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SPACEFLIGHT PAYLOAD DESIGN

FLIGHT EXPERIENCE G - 408

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ABSTRACT

Worcester Polytechnic Institute's first payload of spaceflight experiments flew aboard Columbia, STS-40, during June of 1991 and culminated eight years of work by students and faculty. The Get Away Special (GAS) payload was installed on the GAS bridge assembly at the aft end of the cargo bay behind the Spacelab Life Sciences (SLS-1) laboratory. The experiments were turned on by astronaut signal after reaching orbit and then functioned for 72 hours. Environmental and experimental measurements were recorded on three cassette tapes which, together with zeolite crystals grown on orbit, formed the basis of subsequent analyses.

The experiments were developed over a number of years by undergraduate students meeting their project requirements for graduation. The experiments included zeolite crystal growth, fluid behavior, and microgravity acceleration measurement in addition to environmental data acquisition. Preparation also included structural design, thermal design, payload integration, and experiment control.

All of the experiments functioned on orbit and the payload system performed within design estimates.

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INTRODUCTION

The small self-contained payloads of the National Aeronautics and Space Administration (NASA) - known best as the "Get-Away-Special" (GAS) program - have provided unparalleled opportunities for educational institutions to participate in our nation's space program [1]. The GAS program has also proven to be an excellent mechanism for engineering colleges and private corporations to join together in programs oriented toward the development of space flight hardware [2], thus furthering institutional and industrial relationships [3]. A companion program known as the Advanced Space Design Program, sponsored jointly by the University Space Research Association and NASA, provides opportunities for universities to focus on design issues associated with the exploration of space.

WPI undergraduates have been developing experiments for NASA's GAS program since 1982. Although these experiments were ready to fly in early 1985 [4], [5], the Challenger disaster delayed the flight of the experiments until the spring of 1991. Between 1982 and 1986, five experiments were selected, developed, and tested in sufficient detail to be flight ready. In addition to the flight experiments, there were a number of other support projects conducted by other project teams. These included the development of flight recorders for data collection, a structure for mounting the experiments internal to the GAS canister, and a technical communications project. The four payload experiments are briefly summarized below.

1) **Zeolite Crystal Growth Experiment:** This experiment [6], illustrated in Figure 1, was designed to determine if a low acceleration environment would promote the growth of large zeolite crystals. The experiment required a small, heated reactor vessel with a precision temperature controller which was optimized to use minimum power.

2) **Fluid behavior experiment:** As shown in Figure 2, several methods for measuring the properties of a liquid in zero-G environment were evaluated. A thermodynamic technique was used by recording temperature and pressure in the interior of the modules when a volume change was induced by the stepper motors. Two systems were studied, one using a wetting liquid (Freon on aluminum) and the second using a non wetting liquid (ethylene glycol and water on teflon). Valve motors on each of the modules were opened and closed to study fluid migration. Also, the experiment included the design of an ultrasonic, fluid film thickness measuring instrument accurate to 0.01 mm, and a micro-processor controller was used to sequence the different measurement schemes and to record the data [8].

3) **Microgravity Accelerometer:** This experiment is shown in Figure 3. The accelerometer system detected and recorded low level (10-6G) accelerations along three axes.

4) **Environmental Data Acquisition System:** A completely automated data acquisition system was developed to monitor the canister environment. The parameters measured were interior sound pressure level, triaxial high level accelerations, barometric pressure, temperatures, and battery voltages.

FLIGHT PREPARATION AND RECOVERY

Subsequent to development of flight hardware for individual experiments, a process of payload integration was begun which included flight readiness reviews. Inasmuch as the student project teams developed the experiments individually with only moderate knowledge of other experiments or structural constraints, the integration process quickly identified areas of concern. These included ruggedization, integration of individual experiments into the structure, and development of final check-out procedures. These items were addressed and the payload held in storage until the STS-40 flight opportunity became available.

Flight preparation included a number of rehearsals at WPI where ground procedures were developed and needed tools and supplies identified.

The G-408 payload was shipped to the Kennedy Space Center in December 1990 and the launch preparation team completed their check-out and loading of G-408 during a three day period from February 19 - 22, 1991. Three other GAS payloads, in addition to G-408, were processed through the GAS facility during this period. Although the facilities were excellent and the NASA personnel were very helpful, it is clear that a well prepared and rehearsed checkout procedure is essential. Additionally, several practical tips were developed that can be applied to the design and construction of any GAS payload to promote an efficient and successful payload check-out.

Experiment Access/Removal: Installation of all experiment mounting hardware should be convenient. Blind fasteners that are hidden by another experiment, lead to difficulties during preparation.

Maintenance/Servicing Design Allowance: Experiments should have a mounting assembly that enables an extended, self-supported positioned relative to the main support structure. For example in G-408, the servicing of the Fluid Behavior experiment could have been greatly simplified if the twin cylinder assemblies were mounted on a horizontal sliding mechanism to facilitate the filling with their respective fluids.

Assembly Orientation and Identification: Ample use of guide pins and orientation markers facilitates re-assembly. Cable connectors should be clearly marked with its mate identified. Experiments should be identified in bold markings and service points such as fill ports, test points, etc. should be clearly marked.

Fastening Hardware Selection and Fastening Design: The variety of fastening hardware should be minimized. Tiny hardware should be avoided in favor of more "human-scale" hardware. For those areas of an experiment that are frequently disassembled, the fastening design should be rugged. For example, tapped aluminum holes would not be adequate for these areas.

Protective Packaging of Experiments: Dropped tools or parts as well as spilled liquids can damage experiments because of a lack of shielding. Experiments should be adequately protected from such accidents.

Built-in Test Capability: Capability to evaluate readiness of the payload needs to be provided. For G-408, all experiments were controlled through the Environmental Data Acquisition System (EDAS) for system checking. If one experiment did not function properly, it had to be determined if the experiment, EDAS, the program, or a combination of all three were at fault. Furthermore, the EDAS had to be disassembled and its circuit boards pulled to install a test IC in place of the actual flight IC for each experiment. The control circuits for each experiment should be designed with built-in test capability. A simple fail-safe switch-over to the flight configuration should be provided, preferably from the exterior of the experimental package.

The basic components of a built-in test system for a GAS experimental package would include:

a) Exterior panel of on/off switches to simulate the shuttle control functions for each experiment which connects to payload harness.

b) The BIT circuitry and programming necessary within each experiment to run the test sequence.

c) Output device to process and transfer experimental functions/ response to a PC or other monitoring device.

Additionally, independent indicators for each experiment should be provided as the confirmation check that a function has occurred. On G-408, the click of an engaging relay or the whine of a turning motor was relied upon. However, the GAS Processing Facility is usually a very noisy area and these types of checks cannot be relied upon. An LED display or other such indicating devices could be built for each experiment and plugged into a built-in test tap for each experiment's circuitry.

TYPICAL RESULTS

The GAS relay for this experiment was activated at 00/10:47 MET. The times indicated on Figures 4-6 are relative to that MET. The total run time for the experiment was approximately 72 hours and acceleration data were continuously collected during that time.

Figure 4 shows a two hour record beginning at 04:00 and illustrates two basic types, A and B, of acceleration environment present during the experiment operation.

Figure 5 shows a 12 minute segment illustrating Type A data. Pairs of acceleration pulses occur approximately every two minutes and have magnitudes of 0.5 to 0.7 milli-g's. For the entire 72 hours, this type of record is present unless more substantial activity is present as represented by sequence B. This 12 minute sequence is shown in Figure 6 and includes magnitudes of the order of 2 to 3 milli-g's occurring at intervals of 10.1 seconds.

The Type A sequences resulted from an electromechanical relay used to control the oven heating system for the zeolite crystal growth experiment. The period was approximately 2.0 minutes early in the experiments and became 1.9 minutes near the end of the experiment because the payload temperature was lower resulting in faster heat loss from the oven. Similarly, the duty cycle increased from 17 to 18 seconds over the course of the experiment because lower battery voltage necessitated greater time for the heater to supply the required heat.

The Type B sequences resulted from relays in a power conservation system. Whenever precision temperature and pressure readings were required from the fluid behavior system, the analog circuits would be energized and then de-energized at approximately 10 second intervals.

Between these types of events, accelerations of the order of 100 to 200 micro-g's are found. Thus, the self-induced acceleration of the experiment package greatly exceeded the Orbiter accelerations whenever electromechanical devices were in operation.

The fluid behavior experiment was, similarly, technologically successful and at least partially successful scientifically. The non-wetting module functioned perfectly. This portion contained an ethylene glycol solution in two teflon lined cylindrical containers connected by a ball valve. Initially, the containers were filled 60 percent and 40 percent respectively. The volume of one chamber could be varied, ΔV, using a piston-cylinder assembly which caused a measurable pressure rise as shown in Figure 7. The height of the rise was a measure of the liquid volume in the chamber. Periodically, the valve was opened allowing fluid to migrate between the containers. The height of the pressure rise was a good indication of the liquid volume. The spacecraft accelerations caused the fluid migration between the chambers. The total volume transferred was not large, approximately 10 percent but was certainly measurable. Figure 8 shows the variation of $\Delta V/V$ throughout the period of experiment operation.

The second module contained Freon 11 and aluminum container walls and was, therefore, a wetting system. It was supposed to function as did the non-wetting system except that the fluid transfer would be affected by capillary action. In addition, this system contained an ultrasonic sensing system to monitor the amount of freon in the storage container. When the experiment was retrieved, the storage container still contained the beginning amount of Freon and the variable volume chamber contained none. It appears that there was a leak from one of the chambers at some time during or after the mission.

The zeolite crystal growth experiment functioned as designed and did produce crystals of zeolite A, as expected. The autoclave temperature rose to 98°C and was held steady for 72 hours (Figure 9). Upon return to earth the autoclave was inspected for leaks, and none were noticed. The aluminum end-cap on one of the chambers was squashed and/or deformed, in both chambers. This behavior may have been caused by freezing of the solution later in the flight.

The zeolite A reaction mixture was prepared by mixing 3.8 ml of silica slurry with triethanolamine (TEA) and 5 ml of sodium aluminate solution. The reaction mixture was maintained at approximately 71°F during a 110-day launch delay after mixing, which resulted in the undesirable aging of the mixed gel solution. A parallel experiment was conducted at WPI, using the same raw materials in an identical autoclave to that of the microgravity experiment, and aged for the same period of time. A third experiment used the same solutions, but the reaction mixture was heated to 96°C in a Teflon reactor, with no aging.

Scanning electron microscopy (Jeol JSM-840 SEM) was used to determine the crystal shape, size and morphology of the products and impurity phases. X-ray powder diffraction (Cu K_α radiation, Nicolet 12/V Polycrystalline Diffraction System equipped with Digital Microvax) was used to determine the degree of crystallinity of the samples. Particle size analysis of the products was performed using an Electrozone Celloscope Model 80XY. Powder samples for the size distribution measurements were suspended in deionized water and vibrated in an ultrasonic bath for a few minutes for adequate dispersion. Measurements were made in a 1 wt. % NaCl solution used as an electrolyte. Infra-red transmittance spectra of samples were recorded using Perkin-Elmer 683 Spectrometer.

Analysis of the crystals grown in microgravity showed zeolite A crystals with considerable twinning, and a very small amount of an impurity phase, polycrystalline hydroxysodalite. Some single, well developed zeolite A cubes were also found. The average size of the crystals was about 33 μm. Similar results were obtained from previous terrestrial experiments, and from the control experiment on earth using <u>aged</u> solutions.

The reaction mixtures that were crystallized on earth with <u>no aging</u>, on the other hand, showed a majority of single, well developed zeolite A cubes, occasional twinning of zeolite A crystals, and an almost imperceptible level of hydroxysodalite. The average crystal size was about 50 μm. This is the usual result of crystallization from this reaction composition and processing conditions.

The results described were expected, and are attributed to the long delay between mixing and launch, which resulted in an aged mixed gel solution. To grow larger, more perfect zeolite crystals, it is important to suppress nucleation as much as possible, so that the smaller number of crystals nucleated can grow larger when suspended in solution in the microgravity environment. Aging of the mixed gel solution compromises this process, producing poorly formed crystals, even in the presence of TEA. It therefore seems likely that the aging process which occurred prior to launch led to the crystal growth results obtained. Thus, the microgravity environment probably played little or no role in this experiment.

All in all, the experiment may be considered a technological success, but was inconclusive scientifically. It was not possible to determine what effect microgravity might have on zeolite crystal growth from these results due to the prolonged delay after mixing.

CLOSURE

The individual experiment and control modules were all tested according to the suggested acceleration spectrum [1]. These tests were adequate inasmuch as no mechanical failures occurred. The on-orbit temperature of the payload generally decreased throughout the period of operation. Because the payload was activated relatively early in the flight, the temperatures were always above 7°C, while data were recorded. There was, however, some evidence from the Zeolite experiment that lower temperatures were encountered. The experiment package was powered by Gates J and X cells in a sealed and vented battery compartment. Nominally twice the needed power was provided to accommodate storage and loss of efficiency at low temperatures. As it turned out, the temperatures were higher then expected but the storage was much longer than expected with a net result of achievement of the predicted run-time.

REFERENCES

[1] Get Away Special (GAS), Small Self-Contained Payloads-Experimenter Handbook. NASA Goddard Space Flight Center, Special Payloads Division, 1986.

[2] F.J. Looft, R.C. Labonte, and F.C. Lutz, "The NASA Space Shuttle: A Vehicle for Science and Engineering Education," IEEE Front. Educ. Conf. Worcester, MA, 1983.

[3] F.J. Looft, R.C. Labonte, and F.C. Lutz, "The Space Shuttle - A Vehicle for University-Industry Educational Interaction," IEEE Trans. Educ., pp. 100-104, 1986.

[4] W.W. Durgin and F.C. Lutz, "Designing for Space - Undergraduate Project Education," 38th Congress of the International Astronautical Federation, IAF-87-522, Brighton, 1987.

[5] F.J. Looft, R.C. Labonte, and W.W. Durgin, "The Evolution of the WPI Advanced Space Design Program - A Evolving Program of Technical and Social Analyses Using the NASA Space Shuttle for Engineering Education," IEEE Trans. Educ., pp. 20-26, 1991.

[6] A. Sacco, Jr., "The NASA GAS Program: A Stepping Stone to Education, IEEE Trans. Educ., pp. 27-30, 1991.

[7] W.W. Durgin and J.W. Mattthews, "Fluid Behavior in Microgravity," GAS User's Conf., GSFC, Oct. 1985.

[8] D. Roberti, "An Investigation Using Ultrasonic Techniques to Determine the Parameter of Voids," Master's Thesis, Worcester Polytechnic Ins., 1987.

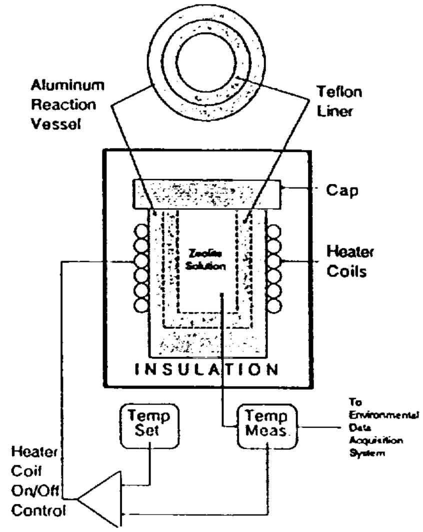

Figure 1 Zeolite Autoclave

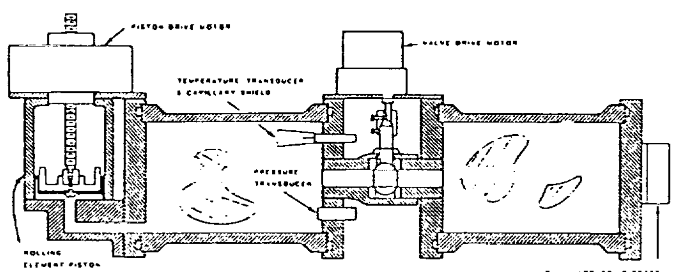

Figure 2 Fluid Behavior Module

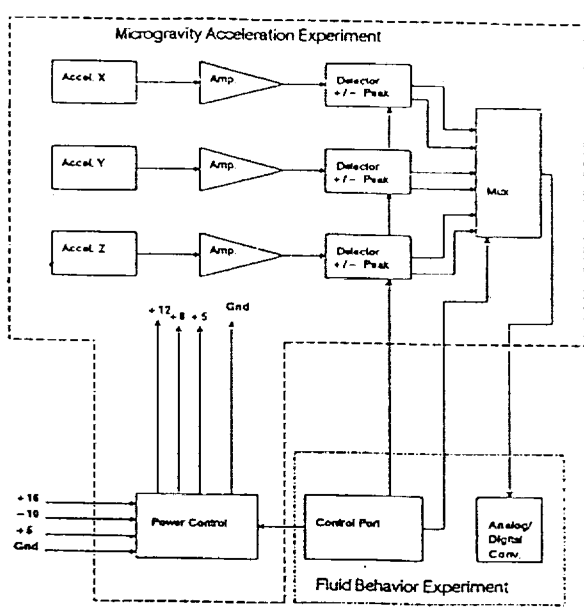

Figure 3 Accelerometer System

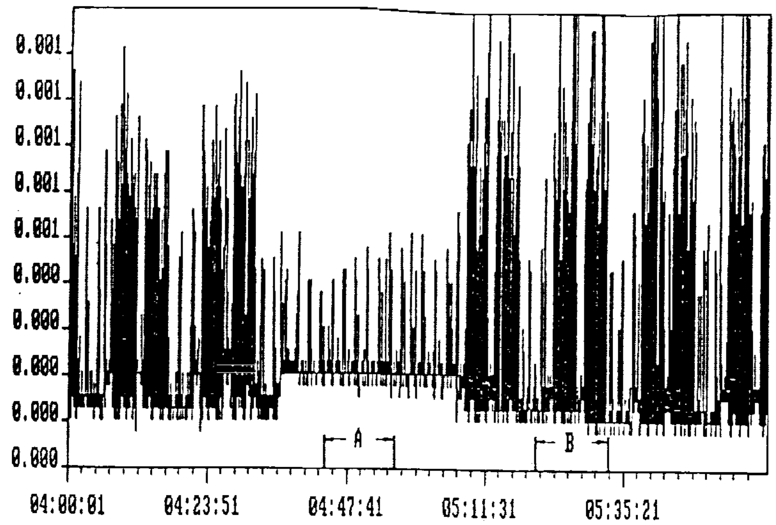

Figure 4 Two Hour Acceleration (g's) Record

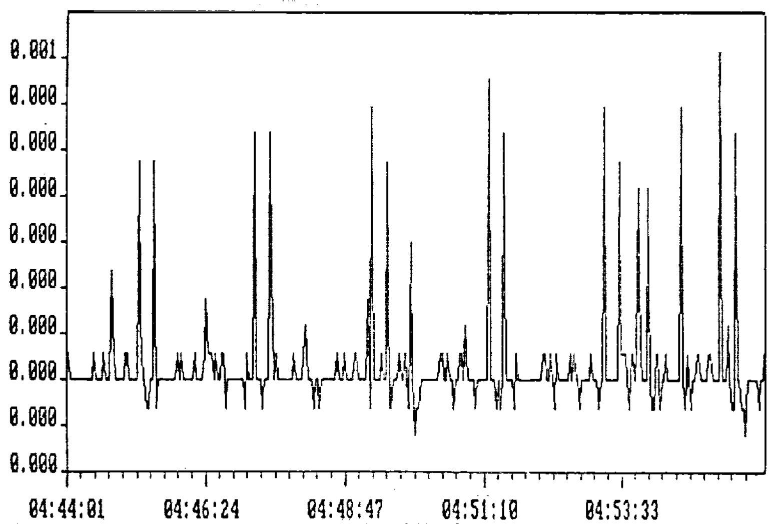

Figure 5 Type A Events

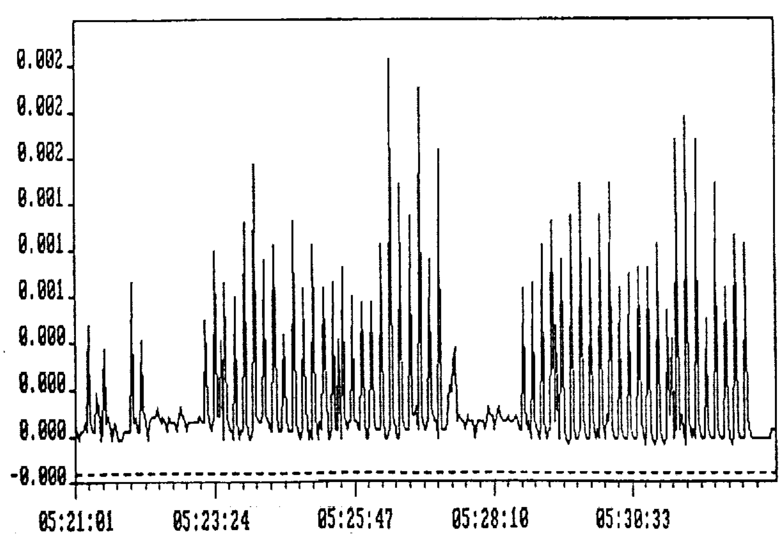

Figure 6 Type B Events

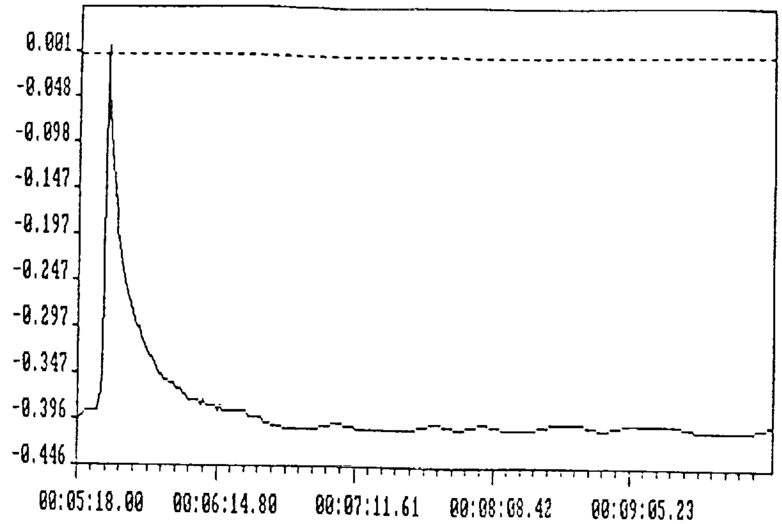

Figure 7 Pressure (psi) Curve

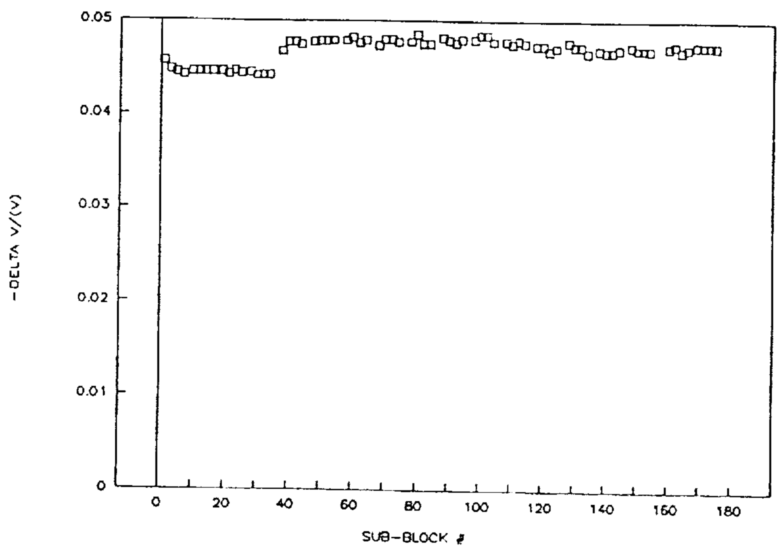

Figure 8 ΔV/V Record

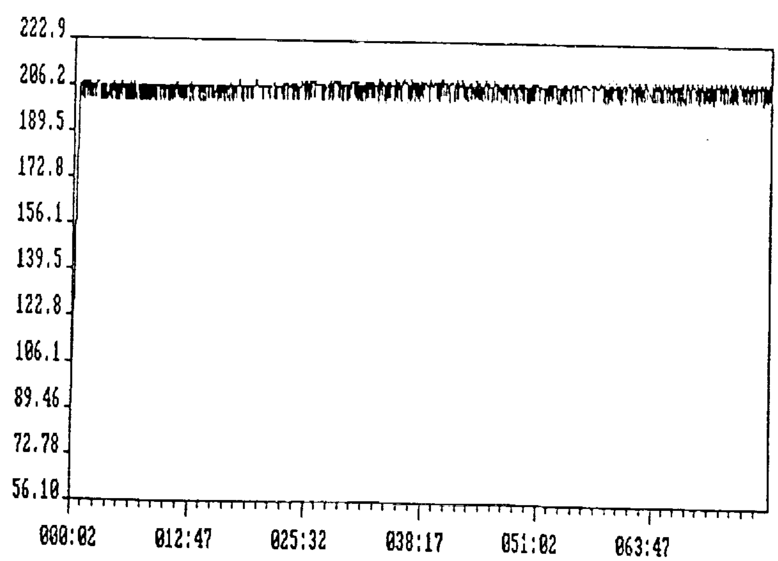

Figure 9 Autoclave Temperature (°F)