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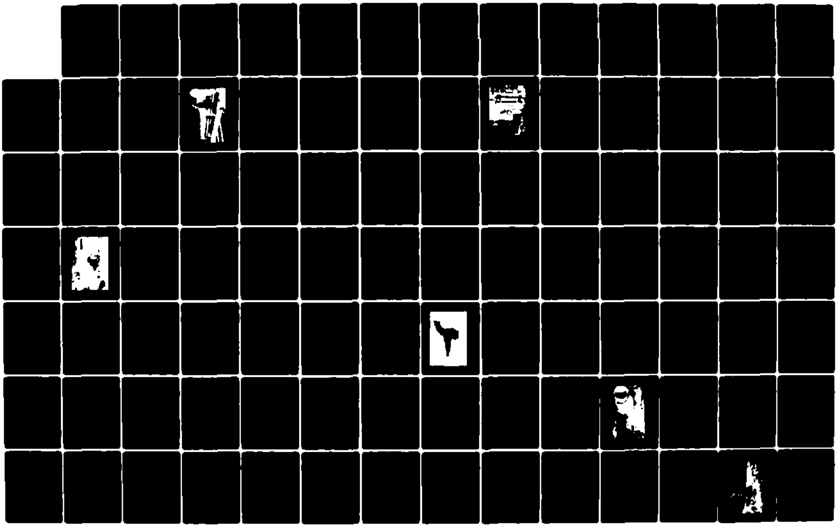

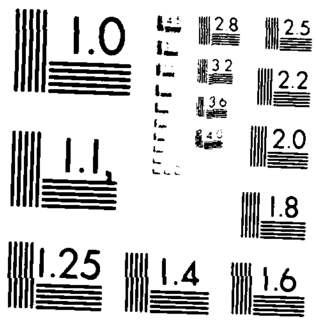

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(Supersedes IMR No. 763)

SURVIVABILITY TESTS ON A NUCLEAR WASTE CASK IN SIMULATED RAILROAD ACCIDENT FIRES

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June 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A test program was executed to determine the survivability of a nuclear waste cask when exposed to a fire due to a train derailment. The particular cask in question was modified to be similar to those which are used for transporting nuclear waste by rail. The modification consisted of adding impact limiters on each end to absorb shock in the event of an accident and a jacket filled with water to serve as a neutron shield. A total of five tests was conducted using a propane torch as the heat source with the center of the torch positioned at different locations on the cask. The torch nozzle was positioned 12 feet

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) from the surface of the cask in the first four tests which constituted a torch fire situation and 20 feet in the fifth test to simulate a pool fire situation. The report presents a description of the nuclear waste cask, the test procedures used in the program, the test data, and some general observations on the test series.

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LIST OF TABLES

LIST OF SYMBOLS

A - Designation for thermocouples positioned on the inside surface of the inner steel shell in the HNPF Cask

ARP - Angular reference point on the HNPF Cask

B - Designation for thermocouples positioned on the outside surface of the outer steel shell in the HNPF Cask

BRL - Ballistic Research Laboratory

C - Designation for thermocouples positioned on the inside surface of the inner steel shell in the HNPF Cask

CC - Axial centerline of the HNPF Cask

D - Designation for thermocouples positioned on the cross-sectional plane located ~60.0 cm from the XPR and on the inside surface of the steel covering on the impact limiter

DOE - Department of Energy

E - Designation for thermocouples positioned on the top of the HNPF Cask lid

F - Designation for thermocouples positioned on the outside of the neutron shield jacket of the HNPF Cask

FACL- Designation for thermocouple which measures the flame temperature near the surface of the HNPF Cask and on the torch centerline

FD - Designation for thermocouples positioned on the outside of the HNPF Cask a short distance from the surface of the impact limiter (measured flame temperature)

FF - Designation for thermocouples positioned a slight distance off the outside surface of the HNPF Cask (measured flame temperature)

FRA - Federal Railroad Administration

G - Designation for thermocouples positioned inside the neutron shield jacket on the HNPF Cask

H - Designation for pressure gauges mounted inside the neutron shield jacket on the HNPF Cask

HNPF- The Hallam Nuclear Power Facility

ISS - The inner steel shell in the HNPF Cask

LS - The lead shield inside the HNPF Cask

NSJ - The neutron shield jacket on the HNPF Cask

LIST OF SYMBOLS (Cont.)

NWSV - The nuclear waste storage volume in the HNPF Cask

OSS - The outer steel shell in the HNPF Cask

PTF - The propane torch facility

SNL - The Sandia National Laboratories

ST - Designation for thermocouples positioned on the outside surface of the impact limiter on the HNPF Cask

TC - Thermocouple

TERA - The Terminal Effects Research and Analysis Group of the New Mexico Institute of Mining and Technology

TIC - The torch impingement center of the propane torch on the HNPF Cask

XRP - The axial reference point on the HNPF Cask

I. INTRODUCTION

The Ballistic Research Laboratory (BRL) has for a number of years participated in a railroad safety research program sponsored by the Federal Railroad Administration (FRA). One of the consequences was the development of a propane torch facility (PTF) which is now routinely used for testing candidate thermal insulation systems for tank cars hauling hazardous materials. The testing procedure consists of placing samples of the thermal systems in the path of the torch flame in a prescribed manner specified by DOT Docket No. HM-144 and to determine if the performance standard (also specified) is met.[1] The work presented in this report is a continuation of this program.

The objective of this work was to determine the survivability of a nuclear waste cask exposed to a fire environment. The cask was subjected to the same conditions as those required for testing thermal insulation systems. The cask in question was an obsolete model which was modified to include several modern components which are now required for use in transporting nuclear waste by rail. The cask was exposed to two categories of fires which can happen in a railroad accident and these were simulated using the PTF. The two types of fires are a "torch fire" and a "pool fire," both described later in the report. The report presents a description of the nuclear waste cask, test procedures utilized, and some general observations of the test data.

The test series was a cooperative effort between the BRL, the Sandia National Laboratories (SNL), and the Terminal Effects Research and Analysis Group (TERA) of the New Mexico Institute of Mining and Technology.

II. TESTING PROCEDURES

The Hallam Nuclear Power Facility (HNPF) cask was made available for testing by the Department of Energy (DOE).[2] The HNPF cask was of an older design and was modified by adding a neutron shield and impact limiters so that it would meet the transportation requirements specified in U.S. Nuclear Regulatory Commission 10CFR71, Appendix B. The HNPF cask was modified by Stearns-Roger Mfg. Co., Denver, Colorado. A photograph of the HNPF Cask in its horizontal test position (also its position during transport) is presented in Figure 1. The neutron shield consists of a corrugated steel jacket which can be filled with water. The impact limiters are made of oak and covered with a 0.318 cm (1/8 in) thick layer of mild steel. The top end of the cask is toward the left in the figure.

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[1] *"Hazardous Materials Regulations of the Department of Transportation by Air, Rail, Highway, Water and Military Explosives by Water including Specifications for Shipping Containers, Bureau of Explosives, Docket No. HM-144, Amdt. Nos. 179-108, PART 179 - Specifications For Tank Cars, Para. 179.105-4," TARIFF No. BOE-6000-B, Issued December 22, 1981, Effective January 22, 1982, Department of Transportation, Washington, D.C. 20590*

[2] *Manuel G. Vigil, Amado A. Trujillo, and H. Richard Yoshimura, "HNPF Spent Fuel Cask Torch Impinging on Water Filled Neutron Shield," SAND82-0704* TTC-0297, March 1982, Sandia National Laboratories, Albuquerque, NM 87185*

Figure 1: The Modified Hallam Nuclear Power Facility (HNPF) Cask in the Horizontal Test Position

A schematic of a cross-sectional overhead view of the HNPF Cask is presented in Figure 2. The empty space in the middle of the cask is for storing the nuclear waste being transported and will be referred to as the "nuclear waste storage volume" (NWSV). The NWSV has a cross-sectional radius of 20.96 cm (8.25 inches). The inside surface of the NWSV consists of a 2.54 cm (one inch) thick 304 stainless steel layer which will be referred to as the "inner steel shell" (ISS). Next to the ISS is a 17.78 cm (7 inch) thick "lead shield" (LS) which is for absorbing gamma rays emitted by the nuclear waste products. Over the outside of the LS is a 3.91 cm (1.5 inch) thick carbon steel (ASTM A516) layer which will be referred to as the "outer steel shell" (OSS). And finally, the cask is covered by a steel corrugated shell which can be filled with water. The water in the corrugated shell is for absorbing neutrons produced by the nuclear waste. This shell will be referred to as the "neutron shield jacket" (NSJ). For test purposes, steel vent pipes were attached to two relief valves installed in the NSJ to direct any release of water and steam from the NSJ in to a holding tank. The steel pipes were supplied by SNL and the holding tank (1500 gallon capacity) was provided by TERA.

A total of five tests was conducted in this series. The directions of the centerline of the torch relative to the test position of the cask for each test are presented in Figure 3. The axial distances of the "torch impingement centers" (TIC) are measured from a reference surface which is the top surface of the cask (cask positioned for loading nuclear waste) with the lid removed. The intersection of this surface with the centerline axis of the cask will be referred to as the "axial reference point" (XRP). A summary of the orientations of the various tests is presented in Table 1. In the table it is noted that there were four side-on tests and one test where the torch was directed at the top of the cask. (This is also noted in Figure 3.) Three of the tests had the NSJ filled with water and two of the tests did not. The distances of TIC from the XRP for Test Numbers 1, 2, 3, and 5 were 289.6 cm (114 inches), 93.3 cm (36.7 inches), 289.6 cm (114 inches), and 93.3 cm (36.7 inches) respectively. The concept of distance between the TIC and the XRP must be interpreted different for Test Number 4 since the TIC was directed toward the top of the cask. Figure 4 presents a photograph of the PTF with the HNPF Cask in a side-on orientation relative to the nozzle of the torch.

The test conditions for the propane torch are summarized in Table 2 and are as specified as test requirements in HM 144. These requirements were determined on the basis of previous experimental and theoretical studies and on actual railroad accident data. Two categories of fires are simulated by these conditions, namely a "torch fire simulation" and a "pool fire simulation." Test Numbers 1, 2, 3, and 4 were torch simulation tests and Test Number 5 was a pool fire simulation test.

The torch fire simulation is a simulation of a situation where a tank car is positioned in the path of a torch flame formed by burning propane escaping from another tank car which has overturned. For this situation the nozzle of the torch is placed 3.66 meters (12 feet) from the surface of the sample being tested, in this case the HNPF Cask. The velocity of the torch flame is maintained at 64.4 km/hr (40 mi/hr) to ensure that the temperature of the flame at the surface of the cask is 1204 ± 56 ^{o}C (2200 ± 100 ^{o}F) and that the diameter of the torch flame is approximately 0.9144 meters (3 feet). The duration of a torch simulation is 30 minutes.

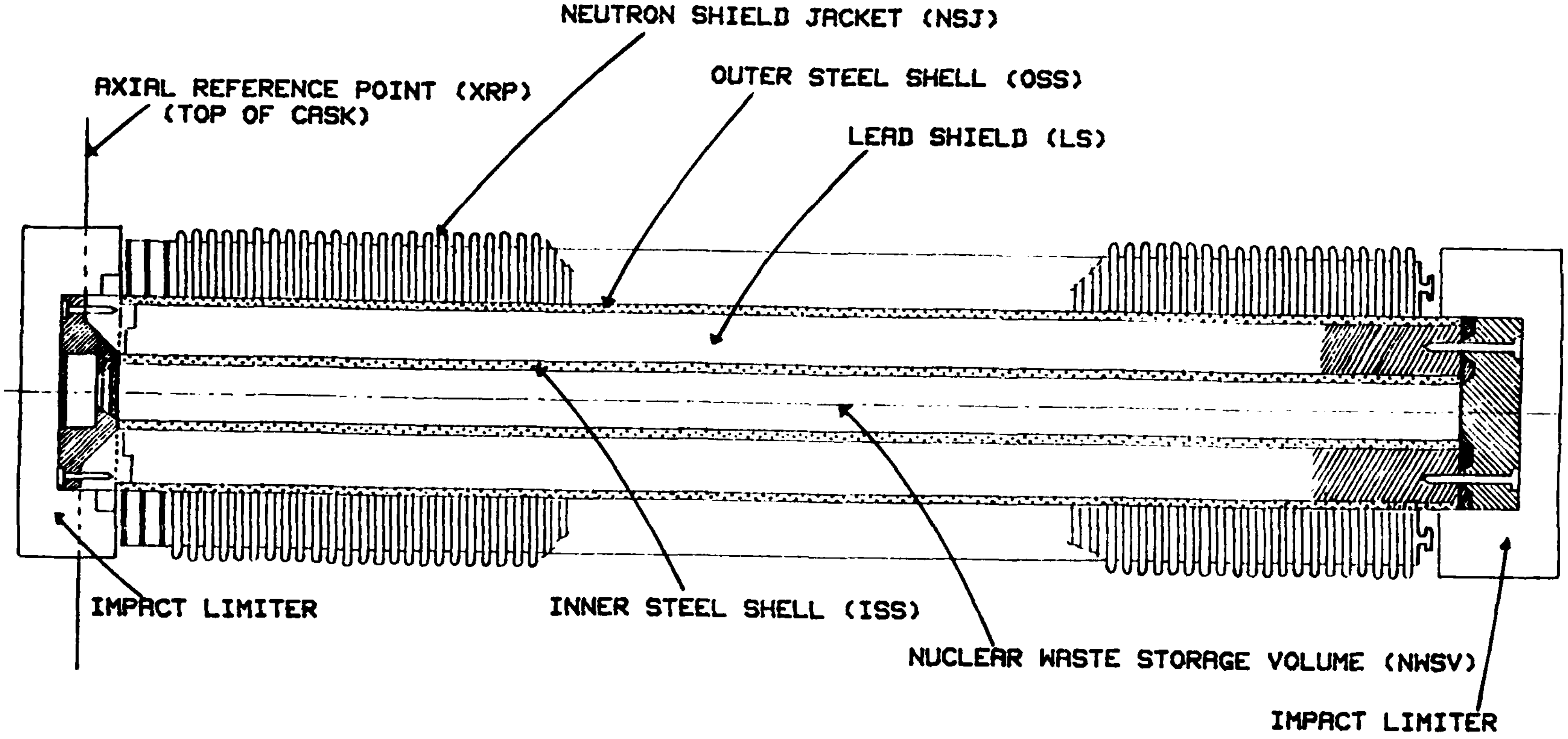

Figure 2: The Primary Components of the Modified Hallam Nuclear Power Facility (HNPF) Cask

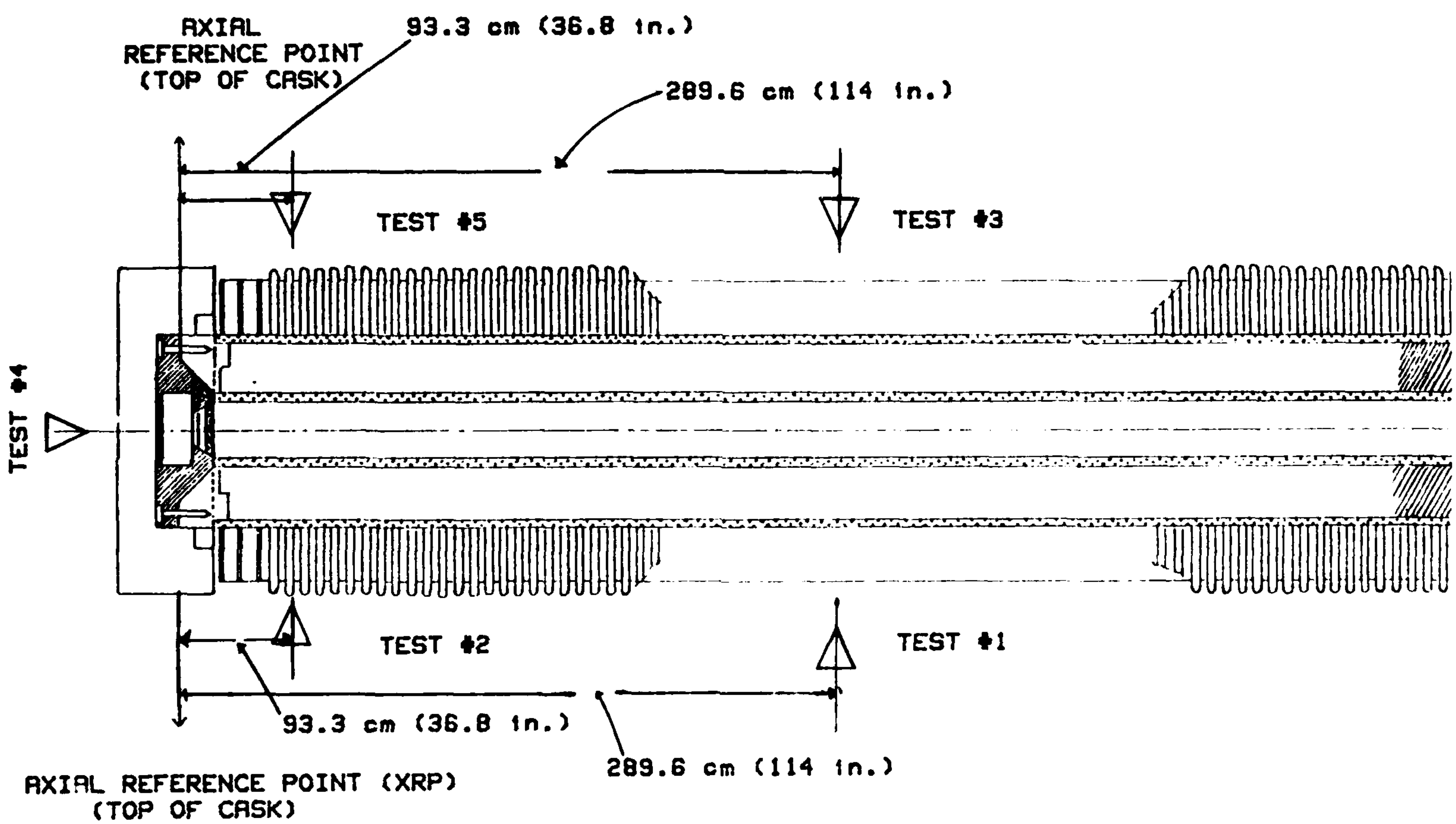

Figure 3: The Positions of the Torch Impingement Centers (TICs) on the HNPF Cask Relative to the Axial Reference Point (XRP)

TABLE 1: TEST CONFIGURATIONS FOR THE PROPANE TORCH AND THE HNPF CASK

Test Numbers	Torch Orientation	Water Content of NSJ	Position of TIC From the XPR
1	Side Impingement	Filled	289.6 cm (114.0 Inches)
2	Side Impingement	Filled	93.3 cm (36.7 Inches)
3	Side Impingement (Opposite Side from Test Number 1)	Voided	289.6 cm (114.0 Inches)
4	End-on With TIC on Center-line of Cask	Voided	***
5	Side Impingement (Opposite Side from Test Number 2)	Filled	93.3 cm (36.7 Inches)

*** *The position of the TIC from the XPR is undefined due to the end-on orientation.*

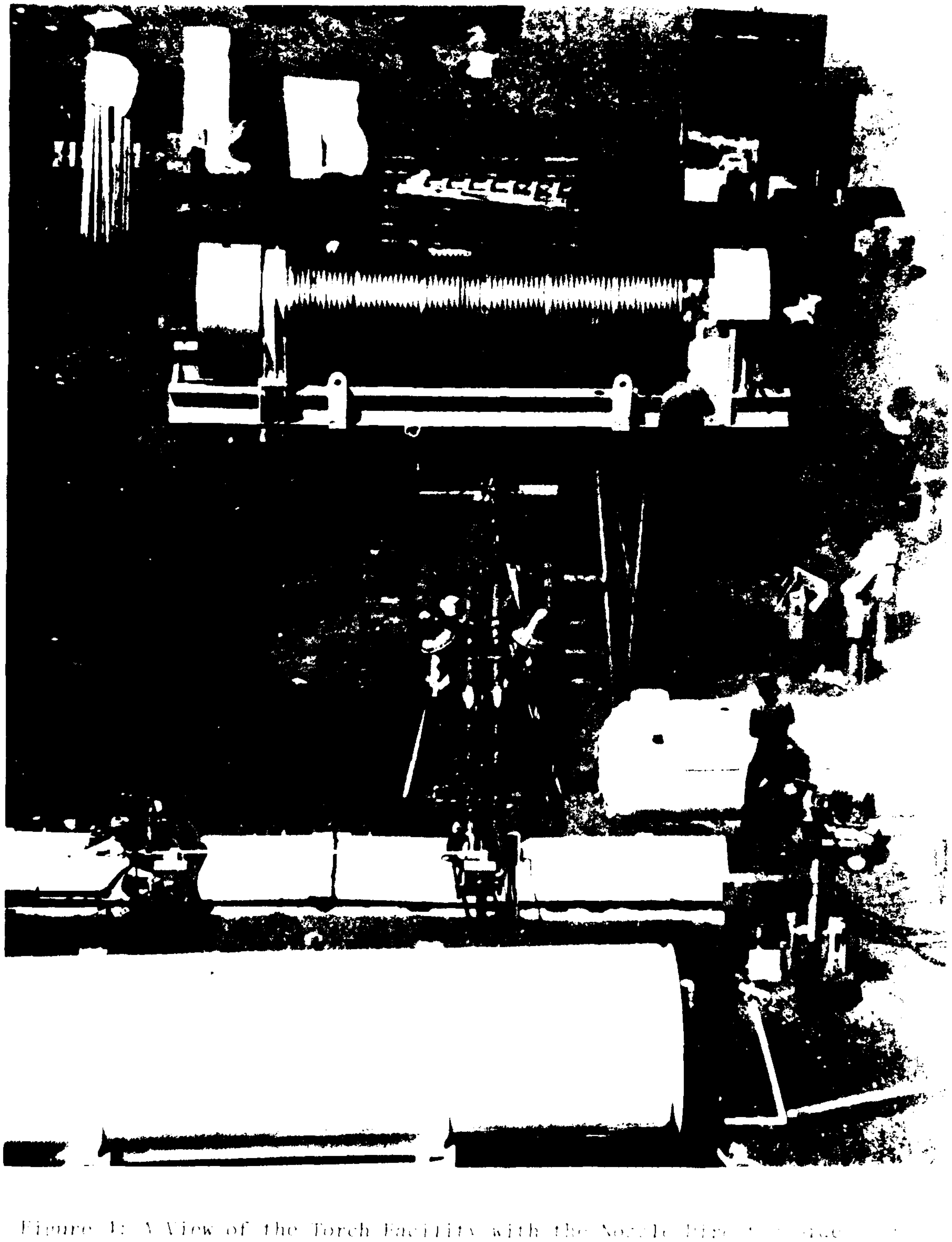

Figure 1: A View of the Torch Facility with the Nozzle Pipe [illegible] the HNPF Cask

TABLE 2: PROPANE TORCH TEST CONDITIONS

Parameters	Torch Fire Simulation	Pool Fire Simulation
Test Numbers	1, 2, 3, and 4	5
Distance From Torch Nozzle to Cask Surface	3.66 meters (12 feet)	6.10 meters (20 feet)
Torch Flame Temperature at Cask Surface	1204 ± 56 ^{o}C (2200 ± 100 ^{o}F)	871 ± 56 ^{o}C (1600 ± 100 ^{o}F)
Torch Flame Diameter	∿ 0.9144 meters (3 feet)	∿ 1.524 meters (5 feet)
Test Duration	30 minutes	100 minutes
Torch Flame Velocity	64.4 km/hr (40 mi/hr)	64.4 km/hr (40 mi/hr)

The pool fire simulation is a simulation of the condition where the tank car is engulfed in a large fire which is not as intense as the torch fire situation. In this case the nozzle of the torch is placed 6.10 meters (20 feet) from the surface of the cask. The temperature of the torch flame is 871 ± 56 °C (1600 ± 100 °F) and the diameter of the torch flame at the cask surface is approximately 1.524 meters (5 feet). The duration of a pool fire simulation test is 100 minutes.

The following types of data were recorded on nine track magnetic tape, Hewlett-Packard Flexible disk, and a terminal printer with samples from each sensor procured every 30 seconds: (1) temperatures for TCs mounted on the cask, (2) pressures for those tests where the NSJ contained water, (3) the ambient temperature, wind speed, and wind direction, and (5) the temperatures of the water bath and the propane as it passes through the orifice of the torch nozzle. The information included real time (hr/min/sec) at the beginning of each sample cycle.

These measurements are for recording essentially three aspects of the tests. Naturally, the temperatures of the flame at the surface of the cask, the temperatures of the TCs mounted on the cask, and the pressures measured in the NSJ are for the purpose of determining the survivability of the cask. The measurements of the ambient conditions are to record the effects of these conditions on the quality of the torch flame and to a lesser degree, the effects on the cask itself. The ambient temperature can be important for some kinds of tests being performed in cold weather, but was not an important factor in these tests although the measurements were recorded. The wind speed and direction are important since the flame can be blown away from the intended TIC and thus degrade the test. The facility has control devices which allows the operator to move the nozzle in order to compensate for the effects of the wind, but in the event the wind speed gets too high, even with this capability, the test has to be terminated. Finally, the temperature of the propane as it passes through the orifice of the nozzle must be at a certain level in order for proper combustion to be achieved. This temperature level is maintained by regulating the temperature of a water bath which surrounds a propane storage tank which directly supplies propane to the torch. Consequently, the temperature of the water bath and the propane at the orifice are usually monitored, but the orifice sensor was not connected in several of the HNPF Cask tests.

III. INSTRUMENTATION

The installation of the instrumentation for measuring physical parameters and the equipment for recording the data was a joint responsibility of SNL and BRL. SNL installed the thermocouples (TCs) and provided connections and wire for attachment of TC lead wires to the BRL reference junction. SNL was also responsible for checking the integrity of the installed TCs prior to attachment. BRL was responsible for recording the data measured by these TCs. The instrumentation for measuring the temperatures were Conax, Type K (Chromel Alumel) TCs. The TCs were attached on various surfaces between the main components of the cask and were designated by alphabetic characters. Each alphabetic character corresponds to a group of TCs attached to a specific surface. Figure 5 presents an overhead cross-sectional diagram of the cask where the various surfaces on which the TCs were attached are indicated. There were TCs designated by the symbol "F" mounted on the outside surface of the NSJ. The outside surface of the OSS had TCs designated with the symbol "B." On the inside of the ISS were TCs designated with symbols "A" and "C." Inside the NSJ were installed TCs designated with the symbol "G" for the purpose of measuring the water temperature. Also, on the outside surface of the impact limiter at the top end of the cask were TCs designated with the symbol "D" and directly on top of the cask lid were TCs designated with the symbol "E." There were other TCs with other designator symbols which will be discussed in later sections of the report. In addition to the TCs, there were two pressure gauges for measuring the pressure in the NSJ when it contained water. These are designated by the symbol "H." The two pressure gauges were Kulite Model HEM 375-250 psig piezoresistive transducers. There were additional data recorded such as wind direction and speed, etc. The sensors for these latter measurements were positioned by the BRL.

A summary of the sensor locations with respect to various reference values for the five HNPF Cask thermal experiments are presented in Tables 3 through 7 in order of the Fluke Channel Number. The test which utilized the greatest number of TCs and which was different from all of the others was Test Number 4. That was because in Test Number 4, the TIC was directed along the CC from the top end of the cask and temperature data on several cross-sectional surfaces were desired. These tables presents all of the TCs and their designators, including additional ones not discussed thus far. The so-called "Theoretical Locations" of the sensors are listed in terms of a radial distance of the surface on which the sensors were placed from the CC, the angular distance of the sensor from the ARP, and the axial distance from the XRP. In practice, it was not possible to place some of the sensors exactly in these locations, but any actual variations were slight. The last two columns of the tables consist of differences between the TIC locations and the location of each of the sensors. For those cases in which the differences are negative, the location of the sensors are differences between the TIC and the reference point value; otherwise, the sensor locations are on the opposite side of the TIC from the reference values. The angular distance for the TICs for Tests Number 1 and Number 2 was 90° and the value for Tests Number 3 and Number 5 was 270°. In the case of Test Number 4, the orientation was such that while it made sense to consider the angular distance to be 90°, the data must be interpreted differently

The technique used to attach the TCs to the inside surface of the ISS is illustrated in Figure 6. These spring-loaded TCs were mounted in an instrumentation frame and placed in the NWSV. As the instrumentation frame was inserted into the cavity, the spring-loaded thermocouples were depressed until their tips were aligned with the inner surface of the ISS. The insertion of the instrumentation frame and the associated spring-loaded TCs was performed carefully to avoid damage to the TCs. Once released, the spring-loaded TCs made good contact with the inner ISS surface.

The technique for attaching the TC sensors in the NSJ is illustrated in Figure 7. This attachment method involved welding stainless steel tubes to the surface of the OSS circumferentially. These tubes provided a means for isolating the spring-loaded sheathed TCs from the water in the NSJ.

The attachment of the sheathed TCs to selected portions of the NSJ's external surface was accomplished using the gasket design illustrated in Figure 8. In this attachment scheme, a threaded stud was first welded to the cask surface. Next, the gasket-type TC was bolted to the stud. This allowed easy

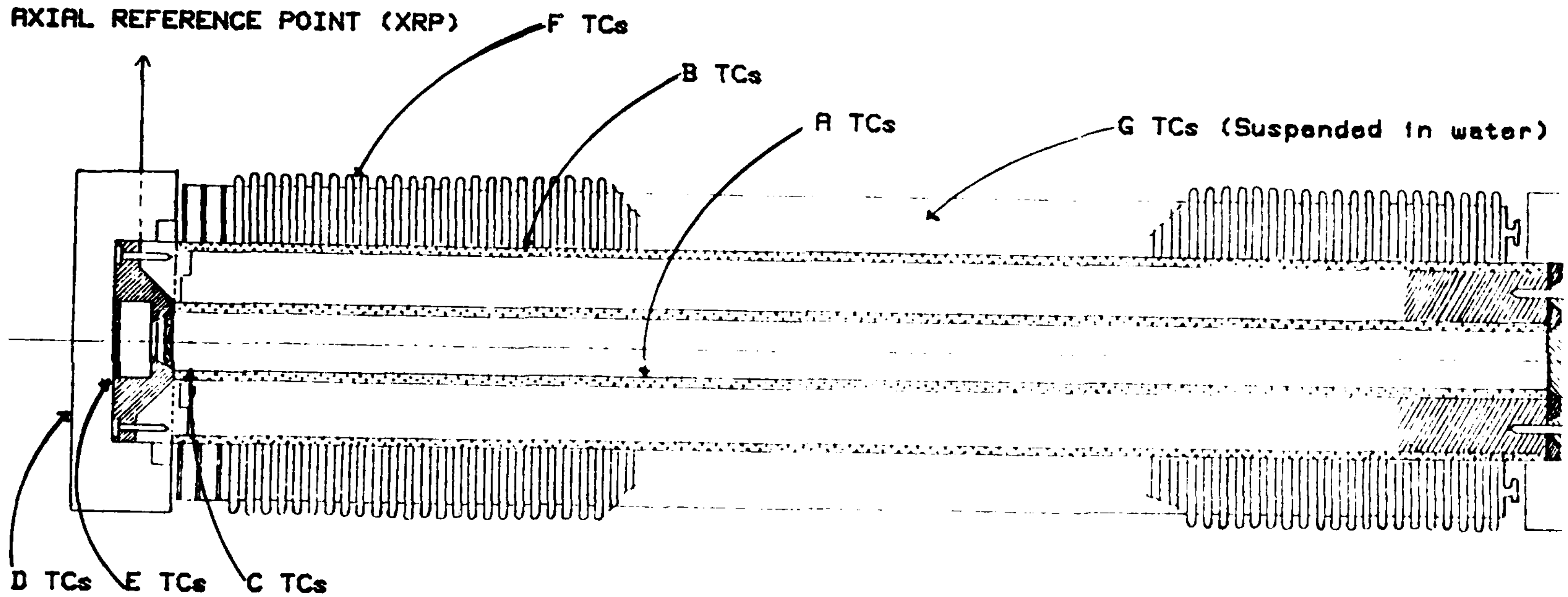

Figure 5: A Schematic of the HNPF Cask Showing the Surfaces on which Groups of Thermocouples were Located

TABLE 3: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 1

Angular Position: 90° from ARP; Axial Position: 289.6 cm from XRP
Neutron Shield Jacket Was Filled With Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
1	A1		23.2	90.0	93.3	0	-196.3
2	A2		23.2	62.1	93.3	27.9	-196.3
3	A3		23.2	117.9	93.3	-27.9	-196.3
4	A4	1	23.2	90.0	289.6	0	0
5	A5	2	23.2	62.1	289.6	27.9	0
6	A6	3	23.2	117.9	289.6	-27.9	0
7	B1		47.3	90.0	93.3	0	-196.3
8	B2		47.3	90.0	63.5	0	-226.1
9	B3		47.3	90.0	123.8	0	-165.8
10	B4	4	47.3	90.0	154.3	0	-135.3
11	B(5.1)		47.3	90.0	31.8	0	-257.8
12	B(5.2)		47.3	34.2	31.8	55.8	-257.8
13	B(5.3)		47.3	145.8	31.8	-55.8	-257.8
14	B6		47.3	62.1	93.3	27.9	-196.3
15	B7		47.3	34.2	93.3	55.8	-196.3
16	B8		47.3	117.9	93.3	-27.9	-196.3
17	B9		47.3	145.8	93.3	-55.8	-196.3
18	B10	5	47.3	90.0	289.6	0	0
19	B11	6	47.3	90.0	259.1	0	-30.5
20	B12	7	47.3	90.0	320.0	0	30.4
21	B13	8	47.3	90.0	350.5	0	60.9
22	B14	9	47.3	90.0	228.6	0	-6.1
23	B15	10	47.3	62.1	289.6	27.9	0
24	B16	11	47.3	34.2	289.6	55.8	0
25	B17	12	47.3	117.9	289.6	-27.9	0
26	B18	13	47.3	145.8	289.6	-55.8	0
27	C1		23.3	90.0	19.1	0	-270.5
28	C2		23.2	20.0	21.6	70.0	-268.0
29	C3		23.2	117.9	19.1	-27.9	-270.5
30	F1		73.7	90.0	93.3	0	-196.3
31	F2		70.5	90.0	62.2	0	-227.4
32	F3		73.7	90.0	123.8	0	-165.8
33	F4	14	73.7	90.0	154.3	0	-256.6
34	F5	15	70.5	90.0	33.0	0	-196.3
35	F6		73.7	62.1	93.3	27.9	196.3
36	F7		73.7	34.2	93.3	55.8	-196.3
37	F8		73.7	117.9	93.3	-27.9	-196.3
38	F9		73.7	145.8	93.3	-55.8	-196.3
39	F10	16	73.7	90.0	289.6	0	0
40	F11	17	73.7	90.0	259.1	0	-30.5
41	F12	18	73.7	90.0	320.0	0	30.4
42	F13	19	73.7	90.0	350.5	0	60.9
43	F14	20	73.7	90.0	228.6	0	-61.0

TABLE 3: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 1
(Continued)

Angular Position: 90° from ARP; Axial Position 289.6 cm from XRP
Neutron Shield Jacket Was Filled With Water

Fluke Channel Number	Sensor* Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
44	F15	21	73.7	62.1	289.6	27.9	0
45	F16	22	73.7	34.2	289.6	55.8	0
46	F17	23	73.7	117.9	289.6	-27.9	0
47	F18	24	73.7	145.8	289.6	-55.8	0
48	F27	25	73.7	325.8	289.6	-235.8	0
49	G1	26	58.1	90.0	93.3	0	-196.3
50	G2	27	58.1	90.0	289.6	0	0
51	G3	28	58.1	270.0	289.6	-180.0	0
52	G4	29	58.1	270.0	522.6	-180.0	233.0
53	H1		70.5	270.0	55.2	-180.0	-234.4
54	H2	30	61.0	270.0	522.6	-180.0	233.0
55	Water Bath Temperature						
56	Torch Flame Temperature (FACL)**						
57	Wind Speed						
58	Wind Direction						
59	Ambient Air Temperature						

* *Orifice sensor was not connected during this test.*

** FACL *is located in the flame near the surface of the cask and on the torch centerline.*

TABLE 4: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 2

Angular Position: 90° from ARP; Axial Position: 93.3 cm from XRP
Neutron Shield Jacket Was Filled Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
1	A1		23.2	90.0	93.3	0	0
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3	A3		23.2	117.9	93.3	-27.9	0
4	A4	1	23.2	90.0	289.6	0	196.3
5	A5	2	23.2	62.1	289.6	27.9	196.3
6	A6	3	23.2	117.9	289.6	-27.9	196.3
7	B1		47.3	90.0	93.3	0	0
8	B2		47.3	90.0	63.5	0	-29.8
9	B3		47.3	90.0	123.8	0	30.5
10	B4	4	47.3	90.0	154.3	0	61.0
11	B(5.1)		47.3	90.0	31.8	0	-61.5
12	B(5.2)		47.3	34.2	31.8	55.8	-61.5
13	B(5.3)		47.3	145.8	31.8	-55.8	-61.5
14	B6		47.3	62.1	93.3	27.9	0
15	B7		47.3	34.2	93.3	55.8	0
16	B8		47.3	117.9	93.3	-27.9	0
17	B9		47.3	145.8	93.3	-55.8	0
18	B10	5	47.3	90.0	289.6	0	196.3
19	B11	6	47.3	90.0	259.1	0	165.8
20	B12	7	47.3	90.0	320.0	0	226.7
21	B13	8	47.3	90.0	350.5	0	257.2
22	B14	9	47.3	90.0	228.6	0	135.3
23	B15	10	47.3	62.1	289.6	27.9	196.3
24	B16	11	47.3	34.2	289.6	55.8	196.3
25	B17	12	47.3	117.9	289.6	-27.9	196.3
26	B18	13	47.3	145.8	289.6	-55.8	196.3
27	C1		23.2	90.0	19.1	0	-74.2
28	C2		23.2	20.0	21.6	70.0	-71.7
29	C3		23.2	117.9	19.1	-27.9	-74.2
30	F1		73.7	90.0	93.3	0	0
31	F2		70.5	90.0	62.2	0	-31.1
32	F3		73.7	90.0	123.8	0	30.5
33	F4	14	73.7	90.0	154.3	0	61.0
34	F5	15	70.5	90.0	33.0	0	-60.3
35	F6		73.7	62.1	93.3	27.9	0
36	F7		73.7	34.2	93.3	55.8	0
37	F8		73.7	117.9	93.3	-27.9	0
38	F9		73.7	145.8	93.3	-55.8	0
39	F10	16	73.7	90.0	289.6	0	196.3
40	F11	17	73.7	90.0	259.1	0	165.8
41	F12	18	73.7	90.0	320.0	0	226.7
42	F13	19	73.7	90.0	350.5	0	257.2
43	F14	20	73.7	90.0	228.6	0	135.3

TABLE 4: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 2
(Continued)

Angular Position: 90° from ARP; Axial Position: 93.3 cm from XRP
Neutron Shield Jacket Was Filled With Water

Fluke Channel Number	Sensor* Number	CRT Channel Number	Theoretical Locations Radius (cm)	Angle (Degrees)	Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Axial (cm)
44	F15	21	73.7	62.1	289.6	27.9	196.3
45	F16	22	73.7	34.2	289.6	55.8	196.3
46	F17	23	73.7	117.9	289.6	-27.9	196.3
47	F18	24	73.7	145.8	289.6	-55.8	196.3
48	F27	25	73.7	325.8	289.6	-235.8	196.3
49	G1	26	58.1	90.0	93.3	0	0
50	G2	27	58.1	90.0	289.6	0	196.3
51	G3	28	58.1	270.0	289.6	-180.0	196.3
52	G4	29	58.1	270.0	522.6	-180.0	429.3
53	H1		70.5	270.0	55.2	-180.0	-38.1
54	H2	30	61.0	270.0	522.6	-180.0	429.3
55	Water Bath Temperature						
56	Torch Flame Temperature (FACL)**						
57	Wind Speed						
58	Wind Direction						
59	Ambient Air Temperature						

* Orifice sensor was not connected during this test.

** FACL is located in the flame near the surface of the cask and on the torch centerline.

TABLE 5: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 3

Angular Position: 270° from ARP; Axial Position: 289.6 cm from XRP
Neutron Shield Jacket Was Void of Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Angle (Degrees)	Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Axial (cm)
1	A7	1	23.2	270.0	289.6	-180.0	0
2	A8	2	23.2	242.1	289.6	-152.1	0
3	A9	3	23.2	297.9	289.6	-207.9	0
4	B10		47.3	90.0	289.6	0	0
5	B11		47.3	90.0	259.1	0	-30.5
6	B12		47.3	90.0	320.0	0	30.4
7	B13		47.3	90.0	350.5	0	60.9
8	B14		47.3	90.0	228.6	0	-61.0
9	B15	4	47.3	62.1	289.6	27.9	0
10	B16	5	47.3	34.2	289.6	55.8	0
11	B17	6	47.3	117.9	289.6	-27.9	0
12	B18	7	47.3	145.8	289.6	-55.8	0
13	B19	8	47.3	270.0	289.6	-180.0	0
14	B20	9	47.3	270.0	259.1	-180.0	-30.5
15	B21	10	47.3	270.0	320.0	-180.0	30.4
16	B22	11	47.3	270.0	350.5	-180.0	60.9
17	B23	12	47.3	270.0	228.6	-180.0	-61.0
18	B24	13	47.3	242.1	289.6	-152.1	0
19	B25	14	47.3	214.2	289.6	-124.2	0
20	B26	15	47.3	297.9	289.6	-207.9	0
21	B27	16	47.3	325.8	289.6	-235.8	0
22	C2		23.2	20.0	21.6	70.0	-268.0
23	F10		73.7	90.0	289.6	0	0
24	F11		73.7	90.0	259.1	0	-30.5
25	F12	17	73.7	90.0	320.0	0	30.4
26	F13	18	73.7	90.0	350.5	0	60.9
27	F14	19	73.7	90.0	228.6	0	-61.0
28	F15	20	73.7	62.1	289.6	27.9	0
29	F16	21	73.7	34.2	289.6	55.8	0
30	F17	22	73.7	117.9	289.6	-27.9	0
31	F18	23	73.7	145.8	289.6	-55.8	0
32	F19	24	73.7	270.0	289.6	-180.0	0
33	F20	25	73.7	270.0	259.1	-180.0	-30.5
34	F21	26	73.7	270.0	320.0	-180.0	30.4
35	F22	27	73.7	270.0	350.5	-180.0	60.9
36	F23		73.7	270.0	228.6	-180.0	-61.0
37	F24		73.7	242.1	289.6	-152.1	0
38	F25		73.7	214.2	289.6	-124.2	0
39	F26		73.7	297.9	289.6	-207.9	0
40	F27		73.7	325.8	289.6	-235.8	0
41	G1		58.1	90.0	93.3	0	-196.3
42	G2	28	58.1	90.0	289.6	0	0
43	G3	29	58.1	270.0	289.6	-180.0	0

TABLE 5: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 3
(Continued)

Angular Position: 270° from ARP; Axial Position: 289.6 cm from XRP
Neutron Shield Jacket Was Void of Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Angle (Degrees)	Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Axial (cm)
44	G4	30	58.1	270.0	522.6	-180.0	233.0
45	FF23H		78.8	270.0	228.6	-180.0	-61.0
46	Orifice Temperature						
47	F1		73.7	90.0	93.3	0	-196.3
48	F3		73.7	90.0	123.8	0	-165.8
49	F4		73.7	90.0	154.3	0	-135.3
50	FF24T		78.8	242.1	289.6	-152.1	0
51	FF26B		78.8	297.9	289.6	-207.9	0
52	Not Used						
53	Not Used						
54	Not Used						
55	Water Bath Temperature						
56	Torch Flame Temperature (FACL)*						
57	Wind Speed						
58	Wind Direction						
59	Ambient Air Temperature						

* FACL is located in the flame near the surface of the cask and on the torch centerline.

TABLE 6: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 4

Angular Position: Center Line on Limiter*: Axial Position: -60 cm from XPR
Neutron Shield Jacket Was Void of Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Angle (Degrees)	Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Axial (cm)
1	B(5.1)	1	47.3	90.0	31.8	***	91.8
2	B(5.2)	2	47.3	34.2	31.8	***	91.8
3	B(5.3)	3	47.3	145.8	31.8	***	91.8
4	C1	4	23.2	90.0	19.1	***	79.1
5	C2	5	23.2	20.0	21.6	***	81.6
6	C3	6	23.2	117.9	19.1	***	79.1
7	D1	7	0	0	-60.0	***	0
8	D2	8	30.6	0	-60.0	***	0
9	D3	9	61.0	0	-60.0	***	0
10	D4	10	30.5	90.0	-60.0	***	0
11	D5	11	61.0	90.0	-60.0	***	0
12	D6	12	30.5	180.0	-60.0	***	0
13	D7	13	61.0	180.0	-60.0	***	0
14	D8	14	30.5	270.0	-60.0	***	0
15	D9	15	61.0	270.0	-60.0	***	0
16	E1	16	0	0	-19.0	***	41.0
17	E2	17	56.2	180.0	-19.0	***	41.0
18	F5	18	70.5	90.0	33.0	***	93.0
19	G1	19	58.1	90.0	93.3	***	153.3
20	G2	20	58.1	90.0	289.6	***	349.6
21	G3	21	58.1	270.0	289.6	***	349.6
22	G4	22	58.1	270.0	522.6	***	582.6
23	FD1 (FACL)**		0	0	-65.1	***	5.1
24	FD15		15.2	0	-65.1	***	5.1
25	FD2		30.5	0	-65.1	***	5.1
26	FD25		45.7	0	-65.1	***	5.1
27	FD3		61.0	0	-65.1	***	5.1
28	FD35		76.2	0	-65.1	***	5.1
29	FD55		15.2	180.0	-65.1	***	5.1
30	FD6		30.5	180.0	-65.1	***	5.1
31	FD65		45.7	180.0	-65.1	***	5.1
32	FD7		61.0	180.0	-65.1	***	5.1
33	FD75		76.2	180.0	-65.1	***	5.1
34	FD4		30.5	90.0	-65.1	***	5.1
35	FD5		61.0	90.0	-65.1	***	5.1
36	FD8		30.5	270.0	-65.1	***	5.1
37	FD9		61.0	270.0	-65.1	***	5.1
38	ST1		0	0	-62.5	***	2.5
39	ST4		30.5	90.0	-62.5	***	2.5
40	ST5		61.0	90.0	-62.5	***	2.5
41	ST8		30.5	270.0	-62.5	***	2.5
42	ST9		61.0	270.0	-62.5	***	2.5
43	Orifice Temperature						

TABLE 6: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 4
(Continued)

Angular Position: Center Line on Limiter. Axial Position: -60 cm from XRP
Neutron Shield Jacket Was Void of Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
44	Not Used						
45	Not Used						
46	Not Used						
47	Not Used						
48	Not Used						
49	Not Used						
50	Not Used						
51	Not Used						
52	Not Used						
53	Not Used						
54	Not Used						
55	Water Bath Temperature						
56	Not Used						
57	Wind Speed						
58	Wind Direction						
59	Ambient Air Temperature						

* *This test is geometrically different from the others in that the torch impingment was onto the end of and along the centerline of the cask. Therefore, the TIC is located at the end of the cask and -60 cm from the XRP.*

** *FACL is located in the flame near the surface of the cask and on the torch centerline. The remaining FD TCs are also in the flame near the surface of the cask but off the torch centerline.*

*** *This angle is undefined in these data since the torch flame impinged onto the end of the cask.*

TABLE 7: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 5

Angular Position: 270° from ARP; Axial Position: 93.3 cm from XRP
Neutron Shield Jacket Was Filled With Water

Fluke Channel Number	Sensor Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
1	FP1		73.7	270.0	93.3	0	0
2	FP2		73.7	293.9	93.3	-23.9	0
3	FP3		73.7	317.8	93.3	-47.8	0
4	FP4		73.7	270.0	62.2	0	-31.1
5	FP5		73.7	270.0	31.8	0	-61.5
6	FP6		73.7	246.1	93.3	23.9	0
7	FP7		73.7	222.2	93.3	47.8	0
8	FP8		73.7	270.0	123.8	0	30.5
9	FP9		73.7	270.0	154.3	0	61.0
10	FF1 (FACL)*		76.2	270.0	93.3	0	0
11	FF15		76.2	282.0	93.3	-12.0	0
12	FF2		76.2	293.9	93.3	-23.9	0
13	FF25		76.2	305.9	93.3	-35.9	0
14	FF3		76.2	317.8	93.3	-47.8	0
15	FF35		76.2	270.0	78.1	0	-15.2
16	FF4		76.2	270.0	62.2	0	-31.1
17	FF5		76.2	270.0	31.8	0	-61.5
18	FF55		76.2	258.0	93.3	12.0	0
19	FF6		76.2	246.1	93.3	23.9	0
20	FF65		76.2	234.2	93.3	35.8	0
21	FF7		76.2	222.2	93.3	47.8	0
22	FF75		76.2	270.0	108.5	0	15.2
23	FF8		76.2	270.0	123.8	0	30.5
24	FF9		76.2	270.0	154.3	0	61.0
25	F1		73.7	90.0	93.3	180.0	0
26	F3		73.7	90.0	123.8	180.0	30.5
27	F4		73.7	90.0	154.3	180.0	61.0
28	F5		70.5	90.0	33.0	180.0	-60.3
29	F6		73.7	62.1	93.3	207.9	0
30	F7		73.7	34.2	93.3	235.8	0
31	F8		73.7	117.9	93.3	102.1	0
32	Not Used						
33	Not Used						
34	Not Used						
35	Not Used						
36	F20		73.7	270.0	259.1	0	165.8
37	F21		73.7	270.0	320.0	0	226.7
38	F22		73.7	270.0	350.5	0	257.2
39	F23		73.7	270.0	228.6	0	135.3
40	B20		47.3	270.0	259.1	0	165.8
41	B21		47.3	270.0	320.0	0	226.7
42	B22		47.3	270.0	350.5	0	257.2
43	B23		47.3	270.0	228.6	0	135.3

TABLE 7: RECORDING CHANNEL ASSIGNMENTS FOR TEST NUMBER 5
(Continued)

Angular Position: 270° from ARP; Axial Position: 93.3 cm from XRP
Neutron Shield Jacket Was Filled With Water

Fluke Channel Number	Sensor** Number	CRT Channel Number	Theoretical Locations Radius (cm)	Theoretical Locations Angle (Degrees)	Theoretical Locations Axial (cm)	Difference From Torch Center (TIC) Angle (Degrees)	Difference From Torch Center (TIC) Axial (cm)
44	B1		47.3	90.0	93.3	180.0	0
45	B6		47.3	62.1	93.3	207.9	0
46	B7		47.3	34.2	93.3	235.8	0
47	B8		47.3	117.9	93.3	102.1	0
48	B9		47.3	145.8	93.3	124.2	0
49	C1		23.2	90.0	19.1	180.0	-74.2
50	C2		23.2	20.0	21.6	250.0	-71.7
51	C3		23.2	117.9	19.1	102.1	-34.2
52	A1		23.2	90.0	93.3	180.0	0
53	A2		23.2	62.1	93.3	207.9	0
54	A3		23.2	117.9	93.3	102.1	0
55	Water Bath Temperature						
56	Not Used						
57	Wind Speed						
58	Wind Direction						
59	Ambient Air Temperature						

* FACL is located in the flame near the surface of the cask and on the torch centerline. The remaining FF TCs are also in the flame near the surface of the cask but off the torch centerline.

** Orifice sensor was not connected during this test.

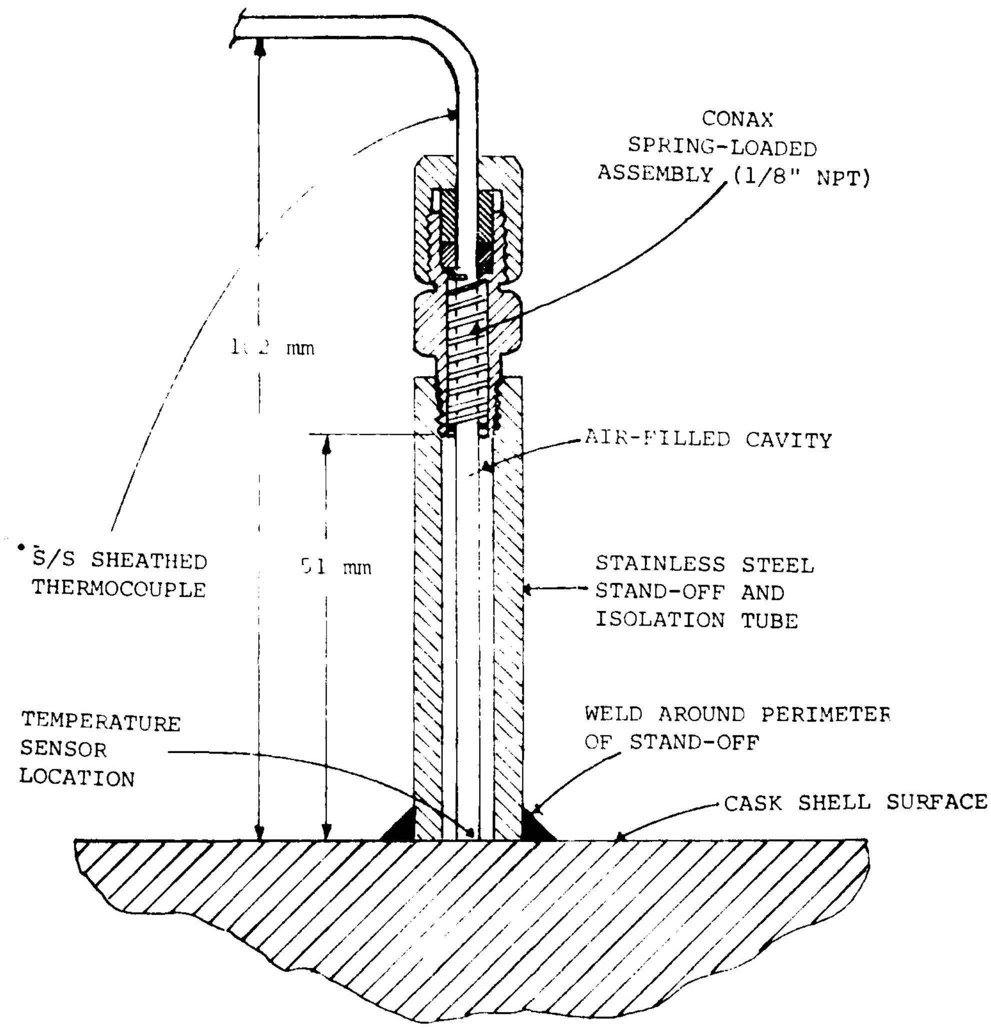

Figure 6: The Thermocouple (TC) Attachment Technique for the Inner Shell Surface (ISS)

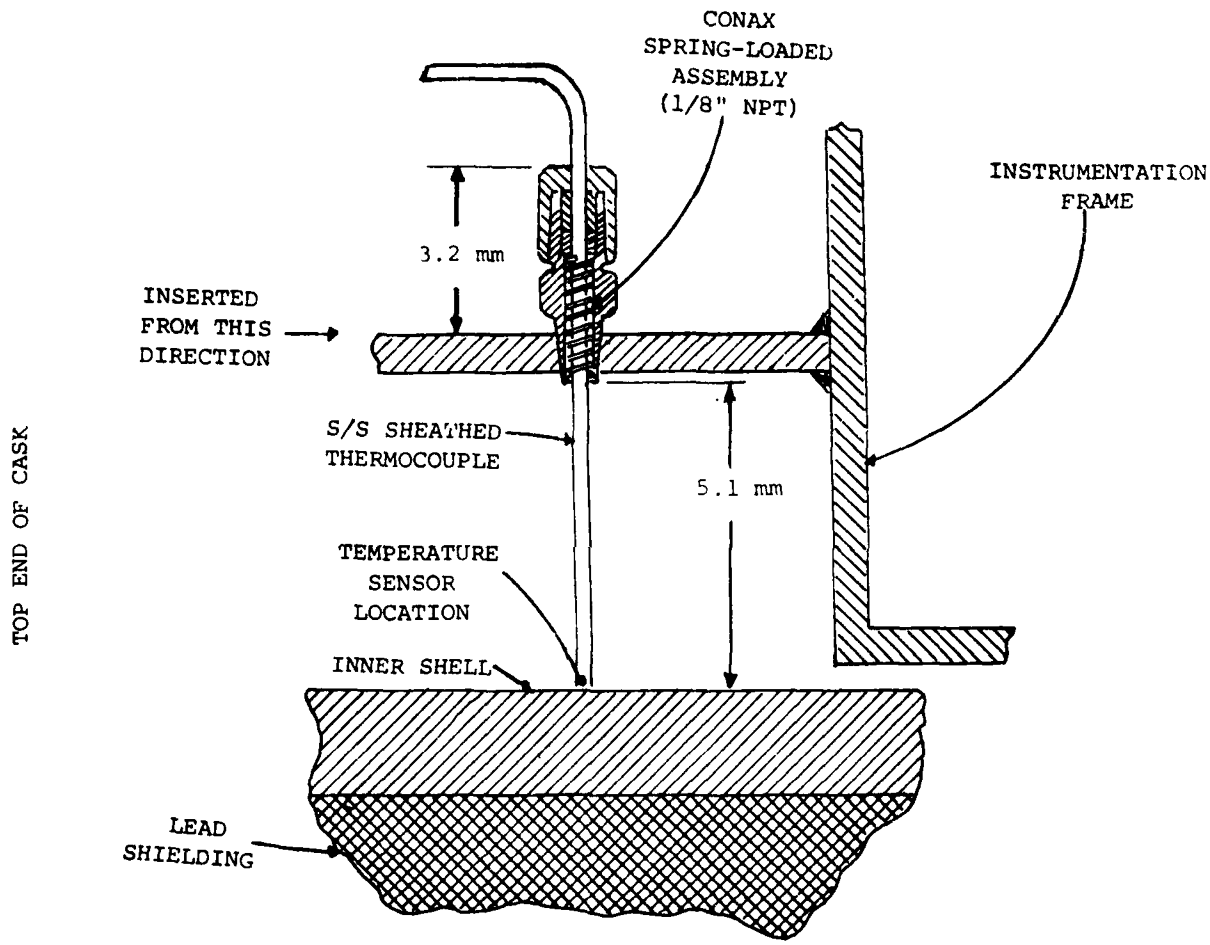

Figure 7: The Thermocouple (TC) Attachment Technique for the Outer Shell Surface (OSS)

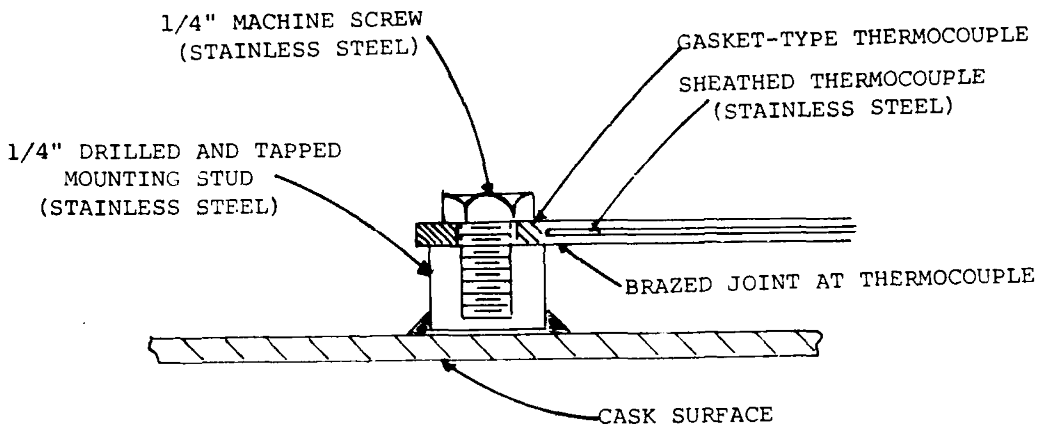

Figure 8: The Thermocouple (TC) Attachment Technique for the External Regions of the HNPF Cask not Exposed to Direct Torch Flames

attachment and removal of TCs in regions of the cask not directly exposed to torch flames and high heat fluxes.

The attachment of TCs in the regions of the cask directly exposed to torch flames required that the sensors be in good thermal contact with the surface whose temperature was being measured. The recommended procedure was to use sheathed TCs with stainless steel tabs pre-welded to the tip region of the TC as illustrated in Figure 9. These tabs prevented "burn through" of the sheathed TC during welding. When the cask surface material was different from inconel, which was required for the sheath, the temperatures required during welding exceeded 2000 ^{o}F.

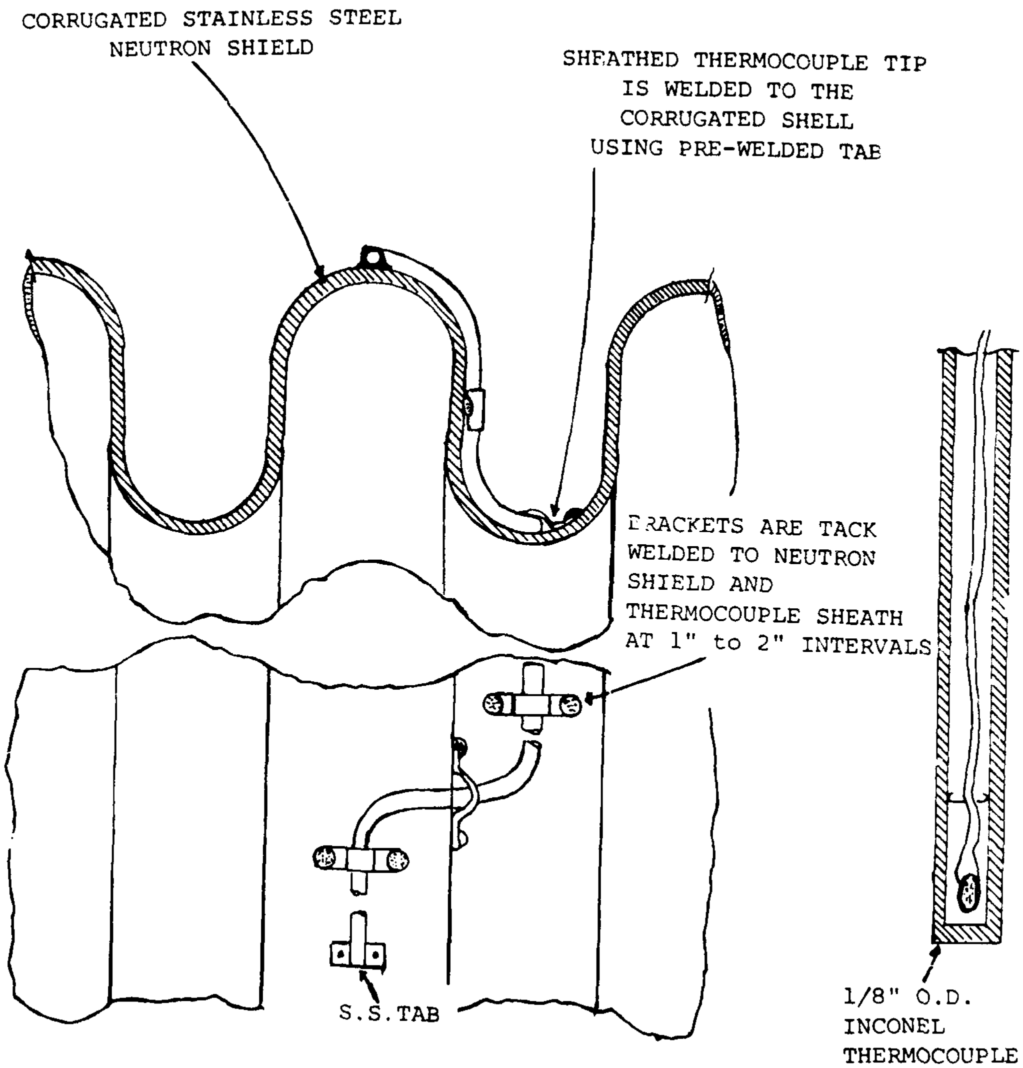

Figure 9: The Thermocouple (TC) Attachment Technique for the Corrugated Surface of the Neutron Shield Jacket (NSJ) of the HNPF Cask

IV. DESCRIPTION OF TEST NUMBER 1

In the first test the torch flame impinged the HNPF Cask on a side; thus, the TIC was located at 90° to the ARP. The axial distance of the TIC from the XRP was 289.6 cm (114 inches). The distance between the torch nozzle and the surface of the NSJ was 366 cm (12 feet) and the test was conducted over a period of 30 minutes; thus, the test was intended to be a torch fire simulation as defined in HM 144. The NSJ was filled with water, so this test was expected to be one of the least severe in terms of potential damage to the cask's internal components. A view of the torch flame impingement on the cask during Test Number 1 is presented in Figure 10.

The data describing physical parameters which constituted the environmental conditions during the experiment are presented in Figures 11 through 14. The wind direction did not change during the test as shown in Figure 11. The wind speed, shown in Figure 12, varied slightly. The water bath, which maintained an appropriate temperature of the propane just before it passes through the orifice of the torch, was set initially at 64 °C and then allowed to drop slowly during the test. (See Figure 13.) Also shown is the ambient temperature, which remained steady at 17 °C. The temperature of the flame of the torch as a function of time is presented in Figure 14. The average temperature was approximately 1100 °C (2000 °F), which was approximately 100 °F below the acceptable range cited in HM-144. However, for the purpose of these tests, this slight variation from the requirements of HM-144 was not considered significant. The 30-minute cut-off of the torch is indicated by the sharp drop in the curve, but the sensor values did not fall instantly to ambient following extinguishment of the torch because the cask continued to radiate heat for awhile until it cooled.

A schematic which shows the relative axial positions of the TCs with respect to the XRP and the TIC for Test Number 1 is presented in Figure 15. The arrows pointing downward to the various lines indicate the positions of the TCs, and the numerical designations are noted above the appropriate arrow. On the left side of the schematic are noted the various cask surfaces the lines represent. In those cases where more than one numerical designation **is** noted, several TCs are distributed in a cross-sectional plane at the axial position where the arrow is positioned. For example, Figure 16 presents a schematic which shows the angular positions of the TCs relative to the ARP at the axial position of 289.6 cm (114 inches) from the XRP. In the same figure, the TIC is shown to be at 90°. As shown, the TCs are positioned in the same angular values from one surface to another. These types of schematics are used throughout the remainder of the report to assist in discussing the temperature data.

The data which describe the variations of the temperature as functions of time for the TCs positioned on the exterior surface of the NSJ are presented in Figures 17, 18, 20, and 21. Figure 17 presents the temperature profiles for the group of TCs which were positioned at the same cross-sectional angle as the TIC (90°), but which were distributed about the TIC in the axial direction as shown in Figure 15. The peak value of F10 was approximately 340 °C, but the peak values of the **surrounding** TCs were in the neighborhood of 420 °C. Since F10 was positioned in the middle, these values indicate that the torch flame was cooler near its center.

Figure 18 presents the temperatures measured by the group of F TCs which were in the same axial cross-sectional plane which contained the TIC, but which were distributed at angles above and below the TIC position. (See Figure 16.)

Figure 10: A View of the HNPF Cask Taken During Torch Thermal Test Number 1.

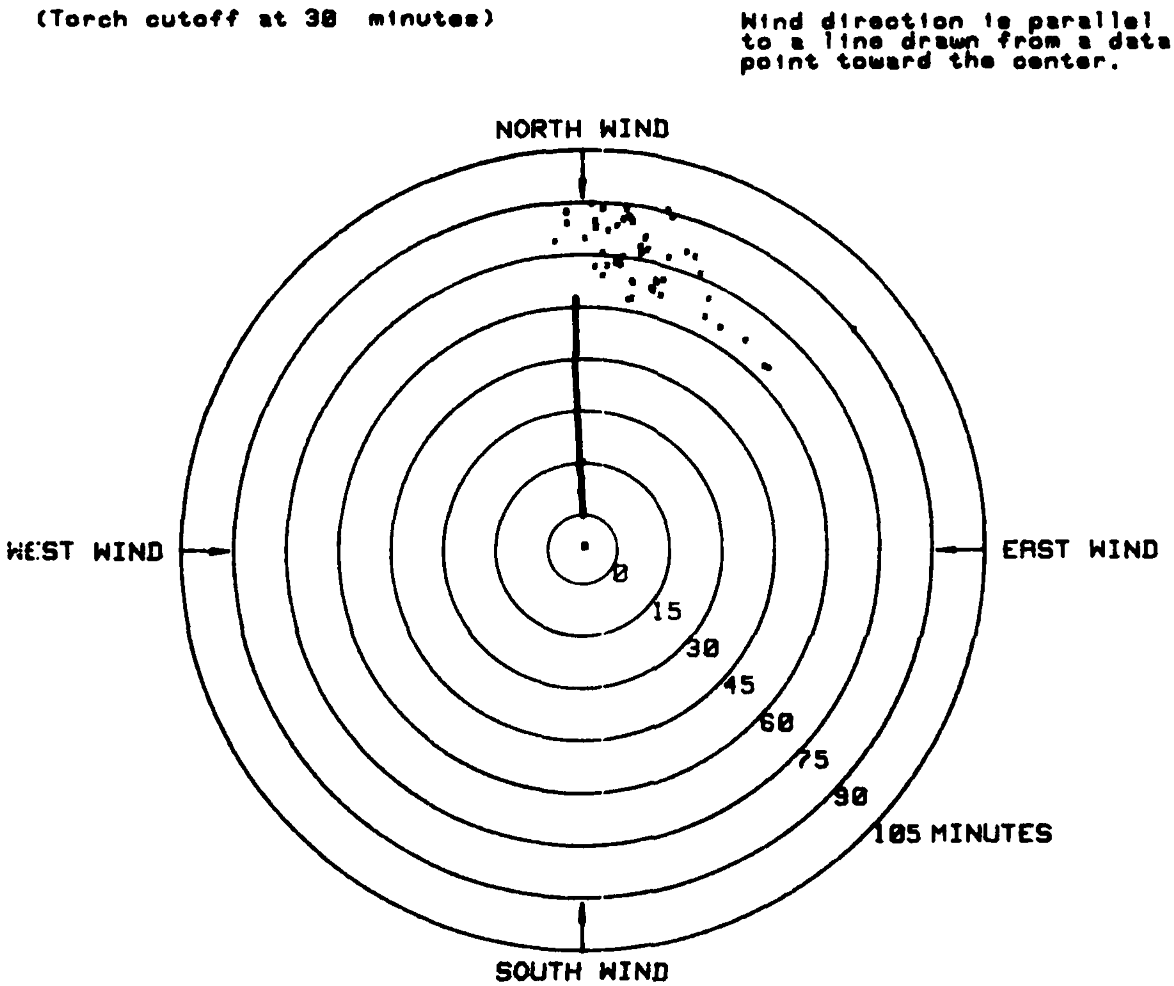

Figure 11: The Wind Direction as a Function of Time During the HNPF Cask Thermal Test Number 1

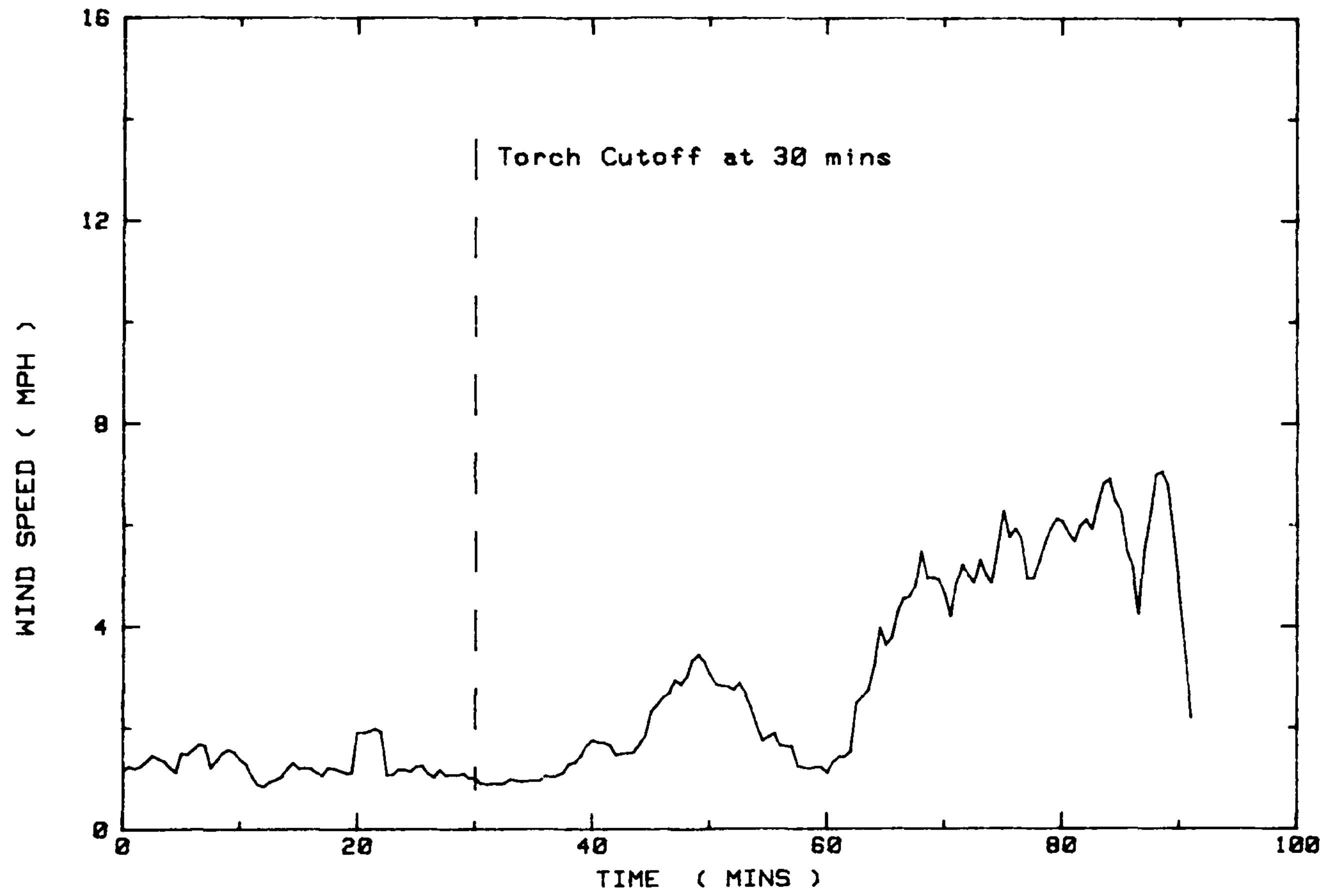

Figure 12: The Wind Speed as a Function of Time During the HNPF Cask Thermal Test Number 1

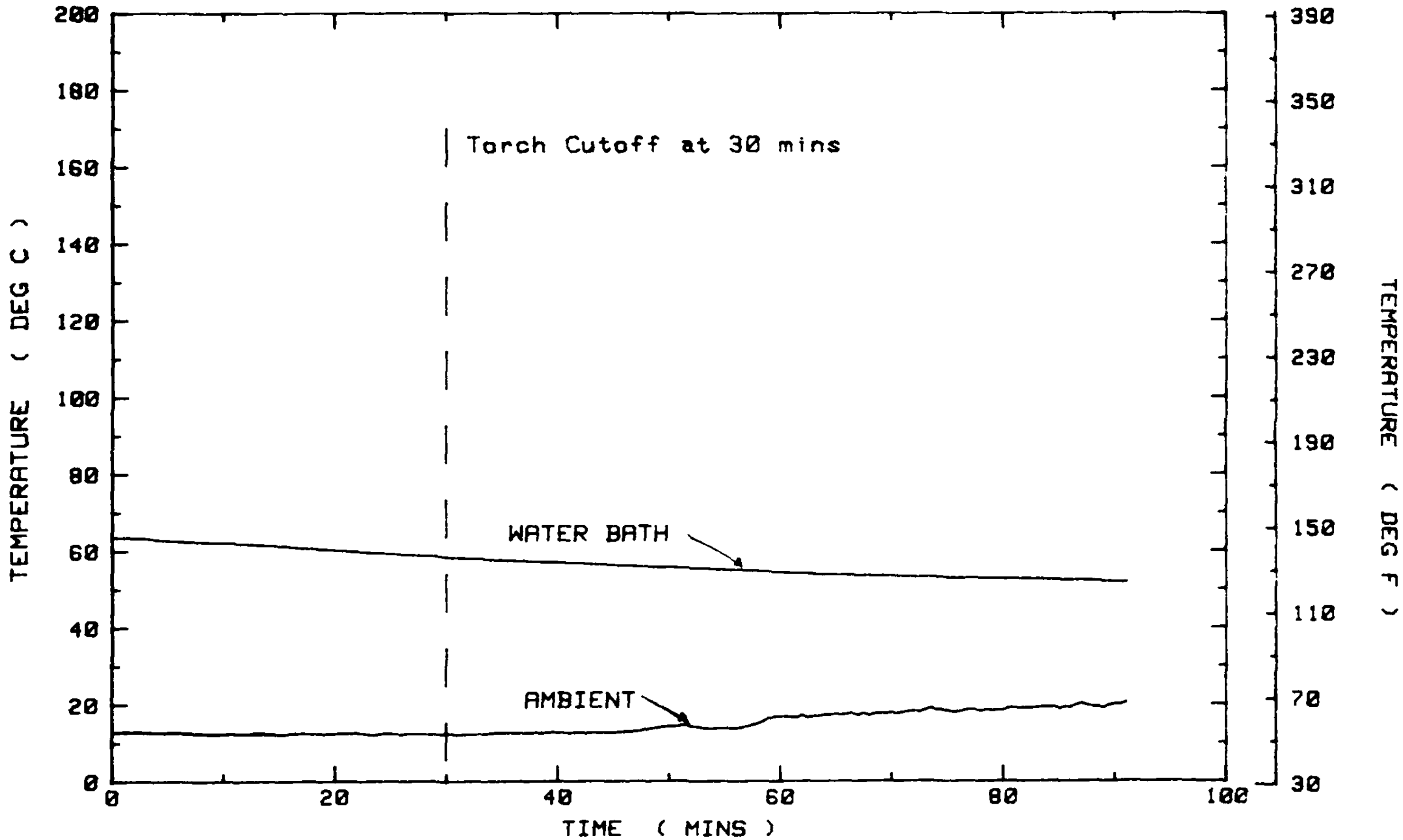

Figure 13: The Ambient and the Water Bath Temperatures as Functions of Time During the HNPF Cask Test Number 1

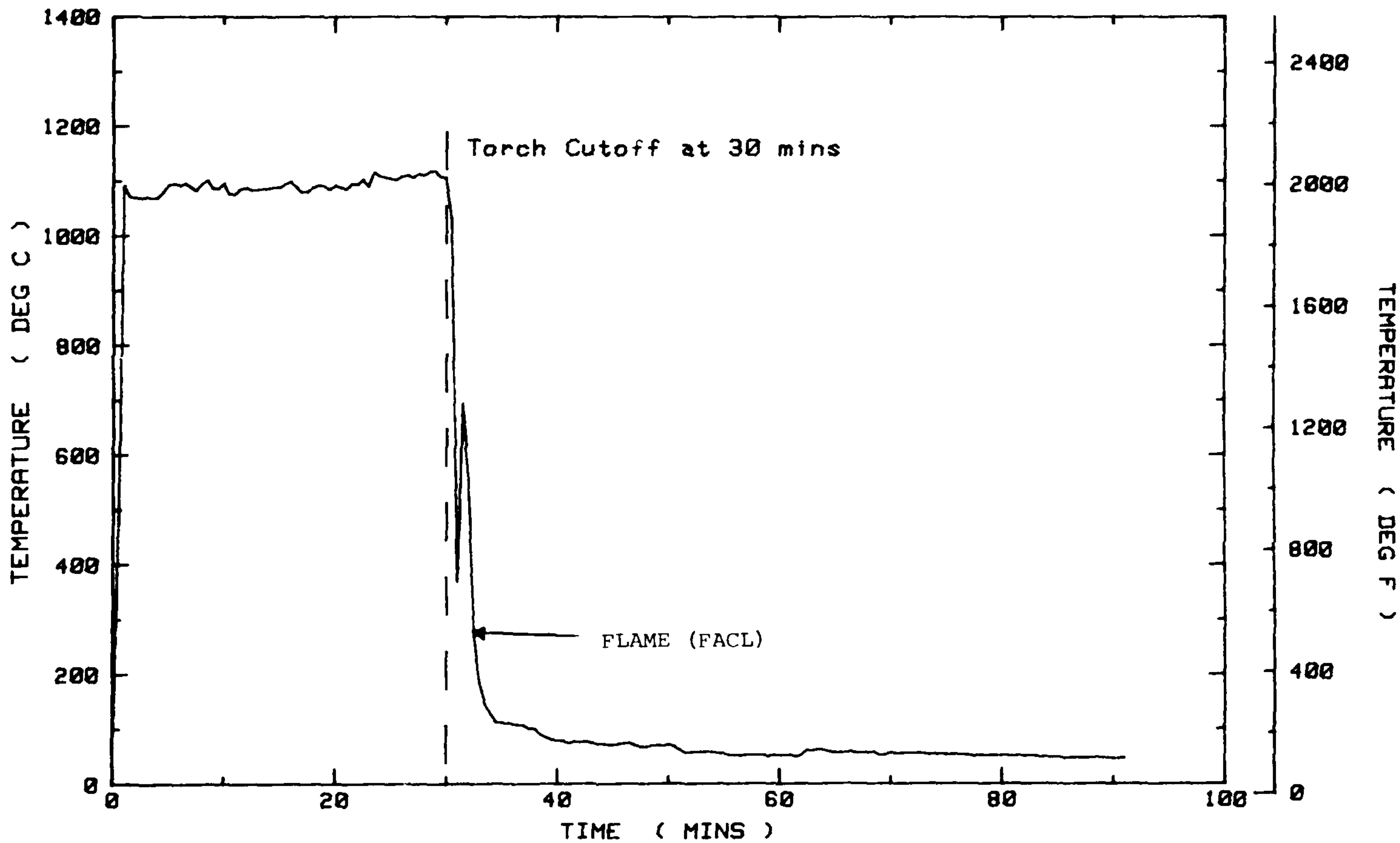

Figure 14: The Flame Temperature of the Propane Torch as a Function of Time During the HNPF Cask Test Number 1

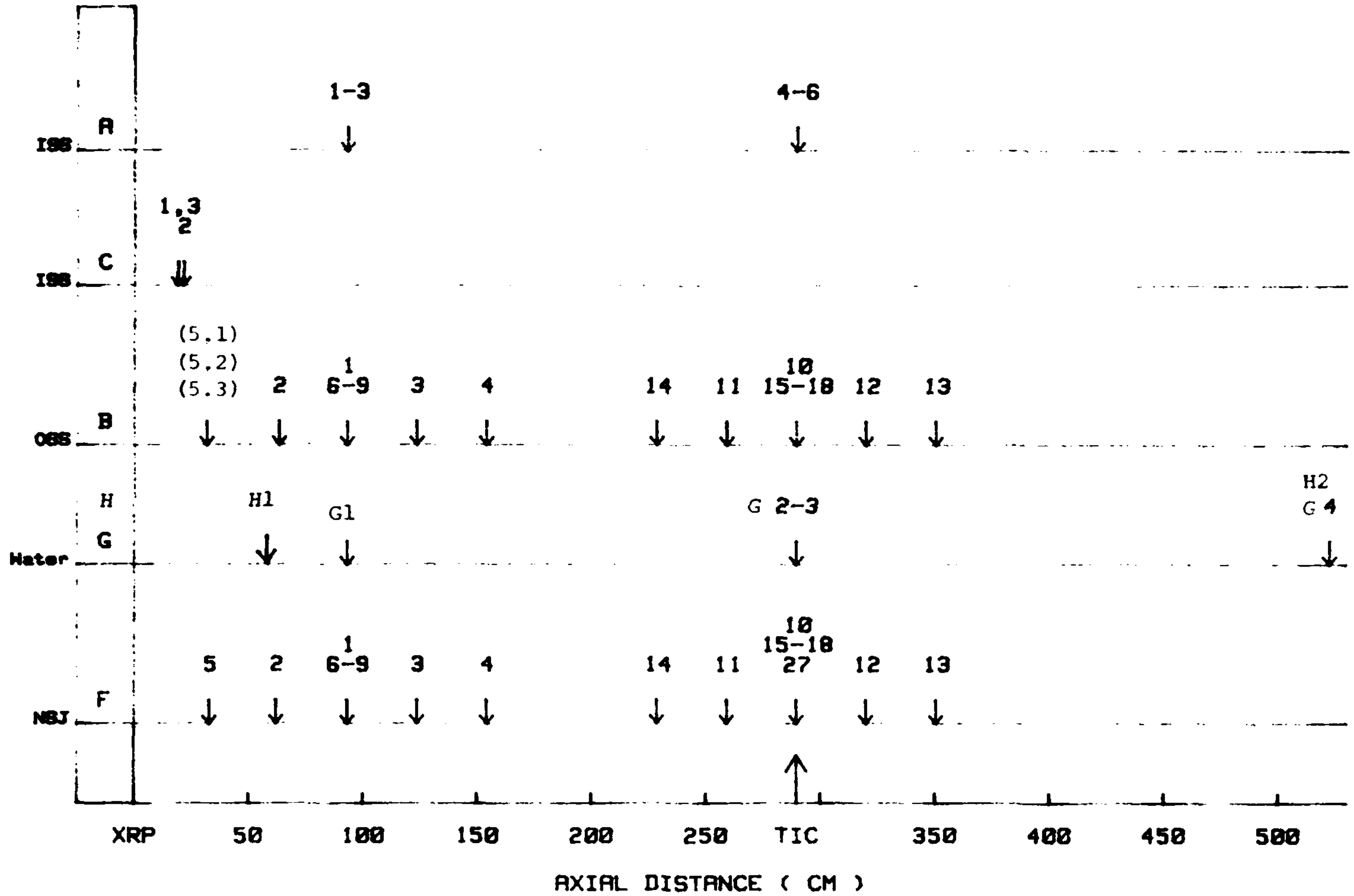

Figure 15: Axial Locations of Sensors Relative to the XRP and the TIC for Various HNPF Cask Surfaces in Test Number 1

TIC -- TORCH IMPINGEMENT CENTER
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

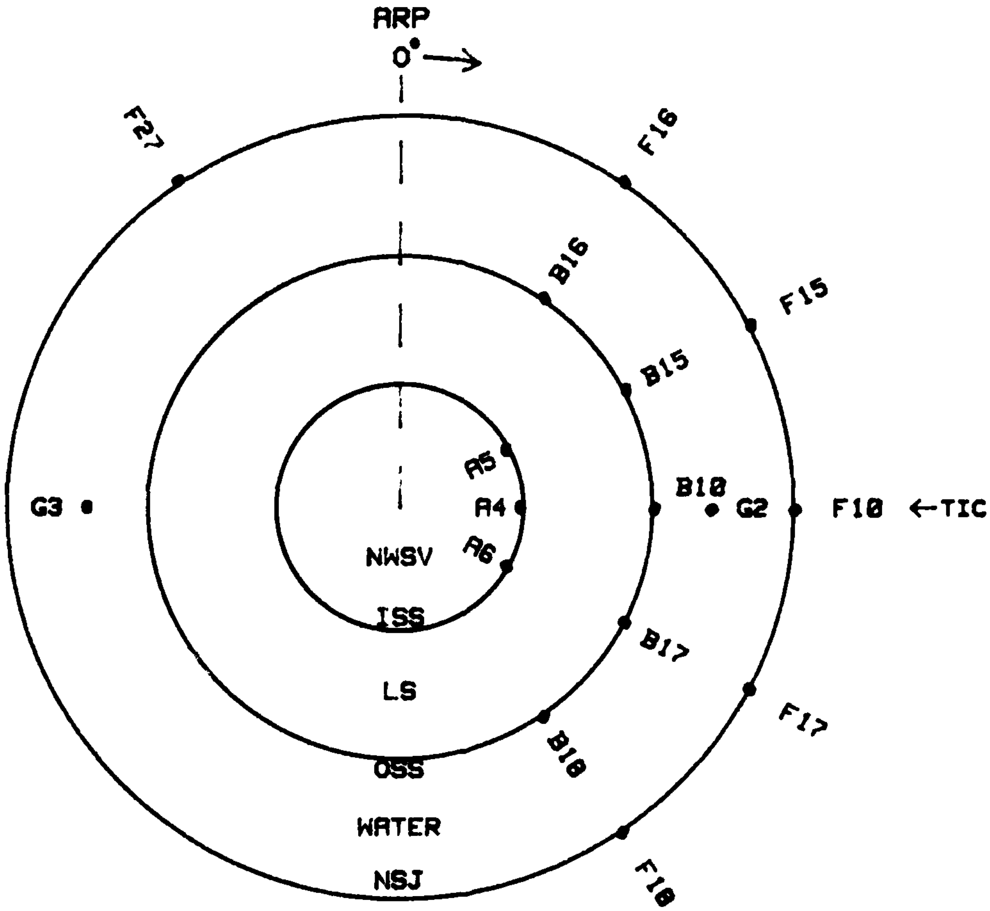

Figure 16: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at 289.6 cm from the XRP as Viewed from the Top End with the TIC Located at 90° for Test Numbers 1 and 2

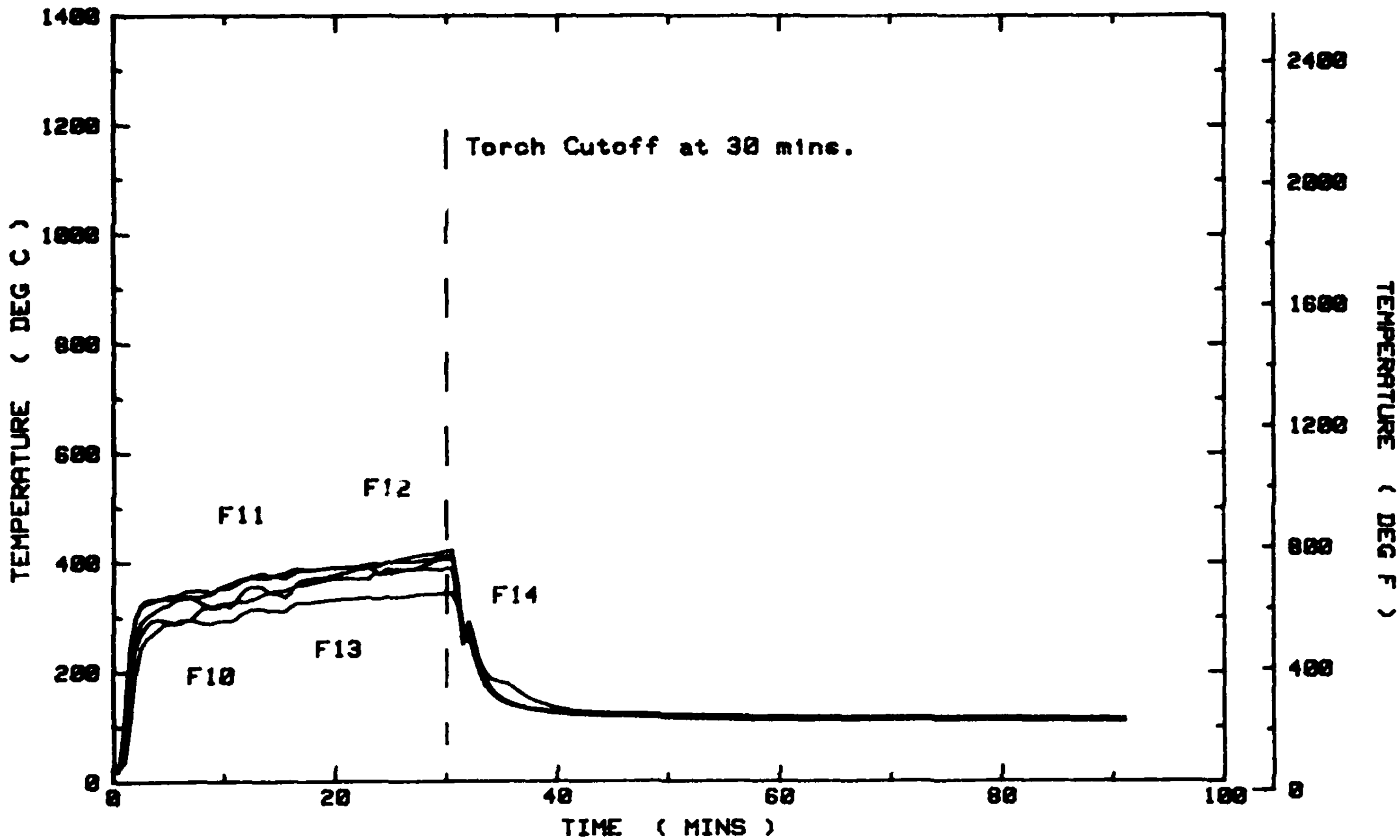

Figure 17: Temperature as Functions of Time for TCs Centered About the Position 289.6 cm from the XRP and Located on the Outer Surface of the NSJ for HNPF Cask Test Number 1

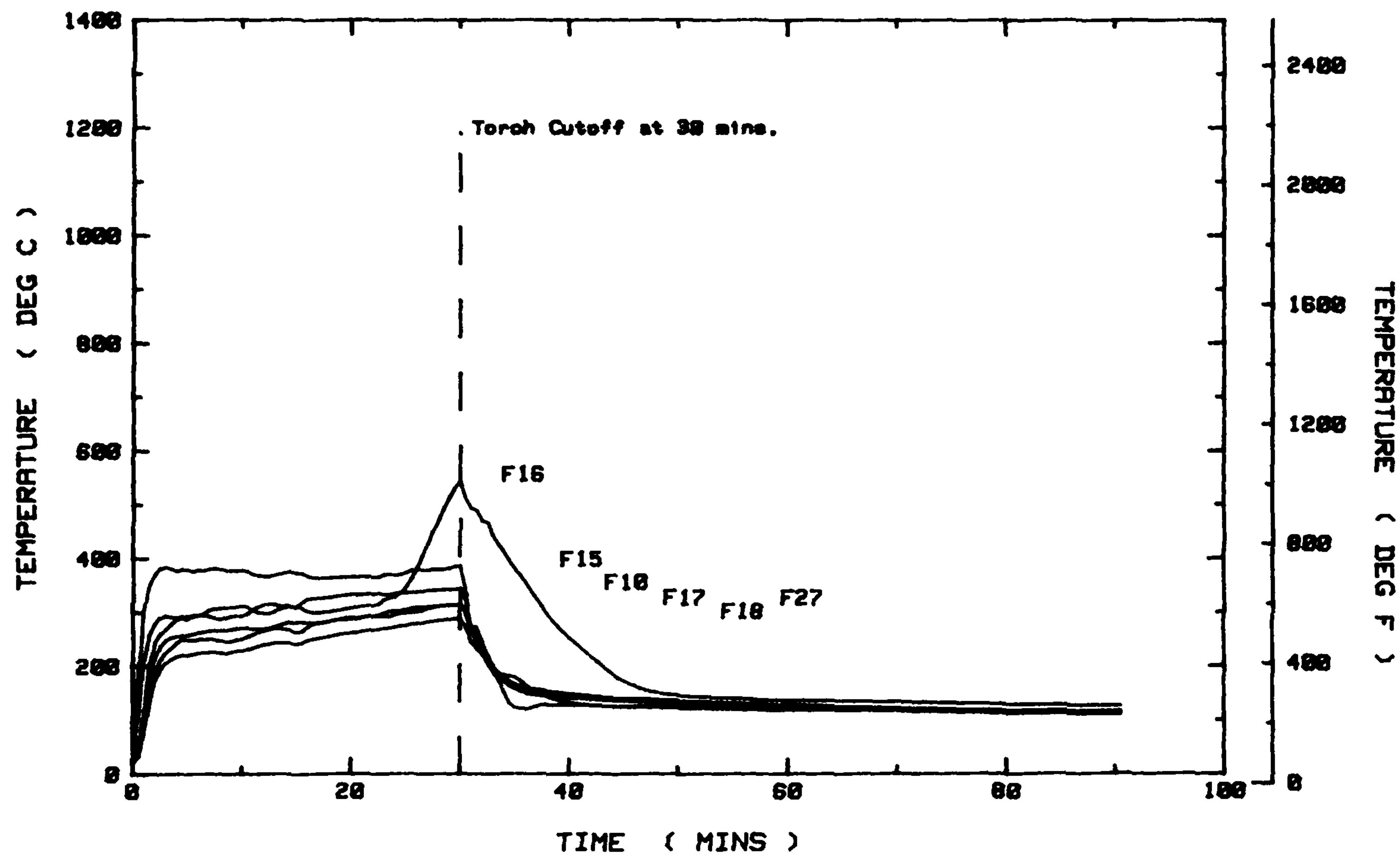

Figure 18: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 289.6 cm on the Outer Surface of the NSJ for HNPF Cask Test Number 1

The TC F16 apparently malfunctioned, so its measurements are assumed to be faulty. Even though the TCs F15 and F17 are at equal angular distances above and below the TIC position, the peak temperature of F15 was 80° C higher than the peak temperature measured by F17. Since F15 was the upper TC and F17 was the lower one, the torch flame apparently deposited more heat toward the upper side of the cask. F18 was positioned below F17 and recorded an even lower valued peak temperature. The TC F27 was positioned at 325°, which is a position on the opposite side of the cask and 35° from the ARP, but its peak temperature measurement was nearly the same value as that measured by F17. This was the case in spite of the fact F27 was much further away from the TIC. This also supports the observation mentioned previously that the torch flame has a tendency to deposit more heat toward the top side of the cask.

The temperature profiles for the TCs which were distributed about the point on the cask with the position of 90° angular coordinate and an axial coordinate of 93.3 cm are presented in Figures 20 and 21. The axial arrangement of these TCs is presented in Figure 19. Figure 20 presents the group of TCs which were all at an angular position of 90°. The TC F4 was the closest one to the TIC and recorded temperature values which reached 300° C several times. As was seen in Figure 17, the F14 TC, which was the closest TC to the F4 TC on the side nearest the TIC, also measured temperatures in the neighborhood of 300° C. The other TCs in the group which contained the F4 TC were positioned further away from the TIC and measured much lower temperature values. This indicated that these latter TCs did not experience any direct contact with the torch flame. The large fluctuations in the measurements by F4 indicate that the edge of the torch flame was oscillating on and off the TC F4 position. The curve in Figure 17 for the TC F14 temperature curve shows that the F14 TC was continuously engulfed by the torch flame as indicated by the smoothness of the curve. The temperature profiles shown in Figure 21, where all of the TCs which measured those values were positioned at 93.3 cm from the XRP, are all similar with the peak value reaching approximately 200° C.

Of all of the TC measurements of temperature, the data indicate that the most serious cases would be for those TC positions near the TIC since TCs positioned there measured the highest temperatures. This would be true unless there were highly vulnerable components further away from the TIC which could be damaged by the lower temperatures. Actually, there were seals which needed to survive if the NSJ were to retain water following the test and these were located near the end of the cask. A criterion for recognizing damage would have been if the NSJ could not contain the water. As the follow-on test showed, the temperature did not reach a level where the seals were damaged because the NSJ was again filled with water for the second test. The temperature of the torch was approximately 1100° C, as mentioned above; therefore, since the peak TC measured temperature on the surface of the NSJ, it can be seen that the water in the NSJ was capable of absorbing a great deal of heat.

Figures 22 through 25 presents the temperature profiles for those TCs which were located on cask surfaces further in toward the center of the cask. Figure 22 shows that the temperature of the water in the NSJ heated up gradually and uniformly throughout since the G TCs were spaced at large distances from one another. The temperature of the water reached 100° C, and, as the other TC temperature profiles show, none of the more inwardly positioned TCs measured higher values, and the values measured became lower as the center of the cask was approached.

TIC -- TORCH IMPINGEMENT CENTER
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD
ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

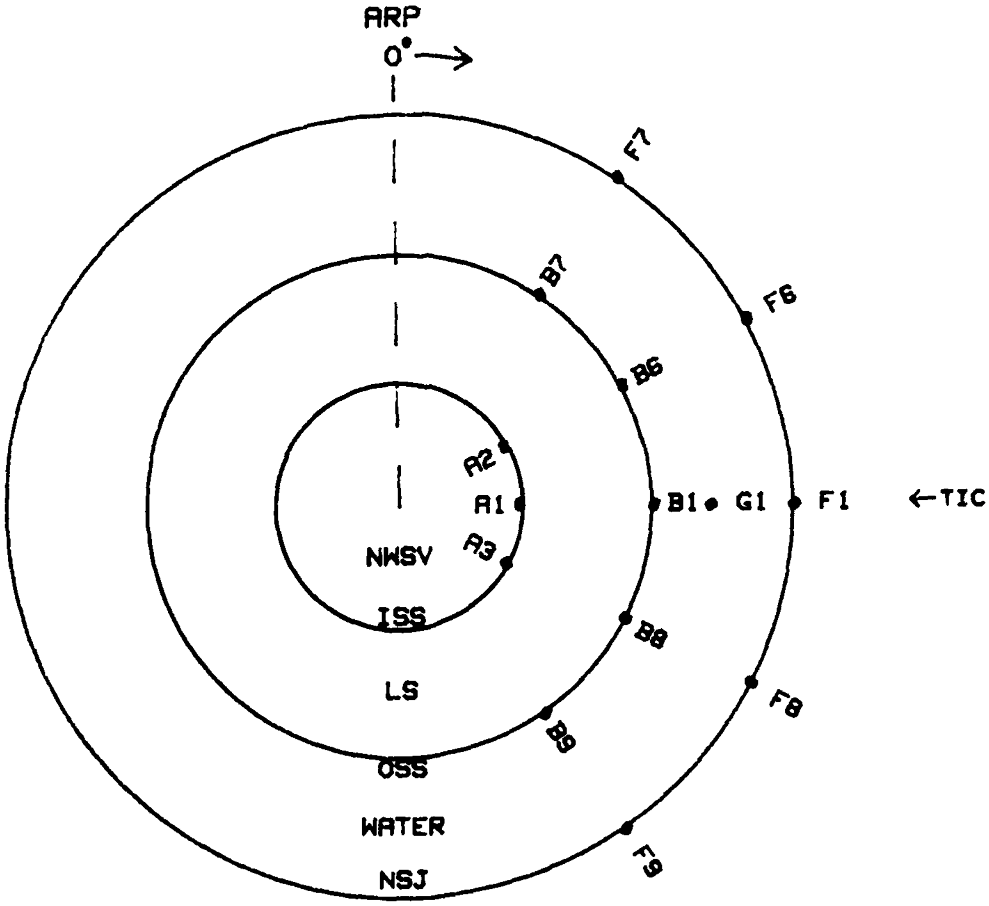

Figure 19: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at 93.3 cm from the XRP as Viewed from the Top End with the TIC Located at 90° for Test Numbers 1 and 2

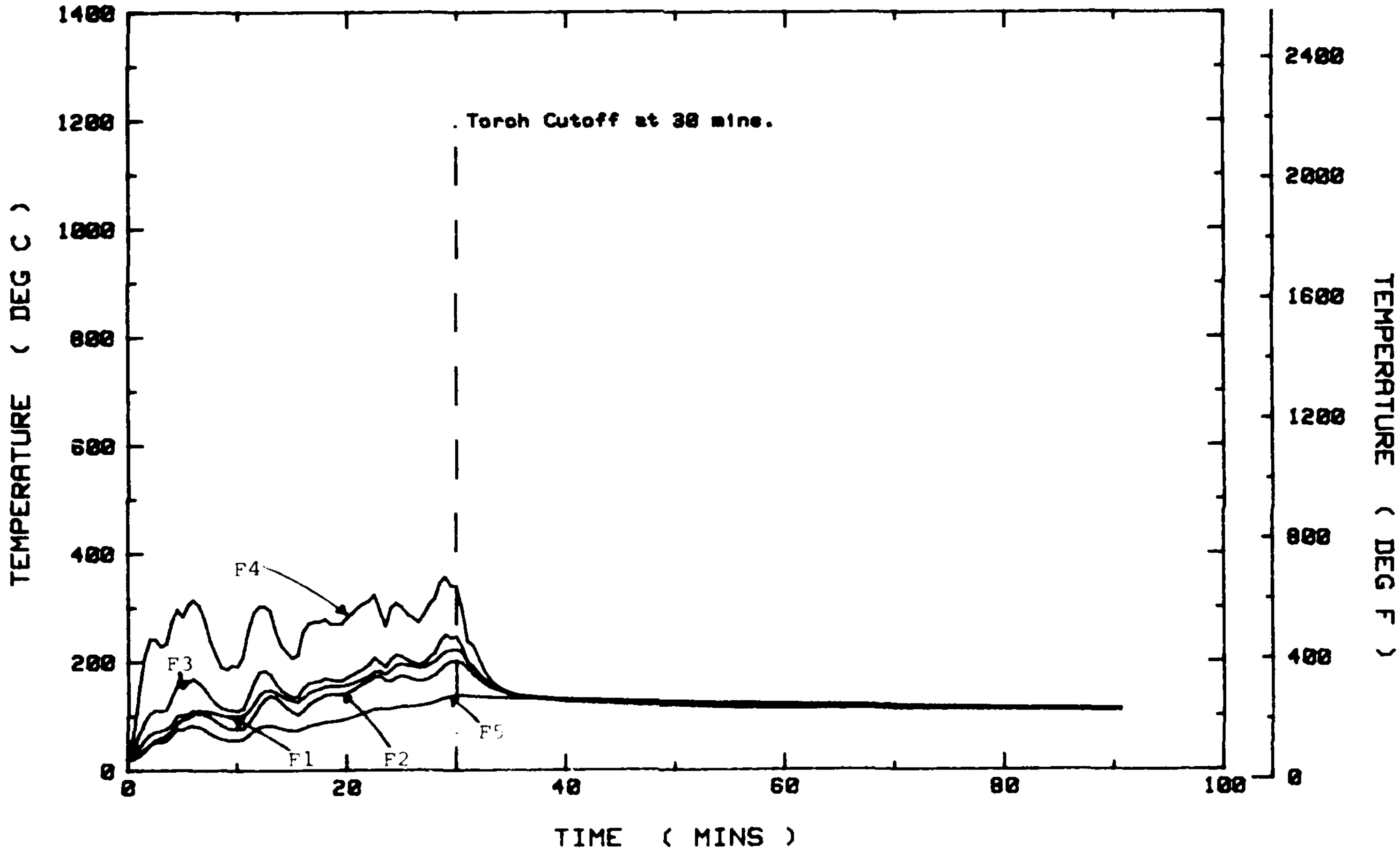

Figure 20: Temperature as Functions of Time for TCs Centered About the Position 93.3 cm from the XRP and Located on the Outer Surface of the NSI for HNPF Cask Test Number 1

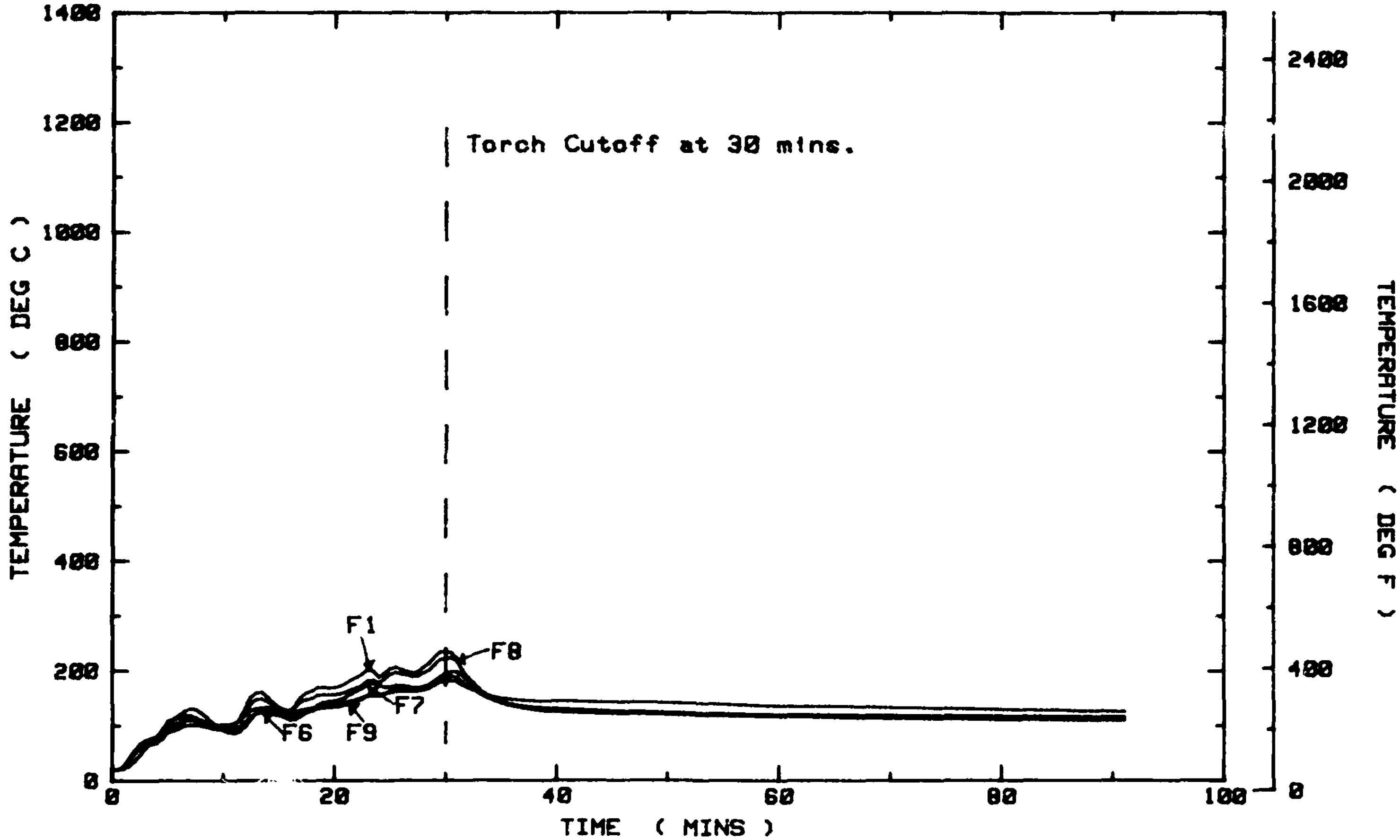

Figure 21: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 93.3 cm on the Outer Surface of the NSJ for HNPF Cask Test Number 1

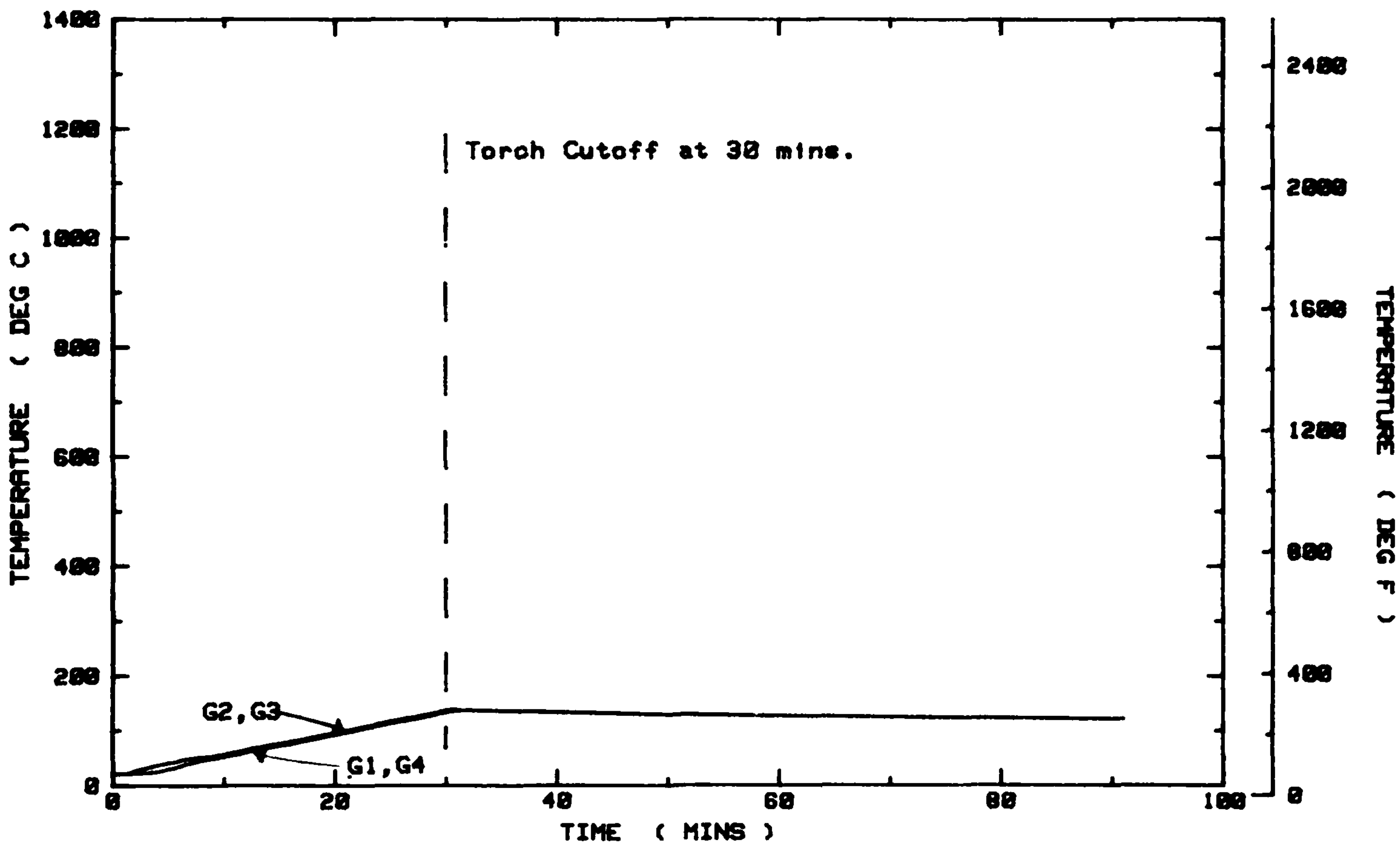

Figure 22: Temperature as Functions of Time for TCs Positioned in the Water of the NSJ for HNPF Cask Test Number 1

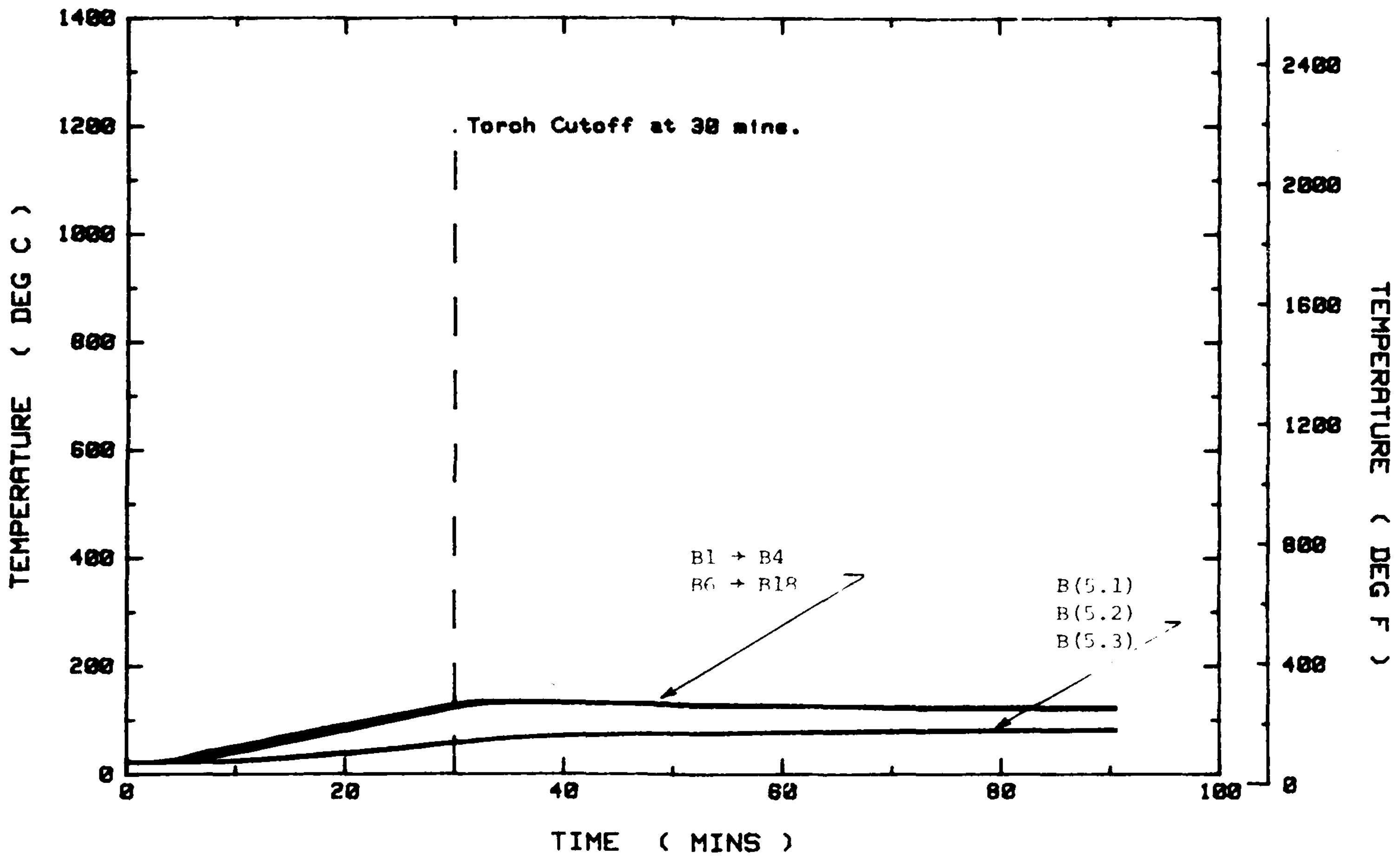

Figure 23: Temperature as Functions of Time for TCs Positioned on the Outer Surface of the OSS for HNPF Cask Test Number 1

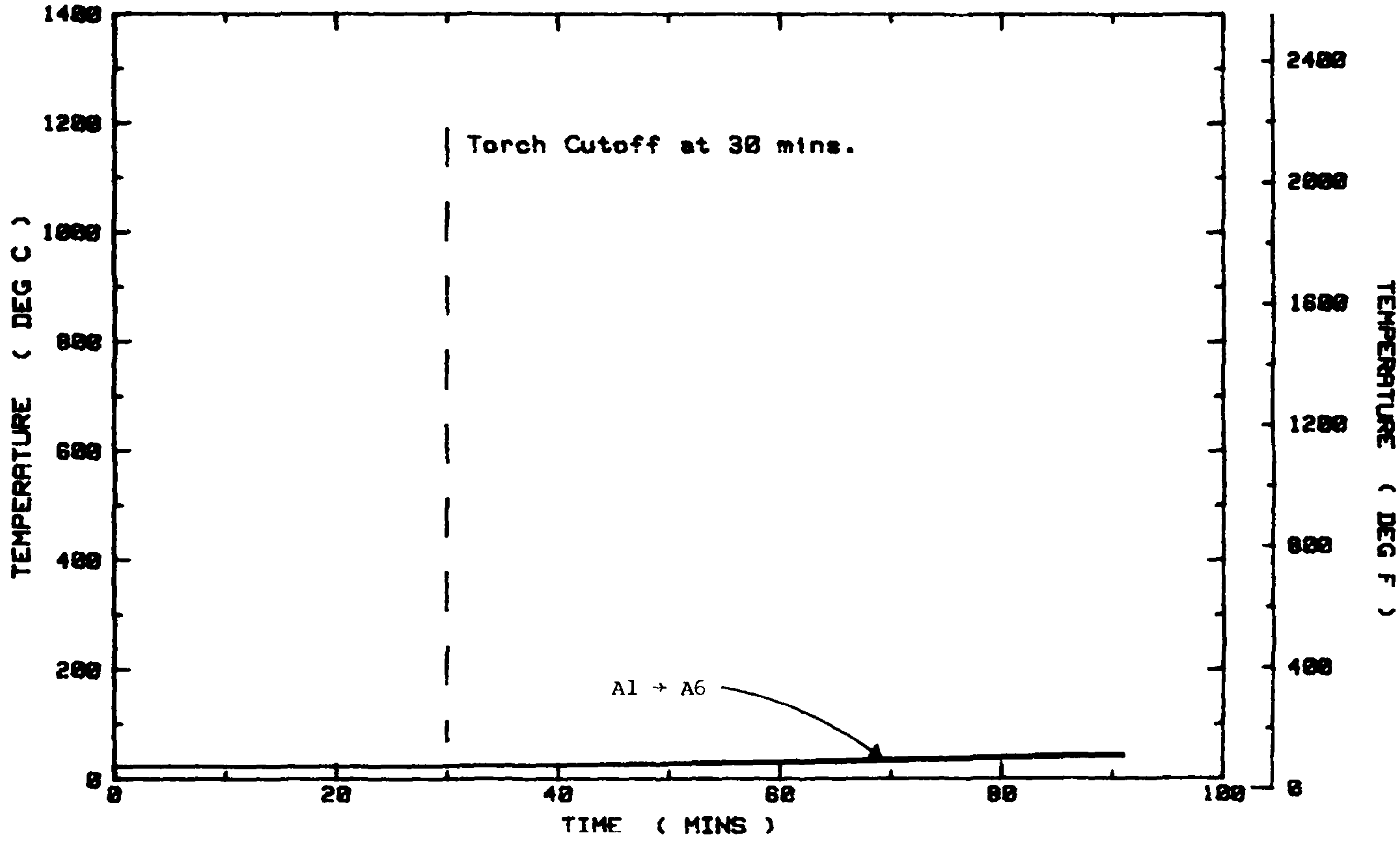

Figure 24: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS for HNPF Cask Test Number 1

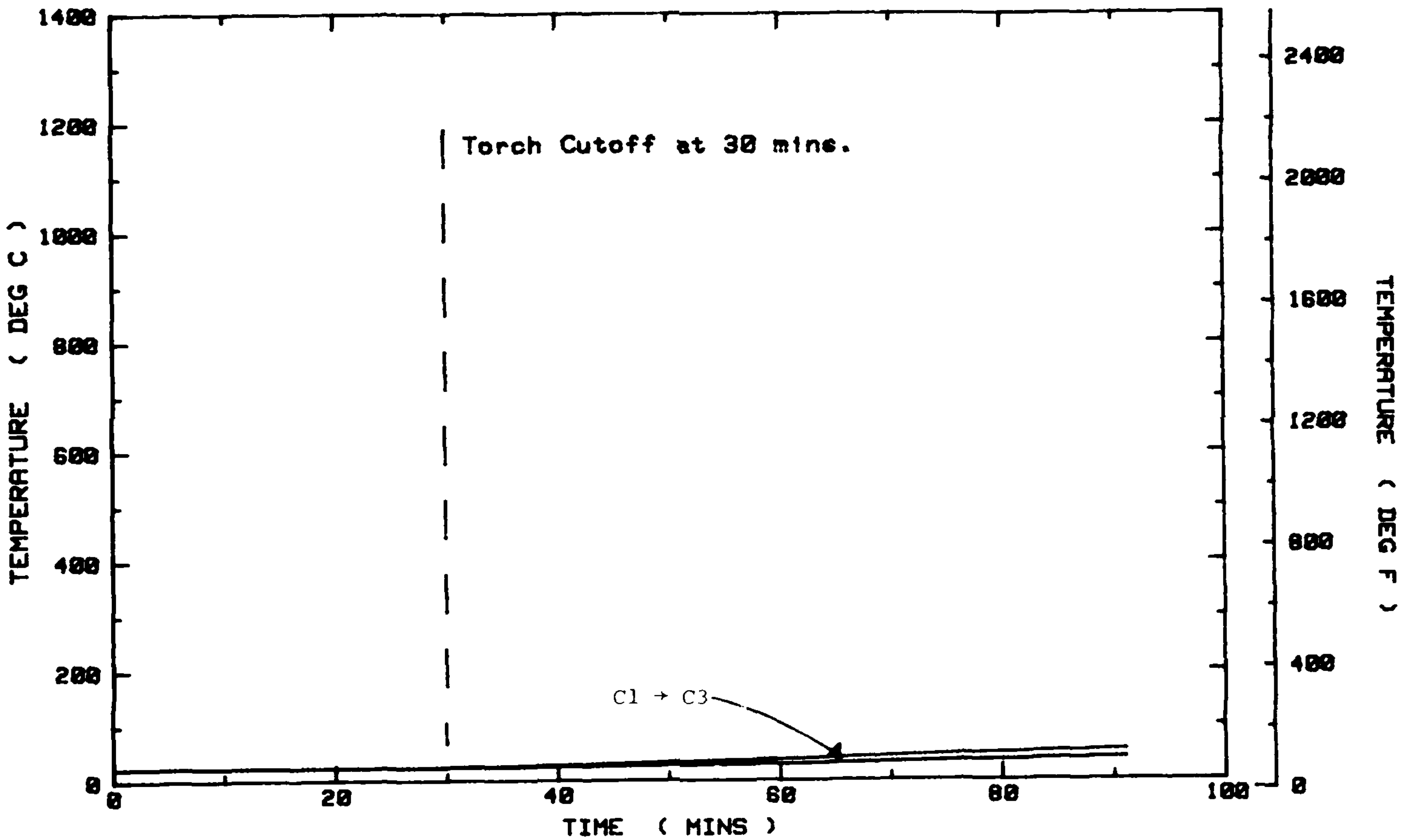

Figure 25: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS near 20 cm from the XRP for HNPF Cask Test Number 1

The pressure level values are presented in Figure 26. The peak value measured by these gauges is approximately 210 psi which corresponded to the setting of the pressure relief valves. The water was vented through the relief valve when the pressure exceeded 210 psi as indicated by the fluctuations. The pressure did not decline permanently until the torch was extinguished, a fact which further indicates that the cask seals were not damaged.

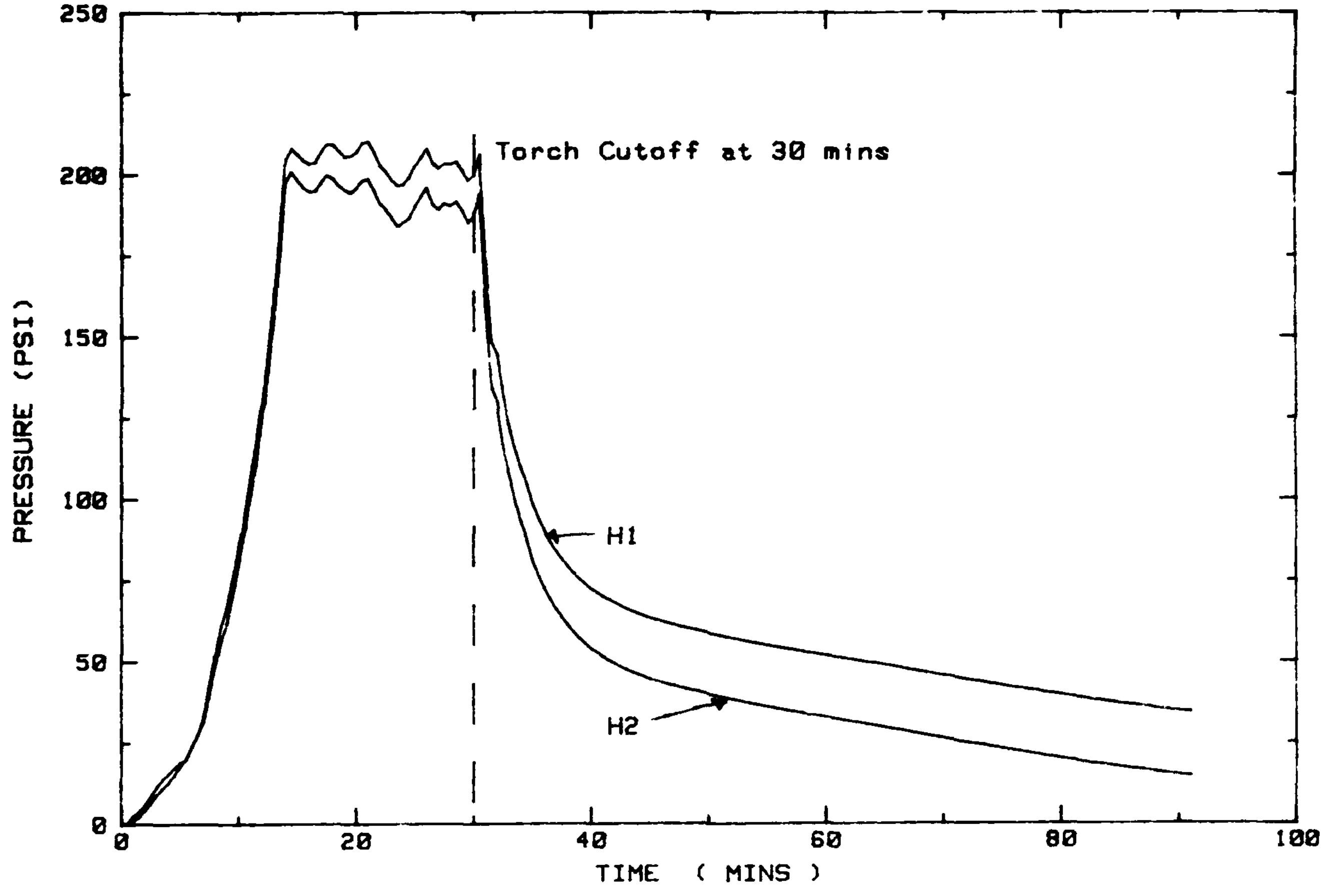

Figure 26: Pressure as Functions of Time Inside the NSJ for HNPF Cask Test Number 1

V. DESCRIPTION OF TEST NUMBER 2

The second experiment of the series was identical to the first except that the TIC was at an axial distance of 93.3 cm (36.7 inches) from the XRP rather than 289.6 cm (114 inches). Therefore, Test Number 2 was also a torch simulation test and the NSJ was again filled with water. Figure 27 presents a photograph of the torch impinging on the HNPF Cask which was taken while the test was in progress.

The data describing physical parameters which constituted the environmental conditions during this experiment are presented in Figures 28 through 31. The wind direction changed somewhat during the first half of the experiment as shown in Figure 28. The wind speed shown in Figure 29 varied a lot but did not exceed three miles per hour which was permissible. The water bath temperature was initially measured to be 70^{o} C and gradually declined from that value throughout the test to approximately 65^{o} C as indicated in Figure 30. Also shown in Figure 30 is the ambient temperature which remained steady at 10^{o} C. The temperature of the flame of the torch as a function of time is presented in Figure 31. The average temperature level for the flame was again approximately 1100^{o} C until the shutdown of the torch after 30 minutes.

A schematic which shows the relative axial positions of the TCs wit' respect to the XRP and the TIC for Test Number 2 is presented in Figure 32. The only difference between this diagram and the one shown in Figure 15 for Test Number 1 is that the location of the TIC is changed to 93.3 cm (36.7 inches). Figure 32 shows that a different set of TCs will be the most important for providing measurements since they are the nearest to the position of the TIC. The same angular distributions are applicable to this case as for Test Number 1 because the TIC is again located at 90^{o}. Therefore, Figures 16 and 19 can be reviewed in order to obtain a fresh reminder of the angular distributions for the TCs.

The data which describe the variations of the temperature as functions of time for the TCs positioned on the exterior surface of the NSJ for Test Number 2 are presented in Figures 33 through 36. Figure 33 presents the temperature profiles for the group of TCs which were positioned at the same cross-sectional angle as the TIC (90^{o}), but which were distributed about the TIC in the axial direction as shown in Figure 32. The peak value of TC F1 reached a temperature of 275^{o} C and remained there until the torch was extinguished. The F3 TC reached a peak value of 500^{o} C and the F4 TC averaged around 400^{o} C, which again indicates that the torch flame was cooler near its center. The F5 TC, which was nearest the end of the cask of this group, only reached a temperature of 275^{o} C which could be reasonable in that it is further from the TIC and perhaps heat escaped from the end of the cask in some way. However, no explanation is available for the 850^{o} C temperature measured by the F2 TC. It appears that this value is in error in view of the other TC measurements in Figure 33 and also the temperature profiles presented in Figure 34. In Figure 34, the group of F TCs which measured these values were contained in the same axial cross-sectional plane which contained the TIC, but which were distributed at angles above and below the TIC position. (See Figure 19.) With the exception of TC F9, which was obviously faulty, all of the TC profiles peaked in the neighborhood of 300^{o} C and remained steady until the torch flame was extinguished. It is interesting that there does not seem to be any variation in the various curves

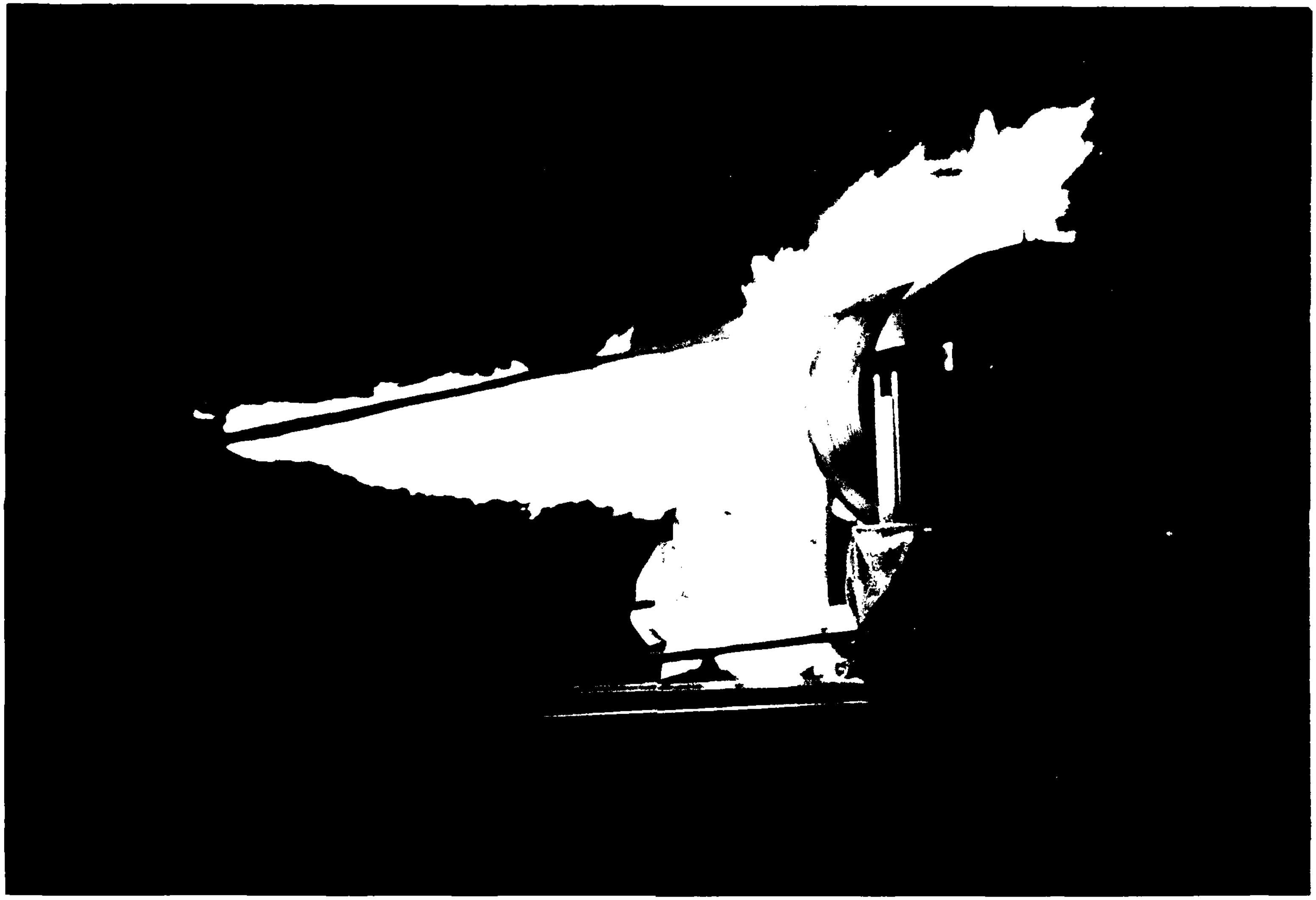

Figure 27: A View of the HNPF Cask Taken During Torch Thermal Test Number 2

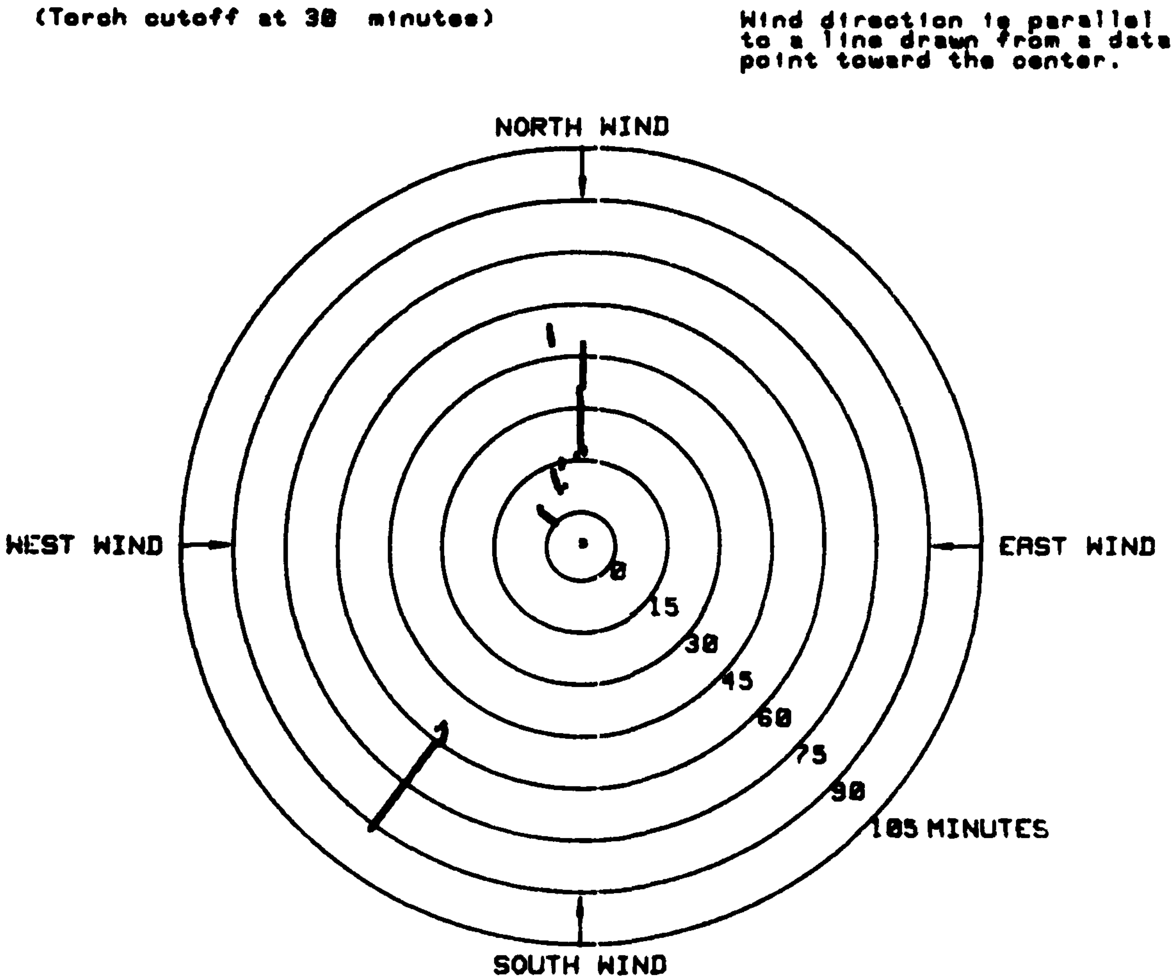

Figure 28: The Wind Direction as a Function of Time During the HNPF Cask Thermal Test Number 2

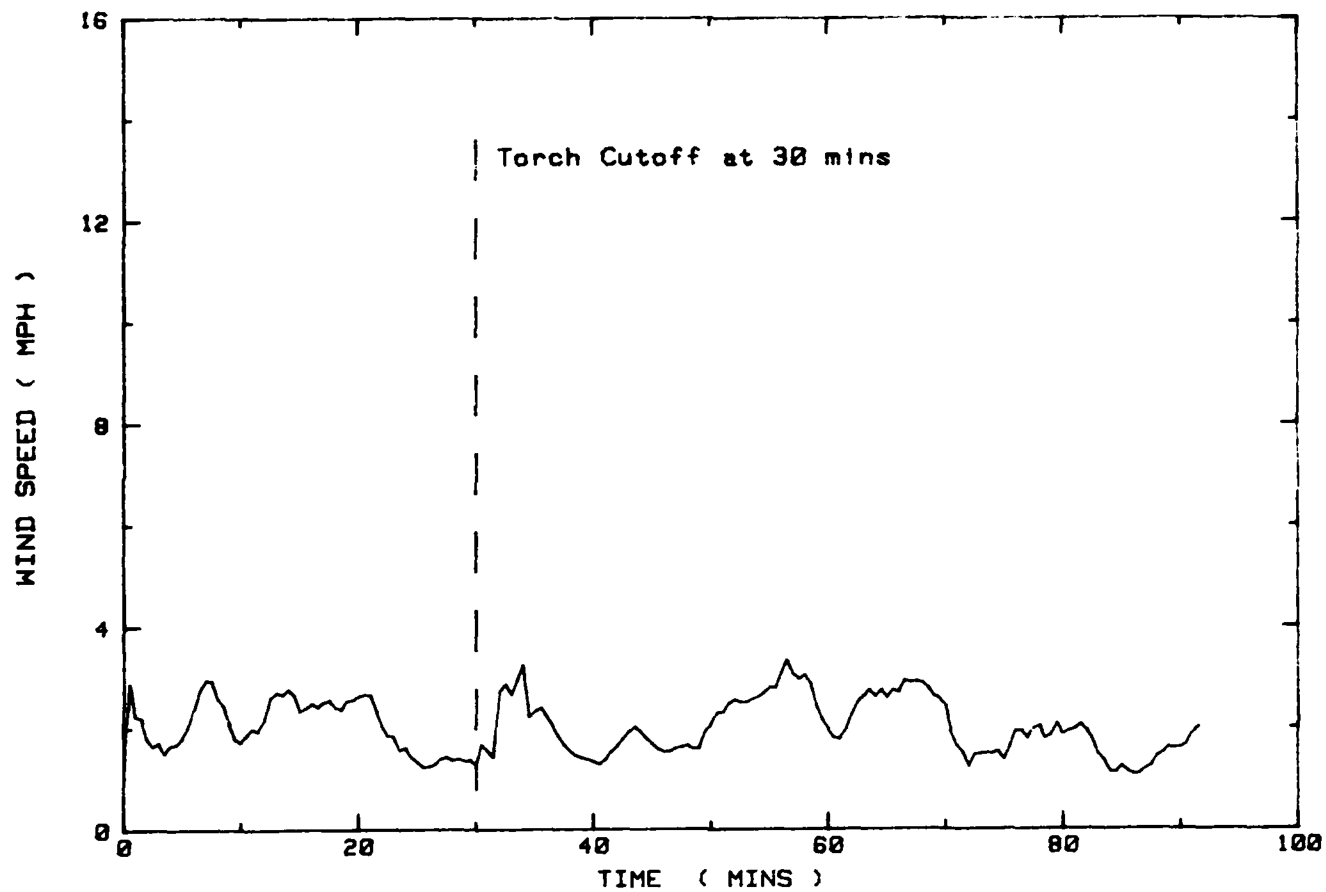

Figure 29: The Wind Speed as a Function of Time During the HNPF Cask Thermal Test Number 2

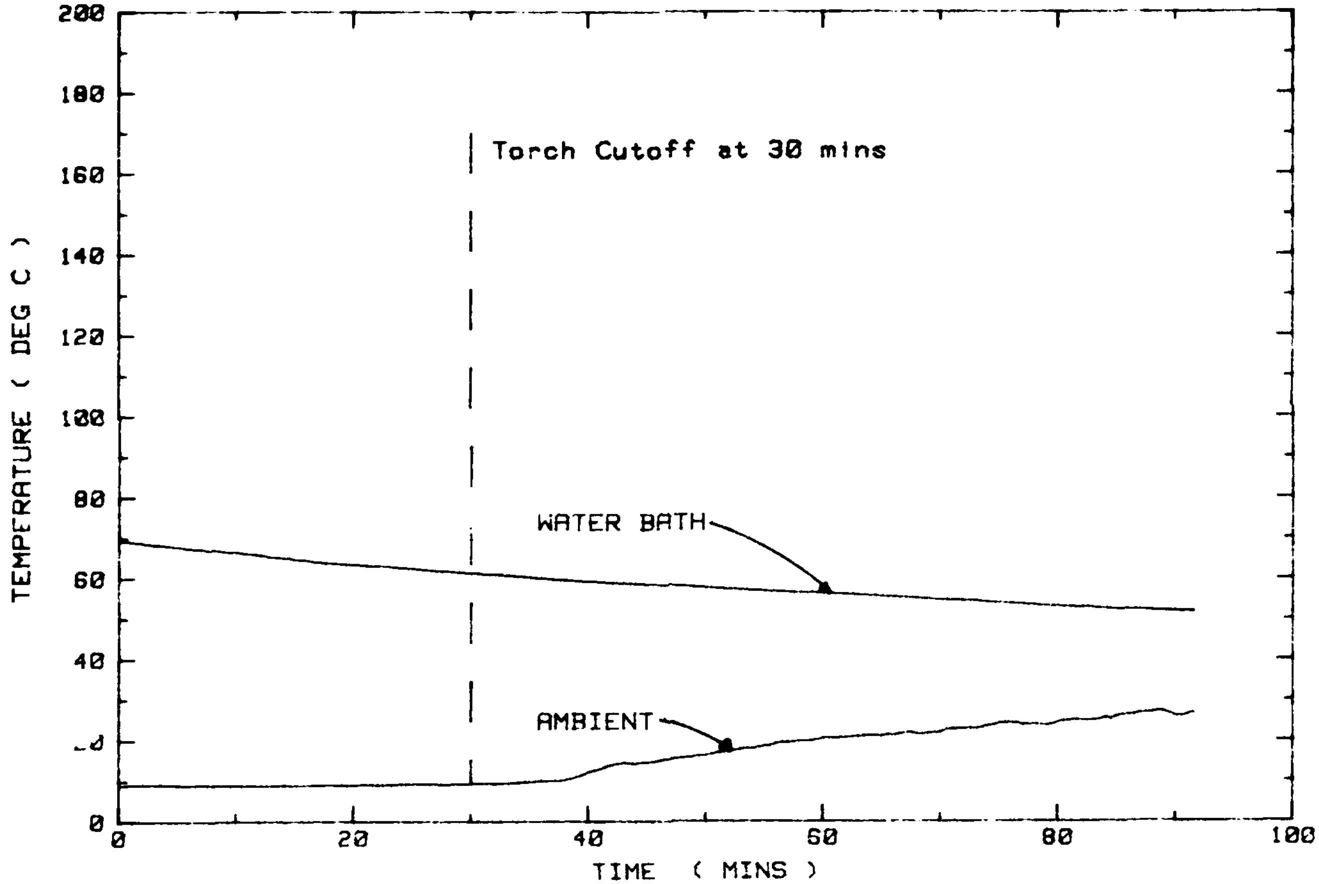

Figure 30: The Ambient and Water Bath Temperatures as Functions of Time During the HNPF Cask Test Number 2

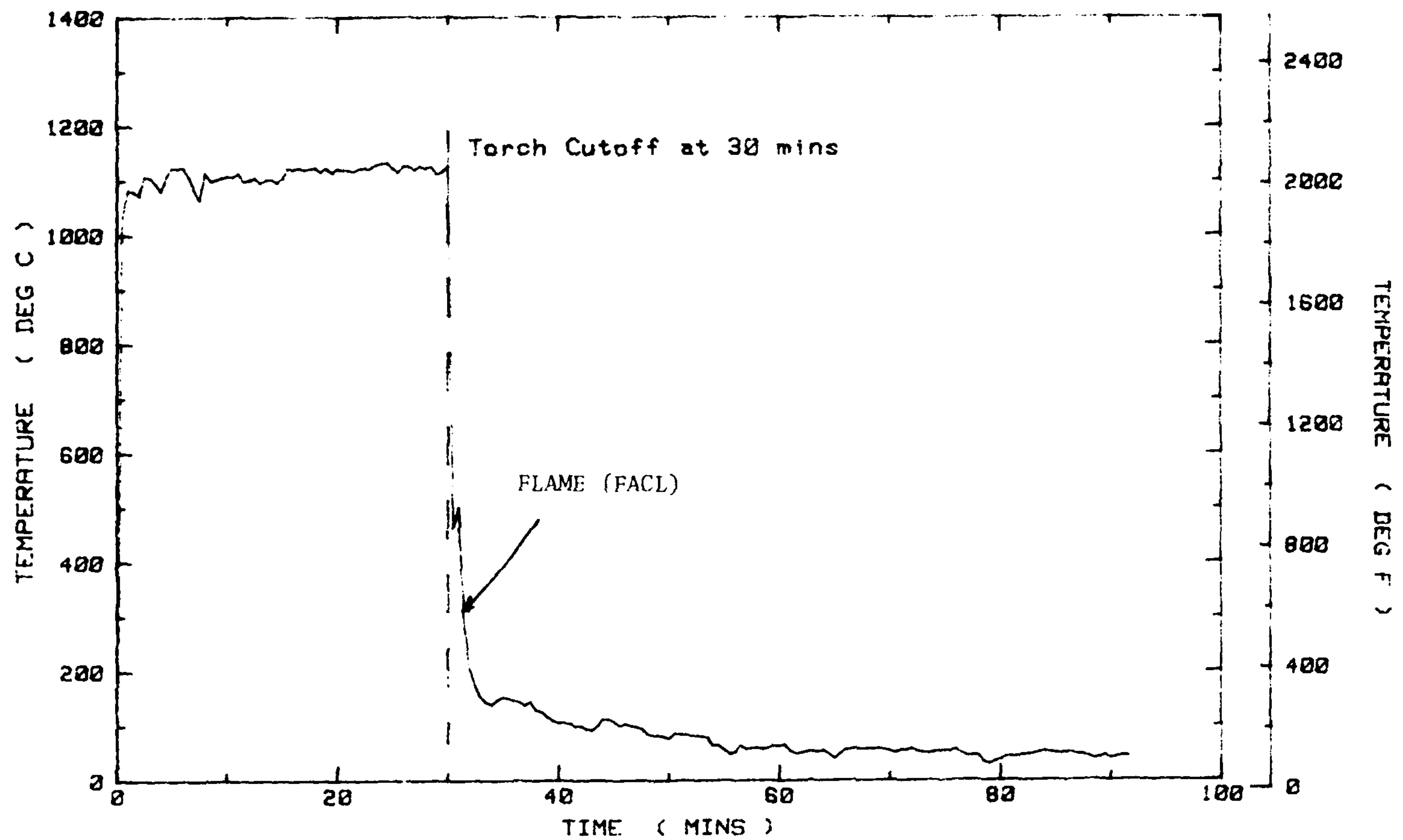

Figure 31: The Flame Temperature of the Propane Torch as a Function of Time During the HNPF Cask Test Number 2

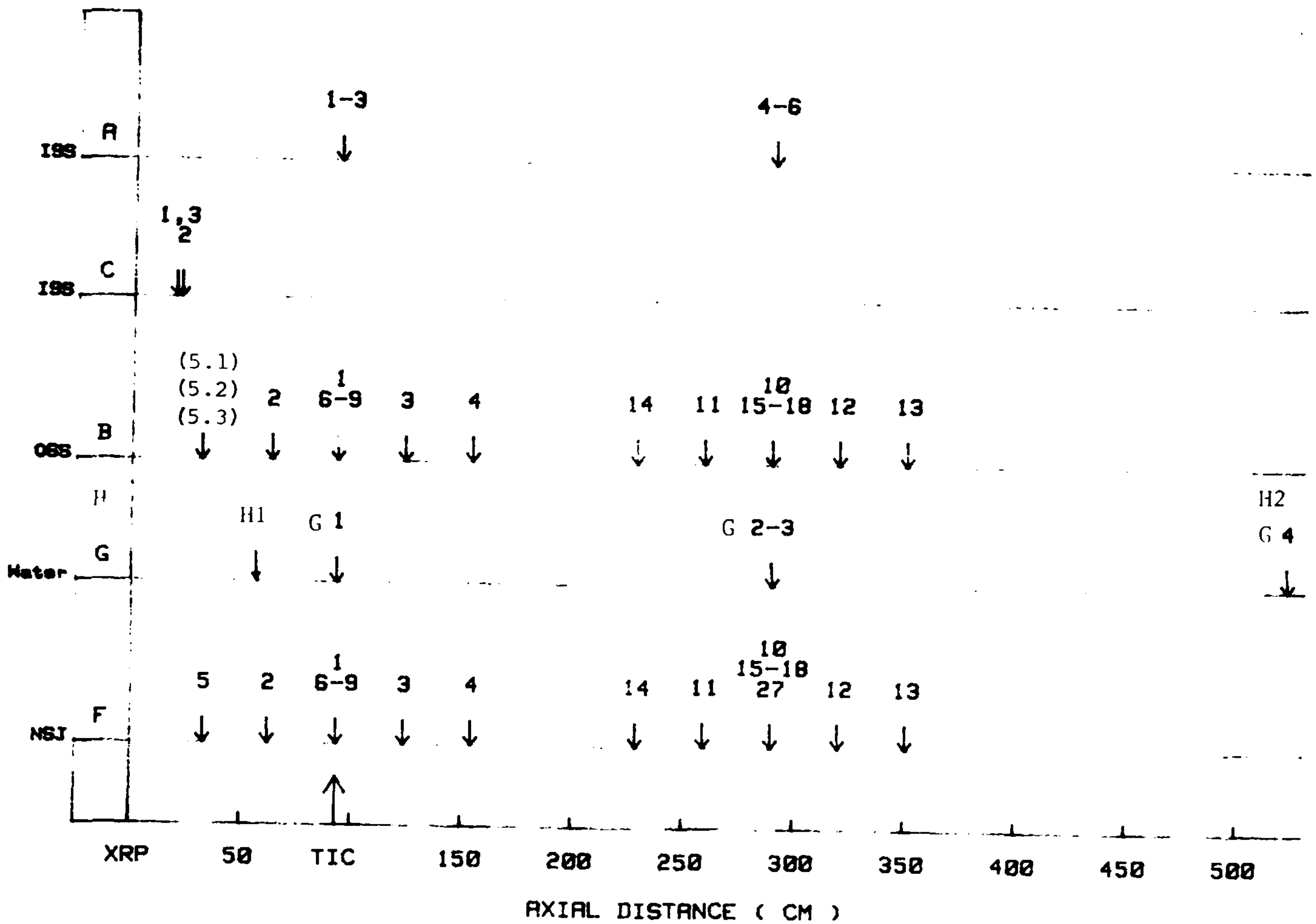

Figure 32: Axial Locations of Sensors Relative to the XRP and the TIC for Various HNPF Cask Surfaces in Test Number 2

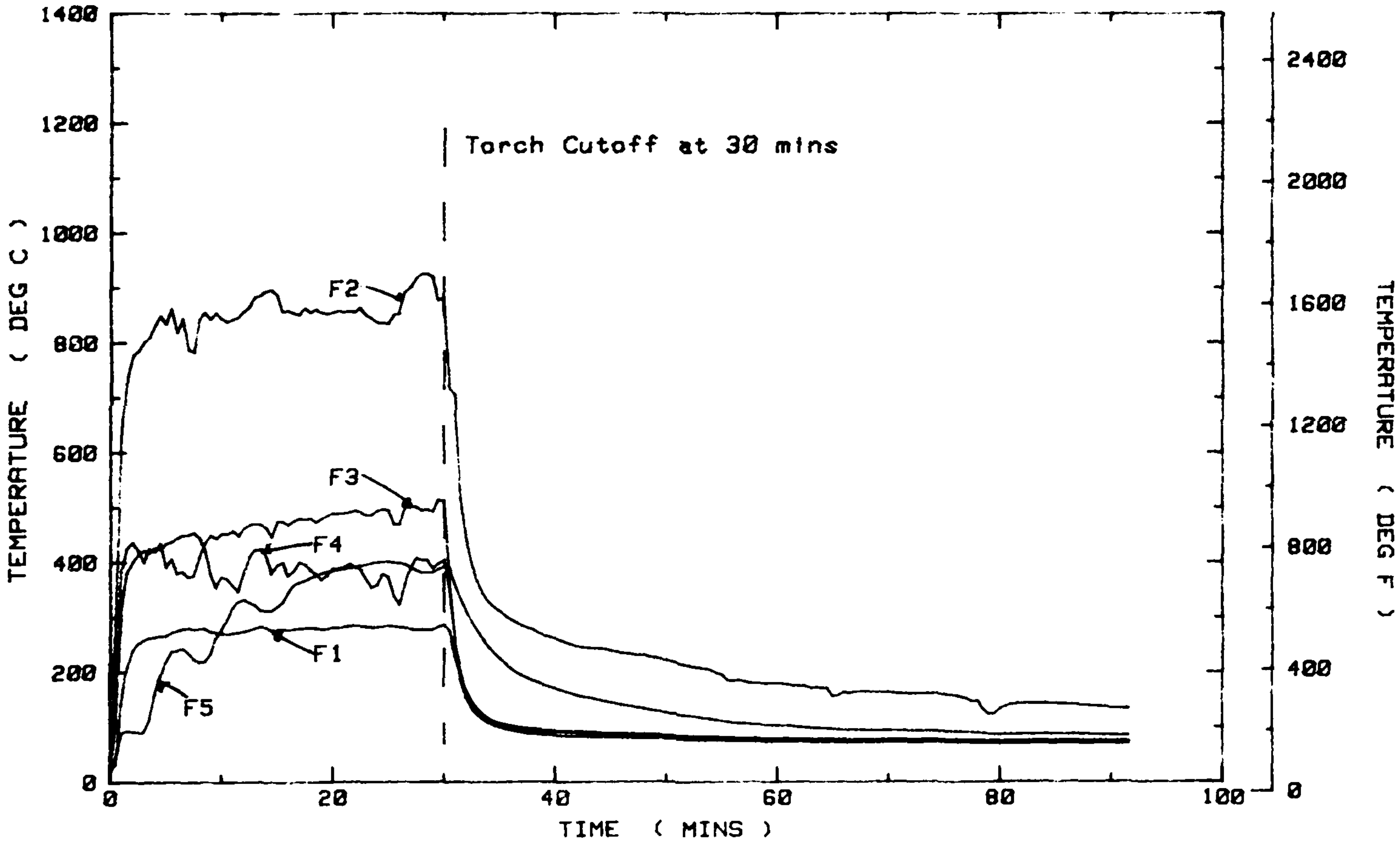

Figure 33: Temperature as Functions of Time for TCs Centered About the Position 93.3 cm from the XRP and Located on the Outer Surface of the NSJ for HNPF Cask Test Number 2

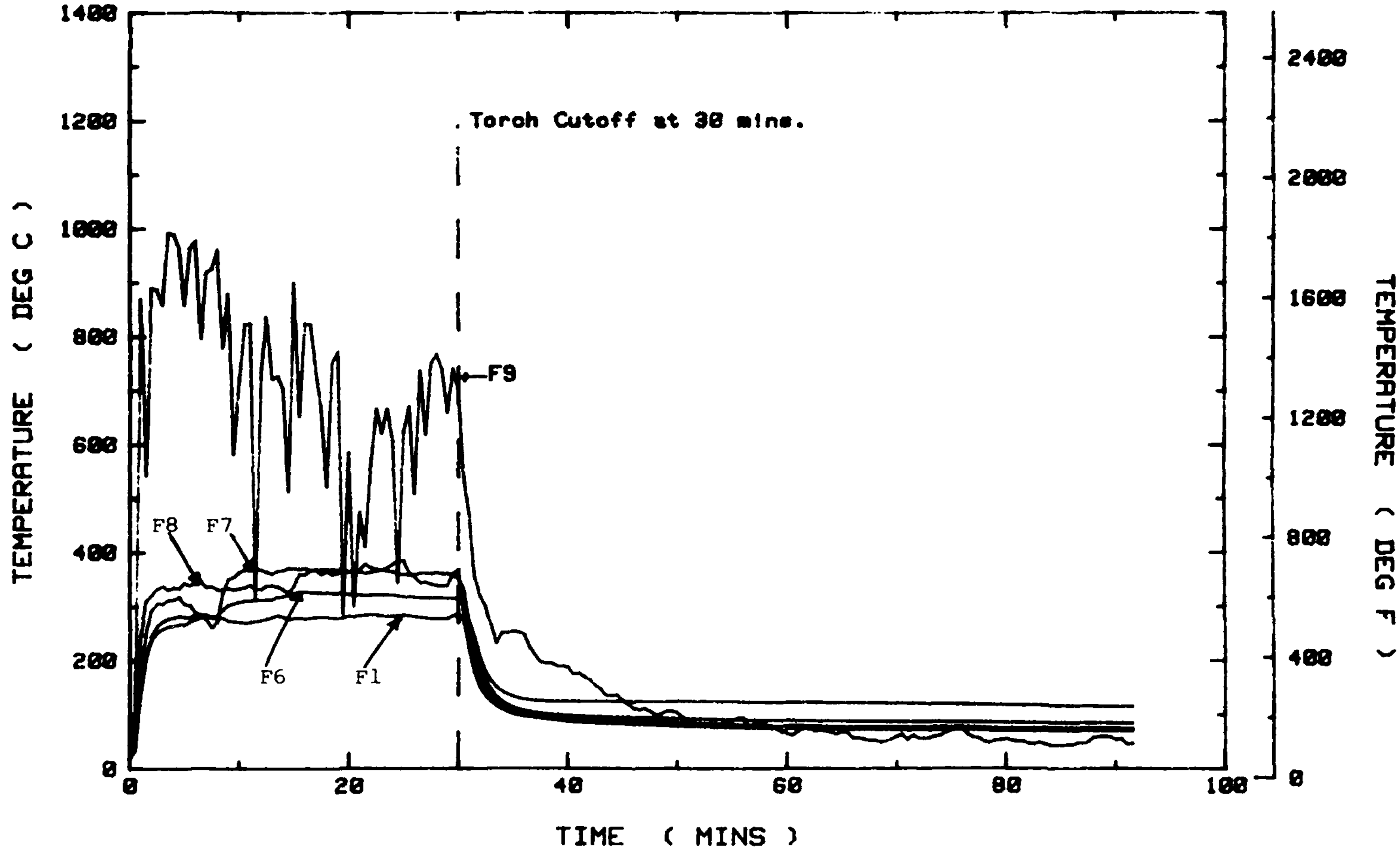

Figure 34: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 93.3 cm on the Outer Surface of the NSJ for HNPF Cask Test Number 2

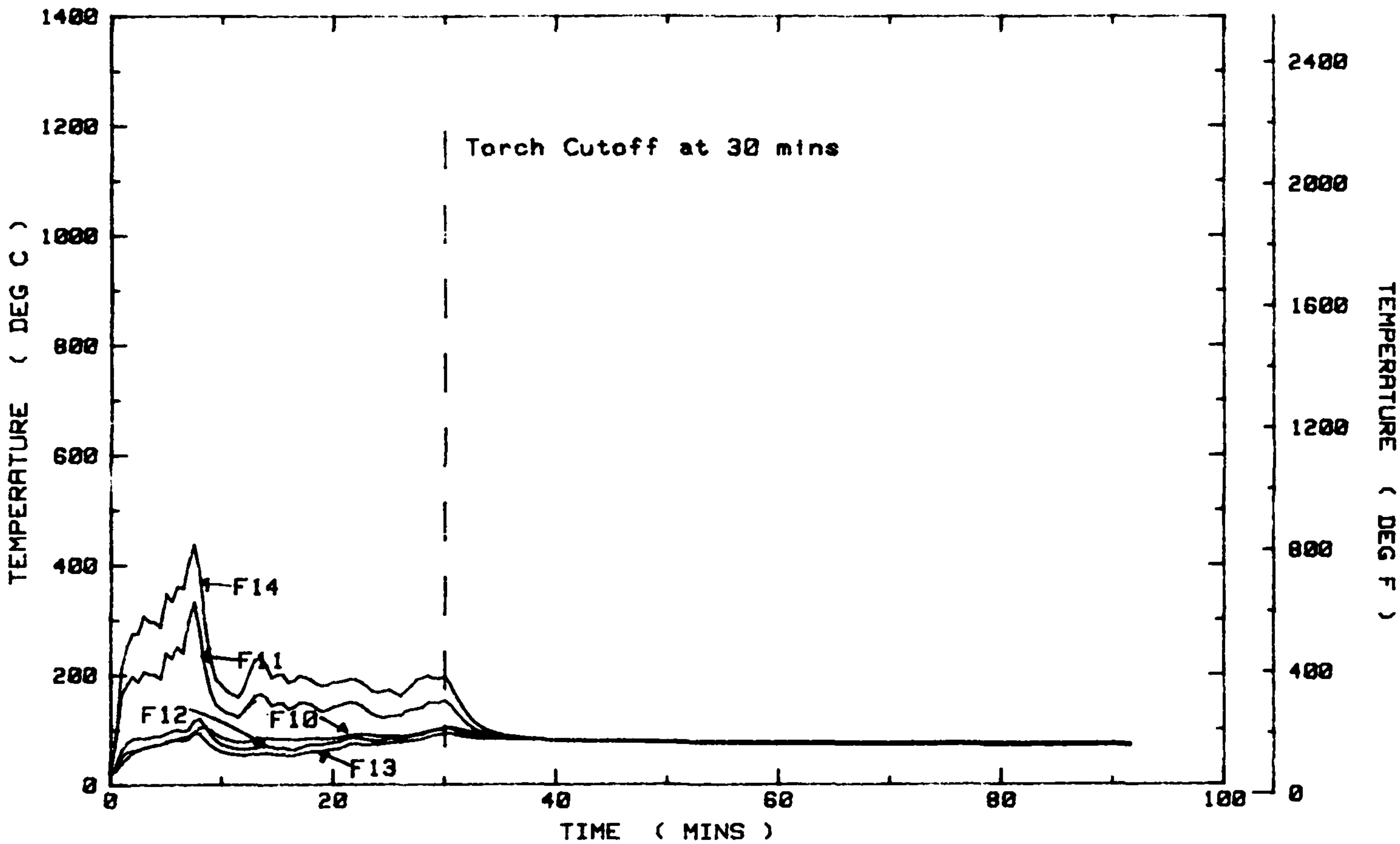

Figure 35: Temperature as Functions of Time for TCs Centered About the Position 289.6 cm from the XRP and Located on the Outer Surface of the NSJ for HNPF Cask Test Number 2

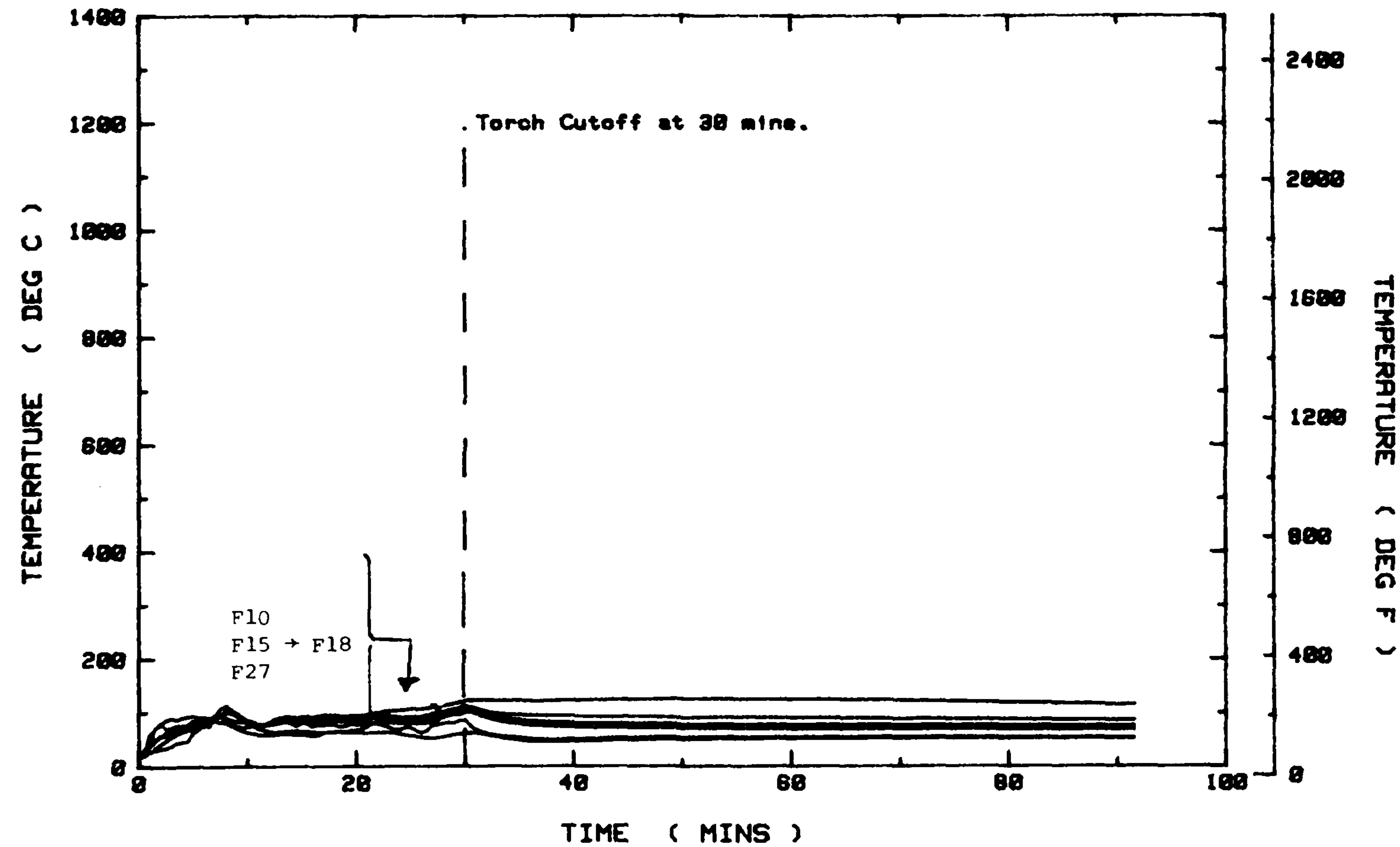

Figure 36: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 289.6 cm on the Outer Surface of the NSJ for HNPF Cask Test Number 2

as a function of TC angular position which seemed to have been apparent in Test Number 1.

The temperature profiles for the TCs which were distributed about the point on the cask with the position of 90° angular coordinate and an axial coordinate of 289.6 cm are presented in Figure 35. The TCs of this group which were positioned closest to the TIC were F14 and F11. Both of these rose to a sharp peak (410° C and 325° C, respectively) and then fell to approximately 200° C and maintained a steady value. The remaining TCs of the group stayed in the neighborhood of 75° C with their measurements. The temperature profiles shown in Figure 36, where all of the TCs which measured those values were positioned at 289.6 cm (114 inches) from the XRP, are all similar with the peak value reaching approximately 80° C. The temperature of the flame was 1100° again so that the effect of moving the TIC was to increase the temperatures about the TIC by approximately 100° C as far as the surface of the NSJ was concerned.

Figures 37 through 40 present the temperature profiles for those TCs which were located on cask surfaces further in toward the center of the cask. The values presented in these figures are similar to the data for the same TCs in Test Number 1, including the fact that the water in the NSJ reached almost 100° C.

The pressure level values are presented in Figure 41 for Test Number 2. It appears that the H1 pressure gauge failed at approximately 18 minutes. The other pressure gauge reached 210 psi and maintained that value for about eight minutes, but then the pressure began to fall rapidly which could be because of a leak in the seals. However, the next two tests were conducted without water in the NSJ so that was not confirmed.

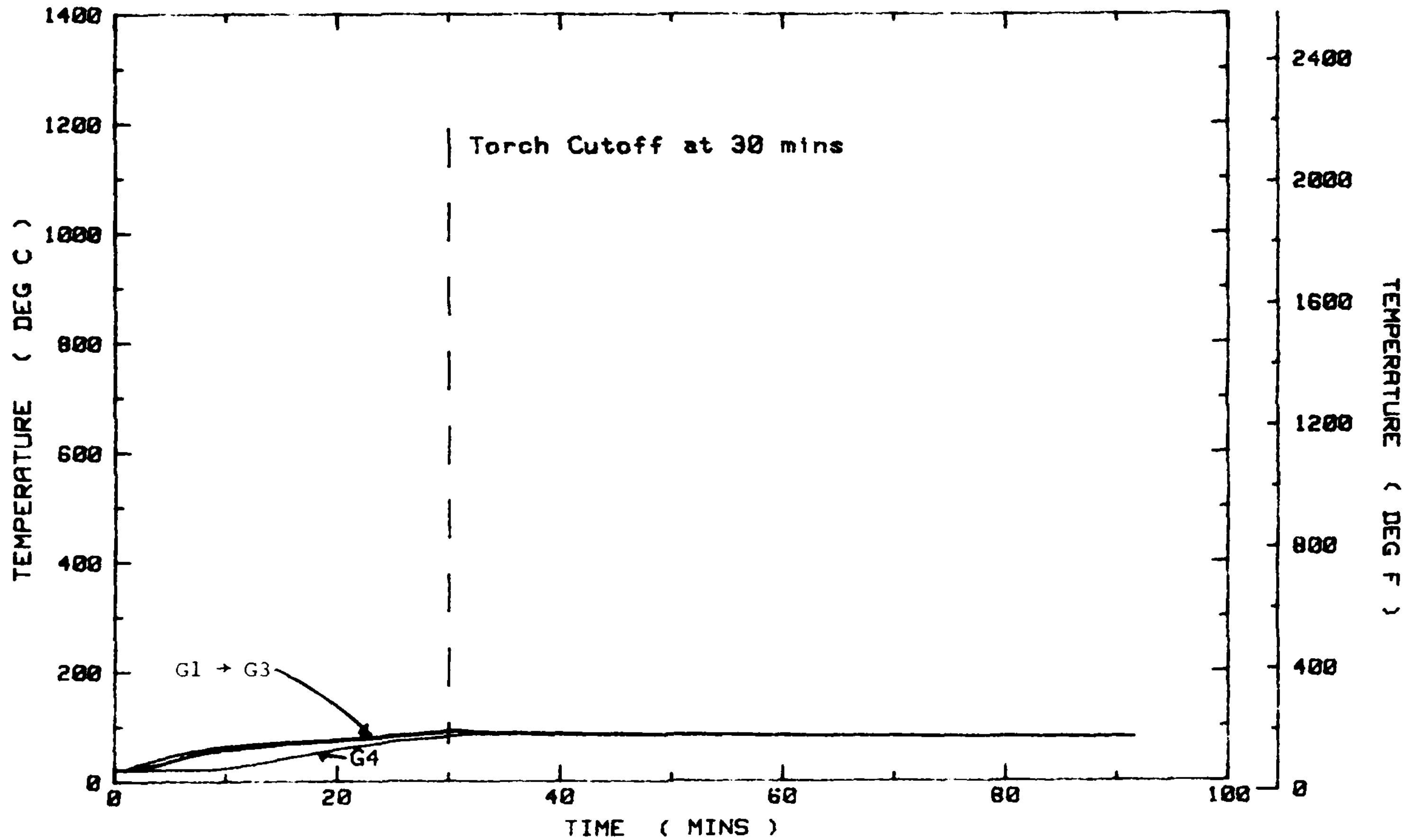

Figure 37: Temperature as Functions of Time for TCs Positioned in the Water of the NSJ for HNPF Cask Test Number 2

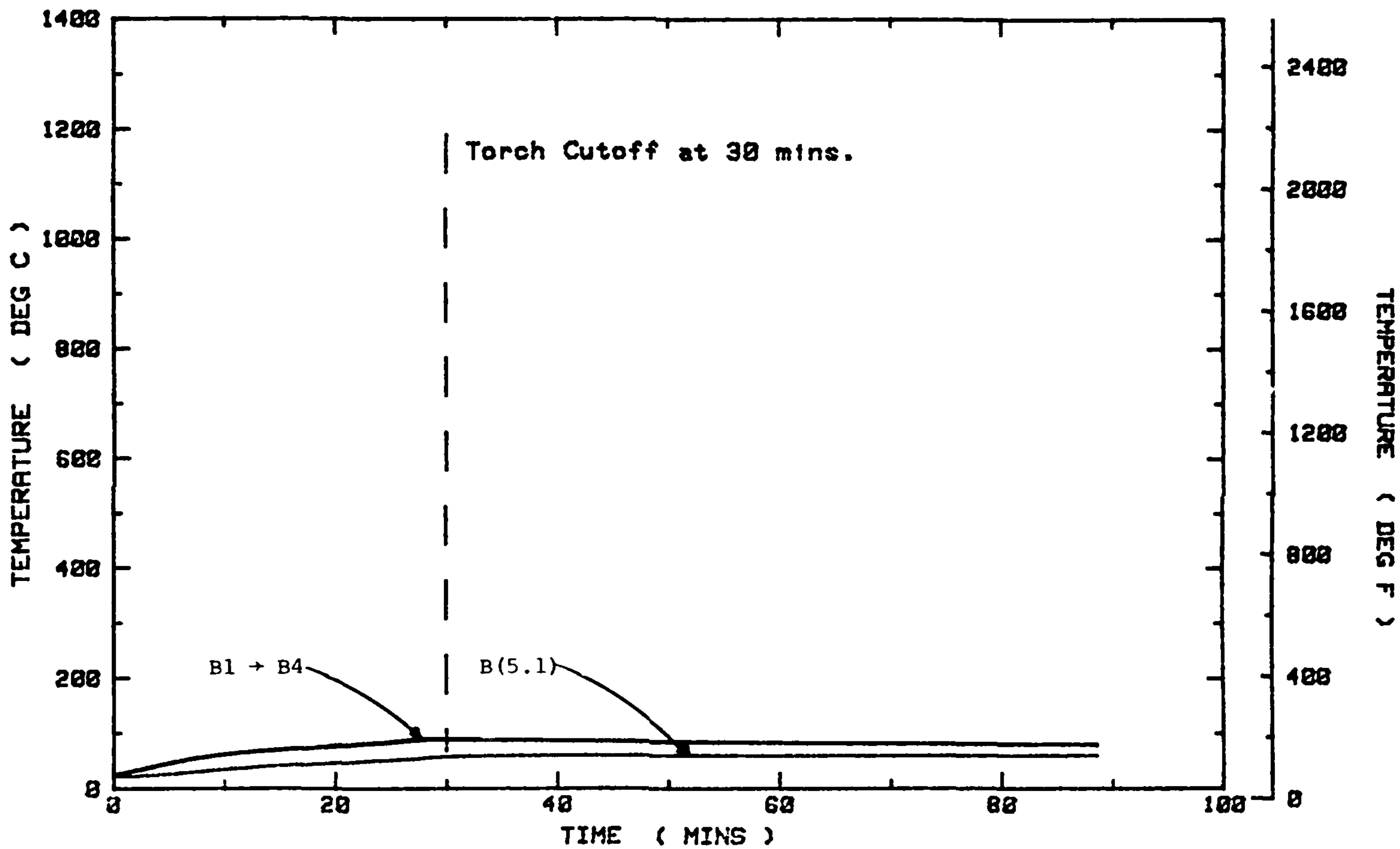

Figure 38: Temperature as Functions of Time for TCs Positioned on the Outer Surface of the OSS for HNPF Cask Test Number 2

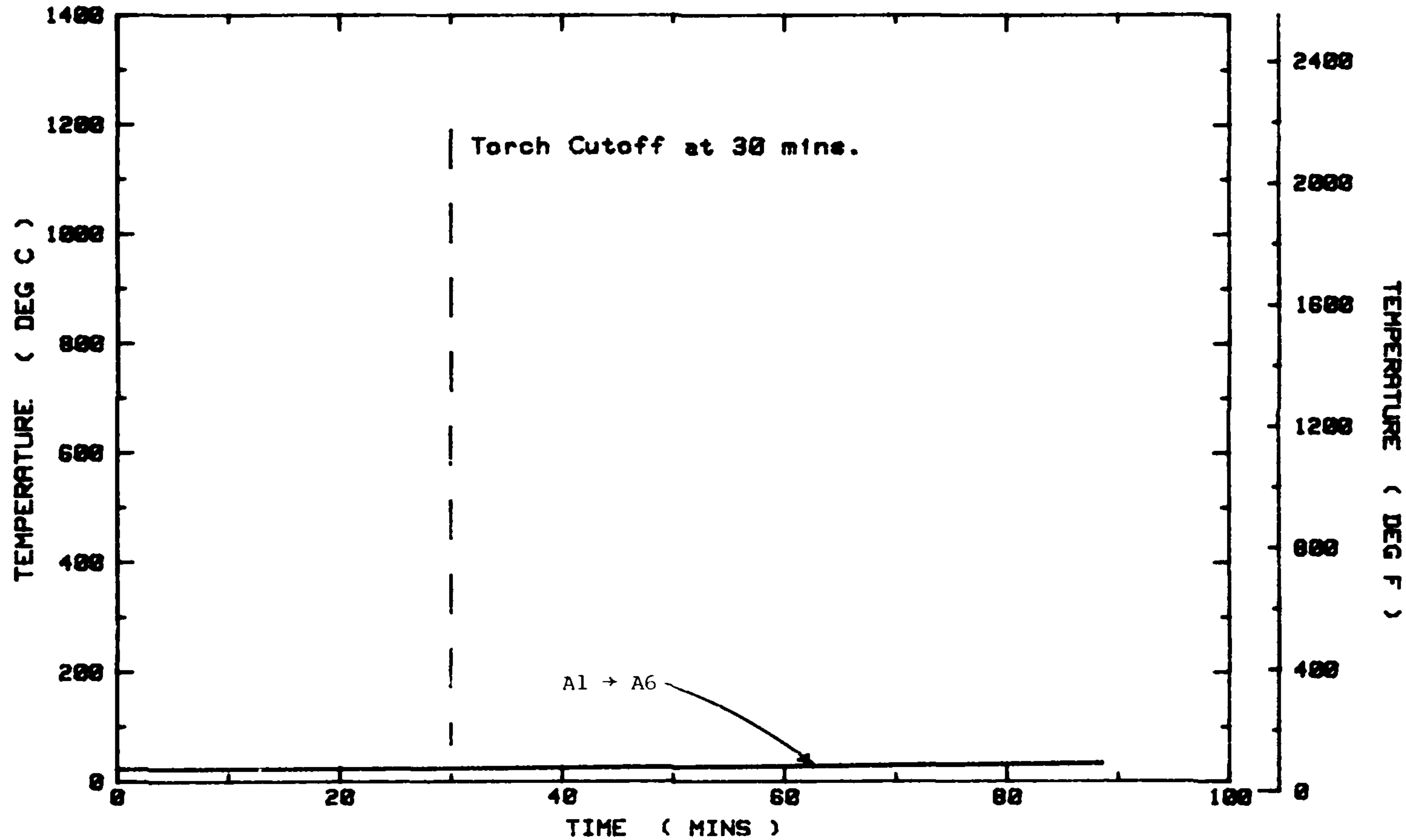

Figure 39: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS for HNPF Cask Test Number 2

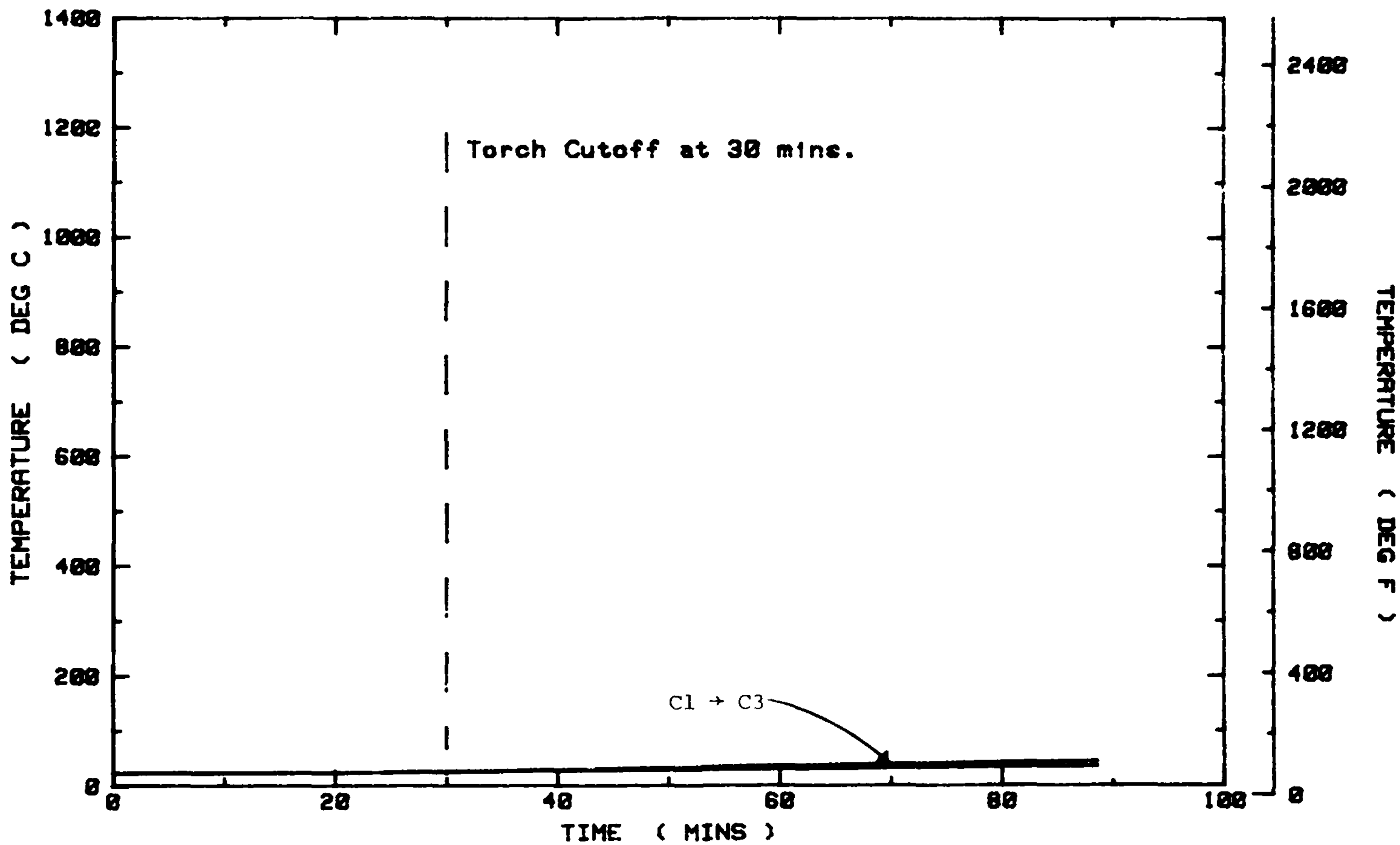

Figure 40: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS Near 20 cm for HNPF Cask Test Number 2

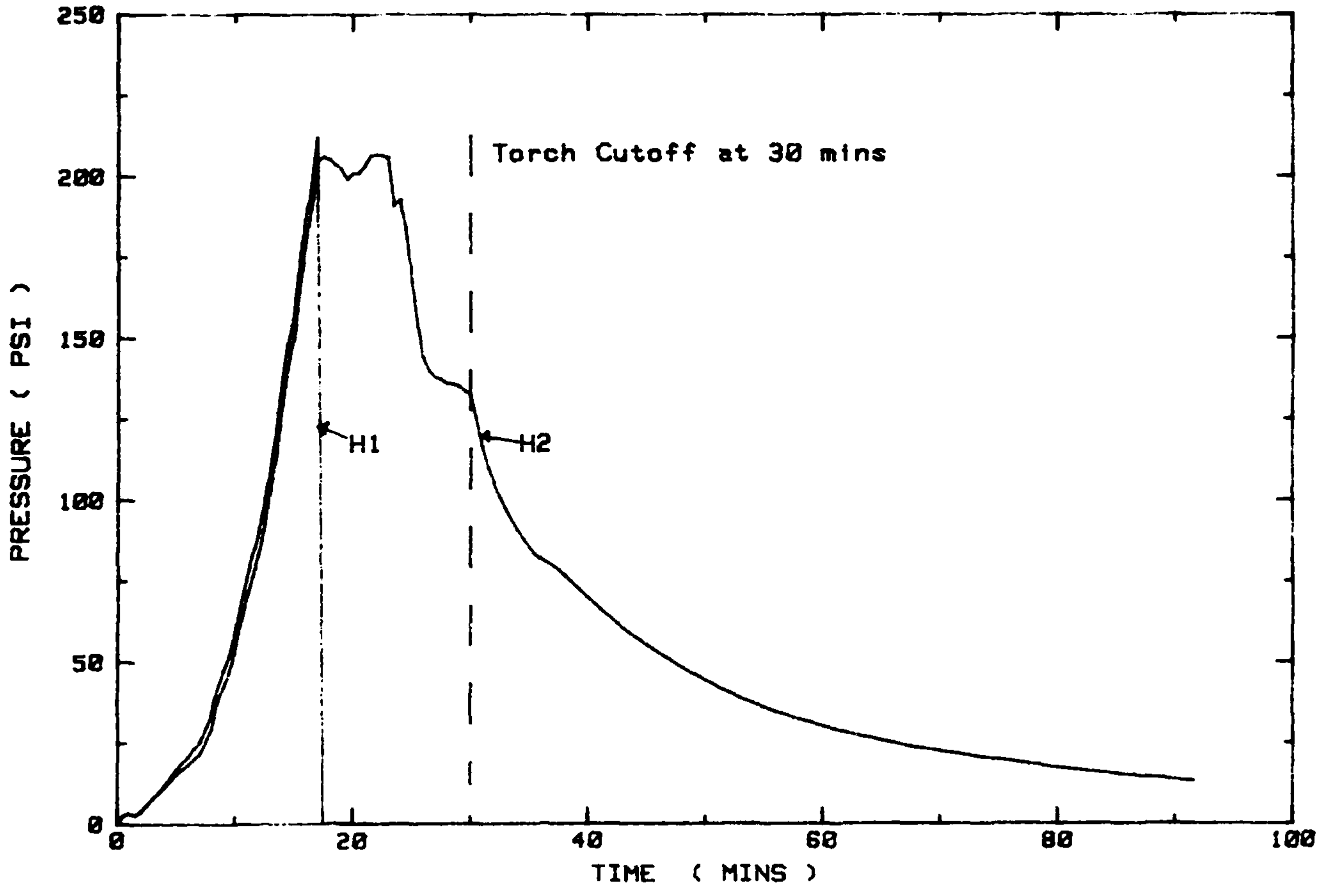

Figure 41: Pressure as Functions of Time Inside the NSJ for HNPF Cask Test Number 2

VI. DESCRIPTION OF TEST NUMBER 3

The third experiment of the series was also a torch simulation test as defined in HM-144. However, the TIC was located at 270° with respect to the ARP and the TIC was 289.6 cm (114 inches) from the XRP. Another important difference from the first two experiments was that the NSJ was voided of any water. Since the test was a torch simulation, the nozzle of the torch was 366 cm (12 feet) from the TIC and the time length of the test was 30 minutes. Figure 42 presents a photograph of the torch impinging on the HNPF Cask taken while Test Number 3 was in progress.

The data describing physical parameters which constituted the environmental conditions during the experiment are presented in Figures 43 through 46. The wind direction changed a great deal during the test as shown in Figure 43, especially over the second half of the execution time. The wind speed, shown in Figure 44, also varied extensively and for a period of twelve minutes exceeded eight miles per hour. Both of these factors required that the torch flame be adjusted in order that the TIC be continuously positioned in as nearly the same location as possible. The water bath was initially placed at a temperature of 40° C and allowed to decline slightly during the test as indicated in Figure 45. In the same figure the temperature of the air is shown to have remained in the neighborhood of 30° C. The temperature of the propane as it passed through the orifice was also steady and only slightly below the temperature of the water bath. The temperature of the flame of the torch as a function of time is presented in Figure 46. The symbol designators are different in this case from in previous tests in that there are two prefix alphabetic characters (FF) rather than one and the symbol "FF" is an acronym for the words "front flame." The average temperature was approximately 1150° C throughout the entire test until the torch was extinguished in 30 minutes following the start of the test. Apparently, the adjustment of the torch direction was sufficient for taking in to account the variations in the wind speed and direction.

The schematic which shows the relative axial positions of the TIC with respect to the XRP and the TIC for Test Number 3 is presented in Figure 47. In this case, in contrast to Test Number 1, practically all of the TCs are concentrated around the cross-sectional plane which contained the TIC. Figure 48 presents the TCs in their angular positions which are in that plane. Since the TIC is positioned at 270°, additional TCs are distributed on that side of the cask and the same TCs used before in previous tests on the other side of the cask are also included.

The data which describes the variations of the temperature as functions of time for the TCs positioned on the exterior surface of the NSJ are presented in Figures 49 and 50. Figure 49 presents temperature data from TCs which were distributed axially along the cask at the angular positions of 90° and 270° with all but F1, F2, and F3 clustered about the axial position of 289.6 cm from the XRP. The TCs F19, F20, F21, F22, and F23 were on the same side as the TIC at 270° with F19 positioned on the axial position of 289.6 cm. F19 measured the lowest values of this group of TCs; thus, again the flame appeared to be cooler near the center. The maximum temperature achieved was 950° C which was only 200° C below the measured flame temperature. Clearly, the reason for this was the empty NSJ. The TCs F10, F11, F12, F13, and F14 were positioned in the axial direction in the same positions as were the TCs just discussed except they were located on the other side of the cask at 90° angular position.

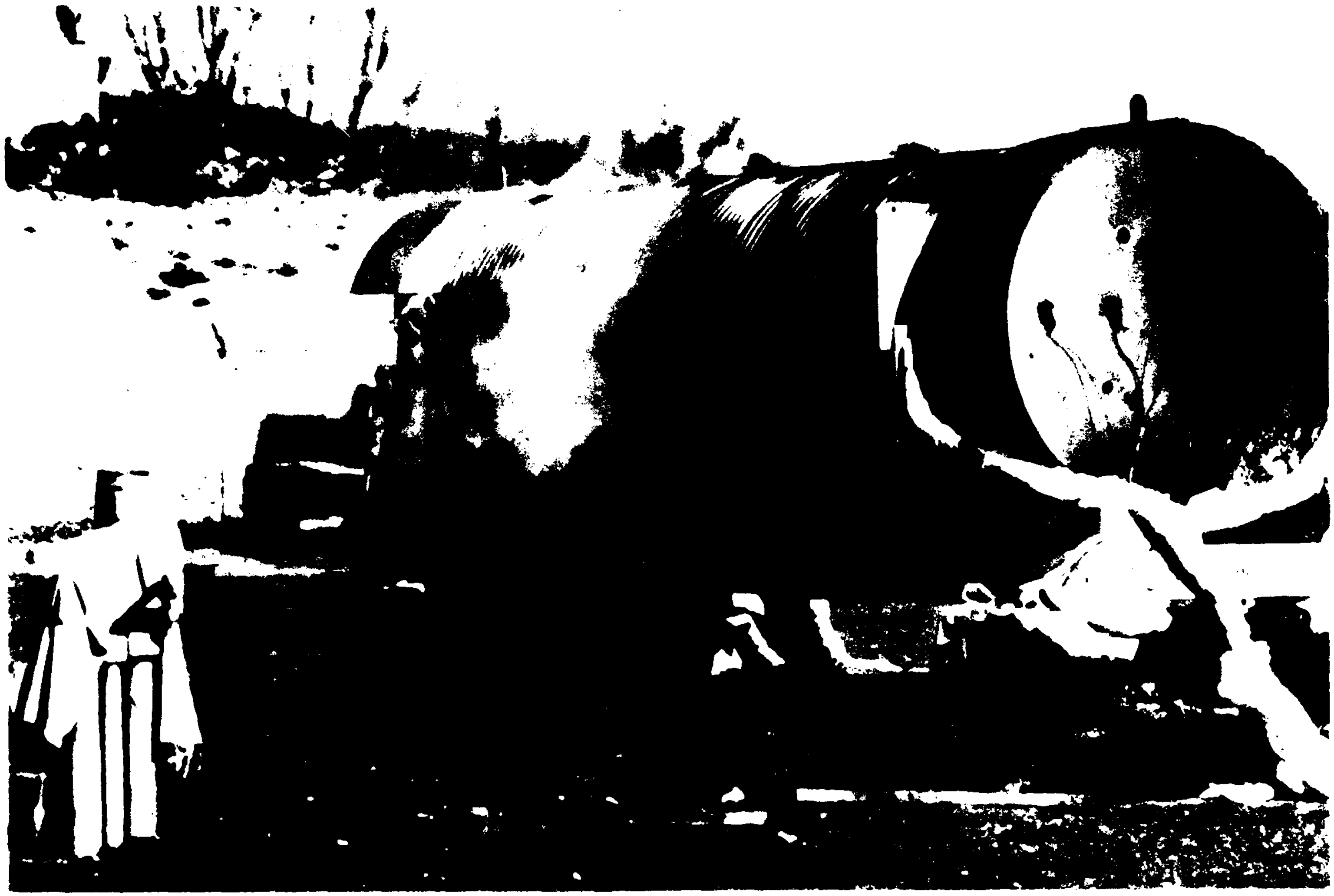

Figure 42: A View of the HNPF Cask Taken During Torch Thermal Test Number 3

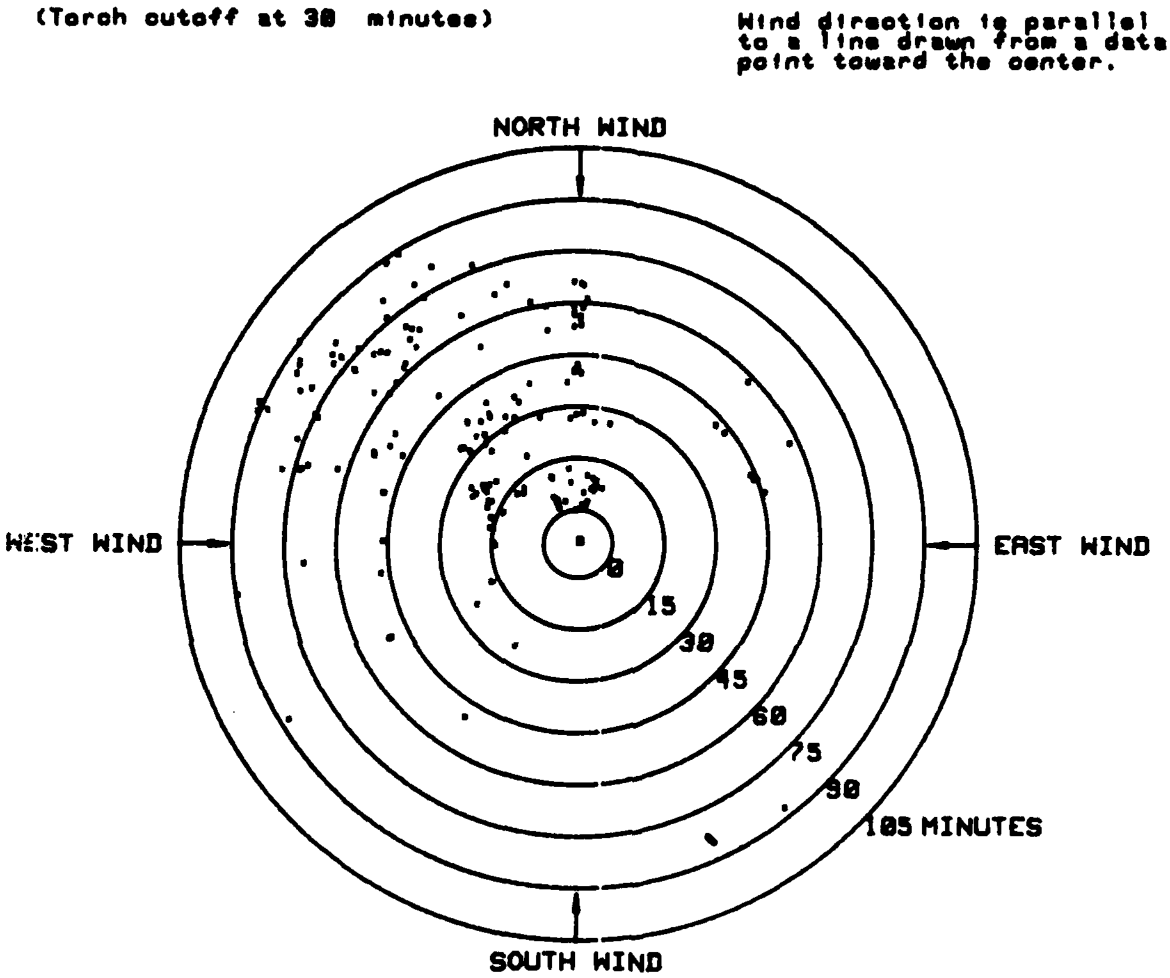

Figure 43: The Wind Direction as a Function of Time During the HNPF Cask Thermal Test Number 3

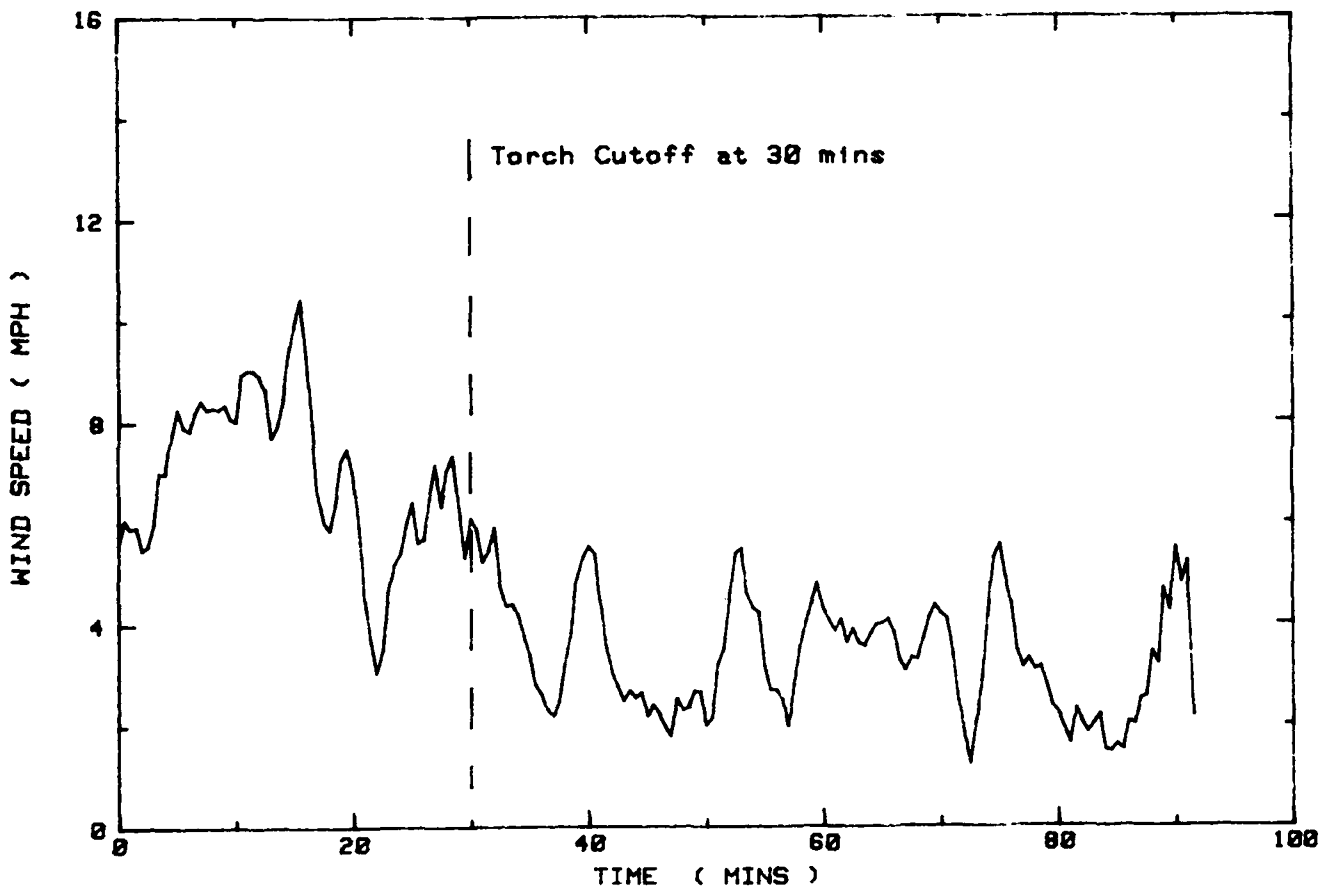

Figure 44: The Wind Speed as a Function of Time During the HNPF Cask Thermal Test Number 3

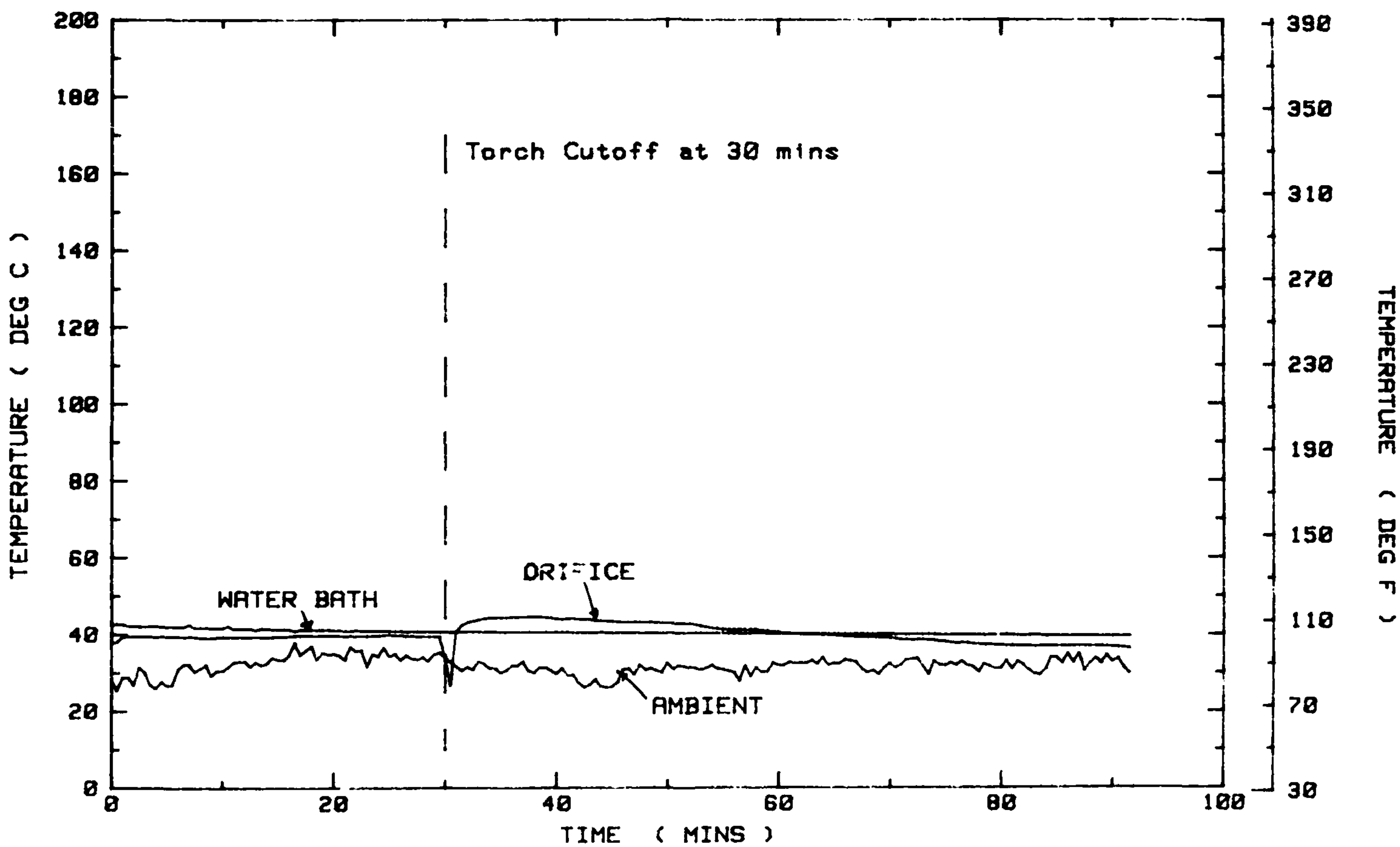

Figure 45: The Ambient, Water Bath, and Torch Nozzle Orifice Temperatures as Functions of Time During the HNPF Cask Test Number 3

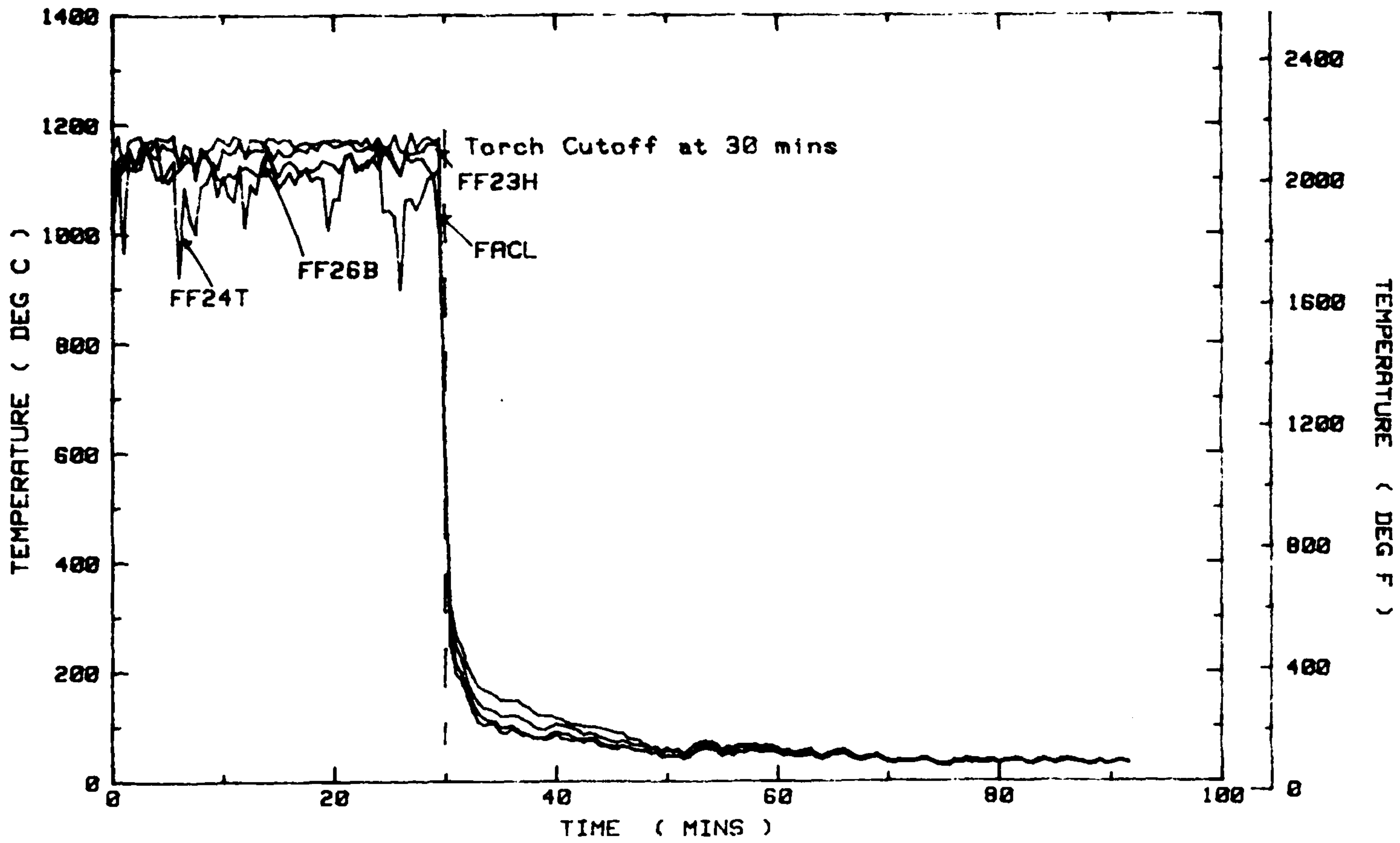

Figure 46: The Flame Temperature of the Propane Torch as Functions of Time for HNPF Cask Test Number 3

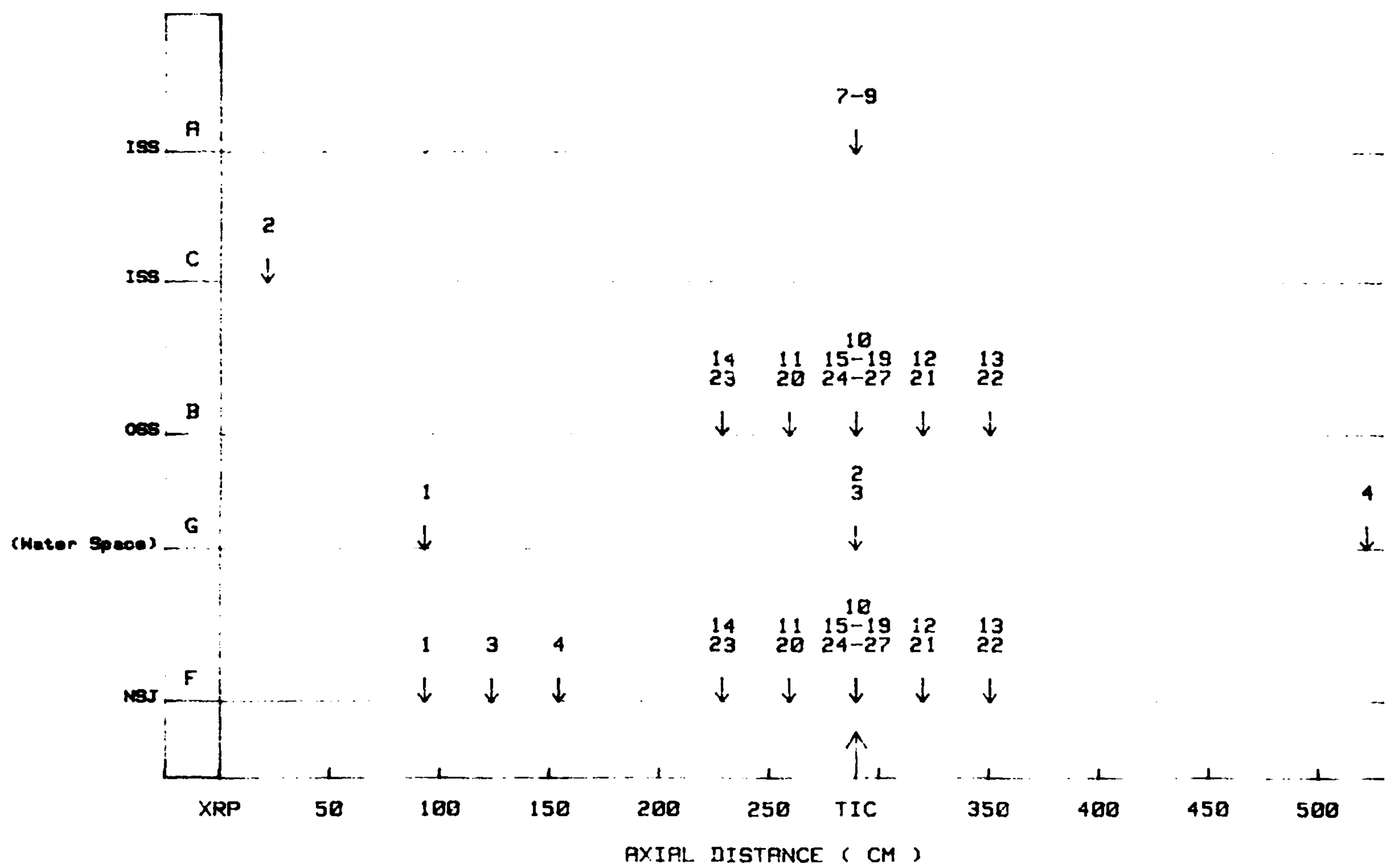

Figure 47: Axial Locations of the Thermocouples (TC) Relative to the XRP and the TIC for Various HNPF Cask Surfaces in Test Number 3

TIC -- TORCH IMPINGEMENT CENTER
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

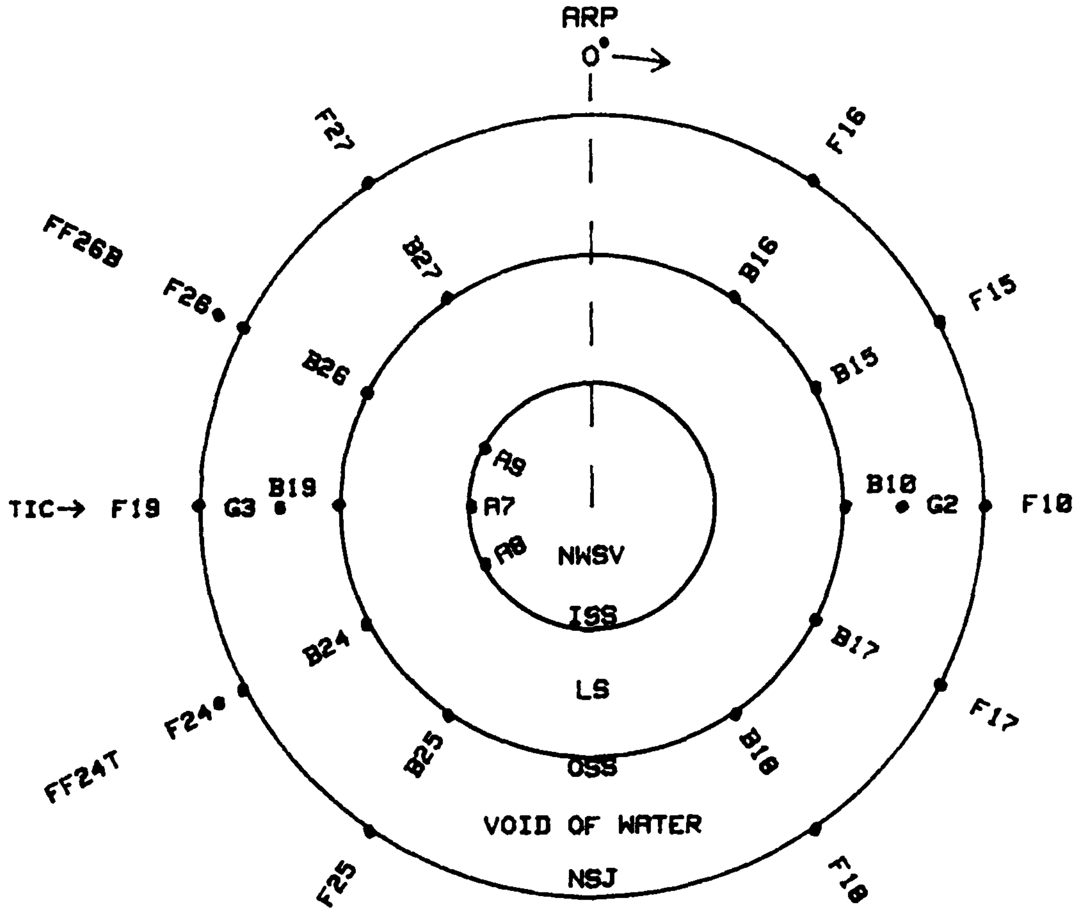

Figure 48: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at 289.6 cm from the XRP as Viewed from the Top End with the TIC Located at 270° for Test Number 3

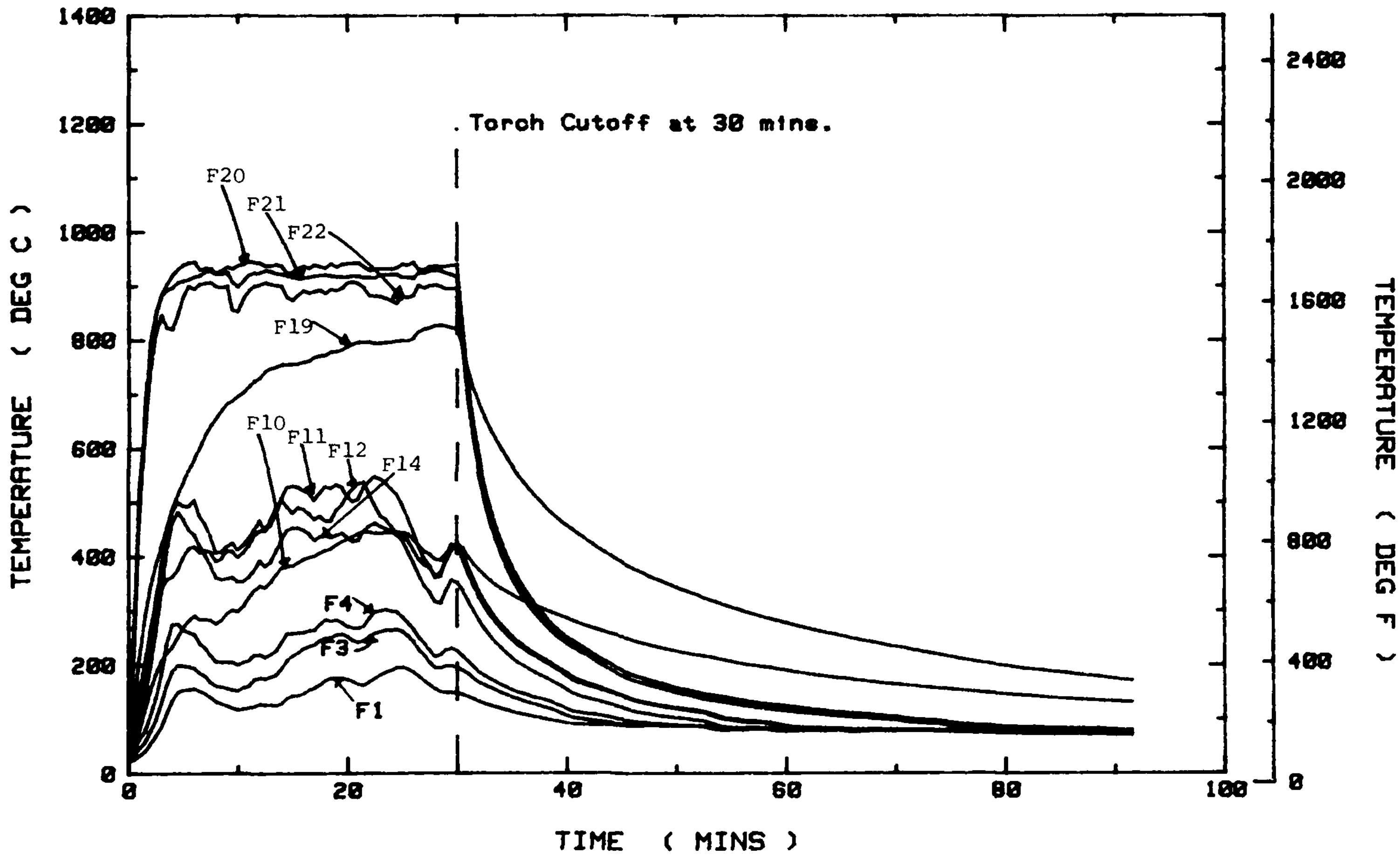

Figure 49: Temperature as Functions of Time for TCs Centered About the Position 289.6 cm from the XRP and Located on the Outer Surface of the NSJ for HNPF Cask Test Number 3

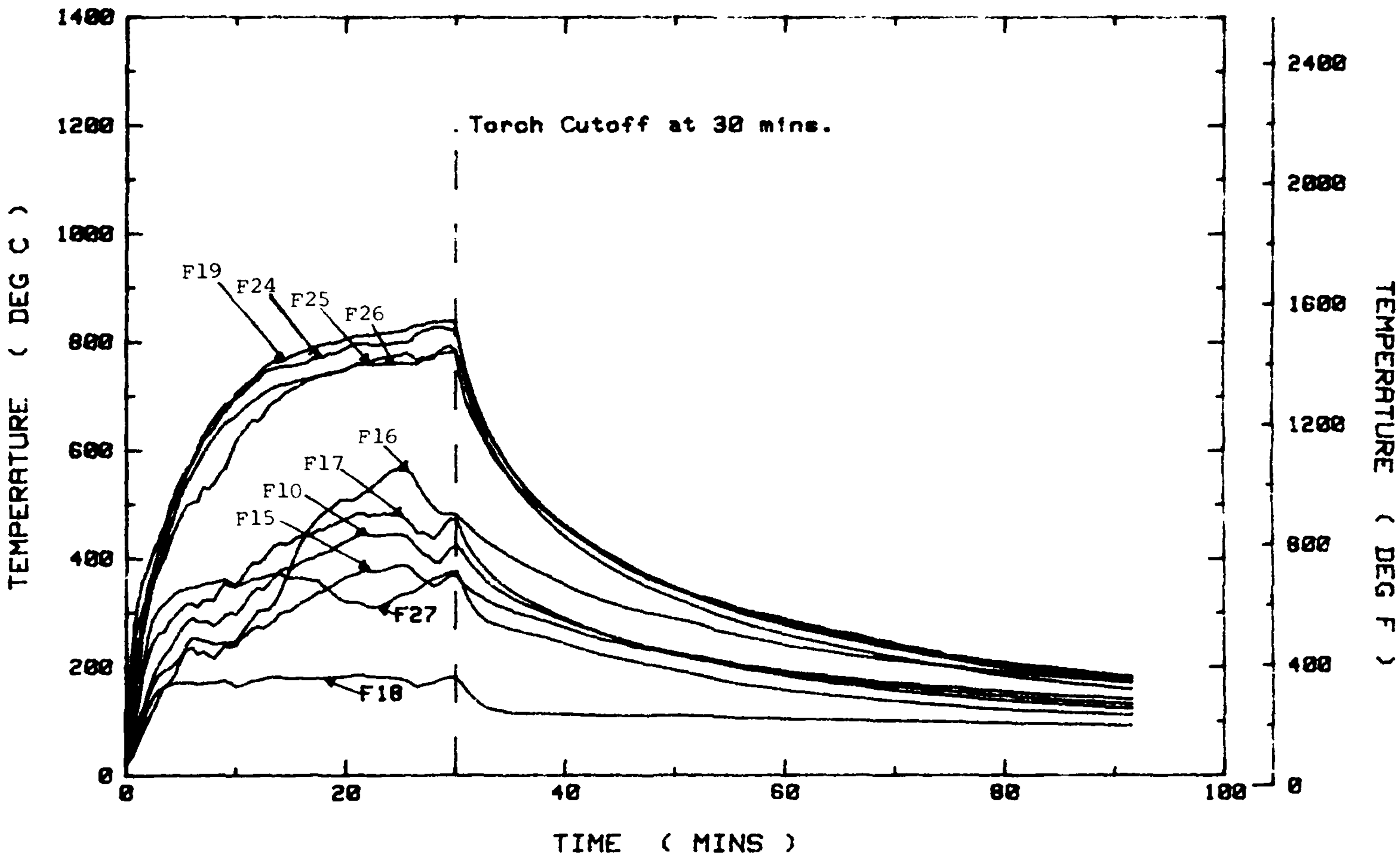

Figure 50: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 289.6 cm on the Outer Surface of the NSJ for HNPF Cask Test Number 3

While there was some spread in their measurements, the average temperature achieved was in the neighborhood of 450 $^{\circ}$C, nearly half that value of the other TCs. The TCs which measured the lowest temperatures were F1, F3, and F4. The reason for this was due to the distance from the TIC (centered about 165 cm from the XRP) and the fact that these TCs were also on the opposite side of the cask from the TIC. Figure 50 presents the temperature profiles for the TCs which were distributed angularly at the axial position of 289.6 cm, the same axial position of the TIC. The TCs F19, F24, F25, F26, and F27 were located on the same side as the TIC. All of these measured temperatures such that the temperature profiles are similar in shape and magnitude except for F27 which apparently made erroneous measurements. It is strange that the general shape of these temperature profiles **is** so much different **from** those presented in Figure 49. Also, these TCs measured about 100 $^{\circ}$C less at the peak values. The remaining TCs in Figure 50 were positioned on the opposite side of the cask from the TIC. The TC closest to the TIC measured the highest temperature (500 $^{\circ}$C) and was designated F16. F18 was the TC located the farthest away from the TIC, and it measured the lowest peak temperature (175 $^{\circ}$C). The effect of not having water in the NSJ is apparent by the values of these data.

The temperature data presented in Figure 51 were measured by the TCs located inside the NSJ which would be measuring the temperature of the water if water had been present. Without the water, G3, which was located at the same position as the TIC, reached a temperature level of nearly 500 $^{\circ}$C. The other TCs (G2, G4, and G1) measured lower temperatures in direct proportion to their distance from the TIC. In the previously discussed test data, these TCs increased gradually and at the same rate because of the water in the NSJ. That was not the case without the water.

The temperature as functions of time for the TCs positioned on the outer surface of the OSS **is** presented in Figures 52 and 53. The TCs which measured the data in Figure 52 were distributed axially around the axial position 289.6 cm. The TCs B19, B20, B21, B22, and B23 were located at 270°, on the same side as the TIC. As the figure shows, at least one of the TCs measured temperatures above 320 $^{\circ}$C which is the melting point of lead. The remaining TCs were positioned on the other side of the cask and measured temperatures not exceeding 110 $^{\circ}$C. Figure 53 presents the TCs which were distributed angularly at 289.6 cm. One of these TCs almost measured temperatures above 320 $^{\circ}$C. An additional factor is that the slope of the temperature curves, when the torch was extinguished, was positive so that if the torch had remained on, even higher temperatures would have been achieved. The significance of these high values is that the OSS is adjacent to the lead shield, so that there is a chance the lead shield partially melted. If so, it could have expanded sufficiently to damage the ISS or the OSS. In order to verify any suggestions about this, the cask will have to be disassembled and the components examined.

The temperature as functions of time for the TCs which were positioned on the inner surface of the ISS **is** presented in Figures 54 and 55. The peak value obtained in these measurements did not exceed 50 $^{\circ}$C. Since the NSJ was void of water, no pressure data were obtained for Test Number 3.

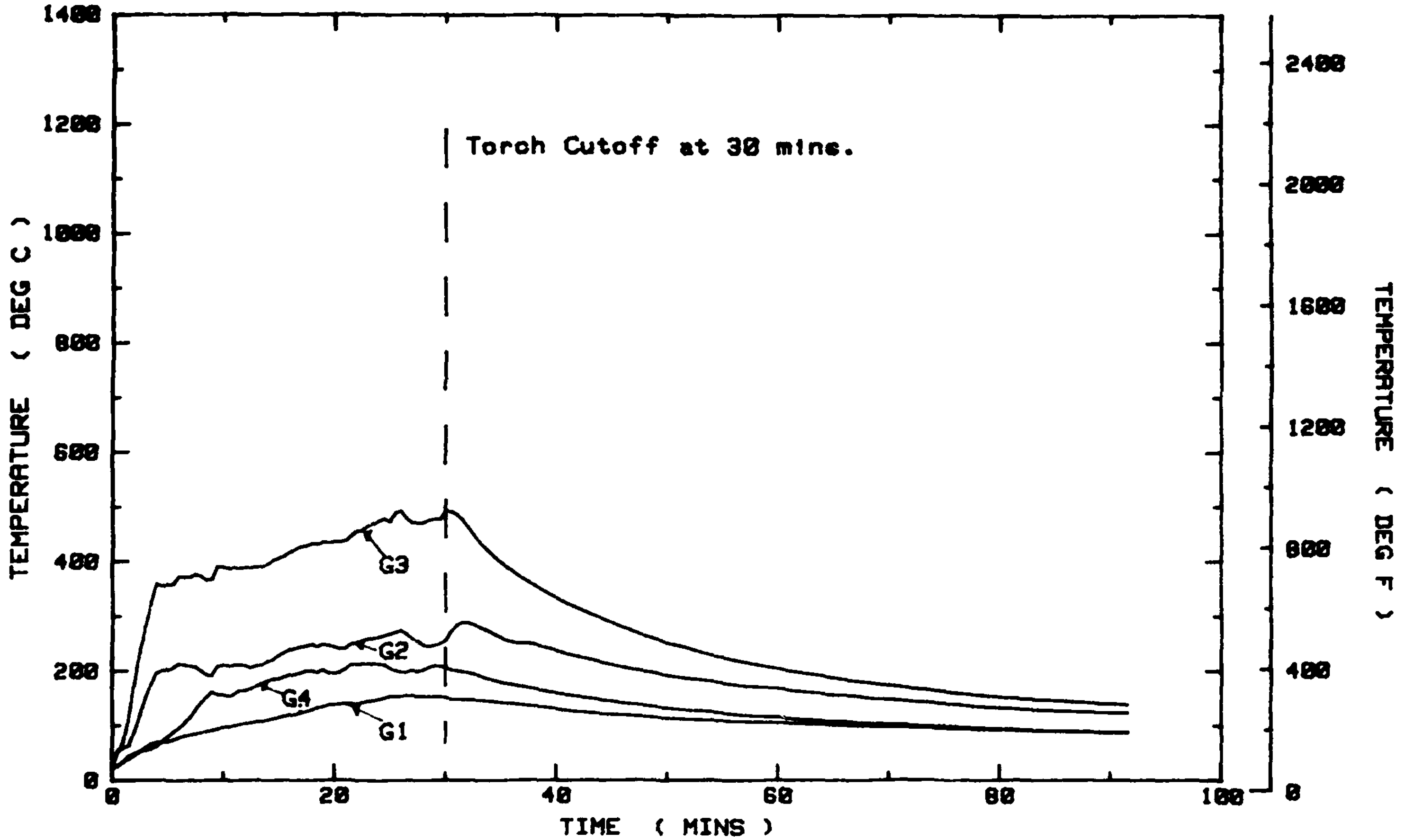

Figure 51: Temperature as Functions of Time for TCs Positioned Inside the NSJ for HNPF Cask Test Number 3

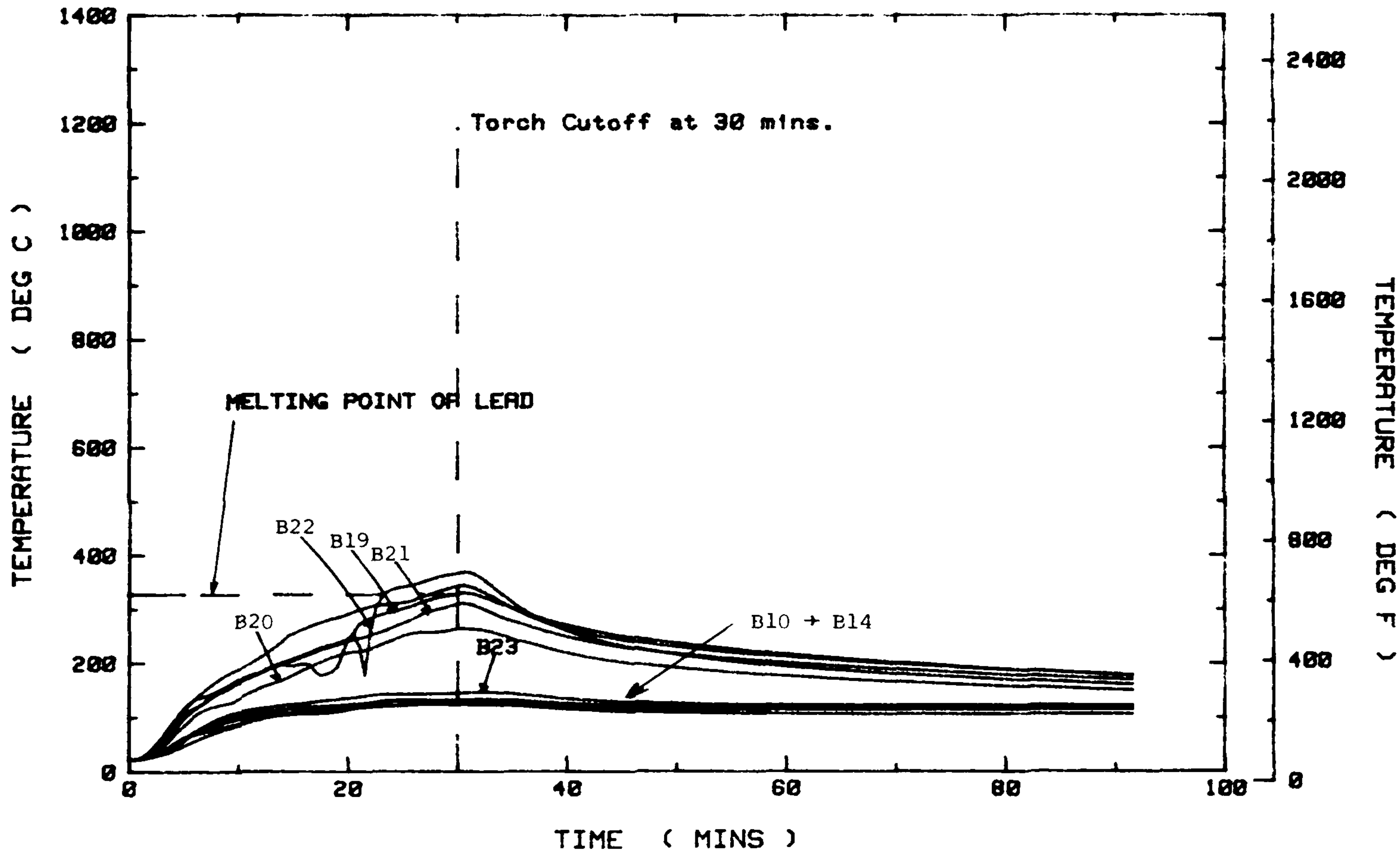

Figure 52: Temperature as Functions of Time for TCs Centered About the Position 289.6 cm from the XRP and Located on the Outer Surface of the OSS for HNPF Cask Test Number 3

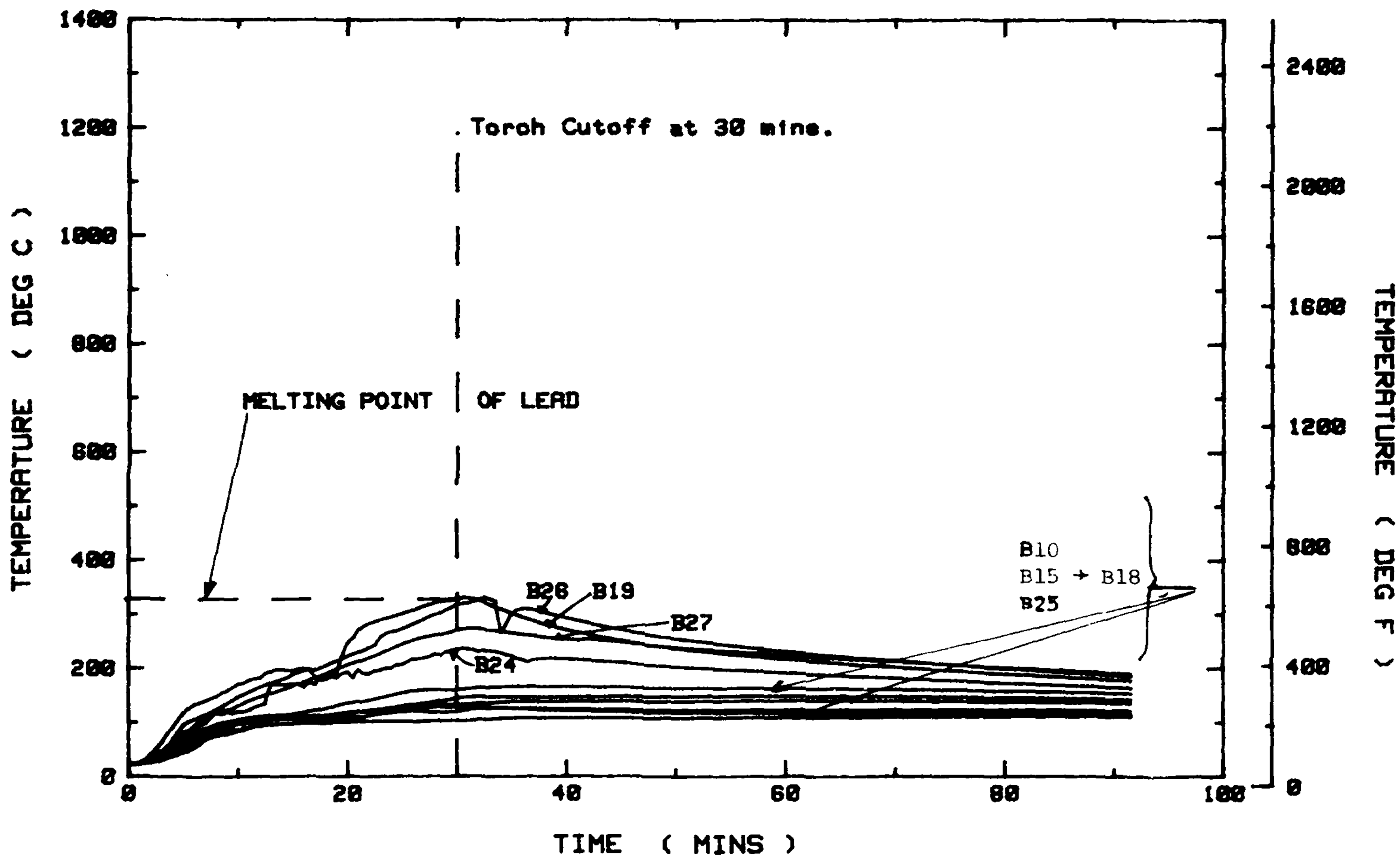

Figure 53: Temperature as Functions of Time for TCs Distributed Angularly at the Axial Position of 289.6 cm on the Outer Surface of the OSS for HNPF Cask Test Number 3

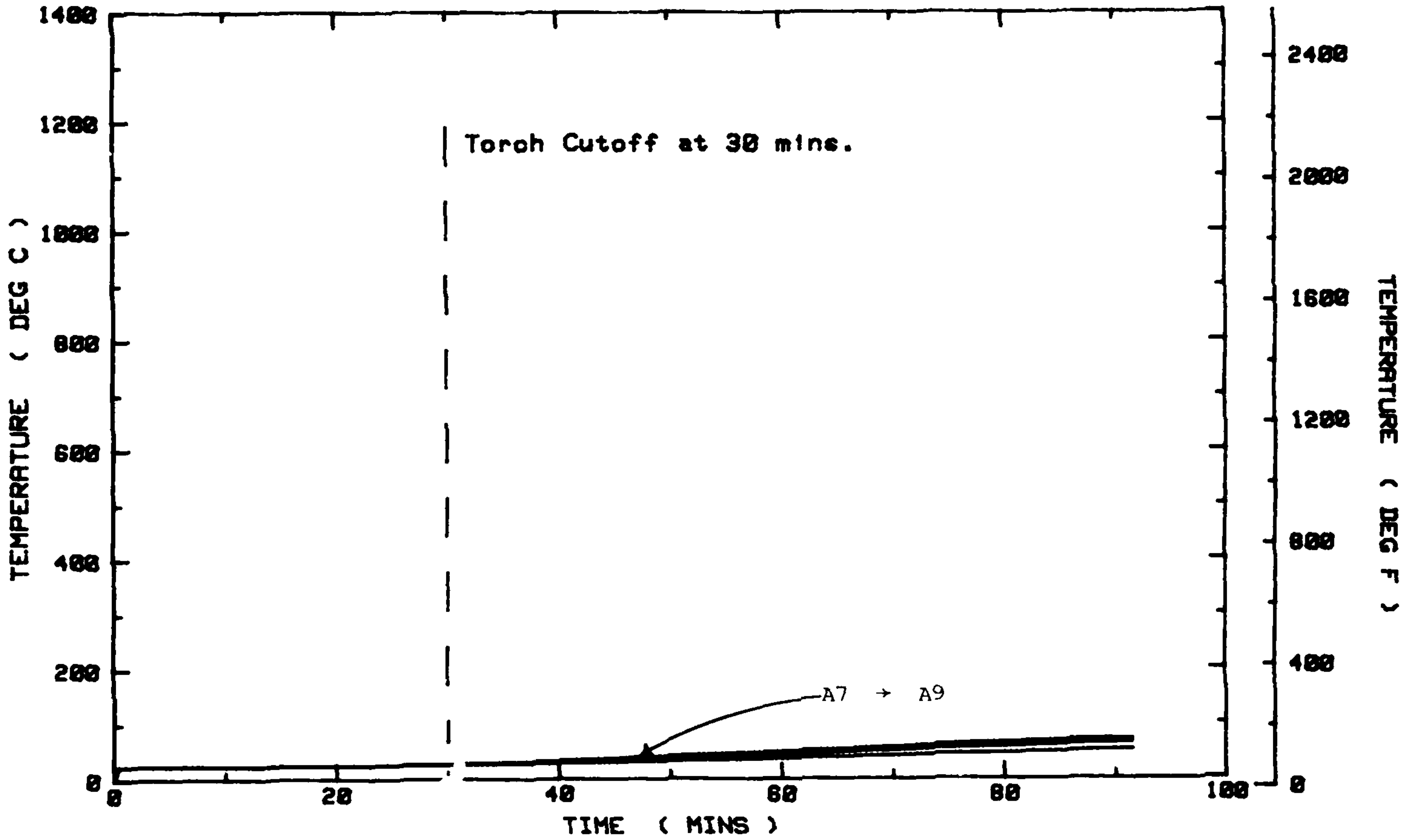

Figure 54: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS for HNPF Cask Test Number 3

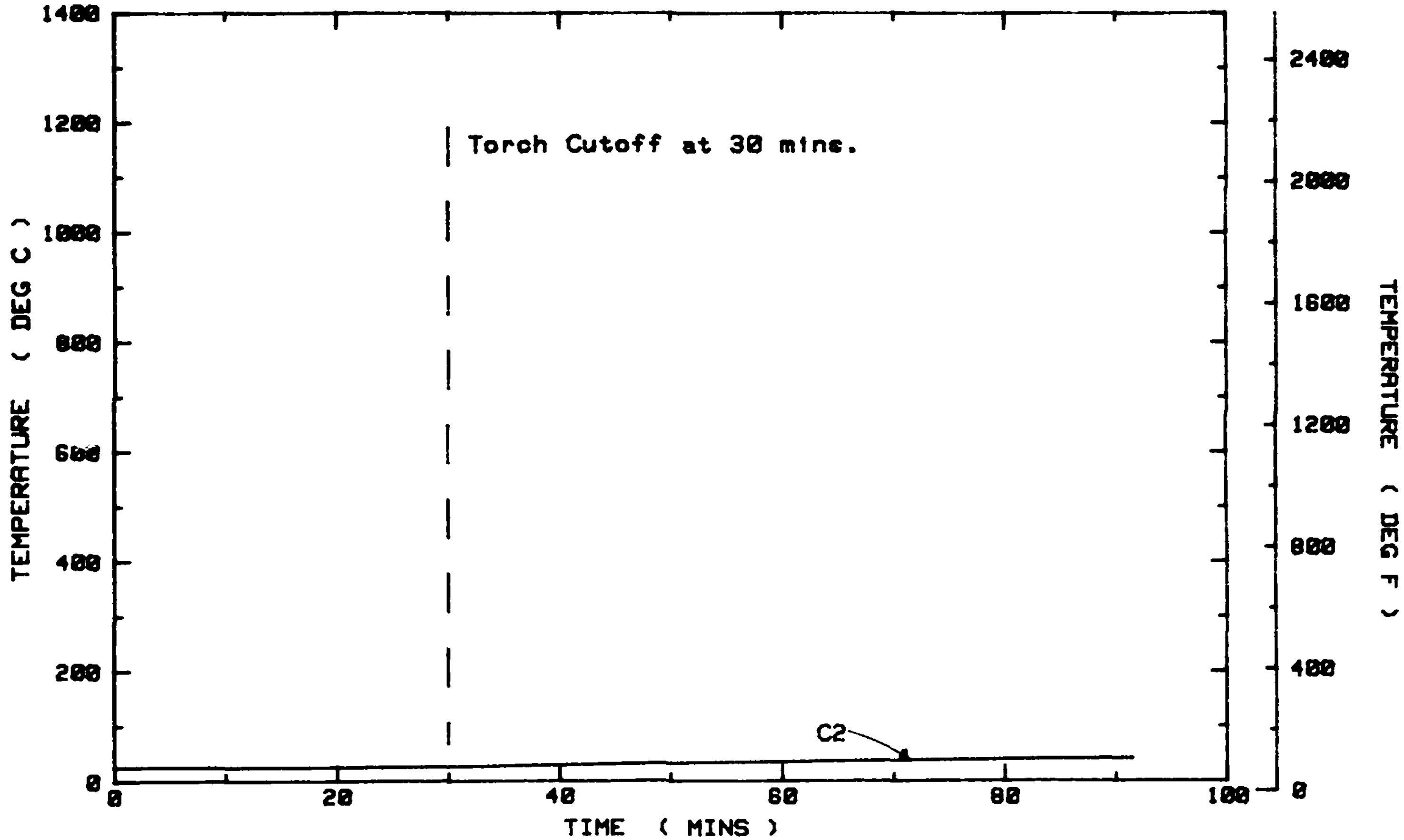

Figure 55: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS Near 20 cm from the XRP for HNPF Cask Test Number 3

VII. DESCRIPTION OF TEST NUMBER 4

The fourth test of the series was different from those previously conducted in that the TIC was directed at the top end of the cask rather than toward the side. The distance between the nozzle of the torch and the surface of the impact limiter was 366 cm (12 feet), so that this was also a torch simulation. Even though the orientation of the cask in relation to the torch was different, the TIC can still be considered to have been directed at 90^{o} relative to the ARP. Also there is some logic in considering that the TIC was at an axial distance of -60.0 cm (23.62 inches) from the XRP, which means that the outside surface of the impact limiter was that distance to the left of the XRP. The NSJ was again voided of water, and the time length of the experiment was 30 minutes. The photograph presented in Figure 56 is a view of the torch impinging on the HNPF Cask in Test Number 4.

Figures 57 through 59 present data describing the ambient conditions and temperatures related to the operation of the torch facility. The wind changed direction frequently during the test and ranged for the most part between a northerly and a westerly direction. The wind speed also varied a great deal with the speed exceeding eight miles per hour over the first seven minutes or so. No doubt if the wind speed had increased above or remained at that level, the test would have been terminated. However, the speed died down and averaged thereafter around four miles per hour. The ambient temperature remained steady around 33 ^{o}C. The temperature of the water bath and the propane passing through the orifice indicates that the torch facility operated normally throughout the test.

The schematic which shows the relative axial positions of the TCs with respect to the XRP and the TIC for Test Number 4 is presented in Figure 60. On the left side of the schematic are noted the various cask surfaces each line represents. The TIC, in this case, is shown directed in the axial direction to indicate the end-on direction of the torch. The symbol FD designates a cross-sectional plane just off the outside surface of the impact limiter. Those TCs with this designation were then used to measure the temperature of the torch flame. The symbol ST was used to designate those TCs which measured the temperature of the outside surface of the impact limiter. The TCs (FDs), which measured the torch flame temperature, were distributed as shown in Figure 61. The temperature level of the torch flame during the experiment was approximately 1200 ^{o}C (2200 ^{o}F) as indicated in Figure 62. The values of all of these TC measurements were about the same, thus indicating a constant temperature across the flame front. Figure 63 presents the distribution of TCs which were designated as STs and were positioned on the outside surface of the impact limiter. The temperature as a function of time for these TCs is presented in Figure 64. The effect of the impact limiter as a heat sink was to reduce the temperature to about 900 ^{o}C (1652 ^{o}F) from the flame temperature value of 1200 ^{o}C (2200 ^{o}F). Figure 65 presents the distribution of the D TCs which were positioned in the cross-sectional plane which consist of the inside surface of the steel covering on the impact limiter. As Figure 66 indicates, the temperature curves corresponding to these TCs are practically the same as those shown in Figure 64.

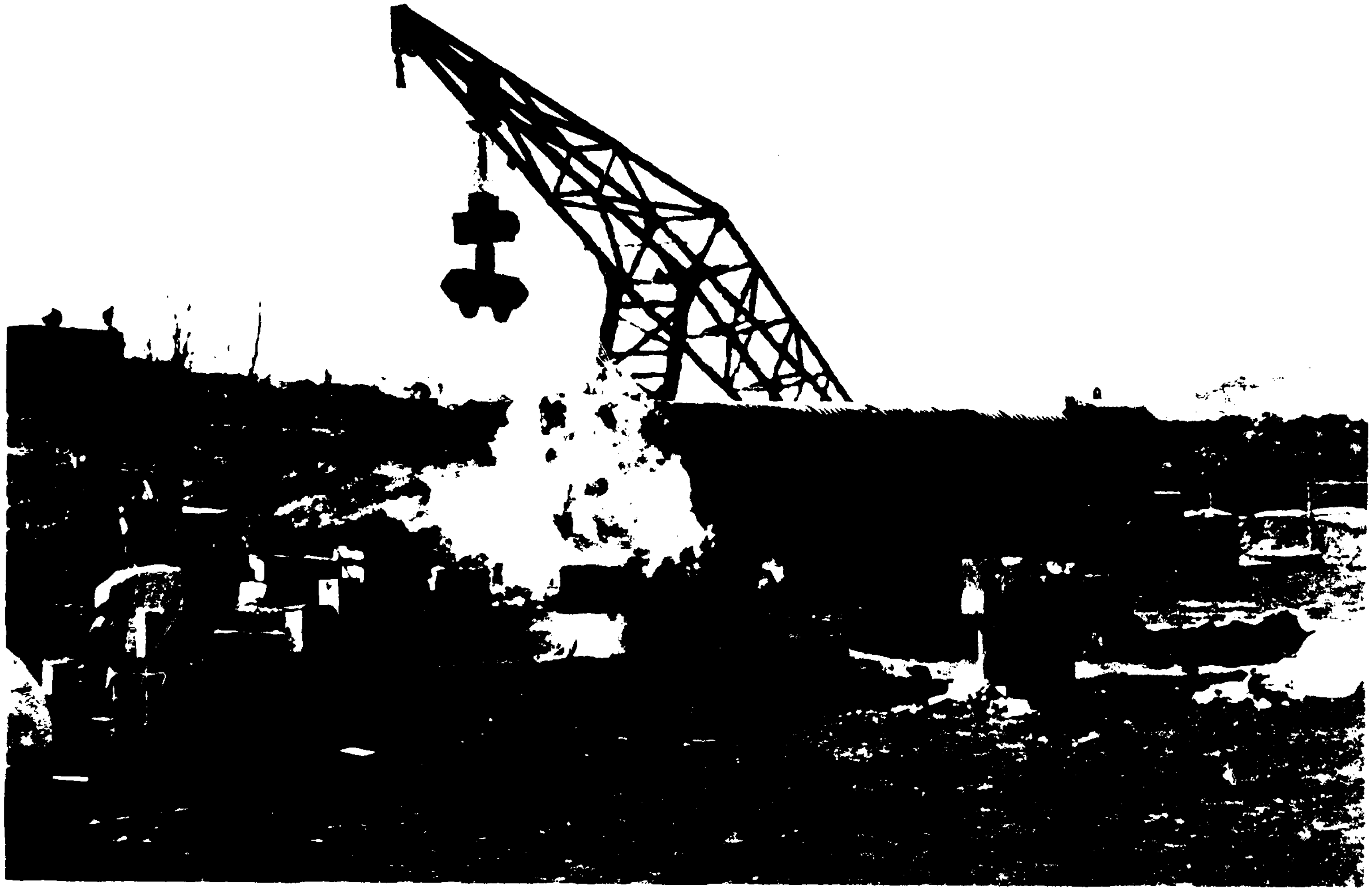

Figure [illegible]: A View of the [illegible] Cask Taken During Torch Thermal Test Number 1

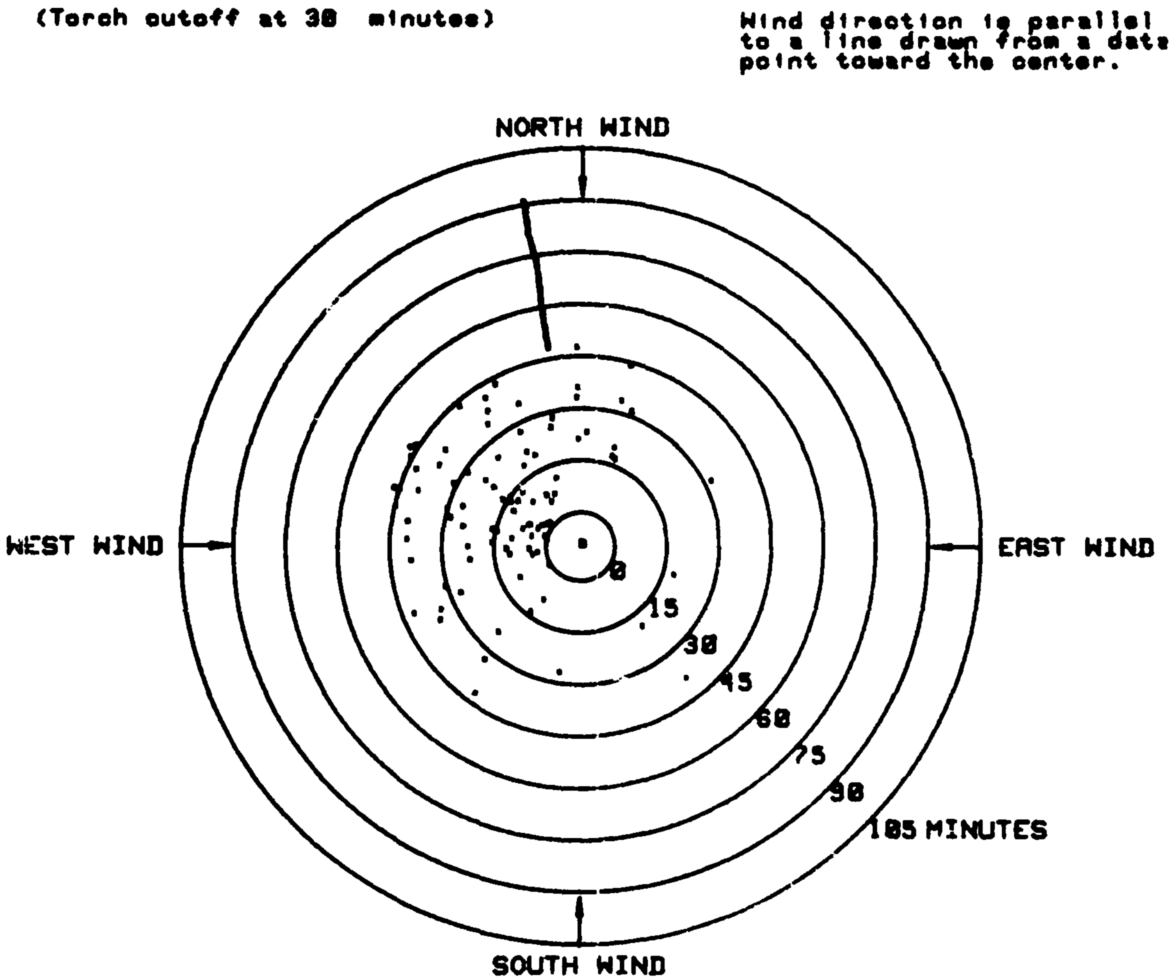

Figure 57: The Wind Direction as a Function of Time During the HNPF Cask Thermal Test Number 4

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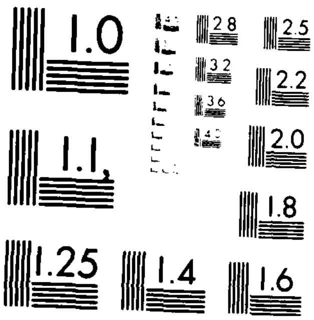

MICROCOPY RESOLUTION TEST CHART

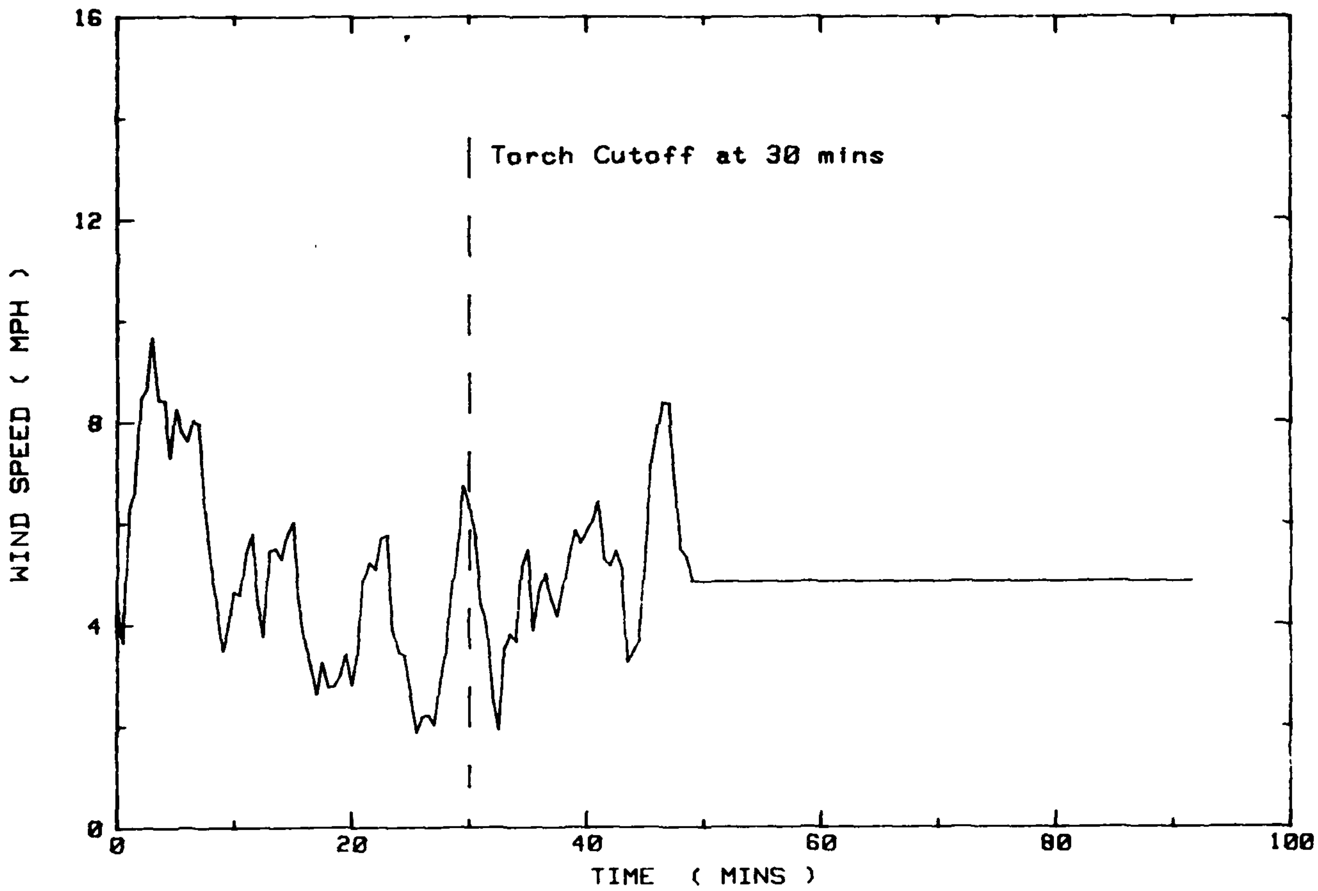

Figure 58: The Wind Speed as a Function of Time During the HNPF Cask Thermal Test Number 4

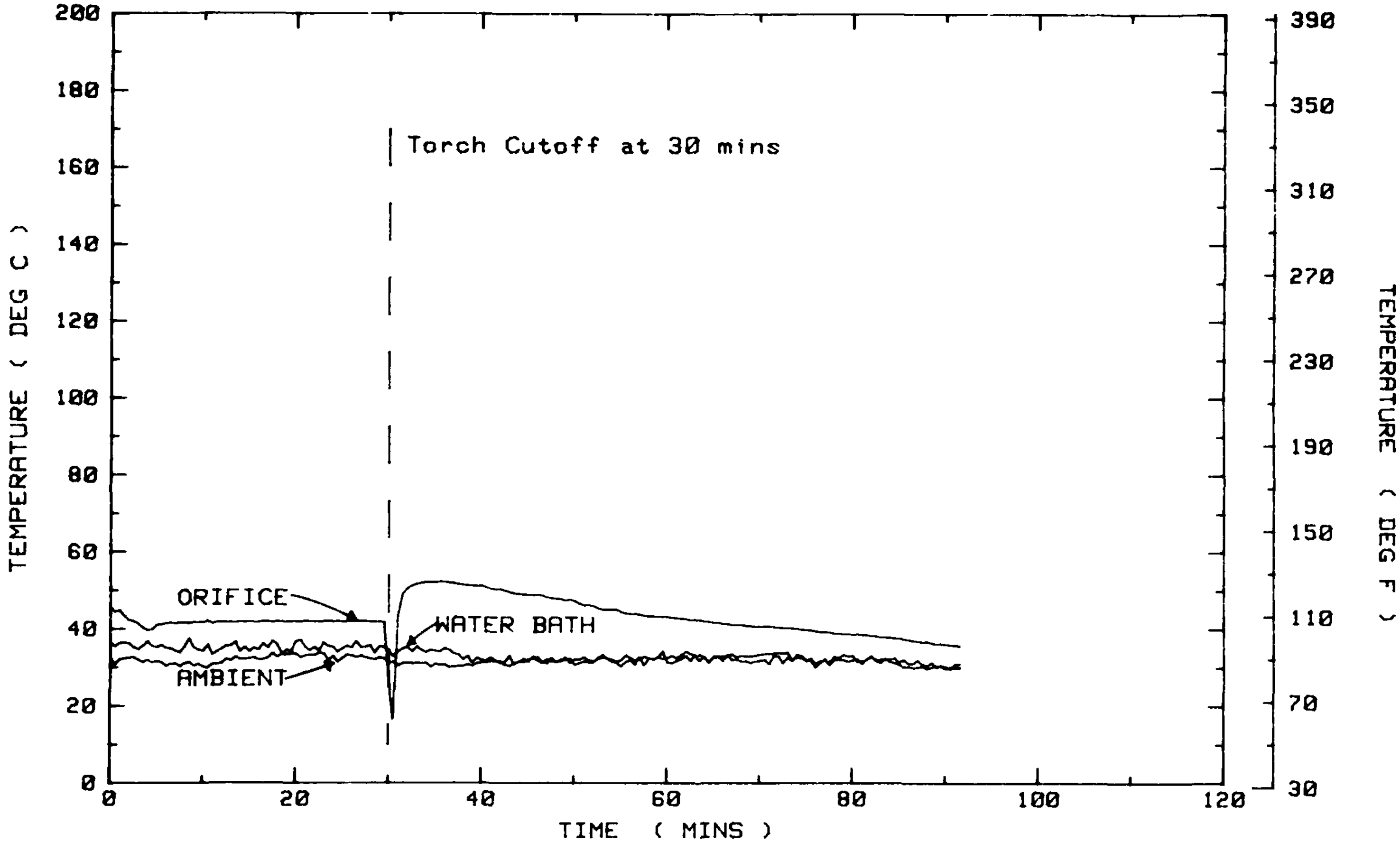

Figure 59: The Ambient, the Orifice, and the Water Bath Temperatures as Functions of Time During the HNPF Cask Test Number 4

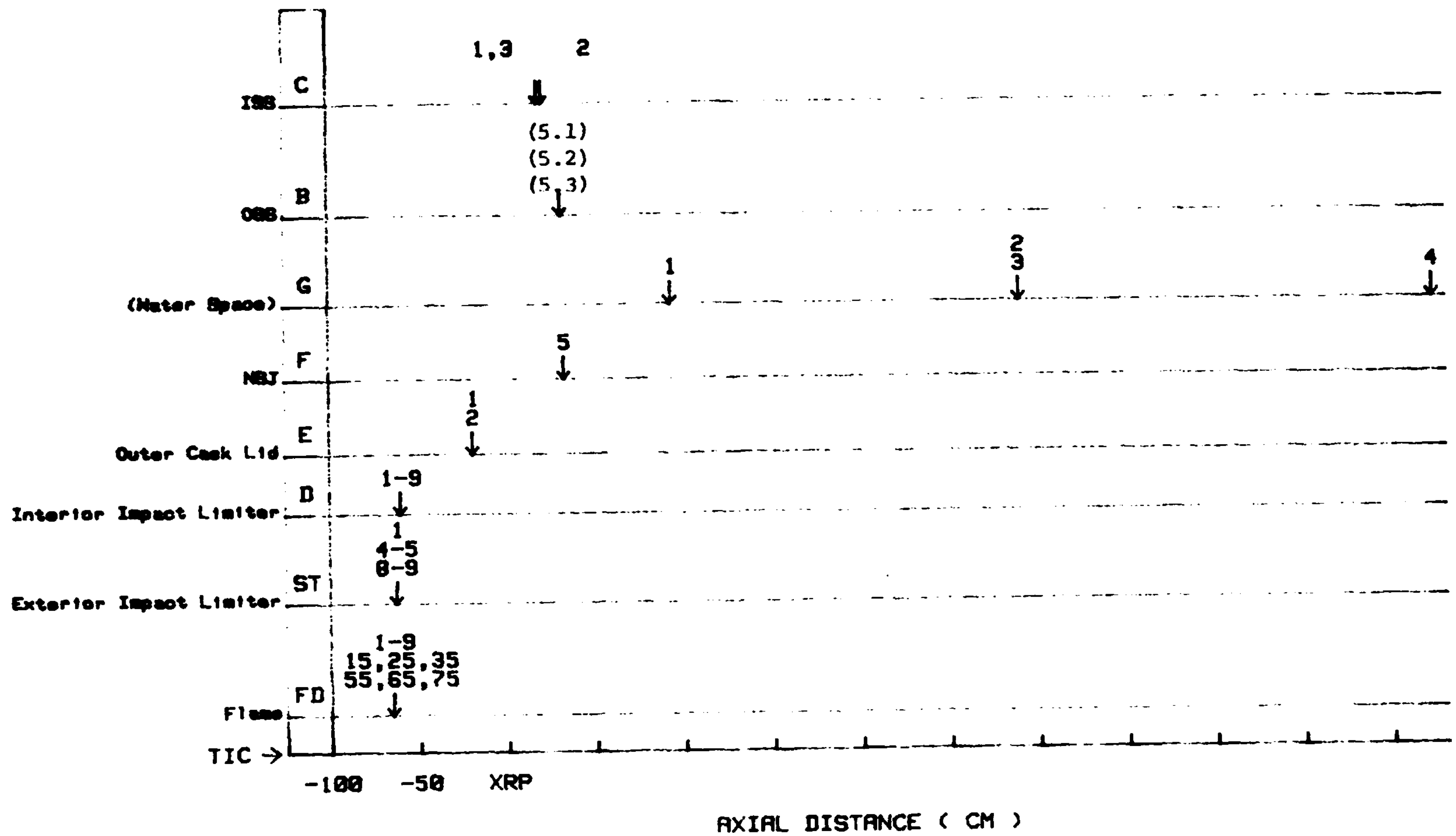

Figure 60: Axial Locations of the Thermocouples (TC) Relative to the XRP and the TIC for Various HNPF Cask Surfaces in Test Number 4

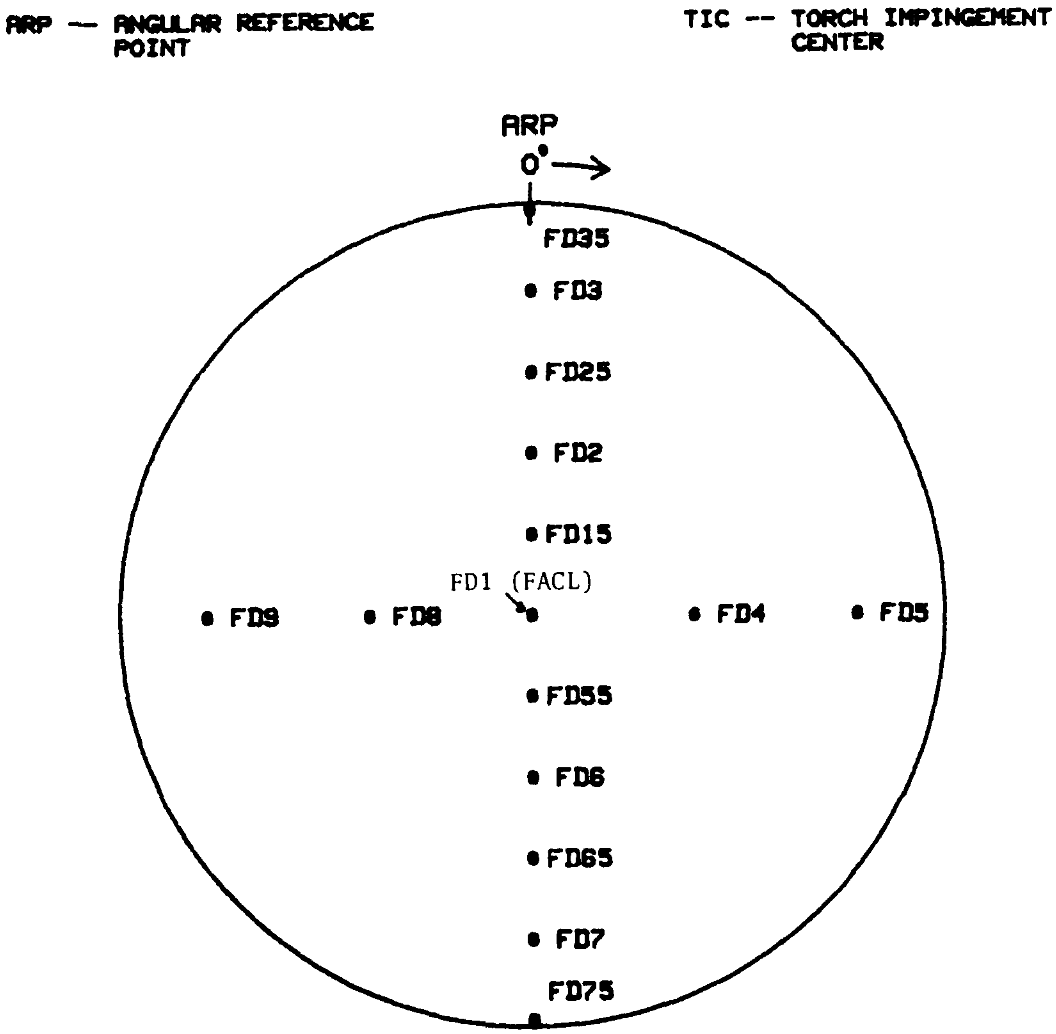

Figure 61: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at -65.1 cm from the XRP as Viewed from the Top End with the TIC Located at the Center of the Impact Limiter for Test Number 4

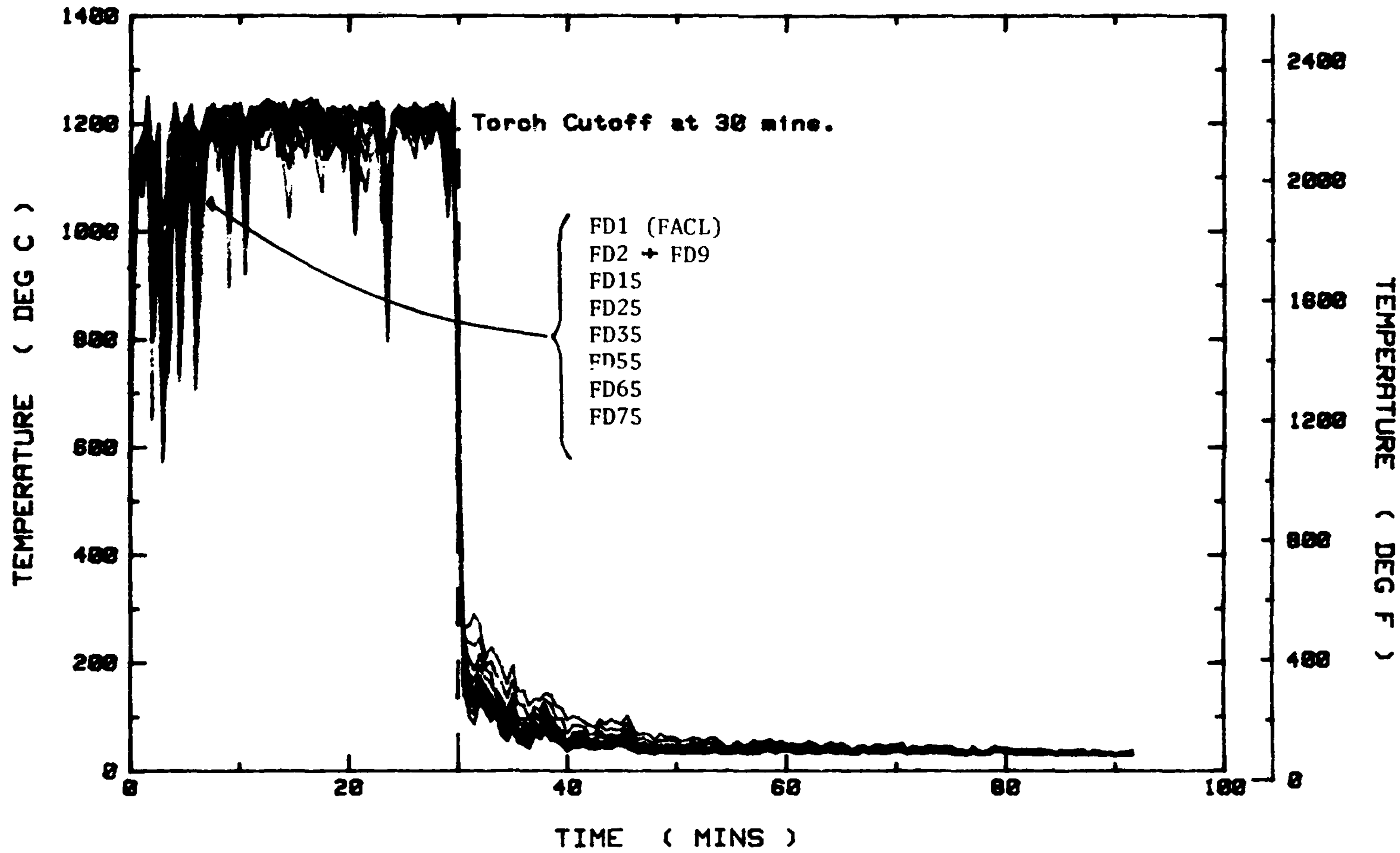

Figure 62: The Flame Temperature of the Propane Torch as Functions of Time for the Exterior Surface of the Impact Limiter for HNPF Cask Test Number 4

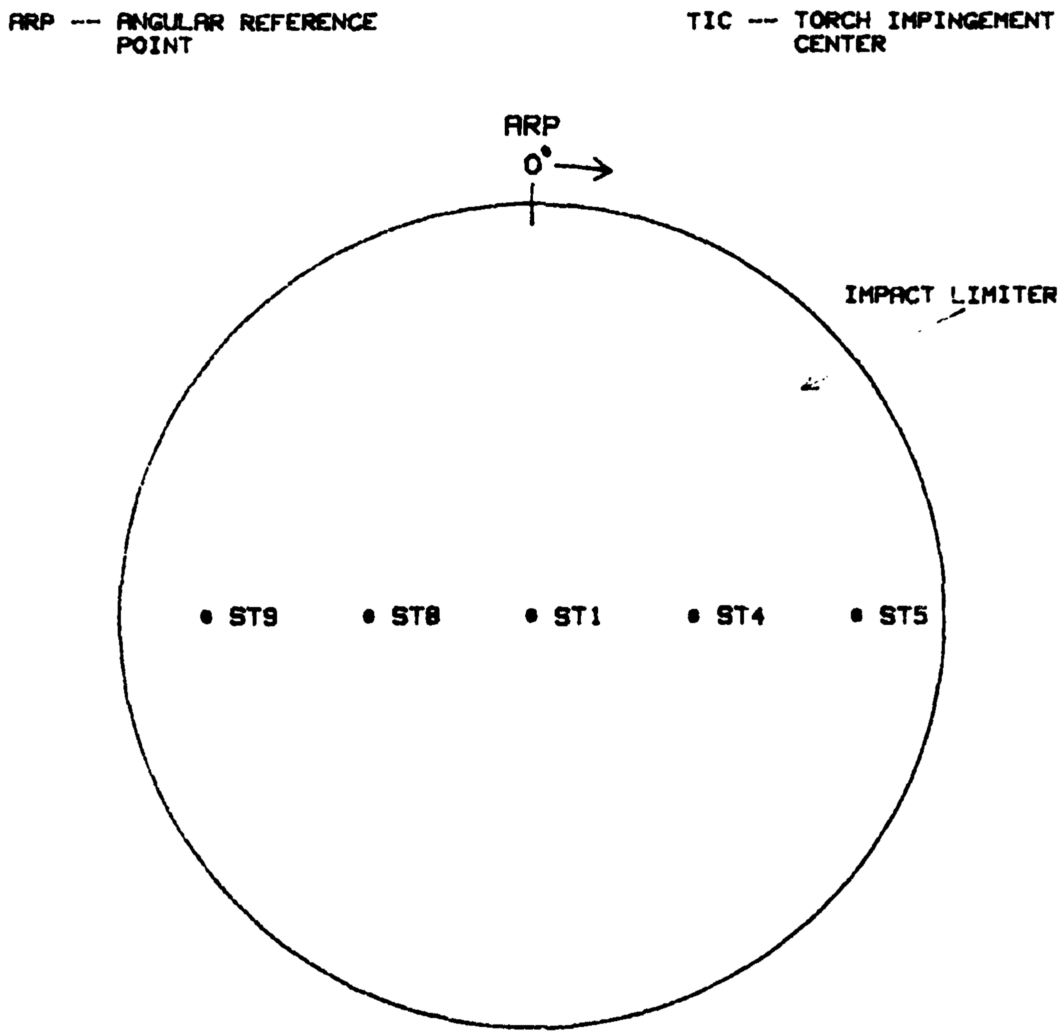

Figure 63: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at -62.5 cm from the XRP as Viewed from the Top End with the TIC Located at the Center of the Impact Limiter for Test Number 4

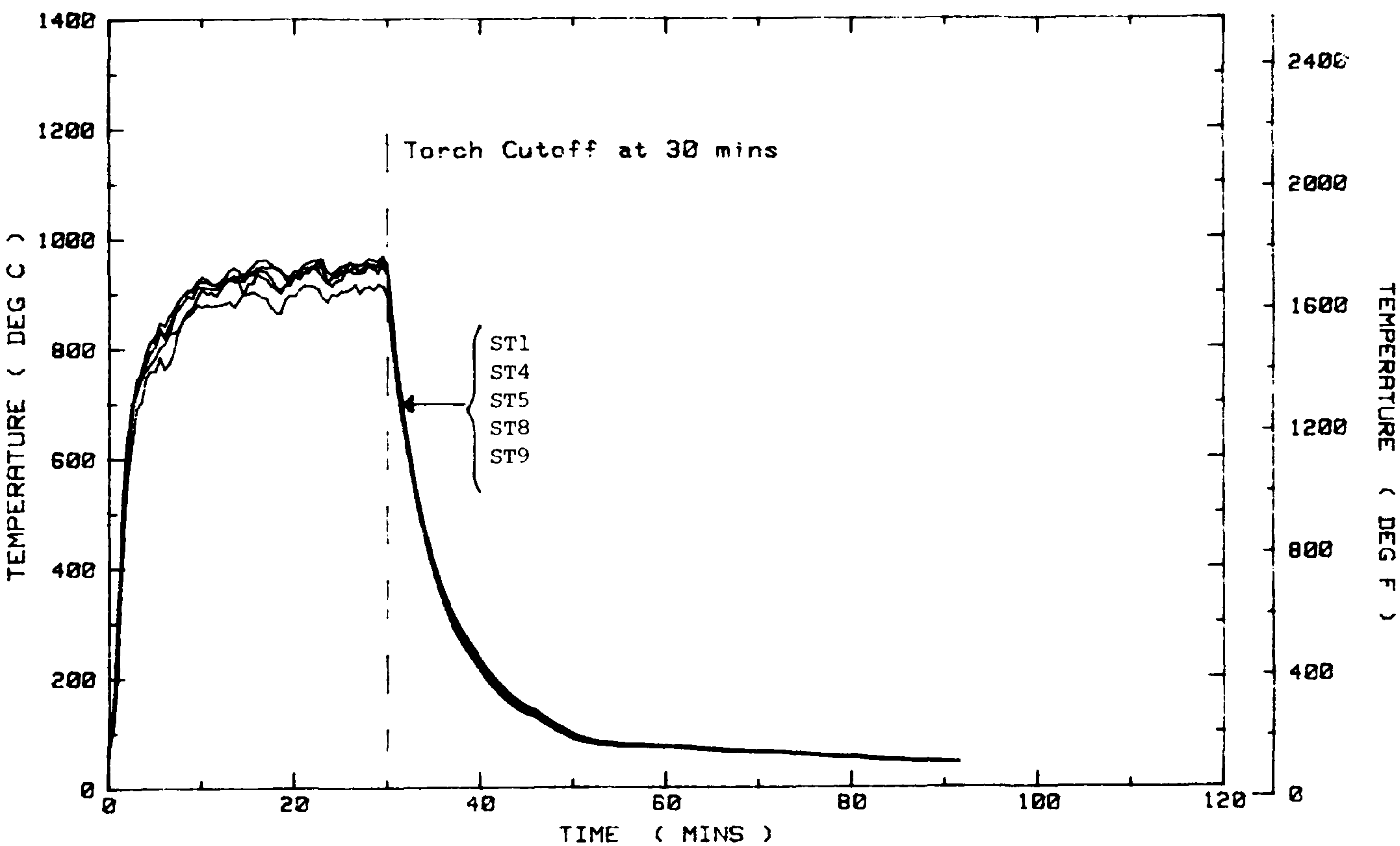

Figure 64: The Temperature as Functions of Time for the Cross-Sectional Plane Through the HNPF Cask at -62.5 cm from the XRP as Viewed from the Top in Test Number 4

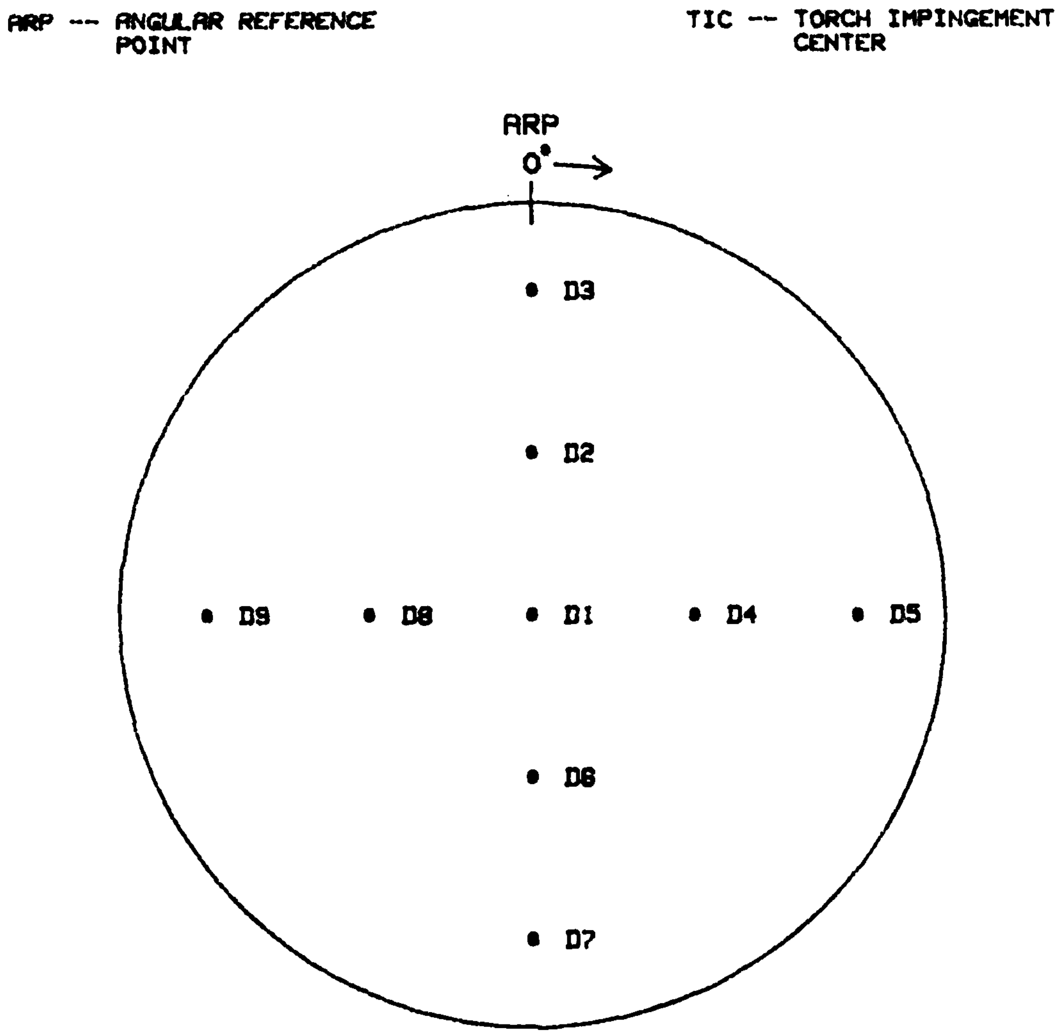

Figure 65: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at -60cm from the XRP as Viewed from the Top End with the TIC Located at the Center of the Impact Limiter for Test Number 4

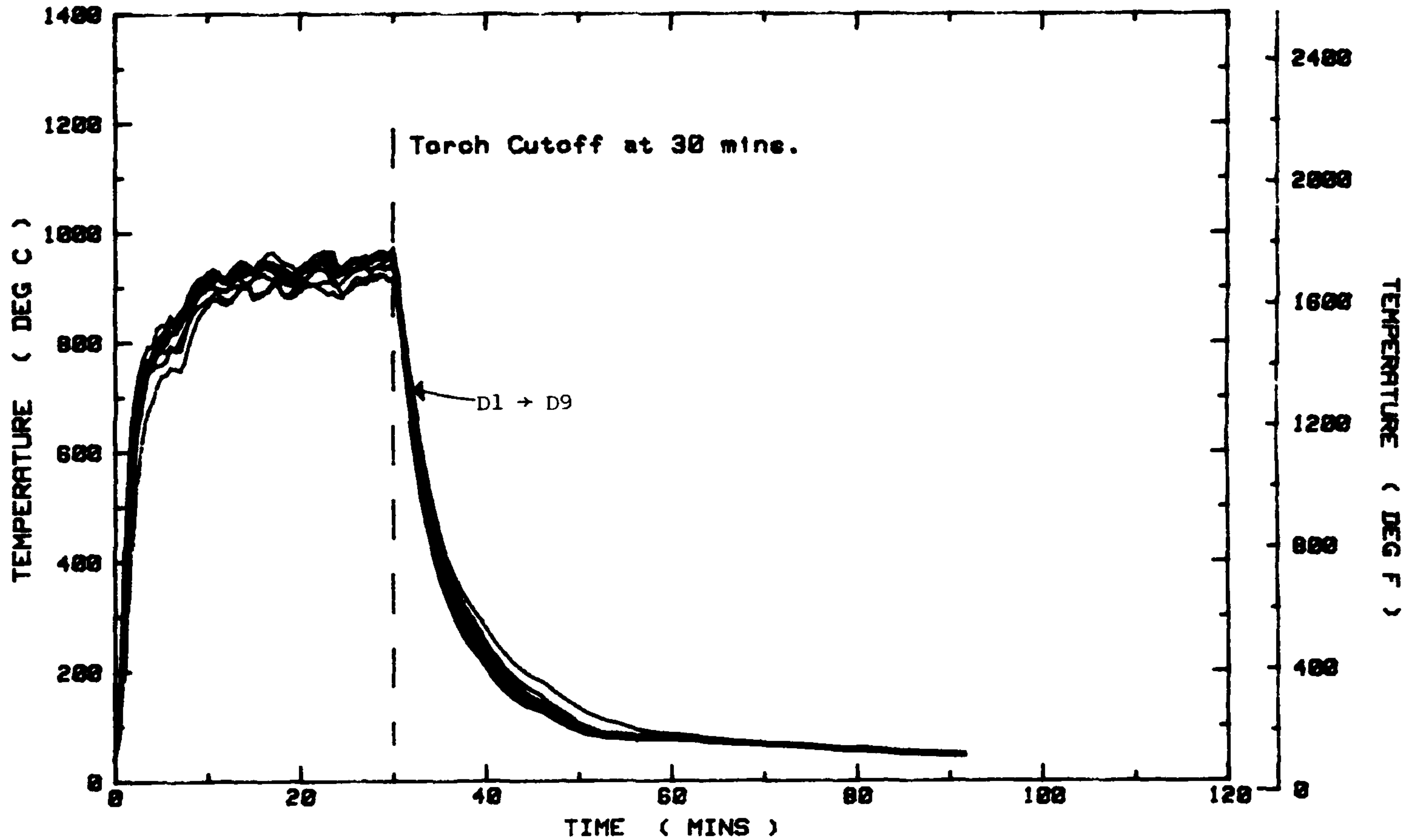

Figure 66: The Temperature as Functions of Time for the Cross-Sectional Plane Through the HNPF Cask at -60.0 cm from the XRP as Viewed from the Top in Test Number 4

Figure 67 shows the distribution of those TCs (E) which were located behind the impact limiter, but on the outside surface of the lid of the cask. As the data in Figure 68 indicates, the temperatures for these TCs were quite low and do not constitute a danger to the components of the cask. Therefore, the impact limiter was demonstrated to be a good insulator for the cask.

The temperature as a function of time for one TC located on the outer surface of the NSJ and 33.0 cm (13 inches) from the XRP is presented in Figure 69. The temperature there reached approximately 250 °C (482 °F), which indicates that the flame did not reach much beyond the impact limiter. The remaining data for TCs located on surfaces which were deeper inside the cask are presented in Figures 70, 71, and 72. The temperature levels measured by all of these TCs were much too low to be considered as a serious threat to the survivability of the cask. Consequently, even though the NSJ was void of water, an end-on torch impingement was shown to be inconsequential.

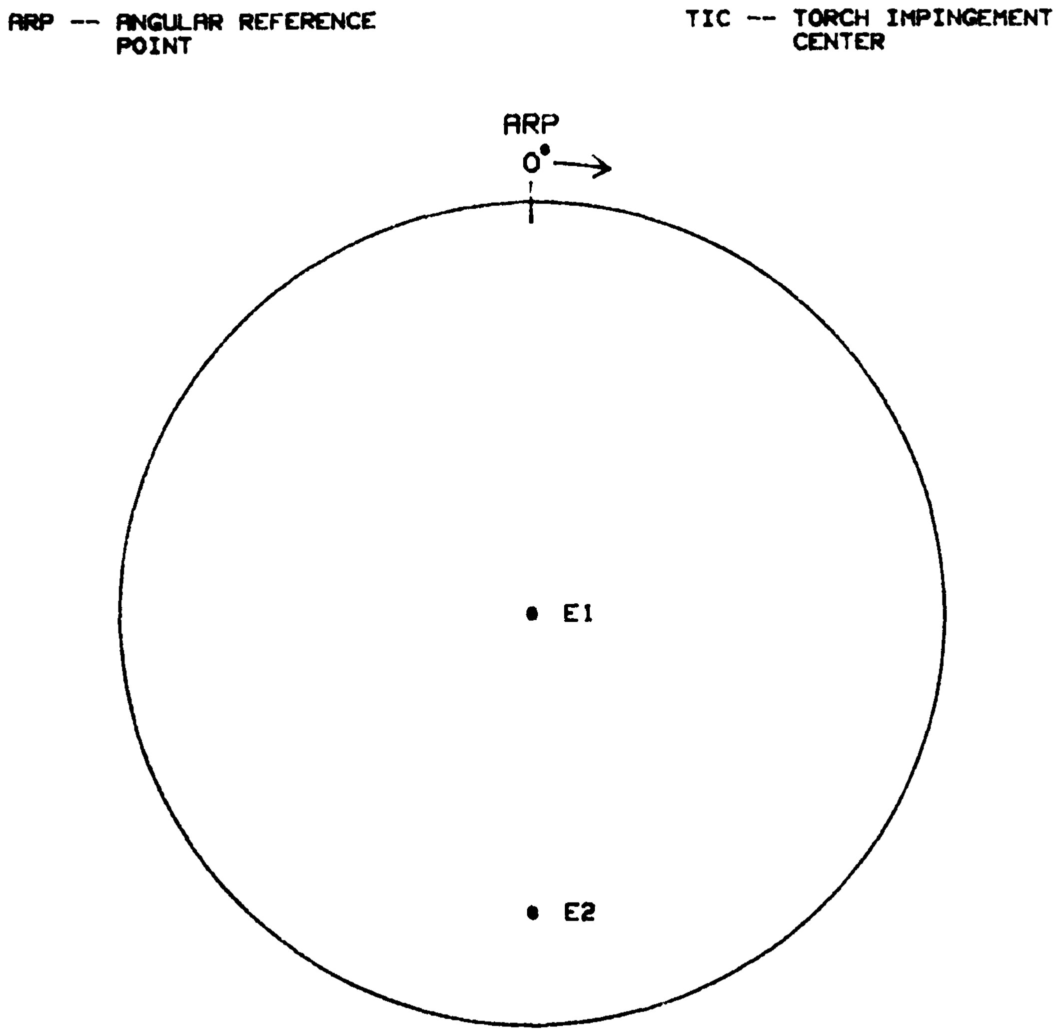

Figure 67: The Spatial Distribution of Sensors in a Cross-Sectional Plane Through the HNPF Cask at -19.1 cm from the XRP as Viewed from the Top End with the TIC Located at the Center of the Impact Limiter for Test Number 4

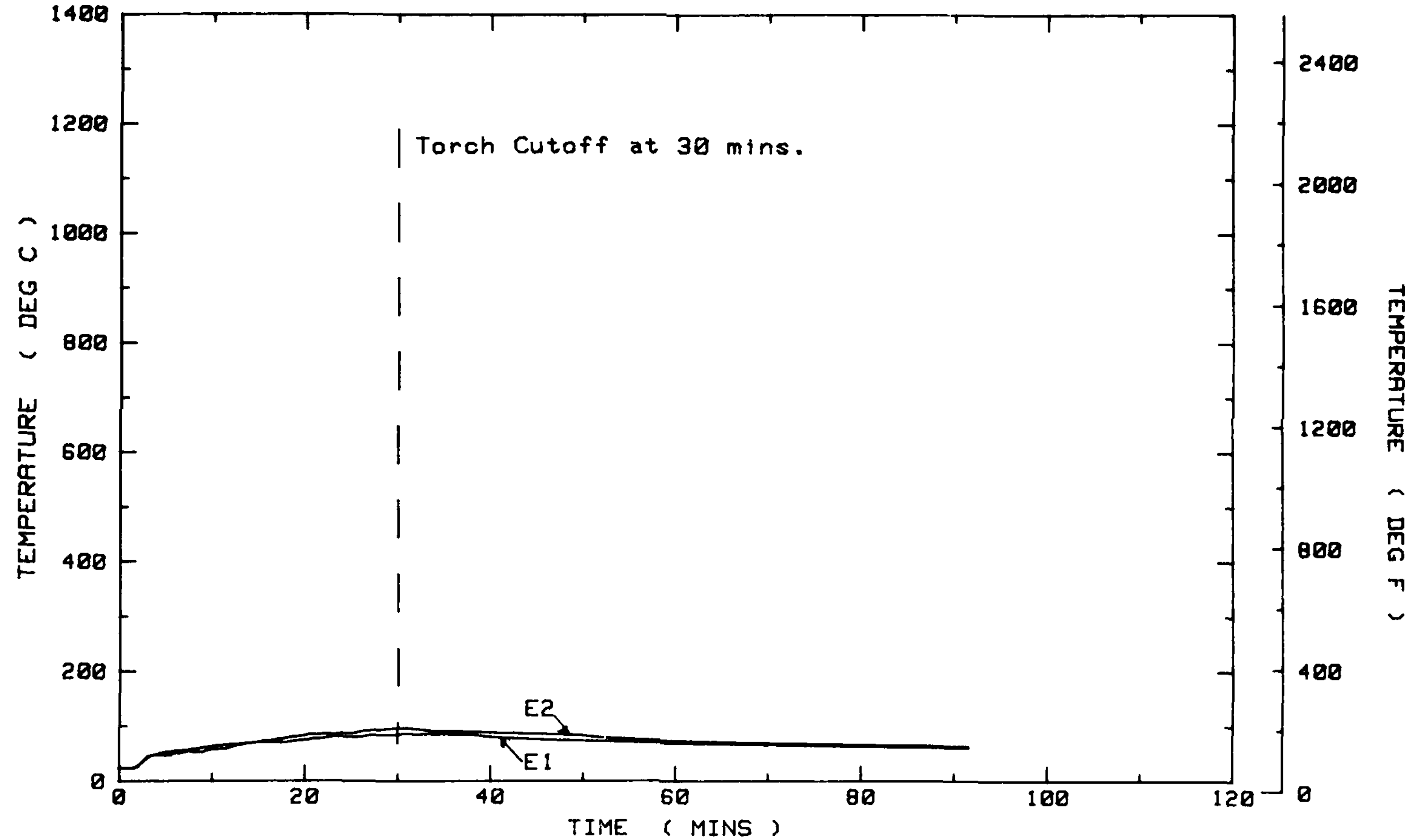

Figure 68: The Temperature as Functions of Time for the Cross-Sectional Plane Through the HNPF Cask at -19.1 cm from the XRP as Viewed from the Top in Test Number 4

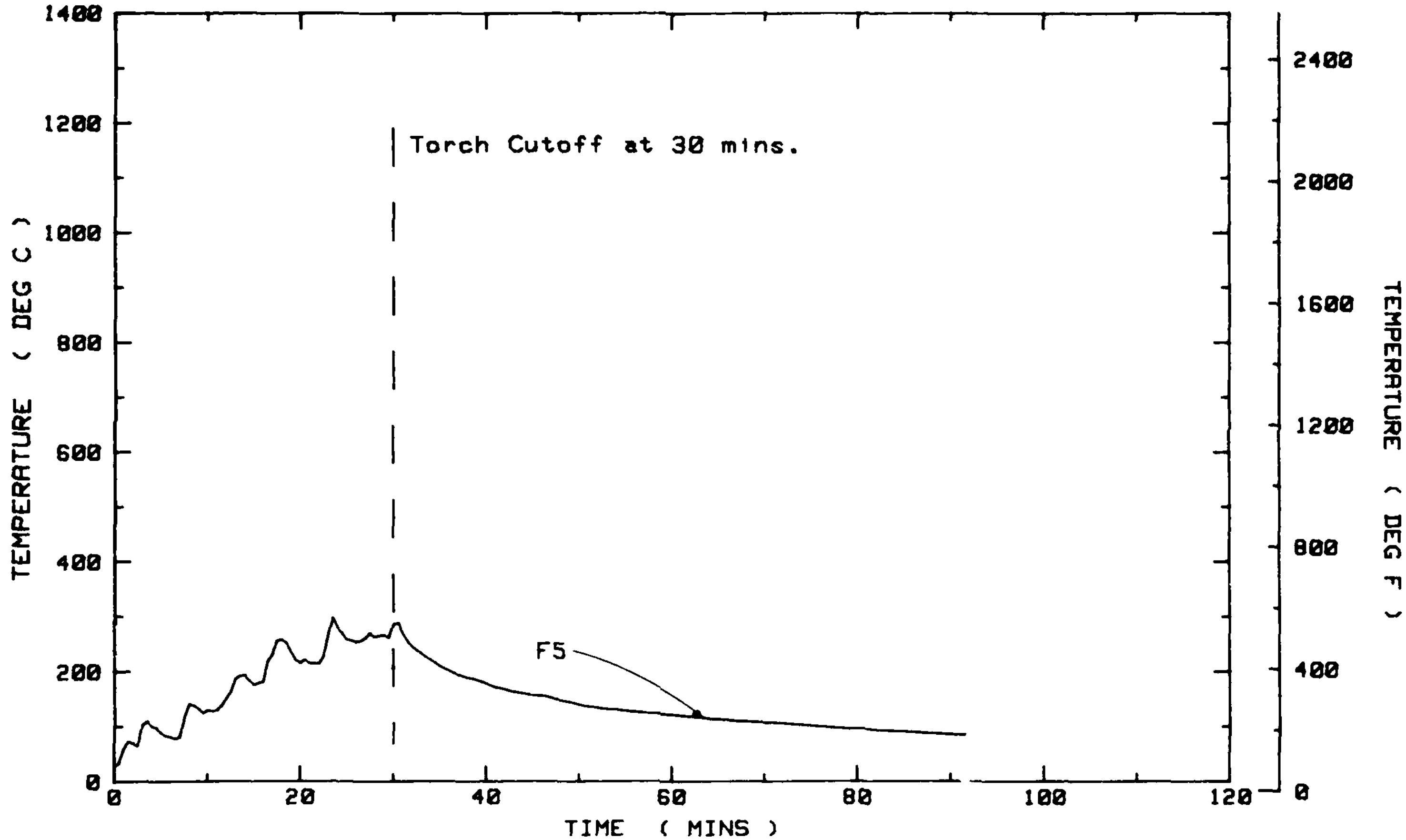

Figure 69: Temperature as a Function of Time for the TC Located at 33.0 cm from the XRP on the Outer Surface of the NSJ for HNPF Cask Test Number 4

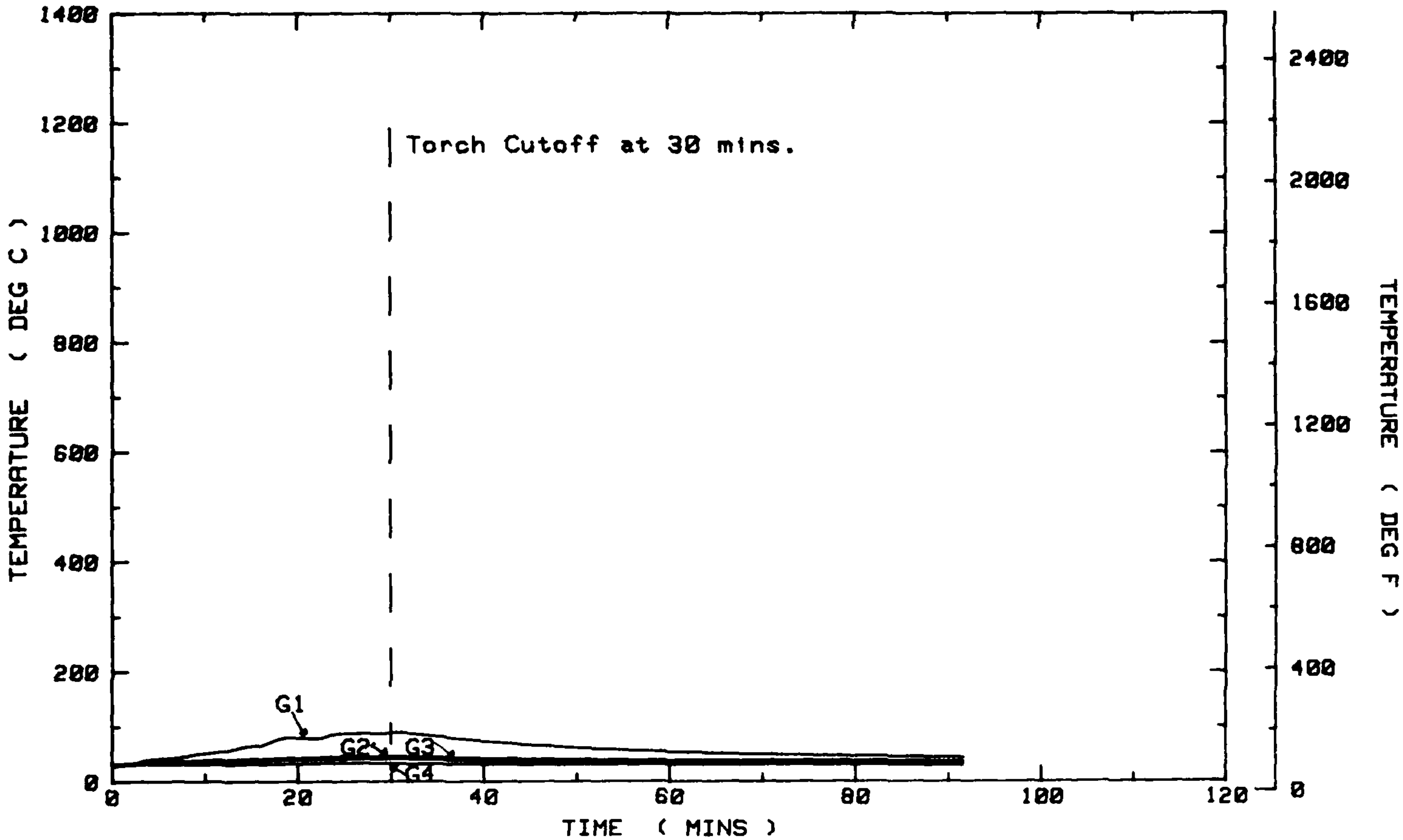

Figure 70: Temperature as Functions of Time for TCs Positioned in the NSJ for HNPF Cask Test Number 4

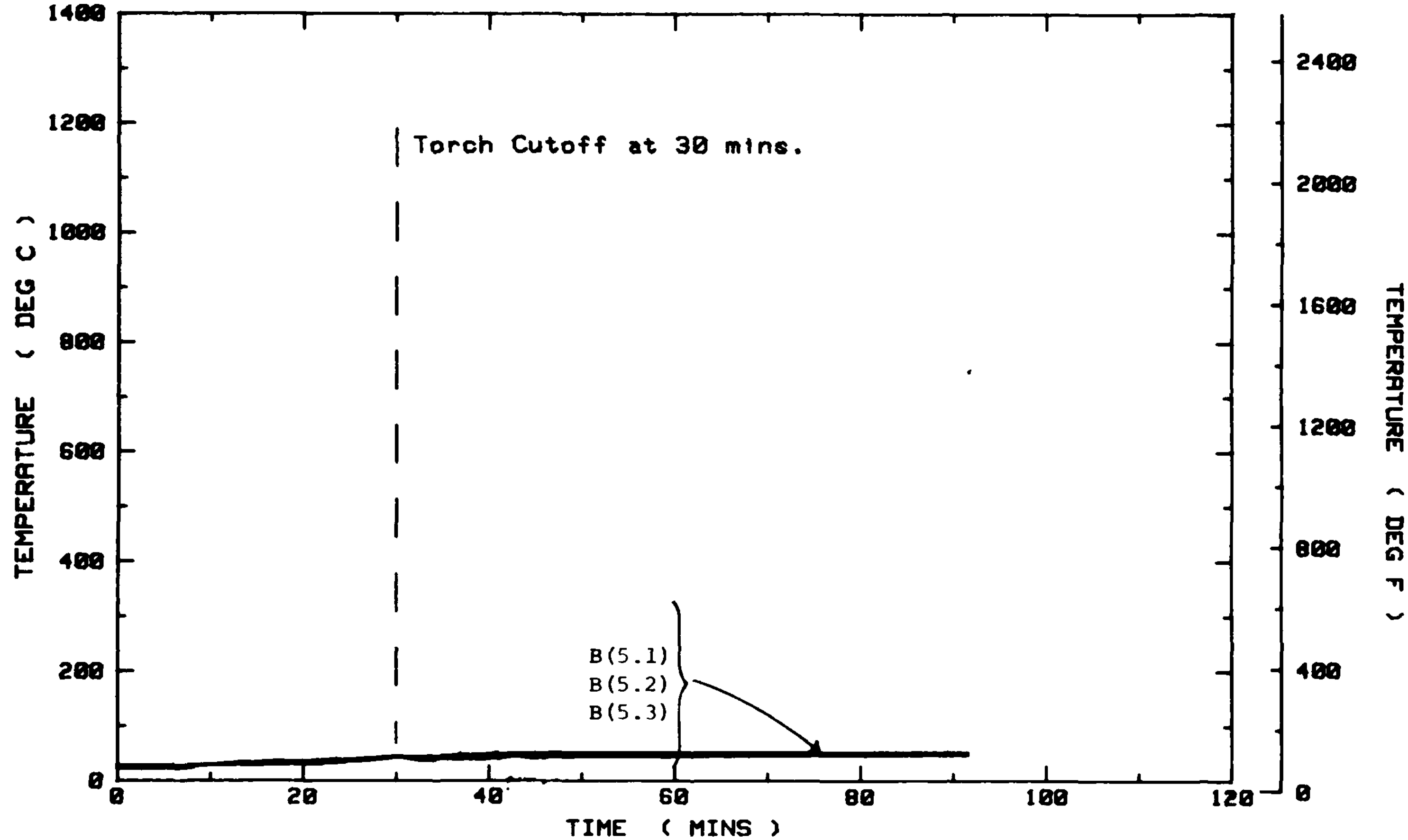

Figure 71: Temperature as Functions of Time for TCs Positioned on the Outer Surface of the OSS for HNPF Cask Test Number 4

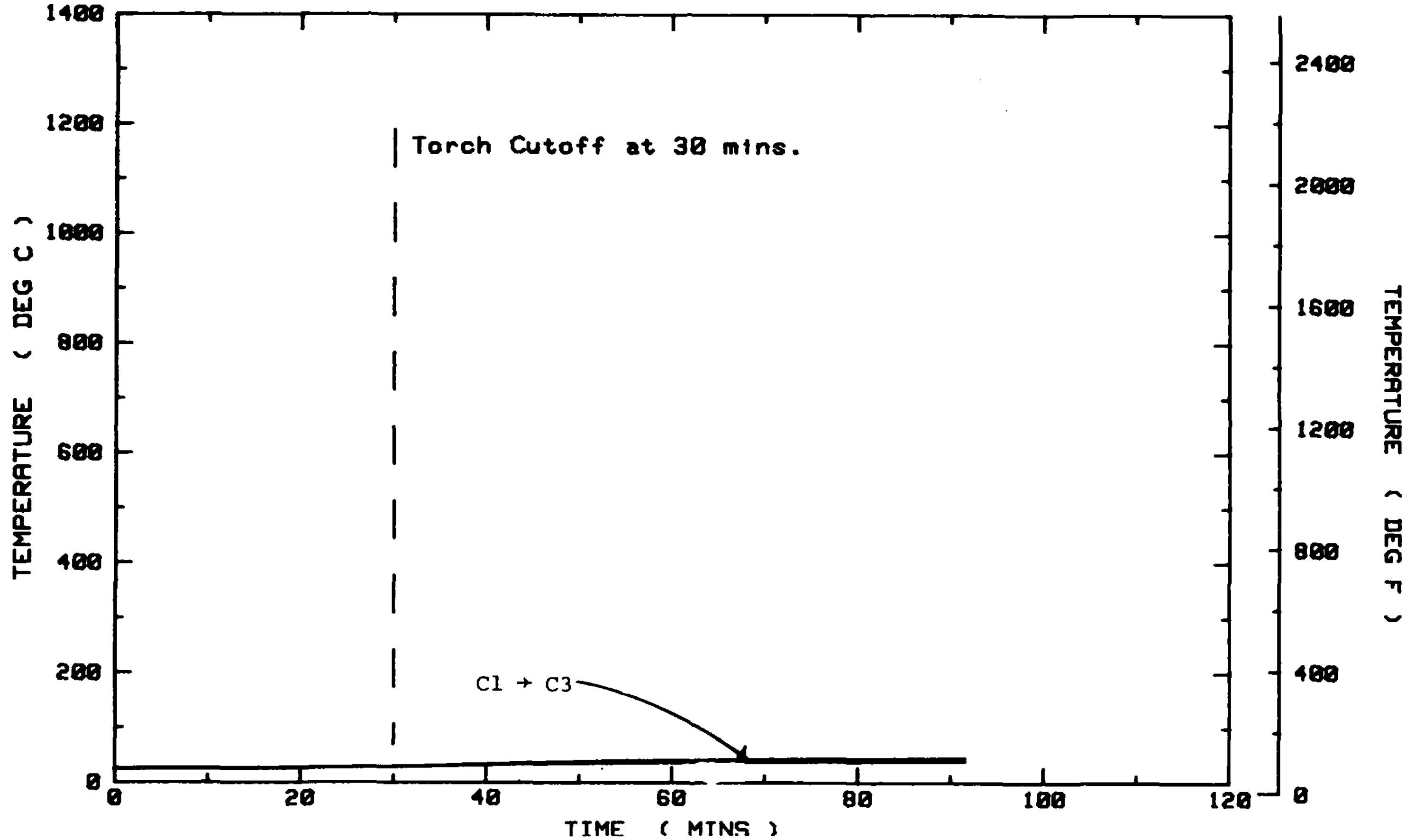

Figure 72: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS for HNPF Cask Test Number 4

VIII. DESCRIPTION OF TEST NUMBER 5

The fifth and final test of the series was a simulated pool fire test conducted according to the standard performance procedure described in HM 144. The intended duration period was 100 minutes, but due to the adverse ambient conditions, the test was terminated at 95 minutes. The nozzle of the torch was 6.1 meters (20 feet) from the TIC. The TIC was positioned at a 270° angular direction and at 93.3 cm (36.7 inches) from the XRP. The NSJ was filled with water, but no pressure measurements were possible since the pressure gauges were not functioning properly and their replacement would have required the disassembly of the cask. Figure 73 presents a photograph of the torch impinging on the HNPF Cask in which the flame is shown to be broader than those in previous tests.

The data describing physical parameters which constituted the environmental conditions during the experiment are presented in Figures 74 through 77. The wind direction changed a great deal during the test as shown in Figure 74. The wind speed varied around 3 miles per hour until about 85 minutes into the test then it increased to levels above 8 miles per hour. (See Figure 75.) Since these conditions made it too difficult to hold the torch flame in position, the test was concluded at 95 minutes. The water bath was set initially at 53 °C (127.4 °F) and that temperature was maintained until approximately 40 minutes had elapsed and then was raised to approximately 62 °C (143.6 °F). The ambient temperature stayed around 40 °C (104 °F) throughout the test. The flame temperature as a function of time is presented in Figure 77. Since the torch nozzle was so far away from the cask, the flame temperature value oscillated a great deal throughout the test. In general, the temperature averaged around 800 °C (1472 °F) for most of the test, but, due to the wind speed and direction changes, this average dropped considerably at 85 minutes into the test.

The schematic which shows the relative axial positions of the TCs with respect to the XRP and the TIC for Test Number 5 is presented in Figure 78. The FP TCs are additional TCs which were added to this test to measure the temperatures on the outer surface of the NSJ. As the figure shows, most of the TCs were concentrated around the TIC.

As Figure 79 indicates, the temperatures measured by the TCs on the outer surface of the NSJ for Test Number 5 did not exceed 150 °C (302 °F). Therefore, this test was not a severe test for the HNPF Cask. As would be expected, the temperatures measured by TCs positioned on the other surfaces interior to the cask were even lower. The highest temperature measured by the TCs on the outer surface of the OSS did not exceed 100 °C (212 °F), and the temperatures measured by the TCs positioned on the inner surface of the ISS were even lower. These observations were made from the data presented in Figures 80 and 81.

Figure 73: A View of the HNPF Cask Taken During Torch Thermal Test Number 5

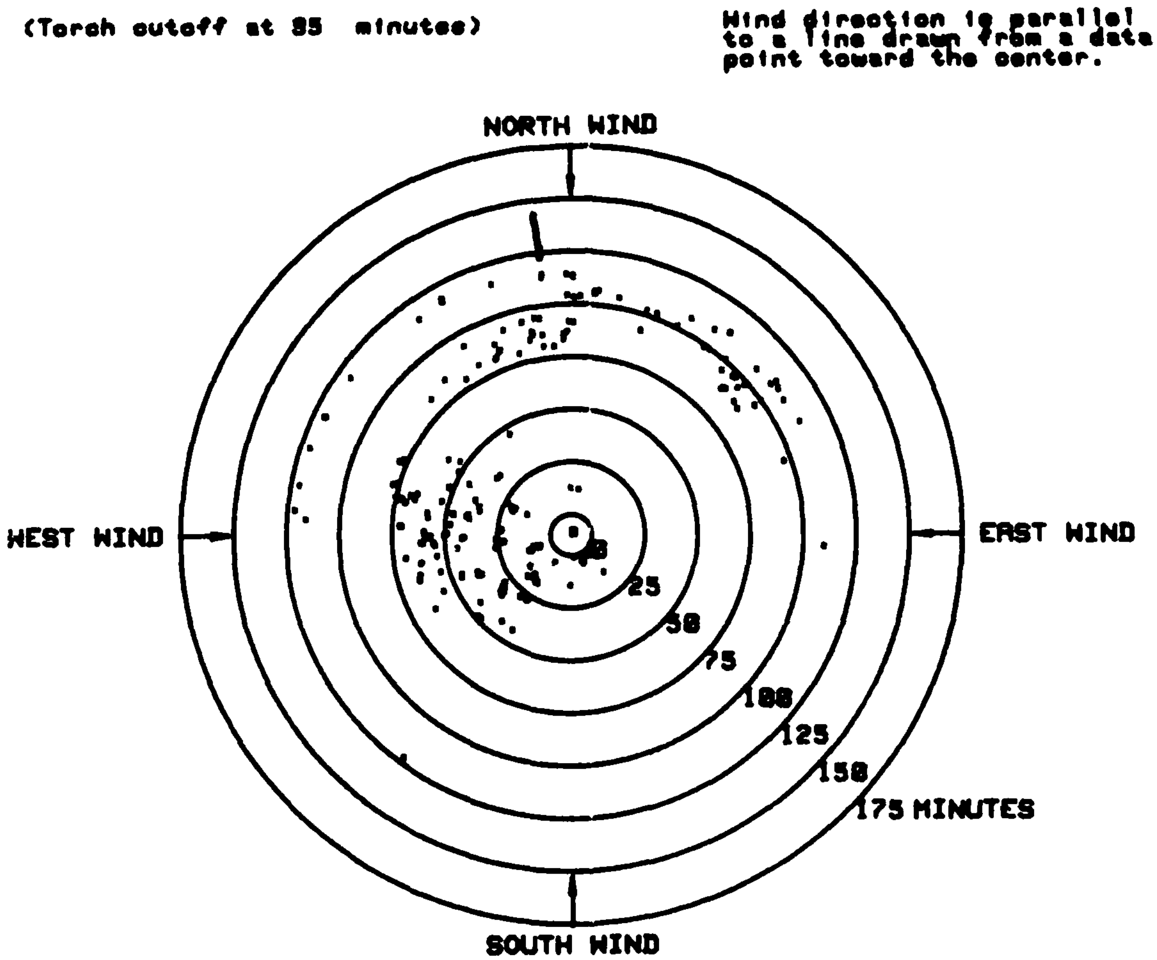

Figure 74: The Wind Direction as a Function of Time During the HNPF Cask Thermal Test Number 5

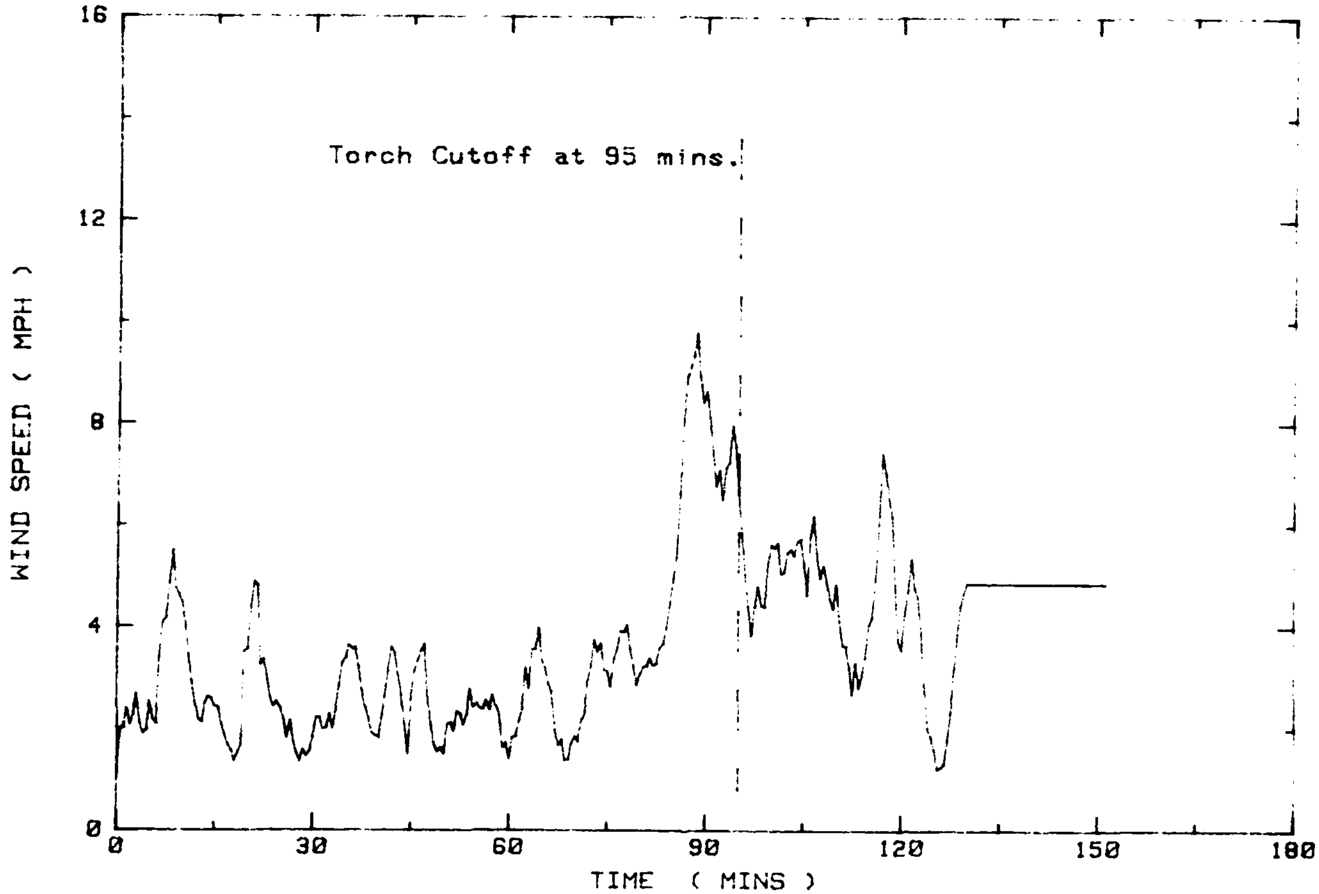

Figure 75: The Wind Speed as a Function of Time During the HNPF Cask Thermal Test Number 5

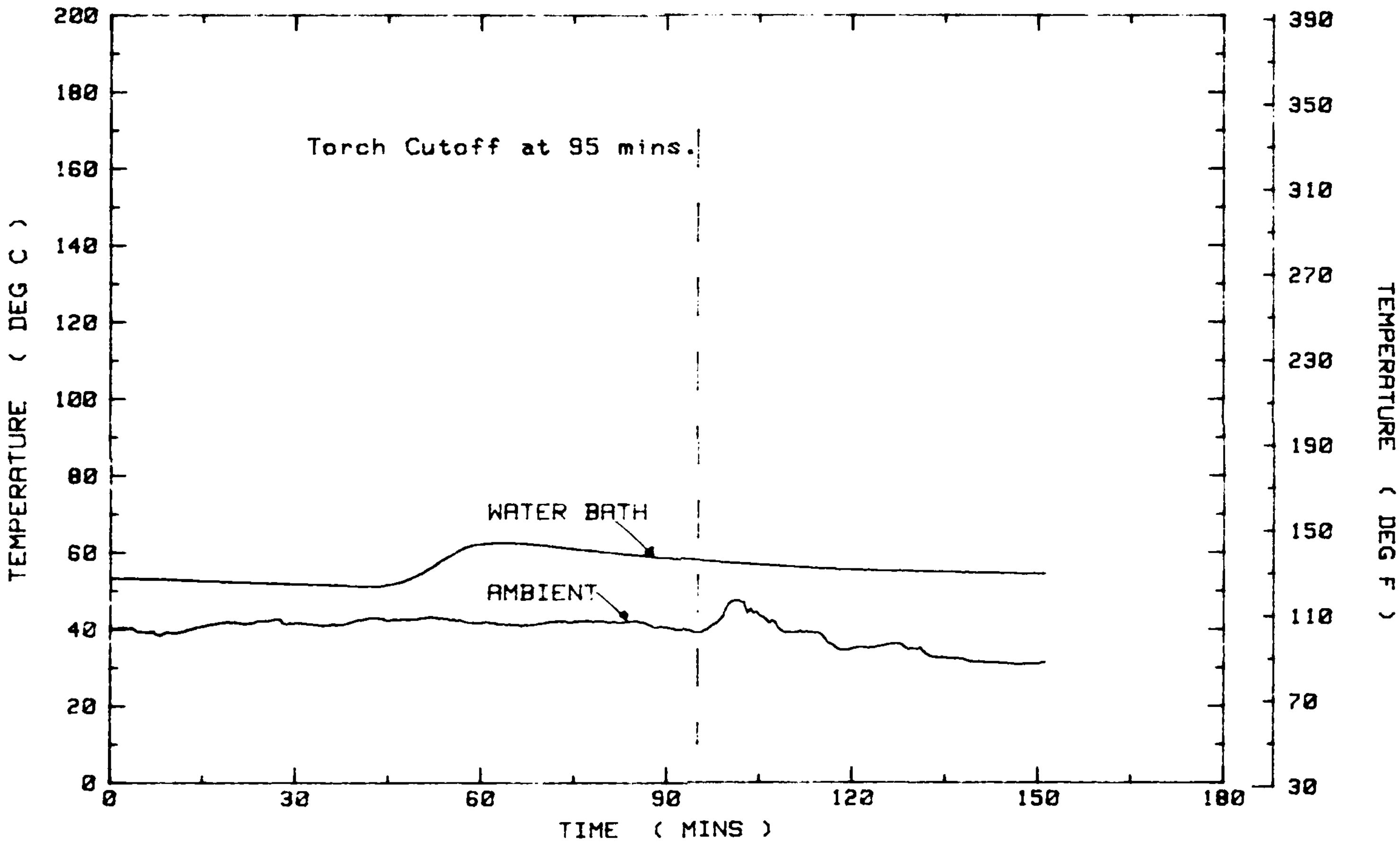

Figure 76: The Ambient and Water Bath Temperatures as Functions of Time During the HNPF Cask Test Number 5

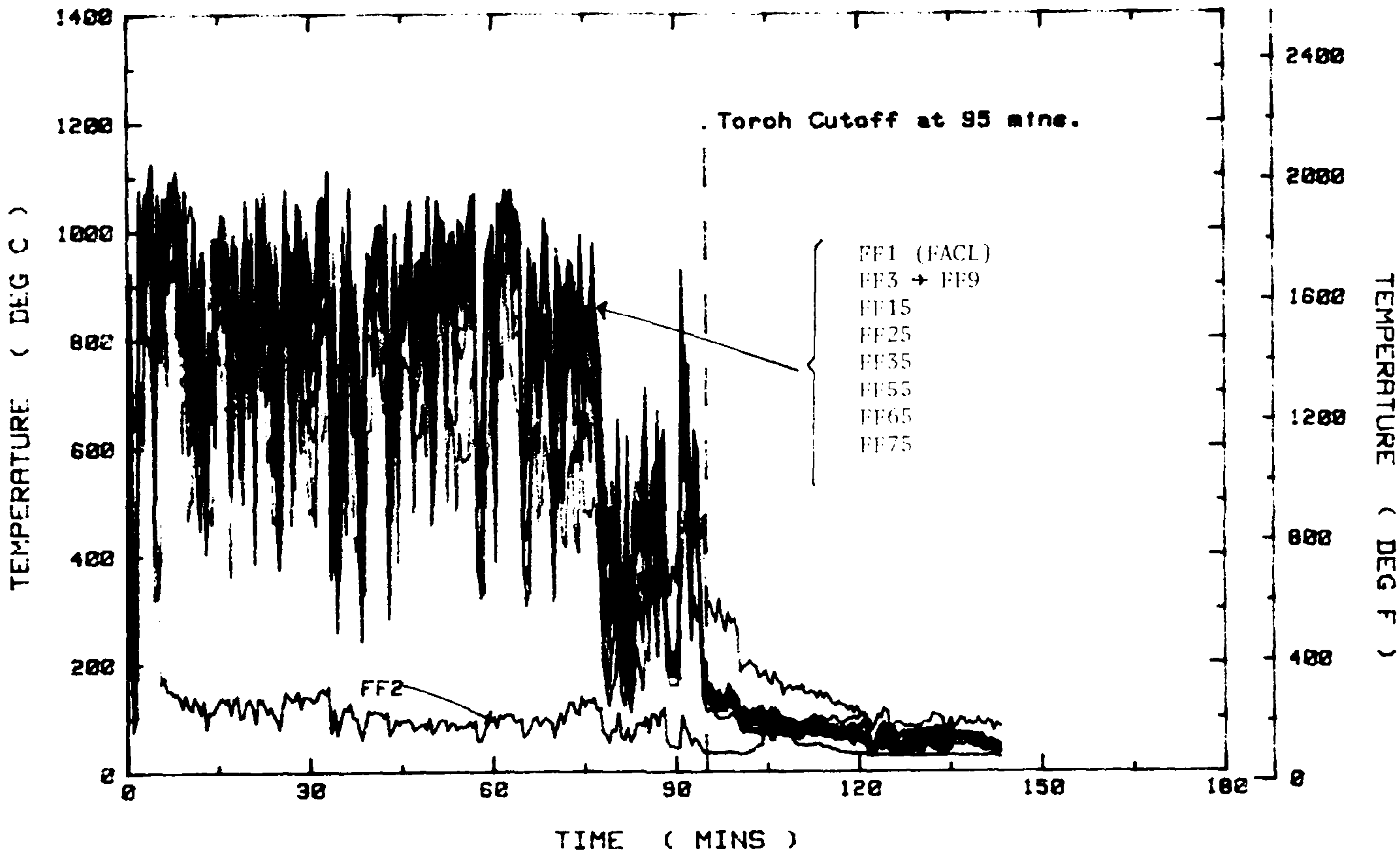

Figure 77: The Flame Temperature of the Propane Torch as Functions of Time During the HNPF Cask Test Number 5

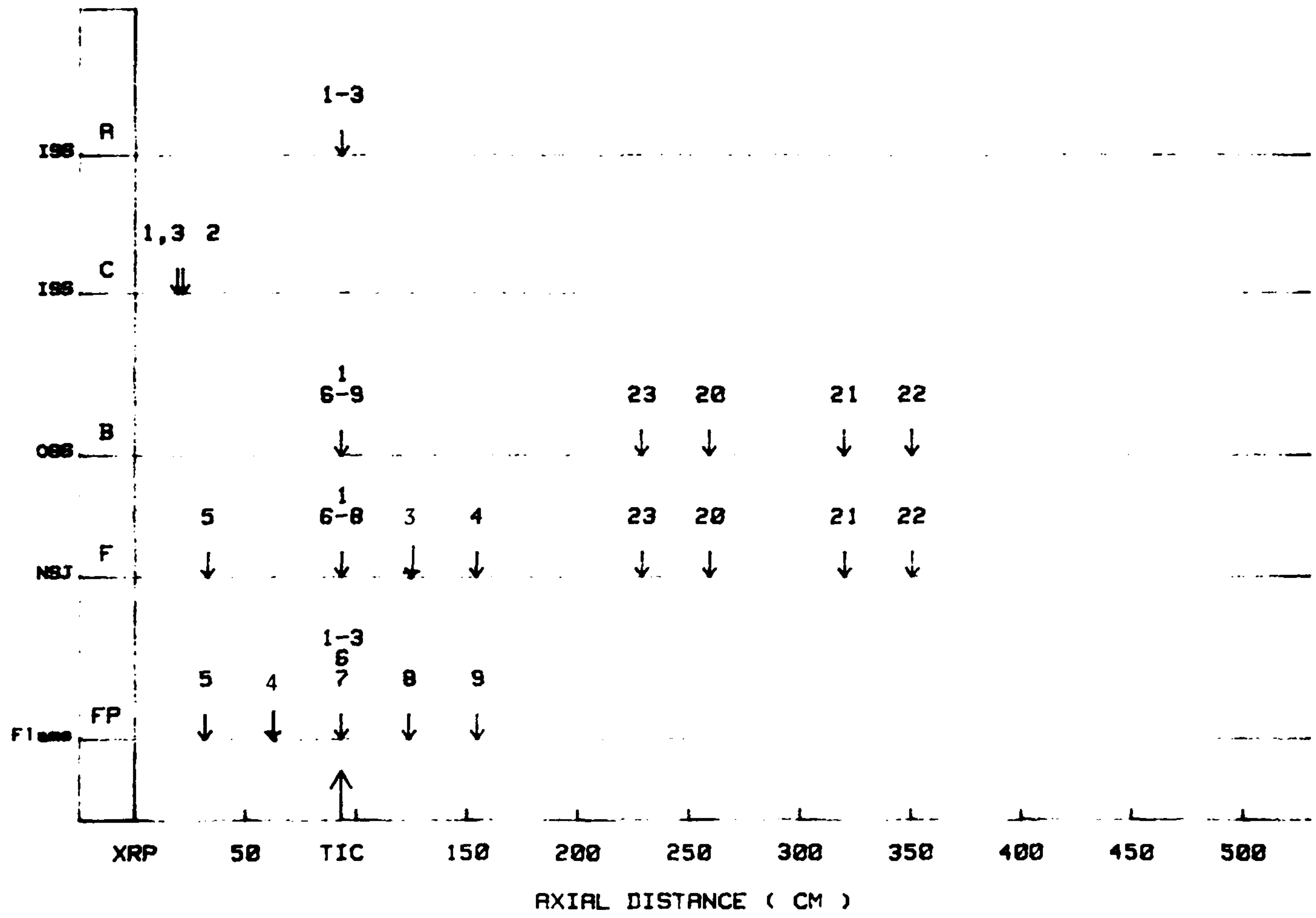

Figure 78: Axial Locations of the Thermocouples (TC) Relative to the XRP and the TIC for Various HNPF Cask Surfaces in Test Number 5

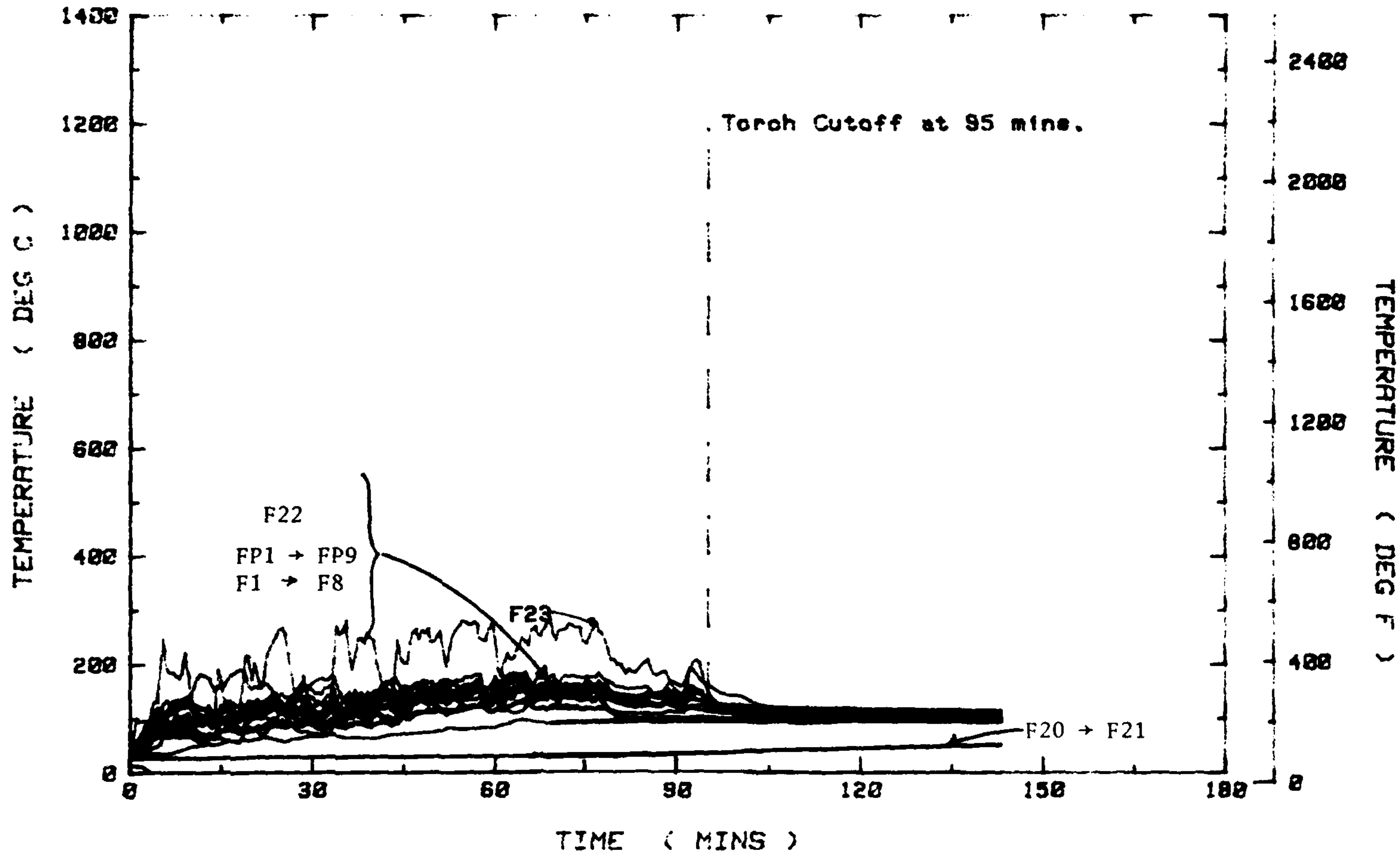

Figure 79: Temperature as Functions of Time for TCs Positioned on the Outer Surface of the NSJ for the HNPF Cask Test Number 5

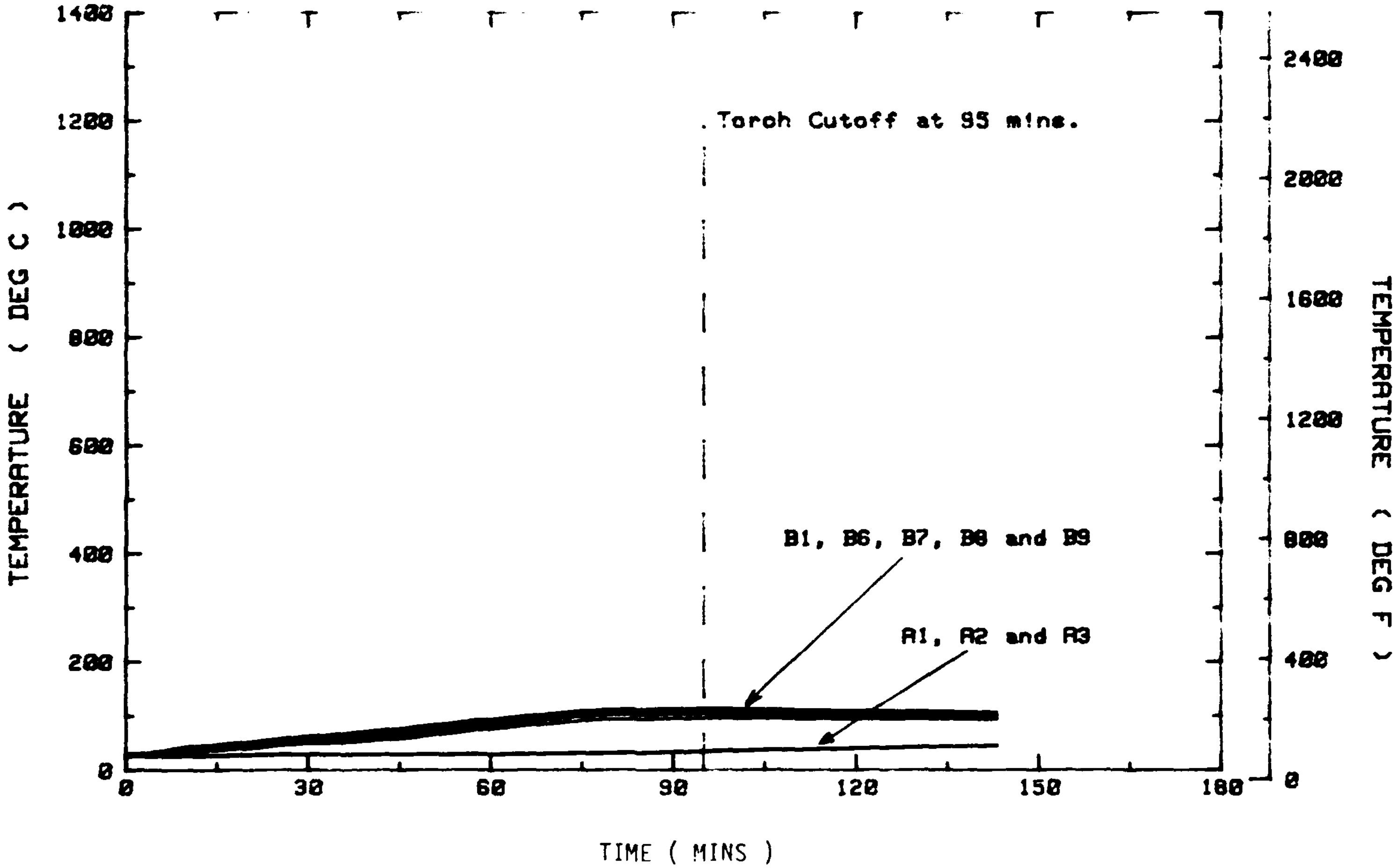

Figure 80: Temperature as Functions of Time for TCs Positioned on the Outer Surface of the OSS (Bs) and the Inner Surface of the ISS (As) for HNPF Cask Test Number 5

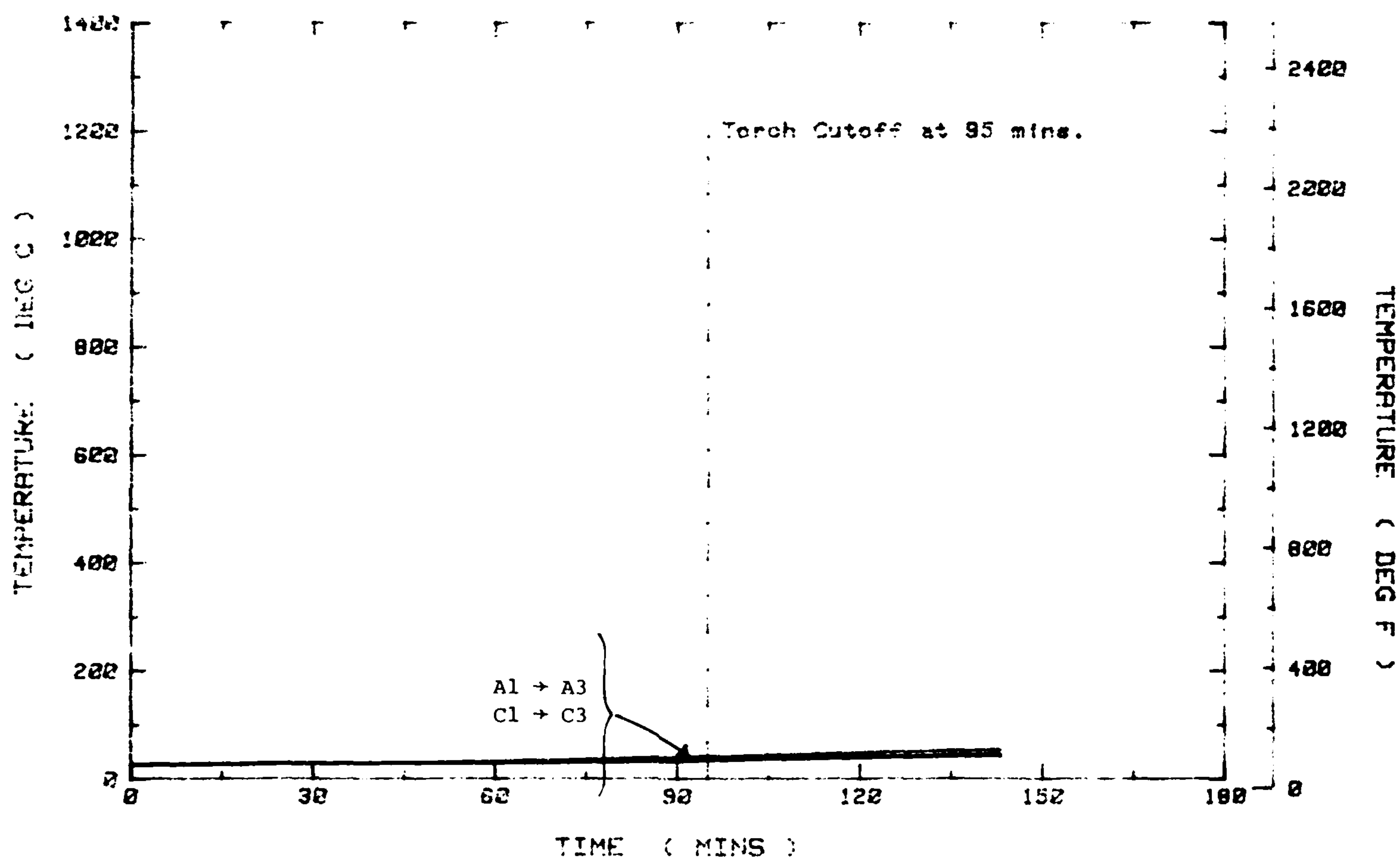

Figure 81: Temperature as Functions of Time for TCs Positioned on the Inner Surface of the ISS for HNPF Cask Test Number 5

IX. SUMMARY AND RECOMMENDATIONS

In general, definite conclusions as to the damaging effects on the components of the HNPF Cask cannot be made because this would require taking the cask apart and an examination made of each part individually. However, certain preliminary observations are possible as indicated in the preceding discussions:

(1) In those cases where the NSJ was filled with water, the temperatures measured in the interior of the cask indicated no damage. However, in Test Number 2 the pressure measurements made in the NSJ indicated that perhaps the seals had been damaged. One of the pressure gauges definitely failed, but the other gauge measured a drop in the pressure level, indicating that perhaps water (or steam) was leaking from the jacket. In the following two tests no water was placed in the NSJ, and in the last test the pressure gauges were not functioning properly; therefore, the condition of the seals could not be inferred from the tests which followed Test Number 2.

(2) There was no danger that the lead shield would be distorted by high temperatures for the duration of those tests where water was in the NSJ. However, in an accident there is a high probability that the NSJ will sustain a rupture thus allowing the water to drain out. The potential threat due to this condition was demonstrated in Test Number 3. In that test, the data indicated that the temperature of the lead shield may have exceeded the melting point of lead because the NSJ contained no water. In addition, the slope of the temperature curve was positive when the test was terminated so that if the test had continued, the temperature of the lead shield would have continued to rise and thus practically ensuring that damage to the OSS or the ISS would have occurred.

(3) The end-on impingement of the cask by a torch fire poses no threat to the HNPF Cask as shown by Test Number 4 in which the NSJ was voided of water.

(4) The pool fire simulation condition is not a threat to the HNPF Cask as indicated by Test Number 5 provided the NSJ is filled with water.

The following are recommendations for continued work on this problem.

(1) The HNPF Cask should be disassembled and the internal parts examined.

(2) Since the water in the NSJ prevented undue temperature buildup in Test Number 5, future pool fire simulation tests should be conducted without the water.

(3) In an accident, the NSJ has a good chance of being ruptured which would allow the water to drain out leaving the cask vulnerable to fires. Therefore, an alternative should be considered such as polyethylene. This material has similiar neutron shielding properties but would not drain out of a ruptured jacket until it had become melted by the fire.

APPENDIX A

This appendix presents the angular distributions of all of the sensors in relation to the angular reference point (ARP) in the various cross-sectional planes through the HNPF Cask.

LIST OF FIGURES

Figure Number | Page Number

LIST OF FIGURES (Cont.)

NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS ---- LEAD SHIELD
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME
ARP --- ANGULAR REFERENCE POINT

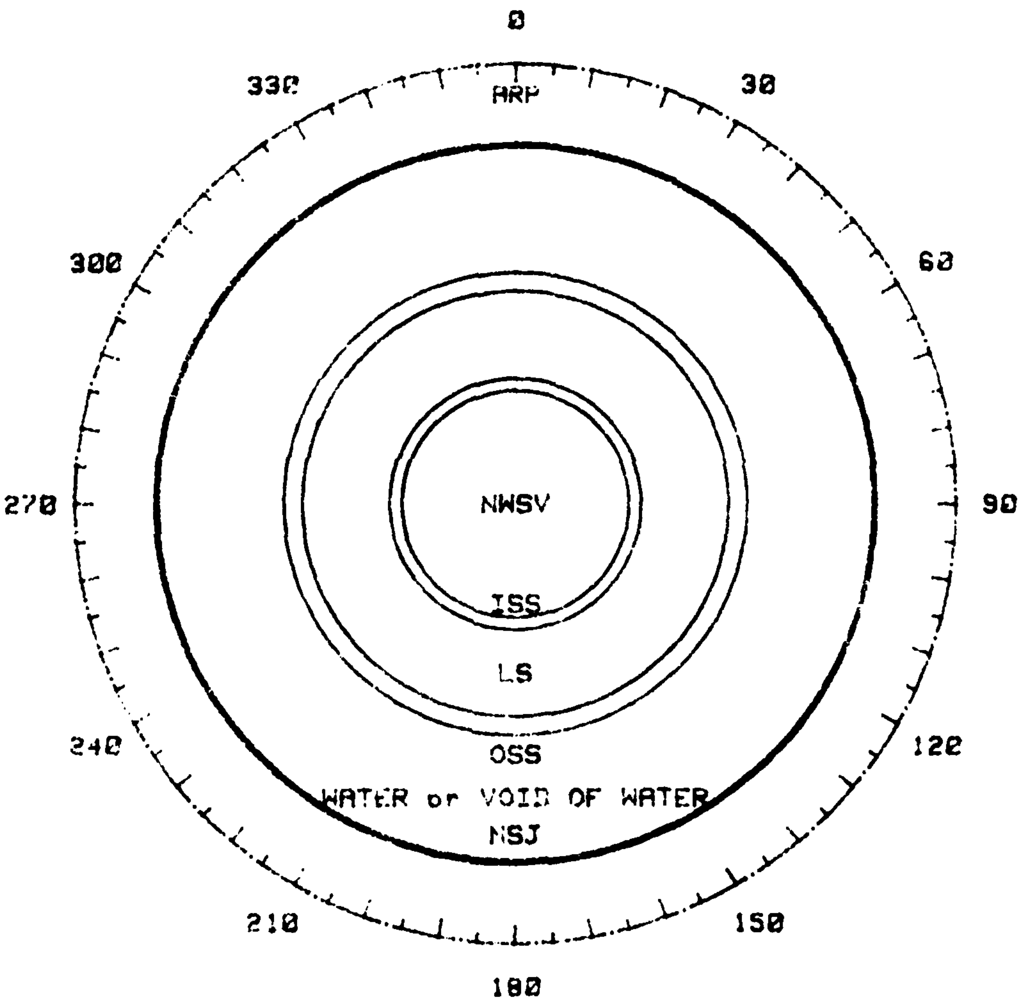

Figure A.1. Cross Section of the HNPF Cask Showing the Angular Distribution in Relation to the ARP and the Various Subsections of the Cask

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

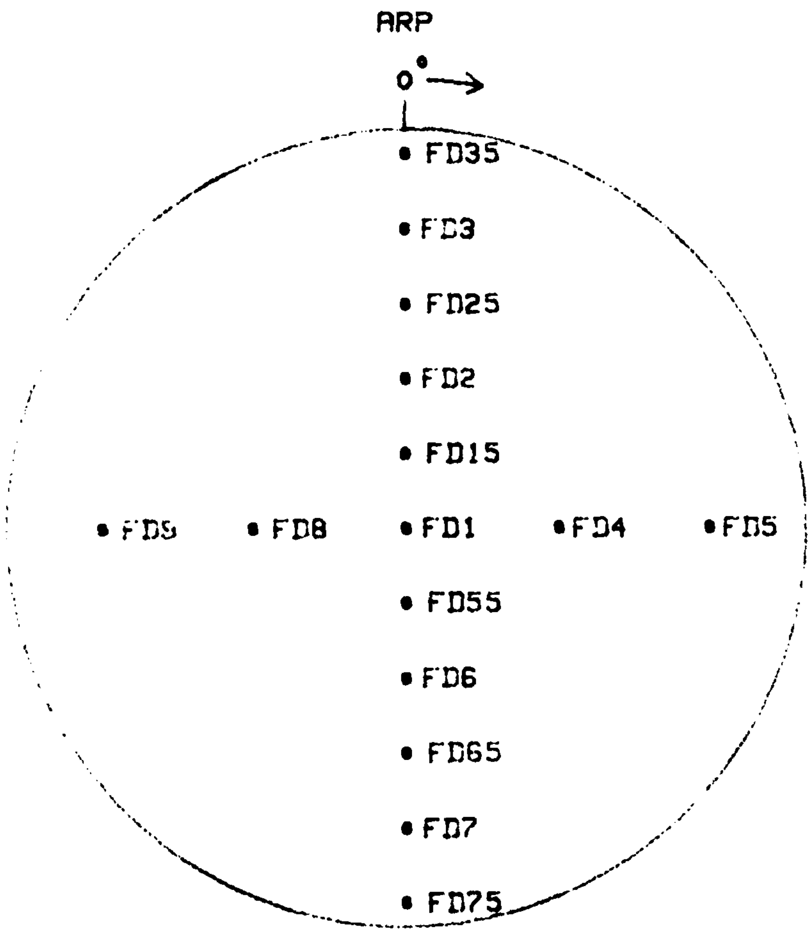

Figure A.2. Cross Section of Cask at -65.1 cm From the XRP Showing Angular locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

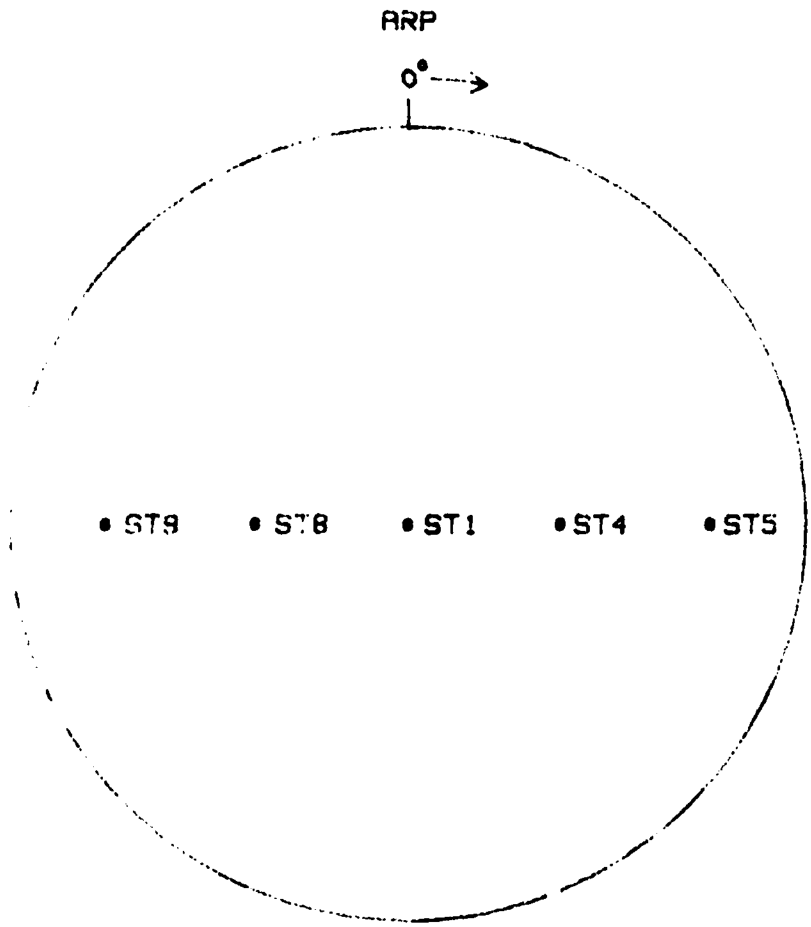

Figure A.3. Cross Section of Cask at -62.5 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

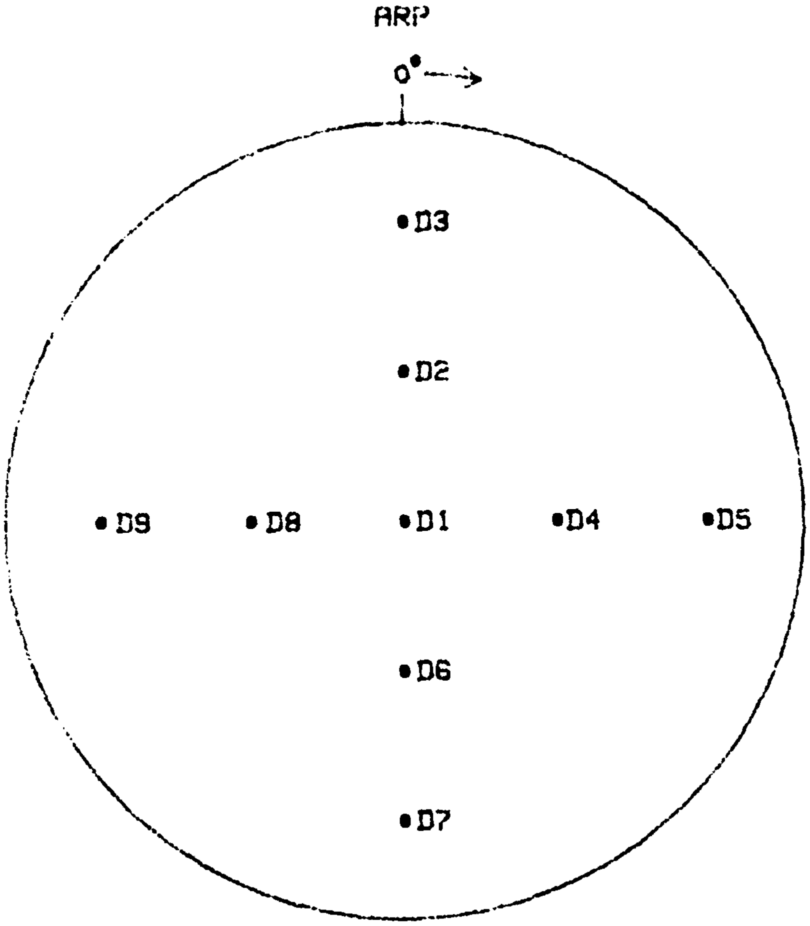

Figure A.4. Cross Section of Cask at -60 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

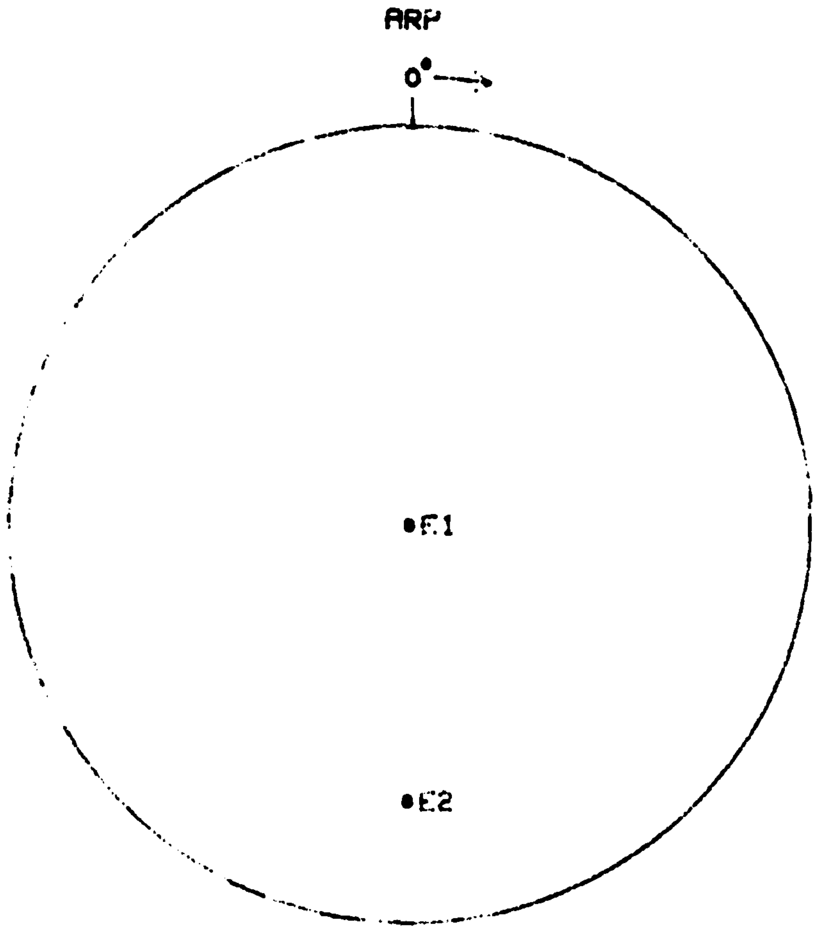

Figure A.5. Cross Section of Cask at -19.1 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD
ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

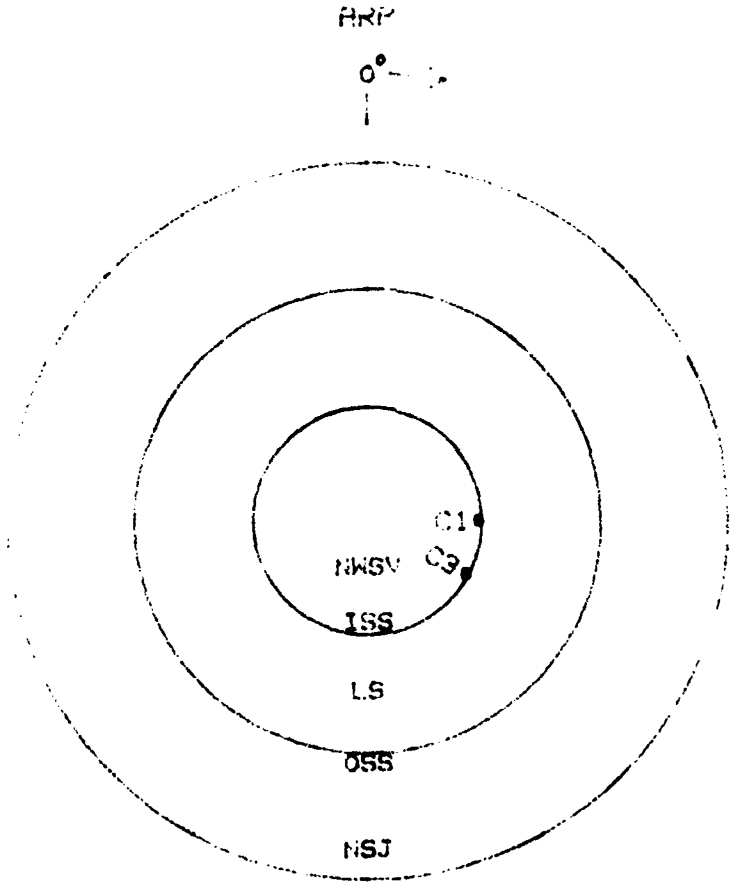

Figure A.6. Cross Section of Cask at 19.1 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

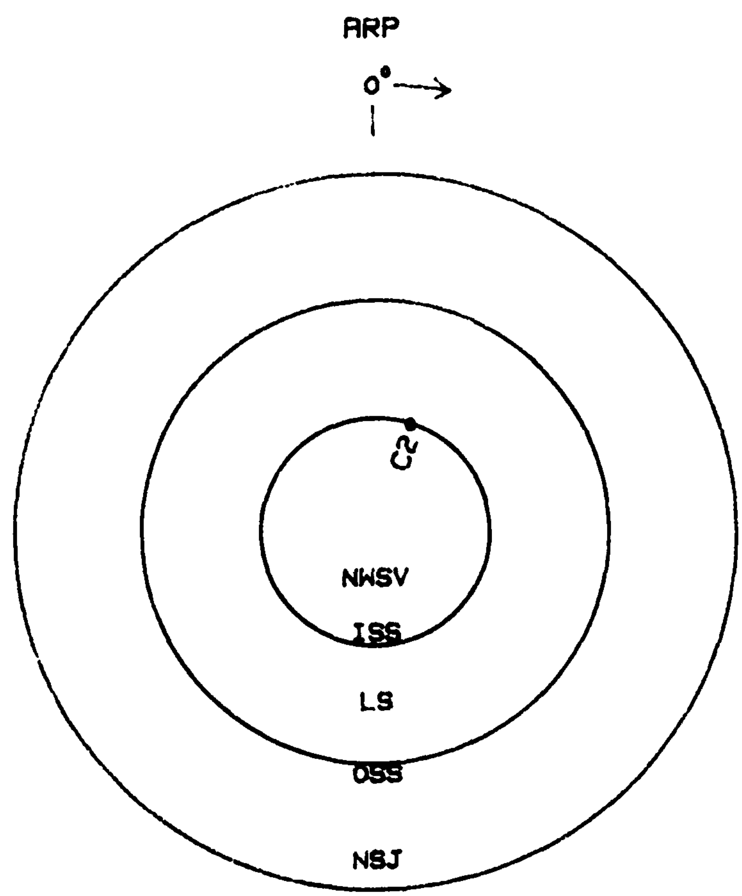

Figure A.7. Cross Section of Cask at 21.6 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD
ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

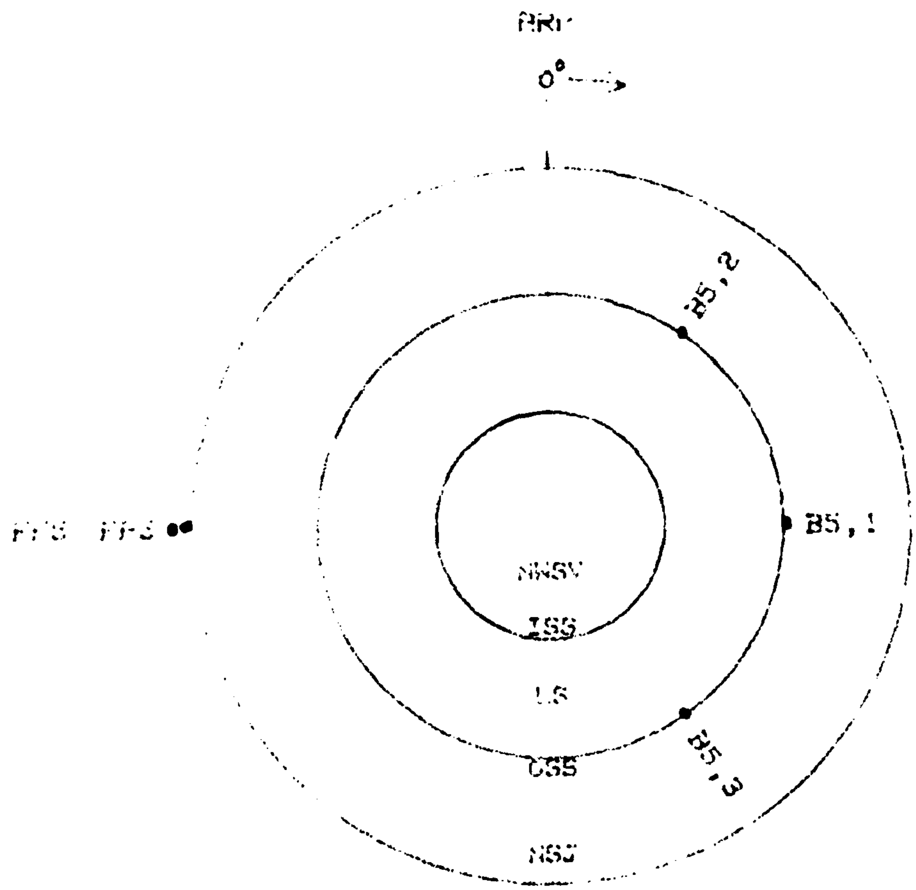

Figure A.8. Cross Section of Cask at 31.8 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

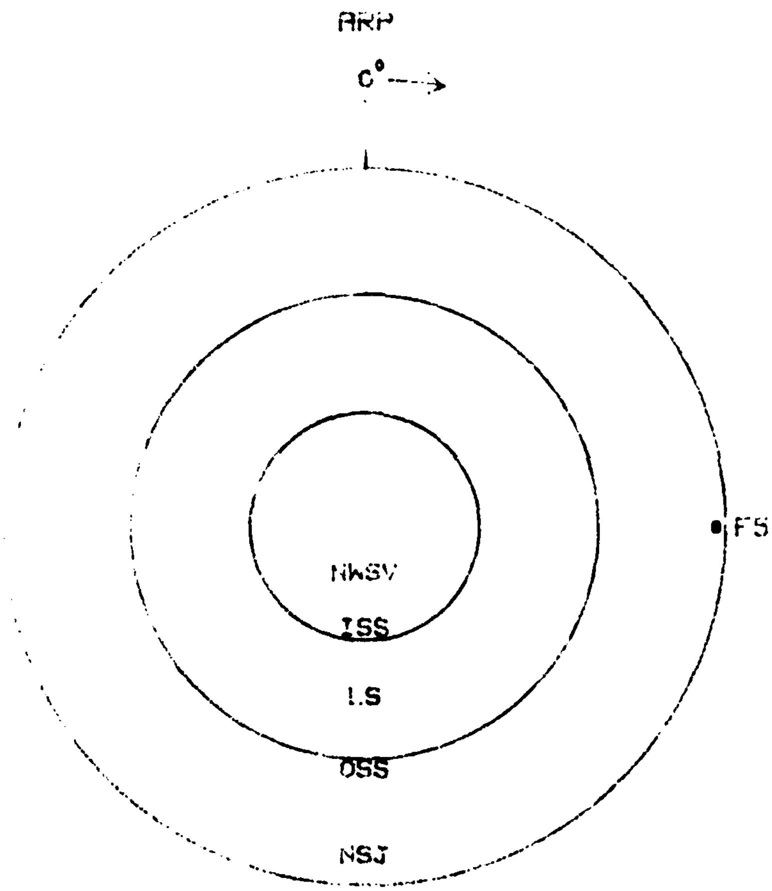

Figure A.9. Cross Section of Cask at 33 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

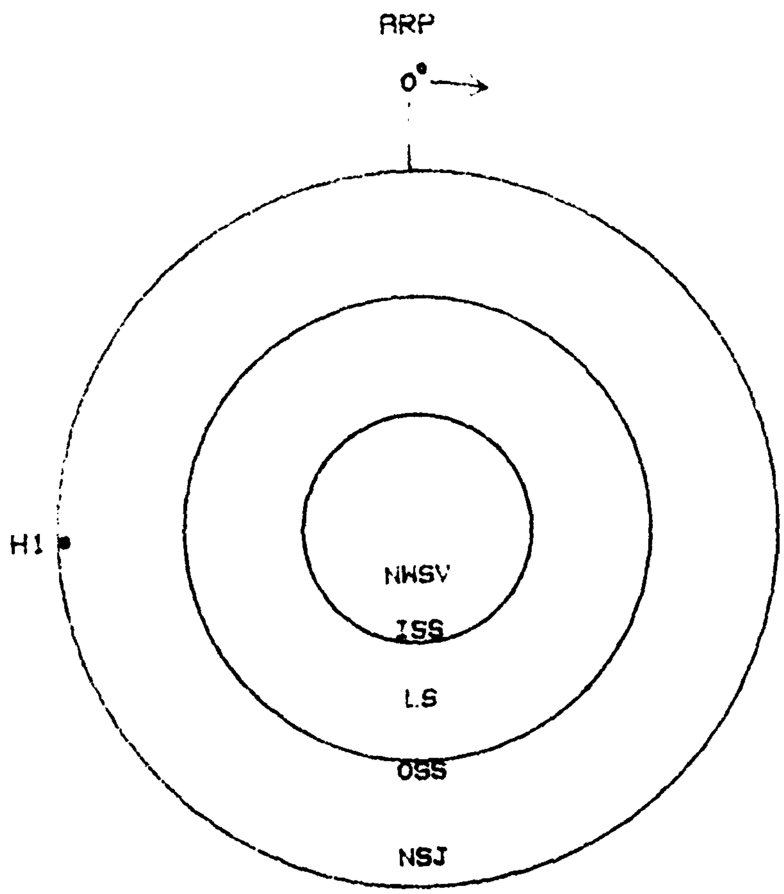

Figure A.10. Cross Section of Cask at 55.2 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

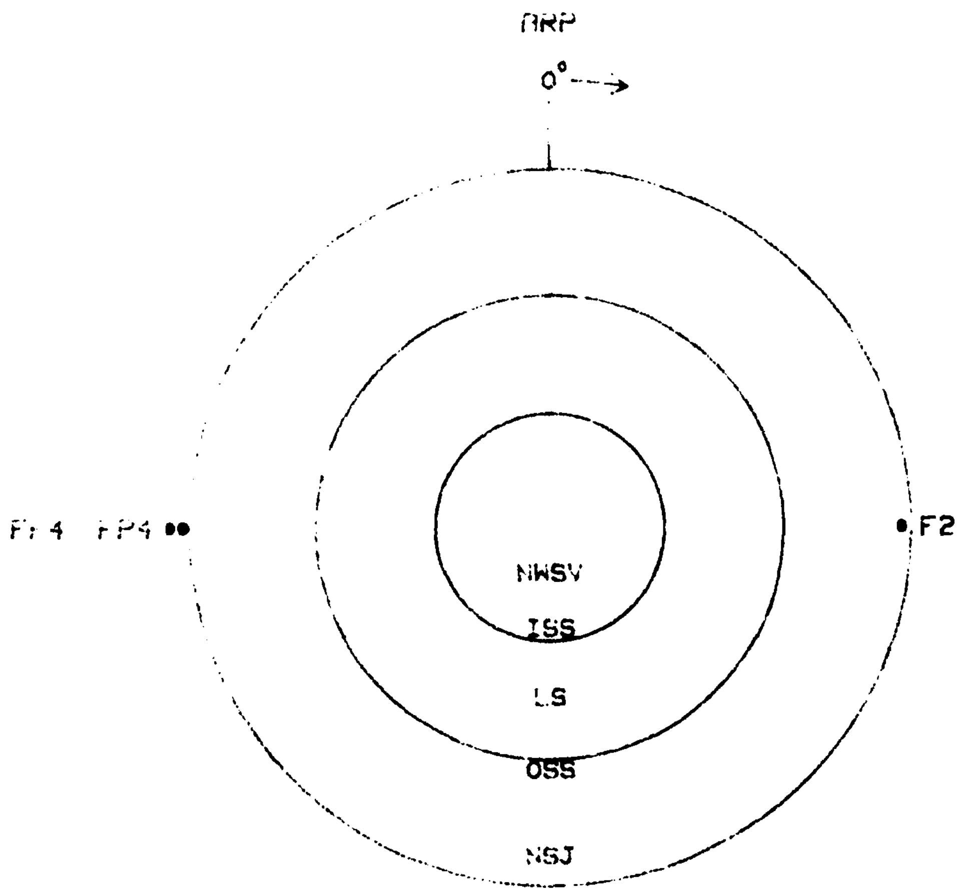

Figure A.11. Cross Section of Cask at 62.2 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

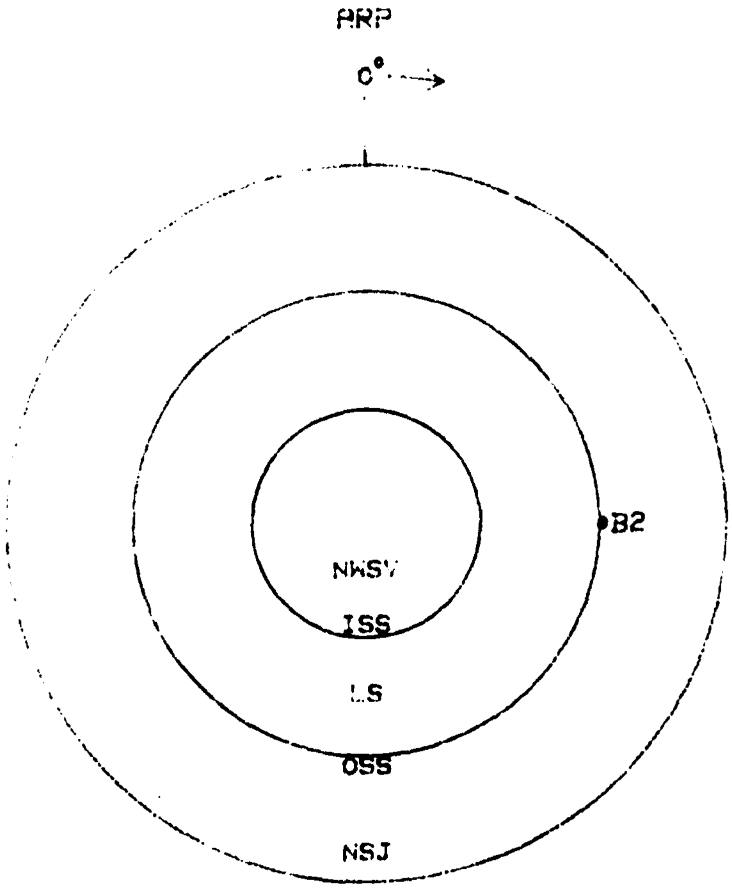

Figure A.12. Cross Section of Cask at 63.5 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD
ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

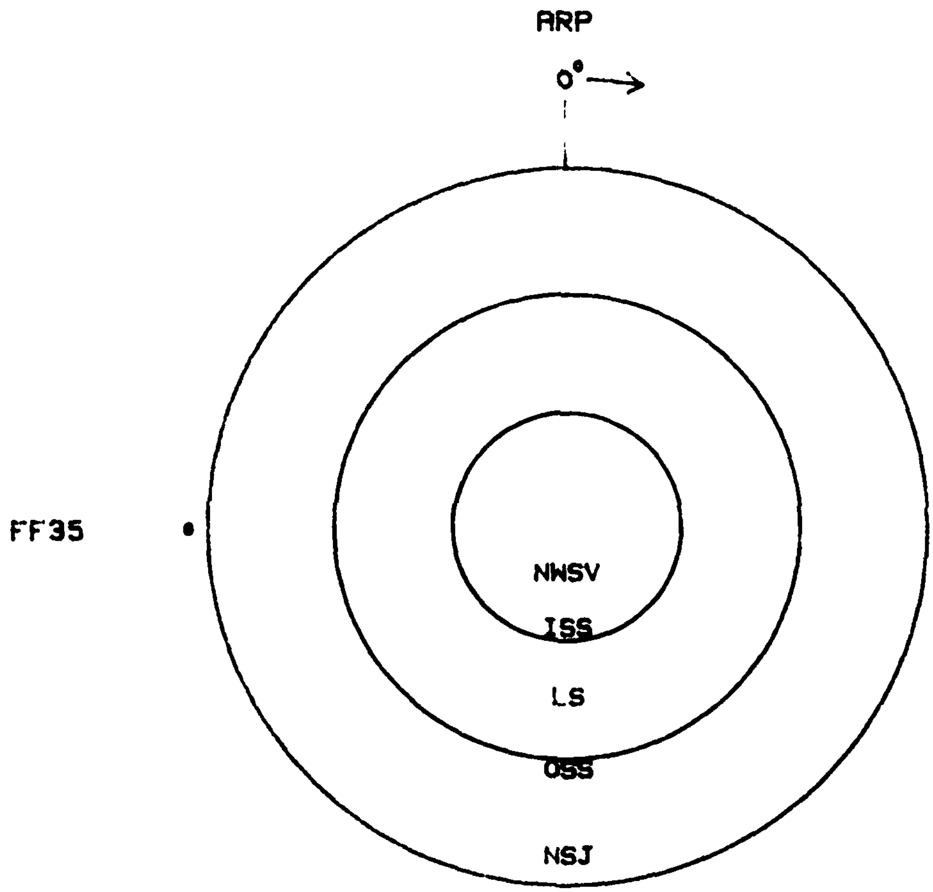

Figure A.13. Cross Section of Cask at 78.1 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP --- ANGULAR REFERENCE POINT
ISS --- INNER STEEL SHELL
NWSV --- NUCLEAR WASTE STORAGE VOLUME

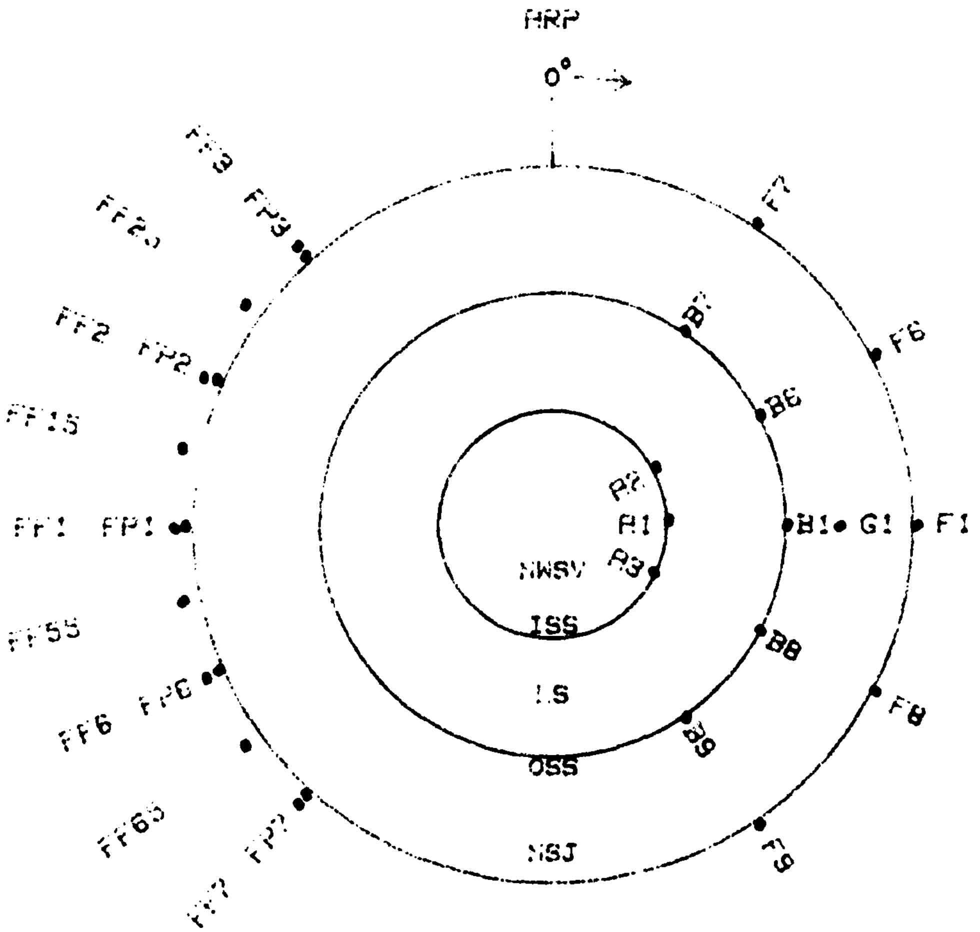

Figure A.14. Cross Section of Cask at 93.3 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

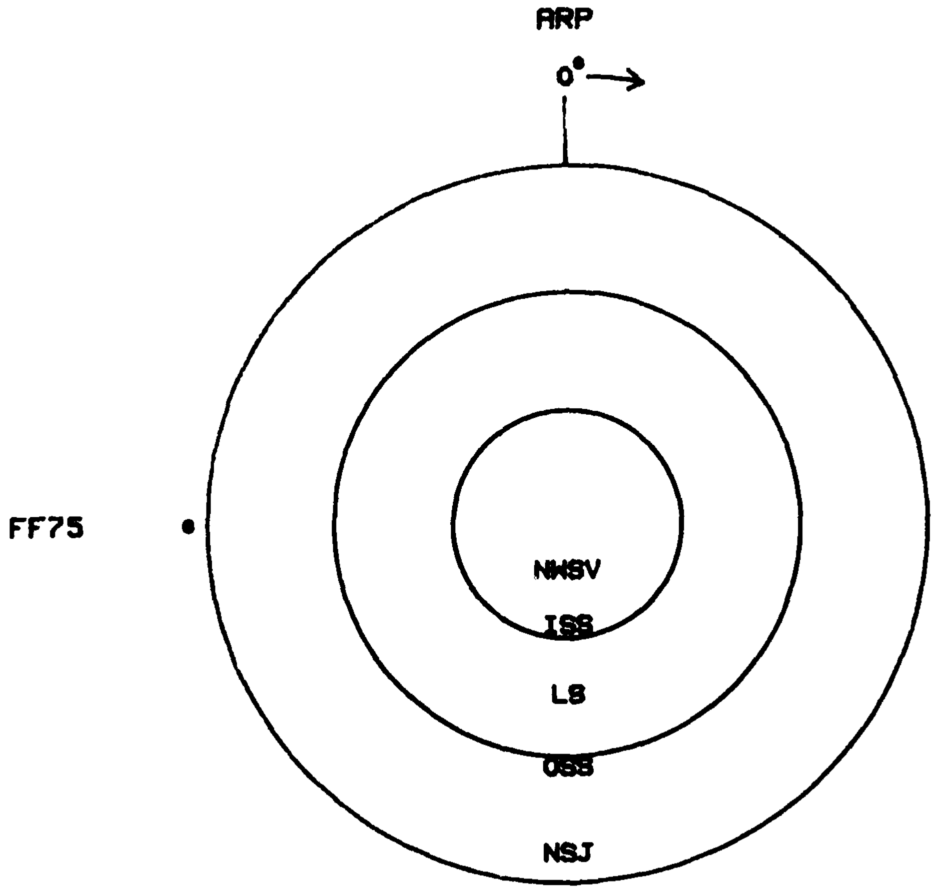

Figure A.15. Cross Section of Cask at 108.5 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

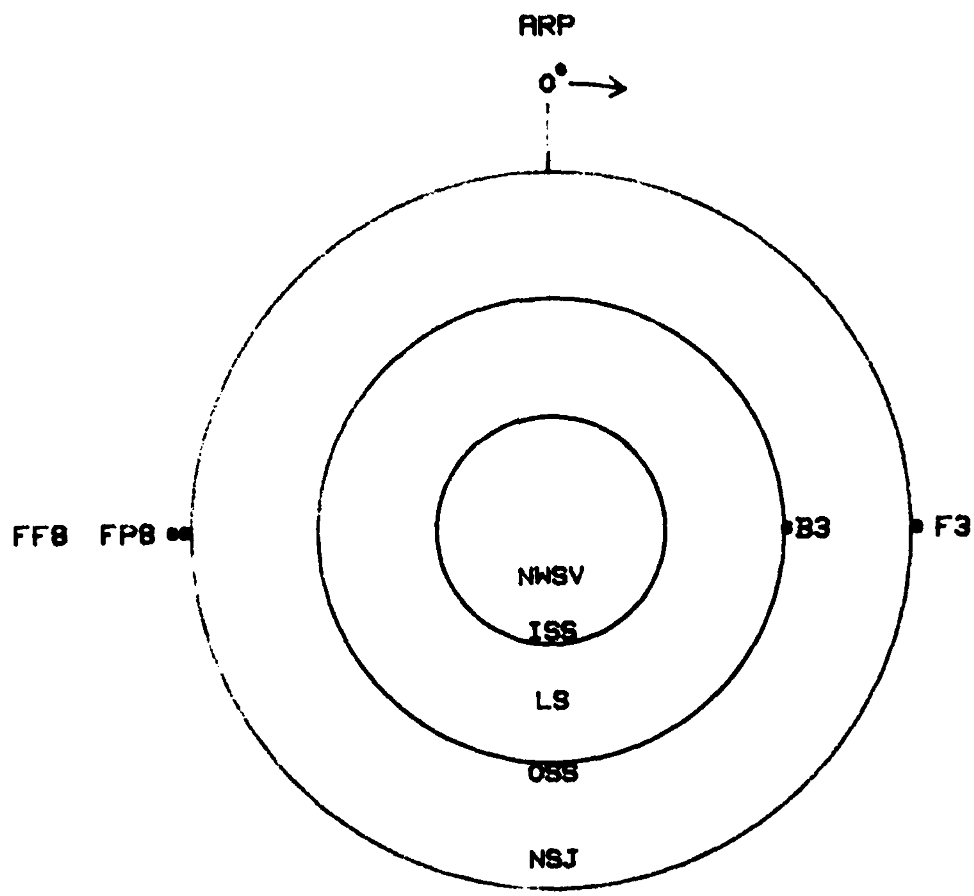

Figure A.16. Cross Section of Cask at 123.8 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

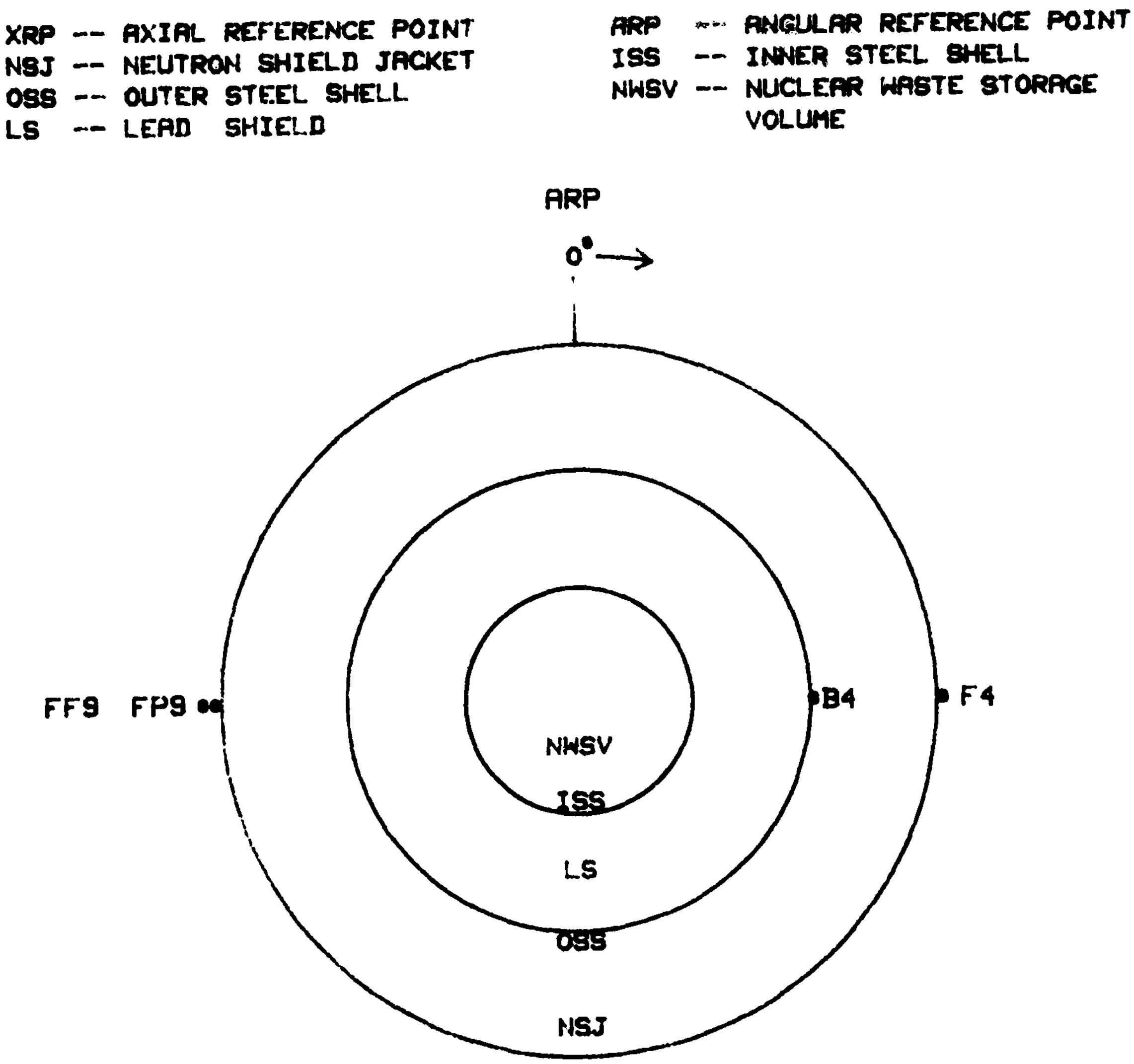

Figure A.17. Cross Section of Cask at 154.3 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

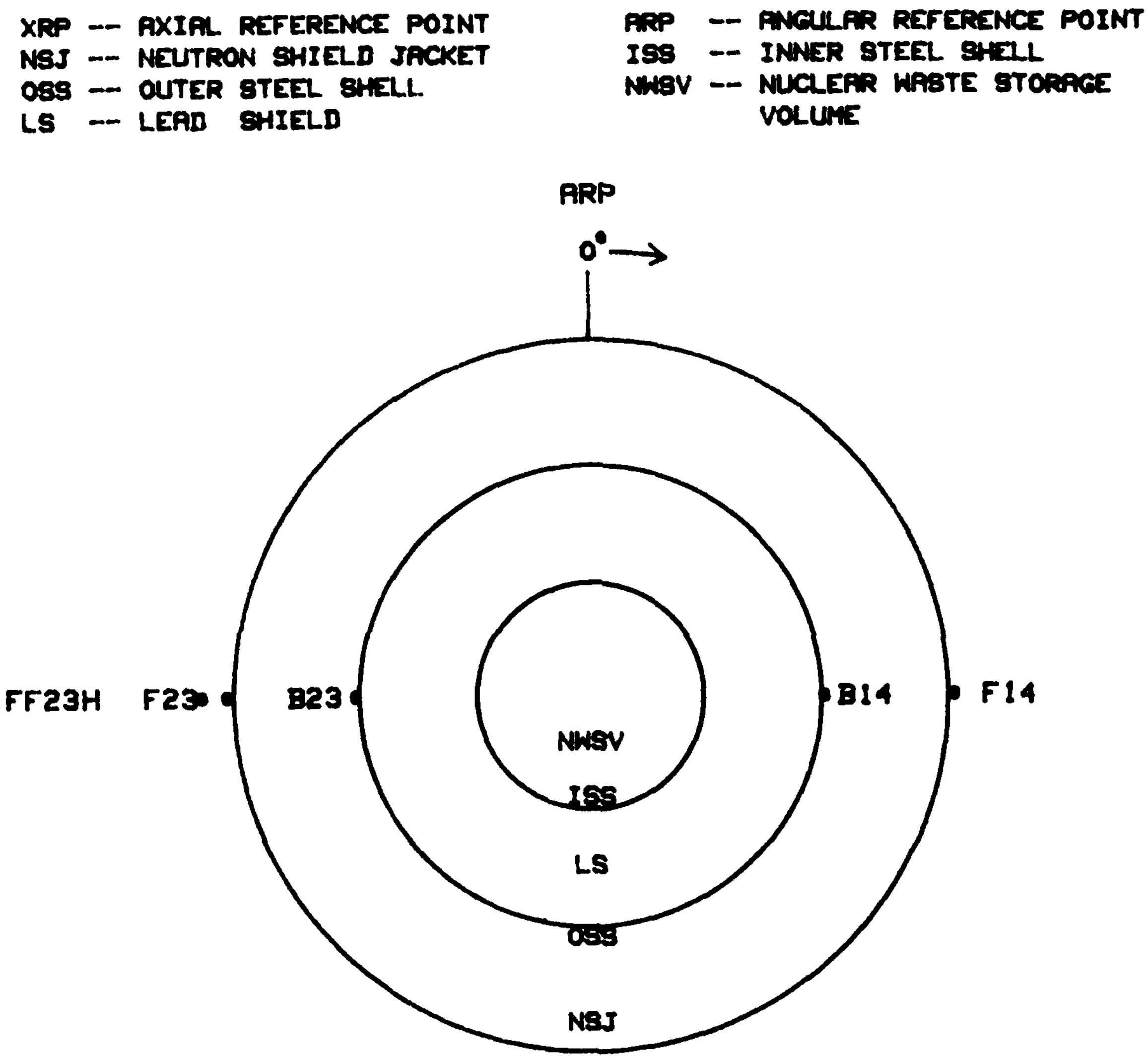

Figure A.18. Cross Section of Cask at 228.6 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

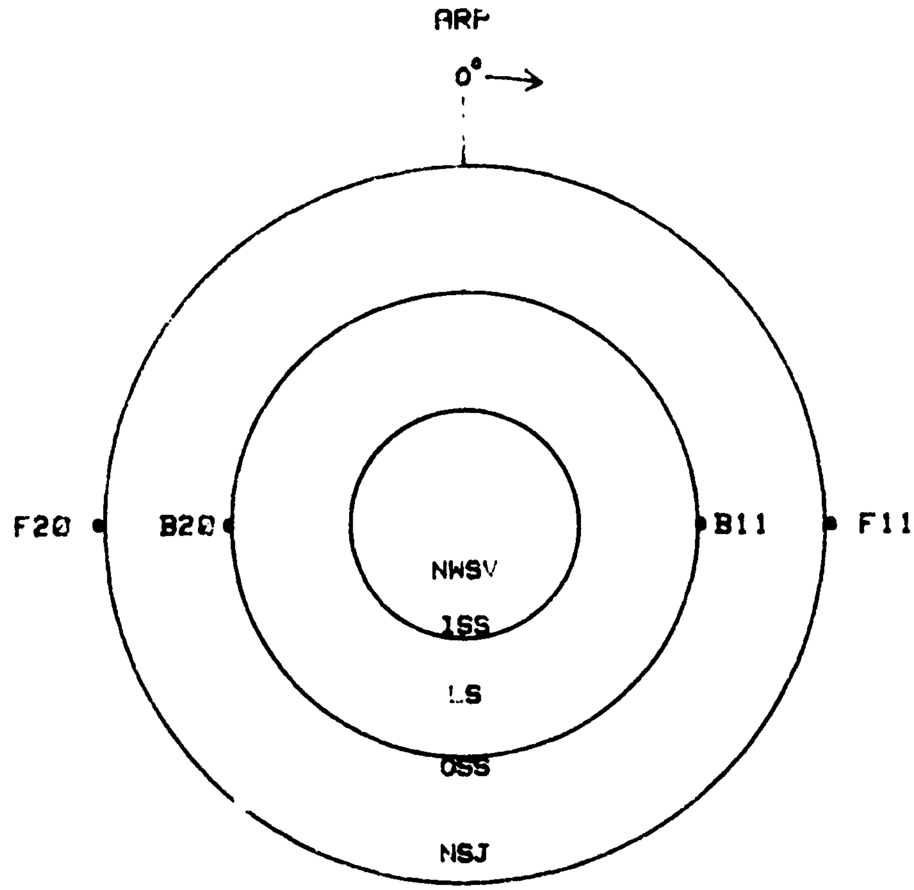

Figure A.19. Cross Section of Cask at 259.1 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

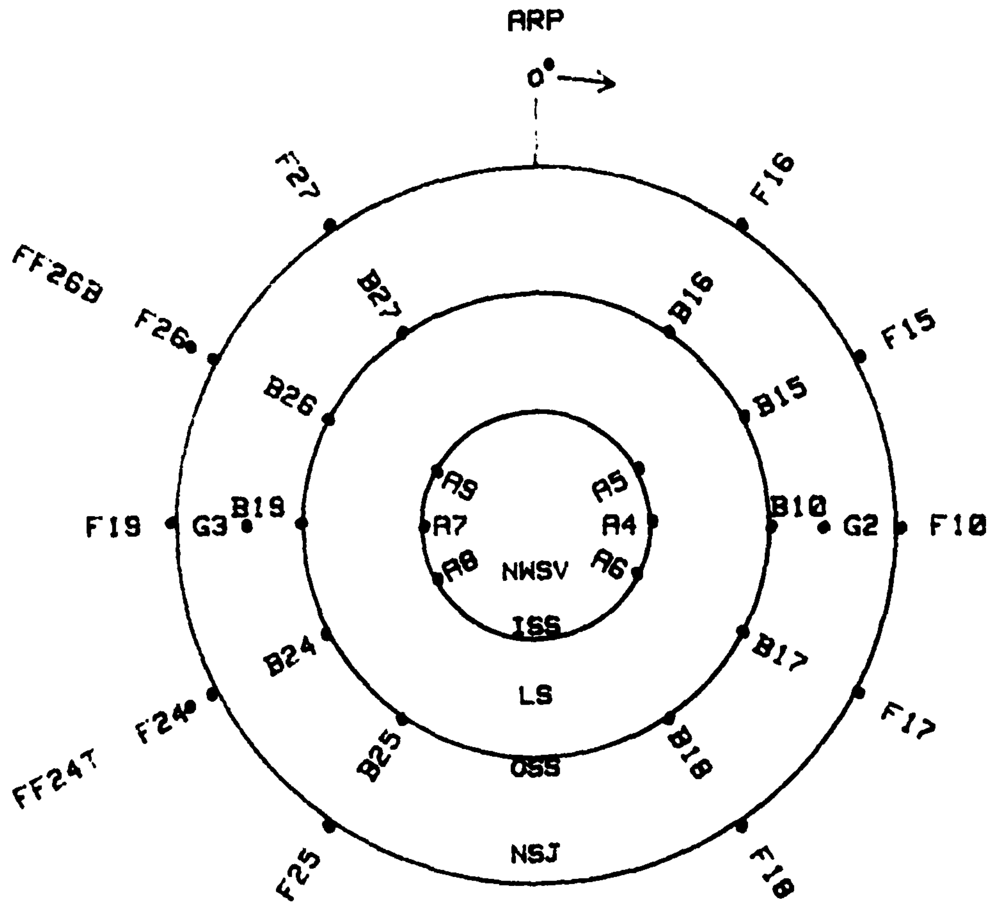

Figure A.20. Cross Section of Cask at 289.6 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

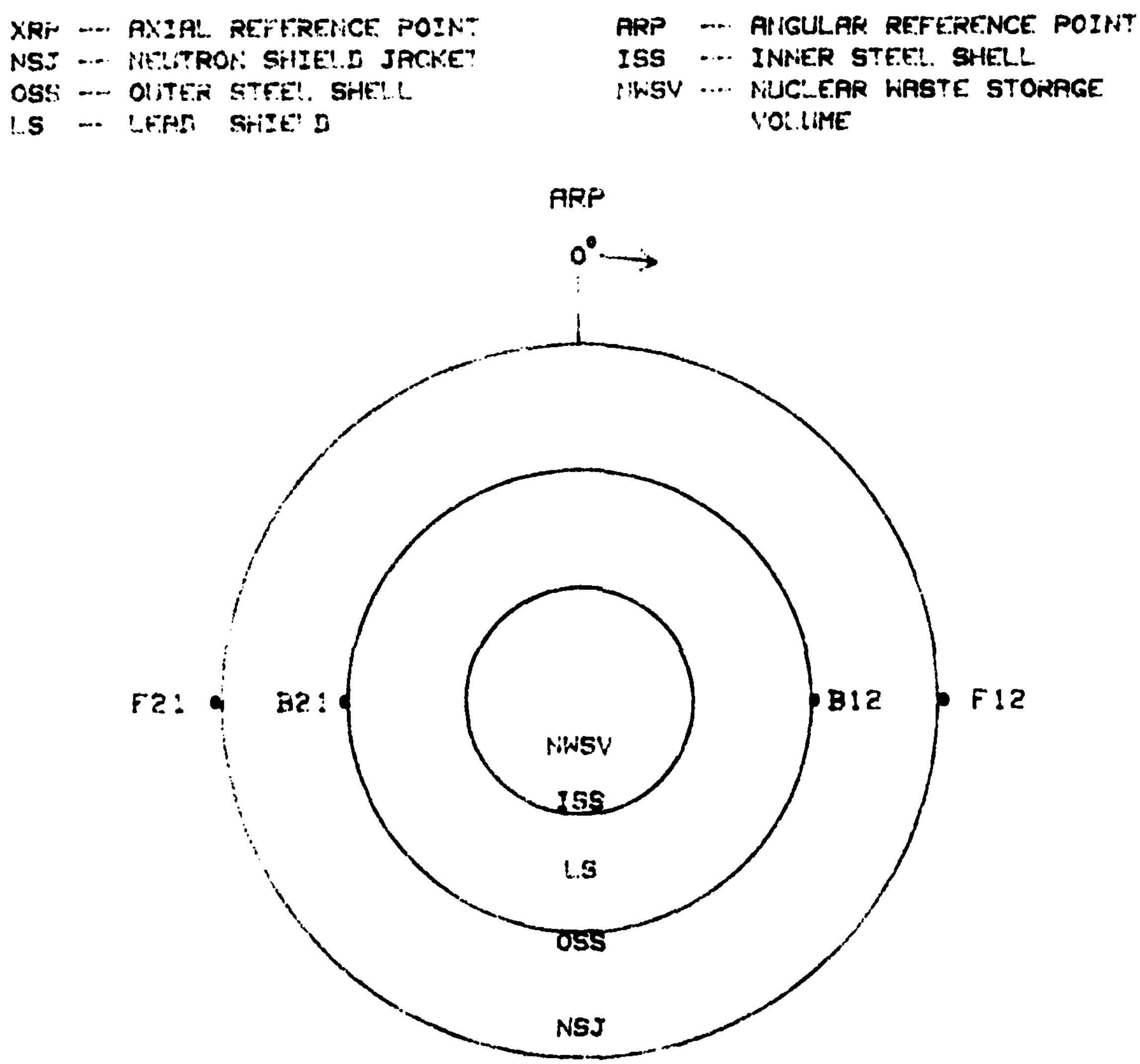

Figure A.21. Cross Section of Cask at 320 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP --- AXIAL REFERENCE POINT
NSJ --- NEUTRON SHIELD JACKET
OSS --- OUTER STEEL SHELL
LS --- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

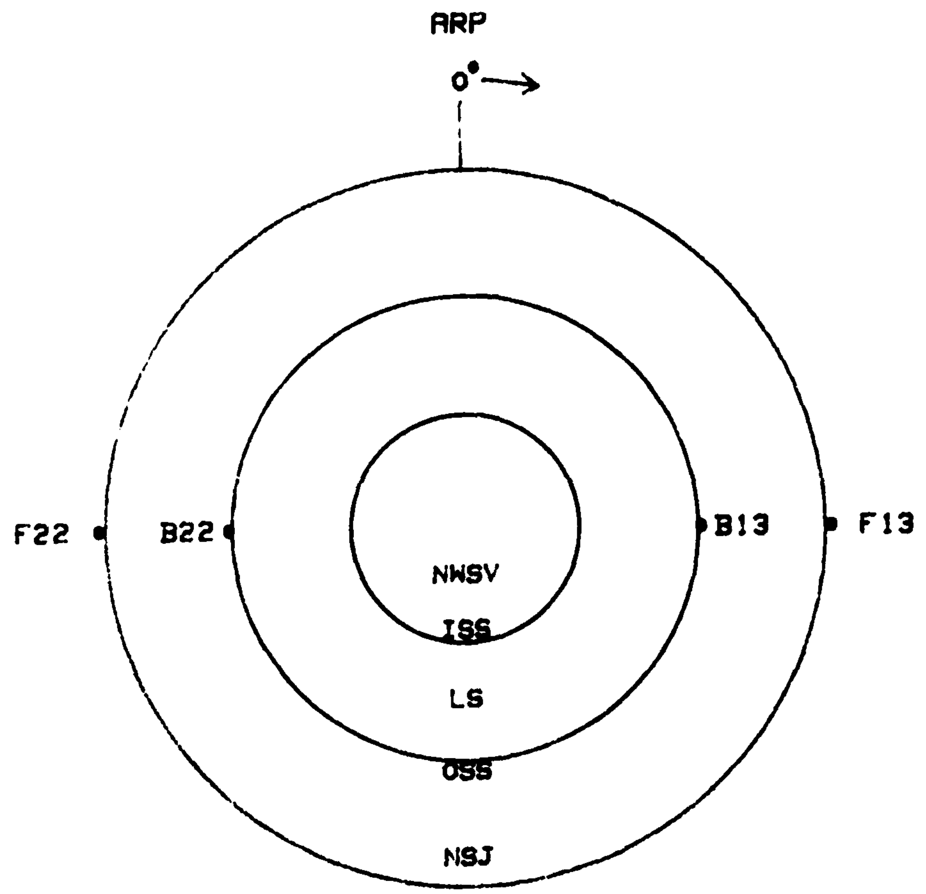

Figure A.22. Cross Section of Cask at 350.5 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed From the Top End

XRP -- AXIAL REFERENCE POINT
NSJ -- NEUTRON SHIELD JACKET
OSS -- OUTER STEEL SHELL
LS -- LEAD SHIELD

ARP -- ANGULAR REFERENCE POINT
ISS -- INNER STEEL SHELL
NWSV -- NUCLEAR WASTE STORAGE VOLUME

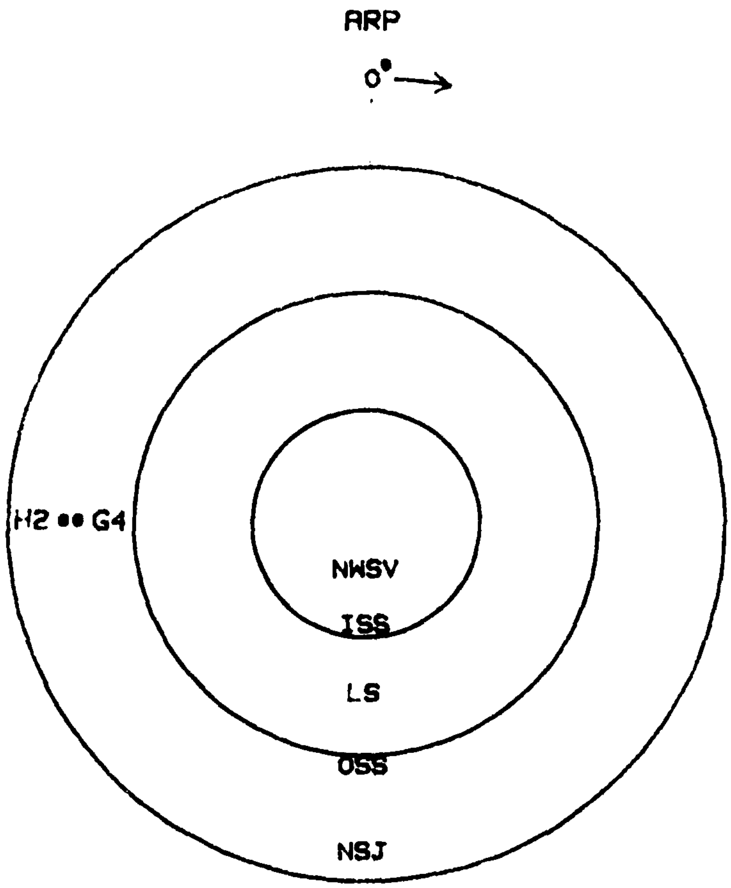

Figure A.23. Cross Section of Cask at 522.6 cm From the XRP Showing Angular Locations of all Sensors in this Plane as Viewed from the Top End

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