AIR-SIDE PERFORMANCE OF RVACS/RACS -- DESCRIPTION OF
THE NATURAL CONVECTION SHUTDOWN HEAT REMOVAL
TEST FACILITY AND SUPPORTING ANALYSIS

by

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>AIR-SIDE TEST FACILITY</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>Segment Test - Mechanical Systems</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Electrical Systems</td>
<td>6</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Heater System</td>
<td>6</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Auxiliary and Instrument Power</td>
<td>11</td>
</tr>
<tr>
<td>1.3</td>
<td>Instrumentation</td>
<td>16</td>
</tr>
<tr>
<td>1.4</td>
<td>Data Acquisition System (DAS)</td>
<td>16</td>
</tr>
<tr>
<td>1.4.1</td>
<td>DAS Operations</td>
<td>16</td>
</tr>
<tr>
<td>1.4.2</td>
<td>DAS Software - Completed Activities</td>
<td>19</td>
</tr>
<tr>
<td>1.4.3</td>
<td>DAS Software - Remaining Activities</td>
<td>20</td>
</tr>
<tr>
<td>1.5</td>
<td>Test Plan</td>
<td>21</td>
</tr>
<tr>
<td>2.0</td>
<td>PRE-TEST ANALYSIS</td>
<td>27</td>
</tr>
<tr>
<td>2.1</td>
<td>Lumped Parameter Analysis</td>
<td>27</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Model Development</td>
<td>27</td>
</tr>
<tr>
<td>2.1.2</td>
<td>Calculated RVACS Test Assembly Performance</td>
<td>32</td>
</tr>
<tr>
<td>2.2</td>
<td>COMMIX-1A Analysis</td>
<td>43</td>
</tr>
<tr>
<td>3.0</td>
<td>REFERENCES</td>
<td>51</td>
</tr>
<tr>
<td>APPENDIX I</td>
<td></td>
<td>52</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Aerial View - Building 310 Area</td>
<td>2</td>
</tr>
<tr>
<td>2.</td>
<td>Test Assembly Configuration</td>
<td>3</td>
</tr>
<tr>
<td>3.</td>
<td>Mechanical Design and Fabrication Status</td>
<td>4</td>
</tr>
<tr>
<td>4.</td>
<td>Mechanical Assembly Status</td>
<td>5</td>
</tr>
<tr>
<td>5.</td>
<td>Test Section in Place</td>
<td>7</td>
</tr>
<tr>
<td>6.</td>
<td>Upper Test Section in Place</td>
<td>8</td>
</tr>
<tr>
<td>7.</td>
<td>RVACS Heater Control and DAS System</td>
<td>9</td>
</tr>
<tr>
<td>8.</td>
<td>Typical Heater Section</td>
<td>10</td>
</tr>
<tr>
<td>9.</td>
<td>Heater Detail</td>
<td>12</td>
</tr>
<tr>
<td>10.</td>
<td>RVACS Console</td>
<td>13</td>
</tr>
<tr>
<td>11.</td>
<td>RVACS Console Configuration</td>
<td>14</td>
</tr>
<tr>
<td>12.</td>
<td>Electrical Control System Block Diagram RVACS/RACS</td>
<td>18</td>
</tr>
<tr>
<td>13.</td>
<td>Test Assembly Performance Map</td>
<td>33</td>
</tr>
<tr>
<td>14.</td>
<td>Performance for Guard Vessel Temperature = 900°F</td>
<td>38</td>
</tr>
<tr>
<td>15.</td>
<td>Effect of Guard Vessel to Collector Gap Size on Guard Vessel Temperatures, Q = 1 kW/ft**2</td>
<td>40</td>
</tr>
<tr>
<td>16.</td>
<td>Effect of Guard Vessel to Collector Gap Size on Air Velocity, Q = 1 kW/ft**2</td>
<td>41</td>
</tr>
<tr>
<td>17.</td>
<td>Effect of Guard Vessel to Collector Gap Size on Relative System Pressure Drops, QW = 1 kW/ft**2</td>
<td>42</td>
</tr>
<tr>
<td>18.</td>
<td>Air Velocity Channeling in RVACS U = 5 M/S, Q = 0 KW/M**2, MUT/MU = 100</td>
<td>45</td>
</tr>
<tr>
<td>19.</td>
<td>Velocity Profiles for Symmetric Heating</td>
<td>46</td>
</tr>
<tr>
<td>20.</td>
<td>Turbulent Kinetic Energy for Symmetric Heating</td>
<td>47</td>
</tr>
<tr>
<td>21.</td>
<td>RVACS Velocity Profile at Exit U = 5 M/S, Q = 0.0, 1-EQ Turb. Model</td>
<td>48</td>
</tr>
<tr>
<td>22.</td>
<td>RVACS Turb. Kinetic Energy Profile at Exit U = 5 M/S, Q = 0.0, 1 EQ Turb. Model</td>
<td>49</td>
</tr>
<tr>
<td>List of Tables</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>I. Control Console Status</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>II. Instrumentation Requirements - RVACS</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>III. RVACS Test Plan</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>IV. RVACS Test Assembly Parameters</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>V. RVACS Loss Coefficients for GE Simulation</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>VI. Estimated Loss Coefficient for ELGO Weather Cap</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>VII. Pretest Parametrics for the RVACS PRISM Experiments</td>
<td>39</td>
<td></td>
</tr>
</tbody>
</table>
AIR-SIDE PERFORMANCE OF RVACS/RACS—DESCRIPTION OF THE NATURAL CONVECTION SHUTDOWN HEAT REMOVAL TEST FACILITY AND SUPPORTING ANALYSIS

by


ABSTRACT

This report contains a description of the construction/fabrication status of the Natural Convection Shutdown Heat Removal Test Facility as of July 1986 and the concomittant pre-test analysis for the PRISM/RVACS (Radiant Vessel Auxiliary Cooling System) configuration installed for the initial experiments. Also included is the initial test plan and contingent test phases. The current schedule anticipates initial power operations in late October. (Since this report was issued in draft form in July, construction has been completed and experiment operations began in November 1986).
1.0 AIR-SIDE TEST FACILITY

This section describes the current status of the ANL out-of-pile experiment test assembly that simulates the GE Radiant Vessel Auxiliary Cooling System (RVACS). This description is an update of the design and fabrication/assembly status presented in reference 1.

The RVACS air-side experiments will be carried out at ANL in Building 310, a facility which provides the required high-bay capability for the full-scale simulation of the guard vessel/collector geometries typical of LMR pool-type designs. Figure 1 is an aerial view of the ANL "300" area, looking northeast. Indicated is the location of Building 310 and also shown is the location of externals pertinent to RVACS, i.e., the exhaust (hot-air) stack, and the meteorological tower. Neither is in place to date.

The Test Assembly is comprised of a structural model, electric heaters, instrumentation, insulation, and a computerized control and data acquisition system. Experiment operation will simulate prototypic reactor vessel temperatures, air flow patterns, and heat removal conditions that would exist for a RVACS system during normal reactor operation and/or a shutdown situation. In general, the system will operate in either of two thermal modes: (1) constant guard vessel wall temperature to 1000°F or (2) constant heat flux to 2.0 kW/ft². In addition, the system will accommodate stepwise variation of either mode singly or in combination.

1.1 Segment Test - Mechanical Systems

Figure 2 illustrates the basic assembly configuration and salient features. A major design change for more prototypic stack effect has been incorporated as shown, i.e., addition of an "S" section and a vertical run and weather cap to approximately 50 ft. above the previous design of the air flow exit (see reference 1). Figures 3 and 4 show the current status of test assembly mechanical design, fabrication, procurement, and in-place assembly.

Major activities completed in the past several months are as follows:
Figure 1. Aerial View - Building 310 Area
Figure 2. Test Assembly Configuration
<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Cap</td>
<td>final Design</td>
</tr>
<tr>
<td>Thermocouple Assy</td>
<td>in Design</td>
</tr>
<tr>
<td>Exhaust Stack (Natural Circulation)</td>
<td>at Procurement</td>
</tr>
<tr>
<td>Fan &amp; Damper</td>
<td></td>
</tr>
<tr>
<td>Ductwork Components</td>
<td>Complete</td>
</tr>
<tr>
<td>Test Sections</td>
<td>Complete</td>
</tr>
<tr>
<td>Base</td>
<td>Complete</td>
</tr>
<tr>
<td>Inlet</td>
<td>at Procurement</td>
</tr>
</tbody>
</table>

Figure 3. Mechanical Design and Fabrication Status
Figure 4. Mechanical Assembly Status
• Service platform installed.
• Forced circulation fan and damper procured.
• Support base fabricated and installed.
• 2-part test section fabricated and installed, thermocouples attached.
• Ductwork between test section and exhaust stack fabricated.

Mechanical activities in progress include:
• Final mechanical assembly drawings.
• Pitot/temperature traverse mechanism support development.
• Procurement of exhaust fan, stack ductwork, weather cap, weather tower.
• Exhaust stack thermocouple assembly design and fabrication.

Figure 5 shows the two 11 ft. vertical test section modules in place with the attached thermocouple leads. Figure 6 is a view of the upper 11 ft. section, showing the side plates and insulation (between side plates and the heated plate) from the heated plate (back side).

1.2 Electrical Systems

1.2.1 Heater System

The heater system design as shown in Figure 7 is not different from that shown in reference 1. Heater resistances have been measured to provide input data for on-line calculation of "local" power (heat flux) during experiments (E^2/R x SCR on-time). Figure 8 shows a typical heater "zone" ready for assembly to the test section. There are 5 heater
Figure 5. Test Section in Place
Figure 6. Upper Test Section in Place
Figure 7. RVACS Heater Control and DAS System
plate zones per 11 foot test section, each with individual heater control (including guard heaters). The center 16 heaters on the heater plate represent one heater zone with the four edge heaters being guard heaters. This array of 20 plate heaters represents 10% of the total heated length in the 22 foot test arrangement. Figure 9 is a closeup picture showing details of the heater leads and the control thermocouple locating studs.

These heaters are designed to operate at 120 V each in strings of four (in Figure 8, the heaters will be wired in series-parallel for 480 V operation). The design limit of the heaters is 2200°F and 1/2 kW. This is substantially more power than required for testing; the heater temperature will be controlled and limited to 1600°F operation. The 440 V power supply and buses are in the installation phase.

1.2.2 Auxiliary and Instrument Power

In addition to heater power, several system components require 110 V service:

- Service power (lighting, etc.).
- Variable speed, reversible fan and damper control power.
- Control console and instrument power (Figures 10 and 11).
- On-line computers/DAS systems (Figures 10 and 11).

The service power and fan/damper power are in the installation phase.

Assembly of the control console is essentially complete, as shown in Table I. Final system checkout will occur when all sensor/transducer connections are complete.
### RVACS Console Configuration

<table>
<thead>
<tr>
<th>(3Ø-480 VAC) (Copper Busses)</th>
<th>HEATER STATUS</th>
<th>ALARM INDICATOR &amp; GFI TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>(40 Heater Fuses) (40 Heater Relays)</td>
<td>UNI-DRIVER</td>
<td>VOLTMETER (Data Precision)</td>
</tr>
<tr>
<td>5-50 Amp</td>
<td>DORIC 240 # 1</td>
<td>PRESXDUCER EXC + OUTPUT (5 CHANNEL)</td>
</tr>
<tr>
<td>4 Channel ISO-Paks</td>
<td>DORIC 240 # 2</td>
<td>BAROMETER + FAST TC P.S.</td>
</tr>
<tr>
<td>480 VAC MONITOR</td>
<td>DORIC 240 # 3</td>
<td>MKS #1</td>
</tr>
<tr>
<td>3-20 Amp</td>
<td>RACK POWER 110V CB</td>
<td>DIGITALLY CONTROLLED AC WIND SPEED + TEMPERATURE + AZIMUTH DEW POINT</td>
</tr>
<tr>
<td>8 Channel ISO-Paks</td>
<td>MAIN DISCONNECT CONSOLE POWER 3Ø-480 VAC</td>
<td>CAMAC SYSTEM</td>
</tr>
<tr>
<td>15V, 24V Power Supplies Fan</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 11.** RVACS Console Configuration
Table I. Control Console Status

<table>
<thead>
<tr>
<th>Custom/Semicustom Subsystem</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alarm Indicator Chassis</td>
<td>Complete</td>
</tr>
<tr>
<td>Ground Fault Interrupt GFI</td>
<td>Complete*</td>
</tr>
<tr>
<td>Heater Status and Contractor Drive</td>
<td>Complete</td>
</tr>
<tr>
<td>480 VAC 30 main &amp; Console Monitors</td>
<td>Complete</td>
</tr>
<tr>
<td>5-Channel Pressure Monitor</td>
<td>Complete</td>
</tr>
<tr>
<td>8-Channel Digitally Controlled 110 VAC</td>
<td>Complete</td>
</tr>
<tr>
<td>Barometer &amp; Fast TC Inputs</td>
<td>Complete</td>
</tr>
<tr>
<td>Access Panel (TC's &amp; Voltage Inputs)</td>
<td>Complete</td>
</tr>
<tr>
<td>Traversing Mechanism Driver Interface</td>
<td>Complete</td>
</tr>
<tr>
<td>Commercial Subsystems</td>
<td></td>
</tr>
<tr>
<td>2 Mks (Baratron) Units Measurement System &amp; Interface</td>
<td>Complete</td>
</tr>
<tr>
<td>Unidriver/CAMAC Interface</td>
<td>Complete</td>
</tr>
<tr>
<td>3-100 Channel DORIC 240</td>
<td>Complete</td>
</tr>
<tr>
<td>Wind and Azimuth System</td>
<td>Complete*</td>
</tr>
<tr>
<td>Temperature &amp; Dew Point Unit</td>
<td>Complete*</td>
</tr>
<tr>
<td>Console Power System</td>
<td></td>
</tr>
<tr>
<td>3Ø 480 VAC Power Circuit (Left Bay)</td>
<td>Complete</td>
</tr>
<tr>
<td>- Main 3Ø Copper Buses</td>
<td>Complete</td>
</tr>
<tr>
<td>- Heater Fuse Blocks</td>
<td>Complete</td>
</tr>
<tr>
<td>- Heater Relays (contractors)</td>
<td>Complete</td>
</tr>
<tr>
<td>- Iso-Paks/Unidriver</td>
<td>Complete</td>
</tr>
<tr>
<td>3Ø 110 VAC Console Instruments/Control Power</td>
<td>Complete</td>
</tr>
<tr>
<td>- 15 kw 3Ø 480V/120V Transformer</td>
<td>Complete</td>
</tr>
<tr>
<td>- 3Ø Fused Disconnect Switch</td>
<td>Complete</td>
</tr>
<tr>
<td>- 6-20A Load Circuit Breakers</td>
<td>Complete</td>
</tr>
</tbody>
</table>

*Not completely checked out.
1.3 Instrumentation

The instrumentation requirements (Table II) have been revised to reflect some changes in secondary experiment objectives and test planning. The status of instrumentation is as follows:

- All of the thermocouples for the heated wall and the duct wall have been installed.
- The 10 radiation shielded TC assemblies, pitot tubes, and the radiation sensors are in procurement.
- The outlet air flow sensor, the stationary pressure sensors, and the heater AC instruments are ready for installation and/or connection to the DAS/control systems.
- A meteorological tower will be installed on the building to measure wind direction, velocity and temperature.

1.4 Data Acquisition System (DAS)

The DAS/heater control system block diagram is shown in Figure 12. A considerable amount of detailed software effort has been completed (naming variables, etc.). The following description is an overview of the DAS/heater control status.

1.4.1 DAS Operations

At periodic intervals the following parameters are recorded:

- All sensors connected to the Doric data loggers.
- Unidriver settings.
- Power input to each heater.
### Table II. Instrumentation Requirements - RVACS

<table>
<thead>
<tr>
<th>Instrumentation Description</th>
<th>Minimum Required Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
</tr>
<tr>
<td>THERMOCOUPLES</td>
<td></td>
</tr>
<tr>
<td>Heater Overtemperature</td>
<td>2 per heater circuit</td>
</tr>
<tr>
<td>Guard Vessel</td>
<td>2 per heater circuit</td>
</tr>
<tr>
<td>Duct Wall</td>
<td>2 per 2 ft elevation</td>
</tr>
<tr>
<td>Duct Wall</td>
<td>2 per 4 ft elevation</td>
</tr>
<tr>
<td>Fins</td>
<td>2 per 2 ft elevation</td>
</tr>
<tr>
<td>Inlet Air</td>
<td>2</td>
</tr>
<tr>
<td>Outlet Air</td>
<td>2</td>
</tr>
<tr>
<td>VELOCITII SENSOR</td>
<td></td>
</tr>
<tr>
<td>PRESSURE SENSORS</td>
<td></td>
</tr>
<tr>
<td>Inlet Static (absolute)</td>
<td>1</td>
</tr>
<tr>
<td>Test Section Differentials</td>
<td>3</td>
</tr>
<tr>
<td>HEATER AC SUPPLY MEASUREMENTS</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>3</td>
</tr>
<tr>
<td>Power</td>
<td>1</td>
</tr>
<tr>
<td>HUMIDITY MEASUREMENT</td>
<td>1</td>
</tr>
<tr>
<td>RADIATION SENSOR</td>
<td>4</td>
</tr>
<tr>
<td>(for heat flux measurement)</td>
<td></td>
</tr>
<tr>
<td>MOYABLE SENSORS</td>
<td></td>
</tr>
<tr>
<td>Pitot Tube</td>
<td></td>
</tr>
<tr>
<td>Differential Pressure and Temperature with radiation shield</td>
<td></td>
</tr>
<tr>
<td>Hot Wire Anemometer</td>
<td></td>
</tr>
<tr>
<td>Radiation Sensor</td>
<td></td>
</tr>
<tr>
<td>(for emissivity measurement)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**

1. Additional quantities of each item may be incorporated with the maximum sampling limited by the data recording system. The data recording system must be capable of accepting up to 297 signals and must be capable of sampling the complete set of signals at a periodic rate not to exceed one minute.

2. The accuracy includes linearity and repeatability. If two values are presented, the greater value indicates the accuracy.

3. The response is the time required to equal 63% of instantaneous change.

4. A separate data recording system (in addition to that identified in Note 1) must be capable of recording the signals from the movable sensors.
Figure 12. Electrical Control System Block Diagram RVACS/RACS
• Control temperature for each heater.

• A moderate number of calculated parameters (TBD).

The heater control algorithm treats each heater string as a separate entity. The heaters are numbered from 1 to 20. Heater 1 is the edge heater for the lowest two foot section, heater 2 the main heater for the first two foot section, etc. Each heater has the following associated variables:

IGNORE - Should heater be completely ignored (for checkout)?

TURNON - Is heater on? (can operate singly)

TRPTMP - Trip temperature. Maximum of any two TCs.

CTLTMP - Control temperature. Avg. of any four TCs.

CTLTYP - Control type (can be set singly for each heater).

CSTTMP - Constant temperature.

MATCH - Match control temperature of another heater.

CSTPWR - Constant power.

CSTUNI - Constant unidriver setting (for startup).

Various variables needed to implement the trip and control algorithms and to detect bad TCs.

1.4.2 DAS Software - Completed Activities

The data processing and display programs (from previous experiments) have been modified to allow for the larger number of parameters required by RVACS.
Camac Checkout Program

CAU - CAMAC Utility. General purpose, but tedious, CAMAC checkout.
TAI - Test Analog Input.
TDI - Test Digital Input.
TDO - Test Digital Output. Includes special command for Unidriver.
MKS - Test MKS Pressure Transducers.
SMC - Test Stepping Motor Controller.
Note: These programs have been used to check all CAMAC interfacing.

Data Acquisition

DAQTSK - Actual data acquisition task. This program, except
for conversion algorithms, is written - has been
partially tested.
DAQ - Operator interface for DAQTSK.

Heater Control

DAQTSK - Also performs heater control. Written but not tested.
HTR - Operator interface for heater control.
HCL - Heater control listing.
HCP - Heater control plotting.

1.4.3 DAS Software - Remaining Activities

- DAQTSK - Conversions for all non-TC parameters -- heater power,
  AC voltage, differential pressure, meteorological data.

- Probe (traverse mechanism) data acquisition and control.

- Special data reduction and displays.

- Lists/diagrams showing signal and power routing.
1.5 Test Plan

From the available design descriptions for the PRISM concept, it appears that the Air-Side Full-Scale Tests performed at ANL should encompass a range of heat fluxes, flow resistances and weather conditions that could exist following an inherent reactor shutdown wherein decay heat removal is entirely dependent upon the passive free convection effects of air flow between the reactor guard vessel (G.V.) and the surrounding duct wall. The initial (Phase I) test plan for the no-fin case is predicated on the following general conditions and strategy:

A. Thermal

1. Uniform G.V. wall temperature distribution to a maximum of 900°F (482°C).

2. Uniform G.V. heat flux to 2 kW/ft² (~ 20 kW/m²).

3. Stepwise variable heat flux in the axial direction to simulate possible stratification of sodium temperatures in the reactor vessel.

4. Prototypic wall emissivities.

B. Fluid Dynamics

1. Very low flow resistance (initial test assembly loss coefficient, \( K = 1.5 \)) to a loss coefficient of approximately ten (\( K = 10 \)), referenced to the heated section cross-sectional area.

2. Flow channel dimensions will simulate a portion of the G.V. and duct wall design such that the air velocity profiles are prototypic.
C. It has been speculated that weather (particularly wind) conditions may affect the RVACS performance. Initially, the tests will be performed with the weather cap in place. Outside and inside ambient conditions will be monitored during testing and possible effects will be investigated. Selected test runs will be duplicated with the weather cap removed or replaced with low loss weather cap.

D. The test matrix as proposed at the ANL/GE meeting of 2/19/86 contains a large number of possible parametric sets for data collection. In addition, the possible number and location of air flow measurements (pressure and temperature) is large. This initial (Phase I) plan proposes to collect data at selected matrix points in relatively large parameter increments and a small number of pitot tube and thermocouple traverses to minimize experiment durations and data acquisition storage requirements. The results of Phase I operation will determine the required extent of the test matrix for Phase II.

E. The Phase I test matrix and possible Phase II (extended) test descriptions are presented in Table III.
<table>
<thead>
<tr>
<th>Time Required</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8 hrs/day)</td>
<td></td>
</tr>
<tr>
<td>(Days)</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE III. RVACS Test Plan**

<table>
<thead>
<tr>
<th>A</th>
<th>Initial System Checkout</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1. Zero Flow, Zero Power - Simulate test run data acquisition and on-line processing for a &quot;steady-state&quot; condition.</td>
</tr>
<tr>
<td></td>
<td>• Check for system leakage.</td>
</tr>
<tr>
<td></td>
<td>• Measure velocity profiles at six axial locations and 5-8 lateral positions.</td>
</tr>
<tr>
<td></td>
<td>• Record and process all system variables for &quot;small&quot; time increments correlated to traverse positions.</td>
</tr>
<tr>
<td>3</td>
<td>2. Zero Power, Forced Convection for range of Re = 1.5 and 2 x 10^5 (V = 15 and 30 ft/sec).</td>
</tr>
<tr>
<td></td>
<td>3. Forced Convection at V = 15 ft/sec (Re = 1.5 x 10^5), Power On.</td>
</tr>
<tr>
<td></td>
<td>• Set fan to V = 15 ft/sec (Re = 1.5 x 10^5)</td>
</tr>
<tr>
<td></td>
<td>• Heater Tests and Bakeout (constant temperature control mode).</td>
</tr>
<tr>
<td></td>
<td>• Zoned Power Tests.</td>
</tr>
<tr>
<td></td>
<td>• Stepwise heater operation for electrical integrity, one zone at a time, control mode -- constant temperature at 250°F, 600°F, 900°F. Heater temp. less than 1600°F.</td>
</tr>
</tbody>
</table>

Note: The table above outlines the RVACS Test Plan with specific tests and procedures for checking and characterizing the system. The time required and comments for each test are provided to ensure comprehensive analysis and testing of the RVACS system.
Table III. RVACS Test Plan (cont'd)

<table>
<thead>
<tr>
<th>Time Required</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8 hrs/day)</td>
<td></td>
</tr>
<tr>
<td>(Days)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Record and process all system variables for "short" time increments - no traverses.

- Alt-Zone Power Tests
  - Stepwise heater operation, all zones on, "equilibrium" tests for constant temperature control mode at 250°F, 600°F, 900°F periodically.
  - Record and process selected variables for approach to steady state (will be relatively long-term since this is the bakeout phase).
  - Record and process all system variables at three equilibrium stages, limited number of pitot tube traverses.

- Heater Tests (constant heat flux control mode).
  - Repeat all-zone power tests at 0.5, 1.0, and 1.5 kW/ft² (5, 10, and 15 kW/m²).
  - Repeat all-zone power tests for stepwise power increments by "zones" (no. is TBD).
  - Heat flux and heat loss validation.

<table>
<thead>
<tr>
<th>T(F)</th>
<th>T⁴(R⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>2.5 x 10¹¹</td>
</tr>
<tr>
<td>600</td>
<td>1.3 x 10¹²</td>
</tr>
<tr>
<td>900</td>
<td>3.4 x 10¹²</td>
</tr>
</tbody>
</table>

This activity is subject to the time limitations for part A (11 days) i.e., these tests may be deferred to Phase III.

- This activity is subject to the time limitations for part A (11 days) i.e., these tests may be deferred to Phase III.
TABLE III. RVACS Test Plan (cont'd)

<table>
<thead>
<tr>
<th>Time Required</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8 hrs/day)</td>
<td>Acquisition of basic data for performance evaluation of the RVACS no-fin design.</td>
</tr>
<tr>
<td>(Days)</td>
<td>For free convection pretest calculations indicate that</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$T_{GV}$ (°F)</th>
<th>$Re$</th>
<th>$Avg. Q_w$ (kW/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>0.75 x 10$^5$</td>
<td>1.1</td>
</tr>
<tr>
<td>600</td>
<td>1.2 x 10$^5$</td>
<td>5.5</td>
</tr>
<tr>
<td>900</td>
<td>1.5 x 10$^5$</td>
<td>11.0</td>
</tr>
</tbody>
</table>

*This activity is subject to the time limitation of part B (i.e. these may be deferred to Phase II). |

15

B. Free Convection Tests

1. Minimum entrance loss, weather cap on at stack exit (minimum exit loss).
   - All-zone constant temperature control mode at 250°F, 600°F, 900°F.
   - Zoned constant temperature control mode (stratification simulation) at 400°F, 600°F, 800°F, 1000°F.*
   - All-zone constant heat flux control mode at 0.5, 1.0, and 1.5 kW/ft$^2$ (5, 10, and 15 kW/m$^2$).

2. Combinations of higher entrance/exit loss conditions.
   - Increased losses up to (possibly) $K = 10$ referenced to test section flow area. Pre-test predictions will be used to determine the additional entrance/exit loss to be added to achieve the desired Reynolds number range for $0.5 \times 10^5$ to $1.5 \times 10^5$. The actual number and configurations will be determined experimentally subject to the exit air temperature limitation of 300°F.
   - For each loss configuration, repeat all or part of tests in B.1 above.
TABLE III. RVACS Test Plan (cont'd)

<table>
<thead>
<tr>
<th>Time Required (8 hrs/day)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Days)</td>
<td></td>
</tr>
</tbody>
</table>

3. Minimum entrance and exit loss, weather cap off.

C. Possible Additional Tests - Phase II

1. During all of the tests above, the outside weather conditions will be monitored (particularly wind velocity and direction). If it appears that experiment data anomalies are related to changing meteorological conditions, procedures will be devised to account for these effects, perhaps by rerunning selected tests during selected meteorological conditions and/or utilizing alternate stack exit design.

2. It is possible that more detailed experiment data will be required for precision in computing performance data, e.g., intermediate values of temperature, heat flux and pressure loss settings.

3. Repetitability Tests, additional combined forced convection, free convection effects.

4. "Long Term" operation, ~ 5 days, perhaps during highly variable meteorological conditions.
2.0 PRE-TEST ANALYSIS

2.1 Lumped Parameter Analysis

A variety of pre-test analyses of the RVACS test assembly have been performed to support the design and predict system performance for various operating conditions. The thermal model used is the same as that presented in Ref. [1]. However, the air flow model has been changed to use form losses instead of the previous factor "\( \alpha \)" (\( \alpha = \) pressure loss in heated zone/total system pressure loss). The model has also been upgraded to remove the previous assumption of air density being a linear function of temperature.

2.1.1 Model Development

The revised air flow equations are:

1. **Net thermal head**

\[
\Delta P_h = \rho_0 \ g \left[ (1 - \bar{\rho}/\rho_0) L_h + (1 - \rho_s/\rho_0) L_s \right] \tag{1}
\]

where

- \( \Delta P_h \) = thermal head
- \( \rho_0 \) = air density at inlet
- \( \bar{\rho} \) = average air density in the heated zone
- \( \rho_s \) = air density above heated zone
- \( L_h \) = heated length
- \( L_s \) = stack length
- \( g \) = acceleration due to gravity

To calculate the average air density, \( \bar{\rho} \), two assumptions are employed:
1. the air temperature rises linearly in the heated zone,* (constant heat flux case)

2. the pressure change is small relative to atmospheric pressure

from assumption no. 1, we have:

\[ T_L = T_o + \frac{T_a - T_o}{L_h} \]

where:

- \( L \) = distance from inlet
- \( T_L \) = air temperature at location \( L \)
- \( T_a \) = air temperature at exit of heated zone

from assumption no. 2, we have, using the ideal gas law:

\[ PV = R T_L \]

or: \( \rho L T_L = P/R = \text{constant} \)

so that: \( \rho = \frac{\rho_o L T_o}{T_L} = \frac{\rho_o T_o}{T_o + (T_a - T_o) \left( \frac{1}{L_h} \right)} \)

then:

\[ \bar{\rho} = \frac{1}{L_h} \int_0^{L_h} \rho \, dL \]

\[ \bar{\rho} = \rho_o \left[ \ln \left( \frac{T_a / T_o}{T_a / T_o - 1} \right) \right]. \quad (2) \]

* Note:

An analysis was made to determine the error incurred when this assumption is retained for the case of the guard vessel wall temperature held constant. This demonstrated that an error in velocity of only 1.3% or less results for velocities of 5 fps or greater.
II. Pressure Losses

A. Friction Loss in Heated Zone

Again invoking the two assumptions given above, the frictional pressure loss, \( \Delta P_{fh} \), in the heated zone can be evaluated from:

\[
\int_0^{L_h} dP_{fh} = \frac{2 f_h G_h^2}{D_h \rho_0} \int_0^{L_h} \left[ T_0 + \left( \frac{T_a - T_0}{L_h} \right) L \right] dL
\]

or

\[
\Delta P_{fh} = \frac{f_h G_h^2}{D_h \rho_0} \left[ L_h \left( 1 + \frac{T_a}{T_0} \right) \right]
\]

where:

\( D_h = \) hydraulic diameter of the heated zone = \( \frac{4 \times \text{flow area}}{\text{wetted perimeter}} \)

\( G_h = \) air mass flow (flux) in heated zone

\( f_h = \) friction factor = \( 0.0791 \text{Re}_h^{-0.25} \)

\( \text{Re}_h = \) Reynolds No. = \( \frac{G_h D_h}{\nu} \)

\( \nu = \) air dynamic viscosity

Subscript \( h \) denotes heated zone

B. Friction Loss in Unheated Zone (Stack)

The air temperature is constant in this region so the pressure loss is:

\[
\Delta P_{fs} = \frac{2 f_s G_s^2 L_s}{D_s \rho_s} \left( \frac{A_{fs}}{A_{fs}} \right)^2
\]

where:

\( D_s = \) hydraulic diameter of stack

\( \rho_s = \) air density in stack
$A_{fh} =$ flow area in heated zone
$A_{fs} =$ flow area in stack
$f_s =$ friction factor in stack $= 0.0791 \text{Re}_{s}^{-0.25}$
$\text{Re}_{s} =$ Reynold's No. in the stack
Subscript $s$ denotes region above heated zone

C. Acceleration Pressure Loss

To determine the acceleration pressure loss, $\Delta P_a$, it is convenient to use a control volume that moves with the flow (Eulerian coordinates) thereby ensuring that the same body of fluid particles are preserved in momentum calculations. Consider the following sketch:

At time $t$ the vertical surfaces of the control volume lie at locations $A$ and $B$. In an added incremental time $\Delta t$ the surfaces move to $A'$ and $B'$ respectively. For steady flow, the small masses of fluid between $A$ and $A'$, and $B$ and $B'$ are respectively:

\[ \Delta m_1 = \rho_1 V_1 A_F \Delta t \text{; where } A_F = \text{area of the control volume normal to the flow} \]
\[ \Delta m_2 = \rho_2 V_2 A_F \Delta t \]

but since, $\rho_1 V_1 = \rho_2 V_2$; $\Delta m_1 = \Delta m_2 = \Delta m$ and $\Delta m = \dot{m} \Delta t$, where $\dot{m}$ is the mass flow rate. Thus, in time $\Delta t$ there is a momentum loss from the control volume of magnitude $\dot{m} \Delta t V_1$ at the inlet and a gain of, $\dot{m} \Delta t V_2$ at the exit. The net change; $\dot{m} \Delta t (V_2 - V_1) = F \Delta t$, where $F \Delta t$ is the net impulse applied to the mass of fluid. We then have:

\[ \frac{F}{A_F} = \Delta P_a = G (V_2 - V_1) = G \left( \frac{G}{\rho_2} - \frac{G}{\rho_1} \right) \]
or:

\[ \Delta P_a = G^2 \left( \frac{1}{\rho_2} - \frac{1}{\rho_1} \right) \]

Thus for the heated zone:

\[ \Delta P_a = G_h^2 \left( \frac{1}{\rho_s} - \frac{1}{\rho_0} \right) \]  \hspace{1cm} (5)

D. Form Losses

System pressure losses due to expansions, contractions, bends, etc. may be expressed as:

\[ \Delta P_K = K_{loss,i} \frac{\rho_i u_i^2}{2} \]

where the subscript \( i \) denotes local geometric conditions in the system and \( K_{loss,i} \) is a constant whose value is appropriate for the geometric change. Referred to the heated zone flow the above equation becomes:

\[ \Delta P_K = K_{loss,i} \frac{\rho_i u_h^2}{2} \left( \frac{A_{fh}}{A_{fi}} \right) = K_{loss,i} \frac{\rho_i G^2 A_{fh}}{2 \rho_0} \left( \frac{A_{fh}}{A_{fi}} \right) \]

Re-defining the form loss constant as:

\[ K_{loss} = K_{loss,i} \left( \frac{A_{fh}}{A_{fi}} \right) \]  \hspace{1cm} (6)

Then:

\[ \Delta P_{Kloss} = K_{loss} \frac{\rho_i G^2}{2 \rho_0} \]  \hspace{1cm} (7)

Summing the system pressure losses we have:
\[ \text{losses} = \frac{G^2}{2 \rho_o} \left( \frac{\rho_i}{\rho_o} \right) \kappa \text{loss} + \frac{2 f}{D_h} \left( \frac{h}{\rho_o} \right) \left( \frac{T}{T_o} + 1 \right) \]

\[ + \frac{4 \rho_o f_s L_s}{\rho_s D_s} \left( \frac{A_{fh}}{A_{fs}} \right)^2 + 2 \left[ \frac{T_a}{T_o} - 1 \right] \]

(8)

For steady flow the sum of system pressure losses must equal the net thermal driving head whereby we equate Eq. (1) to Eq. (8). The resulting equation is solved by iteration to find converged values of \( G \), Reynolds Nos., friction factors, convective heat transfer coefficient, average air density, and exit air temperature. The thermal analysis then proceeds as before to determine temperature of the guard vessel and duct wall simulators.

### 2.1.2 Calculated RVACS Test Assembly Performance

The foregoing equations were incorporated in the previous model of Ref. [1] and the resulting FORTRAN program is listed in Appendix I. The code was then used to calculate system performance based upon current design parameters for the simulation of PRISM. Table IV presents the important dimensions and other parameters used in the calculations. As indicated, the overall system loss coefficient was treated as a parameter. Table V delineates the estimated system losses in a "wide open" configuration and Table VI shows the basis for using a loss coefficient of 1.0 for an ELGO weather cap which has been selected to cover the stack.

Figure 13 depicts a system performance map in terms of Reynolds's numbers and air temperatures vs. heater input power (flux) for the range of loss coefficients assumed. These results show the deleterious effects of high form losses; however, even for the high loss cases, Reynolds's numbers indicating turbulent flow are predicted and air exit temperature levels do not exceed the system limit of 300°F, even at maximum heater power (2 kW/ft²). With an estimated overall loss coefficient of \( \sim 1.5 \) for the test assembly in the "wide open" configuration, Reynold's numbers \( > 1.0 \times 10^5 \) should be easily achievable even at relatively low heater power levels. The map also indicates turbulent flow even for high losses and low heater power.
Figure 13. Test Assembly Performance Map
Table IV. RVACS Test Assembly Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated length</td>
<td>22 ft.</td>
</tr>
<tr>
<td>Stack height</td>
<td>50 ft.</td>
</tr>
<tr>
<td>Heated channel cross section</td>
<td>12&quot; x 52&quot;</td>
</tr>
<tr>
<td>Stack channel cross section</td>
<td>18&quot; x 52&quot;</td>
</tr>
<tr>
<td>Emissivity of surfaces</td>
<td>0.7</td>
</tr>
<tr>
<td>Inlet air temperature</td>
<td>70°F</td>
</tr>
<tr>
<td>Inlet air density</td>
<td>0.0748 lb/ft³</td>
</tr>
<tr>
<td>Overall $K_{\text{Loss}}$ (Referred to inlet)</td>
<td>0 to 10</td>
</tr>
</tbody>
</table>
Table V. RVACS Loss Coefficients for GE Simulation

<table>
<thead>
<tr>
<th></th>
<th>Local</th>
<th>Inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Entrance (Re-entrant)</td>
<td>0.85</td>
</tr>
<tr>
<td>2.</td>
<td>Heated zone to stack transition</td>
<td>0.11</td>
</tr>
<tr>
<td>3.*</td>
<td>S-flue</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>H/W = 3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R/W = 2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-60° bends (0.67 of 90° ea.)</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Weather Cap</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ELGO or none</td>
<td>1.0</td>
</tr>
<tr>
<td>Overall:</td>
<td>ELGO cap or none</td>
<td>2.11</td>
</tr>
</tbody>
</table>

*2-60° Bends: each has a loss that is ~67% of a 90° bend.
Table VI. Estimated Loss Coefficient for ELGO Weather Cap

\[ \Delta p = K_p \frac{u^2}{2} = \rho_{H_2O} \cdot g \cdot h \]

\[ K = \frac{2 \rho_{H_2O}}{\rho_{air}} \cdot g \cdot h \frac{u^2}{2} \]

\[ K = \frac{2 \times 997 \times 9.8 \times (1/12) \times 0.3048}{1.0 \times (\frac{0.3048}{60})^2} \cdot \frac{h}{u^2} \]

\[ K = 1.923 \times 10^7 \frac{h}{u^2} \]

<table>
<thead>
<tr>
<th>( u^* )</th>
<th>( u^2 )</th>
<th>( h^* )</th>
<th>( 1.923 \times 10^7 \frac{h}{u^2} = K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>( 9 \times 10^4 )</td>
<td>0.002</td>
<td>0.427</td>
</tr>
<tr>
<td>400</td>
<td>( 1.6 \times 10^5 )</td>
<td>0.004</td>
<td>0.481</td>
</tr>
<tr>
<td>500</td>
<td>( 2.5 \times 10^5 )</td>
<td>0.007</td>
<td>0.538</td>
</tr>
<tr>
<td>600</td>
<td>( 3.6 \times 10^5 )</td>
<td>0.011</td>
<td>0.588</td>
</tr>
<tr>
<td>700</td>
<td>( 4.9 \times 10^5 )</td>
<td>0.017</td>
<td>0.667</td>
</tr>
<tr>
<td>800</td>
<td>( 6.4 \times 10^5 )</td>
<td>0.025</td>
<td>0.751</td>
</tr>
<tr>
<td>900</td>
<td>( 8.1 \times 10^5 )</td>
<td>0.035</td>
<td>0.831</td>
</tr>
<tr>
<td>1000</td>
<td>( 1 \times 10^6 )</td>
<td>0.045</td>
<td>0.865</td>
</tr>
<tr>
<td>1100</td>
<td>( 1.21 \times 10^6 )</td>
<td>0.057</td>
<td>0.906</td>
</tr>
<tr>
<td>1200</td>
<td>( 1.44 \times 10^6 )</td>
<td>0.069</td>
<td>0.921</td>
</tr>
</tbody>
</table>

*Values of \( u \) and \( h \) are taken from ELGO data.
This is further illustrated in Fig. 14 which again indicates satisfactory system performance for a wide range of loss coefficients. These results were developed for the condition of the guard vessel temperature held constant at 900°F.

Additional parametric calculations were made to determine other system responses, particularly wall temperatures, to variations in loss coefficients, emissivities and heater power levels. Results of these calculations are shown in Table VII. Once again the predicted air exit temperatures are all well within the 300°F limit. However, a few cases that assume high losses and/or high heater power levels, lead to high guard vessel and duct wall temperatures; e.g. guard vessel temperatures well above 1000°F. This will also be an initial system operating limit; therefore such cases, which may challenge system integrity will be avoided, at least in early tests.

An additional set of calculations were made to investigate the size of the guard vessel to duct wall gap on system performance. Previous calculations led to a conclusion [Ref. 1] that the gap size only weakly affected the system. This conclusion is now considered erroneous because it was based on the assumption of low exit/entrance pressure losses, i.e., a value of Ω in the range of 0.5 was used which is equivalent to assuming that the pressure loss in the heated zone represents about half the total system pressure drop. This is equivalent to overall entrance/exit loss coefficients of small fractional values (see Appendix I of Ref. [1]).

Now realizing that system pressure losses are dominated by form losses, the effect of gap size on system performance was re-calculated leading to a much different conclusion regarding its effect. This is demonstrated in Figures 15 to 17. Figure 15 shows the temperature lowering potential afforded by reduction in gap size when any appreciable entrance/exit pressure losses exist in the system. The lower curve is unachievable but shown to indicate the basis of the previous conclusion of low system sensitivity to gap size when losses are small. The other, more reasonable curves, show temperature reductions on the order of 300°F may be achieved by gap size reduction from the current value of 12 inches to - 5 to 6 inches. Although the curves show minima in the 3 to 4 inch range, such small gaps may be infeasible for reactor construction.
Figure 14. Performance for Guard Vessel Temperature = 900°F
Table VII. Pretest Parametrics for the RVACS PRISM Experiments

<table>
<thead>
<tr>
<th>No.</th>
<th>K</th>
<th>ϵ</th>
<th>Q_W (kW/ft^2)</th>
<th>U (ft/s)</th>
<th>10^-5 Re</th>
<th>Ta (°F)</th>
<th>T_GVO (°F)</th>
<th>T_GV (°F)</th>
<th>T_D0 (°F)</th>
<th>T_D (°F)</th>
<th>h</th>
<th>10^3 Δp_T (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>0.7</td>
<td>1.0</td>
<td>16.2</td>
<td>1.49</td>
<td>148</td>
<td>850</td>
<td>927</td>
<td>648</td>
<td>725</td>
<td>2.51</td>
<td>4.07</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>&quot;</td>
<td>&quot;</td>
<td>17.7</td>
<td>1.64</td>
<td>140</td>
<td>809</td>
<td>879</td>
<td>587</td>
<td>657</td>
<td>2.72</td>
<td>3.73</td>
</tr>
<tr>
<td>3</td>
<td>4.0</td>
<td>&quot;</td>
<td>&quot;</td>
<td>12.5</td>
<td>1.14</td>
<td>172</td>
<td>988</td>
<td>1089</td>
<td>842</td>
<td>944</td>
<td>2.02</td>
<td>5.16</td>
</tr>
<tr>
<td>3a</td>
<td>10.0</td>
<td>&quot;</td>
<td>&quot;</td>
<td>9.63</td>
<td>0.849</td>
<td>206</td>
<td>1184</td>
<td>1319</td>
<td>1088</td>
<td>1224</td>
<td>1.60</td>
<td>6.56</td>
</tr>
<tr>
<td>4</td>
<td>0.2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>22.7</td>
<td>2.14</td>
<td>124</td>
<td>716</td>
<td>770</td>
<td>441</td>
<td>495</td>
<td>3.36</td>
<td>2.94</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
<td>&quot;</td>
<td>&quot;</td>
<td>24.0</td>
<td>2.27</td>
<td>121</td>
<td>699</td>
<td>749</td>
<td>414</td>
<td>465</td>
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<td>2.49</td>
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<td>1186</td>
<td>847</td>
<td>940</td>
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Note: These calculations were made for an inlet air temperature of 70°F. Other temperatures listed are for bottom and top of heated zone.
Figure 15. Effect of Guard Vessel to Collector Gap Size on Guard Vessel Temperatures, $Q = 1 \text{ kW/ft}^2$.
Figure 16. Effect of Guard Vessel to Collector Gap Size on Air Velocity, $Q = 1 \text{kW/ft}^2$
Figure 17. Effect of Guard Vessel to Collector Gap Size on Relative System Pressure Drops, $QW = 1$ kW/ft$^2$
The temperature drop with initial gap size reduction occurs because until the friction loss in the heated zone becomes significant, the mass flow rate tends to remain essentially constant. This causes the velocity to increase thereby increasing the heat transfer coefficient and concomitant heat removal at lower ΔT's.

The velocity response to gap reduction is depicted in Fig. 16; it turns over at the points of temperature minima.

Finally Fig. 17 shows relative pressure drop in the heated zone. This clearly shows the dominance of the entrance/exit losses at the larger gap sizes.

Therefore, the previous conclusion on the insensitivity of the system to gap size is reversed. These current results indicate that a potential for considerable improvement in performance can be achieved with a reduced gap size.

2.2 COMMIX-IA Analysis

RVACS Turbulence Modeling Using COMMIX-IA

The design and licensing of a RVACS system will require a detailed understanding of the air-side performance of the natural convecting air stream including such uncertainties as variation in the circumferential variations in the gap between the guard vessel and collector, partially blocked entrances, etc. The purpose of this analysis is to make use of the data obtained in the RVACS experiment to validate COMMIX as a useful tool in the prediction of air-side-velocities and heat transfer coefficients.

COMMIX-IA provides two turbulence models, viz. a constant turbulence model and a one-equation (k) model. Both have been tried in simple representations of the heated zone of RVACS; results have been unsatisfactory for both methods.
Increasing the molecular viscosity of air to simulate the effect of turbulence and then providing such a value as input to COMMIX for the constant viscosity model simply does only that, i.e., it makes the fluid more viscous but does not treat the turbulent eddy diffusivity. Thus, a turbulent flow pattern does not develop and the flow profile across the channel is characteristic of laminar flow. An example is shown in Fig. 18 where the channel exit flow is shown for isothermal conditions with the normal molecular viscosity of the air increased by a factor of 100. The parabolic shape indicates laminar flow.

Calculations were then made using the one-equation turbulence option (k model) available in COMMIX-1A. These results, using default values of adjustable parameters showed the calculated turbulent intensities to be too high. The wall stress was excessive as evidenced by the high pressure drop through the system. Changing parameters in the near-wall model reduced the pressure drop to a value reasonably close to that predicted by a lumped parameter model using a friction factor for fully developed turbulent flow. It was hoped that this change would favorably resolve other calculated quantities, e.g., turbulent kinetic energy magnitude and shape, velocity profiles and magnitude of turbulent viscosity. However, such was not the case and a literature search was then made to find target values of these quantities to be used in further calibration runs. The best data for RVACS calculations to be checked against was found in [2]. This study included both symmetric and asymmetric heating of two channel walls with the latter condition representative of RVACS operation.

Our initial calculations with the one equation model were for the simplest case, i.e., for isothermal conditions. Then target curves were those shown in Fig. 19 (velocity profiles) and Fig. 20 (turbulent kinetic energy) for Grasshof No. = 0.0. Leaving the near-wall adjustable constants as previously determined, a large number of parametric runs were made adjusting remaining constants. None of these calculations provided satisfactory results. The best solutions are depicted in Figs. 21 and 22. Comparing Fig. 22 to Fig. 20 shows the COMMIX calculation yielding turbulent kinetic energy levels approximately a factor of four greater than target values. Similarly comparison of Fig. 21 with Fig. 19 shows that COMMIX predicts a velocity profile that is much too flat.
Figure 18. Air Velocity Channeling in RVACS $U = 5 \text{ M/S}$, $Q = 0 \text{ KW/M}^2$, MUT/MU = 100
Figure 19. Velocity Profiles for Symmetric Heating
Figure 20. Turbulent Kinetic Energy for Symmetric Heating
Figure 21. RVACS Velocity Profile at Exit $U = 5$ M/S,
$Q = 0.0$, 1-EQ Turb. Model
Figure 22. RVACS Turb. Kinetic Energy Profile at Exit
$U = 5 \text{ M/S, } Q = 0.0, \text{ 1 EQ Turb. Model}$
These failures to achieve acceptable results for turbulence modeling using COMMIX-1A and the one-equation model were discussed with code developers at ANL CT Division. It was concluded that the turbulence models in COMMIX-1A were probably inadequate for our purposes, having been developed with emphasis on treating flow through rod bundles. We were advised that superior models are available in COMMIX-1B which contains two-equation (k-ε) modeling of turbulence and that a much greater potential for acceptable results is expected with its use. Unfortunately, to date, COMMIX-1B does not treat air side radiation heat transfer. Nonetheless, current plans are to use COMMIX-1B for RVACS turbulence modeling and to simulate radiation heat transfer by other means.
3.0 REFERENCES


APPENDIX I

This appendix presents a FORTRAN source code listing of the program used to obtain the results presented in Section 2 of this report.

FILE: SMOOTHER FORTRAN A1 ANLVM VM/SP 405 CMS

C
C                  THIS IS A SMOOTH CHANNEL MODEL-NO FINS
C
C OR RIBS          THIS PROGRAM IS FOR SHRS WITHOUT FINS OR RIBS I.E. FOR SMOOTH
C CHANNELS. THE BOUENCY DRIVEN AIR FLOW IS BASED ON EQ'S. DERIVED
C BY P.A. LOTTES. REMAINING FORMULATIONS BY F.B. CHEUNG.

C
C                   UNITS OF OUTPUTS ARE BRITISH 4-15-86
C
C                  *
C
C                  IMPLICIT REAL*8(A-H,O-Z)
C
C REAL
C L,LH,MU,NU,K,LS,KLOSS,KLOSSI
C
C DATA
C RHO,GRAY,BETA,TO,CP,MU,ALPHA,NU,K,SIGMA,AE,AH
C 1/2.00,9.8,0.00367,294.4,1.E3,1.83E-5,
C 2.25E-5,1.58E-5,0.0257,5.67E-8,1.0,1.0/
C DATA
C CCONV/0.01/
C
C WRITE(6,3)
C FORMAT(X,'INPUT H, W, HS AND WS IN INCHES')
C READ(5,*) H,H,HS,WS
C WRITE(6,4)
C FORMAT(X,'ENTER STACK HEIGHT AND HEATED LENGTH IN FEET')
C READ(5,*) LS,LH
C LH=0.3048*LH
C LS=0.3048*LS
C L=LS+LH
C WRITE(6,5)
C FORMAT(X,'ENTER VALUE OF KLOSSI AND EMISSIVITIES FOR RVACS & RV')
C READ(5,*) KLOSSI,EPS,EPSRV
C
C AFH=H*W
C AFS=HS*WS
C DH=4.0*W*H/t2.0*(W+H)
C DHS=4.0*HS*HS/t2.0*(HS+HS)
C AFL=AFH
C KLOSS=KLOSSI*((AFH/AFL)**2)/<RHO**2)
C BRH=H*39.37/12.
C BRH=W*39.37/12.
C BRH=H*39.37/12.
C BRL=LS/0.3048
C BRAFH=AFH/0.3048**2)
C BRAFS=AFS/(0.3048**2)
C BRDH=DH/(0.3048)
FILE: SMOOTHER FORTRAN A1
ANL VM/SP 405 CMS

BRDHS=DHS/(0.3048)
WRITE(6,6) BRH,BRLH,BRLS,KLOSSI,EPS,EPSRV,BRH,BRDH,BRHS,BRWS,BRDHS
> BRH,BRAFH,BRAFS
WRITE(50,6) BRH,BRLH,BRLS,KLOSSI,EPS,EPSRV,BRH,BRDH,BRHS,BRWS
> BRDHS,BRAFH,BRAFS

6 FORMAT(1X,'H=',F10.4,2X,,LH3,,F10.4,2X,1,KLOSS=,,F10.4,2X,IEPS=',F10.4,2X,,EPSRV,,F10.4,2X,,W=I,F10.4,2X,
1.0,DH^'.FIQ^./.IX.'HS^SFIO^^X.'WS^'.F10.4^SFIO^,32X,,AFH=,,F10.4,2X,'AFS=,,F10.4,///)
7 WRITE(6,8)
8 FORMAT(1X,'ENTER VALUE OF HEAT FLUX IN KW/M**2')
READ(5,*), QW
QW=1.3*QW
EPSW=EPS
EPSS=EPS
C THE FOLLOWING ASSIGNMENT OF AW=400 IS AN INITIAL GUESS
AW=400.
C THE FOLLOWING ASSIGNMENT OF G AND TA IS AN INITIAL GUESS
G=1.0
TA=350.
RHOBAR=(RHO*DLOG(TA/TO))/(TA/TO-1.0)
RH0A=RHO*(T0/TA)
RHOI=RHO
11 RE=G*DH/MU
RES=(G*DHS/MU)*(AFH/AFS)
C BLASIUS FRICTION FACTOR
F=0.0791*(RE**(-0.25))
FS=0.0791*(RES**(-0.25))
DPFH=F*LH*(1.0+TA/TQ)/(DH*RHO)
DPFS=2.0*FS*LS*(AFH/AFS)**2)/(RHOA*DHS)
DPAC=(TA/T0-1.0)/RHO
DPFORM=KLOSS*RHOI/2.0
HD=RHO*GRAV*((1.0-RHOBAR/RHO)*LH+(1.0-RHOA/RHO)*LS)
C WRITE(6,*)
WRITE(50,*)
SUMLOS=DPFH+DPFS+DPAC+DPFORM
6NEH=HD/SUMLOS)**0.5
TA=T0+QW*LH/(GNEW*CP*H)
RHOBAR=(RHO*DLOG(TA/TO))/(TA/TO-1.0)
RH0A=RHO*(T0/TA)
C WRITE(6,*)
WRITE(50,*)
OELG=GNEW-G
IF(DABS(DELG).LT.0.01) GO TO 12
G=G+DELG*CCONV
C WRITE(6,*)
WRITE(50,*)
GO TO 11
12 G=GNEW
TA=T0+QW*LH/(G*CP*H)
RH0A=RHO*(T0/TA)
RHOBAR=(RHO*DLOG(TA/TO))/(TA/TO-1.0)
RE=G*DH/MU
RES=(G*DHS/MU)*(AFH/AFS)
C BLASIUS FRICTION FACTOR
F=0.0791*(RE**(-0.25))
FILE: SMOOTHR FORTRAN A1 ANLVH VM/SP 405 CMS

FS=0.0791*(RES**(-0.25))
WRITE(6,9) RE,F,RHOBAR,RES,FS,RHOA
WRITE(50,9) RE,F,RHOBAR,RES,FS,RHOA
9 FORMAT(F10.2,5X,FRIC. FACTOR=',F10.6,5X,'RHOBAR=',F10.6,1X,'DEN
>STACK=',F10.3)
DELPH=F*(G**2)*LH*(TA/T0+1.0)/(DH*RHO)
DELPS=(2.0*FS*(G**2)*LS/(RHOA*OHS))*((AFH/AFS)**2)
DPACL=(TA/T0-1.0)*(G**2)/RHO
DPKLOS=KLOSS*(G**2)*RHOI/2.0
DPLOST=DELPH+DELPS+DPACL+DPKLOS
DPHEAD=RHO*K*G**2*(1.0-RHOBAR/RHO)*LH*(1.0-RHOA/RHO)*LS
DPERR=DPHEAD-DPLOST
PR=NU/ALPHA
DITTUS-BOELTER CORRELATION FOR HW
HH=(0.023*(RE**0.8))*(PR**0.4)*K/DH
WESTINGHOUSE PETUKOV CORRELATION FOR HW
HW=(1.22*(RE**0.457))*(0.72**0.4)*K/DH
F2=1./((1.82*ALOG10(RE)-1.64)**2)
HNUH=RE*PR*F2/8.
HDEN1=PR**(2./3.)-1.
HDEN2=12.7*(F2/8.)**(0.5)
HW=(HNUM/(1.07+HDEN2*HDEN1))*K/DH
BH=QW/(G*CP*H)
BS=BW
AS=T0+(QW-HW*AW-T0))/HD
TERM4=(AH+BW*LH/2.)**4
TERM5=(AS+BS*LH/2.)**4
TERM6=HD*(1.0/EPSH+1.0/EPSS-1.0)
ASNEW=AH+TER4/2.0
DELAS=ASNEW-AH
IF(DABS(DELAS).LT.0.001) GO TO 30
AW=AW-DELAS*CCONV
WRITE(6,*) ASNEW,AS,DELAS,AW,BW
GO TO 10
WRITE(6,40) DELAS
40 FORMAT(1X,'ERROR IN CALCULATED VALUE OF AS=',F10.4)
TA=T0+QW*LH/(G*CP*H)
UAVE=G/RHOBAR
TGV=AH+BW*LH
TFS=AS+BS*LH
TGVBAR=(AH+TGV)/2.0
EPSA=1.0/(2.0/EPSS-1.0)
TRVBAR=(TGVBAR**4+QW/(SIGMA*EPSA))**0.25
TGV=AH
TRV=(TGV**4+QW/(SIGMA*EPSA))**0.25
HOVRAL=QW/(TRV-T0)
TRV=TRV+1.8-459.69
HOVRAL=HOVRAL/5.678263
WRITE(6,43) TRV,HOVRAL
WRITE(50,43) TRV,HOVRAL
43 FORMAT(1X,'QW=',F10.4,5X,'TRV=',F10.4,5X,'HOVRAL=',F10.4,5X,'QW1.E-3')
FILE: SMOOTHBR FORTRAN A1 ANLV VM/SP 405 CMS

QH=QH*(0.3048**2)
WRITE(6,44) QH
WRITE(50,44) QH

44 FORMAT(1X,'HEAT FLUX-(KW/FT**2)='F10.4)
WRITE(6,45)
WRITE(50,45)

45 FORMAT(1X,'AVERAGE REACTOR VESSEL TEMP.(F)='F10.4,
'>AVERAGE GUARD VESSEL TEMP.(F)='F10.4,/)

BRH=H/0.3048
UAVE=UAVE/0.3048
TA=TA*1.8-459.69
AH=AH*1.8-459.69
TGV=TGV*1.8-459.69
TGVBAR=0.5*(AH+TGV)
AS=AS*1.8-459.69
TFS=TFS*1.8-459.69
BRHW=HW/5.678263
G=G/0.435924

WRITE(50,50) BRH,UAVE,TA,AH,TGV,AS,TFS,BRHW,G
WRITE(6,50) BRH,UAVE,TA,AH,TGV,AS,TFS,BRHW,G

50 FORMAT(1X.9F10.4,

DELPH=DELPH/PCONV
DELP=DELP/PCONV
DPACL=DPACL/PCONV
DPKLOS=DPKLOS/PCONV
DPLOST=DPLOST/PCONV
DPHEAD=DPHEAD/PCONV
DPERR=DPERR/PCONV
RATIO=DELPH/DPLOST

BRHIN=12.D0*BRH
WRITE(60,*)
WRITE(6,55) BRHIN, RATIO
WRITE(50,55) BRHIN, RATIO

55 FORMAT(1X,'P LOS FRIC-H='D10.5,2X,'P LOS FRIC-S='D10.5,2X,
'>ACCEL LOSS='D10.5,2X,'FORM LOS='D10.5,2X,'TOTAL P LOSS='D10.5,2X,
'>TOT HEAD='D10.5,2X,'HEAD-LOS ERR='D12.7)
WRITE(6,56)
WRITE(50,56)

56 FORMAT(1X,'END OF CASE $$$ERROR$$$','/)
WRITE(6,60)
WRITE(50,60)

60 FORMAT(1X,'ENTER POSITIVE NO. TO CHANGE GEOMETRY: NEGATIVE FOR
NO CHANGE')
READ(5,*) IGEOM
IF(IGEOM.GT.0) GO TO 1
WRITE(6,65)

65 FORMAT(1X,'ENTER POSITIVE NO. TO CHANGE HEAT FLUX; NEGATIVE
TO TERMINATE')
READ(5,*) IQW
IF(IQW) 104
WRITE(6,66)
WRITE(50,66)
FILE: SMOOTHBR FORTRAN A1 ANLVM VM/SP 405 CMS

100 STOP
END

SHOO2210
SHOO2220