

# Development of an Underarmor 10 Kilowatt Thermoelectric Generator Waste Heat Recovery System for Military Vehicles

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# Quantum Well Thermoelectric Generator for Stryker

- Purpose: Develop preliminary design of Quantum Well thermoelectric generator
  - Army TACOM funded
  - Caterpillar provided engine data
- Working on integrating Quantum Well thermoelectric generator with CAT diesel engine in a Stryker vehicle
  - This program is a primer for integrating with truck system
  - Prior test with PACCAR/Kenworth was oriented towards testing of the 1 kW generator

# Quantum Well Thermoelectric Generator for Stryker

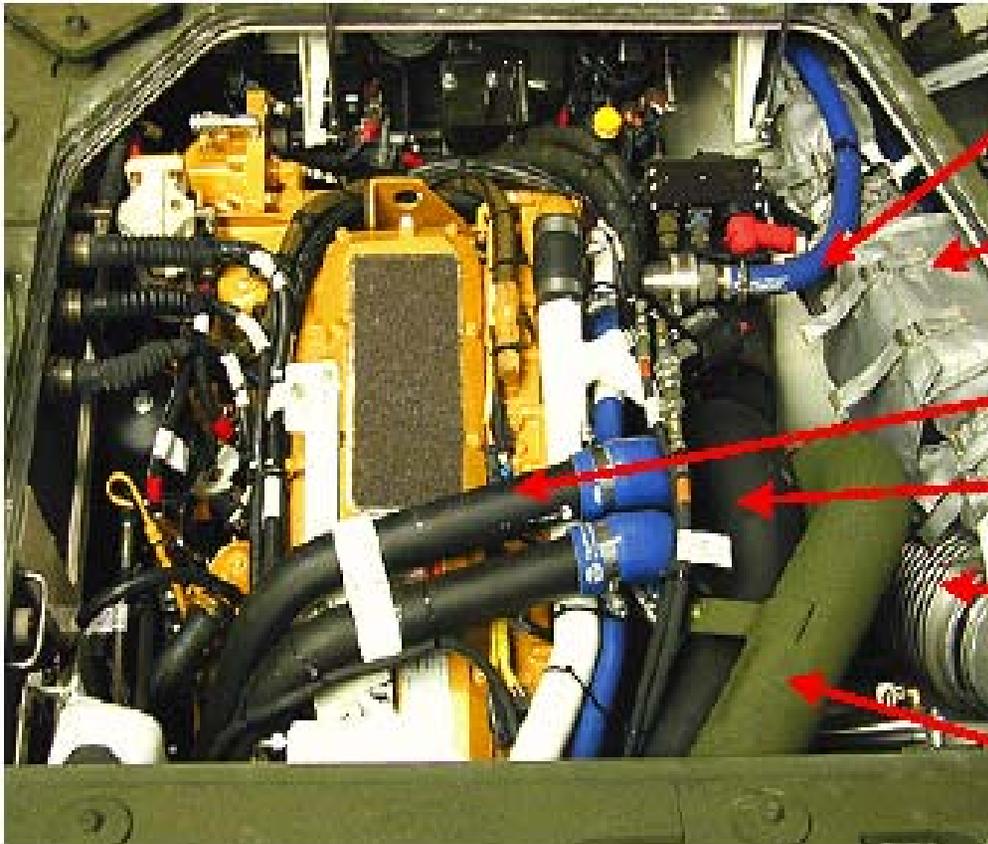
## Preliminary Design Topics

- Stryker vehicle arrangement
- QW TE Generator
  - Design for Stryker
  - Prior TE Waste Heat Generators
- QW TE Module
  - In-Situ APU
- Predicted Performance

# Army Stryker Vehicle



# Stryker Caterpillar 3126 300 hp (224 kW) Diesel Engine



**APU Hydraulic Line**

**APU Exhaust Blanket**

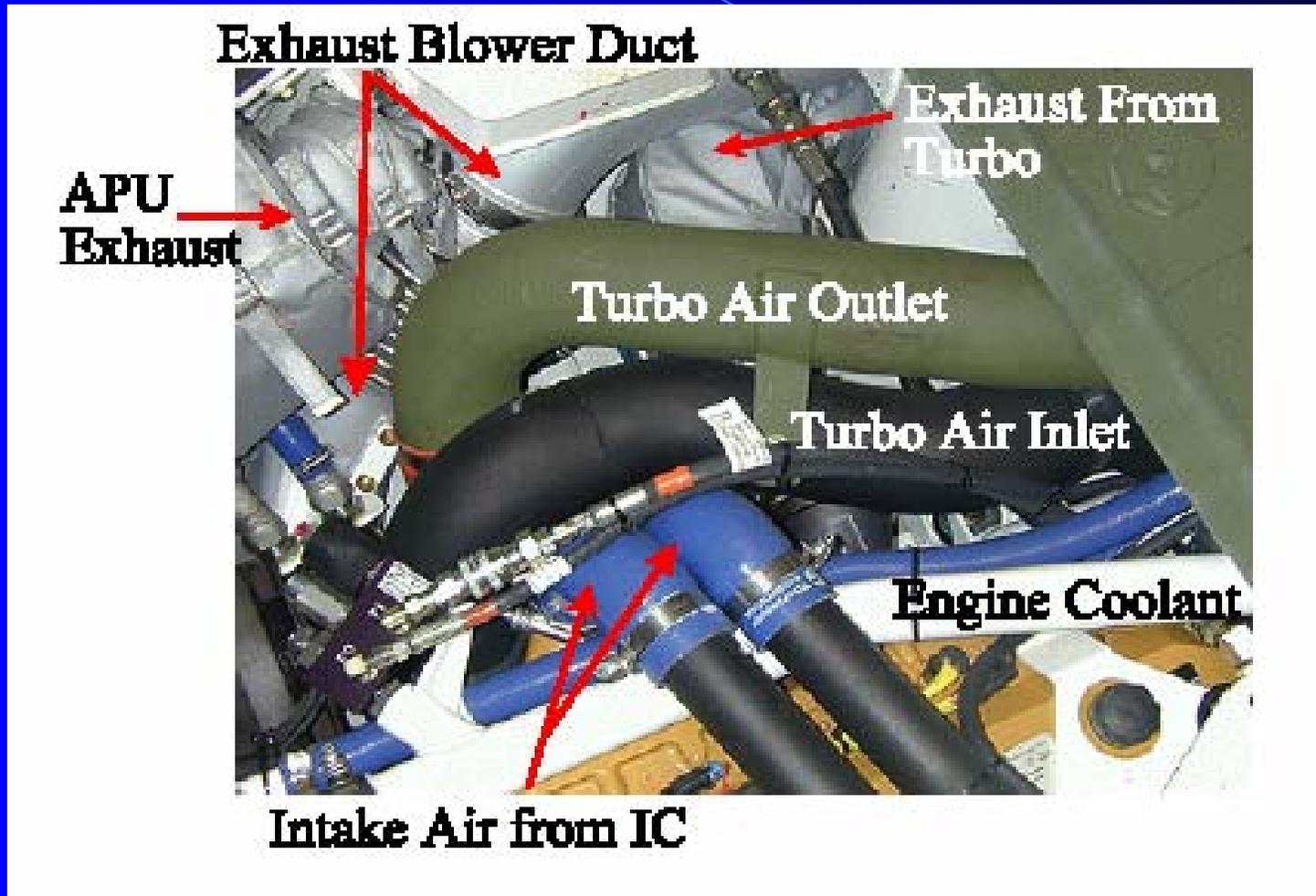
**Intake Air From IC**

**Turbo Air Inlet**

**Exhaust Blower Outlet**

**Turbo Air Outlet**

# Stryker Exhaust Region



# Stryker Strut and Muffler



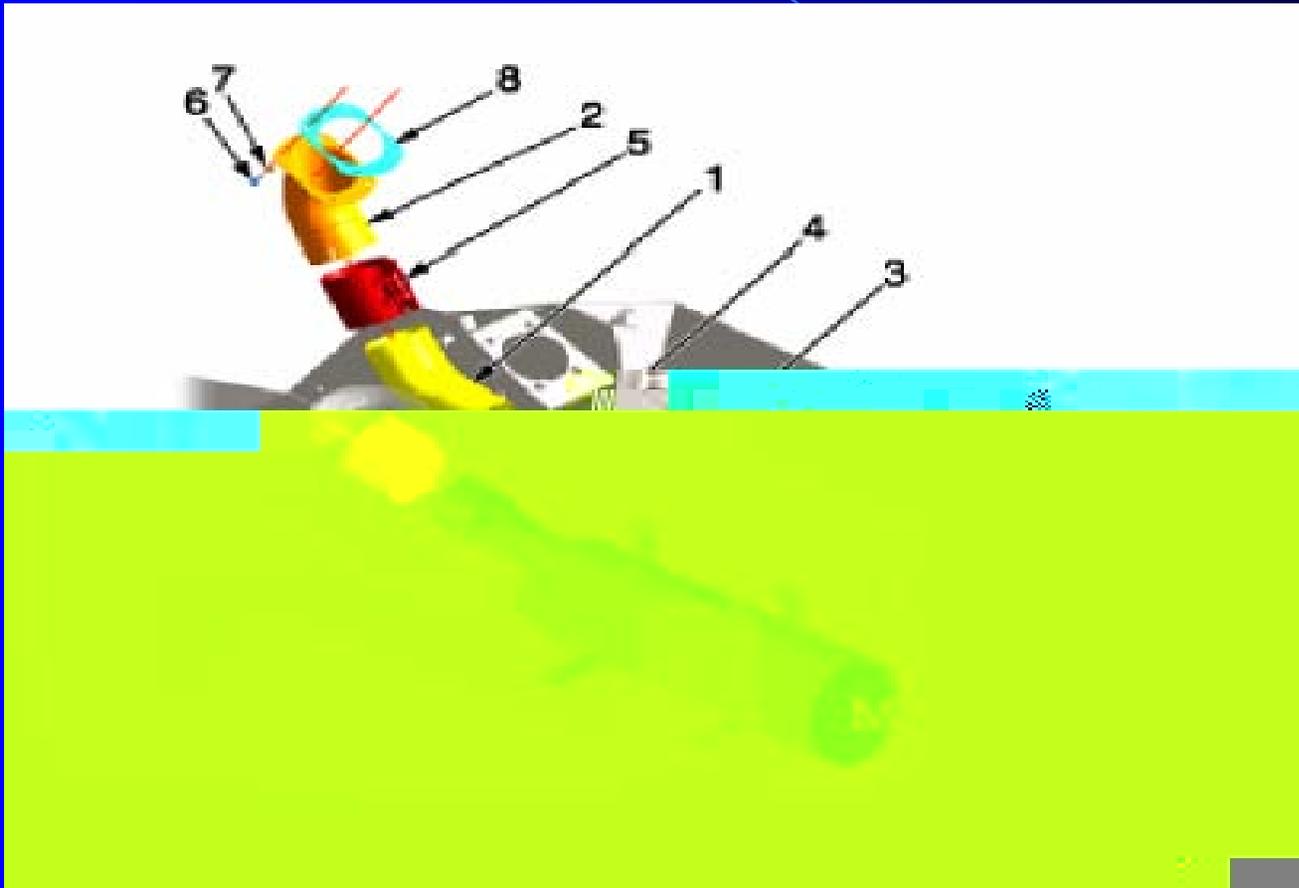
# Stryker Interior in Back of Driver

Similar strut arrangement on other side for muffler

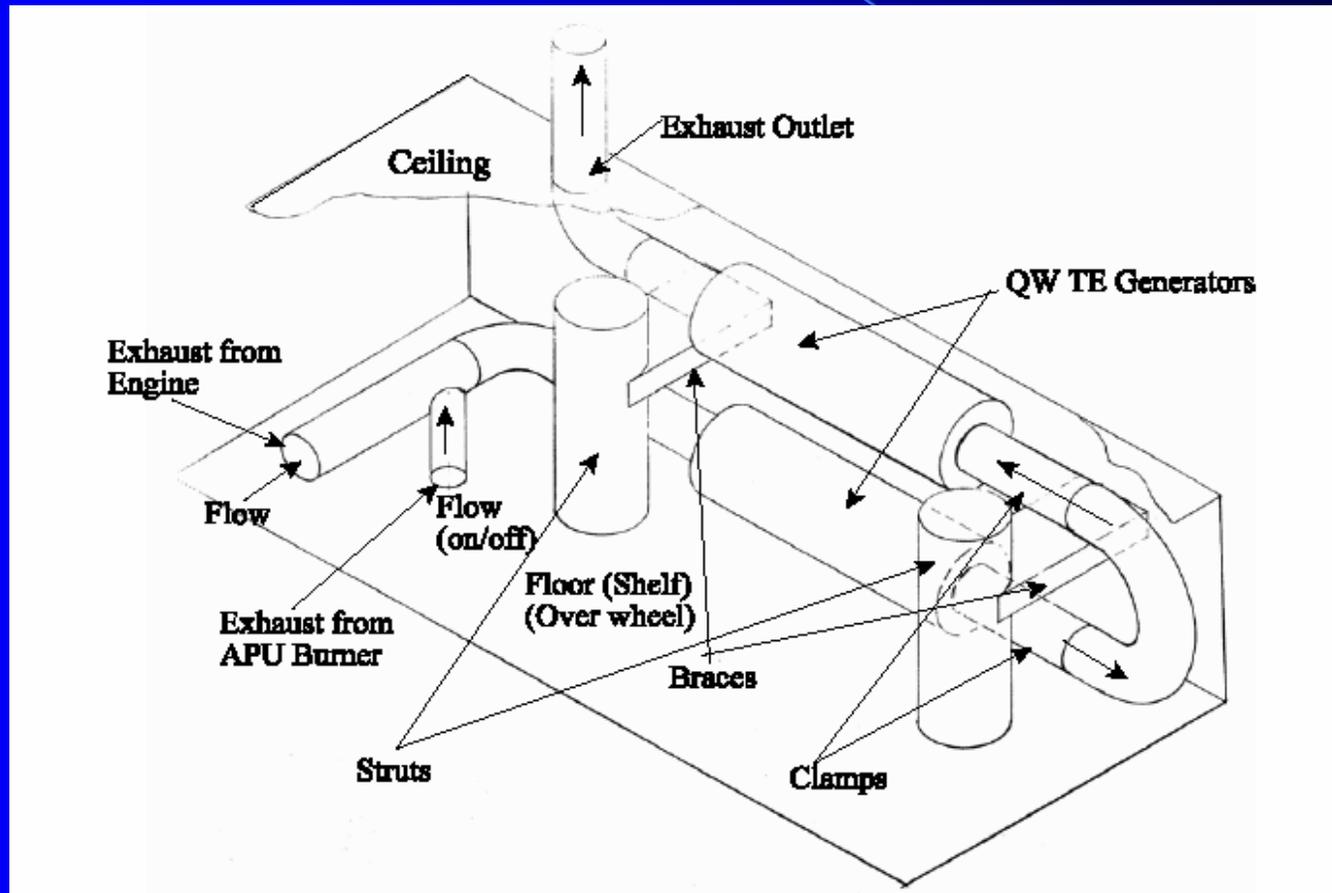


# Stryker Drawing Inside Hull

Muffler can be replaced by QW TE Generators



# Underarmor Arrangement of Two 5 kW<sub>e</sub> QW TE Generators



# Five kW<sub>e</sub> QW TE Generator

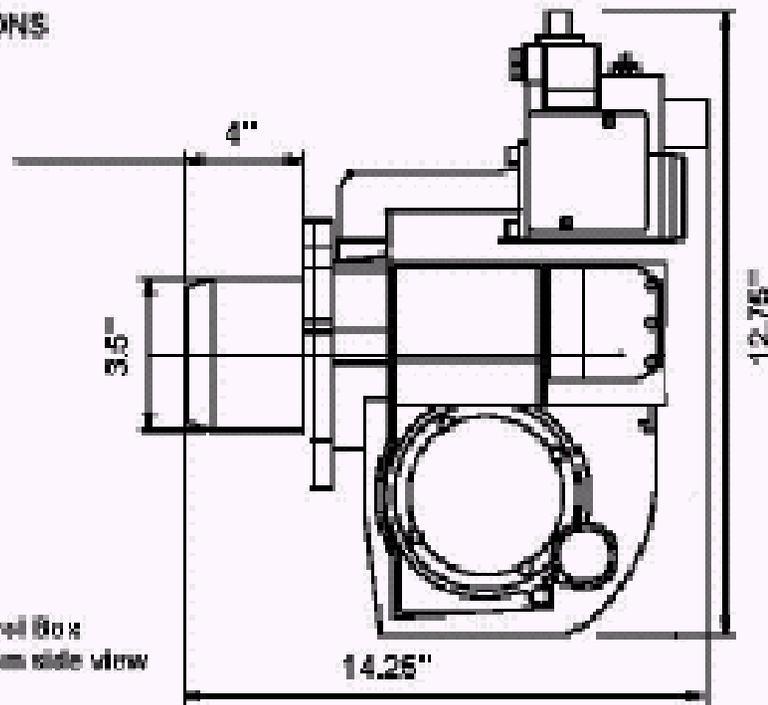
- Packaged in 10 in. diameter by ~27 in. long space
- Exhaust gas QW TE generator pressure drop matched to muffler
  - Swirl enhances gas heat transfer
- Contains 64 QW TE modules in octagonal arrangement
- Separate APU burner

# APU Burner for QW TE Generator

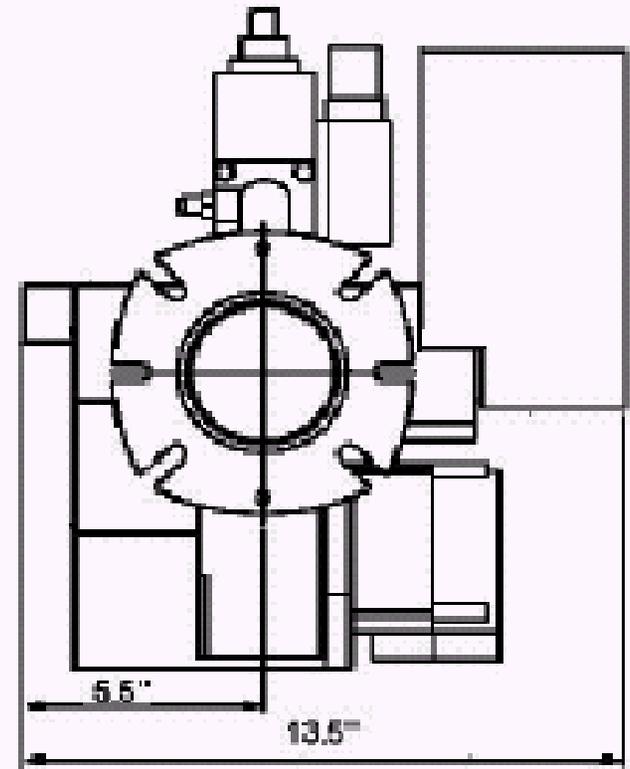
## Pioneer 2K diesel burner from HeatWise

Technical Data  
SU-2A Gas Burner

### DIMENSIONS



Note: Control Box  
Omitted from side view



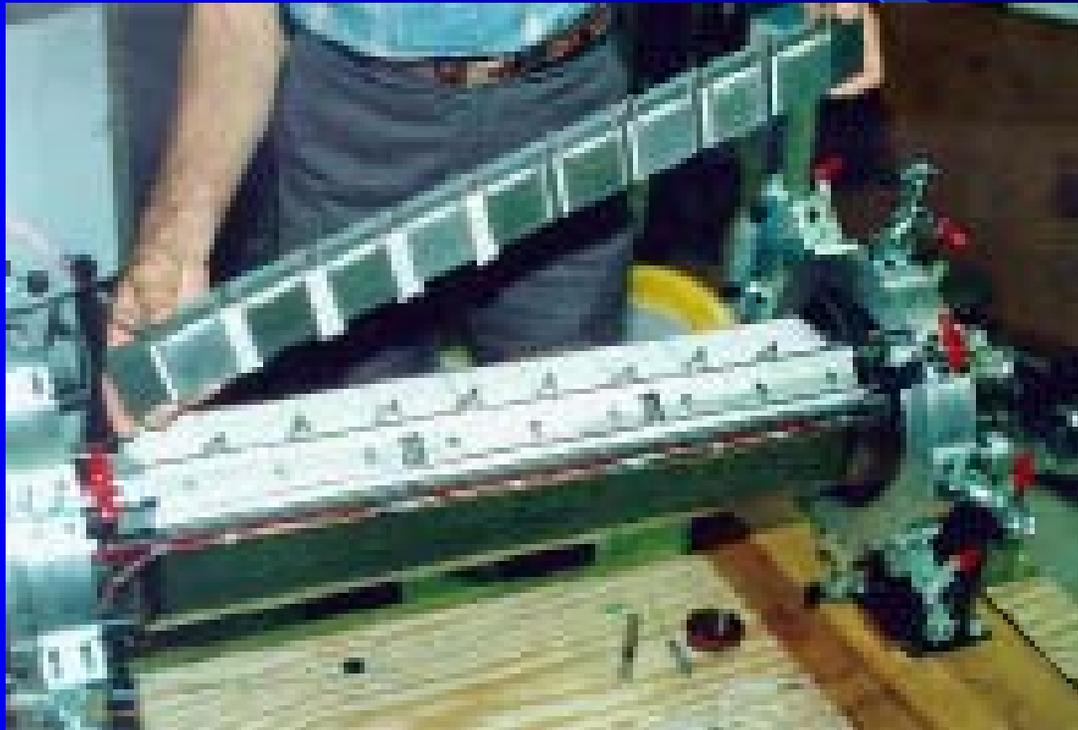
# 1kW<sub>e</sub> Bi<sub>2</sub>Te<sub>3</sub> TE Generator

Mounted under cab of class 8 truck on test track



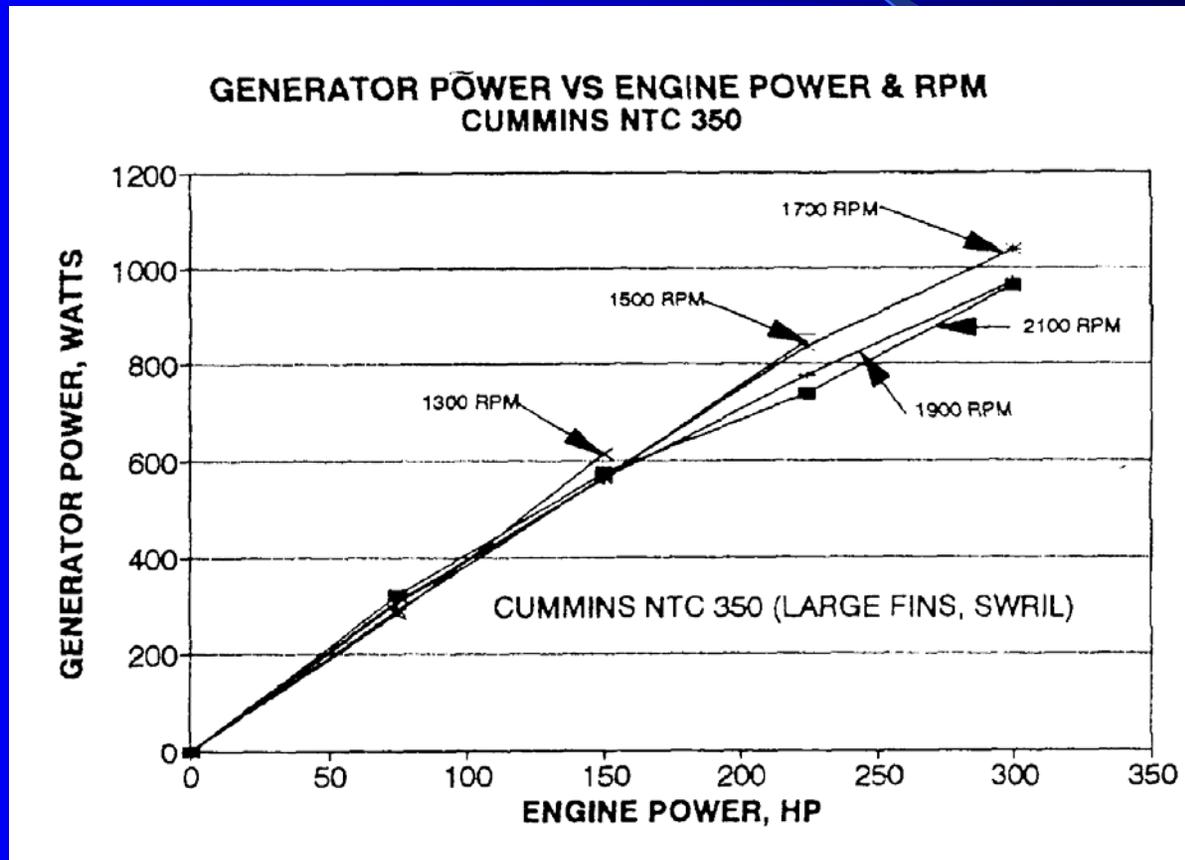
# Assembly of the Array's of 9 $\text{Bi}_2\text{Te}_3$ TE Modules for $1\text{kW}_e$ TE Generator

## Total of 72 Modules



Redundancy provided by parallel connects

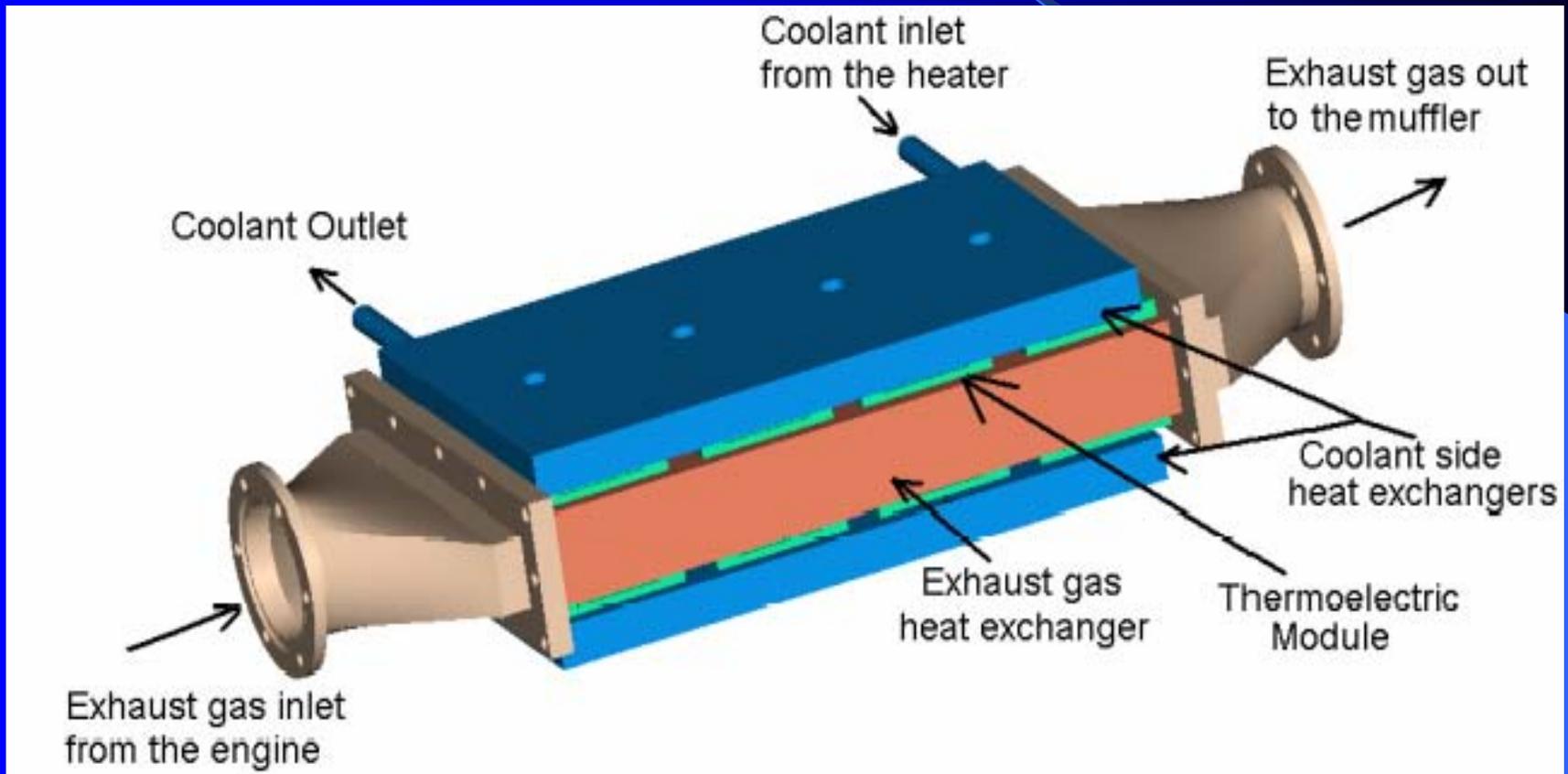
# Data From 1 kW<sub>e</sub> Bi<sub>2</sub>Te<sub>3</sub> TE Generator on Cummins Engine



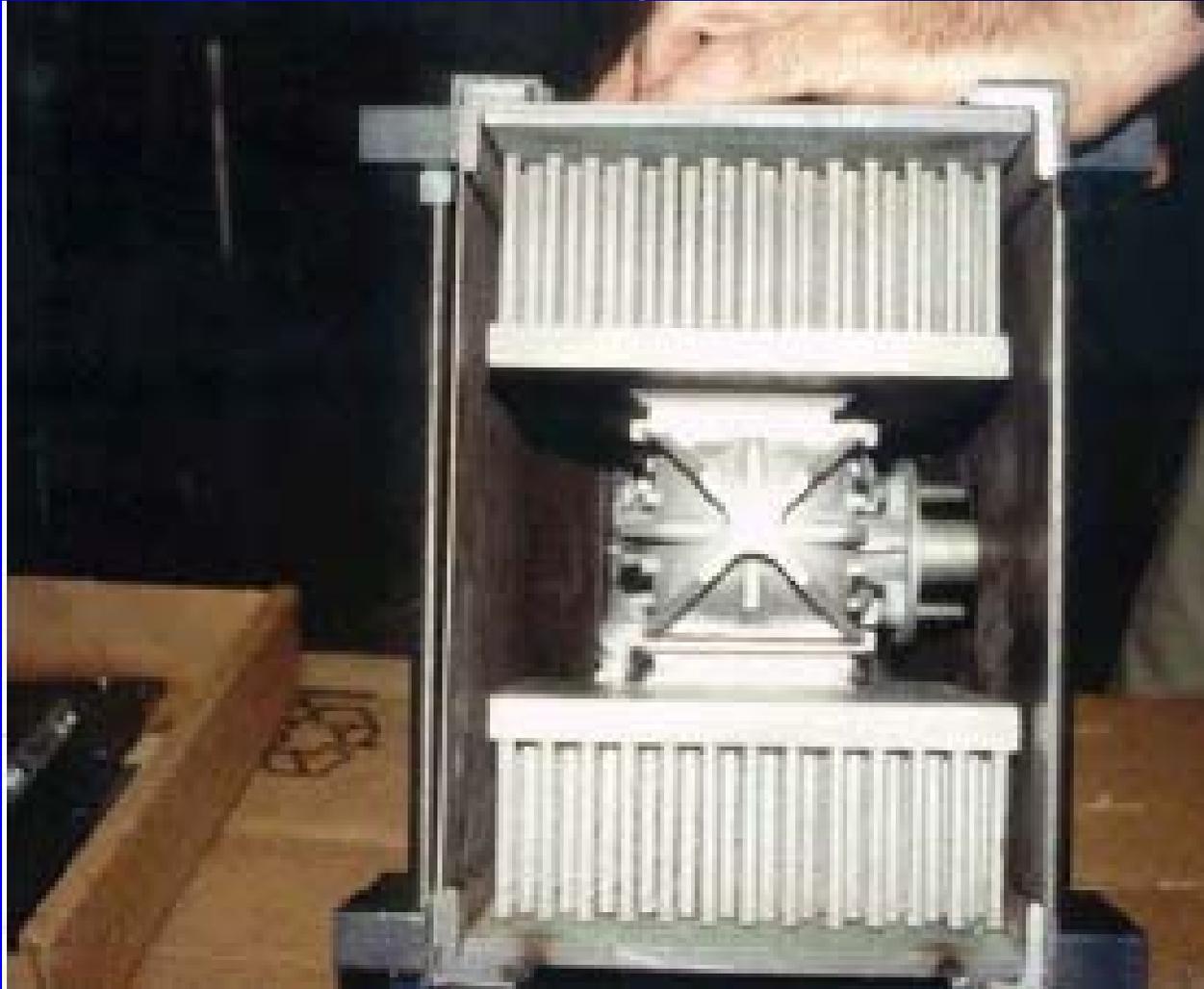
# Rendering of 300 W<sub>e</sub>

## Bi<sub>2</sub>Te<sub>3</sub> TE Generator

Currently under test in Sierra pick-up truck

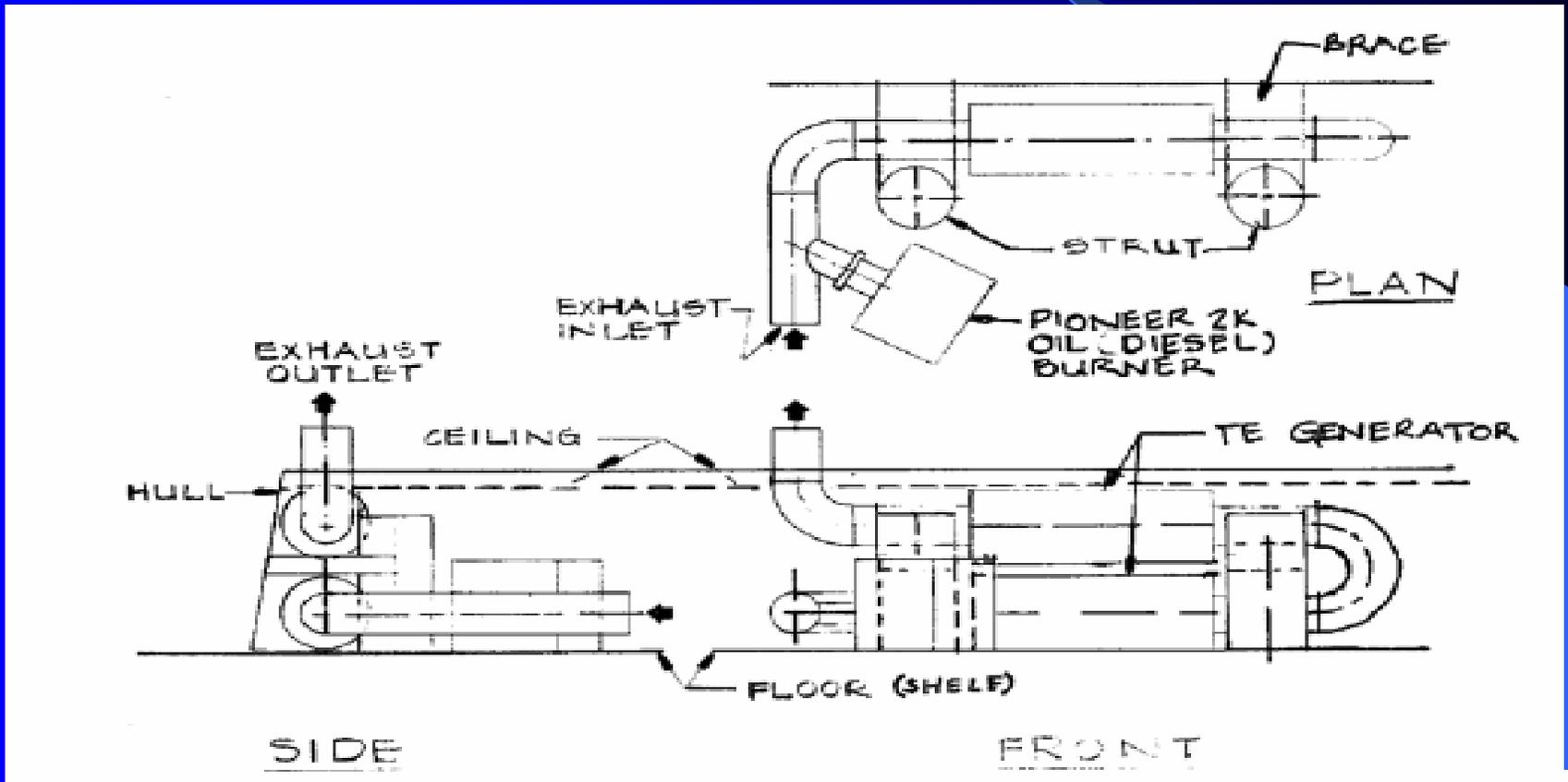


# 20 W<sub>e</sub> Self-Powered Heater

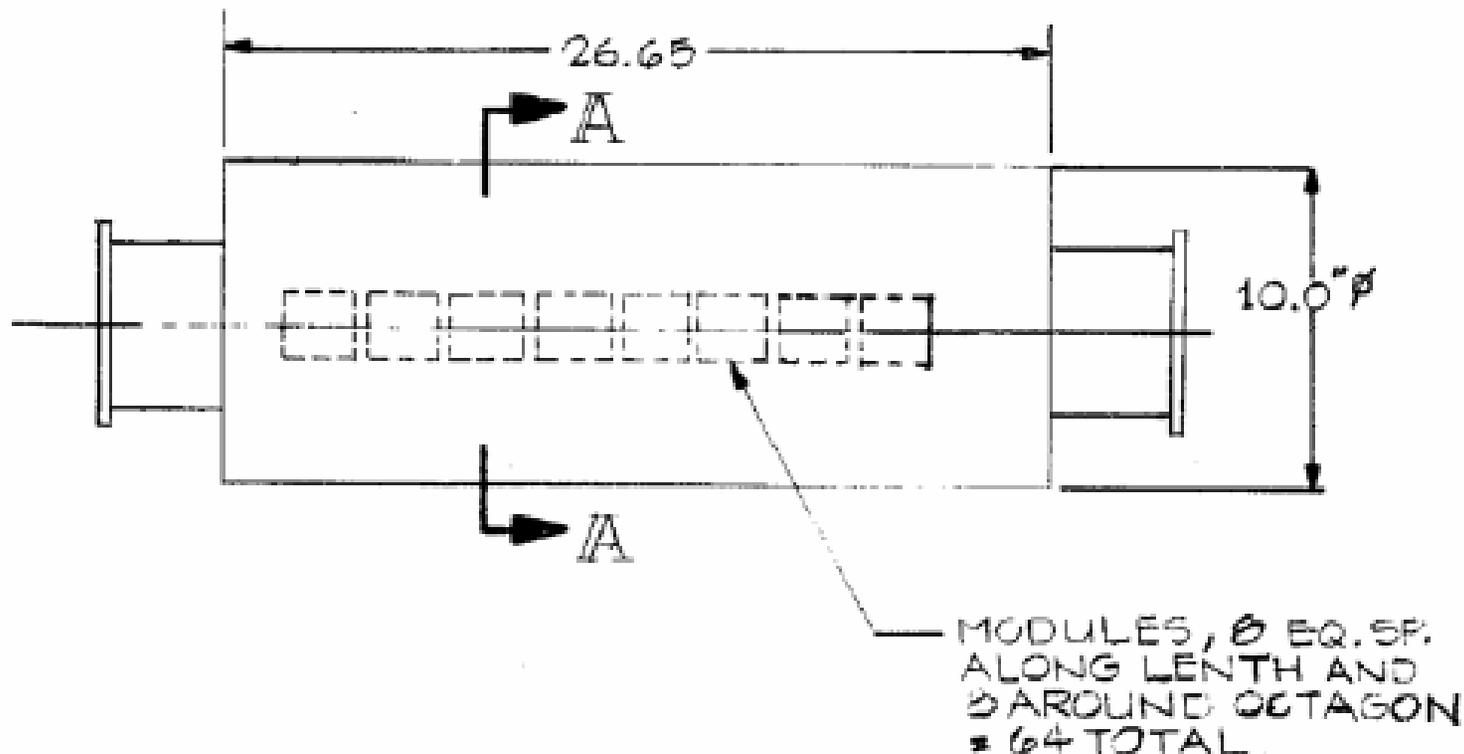


# Stryker Exhaust with Two $5\text{kW}_e$ QW TE Generators

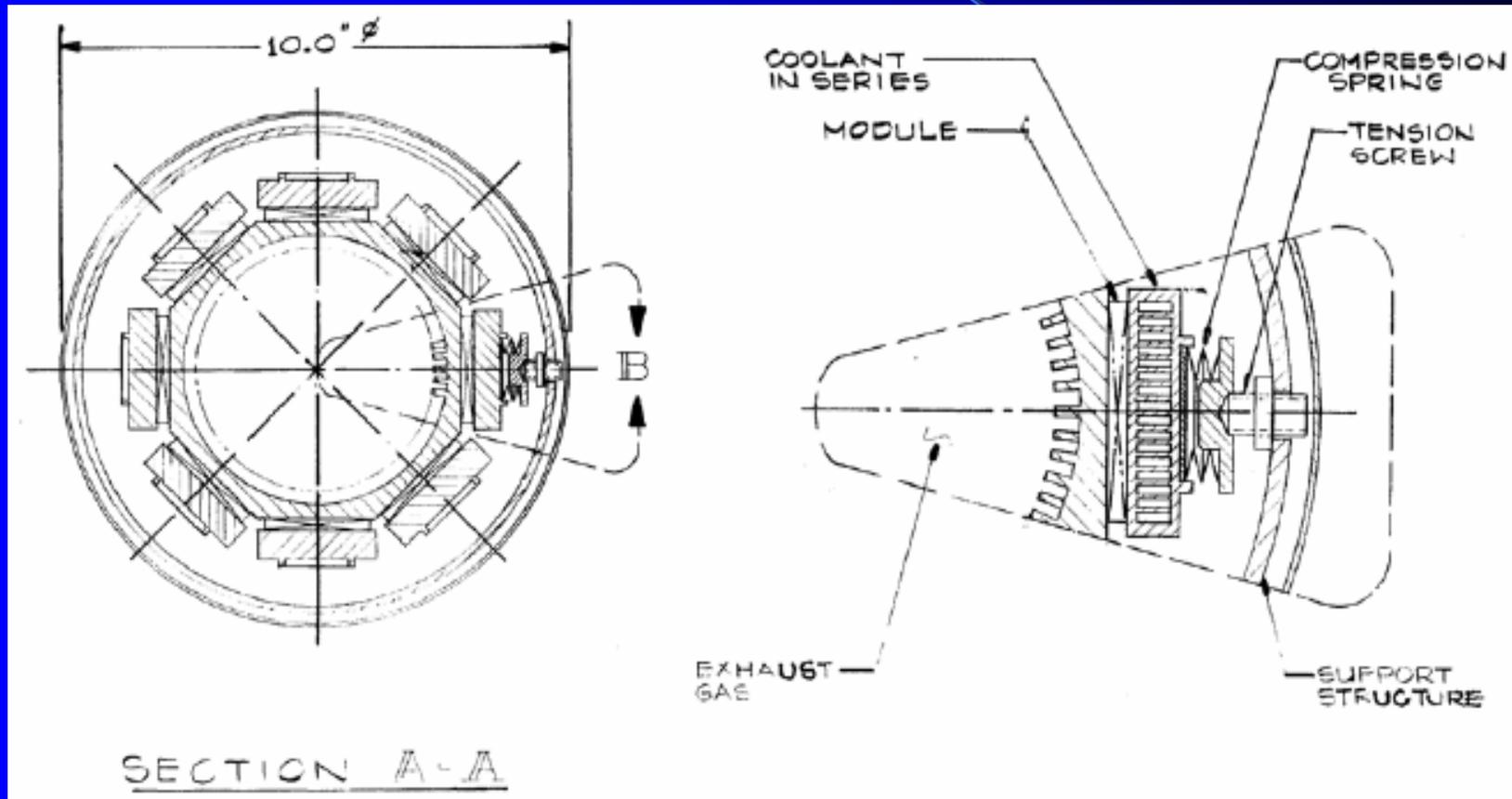
APU Burner shown near exhaust inlet to TE generator



# Side View of One of Two 5 kW<sub>e</sub> QW TE Generators for Stryker

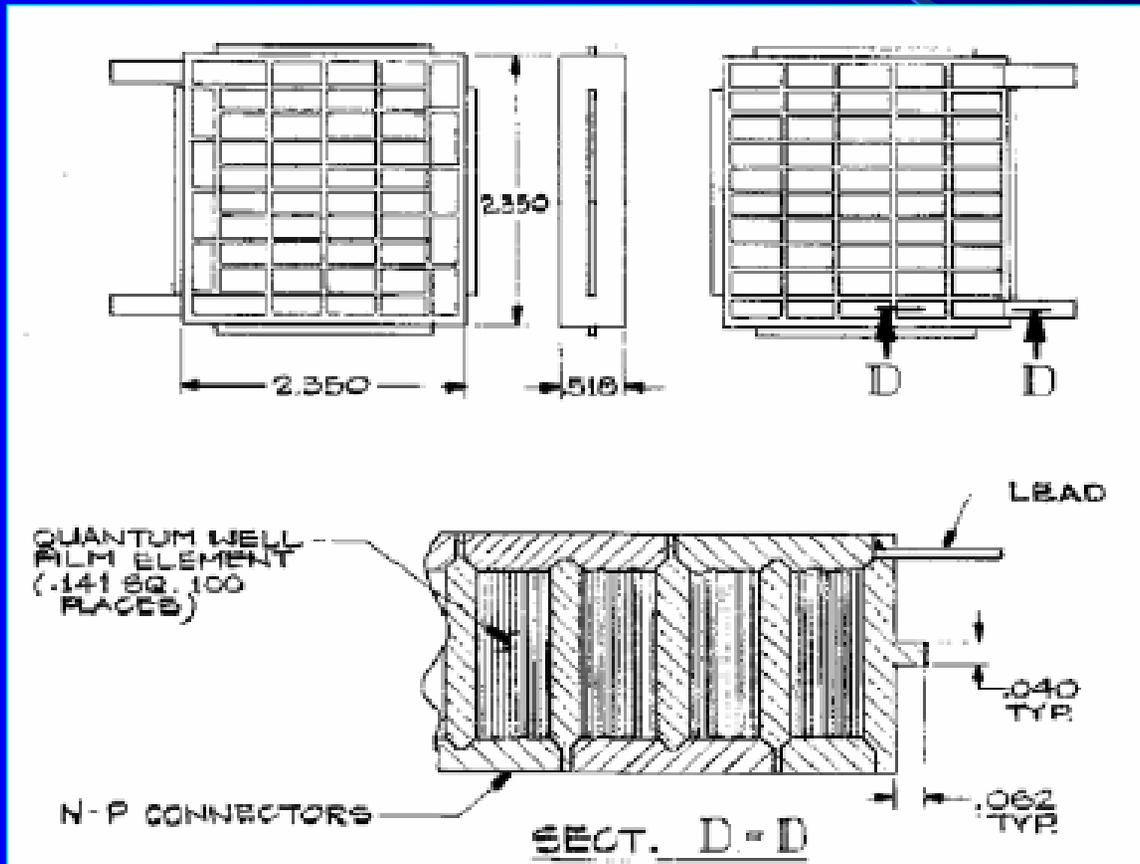


# Cross-section of 5 kW<sub>e</sub> QW TE Generator - Octagonal Arrangement



# QW 50 W<sub>e</sub> Module

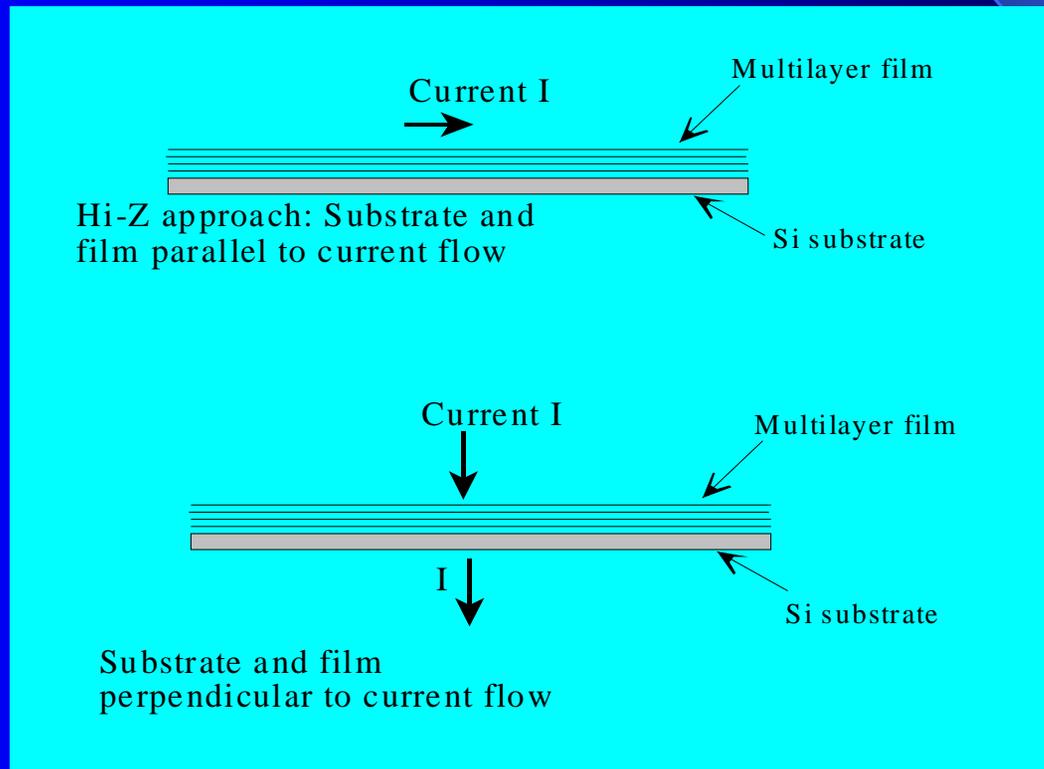
At temperature difference of 200 C provides 3.5 times  
the power of today's Bi<sub>2</sub>Te<sub>3</sub> TE module



# QW Films Parallel or Perpendicular to Current Flow

## Hi-Z uses parallel approach to give higher Zs

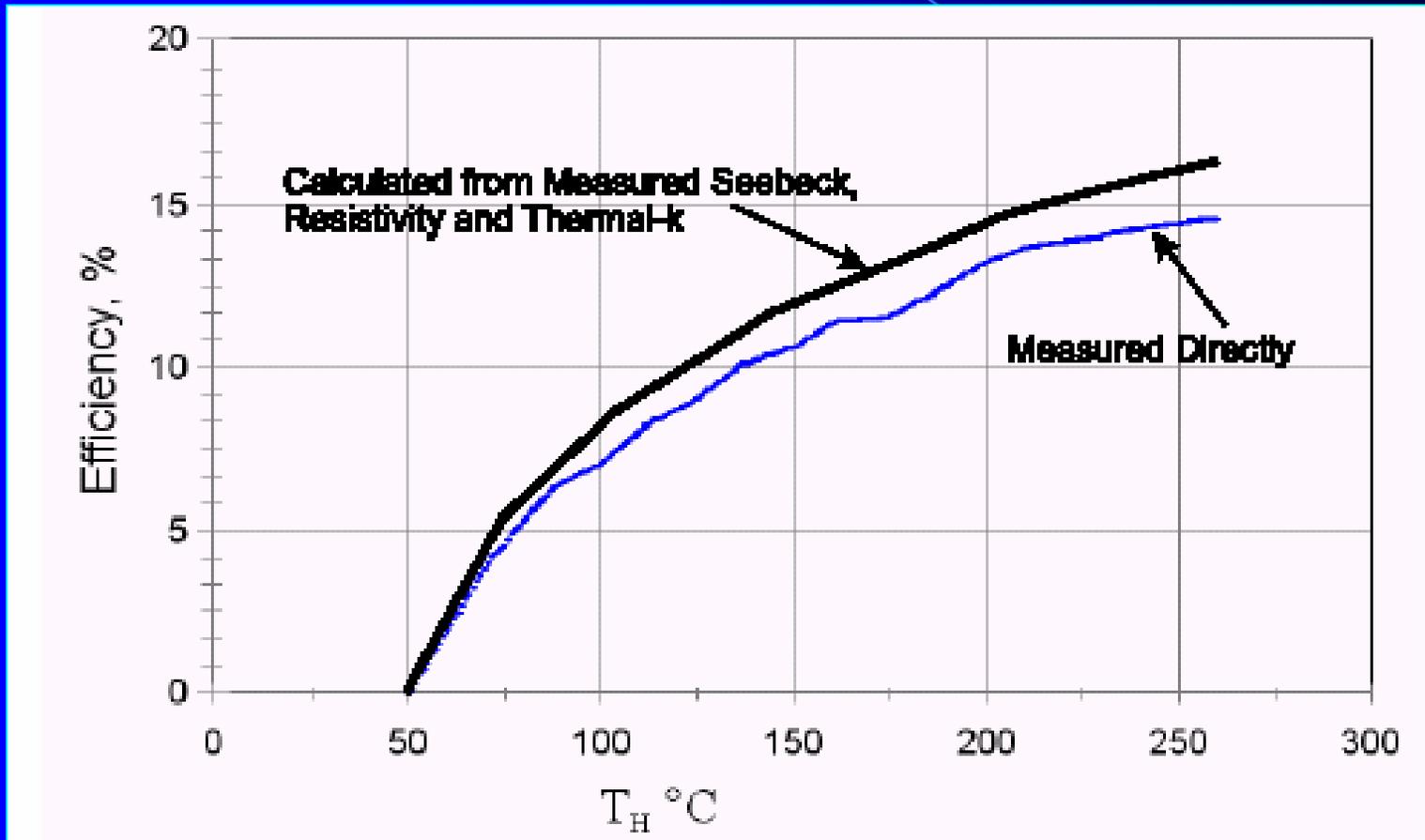
- QW Module with Parallel QW Films  
Films in contact with each other in each element



# QW Couple Efficiency vs. Temperature

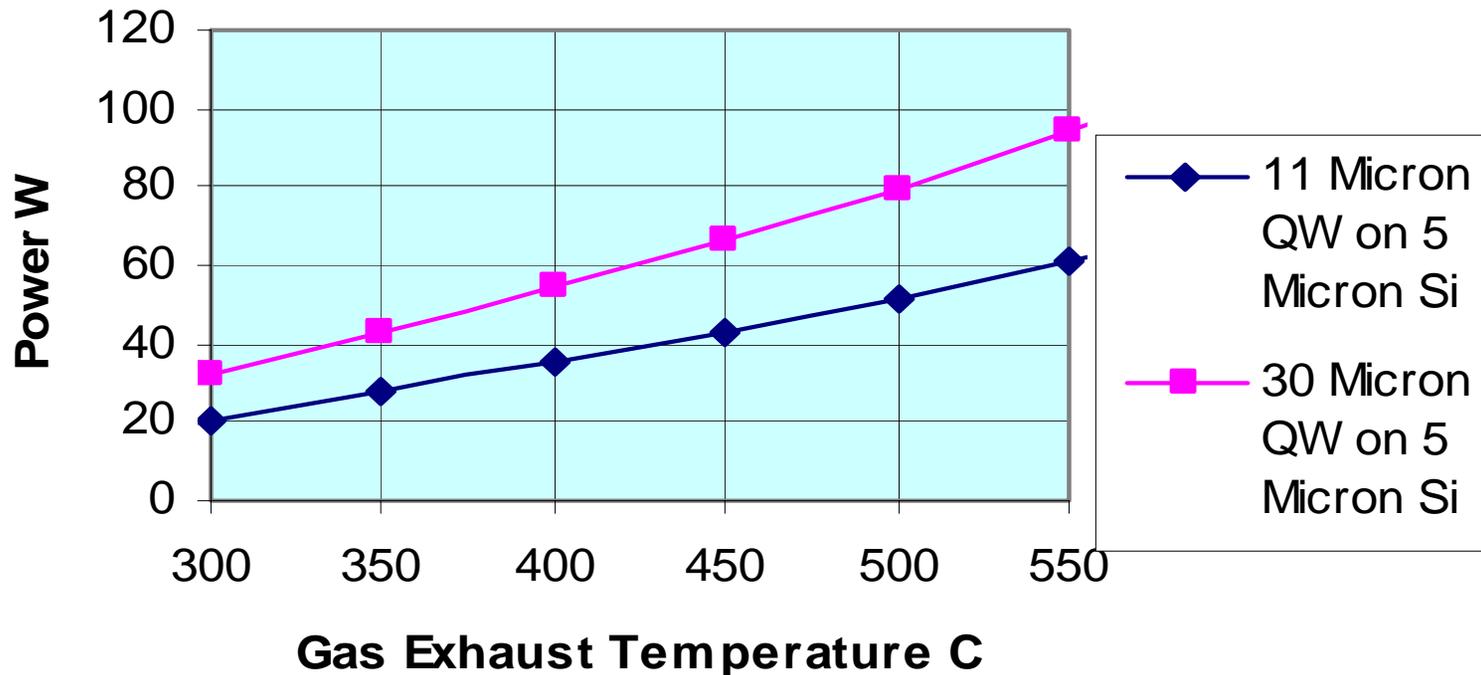
$B_4C/B_9C$  P and Si/SiGe N-type QW are 11  $\mu\text{m}$  thick.

Si substrate is 5  $\mu\text{m}$  thick. Over 100 data points were obtained.



# Predicted QW Module Power

Si Substrate with  $B_4C/B_9C$  P and Si/SiGe N-type QW.  
Thicker films improve efficiency.

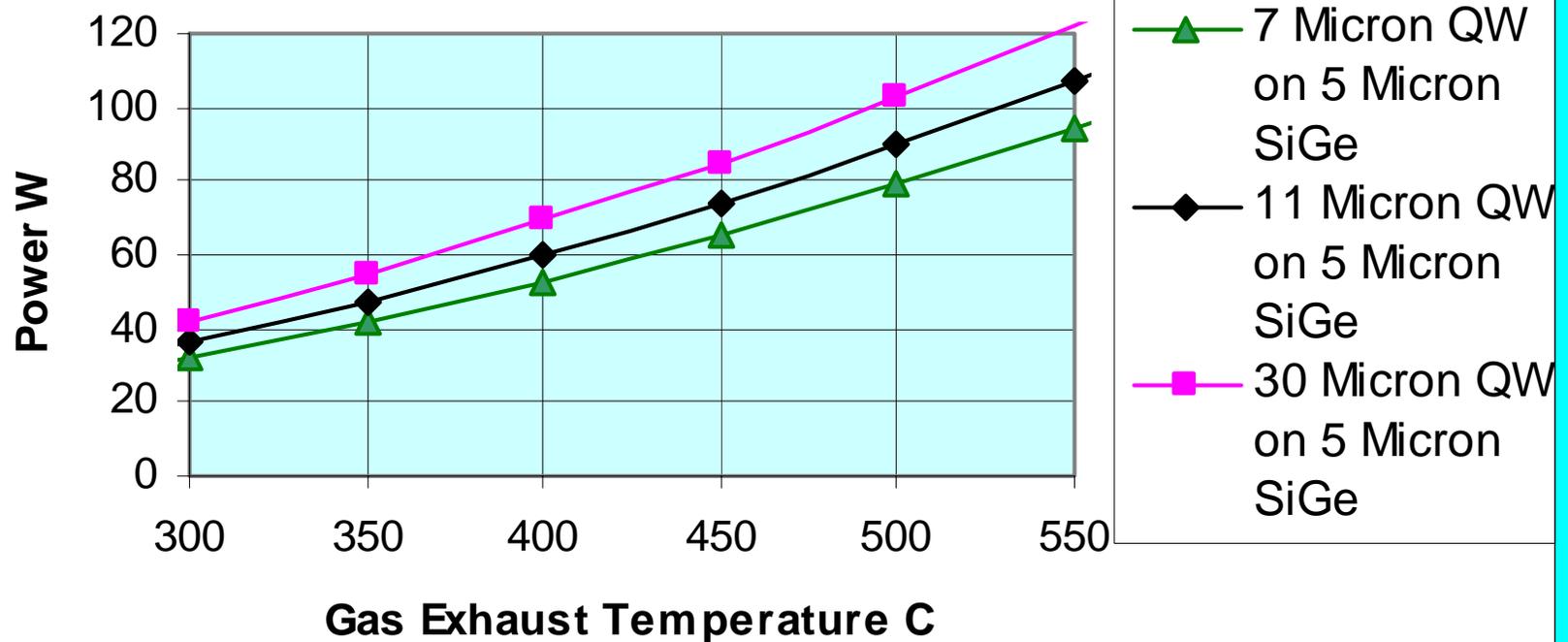


# Caterpillar Diesel Engine

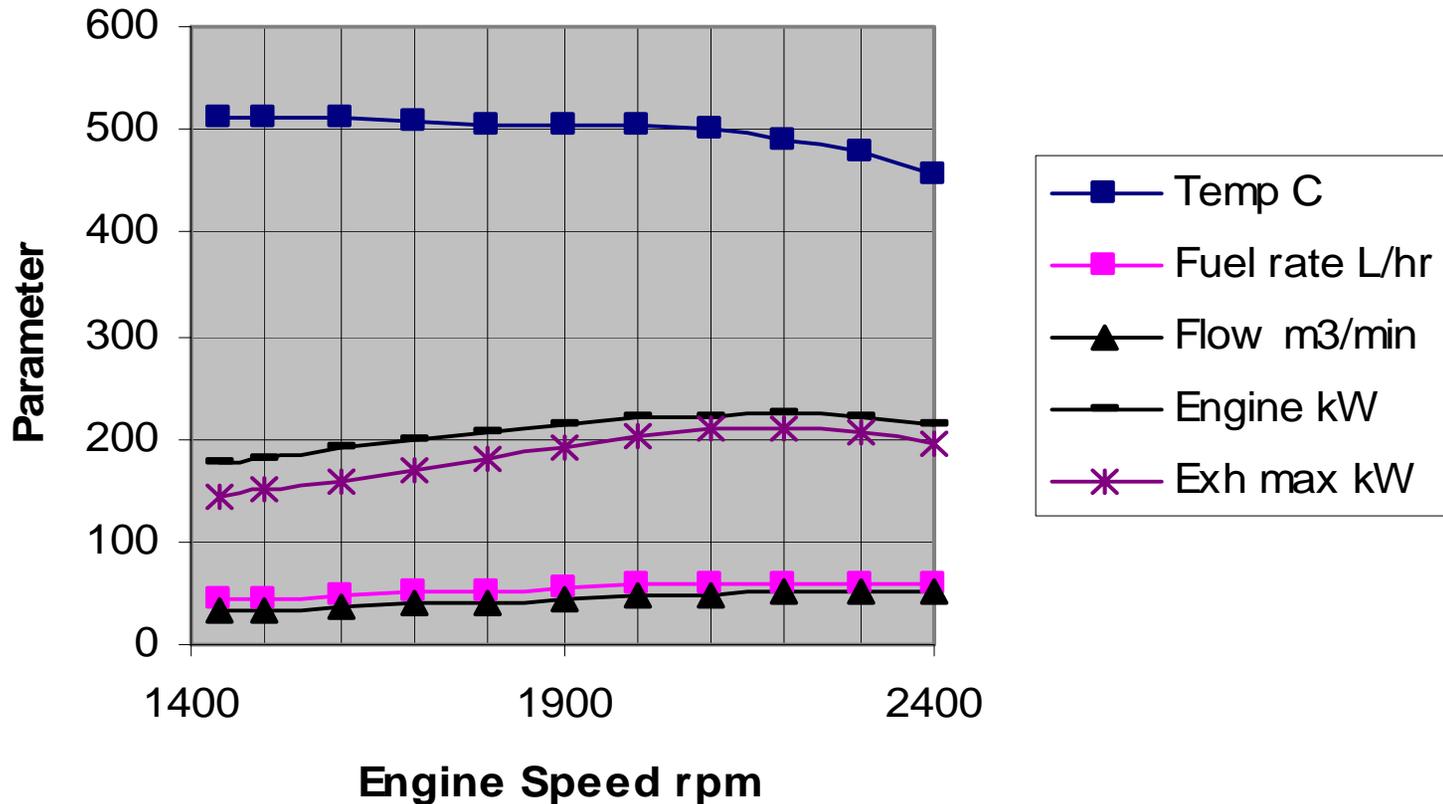
- CAT 3126 300 hp at 2200 rpm
  - Exhaust temperature 495°C
  - Exhaust gas flow 1778 cfm
  - Engine power 224 kW
  - Exhaust power 209 kW

# Predicted QW Module Power

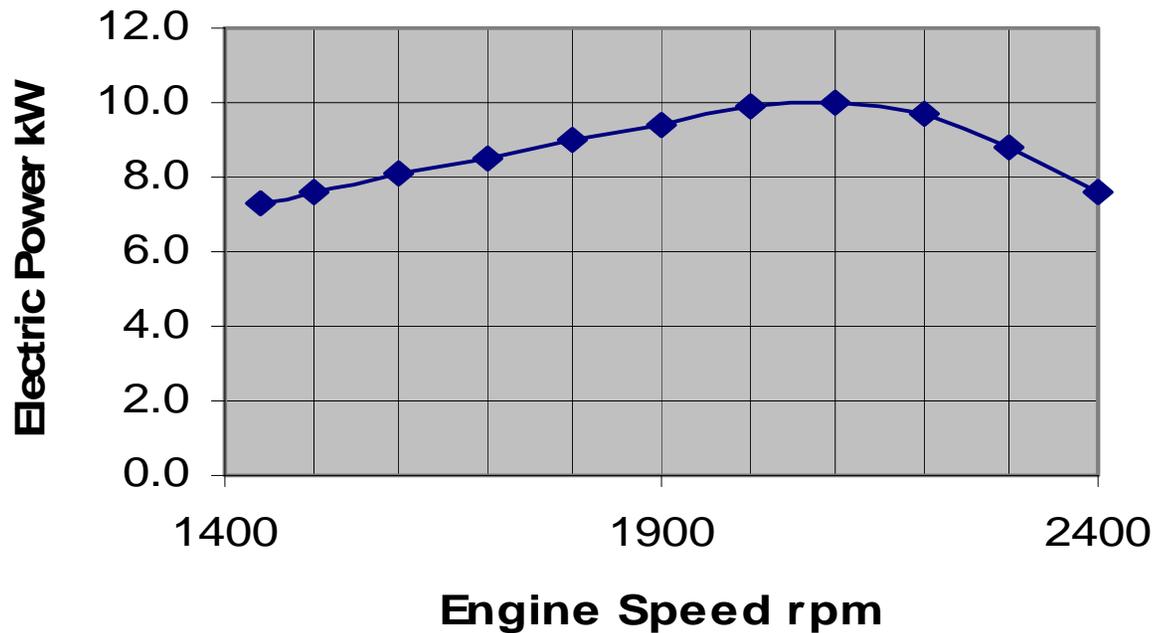
SiGe Substrate with  $B_4C/B_9C$  P and Si/SiGe N-type QW.  
Lower conductivity substrate than Si improves efficiency.



# Stryker CAT 3126 300 hp Diesel Performance Data



# Predicted Stryker QW TE Generator Power



# QW TE Generator for Stryker

## Conclusions

- QW TE generators can be sized to give 10 kW<sub>e</sub> in Stryker exhaust stream
- QW TE modules give 15 to 20% efficiency at Stryker exhaust temperatures
- Continuing QW film development and low resistance ohmic contacts required
- One TE generator with 64 QW modules is predicted to give 5 kW<sub>e</sub>
- QW TE generator gives 3 to 4 times power of Bi<sub>2</sub>Te<sub>3</sub> TE generator in same space