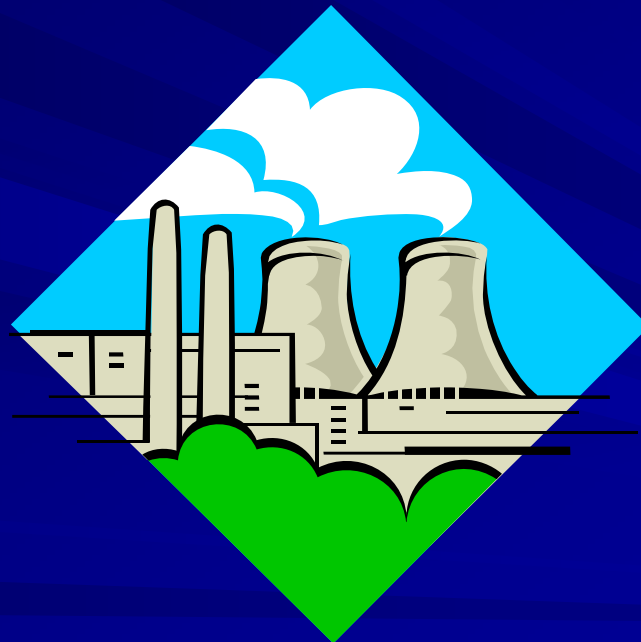


# Bucknell's Cogeneration Power Plant



Presentation designed by Melanie Buczko '07

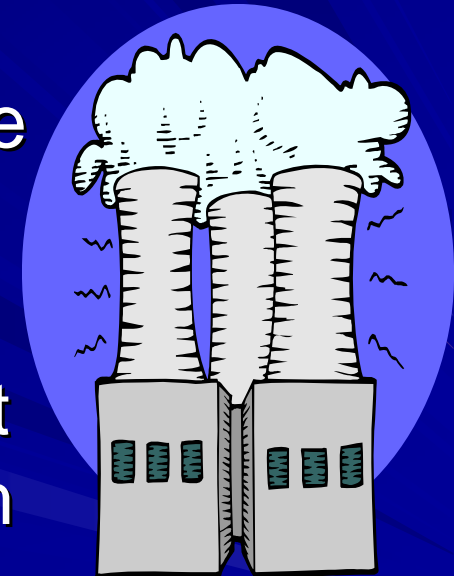
# History

- April 1996 – Bucknell started a project to convert the power plant from a coal burning facility to a gas/oil cogeneration facility
- The University's continuing building program created the need for additional steam production capacity.
- The existing plant could no longer supply steam reliably during peak usage periods.
- This led to the project of a new cogeneration plant to replace the existing plant in order to allow for further growth of campus.



# What is Cogeneration?

- Refers to the process which derives two forms of energy from a single fuel source. Generally, the process produces electricity and steam from the same fuel.
- Bucknell's cogeneration plant is a combined cycle design, meaning that it not only produces electricity and steam from the combustion fuel, but also produces electricity downstream in the process using a steam turbine.



# Why Cogeneration?

- It is a cost effective method of supplying the steam and electric needs of the campus.
- The plant supplies all of the campus' steam needs and 90-95% of campus electricity use.
- Excess electricity generation is sold to the utility company.
- The continuous need for steam combined with the savings on electricity purchases made the cogeneration technology well suited for the university's energy needs.



# Design Criteria

- Provide enough steam generation capacity to satisfy the projected growth of the campus for at least twenty years.
- Supply all of the campus' (1998) electrical load, plus a moderate surplus for future growth.
- Maintain 100% reliable steam production using multiple layers of redundancy. This allows for the maintenance of any of the plant's components without interruption the steam service to the campus.



# Technical Scope

- The plant design includes the following components:
  - Combustion turbine generator, 4800 KW, natural gas or oil fired. 5500 KW peak capacity.
  - Heat recovery steam generator (HRSG), 70,000 pph, with stand-alone fresh air firing, auxiliary fired on natural gas only
  - Two package water tube boilers, 70,000 pph, natural or oil fired
  - Oil storage facility, 50,000 gallons
  - Electric utility interface switchgear
  - Back pressure steam turbine/generator, 1250 KW
  - New control, electrical and ancillary systems
  - Emergency Diesel Generator to provide black start power.

# Total Plant Capacities

## ■ Steam Production

- 140,000 pph peak with 50% redundancy (two 70,000 pph boilers operating with one 70,000 pph backup boiler)

## ■ Electric Production

- 6000 KW ISO design conditions, produced by combustion turbine and steam turbine generators. 6800 KW peak capacity.

## ■ Fuels

- Natural gas with #2 fuel oil back-up.



# Project Cost/Benefit

- The project was completed in 1998 for a total project cost of \$12,000,000.
  - Included all design, construction, management, equipment, and testing costs.
- The plant currently saves the university over \$1,000,000/year in utility costs.



# Environmental Benefits

- The University also had to consider the environmental impacts of the existing plant.
- The original plant was built 50 years ago, when environmental standards were less demanding, so emission improvements were required.
- The new plant produces 75% to 99% lower emissions of pollutants such as Sulfur Dioxide, Nitrogen Oxides, and Particulates than the old plant.

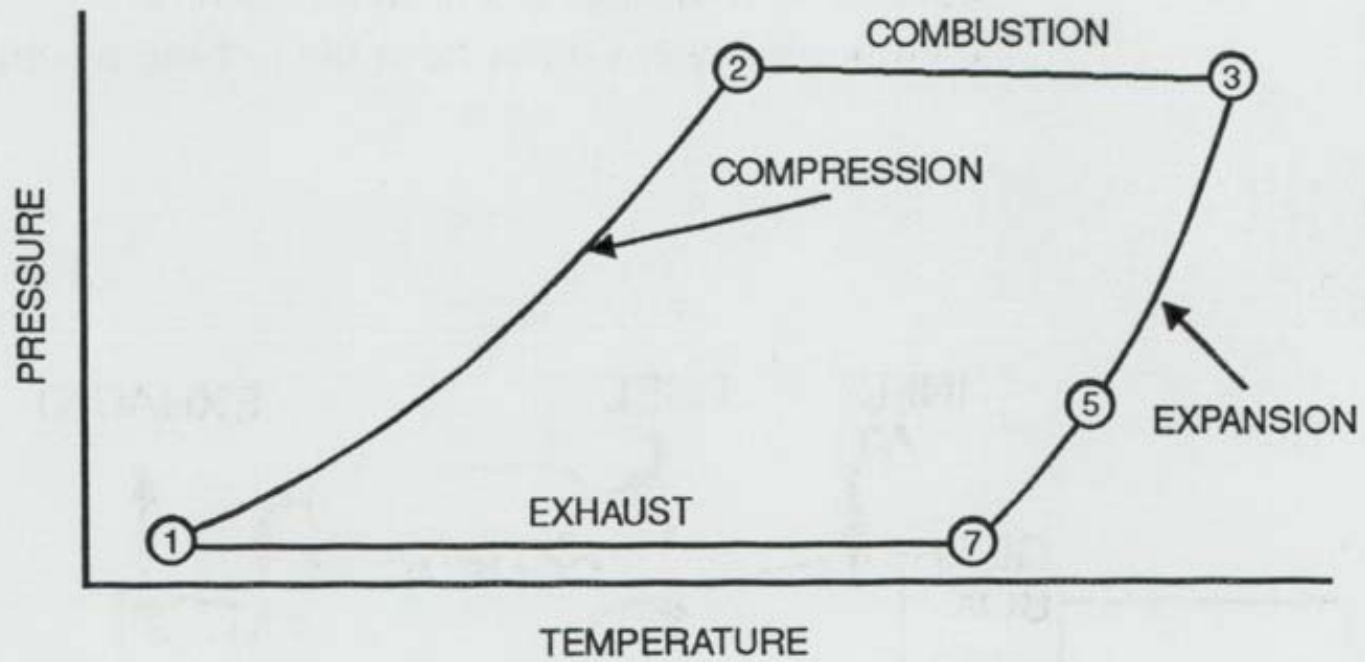


# BU Power Plant Emissions

Annual Emissions (ton/yr)	1996	2006	Percent Reduction
NO <sub>x</sub>	94.7	22.4	76%
CO	112.3	4.9	96%
VOC	0.9	0.4	55%
TSP	100.4	0.9	99%
SO <sub>x</sub>	703.7	1.5	99.8%

# Power Plant Cycle & Equipment

- Gas Turbine Generator

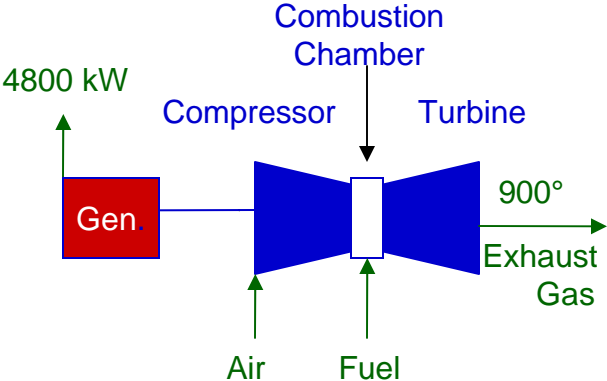


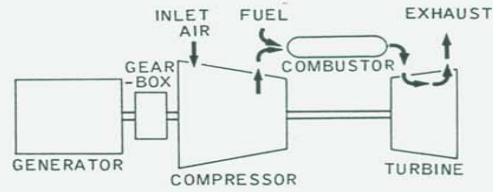
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(B)

*Figure 3-16. Brayton Cycle*

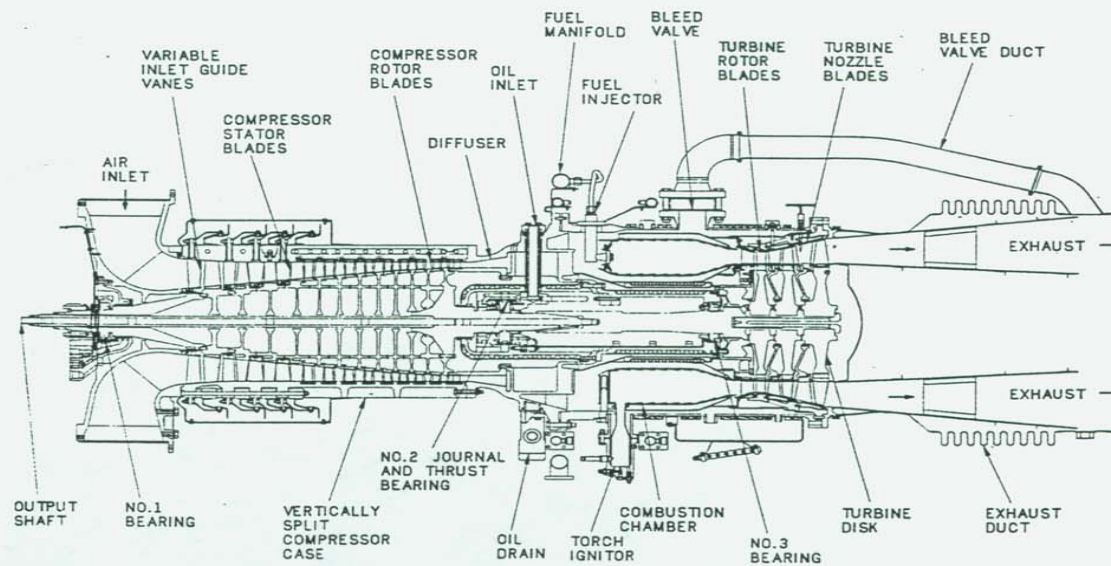
# Gas Turbine





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Figure 3-2. Power Transfer Diagram



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Figure 3-3. Taurus Gas Turbine Airflow

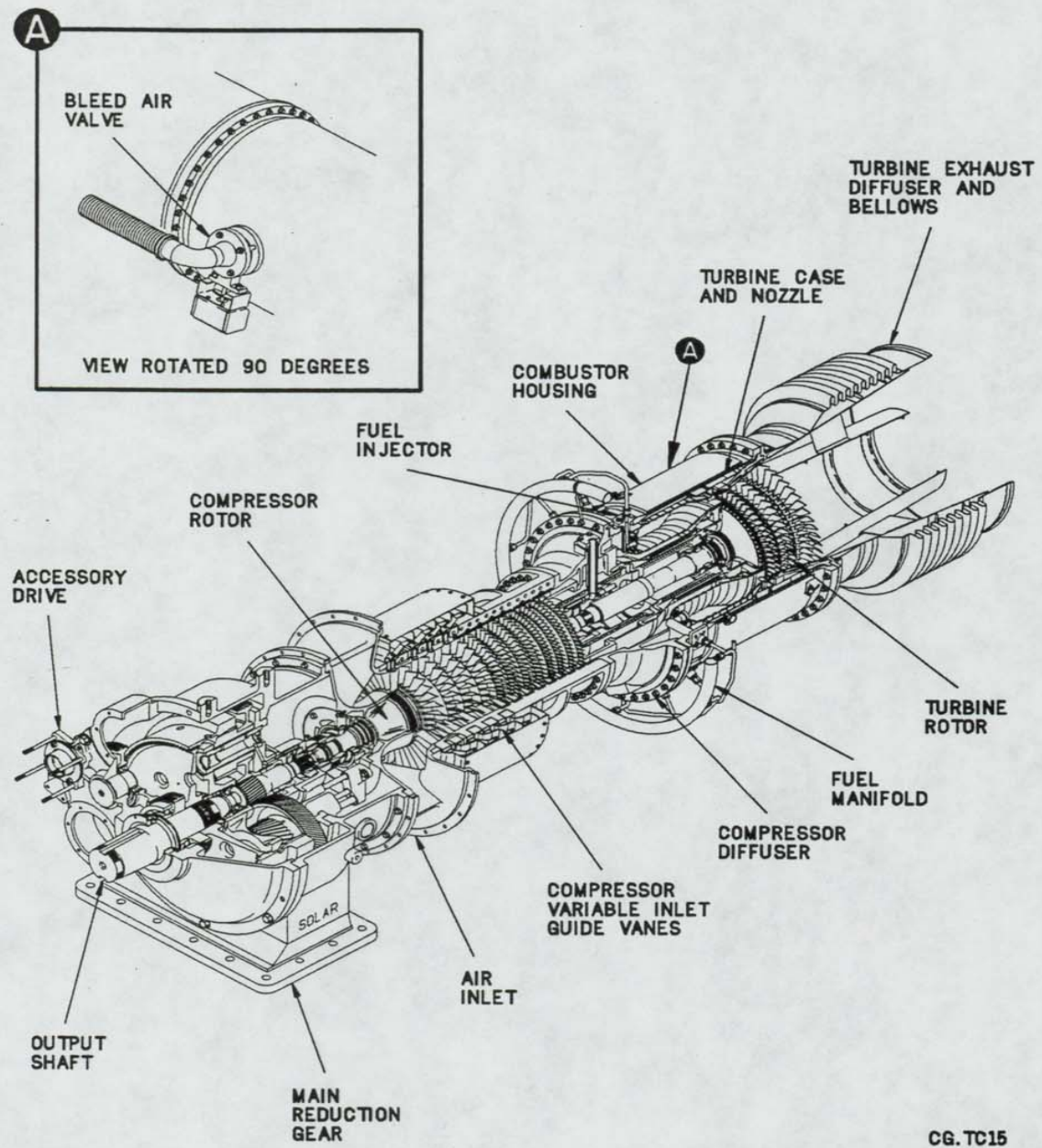


Figure 3-1. Single Shaft Taurus Turbine Cutaway

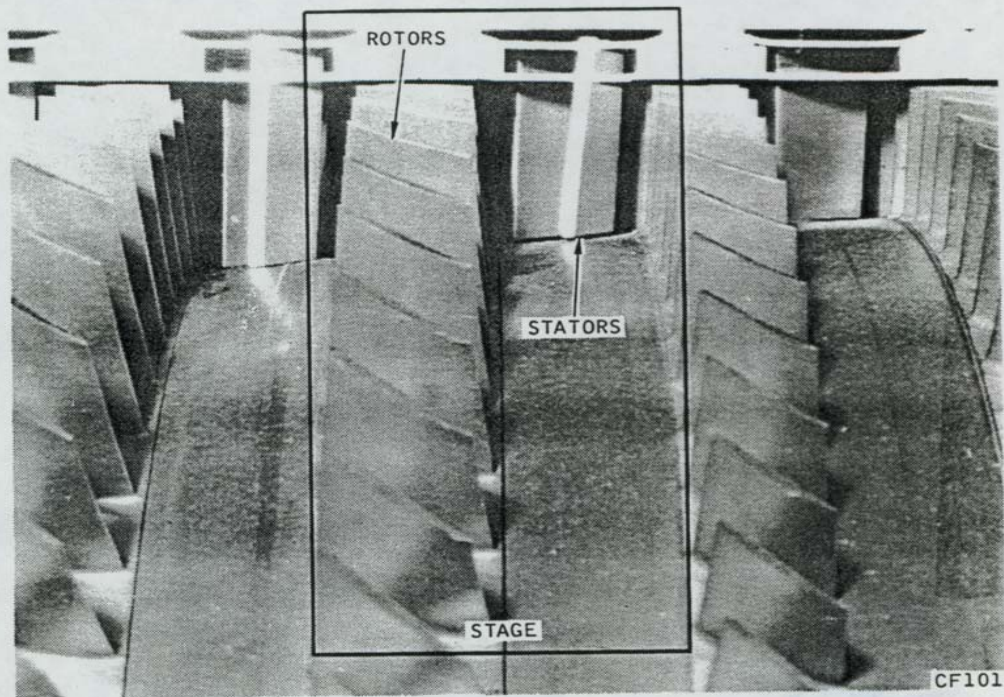


Figure 3-12. Compressor Components

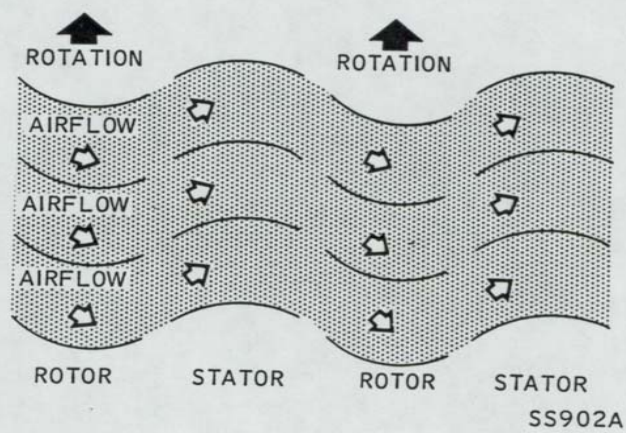
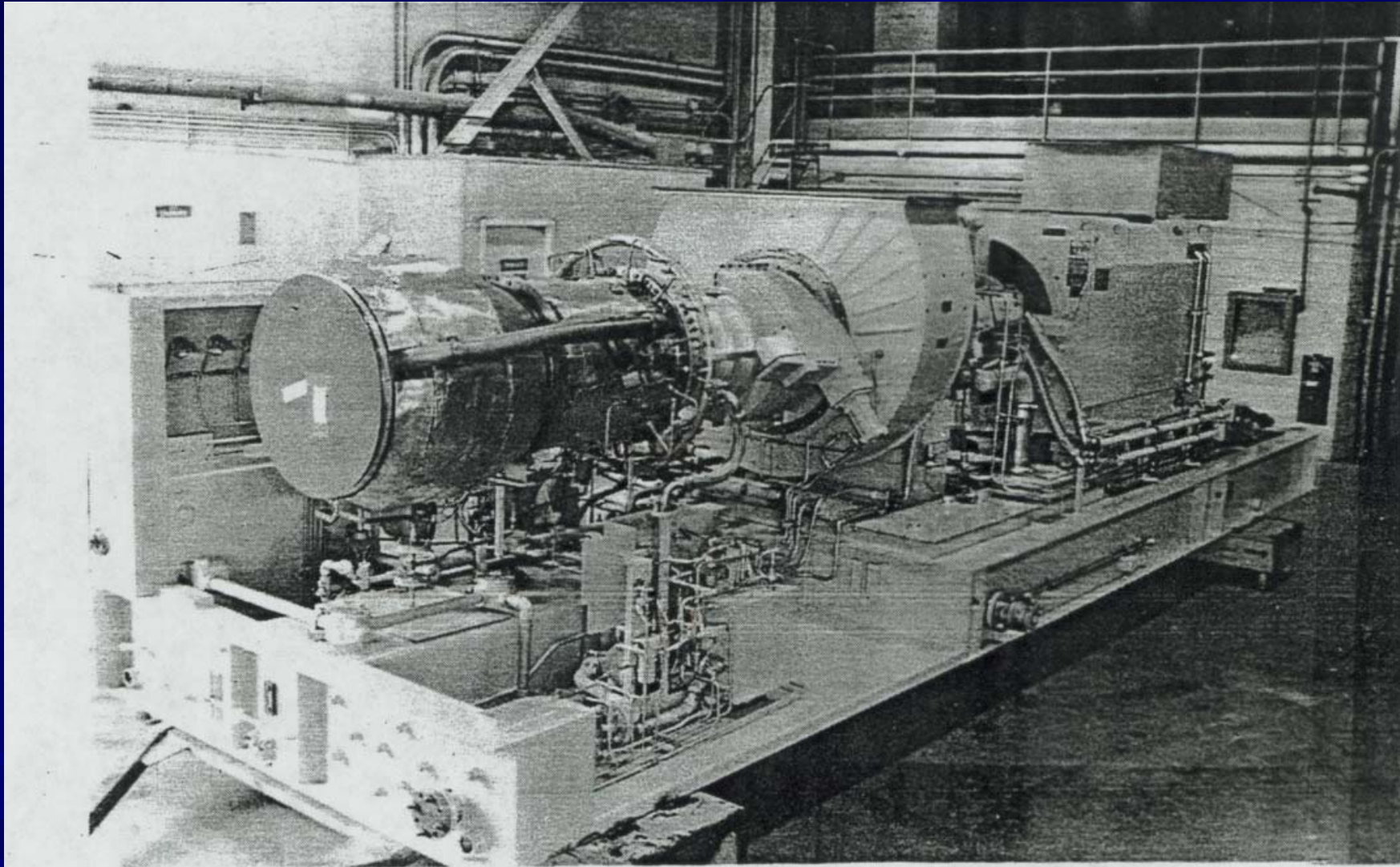


Figure 3-13. Air Flow Across Stator and Rotor Blades



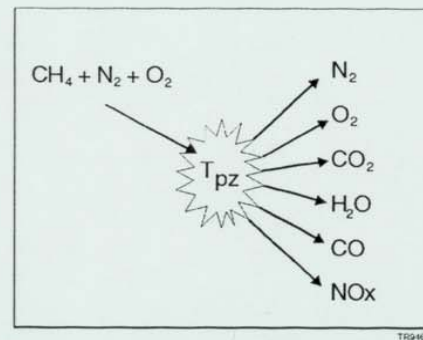
*Figure 2-2. Typical Taurus Generator Set Package*

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## EMISSION CONSIDERATIONS

### NO<sub>x</sub> and CO

NO<sub>x</sub> and CO emissions are by-products of the reaction of hydrocarbons (fuel), nitrogen, and oxygen in the turbomachinery combustion process (Figure 7-10). At high reaction temperatures (2900°F and above), significantly high concentrations of NO<sub>x</sub> are produced through thermal fixation. Because a NO<sub>x</sub> molecule is highly stable, once formed it stays intact through the remainder of the combustion and cooling cycle and is released to the atmosphere through the exhaust stack.



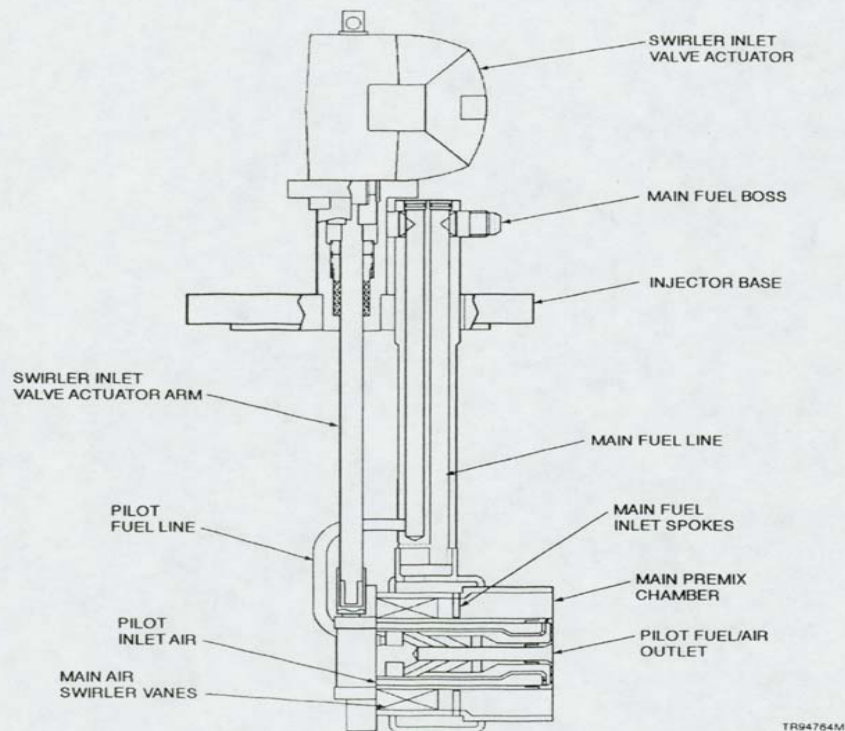
*Figure 7-10. NO<sub>x</sub> and CO Formation*

Carbon Monoxide (CO) is generated as an intermediate product of the oxidation of hydrocarbon fuel. At higher combustion temperatures, this intermediate product oxidizes to carbon dioxide. At lower combustion temperatures (less than 2700°F), CO molecules escape the combustion zone unreacted. This is either due to inadequate reaction or quenching of the reaction due to cooling air entering the combustion liners through diffusion orifices. The result is high CO emissions at the exit of the combustor zone.

With NO<sub>x</sub> formation occurring at high temperatures and high CO emissions at lower temperatures, the challenge of dry low NO<sub>x</sub> combustion is one of operating with a combustion temperature low enough to keep NO<sub>x</sub> formation at acceptable levels and high enough to minimize CO emissions.

## FUEL INJECTORS

The fuel injectors each have a pilot and main passage (Figure 7-7). The flow of main fuel is from the outer passageway through the pre-mixing tubes which are located downstream of the swirl vanes. The main fuel is premixed with air from the swirler before it exits the injector into the combustion zone. Pilot fuel is directed through downstream angled holes located in the central passage along the axis of the fuel injector. Some air from the pilot swirler is mixed with pilot fuel before it exits into the combustion zone. The main portion of pilot air is from diffusion air entering through the diffusion liner. Each fuel injector is equipped with a swirler air inlet valve (SIV) which can operate in either the closed or opened position to change the air flow rate through the main swirler. The swirler inlet valve does not modulate and is operated by a pneumatic actuator located on each injector flange.

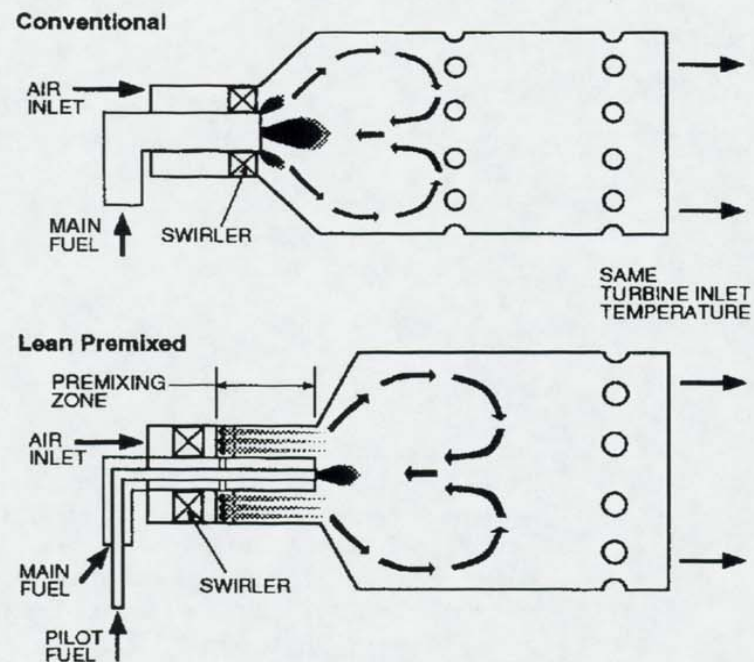


*Figure 7-7. SoLoNOx Fuel Injector*

## TYPES OF COMBUSTION

### Diffusion Flame Combustion

In a standard combustor, fuel enters the combustor through the fuel injectors with combustion air being injected through fixed orifices or separate air injection tubes. The fuel and air unite in the combustion zone (Figure 7-11). This is referred to as diffusion fuel injection; the area of the combustor in which the reaction occurs is referred to as the primary zone. The process of mixing fuel and air simultaneously with combustion results in a highly non-uniform flame operating over a broad range of temperatures (from 2000 to 4000°F). Consequently, conditions exist which are conducive to the formation of both NO<sub>x</sub> and CO emissions.

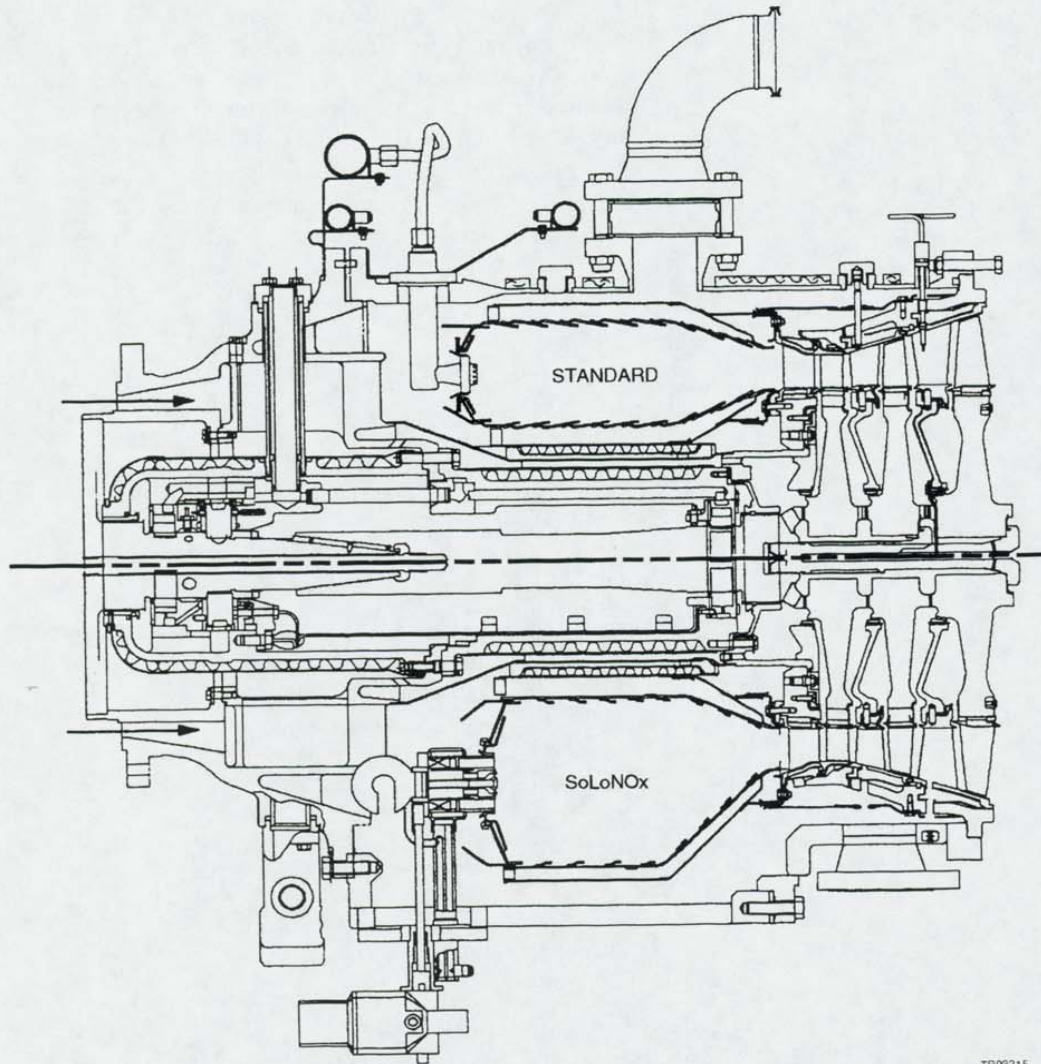


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*Figure 7-11. Standard Vs. Lean Premix Combustion*

## COMBUSTOR

The combustor size is larger than a conventional combustor to maintain combustion efficiency and reduce carbon monoxide levels. Leaner combustion occurs at lower temperatures which produce less nitrous oxides but require more volume to complete the combustion process (Figure 7-8).

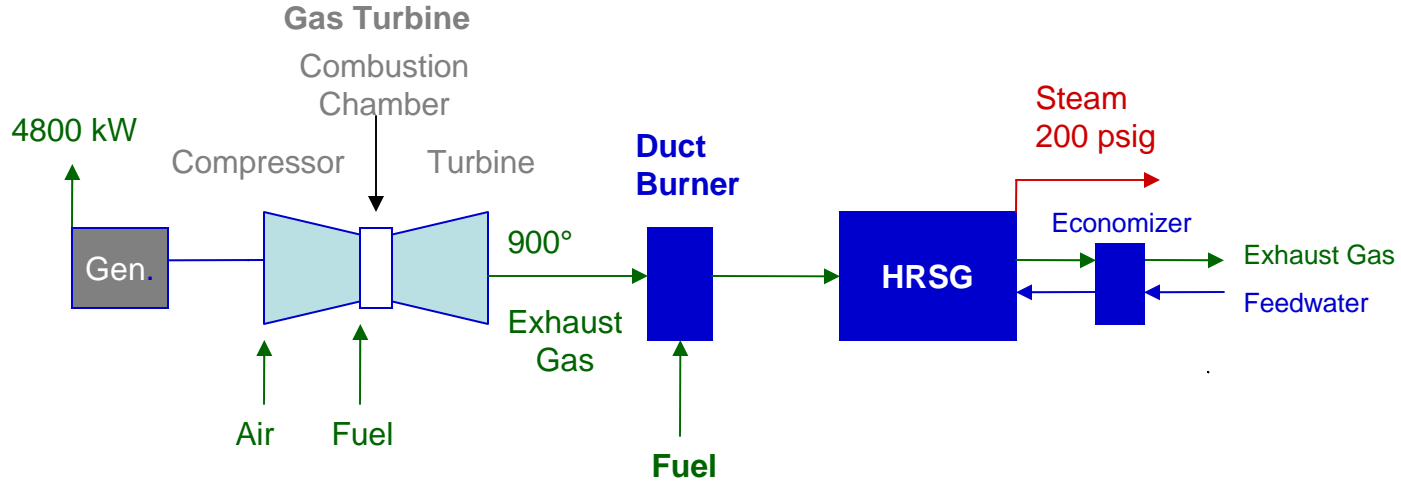


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*Figure 7-8. Comparison of Conventional and SoLoNOx Combustors*

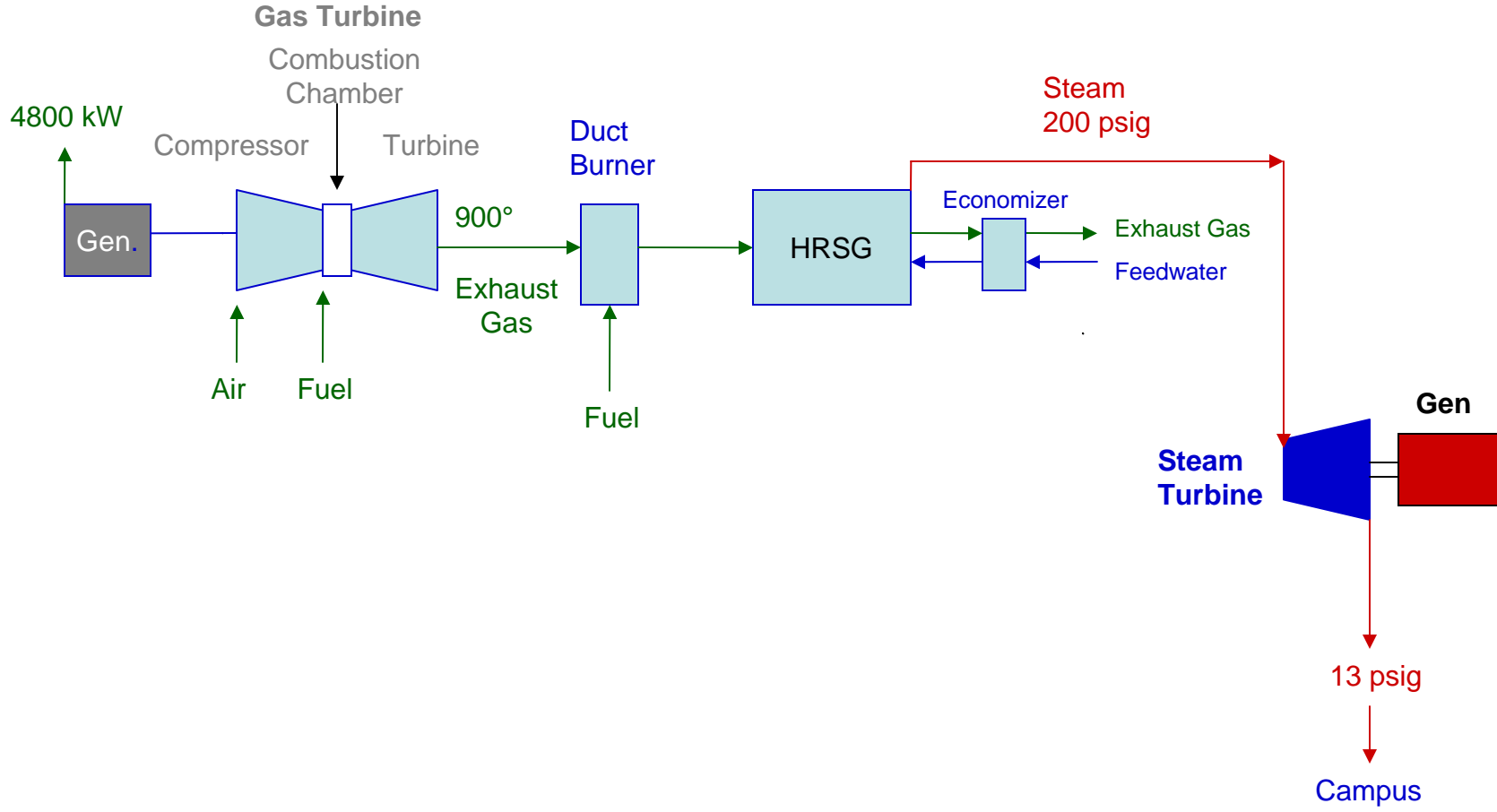
# Power Plant Cycle & Equipment

- Gas Turbine Generator
- Heat Recovery Steam Generator (HRSG)
  - Water tube boiler
  - Natural Gas fired Duct Burner
  - 25,000 pph capacity unfired
  - 70,000 pph capacity with supplemental firing



# Power Plant Cycle & Equipment

- Gas Turbine Generator
- Heat Recovery Steam Generator (HRSG)
- Steam Turbine Generator



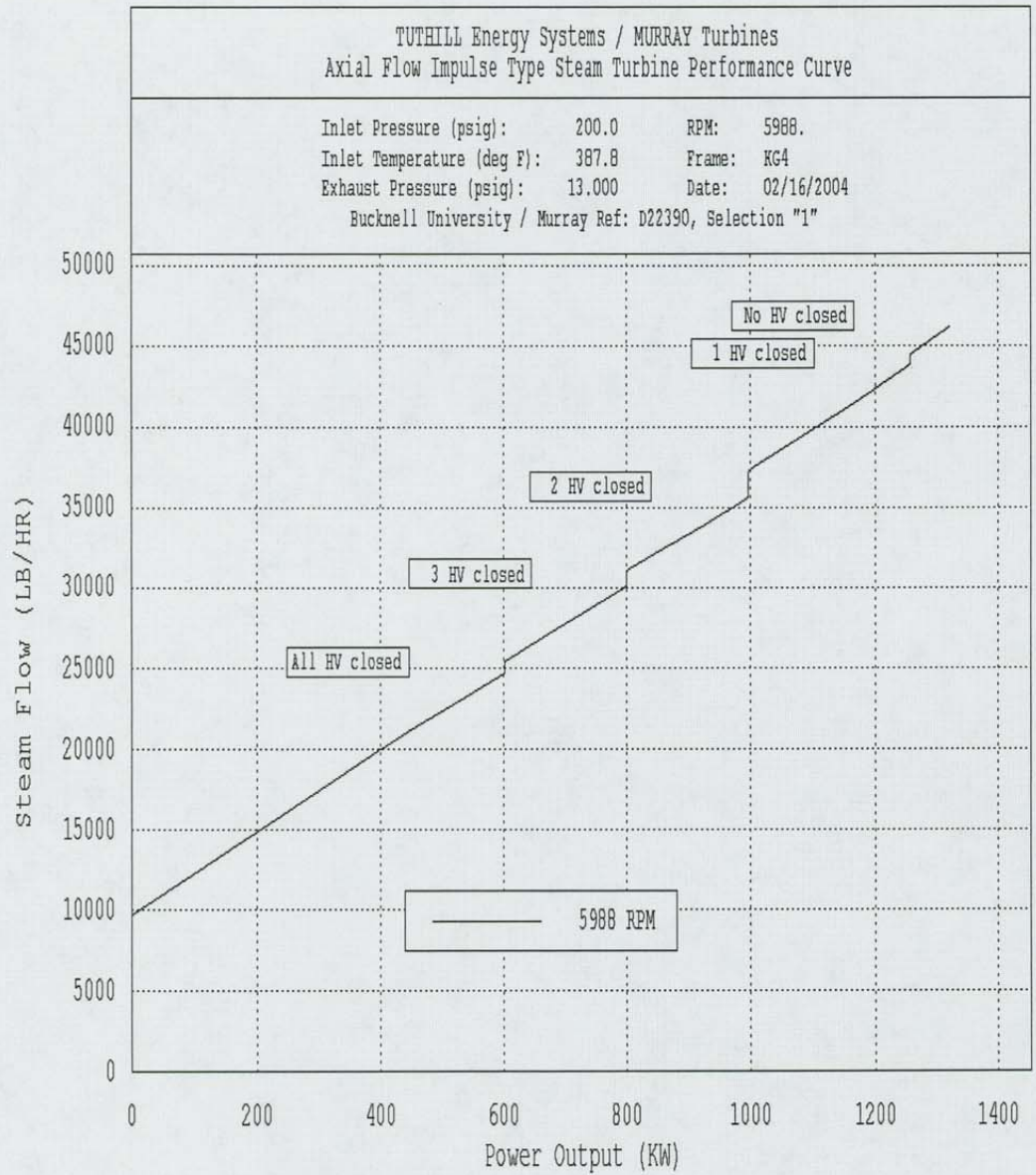


**TUTHILL**  
ENERGY SYSTEMS

Murray Steam Turbines

1106 Washington Street, P.O. Box 967  
Burlington, Iowa USA 52601-0967  
Tel 319 753-5431 Fax 319 752-1616

Bucknell University / Cogeneration Plant – Steam Turbine Replacement / Murray Ref: D22390  
February 18, 2004



# Power Plant Cycle & Equipment

- Gas Turbine Generator
- Heat Recovery Steam Generator (HRSG)
- Steam Turbine Generator
- Feedwater System

