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ANALYSIS OF THE POLAR CRANE PENDANT CABLE FROM THREE MILE ISLAND - UNIT 2

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ABSTRACT

The pendant cable to the polar crane in Three Mile Island - Unit 2 (TMI-2) was suspended near the center of the containment during the March 1979 accident. It sustained considerable thermal damage from the hydrogen burn that occurred. The cable was removed from TMI-2 and cut into sections, which were then analyzed to assess the extent of damage and learn as much as possible about the accident environment (by studying its effect on the cable). Both electrical and materials tests were employed in the analyses, which produced information about the hydrogen burn and contamination levels in containment.

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EXECUTIVE SUMMARY

As a result of the accident at Unit 2 of the Three Mile Island (TMI-2) nuclear power station many questions were raised regarding the accident environment and the equipment's response to that environment. As part of the study to answer these questions, the Cable/Connections Task was formed at Sandia National Laboratories, Albuquerque (SNLA), under the direction of the Department of Energy's Technical Integration Office at TMI-2. Its objectives are (1) to assess the effect of the accident on components of electrical circuits installed in TMI-2, and (2) to learn as much as possible about the accident environment by studying the components. One piece of equipment studied as part of the Cable/Connections Task was the polar crane pendant cable (PCPC).

The specific objectives of this study were to identify any significant changes in material or electrical characteristics that the PCPC experienced as a result of the TMI-2 environment and to use this information to achieve a better understanding of the accident environment.

The PCPC had 41 insulated conductors that provided control circuits to the polar crane in the TMI-2 containment. It was suspended near the center of the containment during the accident, and its outer jacket sustained varying degrees of thermal damage from the hydrogen burn. The samples of the PCPC that were studied include sections taken from three distinct regions of the cable: the charred region, the discolored region, and the undamaged region.

Materials, electrical, and thermal environment studies were employed to analyze the cable. These included

- Tensile/elongation tests, jacket hardness, and insulation density measurements
- Capacitance, insulation resistance, and characteristic impedance measurements
- Thermogravimetric analysis, heat-flux computer simulations and experiments, and containment building geometry analysis

The results of all tests indicated that although the PCPC's outer jacket showed considerable damage, the accident environment had little or no effect on the material properties of the inner insulation or on the cable's ability to perform its intended function. Analysis of the material properties of the outer jacket provided valuable data concerning radiation contamination levels and the hydrogen burn. Radiation measurements of the outer jacket demonstrated that horizontal surfaces in the TMI-2 containment were likely to have much higher contamination levels than vertical surfaces. The char pattern and associated thermal studies provided information about the path taken by the hydrogen burn, enabled the calculation of heat flux levels associated with the hydrogen burn, and confirmed related work done by the Hydrogen Burn Survival Program.

ANALYSIS OF THE POLAR CRANE PENDANT CABLE FROM THREE MILE ISLAND - UNIT 2

1. Introduction

A nuclear accident occurred at Unit 2 of the Three Mile Island nuclear power plant (TMI-2) on March 28, 1979. Despite the severity of the accident, the engineered safety systems operated sufficiently to mitigate the consequences of the accident. While the proper operation of these safety and containment systems is generally recognized, many details concerning the accident and its effects are not clearly understood. Because TMI-2 represents a unique source of information about the effects of a nuclear accident, the Technical Information and Examination Program was established to gather, record, and distribute this information. The Technical Integration Office (TIO) manages this extended effort. The program seeks to identify instruments and electrical components that failed during or after the accident, to identify the causes of failure, and to assess the physical condition of those that did not fail. The Cable/Connections Task of this program is to assess the effect of the accident on electrical circuit components within the reactor building.

The objectives of the Cable/Connections Task are (1) to determine the effect of the containment environment on electrical circuit components and (2) to study these effects to define the containment environment to which each component was exposed. The environment within the containment is complex. During the accident, any of the following conditions may have existed, depending on the location within the

containment: radiation, containment spray, steam, temperature changes, humidity, overpressure, submergence, and hydrogen burn. The components under the purview of the Cable/Connections Task include penetration assemblies, terminal boxes (NEMA boxes, pull boxes), splices, terminal blocks, bulk cable, connectors, and all other components in an electrical circuit from the point of penetration into the containment up to, but excluding, the instrument or unit at the end of the circuit.

The first component studied by the Cable/Connections Task was the polar crane pendant cable (PCPC). This report presents the results of that study.

2. Polar Crane Pendant Cable Description and Orientation

The polar crane pendant cable (PCPC) was the control cable for the 500-ton polar crane in the reactor building. Figure 1 is a cross-sectional view of the TMI-2 containment, showing the PCPC hanging approximately 15 m (50 ft) in the unobstructed space near the center of the containment building. Figure 2 presents a top view of the containment building, showing the position of the polar crane and PCPC relative to structures at the 347-ft elevation. Since the total length of the cable was over 18 m (60 ft), approximately 3 m (10 ft) of the lower end lay upon the D-ring structure at the 347-ft elevation of the containment building. Figure 3 illustrates the attachment of the PCPC to the polar crane. Girder A and the walkway, shown in Figure 3, are massive steel structures whose effects are important in the analysis of the pattern of burn damage to the cable.

Because of the location of the PCPC during the accident, it is considered a prime source of information about both radiation levels and hydrogen-burn phenomena in the

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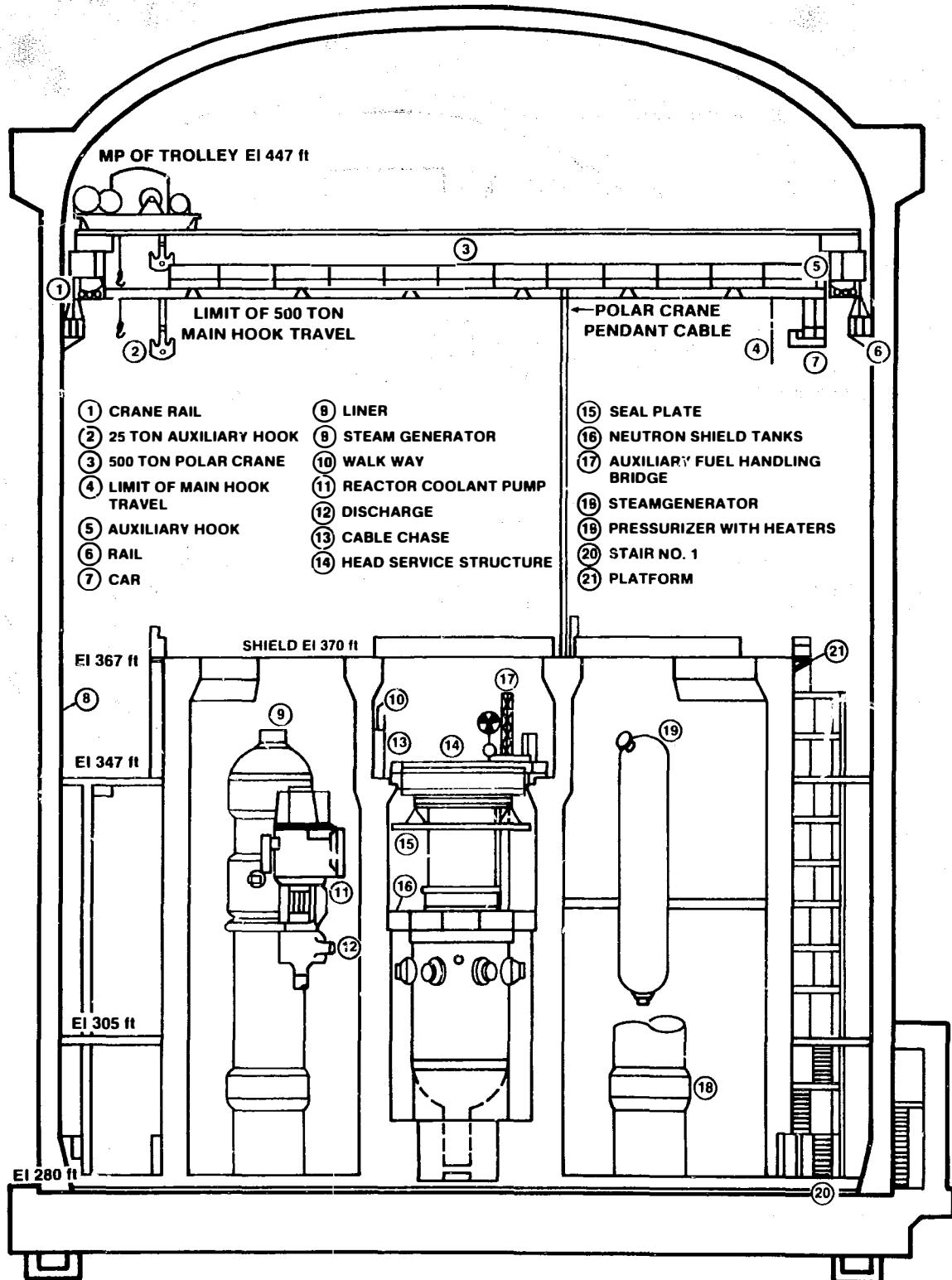


Figure 1. Cross Section of TMI-2 Reactor Containment Building (Looking North to South).

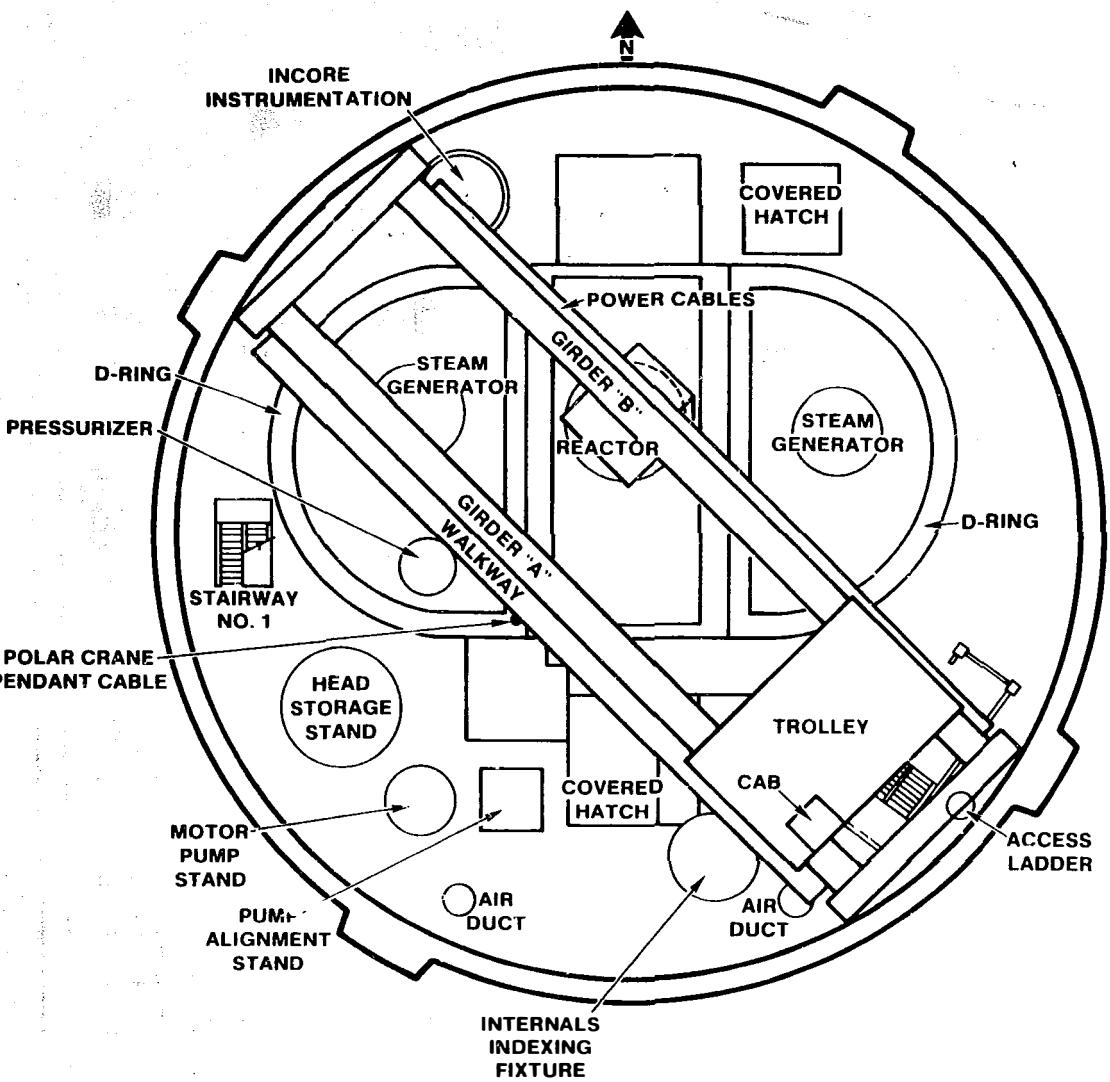


Figure 2. Floor Plan of Elevation 347, with Polar Crane Superimposed.

containment, and it could provide a radiation-dose and hydrogen-burn map through the 15 m (50 ft) of vertical space near the center of the containment building.

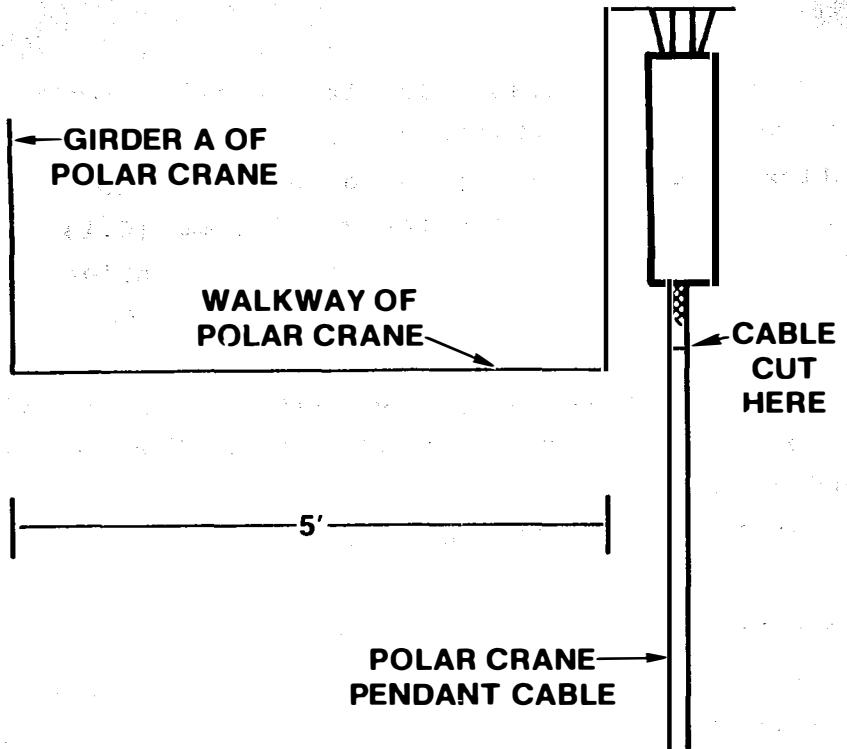


Figure 3. Attachment of PCPC to Polar Crane.

2.1 Cable Description

The PCPC was purchased by the Whiting Corporation, the manufacturer of the polar crane, from Boston Insulated Wire and Cable Company (BIW) in early 1977. The cable jacket is chlorosulfonated polyethylene (DuPont Hypalon™) with a bright yellow pigment (a diarylide pigment) dispersed in ethylene-propylene rubber (EPR). The jacket is approximately half filled with inorganic filler (titanium dioxide, platty talc, lead) and contains an antioxidant (octylated diphenylaniline).¹ The thickness of the jacket varies from 2.4 mm to 3.2 mm (0.09 in to 0.13 in).

Electrically, the PCPC is composed of a 7-strand central conductor and 40 individually insulated conductors surrounding the center conductor in 3 layers. The insulation surrounding each of the 40 copper conductors (16 AWG) is a cross-linked polyethylene with ethylene-propylene diene

monomer rubber. This insulation is approximately half filled with inorganic filler (talc, clay, lead), carbon black, and an antioxidant (trimethylquinoline).¹ The insulation has a nominal outside diameter of 3.2 mm (0.13 in). Each insulated conductor is encased in a 6.6-nylon sheath of 0.1 mm (0.004 in) nominal thickness. The 40 individually insulated conductors are arranged in 3 groups: 6 conductors surrounding the center conductor (inner layer), 14 in the middle layer, and 20 in the outer layer. The entire conductor bundle is wrapped in a black cloth tape. Figure 4 illustrates the cable construction.

2.2 Orientation of Cable in Containment

Refurbishment of the polar crane was a high priority in the recovery and clean-up effort at TMI-2 because the polar crane was required for reactor vessel head removal and subsequent core examination. A work package (see Appendix) was developed for the removal of the PCPC and its replacement. The work package describes in detail the procedure used to mark the cable before cutting to ensure that it would be possible to reconstruct the orientation of the cable as it hung in containment during the accident. Knowledge of the cable orientation is essential in deducing the path of the hydrogen burn from studies of the burn pattern on the cable.

The orientation of the PCPC with respect to north was recorded on the topmost section (section 31), and then about half the cable was laid down on a premarked Herculite™ sheet, taped, numbered, match-marked, and cut between sections 16 and 17. The remainder of the cable was then lowered, and the taping, numbering, and match-marking were repeated on the second half of the cable. The two long pieces of cable were cut into approximately 76-cm (30-in) sections, with sections 1 through 16 cut in one sequence and sections 17 through 31 cut in a second sequence.

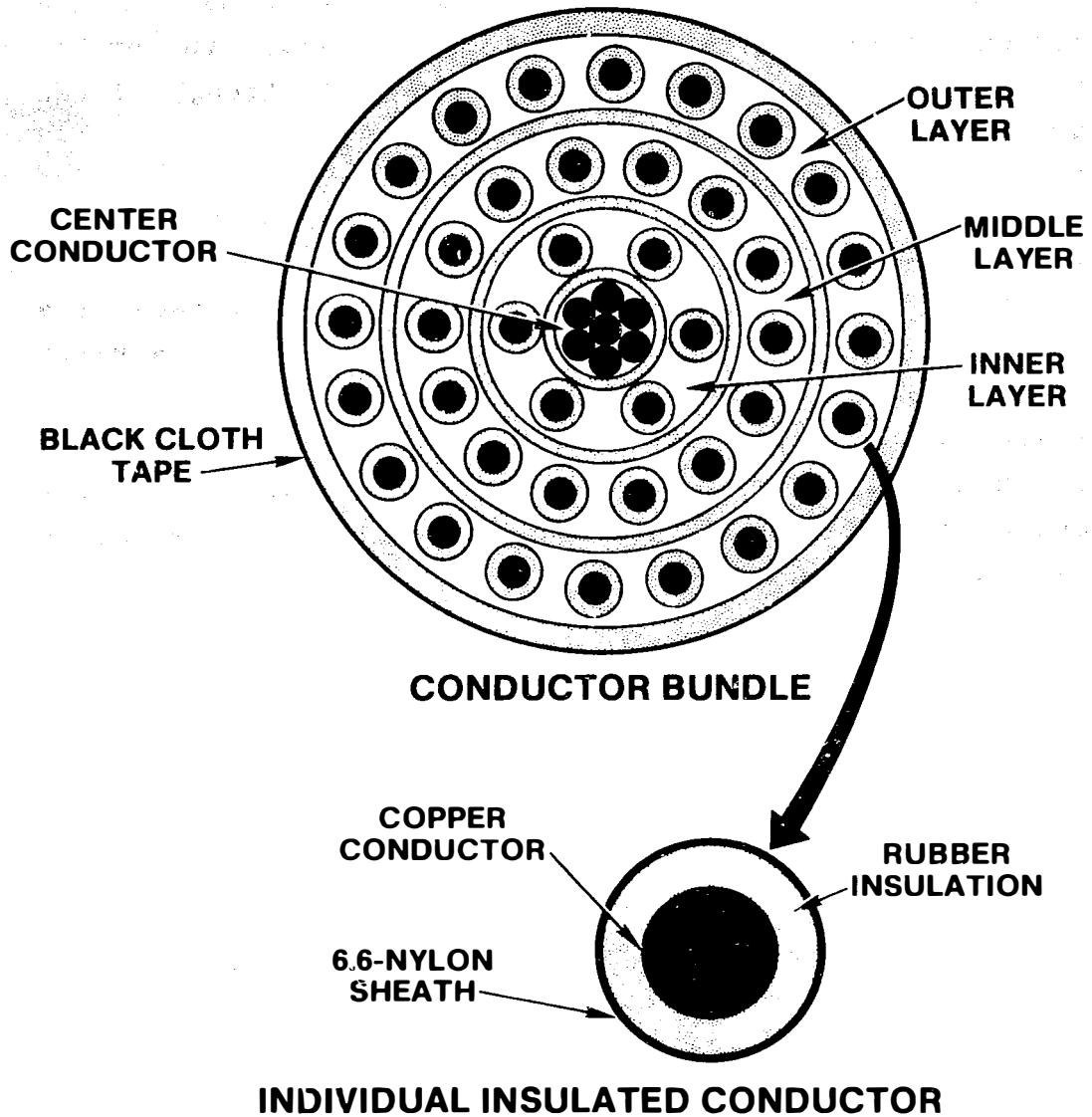


Figure 4. Cross Section of PCPC and Individual Insulated Conductor.

Because the cable was carefully handled so that it did not twist as it was placed on the Herculite™ sheet and because the north orientation mark of section 31 and its corresponding match mark on section 30 are known, the orientation with respect to north for sections 31 through 17 can be determined.

Figure 5 shows the north orientation and match mark for cable section 31. Comparison of the match marks of cable sections 17 through 15 (the transition sections between the upper and lower halves of the cable) shows that these match marks are in approximate alignment and are located on the east side of the cable as it hung in the containment building. Therefore, the approximate alignment of the entire length of cable is known relative to the north orientation of cable section 31.

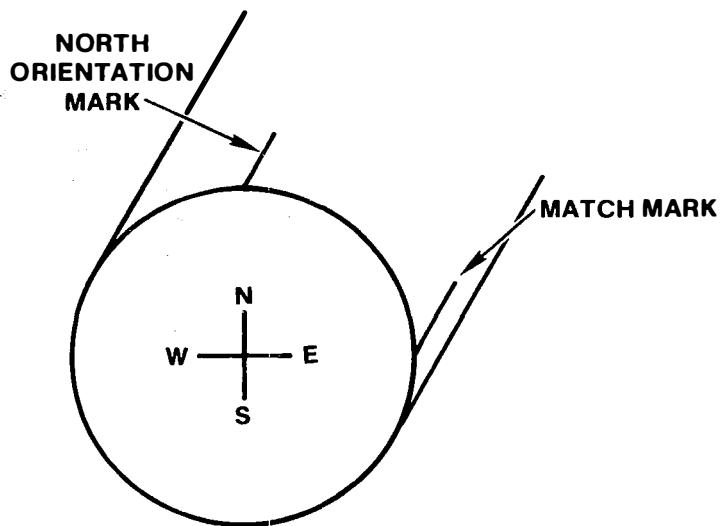


Figure 5. View of PCPC (Section 31) Showing Orientation and Match Marks.

The PCPC was cut and removed from containment on August 23, 1982, and the cable sections were received at Sandia National Laboratories, Albuquerque (SNLA) on October 12, 1982. Because of the match-marking system, each 76-cm (30-in) section of cable is associated with two numbers. In this report, a given cable section will be designated by the smaller of the two numbers associated with each cable section.

3. Cable Materials Analysis

Measurements of the electrical properties of the PCPC sections can yield a more accurate representation of the residual ability of other in-containment circuits to perform their electrical functions than can measurements of the materials properties. However, the materials analysis of the PCPC augments and supports the electrical findings. The testing of electrical components often indicates that changes in material properties occur before changes in electrical performance. Thus, materials analysis may indirectly detect incipient electrical degradation. An analysis of the changes observed in the electrical and materials properties of the PCPC will yield information about the environment to which the cable was exposed during the accident. This report examines both the electrical and material properties of the PCPC, with the materials analysis presented first.

3.1 Visual Examination

The cable sections were shipped from TMI-2 in a 55-gallon drum with appropriate precautions against radiological hazards. The cable sections were unpacked at SNLA and placed end-to-end in numerical sequence to examine the gross physical features of the cable. The length of each cable section was measured, and the γ and combined γ/β

radiation levels were determined. The following observations summarize the major findings of this initial examination:

- Cable sections 3, 4, 5, and 7 showed evidence of physical abuse. Cuts in the cable jacket and signs of abrasion were observed. Heavy-duty sleeving had been put on cable sections 4 and 5, apparently to protect damaged jacket areas. These lower-numbered cable sections did not lie as straight as the other sections, suggesting that the lower end of the cable had been coiled on a horizontal surface and had not hung vertically during the accident.
- Figure 6 presents a plot of radiation level versus cable section number. The measured radiation level of the lower-numbered cable sections was an order of magnitude higher than that of the rest of the sections. This finding is in agreement with other radiation-level observations for TMI-2, in which horizontal surfaces have higher radiation levels than do vertical surfaces because a horizontal surface exposes more area to settling contamination than does a vertical surface. The radiation profile in Figure 6 strongly suggests that the lower end of the PCPC rested on a horizontal surface and that the transition point occurred at about cable section 8. At the time of cable removal, the polar crane control box and some length of the PCPC were observed lying on top of the D-ring. The physical abuse noted previously for the lower-numbered cable sections probably resulted from this portion of the cable lying underfoot before the time of the accident.

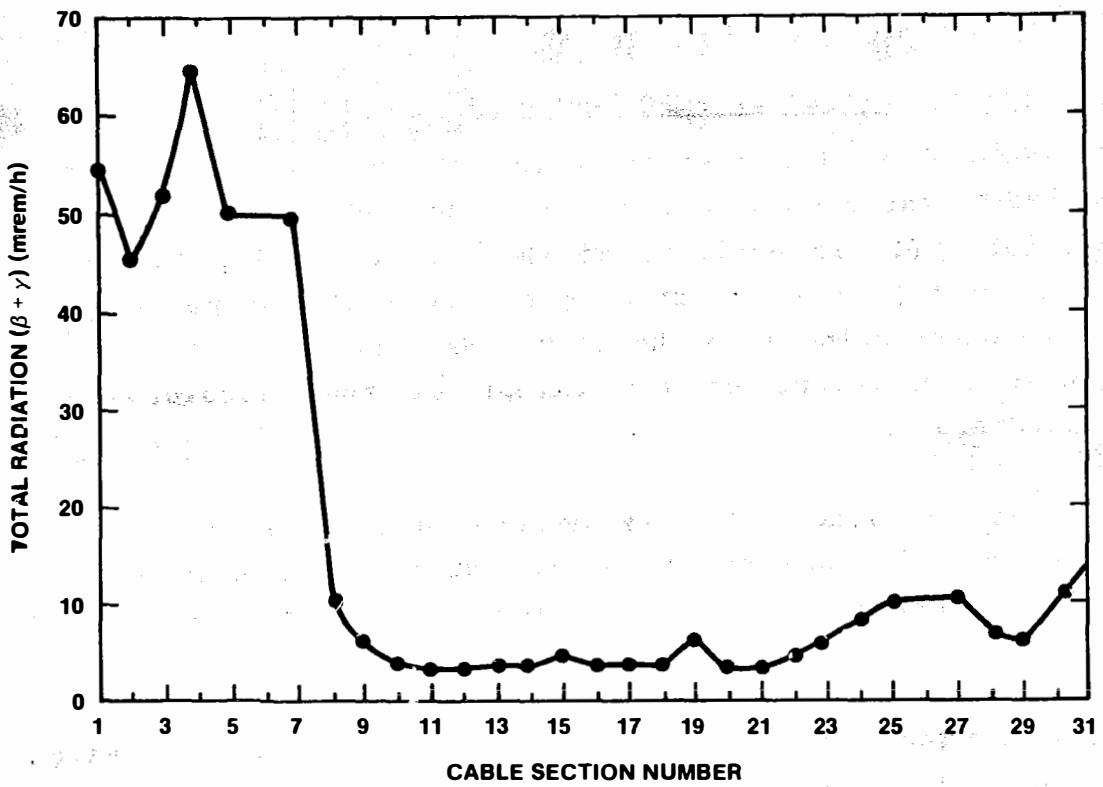


Figure 6. Measured Radiation Level as Function of PCPC Section Number.

- The PCPC can be divided into three distinct regions: a charred region, a discolored region, and an undamaged region free of charring or discoloration. The undamaged cable jacket has a dull, off-white surface, but the subsurface is bright yellow due to the presence of a yellow pigment. In the discolored region, the cable surface is a clearly delineated brown color that penetrates up to 50% of the thickness of the jacket before the bright yellow coloring appears. In the charred region, the cable surface shows black carbon char; beneath the charring is a discolored zone and then the bright yellow layer.

3.2 Identification of PCPC Regions

To aid in the identification of the three regions of the PCPC, three observations were made of the cable jacket material: (1) an estimate of the linear density (gm/cm of cable length), (2) an estimate of the depth of penetration of the discoloring into the jacket material, and (3) a rough angular measurement of the extent of the discolored and charred areas.

For the linear density measurements, a sample of the jacket material was cut from the lower end of each section (except section 31, which was kept intact to preserve the north marker). A circumferential cut was made through the jacket material 18 cm (7 in) from the lower end of each section. The jacket material was then slit along the match marking and peeled away. Each jacket sample was trimmed to a precise 15-cm (6-in) length, the black cloth tape was removed, and the sample was weighed. The weight divided by the length gives the linear density. Figure 7 is a plot of the linear density versus the cable section number. The plot shows a distinct drop in the linear density at cable section 24 (the beginning of the charred region) but shows no change between the discolored and undamaged regions. The decreased density in the charred region suggests a loss of mass due to combustion or volatilization. The smaller weight loss in cable sections 30 and 31 suggests that these two sections should be less charred than other cable sections in the charred region, and this is confirmed by visual observations. The linear density measurements are based upon the assumption that the volume of each cable jacket sample was the same. Because the cross-sectional profiles of the samples are all similar, and the lengths were all trimmed to 15 cm (6 in), this assumption is reasonable.

The transition from the charred to the discolored region of the PCPC, and that from the discolored to the

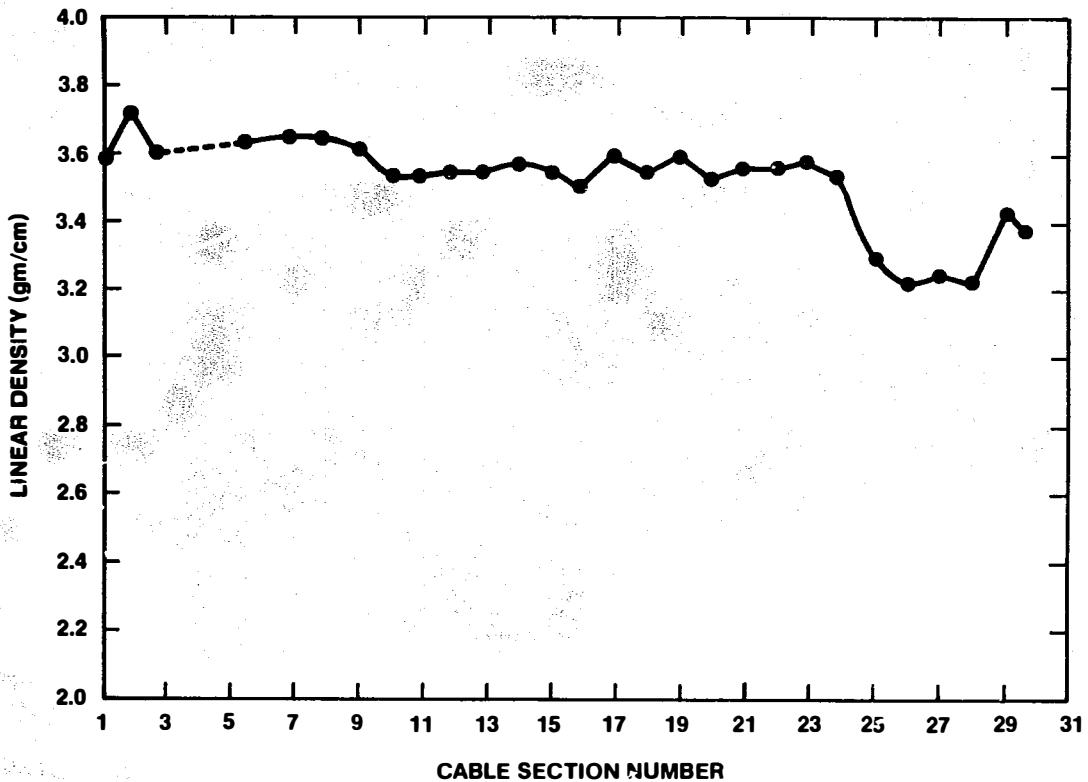
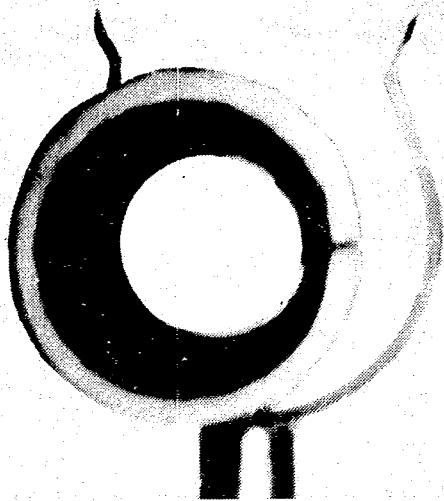
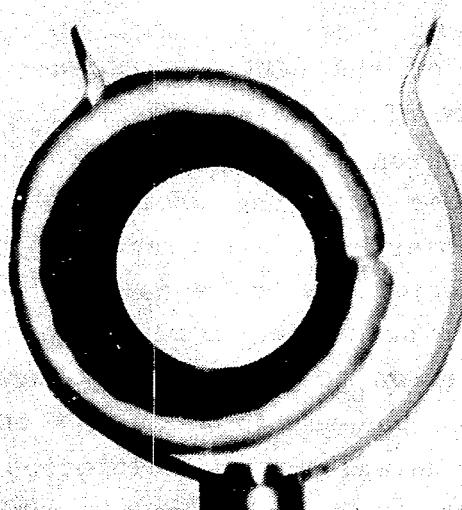


Figure 7. Cable Jacket Linear Density as Function of Cable Section Number.

undamaged region of the cable, were further pinpointed by a visual examination of the cross sections of the test samples. In the charred region, the discoloration beneath the surface charring penetrates into the cable jacket. Figures 8a and 8b show test samples from cable sections 18 and 28, respectively. Test sample 18 shows a partial discoloration at the jacket surface opposite the longitudinal cut. Test sample 28 shows, in addition to surface charring, a circumferential discoloration that penetrates about 40% of the jacket thickness before the normal yellow coloration of the jacket is encountered. Each cable jacket sample was examined to determine the depth of penetration of the discoloration into the cable jacket and the circumferential extent of the discoloration.



(a) Cable Section 18



(b) Cable Section 28

Figure 8. Photographs of Cable Showing Areas of Charring, Discoloration, and Normal Coloration.

The circumferential extent was denoted by a "clock" system in which north is denoted by 12 (o'clock), east by 3, south by 6, and west by 9, with intermediate numbers proportionately spaced. For that part of the cable that had hung vertically in containment, the match mark, along which the cable jacket was slit, corresponds to the east, or 3 o'clock, direction. The thickest part of the jacket was oriented toward the south, or 6 o'clock, direction. The results of this examination are listed in Table 1. These results again confirm the classification of the cable into three regions (undamaged, discolored, and charred) with the transitions occurring between sections 13 and 14 and between sections 23 and 24.

Table 1 shows that the cable jacket colorations (tan, ash, gray, char) approximately match the cable regions determined by the discoloration criteria. It is important to note that cable sections 29, 30, and 31, which were nearest the polar crane, did not show fully circumferential char; the char was on the westward surfaces only. Likewise, the discoloration pattern for test samples 14 to 19 was only on the westward surfaces. These observations are significant in determining the direction of the hydrogen burn in containment.

3.3 Measurement of Elongation vs. Tensile Stress of Conductor Insulation

The removal of 18 cm (7 in) of cable jacket from each cable section exposed the individually insulated conductors. Six of the exposed insulated conductors were cut from cable sections 3, 9, 22, and 28. These cable sections were selected because they represented each region of the PCPC, because cable section 3 was from a high radioactive contamination zone, and because cable section 9 was from a low contamination zone (Figure 6).

Table 1

PCPC Jacket Visual Inspection

Cable Section	Jacket Color	Cable Appearance			Observations
		Undamaged	Discolored	Charred	
1	Tan	yes	no	no	Cut, T-South ^a
2	"	"	"	"	T-East
3	"	"	"	"	Cut, T-South
4					
5					
6	"	"	"	"	T-South
7	"	"	"	"	Cut, T-South
8	White Ash	"	"	"	T-South
9	"	"	"	"	Cloth burn, T-South
10	"	"	"	"	T-South
11	"	"	"	"	T-South, BIW ^b
12	Dark Ash	"	"	"	"
13	"	"	"	"	"
14	Gray		8 to 10, C 5 to 10% ^c	"	"
15	"		9 to 11, 10 to 20%	"	"
16	"		8 to 10, 10 to 20%	"	T-South
17	"		7 to 11, 10 to 20%	"	"
18	"		7 to 11, 10 to 20%	"	"
19	"		7 to 12, 10 to 20%	"	"
20	"		A, ^d 20%	"	"
21	"		8 to 4, 10 to 20%	"	"
22	"		9 to 5, 10 to 20%	"	"
23	"		9 to 6, 10 to 20%	"	"
24	Gray-Trace Char		A, 20%	5 to 7	"
25	Char		A, 20%	A	"
26	"		A, 40%	A	"
27	"		A, 40 to 50%	A	"
28	"		A, 40%	A	"
29	"		A, 20 to 40%	3 to 12	"
30	"		A, 20%	7 to "	"

^aT-South means the jacket was thickest (T) in the southern quadrant.^bBIW means that the words "Boston Insulated Wire and Cable Co." were legible on the jacket sample.^c8 to 10, or similar designation, refers to an orientation scheme in which North is designated 12, East is 3, South is 6, and West is 9, with a given feature being observed in this region.^d5 to 10%, or similar designation, refers to the percent of jacket thickness being discolored.^eA refers to a given feature (discoloration or charring) being observed completely around (A) the jacket sample.

The insulation was stripped intact from the copper conductors after first removing the nylon sheath (Figure 4). The elongation (E) and tensile stress at break (T) of each insulation sample was measured by an Instron™ Table Model 1020 at an ambient temperature of $23 \pm 1^\circ\text{C}$. Samples were gripped by pneumatic jaws with an air pressure of approximately 300 kPa (44 psi). Initial jaw separation was 5 cm (2 in) and samples were strained at 13 cm/min (5 in/min); the strain was monitored with an Instron™ Electrical Tape Extensometer clamped to the sample. Figure 9 presents the results of this elongation and tensile stress study. Examination of these results shows little difference among samples in elongation and tensile strength at break even though the samples were obtained from regions of high heat flux (charred), moderate heat flux (discolored), and low heat flux (undamaged). Additionally, samples from the undamaged region (i.e., from cable sections 3 and 9) showed little difference even though they represent low (9) versus high (3) radiation contamination zones.

The individual insulated conductors are numbered but not color coded; an effort was made to select the same numbered conductors from each cable section. This was not always possible because, in making the longitudinal cut to remove the cable jacket, the insulation on a few of the desired conductors was damaged and they were thus rendered unsuitable for use in this test.

3.4 Shore Hardness Testing

A Shore "A" Durometer with a constant load of 820 g (1.8 lb) was used to measure the hardness of the PCPC jacket; the individual conductor samples were taken from cable sections 3, 9, 22, and 28 and their respective nylon sheaths. Each sample was tested at three points and the three values averaged. The data are presented in Figure 10. The data

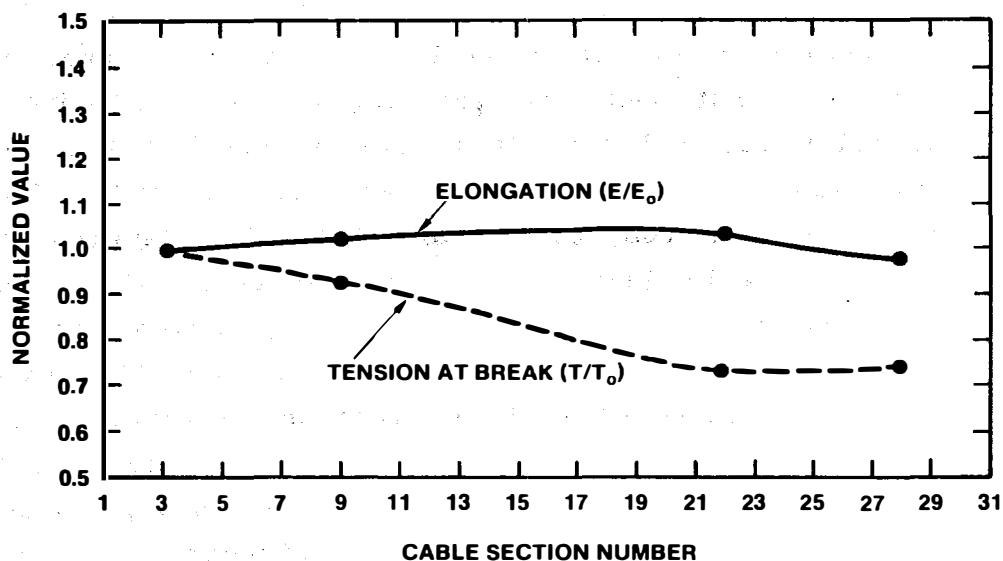


Figure 9. Elongation and Tension of Conductor Insulation as Function of Cable Section Number (Normalized to Value Obtained for Cable Section 3).

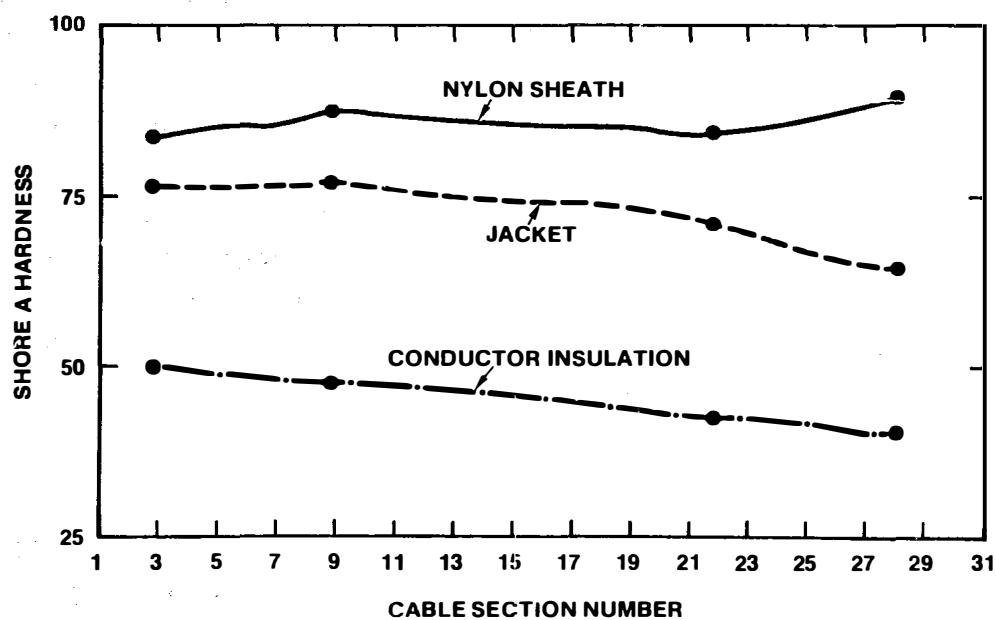


Figure 10. Shore "A" Hardness as Function of Cable Section Number.

show no dramatic difference in hardness between the various cable regions for any of the three types of materials tested.

3.5 Measurement of Density of Conductor Insulation

Attempts were made to determine the densities of the cable jacket, the conductor insulation, and the nylon sheath materials using a density-gradient column technique, which is a sensitive means of determining the density of materials (see Figure 11). However, such sensitivity also means that sample uniformity, water hydration, voids, air bubbles on the sample surface, and other factors must be controlled because they strongly influence the density data. The jacket, nylon sheath, and insulation samples from the cable all were affected by these factors, and no clear determination of density changes in these samples as a function of region could be made. The heavy loading of the jacket and insulation with inorganic filler (approximately 50% by weight) not only affected sample uniformity but also dictated the use of carbon tetrachloride/bromoform and carbon tetrachloride/toluene solvent systems in the density-gradient column. These solvents may extract material from the samples during the course of the density measurement and distort the data generated by this method. Given these limitations, the densities determined for the PCPC jacket and insulation were 1.517 to 1.527 g/cm³ (94.7 to 95.3 lb/ft³) and 1.636 to 1.707 g/cm³ (102.1 to 106.6 lb/ft³), respectively.

4. Electrical Analysis of Cables

Cable sections 3, 9, 22, and 28 were sent to Westinghouse Hanford Co. (WHC) for an analysis of their electrical properties. The principal tests performed were measurements of capacitance, insulation resistance, and characteristic impedance between different conductors in the cable sections.

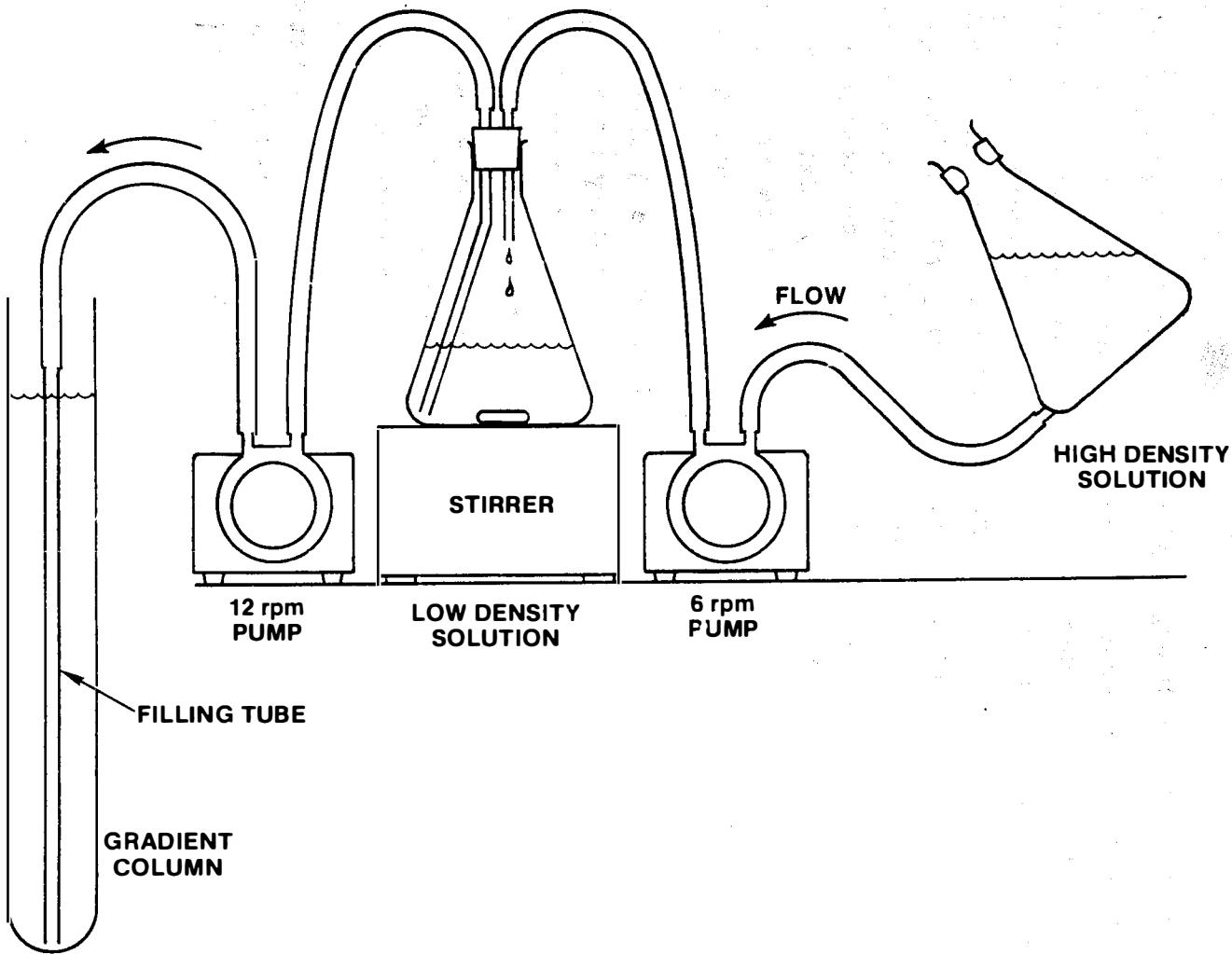


Figure 11. Density-Gradient Column Apparatus.

4.1 Test Description

An illustration of a cable cross section is provided in Figure 12 to aid in the identification of various conductor pairs, as tested and recorded. The cable cross section is divided into "layers" separated by insulation; each layer contains a number of separately insulated conductors. The center of the cable consists of 7 twisted conductors, all in electrical contact with each other, and this group was referred to as the center conductor. The outside layer was identified as L1, the middle layer as L2, and the inner layer as L3. Conductor pairs tested in the same layer were companions (C). As an example of the labeling, the conductor pair (companions) tested in layer 3 (L3) were identified as L3C.

When two layers were bridged by choosing a conductor from each layer (only contiguous layers were bridged), the identification was made by labeling the layers involved (e.g., L1 to L2).

Conductor pairs from a given cable section were chosen and attached to the measurement device as shown in the simplified drawing given in Figure 13. Capacitance measurements were made with a General Radio 1311-A Audio Oscillator and a General Radio 1615-A Capacitance Bridge. Insulation resistance measurements were made with a General Radio 1644 Megohm Bridge. Characteristic impedance measurements were made on the basis of reflected wave fronts recorded with an HP-1415A Time Domain Reflectometer. Loop resistance was not measured because of the short length of the cable sections. All measurements were made on open-ended conductor pairs. An HP-85 Calculator and an HP-3455A Digital Voltmeter (DVM) were used to record decay curves from conductor pairs initially charged to 10 V. Capacitance was calculated from the decay curve, with an example given in Figure 14.

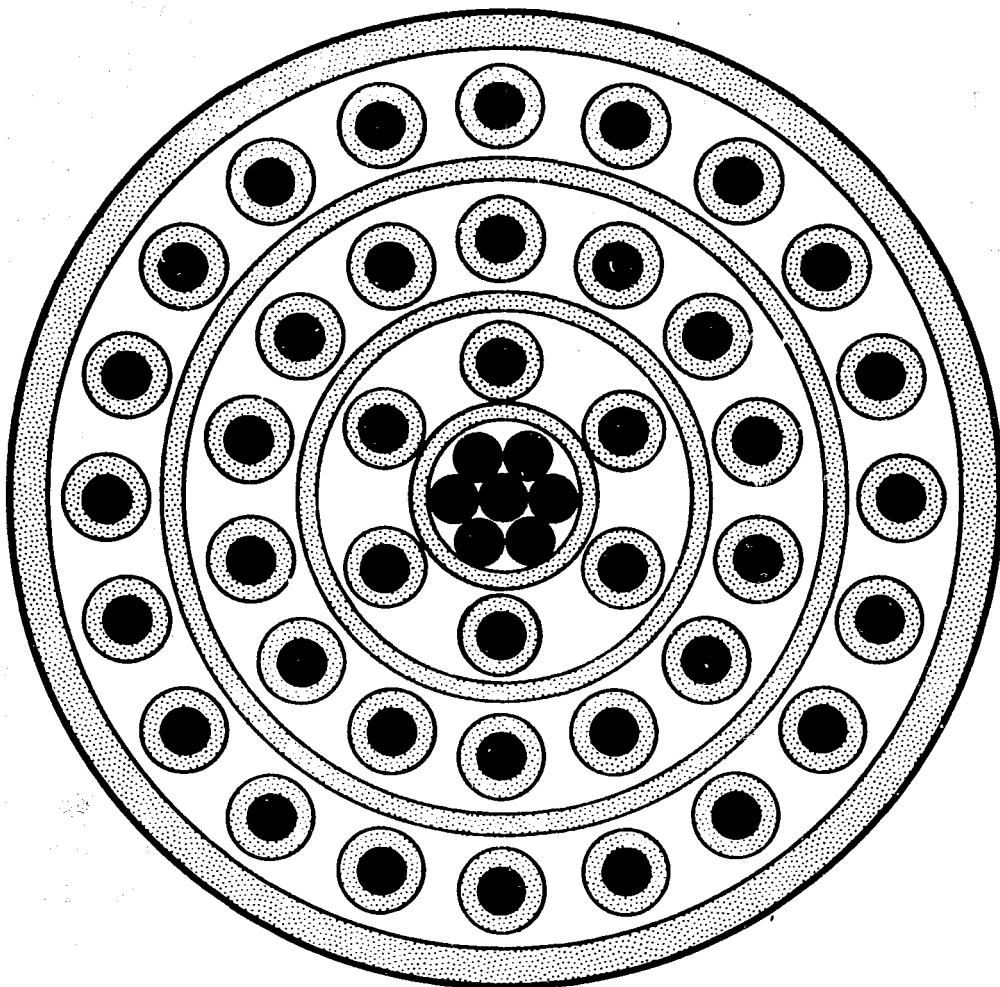


Figure 12. PCPC Cross Section.

1. Center section is composed of 7 twisted conductors, all in electrical contact with each other, and is referred to as the center conductor.
2. Next "layer" out (Layer 3) is composed of 6 conductors, each individually insulated. Each layer is insulated from the other layer. Spacing between conductors is exaggerated within each layer.
3. The layer with 14 conductors is identified as Layer 2. Again, each conductor is individually insulated.
4. The outermost layer is identified as Layer 1, and contains 20 individually insulated conductors.

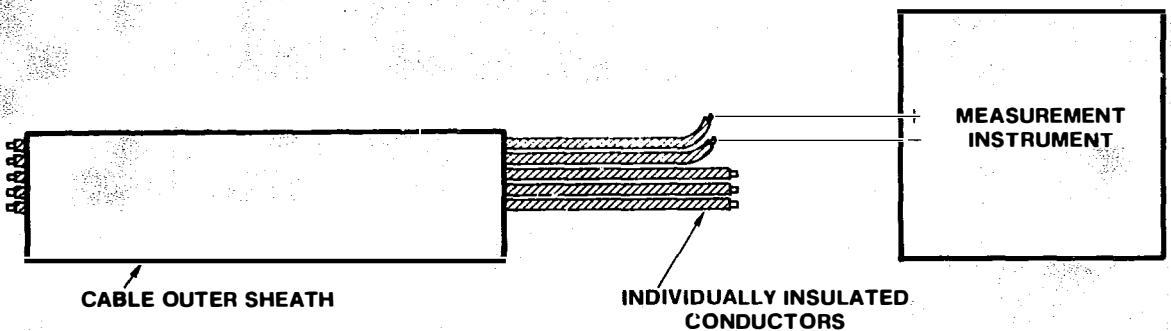


Figure 13. Test Setup.

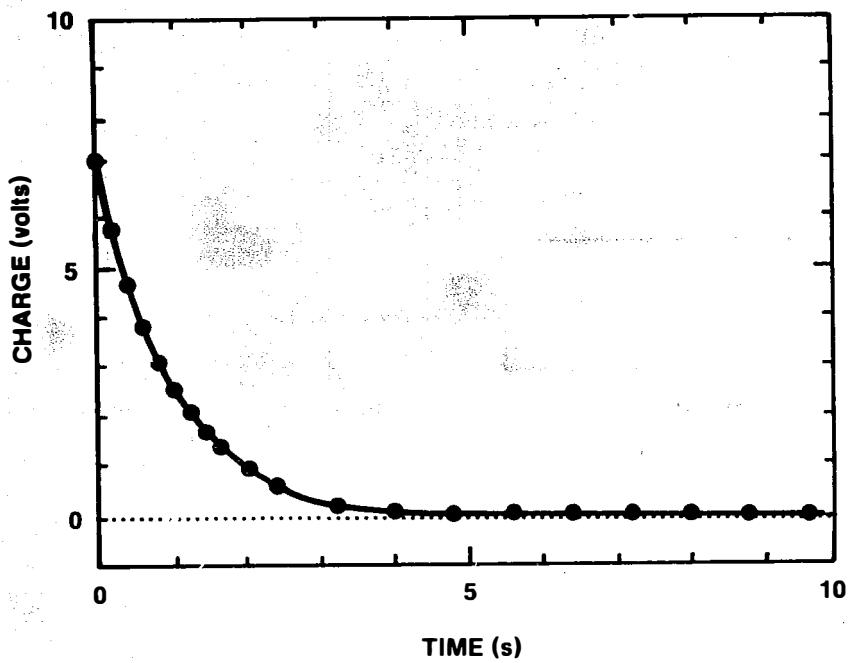
4.2 Test Results

The results of the principal tests are reported in Table 2 and are representative of the data obtained thus far for the PCPC electrical properties. No significant trends were observed in any of the data that would indicate a substantial change in electrical properties between the different sections of PCPC examined.

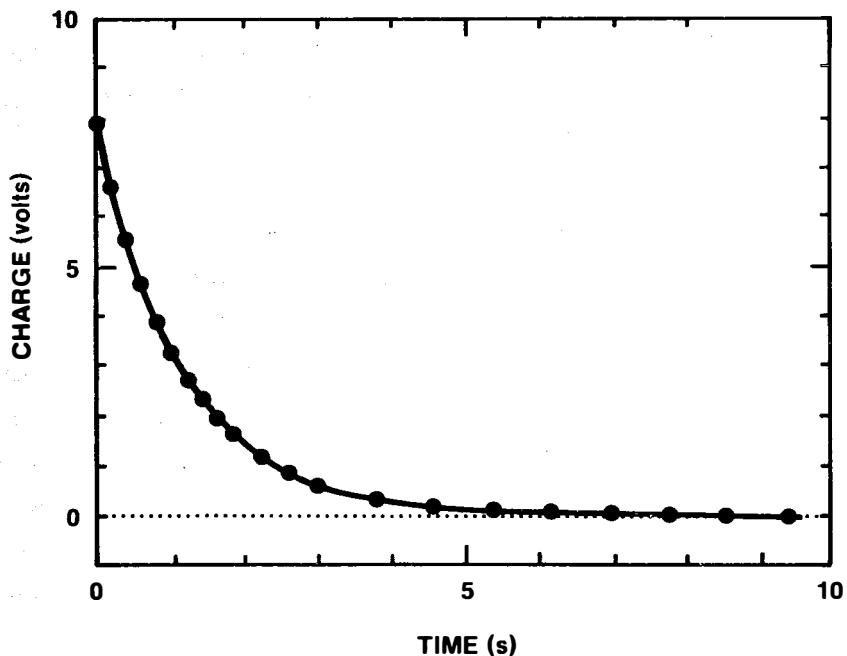
There appears to be a slight decrease in capacitance at 120 Hz with increasing cable section number (i.e., with increasing burn discoloration on the cable jacket). However, this trend is not consistently observed for any other frequency nor in the decay-curve capacitance measurement. It is interesting to note that the decay-curve capacitances (not reported in Table 2) ranged from 60% to 150% of the 120-Hz bridge capacitance values, but were consistent with the trend of increasing capacitance with decreasing frequency.

Although the variation of insulation resistance seems quite large, it is apparently random; large variations are common at these high resistance values.

Additional tests are planned. The partial discharge breakdown test is expected to be of particular interest.



(a) Test Instrument Leads Only. 793pF



(b) L1 to L2 plus Test Instrument Leads. 845pF

Figure 14. Decay Curves for Test System Leads and Test Connection L1 to L2 for Cable Section 3. Least-squares fit determined capacitance of particular configuration. Then capacitance of L1 to L2 was determined as $845 - 793 = 102$ pF.

Table 2
PCPC Electrical Data

Test Loads	Cable Section	Bridge Capacitance (picofarads)			Insulation Resistance (megohms)			Characteristic Impedance (ohms)
		120 Hz	1 kHz	10 kHz	100 V	200 V	500 V	
L1C	3	90.0	74.0	64.9	4.0	9.5	14.0	87.3
	9	86.8	73.1	65.7	10.0		15.0	95.1
	22	81.0	69.3	63.8	8.1	7.2	7.0	97.3
	28	81.0	69.3	63.8	8.1	7.2	7.0	97.3
L2C	3	78.0	65.9	61.3				90.4
	9	77.4	70.8	67.0	10.0			104.4
	22	77.2	66.8	62.1	1.1			93.0
	28	75.3	67.5	63.5				95.1
L3C	3	105.0	79.0	68.8				91.4
	9	81.4	69.4	63.5	6.1		17.5	93.0
	22	91.6	75.6	69.0	1.7		1.2	88.8
	28	77.2	66.9	62.6				95.1
L1	3	57.0	46.6	42.3	3.4	3.0	2.5	
	9	63.6	50.7	46.4	42.0		8.0	133.8
	22	64.0	52.2	46.2	14.0		10.0	137.4
	28	57.4	51.9	48.5	8.4	9.9	5.2	133.8
L3	3	127.0	98.9	87.1	7.4	8.2	5.9	79.5
	9	101.5	85.3	77.2	2.2		2.1	90.9
	22	121.1	97.9	87.8	1.5			74.1
	28	95.2	80.4	74.4	6.3	6.6	6.8	77.8

Test load definitions:

L1C indicates companion leads in the L1 layer.

L2C indicates companion leads in the L2 layer.

L3C indicates companion leads in the L3 layer.

L1 to L2 indicates an L1 lead connected to an L2 lead.

L1 is the outermost layer of the PCPC.

Insulation resistance measured after 3 minutes at applied voltage.

5. Thermal Environment Analysis

Three studies were made to determine the thermal environment within the containment during the accident. First, a thermogravimetric analysis (TGA) was made of samples of the cable sections to determine the temperature at which discoloration occurs. Second, a computer simulation study and heat-flux experiments were used to estimate the heat flux generated by the hydrogen-burn front. Third, the geometry of the containment building was analyzed to determine those features that might affect the deposition of thermal energy on the cable.

5.1 Thermogravimetric Analysis (TGA)

A TGA in air was done on a piece of the cable jacket taken from the undamaged region (cable section 9). This sample was neither charred nor discolored. The TGA trace is shown in Figure 15. The sample contained approximately 47% inorganic filler and showed a step-like weight loss at approximately 260°C (500°F). A second trace run on a fresh sample taken from the same piece of cable jacket was removed from the heating cell when the temperature reached 250°C (482°F) and was observed to have turned brown (discolored). These same two TGA experiments were repeated using fresh samples but with an atmosphere of nitrogen instead of air. Figure 16 presents the nitrogen TGA run and shows that the shape of the TGA trace is similar to the trace for the air TGA run. The second sample had turned brown (discolored) when removed from the heating cell in nitrogen at 260°C. This finding establishes that the discoloration is thermally induced and does not require the presence of oxygen.

Pieces of cable jacket from cable section 9 were placed in each of several melting-point glass capillary tubes and heated in a Fisher-John melting-point apparatus with capillary adapter. A sample removed at 245°C (473°F) showed a

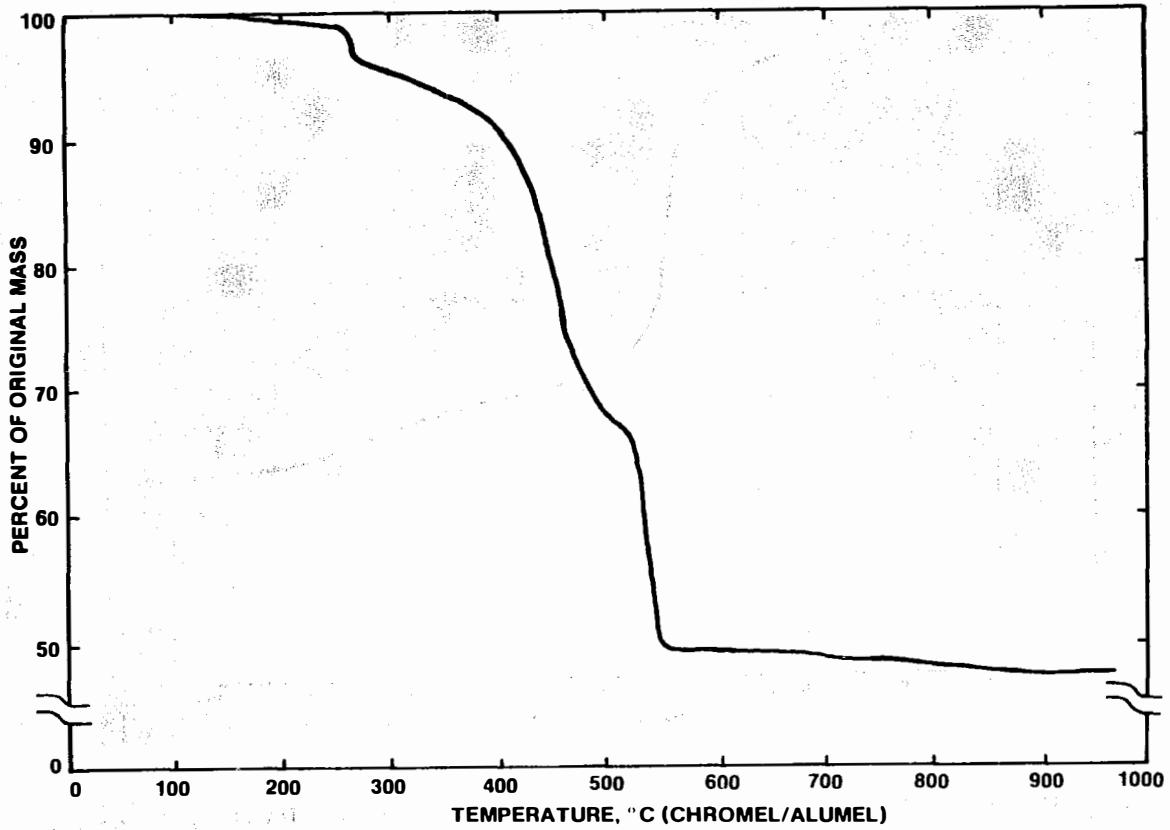


Figure 15. Thermogravimetric Analysis in Air.

slight off-yellow discoloration. A sample removed at 255°C (491°F) showed a tan color, while a sample removed at 265°C (509°F) was dark brown. This information establishes that the yellow to brown discoloration of the polar crane cable jacket occurs in the temperature range from 245 to 265°C (473 to 509°F). This finding suggests that the discoloration pattern observed in the PCPC jackets can be used to indicate temperatures or heat fluxes to which the cable jacket sections were exposed, i.e., that the PCPC reached temperatures greater than 240°C (464°F). This temperature level is significantly higher than the 160°C (320°F) temperature profile to which LOCA-qualified components are subjected. The hydrogen burn at TMI-2 suggests that it may be necessary to consider higher temperatures in the qualification of Class 1E equipment if hydrogen burns are expected.

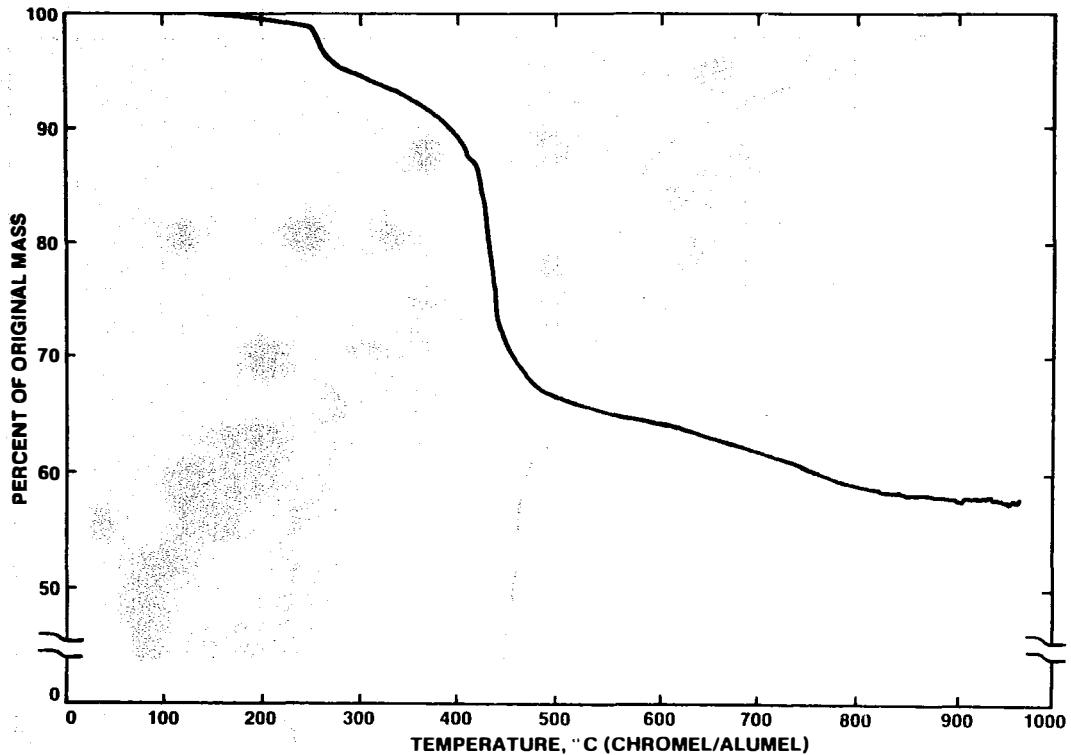


Figure 16. Thermogravimetric Analysis in Nitrogen.

5.2 Heat Flux vs. Time Profile

J. O. Henrie and A. K. Postma have developed an in-depth analysis of the TMI-2 hydrogen-burn event.² They present a temperature vs. time profile for the hydrogen burn that was calculated from recorded pressure data at TMI-2 and from empirical data obtained from shock tube tests. At the request of the Cable/Connections Task, Art Ratzel of SNLA applied information from the Henrie and Postma report to a predictive model that was developed to study hydrogen-flame propagation in enclosed vessels. This effort was undertaken to obtain a heat flux vs. time profile consistent with the estimated temperature vs. time profile developed by Henrie and Postma. It is considered to be a scoping study in that certain physical processes (e.g., forced convection heat transfer, steam condensation, influence of containment spray) were omitted from the analysis because of insufficient data and/or model capability.

Figure 17 presents the results of this analysis as a series of heat flux vs. time profiles generated under various TMI-2 containment conditions. These profiles should be considered preliminary and essentially serve to scope the heat flux experienced in containment at TMI-2. Studies indicate that a minimum heat flux below which ignition of cables cannot occur is in the range of 2 or 3 W/cm² (6300 to 9500 Btu/ft²•h) for many combinations of cable jacket and insulation.^{3 4} The heat-flux range of 4 to 6 W/cm² (12500 to 15800 Btu/ft²•h) presented in Figure 15 is clearly above this minimum flux required for ignition and suggests that the cables in TMI-2 containment may well have experienced thermal change based on a heat flux vs. time profile similar to that shown in Figure 17.

An attempt was made to generate a second estimate of the heat flux vs. time profile present in the TMI-2 containment based on the actual temperatures measured in containment at the time of the hydrogen burn. Bruce Bainbridge and Ned Keltner⁵ of SNLA determined the time-constant response characteristics of an ambient air resistance temperature detector (RTD), in both a shielded and an unshielded condition, and in both the presence and absence of air movement. The RTD was obtained from the pump house at TMI and was of the same model and vintage (Rosemont, 78-0065-001) used in containment at TMI-2.

The time-constant response data, in concert with an unfolding code, permitted the generation of a temperature vs. time profile estimate that was consistent with the temperature data recorded at TMI-2 during the time of the burn. This temperature vs. time profile was then used in conjunction with Ratzel's predictive model to generate an alternative heat flux vs. time profile for the containment at TMI-2. The purpose of developing these estimated heat flux vs. time profiles was to determine whether exposure to such

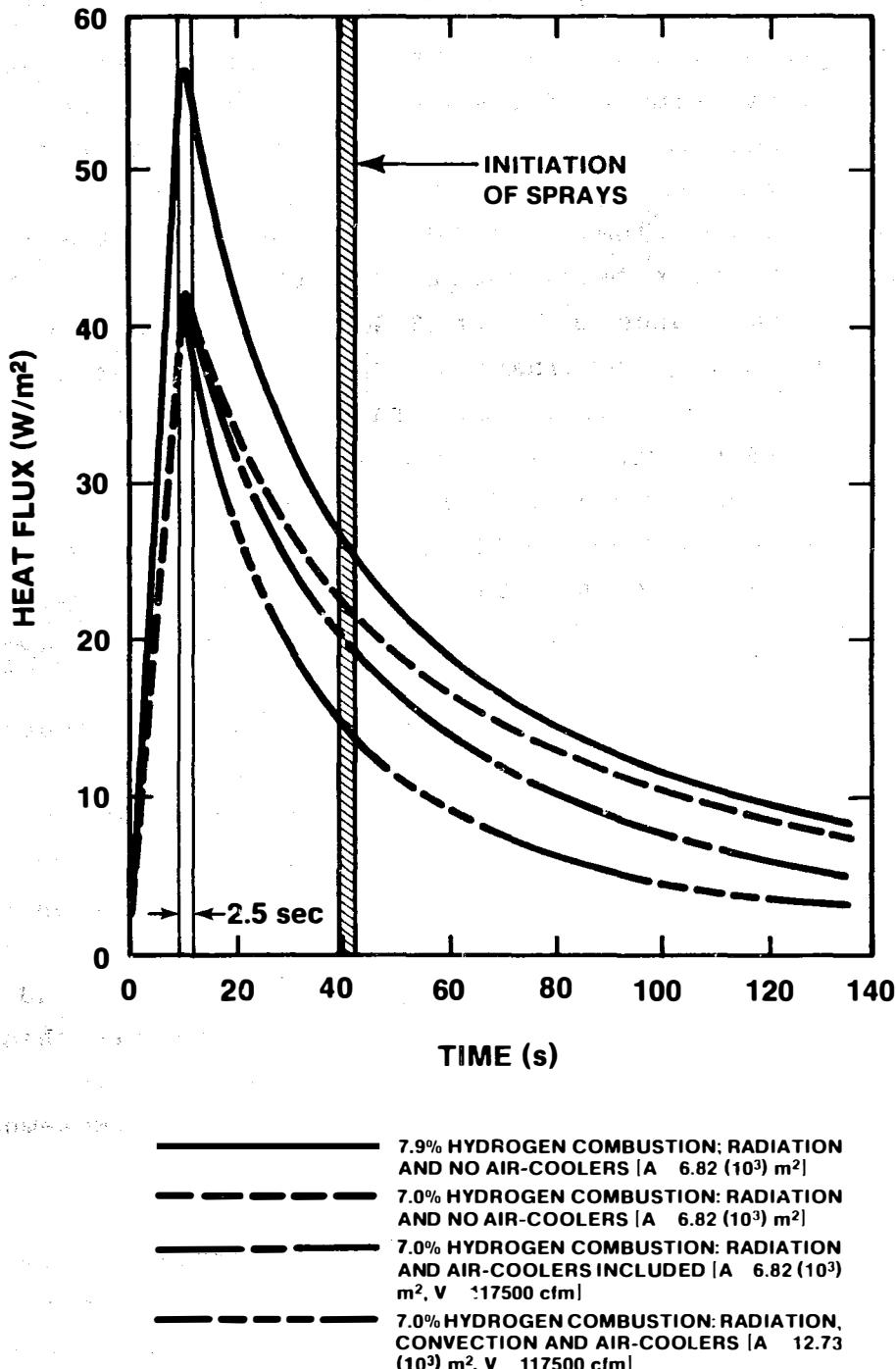


Figure 17. Predicted Heat Flux to Surfaces in TMI-2 Containment for Hydrogen:Air Deflagration and Postcombustion Period.

profiles results in thermal damage to the samples similar to that observed in equivalent material removed from the containment at TMI-2. Samples were then exposed to this profile and the resultant thermal damage compared to actual samples removed from containment.

The desired profile was experimentally generated using the SNLA solar furnace facility.⁶ Prior to exposure, the cable sample was decontaminated using a concentrated decontaminant solution. This decontamination effort reduced the contact radiation levels to background and the γ level to 0.6 mrem/hr. The decontaminated cable, cable section number 11, was cut into two 76-mm (3-in) sections, and four type T thermocouples were attached with epoxy to each cut section of cable. Three thermocouples were mounted on the outer jacket surface, and one thermocouple was mounted inside the cable between the jacket and cable cluster. This arrangement of thermocouples provided an estimate of the temperature at the inner and outer cable-jacket surfaces.

Figure 18 shows three heat flux vs. time profiles. One profile is that developed by Art Ratzel's computer code at SNLA. This code had the major limitation of being unable to simulate the effect of containment spray. Since containment spray is expected to have a significant effect on containment cooldown, an effort was made to estimate a containment spray profile and superimpose this estimated profile on the Ratzel profile at 40 s into the hydrogen burn (the approximate time at which the building sprays began wetting the TMI-2 containment). The shape and quantitative aspects of the estimated containment spray profile were obtained from TMI-2 data on containment average temperature and pressure versus time.² This modified heat flux vs. time profile attempts to consider the effect of containment spray and is also shown in Figure 18. All samples were exposed to this modified heat-flux profile after preheating to approximately

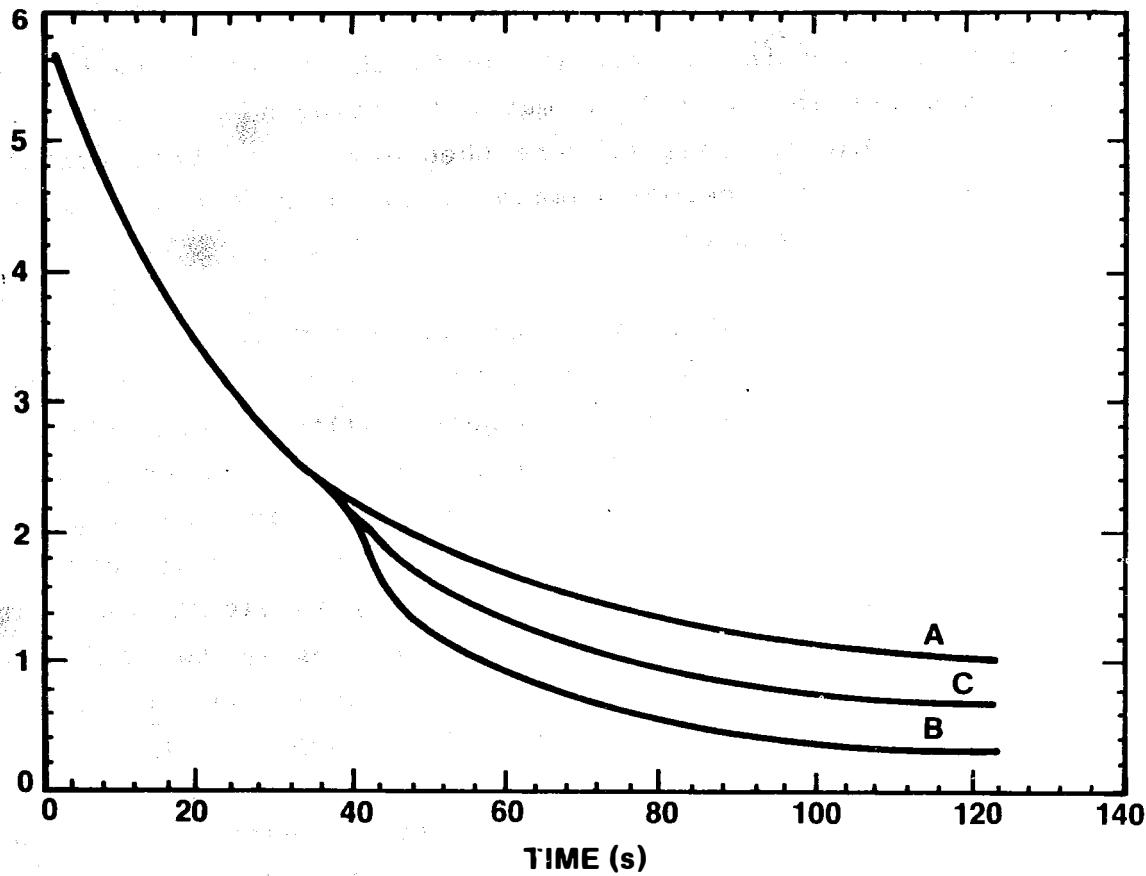


Figure 18. Heat Flux vs. Time Profiles.

- A. Computer analysis
- B. Modified computer analysis
- C. Typical experiment

50°C (122°F). (The temperature in containment at TMI-2 was approximately 50°C before the hydrogen burn.) Figure 18 also presents a typical profile that was experimentally obtained at the solar furnace facility.

Funding for the study of the hydrogen-burn event at TMI-2 should result in the development of a more complete, detailed, and accurate heat flux vs. time profile for TMI-2. Unfortunately, time constraints forced the Cable/Connections Task personnel to use the best profile estimate available (Figure 18) in studying the effect of the hydrogen burn on the PCPC at TMI-2.

The cable samples were mounted vertically between two heat-flux gages at the solar furnace test facility (Figure 19). Figure 20 shows temperature responses recorded for the outer cable-jacket surface thermocouples (1, 2, and 3) and the inner cable-jacket surface thermocouple (4) when the sample was exposed to a heat-flux profile. The outer surface temperature measurements are only approximate, because no special steps were taken to shield the thermocouples from the radiant heat from the the solar furnace. In all studies, the basic profile shape remained the same, varying only the peak heat flux. The solar furnace is not capable of reproducing the calculated profile exactly, but it was adequate for this scoping study. By varying the peak heat flux, it was possible to vary the energy delivered to the sample. The energy delivered equals the product of heat flux and time, or the integrated area under the heat flux vs. time curves of Figure 18.

The goal of these heat-flux experiments was to verify the analytical heat-flux profiles. To do this, the energy delivered to each successive sample was increased until the char that occurred in TMI-2 was observed.

Figure 21 shows the heat-flux profiles for a series of these exposures (smoothed for better legibility). Profile A is the calculated profile, and profile E is the solar furnace profile given in Figure 18. The samples exposed to profiles B and C showed no change. Samples exposed to profiles D and E had some discoloration, and E also produced some ash. The samples exposed to profile F had slight indications that charring may just have been starting. Profile G caused small, but definite areas of char, and profile H clearly produced char.

Although the experimental profile that caused char is somewhat higher than the calculated profile, these data

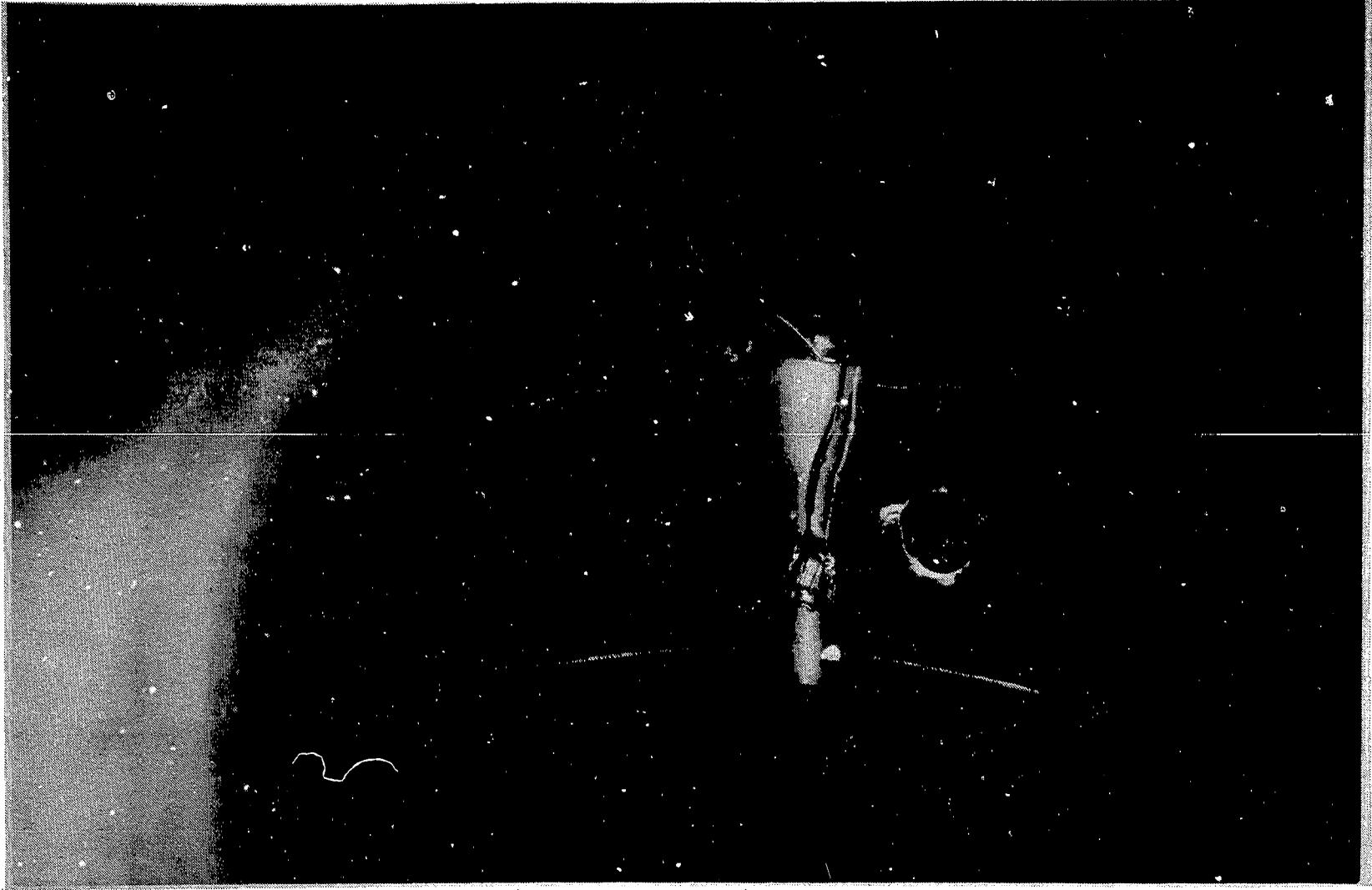


Figure 19. Cable Sample Mounted between Two Heat-Flux Gages at Solar Furnace.

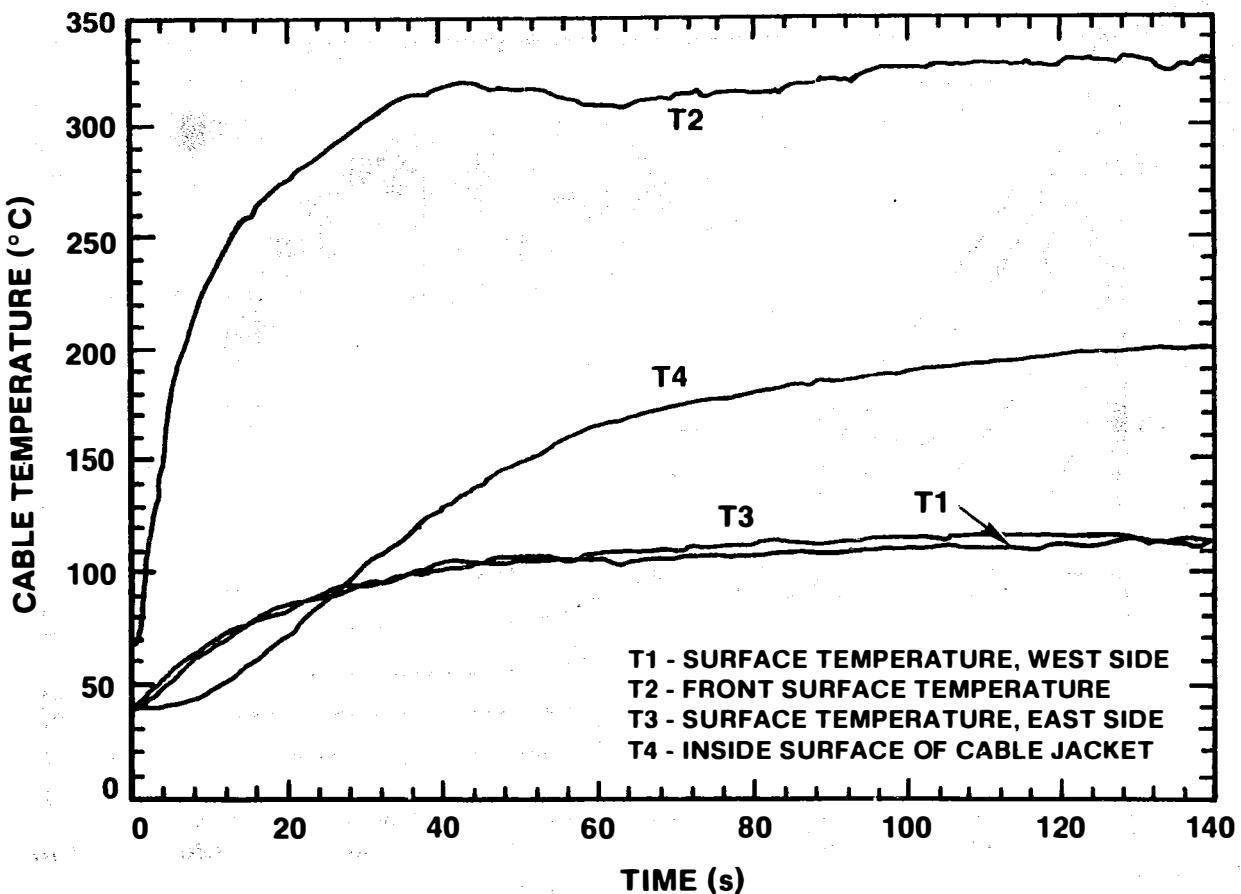
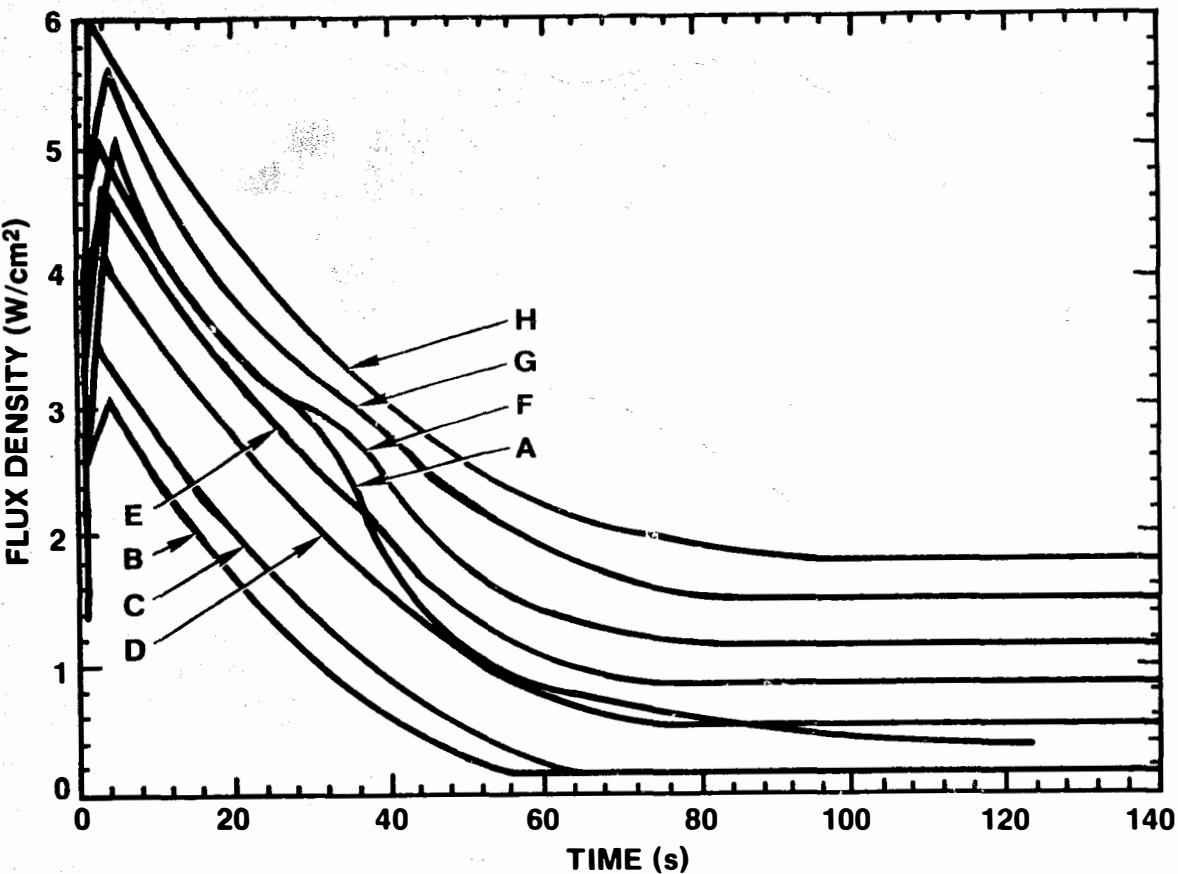


Figure 20. Temperature Response of Cable Jacket Exposed to Heat Flux vs. Time Profile.

establish that the calculated heat-flux profile for the TMI-2 hydrogen burn corresponds reasonably well with the observed burn damage to the PCPC (within the analytical and experimental means employed). The analytical method addresses the average (or bulk) properties of the environment as averaged over the entire volume (including portions of volumes in which the burn may not have occurred). Because of this, the analysis would be expected to give somewhat lower heat-flux values than actually occurred in some areas. The next section discusses the possible variations in the heat flux as related to the pattern of damage on the cable jacket.



**Figure 21. Heat Flux vs. Time Profiles from Solar Furnace.
Effect on samples:**

- A. Computer calculation
- B. No change to sample
- C. No change to sample
- D. Discoloration
- E. Discoloration and ash
- F. Char just beginning
- G. Small areas of char
- H. Char

5.3 Hydrogen-Burn Pattern Analysis

Figure 22 presents a summary of the data with respect to the regions of the PCPC, the cable sections, and their approximate dimensional relation to the polar crane, the D-ring, and the open west stairwell. Cable sections 1 through 7 are not shown because they are believed to have lain on top of the D-ring during the accident.

POLAR CRANE GIRDER A WALKWAY

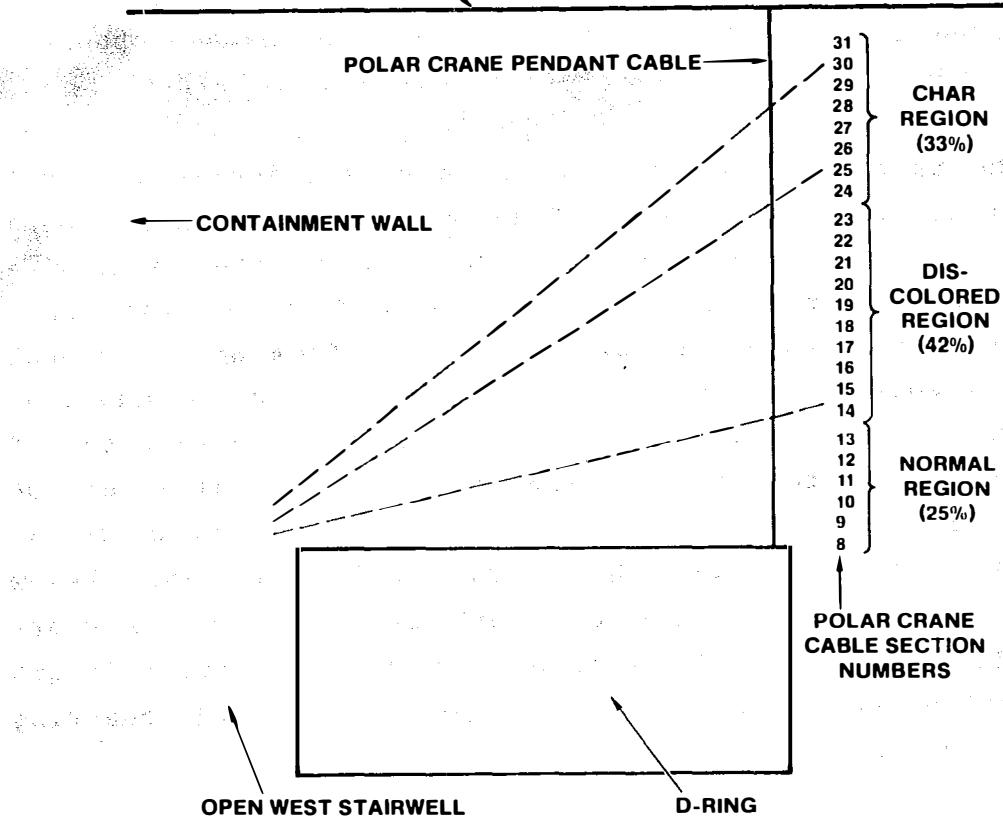


Figure 22. Cable Section Burn Pattern.

The shadowing of the charred and discolored regions around the PCPC point to a hydrogen-burn front that propagated from west to east. These findings are in agreement with the view that the burn originated at some lower level (below the 347-ft elevation) in containment and propagated primarily up the open west stairwell, at which point the burn emerged into the relatively open areas above the 347-ft elevation.² A localized, higher hydrogen concentration may have existed in the west stairwell due to a pressure-release operation that occurred 13 s prior to the burn. The pressure-release operation would have released a steam and hydrogen plume into the open west stairwell. Figure 22 shows schematically how this burn front may have continued up the west stairwell between the containment wall and the D-ring wall, then emerged into the large open cavity and

propagated upward and eastward producing the damage observed on the PCPC.

The uppermost charred region is of particular interest because sections 24 through 29 show either char all around the cable, while sections 29, 30, and 31 show either a directional charred pattern on the west face or else charring along three-quarters of the surface from north through west and south to east (i.e., the northeast cable quadrant shows no char). Figures 23 and 24 show that the very top of section 31 was wrapped with tape or cloth (partially held on by a tie wrap, Figure 23) that ignited and produced an apparent circumferential char. The region of cable below this burned piece of tape or cloth is directionally charred. In the absence of the tape or cloth, the entire length of section 31 would have exhibited directional charring similar to sections 29 and 30.

Possibly, the directionality of the charred pattern is a result of the proximity of the PCPC to the massive polar crane from which the cable was suspended. The upper cable portion (sections 29, 30, and 31) was closest to the crane and would be expected to be most sensitive to any thermal protection afforded by the crane. Such speculation is supported by noting that section 29 was charred from north through west and south to east (northeast quadrant not charred) and that the orientation of the crane itself was roughly northeast of the cable (Figure 2). The fact that cable sections 24 through 28 were circumferentially charred suggests that enough thermal energy was present to circumferentially char cable sections 31 to 29 but that the massive polar crane may have acted as a heat sink, absorbing enough thermal energy to prevent charring on the cable surfaces facing east.

The majority of the cable sections in the discolored region of the PCPC also showed directionality in their dis-

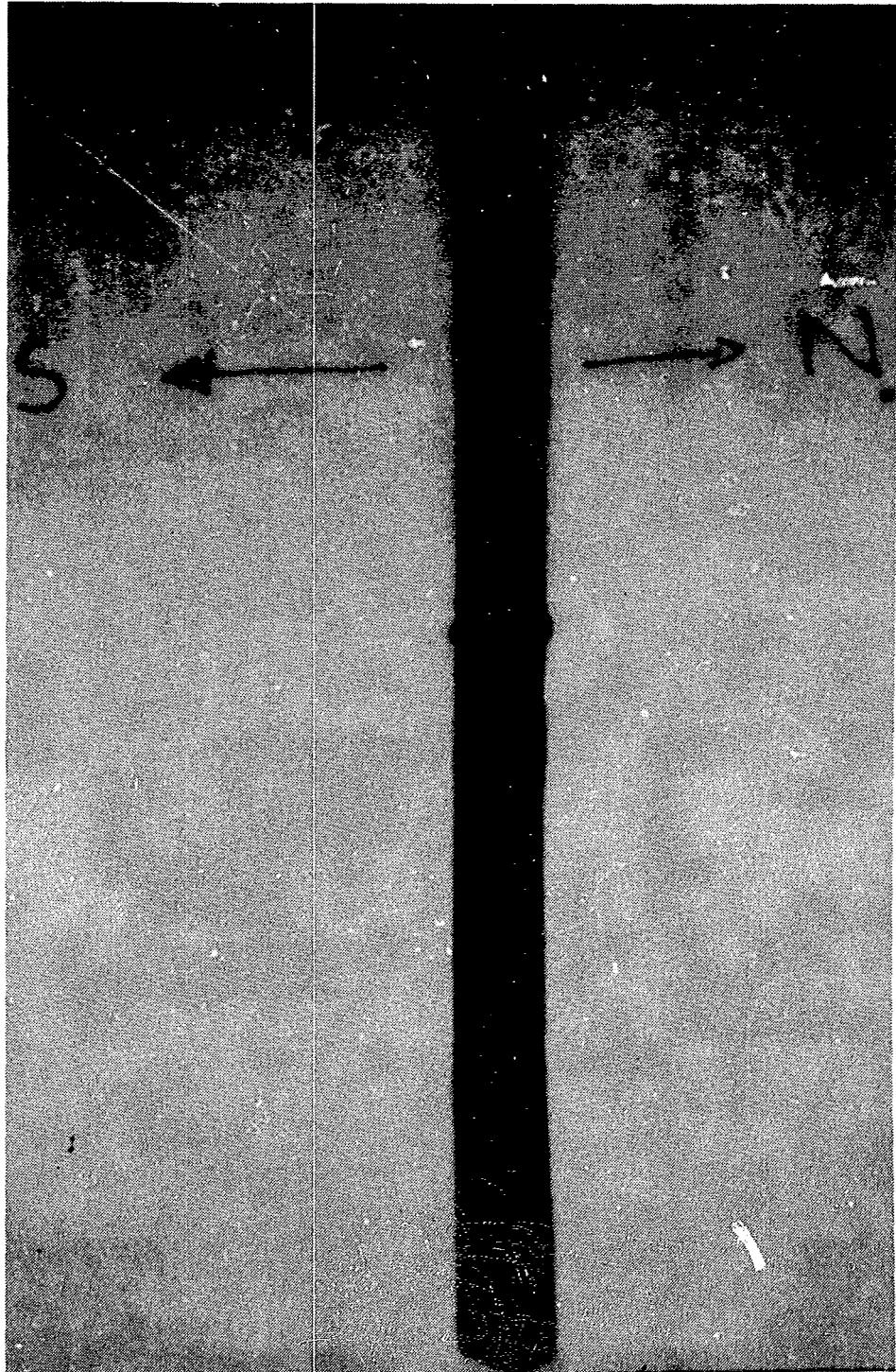


Figure 23. Photo of Cable Section 31 East View.

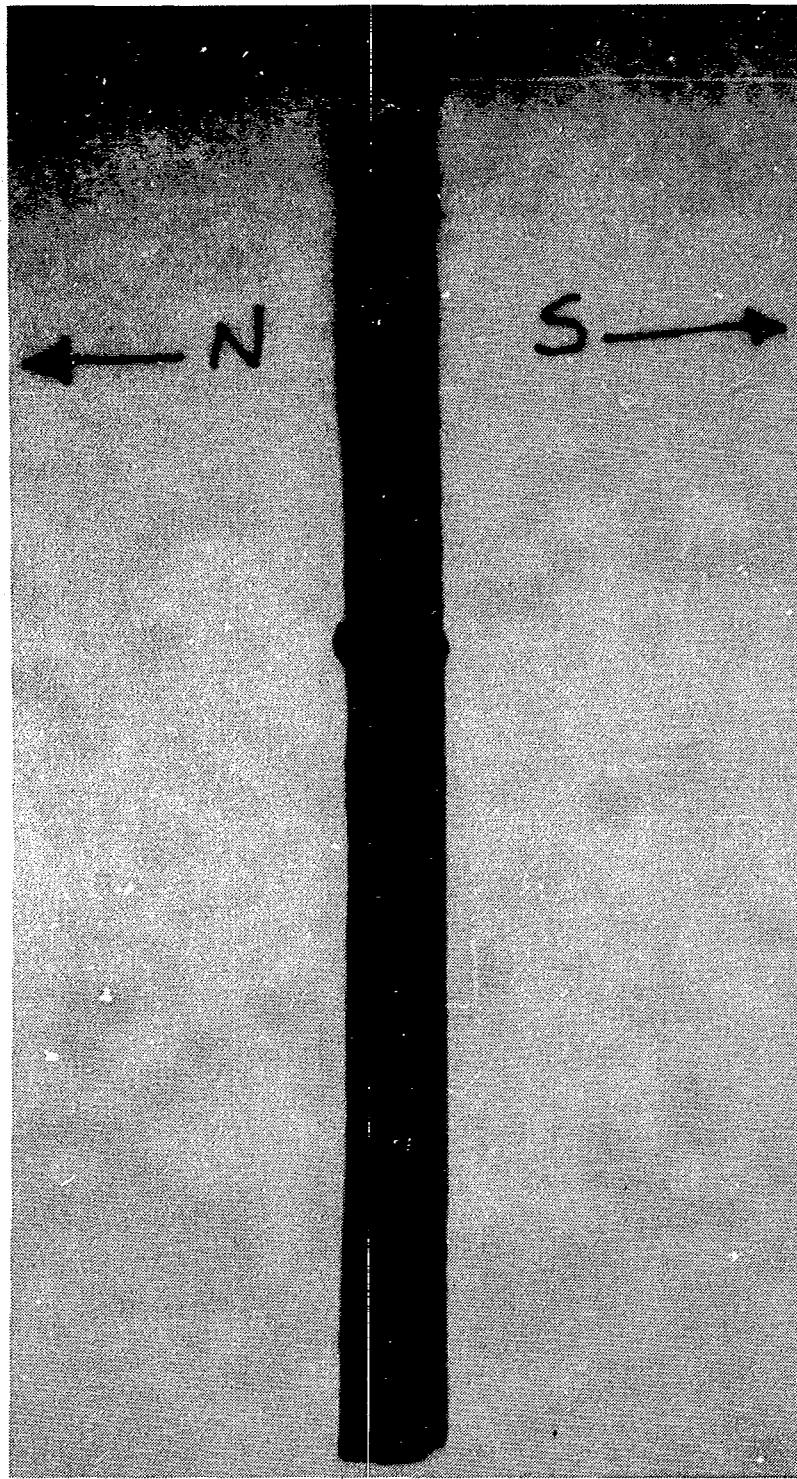


Figure 24. Photo of Cable Section 31 West View.

coloration. The west cable surfaces showed discoloration to various extents and depths, while the east-facing cable surfaces generally showed no discoloration (Table 1).

These observations are consistent with the view that the hydrogen burn propagated from the stairwell upward and from west to east, leaving a residual cloud of extremely hot gases that heated the PCPC by radiation and convection. With increasing elevation, the heat flux on the cable surface also increased and became more uniformly distributed around the cable. This pattern was modified at the top of the cable (sections 29, 30, and 31) by the thermal protection provided by the polar crane. The discolored regions of the PCPC would likewise have experienced more intense thermal energy from this cloud of hot gases on the west-facing cable surfaces, but with thermal intensity sufficient only to discolor and not to char these surfaces. Radiant-energy flux decreases inversely as the square of the distance, and the discolored region of PCPC was farther away from the postulated hot gaseous cloud (Figure 14). The same reasoning applies to the undamaged regions of the cable, because they were even farther from the heat source. The horizontal section of cable lying on the D-ring would also be protected by the massive concrete surface of the D-ring acting as a heat sink.

An alternative explanation (there may be others as well) for the presence of distinct regions of thermal damage in the PCPC (charred, discolored, undamaged) could be that condensed moisture provided thermal protection for the cable. The D-rings penetrate to the basement of the reactor building where the reactor coolant drain tank had been releasing steam into the containment building for 10 hours before the hydrogen burn. If a steam path existed from the containment basement through to the top of the D-rings (367 ft), it is possible that enough water had condensed on the surfaces of

the undamaged lower sections of the PCPC (sections 1 through 15) to protect them from the hydrogen burn.

Less steam would be expected to condense on the PCPC at the intermediate levels (discolored cable region) and even less at the upper levels (charred cable region). Henrie and Postma have calculated that a water film 0.5-mm (0.02-in) thick would absorb the entire heat load by evaporation.² They conclude that objects that were wet with condensed steam would not be heated nearly as much as similar objects that were dry at the time of the burn.

The Cable/Connections Task personnel plan to analyze the cable that hung from the jib crane in the southwest portion of the TMI-2 containment at the 347-ft elevation (depending on availability of cable and funding). Analysis of this cable with regard to burn regions and burn directionality may help to choose between the alternative explanations of the burn patterns observed on the PCPC. The possibility that the hydrogen-burn front itself caused the pattern observed in the PCPC is tentatively rejected because experiments at SNLA³ and other medium-scale hydrogen-burn facilities, using both qualified and unqualified cables, repeatedly showed no evidence of thermal damage (char, ash) to cables on single exposure to a propagating hydrogen-burn front. These observations were corroborated by placing a decontaminated sample of TMI-2 PCPC in the SNLA hydrogen-burn facility and sequentially exposing the same sample to a 7.2%, 7.7%, and 8.9% (by volume) hydrogen burn. (This highest percentage is similar to that calculated for the TMI-2 hydrogen burn.) In all tests, the sample was suspended in the tank with the cable axis normal to the assumed direction of propagation of the hydrogen-burn front, the fans were on, no steam was present, and the gas temperature was 70 to 80°C (158 to 176°F) before ignition. After each

burn, the cable was inspected for evidence of thermal damage. Under these conditions, the PCPC showed no signs of char formation, ash formation, blistering, or discoloration. It is generally thought that hydrogen flames themselves emit very little thermal radiation.⁹ Most of the significant heat transfer from a hydrogen burn to a given component or surface results from radiation and/or convection from the hot gas (air and steam) left after the burn. In small volumes (such as the test facilities mentioned above) the surface-to-volume ratios are much larger than for containment volumes. Because of this, heat transfer (and the resulting thermal damage) from the hot gas to a given component or surface would be much less for the test volumes than for a large volume such as the TMI-2 containment.

The cable was thermally damaged in the large volume and showed no damage in the small volume, thus confirming that the damage to the cable was caused by heat transfer from hot gas rather than the flame front itself.

6. Conclusions

The results of this investigation into the PCPC from TMI-2 are summarized below.

6.1 Physical Abuse of Cable

There are clear signs of physical abuse of the cable sections that lay on top of the D-ring. O. M. Stuetzer has identified cracking in the insulation/jacket combination, aggravated by mechanical stress, as a likely mechanism causing electrical breakdown in a reactor cable.¹⁰ Cracks in the jacket and the insulator of a reactor cable can lead to electrical shortout, especially during an accident, when contaminants, humidity, and/or spray can form a conducting

path to ground or to another cable crack. Stuetzer identifies three specific situations of primary concern:

- Long cable pieces lying in trays or conduits can develop cracks under thermal cycling.
- Cables sharply bent (e.g., around conduit corners) can crack under the mechanical stress produced by thermal cycling or by cable overhang weight.
- Aged cables can be mechanically stressed and cracked by maintenance procedures, i.e., "maintenance accident."

The portion of the PCPC lying on the D-ring showed clear signs of a "maintenance accident" as described by Stuetzer. This section of cable had cuts, abrasions, and even protective sleeves covering the cable jacket, apparently used to reseal a severely damaged section of cable. These observations support Stuetzer's concern about the impact of a maintenance accident on cables that compromises their ability to fulfill their electrical function, especially during a reactor accident scenario.

6.2 Effects of Radiation

The radioactive contamination present on the portion of the PCPC lying horizontally on the D-ring was approximately 10 times greater than that found on a contiguous section of the PCPC that hung vertically. This difference in radioactivity enabled the comparison of properties of the high and low contaminated sections of the PCPC. Results of the evaluation indicated that the contamination caused no dramatic changes in either the material or the electrical properties of the PCPC. Further studies on fission-product deposition on the vertical section of the PCPC might be

extremely valuable in relation to studies on fission-product transport. This information would help to verify computer codes and to augment calculations of the source term, which might provide a clearer estimate of the radiation levels experienced in containment.

6.3 Hydrogen-Burn Effects

A visual examination of the PCPC showed that it could be divided into three regions based on the extent of thermal damage. However, both the materials analysis (see Figures 9 and 10) and the electrical examination (see Table 2) revealed no substantial difference in either of these properties among cable sections taken from each of the three regions. Despite the igniting and burning of the jacket surface in the charred regions of the cable, the mechanical and electrical properties did not differ greatly from those of the undamaged regions.

Thus if the PCPC, which was hanging in free space, displayed no significant change in material or electrical properties, then it is possible to assume that similar cable in TMI-2 could also be expected to have its mechanical and electrical properties essentially intact after the hydrogen burn. Most cable is more protected than the PCPC, for several reasons: (1) these cables are near structures that can serve as heat sinks (e.g., the containment wall), (2) cables protect other cables in cable trays, (3) cables in conduit are protected from the containment environment, and (4) LOCA-qualified cables are likely to be more resistant to thermal effects (the PCPC was not LOCA-qualified). It would be expected that cables with less thermal mass (e.g., single-conductor cables) would be more susceptible to hydrogen burns, depending on the local environment.

It is difficult to draw conclusions regarding the integrity of the rest of the cables (bulk cable) in containment. Further acquisition of in situ electrical test data and analysis of TMI-2 bulk cable by the Cable/Connections Task may establish whether the bulk cable is still usable. Should bulk cable be found to have maintained its mechanical and electrical integrity, this would eliminate a major cost of the plant recovery effort and would also allow research efforts to focus on other electrical circuit components as potential weak links during or after a reactor accident. It should be noted that this work has not addressed long-term degradation of cables; in general, cables may be serviceable immediately after the accident, but their expected lifetimes may be substantially reduced, i.e., the aging mechanisms may have been accelerated during the accident. The question of component life expectancy was not directly addressed in the current Cable/Connections Task. However, the Task's efforts to define component-failure mechanisms and to develop techniques for detecting component deterioration could result in assessing and prolonging component life with respect to both normal plant operation and to nuclear accident events.

6.4 Integrated Approach

The analysis of the PCPC from the electrical, materials, hydrogen burn, and radioactive contamination points of view represents an approach considered by the Cable/Connections Task to be very useful in evaluating the accident at TMI-2 and its effects on electrical components. To be successful this approach required the support and assistance of the TIO and contractor personnel at TMI-2, and to a very large extent this report reflects their efforts.

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4. L. L. Lukens, "Nuclear Power Plant Electrical Cable Damageability Experiments," US NRC Report NUREG/CR-2927 (SAND82-0236), October 1982.
5. Memorandum, B. Bainbridge and N. Keltner, Sandia National Laboratories, "Application of TMI Sensor Response Tests," August 24, 1983.
6. R. Edgar, E. Richards, and G. Mulholland, "Solar Furnace for Flux Gage Calibration and Thermal Effects Testing," Volume 5, Part 3, page 331, in Progress in Solar Energy, American Solar Energy Society, Houston, TX.
7. J. Aragon (SNLA). private communication, March 1983.
8. G. Sliter (EPRI). "Research on Equipment Survivability Under Hydrogen Burn," in NRC/EPRI Second International Workshop on the Impact of Hydrogen on Water Reactor Safety, October 3-7, 1982.

9. E. R. Eckert and R. M. Drake, Analysis of Heat and Mass Transfer, McGraw-Hill, 1972.
10. O. M. Stuetzer, "Status Report on Reactor Cable Breakdown Correlation Study," December 1982.

30-4765

APPENDIX

Work Package for PCPC Removal

WORK PACKAGE	Z	BLDG	AREA	ELEV	ELEV	SEQ	PREPARED BY	DATE August 3, 1982	PAGE 1 OF 14						
		DESCR	SEQ	BLDG	AREA	ELEV	ELEV			TYPE	SYS				
	E	001	90017	-427347	-	-	P/C			ESTIMATED START DATE					
										September 9, 1982					
SCOPE	Polar Crane Pendant and Cable Removal								FINAL REVIEW	DATE					
REV.	DATE	REVISION DESCRIPTION	CE	ES	SUPT	RC	TIN	REV	DATE	REVISION DESCRIPTION	CE	ES	SUPT	RC	TIN
0	8/6/82	Issue for Construction	<i>Lead</i>	<i>NR</i>	<i>and</i>	<i>RPM</i>	<i>100%</i>								
1	8/23/82	General Revisions	<i>Lead</i>	<i>NR</i>	<i>and</i>	<i>P/H</i>	<i>100%</i>								
ITEM NO.	WORK/VERIFICATION ACTV.	SEQUENCING REQ'D.	YES	NO	INSTAL. DOC.	REV.	REV.	SUPT	DATE	CR	DATE				
WORK PACKAGE PREREQUISITES															
1	Obtain an RWP														
2	Ensure ALARA requirements are incorporated into the RWP														
3	Have Plant configured properly and tagged														
4	Obtain a "Tie-in Authorization" IS-ECM No. _____														
5	Obtain "Welding and Cutting Permit"														
6	Arrange for a Fire Watch														
7	Arrange for NDE / Testing														
8	QC Required	YES	NO												
9	Personnel qualified in Polar Crane safety and spider operation.														
10	Refer to attached recommended sequence.														
11	Stage material required in anteroom and airlock when directed.														
20	When directed, three man team enter containment with equipment; stage drum in loading area; two men go to El. 347' and pull drum to El. 347'.														
22	Store drum in location shown; third man go to El. 347'.														
30	Two men ascend to Polar Crane with equipment required; third man remain on El. 347'.														



WORK PACKAGE
PROJECT 13587

DISCIP	SEQ
Electrical	0 0 1 9

PAGE 2 OF 10 9/10/86

ITEM NO.	WORK/VERIFICATION ACTIVITY	INSTAL. DOC.	REV.	REV.	SUPT.	DATE	CIB	DATE
20	When directed, four man team enter containment with equipment at El. 305'.					(S-23-82)		8-23-82
22	Two men ascend to polar crane with required equipment via spider.					(S-23-82)		8-23-82
24	Two men ascend to El. 347' with equipment.					(S-23-82)		8-23-82
30	Mark pendant cable at polar crane with compass orientation (north). Securely lash $\frac{1}{2}$ " handline to pendant cable and chain and tie off handline to walkway handrail.					(S-23-82)		8-23-82
32	Perform survey of polar crane control pendant festoon system in accordance with attached sheet.					(S-23-82)		8-23-82
34	Layout herculite sheet for pendant/cable laydown at El. 347' as shown.					(S-23-82)		8-23-82
40	One man ascend from El. 347' to top of D-Ring, El. 367' at pendant to assist in lowering pendant and cable clear of D-Ring.					(S-23-82)		8-23-82
42	At El. 367', securely lash $\frac{1}{4}$ " tag line to pendant end of cable and drop tag line to man at cable laydown area, El. 347'.					(S-23-82)		8-23-82



WORK PACKAGE

• PROJECT 13587

DISCIP	SEQ
Electrical	0 0 1 9

PAGE 3 OF 9 *lhc*

ITEM NO.	WORK/VERIFICATION ACTIVITY	INSTAL. DOC.	REV.	REV.	SUPT.	DATE	CER	DATE
50	At Polar Crane notify Command Center when pendant cable is ready to be cut and lowered.						✓	8-23-82
52	Command Center to notify personnel at El. 367' when cable is to be cut.						✓	8-23-82
54	Command Center to order pendant cable to be cut.						✓	8-23-82
56	Command Center to order pendant cable to be lowered.						✓	8-23-82
60	Begin lowering pendant cable and chain from polar crane to El. 347'; lower cable to El. 347' using $\frac{1}{2}$ " hand line' third man stand by on D-Ring at point P until pendant clears D-Ring and fourth man at El. 347' controls pendant end of cable with tag line.						✓	8-23-82
62	Third man descend to El. 347' from D-Ring.						✓	8-23-82
64	When approximately one half of cable length (40') has been layed out on premarked herculite sheet notify Command Center.						✓	8-23-82
66	Command Center to order lowering of pendant cable to stop.						✓	8-23-82



WORK PACKAGE

PROJECT 1387

DISCIP	SEQ
Electrical	0 0 1 9

PAGE 4 OF 10

ITEM NO.	WORK/VERIFICATION ACTIVITY	INSTAL. DOC.	REV.	REV.	SUPT.	DATE	CB	DATE
68	Two men @ El. 347' to match mark and cut pendant cable @ an appropriate 30" increment; remove chain from cable and pendant; remove and re-tie $\frac{1}{2}$ " tagline @ new free end of hanging cable: Notify Command Center when ready to continue lowering cable.						<i>Pat</i>	8-23-82
70	Command Center to order lowering of pendant cable to resume.						<i>Pat</i>	8-23-82
80	HP to begin survey of pendant and cable. Perform contact Beta and Gamma Survey every 10' along cable; take smear every 20' along cable (Smears are to be sent to Sample Coordinator for isotopic analysis)						<i>Pat</i>	8-23-82
90	Notify Command Center when cable is completely layed down on Herculite Sheet.						<i>Pat</i>	8-23-82
92	Command Center notify Polar Crane Personnel that lowering is complete; personnel @ El. 347' to release $\frac{1}{2}$ " Handline; Polar Crane personnel to retrieve and coil $\frac{1}{2}$ " Handline for later use. Leave Handline on Polar Crane Walkway.						<i>Pat</i>	8-23-82
94	Polar Crane Personnel to descend to El. 305' via spider; thence return to El. 347' to assist in cutting and bagging cable samples.						<i>Pat</i>	8-23-82
100	Tag and cut pendant cable into 30" long sections (Approx.) Using the pre-marked Herculite laydown sheet as a guide; sleeve each section.						<i>Pat</i>	8-23-82
102	Place cut and sleeved cable sections in four poly bags (4' x 2'), eight sections to the bag, for transporting to the Ante Room.						<i>Pat</i>	8-23-82



WORK PACKAGE

• PROJECT 13587

DISCIP	SEQ
Electrical	0 0 1 9

PAGE 5 OF

9
HB

WORK PACKAGE E-0019
REV. NO. 1.
PAGE 6 OF 10 KAL
9

EQUIPMENT LIST

1. MATERIAL	2. QTY.	3. COMB. CODE	4. STAGING LOCATION	5. POST ENTRY DISPOSITION	6. OUT-CTMT	7. LOCATION
Work Gloves, Large	4 pr.					
2" Cable Cutter	2					
' $\frac{1}{2}$ " Nylon Rope 100 Feet - Coiled	1					
Plastic sleeving (lay flat) for 2 $\frac{1}{2}$ " Cable (4 foot sections rolled in bag)	36					
55 Gallon Drum (Bagged)	1					
Poly Bags. 4' X 2'	6					
Black Marking Pen	2					
35 mm Camera w/ wide angle lens(including Lanyard)	1					
Canvas Tool Bag	2					
Masking Tape	2 rolls					
Straight Bit Screwdriver 8"	1					
' $\frac{1}{2}$ " Nylon Rope 50' - Coiled	1					
8" Lineman's Side Cutters	2					
3' X 80' Long Herculite	1					

8. Material Staged _____ 9. Material in Ante Room _____

10. Review Complete: Staging Coordinator _____
Materials Coordinator _____

WORK PACKAGE E-0019
REV. NO. 0
PAGE 57 OF 100

EQUIPMENT LIST

THIS EQUIPMENT REQUIRED OF PERSONNEL WORKING ON POLAR CRANE.

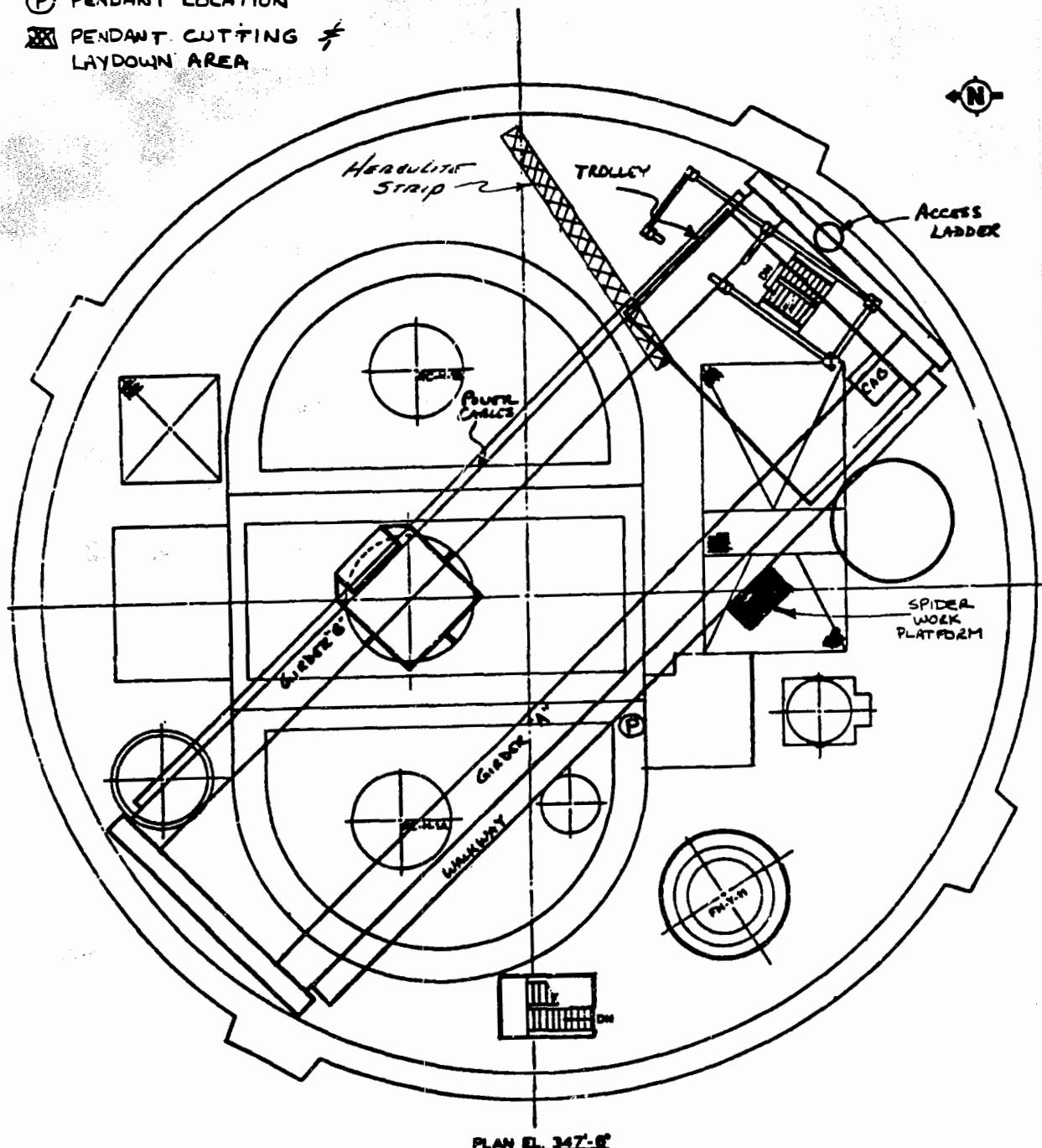
8. Material Staged _____ 9. Material in Ante Room _____

9. Material in Ante Room _____

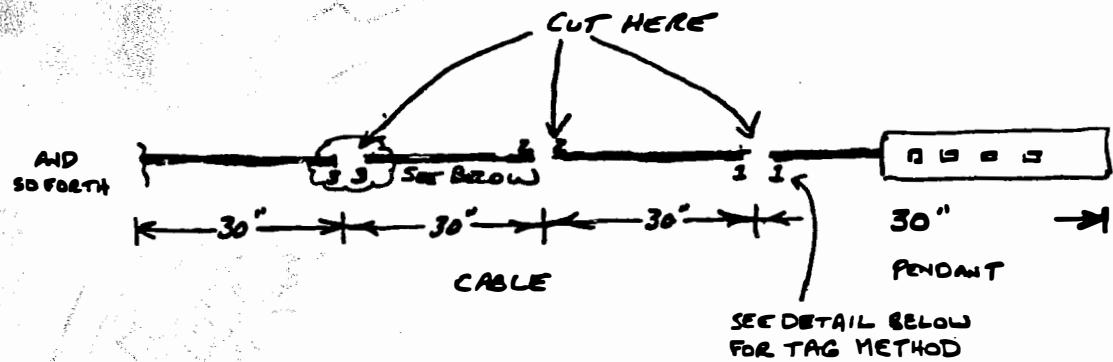
10. Review Complete: **Staging Coordinator** _____
Materials Coordinator _____

POLAR CRANE PENDANT REMOVAL

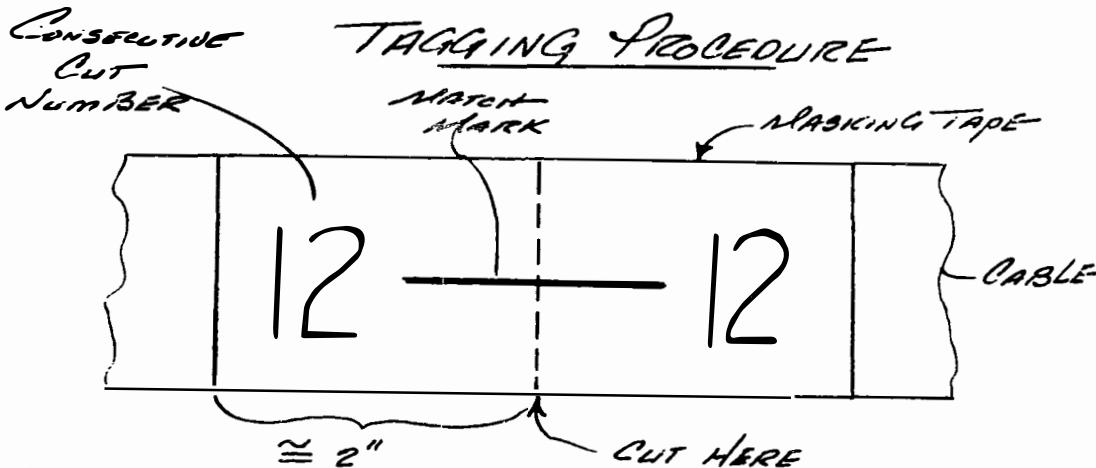
- (P) PENDANT LOCATION
~~(X)~~ PENDANT CUTTING ~~#~~
LAYDOWN AREA



POLAR CRANE POSITION



Apply MASKING TAPE OVER AREA TO BE CUT
COVERING A DISTANCE OF APPROX. 2" EITHER
SIDE OF THE CUT



Distribution

EG&G Idaho Inc.
P.O. Box 88
Middletown, PA 17057
Attn: R. D. Meininger
J. K. Jacoby

DOE/TMI Site Office
P.O. Box 88
Middletown, PA 17057
Attn: W. W. Bixby

Westinghouse Hanford Co.
W/A-56, Bldg. 326
P.O. Box 1970
Richland, WA 99352
Attn: P. Cannon

Bechtel Power Corporation
15740 Shady Grove Road
Gaithersburg, MD 20877-1454
Attn: B. Hopkins - 2D13

1821	R. W. Bild
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2341	G. M. Mueller
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6400	A. W. Snyder
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6420	J. V. Walker
6430	N. R. Ortiz
6440	D. A. Dahlgren
6442	W. A. von Riesemann
6444	L. D. Buxton
6446	L. L. Bonzon
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6446	R. B. Padilla
6446	E. H. Richards (15)
6446	S. St. Clair
6447	P. R. Bennett
6447	D. L. Berry
6447	V. J. Dandini
6449	K. D. Bergeron
6450	J. A. Reuscher
6454	D. J. Sasmor
3141-1	C. M. Ostrander (5)
3151	W. L. Garner (3)
3154-3	C. Dalin (28)
8024	M. A. Pound