DOE/ID/13332

DEVELOPMENT OF THE RADIATION STABILIZED DISTRIBUTED FLUX BURNER

Phase 1 Final Report

John D. Sullivan
Michael J. Duret

June 1997

Work Performed Under Contract No. FC07-95ID13332

For
U.S. Department of Energy
Assistant Secretary for
Energy Efficiency and Renewable Energy
Washington, DC

By
Alzeta Corporation
Santa Clara, CA

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Distribution Category UC-1409

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NOTICE

EXECUTIVE SUMMARY

This report covers the progress made during the first phase of a three-phase DOE-sponsored project to develop and demonstrate the Radiation-Stabilized Distributed-Flux Burner (also referred to as the Radiation Stabilized Burner or RSB) for industrial watertube boilers and process heaters. The RSB was first developed for Thermally Enhanced Oil Recovery (TEOR) steamers which fire with a single 60 MMBtu/hr burner. The burner was developed with the cooperation of the California Energy Commission and Chevron USA in Bakersfield, California. The burner has also since found applications in refinery and chemical plant process heaters.

In both applications, the required emissions levels were 30 ppm NO_x. However, both field and laboratory data have indicated that NO_x levels below 9 ppm are achievable with higher levels of excess air or moderate levels of external flue gas recirculation (FGR). The primary objective of the first year of work was to demonstrate that sub-9 ppm NO_x emissions and sub-50 ppm CO emissions (corrected to 3% oxygen) could be achieved with the RSB in a 3 MMBtu/hr laboratory boiler.

Secondary objectives of Phase 1 include: developing a marketing plan for the 9 ppm NO_x product; developing conceptual boiler designs based on the RSB to increase capacity without adding to the boiler's footprint; identifying a host site for Phase III of the project where a multi-burner boiler will be demonstrated during a 6-month trial; reducing the cost of goods of the burner to assure that the product can be competitive with other very low NO_x burners or other NO_x reduction techniques.

All Phase I project goals were successfully met and are summarized below:

- The RSB achieved sub-9 ppm NO_x and sub-50 ppm CO emissions using high excess air, external FGR, and fuel staging in the 3 MMBtu/hr laboratory watertube boiler.
- The RSB was also tested in a 50,000 lb/hr oil field steamer with fuel staging and consistently achieved sub-20 ppm NO_x and as low as 10 ppm NO_x.

- The RSB consistently achieved sub-20 ppm NO_x and as low as 5 ppm NO_x with high CO_2 casing gas in a 50,000 lb/hr oil field steamer simulating burner performance with external FGR.
- Burner material cost was reduced by 25% on a per Btu basis by increasing the effective surface firing rate at the burner. Further work on reducing burner material cost will continue in Phase II.
- The market for 30 ppm and 9 ppm low NO_x burners has been identified as package boilers in the 50,000 to 250,000 lb/hr size range. The burner retrofit market requires a 30 ppm NO_x product, and the new boiler market requires a 9 ppm product. Alzeta and Babcock & Wilcox have teamed to sell both boiler retrofits and new boilers.
- Alzeta and Babcock & Wilcox have identified boiler designs which take advantage of the compact flame shape of the RSB and can increase steam capacity while maintaining the same boiler footprint.
- Alzeta has teamed with Chevron and Babcock & Wilcox to identify sites to demonstrate the RSB in Phase II and Phase III.

With all Phase I technical goals met, Alzeta is beginning work on Phase II. In Phase II, the RSB will be demonstrated in an industrial watertube boiler. Alzeta and its partners have identified a 100,000 lb/hr watertube boiler that will serve as the Phase II demonstration site.

SECTION 1

INTRODUCTION

The Radiation-Stabilized Burner (RSB) was developed to overcome limitations of traditional radiant porous surface burners. Large-scale industrial applications of radiant porous surface burners have been limited because the low surface heat release rate (less than 150,000 Btu/hr-ft^2) of radiant burners can result in large burner sizes and relatively high costs. The development of the RSB in 1994 dramatically reduced the size requirement and cost of the burner element while maintaining the benefits of controlled flame shape and low emissions traditionally found in radiant burners.

The RSB, commercialized under the name Pyromat CSB, is a premixed, semi-radiant, natural gas-fired burner that uses a patented technique to form radiant and blue-flame zones adjacent to each other on a cylindrical porous surface metal mat. The burner offers surface heat release rates that are up to ten times higher than traditional radiant burners. References 1 and 2 discuss the development and application of the RSB in more detail. Figure 1-1 is a photograph of a 60 MMBtu/hr Pyromat CSB operating in a 50,000 lb/hr oil field steamer.

Currently the RSB can achieve 30 ppm NO_x at moderate levels of excess air and 9 ppm NO_x at high levels of excess air. The goal of this project is to simultaneously reduce NO_x emissions to sub-9 ppm levels at moderate excess air requirements and to extend its application into larger multi-boiler systems.

Extending the burner into larger boiler applications will require designing larger burner elements and applying multiple burner elements into a single furnace. The largest RSB element to date is 60 MMBtu/hr but extending the design to 190 MMBtu/hr is possible. Thus, boilers over 150,000 lb/hr capacity will require multiple burner elements. A multiple burner application is set for Phase III of the project.

The RSB uses a patented technique to form both radiant and blue-flame zones adjacent to each other on the burner surface to lower NO_x emissions relative to fully perforated burners. This selectively perforated technique offers several advantages over fully perforated burners:

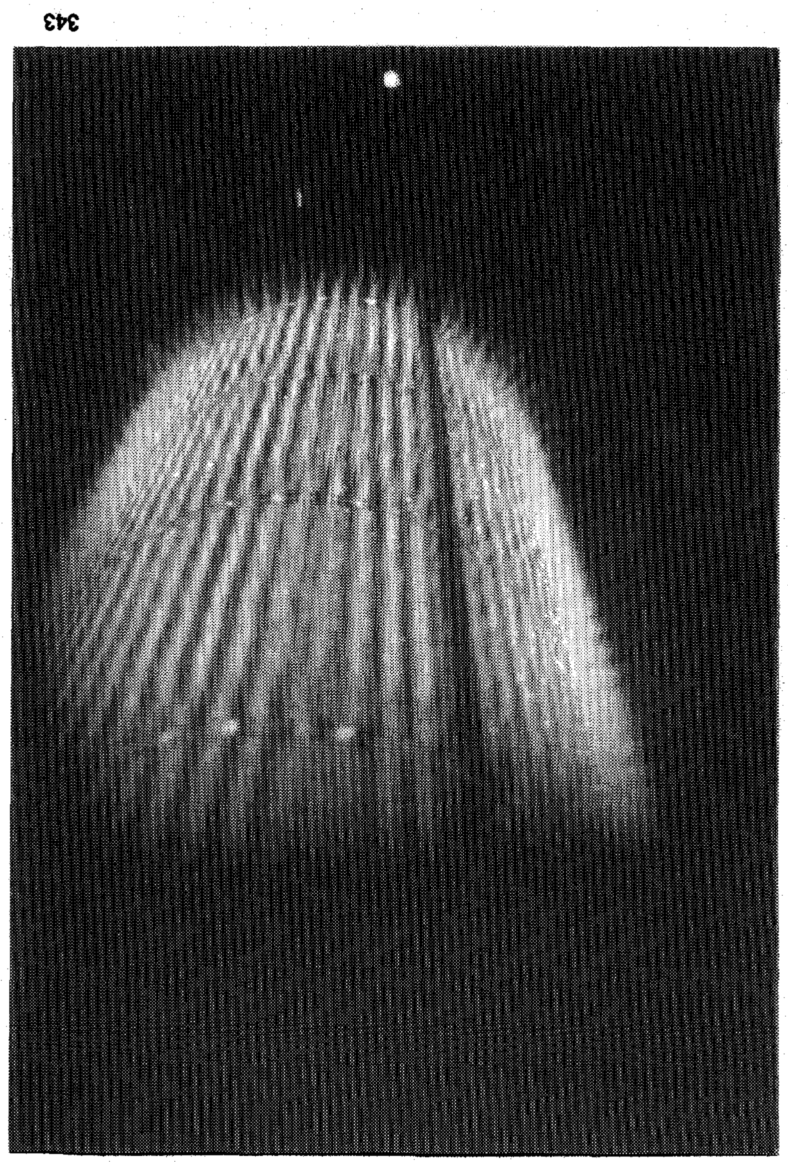

Figure 1-1. Radiant and Blue-Flame Zones are Present on the Burner Surface

1. Lower NO_x emissions at a fixed excess air level
2. Greater flame stability allowing operation with high external flue gas recirculation (FGR) levels or low Btu fuels
3. Greater operating range without combustion-induced noise

This "striped" perforation pattern is shown in Figure 1-2. Two mechanisms contribute to the NO_x reduction in the RSB. The first mechanism is a rapid post-flame quench of each blue-flame zone. Each blue-flame zone acts as a free jet transferring its momentum to the surrounding flue gases and entraining them into the blue-flame zone. This entrainment rapidly cools the flame, lowering the NO_x emissions.

A second effect is the direct "internal flue gas recirculation" effect produced by the entrainment of the products of combustion from the adjacent radiant zones into the blue flame. In the radiant zone, the combustion reaction is completed a few millimeters downstream of the burner surface. The combustion products initially serve to stabilize the attachment of the blue flame above the perforated portion of the burner as well as introduce their somewhat lower energy gases into that blue flame. Both of these effects reduce the flame temperature and the corresponding NO_x formation rate.

1.1 PROJECT ORGANIZATION

The project is divided into three phases that allow an orderly scale up of the burner technology. The phases are summarized below:

- **Phase I: Laboratory Demonstration.** The subject of this report is the results of Phase I work. To accomplish this task, Alzeta used a combination of testing and analysis. Laboratory testing was conducted in Alzeta's 3 MMBtu/hr watertube boiler and a 50,000 pound per hour oil field steamer operated by Chevron USA in Bakersfield, California. Alzeta also used its PROF (PRemixed One dimensional Flame) code to verify the experimental NO_x performance of the burner in both the laboratory and the field. This lays the ground work for Phases II and III by defining the market for new and retrofit burners, developing new boiler concepts that take advantage of the RSB, and locating a host site for the Phase III demonstration.

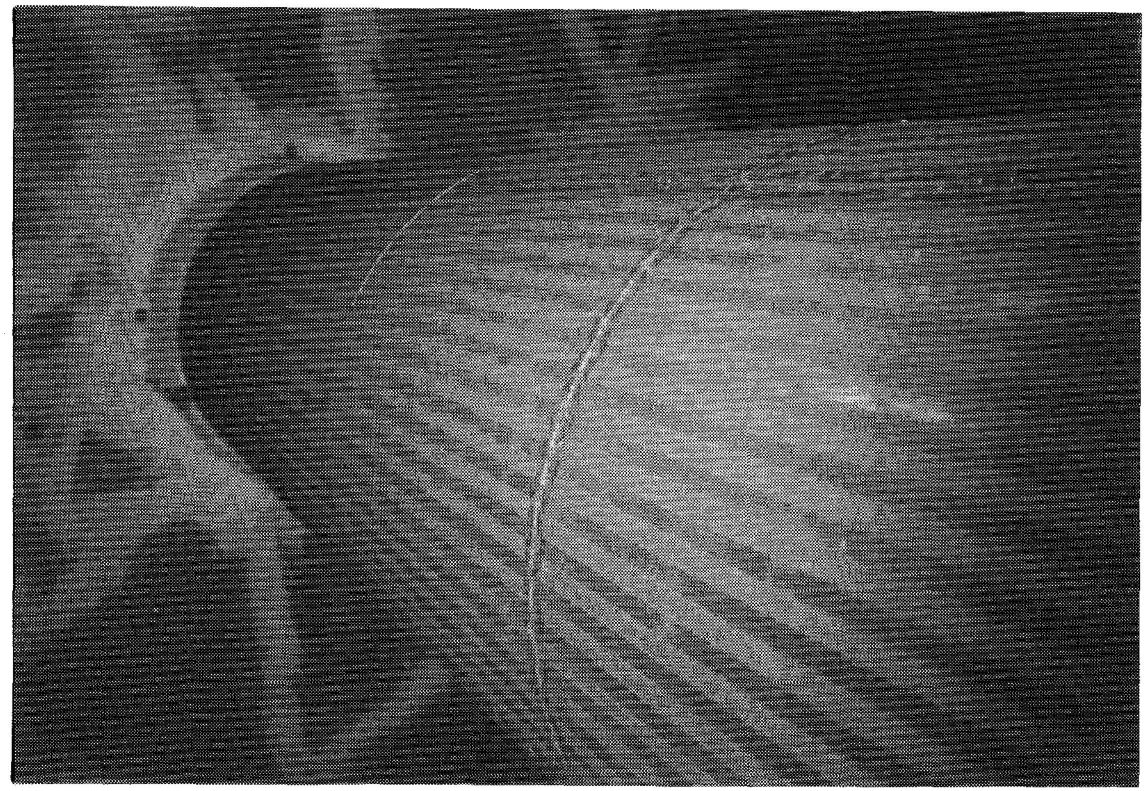

Figure 1-2. RSB Field Test for 62.5 MMBtu/hr TEOR Boiler. Striped pattern of perforated and non-perforated metal mat is clearly visible.

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- **Phase II: Concept Validation at Pilot Scale**

  A pilot scale burner system will be designed, fabricated, and tested in a single burner application such as a package watertube boiler or oil field steam generator. The pilot scale system will be designed into a package boiler with a steam capacity of 50,000 lb/hr. The pilot scale burner will have a maximum fired duty of 120 MMBtu/hr. Results of the Phase II testing will be incorporated into the design of a multi-burner system for Phase III.

- **Phase III: Concept Demonstration**

  A full-scale, multiple burner system will be fabricated based on the tests performed in Phase II. Package boilers span the capacity range of 10,000 lb/hr to 200,000 lb/hr, with capacities of 50,000 to 150,000 lb/hr being the most common. The goal of the Phase III demonstration will be to demonstrate sub-9 ppm NO_x and sub-50 ppm CO emissions at a scale that is representative of the "typical" package boiler, and we have identified host sites with steam capacity of 100,000 to 150,000 lb/hr. Certified emissions tests will be performed before and after the host site facility modification to assess the impact of the new technology. The results will be published in a final report and presented at a technical conference.

1.2 NO_x REDUCTION TECHNIQUES

To achieve sub-9 ppm NO_x emissions with the RSB dramatic reductions in both NO_x emissions and excess air requirements were needed. After reviewing the available literature on NO_x reduction techniques, Alzeta selected the several promising techniques to evaluate both experimentally and analytically and applied them to the existing RSB. The techniques included:

1. High excess air operation to reduce flame temperatures and corresponding thermal NO_x formation rates
2. Improved internal FGR using an optimized selectively perforated pattern on the surface of the metal fiber matrix burner
3. External FGR to reduce flame temperatures and corresponding NO_x formation rates

4. Fuel staging, or the addition of raw fuel downstream of the lean premixed main burner.

5. *Combined external FGR and fuel staging techniques*

The relative advantages and disadvantages of each technique are discussed below.

1.2.1 High Excess Air

Earlier work with the RSB (Reference 1) demonstrated that NO_x emissions below 9 ppm are possible at 50% excess air. In fact, any desired NO_x emissions level can be achieved by a simple excess air adjustment to provide a low NO_x burner (less than 30 ppm) or an ultra-low NO_x burner (less than 10 ppm). The advantage of this NO_x reduction technique is its simplicity in controls and its high reliability and low maintenance requirements. However, for many industrial processes, the additional excess air needed to reduce the NO_x emissions results in an unacceptable loss in thermal efficiency that has greatly limited its acceptance in the marketplace.

1.2.2 Internal FGR

Internal FGR techniques rely on recirculation of the furnace gases within the radiant section of the furnace into the reaction zone of the burner to reduce the peak flame temperature and corresponding thermal NO_x formation rate. High burner throat velocities are used to induce the recirculation zones.

In contrast, the RSB uses a selectively perforated metal burner surface to induce its own unique internal FGR. However, because the flame is distributed over a large burner surface, less furnace gas is recirculated into each blue-flame zone relative to a diffusion burner which has far greater momentum. Further NO_x reductions may be possible by further optimizing the selectively perforated pattern on the burner surface. This could be achieved by increasing the blue-flame jet velocities to induce more furnace gases. However, the momentum of the blue-flame jet is limited by the low pressure of the premixed reactants available in the burner plenum and the large surface area of the burner. A higher pressure combustion air blower could be used to increase the available premix pressure, but a significant operating cost penalty is incurred.

1.2.3 External FGR

The addition of external flue gas to the main flame is an effective and common technique to reduce peak flame temperatures and corresponding thermal NO_x emissions. In external FGR, a portion of the flue gas downstream of the convection section is pumped to the burner using the existing blower and mixed with the combustion air.

In conventional low NO_x burners, NO_x emissions decrease as the level of FGR increases until the stability limit of the burner is reached. The amount of flue gas recirculated is often limited by burner stability and is usually limited to a maximum of about 20%. Above this level, burner stability is compromised and excessive CO emissions can result. For conventional low NO_x burners, the stability limit is reached well before 9 ppm NO_x emissions are achieved.

The major benefit of using FGR as a NO_x reduction technique on the RSB is that FGR is well understood and accepted, and its effectiveness with the RSB has already been demonstrated in Alzeta's laboratory. See Figure 1-3. Because the RSB is a fully premixed surface combustion burner it can operate at higher levels of FGR without excess CO emissions or stability problems. Thus, external FGR was investigated as a NO_x reduction technique for Phase I.

There are efficiency penalties associated with external FGR. First, the additional flow through the boiler reduces the heat transfer and raises the stack temperature slightly resulting in a lower thermal efficiency. Second, the additional brake horsepower needed to pump the flue gas through a larger primary fan (or a separate smaller fan) increases electrical energy costs to operate the boiler.

While both high excess air operation and external FGR lower thermal efficiency and increase operating costs, external FGR is preferred over additional excess air because some of the energy lost in the stack can be recovered by reintroducing it into the burner as preheated combustion air.

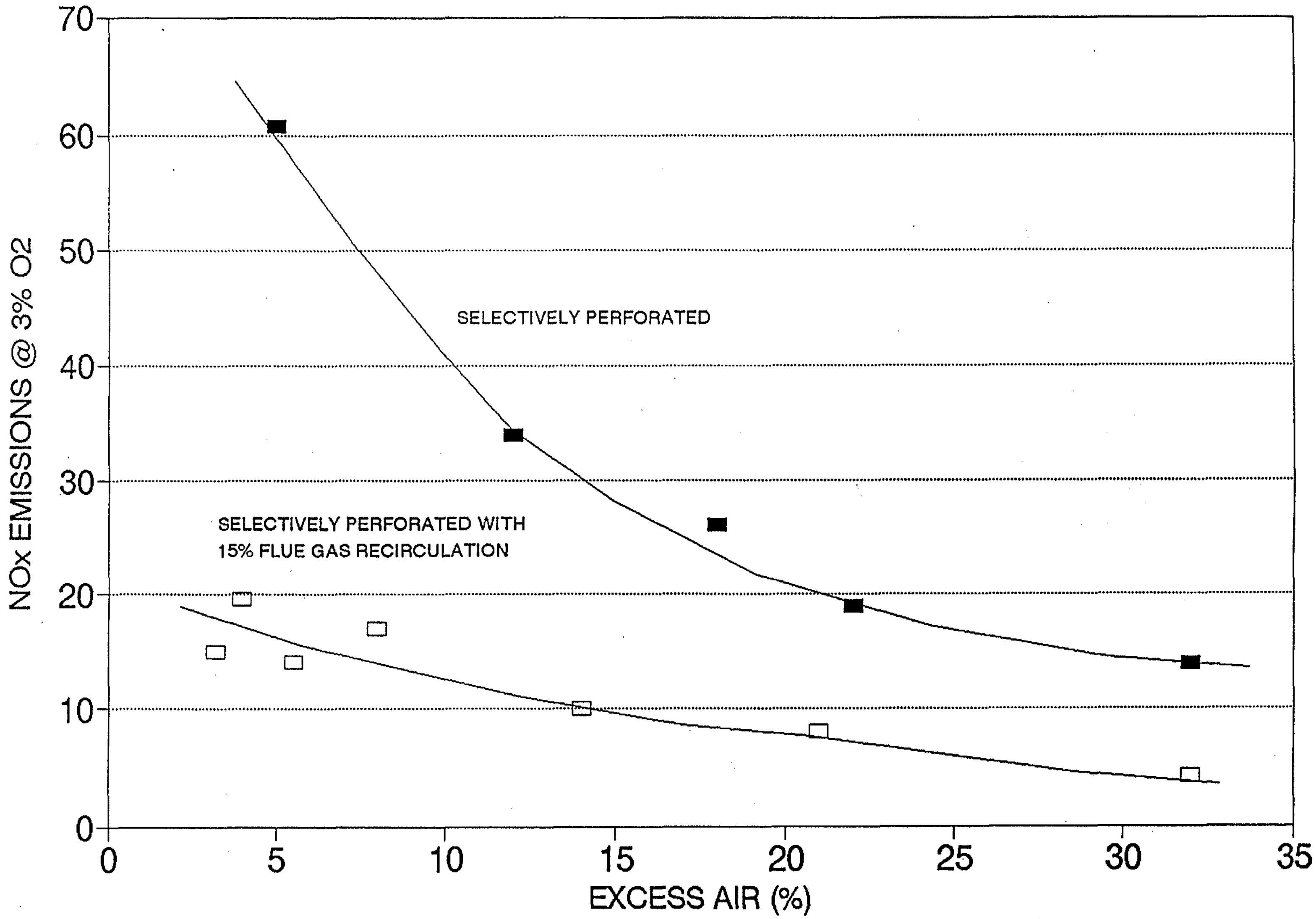

Figure 1-3. Experimental Data Demonstrating the Significant Reduction in NO_x Achieved Simultaneously with Low CO Emissions Using the RSB Concept. Fired Duty -- 1 MBtu/hr-ft2

FGR may be particularly difficult to apply to package boilers because of the relatively large pressure drop built into package boilers to keep the foot print small.

Reference 3 discusses the costs associated with FGR in more detail. Because of the operating penalty associated with an FGR solution, a problem that is most pronounced with package boilers, an external FGR solution was pursued as a contingency option only.

1.2.4 Fuel Staging

Fuel staging is a technique where fuel is introduced into two separate combustion regions, one very lean and the other fuel-rich. This is a common NO_x reduction technique for diffusion burners and can be combined with FGR to further lower NO_x emissions. In the Phase I staging tests, the RSB was operated with a fuel lean primary section. Additional fuel (and in some cases fuel plus inert gases to simulate flue gas) were added downstream of the lean primary stage.

In the first stage, the burner is operated very lean (high excess air) to reduce thermal NO_x formation. Once the first stage has radiated a portion of its energy to reduce its flame temperature by a few hundred degrees, the second, fuel-rich stage is introduced. The secondary fuel is introduced downstream of the first stage to consume the unreacted oxygen and is introduced in such a way to induce furnace gases to cool the reaction while not forming excessive CO levels.

Although fuel staging techniques have not been tried on surface combustion burners at an industrial scale, the RSB is well suited to fuel staging. The RSB has already demonstrated stable, low NO_x operation (less than 10 ppm NO_x) under very lean stoichiometric operation. A secondary, fuel-rich combustion zone can easily be introduced over the surface of the primary burner by using carefully placed fuel nozzles.

The advantage of this technique with the RSB is that the primary burner is a proven ultra-low NO_x burner and is much more stable than conventional burners under very lean conditions. There is no thermal efficiency penalty associated with fuel staging as there is with external FGR. The advantages of fuel staging as a NO_x reduction technique are attractive enough that the technique was also chosen as the primary solution to reduce NO_x emissions on the RSB.

1.2.5 Combined external FGR and Fuel Staging

To achieve ultra-low NO_x emissions, both external FGR and fuel staging can be combined. The recirculated flue gas can be introduced into the primary burner to reduce NO_x emissions in the first stage, or it can be introduced into the second stage to dilute the raw fuel gas. The latter technique is similar to a method commonly referred to as Fuel Induced Recirculation (FIR) and has been recently introduced into the market place by at least one burner manufacturer (Reference 4).

The claimed advantage of adding the recirculated flue gases into the fuel stream rather than the air stream is that a far smaller volume is needed to achieve the same NO_x reduction relative to conventional FGR (Reference 5). Also the fuel pressure available at industrial boiler sites is often high enough to induce sufficient amounts of flue gas to achieve very low NO_x emissions. This technique does not increase operating costs from pumping flue gas such as conventional external FGR does.

This technique can be applied to the RSB if fuel staging alone is not sufficient to achieve sub-9 ppm NO_x emissions.

1.2.6 Conclusions

After evaluating these NO_x reduction strategies and reviewing the available low NO_x products on the market, Alzeta selected the fuel staging option as the most likely to achieve the stated technical goals and achieve market acceptance. However, recognizing that fuel staging alone may not be sufficient in all applications to achieve sub-9 ppm NO_x emissions, alternate NO_x reduction strategies were also investigated. In order of preference, the strategies investigated were:

1. Fuel staging
2. Fuel staging combined with FIR
3. External FGR

Each of these techniques was applied to the RSB and evaluated in Alzeta's 3 MMBtu/hr watertube boiler. Selected staging and FGR tests were also conducted in a 50,000 pph oil field steamer operated by Chevron USA in Bakersfield to verify the laboratory results and test the burner in an actual industrial piece of equipment.

Laboratory and field data were also analyzed with Alzeta's PROF code. The next section discusses the results of these tests in detail.

SECTION 2

LABORATORY AND FIELD TEST RESULTS

This section discusses the results of the tests performed under Phase I of this project. As described in the previous sections, Alzeta added fuel staging and external FGR to the RSB to lower NO_x emissions and excess air requirements. These tests were conducted in two test facilities as described here.

2.1 TEST FACILITIES

Alzeta used two test facilities to evaluate the NO_x emissions performance of the RSB. For initial evaluation of an idea, we used our 3 MMBtu/hr Unilux watertube boiler located at Alzeta's research facility. Unilux is a brand name for a line of small watertube boilers. This facility simulates the thermal environment of a larger industrial boiler yet allows for quick and inexpensive tests that would not be possible in larger test facilities.

The second facility is a 50,000 lb/hr oil field steamer owned and operated by Chevron USA in Bakersfield, California. This piece of equipment was retrofitted with a Pyromat CSB30-4SO-30 burner in 1994, and was modified for fuel staging tests for this program in 1995. The steamer was also modified in 1994 for simulated FGR tests with a high-CO_2 fuel. The following sections briefly describe each test facility.

2.1.1 3 MMBtu/hr Laboratory Watertube Boiler

Alzeta used a bent watertube boiler manufactured by Unilux for its laboratory testing. The boiler has 257 ft^2 of heating surface and is capable of providing 2570 lb/hr of steam at 200 psig. The boiler configuration is an 'O' type with the steam and mud drums directly above each other. A 5-pass convective section sits above the radiant section.

The internal dimensions of the radiant section are approximately 29 inches high by 39 inches wide by 48 inches deep. This provides a space heat release rate of over 100,000 Btu/ft^3 which is typical of the most compact watertube boilers on the market.

A large viewing window on the rear wall of the boiler was added to view the burner when in operation and to record tests with a video camera. The boiler was equipped with thermocouples to measure stack temperature and boiler efficiency. Additional thermocouples and a suction pyrometer were used to measure gas phase temperatures in the radiant section. The facility was connected to Alzeta's pollutant emissions bench where real-time NO_x, CO and stack O_2 measurements were recorded. Figure 2-1 shows the internal tube geometry of the boiler.

The laboratory boiler was equipped with two different RSBs: a planer burner for fuel staging testing and a cylindrical burner for external FGR tests. Both burners were fully modulating and could operate up to full boiler capacity. The planer burner was 2.8 ft^2 (20 inches by 20 inches) and occupied a portion of the front wall of the boiler. This geometry was superior for fuel staging because it more accurately represented the burner-to-tube spacing typical of a large boiler installation.

A cylindrical burner was used for the external FGR tests. The burner was 8 inches in diameter and 12 inches long. Since the flame envelope for the FGR burner is more tightly controlled around the burner surface, burner surface to tube spacing is not a critical parameter to be modeled.

2.1.2 50,000 lb/hr Oil Field Steamer

Alzeta used a 50,000 lb/hr oil field steamer to conduct field tests to verify successful laboratory test results. The radiant section is cylindrical and 37 feet long with an inside diameter of 9.5 feet as illustrated in Figure 2-2. The watertubes make one pass through the radiant section and are 3 inches in diameter and arranged parallel to the centerline on 6-inch centers. The units operate at a steam pressure of 1100 psig corresponding to steam temperatures of 550°F.

The steamer was equipped with a Pyromat CSB30-4SO-30 burner element. The burner was cylindrical and 30 inches in diameter by 120 inches long. The burner was fully modulating and could fire up to full nameplate rating, 62.5 MMBtu/hr. The steamer fired on natural gas and/or casing collection gases. Casing collection gases

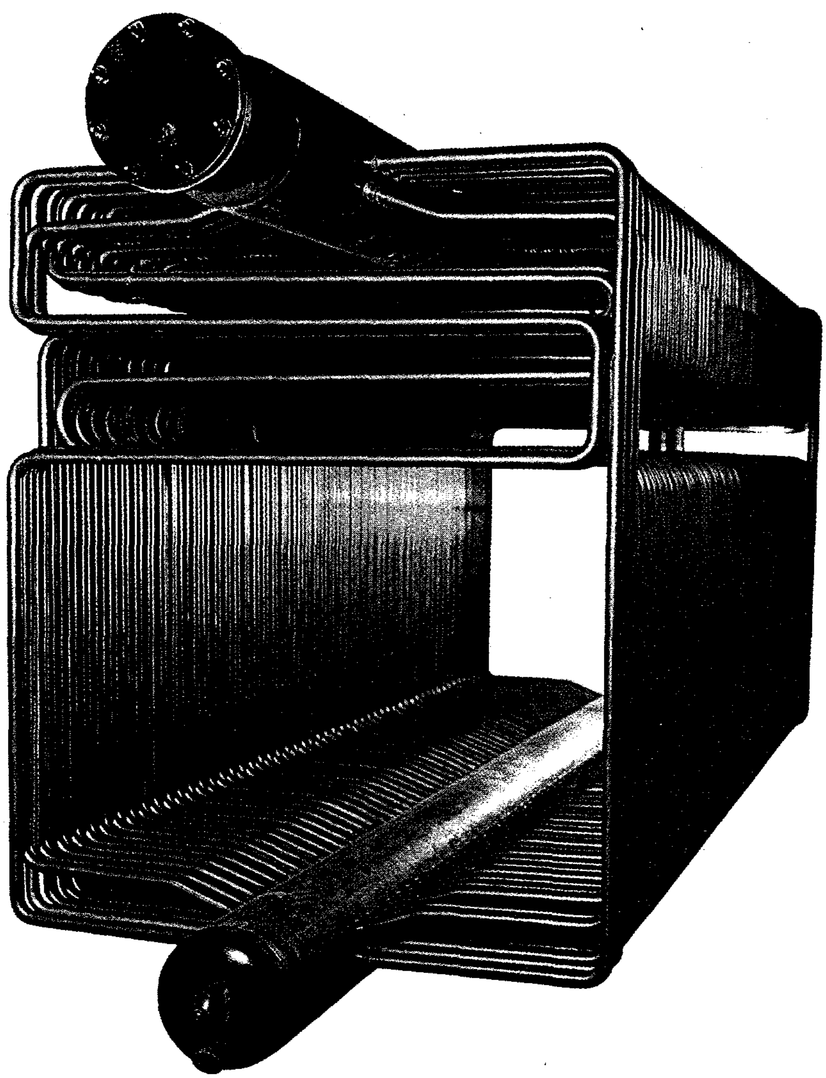

Figure 2-1. Internal Geometry of Bent Tube Boiler (courtesy of Unilux)

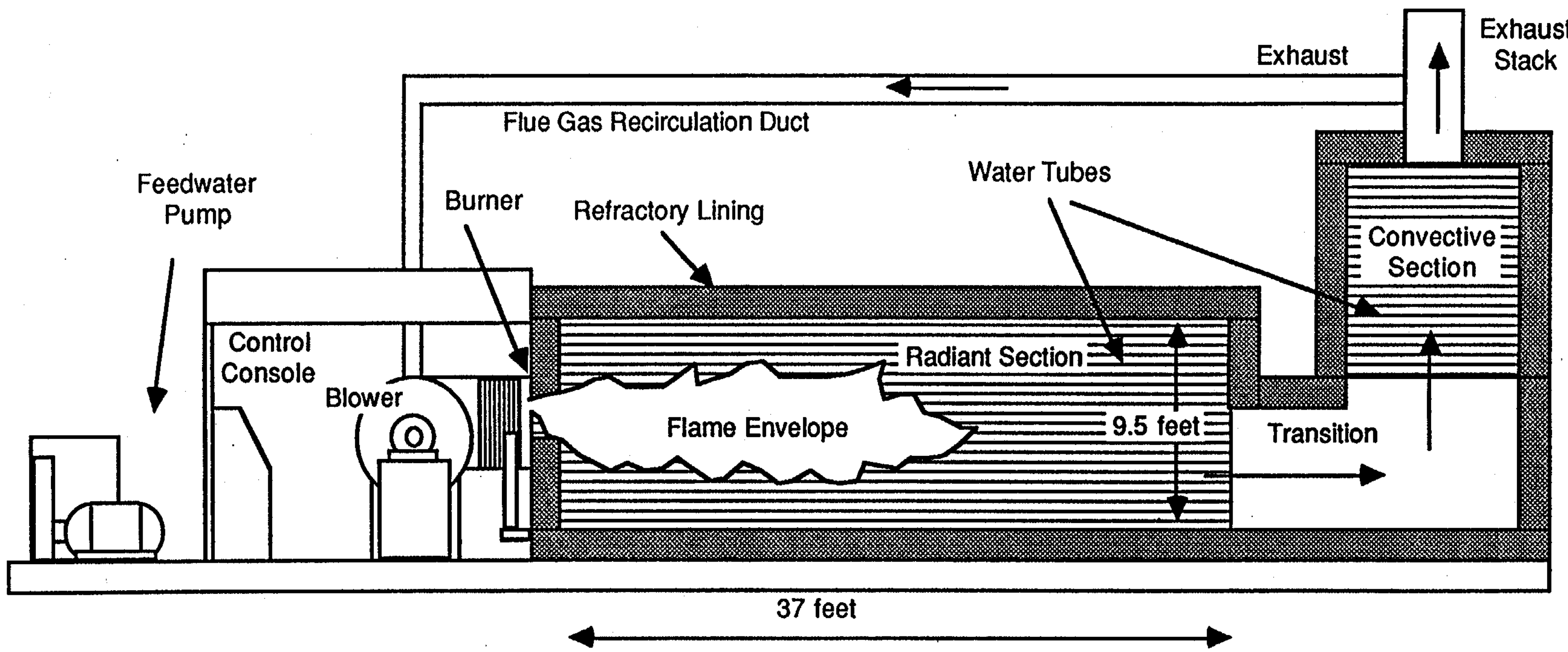

Figure 2-2. Typical 50,000 lb/hr Oil Field Steamer with Conventional Low NO_x Burner Using Flue Gas Recirculation (simplified schematic)

are a low-Btu fuel composed of approximately 50% by volume methane and 50% carbon dioxide. The steamer was equipped with viewports on the front, side, and rear walls to view the burner.

2.2 LABORATORY FUEL STAGING TESTS

The first test was conducted in the 3 MMBtu/hr laboratory watertube boiler. The goal of the first test was to measure NO_x emissions from the primary (surface) burner before the staging fuel was added. Since 70% to 75% of the capacity of the burner goes through the main burner, it is important that its NO_x emissions be much lower than 9 ppm if the whole burner is to be less than 9 ppm.

Figure 2-3 shows the baseline (no fuel staging) NO_x emissions in the laboratory boiler. The burner was able to maintain stable operation at very high excess air conditions at NO_x emissions less than 5 ppm. This test showed that the RSB would serve as a very stable, low NO_x primary burner for a staged fuel burner. CO emissions were less than 10 ppm for all test cases.

Some initial fuel staging tests were conducted by introducing raw fuel gas through two manifolds on each side of the planar burner. While our initial tests showed the NO_x and stack O_2 were both reduced, CO emissions were much higher than the project goal of 50 ppm. See Figure 2-4.

However, given the early yet positive results in the laboratory, Alzeta chose to take advantage of an immediate opportunity to retrofit the 62.5 MMBtu/hr Pyromat CSB burner in the oil field steamer and verify the laboratory results in a full scale industrial piece of equipment. Because we had a limited testing window available in this piece of equipment, we designed a very flexible fuel staging manifold that allowed us to test different fuel injection patterns without changing the hardware.

2.3 FIELD FUEL STAGING TESTS

In the oil field steamer, we were able to use the existing Pyromat CSB30-4SO-30 burner, with some modifications, to verify this NO_x reduction technique at full scale. The burner was modified to accommodate secondary fuel injection by adding a

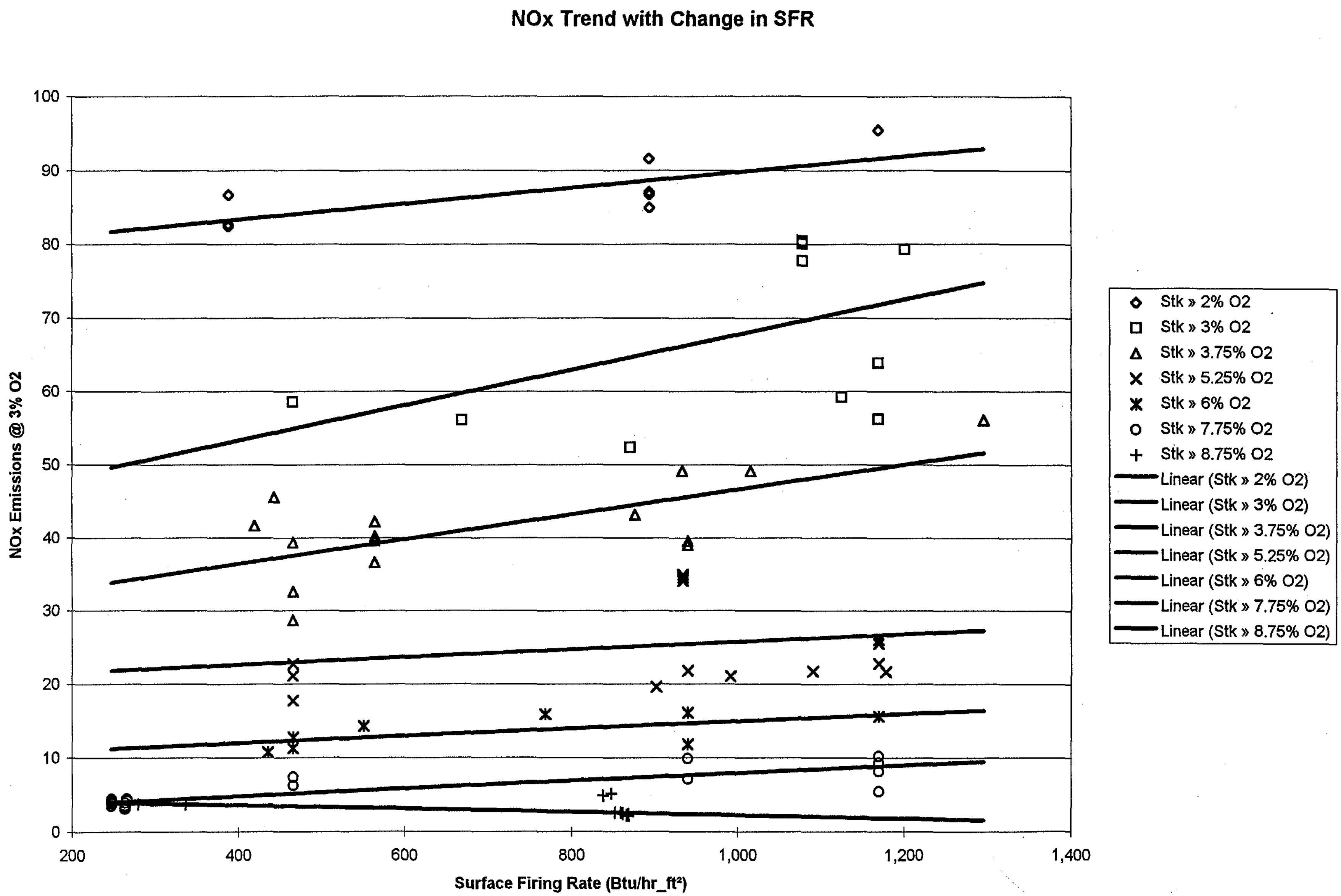

Figure 2-3. Excess Air Curve in Unilux Boiler

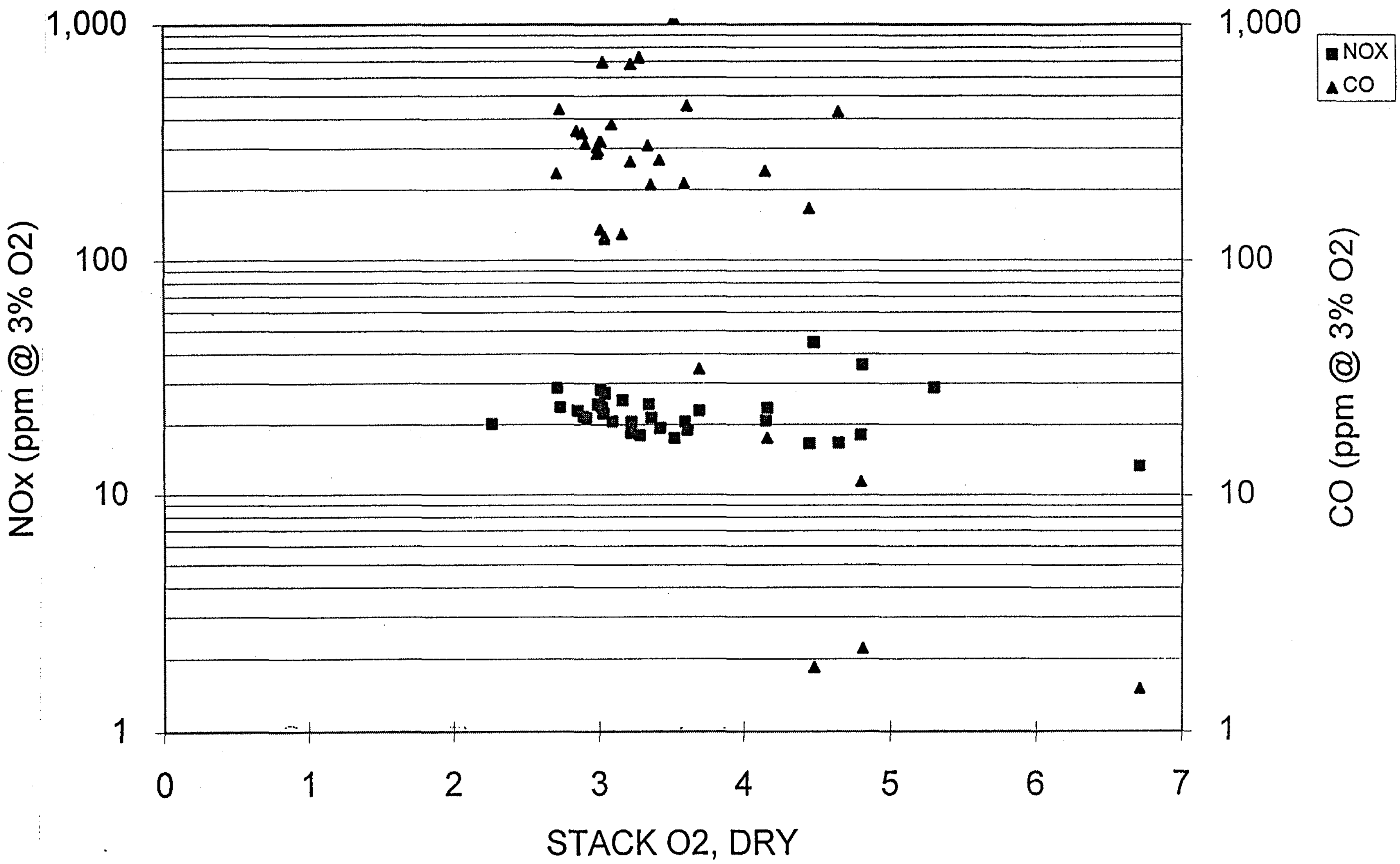

Figure 2-4. Early Staging Data in Unilux Boiler

series of fuel staging manifolds to the end of the last segment. The injectors were supplied by fuel lines inside the burner plenum. Personnel from Alzeta were present to supervise the burner modifications and conduct the tests. The burner was modified and operated by Chevron.

The primary objective of the tests was to demonstrate that fuel staging on a surface combustion burner could reduce NO_x emissions to below 9 ppm with CO emissions less than 50 ppm (corrected to 3% O_2) while operating at stack oxygen levels of 3% or less.

A second objective was to optimize the distribution of the fuel gas into the secondary flame zone and determine the variables needed to achieve the lowest NO_x emissions. A third objective was to assess the cost savings associated with improving the emissions and thermal performance of the burner.

First, the surface combustion burner was operated at a reduced load under very lean conditions where very little NO_x is formed. (We had previously demonstrated NO_x emissions less than 10 ppm at 8% stack oxygen.) Then enough raw gas was distributed around the surface of the burner element to make up the additional capacity and complete the reaction so that the steamer was operating at a more desirable 2% to 3% stack oxygen. It was important to properly distribute the staged or secondary fuel into a combustion zone that was hot enough to oxidize all the fuel, but not so hot as to form large amounts of thermal NO_x in the secondary combustion zone.

Figure 2-5 compares the results of the RSB with fuel staging with the 1994 data when the burner operated as a lean premixed burner without fuel staging. In Figure 2-5, NO_x emissions are plotted as a function of stack oxygen. As opposed to the 1994 data where NO_x emissions are a strong function of stack oxygen, NO_x emissions of the staged burner are relatively flat with stack oxygen. The two NO_x curves have different characteristics corresponding to different NO_x formation mechanisms.

The 1994 NO_x emissions data are characteristic of a premixed burner where additional excess air (higher stack oxygen) reduces NO_x emissions by reducing the peak flame temperature and corresponding thermal NO_x formation rate. The RSB with fuel staging also takes advantage of the very low NO_x emissions at high excess air.

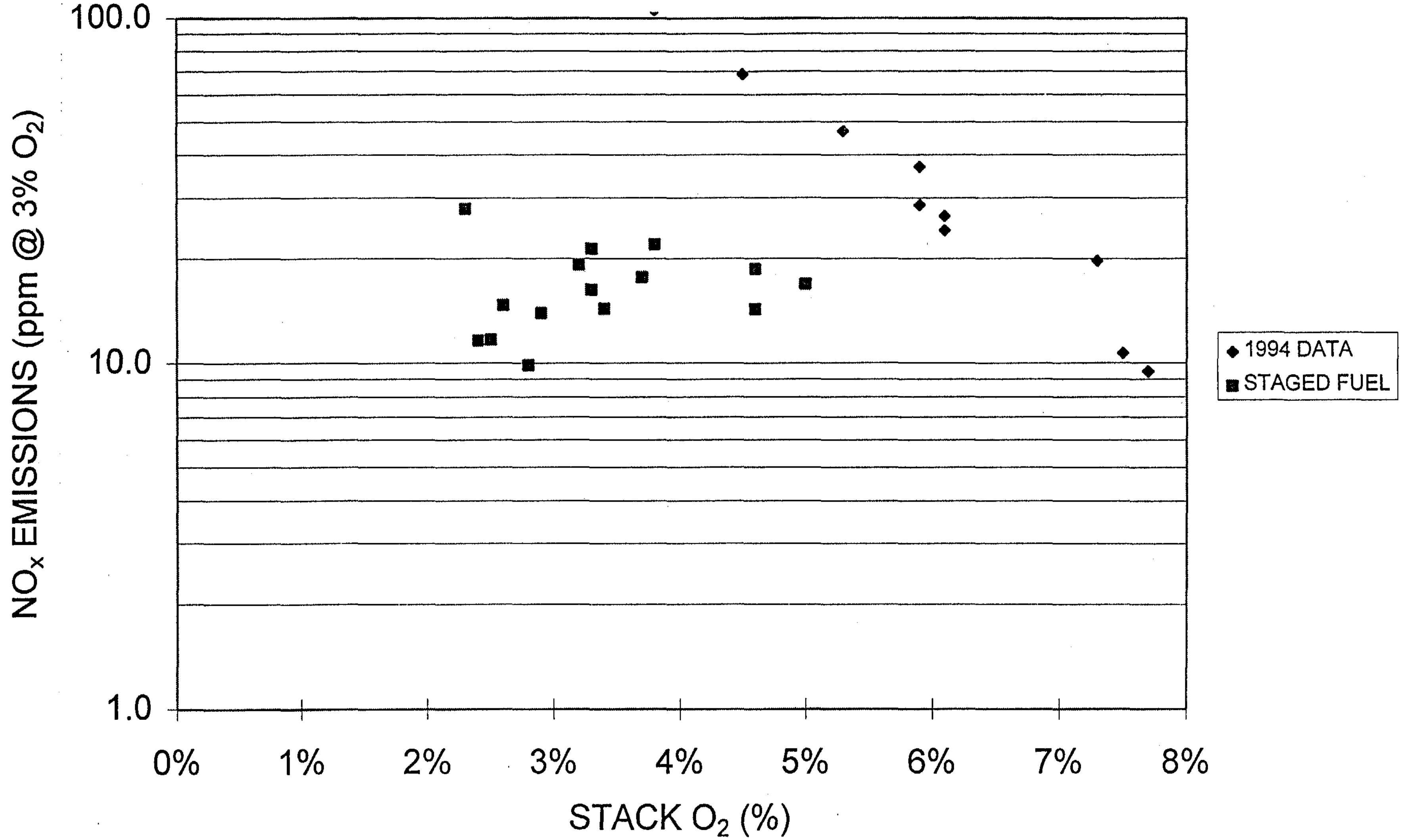

Figure 2-5. Staging Data from Cymric

The primary burner (or surface combustion burner) operates at a reduced load at the highest excess air possible to minimize NO_x formation. Then raw fuel gas is injected around the surface of the burner to form a secondary combustion zone which is also low enough in temperature to limit thermal NO_x formation. The secondary fuel must be injected into a zone which is hot enough to oxidize the fuel, but not so hot as to form significant amounts of thermal NO_x.

The considerable spread in the staged fuel NO_x emissions from 10 ppm to almost 30 ppm is likely due to variations in fuel fraction (amount of staged fuel), the shape of secondary combustion zone, and steamer load. Higher fuel fractions generally resulted in lower NO_x emissions because the primary burner is operating at the highest excess air and lowest NO_x emissions condition. Carbon monoxide emissions were generally well below 50 ppm (corrected to 3% oxygen).

Although we were unable to optimize the fuel distribution of the secondary fuel during this short test series, we did demonstrate that injection angle and velocity are critical parameters for NO_x and CO emissions control. Improper distribution of the secondary fuel can lead to flame impingement or poor mixing of the secondary fuel with the lean combustion products from the primary burner. Both can lead to high carbon monoxide emissions, or in severe cases, soot formation.

The RSB with fuel staging will also provide additional savings in operating costs. By operating at 3% stack oxygen rather than the 6% stack oxygen required to achieve sub-30 ppm NO_x emissions, stack losses will be reduced by 3% or 1.8 MMBtu/hr per steamer. At a fuel cost of $2.30/MMBtu, this results in a savings of $37,000 annually per steamer.

The RSB with fuel staging consistently achieved sub-20 ppm NO_x emissions and sub-50 ppm CO emissions (corrected to 3% O_2) at 3% stack oxygen. By adding a secondary combustion zone to the existing lean premixed surface combustion burner, NO_x emissions and stack oxygen levels were simultaneously reduced. Although we were not able to demonstrate sub-9 ppm NO_x performance as we had hoped, modifications were proposed to further reduce NO_x emissions to the sub-9 ppm levels. These concepts would be tested in the 3 MMBtu/hr test boiler back at Alzeta's laboratory.

Our work also showed that the secondary fuel distribution is critical to the emissions performance of the burner. Proper distribution results in low NO_x and CO emissions and a tight flame envelope with little chance of flame impingement. Improper distribution can result in flame impingement, excessive CO formation or even sooting. More work is needed in this area to assure that fuel distribution remains satisfactory over a broad turndown range.

The RSB with fuel staging will also be more cost competitive and less expensive to operate. The addition of a secondary combustion zone has reduced the requirement for expensive metal fiber mat. Even with the added expense of a secondary fuel staging hardware and controls, substantial savings should be possible. The accompanying reduction in stack oxygen levels will reduce stack losses and operating costs.

2.4 LABORATORY FIR TESTS

Our experience in the oil field allowed us to return to the laboratory knowing that our earlier laboratory results were real and promising.

We fabricated new secondary injection manifolds to add to the planar burner to study the effects of injection angle, injected gas velocity and injector location relative to the main (surface) burner. We also investigated the effect of adding a diluent to the staged fuel (FIR). The addition of diluent was accomplished by premixing fuel with a diluent prior to injection through the fuel staging injectors. Although in practice the intent will be to premix fuel with flue gas, the Phase I tests were conducted with other diluents including air and CO_2. Modeling was used to verify that the results generated with these substitute diluents would adequately reflect performance with flue gas.

The results of these tests are given in Figure 2-6 for NO_x emissions and Figure 2-7 for CO emissions. There is considerable scatter in the NO_x emissions from the various injection geometries with NO_x values ranging from 6 ppm to almost 40 ppm (corrected to 3% O_2, dry). There are several different injection geometries that satisfy the project goal of a sub-9 ppm burner.

The CO emissions were usually higher and more scattered than the NO_x emissions as shown in Figure 2-7. Given the small dimensions of our laboratory boiler,

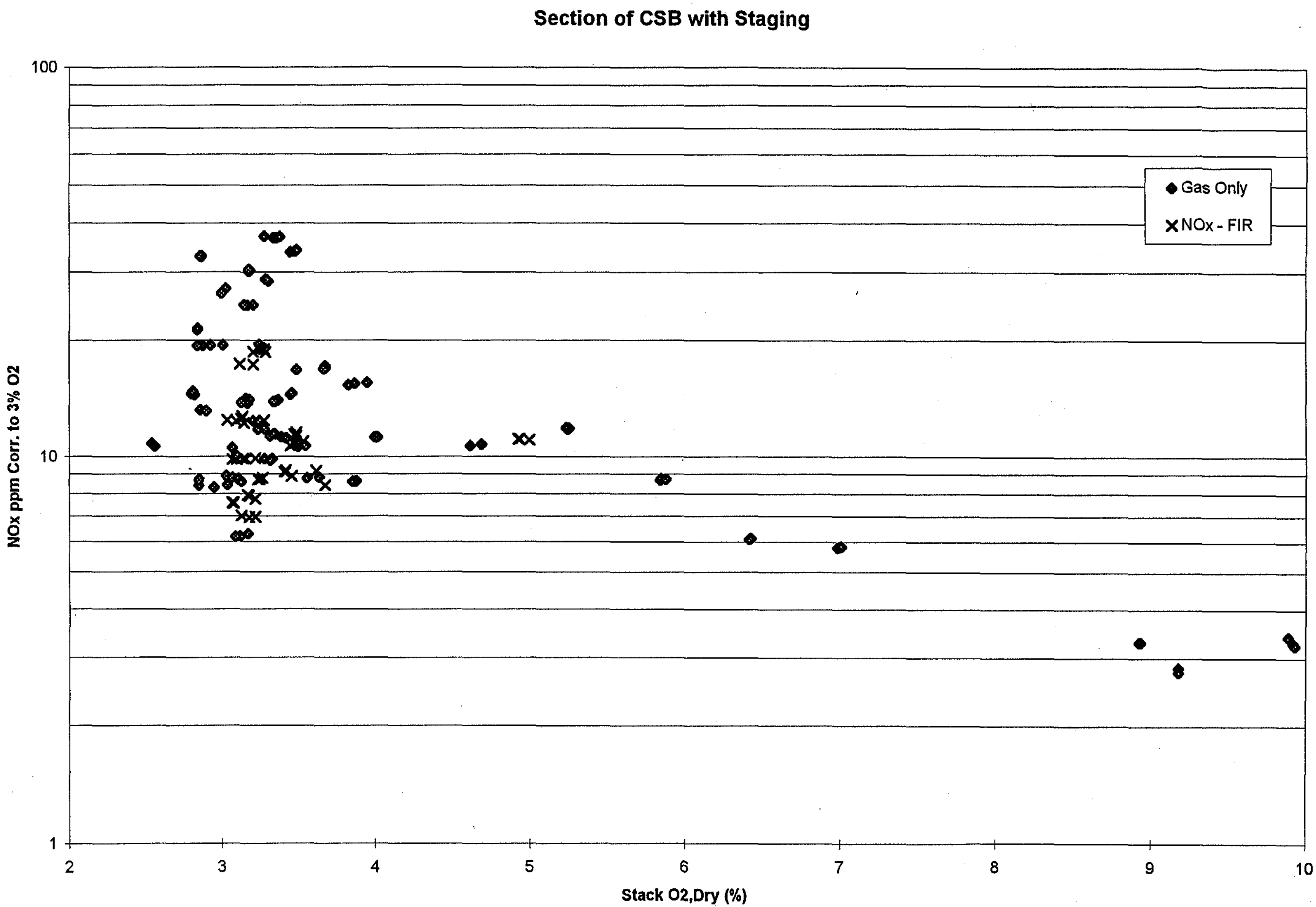

Figure 2-6. NO_x Staging Data as a Function of EA in Unilux Boiler

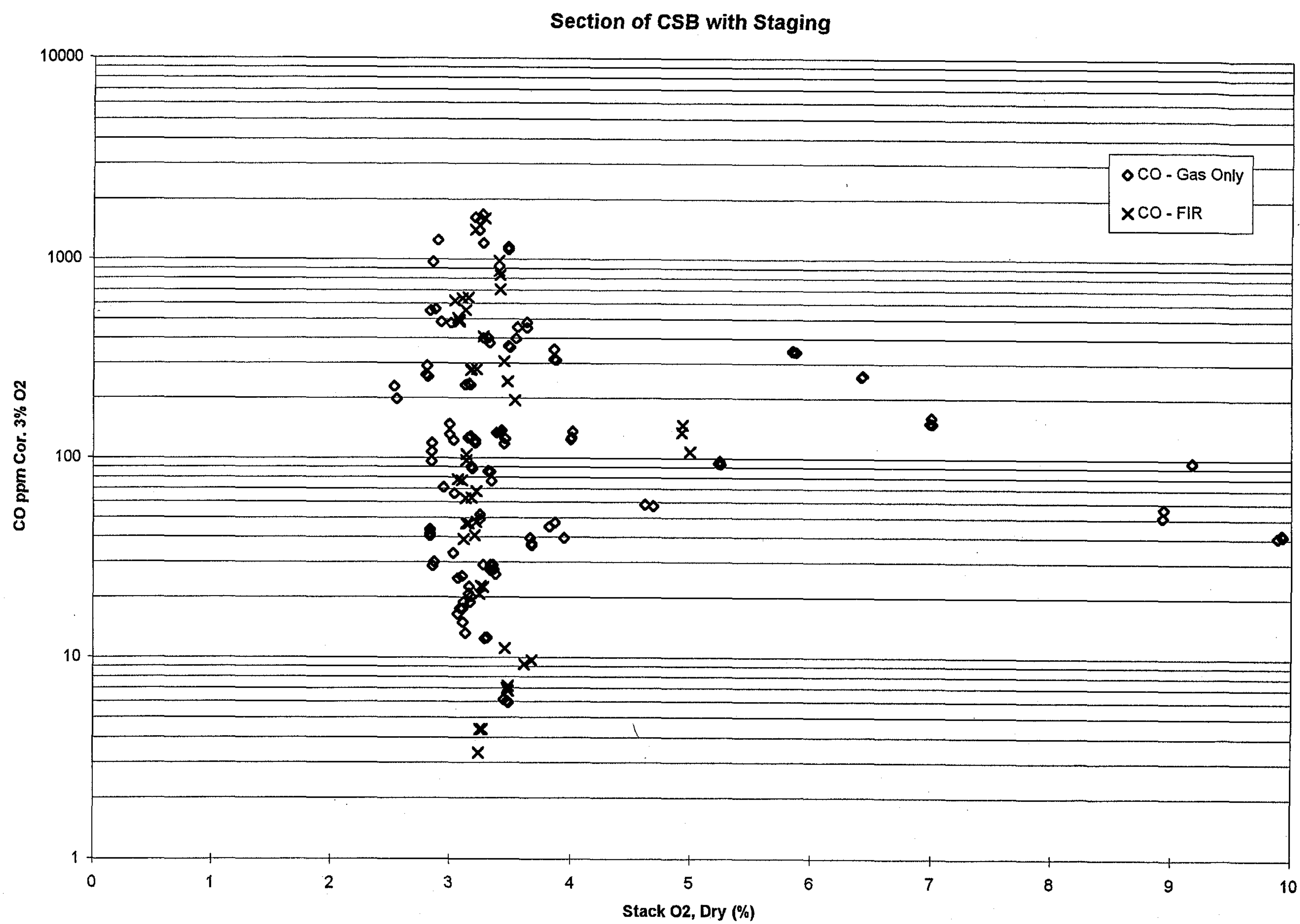

Figure 2-7. CO Staging Data as a Function of EA in Unilux Boiler

we knew that completely oxidizing the CO before the flame enters the convective section would be the greatest challenge. However, in larger hotter systems, complete oxidation of the CO would be easier. In general, NO_x and CO emissions were the lowest when a diluent was added to the stage fuel.

Designing an effective low NO_x burner using the data in Figures 2-6 and 2-7 would be difficult and unreliable, so we attempted to correlate the NO_x emissions to some engineering variable that could be easily specified. We chose an entrainment factor based on turbulent jet theory. The entrainment factor is given by the following equation.

$$F_{ent} = k\,(p_e/p_j)^{1/2} * L/d_j - 1$$

where k = correlation factor

F_{ent} = m_e/m_j

m_e = entrainment mass flow rate

m_j = jet mass flow rate (may include diluent)

L = distance traveled by fuel before intersecting main burner combustion products

dJ = jet orifice diameter

p_e = density of entrained flow

p_j = density of jet flow

For purposes of our work, the term, $(p_e/p_j)^{1/2}$, was assumed to remain constant. The other assumption was that the main burner flow diverged 10 degrees. Any interactions between jets were also ignored (i.e., jets entraining nearby jets).

When the data in Figure 2-6 are plotted as a function of the entrainment factor, a clear trend is shown in Figure 2-8. Figure 2-8 shows that the higher the entrainment factor the lower the NO_x emissions. Thus the best way to reduce NO_x emissions in the second stage (the primary burner is already very low in NO_x emissions) is to use the fuel jets to entrain furnace gases.

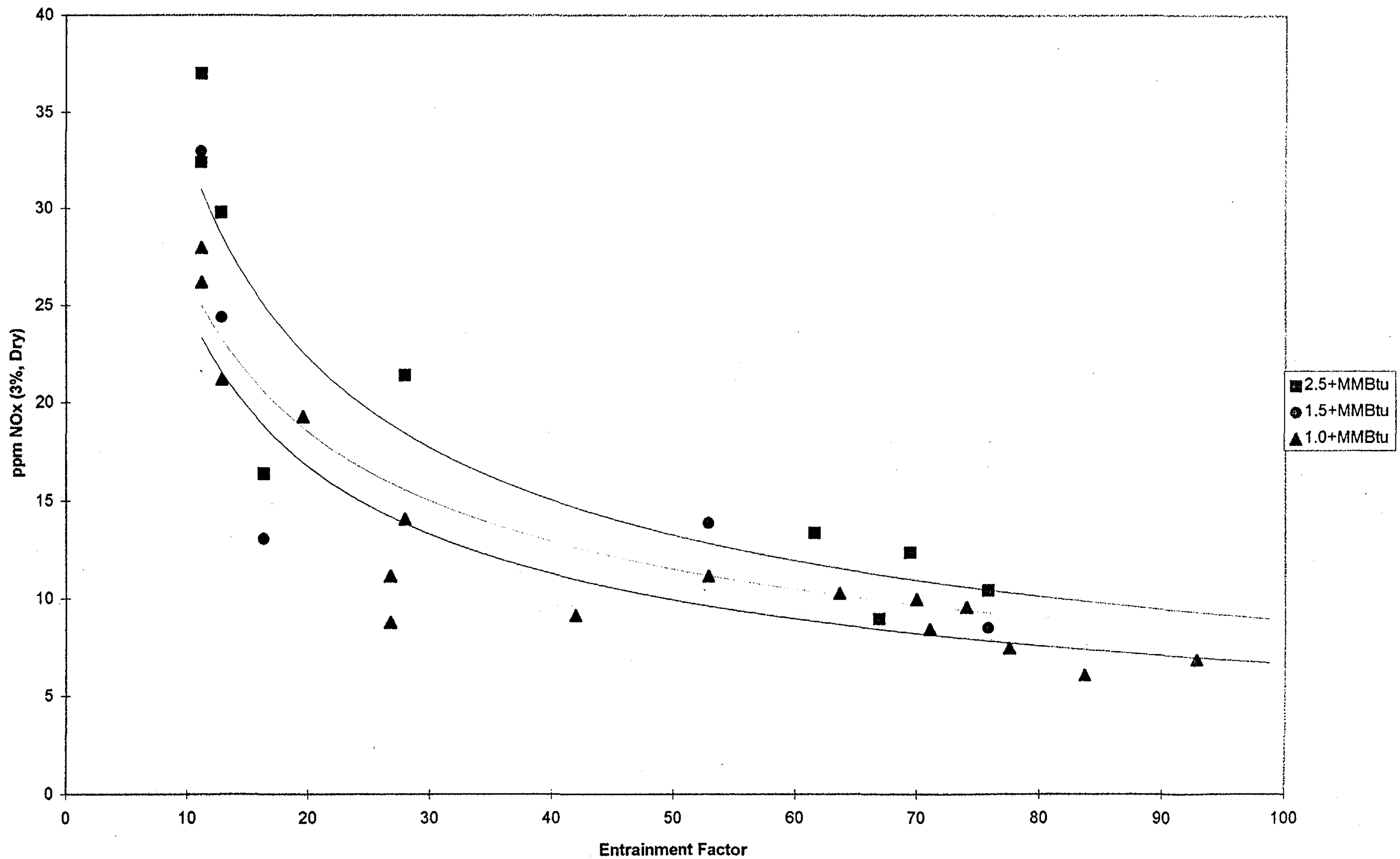

Figure 2-8. NO_x vs. Entrainment Factor

Figure 2-9 takes into account the difference in furnace temperature by dividing NO_x emissions by the absolute furnace temperature and plotting it as a function of the entrainment factor. When this is done the data corresponding to different boiler capacities fall on the same curve.

The laboratory and oil field tests have demonstrated that NO_x emissions less than 9 ppm can be achieved with an RSB equipped with secondary fuel injection. In the laboratory boiler, meeting the project goal of 50 ppm CO is more challenging due to the small size of the boiler. CO was much lower in the oil field steamer because the greater size of the equipment allowed for more time to oxidize the CO. Adding a diluent to the secondary fuel stream such as CO_2 or air, reduces the NO_x and CO emissions by lowering the peak flame temperature in the mixing zone and promoting better mixing of the fuel jet and the furnace gases. NO_x emissions are affected mostlyby peak gas temperatures while CO emissions are most affected by mixing phenomena.

This testing and analysis also show that NO_x emissions can be correlated with the entrainment factor discussed earlier. The entrainment factor is composed of variables that can be easily manipulated in the design phase of the burner to develop a burner that can meet the project goals of 9 ppm NO_x and 50 ppm CO at 3 percent stack O_2.

2.5 LABORATORY EXTERNAL FGR TESTS

A parallel effort was undertaken to study the performance of the RSB with external flue gas recirculation as a means to reduce NO_x emissions. As with most NO_x reduction techniques, the major challenge is to lower NO_x emissions without affecting the already low CO emissions of the RSB.

The laboratory boiler was modified to allow the primary blower to pump flue gas into the air stream where together they mixed with the fuel. The amount of flue gas recirculated was controlled by an in-line damper on the FGR duct.

The NO_x and CO emissions results are shown in Figures 2-10 and 2-11, respectively. As with previous excess air data, NO_x emissions are a strong function of the amount of external FGR recirculated to the burner. Sub-9 ppm NO_x emissions were

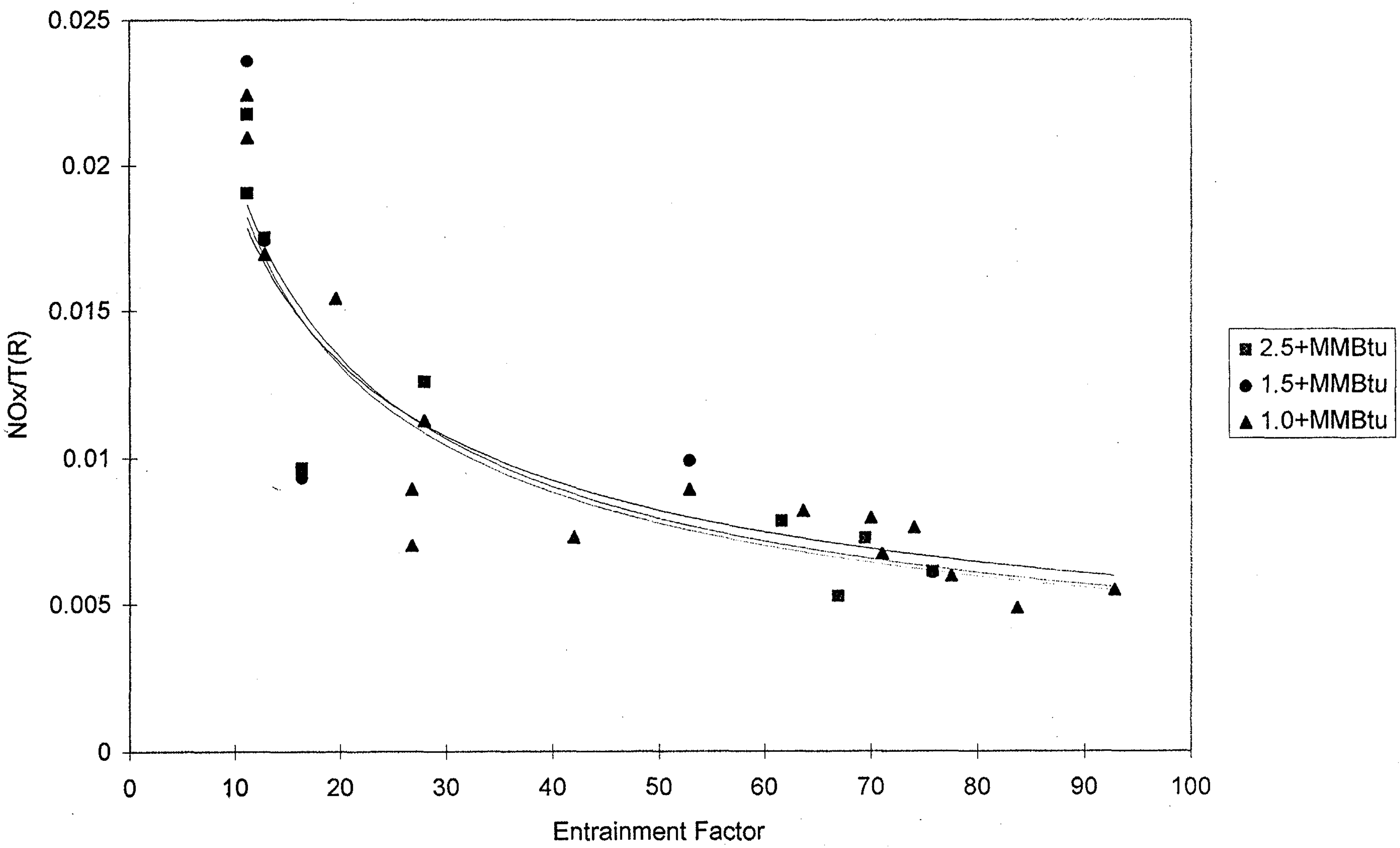

Figure 2-9. NO_x/T vs. Entrainment Factor

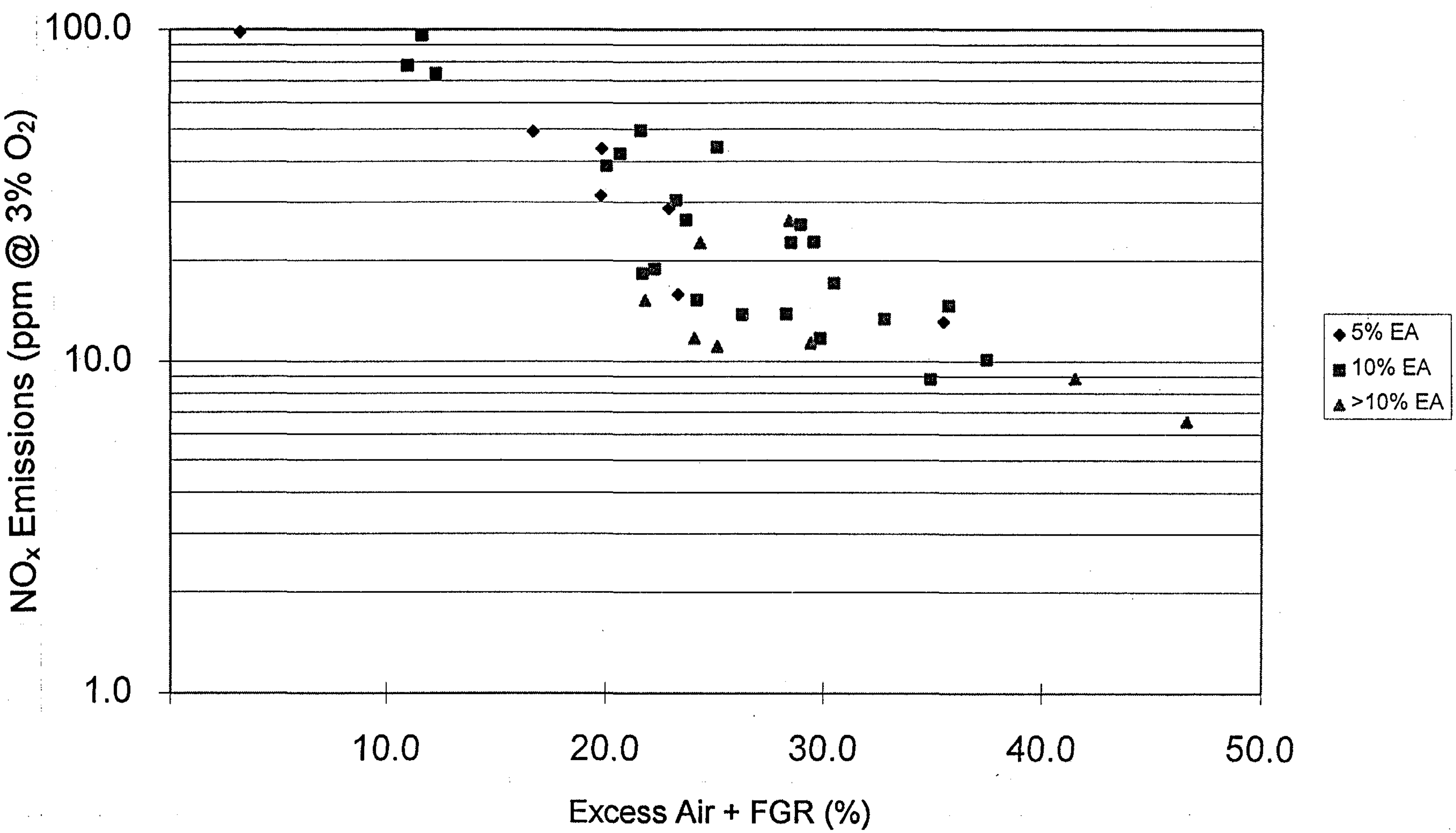

Figure 2-10. NO_x vs. Excess Air Plus FGR in Unilux Boiler

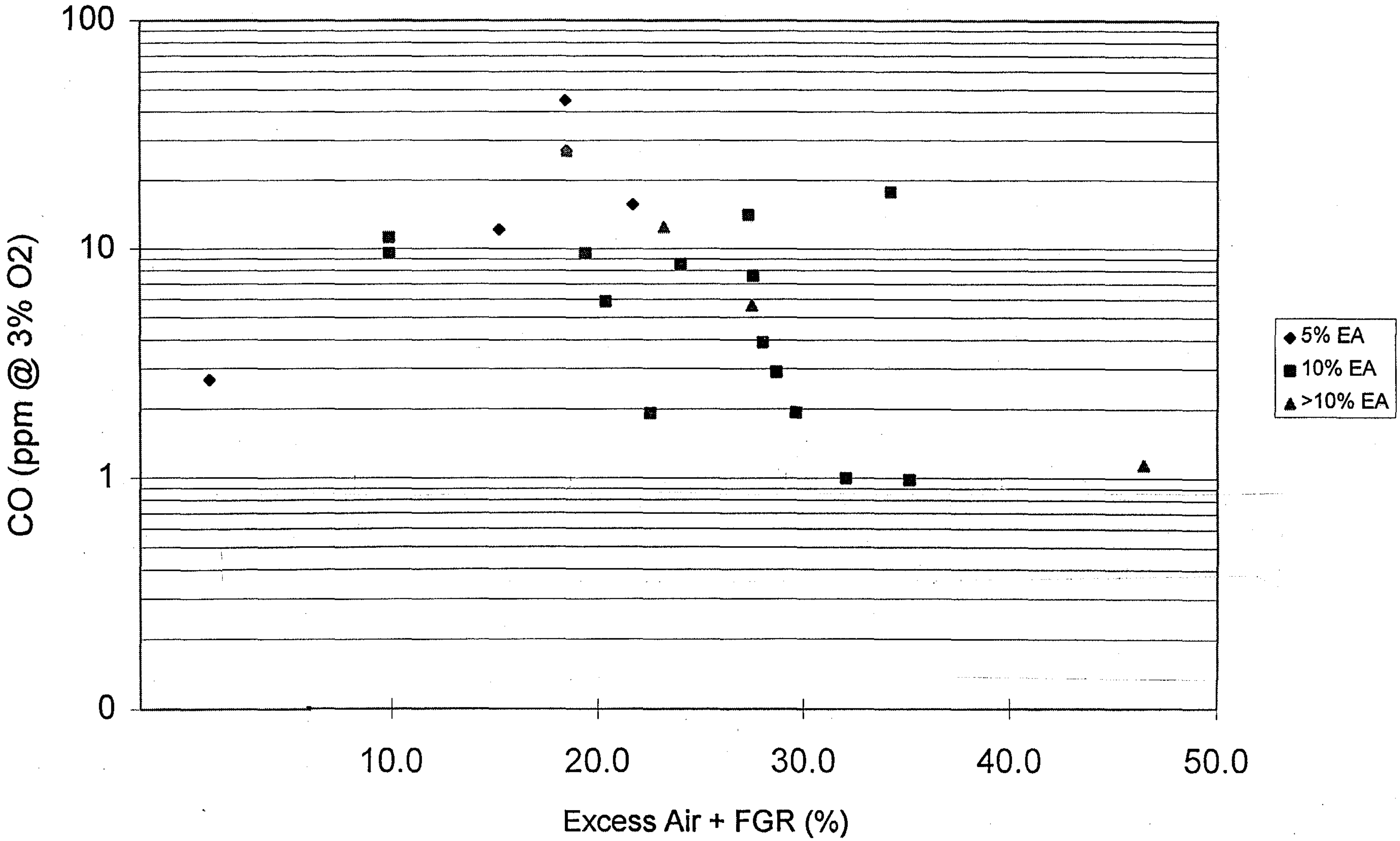

Figure 2-11. CO vs. Excess Air Plus FGR in Unilux Boiler

achieved at FGR rates greater than 30%. In general, the burner operation was stable up to the highest FGR rates. At FGR rates above 30% burner stability was a problem.

These external FGR results are important because they show that an alternative way to get sub-9 ppm NO_x is possible, although, as previously discussed, using FGR as a NO_x reduction technique carries a significant efficiency and operating penalty that we would prefer to avoid. The problem is most significant in package boilers which are designed with a high pressure drop to minimize the size of the boiler.

2.6 FIELD EXTERNAL FGR TESTS

The 50,000 lb/hr oil field steamer also provided Alzeta with the opportunity to verify the laboratory FGR tests in an industrial piece of equipment. As discussed earlier, oil field steaming operations create significant amounts of casing collection gases which must be destroyed by oxidizing it in the field. Casing gas is created when the hot steam is injected into the oil reservoir, heats the crude, and drives off a portion of the volatiles normally trapped in the crude oil. The volatile gases (typically up to 50% methane) together with significant amounts of hydrogen sulfide (up to 5%) and carbon dioxide (balance) collect in the production well casings. If the gas is not removed, the "gas jacket" in the well casing can cut off crude oil production. Therefore, casing gas must be continually extracted from the well casing and destroyed by oxidizing it in the steamers.

Because of the large amount of CO_2 in the casing gas, firing the RSB on casing gas simulates external FGR operation. In fact, by measuring the flow of casing gas to the burner, the amount of CO_2 flowing to the burner can be determined and equated to an equivalent FGR rate.

Because of the limited amount of casing gas available, the oil field burner was reconfigured to fire at 1/4 of its normal capacity. This was accomplished by removing three out of the four segments. The burner was fired on natural gas first, then casing gas was introduced. The flow of natural gas was then reduced to a minimum value to keep the burner ignited.

Casing gas flows varied from 8,000 scfh to 26,200 scfh. This is equivalent to external FGR rates from 5% to 35%. Figure 2-12 shows the NO_x results for these tests.

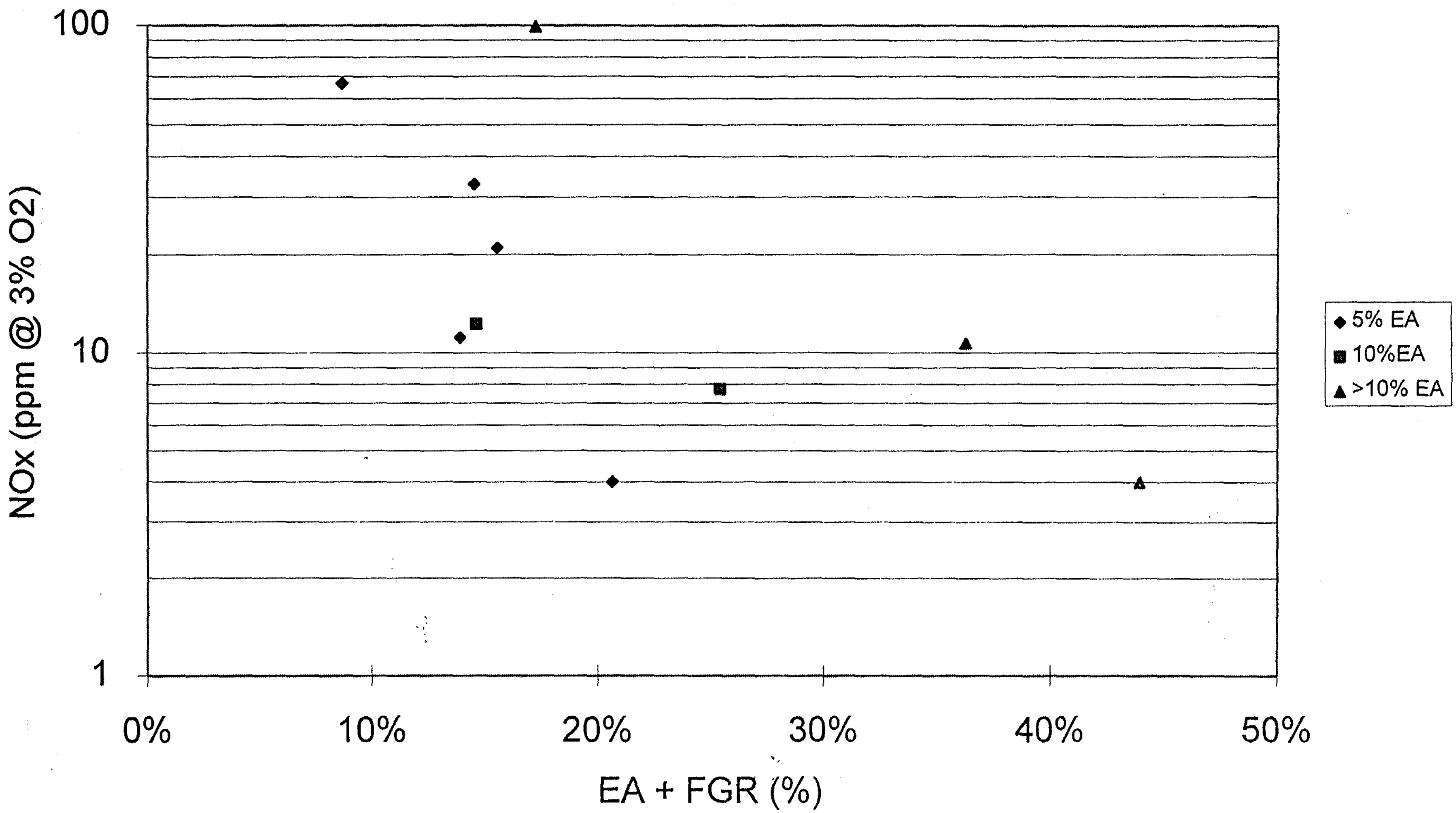

Figure 2-12. FGR Equivalent to Casing Gas Flow in Steamer. CO_2 flowrate in low Btu gas was converted to an equivalent FGR rate.

NO_x emissions below 9 ppm were achieved for FGR rates greater than 20% which compares closely with data collected in the laboratory. Since the steamer was operating at less than 1/4 capacity (due to the limited amount of casing gas available), slightly higher NO_x emissions would be expected at higher capacities. In general, CO emissions were well below 100 ppm for all test points.

2.7 NO_x MODELING WITH PROF

The experimental results were investigated using Alzeta's proprietary combustion kinetics modeling code, PRe-mixed, One-dimensional Flame, or PROF. The model uses a database of information about the reactive species, their reactions, their products, their relative reactivities, and the energy and mass transfer behaviors of various important gases as they relate to temperature. With this information, it generates an energy and a mass balance at a series of nodes along a grid through the reactive flame zone. The gride size and spacing is generated so as to be relatively evenly spaced on the basis of those energy and mass balance concerns and to be centered at a point approximately halfway through the reactive zone. The final solution is arrived at via an iterative process. The code then outputs a table showing the temperature, enthalpy, and heat capacities of the combustion mixture as well as the relative concentrations of the species in the mixture at each grid point.

The code was fed, as input, the relative concentrations of the reactive and non-reactive species in the fuel and air, the initial temperatures, and the premix mass flow rate. The input information was set to values which most closely resembled the conditions of an experimental test point. It was then allowed to run and the output information was compared to the tests from whence the premix input data were taken. In comparison to test points in the Unilux boiler, the combustion phenomena as modeled by PROF produced results which tracked the experimental data with a strong degree of accuracy. The model seems to consistently over-predict the amount of NO_x made in the boiler, likely because the relatively cool tubes quench the thermal NO_x forming reactions. The success with this modeling propelled an effort to model other experimental data. The modeling and tests demonstrated the ability of the Alzeta burner to perform at ultra-low NO_x (<9 ppm) levels with only the addition of excess air.

The next logical choice for modeling was the Struthers boiler at the Cymric oil field. The boiler was recognized as having a very different thermal environment from the small Unilux boiler at Alzeta. It was decided to use this data as a test of the robustness of the model's accuracy. The PROF model did indicate significant NO_x formation in the boiler, but, as expected, the experimental results were much higher than the amounts predicted by PROF. This was primarily because the model used in the code involves only the combustion zone close to the surface of the burner. The boiler has a hotter internal environment, with the tubes farther from the burner and the length of the boiler greater relative to the size of the burner. The high temperature inside the box probably resulted in continued, significant thermal NO_x formation outside of the zone modeled by PROF.

The model was thus enhanced by the addition of a hot box reactor model which was added after the combustion zone. This model involved allowing the output gas mixture to continue to react at the typical temperatures found in the boiler chamber. The reactions were controlled by the temperature and a residence time which was determined by the input gas and air volumes, the temperatures, and the volume of the boiler. The solutions were determined by an iterative process where the boiler was divided into zones, and as in the PROF model, each zone was balanced for mass and energy flow individually and then to fit with the previous and subsequent zones. The zoning of the boiler took into account the segmented nature of the burner and the flow of combustion products from one segment through the combustion zone of the next. With the addition of this model, the results were improved, but still seemed to under-predict the emissions of the boiler. The trend that emerged showed that the higher the actual firing rate, and higher the heating value of the fuel, the more the difference between the modeled and the experimental NO_x. The experimental runs where the Btu content of the gas and/or the firing rate were low were modeled much more effectively, particularly those where the boiler was running at one quarter or lower capacity. This supports the conclusion that the boiler thermal environment is responsible for a significant amount of the NO_x emissions from the boiler. Modeling the behavior of the high temperature and longer residence time of the Struthers boiler was thus beyond the current scope of the model, though the current model does give an effective guide to the general behavior of the burner in a boiler system.

The low Btu gas cases were also used as a verification of the capability of PROF to model the behavior of Flue Gas Recirculation (FGR) since the primary impurities in the casing gas were CO_2, water, and other constituents which closely approximated the dilution of regular natural gas with flue products. In this respect, because these tests could be modeled effectively, the behavior of an Alzeta burner under conditions involving FGR were tested and the performance could then be measured. The modeling resulted in the ability of Alzeta to judge to effectiveness and usefulness of external FGR as a NOx control strategy.

The final avenue of testing lay in the area of fuel staging. Tests were run using the previous Alzeta burner models at high excess air. These models were then used to generate the input for another free flame model for the additional fuel burning in the flue products of the burner. The modeling utilized initial burner stages of 15%, 30%, 45%, and 60% excess air. Then, for comparison, the modeling of the additional fuel needed to bring the stack O_2 back down to 3% wet was added to the system. The emissions were then examined. The results were positive, indicating that the staging of fuel could be used to good effect with Alzeta's current burner technology. The staging of fuel, as modeled, seemed to indicate the possibility that staging was a viable technique for emissions control, the modeled cases yielded sub-9 ppm NO_x at 60% excess air on the initial burner and staged fuel to yield 15% excess air (3% O_2 wet) at the stack. At this point the CO emissions were also low, being around 85 ppm, indicating that the staging technique had the potential to meet project objectives. The staged fuel injection points were determined semi-empirically by trying to find the point in the flue gas at each primary burner firing condition where NO_x production had leveled off and continued distance away from the surface of the burner would not yield significant increases in the emissions. This is not necessarily the point at which staged fuel would be introduced in the actual burner system, as the temperature increase from such a point might change the thermal NO_x production in the staged fuel flame. The location was chosen as a good starting point for estimates of the highest NO_x production in a staged burner using Alzeta's burner as the primary combustor. Another difference between the model and the actual staging possibilities is that the model starts with a well mixed system and calculates the appropriate flame speeds, temperatures, and kinetics for the system when it is used to model the free staged fuel flame. The actual situation could differ significantly from this ideal case, due to non-ideal mixing, and other non-ideal behavior.

In fuel staging, one of the difficulties is to produce simultaneously low NO_x and low CO. This is primarily because the conditions that are typically required to produce low NO_x emissions are low temperatures which tend to lead to incomplete burn-out and thus high CO. Conversely, the conditions for producing low CO involve high temperatures in order to provide complete burn-out and thus tend to encourage thermal NO_x production. The modeling described elsewhere demonstrates that this difficulty can be overcome. The model, having been designed to accurately represent the burner, demonstrates the advantages of the Alzeta product when used in a fuel staging system. The burner itself has shown in modeling and in experimental data that it operates over almost its whole operating range with both low NO_x and low CO. This property makes it ideal for the primary combustor of a staged system because it can be run with stable combustion in a very lean fashion without production of excess CO. The staged fuel is the only portion of the system, then, which exhibits the aforementioned NO_x vs. CO balance. Fuel staging can be used, however, with an Alzeta primary combustor, without excess thermal NO_x or CO production due to the nature of the combustion in the flue products of the primary burner, and the low emissions of the primary combustor.

2.8 CONCLUSIONS

In Phase I of this project, we investigated two NO_x control technologies: staged fuel and external flue gas recirculation (FGR). We achieved the emissions targets using both techniques; however, the fuel staging technique appears to be a superior technique. The lowest NO_x emissions were observed for staged combustion with FIR, but the NO_x and CO data show considerable scatter. This technique will require some additional development. External FGR burners generally require a larger combustion fan to recirculate the flue gases leading to increased operating and maintenance costs. Because there are already a large number of burners that use external FGR and the limitations are well documented, new emissions controls technologies will have to overcome these limitations. We believe that a staged fuel technique forming a secondary combustion zone around the RSB overcomes these limitations and meets the project emissions targets.

After verifying the staging technique in the 3 MMBtu/hr watertube boiler in our laboratory, we scaled up to 62.5 MMBtu/hr using an existing RSB in an oil field steamer operated by Chevron Production Company. We achieved NO_x emissions as low as 10 ppm. After these encouraging results, we returned to our laboratory to refine the burner's performance in the 3 MMBtu/hr watertube boiler. Our laboratory tests confirmed the field results, and by optimizing the secondary flame envelope, NO_x emissions between 6 ppm and 10 ppm were demonstrated.

SECTION 3

MARKET ASSESSMENT AND COMMERCIALIZATION STRATEGY

A commercialization strategy for the RSB is presented that includes a review of the industrial boiler market and a summary of our business plan to commercialize the product. In Section 3.1, the potential market for the RSB in industrial boilers is quantified, recent trends are discussed, and the initial target market for the Alzeta burner product is presented. Energy and environmental benefits provided by the RSB are quantified in Section 3.2, and a business plan for RSB commercialization is presented in Section 3.3. Section 3.4 provides a summary of the potential market, the benefits provided by the RSB, and the business plan.

3.1 INDUSTRIAL BOILER MARKET DESCRIPTION

3.1.1 Market Size

If properly designed, the burner being developed will be applicable to a wide range of boiler configurations and sizes, and because the use of boilers is an integral part of many major industrial processes in U.S. industry, the prospective market for this product is large. Most industrial watertube boilers operate at a high capacity factor, with a greater than 90 percent usage factor being common. Industrial boilers are therefore major fuel consumers and major emitters of environmental pollutants.

Consequently, the higher energy efficiency and significant reduction in NO_x emissions provided by the radiation stabilized burner will have a substantial positive impact, possibly unmatched by other industrial applications for low NO_x technology. The remainder of this section provides information from a variety of sources concerning the market size and scope of applications for this new technology. Information from various sources is sometimes contradictory, and "up-to-date" information is difficult to obtain. However, all information sources define a very large market for low NO_x industrial boilers burners.

Gas Research Institute Market Survey

The Gas Research Institute, through a contract with RCA/Hagler, Bailly, Inc., examined various market aspects of industrial boiler combustion systems (Reference 6). Although this report is approximately 10 years old, more recent data have substantiated results of the GRI survey indicating that many aspects of the industrial boiler market have not changed significantly in the past 10 years. These areas of little or no change include installed capacity, size distribution of industrial boilers, and usage factors. An area of significant change is the shift to natural gas as the primary fuel as the result of lower gas costs and the need to reduce pollutant emissions, but this transition had started at the time of the GRI survey. In addition, this shift should act to increase the advantages of the RSB over competing technologies since the RSB is by design a gaseous fuel burner.

The survey, based on 1985 market data, found that the industrial boiler inventory consisted of just under 37,000 systems with a combined steam heat capacity of roughly 1.5 trillion Btu/hr. Small boiler systems, with capacity less than 25 MMBtu/hr, represent the largest number of installed units. However, a typical industrial boiler (used for process steam requirements) is typically between 50 and 250 MMBtu/hr in size. Most industrial capacity is within this size range.

The study found that industrial boilers represent one of the largest components of industrial fuel consumption. Traditionally, industrial boilers have been single-fuel systems, with natural gas-fired systems accounting for a dominant share of the installed base. Natural gas and fuel oil remain the primary boiler fuels (although as mentioned above, the decrease in gas cost and increased pressure for reduced emissions have enlarged natural gas market share significantly). The North Central and South Central regions of the U.S. account for the majority of industry's boiler units and capacity, with these geographic areas defined in Figure 3-1. The chemical, food, paper, petroleum and primary metals industries are the largest segments of the industrial market. The vast majority of industrial boilers are fossil-fuel-fired watertube systems and were installed prior to 1970.

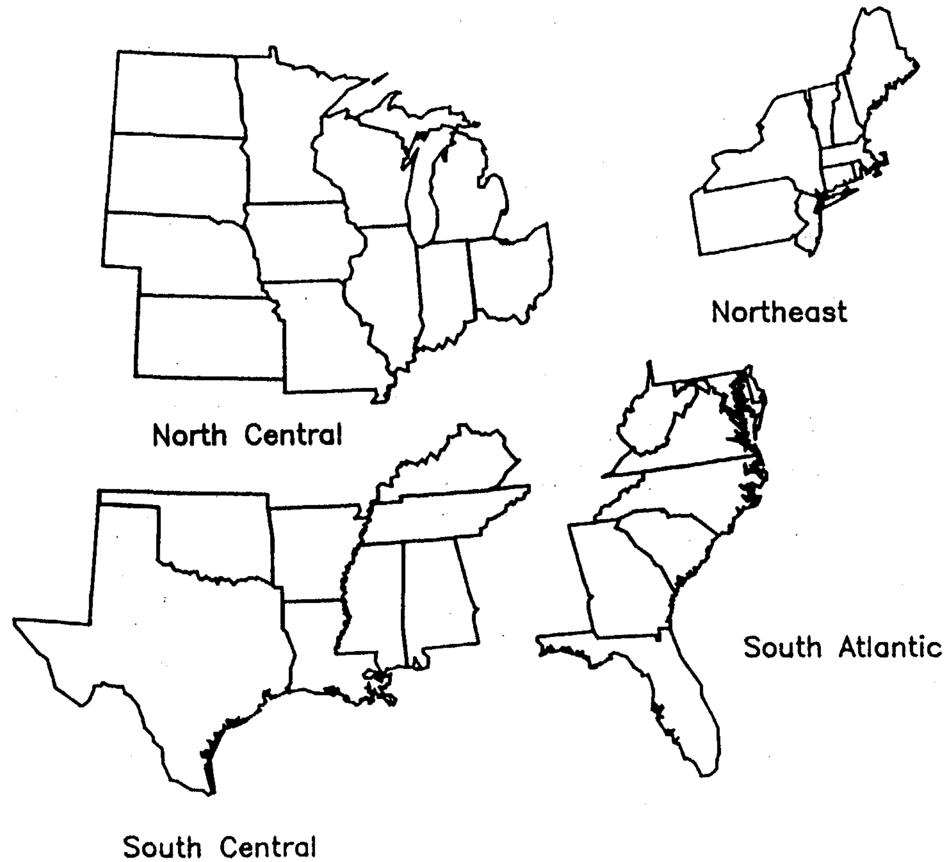

Figure 3-1. States Included in Regional Segmentations

While solid-fueled boilers made in-roads in the industrial market in the late 1970's, generally in response to cost-cutting efforts prompted by fuel price surges,natural gas has remained the dominant industrial boiler fuel, and gas usage is nowdisplacing solid fuels in many locations, either through substitution or co-firing with solid fuels. Boiler fuel choice tends to be influenced most heavily by the availability and reliability of fuel supplies with emissions restrictions playing a lesser but increasing role now that the effects of 1990 CAAA are being felt at the user level.

As noted above, the 1985 industrial boiler inventory is approximately 37,000 units with capacity of 1.5 trillion Btu/hour. Only about half of this capacity is utilized, however. Annual industrial boiler sales for the past several years have been in the neighborhood of $300-400 million (Reference 7). Major manufacturers include Foster Wheeler, Babcock and Wilcox, and Combustion Engineering (part of ABB), as field erected industrial and utility boiler suppliers. Industrial package boiler suppliers include Nebraska Boiler, B&W, ABCO and Zurn Industries. The chemical industry operates the largest number of industrial boilers, 21 percent, followed by the food and paper industries which use 16 percent and 10 percent of the total, respectively, as shown in Figure 3-2.

The largest user of industrial steam is the paper industry which has approximately one-fourth of the installed capacity. The paper industry uses these boilers primarily to provide steam for the paper drying process. Because paper plants tend to operate continuously at near full capacity, boiler utilization factors are high. The chemical and petroleum industries account for 18 percent and 14 percent of installed capacity , as shown in Figure 3-3. While the chemical installations tend to be located primarily on the eastern seaboard and Gulf Coast, refineries (particularly heavy energy users) are more widespread with numerous installations also in the West.

Figures 3-4 and 3-5 show the breakdown of the installed boiler base by primary fuel type in terms of number of installed units and by energy consumption, respectively. Figure 3-4 confirms that the majority of boilers are fired on either natural gas or fuel oil. In terms of capacity, natural gas represents one third of the energy consumption expended for industrial steam generation, followed by coal and pulping liquor. (Keep in mind that this is 1985 data, and gas usage has increased since that

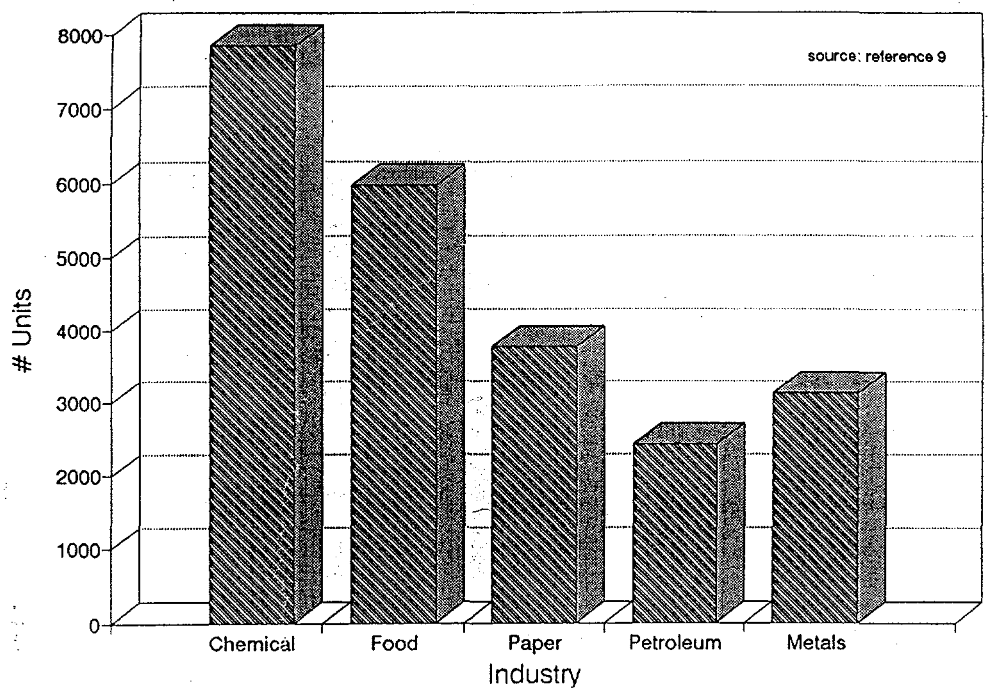

Figure 3-2. Industry Boiler Population by Industry for Boilers with Capacity Greater than 10 MMBtu/hr

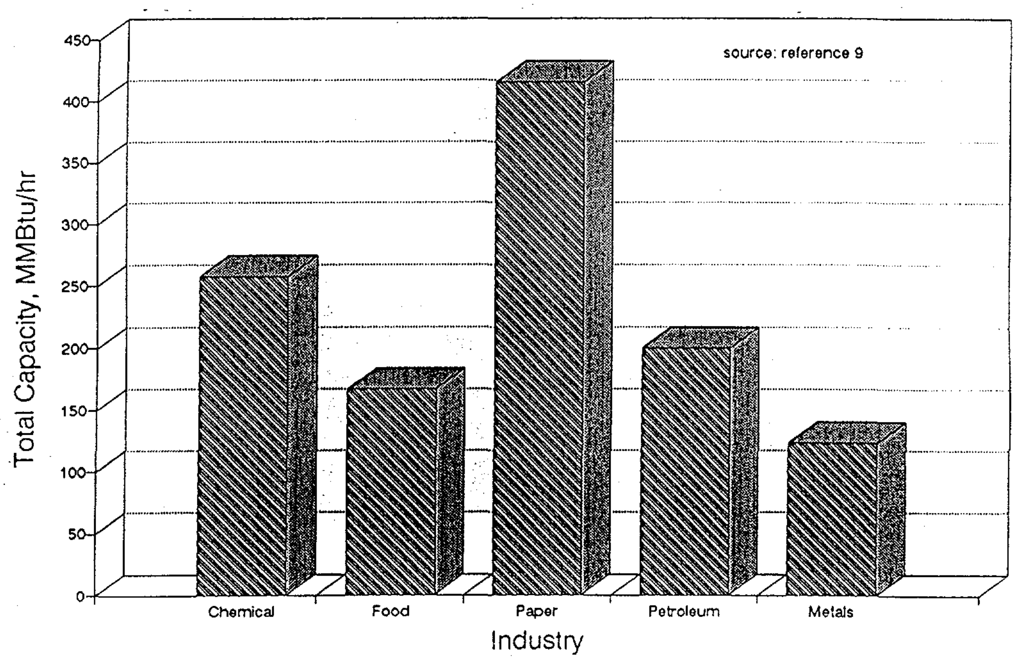

Figure 3-3. Industry Boiler Capacity by Industry for Boilers with Capacity Greater than 10 MMBtu/hr

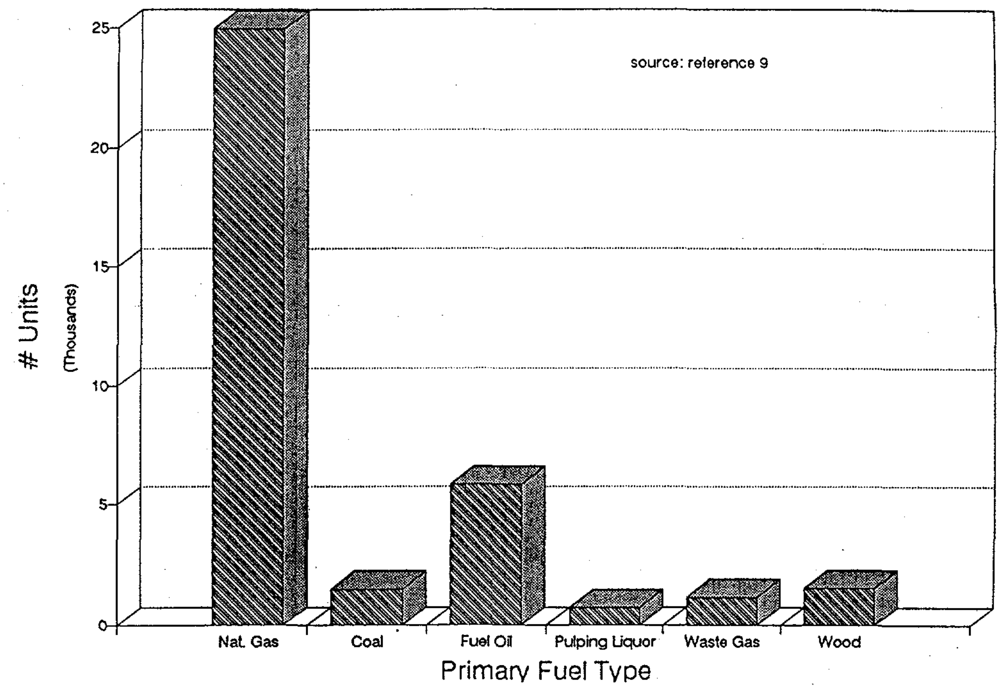

Figure 3-4. Industrial Boiler Population by Fuel Type for Boilers with Capacity Greater than 10 MMBtu/hr

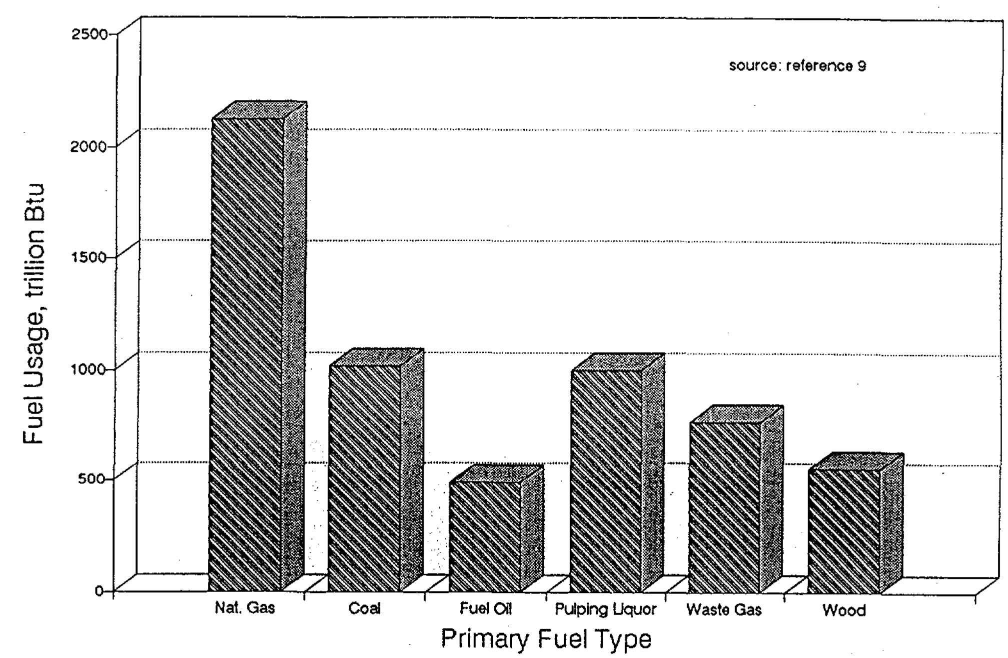

Figure 3-5. Industrial Boiler Capacity by Fuel Type for Boilers with Capacity Greater than10 MMBtu/hr

reactive flame zone. The grid size and spacing is generated so as to be relatively time.) Approximately half of the installed base is dual-fuel capable, and oil is the dominant secondary fuel. In air pollution-impacted areas, propane is increasingly being used as the back-up fuel. In California, fuel oil is now prohibited as a back-up fuel in several air pollution control districts.

Boilers can be divided into two distinct types, fire tube and watertube. The fire tube boiler has a water-jacketed combustion chamber which surrounds the burner flame. Approximately 53 percent of the installed boiler population meets this description, but these are predominantly smaller, lower pressure boilers with capacities up to about 50 MMBtu/hr, with 10-30 MMBtu/hr being a more typical size. Watertube boilers surround the combustion zone with banks of water-filled tubes, and boilers of this design make up 47 percent of the population. Units below 10 MMBtu/hr are more typically used in commercial applications and are not included in the unit count. Boilers above 50 MMBtu/hr capacity are almost exclusively watertube designs, and they therefore constitute the major share of capacity and fuel use.

Boiler Burners (New vs Retrofit Markets)

The design of burners used in boilers depends more on the dominant fuel rather than the boiler type. Approximately 400 new boilers are installed each year, and a typical unit can be expected to last for at least 30 years (References 6-8). Units are operational today that were installed in the 1930's, and in many cases the plant served by a boiler is decommissioned before the boiler is at the end of its life. Figures 3-6 and 3-7 present a breakdown of the installed boiler base by installation date in terms of units and capacity, respectively. The decrease in new installations is evident, and can be attributed to decreased need for additional boiler capacity as domestic heavy manufacturing has declined. The bulk of installed units and capacity were installed in the decade of the 1960's. Now the vast majority of new boilers are sold as replacement units.

Unlike the boilers, burners have life expectancies of the order of 15-20 years. Therefore there is a much larger market (in terms of number of units) for retrofit burners than there is for new boiler installations. Retrofitting boiler burners also represents one

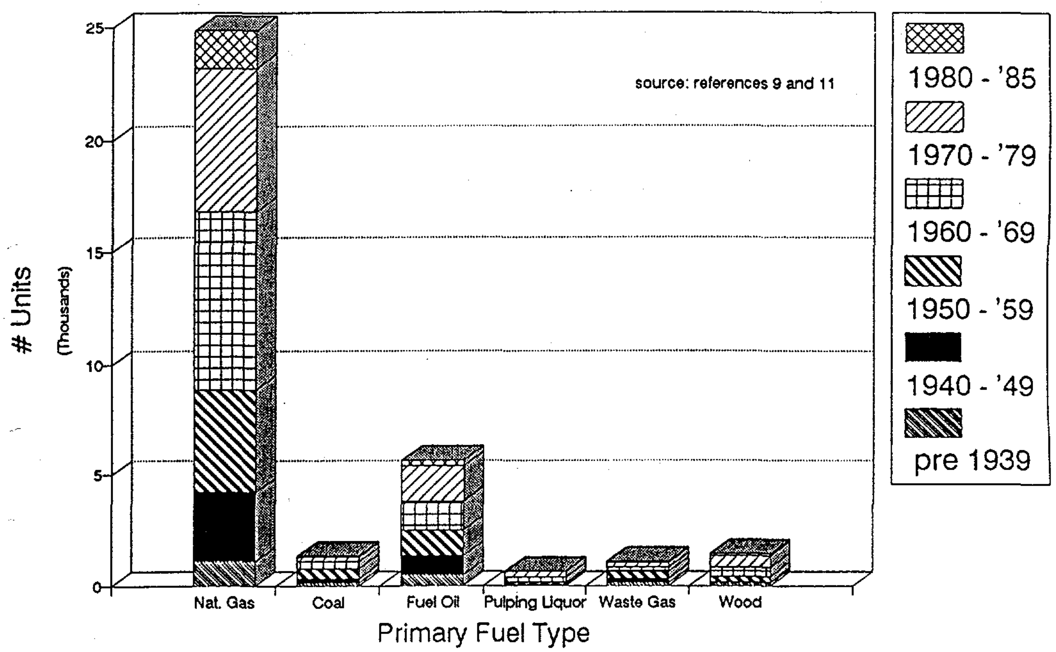

Figure 3-6. Industrial Boiler Population by Installation Date for Boilers with Capacity Greater than 10 MMBtu/hr

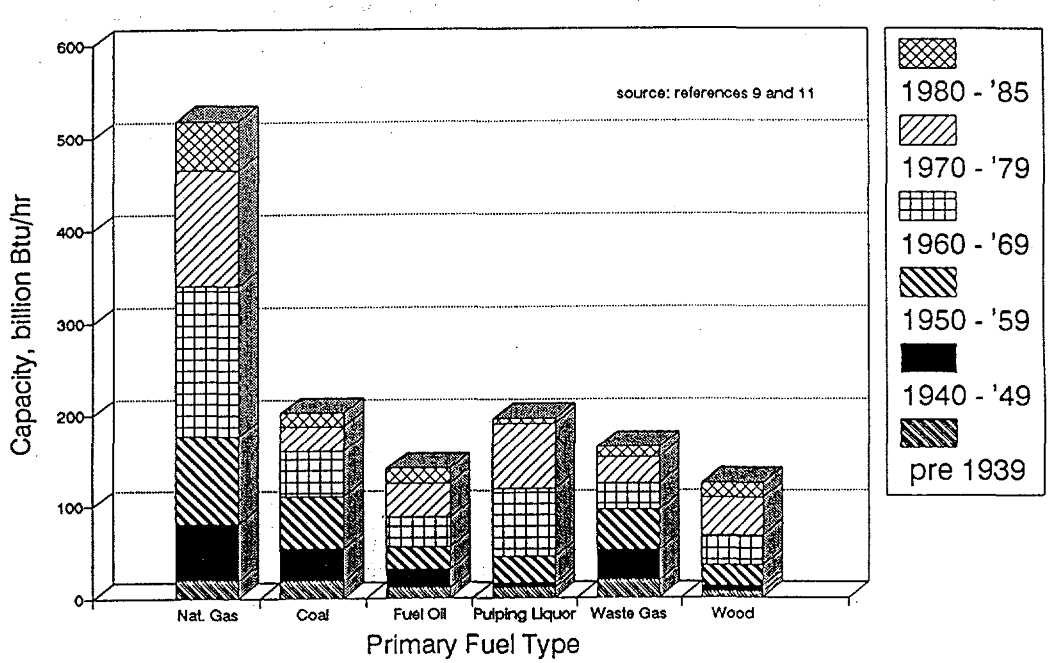

Figure 3-7. Industrial Boiler Capacity by Installation Date for Boilers with Capacity Greater than 10 MMBtu/hr

of the most cost effective ways of reducing NO_x emissions in an industrial plant. Thus, a strategy is emerging in many industrial sectors to "clean up the boiler house" with low NO_x *retrofits as a means of reducing overall plant emissions.* NO_x reduction is typically more cost effective in boilers than in other types of process equipment. In addition, modifying the boiler runs lower a risk of affecting the process than does modifying burners and heaters elsewhere in the plant. Consequently, much low NO_x burner activity is expected to be focused on boilers over the next decade. There are approximately 37,000 potential retrofit sites in the U.S., representing a more lucrative market than burners for the 300-400 new boilers sold every year.

Industrial Gas Technology Commercialization Center Market (IGTCC) Update

IGTCC works with the gas industry to develop and implement strategies to promote new natural gas technologies. As part of this work, IGTCC conducts market research, some of which has been used here to update the GRI market survey. Table 3-1 summarizes data obtained by Alzeta from IGTCC (Reference 9), and shows that the distribution of energy use and boiler units remains substantially as indicated by the GRI work summarized above. While much of the paper industry capacity is fired with non-fossil fuels, chemicals, petroleum, and food represent the major markets in terms of size of units and fossil fuel consumption. In particular, experience in California and other agricultural areas has been that the population trend to use more prepared foods has led to increased capacity requirements in the food industry. This steam is used to process more of the annual crop into precooked, canned, and frozen meals. This trend is expected to continue, and since much of this agriculture is in California and therefore in pollution impacted areas, the food industry in particular will require low NO_x boiler burners (for both new and retrofit applications) to meet future market demand for its products.

TABLE 3-1. IGTCC BOILER DATA (20-250 K lbs/hr)

	Fuel Use 10^{12} Btu/yr	No. Units	Capacity 10^6 lb/hr	Average size K lbs/hr
Paper	1,646	2,423	247	101.9
Chemicals	1,363	3,014	226	75.0
Petroleum	672	1,032	127	123.0
Food	468	584	117	19.9
Primary Metals	328	1,300	57	43.9
Other	748	15,528	219	14.1
Total	5,225	29,131	993 x 10^6 pph	

3.1.2 Target Market for RSB

Based on the market overview of the preceding section, a more specific target market for the Alzeta RSB is defined in this section. The sub-9 ppm NO_x RSB is a extension of technology at Alzeta developed to serve industrial boiler and process heater customers requiring sub-30 ppm NO_x emissions. This original technology, the CSB, was developed to provide sub-30 ppm NO_x emissions in the size range of 10 to 60 MMBtu/hr, limited at the low end of the size range by competition from the Alzeta Pyrocore burner, and at the high end by potential RSB size limitations for a single burner element. The RSB, being viewed as an extension of the CSB technology, targets the same market at the low end in terms of capacity, but through the use of higher capacity burner elements and multiple burner arrays will target boilers with capacity up to 300 MMBtu/hr. At all sizes, it is anticipated that both a sub-30 ppm and a sub-9 ppm product must be provided to simultaneously meet customer needs of cost and performance. Based on Phase I results, the RSB product is presently defined as follows:

Burner Performance Specifications

- Single burner elements scaleable in size from 10 MMBtu/hr to 120 MMBtu/hr
- Multi-burner arrays with undefined total capacity (with package boiler burner arrays topping out at 250-300 MMBtu/hr)

- No fuel staging required to achieve sub-30 ppm NO_x at 5-6 percent stack O_2 with single digit CO emissions

- Staging used to achieve sub-9 and sub-30 ppm NO_x at 2-3 percent stack O_2 (10-15 percent excess air), with the inclusion of either induced FGR in the staged fuel or external FGR in the primary section required to get to sub-9 ppm. CO emissions at both NO_x levels will be below 50 ppm

- Cylindrical metal construction using identical materials of construction for scaling burner elements from 10 MMBtu/hr to 120 MMBtu/hr

<u>**Targeted Boiler Market**</u>:

- 20 to 250 kpph boilers, typically of Package Boiler design

- Operating package watertube boilers in the U.S. in the 20-250 kpph range: 12,000 to 16,000 boilers.

- Of these boilers, 6000 to 8000 boilers in the U.S. are in the 50-250 kpph size range. This is greater than 60 percent of the 25+ kpph boiler population and 46 percent of capacity.

- In these boilers, gaseous fuels are the primary energy source, representing approximately 40-50 percent of fuel usage.

- In the Midwest, Gulf States, and all states west of the Mississippi River, gaseous fuels are a larger percentage of total than the 40-50 percent figure.

- Four industries account for 70 percent of the total installed capacity of 1.5 trillion Btu/hr. These industries are paper, chemicals, petroleum, and food processing.

- Boilers are relatively old, with 2/3 of boilers (and roughly 2/3 of installed capacity) being greater than 15 years old.

- New boilers sales in the targeted size range are in the order of 400 new boilers per year (2.5 percent of installed base per year) with sales primarily being in package boilers or HRSG's

- The retrofit burner market (for sub-30 ppm burners) is much larger, but is also closely tied to regulations and is on the order of 10 percent per year of installed base or 1200-1600 boilers per year.
- The estimated capacity of these products is 7-10 billion Btu/hr of installed new boiler capacity per year, and 60-80 billion Btu/hr of retrofit capacity per year.
- The California retrofit market requires typically sub-30 ppm NO_x, and this will be the first retrofit market targeted for the RSB, with approximately 500 boilers in the San Joaquin Valley needing to be retrofit by December 1997.

Price Information

Estimates by SFA Pacific made in 1995 say that burner cost for 30 ppm NO_x technology is about:

- \$1.30/pph steam (\$1.05/MBtu) at 50 kpph boiler size
- \$0.60/pph steam (\$0.50/MBtu) at 250 kpph size
- As a point of reference, total package boiler installed cost is \$15/pph steam at 50 kpph, and \$6/pph steam at 250 kpph
- Sub-9 ppm technology should command a 50 percent premium over the 30 ppm product, or \$1.52/MBtu at 50 kpph and \$0.75/MBtu at 250 kpph

3.2 EFFICIENCY AND NO_x REDUCTION BENEFITS

Thermal Efficiency Improvements

- **Alzeta's technology can provide significant efficiency benefits in both new and retrofit boilers.** As noted in Section 2, the compact and highly controllable flame shape of the radiant stabilized burner permits tube walls to be located closer to the flame. Thus, in retrofit applications, additional tube walls can be added within the firebox thereby improving boiler heat transfer and efficiency. This approach is not possible with traditional register-type burners because the large, diffuse, and changing flame shape would impinge on the new tube walls providing unacceptable tube life.

R. C. Vetterick of Babcock & Wilcox specifically addresses this benefit in his letter (Appendix A) in which he notes "It is our contention that we can field-modify the PFI type boilers with a division wall tube bank to achieve similar benefits as the U. C. Irvine boiler (sub 9 ppm boiler designed by Alzeta and installed in at the U. C. Irvine Medical center)." Similar modifications could be made to watertube boilers from other manufacturers using other configurations.

The cost and efficiency benefits that could be achieved are substantial. Consider the subset of industrial boilers manufactured by B&W that are prospective candidates for gas-fired retrofits. B&W has identified approximately 1,830 units as prospective candidates sized at 360-600 MMBtu/hr firing rate. Considering the benefits available by retrofitting additional heat transfer surface through a division tube wall, efficiency improvements of 1 to 2 percent could be achievable, possibly better depending on the details of the boiler and modifications made.

Assuming a 1 percent efficiency improvement, an average B&W PFI-type boiler capacity of 480 MMBtu/hr, 50 percent of the installed base to be retrofit, and 50 percent capacity factor yields a prospective energy savings of about 20 trillion Btu/year. Assuming a value of $3.60/million Btu for industrial natural gas yields a financial savings of approximately **$70 million** per year. Extended to the entire addressable market of gas-fired watertube boilers produced by all manufacturers, the potential savings is significantly larger, although much more difficult to quantify.

Power Savings Benefits

Alzeta's RSB technology has shown impressive reductions in the electrical power required to drive combustion air fans compared to conventional register-type burners and external FGR-register burners. Alzeta's CSB retrofit burner applied to a Chevron oil field steam generator (62.5 MMBtu/hr rating) reduced power compared to the conventional North American register burner from 50 blower HP to 30 blower HP. Compared to the comparable North American low NO_x burner requiring 75

HP, the electrical savings are even more significant, having a value of nominally \$16,000/year at an electric power cost of 5 cents per kilowatt hour.

It is reasonable to assume that the power savings for larger boilers would be proportionally the same. To quantify the savings possible at a national level, return again to the B&W estimate of 1,830 PFI boilers that are potential retrofit candidates. Assume that the power required for a conventional low NO_x external FGR register burner is the same as for the Chevron/Struthers TEOR boiler. This power requirement is calculated to be 75 HP/62.5 MMBtu/hr or 1.2 blower HP per MMBtu/hr. The corresponding Alzeta burner would consume 30 HP/62.5 MMBtu/hr or 0.48 blower HP per MMBtu/hr, a savings of 0.72 blower HP per MMBtu/hr. Retrofits of Alzeta technology to 50 percent of the B&W PFI type boiler inventory would save nominally 2.2 billion KwH per year (based on 8700 hours of operation per year) having a value of \$110 million at 5 cents per kilowatt hour. Note that this is a larger savings in energy than that calculated due to improved fuel efficiency as calculated above.

Total value of energy savings can be approximated by summing the fuel and electrical costs avoided, or about **\$180 million** per year. This number is based on a retrofit of 50 percent of the B&W inventory only. Savings for the "addressable market" would be correspondingly larger.

Cost of NO_x Control

The above savings are achieved simultaneous with significant reductions in NO_x emissions, but are achieved only after expenditure of capital funds for boiler retrofits. One can combine capital costs and operating costs to calculate the cost per ton of NO_x reduced. This calculation assumes (as above) that only the inventory of B&W PFI type units (1,830 boilers) suitable for such gas fired retrofits are considered.

Retrofit costs

- Burner: Assume the previously demonstrated Alzeta/Chevron burner installed cost with 30 percent cost reduction because of economy of scale

(2 to 3 times larger burner) and reduced manufacturing costs due to volume.

- ($70,000/burner)(0.70)/62.5 MMBtu/hr = $780/MMBtu burner capacity
- Boiler: Assume B&W PFI type boiler, 480 MMBtu/hr capacity, with addition of division wall tube bank to increase surface area, at a cost of nominally $150,000 (Reference10)
- $150,000/480 MMBtu/hr = $320/MMBtu boiler capacity
- Other retrofit costs: assumed to be 50 percent of burner cost or about $390 per MMBtu/hr of capacity.
- Total retrofit cost is approximately $1500 per MMBtu/hr or about $1.86/lb of steam capacity.
- "Fleet" retrofit costs: Assume 50 percent of units are retrofitted, with a capacity of 480 MMBtu/hr.
- (1,830 units)(0.50)(480 MMBtu/hr)($1500/MMBtu/hr) = $660 million.
- **Pay-back**: $680 million/$180 million savings = **3.8 years** or a simple rate of return of 26 percent assuming no value for NO_x emissions reduction.

NO_x Savings

Uncontrolled gas fired boilers, correctly tuned, typically emit 80-100 ppm of NO_x (corrected to 3 percent oxygen). The new Alzeta burner is targeted to operate below 9 ppm, also corrected to 3 percent oxygen, yielding a conservative savings of nominally 70 ppm, or about 0.085 pounds of NO_x per MMBtu input. Applying this to the inventory of B&W PFI type boilers suitable for retrofit yields the following calculation for annual NO_x saved (using the same assumptions as used above):

(1,830 boilers)(480 MMBtu/hr)(0.50 retrofit)(0.50 capacity factor)(0.0852 lbs NO_x/MMBtu)(8700 hrs/yr)/2000 lbs/ton = **81,400 tons/year**.

Applied to the "addressable" market of all suitable boilers manufactured by all boiler companies, this would provide a significantly larger NO_x savings, one which is, however, difficult to quantify as accurately.

NO_x Costs

Air pollution control districts calculate the value of the emissions avoided in costs per ton by combining the net additional operating costs and the annualized capital costs (typically the capital cost times an annualization factor of 0.167) and dividing by the tons of emissions avoided. On this basis the cost of NO_x control would be (for the B&W inventory of type PFI boilers used throughout this discussion):

[($680 million)(0.167)- $180 million savings]/81,400 tons/yr= -$816/ton.

The negative value means that there is an overall cost savings provided by the retrofit of Alzeta low NO_x burners, not the positive cost of emissions control one normally experiences. Therefore, **the technology proposed has the potential to reduce the cost of emissions control to (and below) zero** which will reduce or eliminate industry reluctance to adopt new pollution control technologies. **Overall, the technology that will be developed will lower the cost of industrial operation and improve the competitiveness of U.S. industry while improving air quality**.

3.3 ALZETA COMMERCIALIZATION STRATEGY

Based on the current ratio of retrofit to new burner sales (on the order of 5:1 to 10:1 using current numbers), it seems to be apparent that a burner manufacturer must be in the retrofit burner market in order to also be able to compete in the burner market for new boiler installations. Without a retrofit product, burner sales volume could be too low to allow economies of scale in burner manufacturer that would allow the manufacturer of a sub-9 ppm product for new boilers to be competitive. Also, without a full line of burner products, it would be difficult to establish a network of sales representatives, particularly since new boiler installations only require sub-9 ppm burners in non-attainment areas. Therefore, since it is doubtful that a sub-9 ppm burner can be developed and sold at no incremental cost over a sub-30 ppm product, it is apparent that a strategy is required that offers the choice of sub-9 or sub-30 ppm NO_x emissions. However, given the current momentum of air quality regulations nationwide, it also seems apparent that a suitable market can be developed that only offers low NO_x burners, with low NO_x being defined as burners that emit less than 30 ppm NO_x. Basically this product would be a premium product relative to conventional burners, but would be required in possibly 50 percent of retrofit and new boiler sales since most retrofits are now motivated by compliance to air quality regulations. To summarize: Alzeta must provide both a sub-30 and a sub-9 ppm product over the next 3-10 years in order to be in the industrial burner business.

Figure 3-8 illustrates in schematic form the steps that we feel must be taken to introduce new burner technology into the market. Key steps are discussed below. Alzeta has been through the entire process of technology development, product field testing, product introduction and initial production ramp up with several combustion products and systems.

Technology Development

The initial step, technology development, is the primary objective of the DOE Phase 1 through Phase 2 funding. Phase 1 DOE funding has produced the technical results described in Section 2, the demonstration of 15 ppm NO_x in an industrial scale field test and 9 ppm NO_x using an improved burner design in the Alzeta laboratory. Technology development will be completed in Phase 2 with a scale-up of the staged burner technology and final development of the sub-9 ppm staging concept.

Business Plan

As part of the DOE Phase 1 project, Alzeta has prepared a first cut business plan for RSB commercialization. Key actions and strategies from this business plan are presented.

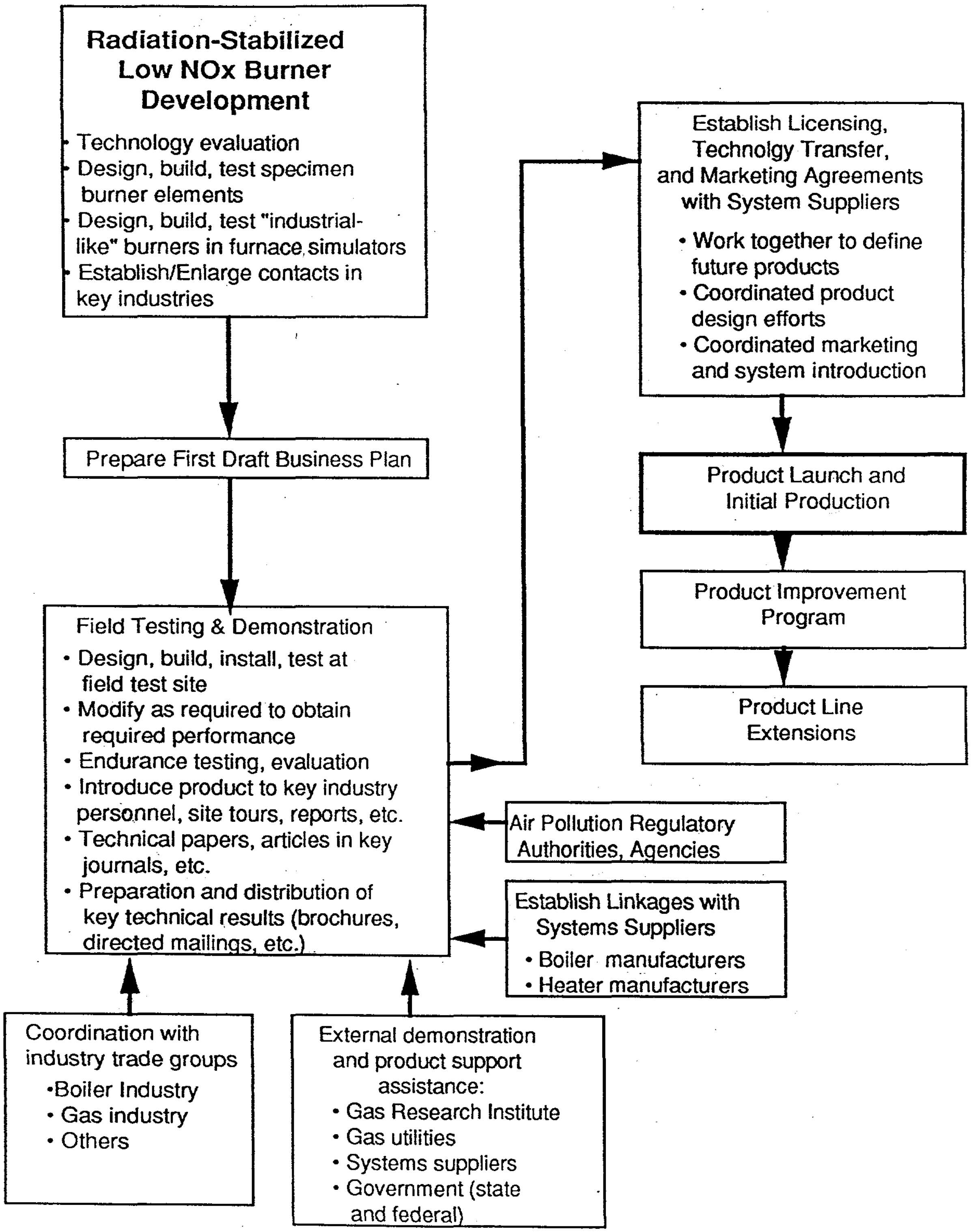

Figure 3-8. Simplified Technology Transfer and Commercialization Plan

Strategic Intent

Alzeta is recognized as a manufacturer of low NO_x burners, primarily for the 30 ppm NO_x market in California. Past attempts by Alzeta to move into large industrial boilers and process heaters have been thwarted by the relatively low surface flux of the Pyrocore burner (requiring very large burner surfaces in large industrial applications) combined with the fragility of the product. The more durable metal product is priced to make its use unacceptable as a radiant burner in industrial applications. However, Alzeta demonstrated a sub-9 ppm package Zurn boiler in the LA basin over 2 years ago that continues to operate as intended. Although a technical success, the product (the RCB) was not a commercial success due to the relatively high cost of the entire boiler package (burners plus derated boiler).

The following changes have occurred over the past 18 months:

- Development of a high-flux metal burner product (the Pyromat SB), that provides the ruggedness of the metal fiber burner with a cost per Btu delivered comparable to the Pyrocore burner
- Extension of the small SB technology to large cylindrical burners for use in process heaters. A 50 MMBtu/hr cylindrical SB (CSB) was demonstrated in 1994. The burner can provide 30 ppm NO_x emissions at 5-6 percent stack O_2.
- Development of a staged fuel version of the CSB that allows Alzeta to guarantee sub-30 ppm NO_x at 2-3 percent stack O_2. This system has now been demonstrated at full-scale in a field demonstration completed in 1995.
- Additional development of the staged-fuel concept that will provide sub-9 ppm NO_x in industrial boilers in 1996.

With these technical advancements, Alzeta is now ready to enter the industrial burner market, focusing first on 30 ppm NO_x retrofits and then later on 9 ppm new installations.

Competitive Advantage

Most, if not all, industrial burner suppliers are selling a sub-30 ppm burner product. Several are also attempting to sell a sub-9 ppm product, and this has met with mixed success. Although battling more established suppliers, Alzeta's product has the following competitive advantages:

- Very good flame stability over a 5:1 turndown range. Competing products have been shown in the field to suffer from "rumble" when changing firing rate.
- Low NO_x burners are often characterized as having "bushy" flames, implying a spreading of the flame which can lead to flame impingement on tubes. The Alzeta burner, with its well controlled flame shape, does not have this problem.
- Higher flux operation, combined with lower cost materials, now make it possible for us to provide a product at the accepted marker rate ($1000 per MMBtu/hr capacity).

Field Test Site Selection

Product acceptance will require successful field tests in customer facilities similar to the application targeted for initial product introduction. The first field tests will occur in Phases II and III, and are anticipated to be in industrial boilers. Sites in NO_x impacted areas, particularly California, are most desirable to Alzeta, and several facilities have been identified.

Licensing, Technology Transfer, and Marketing Agreements

In the industrial burner market, Alzeta does not intend to license burner technology. This is a rapidly changing field, and, in order to compete over the next 5-10 years, new technologies must continually be developed and old technologies refined. In order to stay competitive, it is essential that Alzeta be involved in developing, manufacturing, and selling in order to continue to improve the product.

Different approaches will be taken to penetrate the retrofit and new burner markets. The anticipated scenario for the retrofit market is to team with a manufacturing representative. This rep would sell the Alzeta burner inclusively into a defined market niche and geographic area. In this case the market niche would be industrial boilers in the 20-250 MMBtu/hr capacity range, with different reps assigned to different geographic areas. The advantage of the manufacturing rep approach is that Alzeta can rapidly increase market exposure for the RSB at a minimal cost for marketing and sales support, while still maintaining full control over the technology.

In order to make new boiler sales, Alzeta must work directly with boiler manufacturers. B&W has been identified as the partner with Alzeta in new boilers. The working arrangement with B&W would have Alzeta provide burners to B&W as an Original Equipment Manufacturer (OEM) supplier. As would be typical with other OEM agreements, product discounts would be offered to the boiler manufacturer in exchange for volume purchases and guaranteed levels of sales on a quarterly or annual basis.

Product Launch and Initial Production

With product design and demonstration complete, customer acceptance established (as a result of the technology transfer and advance promotional efforts prior to formal product introduction), and product launch customers identified and cultivated, the company will be in a position to obtain purchase orders for the initial production of new systems. Marketing efforts will have ramped up at this point, and the formal product introduction process will include targeted direct contact of high probability customers, directed mailings, advertising in appropriate trade journals and publications, participation in trade shows, etc.

Product Improvements and Product Line Extensions

Markets and technology continue to evolve, and the products must change to meet changing market requirements. Initially, the company will focus on product line extensions, that is, extensions of the burner technology to other industrial applications and into smaller commercial boilers. Which market segments are targeted in what sequence will depend on market research and product performance at the time the decisions must be made.

In addition to product line extensions, the company will continue its policy of continuing product enhancements and upgrades. The company maintains a tight linkage with its customers, and will continue to do so in the future, recognizing that customer input and suggestions represent a major source of product improvement and application ideas.

3.4 SUMMARY OF MARKET ASSESSMENT AND COMMERCIALIZATION PLAN

Assuming that sub-9 ppm NO_x and sub-50 ppm CO emissions are required only in new installations in ozone non-attainment areas over the next 3 years, any low NO_x product offering must have the flexibility to serve both the sub-30 ppm and the sub-9 ppm markets in a cost-competitive manner.

The total market over the next 3 years for low NO_x retrofit burners in industrial boilers is on the order of $50 million to $80 million per year. The total market for new boiler burners requiring sub-9 NO_x emissions is on the order of $10 million to $30 million per year, if a sub-9 ppm burner is available that eliminates the need for SCR to achieve sub-9 ppm emissions.

The 30 ppm burner retrofit market is regulatory driven, and business appears in "spurts" as air quality management districts move to implement NO_x control standards in ozone non-attainment areas. Compliance dates for the Los Angeles area (SCAQMD) and the San Francisco Bay Area (BAAQMD) have already passed, and with them the spurts of activity that accompanied them. The California San Joaquin Valley Air Pollution Control District (SJVAPCD) has a retrofit compliance date of December 1997, and the activity is this market is starting to accelerate. The message: The sub-30 ppm market is occurring in spurts across the country, and it is happening now. The 9 ppm market (for new applications) is developing more slowly, but presents a better long term market opportunity.

Purchases of steam generating equipment in major U.S. industries is now focused on large package boilers and heat recovery steam generators. The RSB product targets package boilers. Due to design constraints inherent in package boilers, the use of external FGR to reduce NO_x emissions is not practical at FGR levels required to achieve 9 ppm NO_x levels. Therefore, fuel staging will most likely being the burner technology that is successful in the market place.

The RSB product is being developed to serve both the 30 ppm and the 9 ppm NO_x markets. The 30 ppm product is available now. Initial sales of the 30 ppm product are being made now to a) establish Alzeta in the industrial boiler market, b) demonstrate the technology and collect performance data in the less demanding 30 ppm market prior to guaranteeing performance in the more demanding 9 ppm market, c) bring manufacturing costs down now by increasing manufacturing volume prior to formal introduction of the 9 ppm product.

SECTION 4

PHASE II PROJECT PLAN

To expand the applications of this burner into larger package or field-erected watertube boilers, installations using larger burners or multiple burners will be required. The goal of Phase II remains unchanged from our original proposal: to demonstrate 9 ppm NO_x and 50 ppm CO emissions using the RSB (with a secondary flame envelope) in a 50,000 to 100,000 pound per hour steam watertube boiler application. In addition to the Chevron refinery multi-burner boiler application for Phase III, Alzeta has identified several candidate boilers in this capacity range to test a single burner prototype for Phase II.

Phase II is scheduled for 12 months duration and is divided into five subtasks as outlined below.

<u>Task 2.1 Full Scale Experimental Burner Design</u> (3 months)

The primary challenge in this phase is to optimize the combustion characteristics of the secondary flame envelope to minimize emissions over a broad range of turndown, furnace temperatures, and stoichiometry. The second major task is to engineer a cost-effective, simple, yet reliable control package and a fuel and air mixing device based on the use of existing windbox designs.

Additional modeling and design work will be necessary to optimize the combustion characteristics of the secondary flame envelope. Alzeta's chemical equilibrium and kinetics codes and CFD codes will be used to design the fuel injectors needed to create the secondary flame envelope with the proper emissions performance. Phase I data from the oil field steamer and the laboratory will be used to verify our design.

Previous applications of the RSB (lab testing and oil field testing) have not used a windbox to distribute the combustion air to the burner, and almost without exception watertube boilers of these capacities use windboxes. The challenge is to engineer a windbox design that can accommodate the premixed fuel and air requirements of the RSB.

Finally, a combustion control system that can maintain tight control of burner stoichiometry and primary-to-secondary fuel ratio over a broad range of turndown will be designed and specified. A robust control system will be necessary to maintain the very low emissions characteristics of the RSB.

<u>Task 2.2 Full Scale Experimental Burner Fabrication</u> (2 months)

The prototype burner designed in Task 2.1 will be fabricated using existing Alzeta suppliers and our in-house manufacturing capabilities.

<u>Task 2.3 Experimental Burner Testing and Analysis</u> (5 months)

The burner will be retrofit into a 50,000 to 100,000 pound per hour steam watertube boiler. Then several months of operational data will be collected and analyzed including emissions performance as a function of boiler load, stack oxygen, and thermal efficiency by a third party testing service.

<u>Task 2.4 Design Optimization for Field Demonstration</u> (4 months)

The reduced test data collected in the field will be used to implement Phase III of this project which is to extend this technology to even larger boilers which may require 3 to 6 burners to deliver the rated capacity. Detailed design drawings and an economic analysis based on the test data will be prepared for the start of Phase III.

<u>Task 2.5 Management and Reporting</u> (12 months)

Quarterly progress reports will be submitted to DOE. When appropriate, more detailed information on project performance, schedule, and budget will be submitted.

APPENDIX A

Babcock & Wilcox
a McDermott company

Power Generation Group

20 S. Van Buren Avenue
P.O. Box 351
Barberton, OH 44203-0351
(216) 753-4511

April 30, 1994

Robert M. Kendall, President
Alzeta Corporation
2343 Calle del Mundo
Santa Clara, CA 95054

RE: Application of Radiant Stabilized Burner System to Field Erected Boilers

Dear Bob:

We would appreciate the opportunity to participate in the program you are proposing to the Department of Energy. As we understand your program, Alzeta would further develop the burner currently operating in the Struthers steamer for Chevron's enhanced oil recovery operations. This burner would then be retrofit into a field erected boiler of the type which we manufacture. We have suggested a PFI type boiler which is usually designed for a capacity of 300,000 - 500,000 lbs/hr of steam flow. This would be equivalent to approximately 360-600 MMbtu per hour. Gas fired boilers of this type which would be candidates for retrofit total approximately 1,830 units. We recognize the potential to demonstrate improved capacity, very low levels of NO_x and improved efficiency by combining your burner with certain field boiler modifications to this boiler population.

I have had the opportunity to see the Radiant Cell Burner that you developed and have installed at the University of California, Irvine Medical Center. It is our contention that we can field modify the PFI type boilers with a division wall tube bank to achieve similar benefits as the U. C. Irvine boiler. This would take advantage, not only of the low $N0_x$ characteristics of your burner but also of the radiant output from the well defined flame envelop of the burner, enabling the boiler steaming capacity to be maintained, or even increased, over design levels.

We, in Field Service, would be pleased to cooperate with you should you succeed in securing support for your proposed program. Together with the Industrial Plant Improvement Projects Department, we can utilize the Phase I data to design various field modifications necessary for a successful application and demonstration of your burner in a client's boiler. In addition, we would provide conceptual designs for the introduction of the appropriate division wall tube bank for increasing capacity and radiant efficiency of the boiler. If various mutually defined objectives have been met, we could proceed with the fabrication and installation of a tube wall into a host boiler and assist in the subsequent tests.

We wish you well in the success of your proposal. You may use this letter as support for that proposal and refer any specific calls with regard to our interest to me.

Very truly yours,

R. C. Vetterick
Manager, Field Service Operations

RCV259/krc

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