BLAST FURNACE GRANULAR COAL INJECTION PROJECT

Annual Report
January – December 1998

Work Performed Under Contract No.: DE-FC21-91MC27362

For
U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P. O. Box 880
Morgantown, West Virginia 26507-0880

By
Bethlehem Steel Corporation
Bethlehem, Pennsylvania 18016

April 1999

TABLE OF CONTENTS

1.0 INTRODUCTION

This 1998 annual report describes the Blast Furnace Granular Coal Injection project being implemented at the Burns Harbor Plant of Bethlehem Steel Corporation. The project is receiving cost-sharing from the U.S. Department of Energy (DOE), and is being administrated by the Morgantown Energy Technology Center in accordance with the DOE Cooperative Agreement No. DE-FC21-91MC27362.

This installation is the first in the United States to use British Steel technology[1,2] with granular coal to provide a portion of the fuel requirements of blast furnaces. The project was implemented to demonstrate/assess a broad range of technical and economic issues associated with injection of coal into blast furnaces. To achieve the program objectives, the demonstration project was divided into the following three Phases:

Phase I - Design
Phase II - Construction
Phase III - Operation

Preliminary Design (Phase I) began in 1991 with detailed design commencing in 1993. Construction at the Burns Harbor Plant (Phase II) began in August 1993 and was completed at the end of 1994. The demonstration test program (Phase III) started in the fourth quarter of 1995

2.0 BACKGROUND

Bethlehem Steel Corporation's Burns Harbor Plant operates two blast furnaces that produce molten iron in support of steelmaking operations. The furnaces are fueled with coke as part of the raw materials charged through the top of the furnace. The coke was supplemented by natural gas injected along with the combustion air through ports (tuyeres) near the base of the furnace. Each furnace produces about 7000 tons per day of molten iron with the injected fuel providing about 15 percent of the total fuel requirements.

Because of the uncertainty of the long-term supply and cost of natural gas, Bethlehem submitted a proposal in response to DOE's CCT-III solicitation to demonstrate the conversion to, optimization of commercial performance characteristics of granular coal as a supplemental fuel for steel industry blast furnaces. Operating blast furnaces with coal injected directly through the tuyeres into the combustion zone as a supplemental fuel will result in reduced coke consumption, and thereby, decreases the environmental emissions associated with cokemaking. The environmental problems normally associated with the combustion of coal will also be virtually eliminated by direct injection because the potential contaminants, e.g., sulfur, are captured in the blast furnace slag.

Economic benefits will be realized by the reduced demand for coke, the primary blast furnace fuel, and for natural gas and oil, the "conventional" supplementary fuels. Presuming that: (a) the granular coal injection system can be successfully operated at rates of several hundred pounds of coal injected per net ton of hot metal (liquid pig iron produced by the blast furnaces), and that (b) costs for the competing supplemental fuels, natural gas and oil, escalate in a manner projected by the U.S. Department of Energy (DOE), then the annual operating cost savings should make this an attractive investment as well as a technical advancement.

Bethlehem's Coal Injection System Demonstration Project was one of 13 demonstration projects accepted for funding in the third round of the Clean Coal Technology Program competition. A cooperative agreement with a total estimated cost of $143,800,000 was awarded to Bethlehem on November 26, 1990. Under this cooperative agreement, Bethlehem would provide 78.3 percent of the total funding requirements for the demonstration project with the DOE providing the remaining 21.7 percent. As project details were refined, the cost estimate was increased from $143,800,000 to $190,650,000. Major project milestone dates are shown in Figure 1. Additional details on the project were presented at the Annual Clean Coal Technology Conferences conducted from 1993 through 1997.[3,4,5,6,7]

3.0 PROJECT TEST PLAN

The objective of the test program was to determine the effect of coal grind and coal type on blast furnace performance. The start-up operation was conducted with a high volatile coal from eastern Kentucky with 36% volatile matter, 8% ash and 0.63% sulfur. The coal preparation system was operated to provide granular coal with nominal size of 30% minus 200 mesh (74 microns).

During 1998, a trial was conducted to determine the effect of using pulverized coal with a nominal size of 65% minus 200 mesh. Additional trials were conducted to determine the effect of coal types and coal chemistry on furnace performance. The important furnace performance parameters that were closely monitored during these trials were coke rate, raw material movement in the furnace, pressure drop in the furnace, gas composition profiles, iron analyses and slag analyses. The results of the blast furnace trials were evaluated and are documented in the following report.

4.0 BLAST FURNACE OPERATIONS

The granulated coal injection facility at Burns Harbor has been operating since January 1995. The effect of granulated coal on the furnace operation has been very different from that experienced with natural gas as the auxiliary injected fuel. During 1995, a smooth transition from natural gas to coal was accomplished even while major modifications were made to the coal preparation facility. By mid-1995 the coal preparation and delivery systems were operating as designed. The injection rate on C furnace was increased through the summer months and was over 200 pounds/ton for September, October and November. The injection rate on D furnace was kept in the range of 145-150 pounds/ton during the second half of 1995. The facility started up with high volatile coal but during the latter part of 1995, five different low volatile coals were successfully evaluated. The experience with the low volatile coals led to the exclusive use of low volatile coal during 1996. Successful operating practices were also developed during

1996 in order to reach higher levels of coal injection and lower coke rates than during the previous year. In 1997 the coal facility became more consistent and coal was injected at higher levels on both furnaces. During 1998, two important coal trials were completed; the evaluation of a western high volatile granular coal and a comparison of granular and pulverized coal on the blast furnace. Figures 2 and 3 show the progression of coal injection rates during 1998 as well as the reduction in furnace coke rates. Tables 1A and 1B provide the monthly operating summary for 1998 on C furnace and Tables 2A and 2B show the same information for D furnace.

4.1 FURNACE OPERATING CONDITIONS

The combined furnace production in January was over 14,200 NTHM/day with very high coal injection rates and low coke rates. The injected coal rate on C furnace averaged 287 pounds/NTHM; a low coke rate of 667 pounds/NTHM and a low average delay rate contributed to a good production rate of 7390 NTHM/day. The D furnace also had a high injection rate of 227 pounds/NTHM with a 697 pound/NTHM coke rate

In February the drag line conveyor that provides raw coal to the grinding mill serving both furnaces failed. From February 17 - 24 natural gas was substituted for coal. The coke rate was increased on each furnace to maintain operational stability and hot metal quality. The coke rate on C furnace prior to the loss of coal was 660 pounds/NTHM with 260 pounds/NTHM of injected coal. The coke rate was increased to 750 pounds/NTHM with 135 pounds/NTHM natural gas. Similarly, the coke rate on D went from 687 pounds/NTHM with 235 pounds/NTHM coal to 757 with 116 pounds/NTHM of natural gas. Despite the increased coke rate, productivity was maintained by increases in the furnace wind rate.

A winter storm on March 9 caused another disruption to coal injection for a five day period when the stacker/reclaimer at the injection facility was blown down and a primary coal feed belt motor failed. However, power failures in other areas of the plant minimized the impact of the loss of production at the blast furnace.

Above average furnace delay rates on both C and D furnace caused production levels to fall below 14,000 NTHM/day in April. Productivity rebounded during May with both furnaces averaging more than 7000 NTHM/day. However, increased delays in June caused another decrease in the production level. Despite the lower productivity, the injected coal and furnace coke rates on C furnace were very good each month. Natural gas was substituted for coal on D furnace during the latter part of April and all of May as a pulverized coal trial began on C furnace. Coal injection rates on C furnace were between 287 - 295 pounds/NTHM with furnace coke rates averaging 657 - 663 pounds/NTHM. The low fuel rates were helpful in maintaining the production despite higher than normal delay periods. The coke rates on D furnace were high in April and May, averaging 728 and 774 pounds/NTHM respectively, due to the use of natural gas in place of granulated coal. Granulated coal was put back on the furnace in June and the coke rate improved to 708 pounds/NTHM.

Production levels on each furnace exceeded 7000 NTHM/day during July. The combined production of 14,326 was a result of lower coke rates and below average delay rates on both furnaces. The combined production was at its highest level since September 1997. In August, the combined productivity declined to less than 13,500 NTHM/day. Although D furnace maintained a production rate in excess of 7000 NTHM/day, C furnace was lower because of a castfloor breakout and subsequent five day repair from August 26 – 30. Despite the lower productivity in August, injected coal and furnace coke rates were very good during the month. During September, the operation was difficult because of higher delays on both furnaces. The combined average monthly delay rate was considerably above the twenty-month average of 113 minutes per day and the combined average monthly production was less than 14,000 NTHM/day. Higher furnace coke rates at lower coal injection levels also contributed to the decrease. Additionally, the coke rate on both furnaces was increased substantially and the injected coal rate was decreased in preparation for the high volatile Colorado coal trial that started on September 28.

The Colorado coal trial was part of the continuing cooperative agreement with the Department of Energy. For this trial, the BALWAX model predicted that a higher coke rate would be necessary due to the lower carbon content of the Colorado coal. Therefore, in preparation for the trial, beginning on September 10, the coke rate on both furnaces was increased by about 45 pounds/NTHM. The increase caused the monthly average coke rate to rise to 702 pounds/NTHM on C and 729 pounds/NTHM on D in September. The initial plan was to test both granulated and pulverized Colorado coal on C furnace.

Granulated Colorado coal was used on both furnaces beginning on September 28. The operation of C and D furnace during October, from a production standpoint, was difficult because of increased scheduled maintenance on each furnace and the ongoing problems, described later, with the Colorado high volatile coal. Frequent delays on both furnaces and high coke rates caused a serious production shortfall.

On September 29, there was an unanticipated outage on C furnace. This delay extended into the first week of October. Injected coal was replaced with natural gas in order to recover from the extended shutdown. Natural gas remained on the furnace, in various quantities, until October 20. The loss of the steady state operation on C during the injection of high volatile Colorado coal and the necessity of putting natural gas on the furnace required a change in planning for the granulated and pulverized coal trials. The trials were switched to the D furnace in order to sustain an acceptable operating period with the available high volatile coal.

During November, the operating strategy on C furnace was to keep injecting natural gas, maintain as low a coke rate as possible and produce as much iron as possible. The goal for D furnace was to complete a meaningful trial period using pulverized high volatile Colorado coal. The goal for each furnace was accomplished.

On C furnace, natural gas was injected for the entire month and the furnace coke rate was slightly lower than the October rate. The monthly average production of over 7700 NTHM per day was a record high rate. On D furnace, the trial was completed but there were difficulties.

Both coal grinding mills had to undergo emergency repairs to the bullring in order to pulverize the Colorado coal. The hardfacing on mill #2 began on November 4 and was completed on November 6. The repair to #1 mill was done from November 11 to 13. Granular coal was used on the furnace during the repairs to each mill. Immediately following the repairs, on November 13, both mills began producing pulverized coal. The Colorado coal was so difficult to pulverize that both mills were needed to produce the 183 tons per day necessary for D furnace. There was enough coal remaining to complete the fourteen day trial period with the pulverized high volatile coal.

The emphasis during December was to return both furnaces to a more normal and steady state operation. The two furnace trials on D furnace during October and November and the use of natural gas injection on C furnace during the pulverized trial disrupted the operation. The low volatile Buchanan coal that was stockpiled during the trials was put back on both furnaces during the month.

The production level on C furnace remained good during the month and averaged 7153 NTHM/day. By the end of the month, the injected coal was around 270 pounds/NTHM with a coke rate below 700 pounds/NTHM

The D furnace operation also returned to normal following the completion of the granulated and pulverized coal trials. As with C furnace, the resumption of Buchanan coal allowed the injection rates to be increased to above 200 pounds/NTHM and the coke rates to be reduced to around 700 pounds/NTHM by month end. The 1998 monthly averages for the coke, coal and natural gas rates for C and D furnaces are shown in Figures 2 and 3, respectively.

Pulverized Coal Trial With Low Volatile Coal

A pulverized coal trial began on C furnace during the second quarter. The plan was to pulverize low volatile coal because granular low volatile coal had been used successfully in previous trials and there were good base periods to use for comparison.

Preparations for changing the coal size grind began on April 7 when a representative of the William's coal grinding mills started the adjustment process. The initial grind was set to produce pulverized coal, 80% -200 mesh, on both of the mills. In preparation for the trial on C furnace, injected coal was taken off D furnace and replaced with natural gas on April 20. This was done to minimize any adverse effect of the pulverized coal on the overall operation and to insure that the mills could provide the proper amount of coal to C furnace. The trial on C furnace began on April 22, but ended without success because of numerous problems with the coal delivery system. Although three attempts were made to conduct a pulverized trial, it is not possible to make a comparison with granulated coal because there was never more than three consecutive days of complete coal injection. Natural gas had to be injected on the furnace because of either coal blockage in the conveying lines or a shortage of furnace fuel due to low bulk density of the pulverized coal during each of the periods.

The problems that occurred with the pulverized coal were related to the design of the British Steel/Simon Macawber coal delivery system. Unlike pulverized coal injection systems that utilize gravity feed and/or pressure vessel coal flow to the injectors, the granular equipment uses individual screw feeders for each tuyere injector. The twenty eight screw feeders meter the coal from a coal storage vessel to each tuyere line. After the screw feeders discharge into a high pressure air conveying line for each tuyere, the coal is conveyed through these $1^1/_4$ inch diameter pipes to the blast furnace that is approximately 600 feet away.

The first problem was the inability of the screw feeders to deliver enough of the pulverized coal to the individual injectors on each tuyere. The coal storage vessel would fill with the desired amount of coal, but the screw feeders could not empty the vessel in the time required. This problem was due to the change in the bulk density of the low volatile coal in the pulverized state. The bulk density of granular low volatile coal at the screw feeder is approximately 1.5 - 1.8 pound per revolution. The pulverized coal was about 1.0 pound per revolution of the screw feeder. The result of this change in density was that the process called for more coal to be conveyed from the weigh bin to the injectors than the screw feeder, at its highest speed, could convey. Therefore, the furnace could not be operated at the injection rate previously used with granular coal. In addition, the blast furnace became fuel short and required additional coke. This condition does not allow a meaningful comparison to be made between the pulverized and granular coal.

Another problem began during the second day of the trial. The conveying air pressure from the coal facility to the furnace began to increase. The pressure increase was attributed to very fine coal buildup in the $1^1/_4$ inch lines going to the furnace. By April 25, two days into the trial, coal flow to tuyeres 6, 10, 20 and 22 was lost. Natural gas was injected on these tuyeres while attempts were made to clear the blockage. After five days, ten of twenty eight-tuyeres had lost coal flow due to conveying line blockage. Each of these injector lines was sandblasted to reopen. However, the buildup continued and eight days after the trial began granulated coal was put back on the furnace. A combination of granulated coal and manual cleaning finally cleared the coal transport lines.

In order to resume the trial, a new plan was instituted to compensate for the problems. The coal grinding mills were adjusted to produce pulverized coal at 65% -200 mesh. On May 5, the trial began again, but in less than eight hours, the bulk density of the coal at the injectors was 1.08 pounds per revolution. This low density coal created a fuel deficiency at the furnace. Coal demand was reduced and natural gas had to be put on four of the furnace tuyeres.

A second attempt was made to use the 65% - 200 mesh coal. This time, one grinding mill was set to produce 80% -200 mesh coal and the other set for 50% -200 mesh. The plan was to mix the two sizes to provide 65% -200 mesh at the injectors and enough +50 mesh size coal to solve the bulk density problem and prevent line plugging. In addition, the mill demand was varied with 30% on the 80% -200 mesh mill and 20% on the 50% -200 mesh mill. This combination arrangement did produce coal at the injectors with 65% - 200 mesh and 6% + 50 mesh. The trial began again on May 15. Four days later, three injectors plugged and the tuyeres were put on gas. In addition, six tuyere injector conveyor lines had high pressure as the low volatile pulverized coal continued to buildup in the piping. After two weeks of this trial period, because of more line blockage, the coal size was changed back to granular and the plugged coal lines were manually cleaned and opened. On June 1, the trial was discontinued and granular coal was restarted. Within two days most of the conveying line blockage had cleared.

Of the problems experienced during the low volatile pulverized coal trial, the difficulty with the low bulk density at the screw feeder was unexpected. Because the design of the granular equipment is not at all similar to pulverized units, our experience was unique. The problem with the line blockage with pulverized coal is not unusual and several other installations that experienced coal line plugging solved the problem by increasing the size of the coal to 65% -200 mesh. While this was effective with high volatile coal, the low volatile coal that we use is so soft that even grinding to 65% -200 mesh produces a significant portion of ultra fine particles of coal that stick together and cause plating within the coal conveying lines.

4.2 BLAST FURNACE TRIAL RESULTS USING GRANULAR AND PULVERIZED HIGH VOLATILE COAL

General Trial Observations

The use of low volatile coal at Burns Harbor began in 1996 and has resulted in excellent operating performance. These operating results and a subsequent DOE trial conducted in October, 1996 defined the use of low volatile coal for injection in the blast furnace.[1] The base operating period selected for this trial, August 1998, reflects the advantages of the low volatile coal and is shown in Table 4. The coke rate of 683 pounds/NTHM at a coal injection rate of 250 pounds/NTHM resulted in an overall low fuel rate of 935 pounds/NTHM and contributed to the good production level of 7078 NTHM/day. This period provides a good comparison base for the high volatile coal operating periods.

The blast furnace operation using granular, high volatile, western coal during October is shown on Table 3. Compared to the base period, the coke rate is 115 pounds higher at 798 pounds/NTHM. Although the injected coal rate is about 60 pounds/NTHM lower at 191 pounds/NTHM, the increase in coke rate is not proportional to the injected coal decrease. This comparison shows that the low volatile coal supports a lower furnace coke rate than the high volatile coal.

The blast furnace operation using high volatile coal with pulverized sizing is shown as Trial 2 in Table 3. The operating period results are very similar to the granular trial period. The coke rate, coal injection rate and the overall fuel rate are very similar to the operation using granular high volatile coal. The injected coal rate is lower during this period because the two coal grinding mills could only pulverize this amount of coal. The comparison of the Trial 2 to the Trial 1 period shows similar results and leads to the conclusion that the blast furnace process is unaffected by whether the injected coal is granulated or pulverized.

One variable that was of concern during the planning phase of the trial for using pulverized coal was furnace permeability. Table 3 shows that during the base period and the granular trial there was no change in permeability. The values were 1.43 and 1.42, respectively. During the pulverized coal trial, the furnace permeability did decrease to 1.33. However, this was likely because Chinese coke was not on the furnace during the pulverized trial period but was in the burden during the two previous operating periods. We have previously documented the increase in furnace permeability that accompanies the use of larger sized Chinese coke. We believe that the reduction in permeability during this period is attributable to the lack of Chinese coke rather than the use of pulverized coal. This is supported by the fact that the permeability on the D furnace remained low, at 1.36, during December 1998 after the pulverized coal trial had ended and Chinese coke remained out of the burden.

Coal Chemistry and Sizing:

The comparison of injected coal chemistry between the Buchanan and the high volatile, Oxbow coal is shown on Table 4. The large difference in coke rate seen between the aforementioned periods is attributable to the difference in carbon content of the two coals. The Oxbow coal averages 73.2% carbon versus 86.3% for the Buchanan low volatile coal. The increase in coke rate is also due to the higher ash content of the Oxbow coal. Buchanan ash content is 5.23% compared to 11.20% for the Oxbow. The furnace slag volume during the operating period with Buchanan is 430 pounds/NTHM. The higher ash content of the Oxbow causes the slag volume to rise to 461 pounds/NTHM during the first trial. A slag volume increase in the blast furnace results in an increase in the coke rate.

Coal sizing was a concern and was closely monitored during each trial period. Table 5 shows the injected coal sizing for each period as well as the raw coal sizing. The raw coal sizing shown is the size fraction of the coal as measured by the vendor at the shipping site. The product coal sizing shown in the table is the size fraction of the injection coal after grinding in the preparation mills. The granular sizing shown for the low volatile Buchanan and the high volatile Oxbow coal is the monthly average of daily samples taken on D furnace during August and October. The values for the pulverized sizing are the average of ten daily samples taken during the pulverized trial. The minus 200 mesh fraction was determined by using a vacuum pump that draws the entire sample through a 200 mesh screen. This method of screen analysis was done on a daily basis to insure that the grinding mills were set properly. The Burns Harbor Plant laboratory is not equipped for the wet screen analysis, however, two samples were sent to an independent laboratory for wet analysis. The average of the two samples is also shown on Table 5. This method shows that the minus 200-mesh fraction of the injected coal was 74%. The injected coal sizing for each period met the criteria for each trial.

The raw coal sizing shown on Table 5 demonstrates a fundamental difference between high volatile and low volatile coal. The low volatile coal arrives at the coal grinding facility with 83% of the coal already sized at minus one-quarter inch. The grinding mills will work less to achieve the proper sizing for injection than for the high volatile coal that is only 36% minus one-quarter inch. In addition, grinding the low volatile coal with an

HGI of 100 is much easier than grinding the Oxbow coal that has an HGI of 46 – 48. This is demonstrated later.

Furnace Coke Rate Results:

One of the reasons for the October trial period was to determine the coke rate difference between the use of low volatile and high volatile coal. In order to assess the furnace coke rate during a trial, all of the variables that affect the furnace coke rate and are different from the base must be adjusted by using coke correction factors. The variables that are not corrected or adjusted are those affected by the operating variable that is being assessed. After all of the operational coke differences between the base period and the trial period are accounted for, the remaining coke is attributed to the variable being studied. Since the Colorado high volatile coal is higher in ash than the Buchanan coal and is a consequence of the difference between the two coals, we have not adjusted the coke rate for changes in the furnace slag volume. The blast furnace slag volume is directly affected by the injected coal ash.

The result of the first comparison of the base period to the granulated high volatile period is shown in Table 6. The primary correction for the October period is the rather large difference in the injected coal rate. A correction of one pound/NTHM injected coal replacing one pound/NTHM of coke is used for the difference in quantity. Hot metal silicon content did increase substantially during the granular trial period and a correction of 11 pounds/NTHM is used for this factor. After each factor in the analysis is accounted for, we are left with a 46 pound/NTHM higher coke rate in the high volatile trial period than during the low volatile base period. The higher coke rate is attributed to the use of Oxbow coal. This result is plausible because the Buchanan coal is 13% higher in carbon content than the Oxbow coal. Since carbon is the primary fuel source for the furnace, the difference in furnace fuel rates is understandable. In addition, the almost 6% higher ash content of the Oxbow coal is a distinct coke disadvantage. The overwhelming conclusion from this comparison is that the low volatile coal provides a very substantial coke rate advantage to the blast furnace.

The coke comparison of the granular, high volatile trial period to the pulverized, high volatile period is shown in Table 7. The operating periods are very similar and only small corrections were necessary. We included blast furnace slag volume in these corrections because the injection coal type was the same for both periods. The largest corrections were for the decrease in wind volume during the pulverized period and the increase in slag volume. The wind decreased because the furnace permeability was lower. The three pound coke difference for the pulverized versus granular comparison is within the normal plus or minus five-pound error limit and strongly indicates that there is no process difference in the blast furnace with the use of pulverized coal.

Table 8 shows the blast furnace sulfur balance results for both of the trial periods. The sulfur content of all of the raw material inputs as well as the material outputs were monthly average sulfur analyses. The sulfur content of the blast furnace gas is the average of three samples that were taken for each period by Mostardi Platt. The balances are very good for both trial periods.

Coal Grinding Energy Consumption:

The primary reason for adopting the British Steel granular coal injection technology is to inject coal into the blast furnace by the most efficient and cost effective method. The objective of the cooperative demonstration project is to showcase the efficiency of the granular process. One reason for choosing granular over the pulverizing process is presented in Figure 4. The figure shows the energy consumption of both coal grinding mills per ton of coal processed. Four points of interest are shown on the figure.

The first point, May 1998, is a period during which we attempted to pulverize low volatile coal. During this month pulverized coal was produced in the mill but severe line plugging did not allow for an appropriate furnace process trial. This experience was detailed earlier in this report. The energy consumption in April increased from about 10 KWH/ton with granular coal to 14 KWH/ton with pulverized coal.

The granular coal base period is designated as granular low vol in Figure 4. The third point is the result during the high volatile granular period. The increase from 7.5 KWH/ton for granular, low volatile coal to 19.6 KWH/ton for granular, high volatile is very significant. These two points are an added incentive for the use of low volatile coal at Burns Harbor. The last point on Figure 1 shows the rise in energy consumption from the granular period in October to the pulverized period during the last two weeks in November. The KWH/ton increase from 19.6 to 31.4 is very significant in the overall cost of preparing the coal for injection as well as the wear and tear on the mills.

4.3 FURNACE THERMAL CONDITIONS AND REFRACTORY LINING WEAR

The C and D furnace are equipped with a Thermal Monitor System consisting of two components: twenty four thermocouples embedded in the refractory lining of the furnace at three elevations and an extensive system of thermocouples in the discharge water cooling system at nine furnace elevations. The heat loss in the furnace is calculated for the various elevations from the water system thermocouples.

In addition to the array of thermocouples, wear monitors are in the refractories of the furnace at various elevations. These monitors give an indication of the amount of brick that is remaining in the furnace at various elevations.

The furnace operation can be evaluated implicitly by studying differences in these measurements over time. For example, if there are higher heat loads observed in the furnace during a change in the furnace practice, we may imply that the practice change was responsible for the increased heat loads. We have observed, with the refractory wear monitors, that coal injection causes increased wear of the brick lining.

The following figures show the thermal loads on C and D furnace for 1998. Each is identified in the text.

Figure 5 shows the inwall refractory temperatures at three elevations for C furnace. The temperatures at the mantle, row 1 and row 25 have not changed very much during the year. The temperature at row 40 has increased significantly during the last four months of the year. There is no obvious explanation for this increase. Figure 6 shows the thermal load values on C furnace during the year at five elevations. The thermal loads reached a high point at all five elevations during September. The difficulty with the operation, recounted earlier, is the main cause for this increase. However, the operation was returned to a steady state and the thermal loads returned to lower levels in November and December.

Figure 7 shows the refractory temperatures for D furnace during the year. The values are unchanged in the lower stack and mantle area of the furnace. The upper stack temperatures trended higher beginning in July and remained slightly higher during the rest of the year. However, the increase from about 1100° F to 1200° F was not statistically significant. The thermal loads on D furnace are shown on Figures 8, 9 and 10. The calculated thermal loads in most elevations, except for incidental monthly variations, were stable during the year

The refractory wear patterns and the coal injection history of each furnace is shown in Figures 11 and 12.

Figure 11 shows the refractory thickness at three elevations in C furnace. Beginning in January 1997 we observe little or no refractory wear during the year compared to the large loss of refractory in the middle of 1996. The refractory has also shown little wear during 1998. The injected coal rate, also shown on the figure, did vary during the year.

Figure 12 shows the refractory wear measurements for D furnace since 1992. In addition, the injected coal rate is shown. There has been very little refractory wear at the three elevations shown during all of 1996, 1997 and 1998. We also note that since April 1996 the coal injection rate has remained relatively constant.

5.0 SUMMARY

The primary goal of the Clean Coal Project and the Cooperative Agreement with the United States Department of Energy was to demonstrate the advantages of using a granular coal injection facility rather than a pulverized coal injection system. Secondary objectives were to determine the effect of coal grind size and coal type on blast furnace performance. The trials performed during 1998 were important for attaining the goal.

The energy consumption for pulverizing compared to granulating the same coal is significantly higher. High volatile coal required 31.4 KWH/ton to pulverize during this trial and 19.6KWH/ton to granulate the same coal. In addition, the operating data clearly shows that the blast furnace process is unaffected by whether the coal is pulverized or granular at the injection rate used during the trials.

Another conclusion, based on the trial, is that the low volatile coal replaces more coke than the lower carbon content, high volatile coal. This result is very important to the Burns Harbor Plant. Prior to coal injection the plant had to purchase coke to supplement the coke produced by the Plant. Until the successful use of low volatile coal began and large reductions in coke rate were accomplished, the blast furnace was still dependent on some outside purchased coke. At a production rate of 14,000 NTHM/day, the blast furnace is currently self-sufficient with the home coke supply. However, during times of high production, there could be a slight need for external coke. The successful injection of low volatile coal closes a large portion of the coke supply/use gap at Burns Harbor.

6.0 REFERENCES

1. D. S. Gathergood, "Coal Injection Into the Blast Furnace", International Iron & Steel Institute Committee on Technology, April 26, 1988.

2. D. S. Gathergood and G. Cooper, "Blast Furnace Injection - Why Granular Coal?", Steel Technology International, 1988.

3. D Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal *Injection", Second Annual Clean Coal Technology Conference,* Atlanta, GA, September 1993.

4. D. Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal Injection", Third Annual Clean Coal Technology Conference, Chicago, IL, September 1994.

5. L. L. Walter, R. W. Bouman and D. G. Hill, "Blast Furnace Granular Coal Injection", Fourth Annual Clean Coal Technology Conference , Denver, CO, September 1995.

6. D. G. Hill, T. J. Strayer and R. W. Bouman, " An Update on Blast Furnace Granular Coal Injection", Fifth Annual Clean Coal Technology Conference, Tampa, FL, January 1997.

7. D. G. Hill, T. J. Strayer and R. W. Bouman, " Blast Furnace Granular Coal Injection System Demonstration", Sixth Annual Clean Coal Technology Conference, Reno, NV, April 1998.

TABLE 1A
Burns Harbor C Furnace
Summary of Operation

	January 98	February 98	March 98	April 98	May 98	June 98
Prod, NTHM/d Rep	7390	7258	7021	6987	7205	6949
Delays, Min/d	13	18	48	40	22	84
Coke Rate, lbs/NTHM	667	692	679	663	657	658
Nat. Gas Rate, lbs/NTHM	1	54	14	3	6	5
Inj. Coal Rate, lbs/NTHM	287	175	251	295	287	289
Total Fuel Rate, lbs/NTHM	955	920	943	961	950	951
Burden %:						
Sinter	34.0	33.8	32.6	31.0	27.9	30.8
Pellets	65.6	65.8	67.1	68.9	71.9	69.0
Misc.	.4	.4	.3	.2	.2	.2
BOF Slag, lbs/NTHM	0	0	16	58	56	33
Blast Conditions:						
Dry Air, SCFM	134,524	145,479	138,330	137,213	139,992	141,776
Blast Pressure, psig	39.2	38.5	37.9	38.6	38.0	38.2
Permeability	1.16	1.31	1.23	1.19	1.27	1.28
Oxygen in Wind, %	28.2	26.3	27.0	27.3	27.0	26.9
Temp, F	2094	2101	2098	2101	2101	2098
Moist., Grs/SCF	23.0	16.0	19.4	22.1	22.7	22.8
Flame Temp, F	3964	3760	3910	3909	3887	3845
Top Temp, F	192	212	202	225	229	234
Top Press, psig	17.2	16.5	16.1	16.4	16.4	16.4
Coke:						
H2O, %	5.2	5.1	5.1	5.7	5.6	5.3
Hot Metal, %:						
Silicon	.53	.55	.52	.53	.51	.54
Standard Dev.	.133	.136	.152	.137	.143	.144
Sulfur	.036	.031	.039	.031	.034	.033
Standard Dev.	.020	.015	.018	.016	.019	.015
Phos.	.065	.061	.057	.061	.060	.058
Mn.	.43	.39	.39	.41	.38	.37
Temp., F	2719	2695	2687	2708	2725	2715
Slag, %:						
SiO2	35.85	36.31	36.77	36.57	36.86	36.88
Al2O3	9.75	9.59	9.42	9.43	9.41	9.58
CaO	39.64	39.83	40.03	40.29	40.09	40.21
MgO	11.10	11.04	11.06	11.36	11.84	11.54
Mn	.47	.37	.36	.35	.32	.32
Sul	1.56	1.51	1.57	1.59	1.56	1.58
B/A	1.11	1.11	1.11	1.12	1.12	1.11
B/S	1.42	1.40	1.39	1.41	1.41	1.40
Volume, lbs/NTHM	446	420	420	443	448	438

TABLE 1B
Burns Harbor C Furnace
Summary of Operation

	July 98	August 98	Sept 98	October 98	Nov 98	Dec 98
Prod, NTHM/d Rep	7256	6407	6835	6731	7710	7153
Delays, Min/d	45	155	71	47	13	43
Coke Rate, lbs/NTHM	644	666	702	777	753	729
Nat. Gas Rate, lbs/NTHM	8	10	8	100	157	80
Inj. Coal Rate, lbs/NTHM	287	284	254	73	0	118
Total Fuel Rate, lbs/NTHM	938	960	964	950	910	928
Burden %:						
Sinter	35.8	31.8	33.1	33.1	31.2	34.4
Pellets	64.0	68.1	66.7	66.7	68.6	65.4
Misc.	.2	.2	.2	.3	.3	.2
BOF Slag, lbs/NTHM	4	9	9	0	26	9
Blast Conditions:						
Dry Air, SCFM	145,851	146,637	151,533	153,150	164,503	153,119
Blast Pressure, psig	38.3	38.2	38.6	38.2	38.1	38.0
Permeability	1.34	1.33	1.40	1.43	1.72	1.51
Oxygen in Wind, %	26.4	25.9	25.1	25.2	25.6	25.9
Temp, F	2101	2087	2090	2093	2097	2094
Moist., Grs/SCF	22.8	20.4	20.5	13.1	9.1	14.8
Flame Temp, F	3811	3783	3831	3588	3488	3642
Top Temp, F	256	261	257	236	220	231
Top Press, psig	16.7	16.5	17.2	16.4	15.5	17.0
Coke:						
H2O, %	4.9	4.8	5.1	5.3	5.7	6.1
Hot Metal, %:						
Silicon	.51	.55	.53	.60	.46	.55
Standard Dev.	.123	.167	.152	.181	.095	.133
Sulfur	.035	.034	.034	.036	.044	.036
Standard Dev.	.015	.018	.020	.015	.012	.013
Phos.	.058	.058	.060	.059	.058	.061
Mn.	.38	.38	.40	.39	.38	.39
Temp., F	2700	2666	2661	2630	2663	2672
Slag, %:						
SiO2	36.94	36.89	37.02	36.84	36.98	36.47
Al2O3	9.78	9.53	9.63	10.42	10.44	9.98
CaO	40.18	40.22	39.94	39.09	38.74	38.81
MgO	11.39	11.22	11.47	11.29	11.42	11.44
Mn	.34	.34	.37	.37	.39	.40
Sul	1.47	1.47	1.48	1.38	1.25	1.29
B/A	1.10	1.11	1.10	1.07	1.06	1.08
B/S	1.40	1.39	1.39	1.37	1.36	1.38
Volume, lbs/NTHM	438	434	435	430	439	431

TABLE 2A
Burns Harbor D Furnace
Summary of Operation

	January 98	February 98	March 98	April 98	May 98	June 98
Prod, NTHM/d Rep	6898	7020	6776	6677	7008	6851
Delays, Min/d	51	32	59	79	83	53
Coke Rate, lbs/NTHM	697	711	703	728	774	706
Nat. Gas Rate, lbs/NTHM	5	40	13	48	148	187
Inj. Coal Rate, lbs/NTHM	225	159	209	159	0	37
Total Fuel Rate, lbs/NTHM	927	911	925	935	922	930
Burden %:						
Sinter	33.1	33.1	31.7	29.3	24.6	29.1
Pellets	66.5	66.5	67.9	70.5	75.3	70.7
Misc.	.4	.4	.4	.2	.2	.2
BOF Slag, lbs/NTHM	0	0	15	50	70	37
Blast Conditions:						
Dry Air, SCFM	144,300	150,968	147,666	148,437	159,354	146,512
Blast Pressure, psig	38.9	38.2	38.4	37.7	38.5	37.9
Permeability	1.24	1.39	1.30	1.37	1.58	1.35
Oxygen in Wind, %	25.9	25.2	25.1	25.4	26.1	25.7
Temp, F	2090	2077	2078	2088	2069	2095
Moist., Grs/SCF	20.6	16.3	19.0	16.8	8.5	19.8
Flame Temp, F	3918	3783	3850	3756	3517	3753
Top Temp, F	230	228	234	249	258	259
Top Press, psig	16.3	16.5	16.3	16.0	16.7	16.3
Coke:						
H2O, %	5.4	5.2	5.0	5.6	5.6	5.3
Hot Metal, %:						
Silicon	.54	.51	.48	.49	.49	.51
Standard Dev.	.117	.112	.118	.121	.110	.106
Sulfur	.036	.039	.046	.040	.036	.038
Standard Dev.	.017	.015	.020	.021	.013	.012
Phos.	.064	.061	.057	.059	.060	.058
Mn.	.42	.38	.36	.39	.37	.36
Temp., F	2694	2684	2668	2674	2683	2680
Slag, %:						
SiO2	35.72	36.49	37.05	36.81	37.39	37.20
Al2O3	9.74	9.56	9.42	9.46	9.32	9.59
CaO	39.56	39.68	39.86	39.91	39.64	39.81
MgO	11.09	11.05	11.05	11.27	11.77	11.47
Mn	.48	.36	.39	.38	.34	.33
Sul	1.55	1.50	1.54	1.55	1.44	1.54
B/A	1.11	1.10	1.10	1.11	1.10	1.10
B/S	1.42	1.39	1.37	1.39	1.38	1.38
Volume, lbs/NTHM	437	418	430	426	424	428

TABLE 2B
Burns Harbor D Furnace
Summary of Operation

	July 98	August 98	Sept 98	October 98	Nov 98	Dec 98
Prod, NTHM/d Rep	7070	7078	6838	6689	6391	6902
Delays, Min/d	50	42	81	66	119	36
Coke Rate, lbs/NTHM	678	683	729	799	799	744
Nat. Gas Rate, lbs/NTHM	5	2	1	3	0	46
Inj. Coal Rate, lbs/NTHM	243	250	222	191	188	149
Total Fuel Rate, lbs/NTHM	927	935	951	992	987	940
Burden %:						
Sinter	34.9	30.8	32.2	35.3	36.1	34.6
Pellets	65.0	69.0	67.6	64.5	63.7	65.4
Misc.	.2	.2	.2	.3	.2	0
BOF Slag, lbs/NTHM	5	10	10	0	3	12
Blast Conditions:						
Dry Air, SCFM	145,943	149,599	151,916	150,096	140,904	148,894
Blast Pressure, psig	38.3	37.6	38.1	38.0	37.5	38.3
Permeability	1.32	1.43	1.44	1.42	1.30	1.36
Oxygen in Wind, %	25.9	25.5	25.1	25.3	26.3	25.7
Temp, F	2098	2089	2059	2044	2057	2096
Moist., Grs/SCF	22.9	21.2	21.0	19.3	21.5	18.2
Flame Temp, F	3854	3836	3897	3870	3932	3763
Top Temp, F	265	263	259	216	199	246
Top Press, psig	16.5	16.7	17.0	17.0	16.4	16.5
Coke:						
H2O, %	4.7	4.7	4.9	5.1	5.4	6.2
Hot Metal, %:						
Silicon	.48	.49	.52	.60	.54	.52
Standard Dev.	.102	.104	.097	.115	.127	.112
Sulfur	.040	.041	.036	.036	.036	.039
Standard Dev.	.012	.016	.014	.012	.014	.016
Phos.	.058	.058	.060	.062	.061	.061
Mn.	.37	.37	.39	.40	.39	.39
Temp., F	2661	2652	2681	2640	2668	2665
Slag, %:						
SiO2	37.12	37.30	37.17	36.60	36.21	36.41
Al2O3	9.79	9.47	9.63	10.46	10.49	9.96
CaO	39.92	40.09	39.82	39.29	38.98	38.79
MgO	11.36	11.36	11.49	11.26	11.58	11.49
Mn	.35	.36	.38	.37	.37	.41
Sul	1.46	1.45	1.47	1.43	1.35	1.31
B/A	1.09	1.10	1.10	1.07	1.08	1.08
B/S	1.38	1.38	1.38	1.38	1.40	1.38
Volume, lbs/NTHM	432	430	434	461	492	441

TABLE 3

D Furnace
DOE Trials with High Volatile Coal

	BASE Buchanan Coal Granular AUGUST 1998	TRIAL 1 Oxbow, Colorado Coal Granular OCTOBER 1998	TRIAL 2 Oxbow, Colorado Coal Pulverized November 13-26,1998
Production, NTHM/day	7078	6689	6710
Delays, Min/day	48	66	73
Coke Rate, lb/NTHM Rep.	**683**	**798**	**800**
Natural Gas Rate, lbs/NTHM	2	2	0
Injected Coal Rate, lbs/NTHM	**250**	**190**	**183**
Total Fuel Rate, lbs/NTHM	935	990	983
Burden %:			
Sinter	30.8	35.3	35.7
Pellets	69.0	64.5	63.6
Misc.	.2	.1	.7
BOF Slag, lbs/NTHM	10	0	0
Blast Conditions:			
Dry Air, SCFM	149,599	150,096	141,539
Blast Pressure, psig	37.6	38.0	37.4
Permeability	1.43	1.42	1.33
Oxygen in Wind, %	25.5	25.3	26.4
Temp, F	2089	2044	2080
Moist., Grs/SCF	21.2	19.3	22.8
Flame Temp, F	3836	3870	3935
Top Temp, F	263	216	197
Top Press, psig	16.7	17.0	16.6
Coke:			
H2O, %	4.7	5.1	5.2
Chinese Coke, %	14.5	12.3	0
Hot Metal %:			
Silicon	.49	.60	.52
Standard Dev.	.104	.115	.110
Sulfur	.041	.036	.035
Standard Dev.	.016	.012	.014
Phos.	.058	.062	.061
Mn.	.37	.40	.39
Temp., F	2652	2640	2686
Slag %:			
SiO2	37.30	36.60	36.20
Al2O3	9.47	10.46	10.50
CaO	40.09	39.29	38.82
MgO	11.21	11.26	11.72
Mn	.36	.37	.37
Sulfur	1.45	1.43	1.33
B/A	1.10	1.07	1.08
B/S	1.38	1.38	1.40
Volume, lbs/NTHM	430	461	504

TABLE 4

Coal Chemistry Comparison of Low Volatile and High Volatile Coal

Coal	Buchanan			Oxbow, Colorado				
		TRAIN #	#1	#2	#3	#4	#5	**AVERAGE**
Vol. Matter, %	18.00		37.83	37.89	36.62	36.68	36.68	**37.14**
C(%)	86.3		74.44	75.10	72.62	72.39	71.52	**73.214**
O(%)	2.18		8.13	8.03	7.90	8.15	7.74	**7.99**
H2(%)	4.15		5.28	5.26	5.01	5.08	4.91	**5.108**
N2(%)	1.20		1.79	1.76	1.62	1.78	1.66	**1.722**
Cl(%)	.16		.02	.02	.01	.01	.03	**0.018**
Ash, %	5.23		9.51	9.06	12.07	11.90	13.45	**11.198**
Total Mois.,%	6.45		NA	NA	5.79	5.47	6.46	**5.91**
Sulfur, %	.76		.85	.79	.72	.70	.72	**.76**
GHV, BTU/lb	15,000		13,519	13,493	12,962	13,306	12,761	**13,208**
HGI	100		NA	NA	NA	NA	NA	**46 - 48**
Phos. (P2O5),%	.004		.055	.057	.041	.064	.050	**.053**
Alkali, % (Na2O,K2O)	(.030 , .09)		(.262,.087)	(.262,.087)	(.279,.129)	(.361,.148)	(.370,.159)	**(.265,.122)**
SiO2 (%)	1.77		5.16	5.02	5.68	8.09	8.13	**6.42**
Al2O3 (%)	1.14		2.28	2.44	1.99	2.66	2.92	**2.46**
CaO (%)	.63		.36	.37	.31	.42	.39	**.37**
MgO (%)	.10		.18	.17	.20	.24	.28	**.21**

TABLE 5

Raw Coal and Product Coal Sizing Comparison

Buchanan Coal Raw Coal Sizing

Screen Size	% On	% Cum
+2"	0.0	0.0
2x1-1/4"	0.6	0.6
1-1/4x1"	0.7	1.3
1x3/4"	1.7	3.0
3/4x1/2"	4.5	7.5
1/2x3/8"	1.5	9.0
3/8x1/4"	8.0	17.0
1/4x4M	2.0	19.0
4x8M	15.0	34.0
8x16M	17.0	51.0
16x28M	16.0	67.0
28x48M	13.0	80.0
48x100M	11.0	91.0
100x200M	5.3	96.3
-200M	3.7	100.0

Buchanan Coal Product Coal Sizing
Granular Size
August 1998

Screen Size	% On	% Cum
+4M	0.0	0.0
-4x8M	0.2	0.2
-8x16M	2.0	2.2
-16x30M	8.1	10.3
-30x50M	15.3	25.6
-50x100M	28.4	54.0
-100x200M	32.6	86.6
-200x325M	12.2	98.8
-325M	1.2	100.0

Granulated Coal is: 100% -4 Mesh(5mm)
98% -7 Mesh(3mm)
< 30% -200 Mesh

Pulverized Coal is: 65% -200 Mesh

Oxbow Coal Raw Coal Sizing

Screen Size	% On	% Cum
2"	0.0	0.0
1"	17.9	17.9
1/2"	25.1	43.0
1/4"	21.0	64.0
-1/4"	36.0	100.0

Oxbow Coal Product Coal Sizing
Granular Size
October 1998

Screen Size	% On	% Cum
+4M	0.0	0.0
-4x8M	1.1	1.1
-8x16M	6.2	7.3
-16x30M	14.5	21.8
-30x50M	16.6	38.4
-50x100M	18.1	56.5
-100x200M	18.6	75.1
-200x325M	15.1	91.2
-325M	9.8	100.0

Oxbow Coal Product Coal Sizing
Pulverized Size
November 13-26

+ 50 Mesh	- 200 Mesh
0.48%	66.10%

Oxbow Coal Product Coal Sizing
Pulverized Size
2 Sample Average (Wet Analysis)

Screen Size	% Cum
+8M	0.00
-8x16M	0.03
-16x28M	0.18
-28x48M	0.56
-48x100M	7.07
-100x200M	26.24
-200x325M	49.40
-325M	100.00

TABLE 6

BURNS HARBOR D FURNACE ADJUSTED COKE RATE COMPARISON
GRANULAR LOW VOLATILE COAL COMPARED TO GRANULAR HIGH VOLATILE COAL

Coke Correction Variables:	Buchanan Base AUGUST 1998 Granular	Colorado Oxbow OCTOBER 1998 Granular
Natural Gas, lbs/NTHM	2.0	2.0
Coke Correction, lbs coke		**0.0**
Injected Coal, lbs/NTHM	250	190
Coke Correction, lbs coke		**-60.0**
Sinter, %	30.6	35.0
Coke Correction, lbs coke		**+3.5**
Pellets, %	68.5	63.9
Coke Correction, lbs coke		**+3.7**
Wind Volume, SCFM	149,600	149,600
Coke Correction, lbs coke		**0.0**
Blast Temperature, F	2089	2045
Coke Correction, lbs coke		**-7.7**
Added Moisture, Grs./SCFM Wind	21.2	19.5
Coke Correction, lbs coke		**+5.8**
Iron Silicon Content, %	.49	.60
Coke Correction, lbs coke		**-11.0**
Iron Sulfur Content, %	.042	.037
Coke Correction, lbs coke		**-2.5**
Iron Manganese Content, %	.37	.40
Coke Correction, lbs coke		**-0.7**
Coke Ash(Includes Chinese Coke)	7.80	7.80
Coke Correction, lbs coke		**0.0**
TOTAL CORRECTIONS: lbs coke	BASE	-68.9
Reported Furnace Coke Rate, lbs/NTHM	683	798
Corrected Furnace Coke Rate, lbs/NTHM	BASE	729
Coke Rate Difference from Base		**46 Pounds of Coke/NTHM**

TABLE 7

BURNS HARBOR D FURNACE ADJUSTED COKE RATE COMPARISON
GRANULAR HIGH VOLATILE COAL COMPARED TO PULVERIZED HIGH VOLATILE COAL

Coke Correction Variables:	Colorado Oxbow OCTOBER 1998 Granular	Colorado Oxbow 11/13-11/26/98 Pulverized
Natural Gas, lbs/NTHM	2.0	0.0
Coke Correction, lbs coke		**-2.4**
Injected Coal, lbs/NTHM	190	183
Coke Correction, lbs coke		**-7.0**
Sinter, %	35.0	35.7
Coke Correction, lbs coke		**+0.6**
Pellets, %	63.9	63.6
Coke Correction, lbs coke		**+0.2**
Wind Volume, SCFM	149,600	141,539
Coke Correction, lbs coke		**+8.2**
Blast Temperature, F	2045	2080
Coke Correction, lbs coke		**+6.0**
Added Moisture, Grs./SCFM Wind	19.5	22.8
Coke Correction, lbs coke		**-11.0**
Iron Silicon Content, %	.60	.52
Coke Correction, lbs coke		**+8.0**
Iron Sulfur Content, %	.037	.035
Coke Correction, lbs coke		**-1.0**
Iron Manganese Content, %	.40	.39
Coke Correction, lbs coke		**+0.3**
Furnace Slag Volume, lbs/NTHM	461	504
Coke Correction, lbs coke		**-8.6**
Coke Ash(Includes Chinese Coke)	7.80	7.70
Coke Correction, lbs coke		**+2.0**
TOTAL CORRECTIONS: lbs coke	BASE	-4.7
Reported Furnace Coke Rate, lbs/NTHM	798	800
Corrected Furnace Coke Rate, lbs/NTHM	BASE	795
Coke Rate Difference from Base		**-3**

TABLE 8

BURNS HARBOR D FURNACE SULFUR BALANCE
GRANULAR HIGH VOLATILE COAL TRIAL

SULFUR INPUT:	October 1998	**SULFUR OUTPUT**	October 1998
Material:		Material:	
Furnace Coke, Sulfur Analysis	0.72%	Blast Furnace Slag, Sulfur Analysis	1.43%
Tons Coke Used	82830	Tons Produced	47799
Tons Sulfur In	596.4	Tons Sulfur Out	683.5
Injected Coal, Sulfur Analysis	0.76%	Blast Furnace Iron, Sulfur Analysis	0.036%
Tons Coal In	19804	Tons Produced	207373
Tons Sulfur In	150.5	Tons Sulfur Out	74.7
Sinter, Sulfur Analysis	0.02%	Flue Dust, Sulfur Analysis	0.46%
Tons Sinter Used	115766	Tons Produced	1144
Tons Sulfur In	23.2	Tons Sulfur Out	5.3
Pellets, Sulfur Analysis	0.01%	Filter Cake, Sulfur Analysis	0.52%
Tons Sinter Used	211703	Tons Produced	2995
Tons Sulfur In	21.2	Tons Sulfur Out	15.6
Scrap, Sulfur Analysis	0.13%	Top Gas, Sulfur Content	1.7 grs./100SCF
Tons Scrap Used	3546	Gas Produced, MMCF	103,400
Tons Sulfur In	4.6	Tons Sulfur Out	12.5
TOTAL TONS OF SULFUR IN:	**795.9**	TOTAL TONS OF SULFUR OUT:	**791.6**
		SULFUR OUT/SULFUR IN:	**0.995**

BURNS HARBOR D FURNACE SULFUR BALANCE
PULVERIZED HIGH VOLATILE COAL TRIAL

SULFUR INPUT:	November 13-26,1998	**SULFUR OUTPUT**	November 13-26,1998
Material:		Material:	
Furnace Coke, Sulfur Analysis	0.72%	Blast Furnace Slag, Sulfur Analysis	1.33%
Tons Coke Used	37565	Tons Produced	23719
Tons Sulfur In	270.5	Tons Sulfur Out	315.5
Injected Coal, Sulfur Analysis	0.76%	Blast Furnace Iron, Sulfur Analysis	0.035%
Tons Coal In	8595	Tons Produced	93938
Tons Sulfur In	65.3	Tons Sulfur Out	32.8
Sinter, Sulfur Analysis	0.02%	Flue Dust, Sulfur Analysis	0.55%
Tons Sinter Used	52835	Tons Produced	456
Tons Sulfur In	10.6	Tons Sulfur Out	2.5
Pellets, Sulfur Analysis	0.01%	Filter Cake, Sulfur Analysis	0.46%
Tons Sinter Used	94255	Tons Produced	1148
Tons Sulfur In	9.4	Tons Sulfur Out	5.3
Scrap, Sulfur Analysis	0.13%	Top Gas, Sulfur Content	1.1 grs./100SCF
Tons Scrap Used	1070	Gas Produced, MMCF	47,400
Tons Sulfur In	1.4	Tons Sulfur Out	3.7
TOTAL TONS OF SULFUR IN:	**357.2**	TOTAL TONS OF SULFUR OUT:	**359.8**
		SULFUR OUT/SULFUR IN:	**1.007**

FIGURE 1

PROJECT MILESTONE DATES

Begin Detailed Construction Engineering	April 1, 1993
Received State Environmental Construction Permit	August 4, 1993
Start Construction	August 31, 1993
90% Design Review	January 12, 1994
50% Construction Review	June 1994
100% Construction Review	December 1994
Begin Coal Testing Demonstration	November 1995
Complete Coal Testing Demonstration	June 1999

FIGURE 2

Burns Harbor C Furnace - 1998 Injected Coal and Coke Rate Performance

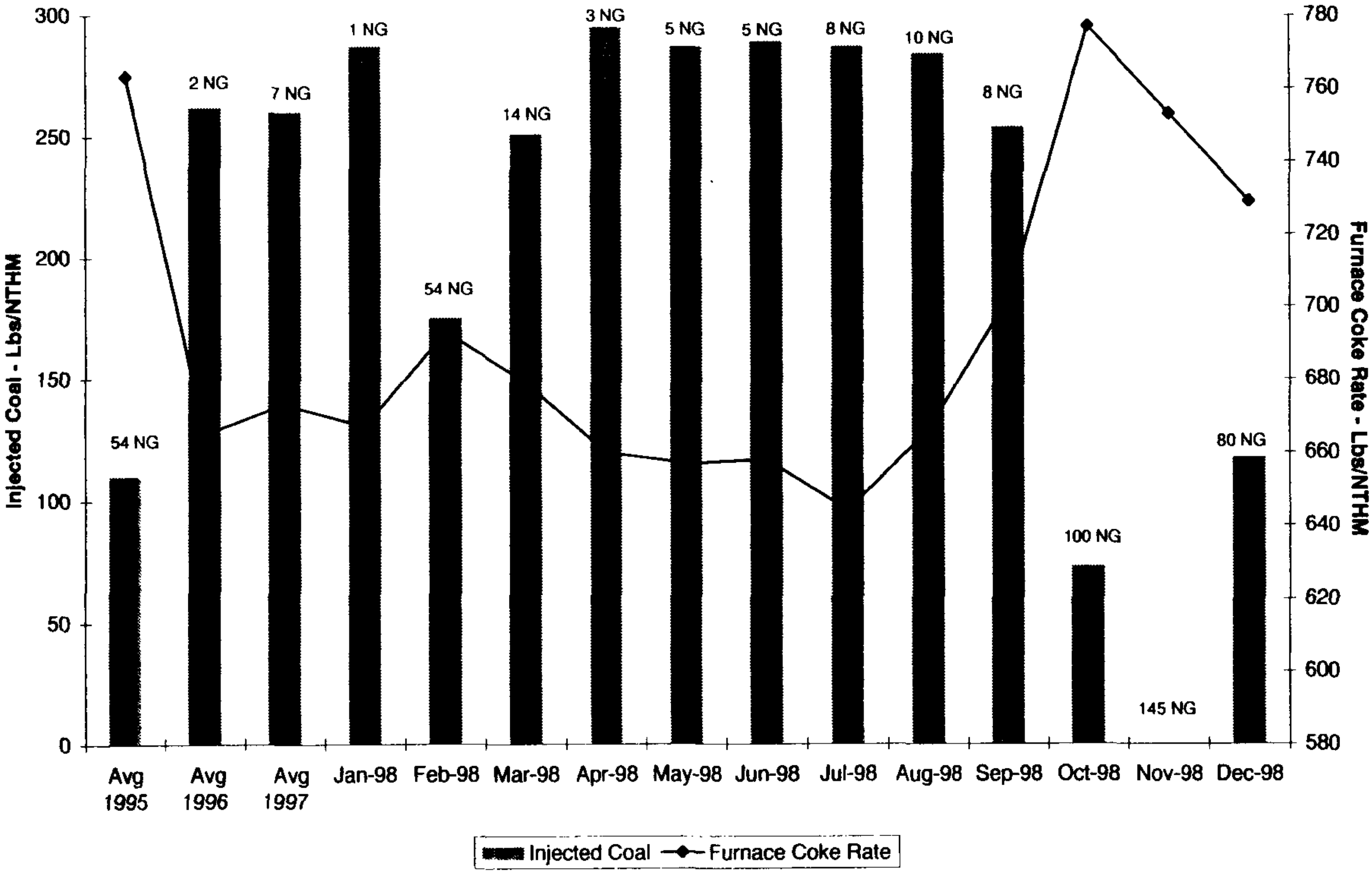
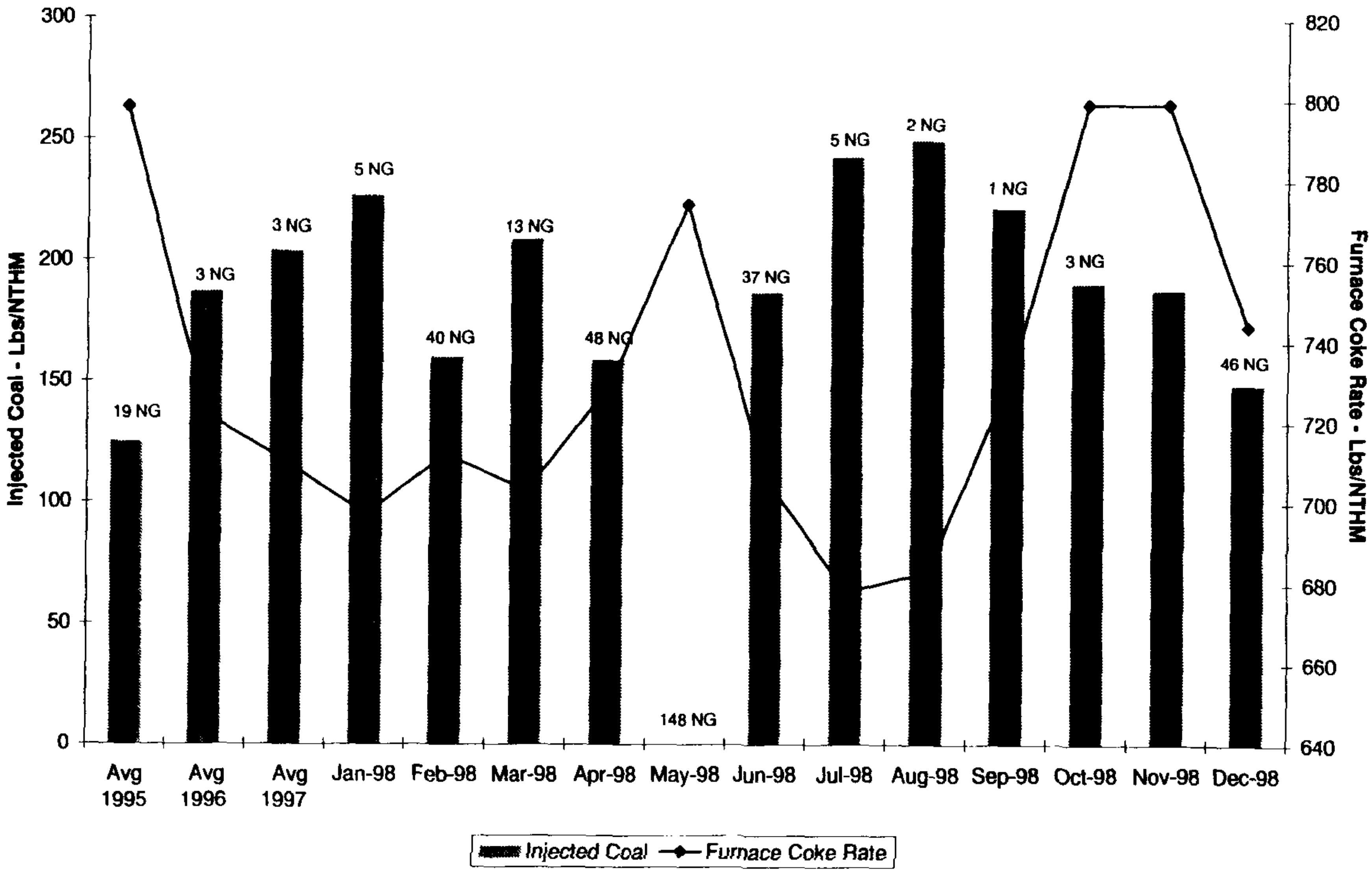


FIGURE 3



Burns Harbor D Furnace - 1998 Injected Coal and Coke Rate Performance

FIGURE 4

BURNS HARBOR - COAL GRINDING MILL ENERGY CONSUMPTION

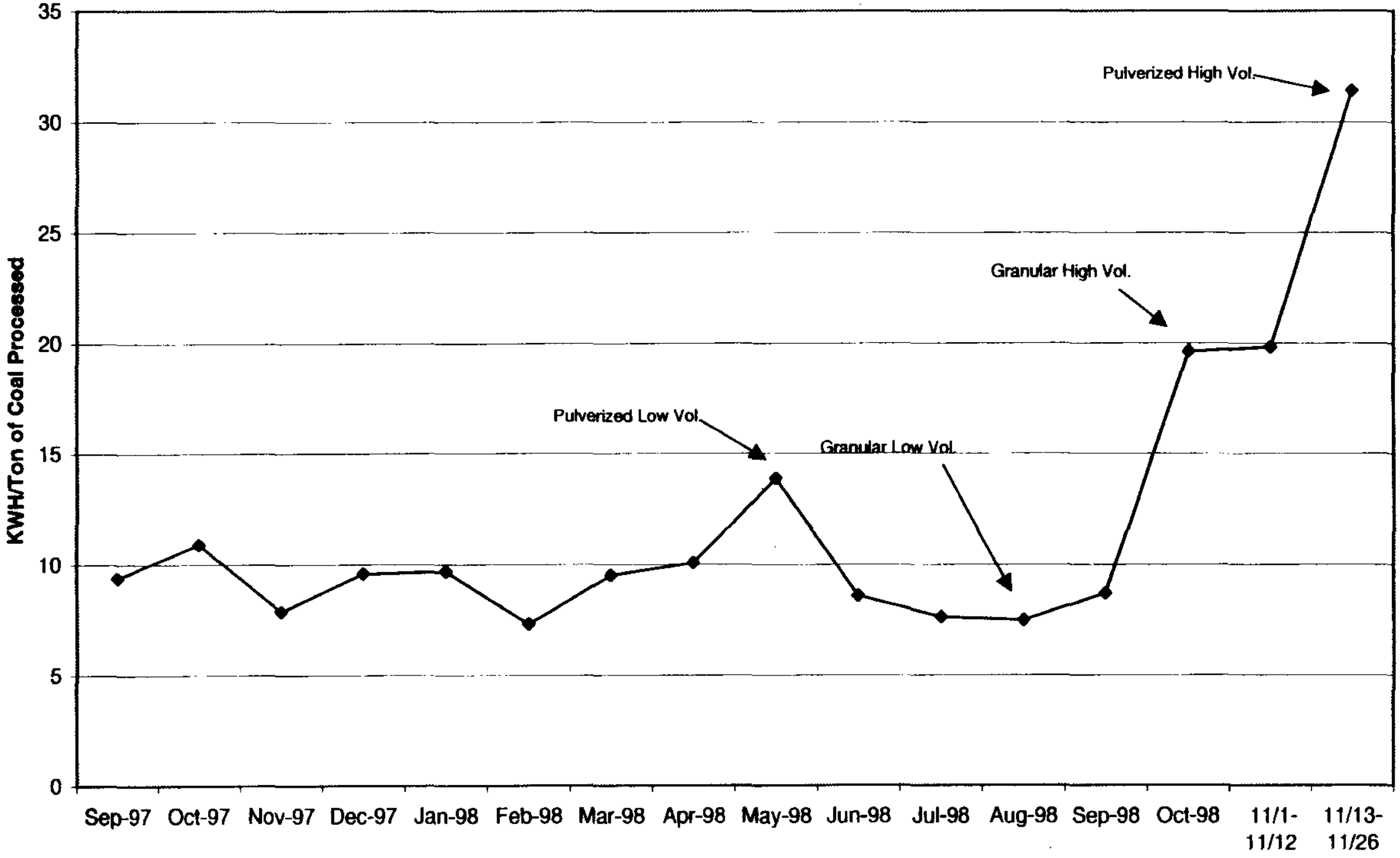


FIGURE 5

BURNS HARBOR C FURNACE-INWALL REFRACTORY TEMPERATURE

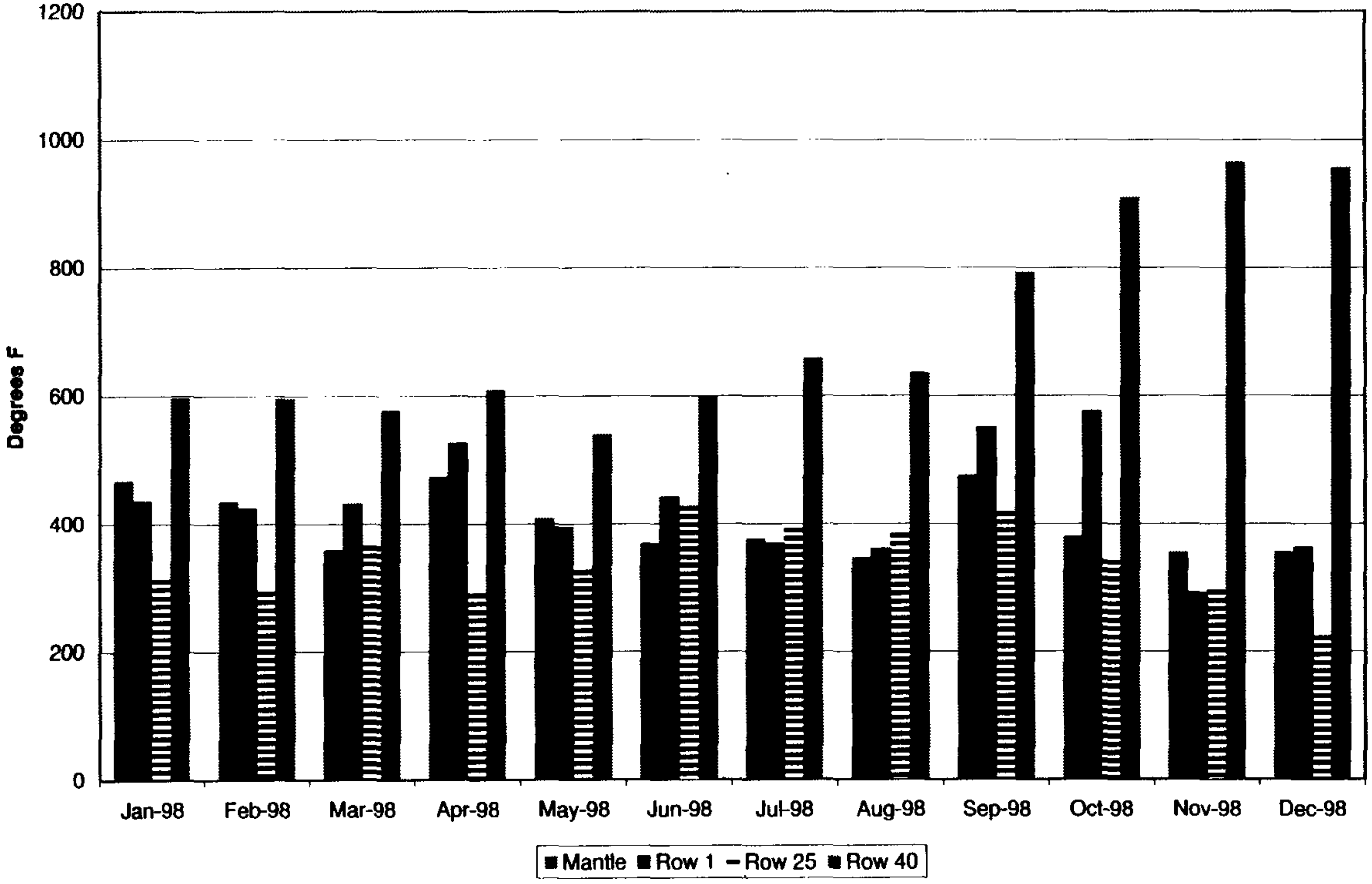


FIGURE 6

BURNS HARBOR C FURNACE THERMAL LOADS

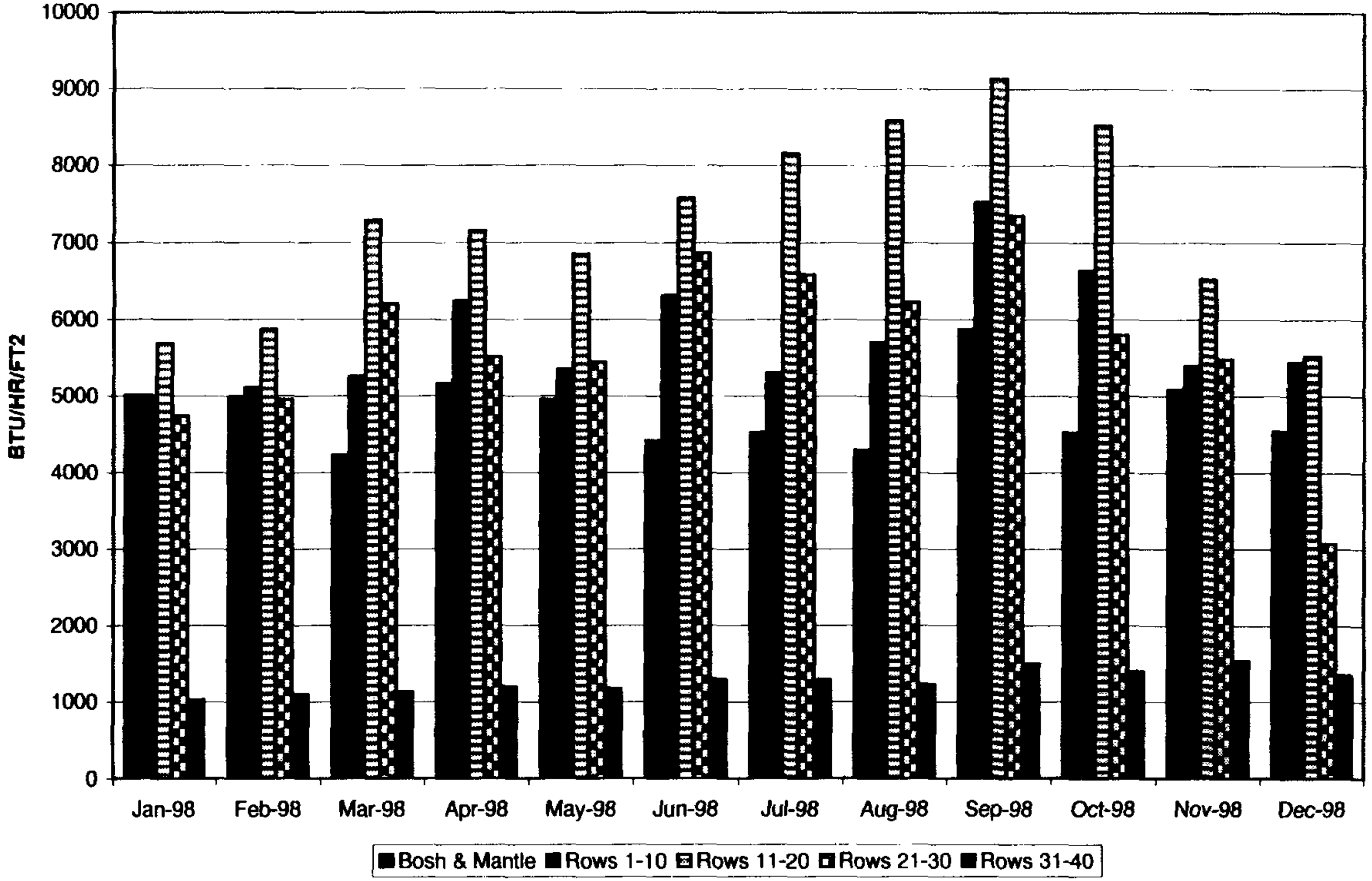


FIGURE 7

BURNS HARBOR D FURNACE - INWALL REFRACTORY TEMPERATURE

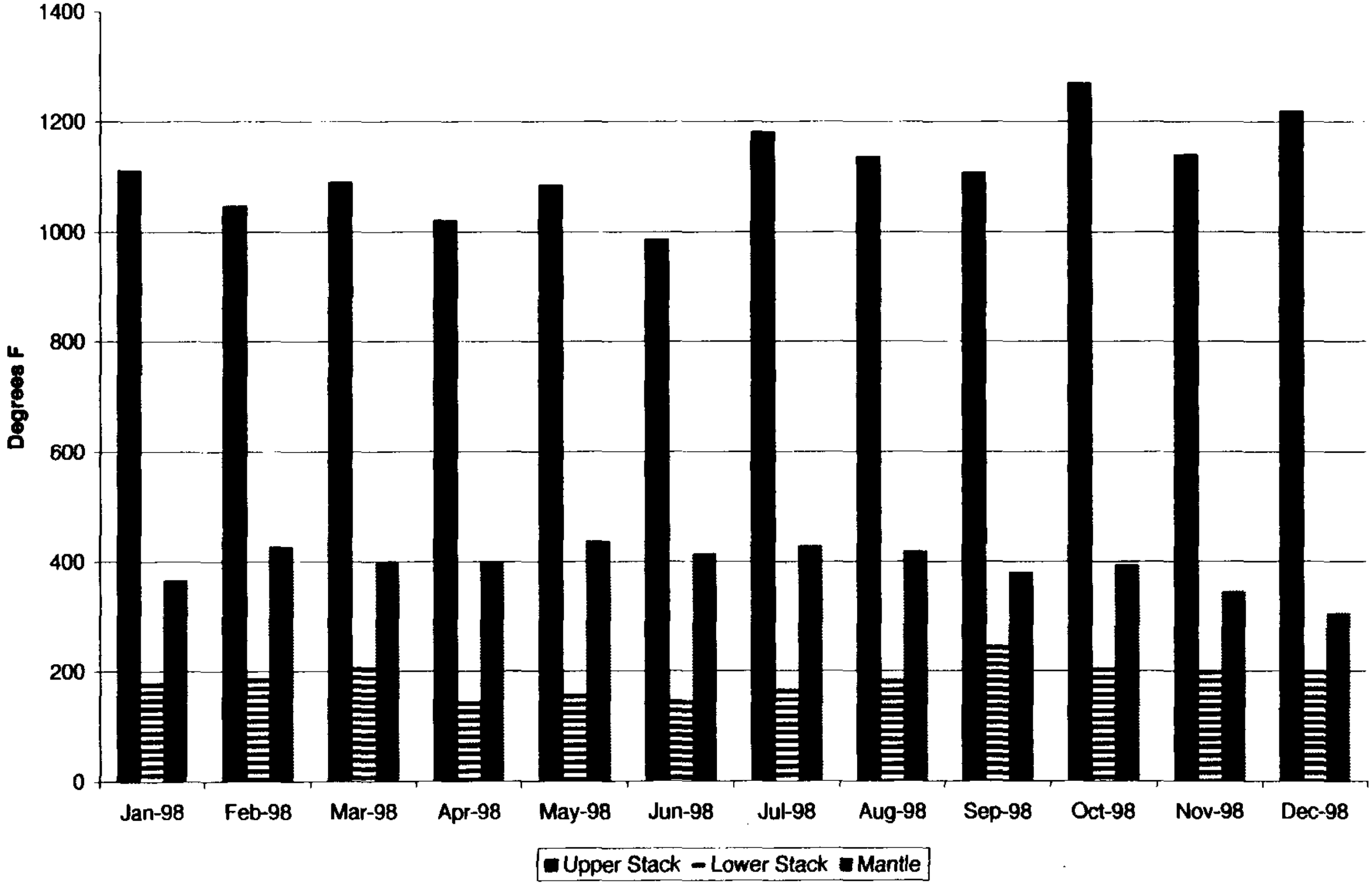


FIGURE 8

BURNS HARBOR D FURNACE - THERMAL LOADS

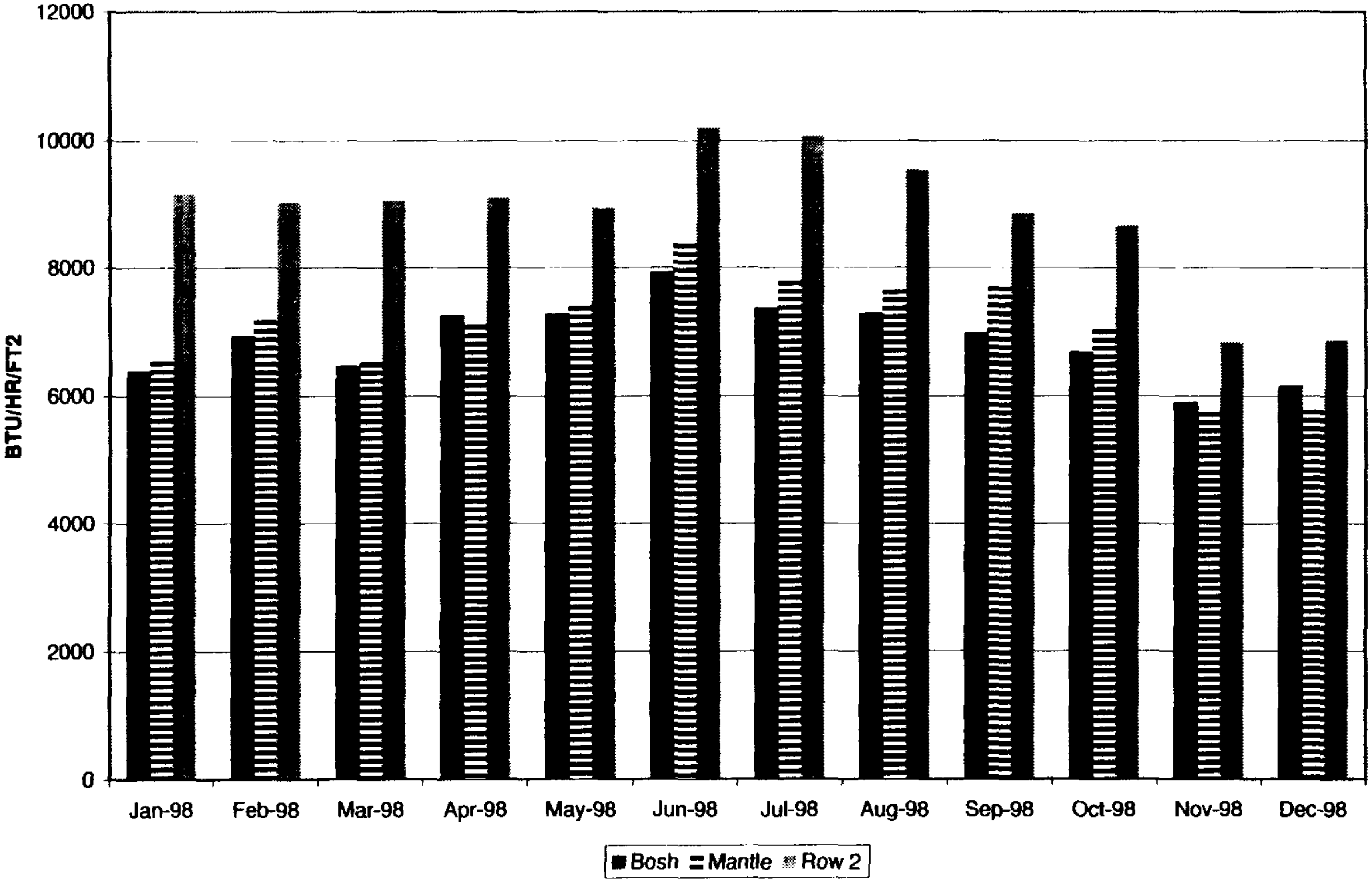


FIGURE 9

BURNS HARBOR D FURNACE - THERMAL LOADS

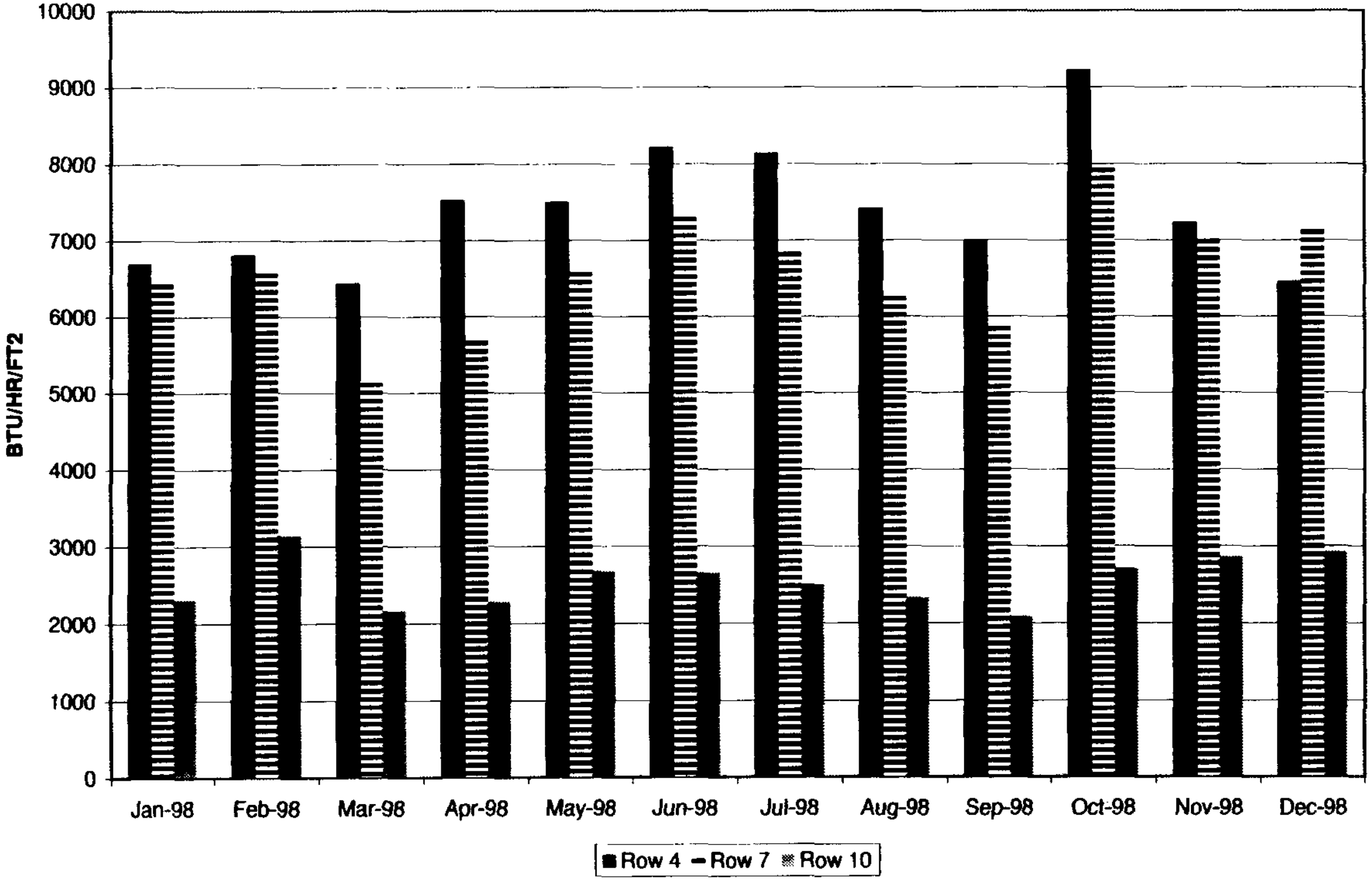


FIGURE 10

BURNS HARBOR D FURNACE - THERMAL LOADS

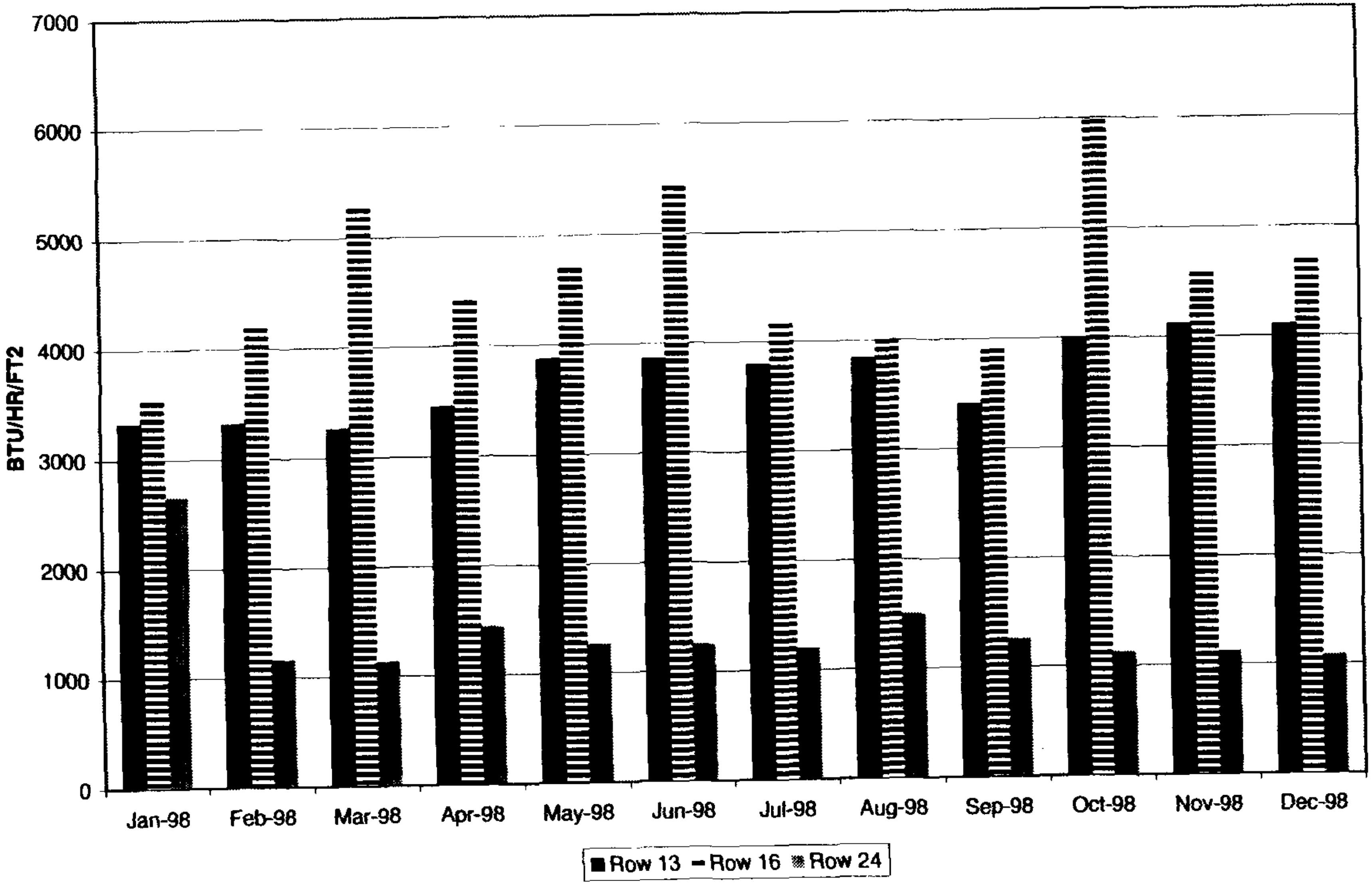
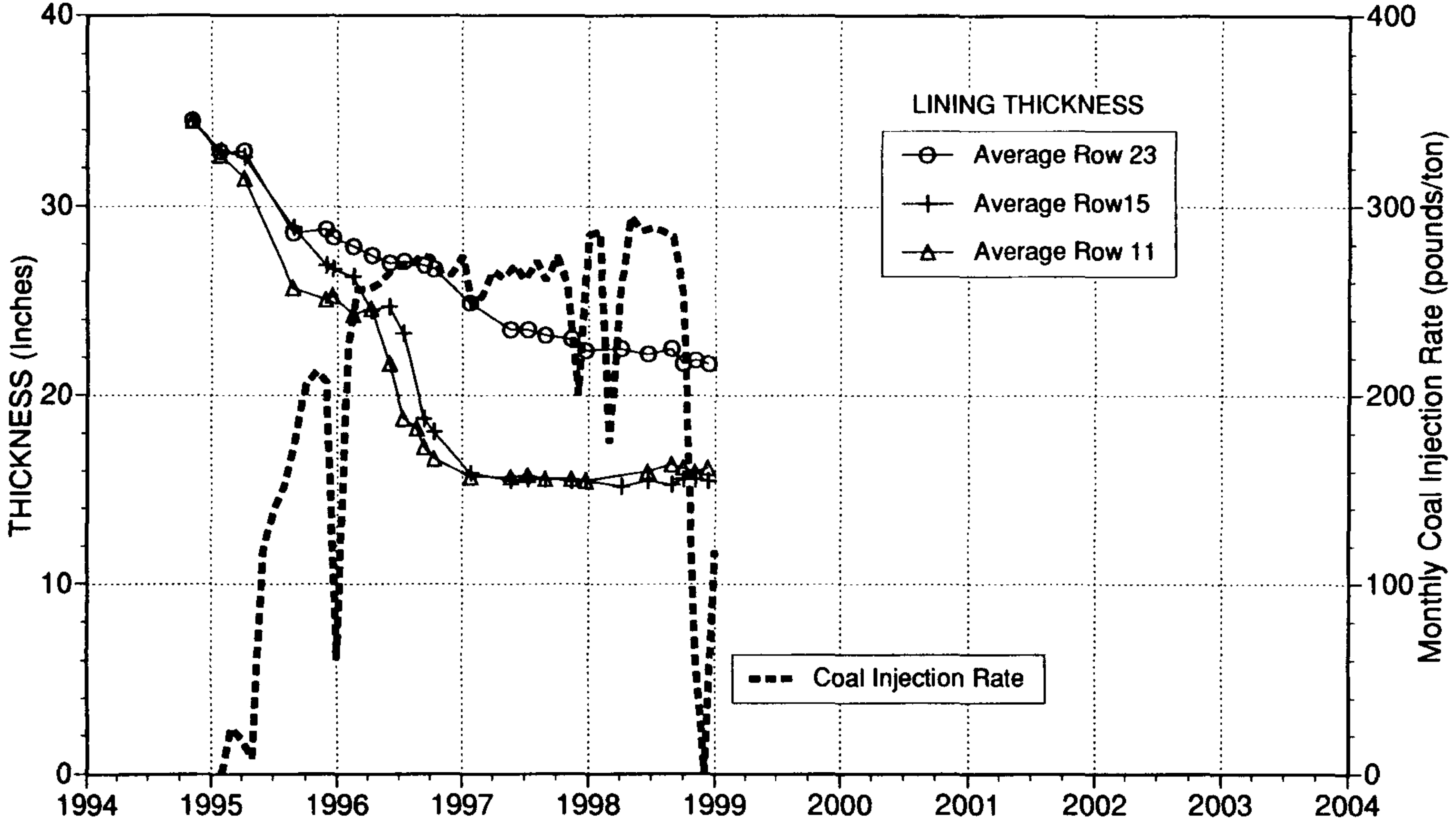
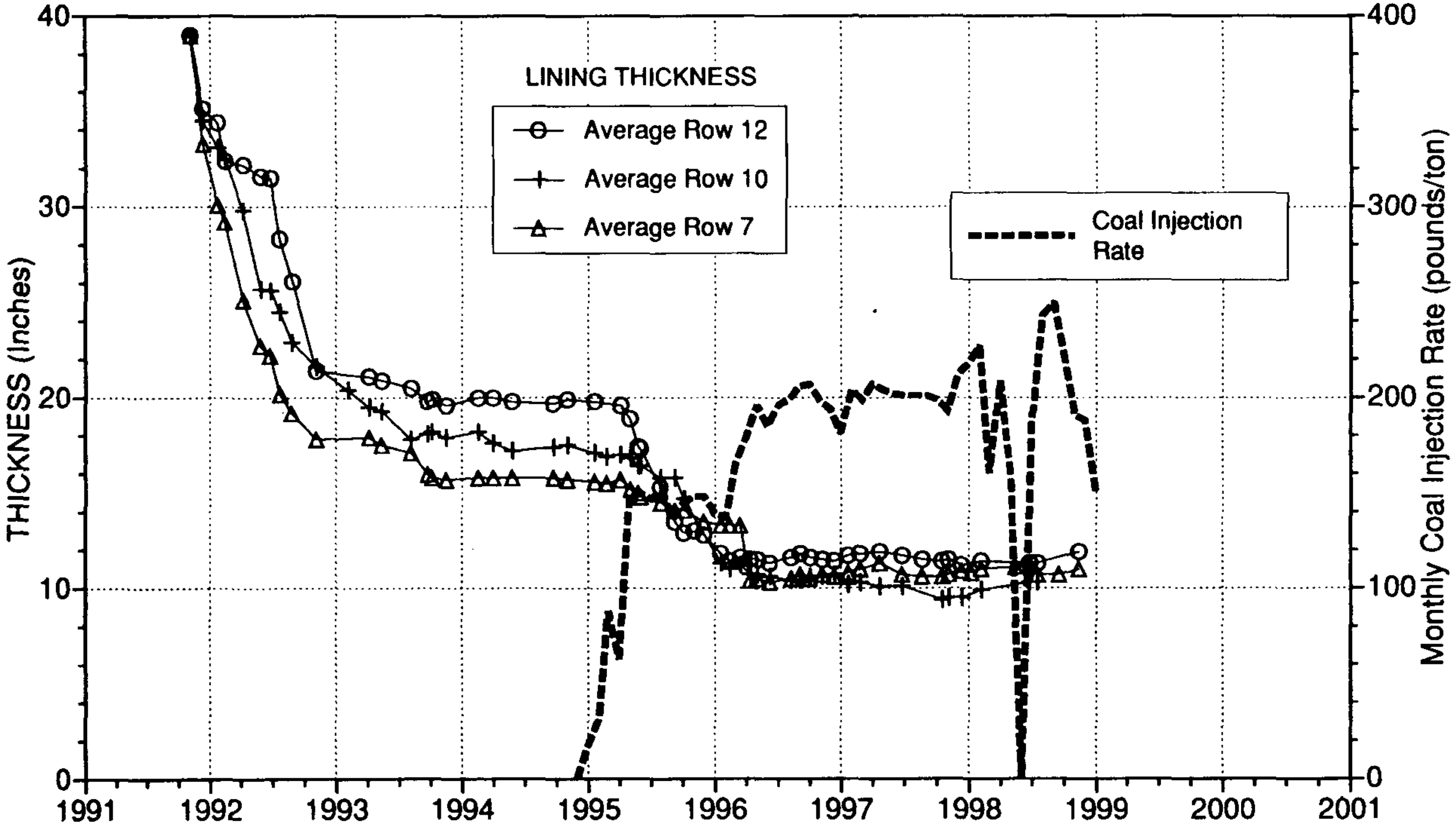


FIGURE 11
LINING WEAR vs. COAL INJECTION
BURNS HARBOR "C" FURNACE



Date Blown In: 11/4/94
Date of Last Measurement: 12/10/98
RAS/JCM

FIGURE 12
LINING WEAR vs. COAL INJECTION
BURNS HARBOR "D" FURNACE



Date Blown In: 11/4/91
Date of Last Measurement: 11/12/98
RAS/JCM