Engineering Design File

Project #23747; 23843

AGC-1 Operational Mockup Results



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Idaho National Laboratory

AGC-1 OPERATIONAL MOCKUP
RESULTS

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NGNP Graphite Qualification Engineering Design File

eCR Number: 555683

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	09/24/07	All	New issue.
1	10/22/07	14, 20, and 24	Comments from DOE

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SUMMARY

This report provides results from the Advanced Graphite Capsule (AGC-1) Operational Mockup testing performed in accordance with PLN-2273, "Test Plan for the AGC-1 Operational Mockup," and the impact of those results on the AGC-1 experiment's design. EDF-8385, "Advanced Graphite Capsule (AGC-1) Load Cell Testing," documents the calibration and benchtop load cell testing. This mockup has verified operational design; determined set points based on the operational behavior of the mockup, allowing the Advanced Test Reactor (ATR) digital control system to be programmed to control the capsule; and developed and verified the programming to be used by the ATR digital control system.

An integrated review of the mockup performance, equipment responses and accumulated error shows that the mockup could be controlled within the stated error band in the test plan (PLN-2273). While testing and implementing these recommendations may further optimize the design, the operational mockup demonstrated an acceptable design for the AGC-1 gas control system.

The table below summarizes design improvements that will be implemented from lessons learned during assembly and testing of the AGC-1 Operational Mockup. Retest of the optimized design will include the 72-hour stable pressure test following implementation of improvements identified below: 1-in. Honeywell load cells, a 300-psig ranged pressure transducer, a zero correction for the load cell indications, a stable 10-V DC power supply, and more accurate digital control system input modules.

Function	Improvement Identified	Consequence and Benefit
	Capsule Design	
Graphite specimen-loading tool	Speeds loading graphite specimens	Extended tray allows for verifying specimen marking before loading
Push rods	Shoulder on push rod should be removed	Push rods could not be assembled as originally designed with the shoulder on one end
Pressure boundary	Pressure boundary pieces need an alignment feature to keep them all aligned	The push rods within the experiment can get twisted if the pressure boundary is not aligned
Pressure boundary	The 5-in. pressure boundary should be gun drilled. Off the shelf material used in the mockup was out of round	No tubing in ASME material approved for pressure service was available in the 5-in. without producing a whole mill run.
Small pneumatic cylinders	Dual-acting cylinder has benefits over the spring-return cylinder in the original design	It is beneficial during installation of the push rods and graphite samples to have the cylinder not return to the fully retracted position. This allows movement of the lower stack to be observable and confirmable during installation.

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Function	Improvement Ider	ntified	Consequence a	nd Benefit
Load cell pinned connection	Load cell pinned conne benefits over being dire screwed into the push b	ection has ectly pars	Load cells cannot be changed out if needed without largely dismantling the experiment	
Funnel	Lip on funnel should be to allow the 5-in. press boundary to slide over	e removed ure the funnel	Cables and tubing would not be lon enough if the 5-in. pressure bounda could not slide over the funnel	
Lower cylinder mounting plate	Lower cylinder mounting plate should be thicker to accept the lower push rods		The lower cylinder more should be thicker to pre- push rods from falling horizontal position	unting plate event the lower out when in the
Lower cylinder mounting plate	It is beneficial to make cylinder mounting plate the weld plates	the lower e one of	The lower pneumatic c becomes fixed and can and the cylinders are m install	ylinder then not move forward uch easier to
Graphite pistons	Graphite pistons should smaller OD on both end extend down into the g body	l have a ds and raphite	The graphite pistons sh smaller OD on both en- samples from being dis ¼-in. lift	ould have a ds to prevent lodged during the
Length of 1/8-in. skewers/rods	Lengthened rods that congraphite specimens and	enter the I spacers	The longer skewer mak	tes loading easier
Developed a backup configuration if the cylinders with position sensors prove unreliable	A backup configuration has been developed using external sensors and regular off-the-shelf cylinders		Improved cylinders wit sensors are being acqui cylinders have unknow to have a backup config	h new position red, but if these n faults, it is best guration
	Senso	ors		
Use 1-in. load cells over ³ / ₄ -in. load cells	From load cell testing I cells have less off-axis error	l-in. load loading	³ / ₄ -in. load cells had sta	bility issues
FGP load cells with silicone gauges	FGP load cells with sili gauges showed high dr	icone ift	Metal foil-type gauges drift	show much less
Entran ELHM load cells	The Honeywell Model cell is less sensitive to loading than the Entran and is more readily ava	31 load side ELHM ilable	The Entran ELHM load sensitive to off-axis load expected to have greated	l cell is very ding and is er error
Test leak tightness of any pneumatic ram	None of the suppliers of pneumatic rams carry N quality assurance progr	f NQA-1 rams	None of the suppliers h incentives to become N for the dollar amount o project	ave economic IQA-1 suppliers rdered on this
Calibrate all load cells and determine accuracy of calibration coefficients	The accuracy and repeat the load cells must be of thoroughly along with constant load	atability of letermined drift over a	Required to program th control	e DCS for load

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Function	Improvement Identified	Consequence and Benefit			
Determine the zero offset which includes load cell and experiment hardware for the load cells	The actual load on the graphic specimens must be determined	Required to program the DCS for load indication			
Adjusted pressure regulator valve actuation ramp	Better control of pressure ramp preventing PRV from opening; negates having to change out pressure regulators	If not, the experiment would not run smoothly			
Don't use liquids to check for leaks where it can enter the pneumatic cylinders	If liquid seeps into the cylinders, the internals could rust	Found out from experience			
	Gas Control Panel				
Use gauges with a tolerance of \pm 1.5 psig in line with pressure transducer	Verification of pressure and operation of a electronic sensor	Defense in depth			
Use VCR connections and diaphragm valves to reduce leakage and assembly time	Reduces labor of building the panel because less time is spent checking for leaks	Defense in depth			
Should install regulator between bulk helium system and pressure controllers in ATR	To prevent pressure increase when installing new high- pressure bottle (saw 1.5 increase in mockup testing)	Lesson learned from mockup testing			
	DCS				
Need new analog/digital modules for 10V	Older A to D boards limited voltage to 5 V	Better response from sensors at 10 V instead of 5 V			
Need cabinet large enough for spare modules and several power supplies	Cabinet did not have room for additional power supplies and backup a to d modules	Make sure DCS at ATR has the required space			
Need very high quality power supply	Need to specify a 10-V DC power supply with no more than 0.01 mV oscillation	Programmatic error controls requires a more accurate power supply			
Start up and Operational Testing					
The voltage supply for the load cells and the position indicators should have remote voltage sensing, where the voltage output is adjusted to match the voltage at the remote terminals. The remote voltage sensing should be located as close as possible to the experiment	Compensates for lead losses	Determined during operational mockup testing and to ensure programmatic error- control requirements are satisfied			

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Function	Improvement Identified	Consequence and Benefit
Using a signal amplifier should be investigated to boost the millivolt signal of the load cells, or 18-gauge wire should be used as much as possible for the load cell wiring outside of the experiment if a signal amplifier is not used for the load cells	Minimize lead losses and noise	Determined during operational mockup testing and to ensure programmatic error- control requirements are satisfied
Adjusting the load cell calculation for power supply fluctuations should be investigated and tested.	Minimize voltage fluctuation effects on load cell indication	Determined during operational mockup testing and to ensure programmatic error- control requirements are satisfied
The position indication calculation as a function of power supply voltage, as implemented in the Operational Mockup, should be used to prevent power supply fluctuations from affecting the position indications	Minimize voltage-fluctuation effects on position indication	Determined during operational mockup testing and to ensure programmatic error- control requirements are satisfied
The pressure controller for the upper and lower pneumatic rams will have to be tuned using vendor-provided software after system installation. The hardware necessary for the serial links to communicate with the pressure controller must be installed to tune the pressure controllers using the vendor- provided software. This tuning should be done with the pneumatic rams isolated	The capability to accurately tune pressure controller to meet specifications.	Determined during operational mockup testing and to ensure programmatic error- control requirements are satisfied

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1. **INTRODUCTION**

1.1 **Next Generation Nuclear Plant**

The Next Generation Nuclear Plant (NGNP) must select a high-temperature gas reactor technology that will provide supply process heat. This reactor will be graphite moderated and helium cooled. Graphite forms the structural core of the two possible reactors. Previous graphites are not available, requiring that new nuclear-grade graphites be used. These new graphites do not have an irradiation performance history; therefore, researchers must obtain irradiated performance data

We understand how neutron-irradiation damage in graphite happens. However, we know less about fundamental models relating specific structures at the micro- and macro-structural level to irradiation behavior. Therefore, we need an extensive irradiation program to develop models that relate structure to the irradiation behavior for the new graphites of interest. The Advanced Graphite Capsule (AGC)-1 experiment is the first advanced graphite-irradiation experiment that will test these new graphites.

1.2 **Experiment Description**

AGC-1 is the first of six capsules to be designed for the Advanced Test Reactor (ATR) and will be located in the south flux trap of ATR. Scientists chose this position because of the requirement to have space above and below the core, and the inherent high fast-flux levels in the experimental position compared to other experimental positions.

The AGC-1 experiment will provide irradiation creep-rate data, which requires matched pairs of stressed and unstressed samples to be irradiated. This is achieved through using the axial flux symmetry in ATR to matched specimens within a vertical channel (i.e., the stressed specimens above the core centerline and the unstressed specimens below the core centerline in each channel). This arrangement places six channels around the periphery of a graphite experiment body with a center channel available for nonstressed specimens. Additional graphite grades are located in the graphite bodies' center channel, where no load will be applied. These graphites will be irradiated to determine the effects on thermal and physical properties.

The load is applied by a gas-control system consisting of six pneumatic rams that are controlled with feedback from six in-line load cells. The load cell signal is processed by a digital controller, which in turn drives a programmable pressure controller to increase or decrease the pressure to meet the required load. The maximum stress state specified for the graphite samples is $3 \text{ ksi} \pm 5\%$ based on the preirradiated specimen diameters. The diameter of the graphite specimens will decrease because of irradiation-induced dimensional shrinkage; therefore,

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specifying a stress state is not an accurate control measure because it depends on diameter.

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A better control is to specify the load from the pneumatic cylinder and its error. The applied pressure controls the load from the cylinder and the force multiplier based on the bore diameter of the cylinder. Therefore, pressure in the cylinder is the controlling parameter because the force multiplier is constant. Using a force multiplier of 2.4 based on the 1.75–in. internal piston in the cylinder, pressure in the cylinders should be 246 ± 4 psig to obtain the 3 ksi stress state. The non-irradiated graphite specimen diameters range from 0.500 to 0.502 in. This range in diameter requires a pressure between 245 and 247 psig to achieve the 3 ksi stress state. Using an average of 246 ± 4 psig gives the best target and is well within the $\pm 5\%$ margin. The pneumatic cylinders are rated for an internal pressure of 250 psig. Controlling an internal force load in an experiment is not routine to ATR operations.

This operational mockup will construct a facsimile of the gas control system and capsule load cells to operate, test, and gain experience in understanding how the mechanical arrangement operates and to verify applied load margins. This operational experience will provide insight on the design feasibility and the necessary programming of the digital controller.

The operational mockup is one of three mockups being performed. The other two mockups deal with fabrication, machinability, weld qualification, and developing assembly procedures.

2. PARAMETERS AND SUBSYSTEMS TESTED

2.1 Verify Operational Design

RESULTS

2.1.1 Load Cells

The load cells have been calibrated and tested on a benchtop. EDF-8385, "Advanced Graphite Capsule (AGC-1) Load Cell Testing," documents the calibration and benchtop load cell testing. The operational mockup testing placed the load cells in a prototypical operating environment by having the load cells between interconnecting rods, cycling the load cells from 0 to "full load" of 240 psig multiple times and minute load changes during the 72-hour pressure tests.

2.1.2 **Position Sensors**

The position sensors are an integral part of the pneumatic rams and have been tested on a benchtop. The operational mockup testing placed the position sensors in a prototypical-operating environment by operating the pneumatic ram from seated to compression multiple times and from seated to retracted. The 72-hour pressure decay test checked the leakage from the integral position sensors.

2.1.3 Gas Control Panel

The gas control panel consisted of manual valves, relief values, pressure transducers, pressure gauges, pneumatically operated regulators, and a pressure controller with the approximate volume of the designed system. The pressure controllers used feedback from the pressure transducers and the control system to control the pneumatically operated regulators. The operational mockup testing checked the functionality of the pneumatically operated regulators and pressure controllers with the approximate volume of the designed system.

2.1.4 Verify Quarter-Inch Movement

The capability to move the graphic stacks up, between irradiation cycles, is integral to the success of the AGC-1 experiment. Upsetting the graphite specimens during reactor outages was a lesson learned from previous graphite irradiations at the Oak Ridge National Laboratory to prevent the graphite specimens from "sticking" in the specimen channels. The operational mockup testing checks the capability of the design to move the graphite stacks upwards a minimum of ¹/₄-in and back to the seated position.

2.2 Determine Programming Parameters for the Control System

2.2.1 Control System Interface with the Operational Mockup

The operational mockup testing will check the algorithms used to convert the signals from the load cells, position indicators, pressure transducers, pressure controllers to engineering units.

2.2.2 Load Control

The capability to control the load on the stacks is integral to the success of the AGC-1 experiment. The operational mockup testing checks the capability of the control system to (1) control the upper pneumatic rams within a specified band and (2) pressurize the lower pneumatic rams in a controlled ramp to move the graphite stacks upwards.

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2.2.3 Verify Control System Can Move Stack Quarter-Inch

The control system has the capability to move the stack, but not limit the movement to a $\frac{1}{4}$ -in. Therefore, the design of the piston in between the stressed and unstressed specimens, the length of the lower push rods, and the shaft travel of the lower rams were changed to limit movement of the entire graphite specimen stack.

3. DESIGN OF MOCKUP

3.1 Capsule

Table 1 shows Idaho National Laboratory (INL) drawings that provide dimensions and descriptions of components for the operational mockup. The North Holmes Laboratory fabricated and assembled the mockup.

Drawing Number	Component Description
600434	Cylinder test stand
636112	Operational mockup assembly
636113	Operational mockup graphite components
636114	Operational mockup gas control panel
635765	Operational mockup heat shield
635763	Operational mockup graphite components details and assemblies

Table 1. Operational mockup drawings.

The AGC-1 operational mockup replicates the upper portion of the actual AGC-1 capsule and a reduced-length core section. The mockup also includes six smaller lower pneumatic rams to upset the stack. The mockup is detailed in INL Drawings 636112 and 636113. Figure 1 shows a sketch of the mockup assembly, and Figure 2 shows the actual Operation Mockup. The mockup uses six pneumatic rams, located in the upper portion of the pressure boundary, to apply a force to the graphite specimens in the graphite core. In the mockup, a single pressure regulator controls all six upper rams, so that all six apply the same force. In the actual AGC-1 experiment, each of the upper rams will be controlled independently so each of the six graphite channels can have different loads applied to the graphite specimen stack. The added complexity in gas control and programming from the actual AGC-1 experiment, the lower rams will be controlled using the same pressure regulator.



Figure 1. Sketch of the AGC-1 operational mockup capsule.



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I
Effective Date:Page: 6 of 33Official Carsule Mockup
Pressure ControllersGas Control
Panel

Figure 2. AGC-1 operational mockup system.

Stainless steel pushrods connect the six rams to the load cells. Stainless steel pushrods also connect the in-line load cells to the graphite pushrods in the graphite body. Feedback to control pressure in the upper rams is supplied by an inline load cell in each of the six pushrod assemblies. The load cell measures individual loads on each pushrod. The six upper rams have linear resistive transducers inside the cylinder to measure the position of the piston in the cylinder. The six upper rams load graphite specimens in the upper half of the graphite body (from the core centerline upward) as shown in Figure 3. The graphite specimens from the core centerline downward do not see the load because of the piston, which bottoms out over the lower graphite specimen channel. This arrangement is necessary to interpret the creep growth in the graphite specimens with and without load.



Figure 3. Sketch of reduced graphite core section.

Figure 4 shows six smaller rams positioned below the graphite body to move the six graphite specimen stacks upward during a reactor outage.



Figure 4. Sketch of lower end of the mockup showing the pneumatic rams used to upset the graphite stack.

The operational mockup, assembled and tested in the North Holmes Laboratory, uses threaded connections throughout the assembly, allowing quick disassembly and assembly. The experiment was strapped to a building column support in the vertical position using metal braces to secure it.

Testing on individual load cells was accomplished by a test rig fabricated at the INL. The load cell test apparatus, shown in Figure 5, uses one of the upper pneumatic rams and a single load cell or two load cells in line. The use of two load cells provides for the comparison of the load cell outputs. The fixture requires a high pressure helium supply, a 10-V DC power supply, and a calibrated digital multimeter to operate.

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Figure 5. Load cell test apparatus.

3.2 Load Cells

The load cells used for the operational mockup were an Entran ELHM load cell with a range of -1000 to +1000 lb (10 mV to -10 mV output). Each load cell was calibrated from 0 to 1000 lb compression at the INL Standards and Calibration Laboratory (S&CL) using a 10-V excitation and provided with coefficients for a binominal equation (A+B*mV+C*mV^2, where mV is the output signal in millivolts). EDF-8385, "Advanced Graphite Capsule (AGC-1) Load Cell Testing," documents the calibration and benchtop load cell testing. The coefficients were used in the control system to convert the millivolt signal to pounds. The conversion calculation was verified and documented in Laboratory Notebook LAB-1040.

3.3 Pneumatic Rams

The pneumatic rams with position indication used for the operational mockup were a Numatics Accu M Series with a range of 0 to 250 psig and a stroke of 2-in. The upper stack rams have a bore of 1.75–in. and the lower stack rams have a bore of 9/16–in. Each position indicator was checked with a 10-V source to determine the fully inserted voltage (0-in.) and the fully withdrawn voltage (2-in.). The coefficients were used in the control system to convert the voltage signal to inches. The conversion calculation was verified and documented in Laboratory Notebook LAB-1040.

3.4 Graphite Core

The graphite core mockup design was changed to shorten its length due to space considerations. The graphite core is shown in Figure 3. Dimensions of the piston between the stressed and unstressed specimens were changed so that bottom end extended down into the bottom ¹/₂-in specimen channel. A ¹/₄-in gap was placed between the bottom spacer and the piston. An alignment rod transverses the gap between the last specimen and the graphite piston and maintains alignment of the stack as it moves upward. The stroke on the lower rams shown in Figure 4 is limited to half an inch and pushes up on the push rods to close the ¹/₄-in gap between the spacer and piston in Figure 3. The remaining ¹/₄-in upward travel forces the piston upward. The end of the piston descends into the bottom specimen channel 3/8 of an inch, so the ¹/₄-in movement never pushes the piston out of the bottom specimen channel. Thus, the graphite spacer in the lower specimen channel.

3.5 General Layout and Overall Operational Design

The mockup gas control system consists of controlling instrumentation (i.e., valves, pressure sensors, pressure regulators, pressure relief valves, and tubing) mounted on a steel panel, digital controllers, and controlling software. Figure 2 shows the panel used to locate mechanical instrumentation necessary for controlling air pressure in the upper and lower rams. Bottled, ultra-high purity helium and conditioned plant air are used as the working gases. Helium is the working gas for the pneumatic rams, and plant air controls the two pressure controllers, which control the air-operated regulator supplying helium to the pneumatic rams. Plant air comes from a source before oil is added and is dried and filtered. In the actual experiment, there could be up to 300 ft of 1/16-in. tubing between the experiment and the control panel. A section of larger diameter tube is used to represent the volume of tubing between the experiment and control panel. This volume mimics the delay times for pressure changes inherent in the length of tubing. The programmable regulator uses plant air to control the metering valve, which regulates helium pressure in the rams. The panel contains two pressure sensors and pressure relief values to measure the controlling pressure and protect the cylinders from overpressurization in the upper and lower helium circuits.

3.6 Pressure Control Panel

The pressure control panel consists of the manual valves, pressure gauges, pressure transducers, and pressure controllers for the operational mockup. The high pressure helium supply is divided into separate gas circuits for the upper and lower pneumatic rams. The six upper rams are dual action, which allows for pressure to be introduced on either side of the piston. The differential pressure in the ram controls the movement of the piston. In the mockup, a single pressure regulator controls all six of the upper rams, but pressure is applied to only one

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side of the piston at a time. In the mockup and the actual experiment, the lower rams are controlled in gang by a separate pressure regulator. Signals from the pressure regulator, pressure sensor, and inline load cells go to the control system to be converted to measurable units. The converted and raw signals are used as inputs to the control system for the programmed logic governing the operational behavior in the upper and lower rams. The position indicator signal from the upper rams will be examined to see if it can be used to independently confirm that the upper rams' stem is controlled by the control system.

3.6.1 Pressure Control

The pressure-control system consists of an upper stack and lower stack. Each stack system consists of a Tescom 100 series pressure transducer ranged 0-1500 psig, a Tescom air actuated high-pressure regulator rated for 1500 psig, and a Tescom ER3000 digital pressure controller. The pressure transducers and the remote set point for digital pressure controllers are connected control system for automatic control of the pressure controllers.

3.6.2 Differences between the Actual Pressure Control Panel and the Operational Mockup Pressure Control Panel

The operational mockup pressure control panel was designed to replicate the initial design of the actual pressure control panel with the following variances:

- A single pressure controller for the upper six pneumatic rams, whereas the actual pressure control panel will have six individual pressure controllers.
- A 1-in. tube was installed in the lower and upper pressure control channels to simulate actual volume of the installed system including the capsule.

3.7 Control System

The operational mockup control system consists of two adjustable DC power supplies, a 24-V DC power supply, an uninterruptible power supply, and a digital control system.

Originally, a single 10-V DC power supply was going to be used to provide source power to the upper ram position indicators and to the load cells. However, the final design used a separate 5-V DC supply for the upper ram position indicators and a 10-V DC supply for the load cells, because the analog input module for the digital control system could not be calibrated for 10 V but could be calibrated for 5 V for the position indicators. The position indicators and load

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cells use these power sources to provide a data signal to the control system for monitoring of upper ram position and individual loads on the graphite samples. Electrical data connections from the gas control panel also are connected to the control system to provide monitoring and control of upper and lower ram pressures. Programmed software in the control system will computationally decide on actions necessary to control pressure in the upper rams. The control system uses a 24-V DC power supply, which is not required to be calibrated because it powers electrical equipment and sensors that are not sensitive to supply voltage variations.

The digital control system is a scaled-down version of the full-size Mesto Automation control system in use at ATR. The digital control system consists of an input/output rack, operator/engineering workstation, history workstation, and a network switch. The input/output rack contains a 15-channel high-level analog input module (0 to 6 V), a 15-channel low-level analog input module (0 to 600 mV), an 8-channel analog output module, and a distributed processing unit. The high-level analog input module monitors the two pressure transducers, the six position indicators, the 5-V power supply output, and the 10-V power supply output through a signal conditioner. The low-level analog input module monitors the six load cells outputs. The analog output module sends the remote set point to the two pressure controllers. The distributed processing unit executes all assigned transformation processing and control algorithms. The digital control system operates using Metso Automation configurable software controlled under PLN-1726, "Research and Development General Software Management Plan."

3.8 Calibrations

For the operational mockup, two types of calibrations were performed on the equipment. Equipment with a "Material and Test Equipment (M&TE) calibration were calibrated at the INL Standards and Calibration Laboratory (S&CL). Equipment with an "Installed—Calibration" calibration type were calibrated at the North Holmes Laboratory using M&TE-calibrated equipment. Calibration of installed equipment was recorded in the laboratory notebook LAB-1040.

3.8.1 Material & Test Equipment Calibrations

Table 2 shows calibration of the equipment that was checked at the S&CL. After completing mockup testing, the calibration of equipment will be checked at the S&CL.

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Table 2. S&CL calibrated equipment.

Equipment	S&CL Tracking Serial Number	Accuracy	Calibration Due Date
Fluke 187 digital multimeter	721016		03/08/08
Fluke 789 process meter	724813	(<i>a</i>) 20 mA \pm 0.01 mA	07/16/08
Pressure to upper pneumatic rams (PI-100-1)	724405	± 1.5 psi	08/13/07
Pressure to lower pneumatic Rams (PI-200-1)	724904	± 1.5 psi	08/13/07
Outlet pressure of bottle Regulator (PI-100)	724752	± 75 psi	06/14/08
Instrument air pressure to pressure controllers (PI-500)	722429	± 1.5 psi	06/27/08
Load cell 1	724390	@ -5.5621 mV (≈ 600 lb) +3.5 lb	12/15/07
Load cell 2	724390A	@ -6.0162 mV (≈ 600 lb) +4.2 lb	12/15/07
Load cell 3	724390B	@ -5.6211 mV (≈ 600 lb) -4.9 lb	12/19/07
Load cell 4	724390C	@ -5.9857 mV (≈ 600 lb) +2.3 lb	12/19/07
Load cell 5	724390D	@ -6.0332 mV (≈ 600 lb) +3.8 lb	12/19/07
Load cell 6	724390F	@ -5.8906 mV (≈ 600 lb) +2.7 lb	12/15/07

3.8.2 Installed—Calibrations

The following equipment (see Table 3) was checked for accuracy at the NHL by comparing indications of the equipment to indications of Material & Test Equipment calibrated at the INL S&CL. The methods and detailed results are recorded in Laboratory Notebook LAB-1040.

Table 3. Installed equipment accuracy.

Equipment	Accuracy
Pressure transducer inputs (4-20 mA)	± 0.8 psig
Position indicators (0-5 V)	$\pm 0.006 \text{ V}$
Load cell inputs (-10 to 10 mV)	$\pm 0.02 \text{ mV} (\approx 1 \text{ lb} @ 600 \text{ lb})$

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3.9 Total Accuracy of Pressure, Position, and Load Measurements

The total channel accuracy of the upper pneumatic ram pressure, pneumatic ram position indications, and the load cells were determined using the root-mean-squared (RMS) method (the square root of the sum of the errors squared). Table 4 shows the error calculations for a pressure transducer ranged to 1500 psig (installed) and the error for a pressure transducer ranged to 300 psig. Researchers have proposed replacing the 1500 psig transducer with a 300 psig to increase pressure-channel accuracy. Refer to Table 4 for the error calculation for the position indicators. Refer to Table 4 for the error calculation for the load cells at 600 lb. The load cell error is given in a range because each load cell was individually calibrated by the INL S&CL.

Equipment	Total Error (RMS)
Pressure inputs (0 to 1500 psig)	± 3.9 psig
Pressure inputs (0 to 300 psig)	± 0.8 psig
Position indicators (0 to 2-in.)	± 0.02-in.
Load cell inputs (@ 600 lb)	3.8 to 5.7 lb

Table 4. Instrument channel errors.

3.10 Controllability to 3000 ksi

The primary objective of the AGC-1 experiment is to load graphite specimens to $3000 \text{ ksi} \pm 5\%$ (2850 to 3150 ksi). This corresponds to a load of 589 (560 to 618) lbf for 0.5-in. diameter specimen. The pneumatic ram design has a factor of 2.4 psig per lbf and a load of 589 lbf corresponds to a pneumatic ram pressure of 245 (233 to 257) psig.

Table 5 shows the control band including instrument error for using either the load cell indication or the pneumatic ram pressure indication to load the graphic specimens to 3000 ksi. The maximum pneumatic ram pressure is 250 psig. The maximum pressure at the pressure transducer, not to exceed the 250 psig limit, is 246 psig for the 1500 psig transducer and 249 psig for the 300 psig transducer. The 300 psig ranged transducer should be used to allow for the maximum control range. The control band for controlling the load to the graphic specimens can be expanded if both the load cell and pressure channels accuracies are increased.

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Table 5. Load control band with instrument error.

	ksi	Pounds- force	Pounds-force with 5.9 error	Pneumatic Ram Pressure (1500 psig range)	Pneumatic Ram Pressure (300 psig range)
Nominal	3000	589	589	245	245
High	3150	618.5	612.8	246	249
Low	2850	559.6	565.3	242	234

3.11 Control Systems Operational Checks

The following checks where performed to verify operability of the control system. The methods and detailed results are recorded in Laboratory Notebook LAB-1040.

- Verified load cell calculation at -5 mV. The maximum error was 0.02 lb.
- Verified position indication calculation with variable voltage input at 2.501 V. The maximum error was 0.001-in.
- Verified the upper pressure indicator and any of the six loads cell can be used for pressure control.

4. TESTING AND RESULTS

4.1 Test 1 - Apply Incremental Pressure to Each Upper Cylinder

4.1.1 Objective 1—Determine Actual Load Applied Versus Input Pressure to the Upper Cylinders

Pressures of 10, 50, 100, 150, 200, 225, and 240 \pm 4 psig were supplied to all six upper pneumatic rams to extend each of the upper cylinders. At 10 psig, the push rods were marked with blue ink to establish a visual reference to the top of the funnel. At approximately 100 psig, the position marks started to disappear into the funnel. At 240 psig, the push rods were marked with black ink. Figure 6 shows the blue and black match marks when the rods are extended upwards. The distance between the 10 psig and the 240 psig mark was approximately 0.1-in. as measured with a machinist rule. Table 6 shows the output of each load cell (millivolts and converted load in pounds) as a function of supply pressure as indicated on the control system. Table 7 shows the output of the load cell is linear to pressure between 50 to 200 psig (20 to 80% of the 250 psig range of the pneumatic ram); however, the output of the

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load cell is not linear outside of the 20 to 80% operating range of the pneumatic ram. Figure 8 – Test 1 – pneumatic ram position as a function of lower pneumatic pressure.



Figure 6. Test 2 - rods extended upward with match marks.



Figure 7. Test 1 - load cell output as a function of supply pressure.

4.1.2 Objective 2—Demonstrate that All Six Upper Cylinders Operate Similarly

Pressures of 10, 50, 100, 150, 200, 225, and 240 \pm 4 psig were supplied to all six upper pneumatic rams to extend each of the upper cylinders. Table 6 shows the output of each load cell (millivolts and converted load in pounds) as a function of supply pressure as indicated on the control system.

- As Table 6 and Figure 7 show, the millivolt output of the load cells are not the same with the same supply pressure. The outputs ranged from-4.773 mV (LC-2) to -5.991 mV (LC-1).
- It is imperative that the load cell output as a function of load be determined at the S&CL, because the load cell outputs vary between load cells for a given load.

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Table 6. Test 1 - incremental pressure to all cylinders.

		TC-0 (102)	6.1	22.1	104.3	228.5	355.7	490.5	533.2	570.8	
	LC-6	(mv)	-0.061	-0.217	-1.024	-2.246	-3.495	-4.82	-5.239	-5.609	
	LC-5	(0I)	-86	4.8	87.4	218.5	345.9	482.3	525.4	563.9	
	LC-5	(mv)	0.081	-0.04	-0.82	-2.057	-3.257	-4.548	-4.951	-5.315	
	LC-4	(OI)	64.8	59.3	119.4	252.4	380	515.2	558.5	597.2	
	LC-4	(mv)	-0.646	-0.591	-1.19	-2.518	-3.792	-5.141	-5.576	-5.958	
	LC-3	(III)	24	39.4	126.6	263.4	398.3	539.3	588.4	628.6	
o.	LC-3	(mv)	-0.226	-0.378	-1.183	-2.484	-3.748	-5.073	-5.533	-5.915	
cymuci	LC-2	(III)	-14.4	1	68.9	175.3	284.4	405	442.8	476	
	LC-2	(mv)	0.143	-0.01	-0.692	-1.761	-2.852	-4.062	-4.441	-4.773	
ital press	LC-1	(III)	57.3	51	126.5	272	412.6	561.1	605.2	646.8	
	LC-1	(IMV)	-0.529	-0.47	-1.17	-2.519	-3.821	-5.197	-5.605	-5.991	
1 auto 0. 1 cst 1 -	PT-100-1	(Bisd)	0	8	48.3	98.3	150.3	203.6	223.5	239.5	

Table 7. Test 1 - pneumatic ram position as a function of pressure.

	Delta	(in.)		0.002	0.016	0.026	0.022	0.023	0.006	0.005	0.100
	ZI-6	(in.)	0.941	0.943	0.959	0.985	1.007	1.03	1.036	1.041	
	Delta	(in.)		0.002	0.017	0.028	0.025	0.025	0.007	0.006	0.110
	ZI-5	(in.)	0.871	0.873	0.89	0.918	0.943	0.968	0.975	0.981	
	Delta	(in.)		0	0.012	0.026	0.023	0.023	0.007	0.006	0.097
5	ZI-4	(in.)	0.933	0.933	0.945	0.971	0.994	1.017	1.024	1.03	
	Delta	(in.)		0.002	0.015	0.028	0.025	0.024	0.008	0.006	0.108
	ZI-3	(in.)	0.938	0.94	0.955	0.983	1.008	1.032	1.04	1.046	
	Delta	(in.)		0.003	0.016	0.027	0.023	0.023	0.007	0.006	0.105
unicod II	ZI-2	(in.)	0.937	0.94	0.956	0.983	1.006	1.029	1.036	1.042	
	Delta	(in.)		0	0.014	0.03	0.025	0.024	0.007	0.006	0.106
	ZI-1	(in.)	0.948	0.948	0.962	0.992	1.017	1.041	1.048	1.054	
	PT-100-1	(psig)	0	8	48.3	98.3	150.3	203.6	223.5	239.5	Total delta

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4.1.3 Objective 3—Demonstrate that the Control System and Pressure Controlling Computer Can Operate Together to Control the Pressure in Six Upper Rams

To demonstrate that the control system and pressure control system can control the pressure to the pneumatic rams, the following checks were performed.

- Researchers used a calibrated handheld digital multimeter to obtain measurements of the pressure transducers voltage, to verify the pressure transmitter and control system to determine the pressure accurately. Table 8 shows the maximum error between the control system and transmitter was 1.85 psi (0.12%).
- The control system was used to provide the pressure control set point to the pressure controller, and the desired pressure was maintained as indicated on the control system and pressure gauge.

PI-100-1 (psig)	PT-100- 1 (psig)	Gauge to Control System Error (psi)	PT-100-1 V across 250-ohm resistor	Volts to Pressure Conversion	Transmitter to Control System Error (psi)
11	9.41	1.59	1.026	9.75	0.34
48	48.07	-0.07	1.13	48.75	0.68
99	99.4	-0.4	1.27	101.25	1.85
150	150.3	-0.3	1.40	150	-0.3
199	198.7	0.3	1.53	198.75	0.05
224	223.9	0.1	1.598	224.25	0.35
240	240.6	-0.6	1.642	240.75	0.15
Maximum error control system (gauge to psi)	1.59	Maximum error tra control system (psi	nsmitter to)	1.85

Table 8. Test 1 - pressure gauge, pressure transmitter, and control system indications.

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4.2 Test 2 - Shift the Entire Graphite Stack Upward 1/4-in. Using the Upper and Lower Cylinders

4.2.1 Objective 1—Demonstrate that the Lower Cylinders Can Shift the Graphite Stack Upward Roughly 1/4 in

The upper pneumatic rams were pressurized to 20 psig to establish the upper graphite specimen stacks were fully seated. Initial position readings were taken. This was verified by location of the blue match mark. The pressure supply to the upper stack was isolated and vented to atmosphere. The pressure to the lower pneumatic rams was increased in approximately 15 psi increments until all six graphic stacks were shifted upward approximately 1/4-in. Position 6 started moving upward at 60 psig and continued moving until the stack reached the stop. Positions 2 and 5 started moving at 75 psig and continued moving until the stacks reached the stop. Positions 1 and 3 started moving upward at 90 psig and Position 3 continued moving until the stack reached the stop. Position 4 started moving upward at 155 psig and continued moving until the stack reached the stop. Position 1 reached the stop at 170 psig. The pressure to the lower pneumatic rams was held at 170 psig and final position readings were taken, and a machinist rule was used to measure approximate movement (0.3 to 0.375 in. – see Figure 9). Table 9 shows the stacked were raised between 0.292 and 0.354 in. Figure 9 – Test 2 – pneumatic ram position as a function of lower pneumatic pressure. The pressure controller (Tescom ER-3000) had to be tuned using vendorprovided software to control pressure to the lower pneumatic rams. The pressure controller's final tuning parameters are listed in Table 11.

- The lower pneumatic rams can shift the graphic stack up until the stack reaches the lower stop (0.292 to 0.354 in.). Typically, once a stack started to move, the stack would continue to move up while pressure to the lower pneumatic rams was held constant.
- The pressure controller for the lower pneumatic rams will have to be tuned using the vendor-provided software after system installation. This tuning should be done with the pneumatic rams isolated.







Figure 8. Test 1 - pneumatic ram position as a function of supply pressure.



Figure 9. Test 2 - pneumatic ram position as function of lower pneumatic pressure.

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Initial Position (in.)	Up Position (in.)	Delta (in.)	Final Position after Seating at 20 psig	Delta to Initial Position (in.)
0.948	0.594	0.354	0.946	0.002
0.938	0.646	0.292	0.942	-0.004
0.939	0.650	0.289	0.941	-0.002
0.933	0.633	0.300	0.931	0.002
0.871	0.520	0.351	0.874	-0.003
0.942	0.649	0.293	0.944	-0.002

Table 9. Test 2 - seated and raised position indications.

4.2.2 Objective 2—Show that the Upper Cylinders Can Shift the Graphite Back to the Seated Position After the 1/4-in. Shift

After raising the stacks, the lower pneumatic rams were depressurized and the stacks did not move downward. The upper pneumatic rams were slowly pressurized to 20 psig. Positions 2, 3, 5, and 6 moved down at approximately 6 psig and all positions moved down at 10 psig. The upper pneumatic rams were pressurized to 20 psig to verify the stacks were fully seated. Another set of position indications verified that the stacks returned to the originally seated position. Table 9 shows the stacks returned to the original positions.

• The stacks can be reseated after the stacks are raised. The upper pneumatic rams needed a pressure of 10 psig to ensure the stacks were seated.

4.3 Test 3 - Apply Simultaneous Load Test for Upper Cylinders

4.3.1 Objective—Verify the Mockup Can Withstand the Forces Exerted When All Six of the Upper Cylinders are Pressurized to 240 ±4 psig with the Lower Cylinders Vented to Atmosphere

This test was performed in two stages: one stage where the gas supply was isolated after reaching the test pressure of 240 psig to determine leakage, and in the second stage the supply was not isolated to determine functionality of automatic pressure control.

For both tests, the control system was used to automatically ramp pressure at a target rate of 20 lb/min to the target pressure of 240 psig (236 to 244) and the tests were performed for at least 72 hours. After 72 hours, the time on the control system was incorrect by more than 3 hours, owing to an erroneous clock in the history computer. Figure 10

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shows the pressure ramp and Figure 11 shows the pressure ramp rate. As Table 10 and Figure 12 show, the pressure control was maintained within the band of 236 to 244 psig and there were no changes in the position indicators. No changes in the position indication show that the mockup can withstand the forces when all six cylinders are pressurized.





Figure 10. Test 3 - automatic pressure control ramp.







Figure 11. Test 3 - pressure ramp rate as a function of pressure.



72-HOUR PRESSURE CONTROL

Figure 12. Test 3 - 72-hour pressure hold.

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Table 10. Test 3 –	72-hour pressure	control.			
	Minimum	Average	Maximum	(Max-Min) * Averag	<u>100%</u> e
Pressure	237.7	240.0	243.2	2.3	
Load Cell 1	637	642	649	1.8	
Position 1	1.034	1.034	1.034	0	
Load Cell 2	473	476	482	1.8	
Position 2	1.023	1.023	1.023	0	
Load Cell 3	626	628	630	0.8	
Position 3	1.021	1.021	1.021	0	
Load Cell 4	584	590	597	2.1	
Position 4	0.971	0.971	0.971	0	
Load Cell 5	559	562	568	1.5	
Position 5	0.919	0.919	0.919	0	
Load Cell 6	567	570	575	1.4	
Position 6	1.019	1.019	1.019	0	

The upper cylinder pressure controller (Tescom ER-3000) had to be tuned using vendor-provided software to automatically control the pressure in the required band (236 to 244 psig). Table 11 lists the pressure controller's final tuning parameters. The pressure control on the mockup system has an upper range of 1500 psig. More precise pressure control may be obtained by using smaller range pressure control devices.

- The pressure control system can automatically control pressure to within the specified band (236 to 244 psig).
- The mockup can withstand the forces when all six cylinders are pressurized to 240 psig.
- The leakage of the gas panel was 50 psi for 108 hours. This converts to less than 1 cc per minute, which will have no impact on the bulk helium system.
- The pressure controller for the upper pneumatic rams will have to be tuned using the vendor-provided software after system installation. This tuning should be done with the pneumatic rams isolated.

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- Further testing will be required if the automatic control of the upper pressure controller is to be based on the load cell output and not pressure supplied to the upper pneumatic ram.
- A lower range pressure transducer and possibly a lower range pressure regulator should be investigated for pressure control if the current pressure control (± 3 psig) is not adequate to meet program objectives.
- A stable time clock or source will need to be included in the final design and fabrication.

Table 11. Final tuning parameters for pressure controllers.

				Rate Limit	Output	Minim W	um Pulse /idth
Controller	Gain	Reset	Rate	(psi/min)	Limit	Inlet	Outlet
Control system – PIC- 100-1 (upper pressure controller)	0.25	0.9	0.0	0.4	16%		
Control system – PIC- 200-1 (lower pressure controller)	0.25	0.9	0.0	0.2	16%		
PCV-100-1 (upper pressure controller)	33.3	1.12	0.16			5	4
PCV-200-1 (lower pressure controller)	50	0.16	0.75			5	11

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4.4 Test 4 Determine Supply Pressure and Power Supply Variation Effects

4.4.1 Objective 1— Determine the Effects of Varying Supply Pressure to the Pressure Controllers

With the pressure controller set point set at 240 psig, the supply pressure to the pressure controller was set to 1900 psig, 800 psig, and changed from 800 to 1900 psig to determine the effects of supply pressure on the pressure controller. The pressure increase from 800 to 1900 psig simulated a bottle pressure change on the ATR Bulk Helium System without a regulated supply. During the pressure increase the outlet pressure of the pressure controller increased by 1.2 psig, however the pressure controller responded and reduced the output pressure. As Table 12 shows, the pressure controller can control pressure with varying supply pressure.

• The upper pressure controller can control pressure with varying supply pressures. To minimize pressure oscillations during bottle changes, however, a regulator should be used between the ATR Bulk Helium System and the pressure controller.

	Pressure	e Controller S	upply Pressure
Pressure	1900 psig	800 psig	800 to 1900 psig
Min	240.1	240.3	240.4
Average	241.4	241.2	241.4
Max	243.4	242.1	242.4

Table 12. Test 4 - changing supply pressure to pressure controller.

4.4.2 Objective 2—Determine the Effects of Varying Power Supply Voltage on the Load Cell and Position Indications

With the pressure controller set point set at 240 psig, the power supply voltage to the load cells was lowered from 10 V to 8 V in 0.2 V increments to determine effects on the load cell output. Figure 13 shows the output of the load cell (millivolts) is linear with the power supply voltage. It is suspected that the load cell output can be adjusted for power supply changes as shown in Figure 14.

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Figure 13. Test 4 - load cell output as a function of power supply voltage.



Figure 14. Test 4 - recalculated load cell output as a function of power supply voltage.

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With the pressure controller set point set at 240 psig, the power supply voltage to the position indicators was lowered from 5 V to 4 V in 0.1 V increments to determine effects on the position indicator output. Figure 15 shows the output of the position indicators (volts) is linear with the power supply voltage. The position indications on the control system have been adjusted to account for supply voltage changes. Figure 16 shows the control system corrected position indication calculation is correctly functioning, because the position indication does not change with power supply changes.

- Adjusting the load cell calculation for power supply fluctuations should be investigated and tested to increase load cell indication accuracy.
- The position indication calculation as a function of power supply voltage should be used to prevent power supply fluctuations from affecting the position indications.



Figure 15. Test 4 - position indicator voltage output as a function of power supply voltage.





Figure 16. Test 4 - recalculated position indicator output as a function of power supply voltage.

4.5 Test 5 Determine the Long Lead Voltage Drop Effects on the Load Cell and **Position Sensor Measurements**

4.5.1 **Objective 1—Determine the Effects that Long Electrical Leads** Lengths Have on Accuracy Caused by Voltage Drop on Load Cells

A pneumatic ram and load cell was installed in the load cell tester with varying wire lengths and sizes connected to the output of a load cell to determine the effects. Researchers obtained data by pressurizing the load cell up to 250 psig in increments of 50 psi. They obtained baseline data by measuring the load cell output at the ends of the load cell 30-gauge wire. The second set of data was obtained with approximately 60 feet of 22-gauge wire (the approximate distance between the experiment and control system) connected between the power supply and the load cell. The third set of data was obtained with the 22-gauge wire with the power supply output adjusted so that the voltage at the end of the wire matched the baseline voltage. The fourth set of data was obtained with 60 feet of 18-gauge wire connected between the power supply and the load cell. The fifth set of data was obtained with the 18-gauge wire with the power supply output adjusted so that voltage at the end of the wire matched the baseline voltage. As Figure 17 shows, the 22- gauge wire without a voltage adjustment is unacceptable, with a 25-lb difference to the

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baseline data. The 18-gauge wire performed with fewer signal losses than the 22-gauge wire.

- The voltage supply for the load cells and the position indicators should have remote voltage sensing, where voltage output is adjusted to match voltage at the remote terminals. The remote voltage sensing should be located as close as possible to the experiment.
- The use of a signal amplifier should be investigated to boost the millivolt signal of the load cell.



Figure 17. Test 5 - load cell output as a function of wire size.

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4.5.2 Objective 2—Determine the Effects that Long Electrical Lead Lengths Have on Accuracy Caused by Voltage Drop on Positions Sensors in the Pneumatic Rams

To determine the effects of varying wire size on the output of a position indicator, a pneumatic ram's position indication was connected to a power supply with varying wire lengths and sizes. Researchers obtained baseline data by measuring the voltage at the ends of the indicators leads at full in, full out, and the width of a V-block. The second set of data was obtained with 60 ft of 22-gauge wire connected between the power supply and the position indicator. The third set of data was obtained with 60 ft of 18-gauge wire connected between the power supply and the position indicator. Table 13 shows no essential difference existed. This result is expected, as the output of the position indicator is a voltage and not a signal source.

• The wire size for the position indicator (18-gauge or 22-gauge) does not make a difference in position indication accuracy.

	Baseline	22-Gauge Wire	Delta Position	18-Gauge Wire	Delta Position
Position	Voltage Output	Voltage Output	Indication	Voltage Output	Indication
0"	0.8091	0.8071	0.000	0.8216	0.003
2"	9.981	9.982	0.000	9.987	-0.001
V-Block					
- 1.273"	6.661	6.661	0.000	6.658	0.001

Table 13. Test 5 - Position indication as a function of wire size.

5. IMPACT ON AGC-1 DESIGN AND OPERATION

This section details testing results that will impact design and operation of the AGC-1 experiment.

5.1 Experiment

• The load cell output as a function of load must be determined at the S&CL, because load cell outputs vary between load cells for a given load. The calibration factors provided by the S&CL will be implemented on the control system.

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5.2 Control System

- The voltage supply for the load cells and the position indicators should have remote voltage sensing, where voltage output is adjusted to match voltage at the remote terminals. The remote voltage sensing should be located as close as possible to the experiment.
- The use of a signal amplifier should be investigated to boost the millivolt signal of the load cells.
- 18-gauge wire should be used as much as possible for the load cell wiring outside of the experiment if a signal amplifier is not used for the load cells.
- Adjusting the load cell calculation for power supply fluctuations should be investigated and tested.
- The position indication calculation as a function of power supply voltage, as implemented in the Operational Mockup, should be used to prevent power supply fluctuations from affecting the position indications.
- The wire size for the position indicator (18-gauge or 22-gauge) does not make a difference in the position indication accuracy.
- The pressure controller for the upper and lower pneumatic rams will have to be tuned using the vendor-provided software after system installation. The hardware necessary for the serial links to communicate with the pressure controller must be installed to tune the pressure controllers using the vendor-provided software. This tuning should be done with the pneumatic rams isolated and will be included in the system operability testing performed after system installation.
- A new analog input module that can handle 4-20 mA and 0-10 V inputs needs to be investigated to monitor power supply voltage.
- Further testing will be required if the automatic control of the upper pressure controller is to be based on the load cell output and not pressure supplied to the upper pneumatic ram.
- A lower range pressure transducer and possibly a lower range pressure regulator should be investigated for pressure control if the current pressure control (± 3 psig) is not adequate to meet program objectives.

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• The measurement inaccuracies for the load cell measurements needs to be as low as reasonably achievable to minimize the load cell error and to increase the control band. To minimize the error, the following need to be investigated: more stable power supply, a filter for the low signal, testing to determine what type or brand of a signal conditioner will minimize low-signal noise while not increasing channel error, and location in the ATR facility of any signal conditioners.

5.3 Gas System

- The pressure controller can control pressure with varying supply pressures. To minimize pressure oscillations during bottle changes, however, a regulator should be used between the ATR Bulk Helium System and the pressure controller.
- There was no noticeable delay in the pressure control owing to system volume.

5.4 Operation

- Leakage of the gas panel was 50 psi for 108 hours. This converts to less than 1 cc per minute, which will have no impact on the bulk helium system.
- The lower pneumatic rams can shift the graphic stack upward until the stack reaches the lower stop (0.292 to 0.354 in.). Typically, once a stack started to move, the stack continued to move up while pressure to the lower pneumatic rams was held constant.
- The stacks need be reseated after the stacks are raised. The upper pneumatic rams needed a pressure of 10 psig to ensure the stacks were seated.