Oral Presentation/Viewgraphs Summary:

The Brayton Power Conversion Unit (BPCU) located at NASA Glenn Research Center (GRC) in Cleveland, OH is a closed cycle system incorporating a turboaltemator, recuperator, and gas cooler connected by gas ducts to an external gas heater. For this series of tests, the BPCU was modified by replacing the gas heater with the Direct Drive Gas heater or DOG. The DOG uses electric resistance heaters to simulate a fast spectrum nuclear reactor similar to those proposed for space power applications. The combined system thermal transient behavior was the focus of these tests. The BPCU was operated at various steady state points. At each point it was subjected to transient changes involving shaft rotational speed or DOG electrical input. This paper outlines the changes made to the test unit and describes the testing that took place along with the test results.

TEST RESULTS FROM A DIRECT DRIVE GAS REACTOR SIMULATOR COUPLED TO A BRAYTON POWER CONVERSION UNIT

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Introduction

- Component level tests of fission surface power systems typically do not require a nuclear heat source to obtain valuable data.
- Past tests have used relatively simple electric heaters, which do not accurately replicate proposed reactors.
- As testing transitions from the component level to the system level, the interaction between the reactor and the rest of the system becomes important and a more accurate representation of the reactor is required.

Introduction
BPCU

- The Brayton Power Conversion Unit (BPCU) is a closed Brayton cycle power conversion unit previously used in both solar dynamic and ion thruster testing at GRC.
- It contains a common shaft turbine-alternator-compressor, recuperator, and gas cooler connected by gas ducts.
- The rotating assembly is the only moving part and is supported by gas foil bearings.

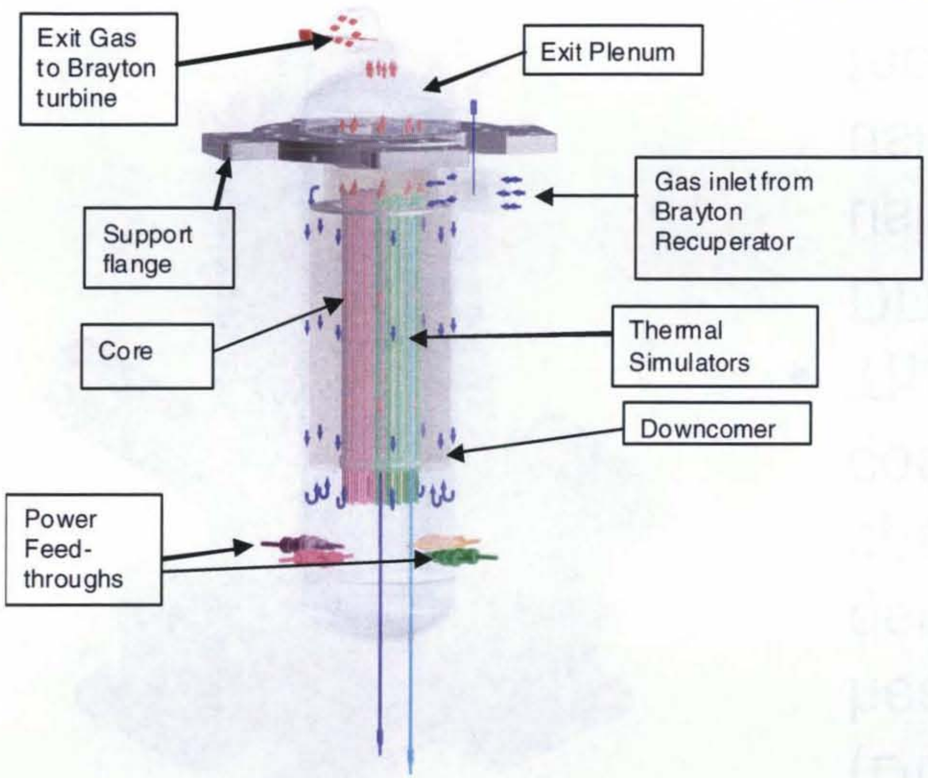
Introduction
BPCU

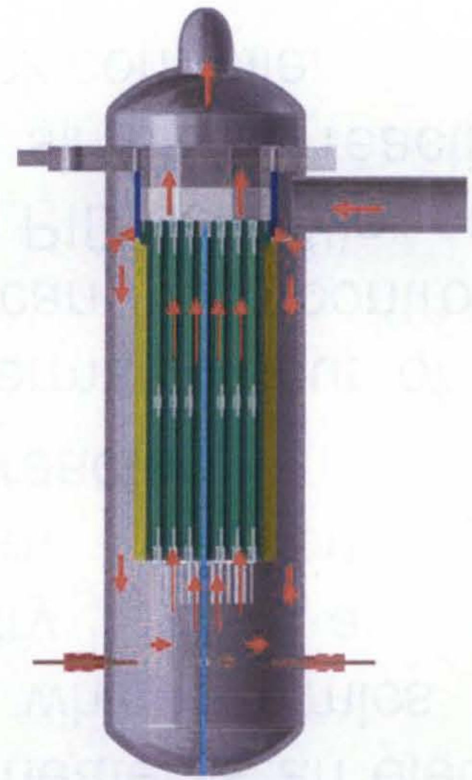
- The BPCU is optimized for use with a working fluid of 62.7 mole % Helium and 37.3 mole % Xenon gas mixture with an average molecular weight of 83.8 g/mol.
- Design power is 2 kWe on He-Xe at 1100 K heater exit temperature, 283 K compressor inlet temperature, and 52,000 rpm shaft speed.
- BPCU is operated via a standalone PMAD system contained in a dedicated rack located outside of the vacuum chamber.
- Shaft speed control is managed by parasitic loading.

Introduction
DDG

- The Direct Drive Gas (DDG) heater is an electric heater which mimics the geometry of a fast spectrum neutron gas-cooled reactor.
- The thermal output of the DDG can be controlled using a PID controller or by using a simulated reactivity feedback controller.

Introduction
DDG





- Compressed, preheated gas enters the DDG from the side, flows down the outer annulus, flows up through the electric heater elements simulate fuel rods and out the top to the turbine inlet.

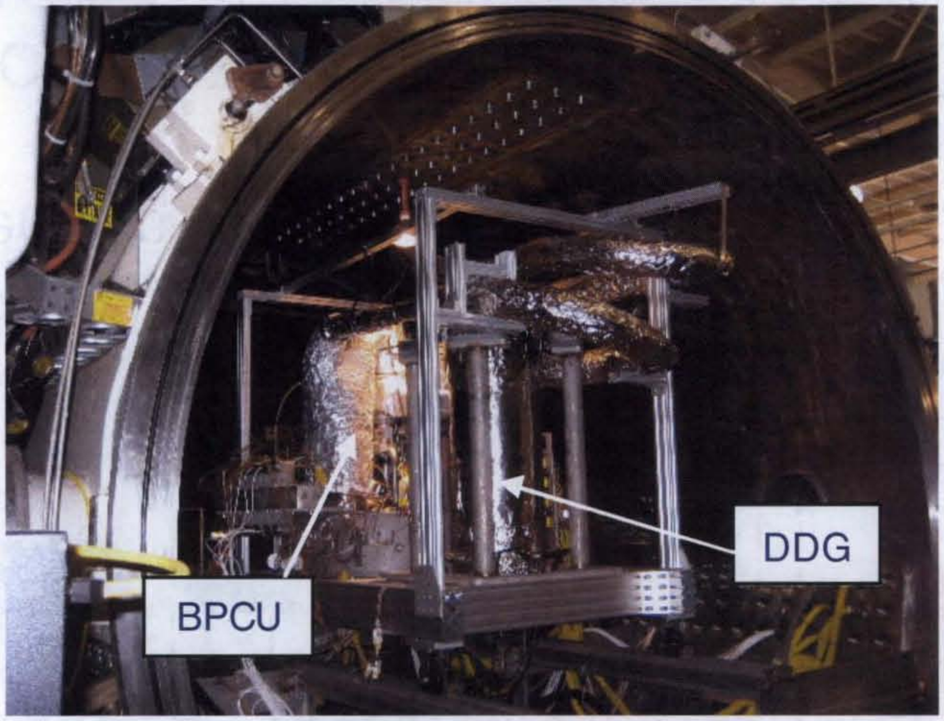
Introduction
DDG

- The DDG resistance heaters are mounted inside channels in a solid stainless steel core block.
- Capable of heating a mixture of He/Xe or other inert gas to deliver up to 15 kWe of power at an operational temperature of 1000 K, operational pressure of 689.5 kPa, and mass flow rates of up to 0.2 kg/s.
- In order to eliminate potential leak paths, the DDG was modified by changing the outer pressure vessel from a flanged and bolted design to an all welded configuration.
- This redesign provided increased performance and allowed straightforward integration with the Brayton system at GRC.

Introduction

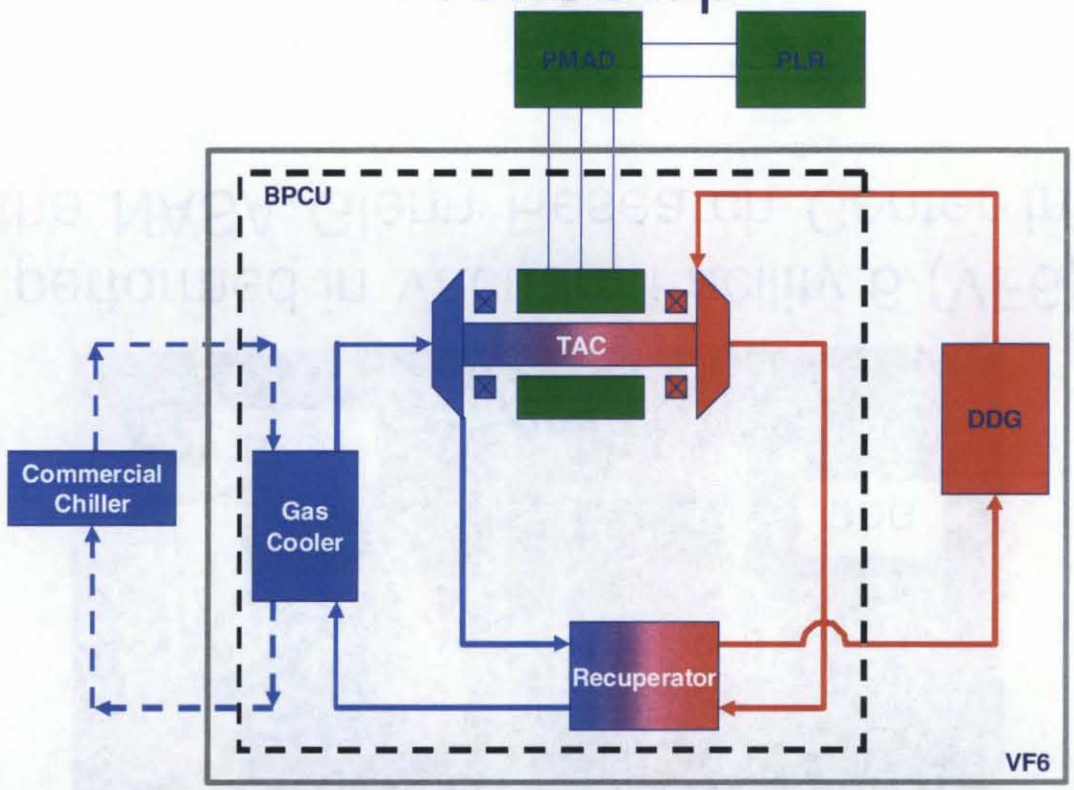
- The BPCU-DDG test integrated the DDG into the BPCU test loop.
- Various characterization tests were run to determine important test parameters, such as thermal time constants.
- After characterization was complete, the reactor's response to a change in Brayton shaft speed was observed, followed by the Brayton response to a change in simulated reactivity insertion.

Test Setup



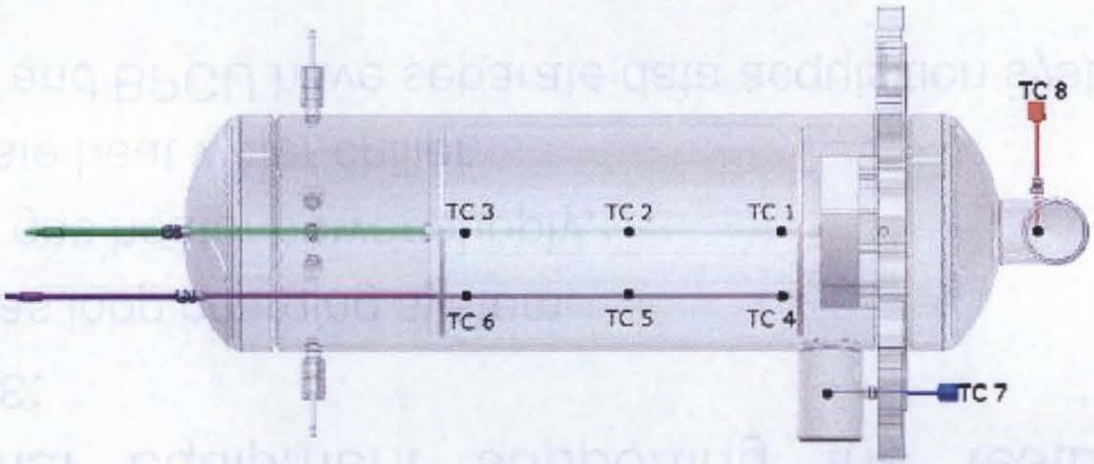
- Testing performed in Vacuum Facility 6 (VF6) of building 301 at the NASA Glenn Research Center in Cleveland, Ohio.

Test Setup



- This schematic shows the general layout of the testbed.
- The BPCU has temperature and pressure instrumentation at every pertinent thermodynamic state point.

Test Setup



- The DDG has 8 thermocouples located in the core block along the gas flow path.
  - TC-1 Center, 5 cm from core exit face
  - TC-2 Center, 26.7 cm from core exit face
  - TC-3 Center, 48.3 cm from core exit face
  - TC-4 Side, 5 cm from core exit face
  - TC-5 Side, 26.7 cm from core exit face
  - TC-6 Side, 48.3 cm from core exit face
  - TC-7 Inlet Gas Temperature
  - TC-8 Exit Gas Temperature

Test Setup

- Three instrumentation racks house the BPCU Power Management And Distribution (PMAD), data acquisition, and BPCU test support equipment control electronics.
- A standalone computer controls the DDG and provides data acquisition
- Additional equipment supporting the testbed operation includes:
  - the gas loop charging system,
  - DDG gas heater power supply,
  - a waste heat water chiller,
  - DDG and BPCU have separate data acquisition systems.

Testing

Summary

Testing was conducted in three phases consisting of:

- Heater Output Power Control Testing,
- Heater Exit Temperature (HET) Control Testing, and
- Simulated Reactivity Control Testing.

Testing

Heater Output Power Control Tests

- These tests examined the thermal response of the system to perturbations of heater output power and shaft speed and to provide initial operational checkout data of the test rig.
- PID constants to be estimated for use in subsequent temperature control testing.
- Steady-state conditions were defined as a HET change of less than 2°C over a 10 minute span (approximately 90 minutes to achieve).
- Data post-processing revealed that HET had reached steady-state, however, electric power output was still trending with time. Subsequent tests used electrical output power.

Testing

HET Control Tests

- PID control was used to provide constant HET
- The resulting DDG power level was used as input to the simulated reactivity control testing.
- The large thermal time constants of the system required substantial controller gain.
- During temperature perturbations, the heater power was manually controlled until HET was within 10ºC of the desired setpoint before engaging PID control to avoid high heater power spikes.
- No such considerations were required when initiating a speed perturbation.

Testing

Simulated Reactivity Control Tests

- A simulated reactivity feedback control loop was used to assess the overall system response.
- Two types of tests were performed:
  1. The inherent response of the reactor simulation to a step change in shaft speed (gas flow rate).
  2. Control drum maneuvers were simulated by commanding the reactivity controller model to insert positive or negative reactivity.
- Important Note: A companion paper goes into considerable detail on the simulator methodology and results from the simulated reactivity testing.

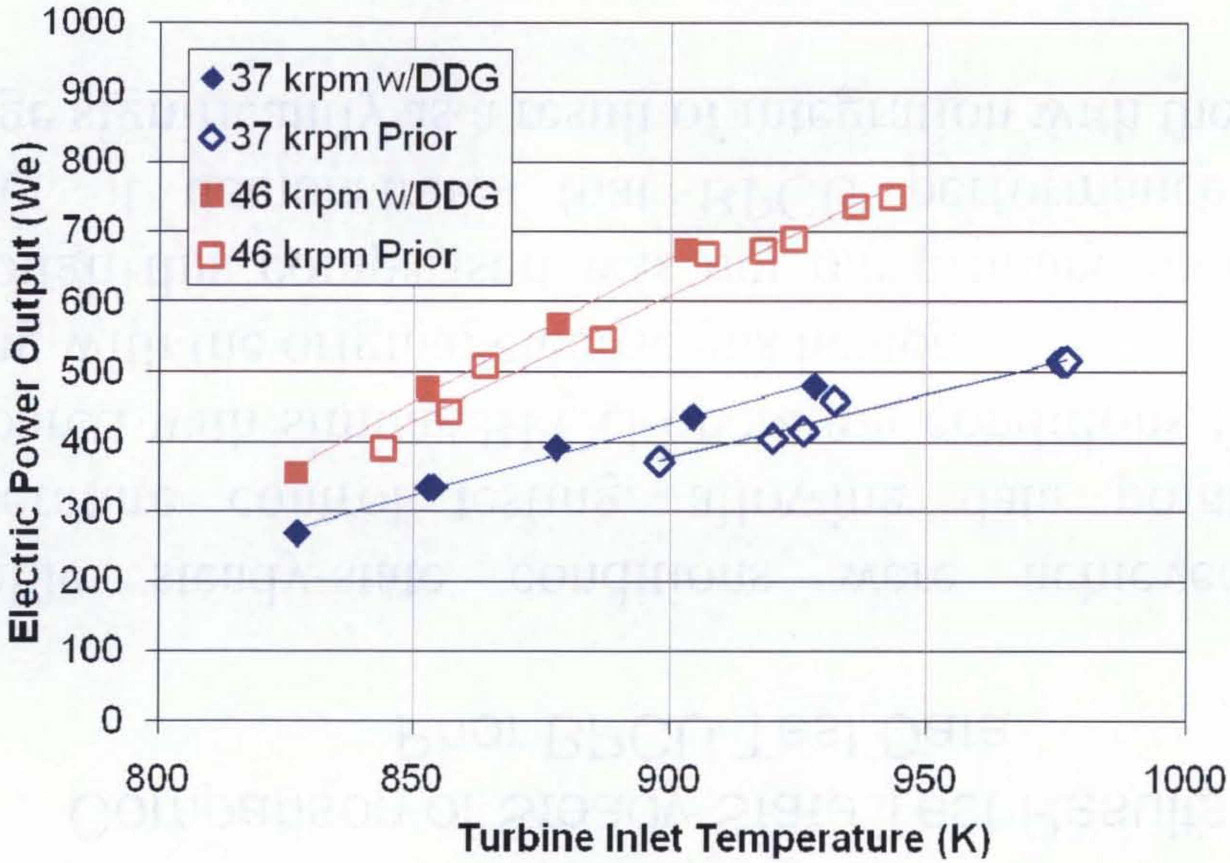
Test Results

Comparison of Steady State Test Results with Prior BPCU Test Data

- Reliable steady-state conditions were achieved during temperature control testing, allowing data points to be compared with similar BPCU operating conditions from prior testing with the original electric gas heater.
- Although this comparison was not the primary focus of this testing, it demonstrates that BPCU performance did not change significantly as a result of integration with the DDG.

Test Results

Comparison of Steady State Test Results with Prior BPCU Test Data



Test Results

Comparison of Steady State Test Results with Prior BPCU Test Data

- The BPCU/DDG combination electrical power output was comparable to prior tests with the previous electric heater, when operating at the same hot-end temperatures.
- This demonstrates that BPCU performance did not change significantly as a result of integration with the DDG.

Test Results

Selected System Transient Response Test Results

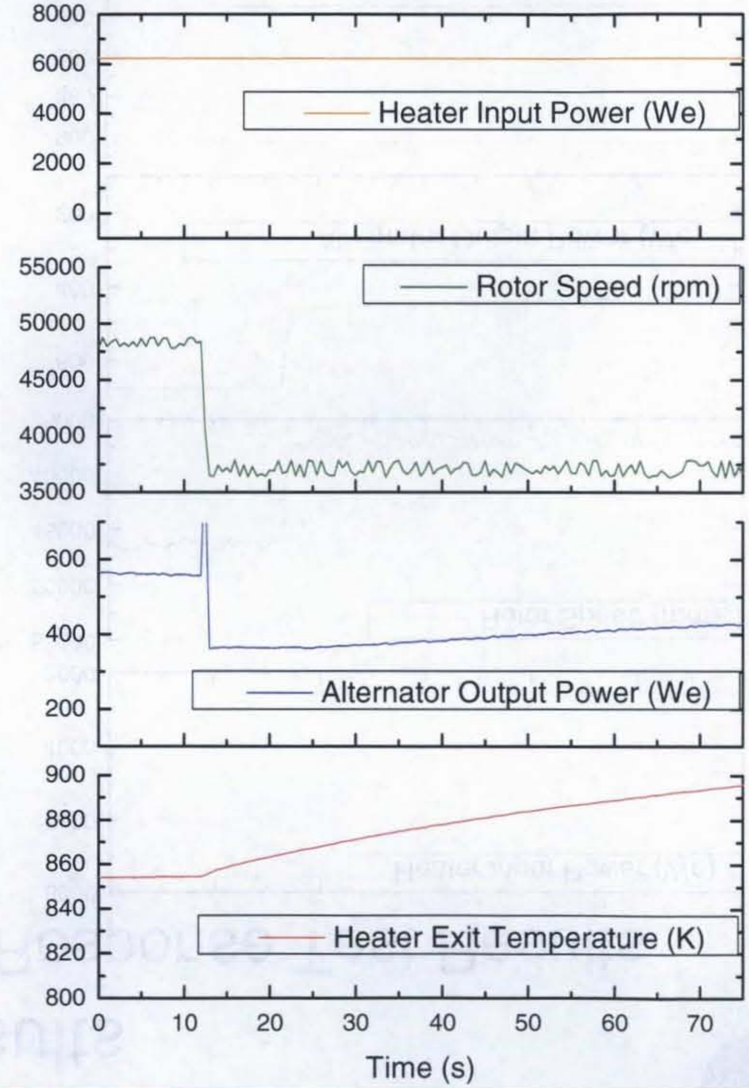
- Three different DDG control schemes are compared.
- a negative step change in BPCU shaft speed is introduced decreasing the gas loop mass flow rate.
- Selected test results are shown for comparison

Test Results

Selected System Transient Response Test Results

Phase I:

- DDG power is held constant at 5500 We without controlling the HET
- HET rises in response to the reduction of mass flow.
- BPCU power output initially drops and then begins to rise as the HET increases. This test point was discontinued when the HET exceeded 900K.

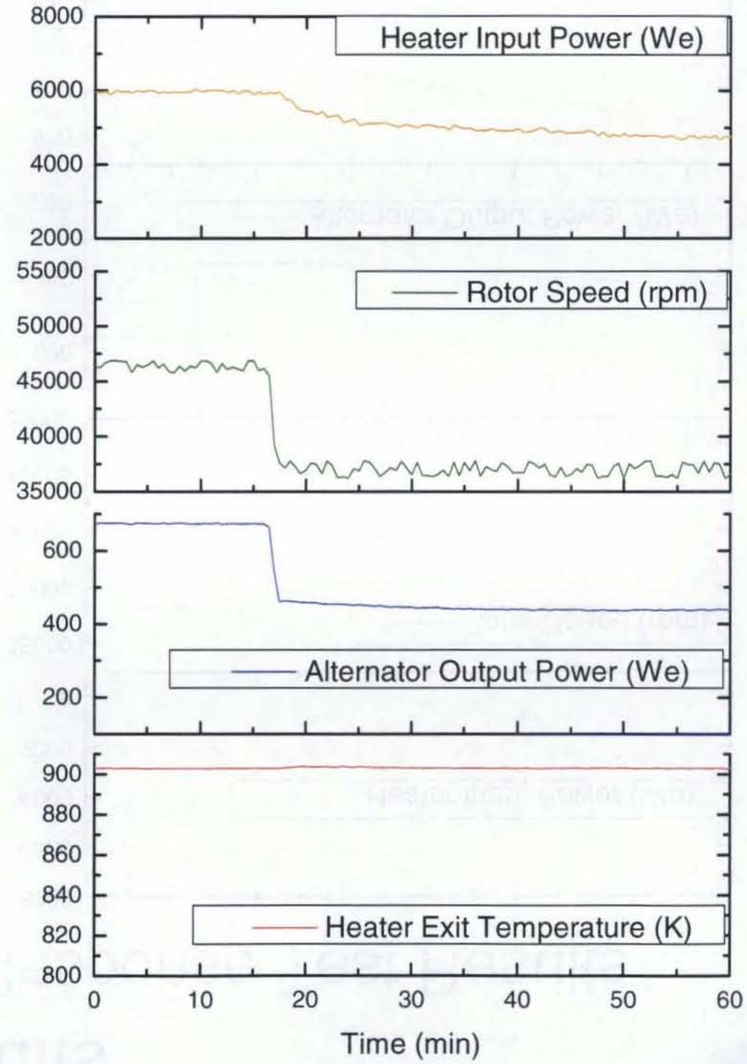


Test Results

Selected System Transient Response Test Results

Phase II:

- DDG HET is held constant at 900 K under PID control.
- In response to the reduced mass flow, the DDG heater power gradually declines.
- BPCU power output drops in response to the reduced mass flow and then stabilizes at a lower output power.

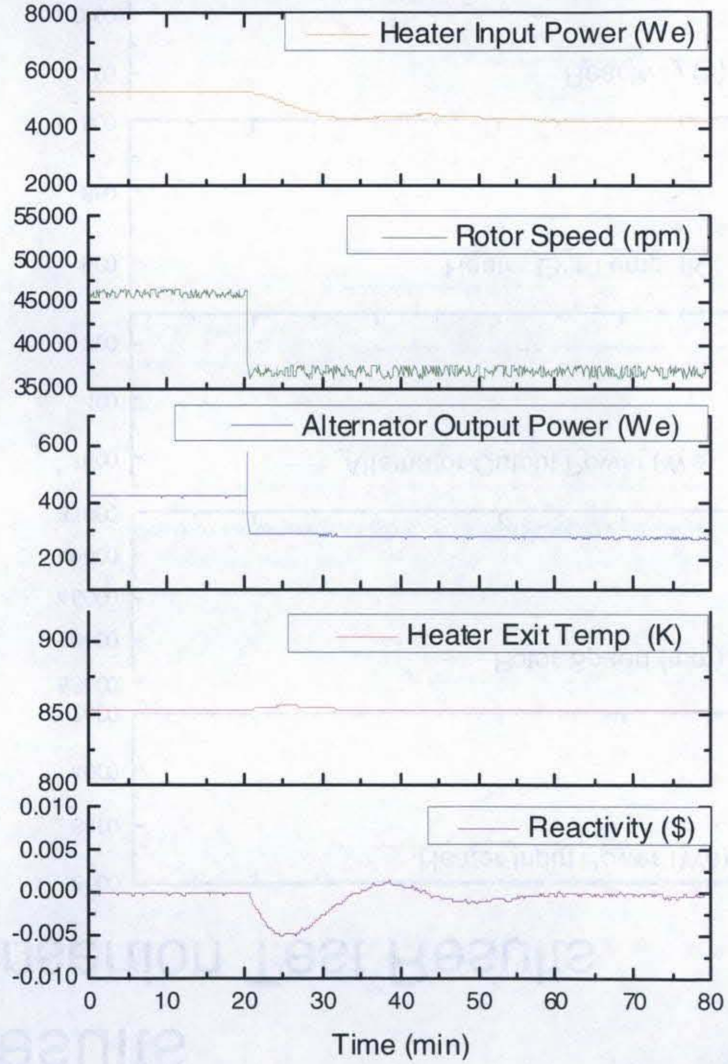


Test Results

Selected System Transient Response Test Results

Phase III:

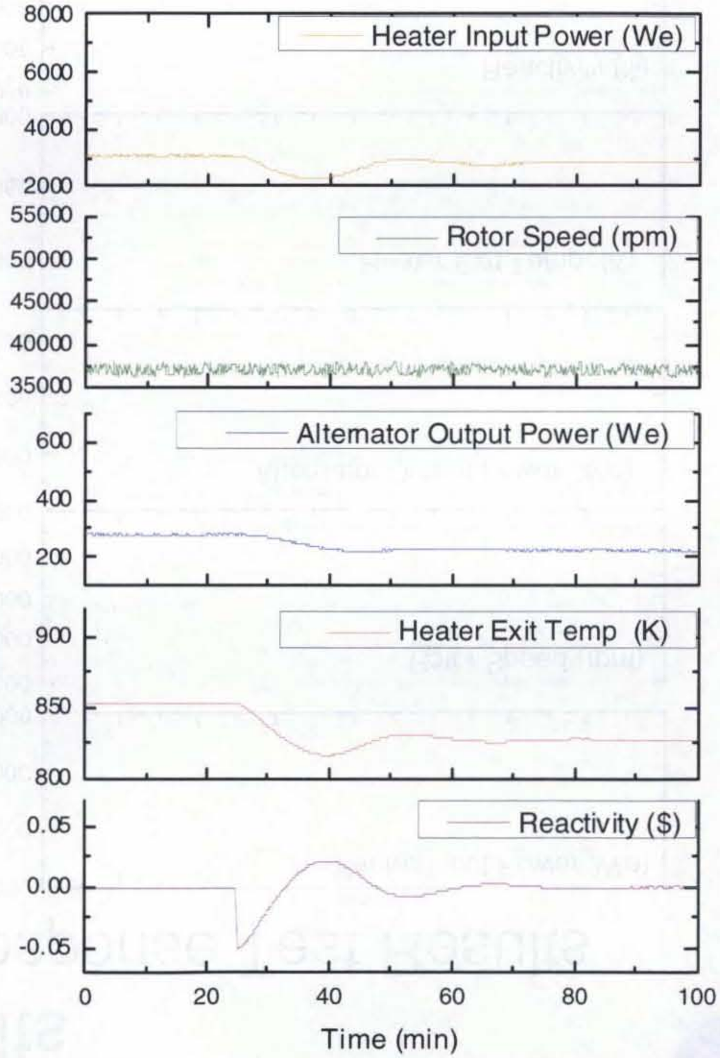
- no parameter held constant-DDG reactivity control is used to simulate reactor response.
- BPCU power output similar to PID control.
- HET maintains a fairly constant value
- DDG simulated reactivity and heater input power both exhibit a damped waveform response.



Test Results

Simulated Reactivity Insertion Test Results

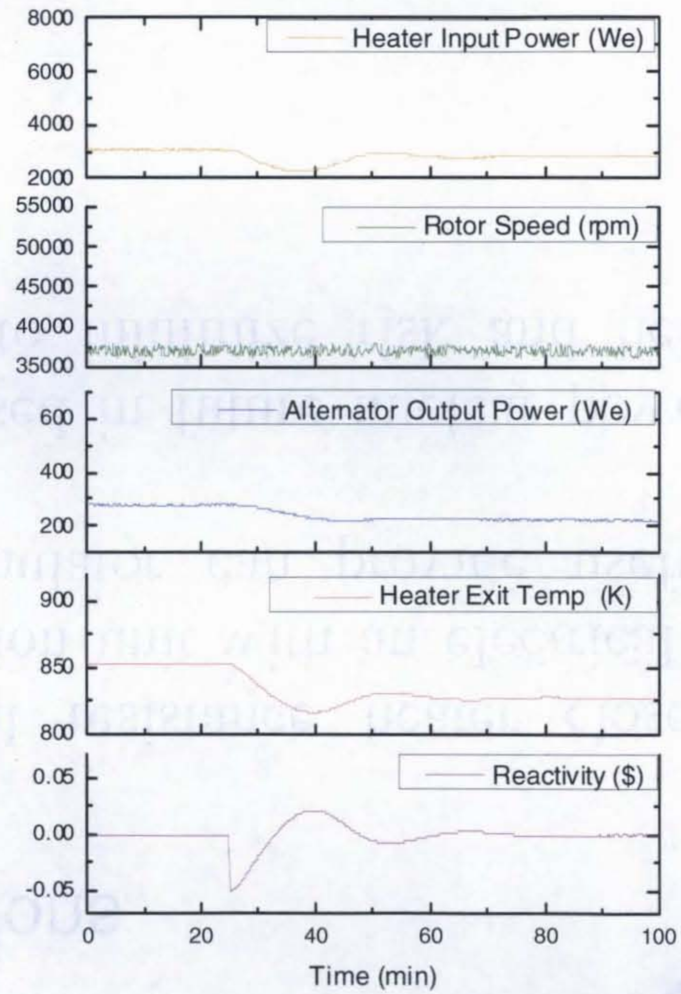
- Interesting test results are obtained by operating the DDG using reactivity control and introducing a simulated negative reactivity insertion.
- The amount of reactivity insertion is roughly an order of magnitude greater than the DDG reactivity response from the reactivity control response tests.



Test Results

Simulated Reactivity Insertion Test Results

- The HET shows a damped waveform response and the overall reactivity response is almost a mirror image.
- The BPCU rotor speed is unaffected. However BPCU alternator output drops in a damped response fashion similar to the HET response.



Conclusions

- These tests demonstrated that:
  - replacing a simple electrical resistance heater closed Brayton cycle power conversion unit with an electrically powered nuclear reactor simulator can provide useful system response data and,
  - this type of testing can be used in future nuclear power system development efforts to minimize risk and help characterize system response.

ACKNOWLEDGMENTS

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