INTERNATIONAL INTERMEDIATE BULK CONTAINER FIRE TEST PROJECT

Scoping Tests

TECHNICAL REPORT

Prepared by

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FOREWORD

The International Intermediate Bulk Container Fire Test Project was initiated in 1995 with the aim of improving fire protection associated with the storage of combustible liquids in non-metallic intermediate bulk containers (IBCs). The project has independently documented protection criteria which might be incorporated into a wide range of codes, standards and insurance guidelines. Currently, IBCs are recognized by transportation regulatory authorities for intrastate, interstate and international shipping. Generally, fire and building codes have been silent on protection guidelines for these containers. Where there is recognition of IBCs, their use and storage in buildings has been severely limited or prohibited because of the lack of fire test data on their protection. Insurers and fire inspectors also have had limited information on which to base protection guidelines.

This report - part of Phase I of the project - is a step in the process of quantifying potential failure mechanisms of IBCs for a range of potential exposure fires. A subsequent report will document Required Delivered Density tests of IBCs single- and two-high (stacked). It is anticipated that Phase II of the project will be mounted to conduct large-scale fire tests of representative real-world storage/use scenarios. It is to be separately reported.

The Research Foundation expresses its gratitude to project technical director Joseph Scheffey of Hughes Associates for the thorough preparation of this report, and Underwriters Laboratories Inc. for its professional conduct of the fire tests and presentation of the data. The Foundation and its author thank the project's Technical Advisory Committee listed on the following page for their contributions of expertise and the financial resources required to complete this first phase of the project. Of course, participation does not necessarily constitute a participant's endorsement of every statement in this or the cited reports.

THE INTERNATIONAL INTERMEDIATE BULK CONTAINER FIRE TEST PROJECT

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Fire Testing of Intermediate Bulk Containers -

Failure Mechanism Tests

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Additionally, the sponsors of the project are recognized. . .

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BACKGROUND

The National Fire Protection Research Foundation (NFPRF) is conducting a research project aimed at improving fire protection associated with combustible and flammable liquids stored in non-metallic intermediate bulk containers (IBCs). New technologies, intermodal transportation opportunities, and space utilization needs have resulted in the introduction of intermediate-sized plastic and composite containers for combustible and flammable liquids. These containers may also be used individually as part of a process operation.

Currently, IBCs are recognized by transportation regulatory authorities for intrastate, interstate, and international shipping. Generally, the model building, NFPA, and Uniform Fire Codes are silent on protection guidelines for these containers. Where there is recognition of IBCs, their use and storage in buildings is severely limited or prohibited because of the lack of fire test data for their protection. Insurers and fire inspectors also have limited information on which to base protection guidelines.

The overall objective of the research project is to develop protection criteria which could be incorporated into a wide range of codes and insurance guidelines. The trend is to use fire test data and engineering analysis to develop appropriate protection criteria. Such criteria could include the type and size of container, the liquid type, the storage configuration, and the specific storage location and use (e.g., bulk warehousing or operations and use).

Documentation has been ongoing for flammable/combustible liquid fire protection. Some work has already been done on the response of IBCs when exposed to fire. This project extends that work to quantify potential failure mechanisms of IBCs for a range of different types/styles of IBCs. It is anticipated that a follow-on effort (Phase II) will subsequently be initiated to conduct large-scale fire tests of representative real-world storage/use scenarios. This report documents the results of the initial Phase I tests.

OBJECTIVES

The objective of Phase I was to identify failure mechanisms and time to failure of commercially available IBCs when exposed to a liquid hydrocarbon pool fire. For these scoping tests, failure was defined as discharge of contained liquid through a breach in the product area. It was planned that optional phases would investigate fuel-laden IBCs, failure mechanisms associated with an array of IBCs and investigate effects of a three-dimensional (running fuel) fire ignition source.

APPROACH

The general approach to the NFPRF project was to conduct a series of scoping tests (Phase I) to identify failure mechanisms of containers and initiate the investigation of large-scale storage factors (e.g., fuel stacking/storage configuration, and exposure fire effects). Large-scale fire tests with complete storage arrays and suppression systems would follow in Phase II. Prior to the initiation of testing, a brief literature search was conducted. This search yielded little data since IBC technology applied to combustible/flammable liquid storage is a recent development.

The approach used in the Phase I scoping tests was to expose representative IBCs to a hydrocarbon pool fire. The pool fire was used to determine fundamental container failure mechanisms. A total of 23 units, having a capacity ranging from 110 - 610 gal (416 - 2309 ℓ), were evaluated in Phase I. The units were rigid plastic and composite IBCs, with DOT shipping designations of UN31H1 (all plastic) and UN31HA1 (plastic/steel composite). One fiberboard (corrugated cardboard) composite unit (UN31HG1) was tested. For these tests, the IBCs were water-laden to full capacity. The exposure was a 25 ft^2 (2.3 m^2) heptane pool fire.

STORAGE OF FLAMMABLE AND COMBUSTIBLE LIQUIDS IN IBCs

Description of Intermediate Bulk Containers

Rigid intermediate bulk containers are small, reusable, portable containers commonly used for the shipment of chemicals. These containers are most commonly used in the place of metal, composite, or plastic drums. As the name suggests, they are of *intermediate* size, larger than drums but not as large as the commonly seen portable tanks. They come in different shapes, the most common ones being rectangular (cubical) and cylindrical. Most IBCs have openings in the top of the liquid containment vessel to accommodate fill, discharge, venting, and vacuum relief devices. Most IBCs also have one opening in the bottom which consists of a valve that may be protected by a secondary liquid-tight closure.

The design of IBCs permits the handling of chemicals through closed systems. This promotes workplace safety, a major reason for their increasing popularity in the last few years. Federal and local workplace rules promote such closed systems for handling hazardous chemicals. IBCs for hazardous materials must be built to withstand federally and internationally mandated hydrostatic, leakproofness, stacking and drop tests. IBCs typically range in size from 120-gallon (454 ℓ) to 330-gallon (1249 ℓ) capacity although a few are larger. Under the U.S. Department of Transportation (DOT) regulations, such containers are permitted to have a liquid volume up to 793 gallons (3000 ℓ). Under recently adopted NFPA 30 code definitions, however, these units may not exceed 660-gallon (2498 ℓ) capacity.

These containers may be made of metal, plastic or combinations of metal and plastic materials. These various types of containers are referred to as (1) metal IBCs, (2) rigid plastic IBCs, and (3) composite IBCs, respectively. There are other types of IBCs called *flexible* (so-called bulk bags) which currently are not permitted by DOT for the shipment of hazardous liquids. Rigid IBCs used for flammable and combustible liquids incorporate a venting device or must be so constructed that they will not permit pressure build-up of the contents in a fire and will relieve safely without rupture of the liquid containment vessel. Metal IBCs are made entirely of metal, most frequently from steel or aluminum. Rigid plastic IBCs are almost always made from polyethylene by the rotational molding process. These containers may consist of a single shell or be constructed using a double-wall configuration. Some plastic double-wall IBCs incorporate solid insulating foam between the inner and outer shell.

Composite IBCs are combination containers constructed so that the inner tank is encased within an outer support structure. These IBCs consist of two separate structures, one being the liquid containment vessel and the other being a separate outer encasement unit that contains the inner vessel during transportation, storage, and use. The inner vessel is a liquid-tight container frequently made from polyethylene by the blow-molded process. The outer support structure may be made from many different materials such as steel, plastic, fiberboard, or wood. The outer structure may be solid material such as light or heavy gauge sheet steel or consist of an all-plastic secondary liquid-tight encasement. Alternatively, the outer component may consist of a metal angle-iron and post frame structure, a cage made from metal rod or tubing, or plastic stacking structure surrounding the liquid containment vessel and designed to protect it during handling. Fiberboard and wood are also used as outer protection for certain IBCs, but these types are not presently being evaluated by the NFPRF IBC project.

Literature Review

The results of the literature search are included in Appendix A. Previous testing has been conducted to identify failure mechanisms of IBCs when exposed to fire [1,2]. These fires have included a point ignition source, small pool exposure fires, and large pool exposure fires. Point ignition source tests have indicated that IBCs are relatively resistant to that type of fire scenario, e.g., failure does not occur over a time range of 30 minutes [1]. Tests conducted by the U.S. Coast Guard [2] indicated the following:

- The most common failure made of polyethylene (PE) tanks involves thermoplastic softening followed by structural collapse; no pressure build-up was observed for exposed fuel-laden IBCs.

- Failure times for PE tanks were independent of fuel volatility for the range of exposure fuels tested (marine diesel and ethyl alcohol).

- Failure times were independent of pool fire size when the fire was in direct contact with the IBC. The time to failure for PE containers is primarily dependent on tank wall thicknesses, not tank capacity.

The testing in Phase I was designed to extend the failure mechanism data over a range of commercially available IBCs. The variables which are anticipated to have an effect included container wall thickness, outer structural shell material (plastic, steel mesh, or steel sheet), and pallet type (wood, steel, or plastic). It was anticipated that the blow molded units, having thinner wall thickness, would fail before rotationally molded units having a thicker wall. The configuration of the discharge valve assembly was also though to have an impact on failure time.

Test Philosophy

The general test philosophy adopted for the NFPRF project followed the guidelines established in the new Appendix E of NFPA 30, 1996 Edition. This appendix provides a framework for conducting large-scale fire tests to develop protection criteria for the storage of flammable and combustible liquids. This scoping test series was designed to identify principal failure mechanisms for a wide range of designs.

Several test design factors merit discussion. Heptane was used as the design test fire because it is the most hazardous liquid under consideration (Class IB). It also provides a repeatable test fuel, improving test-to-test repeatability. It should be noted that heptane would not, in all likelihood, be stored in an IBC. The most recent edition of NFPA 30 allows rigid plastic and composite IBCs to be used for storage of Class II and Class III liquids only. Chlorinated hydrocarbons and aromatic fuels are typically not stored in IBCs because they can chemically attack polyethylene. This can cause softening of the bottle and ultimately container failure. Chemical reaction with aliphatic hydrocarbons is less of a problem. Manufacturers provide specific recommendations for chemical storage in IBCs. For example, most manufacturers do not recommend the storage of heptane, while liquids such as mineral spirits (IC) and alcohols (IB, IC, II), are commonly stored. Many stored chemicals involve recipes of many ingredients, including IB liquids that are non-miscible in their pure state. The resulting mixture may or may not have a low flashpoint; the overall hazard of the liquid would have to be judged using additional factors such as the heat of combustion, reactivity, or rate of heat release (see Ref [3]). The use of heptane in this phase of the research project is appropriate and acceptable. Discussions in future phases will be required to identify appropriate test fuels, since this will effect protection schemes.

There was concern that the heat of combustion of different fuels (e.g., Class IB heptane vs. Class II mineral spirits or Class III motor oil) would effect exposure to the IBCs in these tests and, therefore, the failure times. While the heats of combustion do vary for the fuels, the flame heat flux from non-alcohol type hydrocarbon fuels are estimated to be roughly equivalent [4]. The Coast Guard found no differences between marine diesel and alcohol as the test fuel [2]. One test was performed in this test series to address this issue.

To have an exactly repeatable scenario, the heat flux to the container should remain constant. For relatively thin flames (less than the diameter of the pool), flame thickness will affect emitted heat flux. Since the IBC units were different sizes, pan size in each test would have to be changed to maintain a uniform exposure dimension around each unit. To achieve maximum heat flux (i.e., thick exposure flame), a much larger pan would be required. The use of a larger pan might prevent identification of failure times. It was concluded that for these scoping tests, these variables would be ignored since it was the objective to determine general failure times and mechanisms. A constant fire size (25 ft^2 (2.3 m^2)) was adopted. Since the exposed plastic units generally ignited or melted very quickly, this should reduce the impact of these variables. Any effects would impact smaller dimensional units, which would have a "thicker" exposing flame. Temperature data was measured at the exposed face of units to determine if any effects were obvious.

TEST MATERIALS

A total of 23 units were evaluated in the Phase I failure mechanism trials. The general construction of the IBCs under consideration were discussed in the previous section. Table 1 provides a physical description of all units. The units are described by number. The manufacturer of each unit is on record at NFPA and Underwriters Laboratories (UL). While the generic description of rigid plastic or composite can be applied to all units, it can be seen that there are a significant number of design variables between individual units. These variables include the following:

Capacity of Unit: The capacity of units ranged from 110 to 610 gal (416 - 2309 ℓ). The most common units were 275 - 330 gal (1041 - 1249 ℓ), which is the equivalent of five or six standard drums.

Dimensions: The nominal outside dimensions are given. Cylindrical units are reported by the diameter.

UN Designation: The UN shipping designation for each unit is given, 31H for rigid plastic (Figure 1) and 31HA (plastic bottle plus steel outer) or 31HH (plastic bottle plus plastic outer) for composite units (Figure 2). Exceptions to these designations include Units 10, 17, 15, 21, and 22. To further investigate variables of construction, the design of the containment vessel, or "bottle", is detailed. Additionally, the outside container or structural assembly is delineated. For all plastic units, this outside unit may be an integral unit (31H) or separate structural system (31HH). Encapsulation provided by the outer structure is also noted. Total encapsulation is defined as being provided by the outer container/structure if it provides a measure of protection and totally contains the liquid-bearing "bottle" area. Figures 3, 4, and 5 show total

Table 1. IBC Materials of Construction

Unit	Capacity gal (l)	Nominal dimensions l x w x h in. (m)	UN/DOT Shipping Designation	Bottle		Outer Container					Pallet				Valve
				Material	Thickness in. (mm)	Material	Thickness in. (mm)	Encap-sulation	Outer Acts as Insulator	Viewing Holes	Material	Integral w/outer or bottle (yes/no)	Pallet legs (solid/ hollow)	Cushion material & thickness	Doghouse Protection (yes/no)
1	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.07-0.12 (1.8-3.0)	steel mesh cage	0.25 (6.4)	no	no	NA*	steel	no	N/A	molded fiber	no
2	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.07-0.12 (1.8-3.0)	steel mesh/ blanket	0.25 (6.4)	no	yes	NA	wood	no	N/A	egg crate	no
3	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.07-0.12 (1.8-3.0)	steel tube cage	0.25 (6.4)	no	no	NA	steel	no	N/A	none	no
4	330 (1249)	48 x 45 x 70 (1.2x1.1x1.8)	31HH1	RM LLDPE	0.2-0.3 (5.0 7.6)	PE & Pu	0.5 - 2 (13-51)	yes	yes	yes	PE	yes	solid	none	yes
5	400 (1514)	42 x 42 x 68 (1.1x1.1x1.8)	31HA1	RM HDXLPE	0.375 (9.5)	steel	0.375 (9.5)	yes	no	no	steel	yes	N/A	plastic 0.31 in.	yes
6	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.07-0.12 (1.8-3.0)	steel mesh cage	0.25 (6.4)	no	no	NA	steel	no	N/A	egg crate	no
7	300 (1136)	40 x 48 x 64 (1.0x1.2x1.6)	31HA1	RM LLDPE	0.20-0.25 (5.0-6.4)	steel/PE coating	0.25 (6.4)	no	no	NA	steel	yes	N/A	none	yes
8	330 (1249)	48x48x63.25 (1.2x1.2x1.6)	31HA1	RM LLDPE	0.20-0.25 (5.0-6.4)	steel sheet & mesh	0.25 (6.4)	no	no	NA	steel	yes	N/A	plastic	no
9	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.06-0.12 (1.5-3.0)	steel sheet	0.1 (2.54)	yes	no	no	wood	no	N/A	foam polystyrene	yes
10	330 (1249)	46 x 46 x 60 (1.2x1.2x1.5)	31H1	RM LLDPE	0.5 (12.7)	NA	NA	no	no	NA	LLDPE	yes	hollow	none	no
11	330 (1249)	45 x 48 x 67 (1.1x1.2x1.7)	31HH1	RM LLDPE	0.31-0.38 (7.9-9.7)	LLPDE & PU	0.25 (6.4)	yes	yes	yes	PE	yes	solid	none	yes
12	120 (454)	42 x 31 x 53 (1.1x.8x1.3)	31HH1	RM HDXLPE	0.3125 (7.9)	PE & PU	0.3125 (7.9)	yes	yes	yes	PE	yes	hollow	none	no
13	330 (1249)	40 x 46.5 x 54 (1.0x1.2x1.4)	31HH1	BM HMW/HDPE	0.06-0.12 (1.5-3.0)	RIM DCPD	0.125 (3.2)	yes	yes	yes	RIM DCPD	yes	hollow	none	no
14	330 (1249)	44 x 47 x 54.5 (1.1x1.2x1.4)	31H2	RM LLDPE	0.375 (9.5)	NA	NA	no	no	no	RM LLDPE	yes	hollow	none	yes

*NA - Not applicable

Table 1. IBC Materials of Construction (Cont'd)

Unit	Capacity gal (l)	Nominal dimensions l x w x h in. (m)	UN/DOT Shipping Designation	Bottle		Outer Container					Pallet				Valve
				Material	Thickness in. (mm)	Material	Thickness in. (mm)	Encap-sulation	Outer Acts as Insulator	Viewing Holes	Material	Integral w/outer or bottle (yes/no)	Pallet legs (solid/ hollow)	Cushion material & thickness	Doghouse Protection (yes/no)
15	120 (454)	36 dia x 51.25 (.9 dia x 1.3)	31H2	RM LLDPE	0.5 (12.7)	NA	NA	yes	yes	no	RM LLDPE	yes	hollow	0.25 in.	N/A
16	120 (454)	41 dia x 52 (1.0 dia x 1.3)	31HH1	RM HDXLPE	0.375 (9.5)	RM HDXPLE	0.25 (6.4)	yes	yes	no	RM HDXLPE	yes	hollow	none	N/A
17	220 (833)	45 x 45 x 45 (1.1x1.1x1.1)	31H2	RM LLDPE	0.3-0.5 (7.6-12.7)	NA	NA	no	no	no	RM LLDPE	no	hollow	none	yes
18	120 (454)	42 x 42 x 47 (1.1x1.1x1.2)	31H2	RM LLDPE	0.20-0.25 (5.0-6.4)	NA	NA	no	no	no	RM LLDPE	no	hollow	none	N/A
19	110 (416)	44 dia x 45 (1.1 dia x 1.1)	31HH1	RM LLDPE	0.25 (6.4)	RM LLDPE	0.25 (6.4)	yes	yes	no	RM LLDPE	yes	hollow	plastic	N/A
20	275 (1041)	48 x 40 x 46 (1.2x1.0x1.2)	31HA1	BM HMW/HDPE	0.07-0.12 (1.8-3.0)	steel mesh cage with blanket	0.25 (6.4)	no	yes	NA	wood	no	N/A	egg crate	no
21	275 (1041)	48.5x42.5x47 (1.2x1.1x1.2)	31HG1	BM HMW/HDPE	0.06-0.12 (1.5-3.0)	cardboard	0.25 (6.4)	NA	NA	yes	wood	no	N/A	none	no
22	360 (1363)	46x46x54.25 (1.2x1.2x1.4)	31H2	RIM DCPD	UNKNOWN	NA	NA	NA	NA	no	RIM	no	hollow	none	no
23	610 (2309)	98 x 48 x 60 (2.5x1.2x1.5)	31H1	RM HDXLPE	0.375 (9.5)	steel (lower saddle only)	0.25 (6.4)	no	no	no	steel	no	N/A	none	no

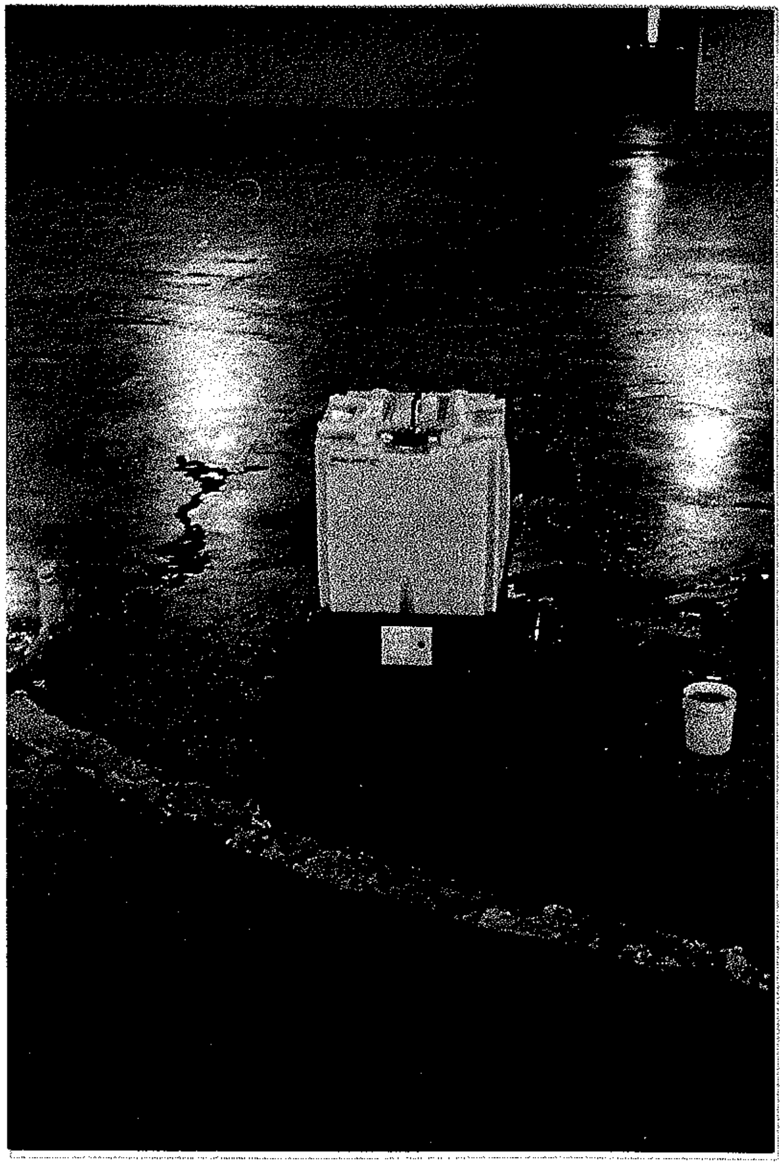


Figure 1—31H All-plastic IBC
(Unit 14)

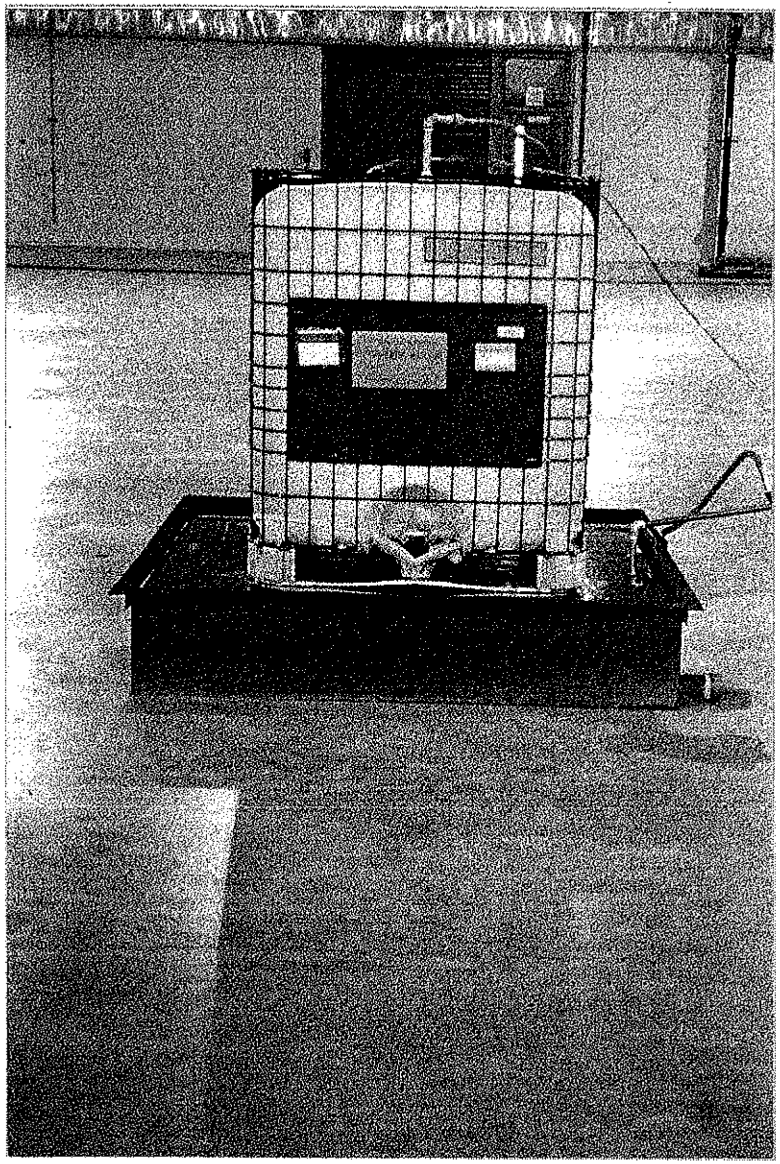


Figure 2—31HA Composite IBC
(Unit 1)

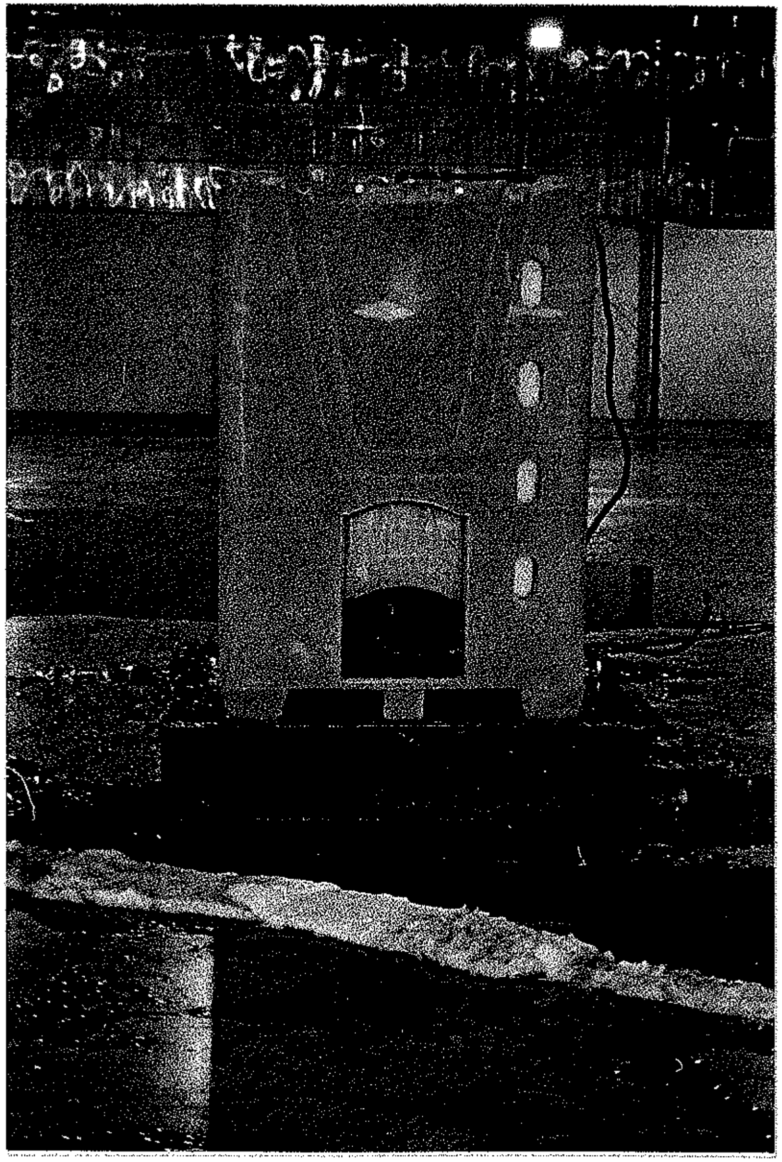


Figure 3 — 31HH IBC with encapsulation
(Unit 11)

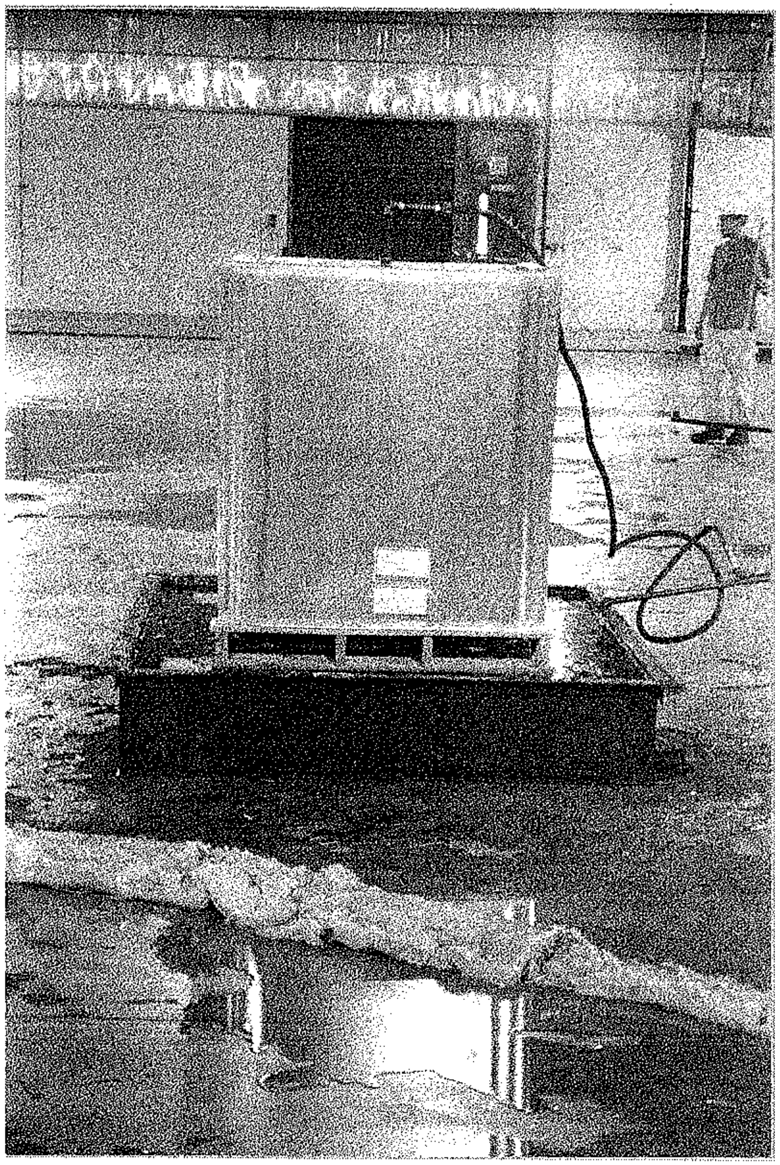


Figure 4 — 31HA IBC with encapsulation
(Unit 9)

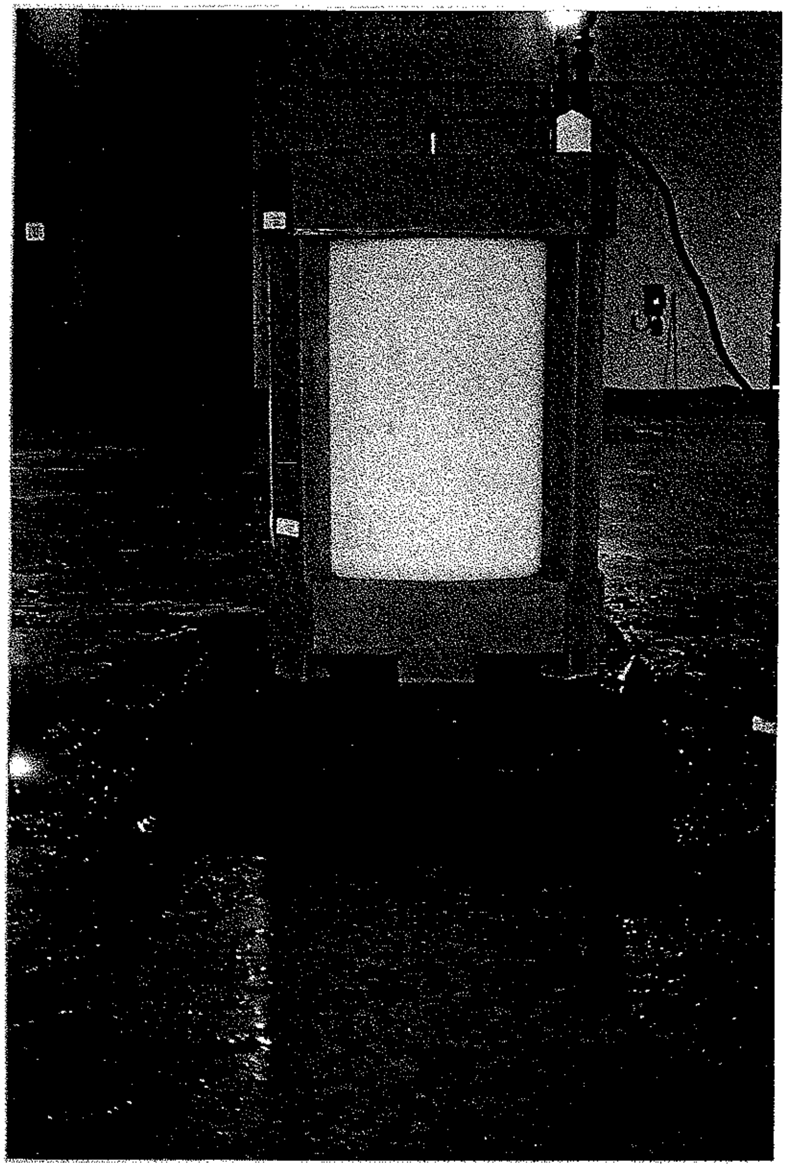


Figure 5 - 31H IBC, non-encapsulated,
with support structure (Unit 10)

encapsulation by a 31HH plastic unit (Figure 3), total encapsulation by a 31HA unit (Figure 4), and a non-encapsulated 31H unit with a plastic supporting structure (Figure 5). Figure 2 shows a non-encapsulated 31HA composite unit.

Bottle Materials of Construction: Bottles were manufactured using the blow-molded (BM) and rotational molded (RM) processes. Blow molded units were constructed of high molecular weight/high density polyethylene (HMW/HDPE). Their nominal thickness ranged from 0.06 - 0.12 in. (1.5 - 3.0 mm). Rotational molded units were constructed of linear low density polyethylene (LLDPE) or high density cross-linked polyethylene (HDXLPE). The thickness of these bottles ranged from 0.2 - 0.5 in. (5.0 - 9.7 mm). Additionally, two IBCs were constructed using the reaction injection molded (RIM) process (Units 13 and 22). These units were constructed of dicyclopentadyene (DCPD).

Outer Container/Structure: The materials of the outer container/structure varied considerably. Metal 31HA units included 0.25 in. (6.4 mm) steel mesh (Units 1, 2, 6, and 20), steel tubing (Unit 3), 0.1 in. (2.5 mm) sheet steel (Unit 9), and combination mesh and sheet/plate steel (Units 7, 8, and 23). Only Unit 9 (Figure 4) could be considered as providing complete encapsulation. Unit 12 had polyethylene encapsulation except for the valve opening (doghouse) area. The 31HH units included single-layer outer containment structures (Units 10, 14, 15, and 17) ranging in thickness between 0.3 - 0.5 in. (7.6 - 12.7 mm). These units were constructed using LLDPE. Other units had a triple layer of plastic material, consisting of a layer of polyurethane (PU) sandwiched between two layers of polyethylene (Units 4, 11, and 2). Unit 13 had a 0.125 in. (3.2 mm) outer of RIM DCPD.

Two blow-molded units were protected by protective blankets. Unit 2 was protected with a 12 oz/yd^2 (340 g/cm^2) aluminum-faced fiberglass blanket. The blanket was placed on the unit just prior to the fire test and was not part of a fixed installation. The intent would be to place the blanket on the IBC in the field. Unit 20 had similar protection, with a lighter weight blanket (3 oz/yd^2 (85 g/cm$^{2)}$)). Unit 21 had a fiberboard outer structure. This unit was included for informational purposes only and is not intended to store flammable liquids.

Table 1 includes a description of whether the outer structure acted as an insulator. Plastic, even though it burns, acts as an insulator for the inner bottle. Steel is not an insulator. Table 1 also notes whether viewing holes are located in units with an outer, encapsulating structure. The insulator and viewing hole information is provided for the failure mode analysis.

Pallet Material: Pallet material was thought to have a potential impact on results. Table 1 describes the pallet material of construction (wood, steel, or plastic). If the pallet was constructed as part of the container unit, it was considered "integral" with the unit. For plastic units, the legs of the pallet or base supporting structure were either solid or hollow. Where they were solid, a plastic fill material had been added to the hollow structure. Many units had a cushion at the bottom of the bottle, to provide stability between the bottle and pallet structure. In many cases, this cushion extended out below the valve assembly to provide protection to this area (see Figure 2). Cushioning provided for each unit is shown in Table 1.

Valve Assembly: Most units were provided with a valve assembly located at the bottom of the IBC. These valve assemblies, typically 2 in. (5.1 cm) in diameter, are indented into the unit to provide protection (see Figures 1, 2, and 5). This indentation creates an open space for operations, commonly called a "doghouse." Many units had a cover or door to protect the valve doghouse area (see Figures 3 and 4). Protection provided to the doghouse is noted in Table 1.

TEST SETUP AND PROCEDURES

Facility and Instrumentation

The tests were conducted in Underwriters Laboratories (UL) Large Scale Test Facility. The tests were conducted in a room 120 ft by 120 ft (36.6 m by 36.6 m) with a ceiling height of 60 ft (18.3 m). The room was equipped with a moveable ceiling 100 ft long by 100 ft wide (30.5 m x 30.5 m). For this series of tests, the moveable ceiling was set at a height of 49 ft (15 m). The test pan was placed 30 ft (9 m) from the nearest wall. The steel pan used for this test program was 5 ft long by 5 ft wide by 1 ft high (1.5 m x 1.5 m x 30.5 cm).

The instrumentation for this series of tests consisted of temperature, pressure, heat flux, and VHS video. The data was collected with a Fluke Instruments model Helios 2287A at a 5 second scan rate. The following instruments were used:

- Temperature - Type K iconel-sheathed thermocouples 1/16-inch diameter.
- Pressure - MKS Instruments, Model: Baratron, Range 0-1 TORR, Output 0-10 VDC, Serial No. 60267-1.
- Heat Flux - Medtherm Corporation, Model 64-5-20/AP-1-60, Sensor: Schmidt-Boetler, 60° View, Total Heat Calorimeter, Calibrated at 6.11 mV at 5 Watts/cm^2.

A description of the instrumentation used in each test is provided in Table 2. The exact locations of the instrumentation are on record at UL. The pressure readings were taken in the ullage space. The pressure tap was installed in the top fill cap of the IBC, inserted so that the connection at the cap was liquid and air tight. Figures 1 through 5 show the pressure tap assembly extending from the top of the unit. The heat flux was measured 5 ft (1.5 m) from the edge of the pan, 18 in. (45.7 cm) above the base. Internal temperatures were taken in the ullage and at 12 in. (30.5) and 24 in. (71 cm) below the liquid surface. The external

Table 2. Test Instrumentation

Unit	Test Code	Pressure	Heat Flux	External Thermocouple Located 18 in. (45.7 cm) Above Base	Thermocouples Located in Ullage Space	Thermocouples Located 12 in. (30.5 cm) Below the Waterline	Thermocouples Located 24 in. (61 cm) Below the Waterline
1	06039601	1	0	0	1	4	4
2	06039602	1	0	0	2	4	4
3	06039603	1	0	0	2	4	4
4	06039604	1	0	0	2	4	4
5	06049605	1	1	1	2	4	4
6	06059601	1	1	1	1	1	1
7	06059602	1	1	1	1	1	1
8	06059603	0	1	1	1	1	1
9	0605604	0	0	1	1	1	1
10	06059605	0	0	1	1	1	1
11	06059607	1	1	1	1	1	1
12	06059608	1	1	1	1	1	1
13	06069601	1	1	1	1	1	1
14	06069602	1	1	1	1	1	1
15	06069604	1	1	1	0	0	0
16	06069604	1	1	1	1	1	1
17	06069605	1	1	1	1	1	1
18	06069606	1	1	1	1	1	0
19	06079601	0	1	1	1	1	1
20	06079602	0	1	1	1	1	1
21	06079603	0	1	1	1	1	1
22	06079604	0	1	1	1	1	1
23	06079605	0	1	1	1	1	1

temperature was taken 18 in. (45.7 cm) above the base, within ½ inch (1.3 cm) of the sample face. Figures 6 and 7 provided a typical layout of the instrumentation. The interior liquid temperatures installed on a standard rake (Figure 7) were reduced from four per level to one per level as testing continued. It was recognized that the liquid temperature was not increasing and that each test resulted in damage to the interior thermocouples.

Design and Procedures

The IBC was instrumented with thermocouples and the pressure transducer as described in the previous section. The unit was then filled with water to its rated capacity and placed in the fire test pan. A minimum of four concrete blocks in the test pan were used to support the IBC. Where units had separate support legs instead of a continuous pallet, each leg was supported by a block. The intent was to provide support similar to that when a unit is on the floor. The instrumentation was connected and operation verified. The test pan was filled with water so that the liquid level just came over the concrete blocks. Again, this simulated a unit standing on the floor of a storage facility. Liquid could flow under the unit,but there was only a gap equal to the pallet height between the liquid and the IBC bottle. This created a freeboard in the fire test pan of 1 in. (2.5 cm).

To create the fire exposure, heptane was pumped into the test pan at a rate of 1.8 gpm (6.8 ℓpm) for one minute prior to ignition. When the test team was ready, the fuel was ignited and the data acquisition system was started (Time zero). The flow of heptane from the fueling system was initiated to keep a relatively constant liquid level. During testing, it was found that the fuel flow rate was roughly 1.8 gpm (6.8 ℓpm). The fuel flow was continued until one of three conditions occurred: (1) five minutes had elapsed, (2) liquid was observed leaking from the IBC, or (3) the fire grew to an unacceptable size as determined by the on-scene test director.

In Test 6, kerosene was used in placed of heptane. Ten gallons (37.8 ℓ) of kerosene was placed in the pan. A total of eight ounces of heptane was poured along the four edges of the pan. The fuel was then ignited.

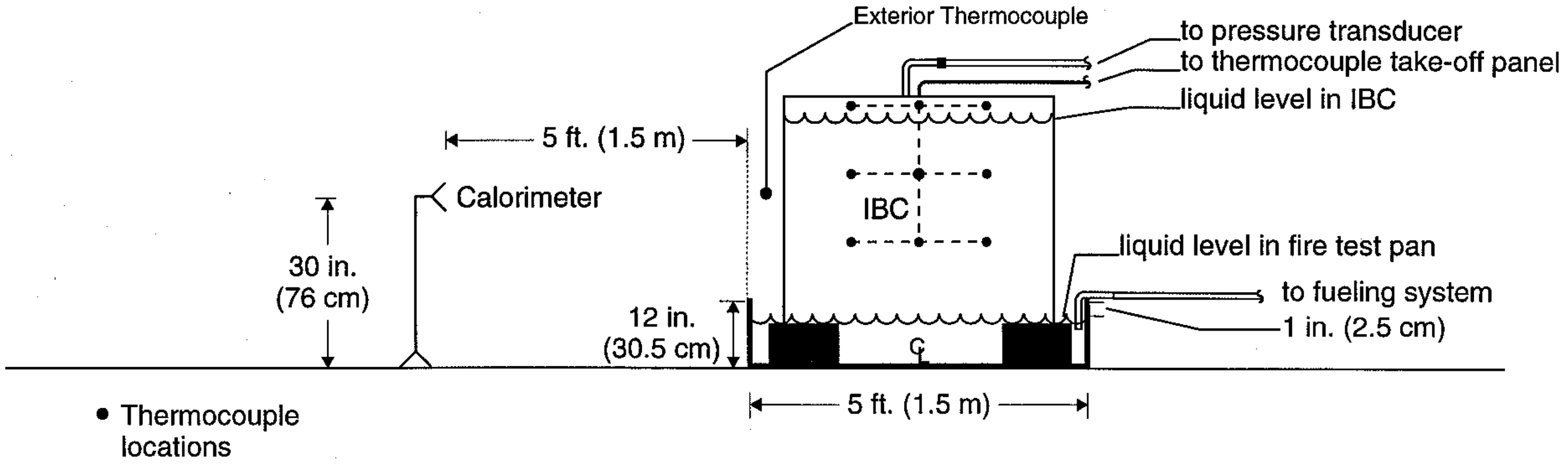
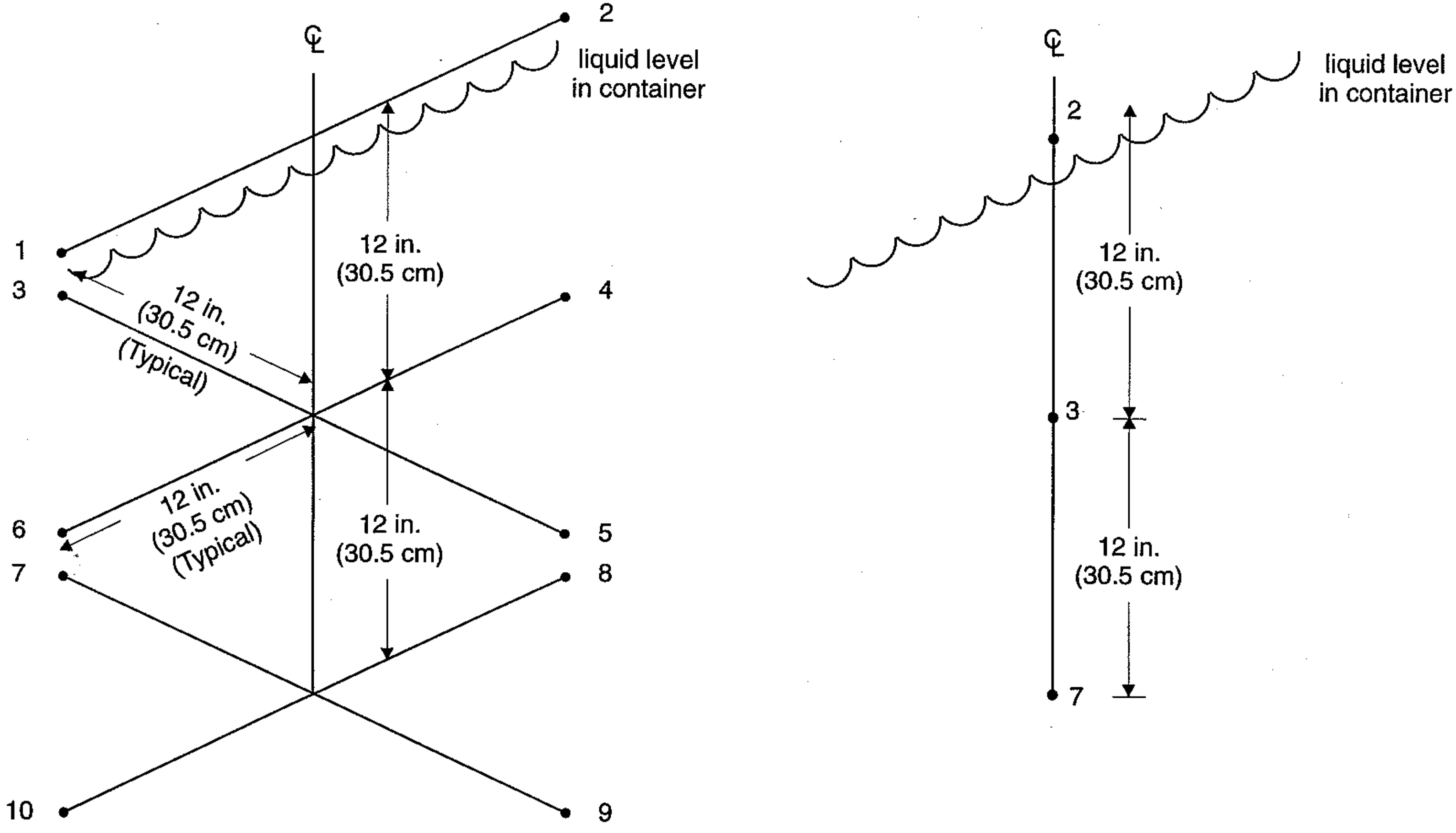


Figure 6 — Section view of test set-up



Full Thermocouple Array
(Tests 1-5)

Reduced Thermocouple Array
(Tests 6-23)

Figure 7 — Internal thermocouple array

After each test, the IBC was removed to outside the test facility for visual inspection.

RESULTS AND DISCUSSION

General Results

Table 3 outlines the fire test results. Included is the test date, time when heptane flow was secured, time to failure, and general comments with respect to the results. Detailed descriptions of individual tests are included in Appendix B. Instrumentation data is included in Appendix C.

Failure mechanisms were defined as a breach in the product area (i.e., liquid flowed out of units) or physical collapse of the unit. Breach in product area was further defined by either:

(1) Failure in the liquid area;

(2) Failure in the ullage, including any failure at the interface of the ullage and the liquid surface which resulted in liquid flow out of the unit; or

(3) Liquid leakage at the valve area.

In the initial tests, there was a problem identifying the appropriate time to secure the fuel. When the plastic started to burn (as indicated by sizzling or hissing as noted in Appendix B), this was initially interpreted as liquid discharging into the pan. This may actually have been boiling/vaporization of water in the fuel layer. Also, dripping of molten plastic sometimes made it difficult to determine when liquid or molten plastic was dripping into the pan.

Table 3. Fire Test Results

Unit	Test Date	Heptane Secured (sec)	Time to Failure (sec)	Failure Mechanism: Breach in Product Area	Failure Mechanism: Physical Collapse	Failure Mechanism: Valve Area	Comments
1	6/3/96	54	89	X	X		metal cage still intact; complete melting of bottle
2	6/3/96	120	NA				unit with blanket did not leak, but did weaken and deform; heptane shut off prematurely
3	6/3/96	87	115	X	X		metal cage still intact; complete collapse of plastic bottle
4	6/3/96	84	1090	X			failure at mid level viewing hole; top melted down
5	6/5/96	260	890	X		X	metal cover over valve at start of test; cover fell off prior to failure
6	6/5/96	10 gal kerosene	98	X			kerosene used for fire; metal cage intact; physical collapse of bottle; no difference due to fuel
7	6/5/96	191	191	X			breach at point where metal stand meets bottle, high stress point
8	6/5/96	179	178	X			pinhole leaks where metal mesh contacted bottle (natural stress points)
9	6/5/96	233	352	X (ullage)		X	leaks at ullage and valve areas - time extended compared to unprotected BM units
10	6/5/96	126	555	X (ullage)	X		initial liquid from top; then general structural failure of unit; individual structural pieces fell off during test
11	6/5/96	300	1106	X			failure at viewing hole
12	6/5/96	300	980	X (ullage)	X		large bulging prior to failure; tipped over, but some liquid leakage from top just prior to tipping; top completely burned off

Table 3. Fire Test Results (Cont'd)

Unit	Test Date	Heptane Secured (sec)	Time to Failure (sec)	Failure Mechanism			Comments
				Breach in Product Area	Physical Collapse	Valve Area	
13	6/6/96	164	170	X	X		breach at viewing holes; after initial breach, unit completely collapsed
14	6/6/96	272	589	X (ullage)	X		liquid from ullage, then structural collapse; top burned away
15	6/6/96	193	1312	X (ullage)			unit sagged and deformed, longest lasting unit although top had melted off at 500 sec; round structure appeared to be an advantage
16	6/6/96	222	515	X (ullage)			bottle did not fail; leak at drybreak gasket
17	6/6/96	229	314	X (ullage)			breach at interface between ullage and liquid; failure at corner stress points
18	6/6/96	300	618	X (ullage)			failure at top
19	6/7/96	139	663	X (ullage)			top melted away; bottle sagged, but kept basic round shape
20	6/7/96	300	672	X (ullage)			unit protected by blanket; leakage from top of unit at corner stress point; small weep holes; heptane self-extinguished due to fuel depletion at 480 sec
21	6/7/96	157	156	X			pinhold leaks in liquid area, then total collapse
22	6/7/96	122	230	X			numerous weep holes
23	6/7/96	289	339	X			horizontal unit; failed at top of unit at stress point where steel saddle intersected base steel support unit

As tests continued, it became clear that extending the duration of the pool fire to 5 minutes was not necessarily required to sustain full involvement of the IBC. The IBC was fully involved as a result of burning plastic (Figure 8). The on-scene test director judged when to secure the fuel based on liquid leakage, involvement of the IBC, or overflow of the pan (based on melting/dripping plastic). The 5-minute duration of fueling remained the default ending time for securing the fuel. It should be noted that dripping/falling plastic actually contributed to reduce burning of the heptane pool fire in some cases. In these situations, a charred plastic seal was formed (see Figure 8, where pool fire area is not burning).

Thin, blow-molded units failed rather quickly (Tests 1 and 3) with leakage from the liquid areas in less than 2 minutes. Ultimately, the units were completely consumed. Protecting these units, in the form of portable protective blankets (Tests 2 and 20) or complete encapsulation (Test 9) dramatically extended the time to failure. Cardboard did not act as an insulator (Test 21). RIM materials (Tests 13 and 19) performed about the same as the blow-molded units. Because of their thicker body construction, rotational molded units showed an increased time to failure (5 to 21 minutes). In particular, units with an outside insulating layer or layers demonstrated the longest time to failure. In many cases, the primary mode of failure for these units was liquid leakage at the ullage/liquid interface or actual physical/structural collapse.

As the fire continued to burn, the ullage would soften (since there was no liquid heat sink in back of it) and ultimately collapse on top of the liquid. In many cases, liquid would start to pour out at the top, or a hole would be created at the liquid/ullage interface (Figure 9). In other cases, there was structural collapse, with the unit tipping over.

The instrumentation data indicated that there was no significant pressure rise in the units. The temperature of the liquid did not rise significantly.

The next sections describe the failure mechanisms and instrumentation data in greater detail.

Figure 8 — IBC fully involved with fire
(Test 15, 6 minutes after ignition)

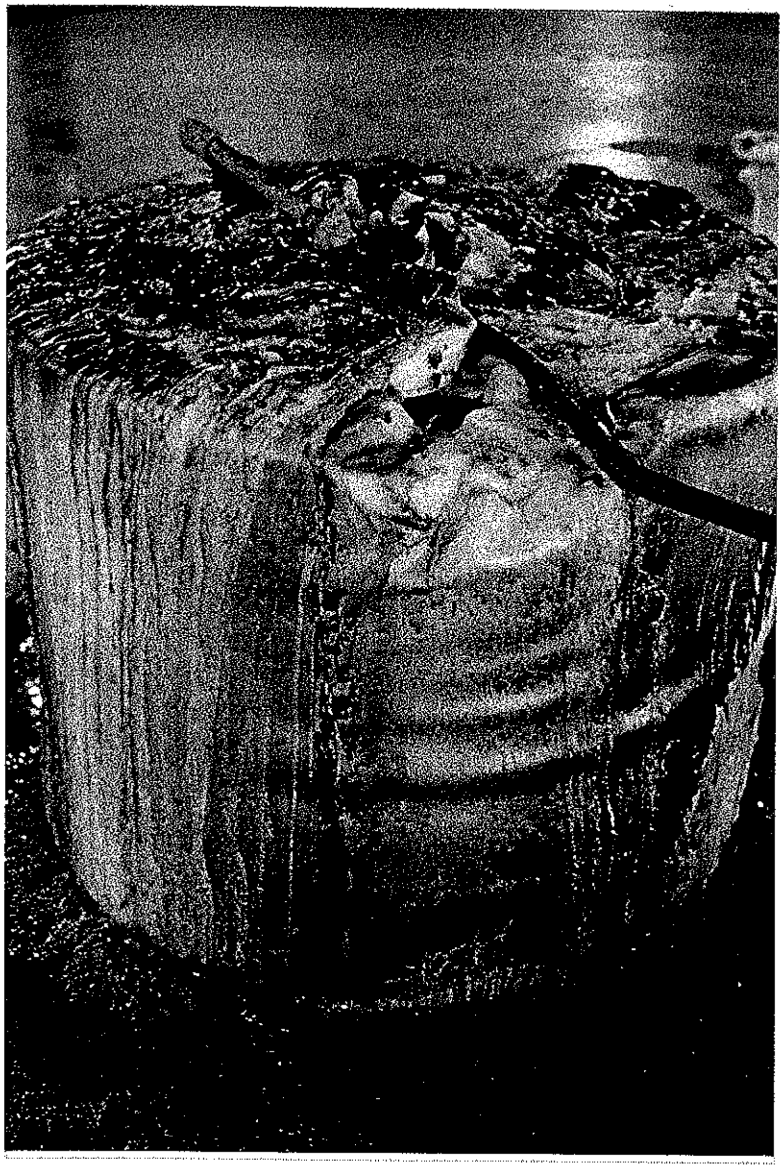


Figure 9 — Holing at liquid/ullage interface
(Unit 15, post-test)

Failure Mechanisms

As described earlier, failure of the units was categorized by a breach in the liquid area, a breach in the ullage which cause liquid to flow, or physical collapse of the unit. Breaching of the liquid area was also identified if it occurred at the valve or valve area (doghouse).

Failure can roughly be characterized as a function of container thickness as shown in Figure 10. This shows that there is a general increase in failure time with an increase in container thickness. Tests 13 and 22, where the RIM material was used, are excluded from the graphical analysis, along with the fiberboard unit (Test 21). This analysis does not distinguish between failure mechanisms (e.g., liquid breach vs. structural collapse). The "outlyers" on the graph, Tests 9 and 20, indicate the improvement provided by a noncombustible shield (not included in the container "thickness").

Failure in Liquid Area

Failure in the liquid area occurred in Tests 1, 3, 4, 5, 6, 7, 8, 11, 13, 22, and 23 as shown in Table 3. Time to failure is relatively rapid (less than 2 minutes) for the uninsulated/unencapsulated blow-molded units which are comparatively thin (Tests 1, 3, and 6). Pinhole leaks at metal/plastic interfaces grew rapidly and multiplied, resulting in complete collapse of the units and discharge of the liquid (Figure 11). Failure times increased for "thin" rotational mold units (Tests 7, 8, 23; failure times 3-5.5 min). Again, the units were susceptible to complete meltdown. The greatest times were recorded for the thick, encapsulated units (Tests 4, 11, 12; failure times 16 - 18.5 minutes). There were some specific "weak links" associated with failures in the liquid area. A common failure mechanism in the liquid area occurred at steel/plastic interfaces, which are typically high stress points (see Figure 12). Other thicker units, which had inherently longer times to failure, breached at viewing holes (Figure 13) located in the outer encapsulating unit (Tests 4 and 11). One of the RIM units also breached at a viewing hole (Test 13). A failure occurred in Test 23 at the saddle/band interface with the bottle, again, a high stress point.

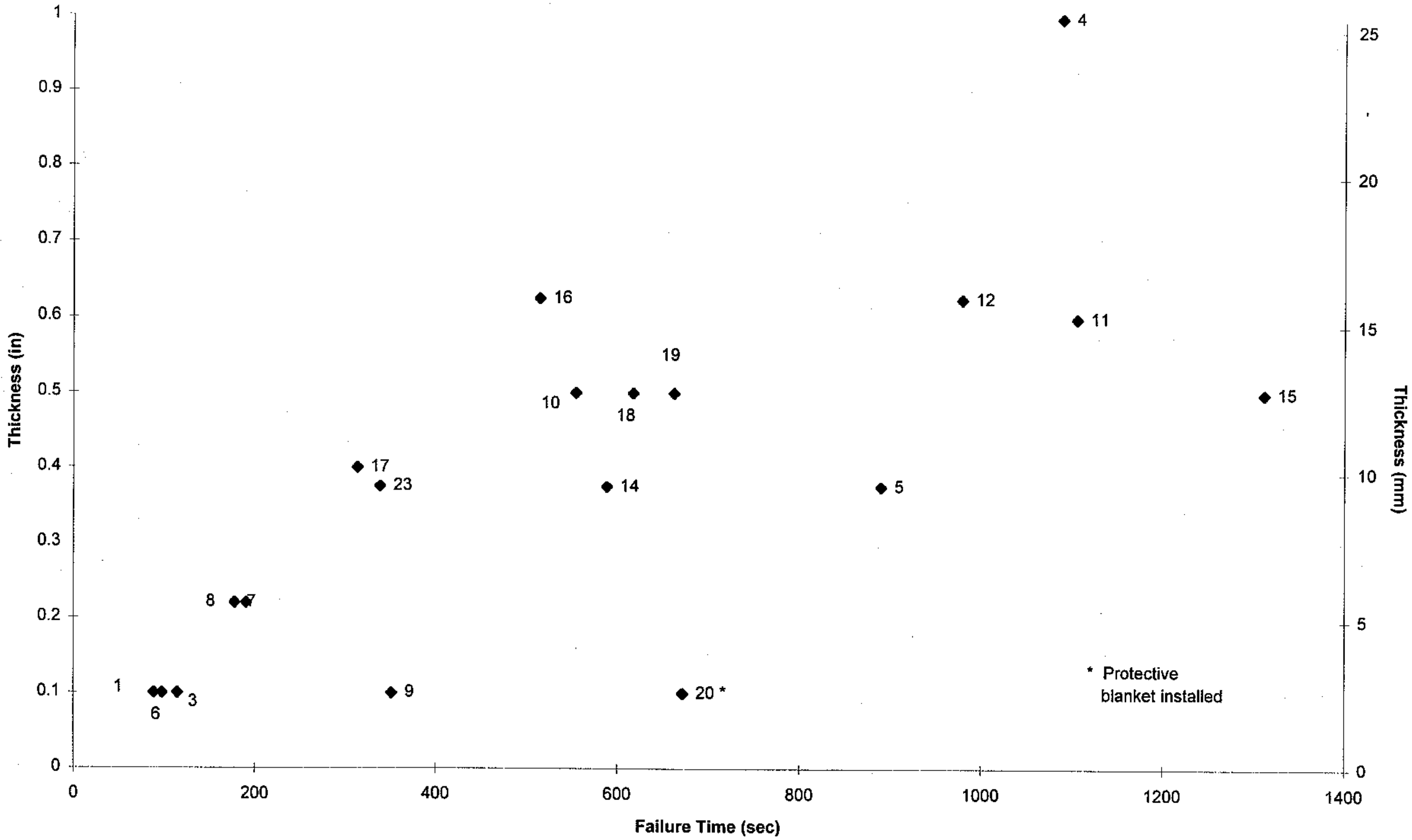


Figure 10 - Comparison of container plastic thickness with failure time

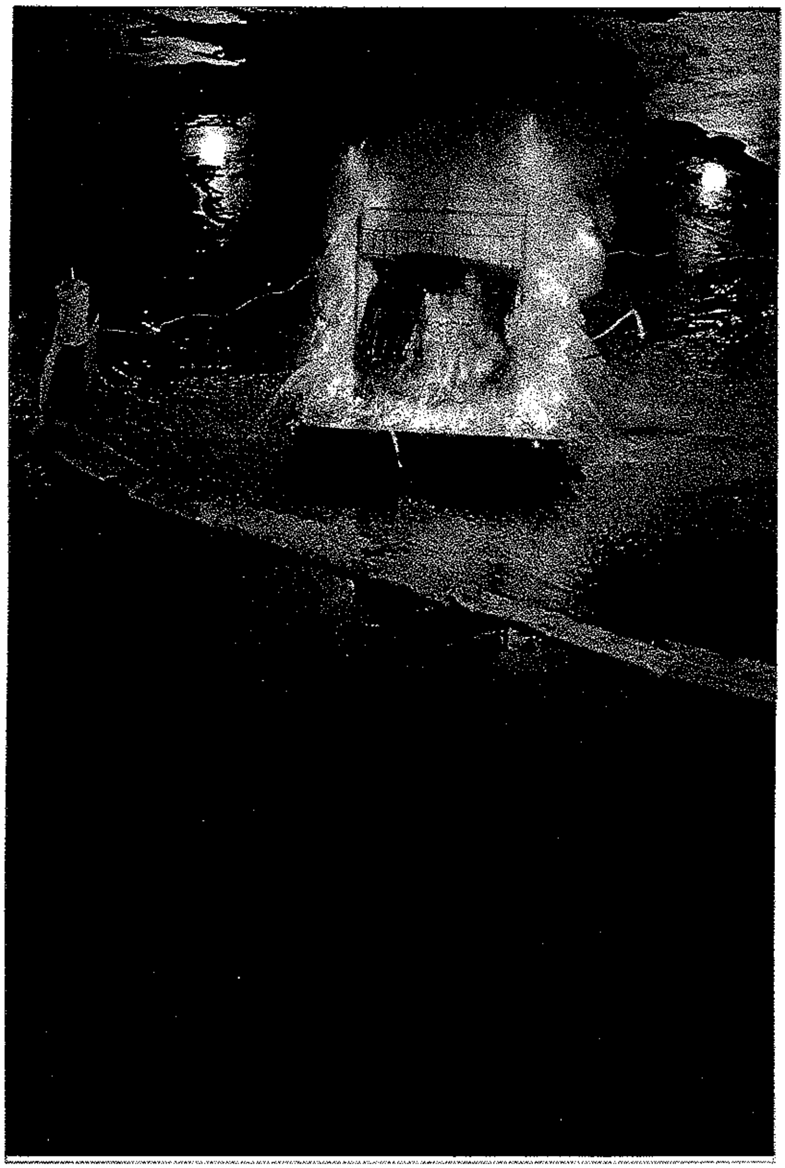


Figure 11 - Failure of unprotected blow-molded IBC
(Unit 6, 2.5 minutes after ignition)

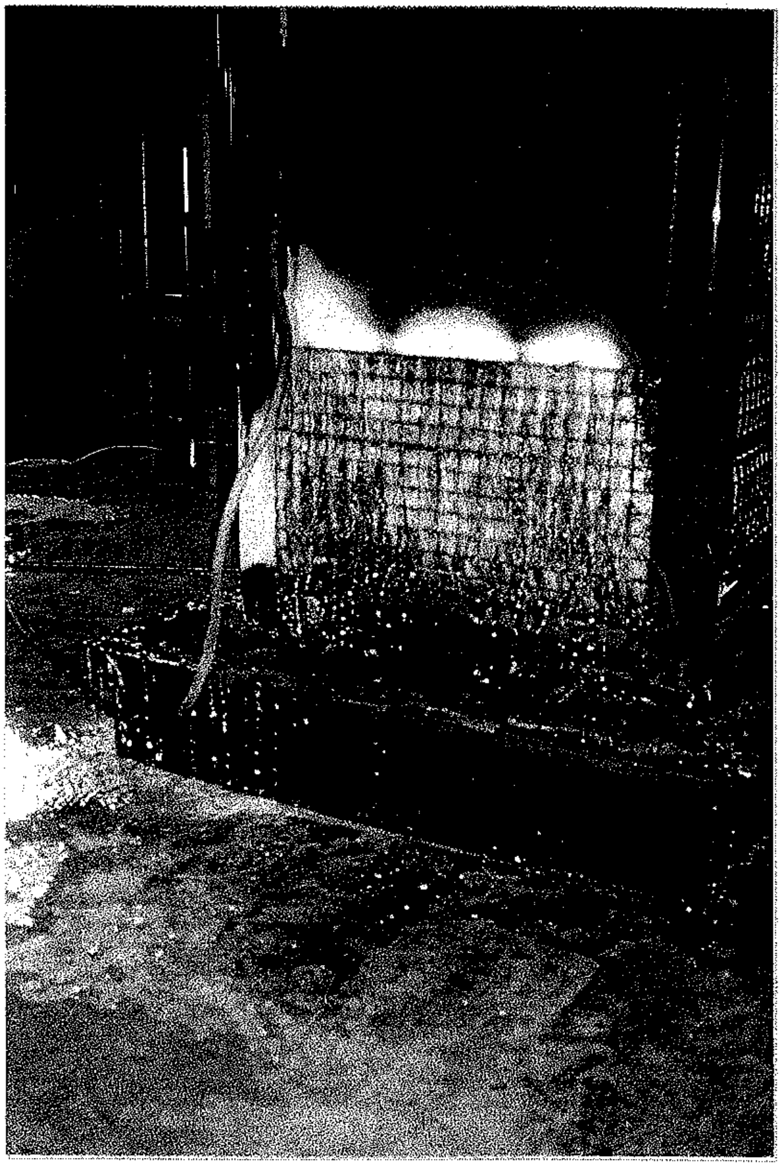


Figure 12 — Failure of IBC at steel/plastic interface
(Unit 8)

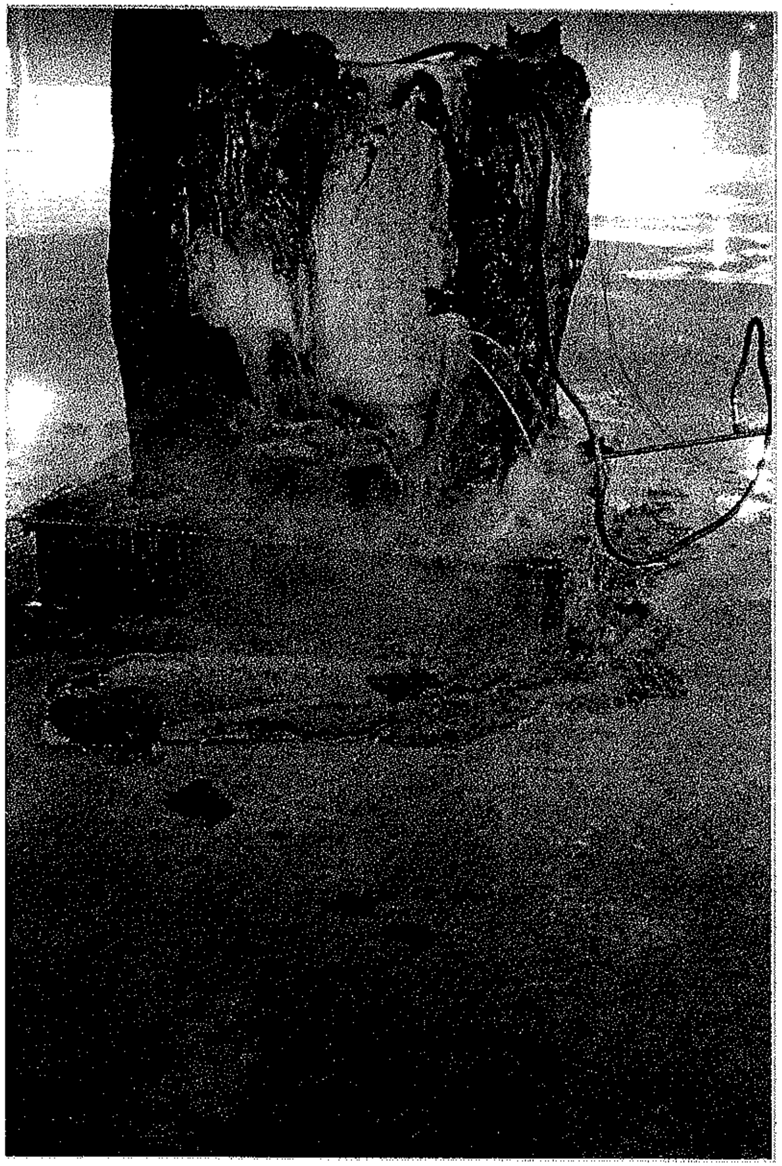


Figure 13 — Failure of IBC at viewing hole area
(Unit 4)

The RIM materials ignited and burned vigorously, resulting in relatively rapid liquid discharge and complete consumption of the unit.

Tests 9 and 20 demonstrated that blow-molded units can be designed to prevent catastrophic discharge of liquid. In Test 9, the unit was encapsulated in non-liquid tight sheet steel (see Figure 4). A small leak in the valve area occurred after five minutes of exposure. After over eight minutes of exposure in Test 20, a blow-molded unit with a protective blanket had just small weep-hole leaks at the top of the unit.

The tests demonstrated that many units can survive a relatively long duration exposure without catastrophic discharge of liquid. Figure 9 shows Unit 15 after 21 minutes of fire exposure/burning. The unit was essentially in-tact, with a hole in the ullage.

Failure in Ullage

Failure in the ullage/liquid interface was characterized by burning of the unit top, melting of the ullage plastic (unprotected by an interior liquid heat sink), and finally a hole/breach at the liquid interface that resulted in liquid discharge out of the container. Tests 10, 12, 14, 15, 16, 17 and 19 were characterized by this failure mechanism. While this type of failure occurred after a substantial time of exposure (9-21 minutes), ignition/melting of the ullage plastic occurred much earlier. Ignition of the ullage top of unit generally occurred during the initial 1-2 minutes of the test. In many cases, a plastic cap at the top of the unit was the first material to ignite (e.g., Test 5 where an LLDPE cap ignited at 138 seconds into the Test). It should be noted that the pressure transducer arrangement (Figure 14) was heavier than a cap alone, resulting in an increased force being applied to the ullage. It is believed that this contributed to more rapid collapse of the ullage. For example, the ullage in Test 20 without the pressure transducer did not exhibit collapse of the ullage as observed in other similar units.

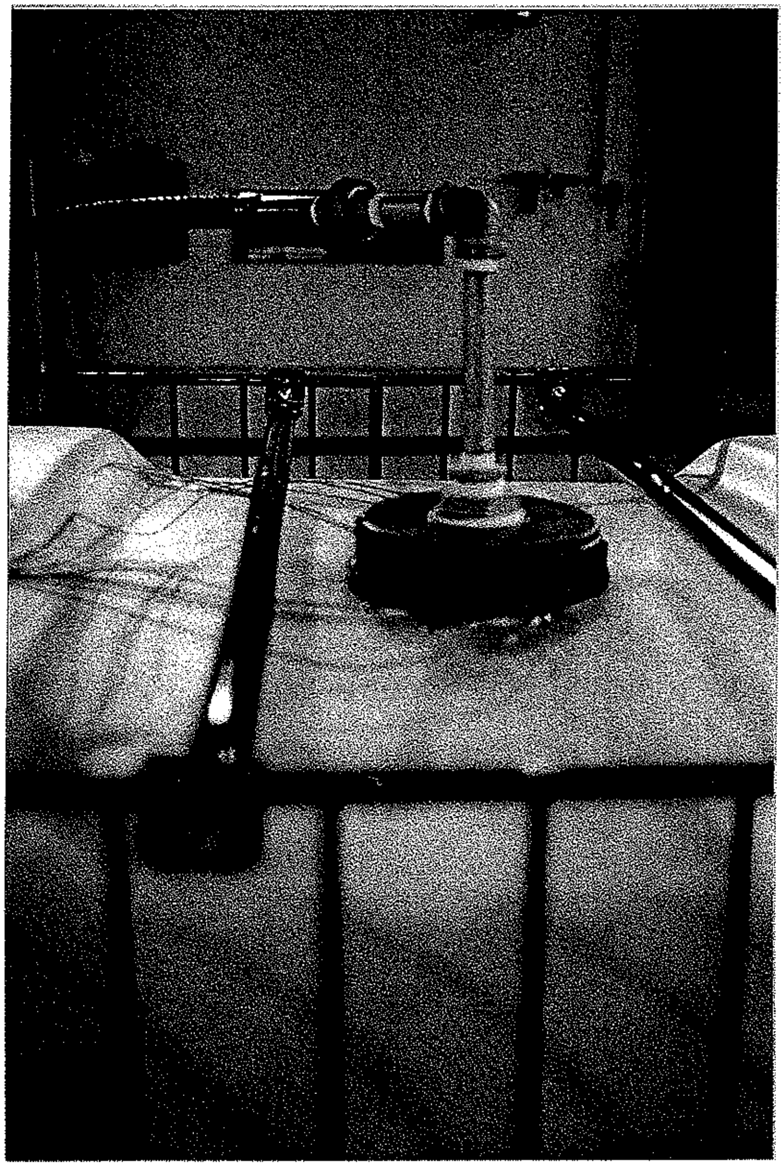


Figure 14 - Pressure tap arrangement (Unit 1)

Valve Area

Prior to testing, the plastic valve was believed to be a weak point which would contribute to failure. Associated with this was the indented doghouse area, which was believed to be susceptible to damage. Previous fire test efforts led manufacturers to improve the doghouse and valve area. For example, in many units, the cushion or base of the unit now extends under the valve. This may help protect valve assembly.

In the tests, failure in the valve area occurred only twice (Tests 5 and 9). In Test 5, failure in the liquid area and the valve area occurred concurrently, nearly 15 minutes into the test. In Test 9, liquid was leaking in the valve area but not in the valve itself. The leak occurred near the top of the doghouse, a high stress area. Figure 15 shows the result of the fire insult to a valve area which did not leak.

Based on the results of these tests, the valve assembly itself was not shown to be a major problem.

Physical Characteristics

Physical factors were identified to investigate possible failure mechanisms. These included the type of polyethylene used (or change to an alternative material, e.g., RIM DCPD), pallet material, and the design of pallet legs (particularly for plastic units). Additional factors included whether the bottle was integral with any outer encapsulating structure, the provision and construction of any cushion material, and protection of the doghouse with a door.

Structural Stability and Collapse

Structural collapse resulted in or contributed to failure in four tests (Tests 10, 12, 13, and 14). In all cases, the units had hollow legs supporting the pallet/unit. In Test 10, there was general structural failure as the unit fell apart. In Test 12, the unit tipped over due to

Figure 15 - Valve area damage with no failure (Unit 8)

failure of a hollow leg. This resulted in liquid discharging from a hole in the ullage near the liquid interface. In Test 14, there was liquid flow from the ullage and then structural collapse. In Test 13, with the RIM material, there was also physical collapse of the unit.

While all units that exhibited structural collapse as a failure mode had hollow support legs, the remaining units with hollow legs failed by other mechanisms. The use of hollow legs in Test 15, 16, 17, 18, 19, and 22 did not result in physical collapse. This difference is attributed to the specific design of individual units. For example, round units appeared to generally perform better than square or rectangular units. Higher stress points are created at corners of square/rectangular units, and these units appear more susceptible to toppling due to the failure of a hollow leg. The truly round units (Tests 15, 16, and 19) all failed at the ullage (see Figure 9). They did not exhibit structural failure. Some of the taller units (height at least one foot greater than the width) also exhibited inherent stability. Tall units (Tests 4, 5, 10, 11, 12, and 15) all had a relatively long time to failure. Units 10 and 12 did tip over, but only after a lengthy exposure (11 and 16 minutes, respectively). These units had greater thickness of materials, which could contribute to the overall stability of the unit.

Other Physical Factor

Besides the general correlation established for thickness (Figure 10), and the issues involving hollow legs/configuration, no other failure mechanism trends were identified. Different types of plastic material were identified (LLDPE, HDXLPE, HMW/HDPE, RIM). No specific trends inherently related to different plastics alone were identified. The manufacturers indicated that low density PE is more flexible and exhibits less crystallization when produced. The melting point of these materials is on the order of 215°F (102°C). High density PE has a more crystalline structure and exhibits a higher melting point (250°F (121°C)). LLDPE, with a density of 0.93 lbs/cm^3 (42.18 g/cm^3), tends to have a melting point toward the higher end of the range. Cross-linking (HDXLPE) results in crystalline structures up to the melting point, but it does not flow above the melting point. This may give it a slightly better inherent resistance to high temperature. There are essentially no differences in the inherent heat of combustion of the PE products.

Pallet material was a factor only in those plastic structures which exhibited collapse. Wood and steel did not appear to contribute to the overall failure mechanisms observed. No correlations were observed between units where the bottles were an integral part of the overall structure compared to units where the bottles were essentially independent of the outer structure.

Doghouse protection, as noted earlier in the valuation of valve area failures, did not appear to be an important factor. There was no apparent positive or negative effect of having a doghouse door to protect this area. Plastic doors, where provided, melted and fell off. No trends were observed with the provision or construction of cushion materials.

Fire Characteristics and Temperature/Pressure Response

Instrumentation data is summarized in Table 4. All data is presented in terms of activity before failure as defined in Table 3. The summarized data includes total heat flux as measured 5 ft (1.6 m) from the edge of the test pan, pressure rise in the ullage, and ullage and liquid temperature. Data for the pressure and ullage temperature include the test time when the maximum readings occurred.

Exposure of IBC

The fuel flow rate to the test pan averaged 1.8 gpm (6.8 ℓpm). For a free burning scenario, this would equate roughly to a 4 MW fire. Because of the restrictions in the fuel surface, the actual rate of heat release was probably lower.

The maximum total heat flux ranged from 14 - 57 kW/m^2. This can be used to approximate the heat flux to the IBC. This is somewhat less than typical "thick" flame heat fluxes, which are on the order of 100 kW/m^2. This is reflected in the exposure temperatures recorded, which generally were in the range of 1000° - 1500°F (537 - 816°C). It is expected that running fuel fire scenarios may result in short duration exposures greater than those observed in these tests, but suppression systems will be designed to address this scenario.

Table 4 - Pressure and Temperature Data

		Pressure			Ullage Temperature		
Test	**Maximum Heat Flux** (kW/m^2)	**Maximum Pressure** psi (Pa)	**Time for max pressure** (sec)	**Duration of Positive Pressure** (sec)	**Maximum Ullage Temp** °F (°C)	**Time for max temp** (sec)	**Maximum Liquid Temp** °F (°C)
1	No data	0.027 (186.2)	12-39	0-61	125 (52)	87	69 (21)
2	No data	0.0016 (11.0)	21	0-81, 306+	112 (44)	189-204	74 (23)
3	No data	0.015 (103.4)	6-9	0-42	134 (57)	99	72 (22)
4	No data	0.004 (27.6)	483	0-483	319 (159)	466	85 (29)
5	28	0.009 (62.1)	0	0-21	246 (119)	303	74 (23)
6	19	0.027 (186.2)	98	0+	66 (19)	89	64 (18)
7	14	0.0034 (23.4)	21	0-191	72 (22)	185	66 (19)
8	15	No data	No data	No data	83 (28)	174	69 (21)
9	No data	No data	No data	No data	149 (65)	305	94 (34)
10	No data	No data	No data	No data	353 (178)	468	95 (35)
11	21	0.006 (43.4)	63	0-72, 108-762	109 (43)	565	120 (49)
12	23	0.002 (13.8)	202	0 - 980	931 (499)	838	69 (21)
13	42	0.0086 (59.3)	43	0-144	124 (51)	135	101 (38)
14	19	0.027 (186.2)	552	0-303	167 (75)	267	74 (23)
15	28	0.0013 (9.0)	24	0-297	No data	No data	No data
16	33	0.005 (34.5)	300	0-198	78 (26)	354+	73 (23)
17	23	0.0001 (0.7)	153	0-216	68 (20)	300	74 (23)
18	28	0.006 (41.4)	207	0-207	89 (32)	594	68 (20)
19	57	0.027 (186.2)	255	0-360	89 (32)	345	72 (22)
20	38	No data	No data	No data	68 (20)	460	82 (28)
21	47	No data	No data	No data	65 (18)	constant	67 (19)
22	52	No data	No data	No data	145 (63)	188	94 (34)
23	57	No data	No data	No data	216 (102)	339	67 (19)

*** All data before failure**

The profiles of the heat flux and exterior temperature mirror the individual fire conditions. As such, they do not follow a constant pattern. For example, some units burned vigorously for several minutes, and then died down as plastic covered the exposing fire. The most consistent results occurred when the plastic fuel from a unit was not involved, e.g., Tests 2, 8, 20 and 21.

Test 20, where a protective blanket was used, shows that when there was a full five minutes of fuel flow, the residual fuel burned for an additional three minutes of full burning for a total exposure of eight minutes. As noted earlier, several tests were required to establish appropriate fuel flow procedures. In any event, when exposed plastic in heavy walled IBCs (e.g., rotomolded) was subjected to the fire, it rapidly ignited and burned at heat release rates well above the exposure fire (see Figure 8). Thin walled IBCs (e.g., blowmolded) did not generate a significant plastic fire because of the heat sink provided by the liquid lading. These units, however, melted rapidly where unprotected. Even with relatively long times to failure, all plastic IBCs will require protection designs that address the potential involvement and fuel contribution of the unit itself.

The results of Tests 1 and 6 were nearly identical, indicating no variation between the diesel fuel and heptane for these exposure tests.

Pressure Rise

Pressures which would potentially jeopardize the container integrity were not observed. A very low pressure range transducer (± 0.027 psi, 186 Pa) was used. In only 4 tests (Tests 1, 6, 14, and 19) was the range exceeded, and there was no evidence that pressure ever came close to the design pressure of the units (typically 14.7 psi, 100 kPa).

Typically, where there was a measurable pressure rise in the container (e.g., 0.005 - 0.01 psi), there was subsequently an inversion of the pressure characteristic to negative. This may have been a result of expansion of the bottle creating a vacuum in the ullage. It is unlikely that the negative pressure characteristic was a result of a breach in the container, which should result in an ambient reading. Specific pressure data in Appendix A might be used to judge when holing occurred in the ullage. For example, in Test 17, there was leakage from the unit at 314 seconds. This tracks with the pressure data returning to ambient (see Figure C79).

Rigid plastic IBCs are inherently self-venting due to softening or melting of the plastic structure or fill caps. Generally, this melting occurred where there was no liquid, e.g., at the ullage or fill cap.

Collapse of the top of the IBC unit probably effected pressure data. Where this occurred, the pressure transducer tap was subject to immersion in the liquid. Pressure data should be carefully reviewed in view of the specific test and physical response of the unit to the fire (see Appendix B descriptions).

Ullage Temperature

Again, general characteristics of the ullage temperature must be considered with regard to the physical response of the individual units. Ullage temperatures, before the failure criteria was achieved, ranged from 65 - 931°F (18 - 499°C). No direct correlations can be made using this data. For example, temperatures were maintained below 100°F (38°C) in Tests 6, 7, 8, 16, 17, 18, 20, and 21. There is no trend related to failure times. There were relatively quick failures (e.g., 3 minutes or less; Tests 6, 7, 8, and 21) and longer times to failure (e.g., greater than 8 minutes, Tests 16, 18, 19 and 20). Where ullage temperatures exceeded 200°F (93°C) at the time of failure, failure times again were mixed. Tests 4 and 5 represented two of the best units in terms of failure criteria, but clearly the tops were involved well before failure (see Appendix C, Figures C14 and C19). When tops started to collapse, this sometimes caused the ullage thermocouple array to collapse into the liquid. This is reflected in the data when temperatures rapidly dropped. Ullage temperatures are more closely related to top burning characteristics than liquid temperature rise.

Liquid Temperature

Internal liquid temperatures ranged from 66-120°F (19-49°C). Generally temperatures remained at or near ambient. All but 6 units (Tests 4, 9, 10, 11, 13 and 22) remained below 85°F (29° C). Units 4 and 11 were long duration tests (greater than 18 minutes). Tests 13 and 22 involved the RIM material.

SUMMARY AND CONCLUSIONS

Twenty-three IBCs, representing a broad spectrum of the commercial market, were subjected to a pool fire exposure. Time to failure, i.e., for liquid to discharge from the units, ranged from approximately 1.5 minutes to over 20 minutes. Rapid catastrophic failure, i.e., rapid discharge of the container, was an infrequent occurrence. Relatively thin, unprotected blow-molded and RIM IBCs experienced the most rapid failure in terms of time to breach the container and discharge of large quantities of liquid. It was demonstrated that prevention of rapid failure of blow-molded units, along with containment of the liquid, could be achieved by providing portable or *in-situ* encapsulation.

IBCs generally failed as a function of the thickness of the plastic container. The modes of failure, however, did not necessarily correlate as a function of thickness. The most common failure modes involved small leaks in the liquid area at inherent stress points (e.g., metal/plastic interfaces) and holing at the ullage/liquid surface interface. There were several instances of structural collapse, always involving units with hollow plastic legs. Other units with this design feature did not result in structural collapse, suggesting that other features also contribute to structural stability. For example, round units appeared to be inherently more stable than square or rectangular units. None of the composite IBCs with metal structural support frames suffered structural collapse. Failure at the valve mechanism was not a problem in these tests.

No significant pressure or liquid temperature rise was observed. Self-venting characteristics of units provide inherent pressure relief. The ullage temperatures recorded in these tests tracked more closely with combustion of the top of the container, rather than from any temperature rise of the liquid.

These tests allowed manufacturers to observe the response of IBCs to a severe fire insult with the anticipation that additional design improvements may be made to individual units. The ability to prevent catastrophic discharge of liquid from encapsulated blow-molded IBCs, and the inherent insulation provided by thicker rotational molded IBCs, suggests that warehouse designs can be developed to protect liquid-filled IBCs. The inherent combustibility of most of the units must be addressed in these designs. It is appropriate to continue development work in this area. Multiple/stacked units, type of liquid stored, warehouse ceiling height, and three-dimensional exposure fire scenarios should be considered with respect to protection system design development.

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APPENDIX A

Literature Review

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APPENDIX B

Individual Test Summaries and Observations

Individual Test Summaries

Test/Unit # : 1

Date of test: 6/3/96
Approx time of day: 10:10 a.m.

Time (sec)	Observation
0	Ignition
54	Heptane off
89	First breach, left side, large water stream
104	Second breach, right side, large water stream
105	Plastic sagging as water level drops
143	Unit has sagged to 2/3 height
168	Unit has sagged to 1/2 height
210	Unit has sagged to 1/3 height
231	Partial fire die down
255	Fire extinguished

Description of failure: First breach approx 1 ft above base on left side, failed at the mesh line, soon had failure on right side; physical collapse of bottle

Additional notes: Mesh cage still fully in tact; after breach, as water leaked, plastic sagged, water level appeared to be related to plastic failure; cap used for pressure tap was not the cap supplied with the unit

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Test/Unit # : 2

Date of test: 6/3/96
Approx time of day: 12:00 p.m.

Time (sec)	Observation
0	Ignition
47	Blanket burning off
60	Covering sinking in
79	Burning at top
103	Hissing and crackling
120	Heptane off
140	More crackling
153	Heptane disturbance
224	Heptane burn out at back corner
251	Most heptane out, burning out at top
449	Top fire out, self extinguished; some burning at bottom
600	Fire out; self extinguished

Description of failure: Unit melted down above water line (heat sink effect of water); unit did not leak

Additional notes: Right side had hot metal, started to effect right side, began to fray; post-test inspection indicated that unit probably would not have lasted much longer; undetermined flaming material was at top; upon removal of cover, steel grids appeared to be melting plastic, but not through; blanket seemed to be very effective in comparison with Test 1; no damage to valve

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Test/Unit # : 3

Date of test: 6/3/96
Approx time of day: 2:10 p.m.

Time (sec)	Observation
0	Ignition
67	Hissing*
87	Heptane off
89	Crackling*
95	Small leak audible
110	Larger breach on front panel
115	Front breach; small leak at front right, bulging around corner
142	Top cave in
147	Big rupture on left side, left front corner
150	Heavy flow out on left
175	Unit reduced to 1/2 original size
225	Plastic with water level
260	Fire extinguished

Description of failure: Failure at left side, second at front right; physical collapse of plastic bottle

Additional notes: Fire seemed to lean left; after water began leaking, plastic sagged; *hissing and crackling sounds may have been due to boiling of water droplets dispersed in the heptane layer, or alternately, boiling and burning of heptane droplets dispersed in water layer.

Test/Unit # : 4

Date of test: 6/3/96
Approx time of day: 3:10 p.m.

Time (sec)	Observation
0	Ignition
45	Fire leaning to left side of unit
84	Heptane off
90	Hissing; top on fire
100	Some bulging and sagging
136	Hissing, molten plastic hitting water
140	Top very involved in burning
210	Leaning left
232	Heptane out; water boiling; plastic fire; tank settled
284	Molten plastic; unit weakening, melting
380	Outer right bulging
480	Top on fire; unit leaning left, but fire still favors left side
600	Continued molten plastic; unit is melting
660	Unit deformed
740	Unit is sagging, falling, buckling
780	Fire now favors right side; left side clear
840	Top has not melted out
900	Plastic or water overflow
936	Top, right piece fell off, fire on right side
1090	Water breach approx 2 ft up right front corner; small weep holes; plastic sagging and melting away at breach
1122	Second liquid stream
1140	Fire extinguished

Description of failure: Holing at top; failure at mid level viewing hole; overall weakening and deformation of unit due to melting of plastic throughout test

Additional notes: Even though the heptane was secured at 232 seconds, fire remained from plastic fire

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Test/Unit # : 5

Date of test: 6/5/96
Approx time of day: 7:30 a.m.

Time (sec)	Observation
0	Ignition
45	Flaming between outer and bottle
90	Hissing
117	Unit settling
138	Flaming at top outlets, flame favoring right
210	Hotter fire; burning plastic; top well involved
260	Heptane off; plastic dripping; loud noise
317	Flame height 2X unit height
300-360	Pressure tap dropped down
330	Top collapsing
332	Heptane 90% out; unit totally engulfed
360	Splitting outer plastic; unit weakening
420	Top mostly collapsed
460	Top on fire; bottom fire mostly out
540	Tall flames from top
810	Crackling; top, front valve area, and right bottom corner on fire
890	Water breach on right side
895	Water dripping at valve area
915	Extinguished

Description of failure: Breach at right panel; failure at valve

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Test/Unit # : 6

Date of test: 6/5/96
Approx time of day: 9:10 a.m.

Time (sec)	Observation
0	Ignition
30	Crackling; intense fire and smoke
60	Plate burning, front
98	Breach on left side approx 18" up at edge
102	Breach on right side
120	Leak at right rear; bottle deforming
150	Bottle settling and deforming
222	Test over, fire self extinguished

Description of failure: First breach approx 18" up on left edge; second breach on right side

Additional notes: Diesel fuel used, intense and smoky fire; As water leaked, plastic melted and sagged; at end of test, bottle was completely settled and almost totally melted

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Test/Unit # : 7

Date of test: 6/5/96
Approx time of day: 10:25 a.m.

Time (sec)	Observation
0	Ignition
39	UN plate off
58	DOT plate off
80	Pressure tubing on fire
110	Burning at edges
130	Hissing, plastic hitting water
151	Cap burning
191	Heptane off; breach, weep holes develop where metal stand meets bottle; leak at center
192	Multiple leaks at front face
230	More pinholes at metal/plastic interface
265	Good plastic fire, fully involved; many small leaks
300	Leaks out of bottom
335	Lots of small leaks, random pattern; plastic mostly melted
380	Fire extinguished

Description of failure: Failed at high stress point; breach at point where metal stand meets bottle

---

Test/Unit # : 8

Date of test: 6/5/96
Approx time of day: 11:25 a.m.

Time (sec)	Observation
0	Ignition
60	Lots of fire in doghouse area, burning between metal and bottle
117	Crackling and popping
143	Unit fully engulfed; hissing
164	Louder crackling and hissing
178	Pinholes on backside; leakage
179	Heptane off
200	Splitting plastic; unit weakening
219	Top down significantly
269	More pinhole leaks on different sides
300	Water leak from pan; heptane burning down
383	Fire extinguished

Description of failure: Weep hole breach approx 18" above bottom on mesh grid, back side

Additional notes: Unit resisted fire, took long time to catch on fire

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Test/Unit # : 9

Date of test: 6/5/96
Approx time of day: 1:30 p.m.

Time (sec)	Observation
0	Ignition
120	Nothing obvious, top cap tilted
160	"Sounds" like water, but unconfirmed
194	Fire at edge of fuel pan
215	Growing fire; totally engulfing unit
220	Hissing; audible (plastic/water)
233	Heptane off; breach on top; crackling; cap burning
270	Top caps well involved
343	Some bulging at sides
352	Water leaking at valve; fire burning down
450	Fire died down

Description of failure: Some leaks at top; failure at valve location; no catastrophic dumping of liquid as observed in unprotected blow-molded units

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Test/Unit # : 10

Date of test: 6/5/96
Approx time of day: 2:55 p.m.

Time (sec)	Observation
0	Ignition
30	Fire in doghouse
71	Plastic hitting water
93	Plastic spitting out; unit melting at top and sides
126	Heptane off
180	Fully involved; unit totally on fire, melting, falling plastic
194	Pressure tap falls off
195	Loud noise
210	Outer shell melting
240	Top melted off
268	Pool fire out; unit on fire; intensity down
360	Unit burning and melting slowly
447	Outside supports collapse
480	Back support off
516	Pillar falls
540	Fire intensity down
555	Water at bottom of sump; running off top
600	Pillar falls
640	Tipping severely
610	Unit settling and buckling at bottom
655	Unstable, unit falls and spills
665	Fire extinguished

Description of failure: Liquid from top ullage area, then general structural failure of unit, unit fell apart and tipped over

---

Test/Unit # : 11

Date of test: 6/5/96
Approx time of day: 3:55 pm

Time (sec)	Observation
0	Ignition
30	Unit ignited
147	Bottom right hole has fire
165	Intense, hot fire
180	Fire between bottle and outer; melting plastic falling off unit
221	Molten plastic obvious at doghouse
300	Heptane off; plastic displacing heptane on right side
330	1/2 door at doghouse off
460	Fire intensifying on front, right, rear; no fire on left
613	Intense fire; flame height 2X height of unit
720	Top fully involved
735	Leaning left
760	Door fell off
780	Fully involved, all sides
900	Molten plastic
960	Top fire intense
1050	Unit very molten; leaning left
1090	Bulge at right; peeling side
1096	Right, front edge panel fell off
1106	Weep breach
1110	Water leak, right front; unit falling apart
1130	Fire extinguished

Description of failure: Failure at viewing hole approximately 22 in. above bottom; weep breach; general weakening of structure

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Test/Unit # : 12

Date of test: 6/5/96
Approx time of day: 5:40 p.m.

Time (sec)	Observation
0	Ignition
60	Boiling noise
120	Top well involved
157	Fuel surface die down; front left and right
195	"Waterfall" of plastic at front left and doghouse
210	Unit totally engulfed; molten plastic falling from unit
254	Cap flew off (or some material) approx 7 ft away
270	Noticeable deformation and bulging on both sides
300	Heptane off
353	Buckling out at bottom
360	Large bulging approx 1 ft from base on both sides
408	Molten plastic increasing; unit melting
461	Fully involved (has been); little fire in pan; continued spitting
540	Fire continues strong; unit weakening
660	Slight die down (sound and flame height)
780	Definite die down
825	Urethane starting to peel from top front; unit sagging at top center
900	Fire at top and bottom, middle not much
952	Leaned left; water spilled from top
960	Sagged over; some water leaked from top
980	Tipped over completely to the left
990	Fire extinguished

Description of failure: Structural failure, unit tipped; top ullage area had completely burned off

---

Test/Unit # : 13

Date of test: 6/6/96
Approx time of day: 8:15 a.m.

Time (sec)	**Observation**
0	Ignition
30	Unit mostly engulfed
35	Sizzling sound
56	Top sagging in middle
60	80% involved; plume 2X unit height
81	Very involved; dark, black smoke
120	Molten plastic
130	Material falling out of pan; hottest fire by far
164	Heptane off; failure 2/3 up face at view holes; breach upper front area
170	Leaks springing all over unit
200	Structural failure; total collapse of unit into pile of molten plastic; complete cave in
220	Collapsed unit continues to burn and melt
234	Fire extinguished

Description of failure: Breach upper front area at viewing holes; total structural collapse; once initial breach occurred, unit completely failed structurally

Additional notes: Unit not at all resistive to fire; burned quickly

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Test/Unit # : 14

Date of test: 6/6/96
Approx time of day: 9:50 a.m.

Time (sec)	Observation
0	Ignition
50	Black base ignited
75	Starting to sizzle; doghouse door off
100	Flames out of valve area
150	Well involved;
170	Unit totally engulfed
178	Top ullage area (air) breach; melt down
200	Top on fire
240	Bottom right melting
254	Bulge at right bottom
270	Unit tipped right
272	Heptane off
300	Unit tipping, but still no spilling or leaking; left bottom corner melting
311	Bulging at right and center
330	Middle sagging; sides bulging slowly
340	Holes obvious at top
360	Top middle cave in; molten plastic at top; sides bulging
390	Unit slowly caving in and melting
400	Top almost completely burned away
480	Unit stable, but very deformed; still no leaks
580	Top very involved
589	Water from top on right front
600	Unit very deformed; bulging
687	Spitting
690	Buckling at both sides near base
696	More off top
700	Collapsed down
711	Leakage
720	Fire extinguished

Description of failure: Liquid from ullage, then collapse

Test/Unit # : 15

Date of test: 6/6/96
Approx time of day: 11:25 a.m.

Time (sec)	Observation
0	Ignition
60	Sizzling
75	Top started to burn
120	Fully involved; flame height 3X unit
150-165	Top deformation; bulging
180	Top melting off; oozing over sides
193	Heptane off
199	Top fell into fuel
210	Top completely melted away; sides deforming
230	Sign of die down; base, top and small pool
325	Increase due to increase pool size; heptane burning through melted PE
480	Top down to water level, but still PE there to confine liquid
500	Liquid at top, but not discharging
615	Fire favoring right side
720	Melted down; slumping; bottom flattening out
840	Fire shifted to left side
990	Left side self extinguishing; fire on right side
1040	Right side dying out; tilting left a little
1200	No liquid; breach at top; small fire at bottom
1305	Self righted
1312	Liquid leaked from top; melted transducer hose

Description of failure: Breach at top; leakage from top; apparent advantage of round bottle/structural stability

Additional notes: Fire self extinguished at end of test

Test/Unit # : 16

Date of test: 6/6/96
Approx time of day: 2:05 p.m.

Time (sec)	Observation
0	Ignited
60	Sizzling
85	Well involved flame height 2-3X unit height
177	Lowered; sagged and buckled
197	Sides peeling away; "artichoke" effect
222	Heptane off
225	Tank tipped left; still fully engulfed; molten plastic
230	Plastic upper fire; top piece (drybreak) completely separated from outside; still attached to tank
303	Significant die down; down to sphere bottle; leaning forward
420	More die down
433	Holes visible in top; flames coming through
515	Water dripping out; drybreak at bottle/neck interface
550	Fire extinguished

Description of failure: Bottle did not fail; leak at gasket

Test/Unit # : 17

Date of test: 6/6/96
Approx time of day: 3:56 p.m.

Time (sec)	Observation
0	Ignition
60	Sizzling; PE involved
127	Flaming at top edge, cap and center
170	Well involved; flame height 2.5X unit height
229	Heptane off
230	Some bulging at sides
270	Base going down fast
297	Starting to lean right
305	Top sagging at center
314	Leak at interface of ullage and liquid line
330	Fire extinguished

Description of failure: Failure quicker than expected; breach at interface between ullage and interface; failure at corner stress points

Additional notes: Very hard to extinguish because fuel was entrapped below collapsed base; doghouse door fell off during test

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Test/Unit # : 18

Date of test: 6/6/96
Approx time of day: 5:20 p.m.

Time (sec)	Observation
0	Ignition
108	Unit totally engulfed
180	High flames, at least 2X unit height
223	Fully involved; flame height 2.5X unit; base melting
259	Top "ears" collapsing, top slowly caving in
300	Heptane off
385	Fire dying down; mostly top and base on fire
410	Bulging sides
420	Top deforming; molten plastic
450	Bottom collapsing; buckling; unit getting shorter
540	Unit engulfed; bulging sides; buckling at base
618	Water leakage; from top, right back; fire shifted left
627	Leakage failure
640	Fire extinguished

Description of failure: Breach, leakage from top; fuel entrapped below collapsed base

---

Test/Unit # : 19

Date of test: 6/7/96
Approx time of day: 8:25 a.m.

Time (sec)	Observation
0	Ignition
60	Hissing; starting to spit
91	Loud crackling; spitting
100	Edge burning; top edge igniting
130	Flame height 2.5X unit
139	Heptane off
172	Bottle exposed on bottom
185	Die down; top fell on fire; dampened fire
265	Starting to lean left; top on fire
331	Left side has most burning
360	Molten plastic
372	Left side top melted down; base essentially melted down; water leakage at transducer hose; no stress on bottle
460	Top deforming and melting away
478	Top "donut" 90% gone; burning on top
530	More total involvement; envelopment
578	Mostly bottle left
600	Unit weakening
663	Water leakage out of front
680	Fire extinguished

Description of failure: Leakage from front breach where bottle flattens out

---

Test/Unit # : 20

Date of test: 6/7/96
Approx time of day: 9:50 a.m.

Time (sec)	Observation
0	Ignition
55	Burning at top edges left and right; apparently heptane vapor burning at needle holes in blanket seam
60	Some bulging of blanket at side
159	More burning; no hissing
201	All top edges burning, apparently heptane vapor burning at needle holes in blanket seam; higher intensity
270	Much less intense fire overall
300	Heptane off
380	Good fire; even burning around unit
400	Fire at edge of pan
471	Crackling
495	Heptane die down
62	Sign of die down; level of water is OK
580	Die down; only base and top on fire
600	Fire on top dying down, very small
610	95% fire out; burning at left back only
672	Leakage observed
710	Fire essentially out
713	Small flame; attached to pallet
734	Water leaking

Description of failure: Leakage, from small weep holes at top of unit

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Test/Unit # : 21

Date of test: 6/7/96
Approx time of day: 12:00 p.m.

Time (sec)	Observation
0	Ignition
36	Cardboard peeling
55	Well involved
60	Cardboard peeling, splitting, crumpling off
85	Pieces of cardboard falling off
113	Sizzling
156	Breach, pinholes
157	Heptane off
170	Large pieces of cardboard flying off
175	Full collapse
200	Fire extinguished

Description of failure: Failure at front approx 18" up, then full collapse

---

Test/Unit # : 22

Date of test: 6/7/96
Approx time of day: 1:25 p.m.

Time (sec)	Observation
0	Ignition
35	Sizzling
60	Holding ring on fire
74	Top well involved
90	Well involved
122	Heptane off
136	Top dropping off
140	Large fire; molten plastic falling and spitting from unit
180	Larger pieces of plastic falling off
195	Side eroding
200	Very molten; unit literally falling apart
214	Slumping
220	Entire lid burned off; die down
230	Liquid leakage begins
232	Water left top at water line; lid dropped inside and floating on top
250	Fire extinguished

Description of failure: Leakage through a number of weep holes, breach at top, structural weakening of unit

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Test/Unit # : 23

Date of test: 6/7/96
Approx time of day: 2:40 p.m.

Time (sec)	Observation
0	Ignition
45	Sizzling; large opening at top; not directly involved
60	Loud crackling and sizzling
143	Hot fire; well involved; flame height 2.5X unit
176	Molten plastic out of pan left side; deform of front top
200	Unit totally engulfed; molten plastic falling off
289	Heptane off
300	Spread to back of unit
308	Pieces falling off
317	Die down
334	Water leak off of top at saddle
339	Liquid leakage
360	Fire extinguished

Description of failure: Leakage from breach at top of unit at stress point where steel saddle intersected base steel support unit; also hole, leak at top of unit

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APPENDIX C

Instrumentation Data

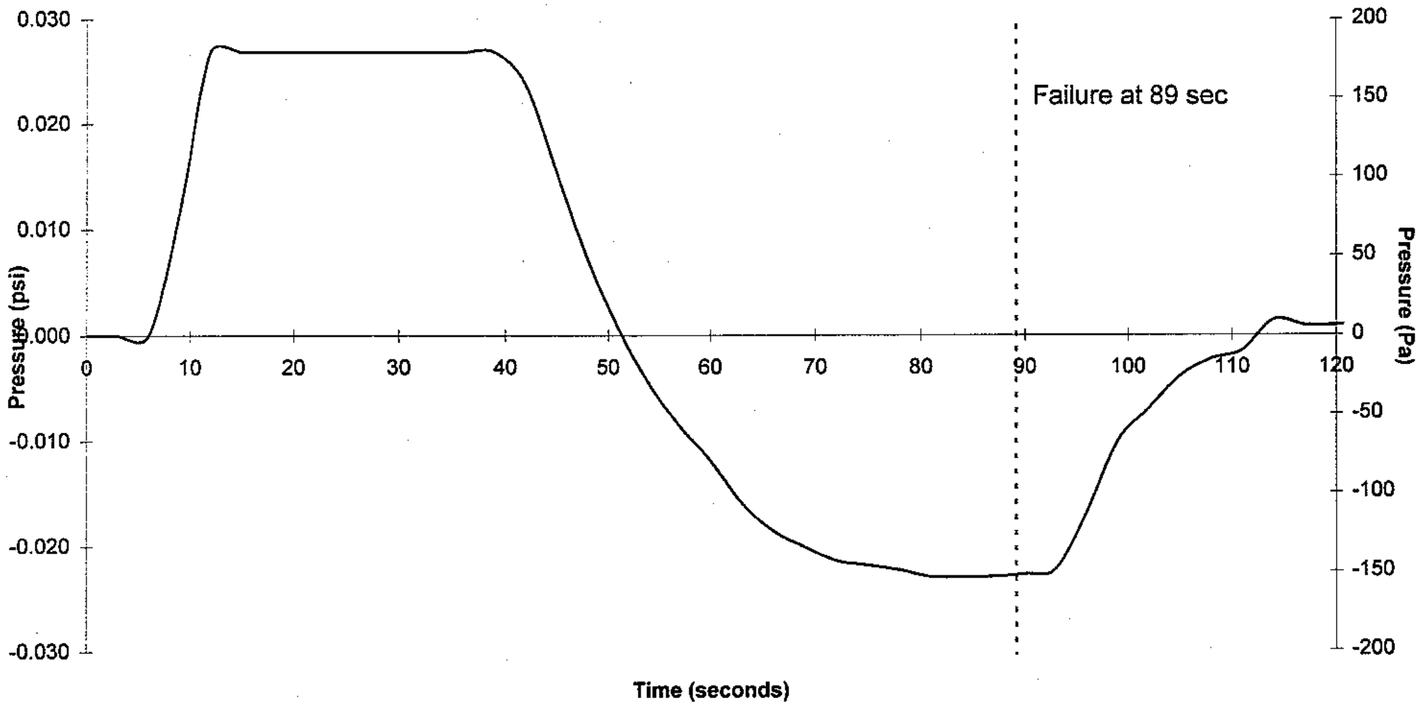

Figure C1: Test #1 Pressure

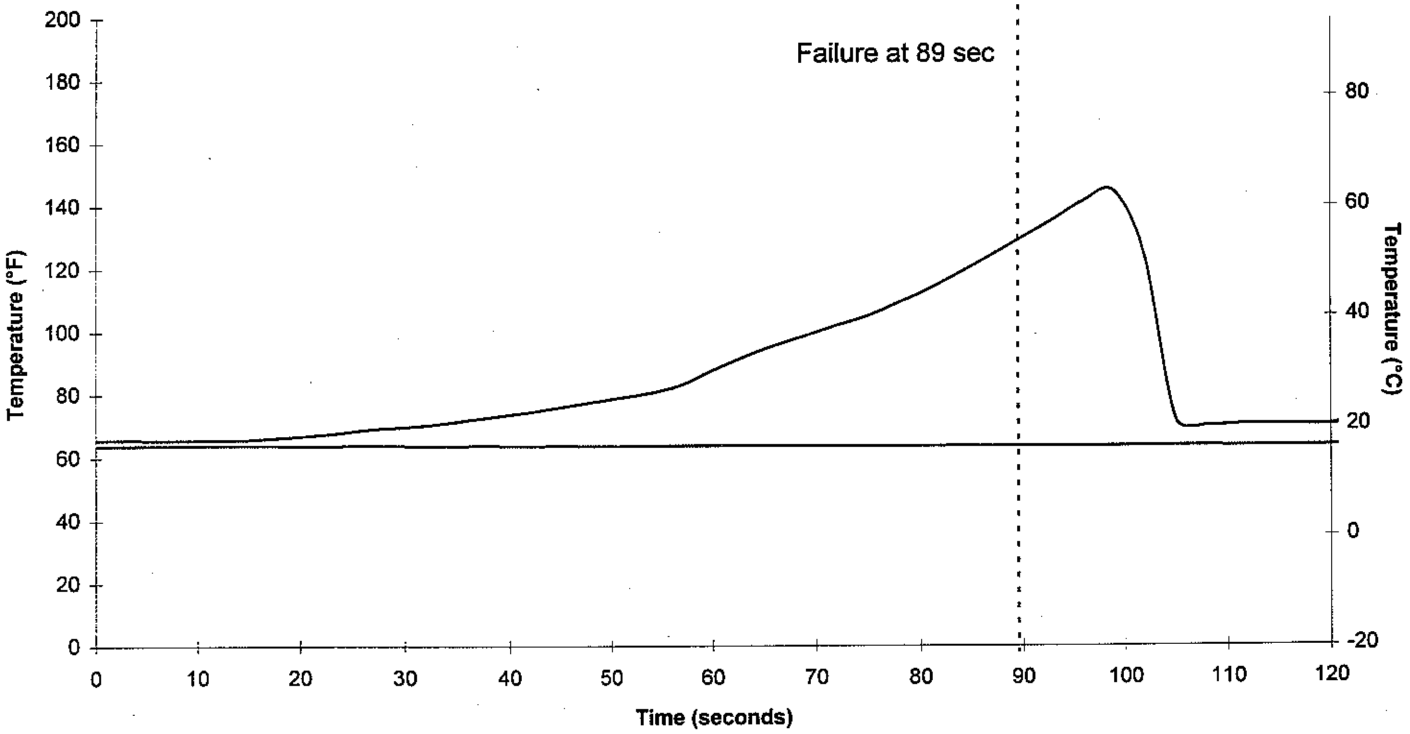

Figure C2: Test #1 Ullage Temperature

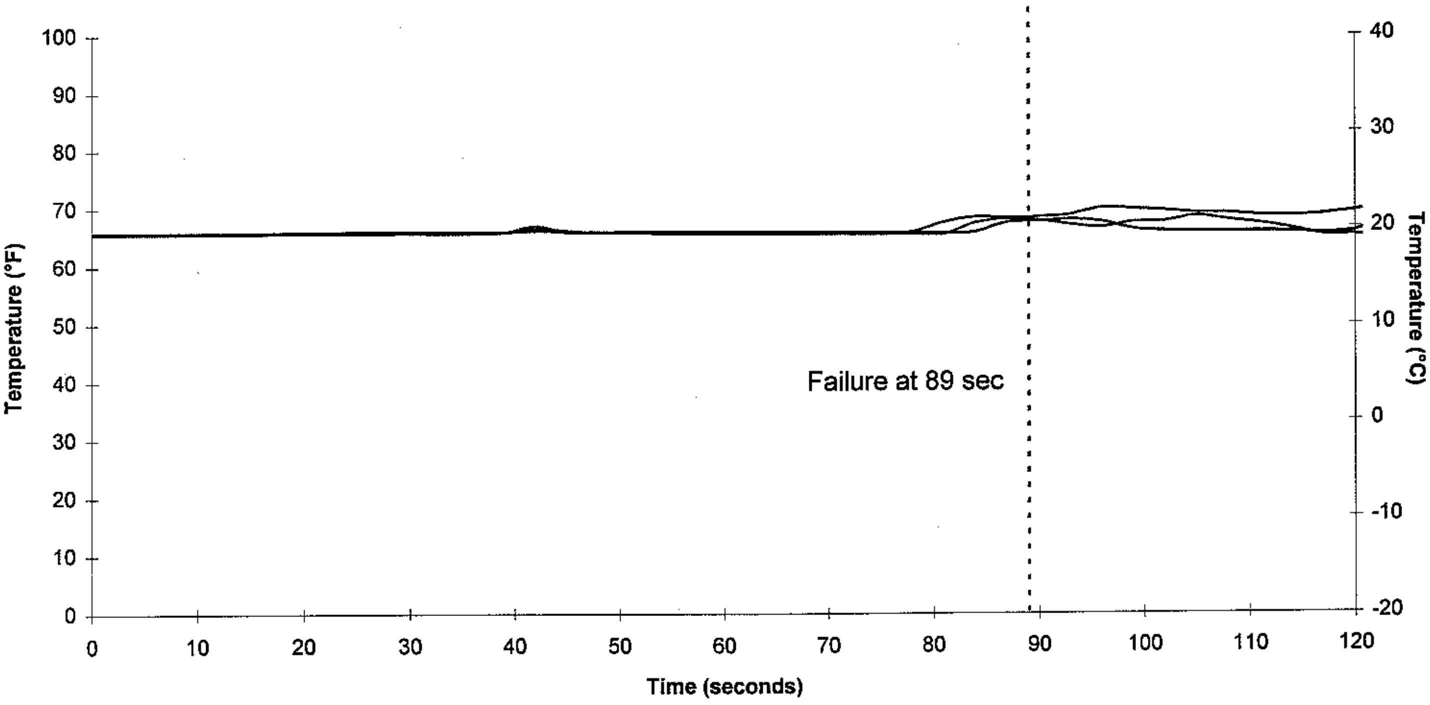

Figure C3: Test #1 Liquid Temperature 12" below water line

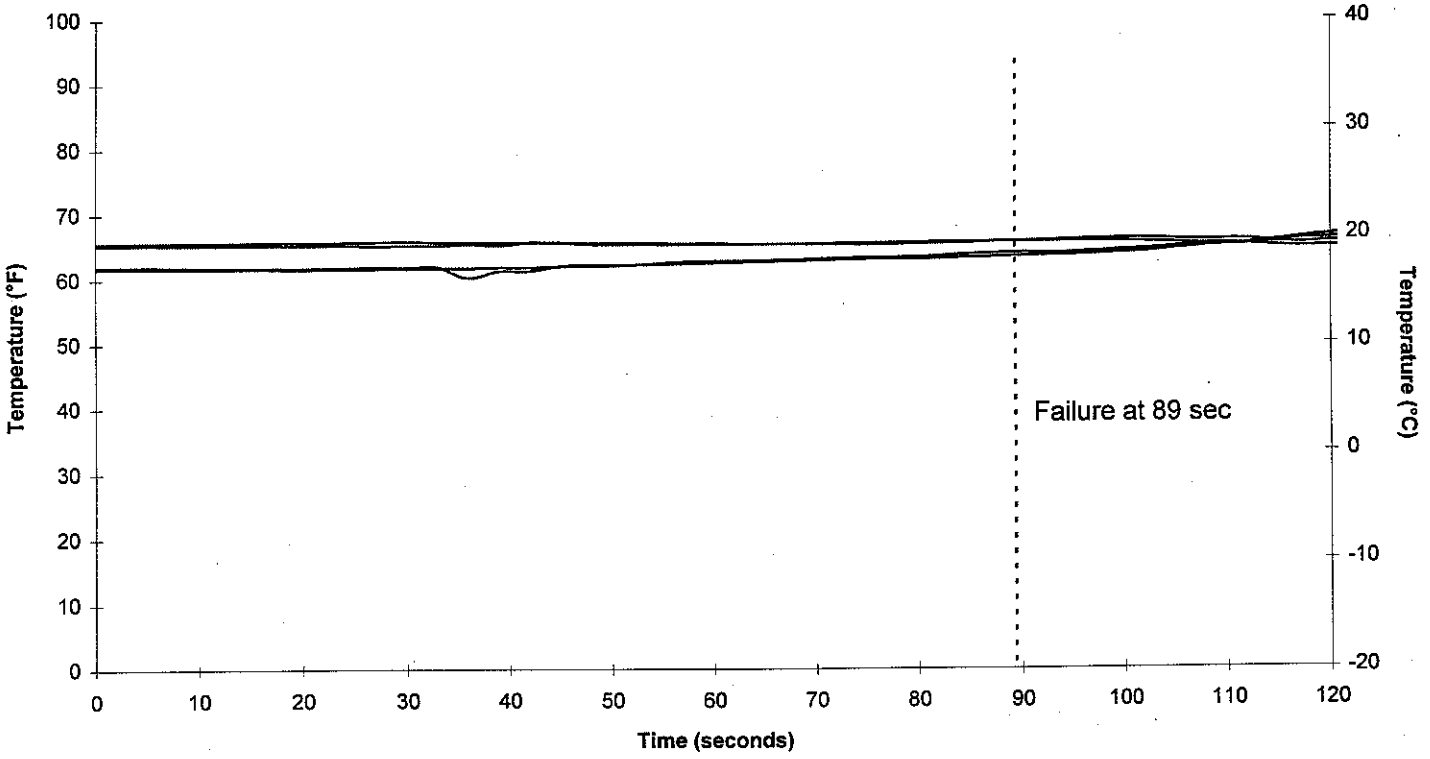

Figure C4: Test #1 Liquid Temperature 24" below water line

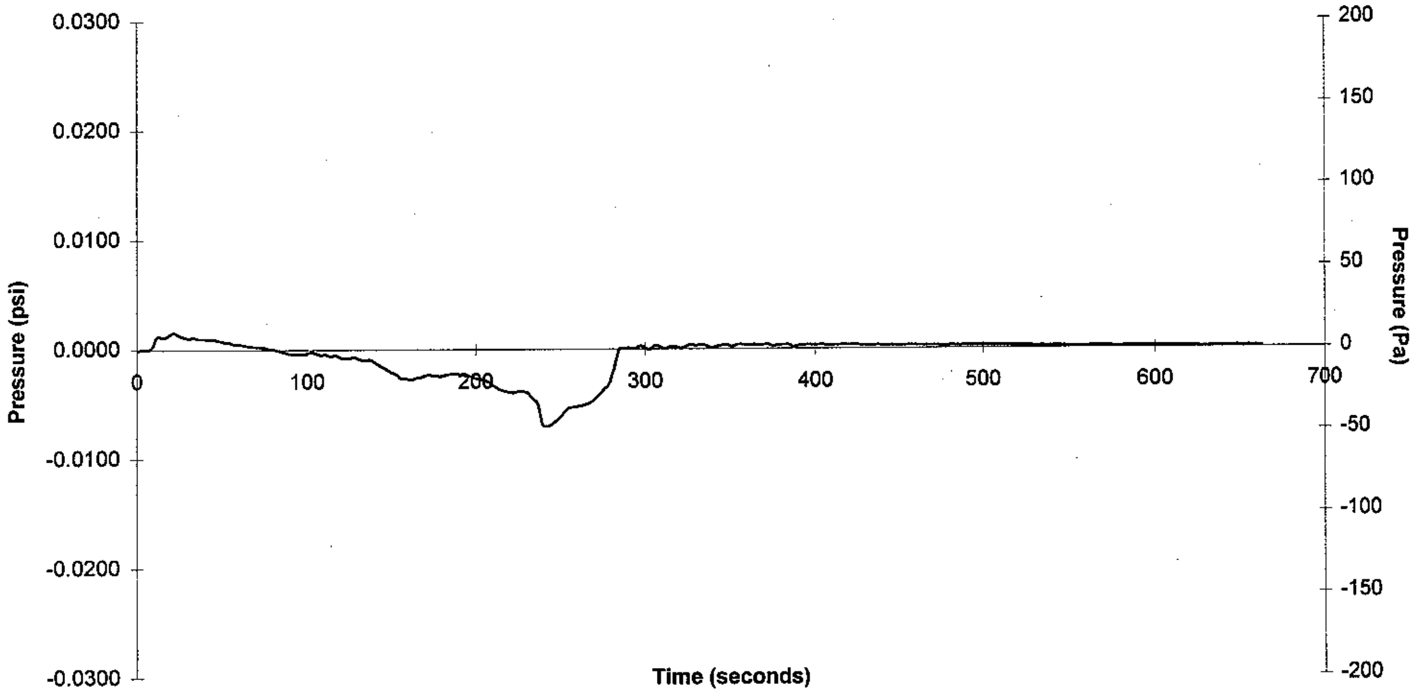

Figure C5: Test #2 Pressure

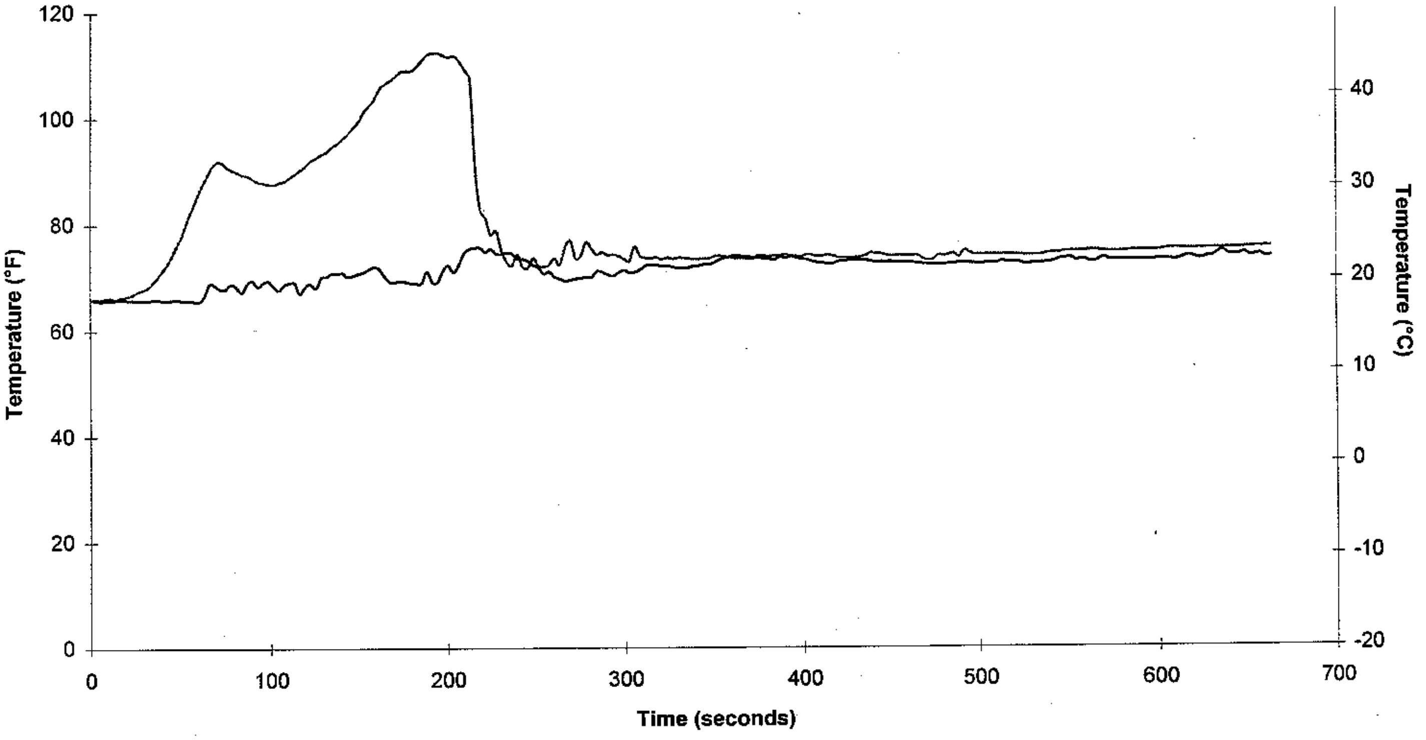

Figure C6: Test #2 Ullage Temperature

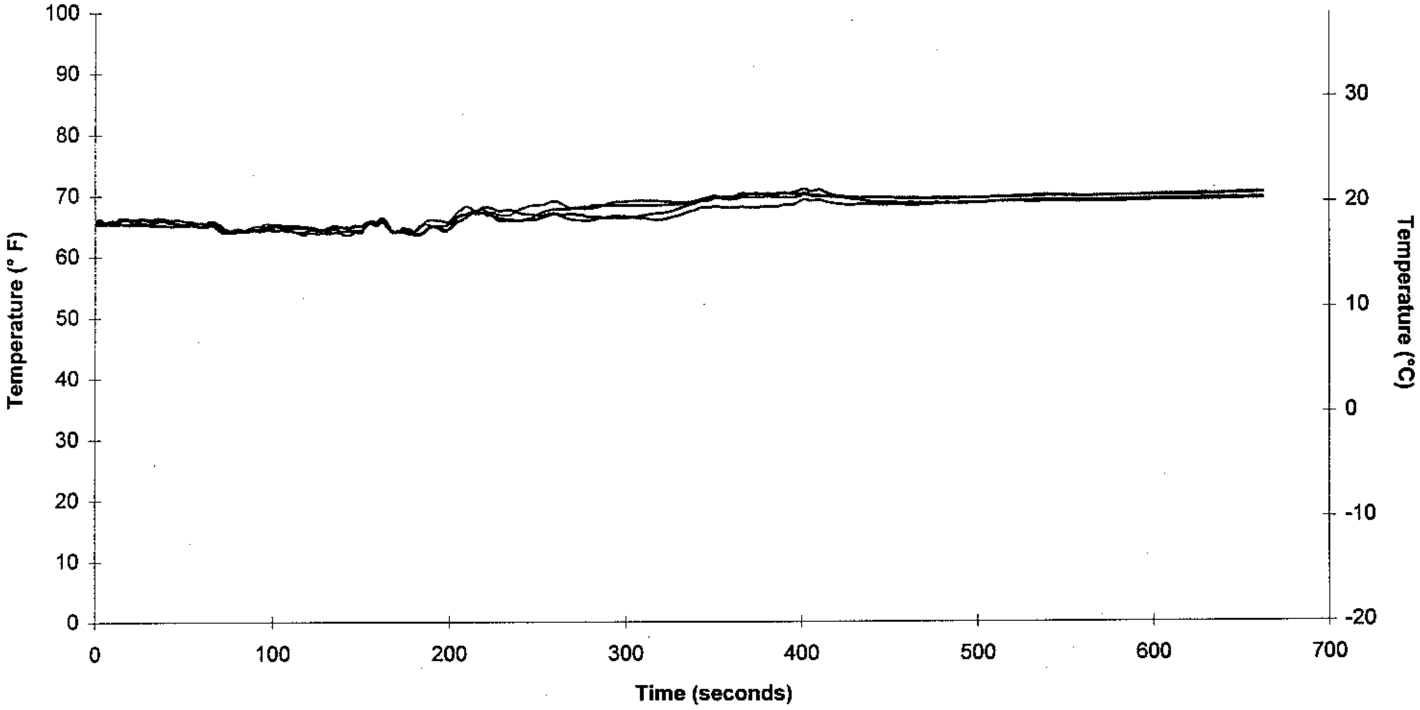

Figure C7: Test #2 Liquid Temperature 12" below water line

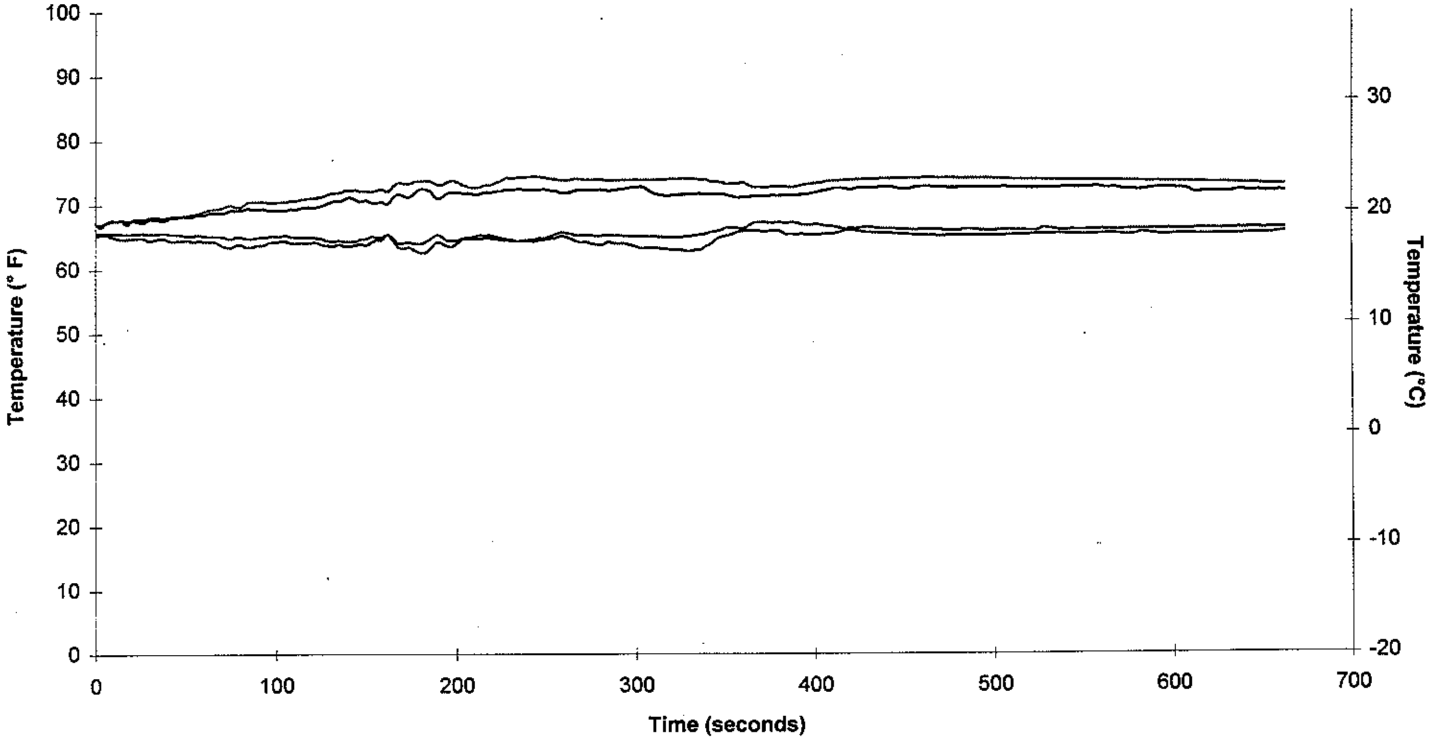

Figure C8: Test #2 Liquid Temperature 24" below water line

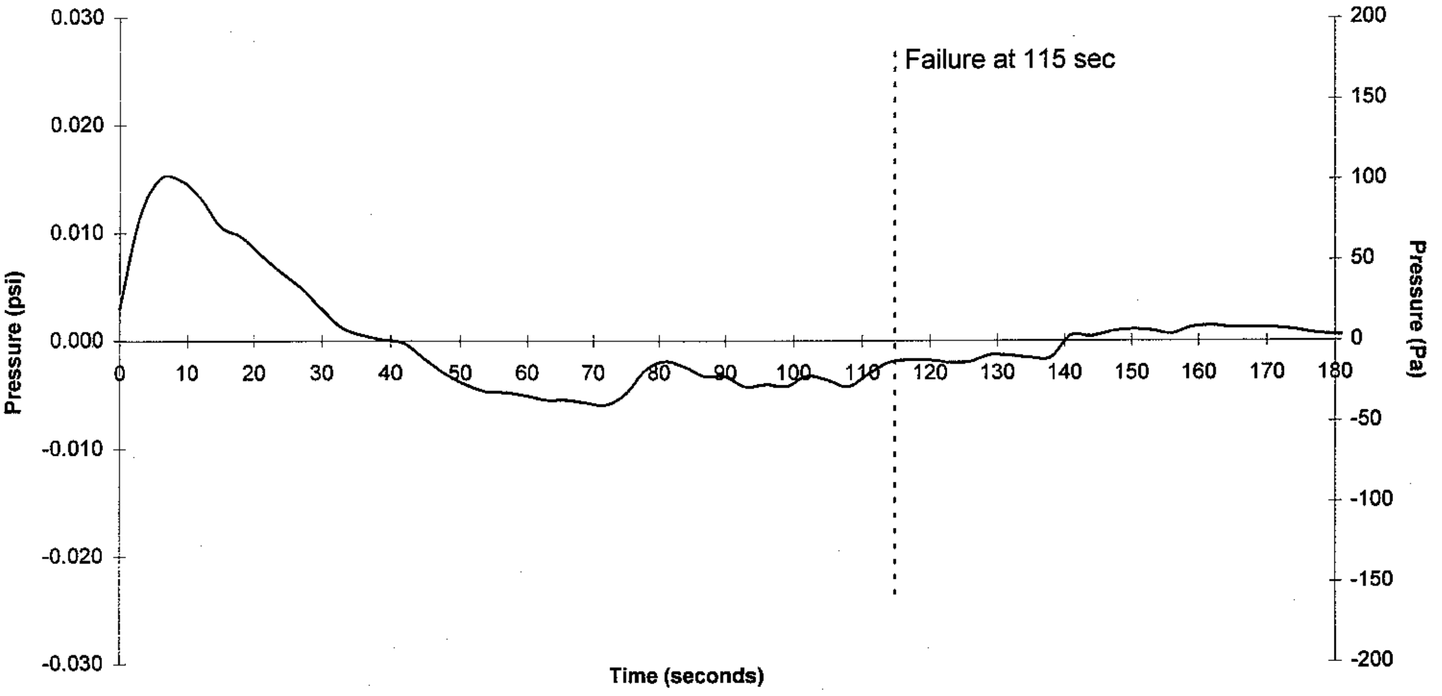

Figure C9: Test #3 Pressure

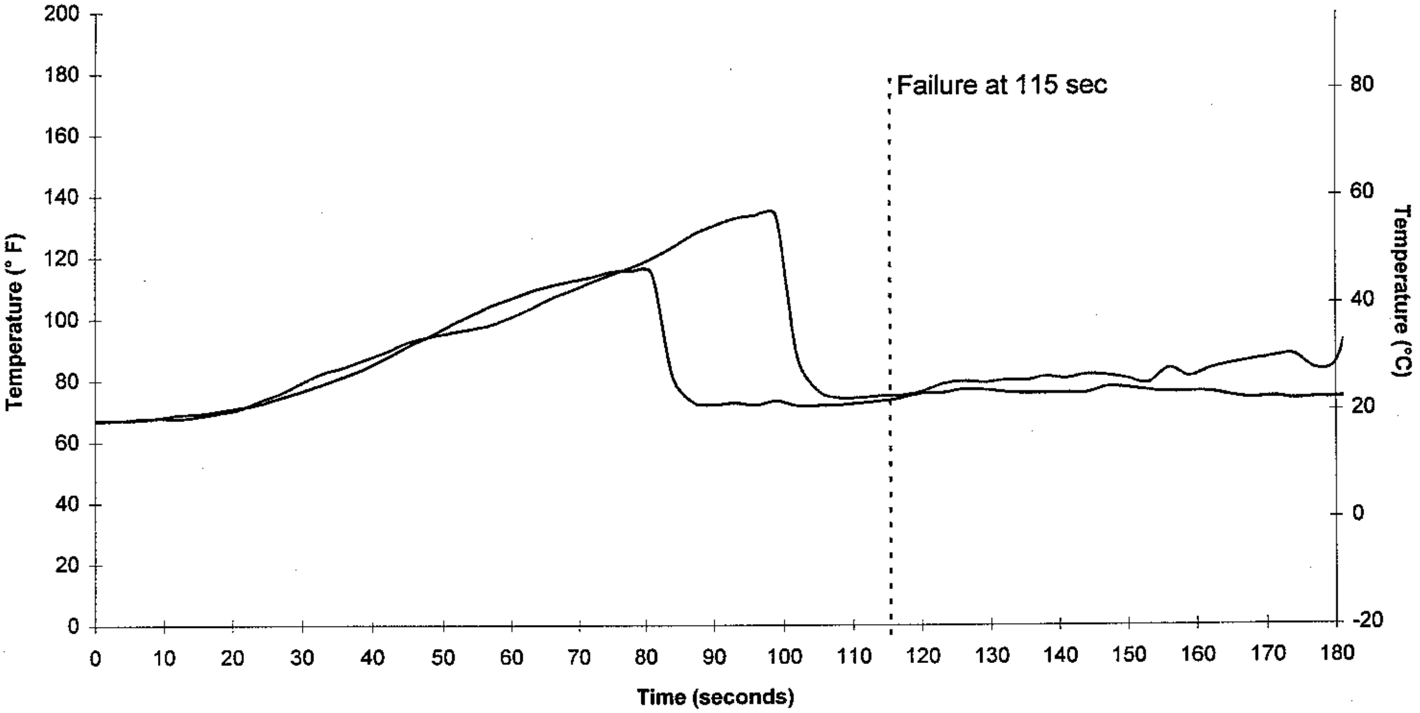

Figure C10: Test #3 Ullage Temperatures

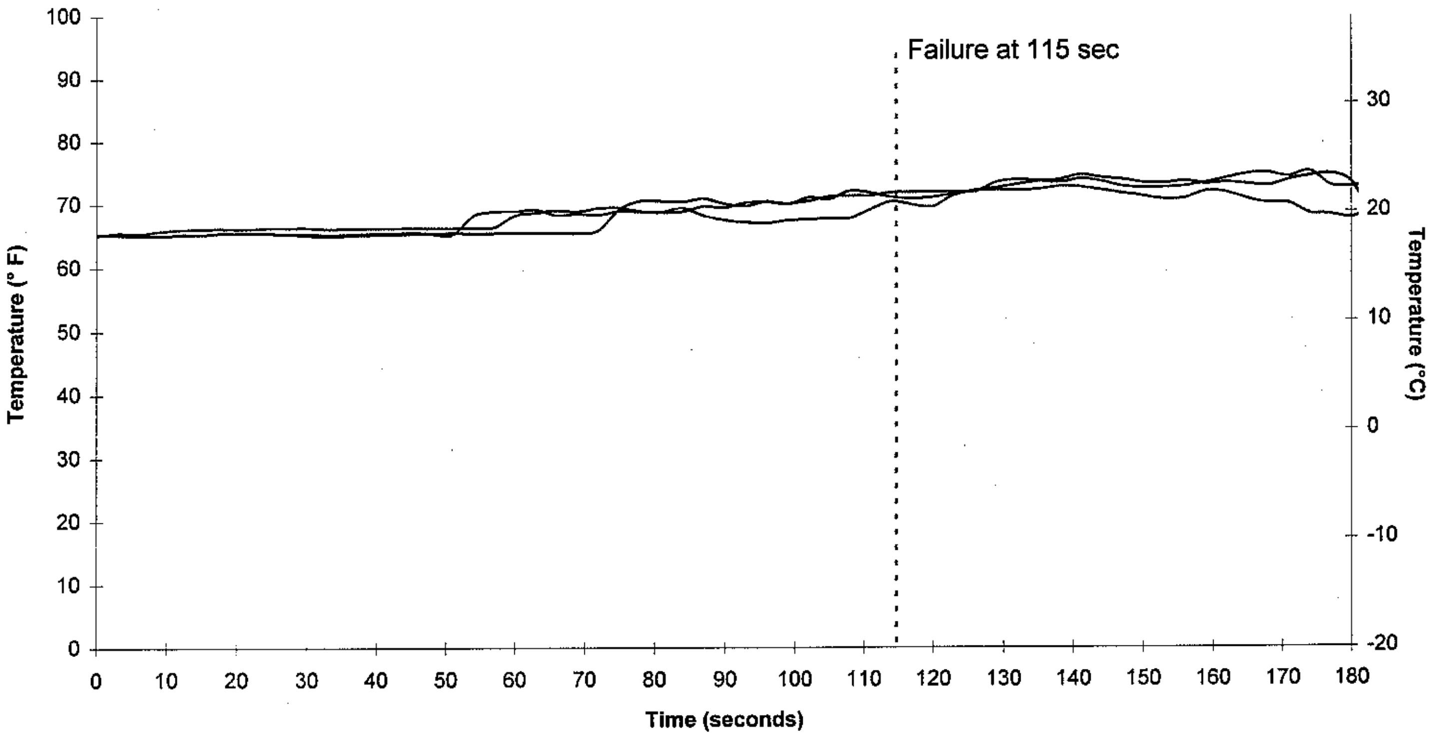

Figure C11: Test #3 Liquid Temperature 12" below water line

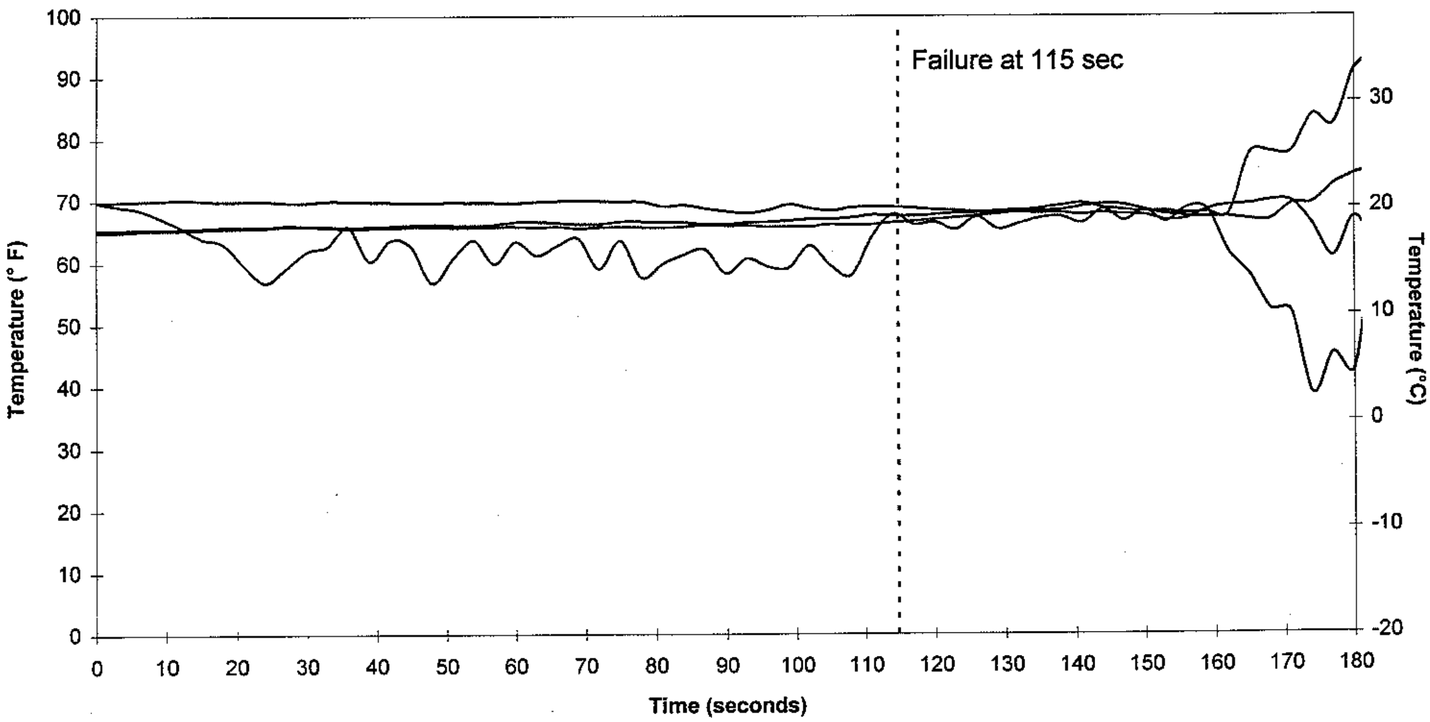

Figure C12: Test #3 Liquid Temperature 24" below water line

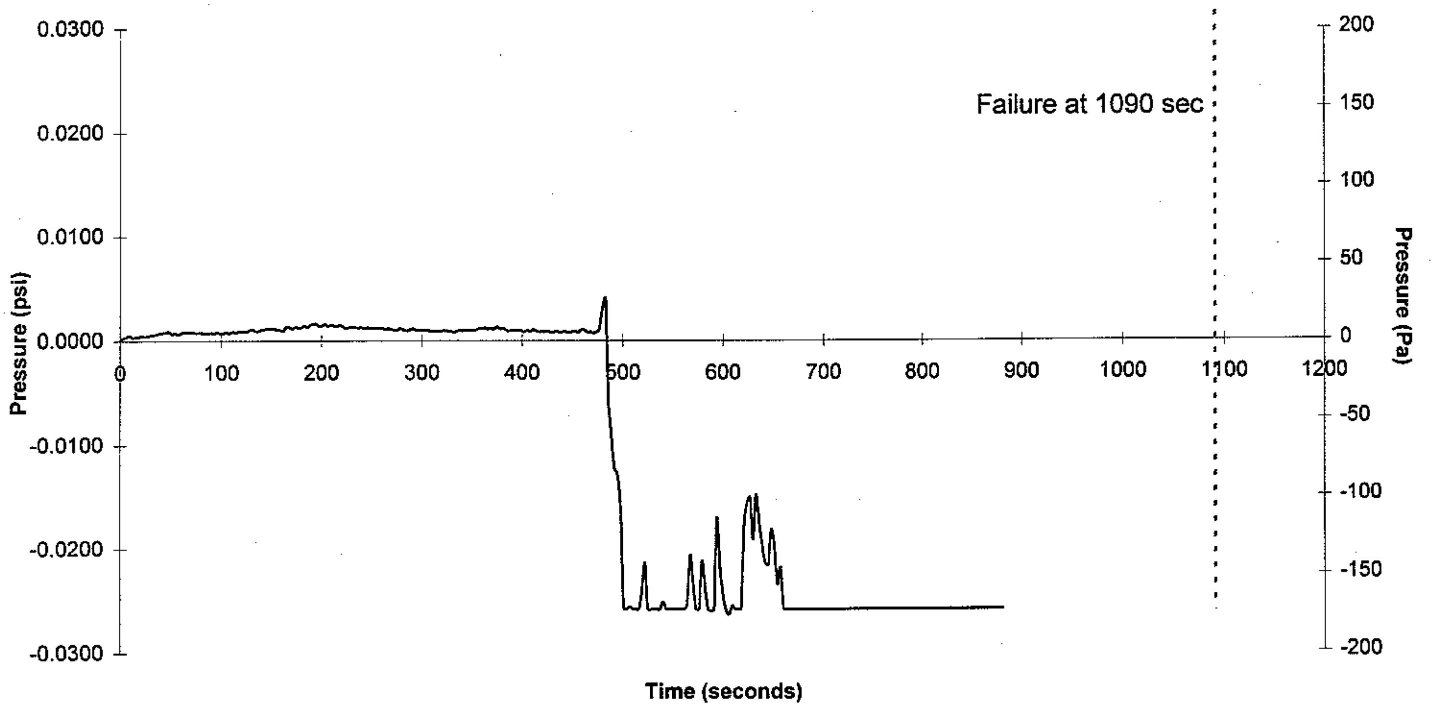

Figure C13: Test #4 Pressure

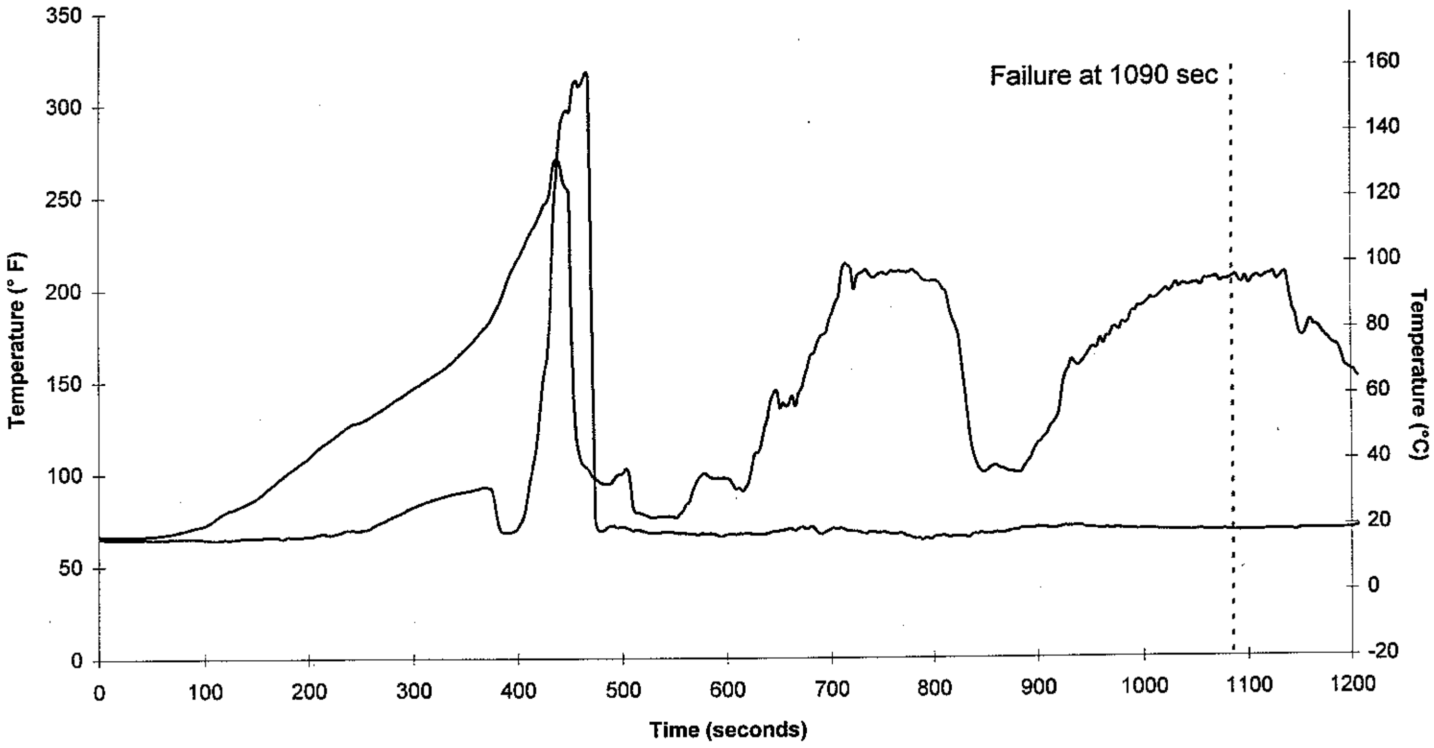

Figure C14: Test #4 Ullage Temperature

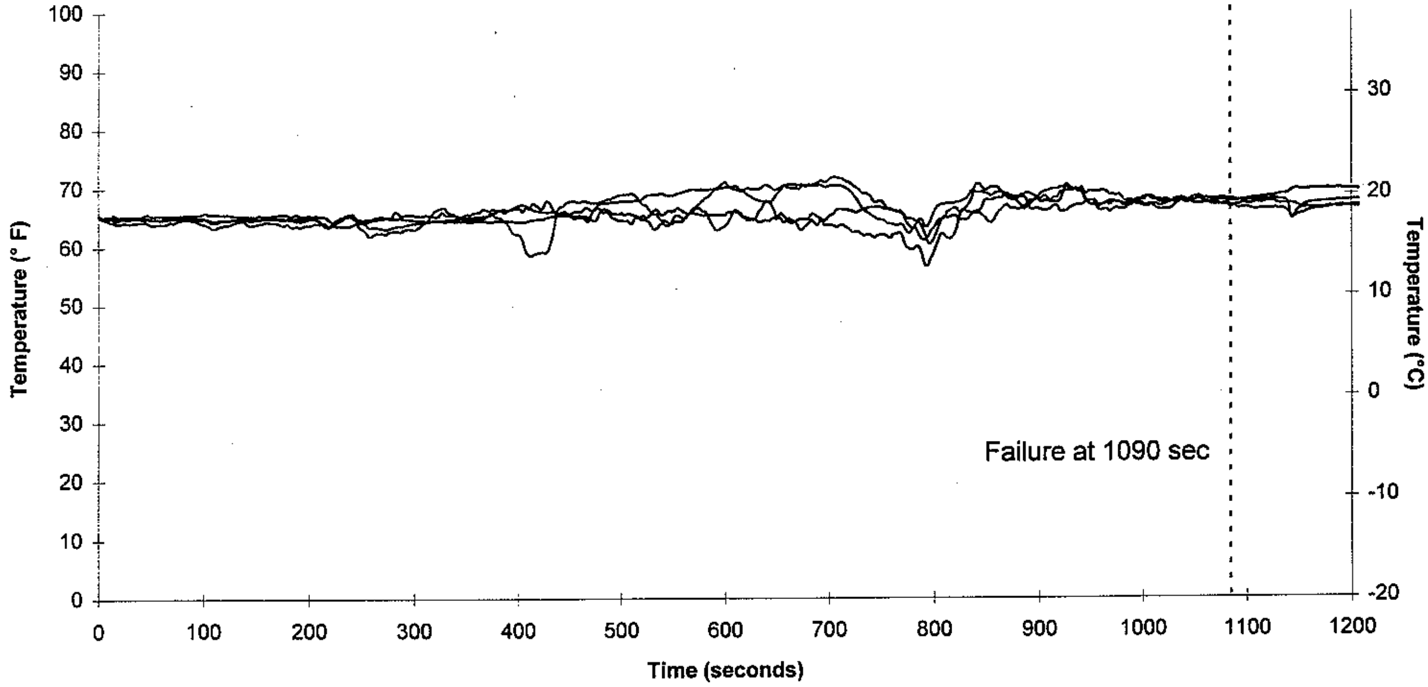

Figure C15: Test #4 Liquid Temperature 12" below water line

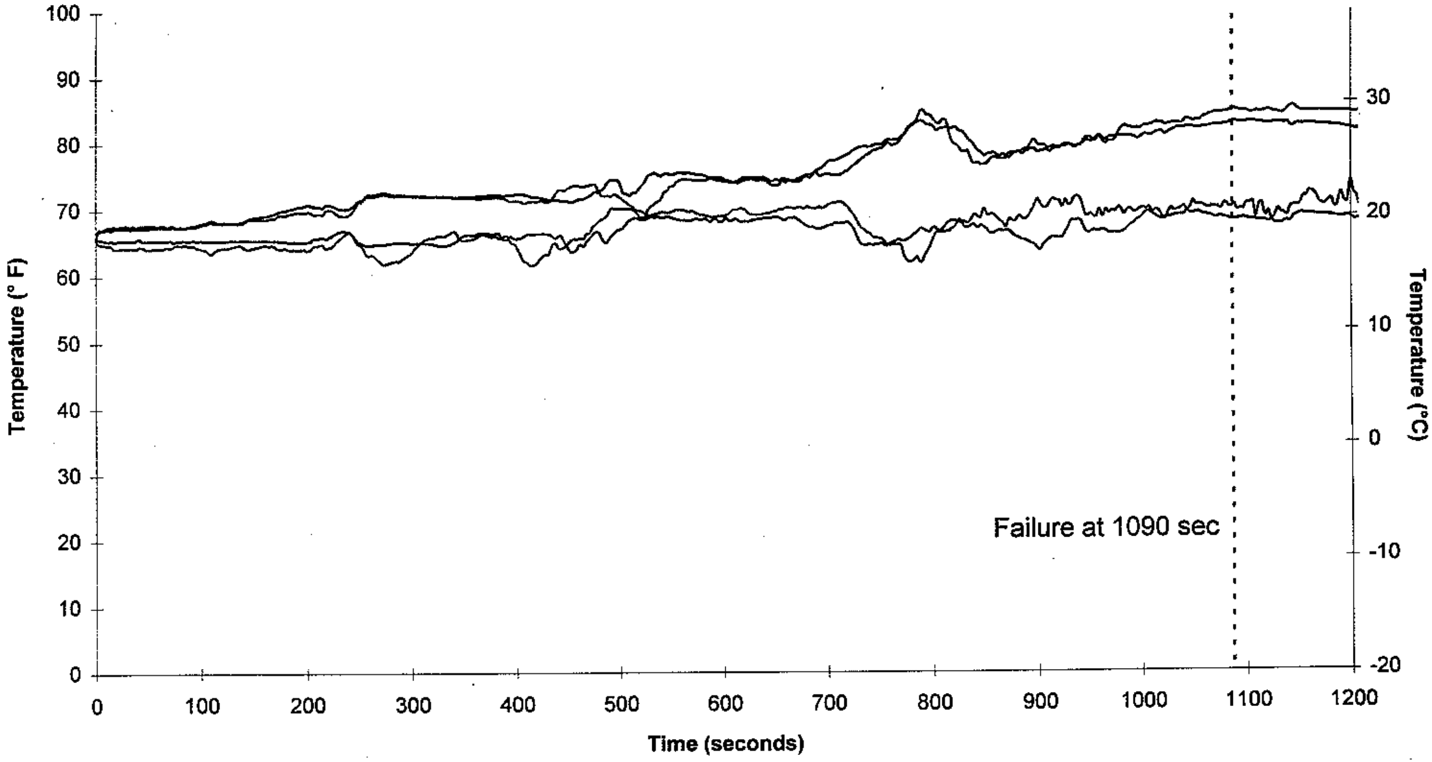

Figure C16: Test #4 Liquid Temperature 24" below water line

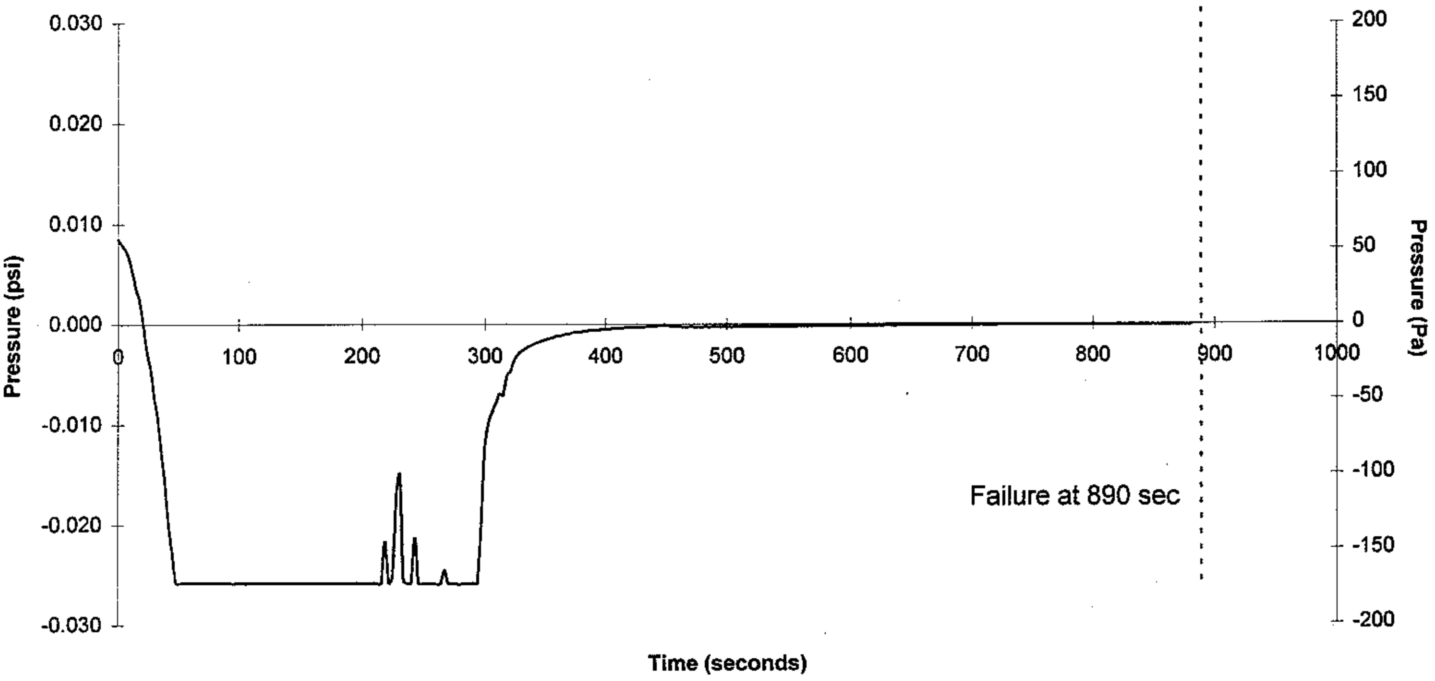

Figure C17: Test #5 Pressure

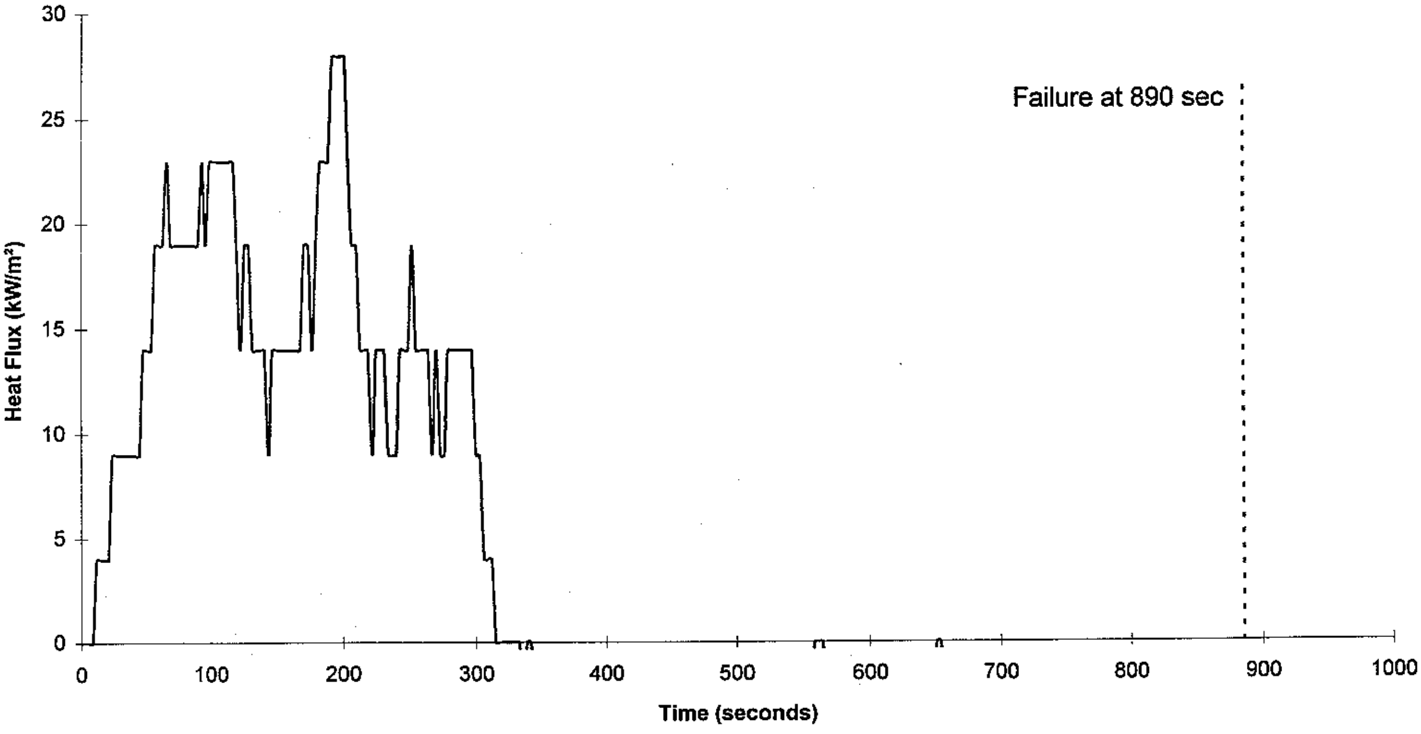

Figure C18: Test #5 Heat Flux

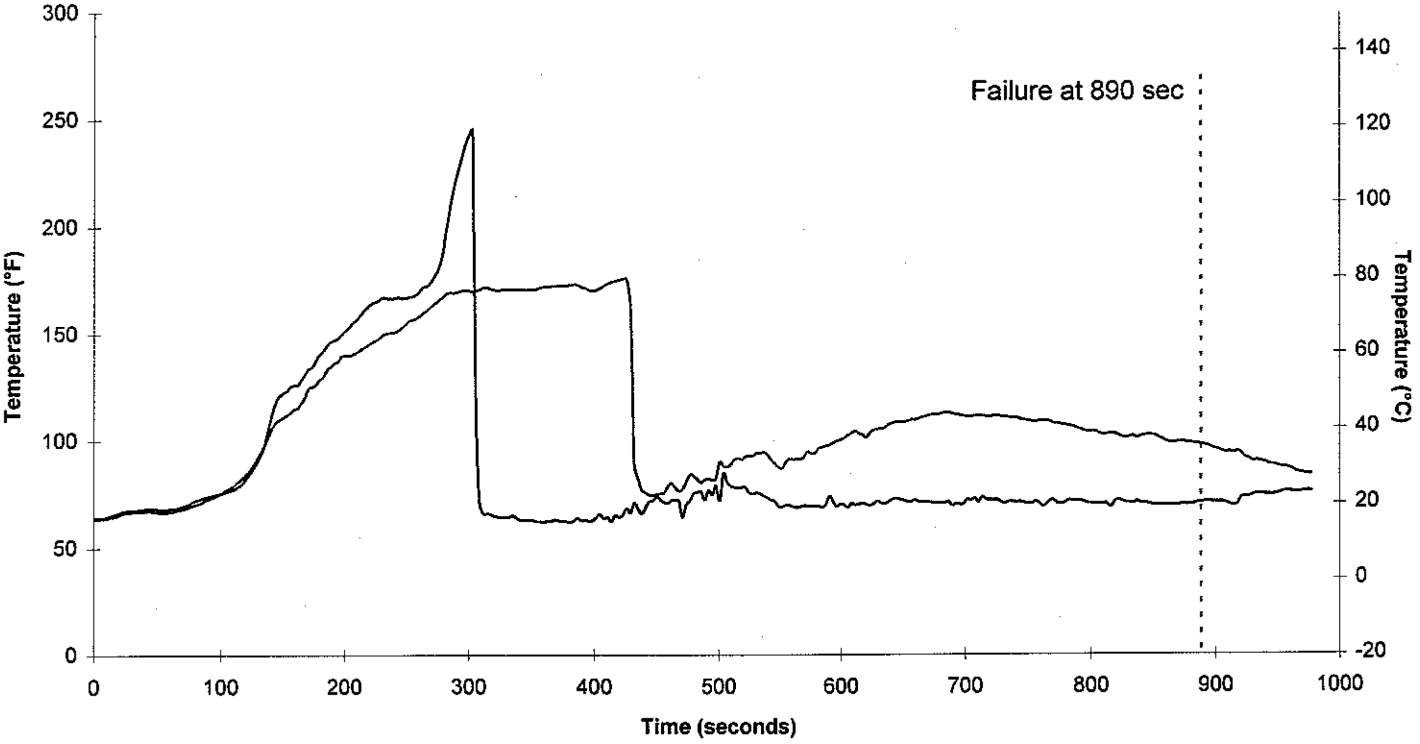

Figure C19: Test #5 Ullage Temperature

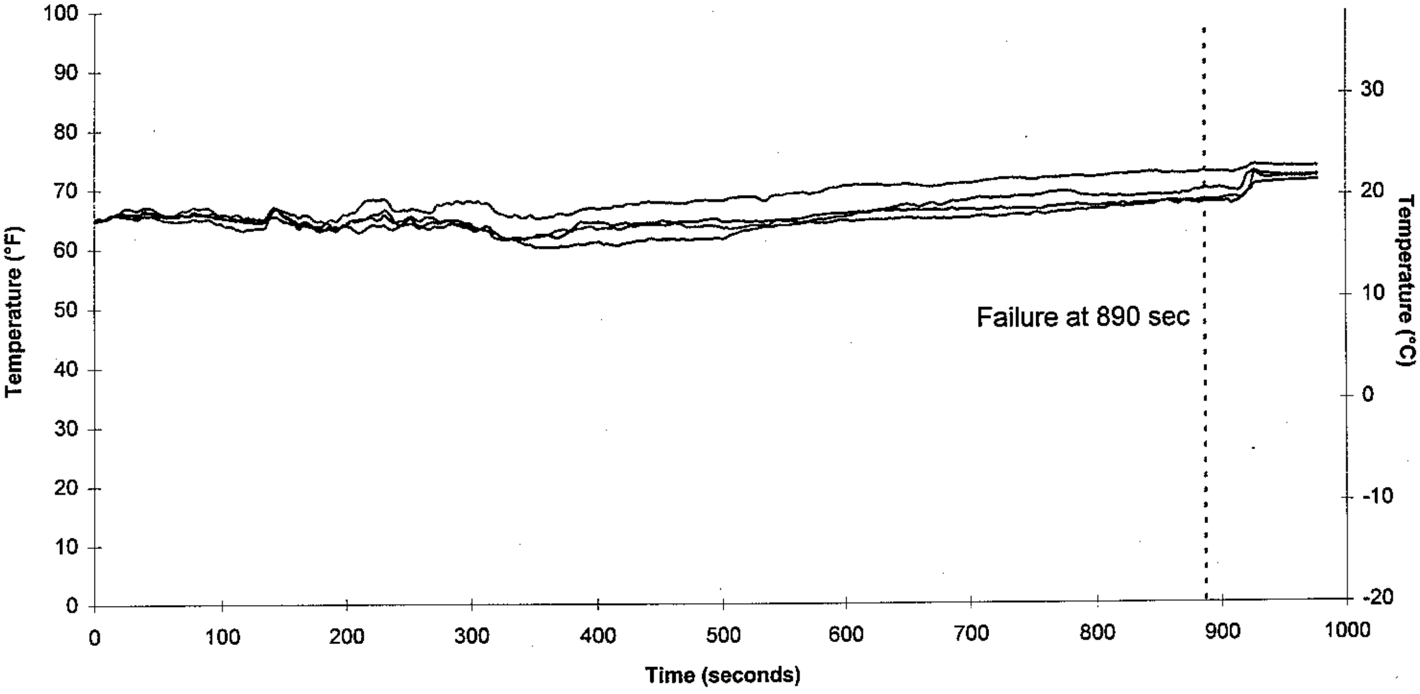

Figure C20: Test #5 Liquid Temperature 12" below water line

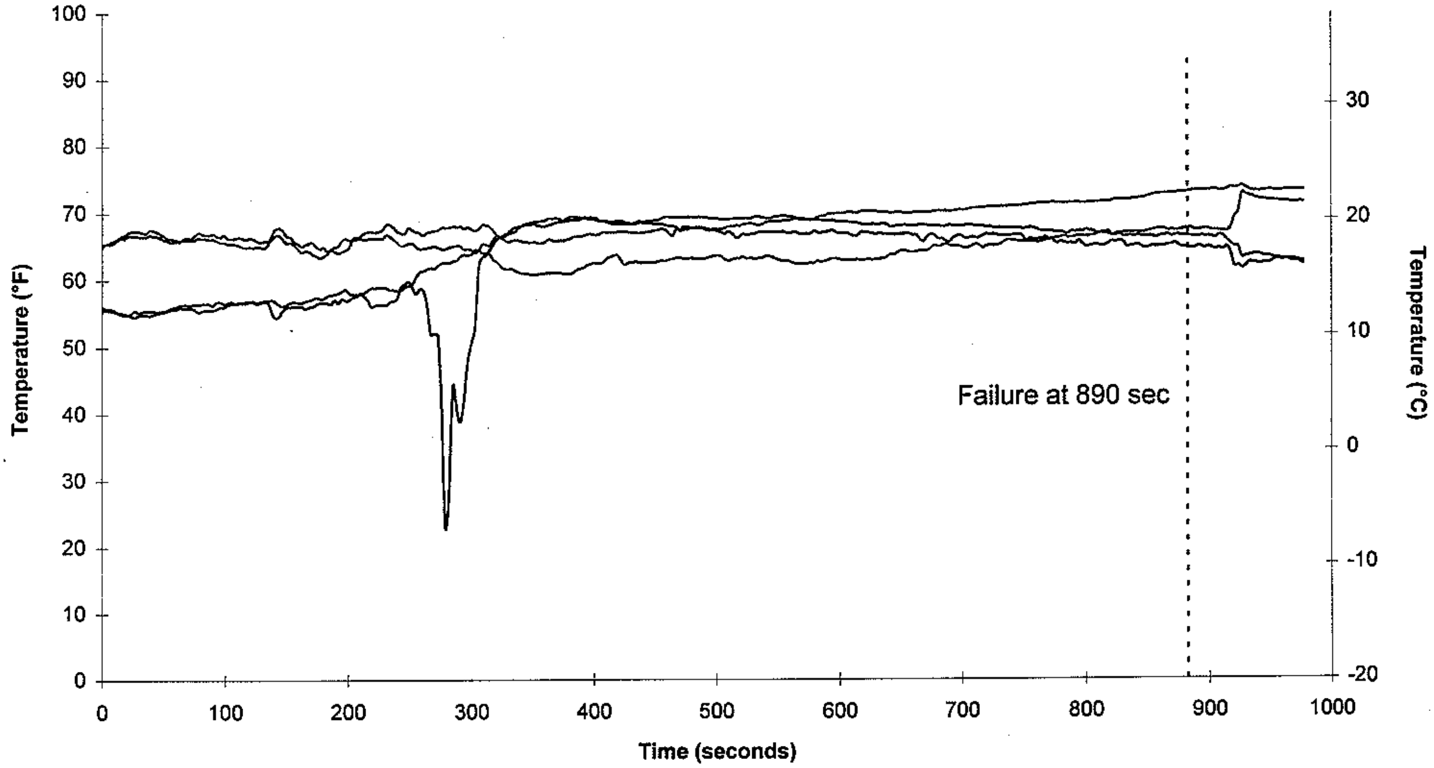

Figure C21: Test #5 Liquid Temperature 24" below water line

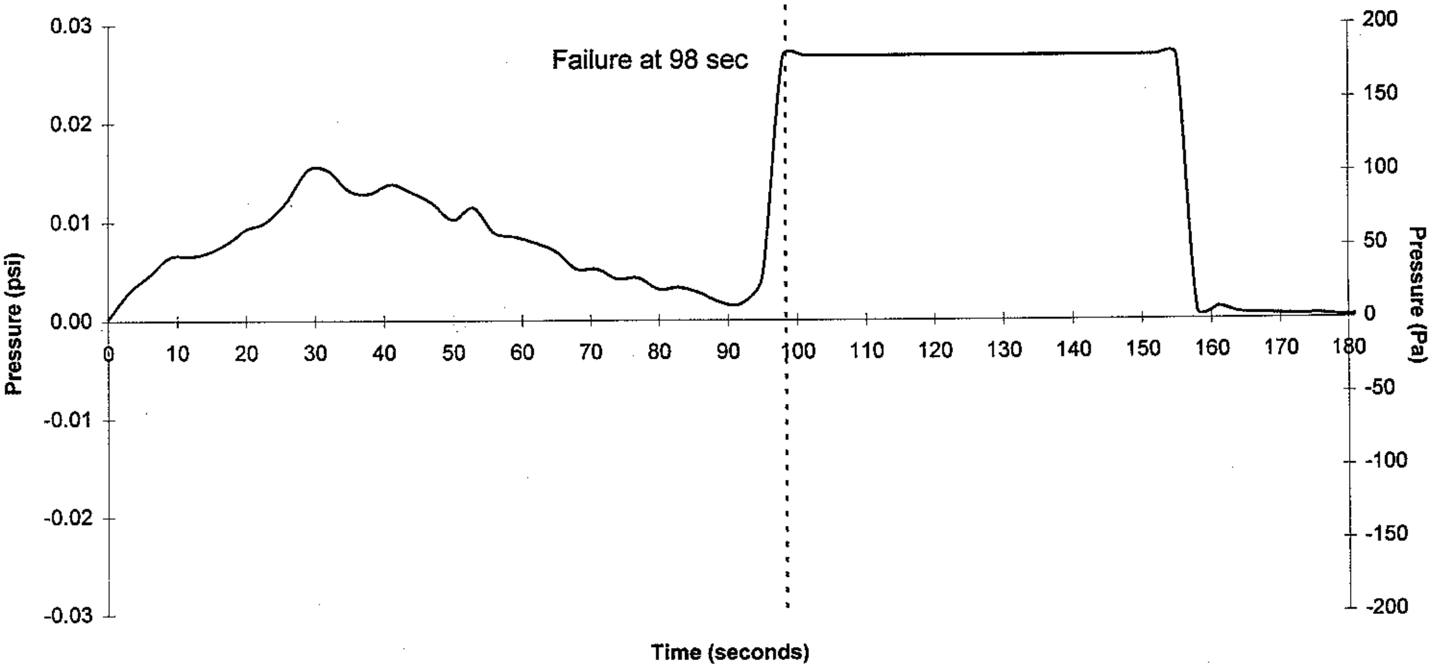

Figure C22: Test #6 Pressure Data

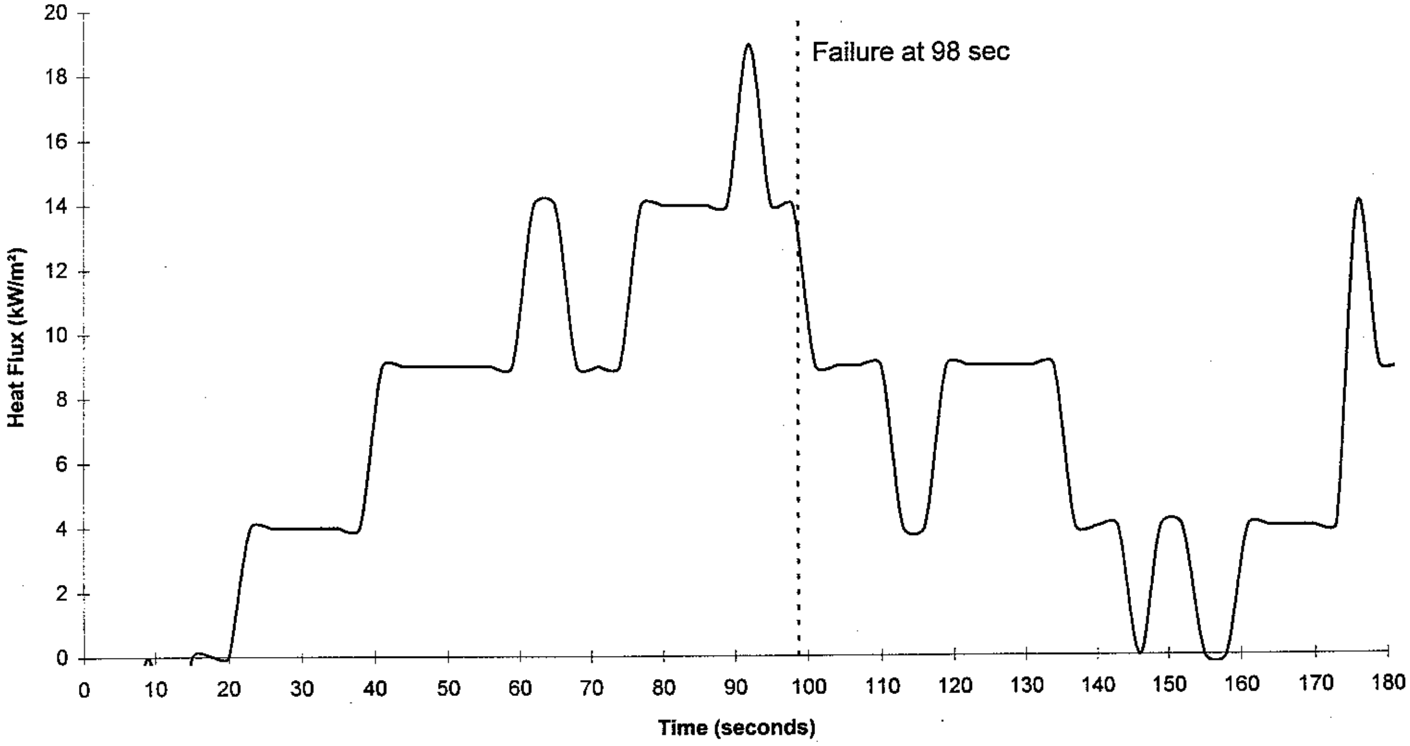

Figure C23: Test #6 Heat Flux

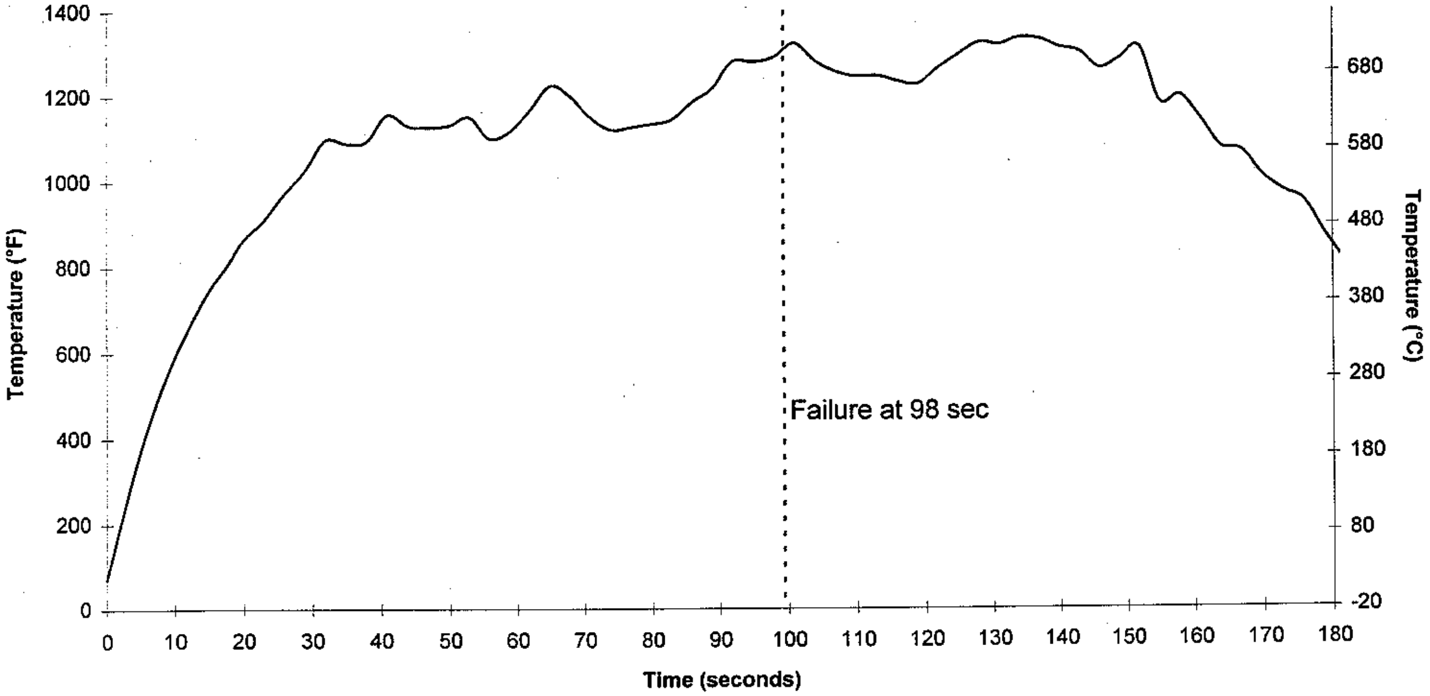

Figure C24: Test #6 External Temperature

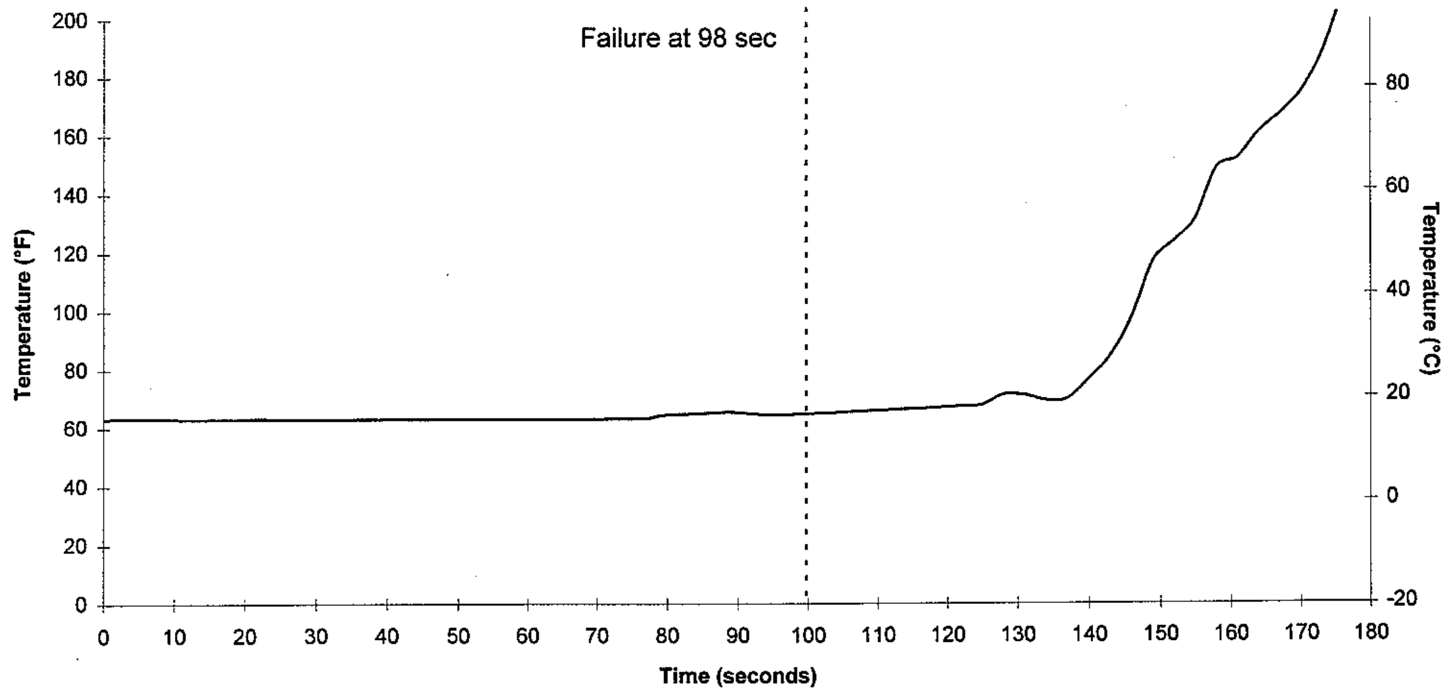

Figure C25: Test #6 Ullage Temperatures

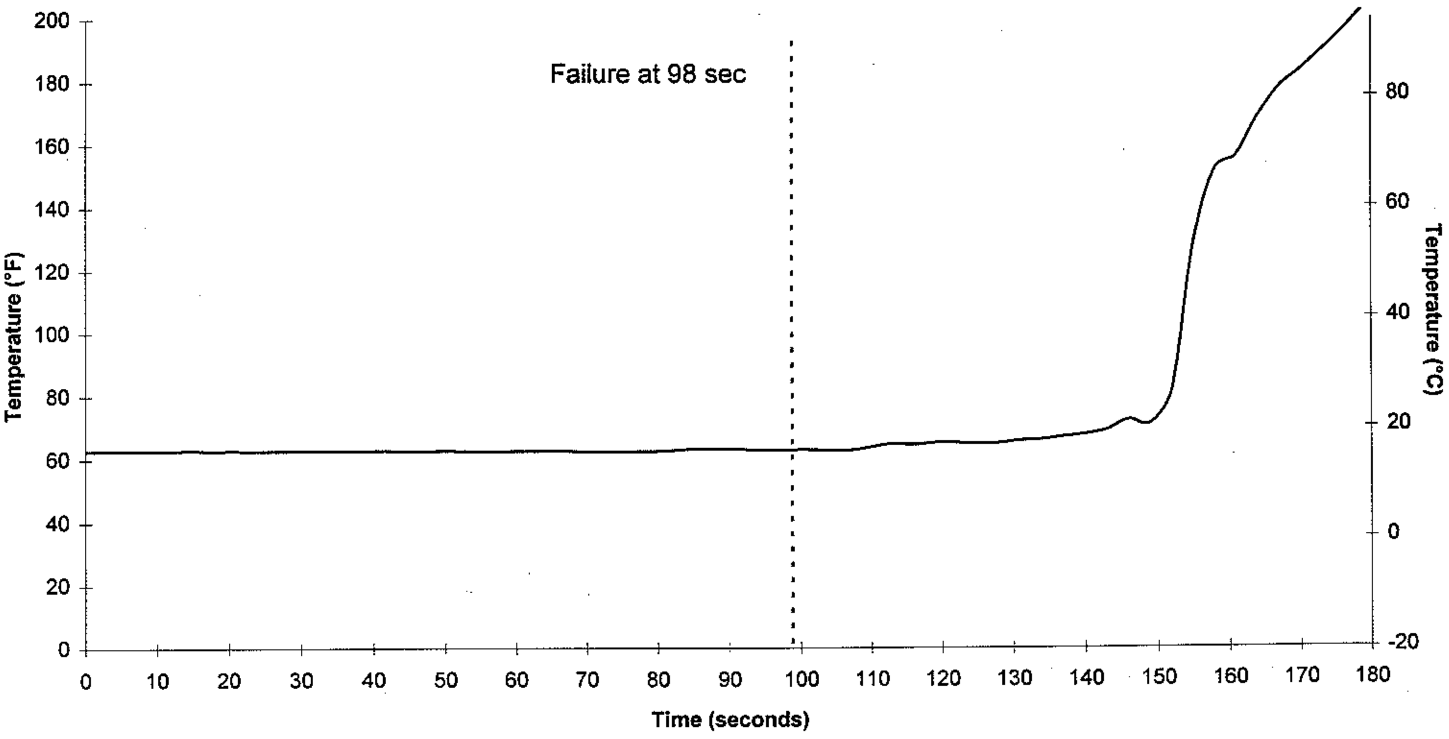

Figure C26: Test #6 Liquid Temperature 12" below water line

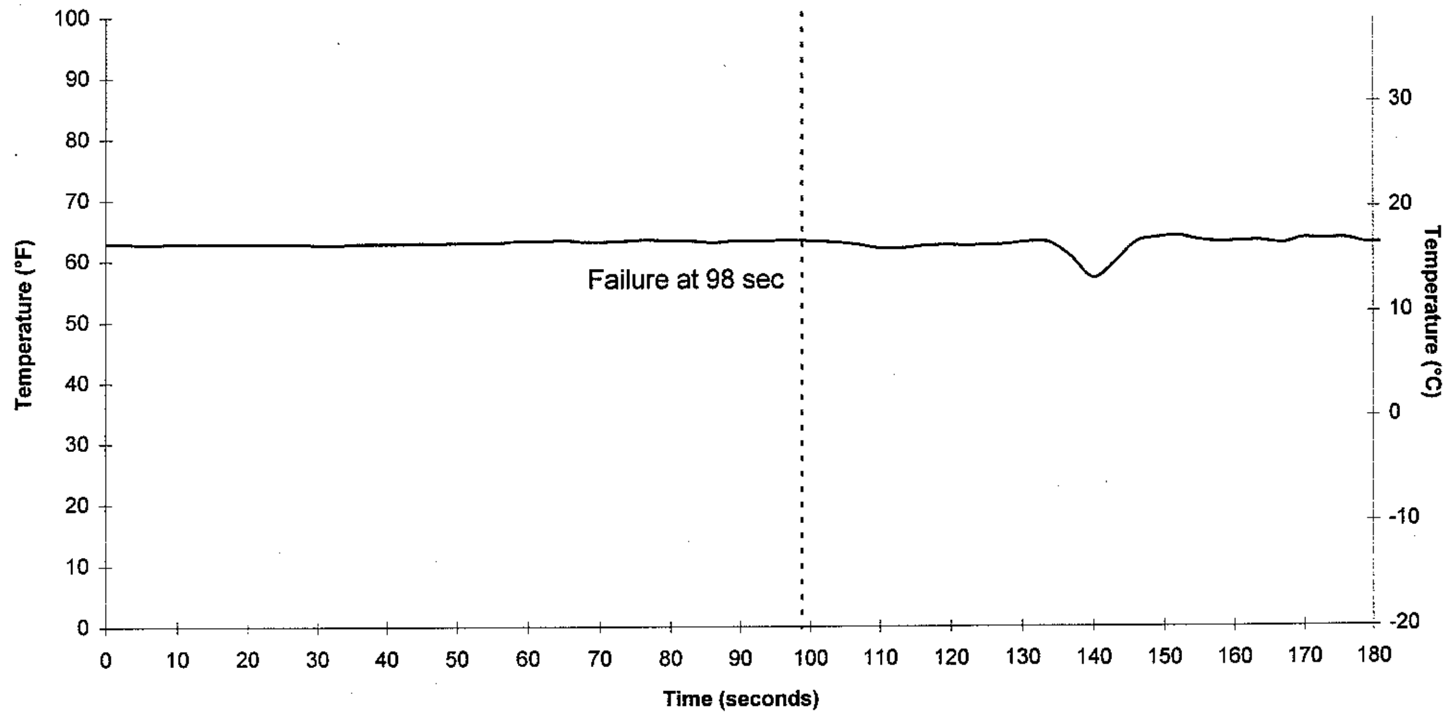

Figure C27: Test #6 Liquid Temperature 24" below water line

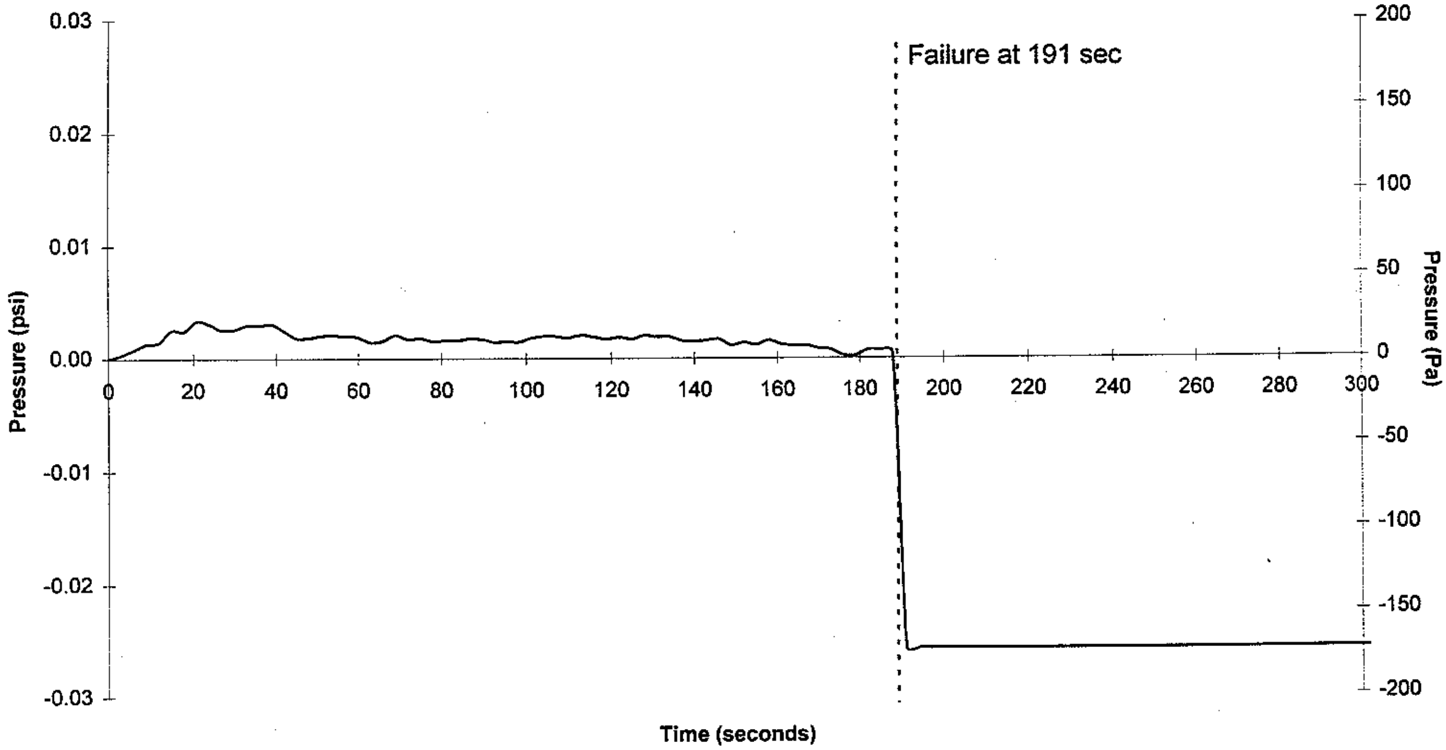

Figure C28: Test #7 Pressure Data

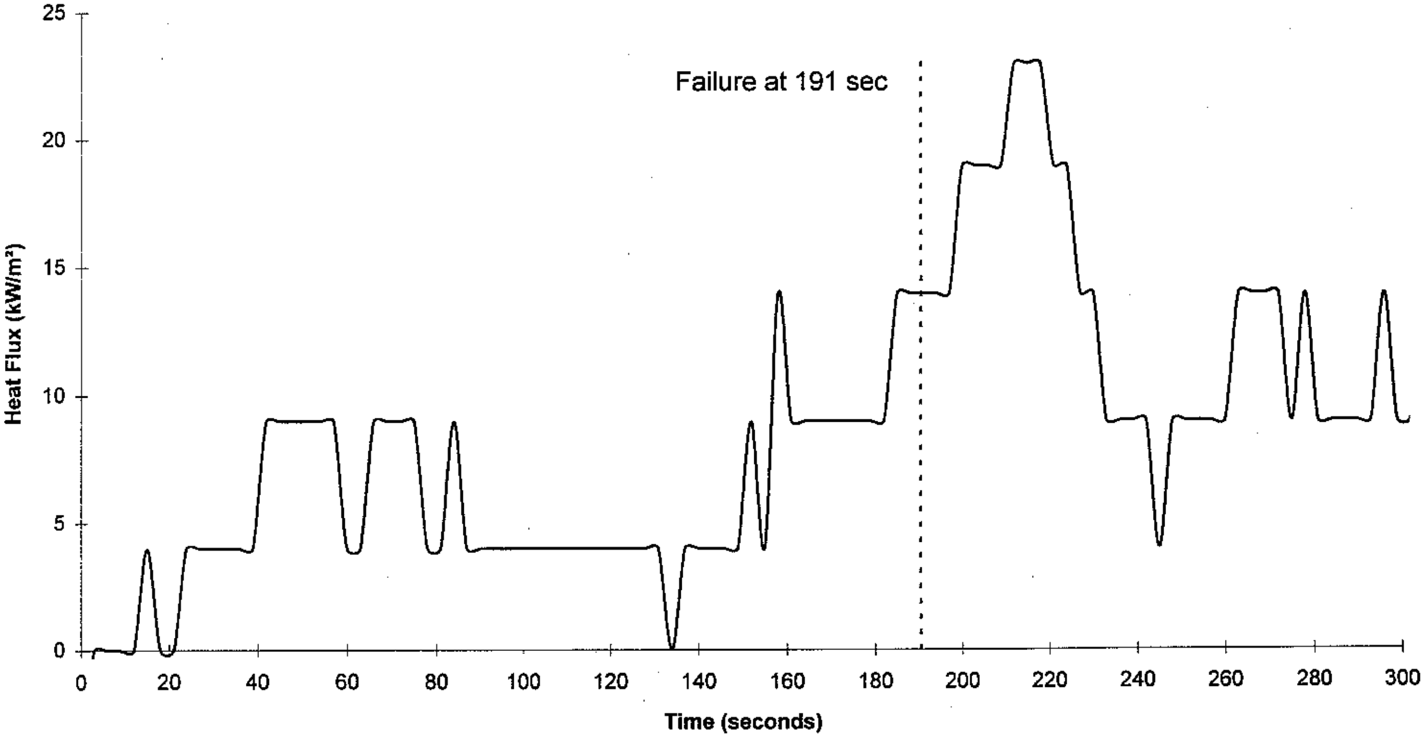

Figure C29: Test #7 Heat Flux

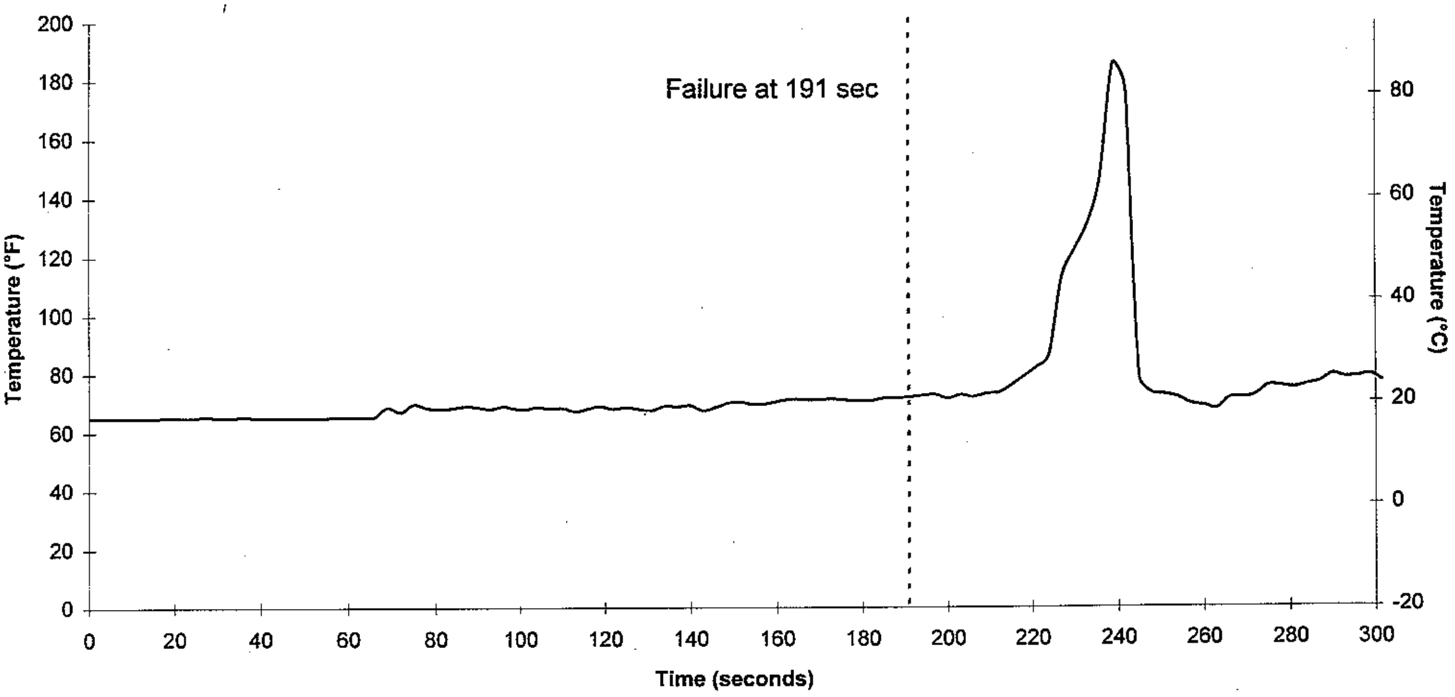

Figure C30: Test #7 Ullage Temperature

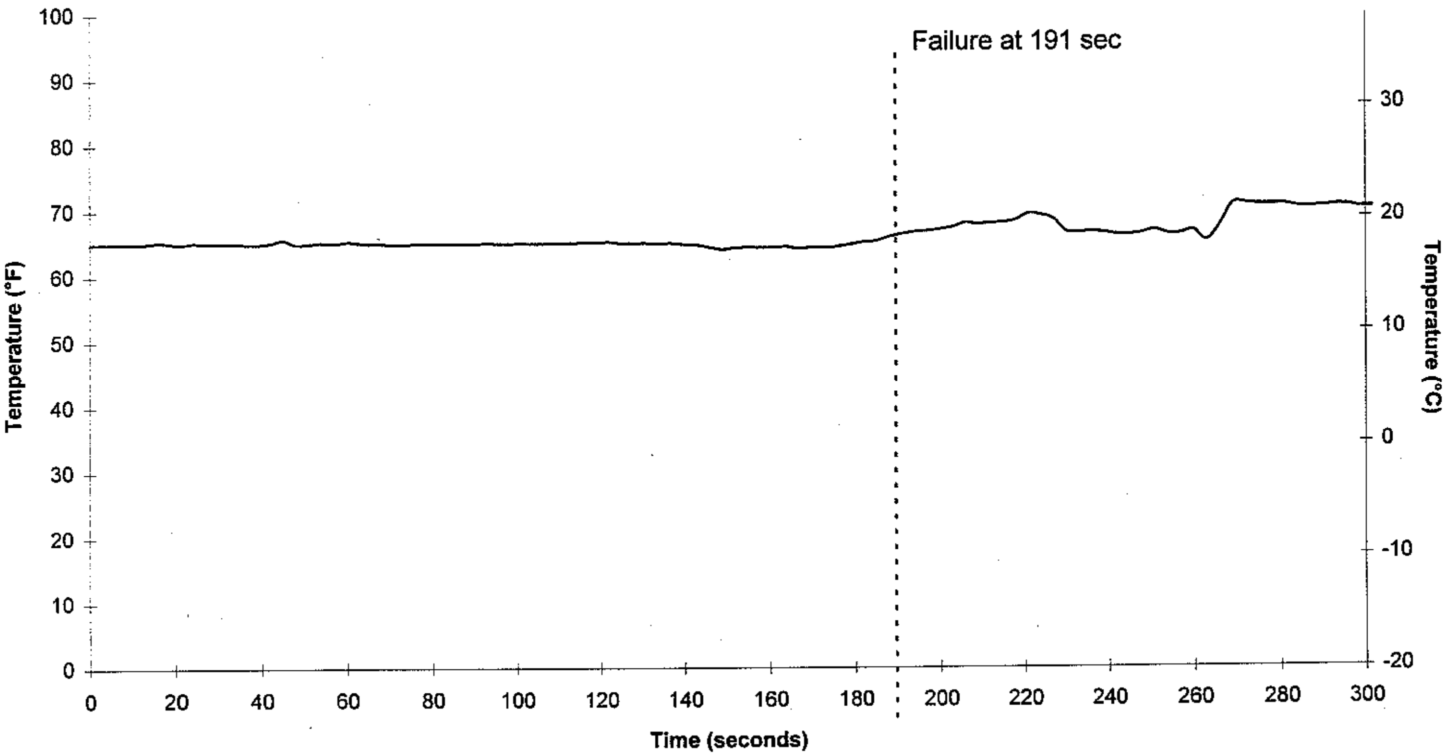

Figure C31: Test #7 Liquid Temperature 12" below water surface

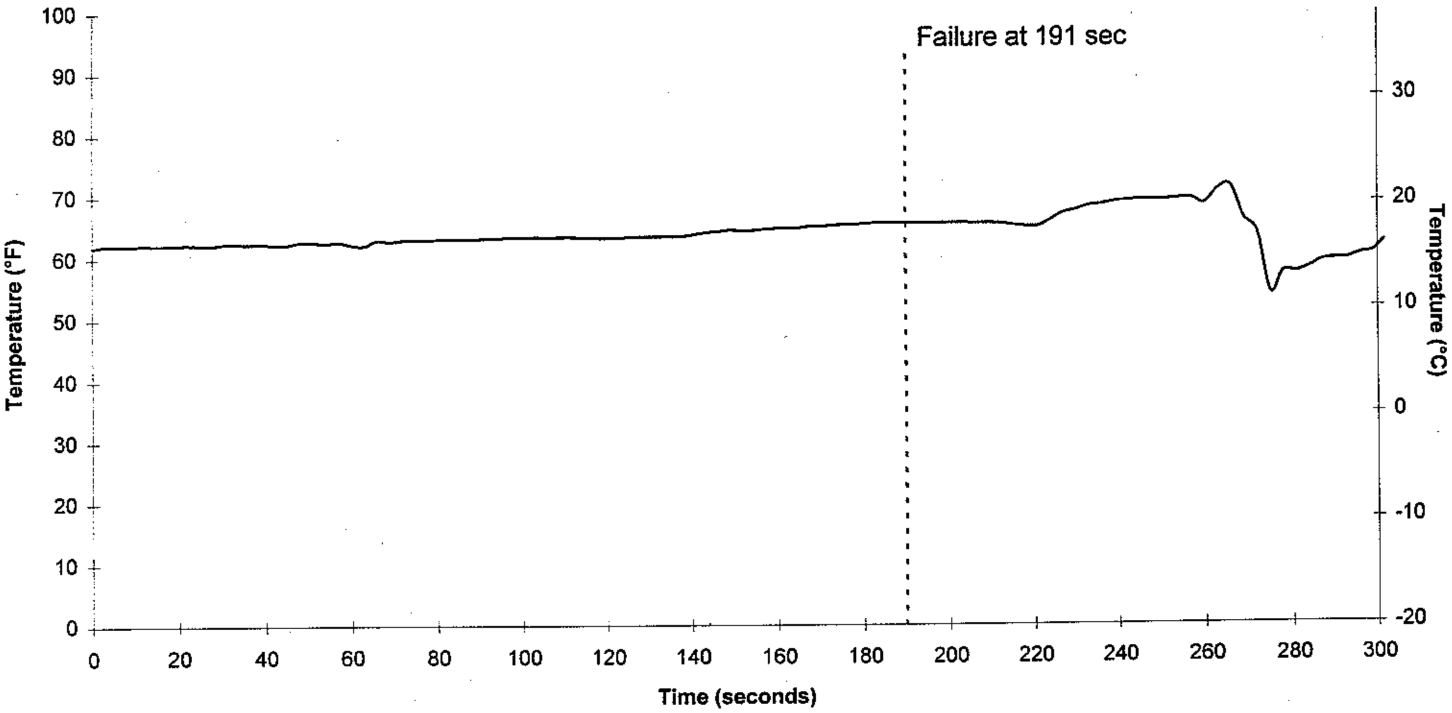

Figure C32: Test #7 Liquid Temperature 24" below water line

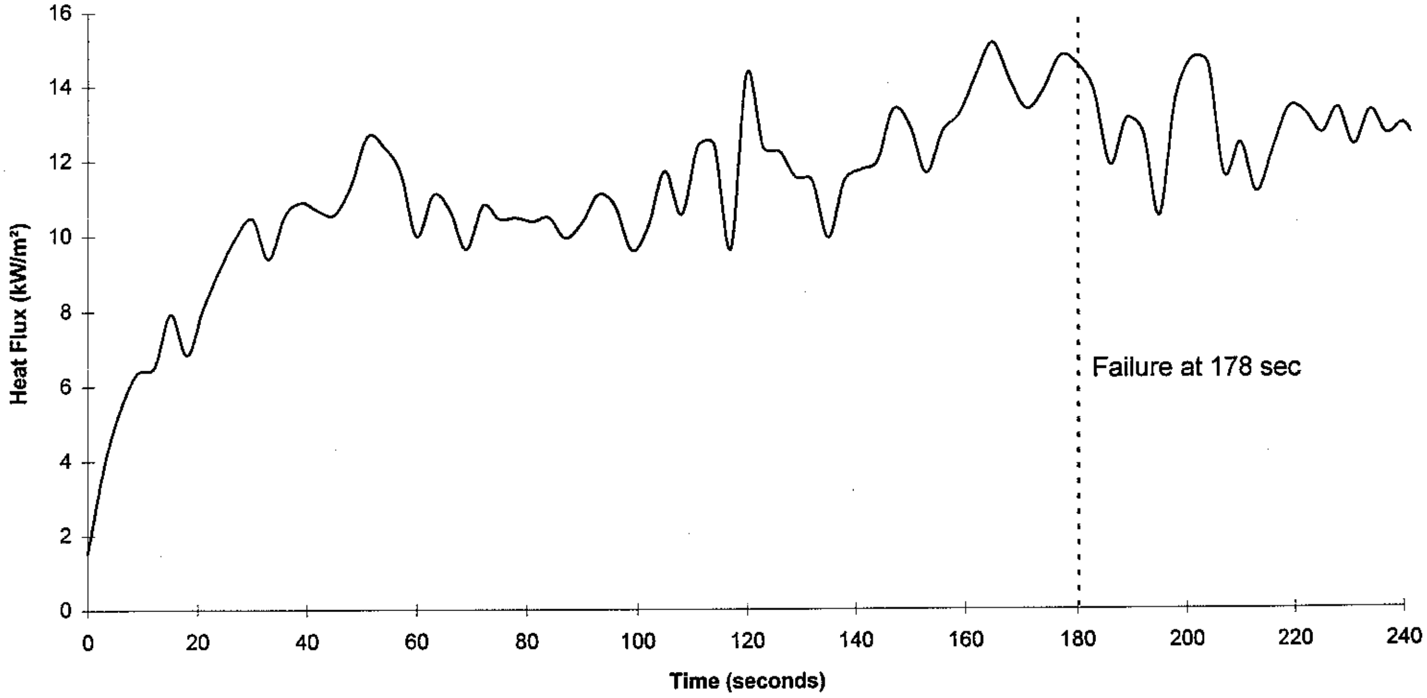

Figure C33: Test #8 Heat Flux

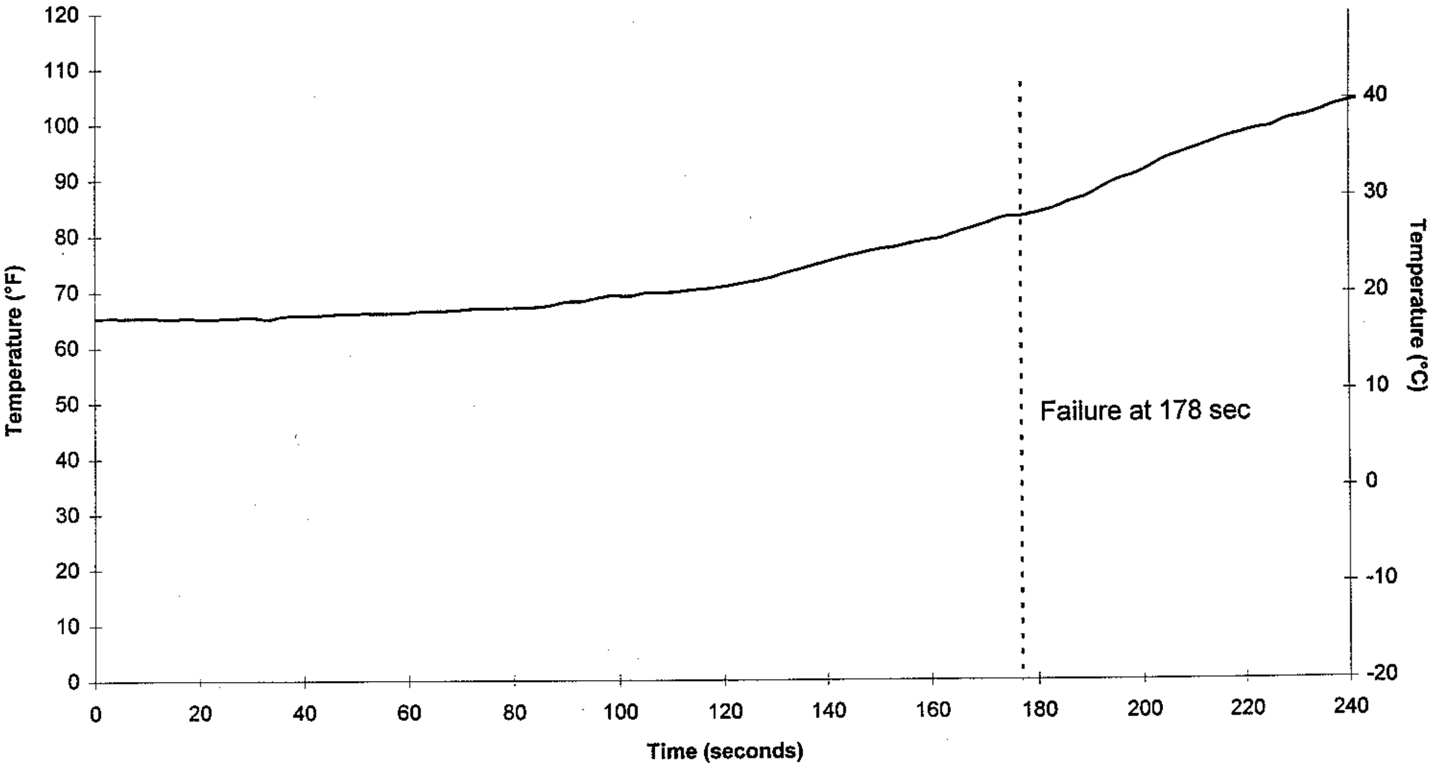

Figure C34: Test #8 Ullage Temperature

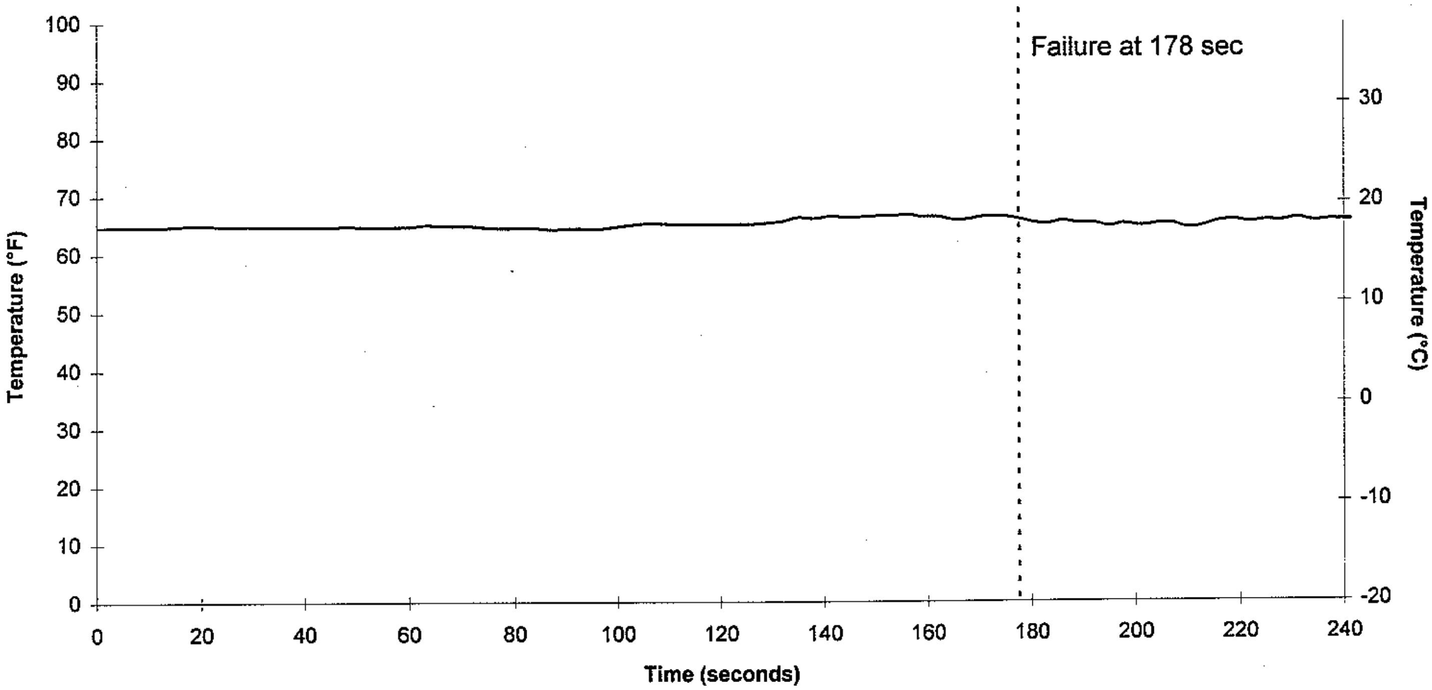

Figure C35: Test #8 Liquid Temperature 12" below water line

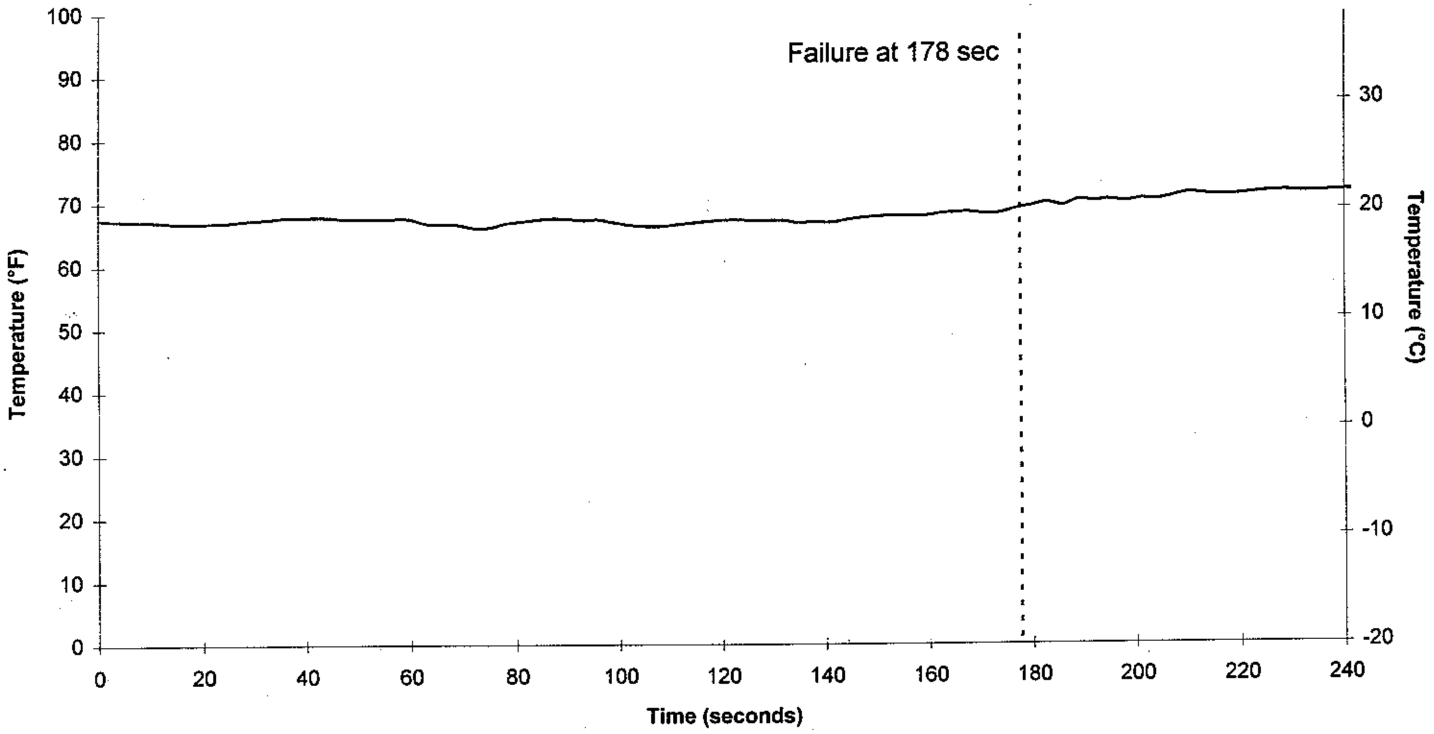

Figure C36: Test #8 Liquid Temperature 24" below water line

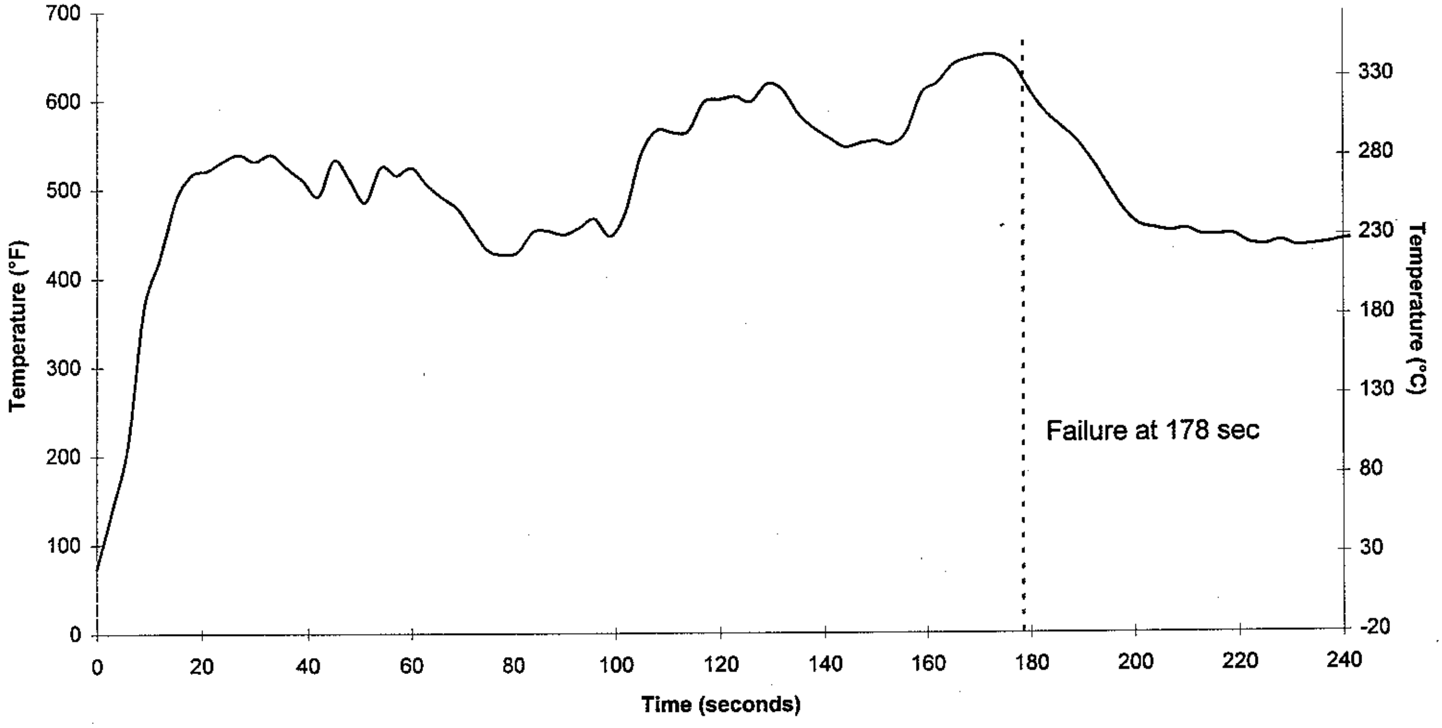

Figure C37: Test #8 External Temperature

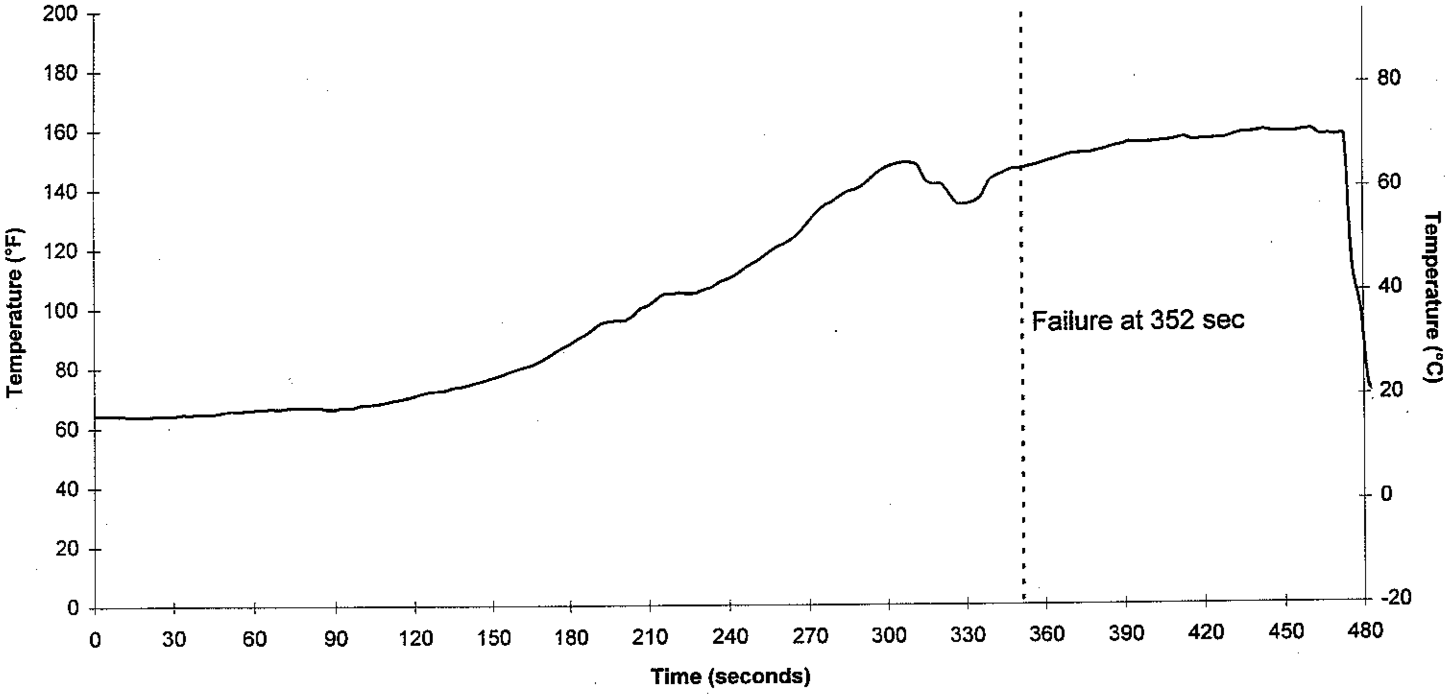

Figure C38: Test #9 Ullage Temperature

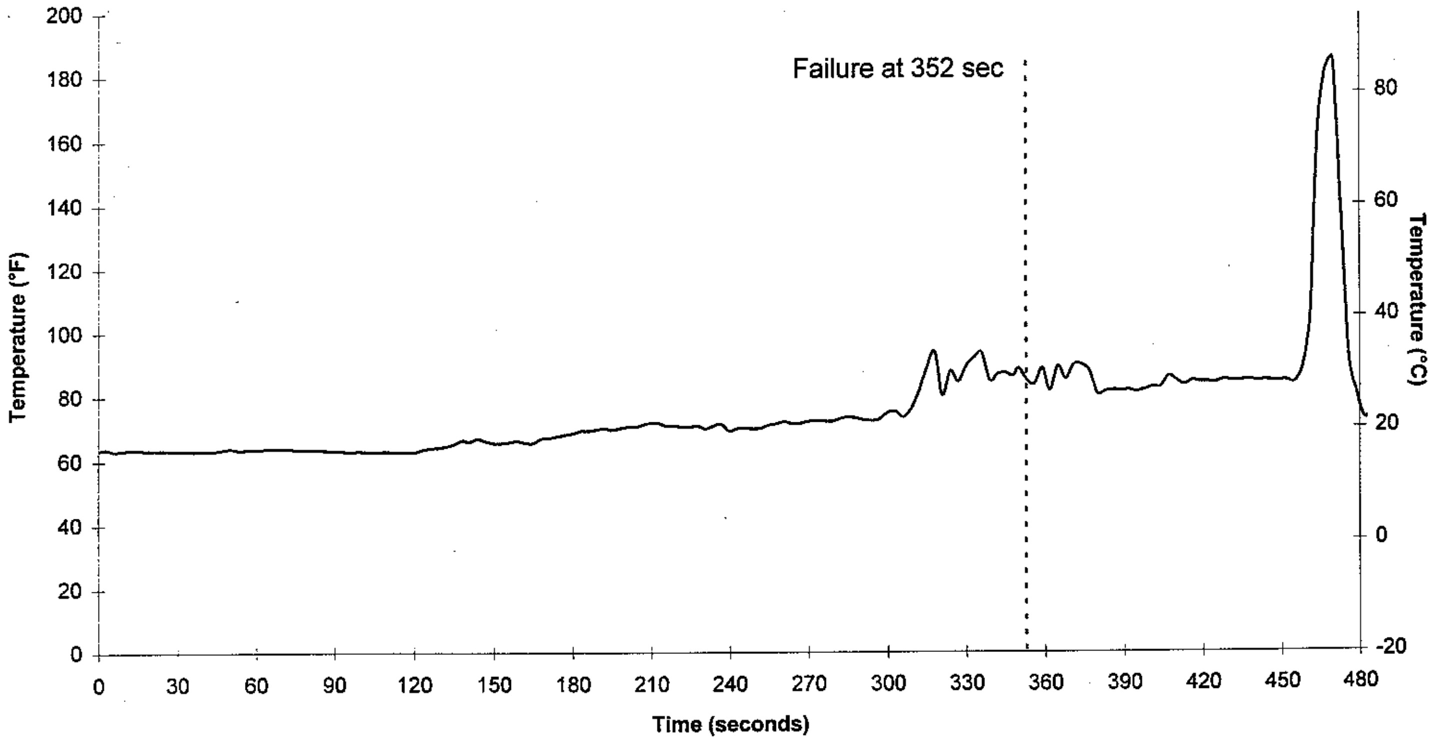

Figure C39: Test #9 Liquid Temperature 12" below water line

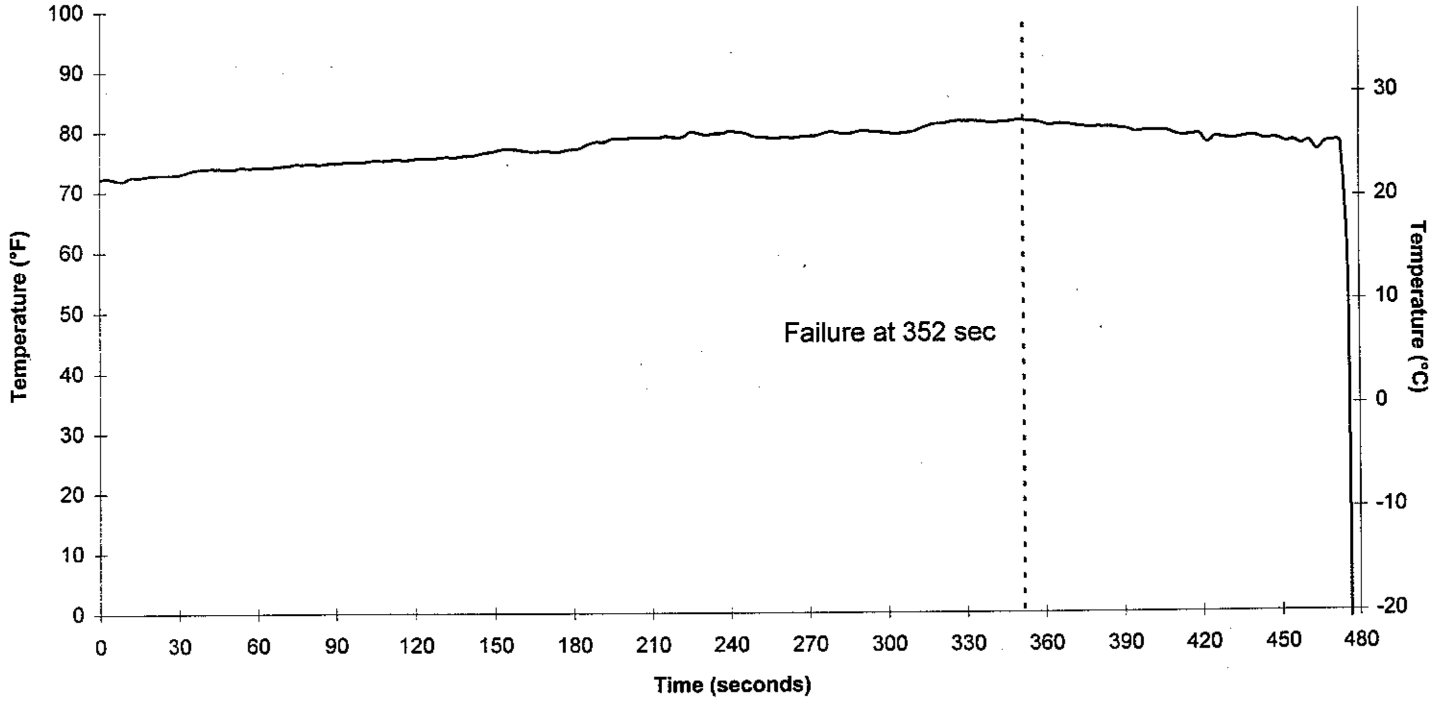

Figure C40: Test #9 Liquid Temperature 24" below water line

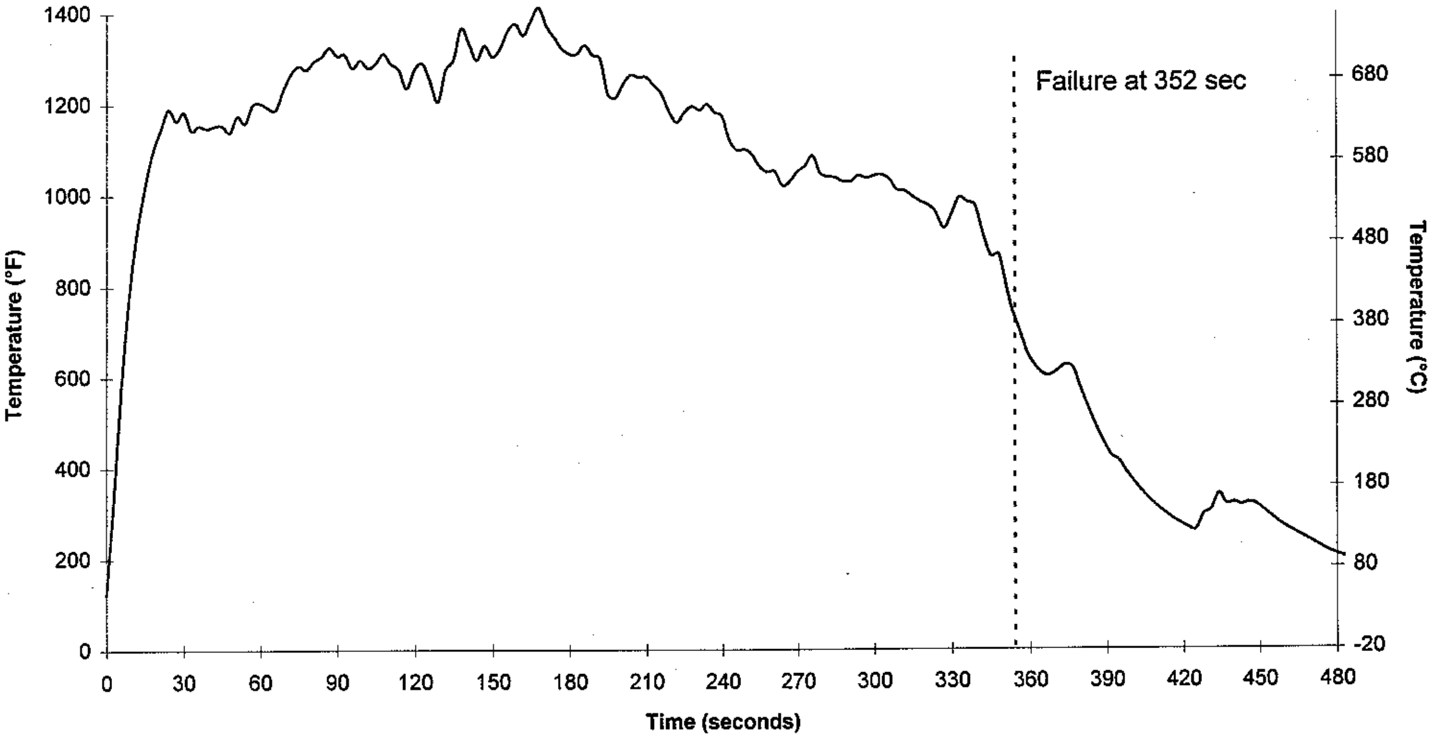

Figure C41: Test #9 External Temperature

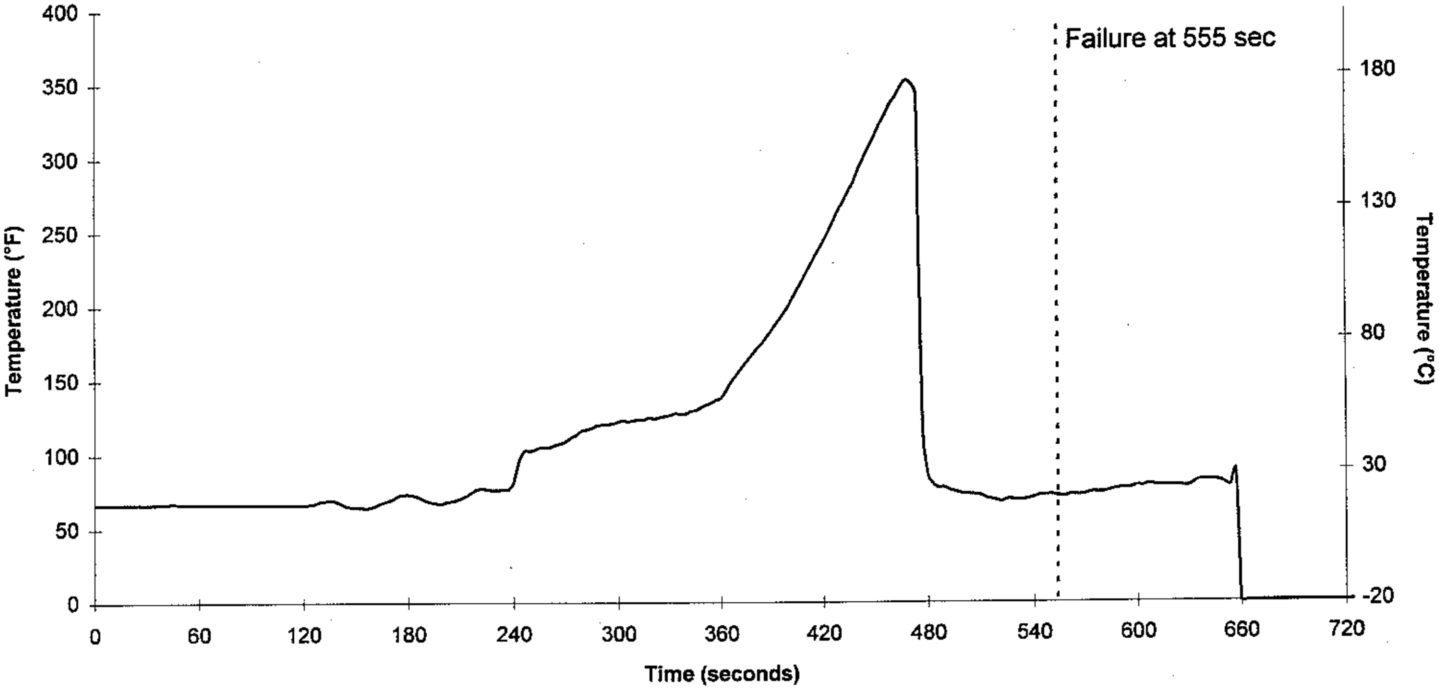

Figure C42: Test #10 Ullage Temperature

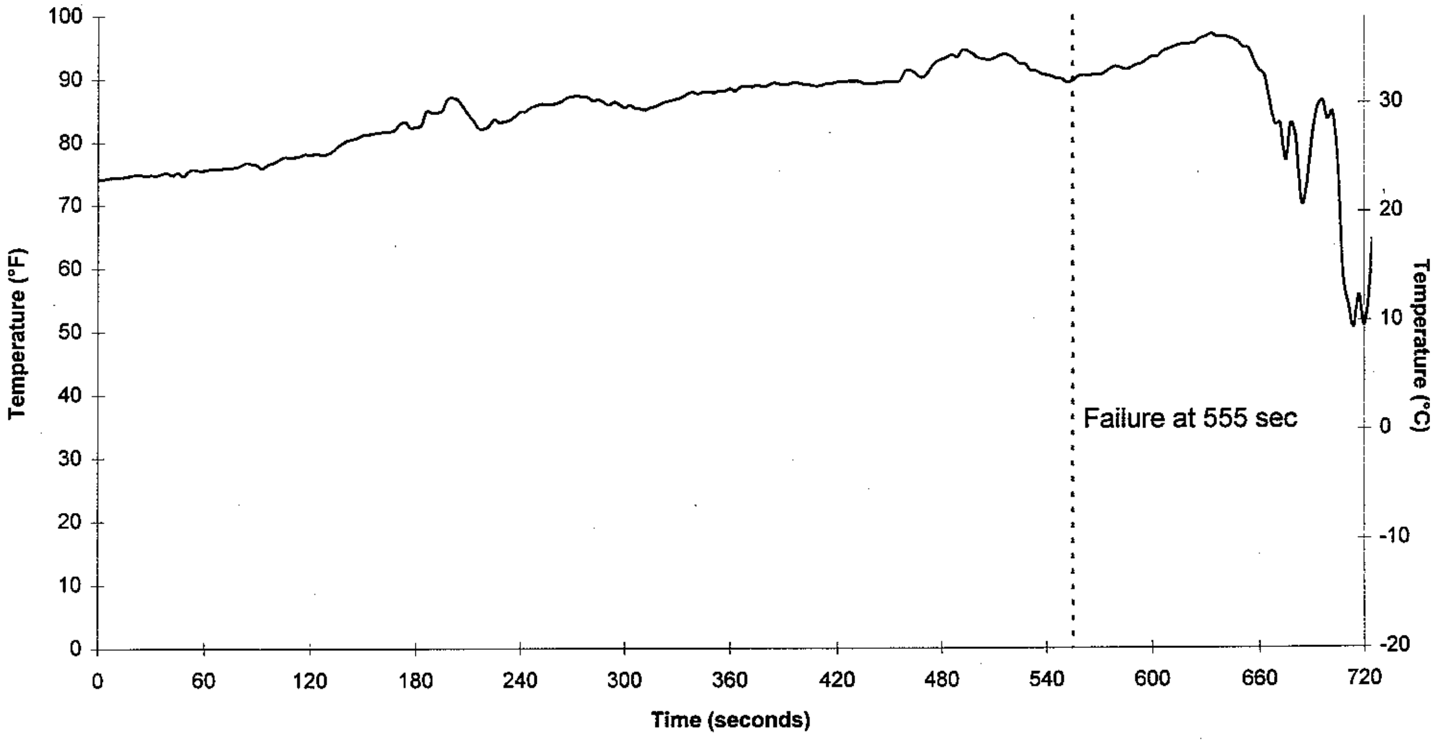

Figure C43: Test #10 Liquid Temperatures 12" below water line

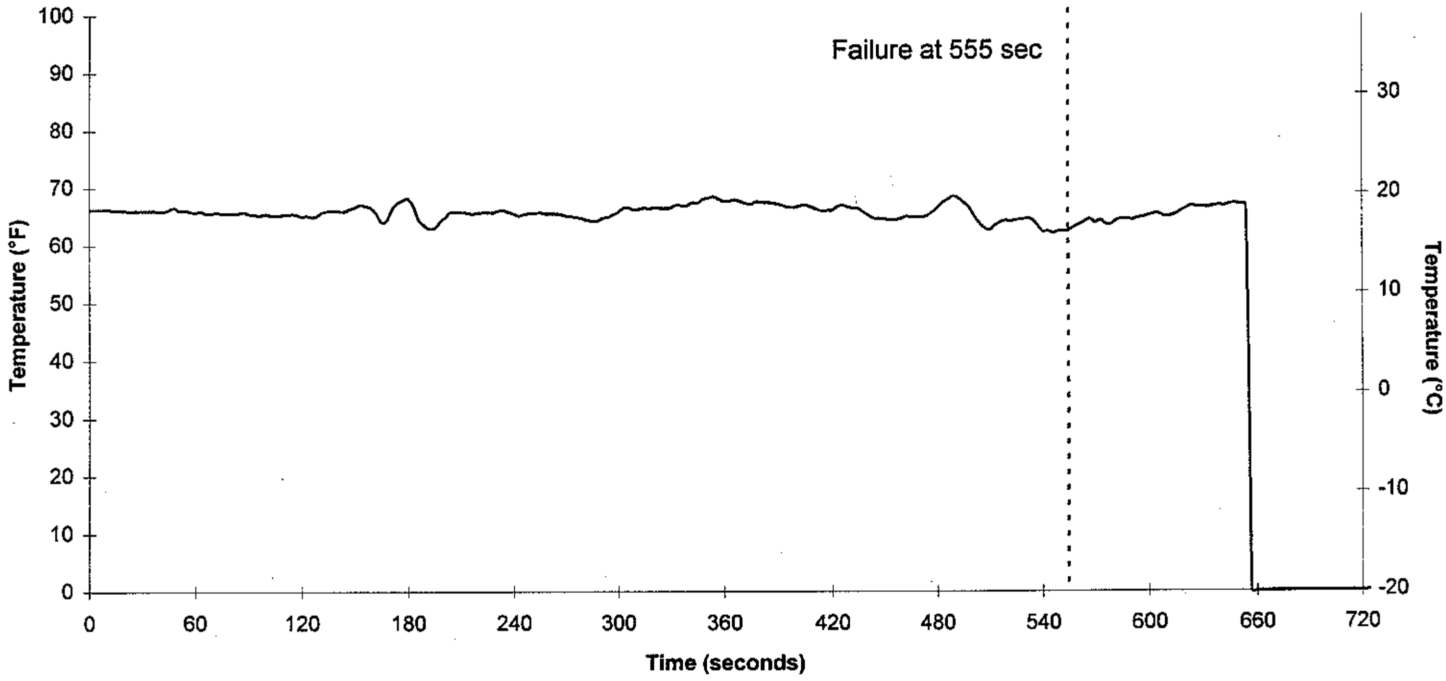

Figure C44: Test #10 Liquid Temperature 24" below water line

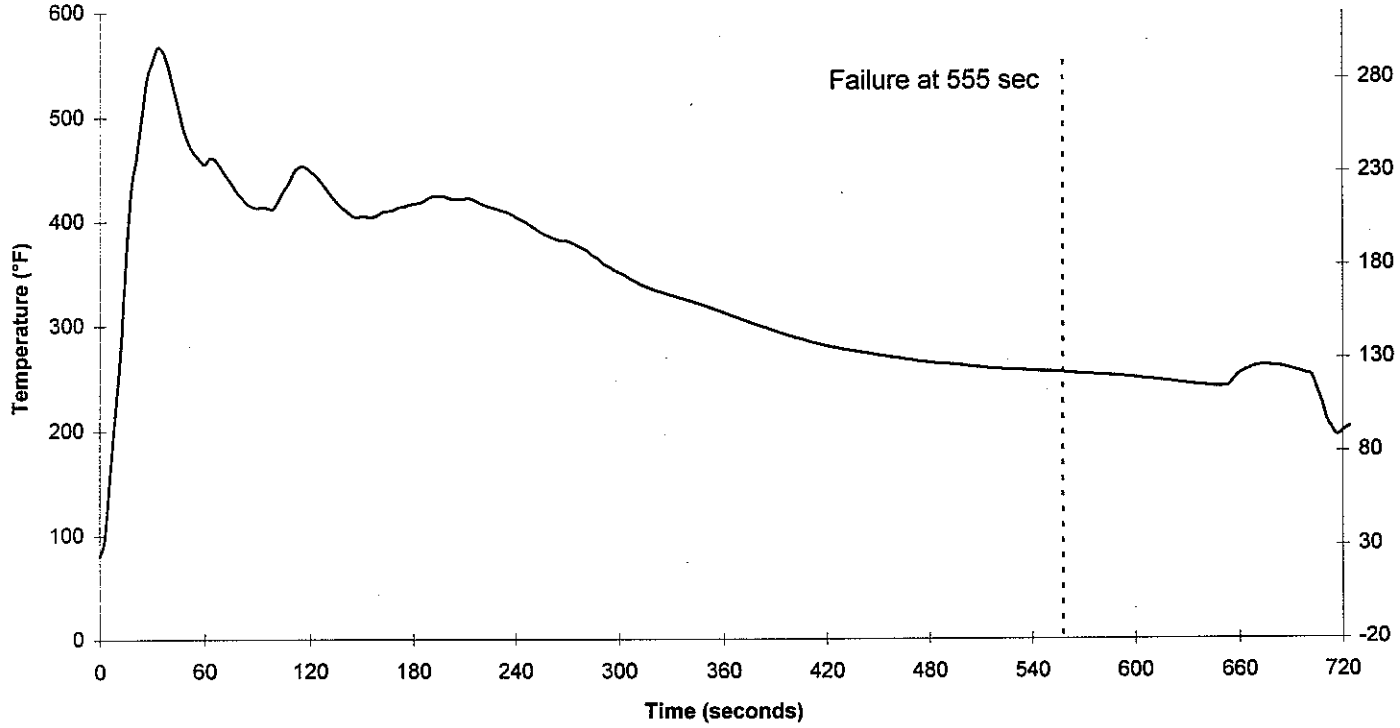

Figure C45: Test #10 External Temperature

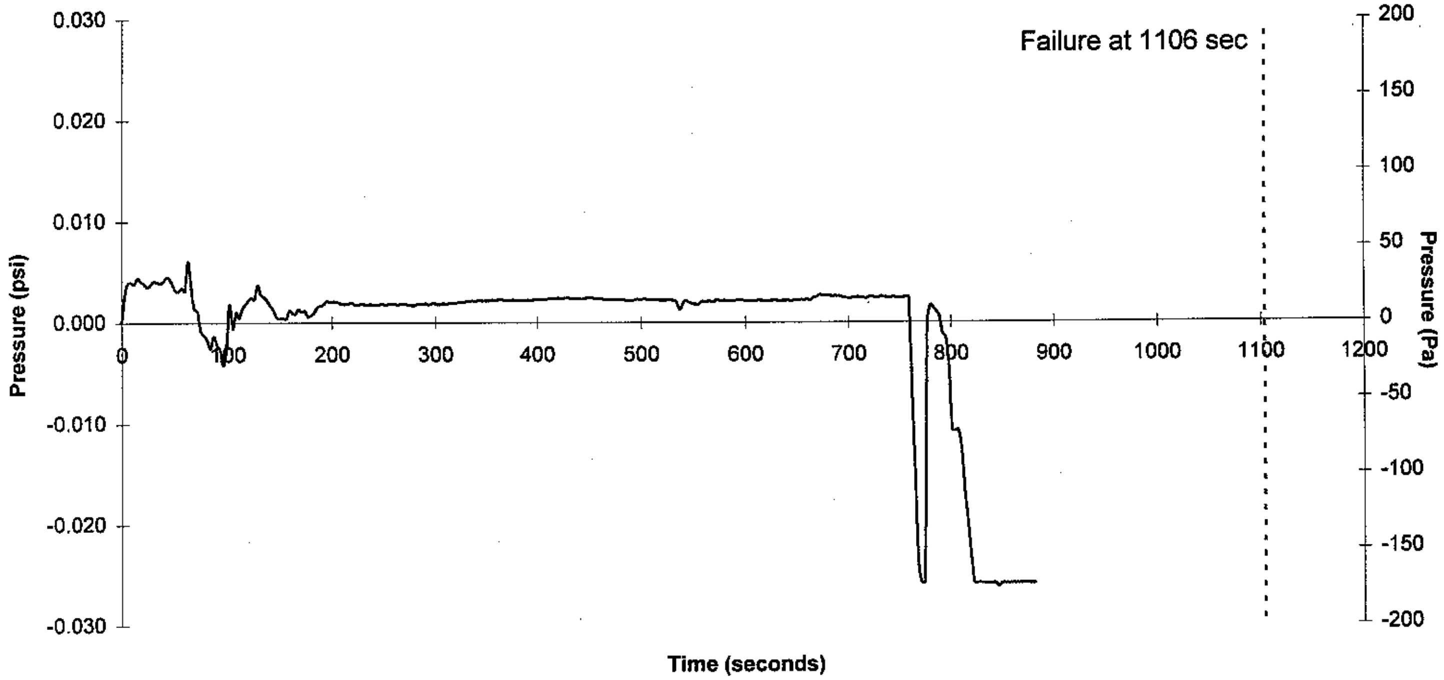

Figure C46: Test #11 Pressure

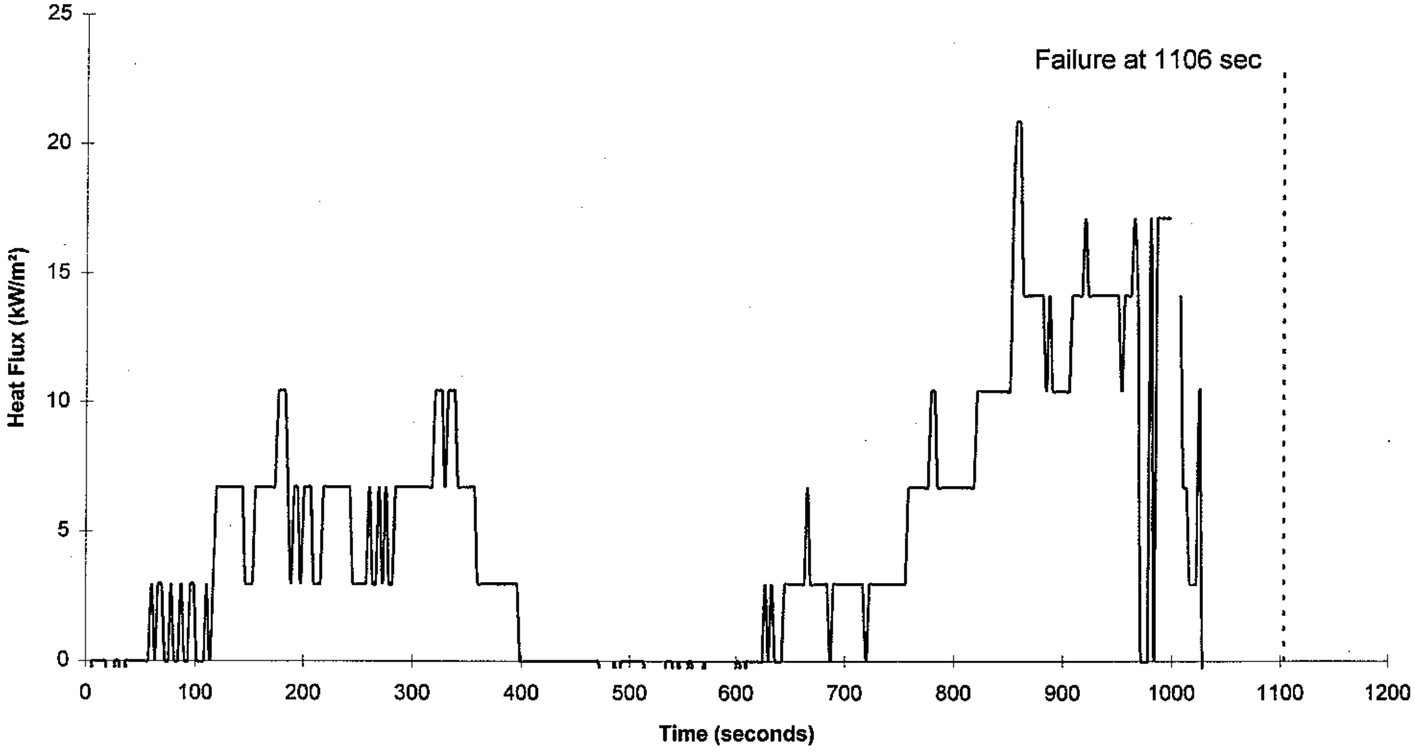

Figure C47: Test #11 Heat Flux

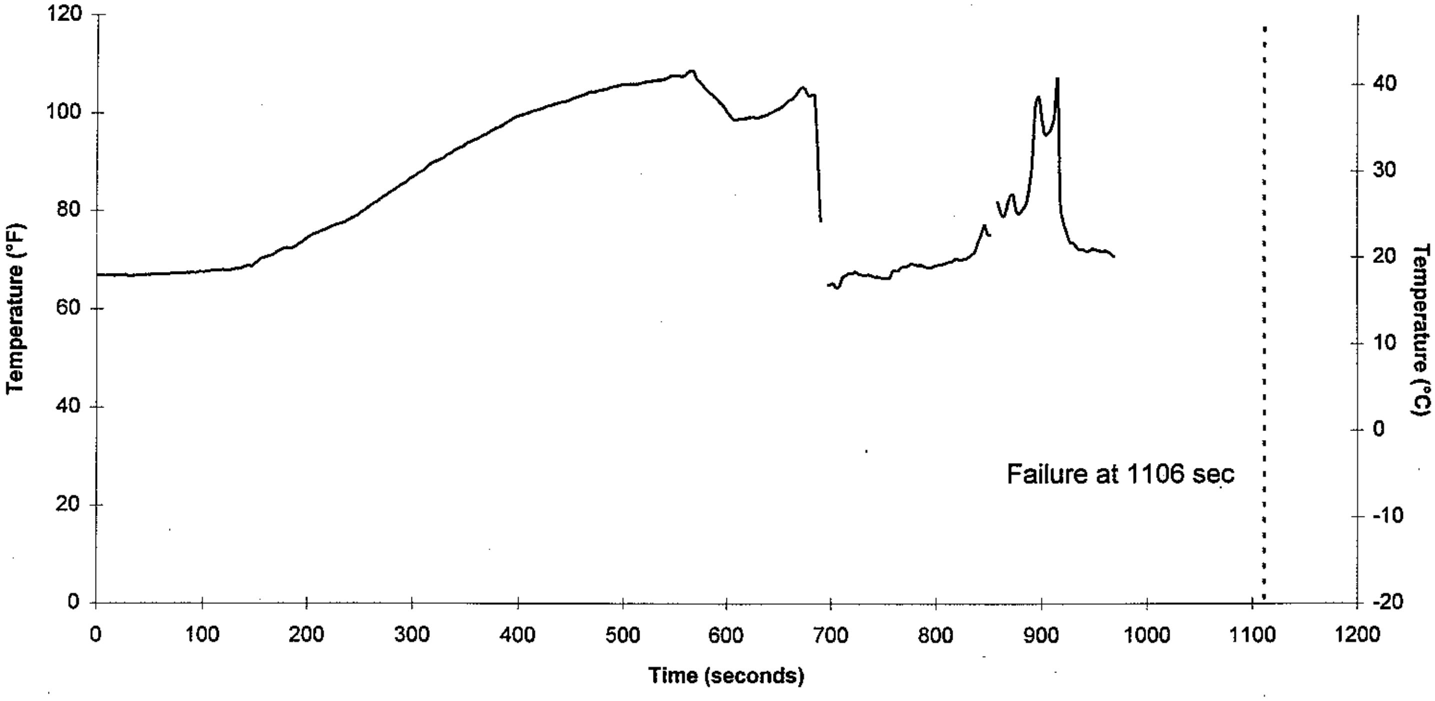

Figure C48: Test #11 Ullage Temperature

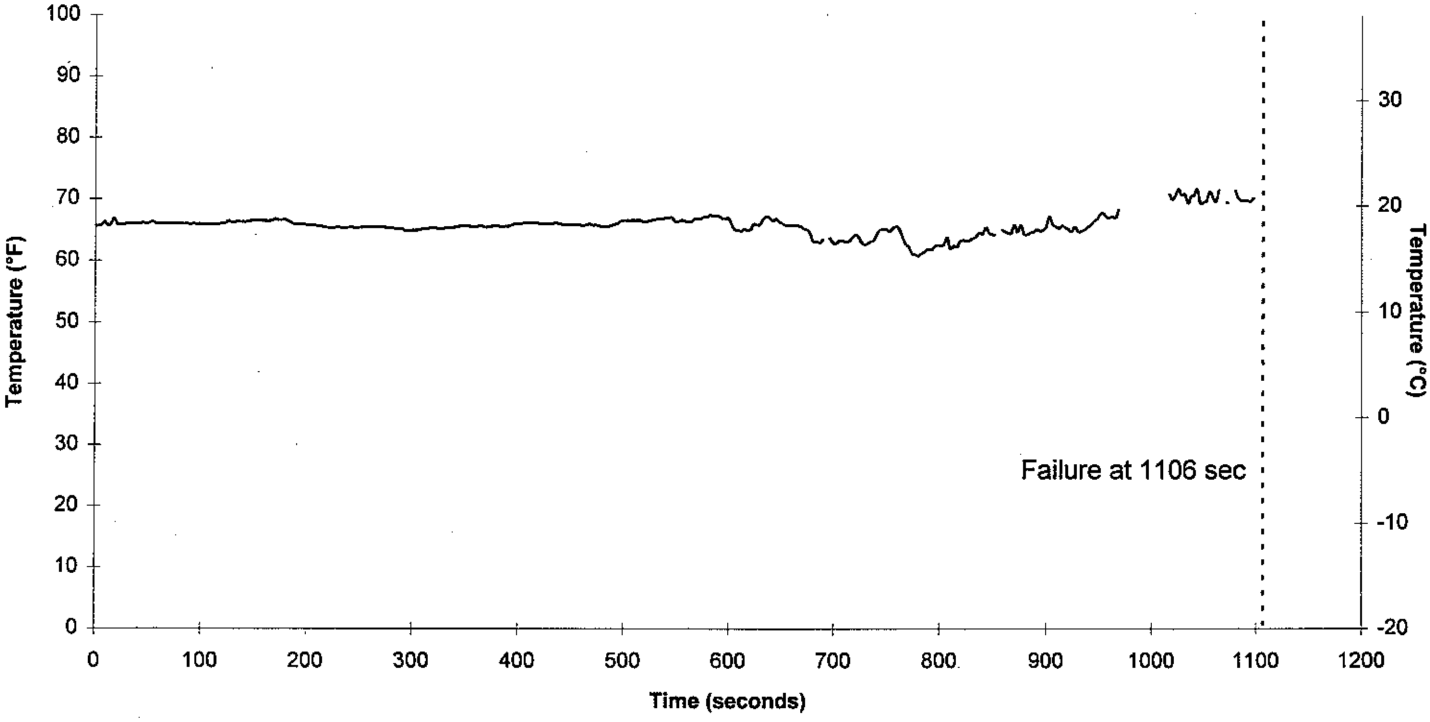

Figure C49: Test #11 Liquid Temperature 12" below water line

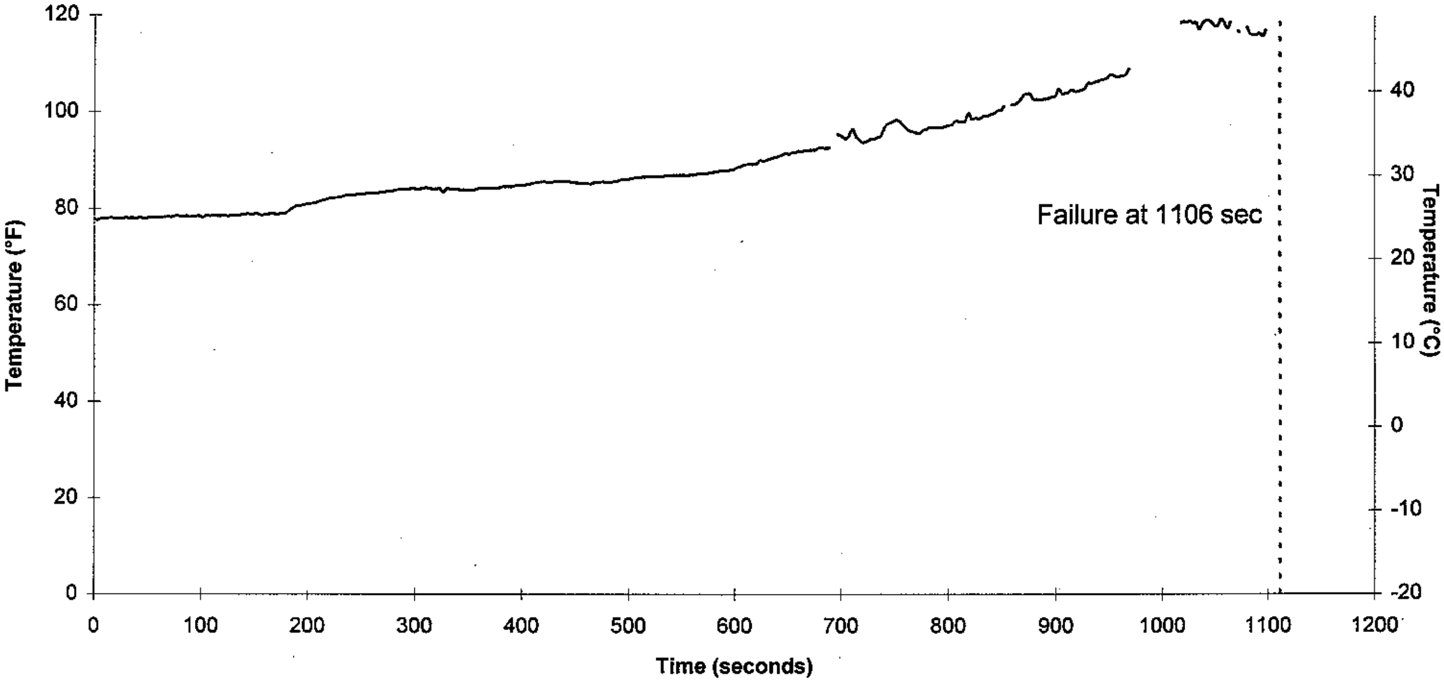

Figure C50: Test #11 Liquid Temperature 24" below water line

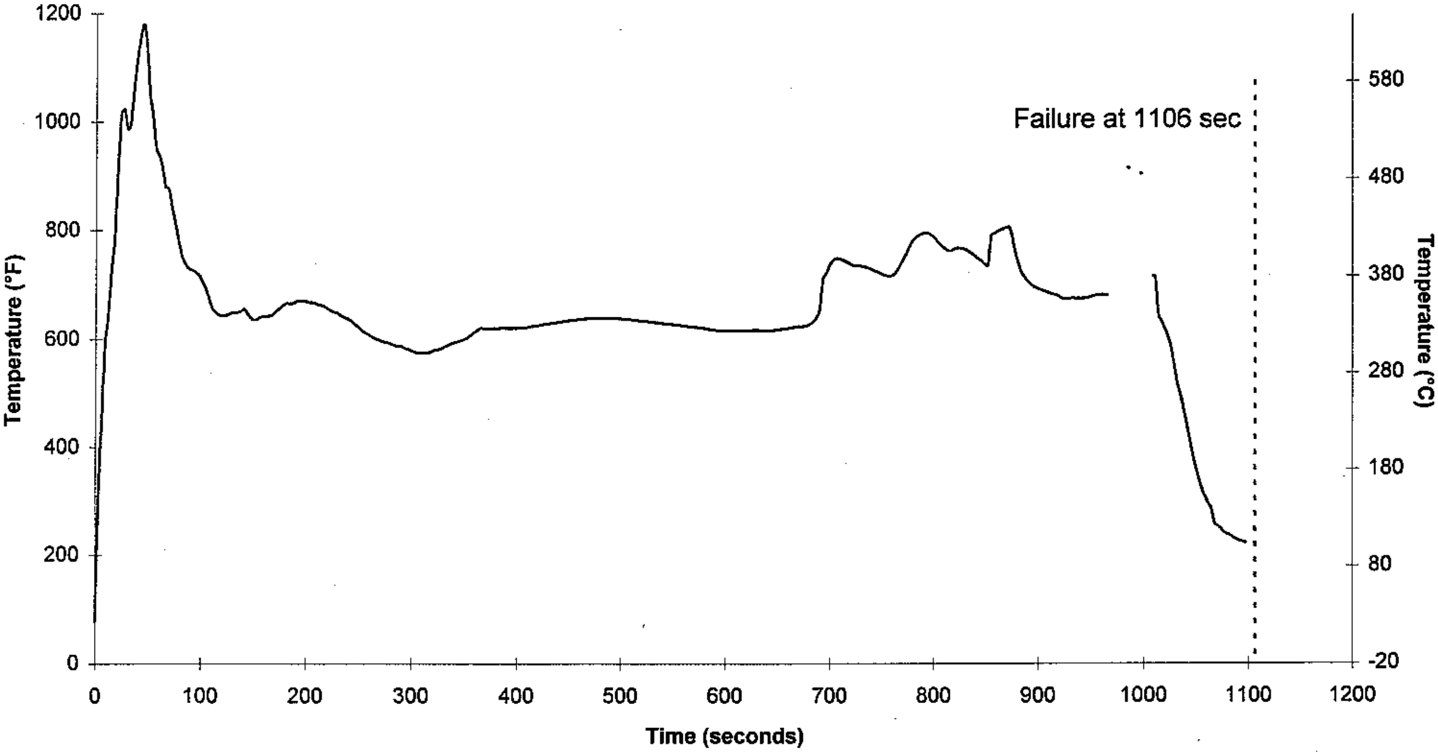

Figure C51: Test #11 External Temperature

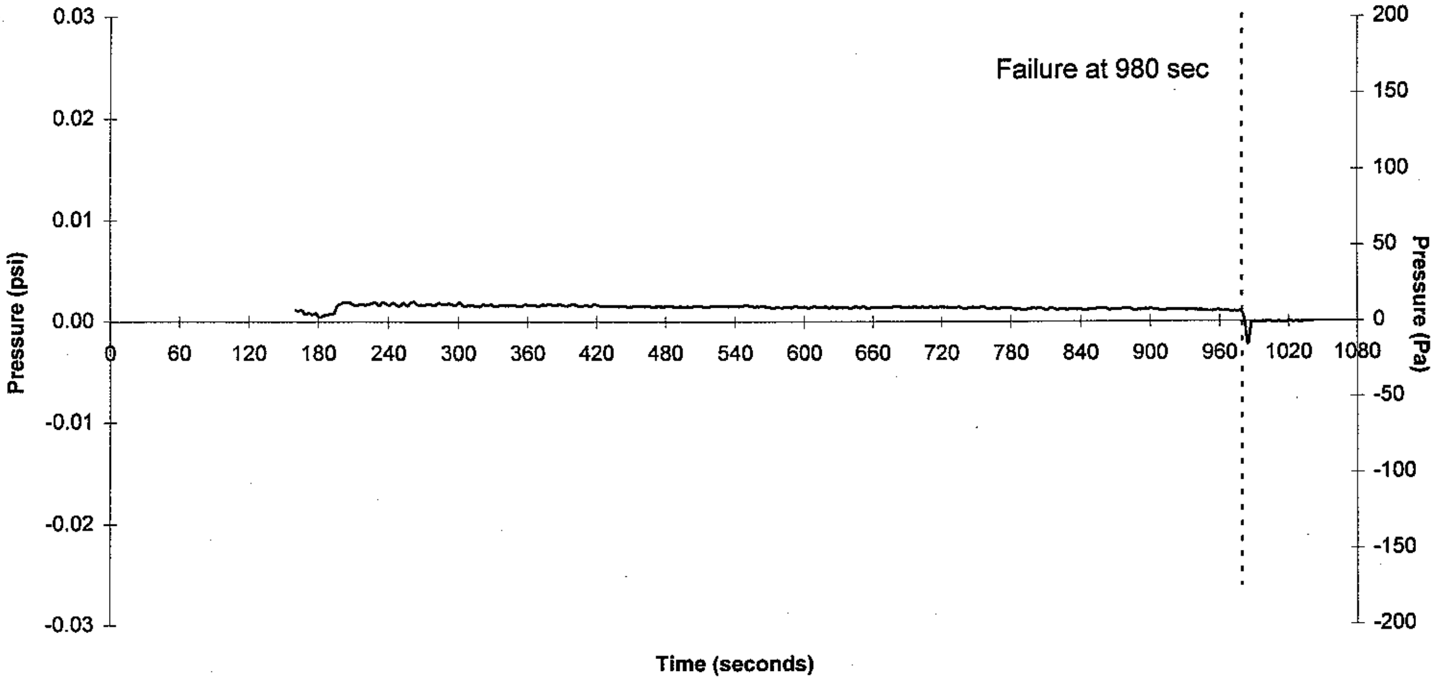

Figure C52: Test #12 Pressure

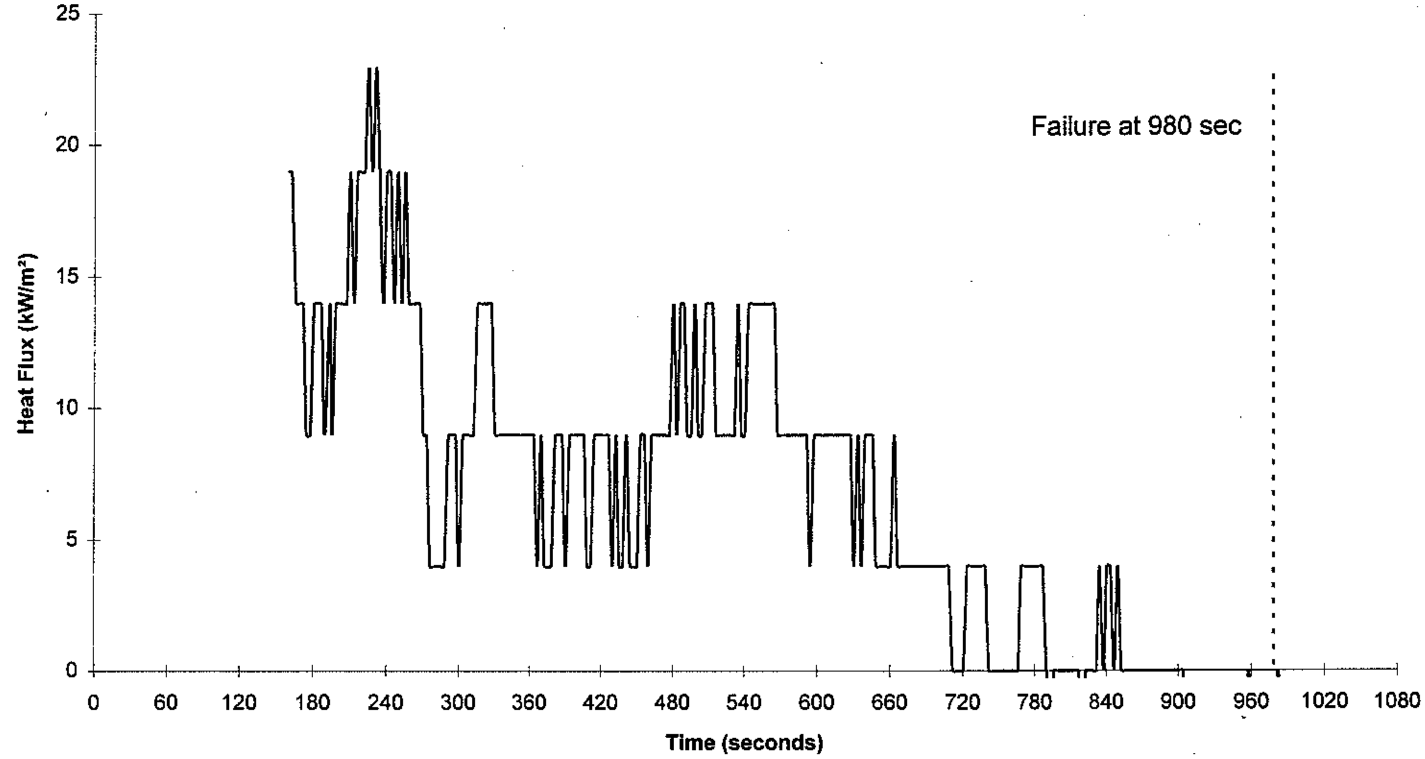

Figure C53: Test #12 Heat Flux

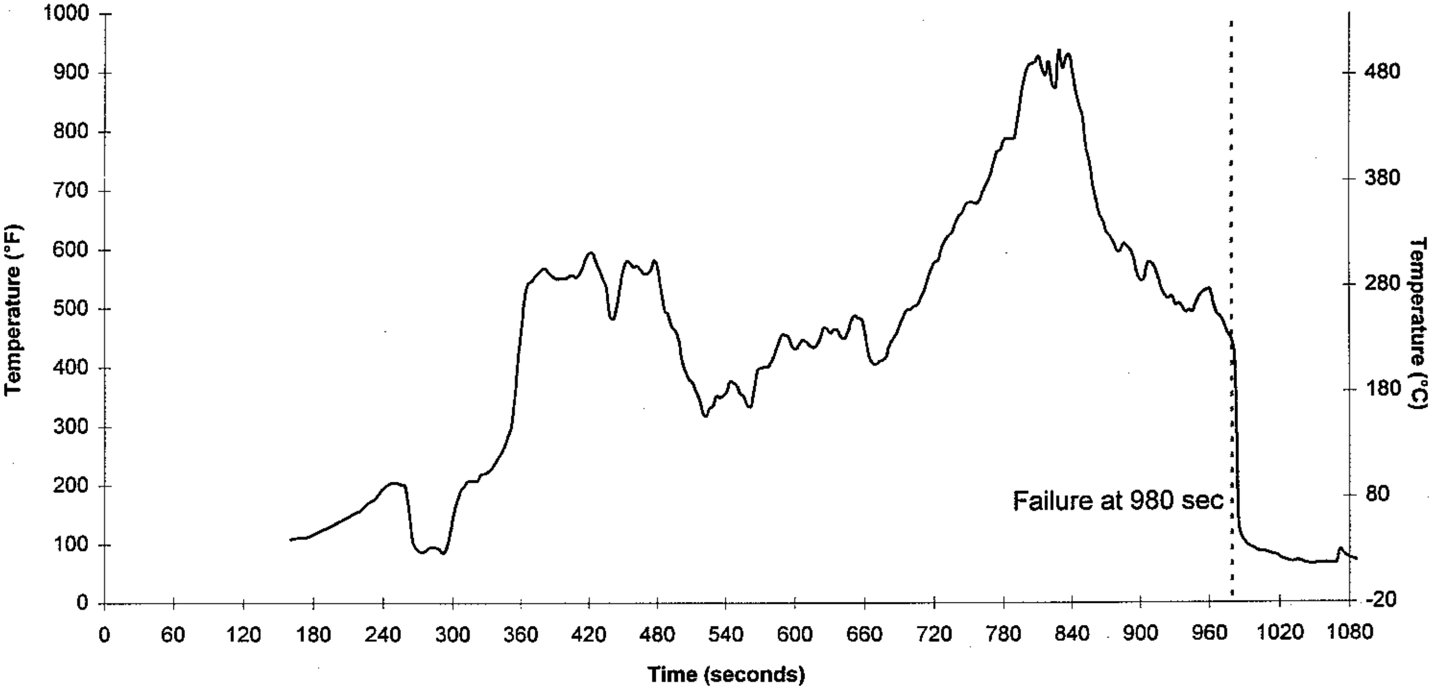

Figure C54: Test #12 Ullage Temperatures

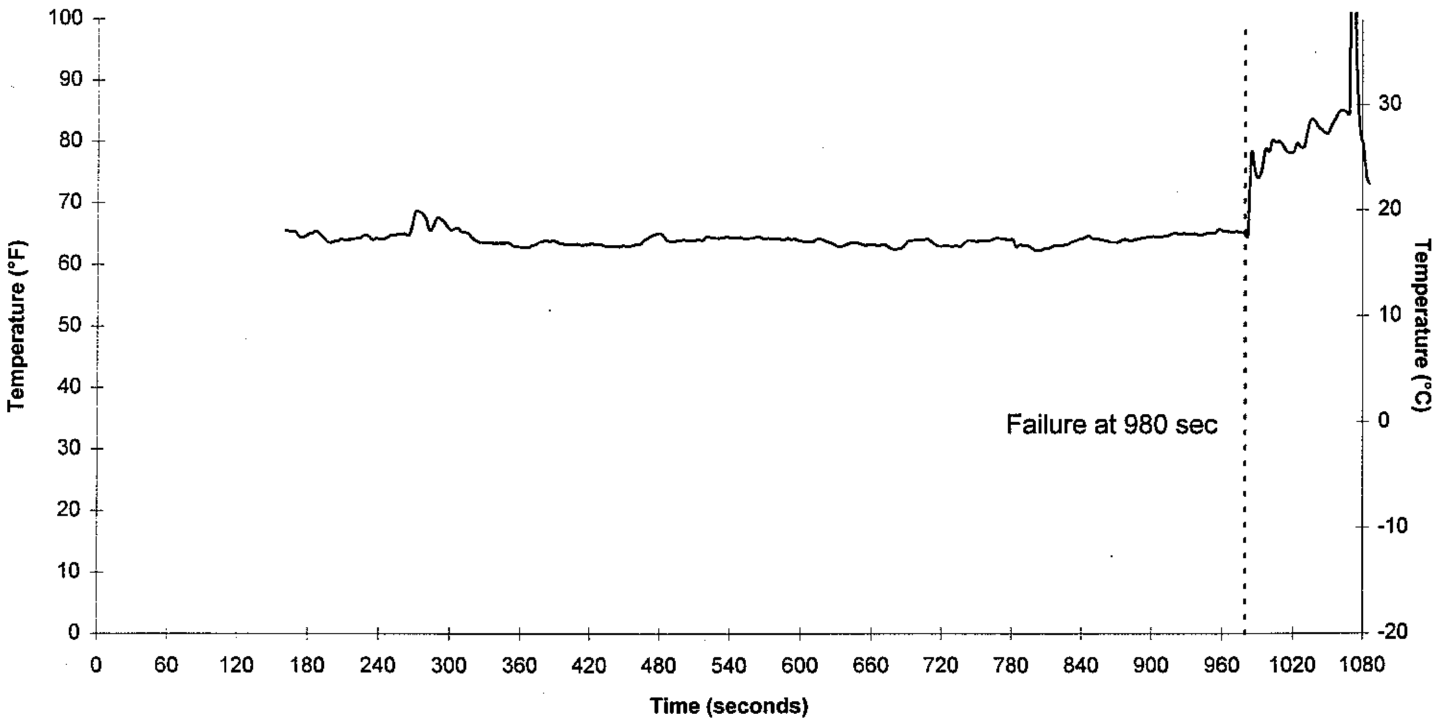

Figure C55: Test #12 Liquid Temperature 12" below water line

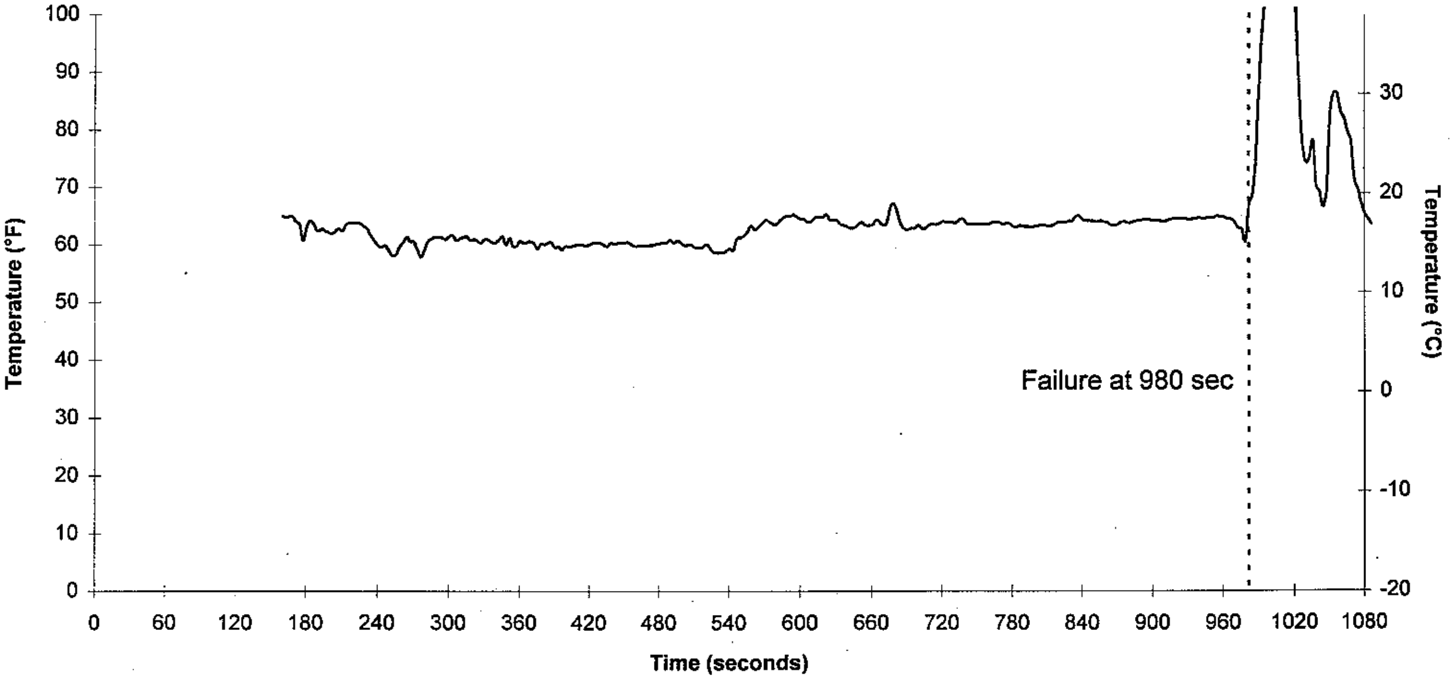

Figure C56: Test #12 Liquid Temperature 24" below water line

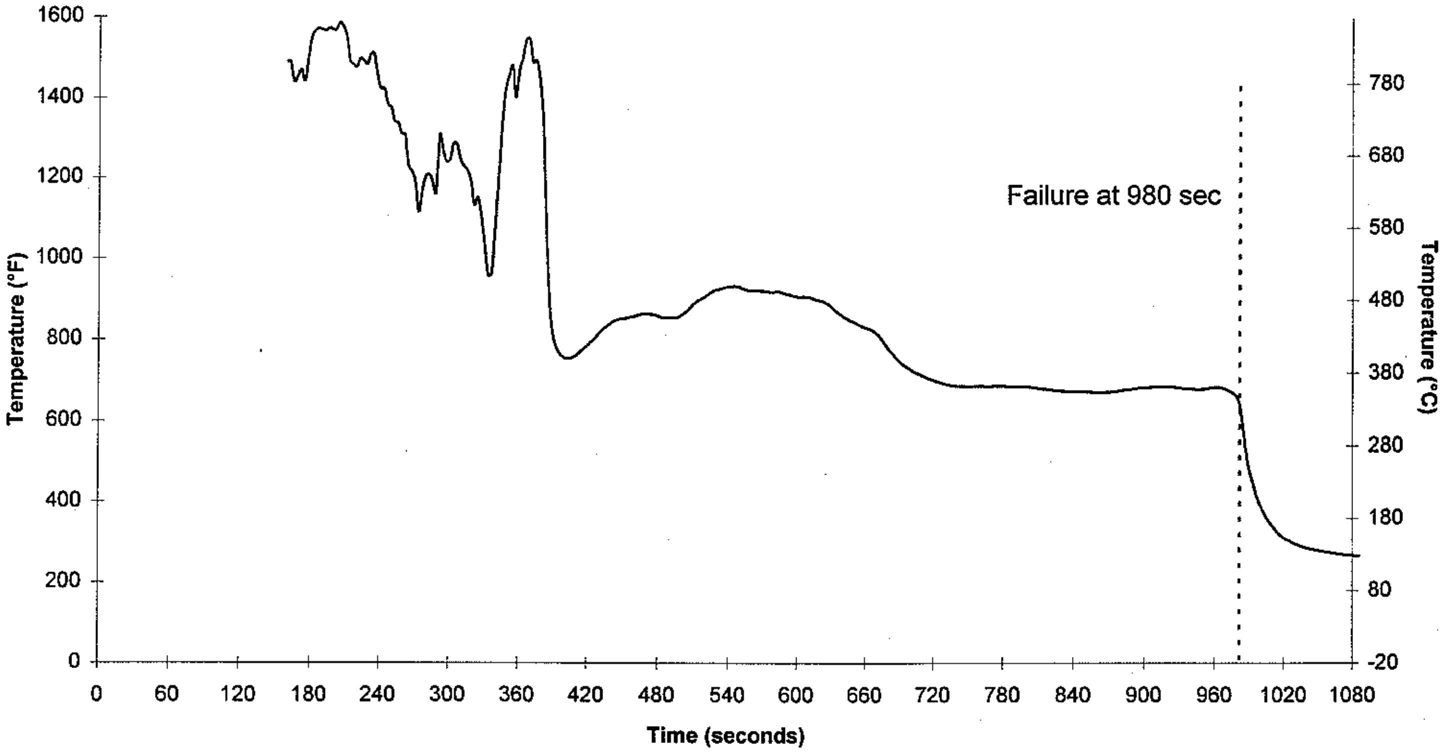

Figure C57: Test #12 External Temperatures

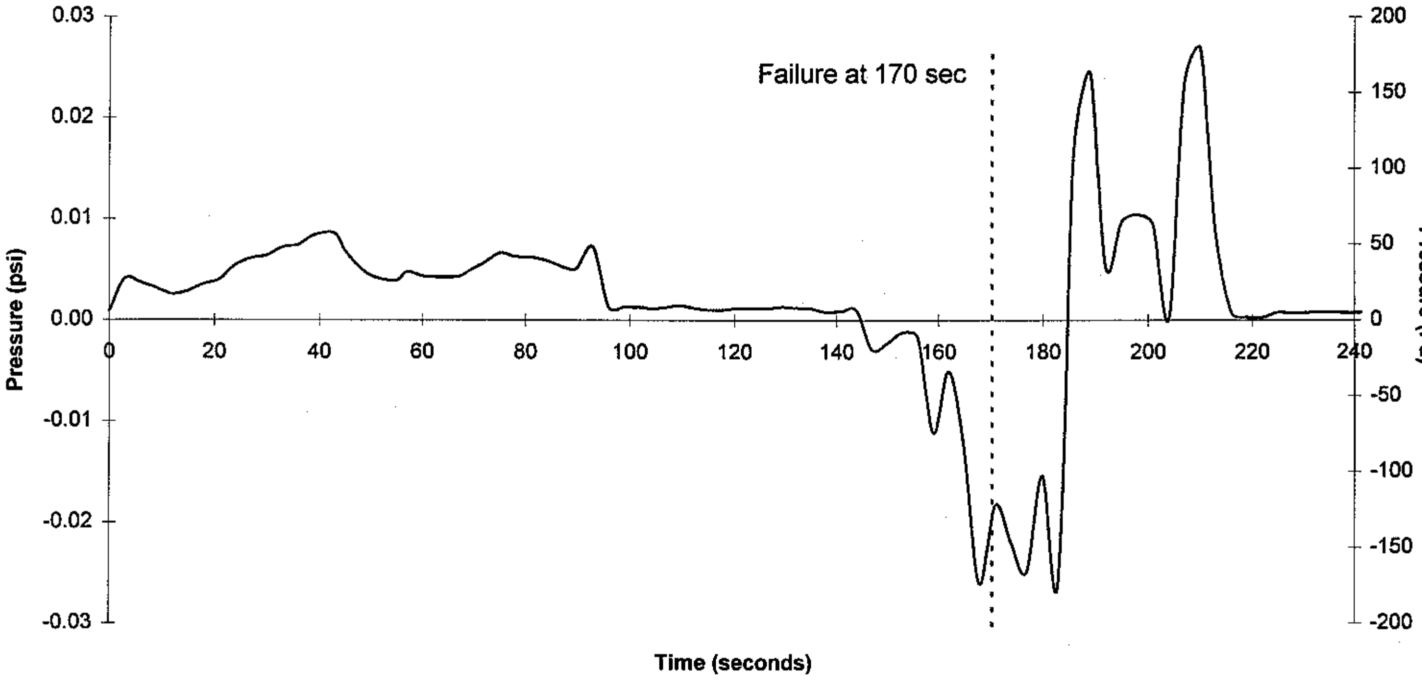

Figure C58: Test #13 Pressure

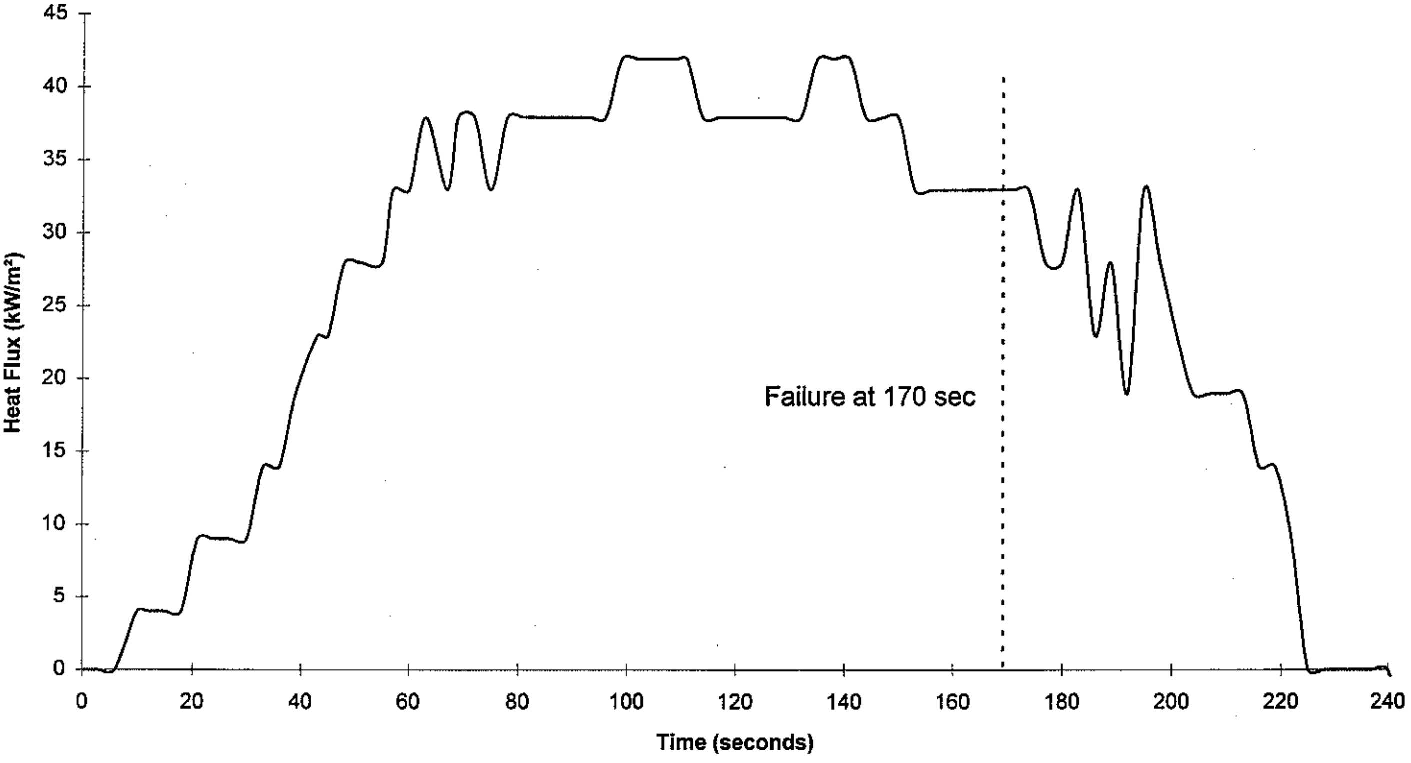

Figure C59: Test #13 Heat Flux

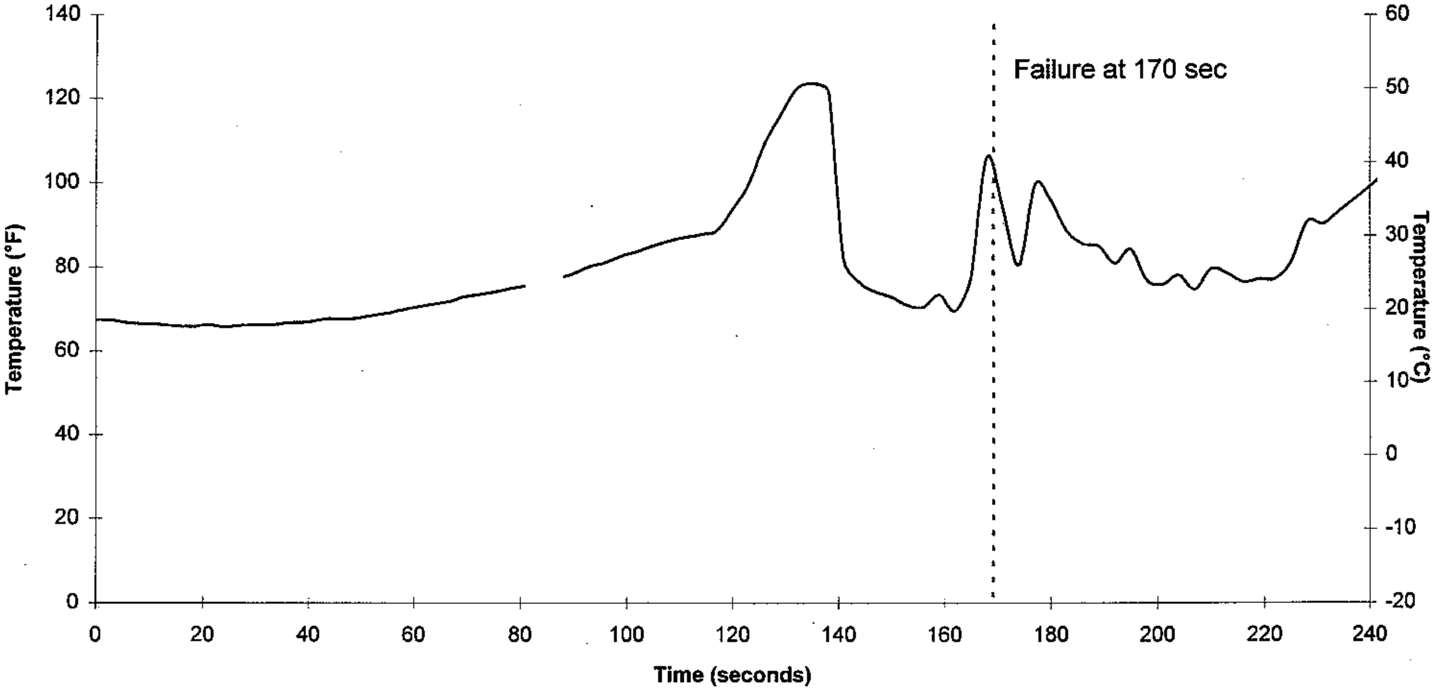

Figure C60: Test #13 Ullage Temperatures

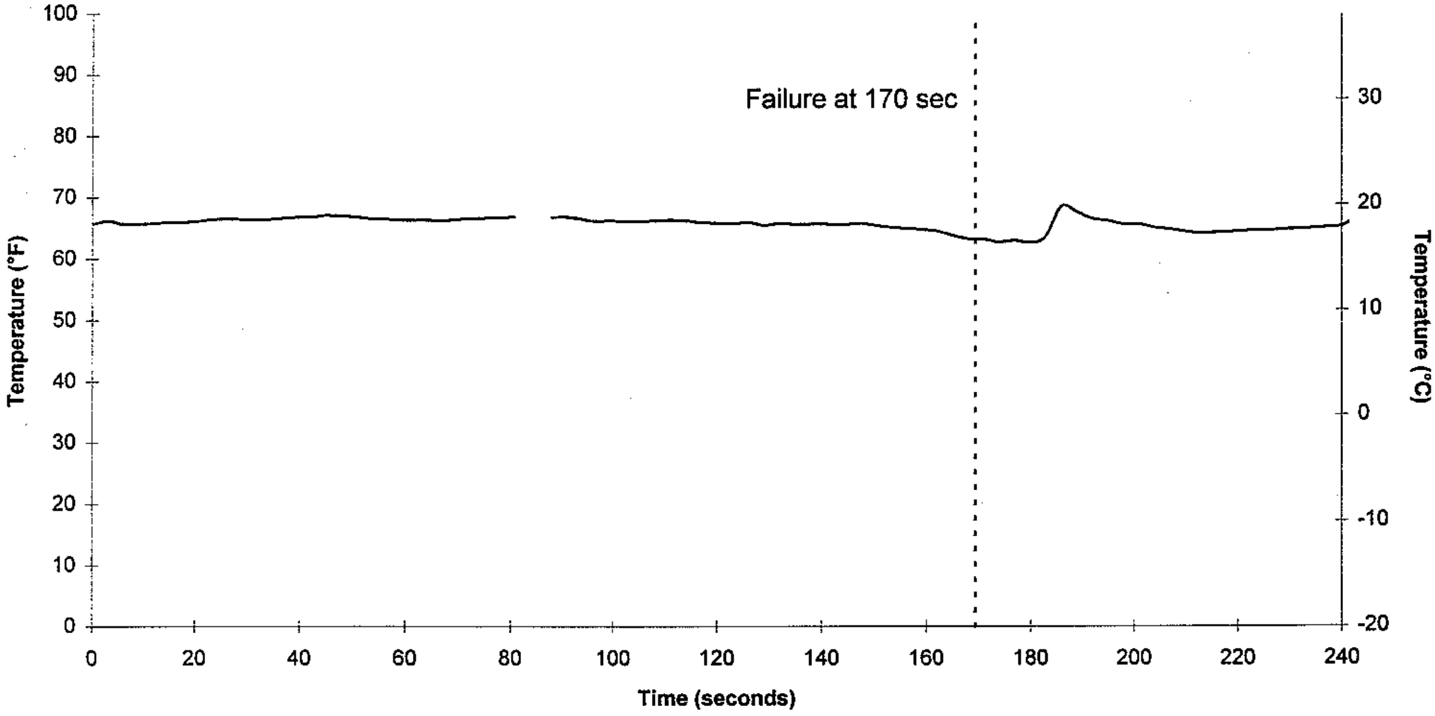

Figure C61: Test #13 Liquid Temperature 12" below water line

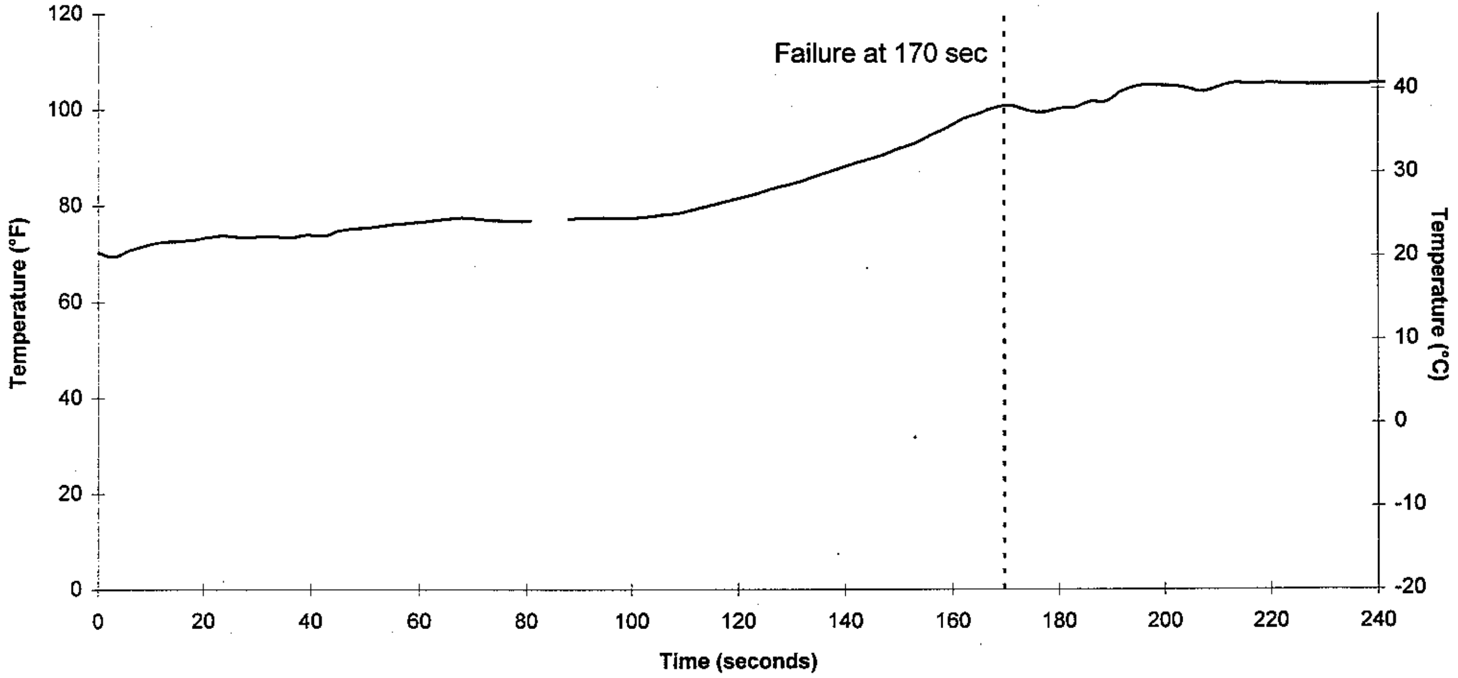

Figure C62: Test #13 Liquid Temperature 24" below water line

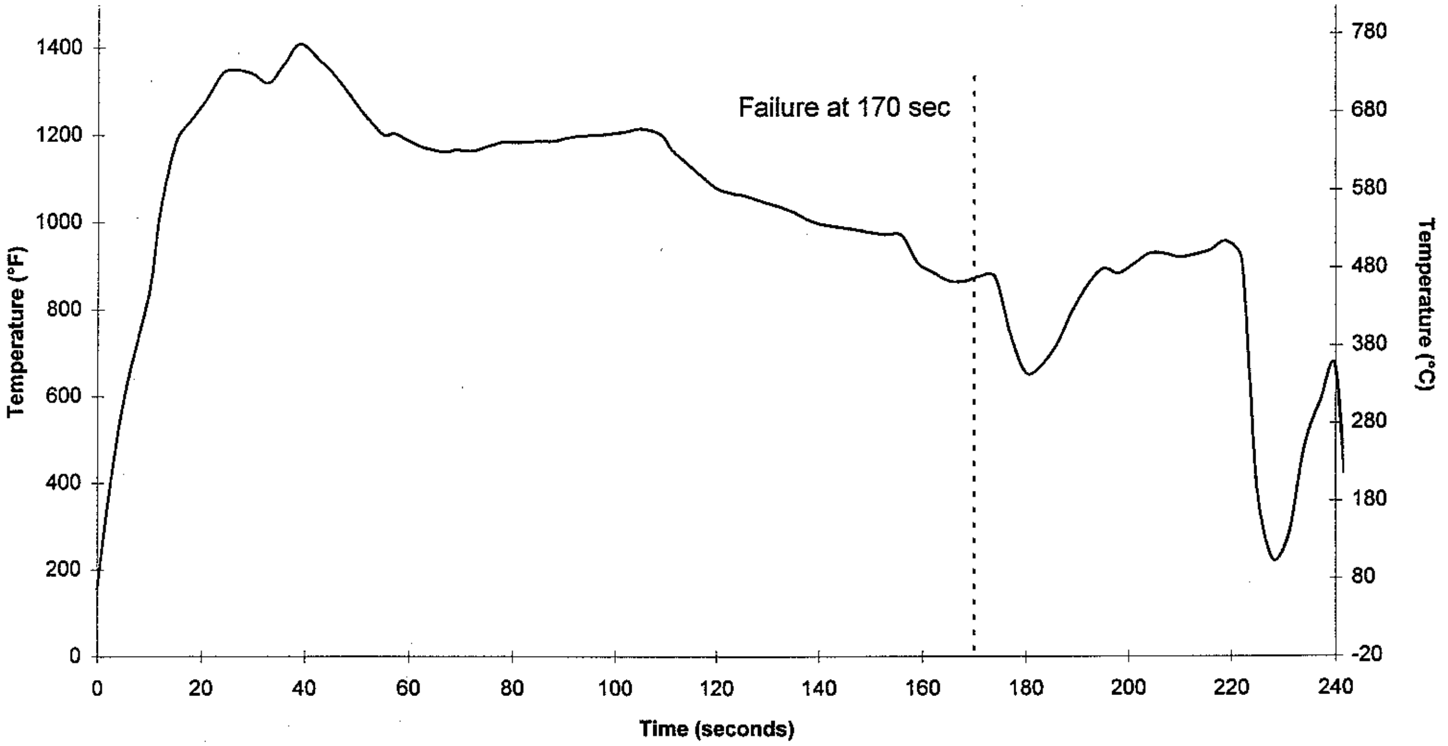

Figure C63: Test #13 External Temperatures

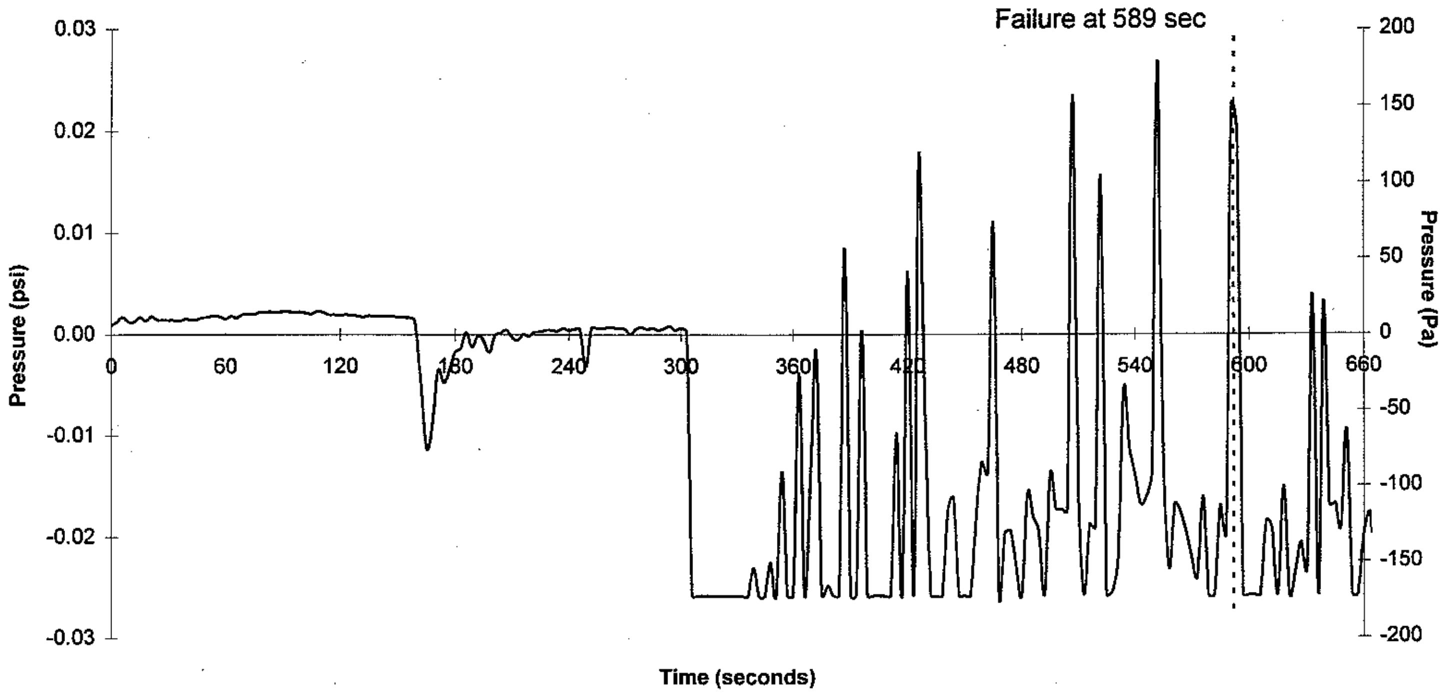

Figure C64: Test #14 Pressure

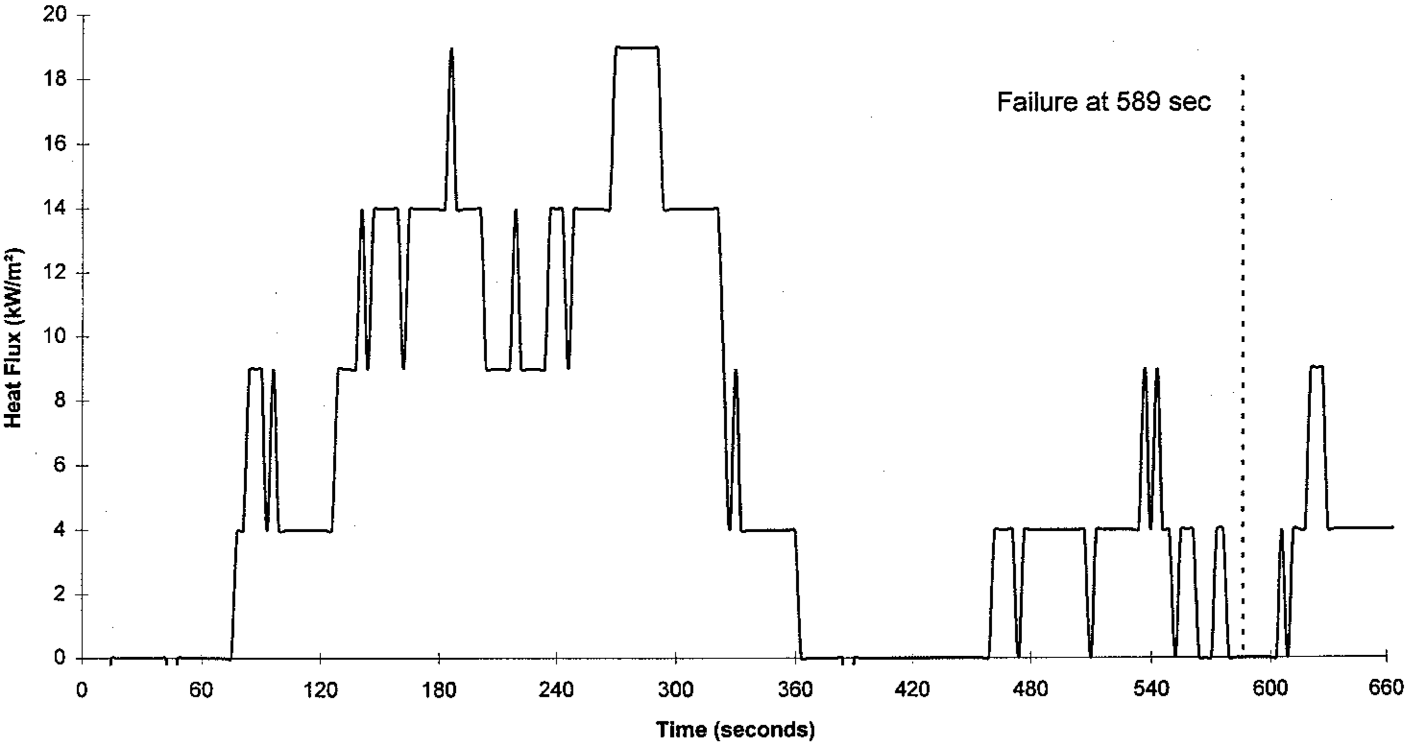

Figure C65: Test #14 Heat Flux

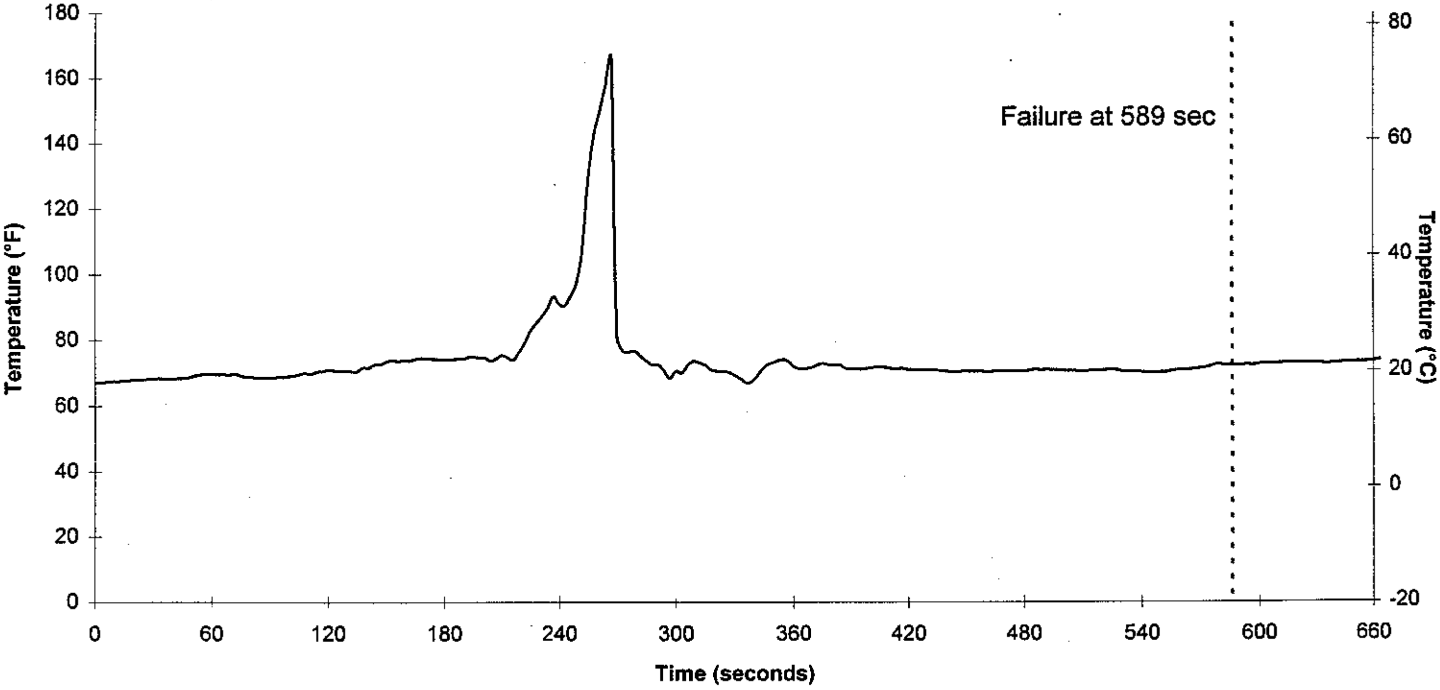

Figure C66: Test #14 Ullage Temperatures

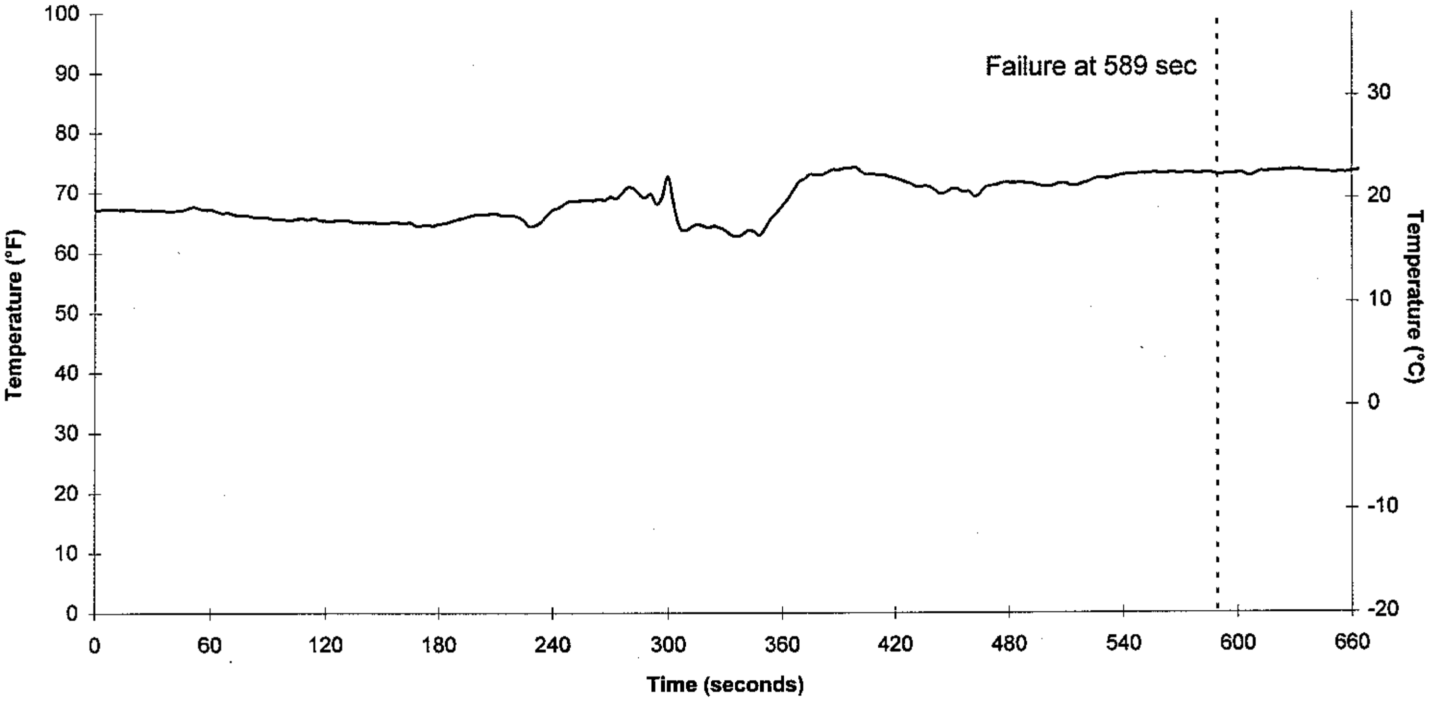

Figure C67: Test #14 Liquid Temperature 12" below water line

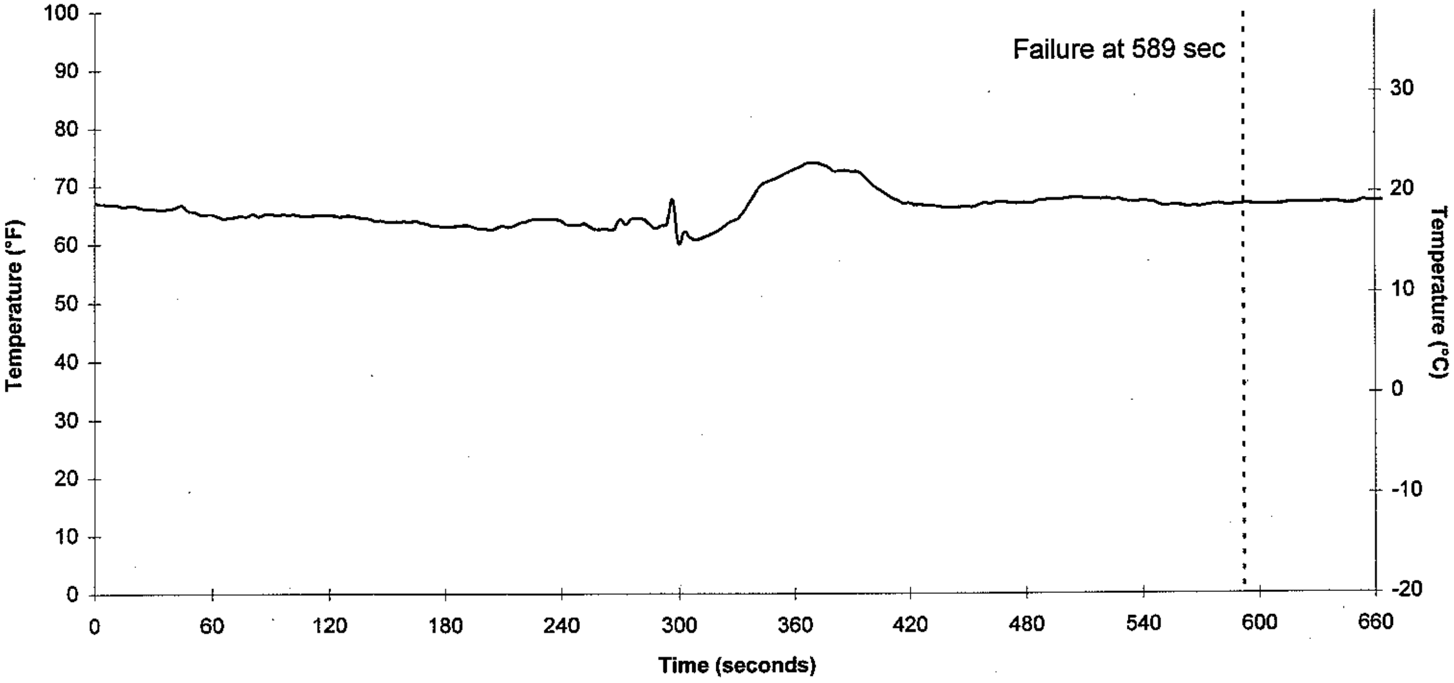

Figure C68: Test #14 Liquid Temperature 24" below water line

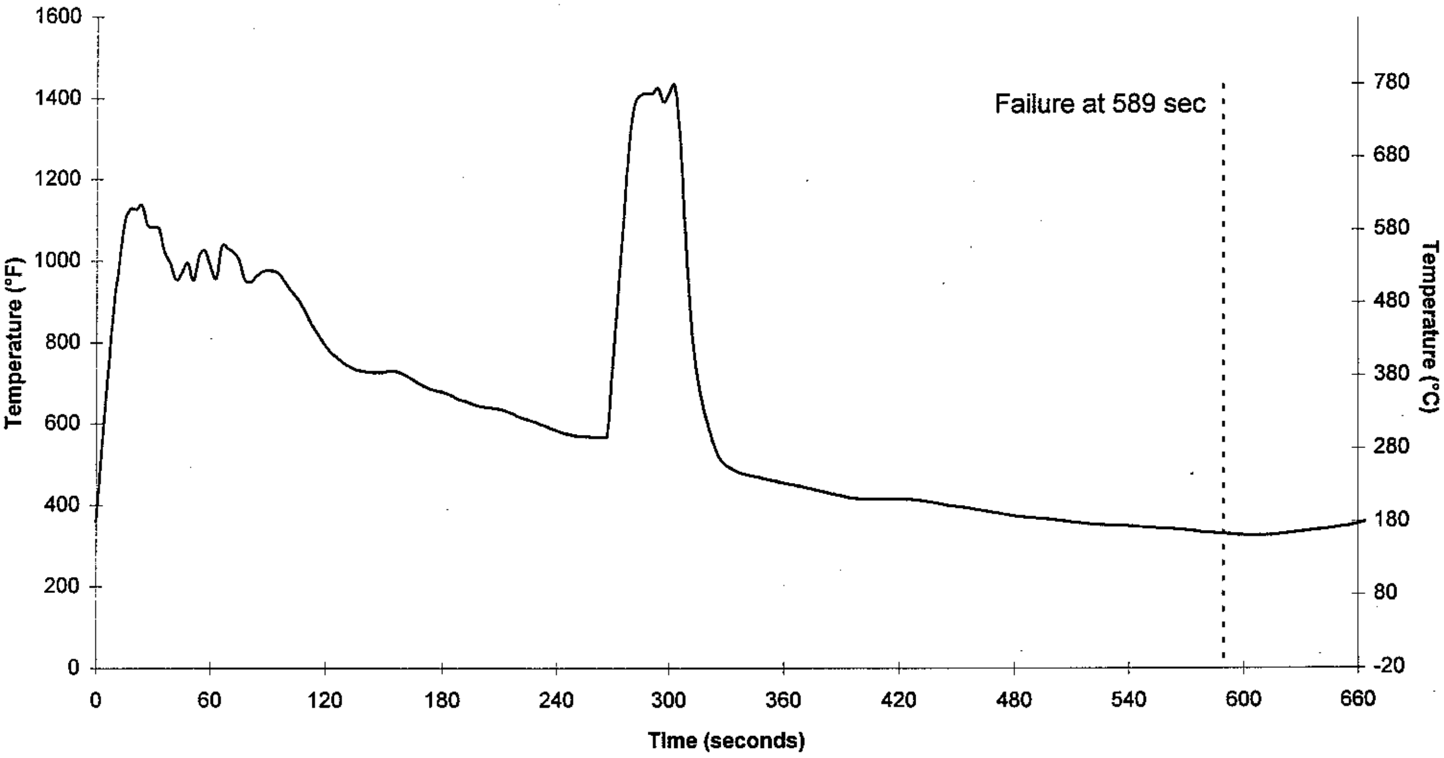

Figure C69: Test #14 External Temperatures

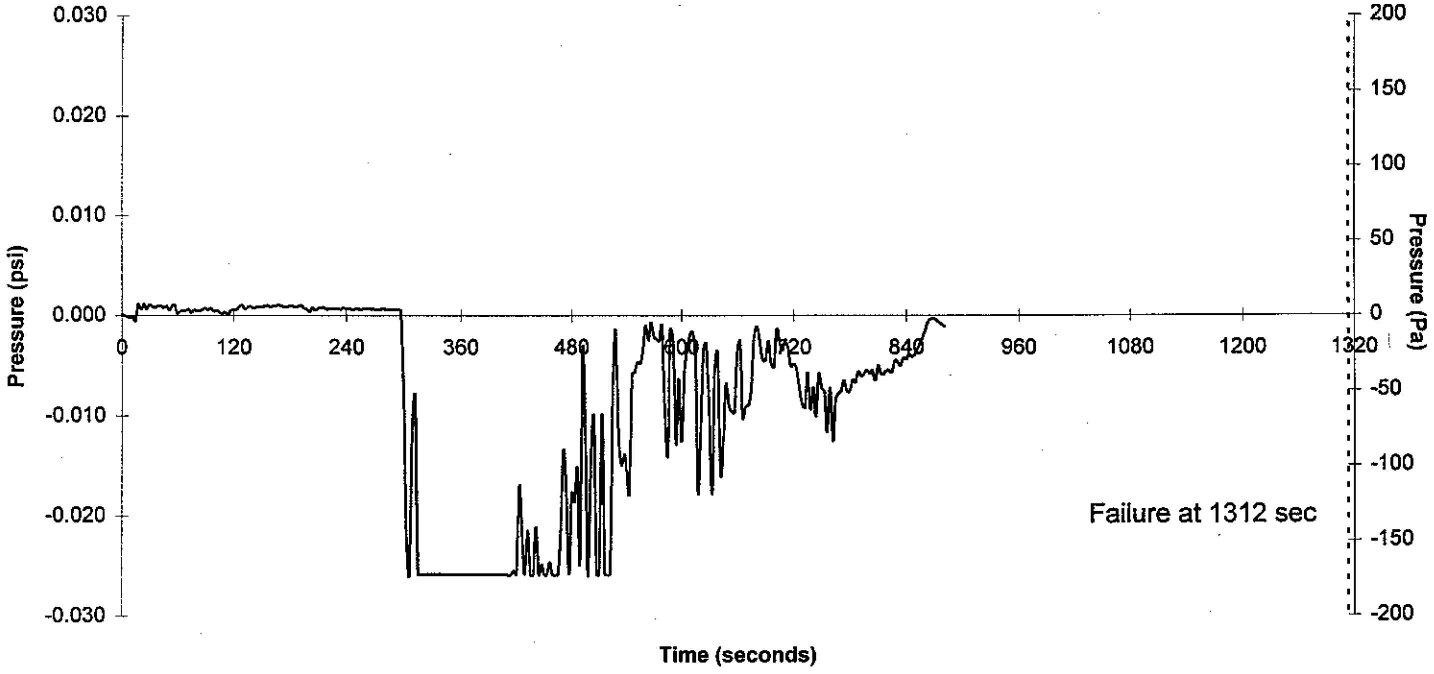

Figure C70: Test #15 Pressure

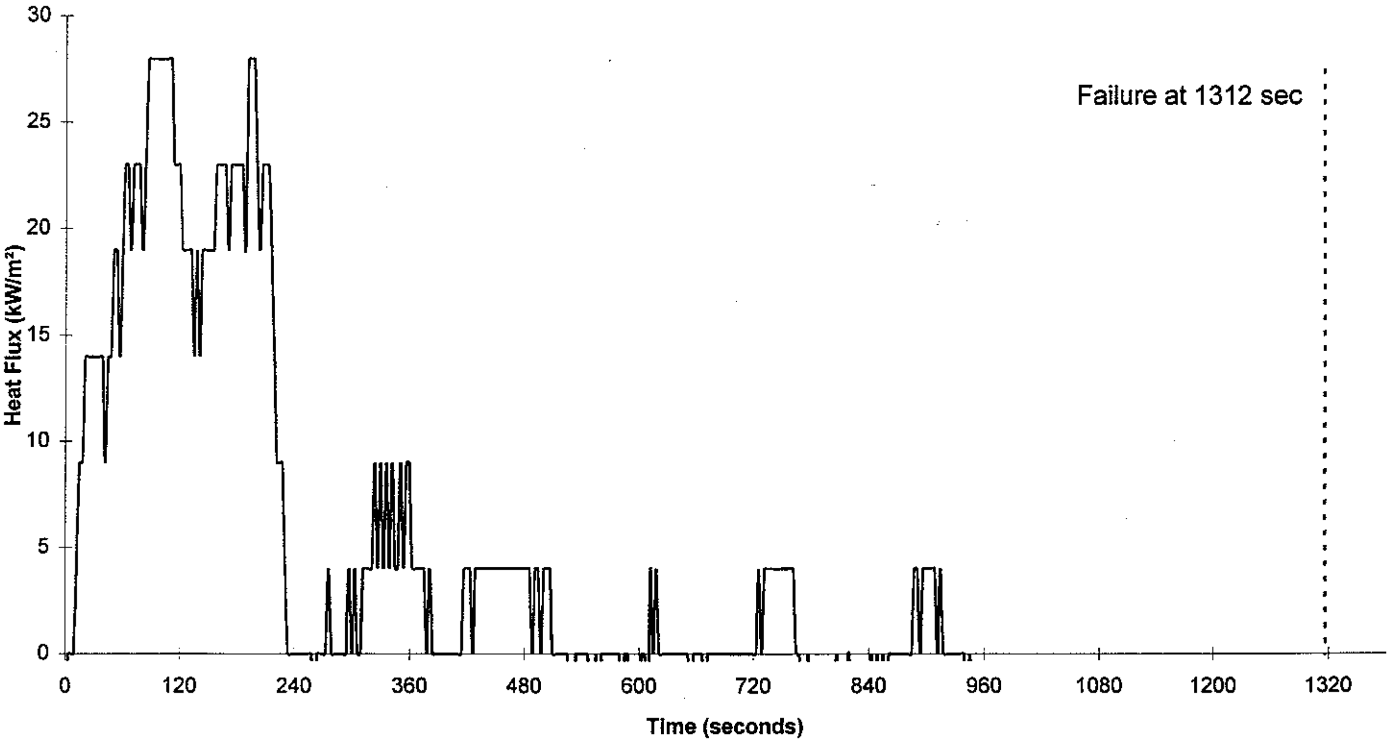

Figure C71: Test #15 Heat FLux

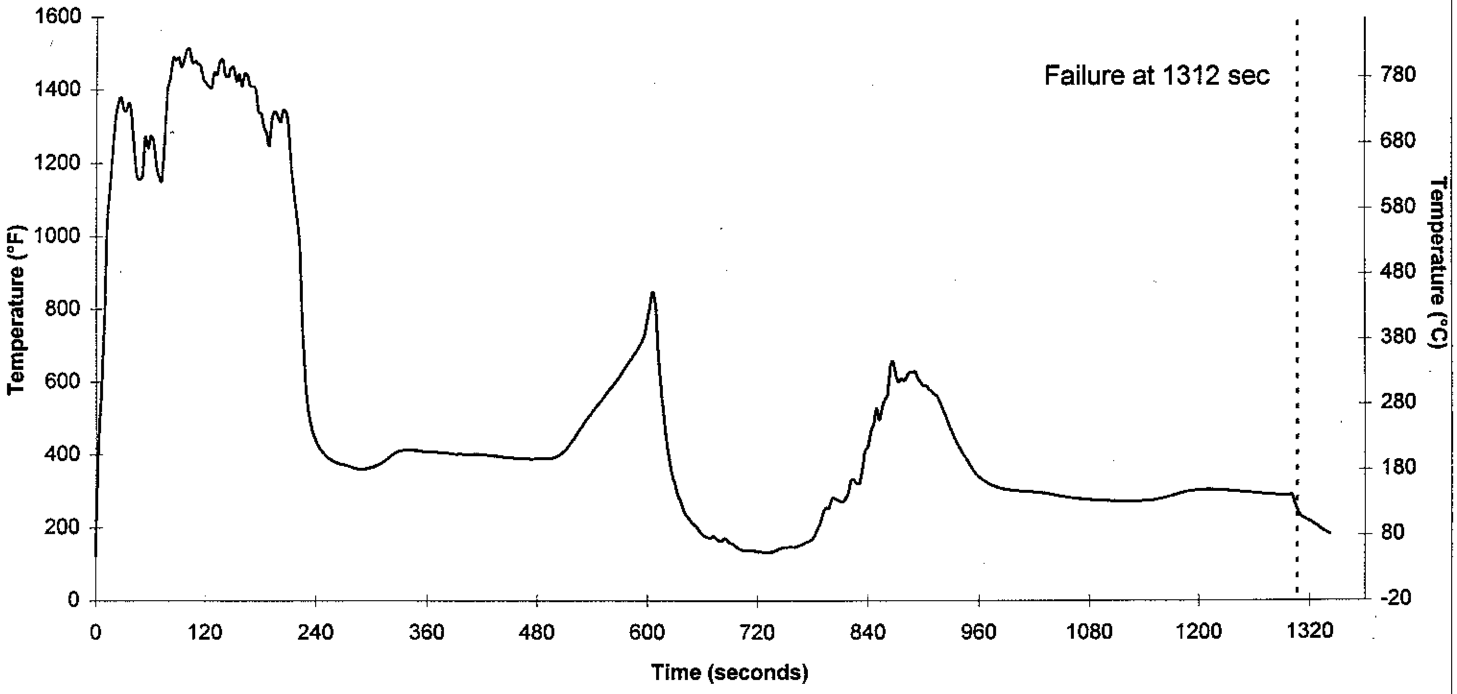

Figure C72: Test #15 External Temperature

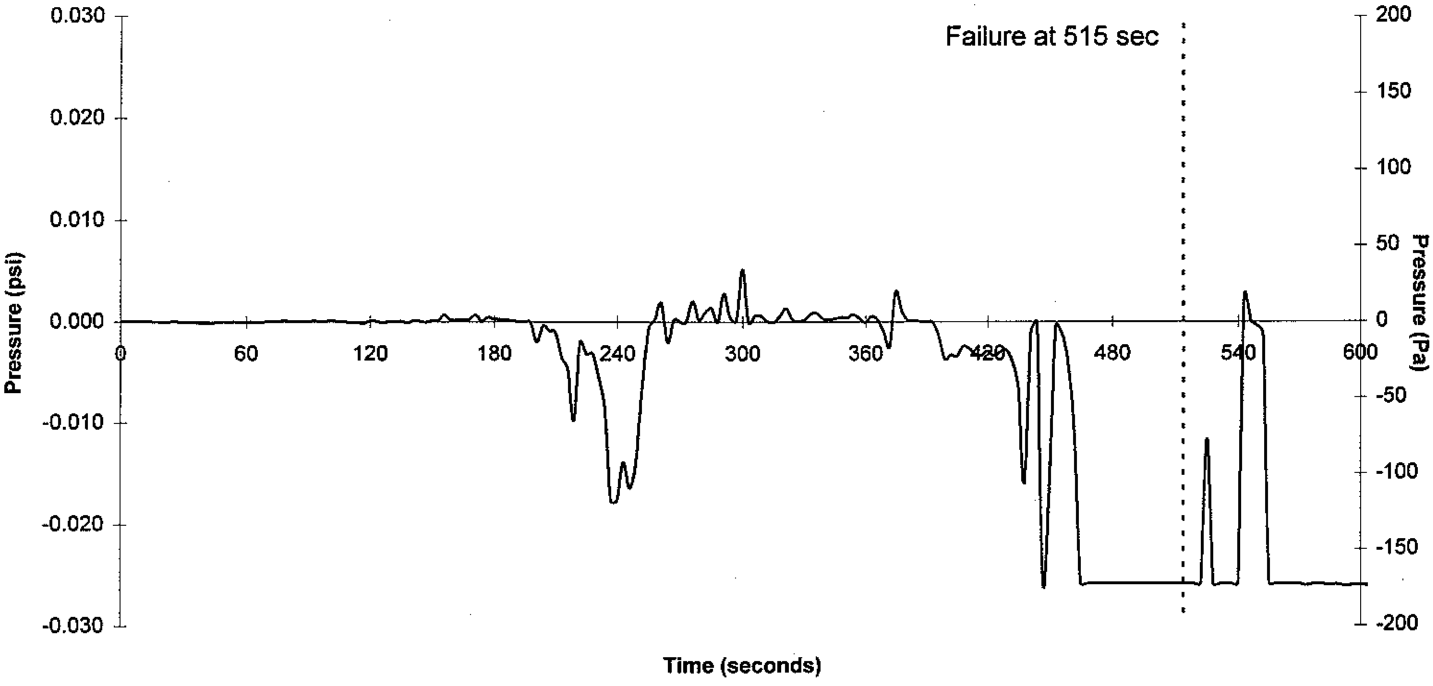

Figure C73: Test #16 Pressure

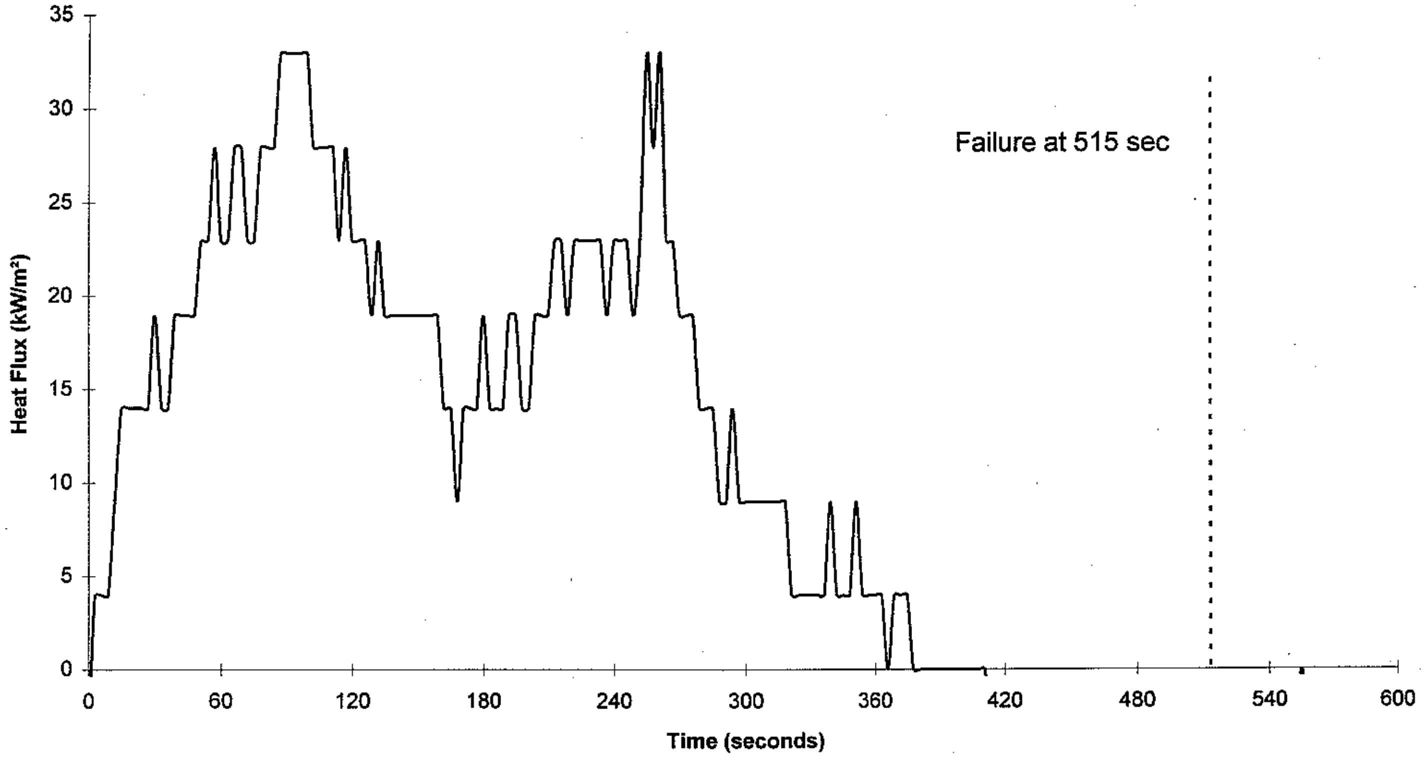

Figure C74: Test #16 Heat Flux

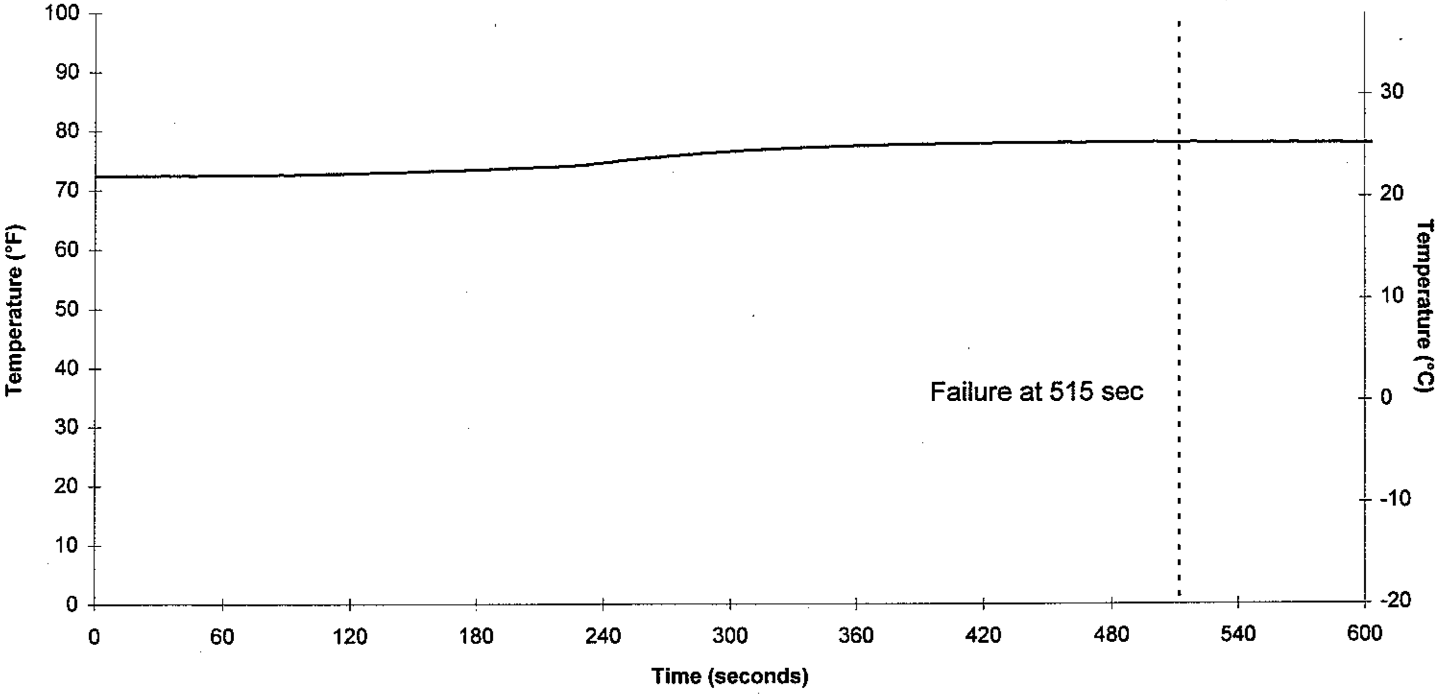

Figure C75: Test #16 Ullage Temperatures

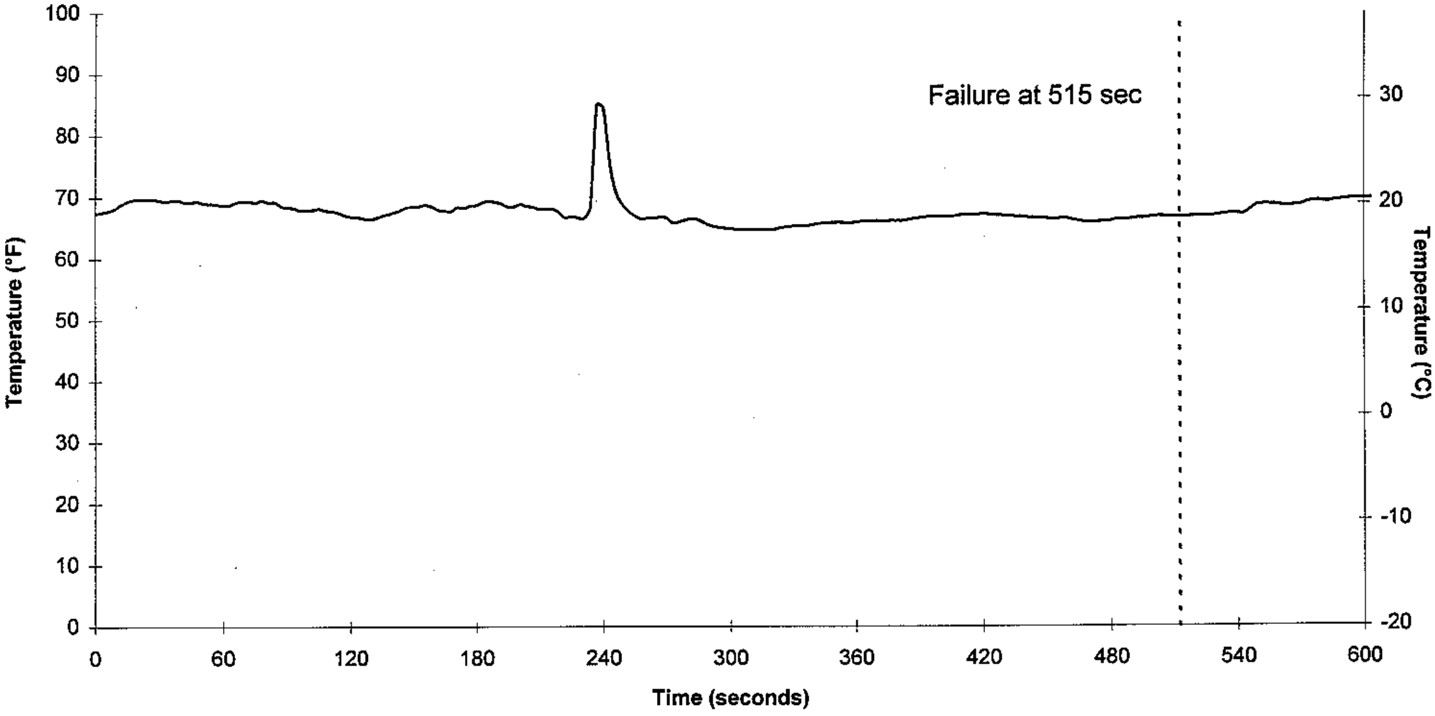

Figure C76: Test #16 Liquid Temperature 12" below water line

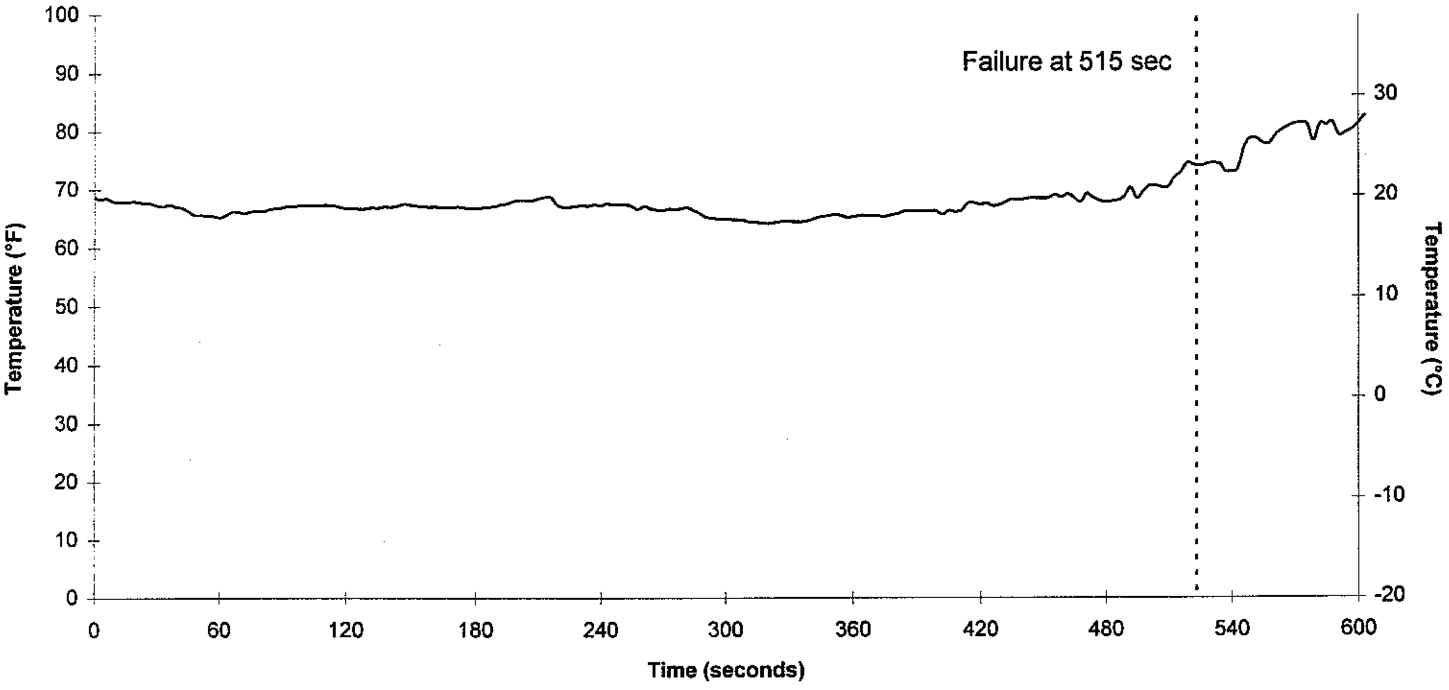

Figure C77: Test #16 Liquid Temperature 24" below water line

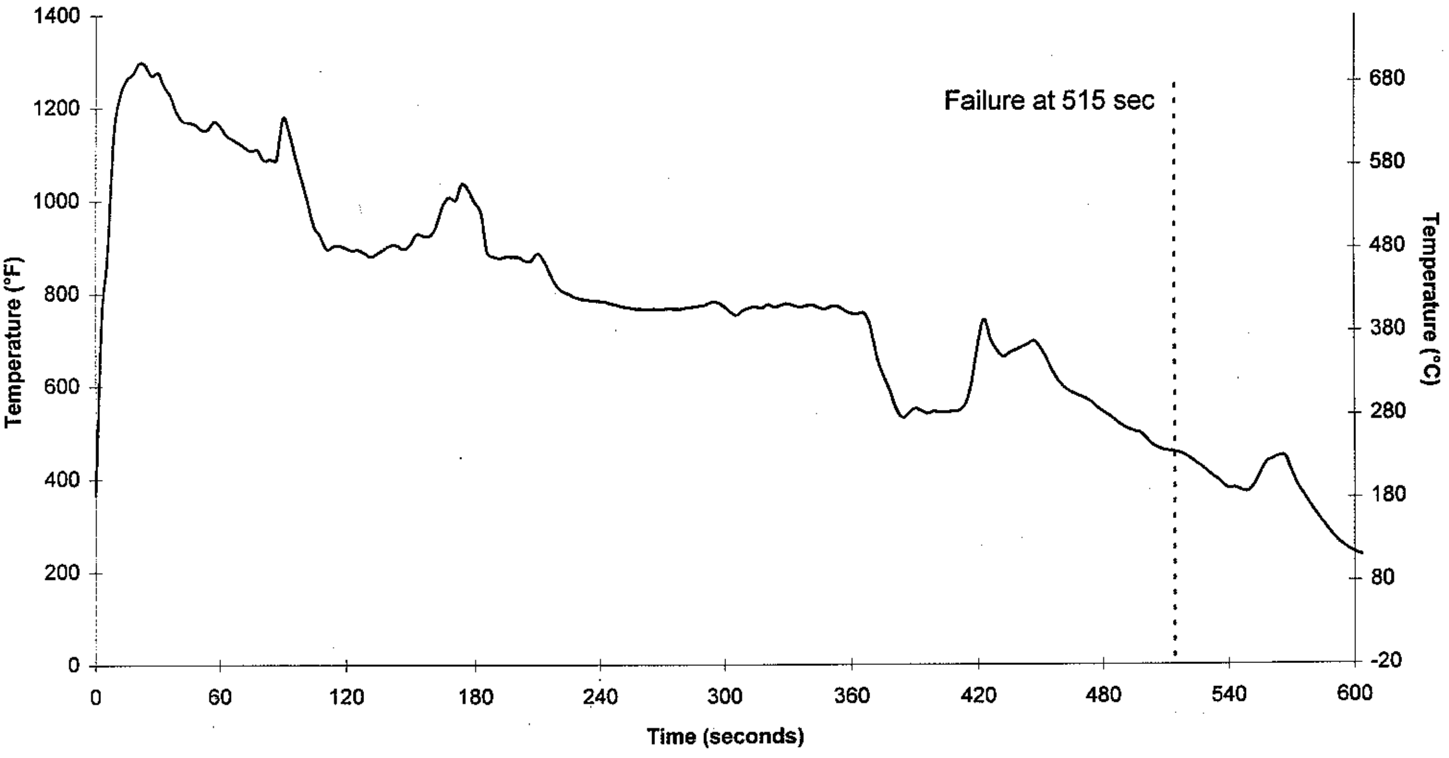

Figure C78: Test #16 External Temperatures

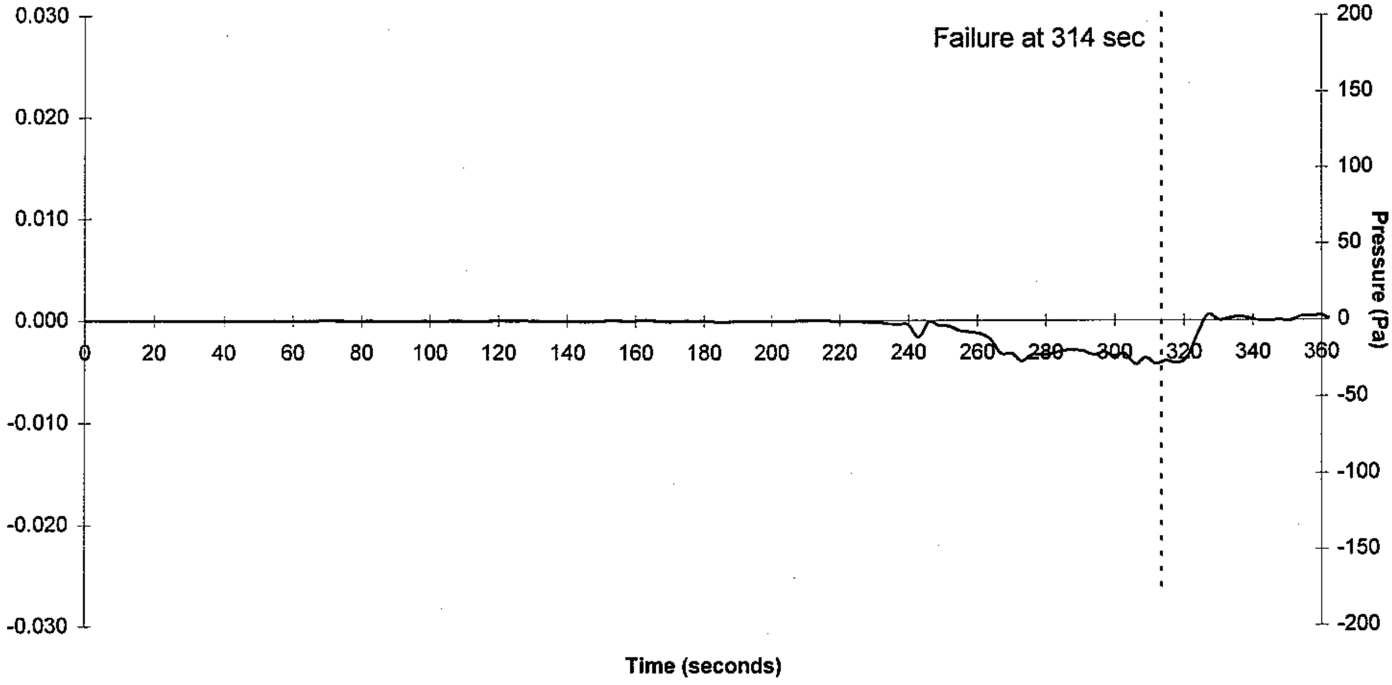

Figure C79: Test #17 Pressure

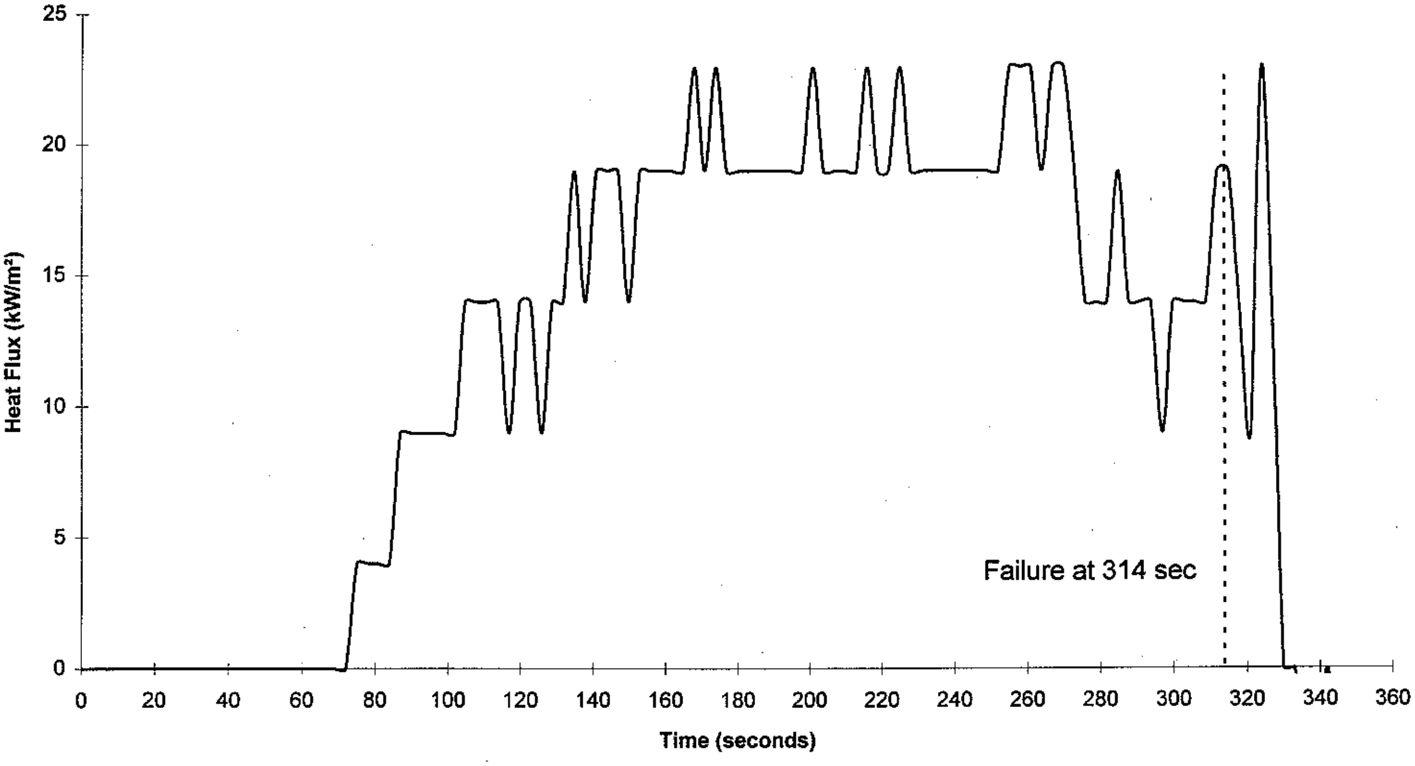

Figure C80: Test #17 Heat Flux

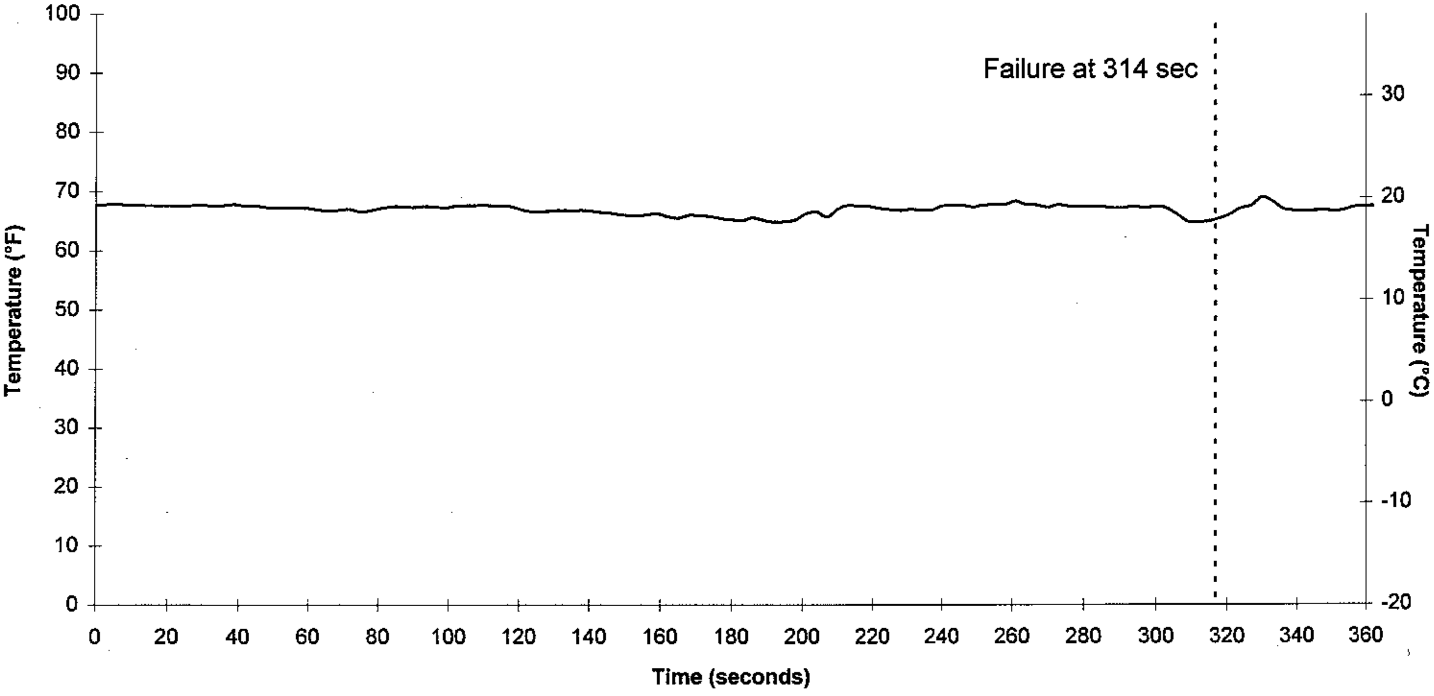

Figure C81: Test #17 Ullage Temperatures

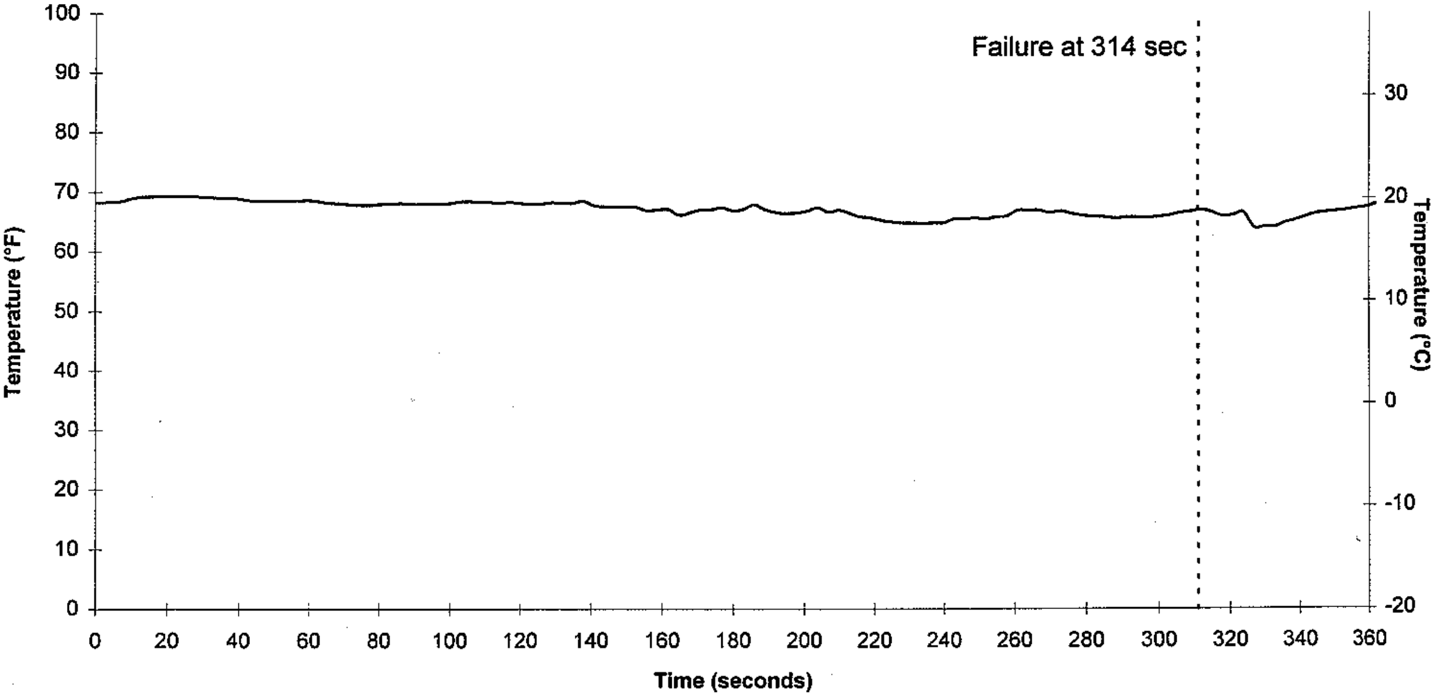

Figure C82: Test #17 Liquid Temperature 12" below water line

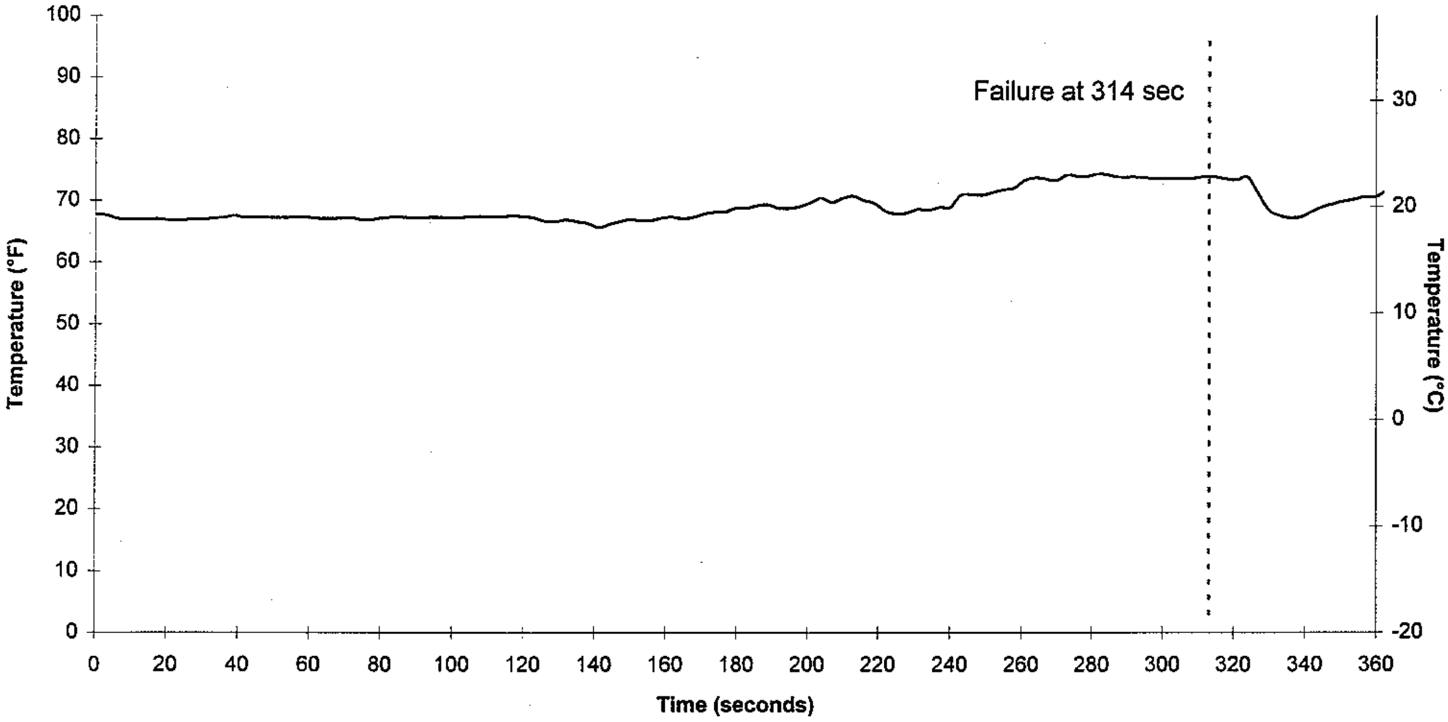

Figure C83: Test #17 Liquid Temperature 24" below water line

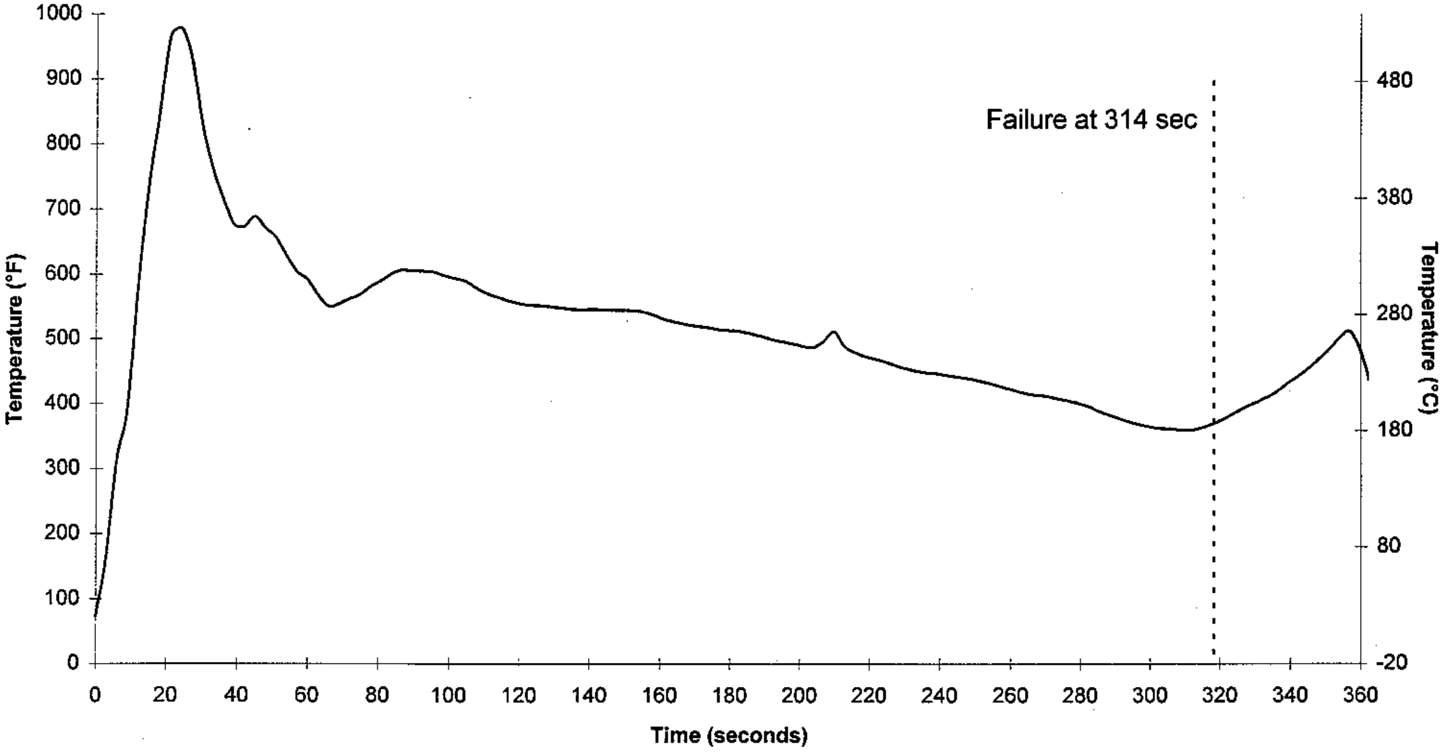

Figure C84: Test #17 External Temperatures

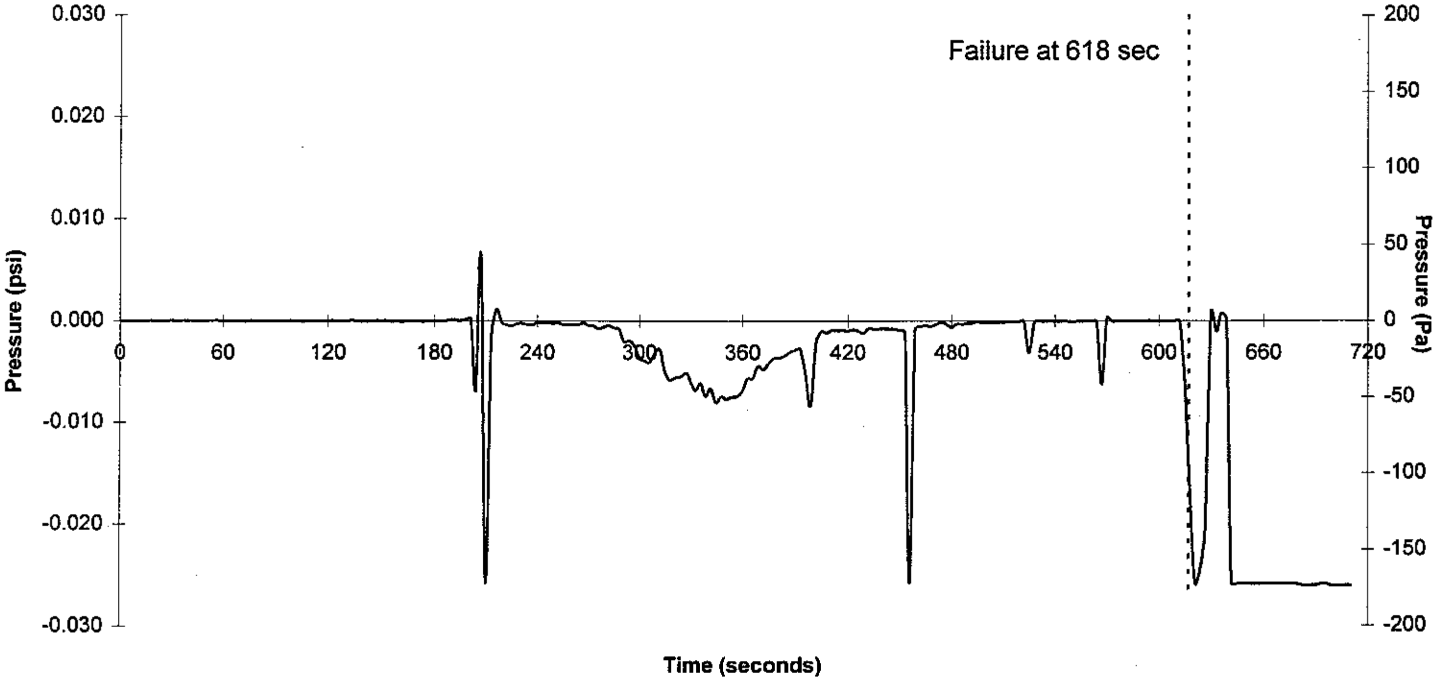

Figure C85: Test #18 Pressure

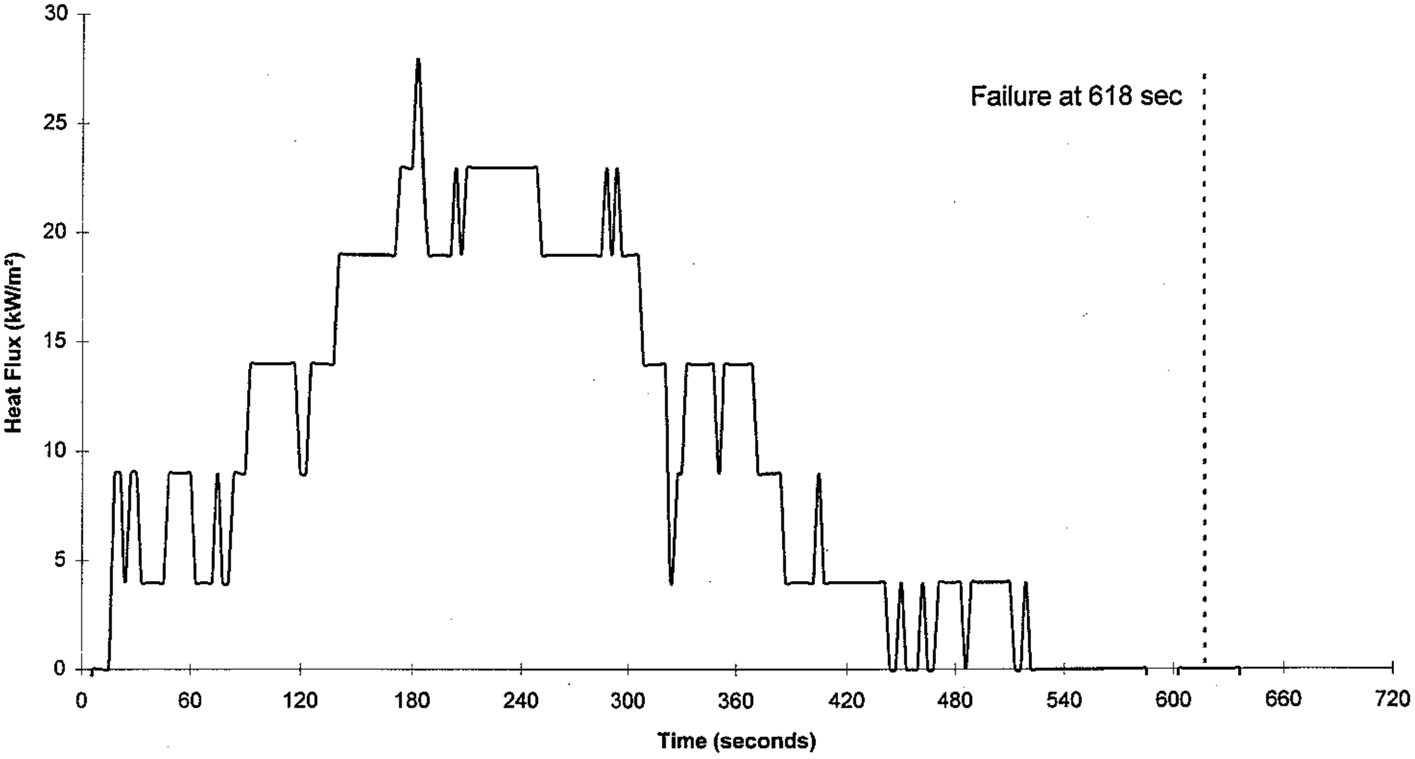

Figure C86: Test #18 Heat Flux

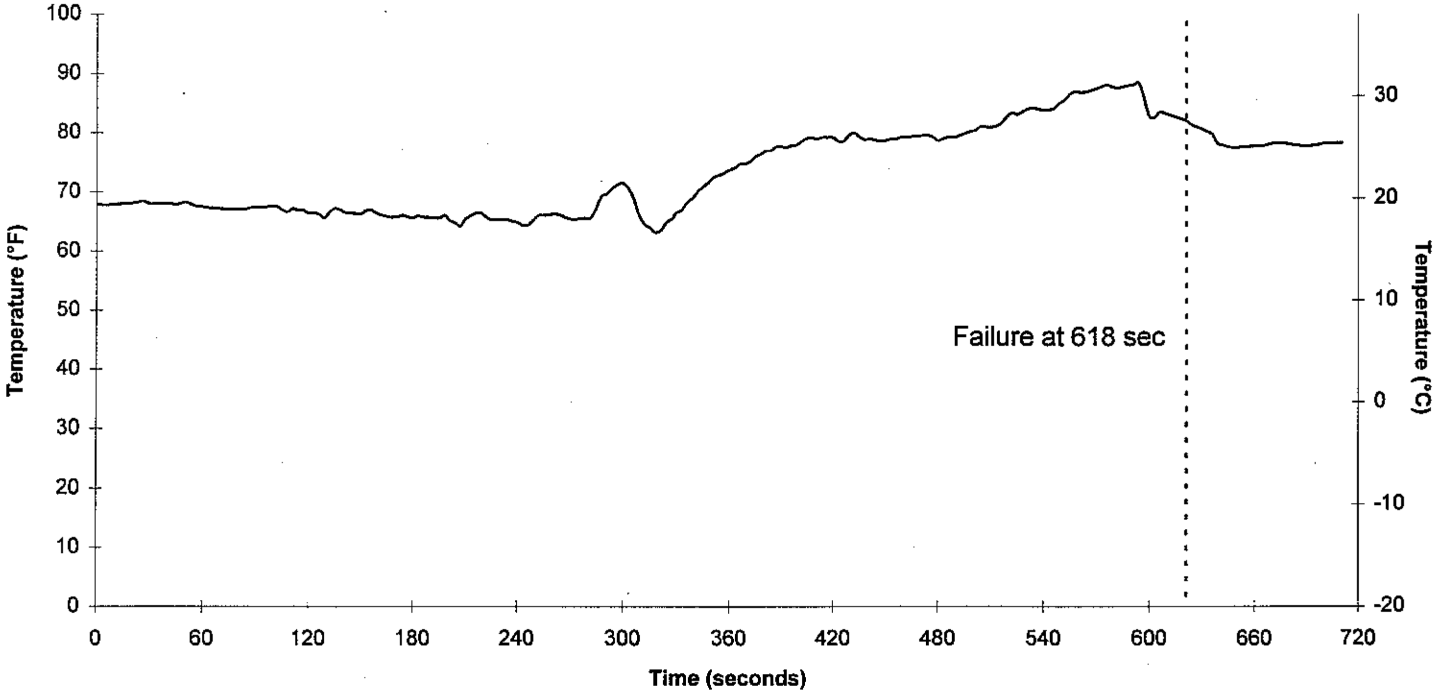

Figure C87: Test #18 Ullage Temperatures

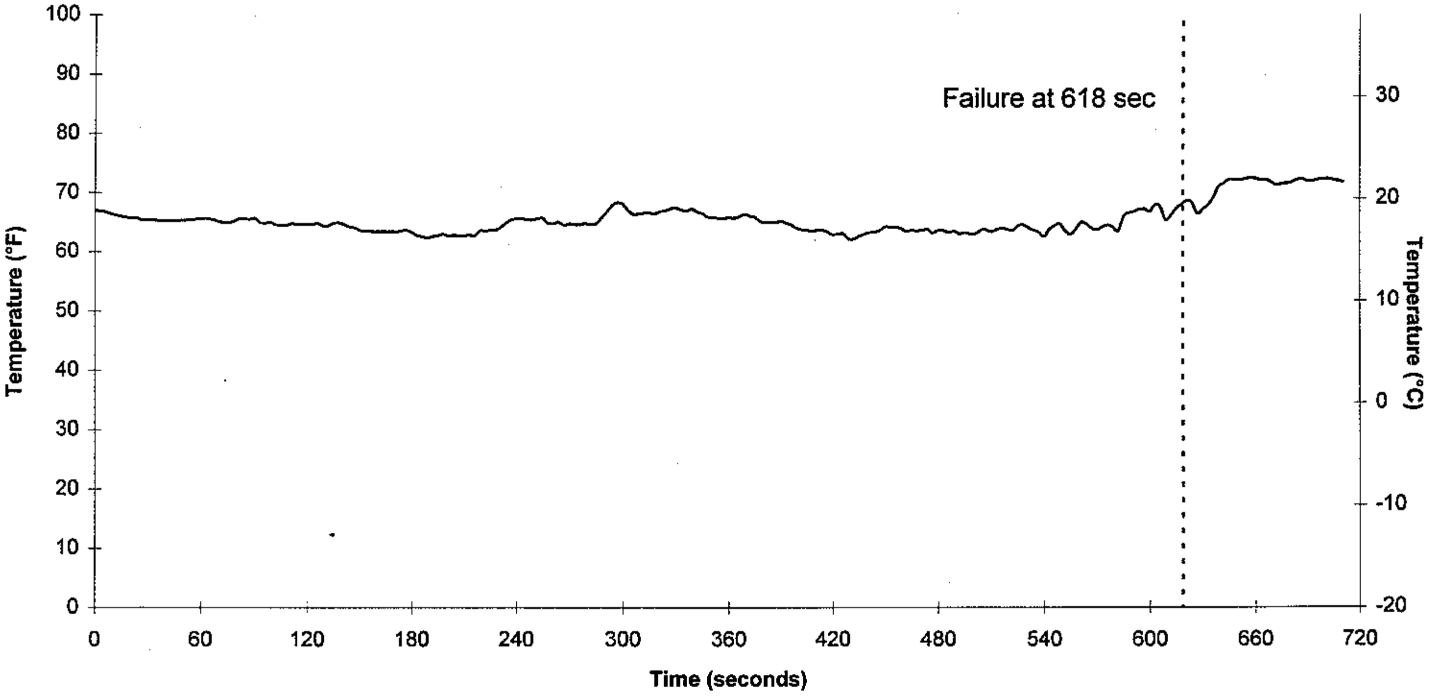

Figure C88: Test #18 Liquid Temperature 12" below water line

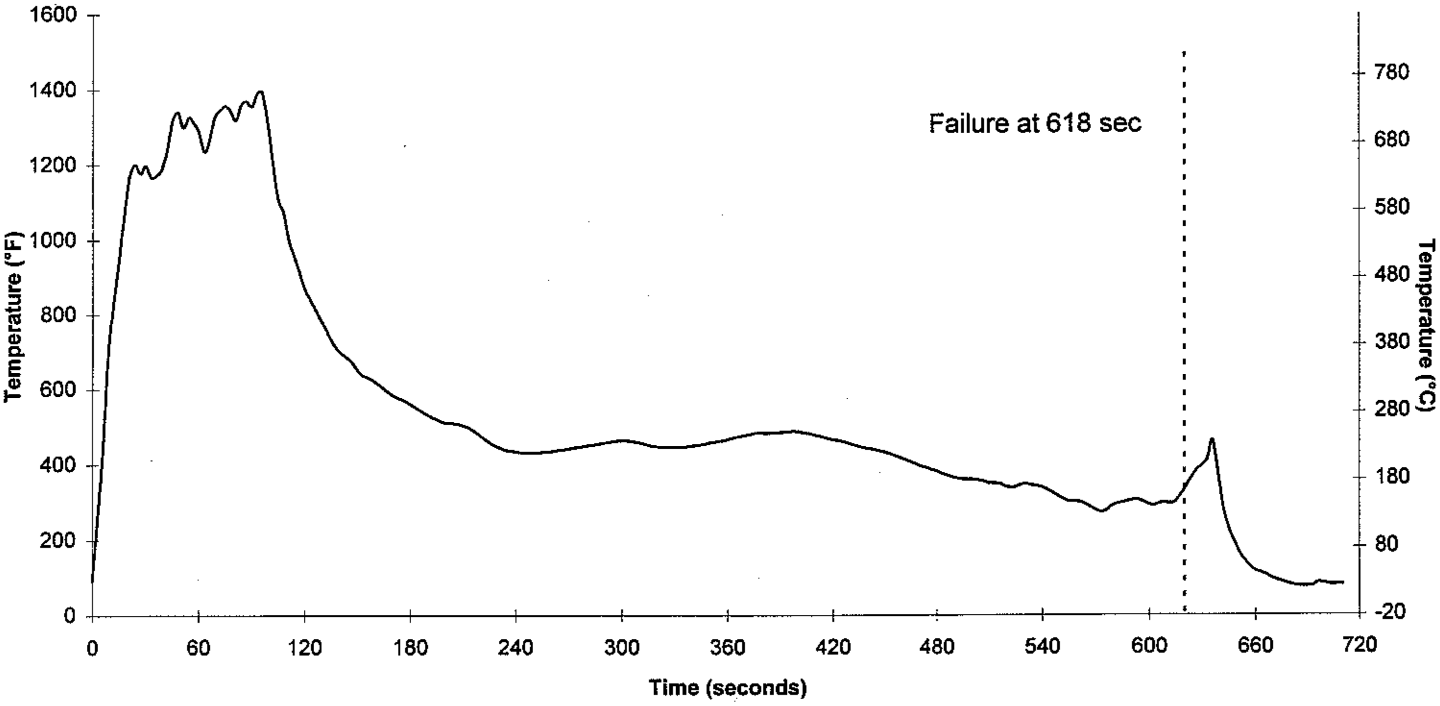

Figure C89: Test #18 External Temperatures

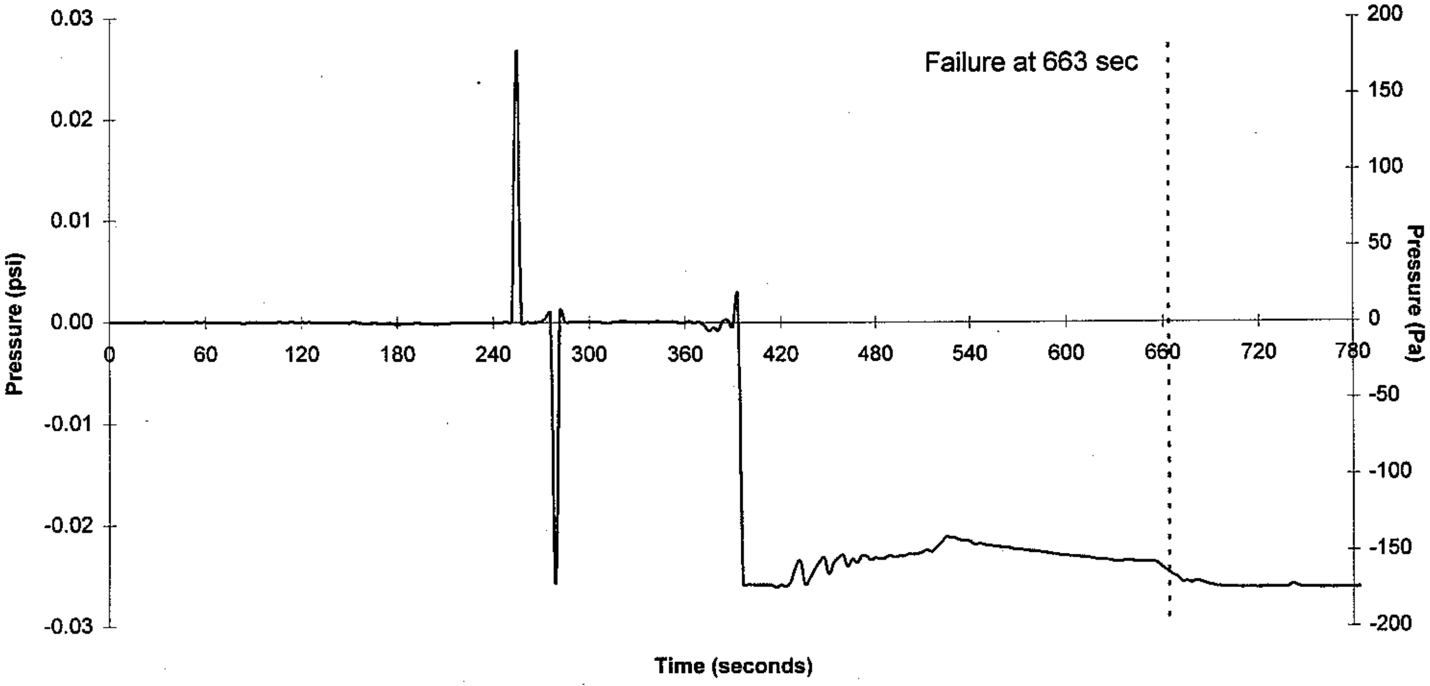

Figure C90: Test #19 Pressure

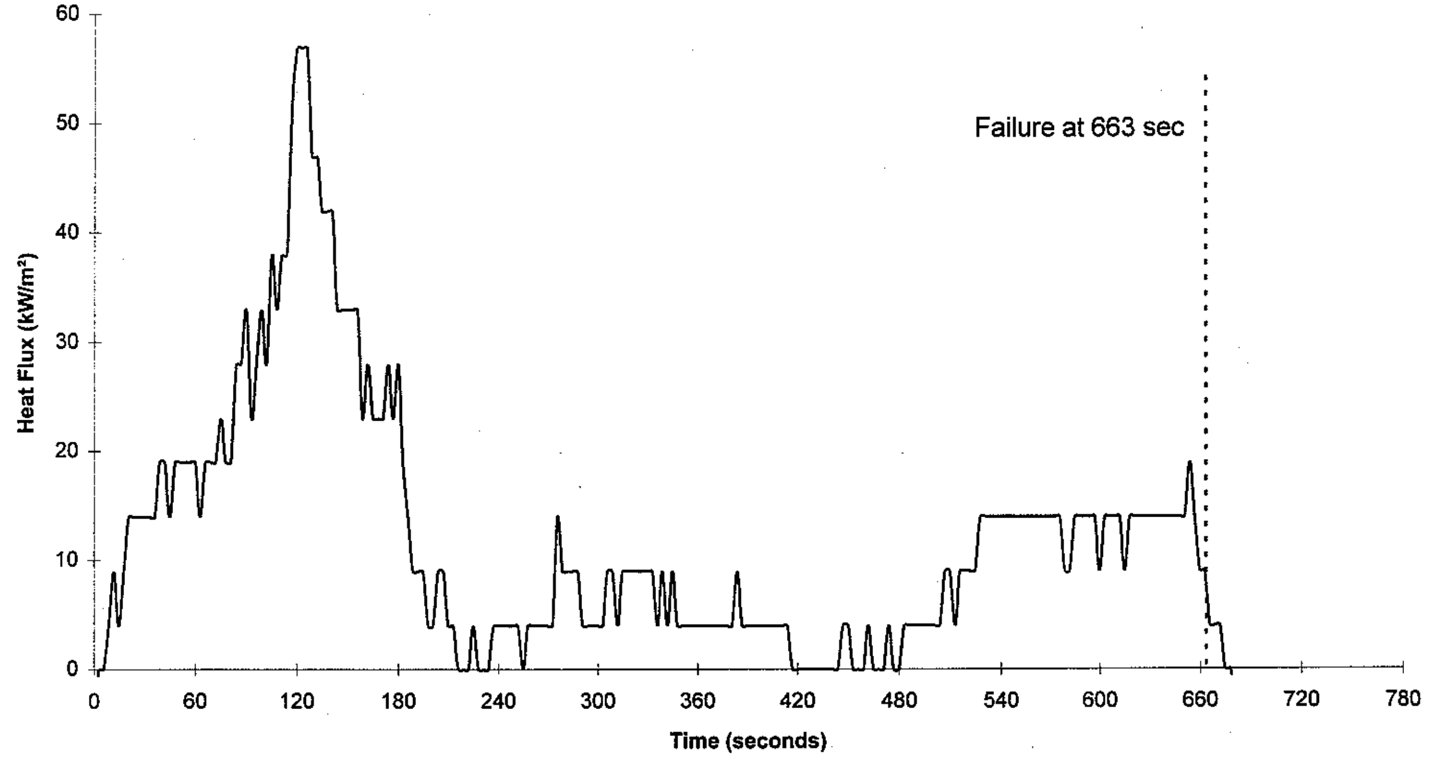

Figure C91: Test #19 Heat Flux

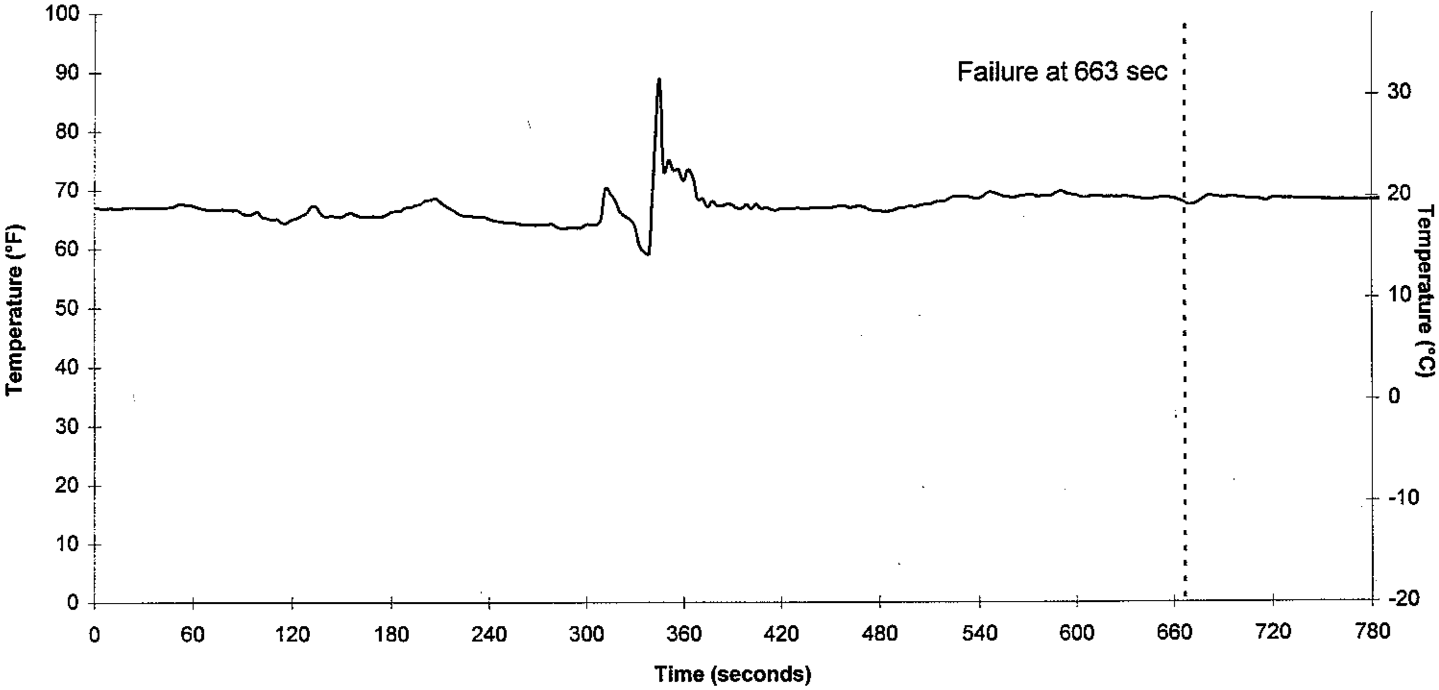

Figure C92: Test #19 Ullage Temperatures

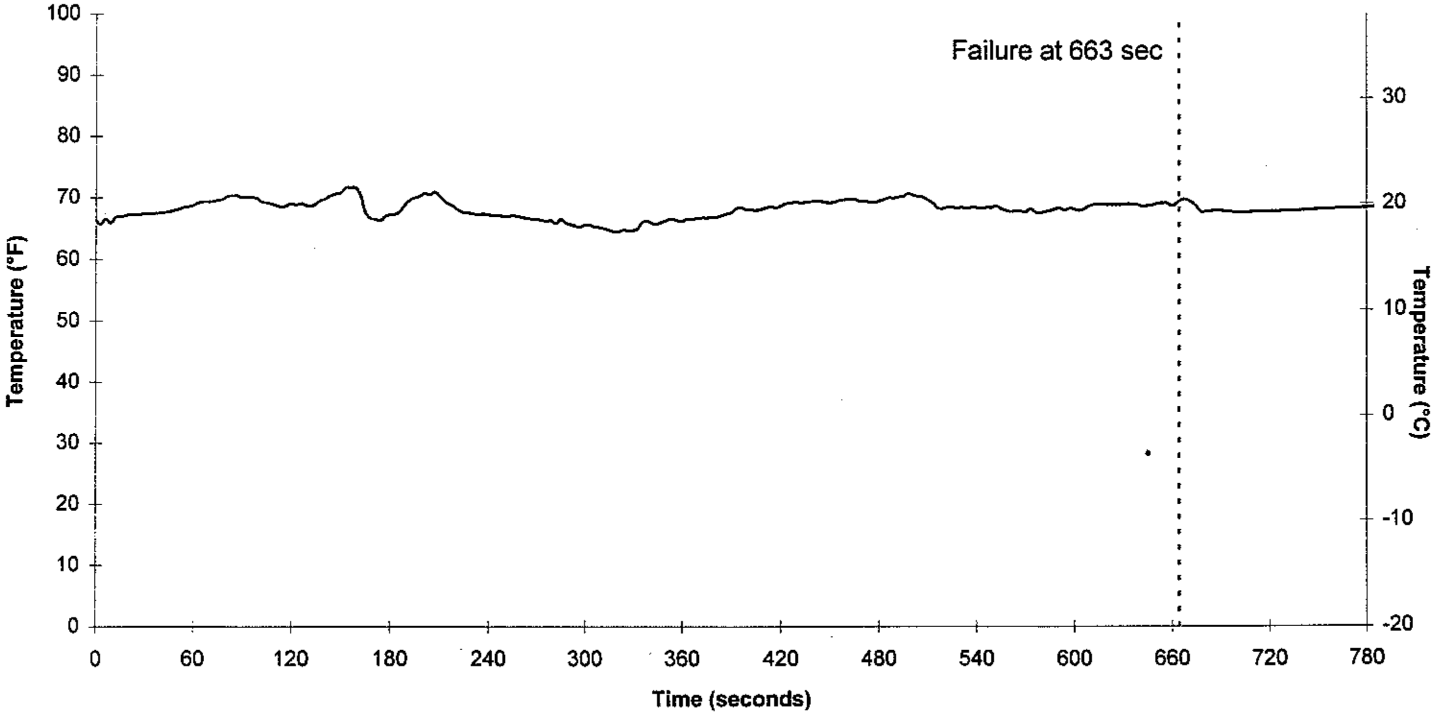

Figure C93: Test #19 Liquid Temperature 12" below water line

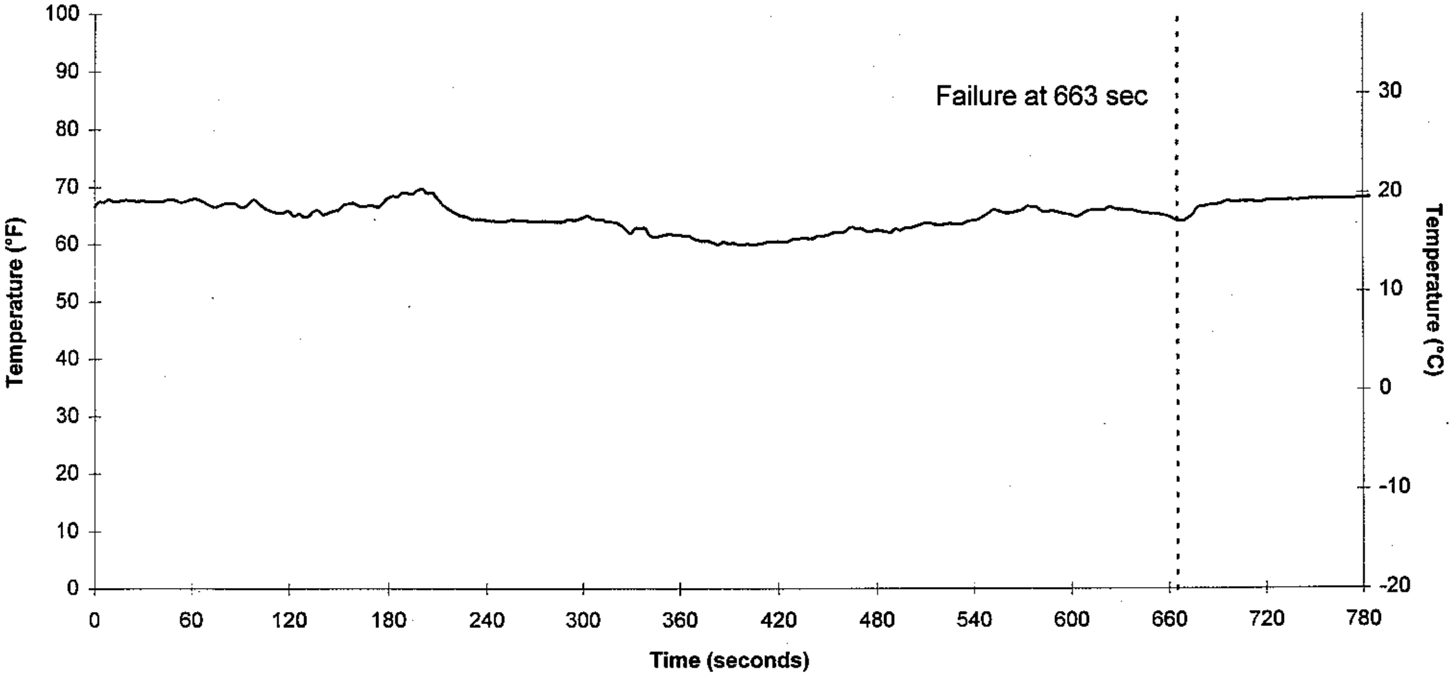

Figure C94: Test #19 Liquid Temperature 24" below water line

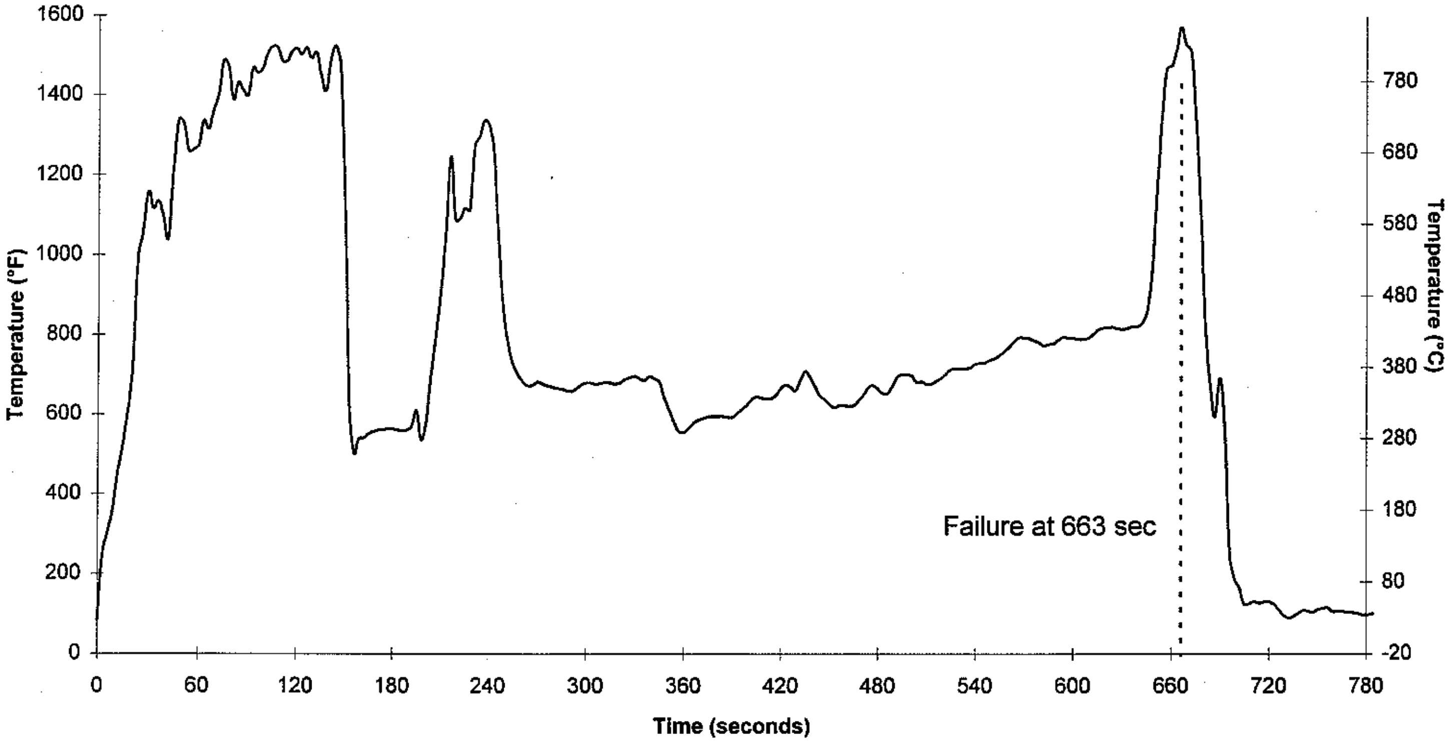

Figure C95: Test #19 External Temperatures

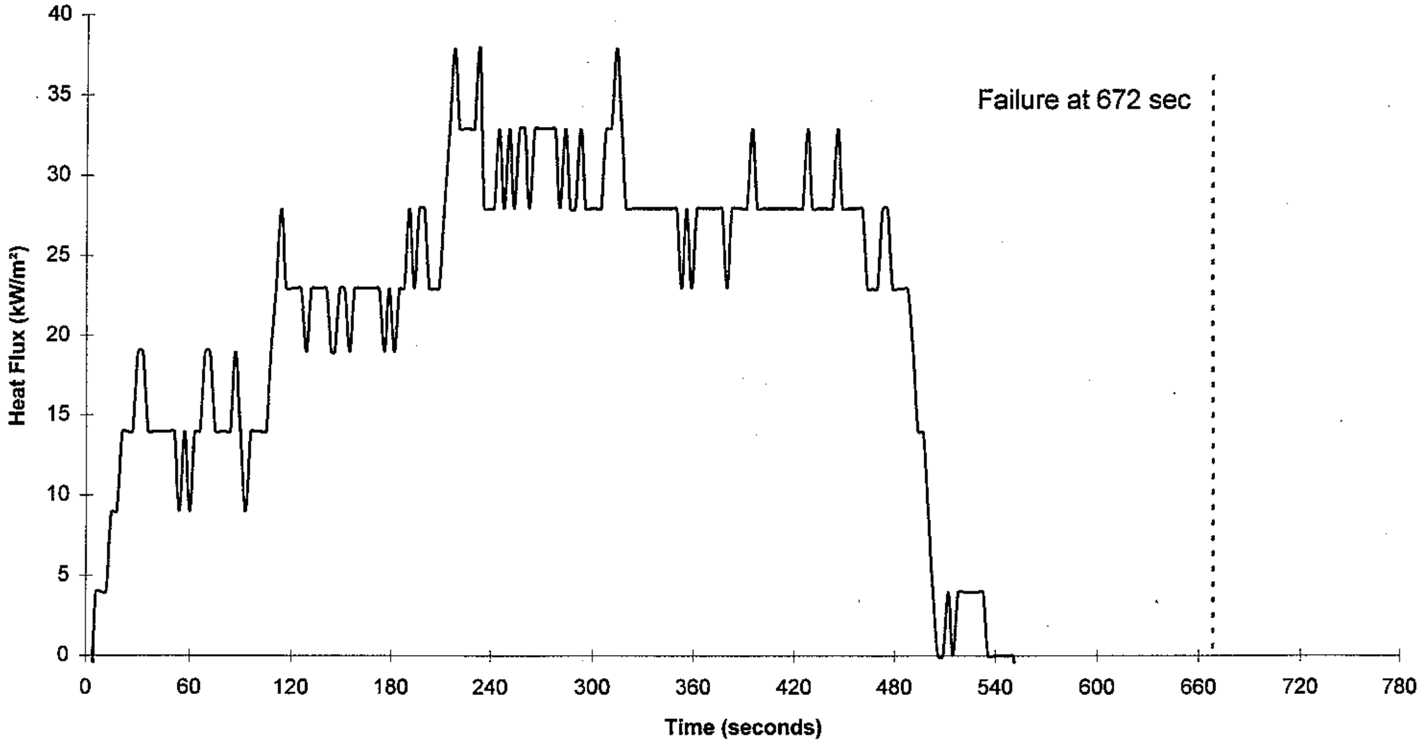

Figure C96: Test #20 Heat Flux

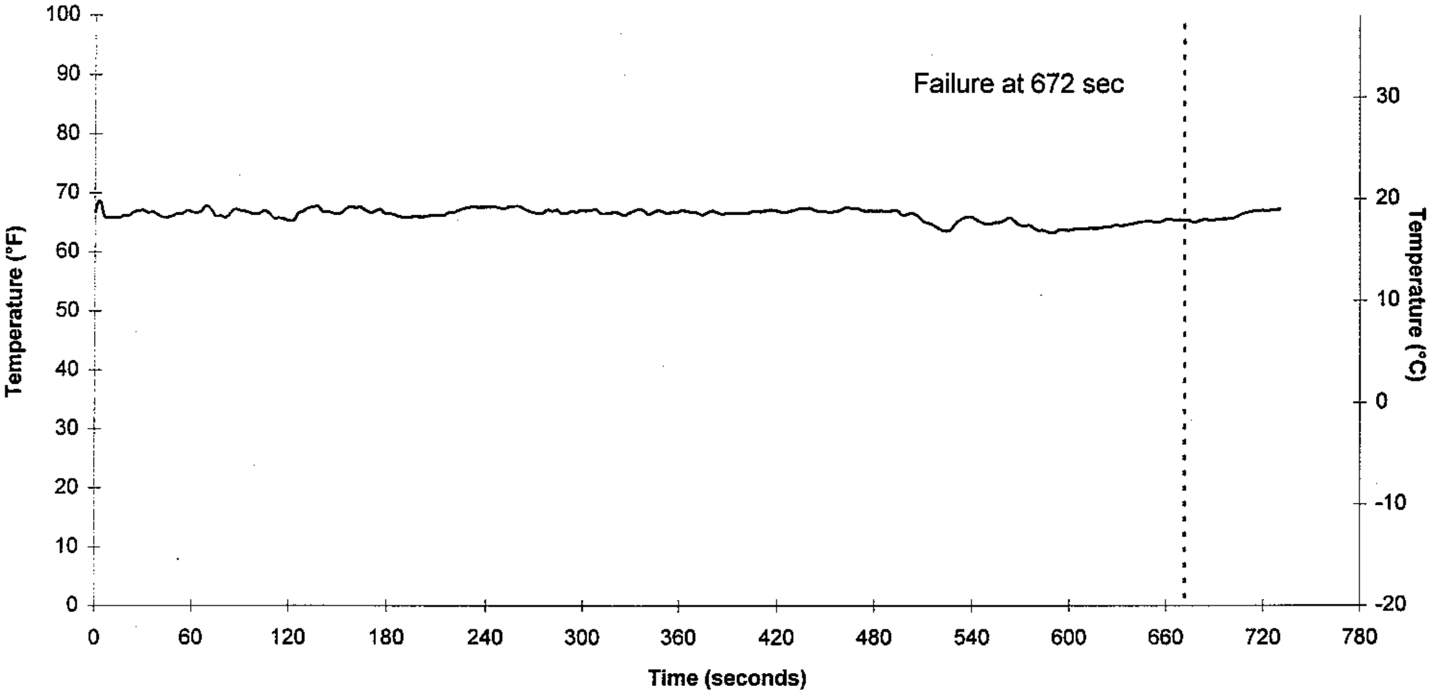

Figure C97: Test #20 Ullage Temperatures

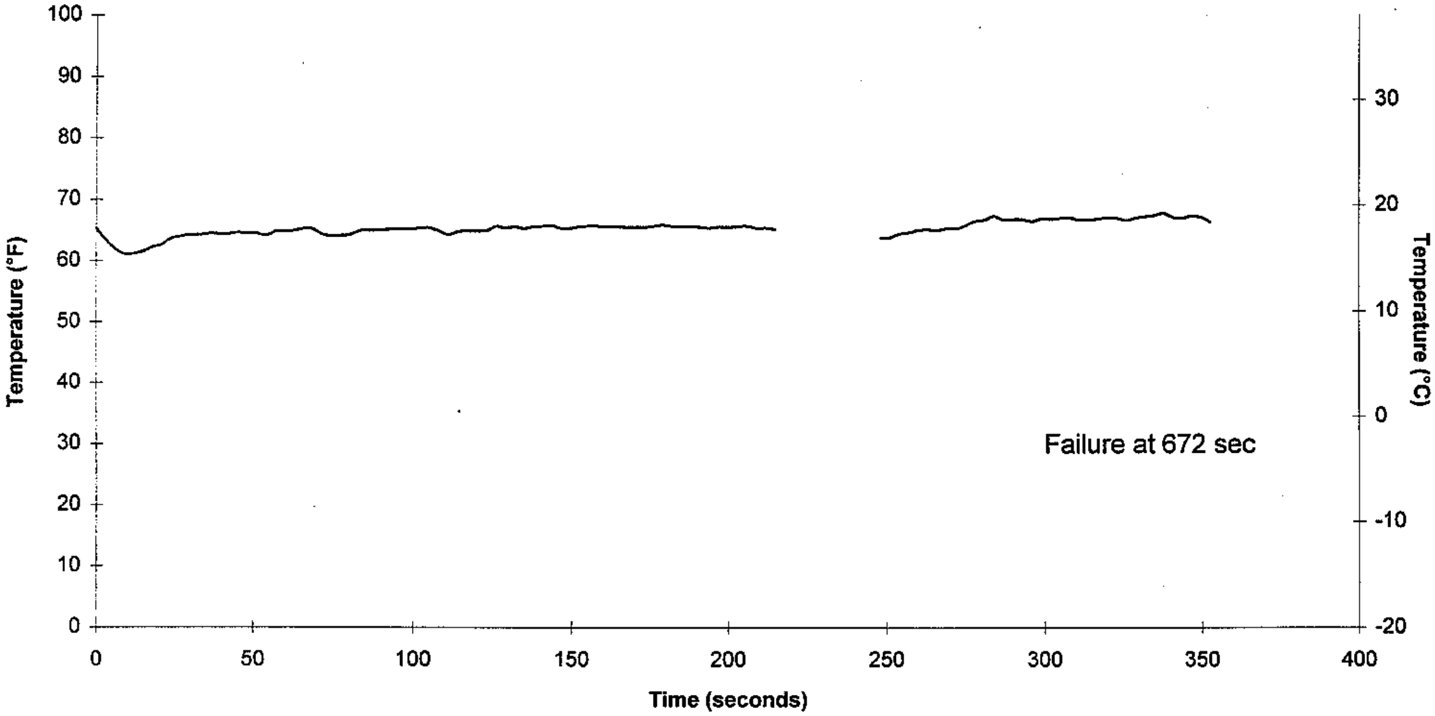

Figure C98: Test #20 Liquid Temperature 12" below water line

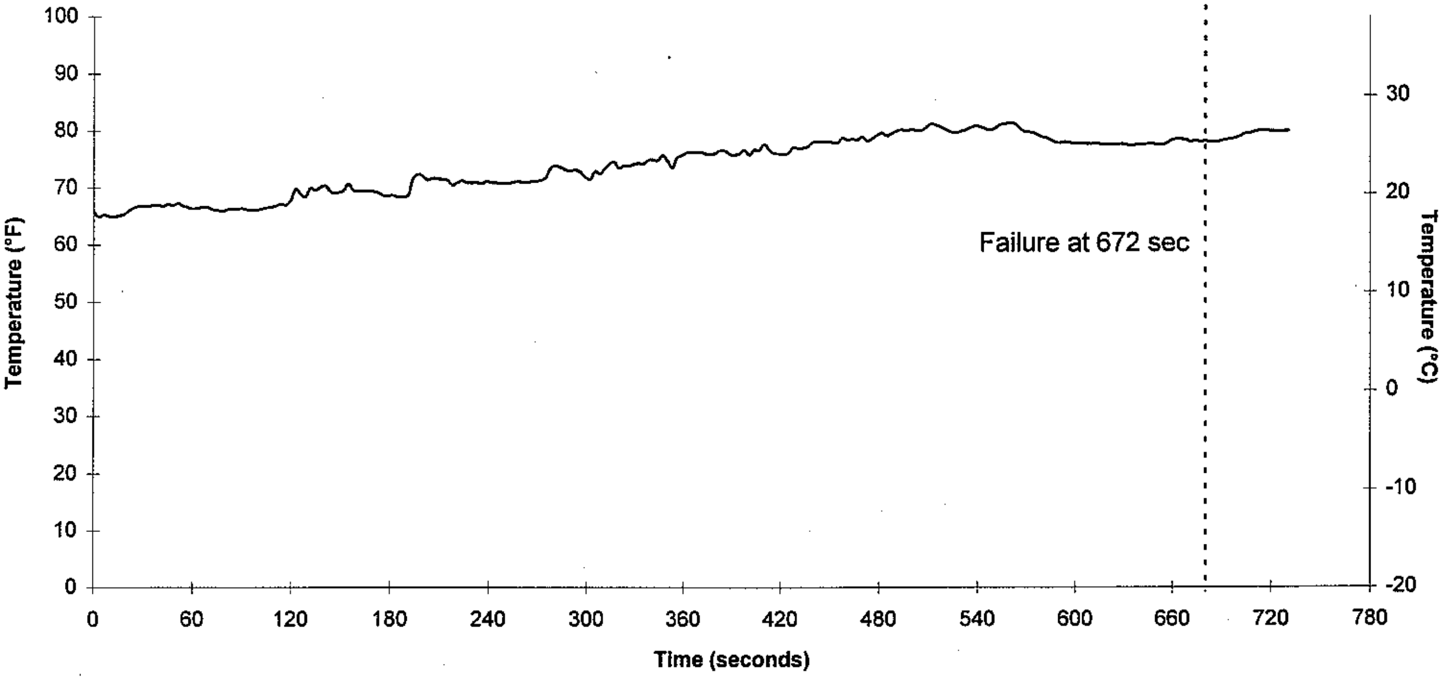

Figure C99: Test #20 Liquid Temperature 24" below water line

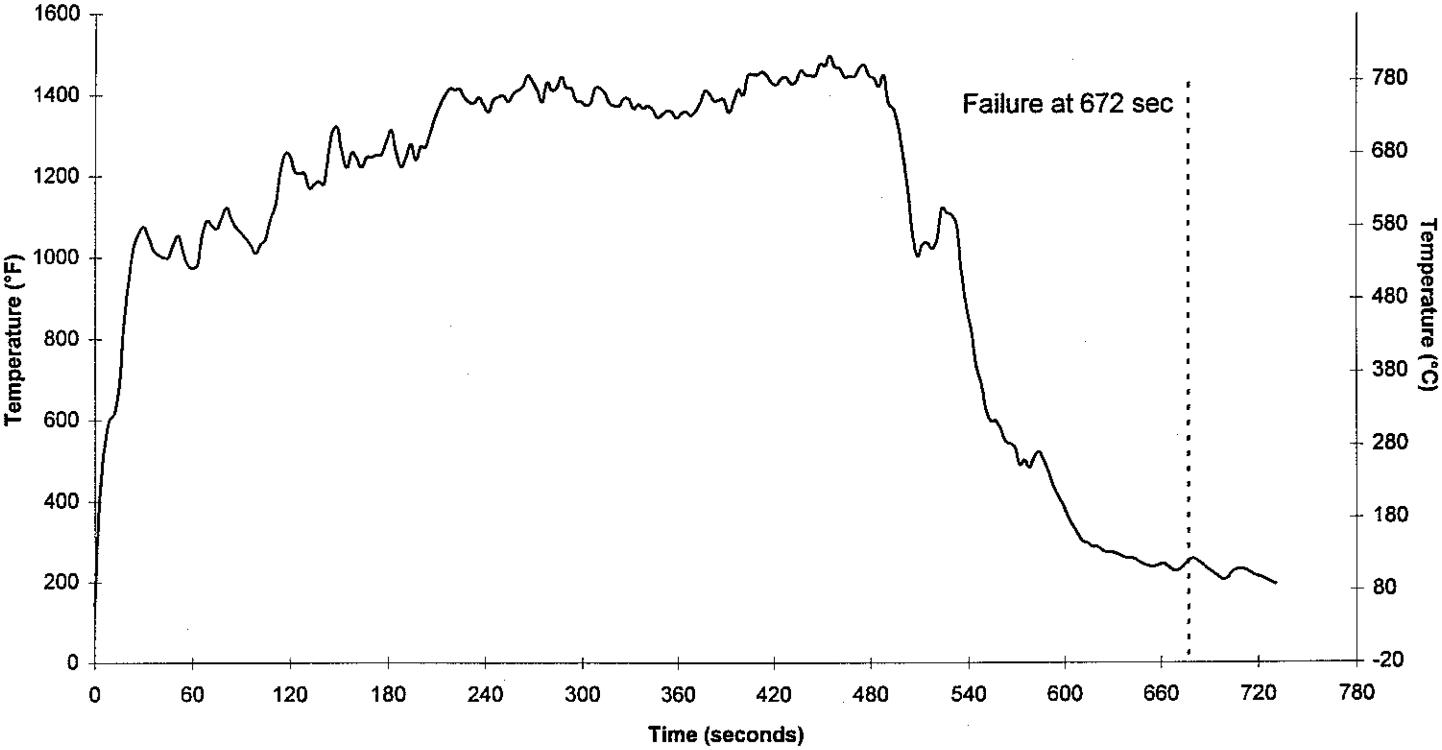

Figure C100: Test #20 External Temperatures

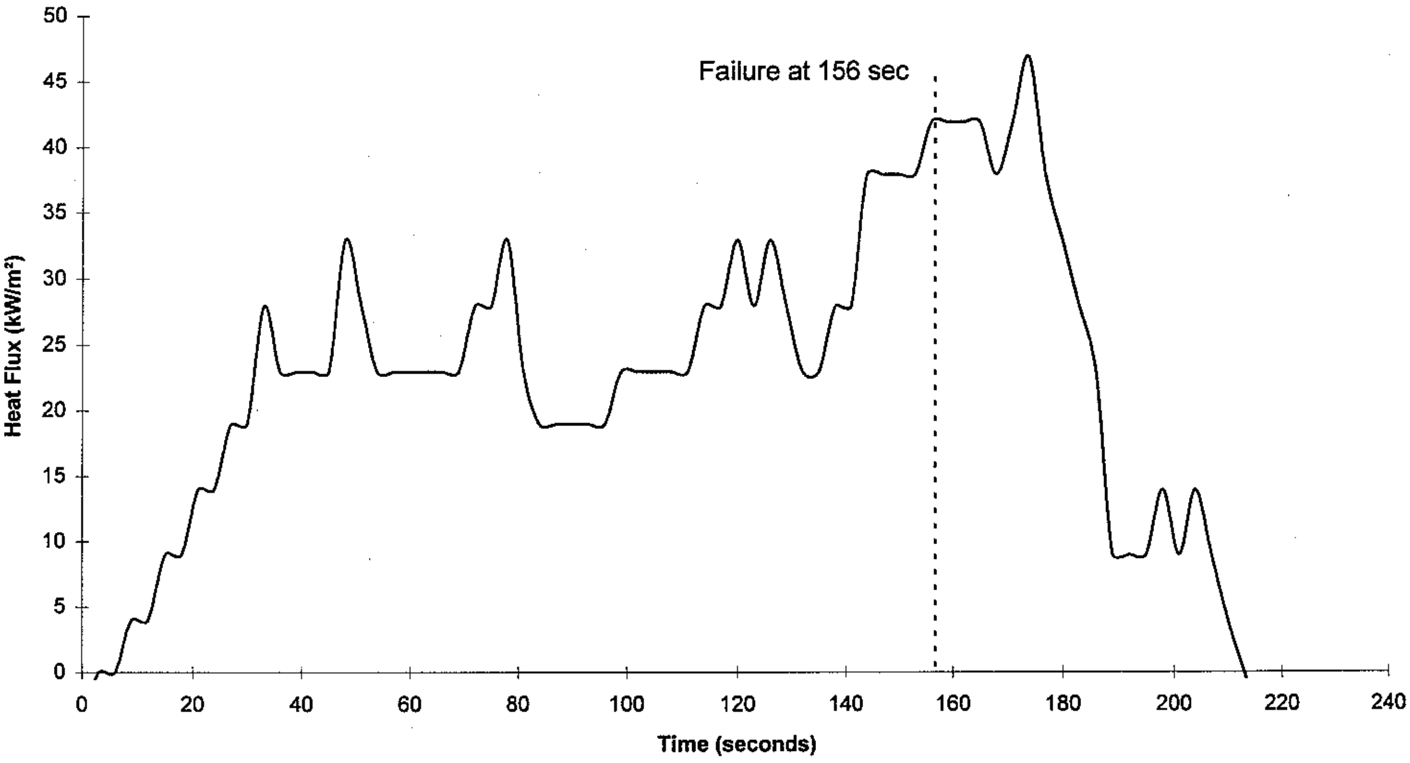

Figure C101: Test #21 Heat Flux

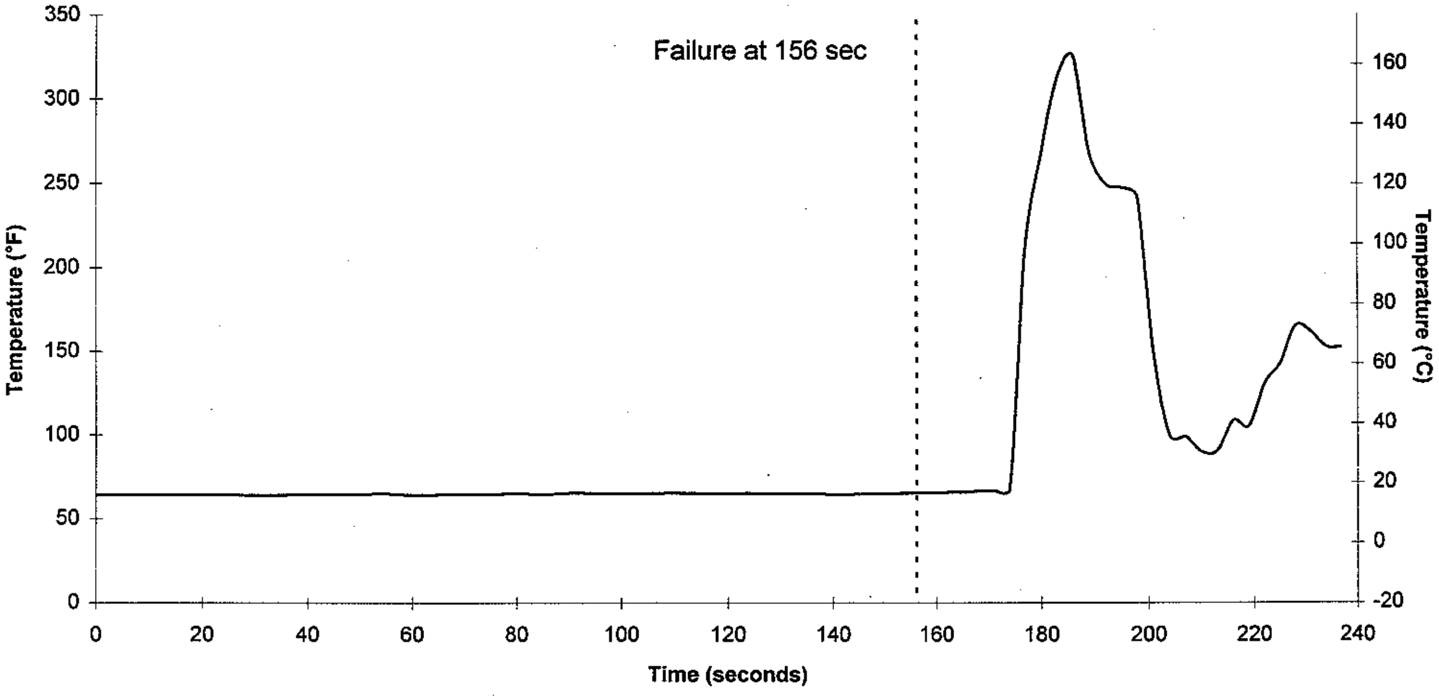

Figure C102: Test #21 Ullage Temperatures

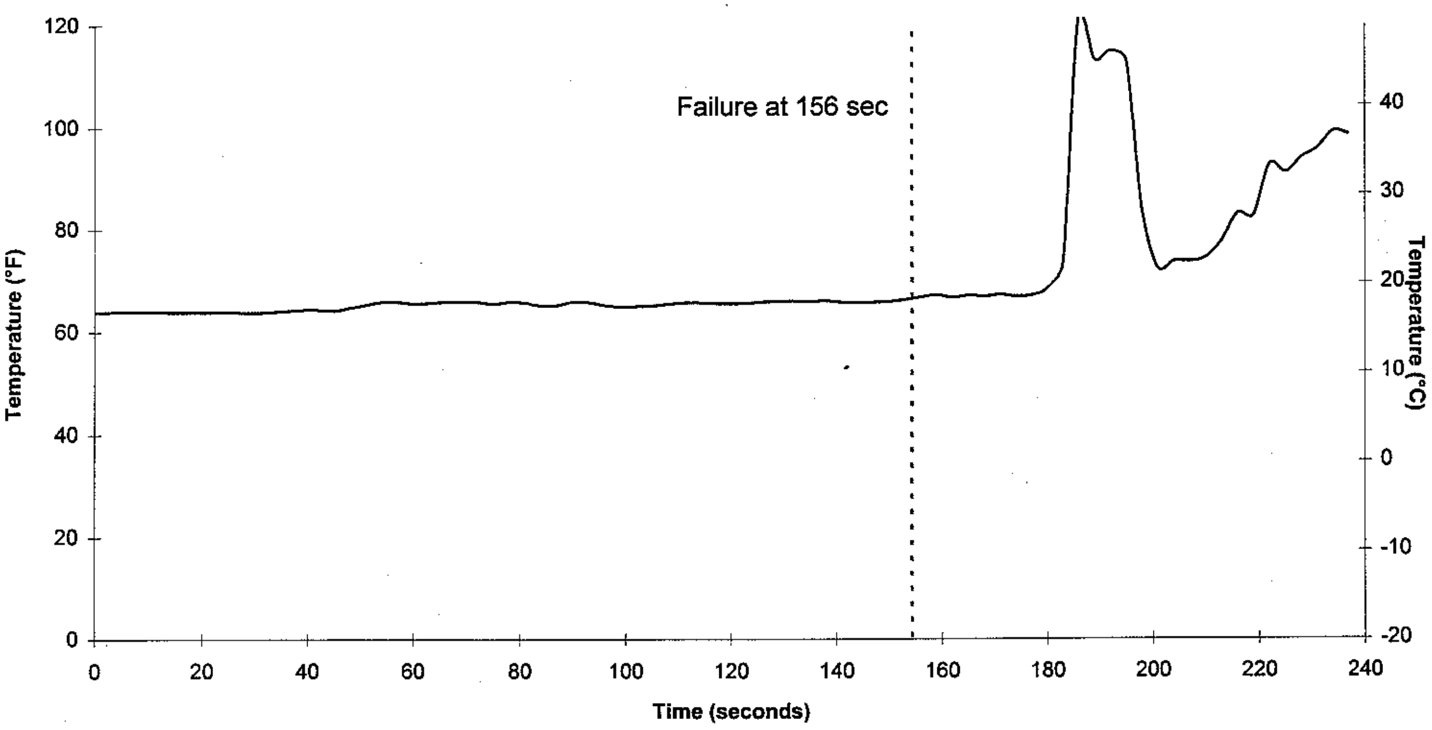

Figure C103: Test #21 Liquid Temperature 12" below water line

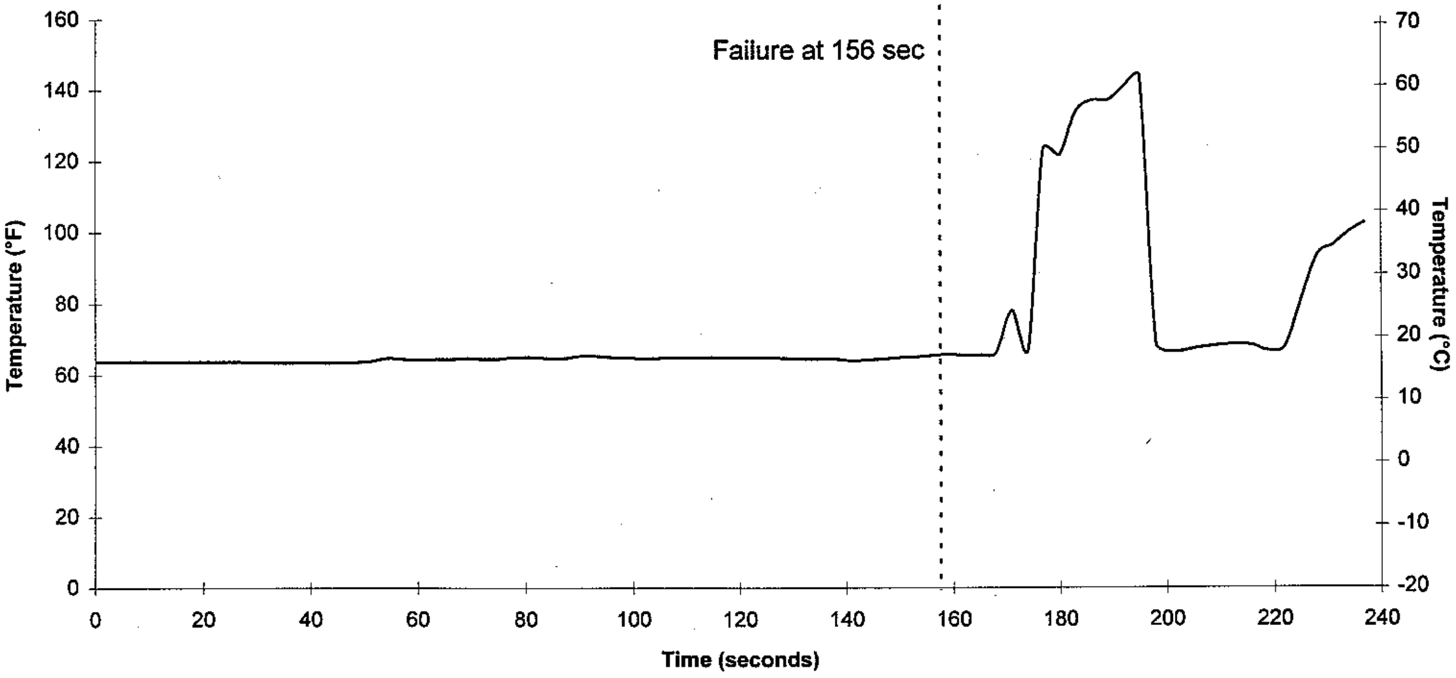

Figure C104: Test #21 Liquid Temperature 24" below water line

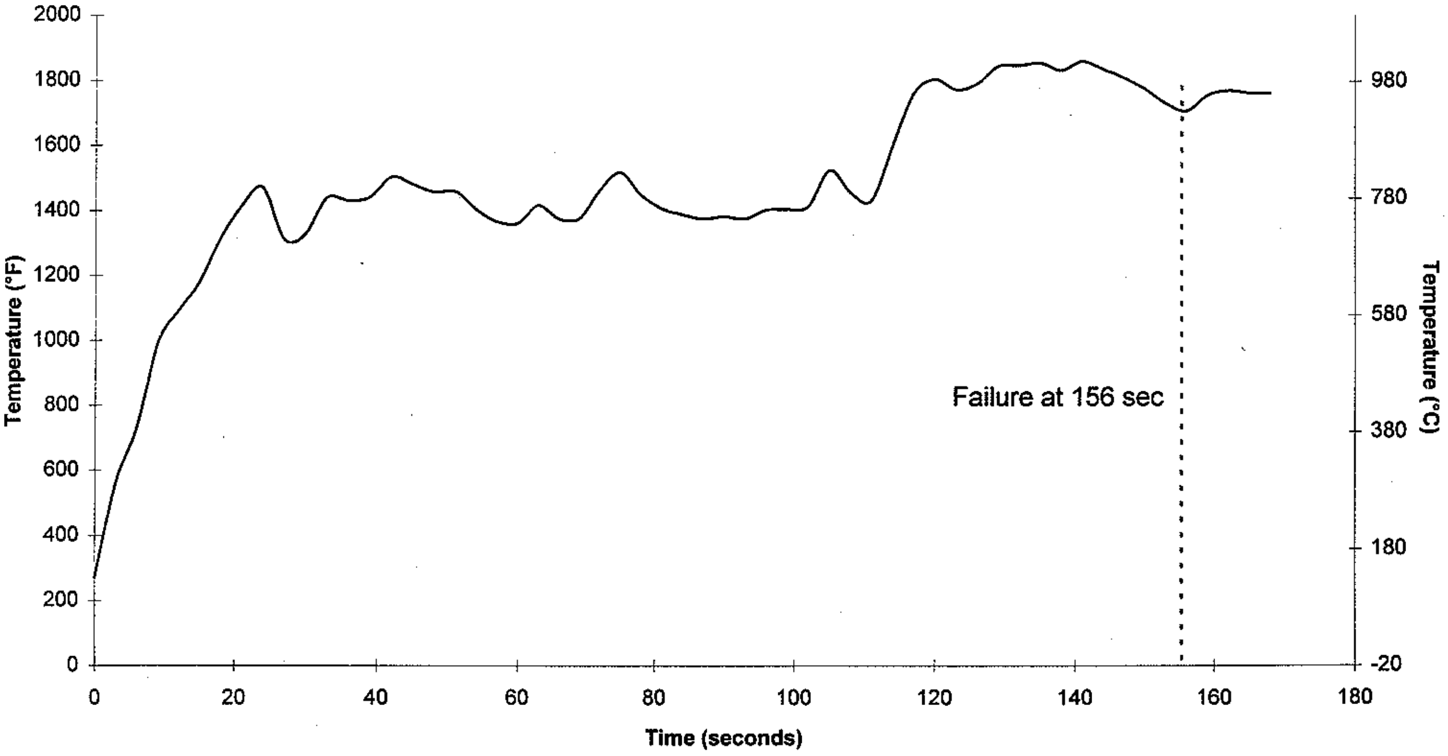

Figure C105: Test #21 External Temperatures

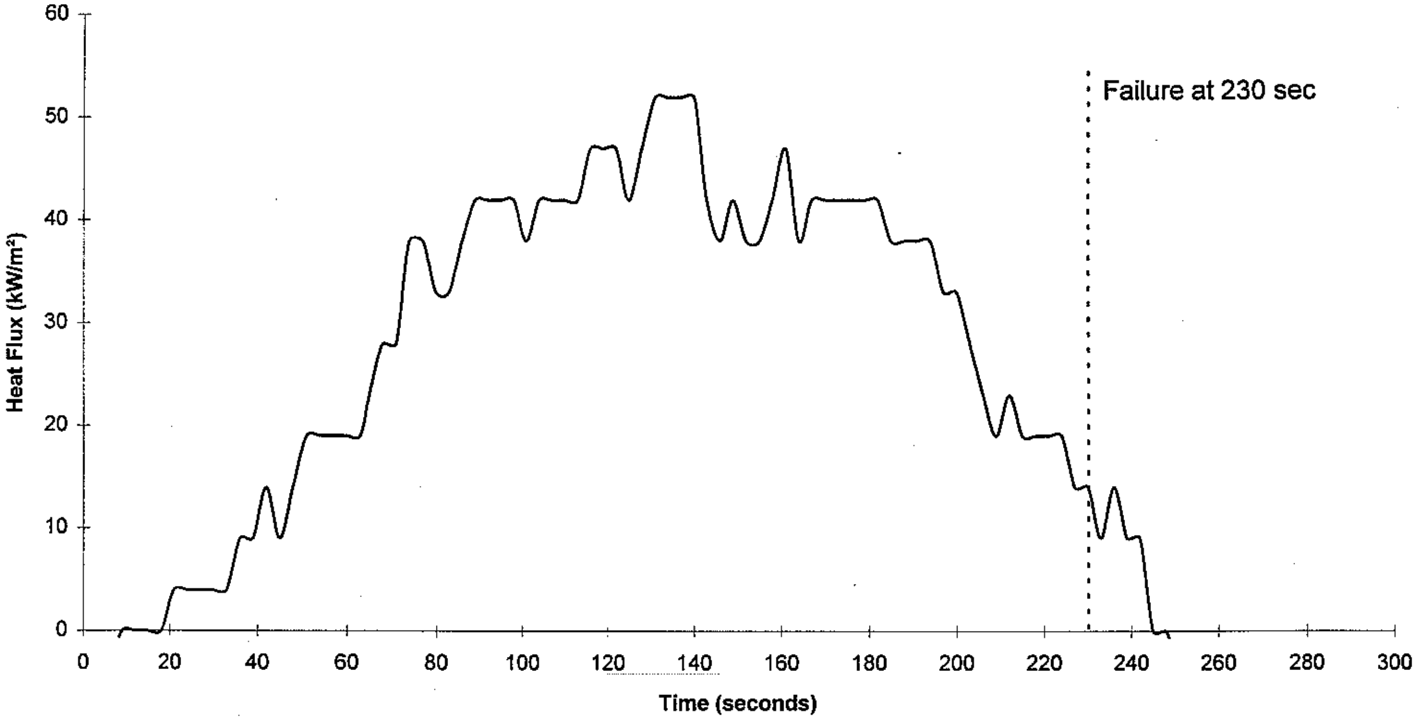

Figure C106: Test #22 Heat Flux

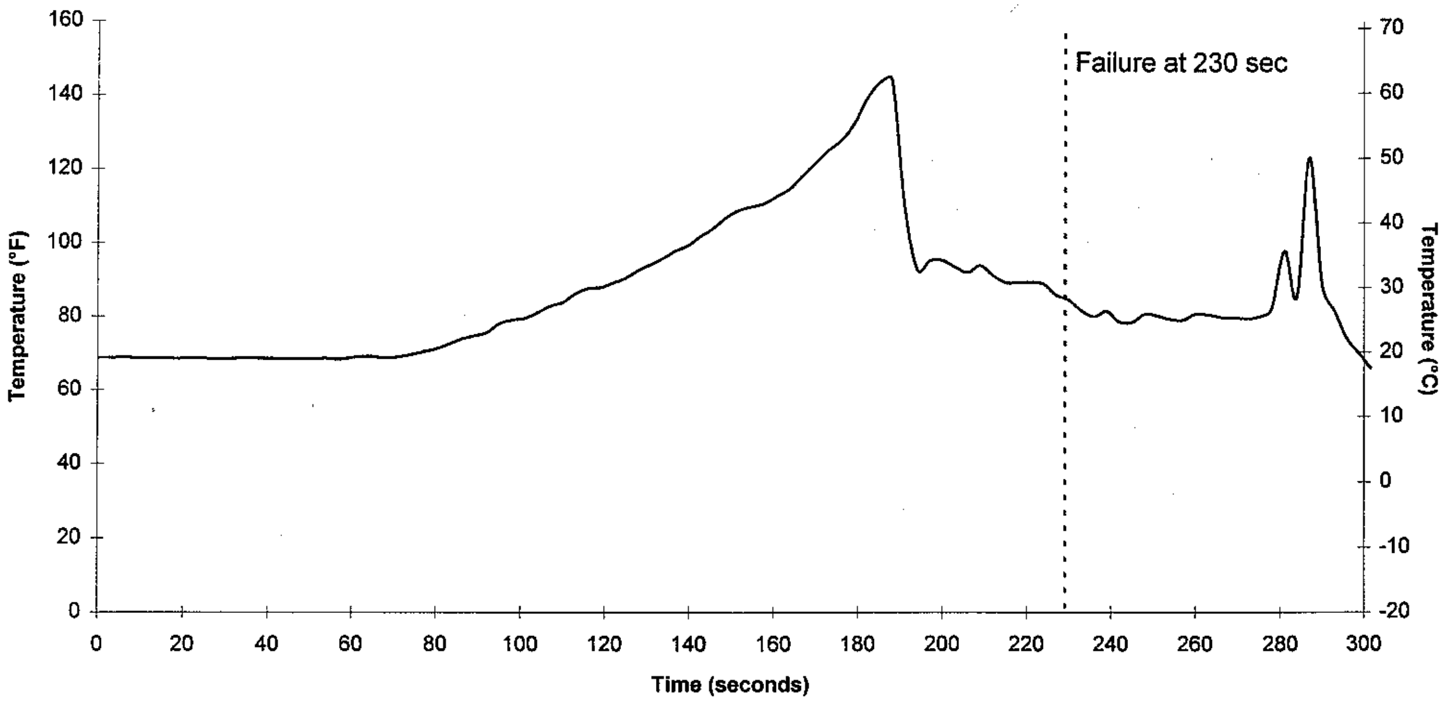

Figure C107: Test #22 Ullage Temperatures

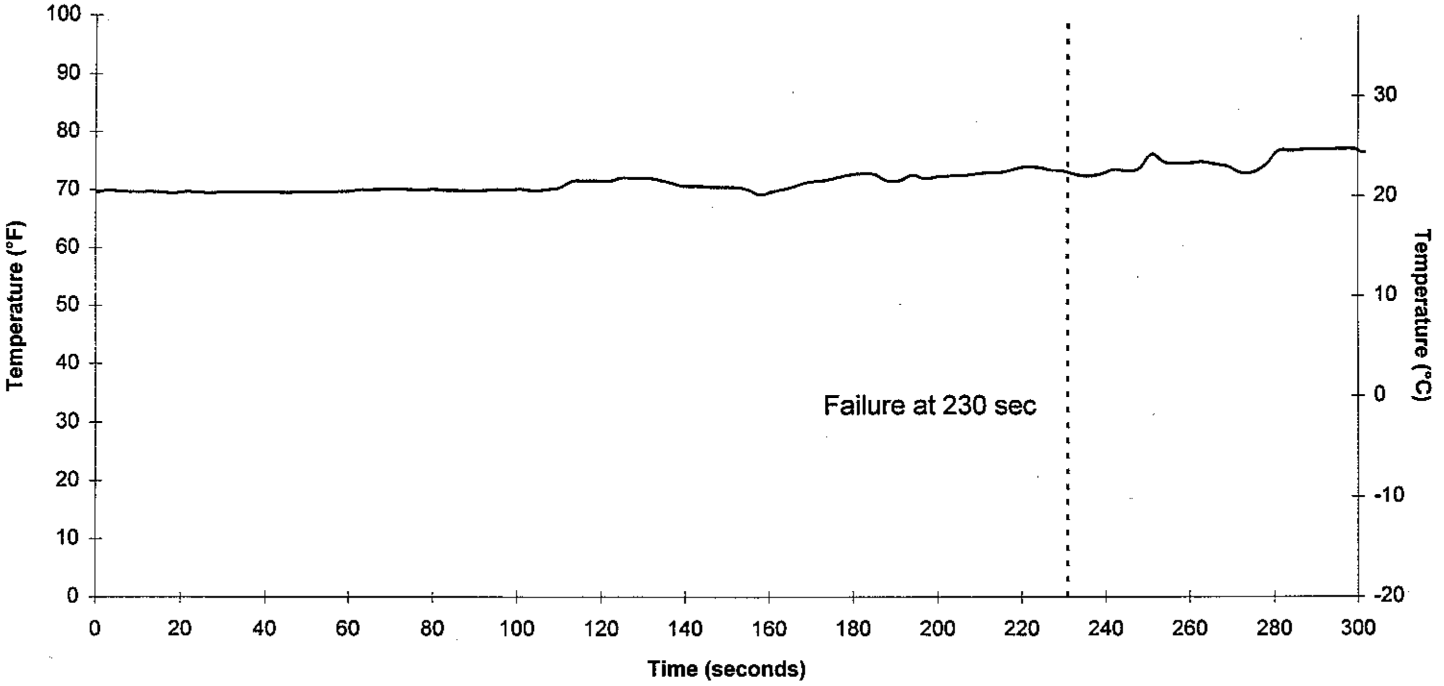

Figure C108: Test #22 Liquid Temperature 12" below water line

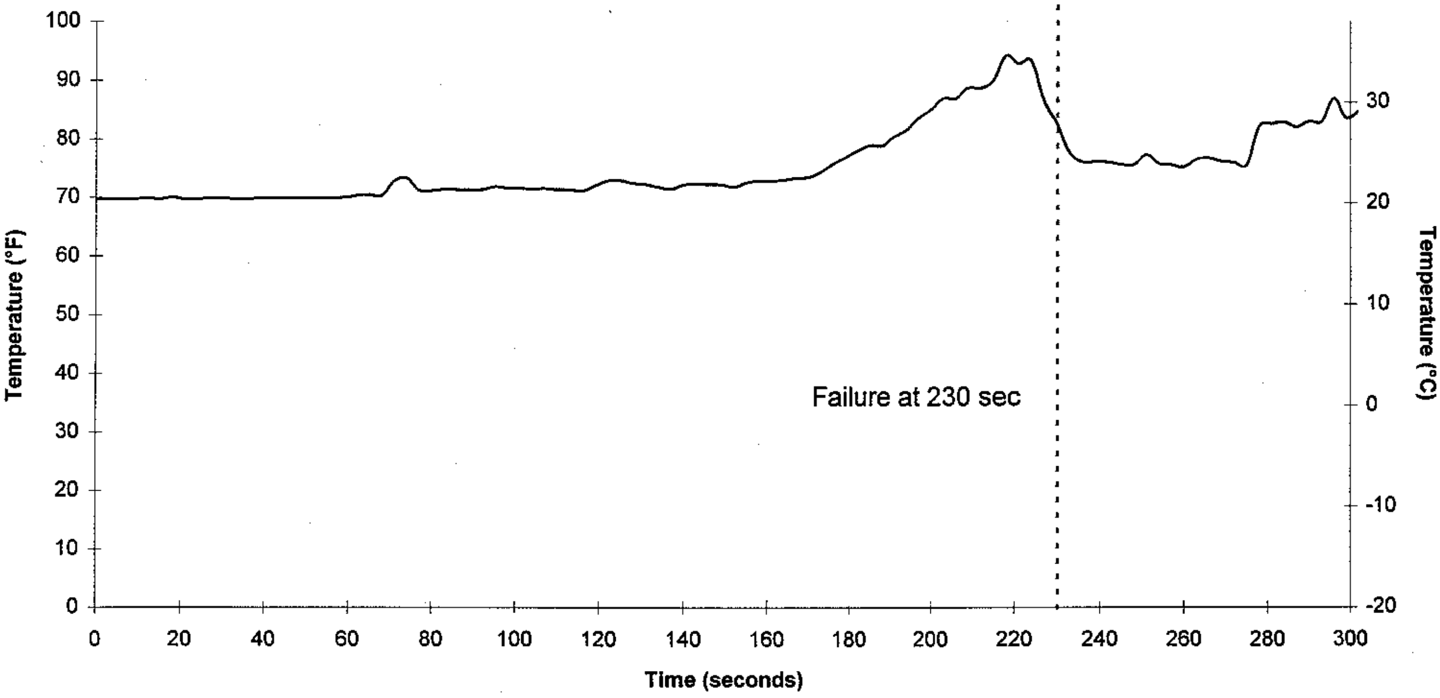

Figure C109: Test #22 Liquid Temperature 24" below water line

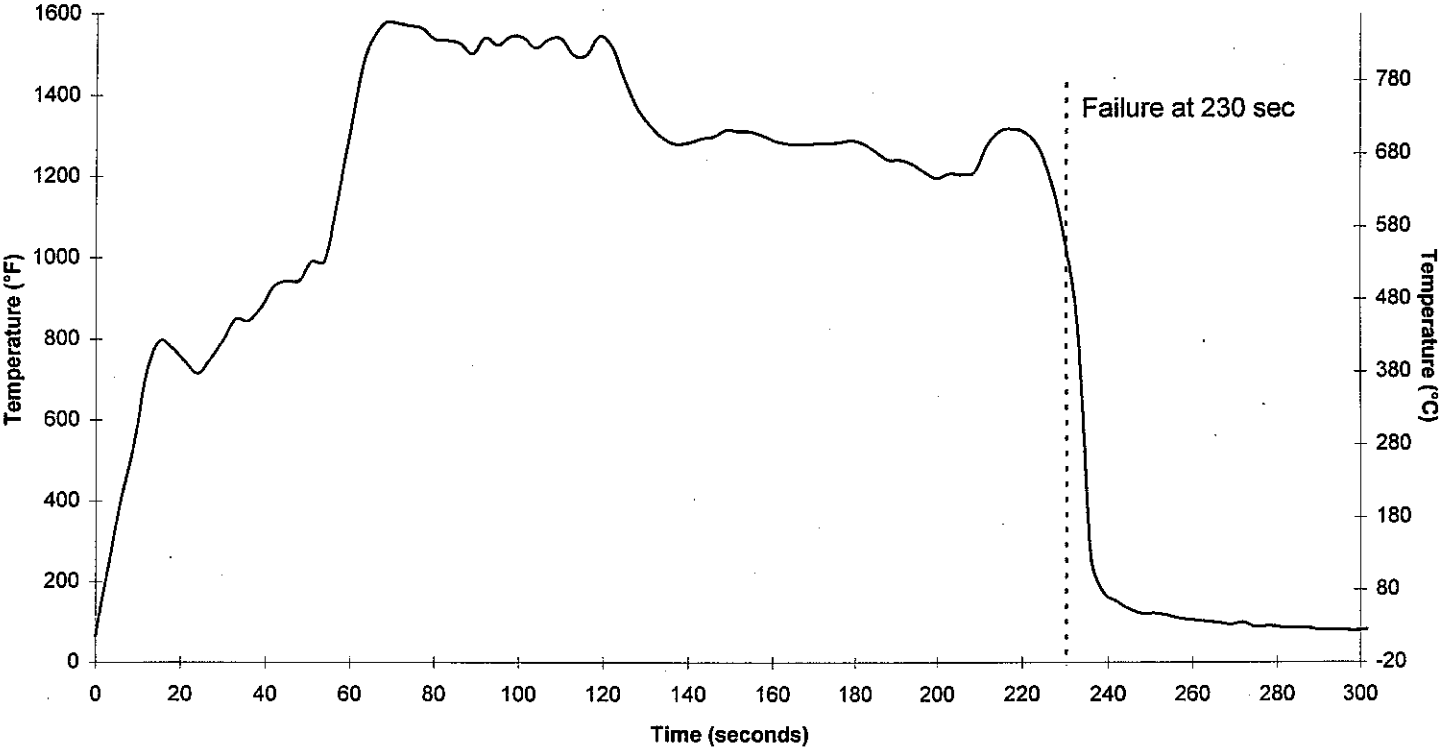

Figure C110: Test #22 External Temperatures

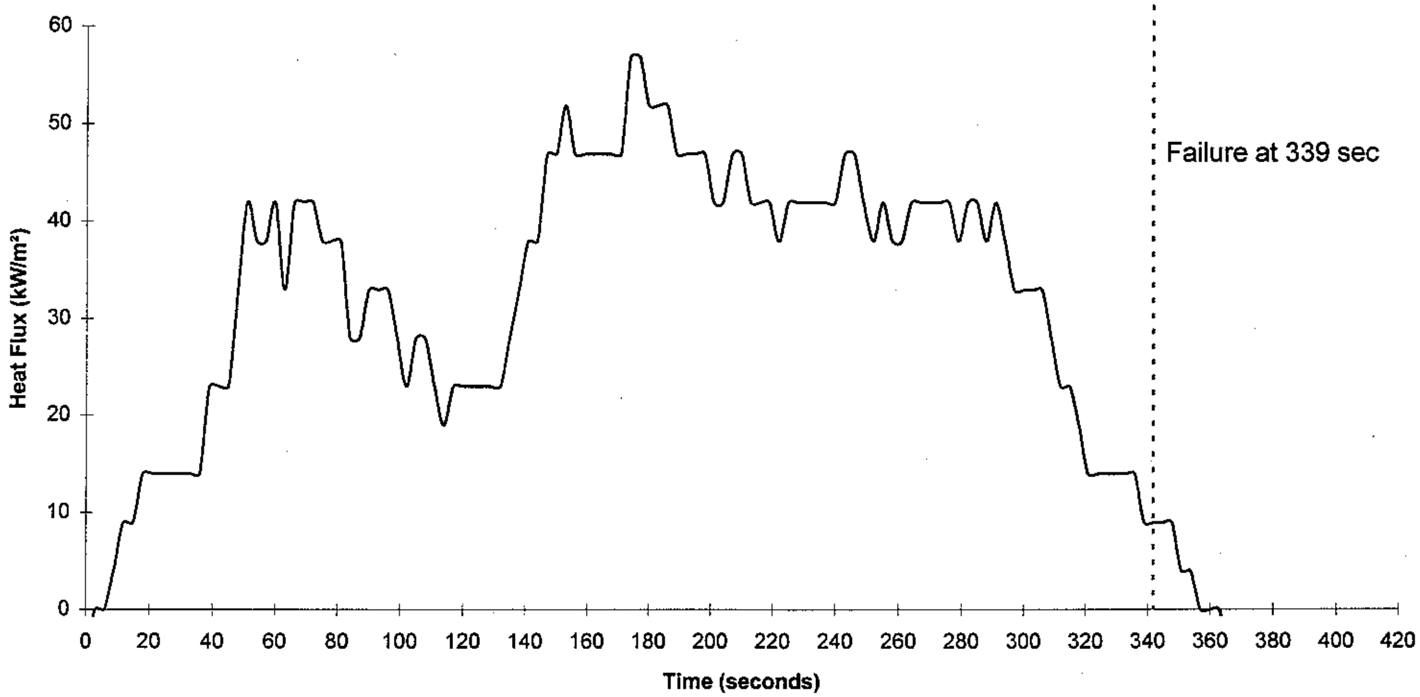

Figure C111: Test #23 Heat Flux

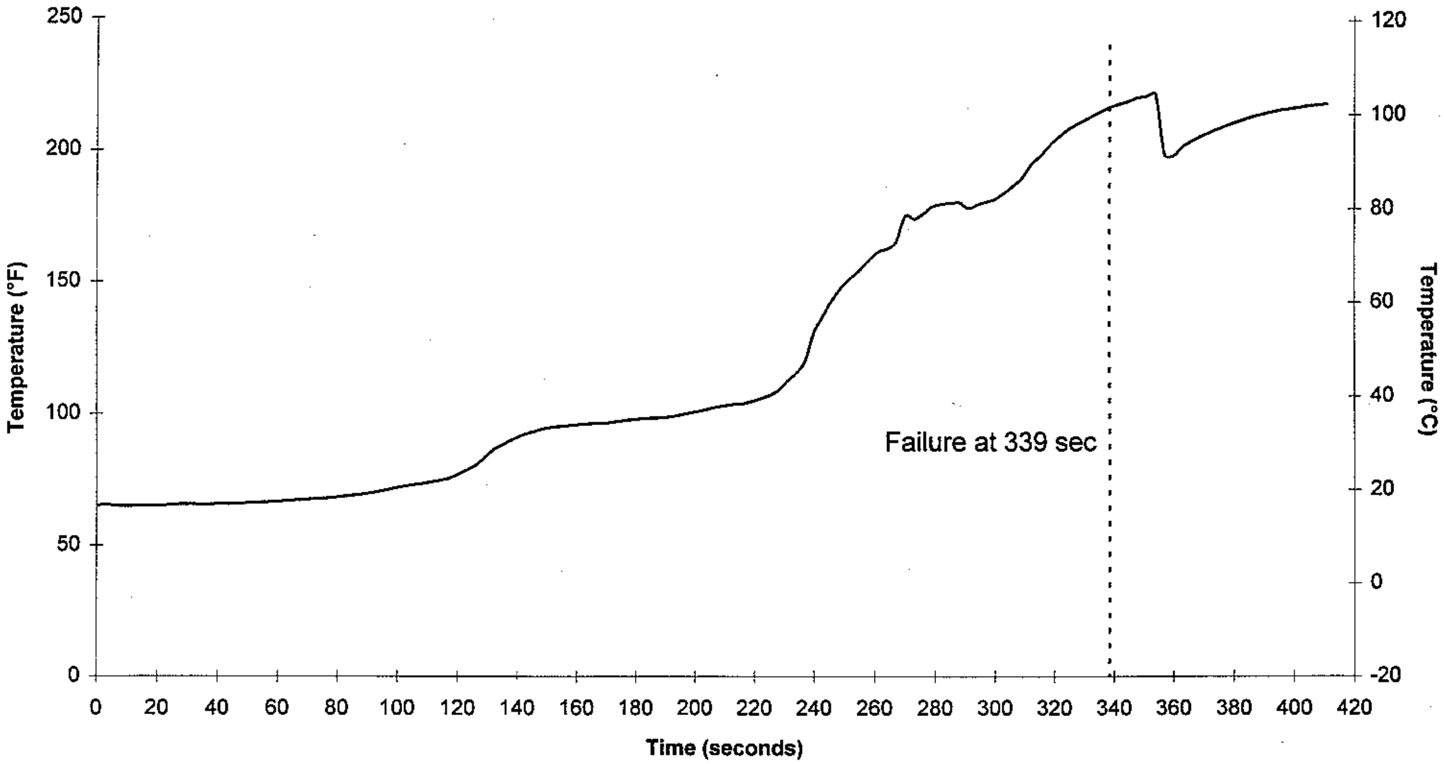

Figure C112: Test #23 Ullage Temperature

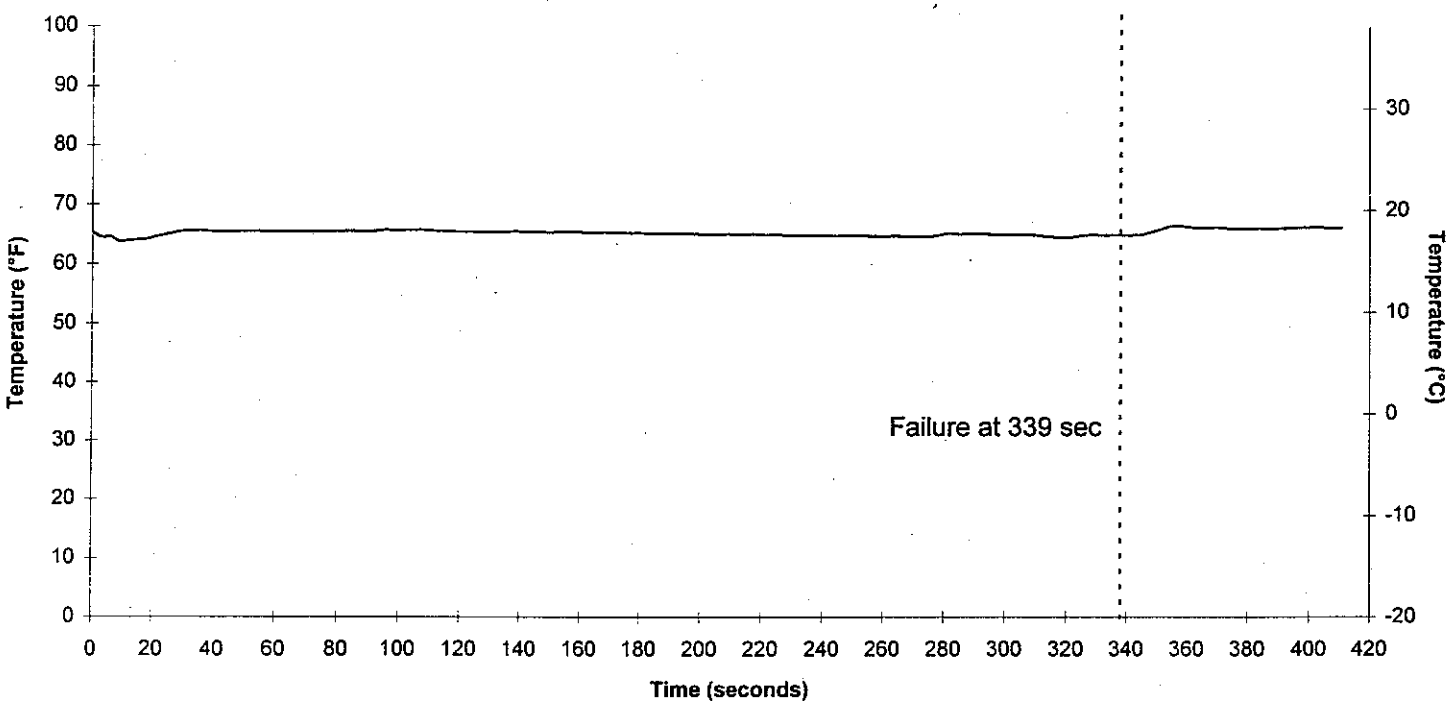

Figure C113: Test #23 Liquid Temperature 12" below water surface

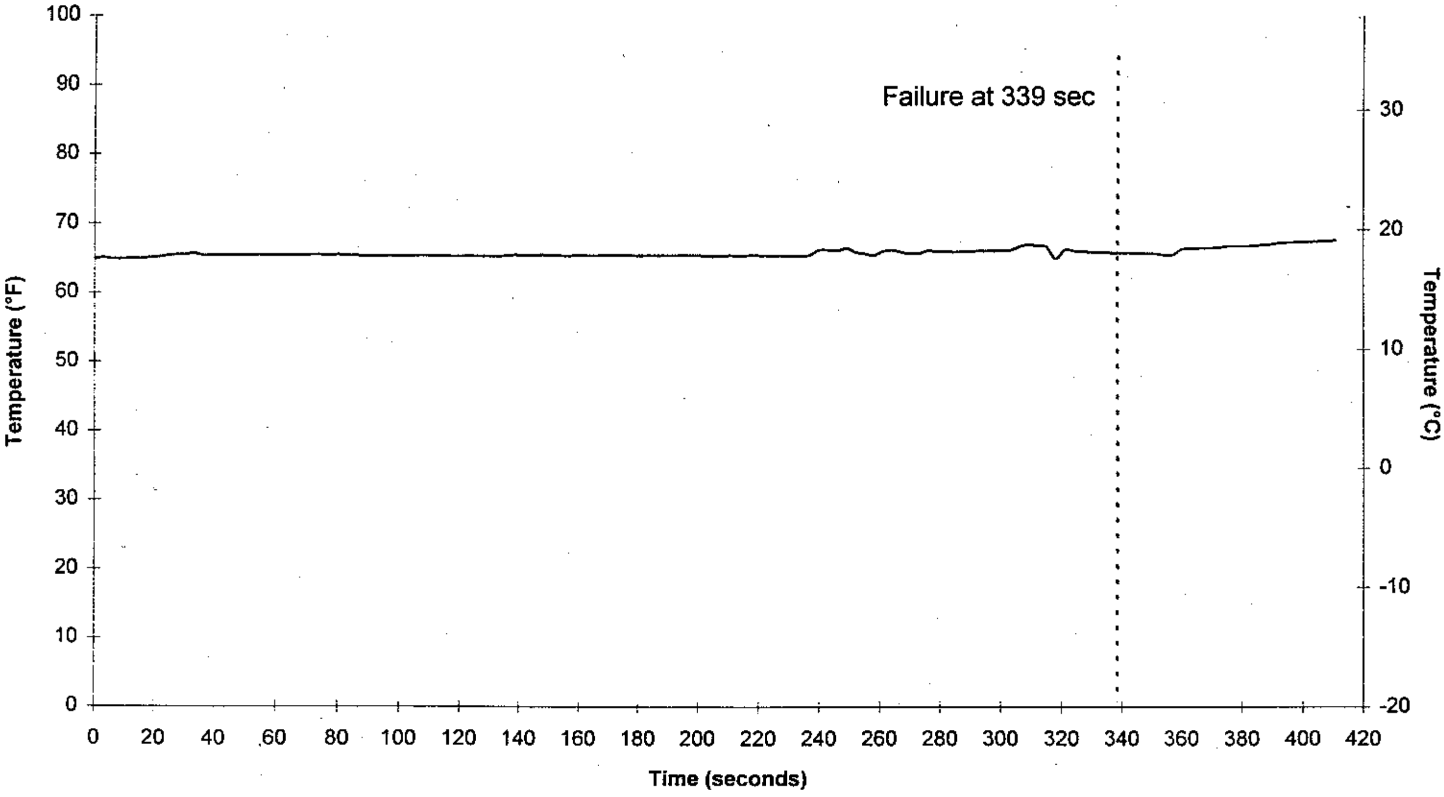

Figure C114: Test #23 Liquid Temperature 24" below water line

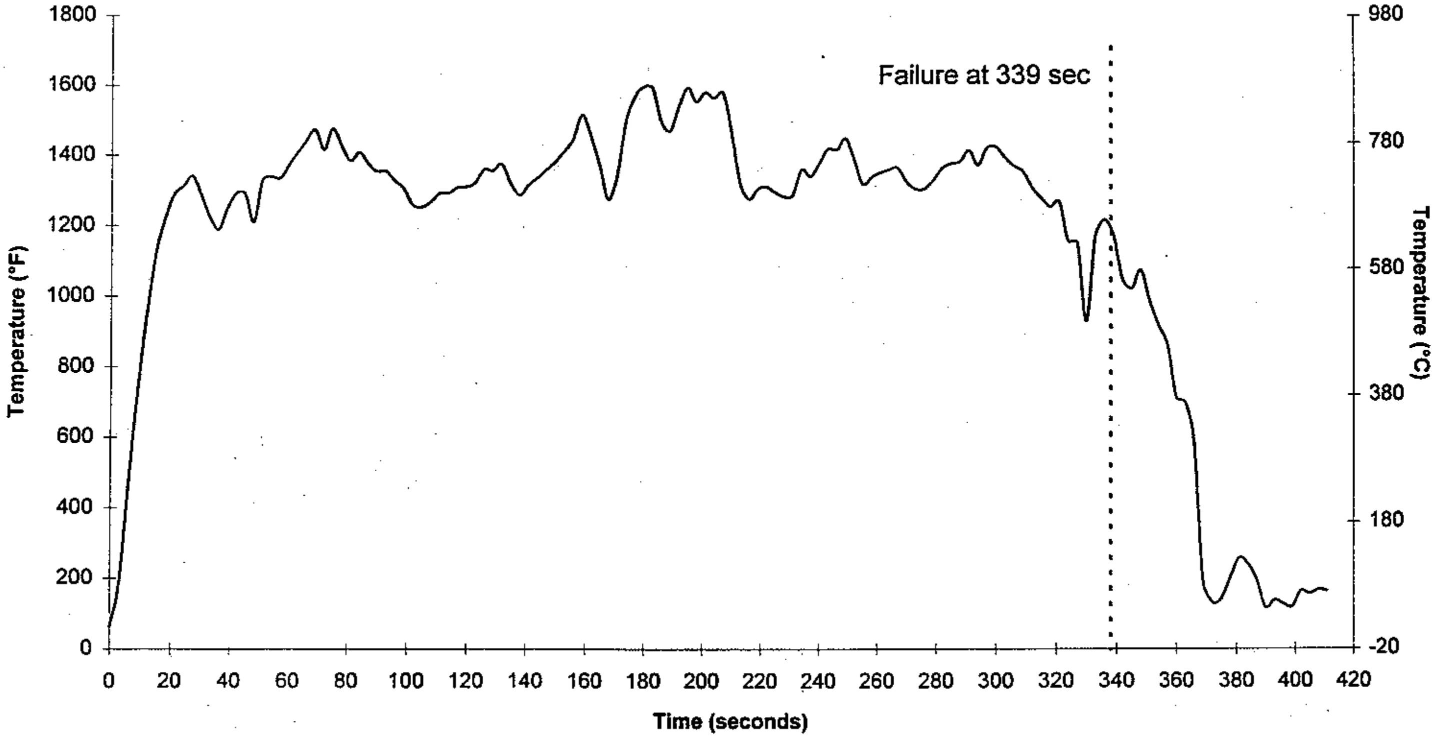

Figure C115: Test #23 External Temperature