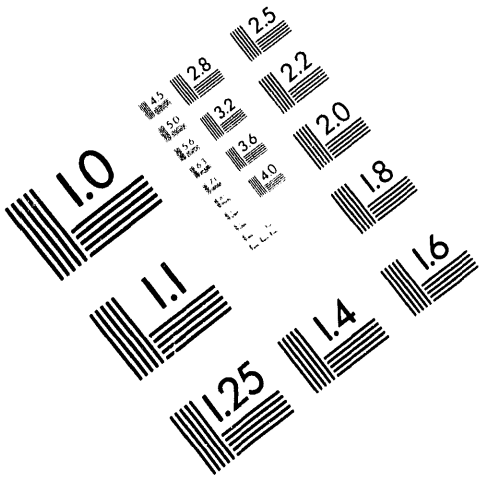

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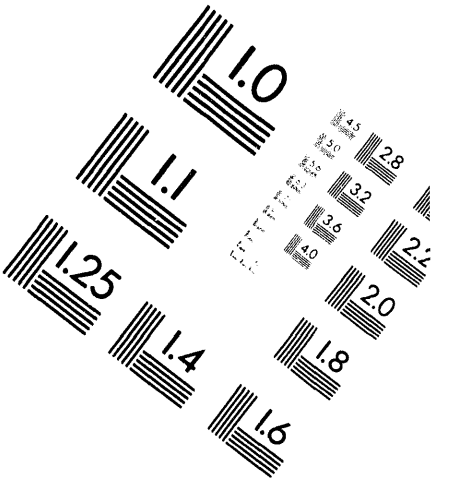

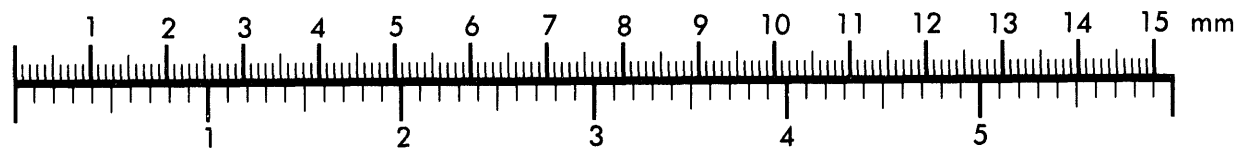

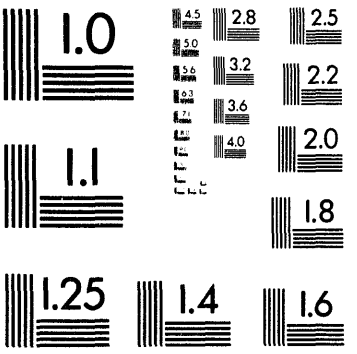

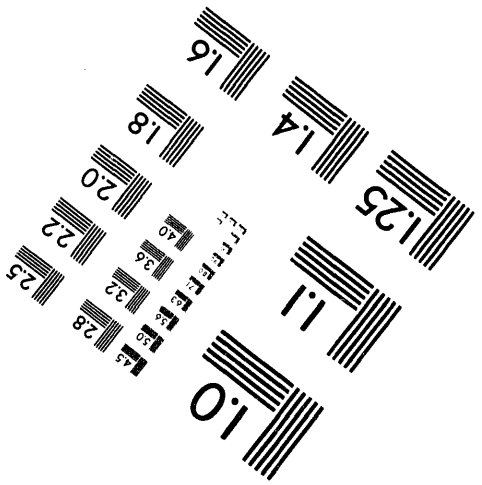

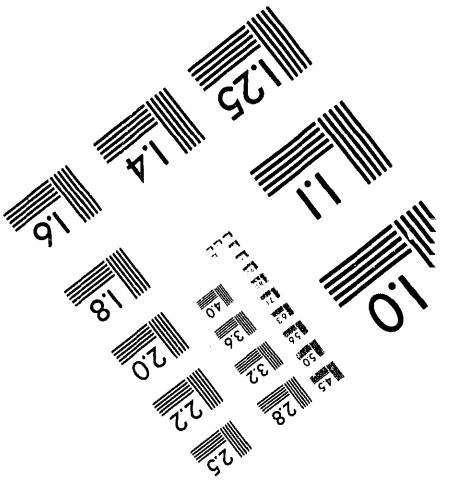

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DOE/PC/92158--T7 Ju-1 2

QUARTERLY TECHNICAL PROGRESS REPORT

FINAL

Report Period: ~~Second~~ First Quarter FY94 (1/94-3/94)

Engineering Development of Advanced Coal-Fired Low Emission Boiler Systems
DE-AC22-92PC92158

Riley Stoker Corporation
5 Neponset Street
P.O. Box 15040
Worcester, MA 01615-0040
Contract Period (total): October 1, 1992 to August 31, 2000

TECHNICAL PROGRESS

Summary

The major task during this quarter was testing and evaluation of the 25 MBtu/hr Toroidal Vortex Combustor (TVC) at Textron Defense Systems' (TDS) Haverhill laboratories. The tests were completed and the results are being evaluated along with other scale up and integration issues. The preliminary conclusion is that the NOx performance and current design uncertainties do not justify the development risk within the LEBS timetable. Further program effort will focus on advanced U-firing arrangements.

The second major effort during the period was the engineering development of the moving bed copper oxide system for SOx/NOx control. Through application of a DOE-developed model and the team's engineering analysis, significant progress was made on developing an improved process design. Work began on a small scale test of the moving bed concept under realistic temperature and dust loading conditions.

Work continued through the quarter on finalizing the Preliminary Engineering Design, Design Deficiency Analysis, and Research, Development, and Test Plan. The Design and Development Report containing these three deliverables was released in March. Sargent & Lundy printed and distributed the report to team members, as well as to the advisory panelists. The advisory panel numbers approximately fifteen organizations as of the end of the period.

Emission Control

Emissions control work focused on developing the preliminary design of the copper oxide combined SO2/NOx control process. Sargent & Lundy submitted two LEBS-

related proposals to the Illinois Clean Coal Institute, both of which involve copper oxide development. We have also written a preliminary Cooperative Research and Development Agreement (CRADA) and met with Henry Pennline of PETC to discuss the potential CRADA. Riley, Teco, and Sargent & Lundy participation as a team is an excellent fit with our LEBS development interests.

Teco implemented a DOE-developed model of the moving bed using a published listing. We are beginning to evaluate the effect of alternative copper oxide sorbent geometry. DOE's previous tests have focused on the 1/16" spheres used in the development of the fluidized bed copper oxide process. Larger sorbent sizes would give slower reaction and require a larger bed volume, but could decrease face area and handling problems. The effect of sorbent size on reaction rate was estimated using the limited information from published work and some general reaction rate equations. Absorber requirements were then evaluated for constant SO2 removal (99%), pressure drop, and Cu/S (i.e., circulation rate). By way of example, this estimate indicated that a 1/8" diameter sorbent substrate would require about 15% larger bed volume compared to the 1/16" base case. However, the face area is reduced by over 40%, reducing plan area and sorbent distribution problems. The optimum size depends on relative sorbent and absorber vessel costs. The reaction rate estimate is uncertain, but this illustrates the importance of generating good rate vs. size data.

Riley completed the design of a moving bed absorber simulator to be installed in the PSCF (nominal 3 million Btu/hr, pc fired). The device will test pressure drop, particulate removal, and operability of granular beds of various size spheres. We will use inert substrate material and will not attempt to run the SO2 or NOx chemistry in the remainder of Phase 1. At the end of the period, parts were on site ready for assembly.

TVC Testing and Evaluation

The primary effort in this reporting period was completion of testing of the Toroidal Vortex Combustor at Textron's Haverhill laboratories. This represented the major experimental portion of the Phase 1 program, and was a key task in providing data for selection of a firing system for further development.

Analytical issues. As described in the preceding Quarterly Progress Report, Textron completed three runs in December during which Riley was unable to provide independent sample analysis. Early in the current period, Riley set up independent sampling for NOx and CO2 (the latter as an indication of stoichiometry) for Runs 4 (January 13) and 5 (January 25). Riley's measurements were all taken at the "lower elbow", i.e., in the short duct following the exhaust housing (impact separator vessel). The sample was withdrawn through a (warm) water cooled probe, heated ceramic filter, and heated line to a Teco Model 800/10 combination. The 800 simply contains the normal Model 10 capillaries in a heated zone, so that the sample is under high vacuum before it goes to the Model 10 at more or less ambient temperature.

The sample was also diluted with about 50% air during most sampling in order to: 1) ensure oxygen for conversion of the NO precursors NH3 and HCN to NO with the analyzer in NOx mode; 2) avoid potential stripping of the oxide layer in the converter with a reducing sample. The latter effect has been observed in certain converter modules at Riley wherein an oxygen free NO calibration gas gives an

apparent response of zero after a brief period of operation in the NOx mode. However, there seemed to be no difference with or without dilution air in the 1-2 hour test periods of these runs.

The primary span calibration gas was 288 ppm NO, balance N2. As a check for response under reducing conditions, an 88 ppm NO in 10% CO/balance N2 gas was also used. The calibration gases were admitted to the sample probe upstream of the heated ceramic filter. The gases agreed to within 5-10% of one another. This is more error than desired (nominal 2% accuracy gases), but does not impact the interpretation of results significantly.

No difference above noise/drift was apparent between NOx and NO modes at the richest conditions tested in Runs 4 and 5, about 0.7 SR. As configured, the NOx mode should detect the sum of NO and precursors HCN and NH3 which are converted to NO within the analyzer. Riley also provided wet chemical analysis for NH3 and HCN. The wet analysis may be suspect because of short sample time, particularly with NH3 (a "sticky" gas which can be lost in the sample system). However, the sum of wet analysis NH3 and HCN was 4-12 ppm for the tests in Runs 4 and 5, confirming that precursor concentration was low under these conditions.

Textron had reported NOx values of 0.0254 lb/MBtu for Run 1 on the Illinois 5 test coal, and 0.0204 lb/MBtu for Dorchester coal in Run 3. We had noted in the report for December that the NOx in these runs dropped quickly on transition to fuel rich conditions, but then decayed to very low values over a period of about 20 minutes. Initially in Run 4, the Textron NOx value agreed with the Riley value near stoichiometric conditions (>1000 ppm), but decayed to 20-50 ppm over a ten-twenty minute period following transition to 0.71 SR. The Riley analyzer dropped quickly to about 500 ppm on transition to rich conditions, and remained stable. A second Textron analyzer ("Analyzer 2) put on line at that point agreed with the Riley value, in the 500 ppm range (about 0.5 lb/MBtu as NO2, input Btu basis). In Run 5, both Textron analyzers again agreed near stoichiometric, but the original ("Analyzer 1") again showed rapid decay after going rich. Both were then switched to NO mode, and agreed reasonably with ours. Near the end of the run both were switched briefly to NOx. Textron Analyzer 1 decayed rapidly; Analyzer Two appeared to decay, but much more slowly.

In the runs 1-3 in December, the analyzer was always on NOx mode. The apparent NOx was high near stoichiometric, and vanishing at fuel rich conditions.

We do not yet understand the analyzer problem, since all three analyzers are Teco Model 10's of various vintages. The first hypothesis was lack of O2 for the converter, but TDS Analyzer 1 is reported to be set up with air dilution conditioning. Furthermore, the Riley analyzer did not experience a noticeable decay when the dilution air inlet was closed off during fuel rich sampling.

While we do not understand the cause of the analytical difficulty in Runs 1-3, we are confident that the values measured for Runs 4 and higher are correct. Given the constraints on the schedule and budget, exploring the analyzer behavior was a lower priority than completing as many combustion tests as possible with the remaining resources.

For Run 6 (February 7) and Run 7 (February 17), the sample system included a condenser for the NOx sample, in contrast to the hot system in earlier runs. This had no apparent effect on the measurement.

Combustion results. The results of Runs 4 and 5 indicated that the TVC primary zone NOx levels (all measurements taken at the exhaust housing exit, no final combustion air added) are about 0.7 lb/MBtu at 0.8 SR, and about 0.45 lb/MBtu at 0.7 SR.

Run 6 explored a wider range of stoichiometry, with actual values ranging from 0.85 to 0.65 SR at full load of 25 MBtu/hr, and 0.65 to 0.60 SR at 60% load. At 0.65 SR, the low load case had slightly higher NO values than full load. Precursor samples were limited to one set (NH3 and HCN) per condition, but indicate somewhat higher precursor values for low load (91% of Total Fixed Nitrogen as NO vs 96% at full load). At SR of 0.7 or higher, NO accounted for 98-99% of TFN. The NO results generally followed the trends seen previously Grab samples of gas were taken for analysis of H2, CO, and CO2 in the lab (by gas chromatography) to help resolve the carbon conversion issue.

Run 7 looked at an intermediate load of about 80%. At 0.63 SR, NO again accounted for about 90% of TFN. A very rich condition at full load was also tested. At 0.55 SR, the rich zone NO was just under about 0.18 lb (as NO2)/MBtu. However, NO at this point accounted for only less than 70% of the fixed nitrogen, with a total of 0.26 lb/MBtu TFN expressed as NO2. Additional gas samples were taken for lab analysis.

Both particulate and gas analysis indicate that conversion of carbon to the gas phase is greater than 98% at a stoichiomtry of 0.8 or higher. At richer stoichiometries, the two methods of calculating carbon coversion diverge. At 0.6 SR, the solids indicate about 8% unreacted carbon, while the gas analysis indicates 15-20% unreacted carbon.

Particulate samples were also analyzed for nitrogen. The potential contribution of char nitrogen to final NO emission is low at moderately reducing conditions. However, oxidation of char nitrogen is a sigificant potential source of NO at lower richer primary zone stoichiometries, of the order of the gaseous precursors.

Textron proposed to modify the TVC in order to improve performance. Program funds were unavailable to support the modification and test. However, Textron executed the modification and one additional test run under their internal support, referred to as IRAD.

While we did not support the modification and test under LEBS work, we did support the test with analytical services similar to those described previously above. The test was executed March 29. The details of the combustor modification and the Textron process data are proprietary to Textron. However, the NOx and precursor measurements supported under LEBS will be incorporated into the presentation of TVC results. Nominal test conditions were as follows: 20 MBtu/hr, 0.83, 0.77, 0.71, and 0.63 SR; 30 MBtu/hr, 0.83 SR; 15 MBtu/hr, 0.77 SR. The NOx performance was indistinguishable from previous tests when plotted against nominal stoichiometry.

The primary stage NO emissions for these tests are shown as ppm (dry, as-measured) and as lb NO2/MBtu (input Btu basis) in Figures 1 and 2. Figure 3 is a plot of NO/TFN vs stoichiometry.

Detailed results of the test program will be reported in a separate document. Results exclusive of the IRAD run were presented to PETC orally on March 7.

TVC model results. Hardware modifications have been proposed for the TVC in order to improve the NOx performance. Reaction Engineering ran a simple model to evaluate the potential improvement of additional residence time. They assumed an initial value of 550 ppm (wet, uncorrected) at 0.7 SR, . This is the value observed in the existing TVC, and is consistent with previous REI model results for the TVC (stirred and plug flow isothermal, no fluid dynamics). All components are assumed to be in the gas phase. The conclusion was that no improvement would be expected with the minor modifications feasible within the current phase of testing.

Firing system status. The test results are being evaluated along with scale up, constructability, boiler integration, and materials issues. Our preliminary conclusion is that the NOx performance and current design uncertainties do not justify the development risks for the LEBS timetable, which requires relatively rapid commercialization. We plan to focus further program effort on advanced U-firing arrangements.

3-D Model

We forwarded REI a package of data on operation of Staudinger Unit 3 as originally configured, and with two levels of retrofit staging NOx control. REI's modeling to date has been limited to relatively simple kinetic models using plug flow or stirred tank assumptions for flow. With the current effort, they will set up a fluid dynamic, reacting model of the Staudinger boiler- a wet-bottom, U-fired Benson- and attempt to duplicate the experimental NOx results. Following model validation, we will begin adding advanced staging and coal reburning to the model.

Industry Advisory Panel

Sargent & Lundy issued a broadcast letter soliciting membership in a LEBS Industry Advisory Panel to over 70 organizations. About fifteen have accepted so far. We plan to hold a meeting specifically for the panel members on May 25. This is an excellent means of gaining visibility and support for the project, and will help locate potential hosts for the Proof of Concept facility. A team-only project review meeting is planned for May 4.

Robert Beittel 4/15/94

Roderick Beittel
Program Manager

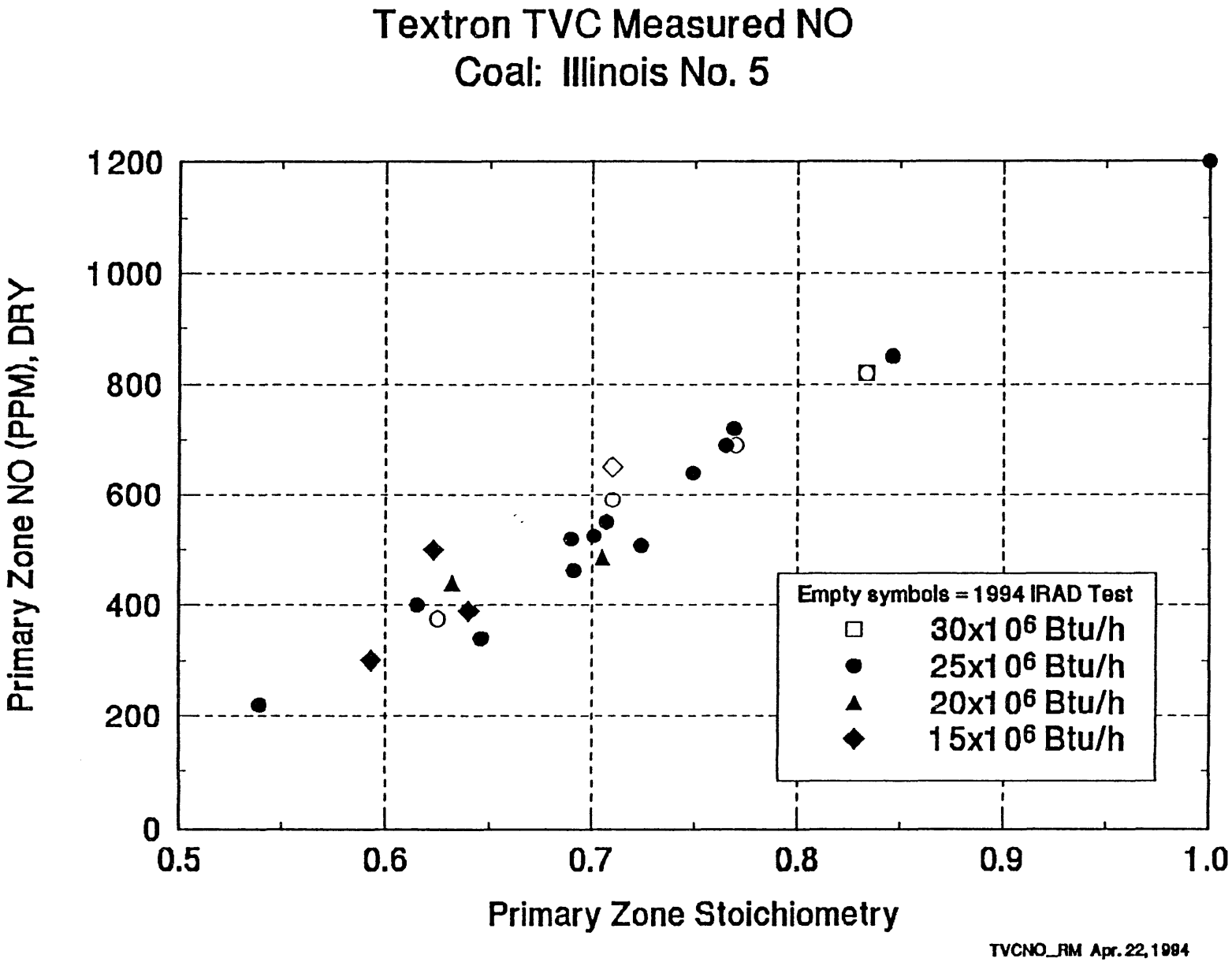
Textron TVC Measured NO
Coal: Illinois No. 5
Primary Zone NO (PPM), DRY
1200
1000
800
600
400
200
0
0.5
0.6
0.7
0.8
0.9
1.0
Primary Zone Stoichiometry
Empty symbols = 1994 IRAD Test
30x10^6 Btu/h
25x10^6 Btu/h
20x10^6 Btu/h
15x10^6 Btu/h
TVCNO_RM Apr. 22, 1994

Figure 1

Textron TVC NOx Emissions
Coal: Illinois No. 5

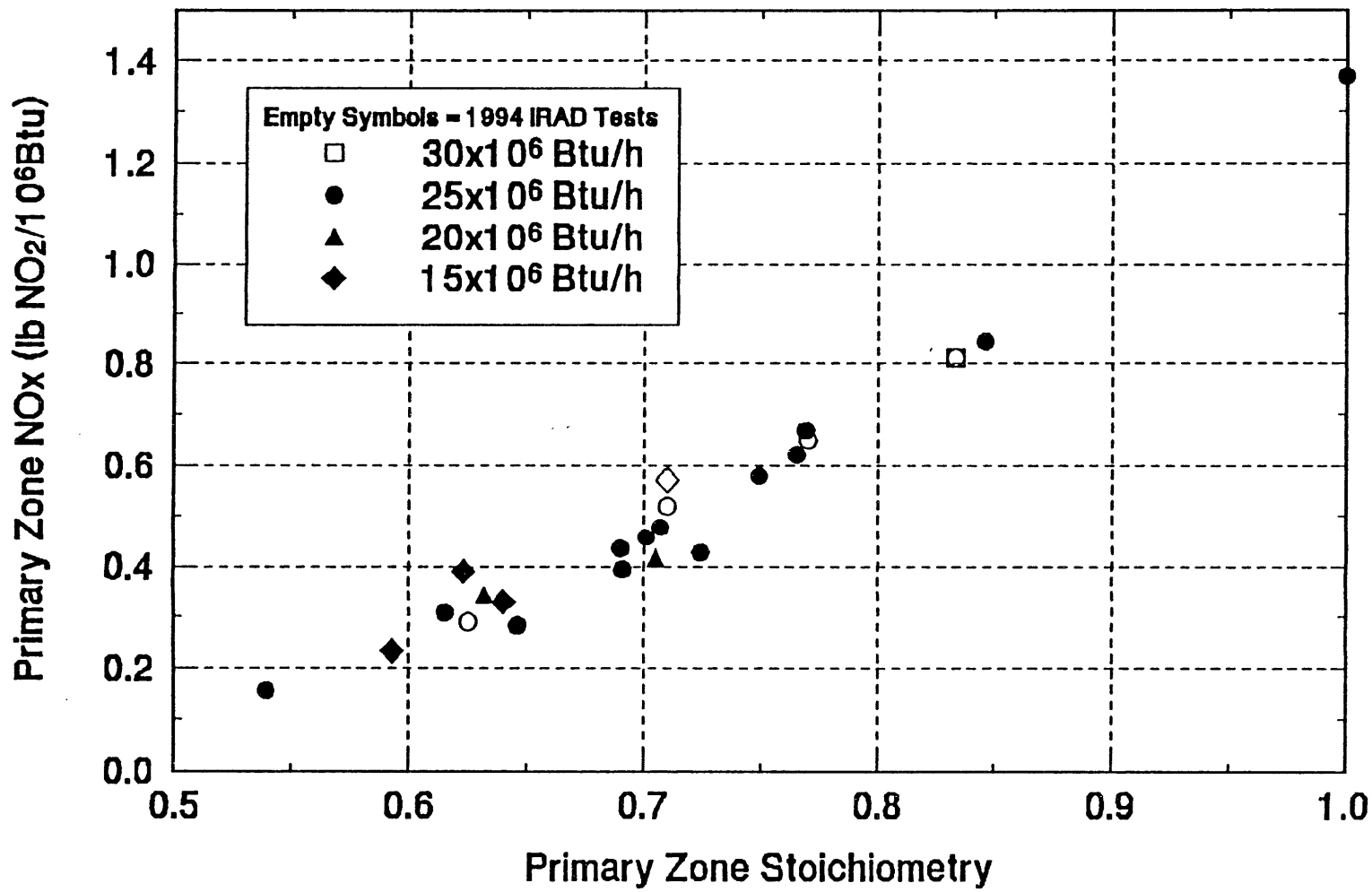

Figure 2

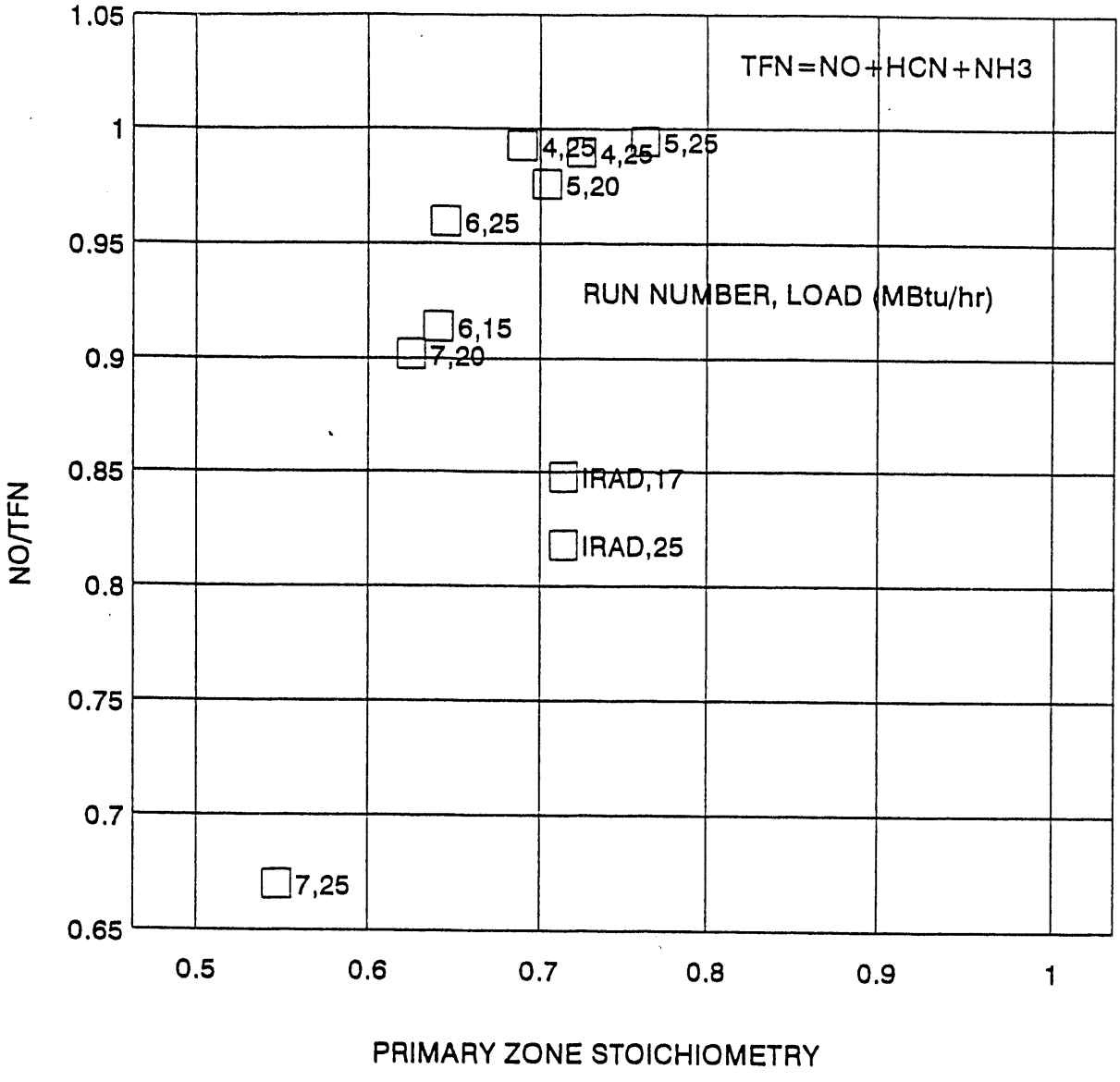

Figure 3. Primary Zone TVC NO/TFN

DATE
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9/8/94
END