Preliminary Results and Power Analysis of the UAH SEDS G503 GAS can

Lyle B. Jalbert, Steven Mustaikis II and Philip Nerren
University of Alabama in Huntsville

ABSTRACT

The G-503 Get Away Special (GAS) Canister contained four experiments. A stainless steel corrosion experiment, an experiment to mix and cure concrete, a plant root growth chamber, and a group of 8 chambers to characterize diatom growth cycles in microgravity. As would be expected for this selection of experiments a significant amount of power was required to carry out these investigations over several days in a GAS environment. This was accomplished through the use of low power experiment control circuitry, heaters, and an estimated 3.6 kWh battery pack. The battery was designed around 120 standard Duracell Alkaline F cells. This pack weighed 29.5 kg (65 lbs) including a DC/DC converter and the power distribution bus for all of the experiments. Although not rechargeable, this configuration was a fraction of the cost of rechargeable systems and did not require venting to the outside of the can. Combing this with the long term storage performance, 85 percent of initial capacity after four years at 21°C (70°F), this guarantees sufficient power even with unexpected launch delays. This paper describes the experiments, there operation and initial results. Also, the performance of the power system during the STS-68 SRL2 mission will be addressed.

INTRODUCTION

The G-503 payload was sponsored by the Students for the Exploration and Development of Space (SEDS) through the University of Alabama in Huntsville (UAH). The objective of the payload was to successfully complete the following experiments. Diatom growth and survivability in a cosmic radiation and microgravity environment, the mixing and curing of concrete, a study of microgravity influenced root growth, and a study of corrosive pitting in stainless steel. The first three were built by students at UAH while the last was done by students from the University of Alabama at Birmingham. Support for these experiments came from UAH, the Alabama Space Grant Consortium, Master Builders of Cleveland Ohio, and NASA Marshall Space Flight Center.

The Microgravity and Cosmic Radiation Effects on Diatoms (MCRED) was the first test of a concept for a bioregenerative life support system to be used on space station and Lunar/Mars expeditions. The experiment was designed to grow a series of diatom cultures in a controlled environment in low earth orbit.

The Concrete Cured In Microgravity (ConCIM) experiment was designed to give scientists and engineers valuable data about the characteristics of mixing and curing concrete in a microgravity environment. To gain accurate maximum strength of mixture data the concrete had to be cured for at least seven days in a microgravity environment. Once the experiment was recovered, the strength and chemistry of the space concrete was measured against the strength and chemistry of a ground based control sample.

The Root Growth In Space (RGIS) experiment was to study effects of microgravity on the early stages of germination of several seed types. The specific effects to have been examined included production of gases during germination and the development and distribution of chemicals and hormones affecting gravitropism.

The Microgravity Corrosion Experiment (COMET) was designed to examine the effects of microgravity on the initiation and growth of pitting in metals. Pitting is an extremely localized corrosion phenomenon which initiates on exposed surfaces and results in holes in the metal. Unlike many types of corrosion, pitting is difficult to predict. COMET induced pitting in a stainless steel sample in order to study it in the absence of gravity and determine what forces drive this type of corrosion. The experiment has applications on earth as well as in space for preventing pitting in corrosive material piping systems.

To make a complete study of the biological systems enough biomass had to be grown to allow for comparisons. This set the required time for operation of all environmental systems in the GAS can at 8 days. Three of the experiments required positive thermal control and operating temperatures in the 21 to 25°C range. Hence activation of the payload was required as soon as possible so as to maintain the thermal environment of prelaunch for the experiments. This was achieved through the use of the baroswitch which turned on all experiment and thermal control circuitry at 18,300 m (60,000 feet). This also initiated a two hour timer which, at its completion provided main power to the experiments which started their nominal operations. In the event of a problem in the nominal operations a battery health monitoring circuit was provided which, at a set voltage initiated the proper shutdown of all experiments. These procedures allowed full control of all operations within the GAS can thus ensuring that the power pack would be at an optimal operating temperature at the start of the experiments.

EXPERIMENT HARDWARE

G503 used an internal experiment support structure which consisted of a rectangular aluminum plate which divided the canister longitudinally. One end of this plate was bolted to the machined rib of a round plate which was bolted directly to the GAS standard experiment mounting plate.

The MCRED experiment (see figure 1) consisted of 8 acrylic growth chambers with dehydrated diatom cells in six chambers and aqueous algae cultures in the remaining two chambers. Each device was designed to function as a self contained, closed, environmental control chamber. At the onset of the experiment each chamber would be flooded with aqueous Guillard fresh water growth media with vitamins by 6 separate valves. A 1 Watt white fluorescent light source for photosynthesis was provided; 1 light for two chambers. The experiment had environmental sensors for monitoring the temperature, pressure, light intensity, and pH of each chamber. A heater operating at 25°C was mounted on the outside of all the chambers. The temperature was controlled by bimetallic switches located inside the experiment housing. An embedded electronic processor controlled the experiment. The processor began its preprogrammed timeline when it received main power. At that time, it was to flood each of the six growth chambers with nutrient solution. Once all chambers were flooded, the controller was to begin taking data from the 32 on-board sensors every 15 minutes. The lights would be on for 12 of every 24 hours allowing for light and dark phases of photosynthesis. Every 24 hours a chamber was to be flooded with 1.5 % glutaraldehyde in order to 'fix' the specimen. After two chambers were 'fixed' the light supporting those chambers was to be turned off to conserve power.

However, several problems occurred. First, a software problem caused the experiment lights to be turned on and remain in that position for the whole mission. Second, it has been determined post flight, that due to the one month launch delay the nutrient storage and delivery system had lost pressure. This loss of pressure was due to a leak in the nutrient interfaces to the valve assembly. The leak resulted in a pressure drop in the delivery system as well as loss of some fluid. Therefore there was not enough pressure to open an in line 13.79 kPa (2 psi) check valve. Third, there was a short in the sensor bundle which pulled all the data lines to ground resulting in a loss of data.

However some interesting results were found. These diatoms experienced some severe conditions. The aqueous cultures were loaded in the GAS experiment in June 1994. They sat in the sealed can (103.4 kPa (15 psi)), in the dark with no environment support except for external temperature control (20 °C) for 4 months. They were exposed to high g loads at lift off and then microgravity for several days at elevated temperatures in constant light and then freezing darkness. Upon landing in California they were in the dark at desert temperatures for 3 weeks. The cultures were finally collected and fresh water with growth media added. The cultures began to grow vigorously and continue to grow to this day. If these defined mixed cultures can survive all of this abuse, they can surely survive the conditions of space station and other similar systems.

The ConCIM experiment (see figure 2) was conducted inside a single mixing chamber (For a full description of the hardware see [1,2]). At launch the chamber was filled with a mortar mixture of 50/50 sand and Portland cement. A helical blade inside the chamber was driven by a motor/gearhead assembly after activation by the controller circuit. With the blade turning, a mixture of water and Polyheed (a water reducing admixture provided by Master Builders Inc. of Cleveland OH) was released into the chamber from an external nitrogen back-pressurized piston accumulator. To prevent pressurization when the water was injected the chamber was evacuated. At the end of the mix cycle an actuator was to release an internal false bottom in the chamber that was supposed to move up the chamber until an equilibrium position was reached at which point no free volume would remain within the mixing chamber. Since the curing of concrete is an exothermic reaction no insulation was required around the mixing chamber. However the water/admixture solution had to be kept from freezing thus a heater was wrapped around the accumulator. The heater was controlled by bimetallic switches operating at a temperature of 15°C . A temperature monitor recorded the temperature of the concrete chamber via a thermocouple placed in the chamber.

The experiment had one failure; the false bottom did not release which resulted in some large voids in the unmixed portion and around the blade. The failure of the false bottom produced three different levels of hydration and a non mixed section. These samples are providing information on hydration products and mixing characteristics. Compressibility strength tests and petrographic analysis was performed on a central core sample. These measurements have revealed higher compressibility strengths and less entrained voids. Further results will be published as they become available.

The RGIS experiment (see figure 1) consisted of a single growth chamber in which seeds were placed prior to launch. Once in orbit a water/fertilizer solution was to be delivered to the seeds via a magnetically geared pump. The experiment required a temperature of 25±5 °C. This was accomplished by a sheet heater placed on the growth chamber. The whole experiment was insulated from the rest of the canister. At the end of the experiment a glutaraldehyde solution was to be used to stop further growth. Unfortunately due to some problems with the delivery system the seeds never received the water/nutrient solution and no growth was seen.

COMET (see figure 2) was conducted inside a 30.5 cm (12") acrylic tube that was 7.6 cm (3.0") in diameter. The tube was sectioned off into 3 separate chambers. At integration the chamber at the bottom of the tube contained the samples. The middle chamber contained a 6% ferric chloride solution designed to cause pitting on the stainless steel samples. The top chamber contained mineral oil to stop the pitting and preserve the pitting that occurred on-orbit. The experiment had a sheet heater coupled with bimetallic switches to maintain the temperature of the middle chamber at 27 ± 2°C. For insulation, a 0.64 cm (1/4") bat of Fiberfrax insulation was wrapped around the heater and the rest of the exposed acrylic chamber. When main power was received, the control circuit activated the motor/gearhead and retracted the sample from the lower chamber into the middle chamber where the pitting took place. At shutdown, the control logic once again started the motor/gearhead and the sample was pulled into the mineral oil chamber.

COMET worked as planned and produced pitting in the samples which showed some morphological differences. Typically a pit is a pinhole with subsurface degradation of the steel while the pits on the microgravity sample were spread more along the surface.

G503 BATTERY RESULTS

The G503 payload had a Zinc-Manganese Dioxide battery pack. The pack contained 120 Duracell F-size batteries, configured for +29.6 VDC (after diode drop) and 120 Amp-Hours, yielding approximately 3.6 kilowatt hours. The battery pack consisted of 6 parallel strings of 20 cells in series to achieve the desired voltage and amperage. The cells were packed in an aluminum semicircular battery box on one side of the can (see figure 1). The base of the box contained spaces for the DC/DC converter and battery health monitoring circuit. A semicircular conduit located against the central plate provided access to the battery leads and DC/DC converter connections. Each cell of the pack was wrapped in a Kynar sheath to insure that the cells could not be shorted together. As well, all exposed battery surfaces and the battery box were coated with a conformal coating which was resistant to KOH. The series strings were separated by Pellon, an electrolyte absorbent material, in case of leakage. A combination of an acrylic sheet and Pellon was used between the battery layers and the battery box to electrically isolate the batteries from the battery box and also provide some insulation. With this choice of battery type it was possible to vent the battery to the inside of the GAS container. The complete battery and power distribution system (PDS) weighed approximately 29.5 kg (65 lbs). Similar rechargeable systems of the same mass have far less total power.

The G503 electrical subsystems comprised the PDS, thermal and experiment control circuitry and temperature recorders. The PDS had a 300 watt DC/DC converter powered by the experiment battery. Power was distributed through a 150 watt +5VDC power bus and a 150 watt +12VDC bus. There were 15 ampere fuses on both the positive and negative sides of the battery. The PDS was energized as planned at 60,000 feet by a baroswitch which set GCD A to HOT. At this time all heaters were energized to maintain a constant temperature in each experiment. The thermal control circuit consisted of bimetallic switches on both leads of the heaters. These switches provided a simple safe redundant system which required no external power. After a 2 hour onboard timer expired all experiments began there nominal operations. For mission success each experiment had its own micro controller. During the mission three temperature monitors recorded data, two on experiments and one for the complete can. The monitors were +5VDC temperature loggers which stored there data in an EEPROM. The data were used to characterize the on-orbit thermal environment as seen by the experiments.

The battery provided experiment and thermal control power for 170.48 hours as calculated from the data of the temperature monitors(see figure 3). At that point the battery voltage had dropped to 17.2 volts which was pre-selected before launch as a cutoff voltage. This was set to insure that the batteries did not go below 16 volts which is the dead cell voltage for the packs. Below this value cell reversals can happen causing the reverse charging of single cells and there eventual explosion since F-cells do not have a vent to allow excess gases to escape. This occurrence was observed in ground tests when the packs reached 10 volts. Therefore at 17.2 volts the battery health circuit in the battery box sent an equivalent GCD C HOT signal to the three experiments which had procedures that needed to be carried out before shut down . 10 minutes after this signal the circuit disabled the DC/DC converter. From this point until the complete shut down of the G503 payload by the astronauts the battery only powered a single temperature monitor.

The power consumption data for the mission as calculated post flight are shown in table 1. The total power used was 3,543 watt hours. Almost exactly as expected from the battery data provided by Duracell. However the battery only lasted 170.48 hours. To understand why the battery did not last the required eight days let's examine what did and did not work on each experiment.

- The COMET experiment from UAB worked as planned with their heater cycling on and off throughout the mission (50% duty cycle)(see figure 3).
- The ConCIM experiment also worked as planned. However as evident from the temperature profiles(see figure 3) the large heater located on the outside of the accumulator which was set to turn on at 15°C cycled on and off for most of the mission (50% duty cycle assumed) maintaining the overall temperature of the can just below 15°C until the it was shut off when the health circuit disabled the DC/DC converter.
- The RGIS experiment did not work properly. The temperature monitor became disconnected and thus no temperature flight data was recorded. We have assumed a 50% duty cycle on the heater for calculation of total used power.
- The MCRED experiment also failed to operate correctly. An error in the program caused the onboard controller to lock up after 12 hours. At this point all 4 lights were on in this experiment. From ground tests before flight the amount of heat the lights produced was more than sufficient to keep the heater from turning on.

Hence with the lights staying on in MCRED this experiment drew more power than originally calculated. The battery health monitoring circuit performed correctly sending the shutdown signal to the experiments and allowing all experiments to be properly turned off. These results give us confidence that, had all experiments worked as originally programmed, the battery would have provided power for eight or more days.

Summary

The G503 GAS can was a success. Two out of the four experiments worked well and are providing good data for analysis. A large disposable battery pack was built and flown which provided sufficient power and long life at a fraction of the cost of rechargeable systems. A compartmentalized approach for control of all experiments insured that a single failure would not destroy all of the science. The single battery pack provided an easy way to distribute power to all experiments while insuring sufficient power for proper sequencing of the experiments. All of the people involved in this payload were new to the process of flying shuttle payloads and have learned a great deal from this very enjoyable experience.

References

[1] Mark A. Bury et. al, *Concrete and Mortar Research Aboard the NASA Space Shuttle*, **Concrete International** September 1994, pp. 42-46.

[2] Mark A. Bury, Lyle Jalbert and Steven Mustaikis II, *Taking Concrete to the Outer Limits*, **Concrete Construction** July 1995, to be published

Experiment	Volts	Amps	Watts	Hours Operated	Total Watt-Hours
Experiment #1 (MCRED)					
Lights (VAC)(4)	270.00	0.005	1.35	673.92	909.79
Inverter(2)	5.00	0.054	0.27	336.96	90.98
Controller	5.00	0.060	0.30	168.48	50.54
	12.00	0.013	0.16	168.48	26.28
	-12.00	0.004	0.05	168.48	8.09
Valves(16)	12.00	1.333	16.00	0.00	0.00
Heater	5.00	1.000	5.00	0.00	0.00
Signal Cond	12.00	0.333	2.00	168.48	336.96
Sensors	12.00	0.083	0.50	168.48	84.24
				Total MCRED	**1,506.89**
Experiment #2 (CONCIM)					
Motor	12.00	6.700	80.40	0.17	13.40
Solenoid Valve	12.00	1.000	12.00	0.033	0.40
Actuator	12.00	0.146	1.75	0.017	0.03
Heater	12.00	0.500	6.00	85.24	511.44
Temp. Monitor	5.00	0.001	0.01	168.48	0.84
				Total CONCIM	**526.11**
Experiment #4 (RGIS)					
Pumps(2)	12.00	0.170	2.04	0.20	0.41
Heater	5.00	1.000	5.00	85.24	426.20
Temp. Monitor	5.00	0.001	0.01	0.00	0.00
				Total RGIS	**426.61**
Experiment #5 (COMET)					
Motor	12.00	0.083	1.00	0.020	0.02
Heater	5.00	1.000	5.00	85.24	426.20
Temp. Monitor	5.00	0.001	0.01	168.48	0.84
				Total COMET	**427.06**
System Interface					
Interface Logic	5.00	0.050	0.25	257.44	64.36
Temp. Monitor	5.00	0.001	0.01	257.44	1.29
				Total	**65.65**
		Total Experiment Power			**2,952.31**
		DC/DC Converter Overhead			**590.46**
		Total Power Required			**3,542.78**

Table 1. G503 power usage during the STS-68 mission. Total power is calculated from assumptions based on temperature monitor data and post flight analysis of each experiment. The DC/DC converter is 80% efficient (calculated from preflight ground tests). Power lost to battery internal resistance and diode drop has been ignored for these calculations

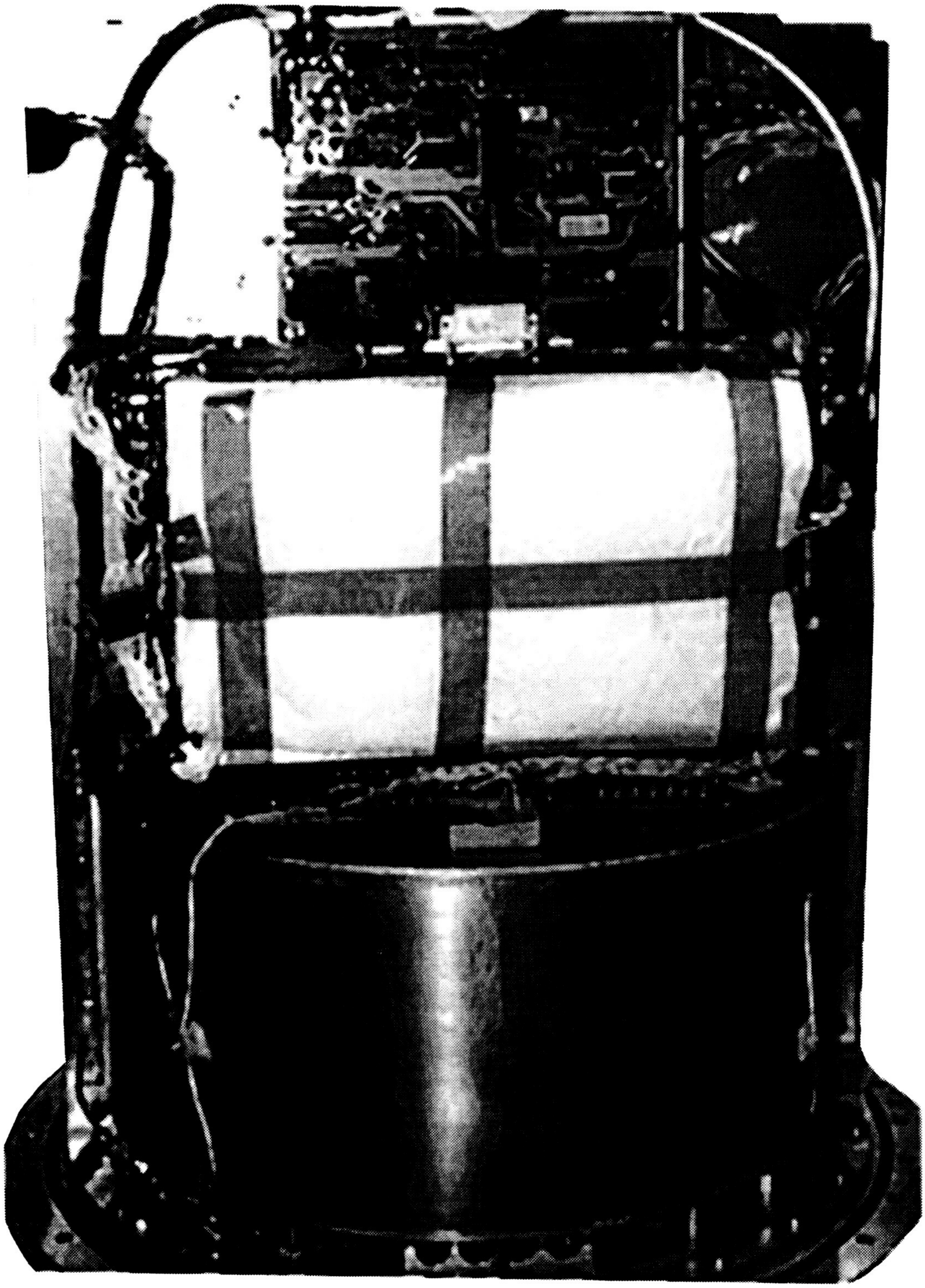

Figure 1. From Top to Bottom - the RGIS experiment with the MCRED electronics covering it, MCRED experiment chambers and plumbing (behind absorbent material), and then the battery pack with the power bus on top of it and the DC/DC converter underneath. The thermocouple for the can temperature monitor was placed at the top of the battery pack against the central plate.

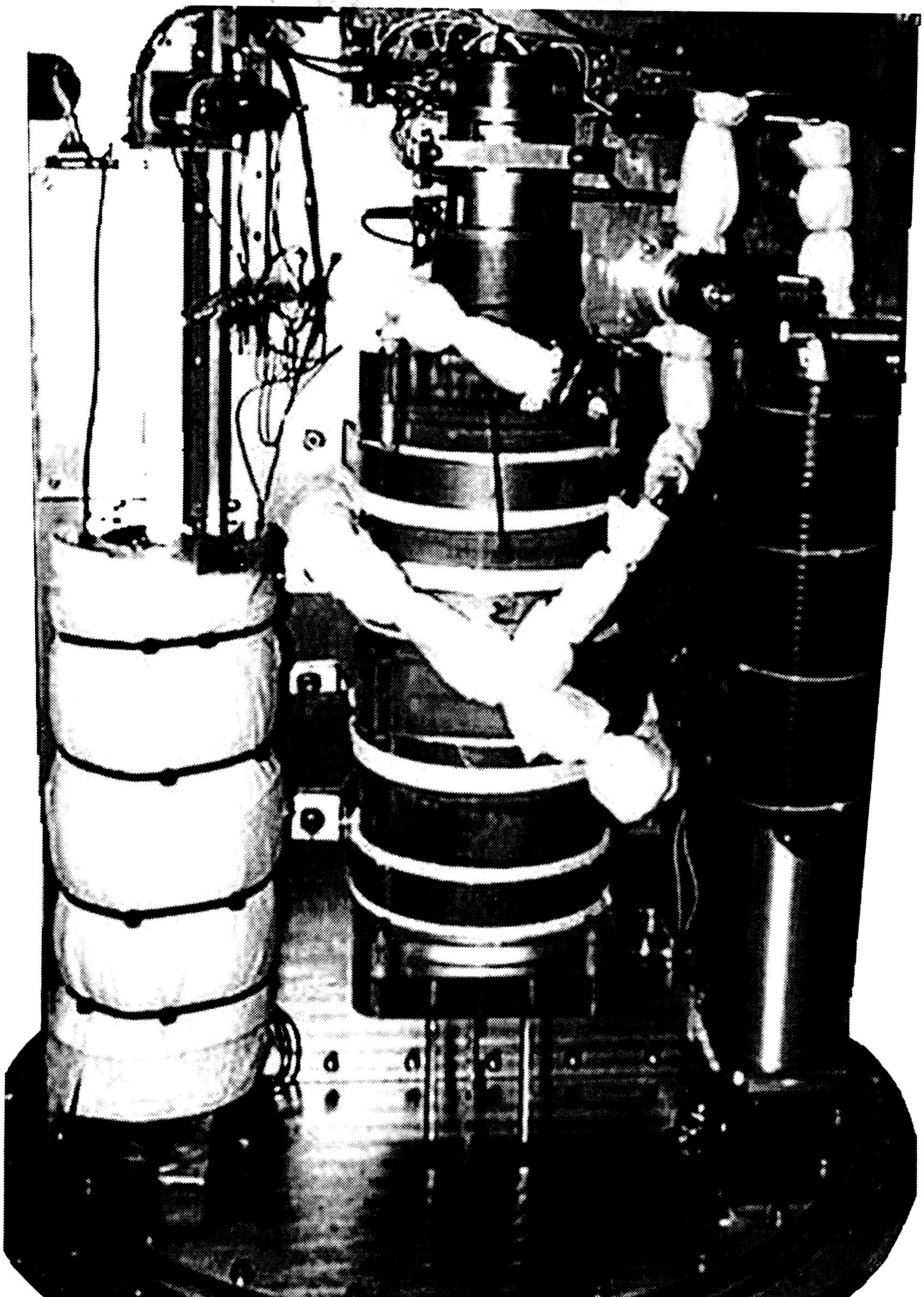

Figure 2. The other side of G503 had the COMET experiment on the far left, the ConCIM mixing chamber and motor in the center, and the accumulator with the heater (set to turn on at 15°C) wrapped around it on the far right. The thermocouple for COMET was placed in its central chamber (hidden by insulation) while ConCIM's thermocouple port is just visible above the "2" on the mixing chamber.

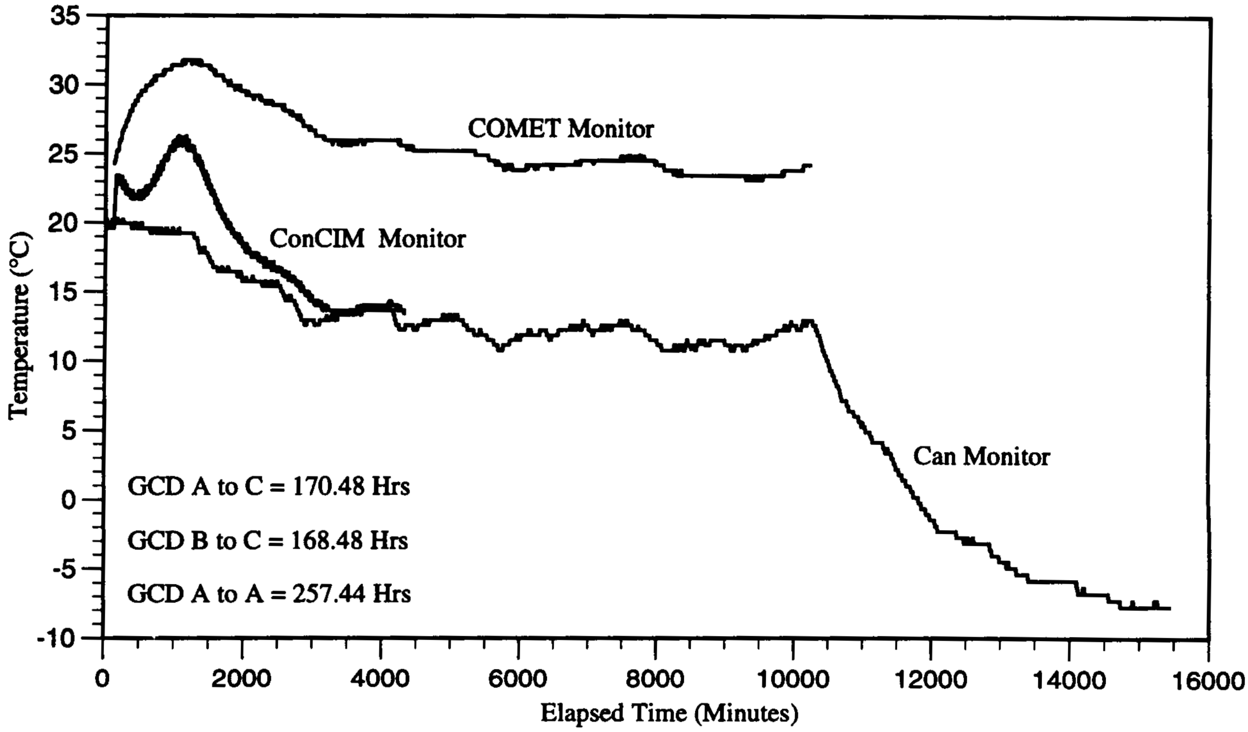

Figure 3. Temperature data from the 3 monitors in the can - The total time the experiments were powered is calculated from this data. The COMET monitor was on from GCD B to HOT, end of the two hour timer, until GCD C to HOT, when the battery health monitoring circuit shutdown disabled the DC/DC converter. The ConCIM monitor was on from GCD A to HOT and thereafter for 72 hours. The can monitor was on from GCD A to HOT (baroswitch) until GCD A to LATENT (astronauts).