g}/\text{m}^3$. Both values were recorded at the Carroll Island Station on June 20, 1980.

The maximum recorded daily total suspended particulate concentration was $132 \mu\text{g}/\text{m}^3$ and is below the $150 \mu\text{g}/\text{m}^3$ secondary standard. It occurred on August 7, 1980 at the Matthew Church site.

IV. . Conclusions.

The monitoring network recorded no concentrations in excess of any of the National Ambient Air Quality Standards for sulfur dioxide and total suspended particulates.

TABLE 1:

Instrumentation

Crane (BG&E)

- Thermo - Electron (Model 43) SO₂ analyzer, utilizing pulsed fluorescence method of detection.
- * Sierra Instruments (Model 235) High Volume Cascade Impactor attached to General Metal Works High-Volume Sampler

Bengies (BG&E)

- Thermo - Electron (Model 43) SO₂ analyzer
- * General Metal Works (Model 2000H) High-Volume Sampler

Carroll Island (Enviroplan, Inc.)

- Meloy Labs. (Model SA700) SO₂ analyzer, utilizing fluorescence method of detection
- * General Metal Works (Model 2000H) High-Volume Sampler

Matthew Church (Enviroplan, Inc.)

- * Meloy Labs. (Model SA700) SO₂ analyzer
- * General Metal Works (Model 2000H) High-Volume Sampler

TABLE 2: Summary of Maximum Concentrations ($\mu\text{g}/\text{m}^3$)

A. Sulfur Dioxide

	<u>Carroll Island</u>	<u>Matthew Church</u>	<u>Bengies</u>	<u>Crane</u>
Highest 3 Hr	286 (6/20)	111 (7/14)	140 (7/14)	86 (9/12)
2nd Highest 3 Hr	208 (6/20)	92 (8/28)	120 (7/14)	82 (5/13)
Highest Daily	108 (6/20)	52 (9/7)	51 (4/19)	37 (4/19)
2nd Highest Daily	49 (6/8)	45 (8/28)	43 (7/30)	35 (9/28)
Average Hourly	20	16	19	13

B. Total Suspended Particulates

	<u>Carroll Island</u>	<u>Matthew Church</u>	<u>Bengies</u>	<u>Crane</u>
Highest	94 (6/2)	132 (8/7)	118 (8/1)	89 (7/2)
2ND Highest	79 (8/1)	105 (6/2)	98 (6/2)	77 (8/1)
Geometric mean	42.2	59.1	57.5	41.1

Note:
concentration (date)

LOCATION of AMBIENT AIR MONITORS

SCALE
0 1000 2000 Feet

TABLE 3: National Ambient Air Quality Standards

A. Sulfur Dioxide

	<u>Primary</u>	<u>Secondary</u>
Annual Average	80 $\mu\text{g}/\text{m}^3$	
24-HR Average	365 $\mu\text{g}/\text{m}^3$	
3-HR Average		1300 $\mu\text{g}/\text{m}^3$

B. Total Suspended Particulates

	<u>Primary</u>	<u>Secondary</u>
Annual Average	75 $\mu\text{g}/\text{m}^3$	60* $\mu\text{g}/\text{m}^3$
24-HR Average	260 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$

*guideline