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# ANALYSIS AND TESTING OF THE HP-R-214 DOME MONITOR CABLE FROM THREE MILE ISLAND UNIT 2

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## ABSTRACT

After the accident at Three Mile Island, Unit 2, two sections of a cable connected to the HP-R-214 dome monitor were removed for testing. One section had been directly exposed to the accident environment; the other had been installed in conduit. In addition, an unused section of cable, which was from the same reel as the dome monitor cable, was available as a control sample. These three sections were subjected to material tests, including density profiling, tensile-strength and elongation tests, and chemical analyses, to assess the effect of the accident on the cable and to identify whether any differences existed between the in-conduit and out-of-conduit sections.

## ACKNOWLEDGMENTS

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# EXECUTIVE SUMMARY

The accident at Unit 2 of the Three Mile Island (TMI-2) nuclear power station raised many questions regarding the accident environment and the equipment's response to that environment. As part of the study to answer these questions, the Cables/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 HP-R-214 dome monitor cable.

The dome monitor cable had 20 conductors that provided both power and instrumentation circuits to the HP-R-214 dome radiation monitor in the TMI-2 containment. (An analysis of the dome radiation monitor is reported in Reference 1.) The samples of the dome monitor cable that were studied include (1) a section of the cable that was taken from the TMI-2 containment but was not installed in conduit, (2) a section of the cable that was installed in conduit in the TMI-2 containment, and (3) a section of cable that was from the same reel as the other sections but was never installed (control section). The specific objectives of this study were to identify whether the cable experienced any significant changes in material or electrical characteristics as a result of the TMI-2 environment and, if any changes were found, to examine their significance with regard to the performance of the cable's intended function.

# ANALYSIS AND TESTING OF THE HP-R-214 DOME MONITOR CABLE FROM THREE MILE ISLAND-UNIT 2

## 1. Introduction and Program Objectives

After the accident at Unit 2 of the Three Mile Island (TMI-2) nuclear power plant on March 28, 1979, many questions were raised regarding the accident environment and the equipment's response to that environment. To answer these and other questions and to coordinate technical investigation of the accident, the Department of Energy set up the Technical Integration Office (TIO) at TMI-2. One of the tasks assigned by the TIO is the Cables/Connections Task, underway at Sandia National Laboratories in Albuquerque, New Mexico (SNLA).

The objectives of the Cables/Connections Task are (1) to assess the effect of the accident on components of electrical circuits installed at TMI-2, and (2) to learn as much as possible about the accident environment by studying the components. To accomplish these objectives, Task personnel examine and test various cables or other samples removed from TMI-2. One piece of equipment studied as part of the Cables/Connections Task was the HP-R-214 dome monitor cable. This report documents the results of that investigation.

## 2. Objectives

The specific objectives of this study were to identify any significant changes in material or electrical characteristics experienced by the dome monitor cable as a result of the TMI-2 environment and, if any existed, to examine the significance of these changes with regard to the performance of the cable's intended function. The latter examination might then provide insights into the performance of other reactor circuits exposed to similar environments (for example, circuits that are rated Class 1E and must be qualified for loss-of-coolant-accident [LOCA] environments).

This report documents only the materials analysis of the cable. The electrical analysis of the cable was conducted at Hanford Engineering Development Laboratory and will be reported separately.

## 3. Cable Description

### 3.1 Location and Function

The HP-R-214 dome radiation monitor was located on top of the roof of the elevator shaft at a containment building elevation of 372 ft. Figures 1 and 2 indicate the approximate location of the dome monitor in the TMI-2 containment. Figure 3 shows the dome monitor and cable before they were removed. The cable was installed in conduit, except for the 1-m (3-ft) portion nearest the monitor. The cable's function was to provide both power and instrumentation channels for the dome monitor.

### 3.2 Physical Description

The cable was labeled "Anaconda-Continental Type NSGA-20 cond, #16 AWG, 125°C, 300 V-1975." The cable had 20 conductors, each individually insulated with silicone rubber.

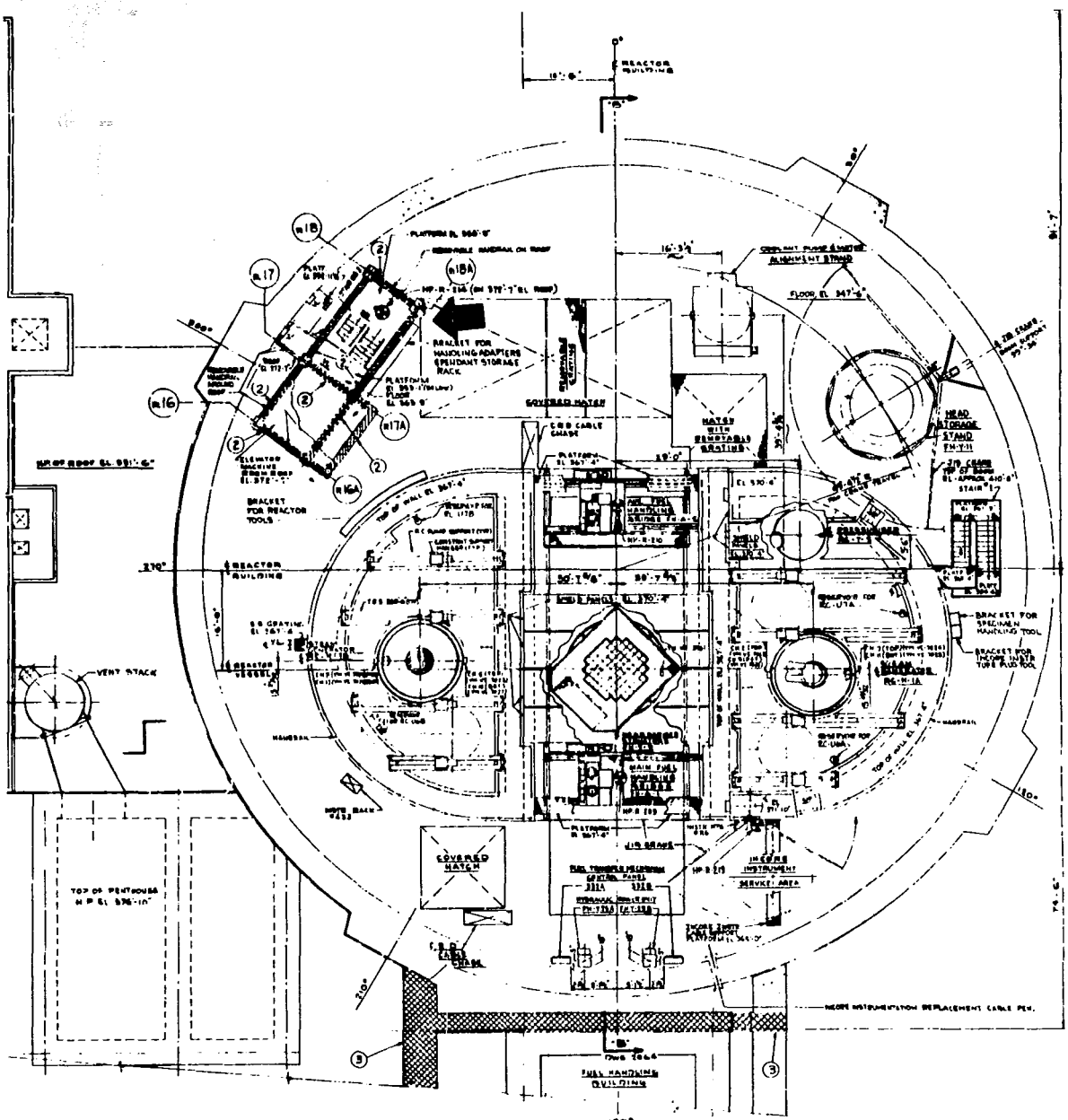


Figure 1. TMI-2, 345-ft Plan Layout. Dome monitor HP-R-214 is located on top of elevator shaft as shown by bold arrow (Ref. 1).

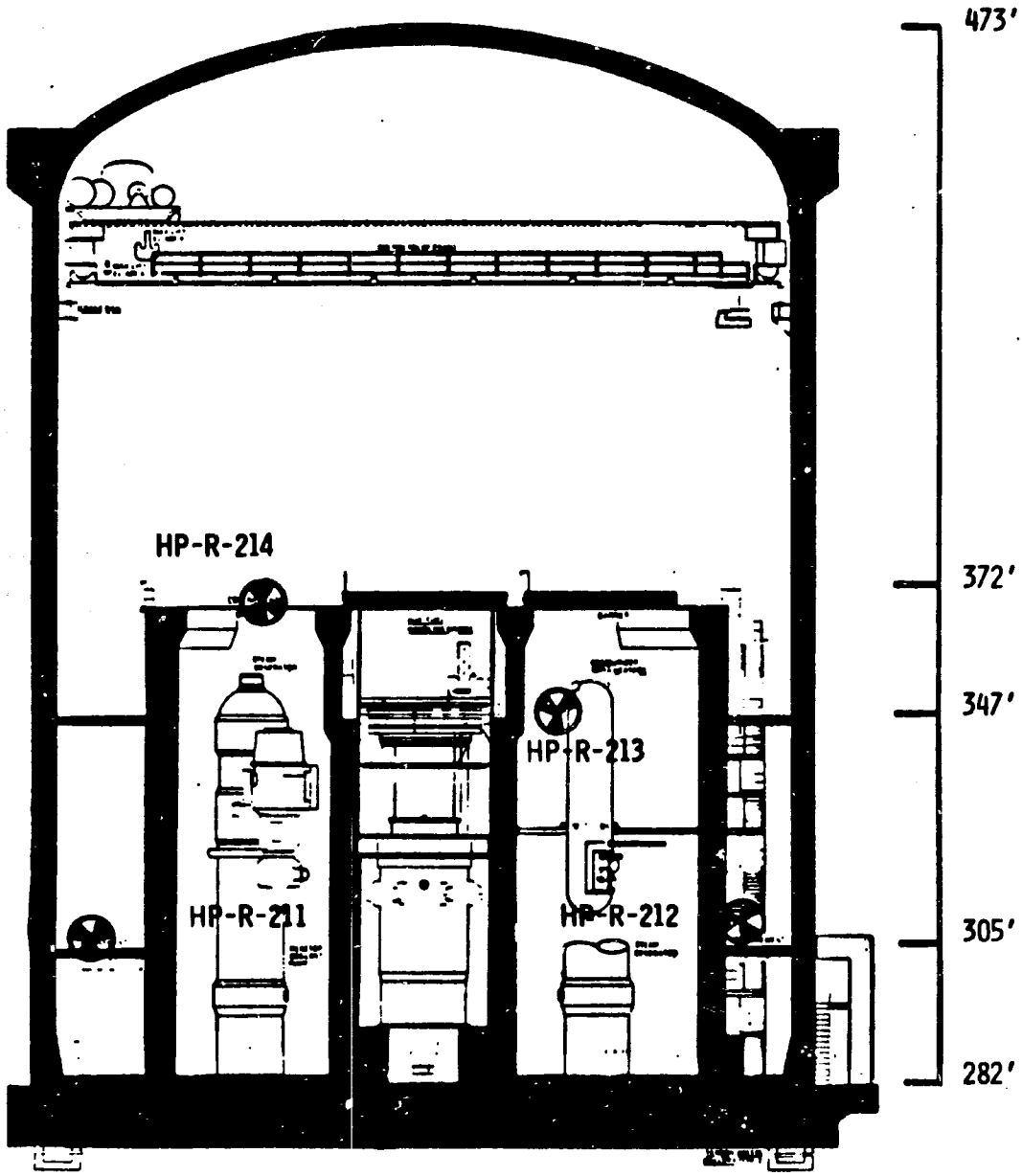


Figure 2. Location of HP-R-214 Dome Monitor in TMI-2 Containment Building (Ref. 1).

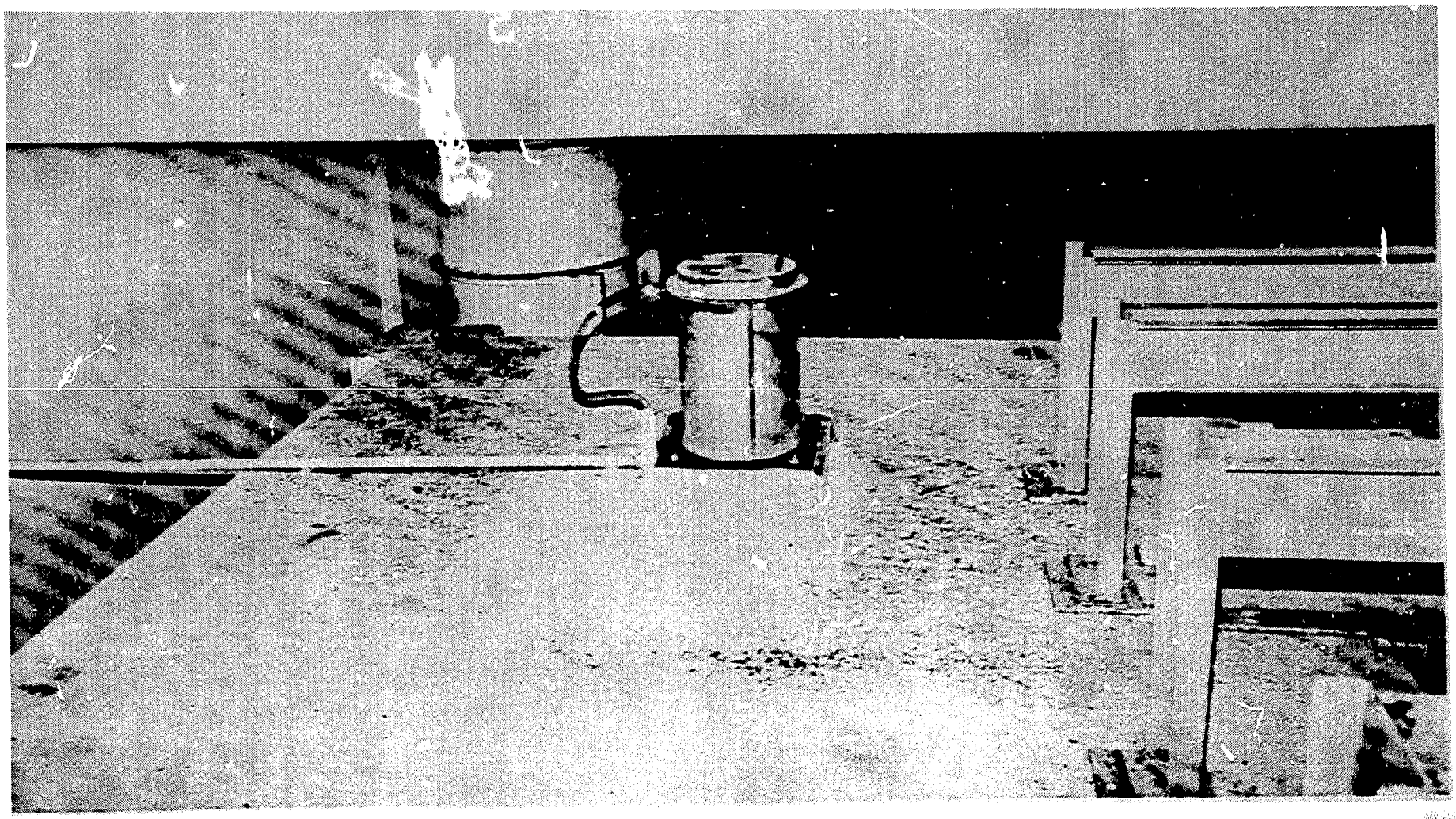

Figure 3. HP-R-214 Dome Monitor and Cable in Place on Top of Elevator Shaft in TMI-2 (Ref. 1).

A braided fiberglass sheath surrounded the silicone rubber insulation. The bundle of conductors was wrapped with 2-mil aluminum and mylar foil, and the cable's outer jacket was braided asbestos.

Figure 4 shows the bundle of conductors with the jacket and wrap removed. The fiberglass sheaths are color coded to easily distinguish each conductor (however, on some areas the colors had faded). We used a numbering system to identify individual conductors: conductor #1 is the center conductor, #2 through #7 are in the middle layer, and #8 through #20 are in the outer layer.

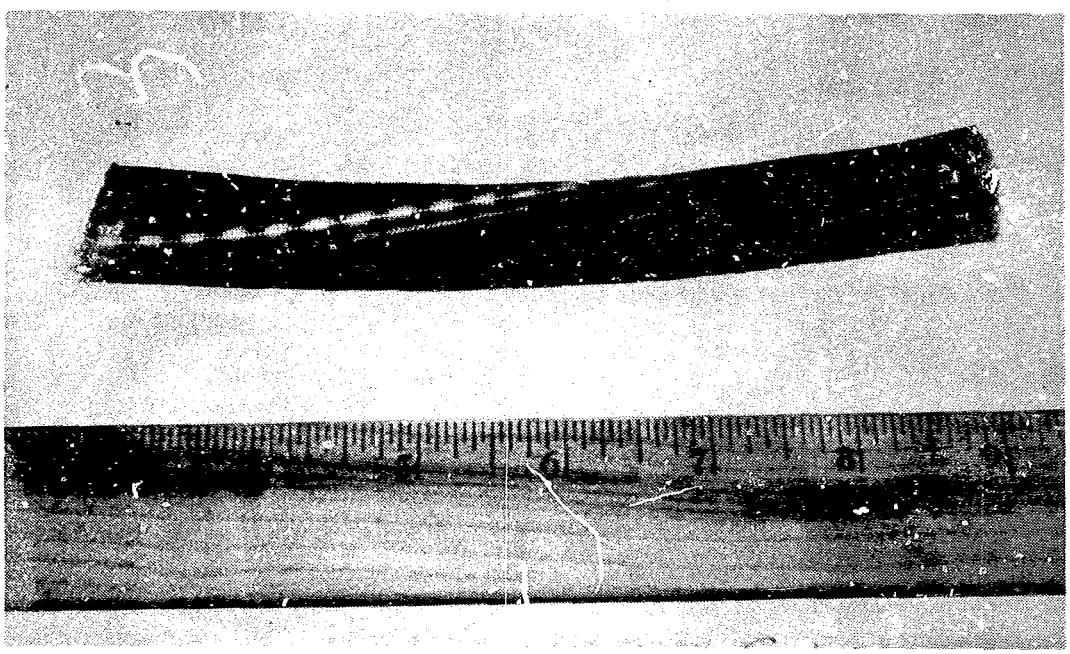

Figure 4. Conductor Bundle from Dome Monitor Cable from TMI-2.

We analyzed samples from both the "in-conduit" and the "out-of-conduit" sections of the cable. The out-of-conduit section, about 1-m (3-ft) long, was located between the dome monitor and the in-conduit section. The in-conduit section was approximately 8-m (26-ft) long and was located about 1 to 9 m (3 to 29 ft) from the dome monitor. When we received the in-conduit section of cable, one end was taped,

and the other end was not. The taped end was the end closest to the dome monitor. We tested samples from each end of this section. In addition, we tested a control sample, which was an unused section of cable from the same reel as the dome monitor cable. The control sample had been stored on the reel at TMI-2 and was not exposed to the accident environment. Figures 5 through 7 show the three different sections of cable.

### 3.3 Decontamination

Before testing, the cable was decontaminated. Most of the contamination was contained on the cable jacket. After the jacket was removed, the radiation levels from the other materials were comparable to, or less than, background levels. Wipe tests of the cable jacket material indicated that most of the contamination was deeply imbedded in the fibers. The neutron-activation analysis was performed on the jacket material after surface contamination was reduced to the lowest possible levels by dry-wiping. When present, boron was dissolved from the jacket sample for the wet-chemistry analysis. The boron was separated from the radioactive contamination in the solution by passing the solution through a boron-selective ion-exchange resin (Amberlite XE243).

### 3.4 Tests Conducted

Several tests were used to analyze this cable, including tensile/elongation testing of the silicone insulation, density measurements of the silicone insulation, and chemical analyses of the asbestos jacket and fiberglass sheaths. Originally, we had planned to conduct hardness testing on the silicone insulation, but the results of the density tests indicated that hardness tests would not be productive. No thermal analyses were conducted because there were no indications that the cable had been thermally damaged. Although a hydrogen burn did occur in the TMI-2 containment,

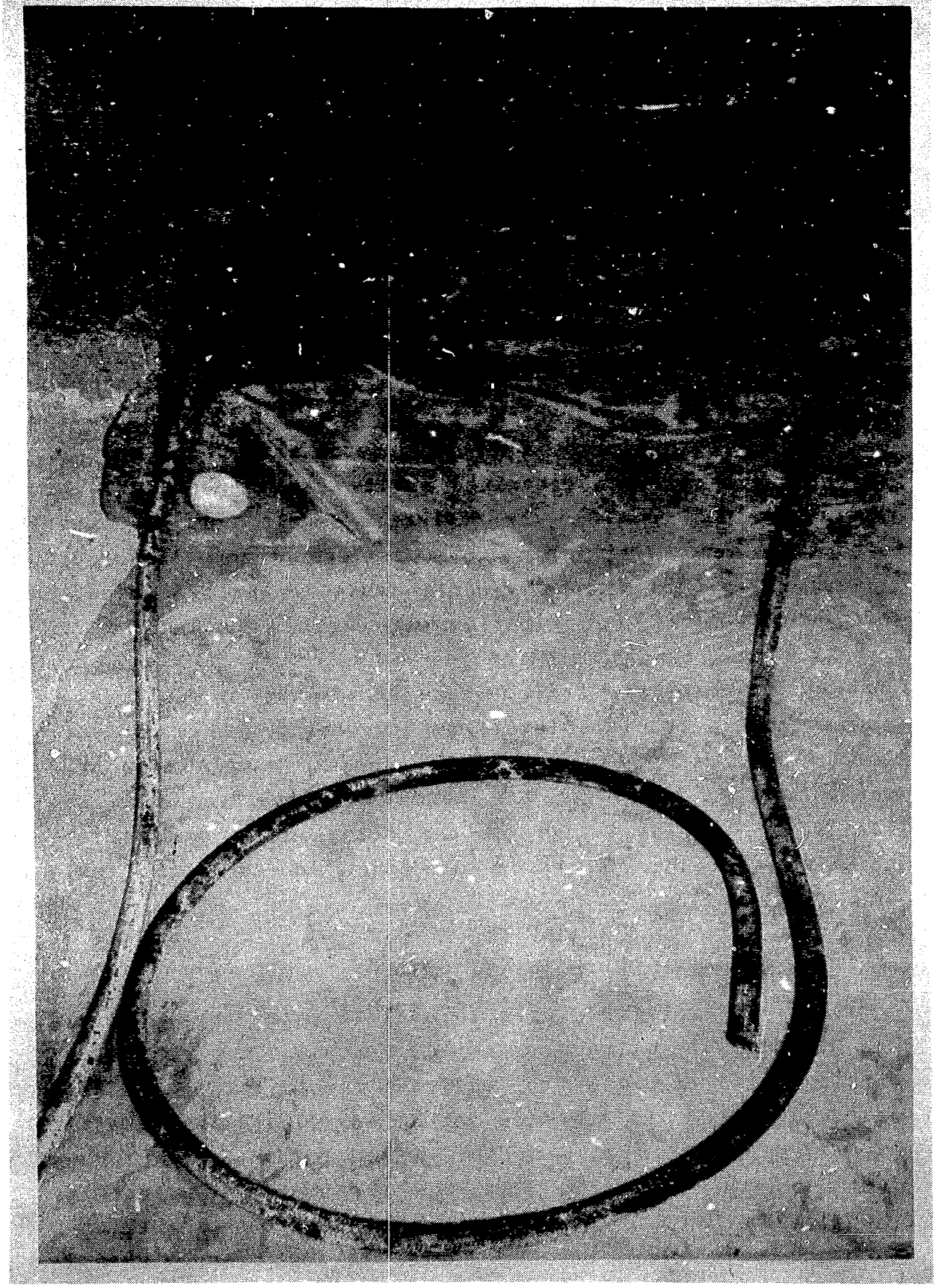

Figure 5. Section of Dome Monitor Cable Installed In Conduit in TMI-2.

Figure 6. Transition Between In-Conduit Section (right) and Out-Of-Conduit Section (left) of Dome Monitor Cable.

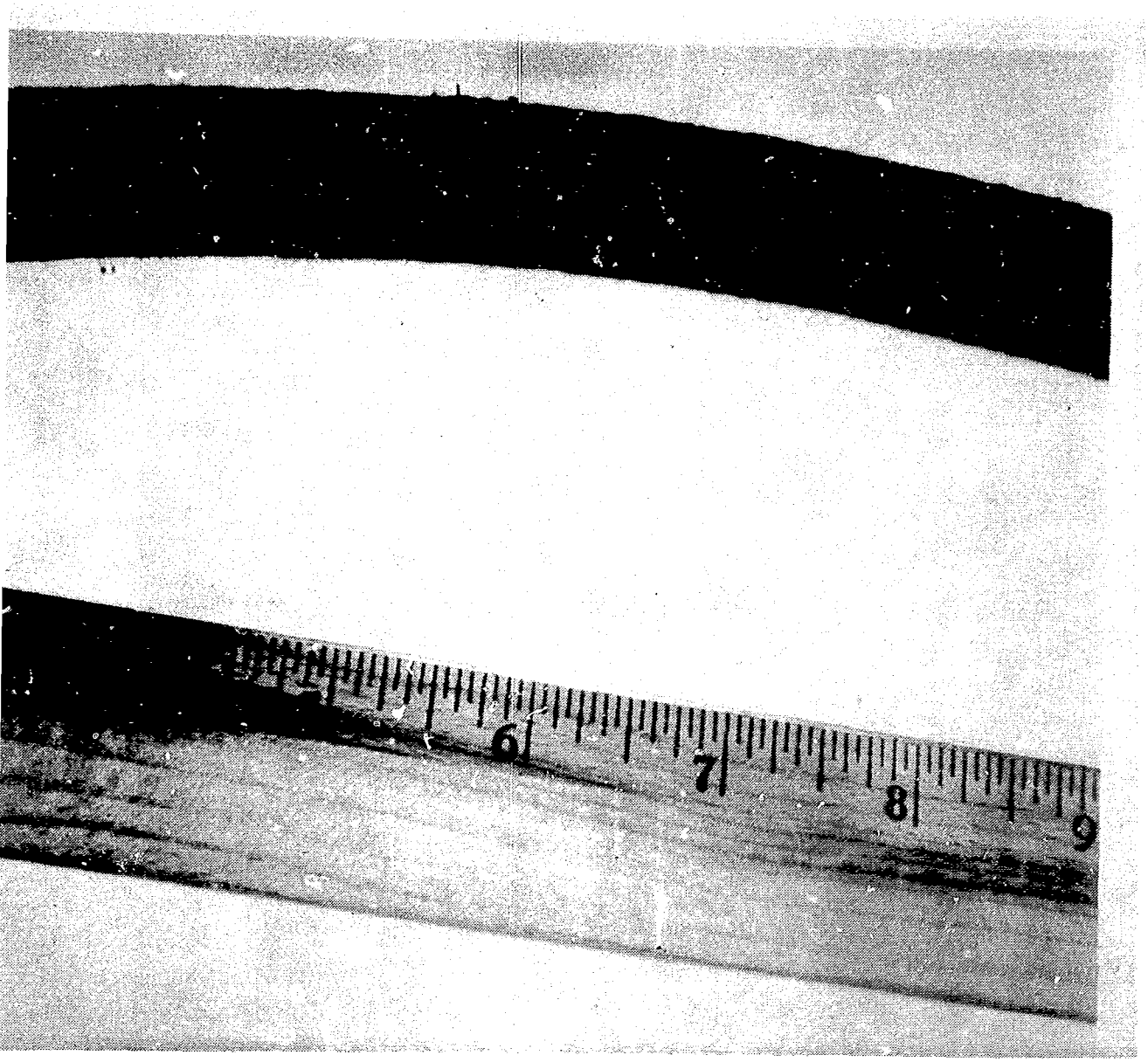


Figure 7. Control Sample of Dome Monitor Cable Taken from TMI-2 Reel.

the dome monitor cable appears to have been sufficiently protected from it by the thermal mass and shielding provided by the floor and the conduit.

# 4. Tensile and Elongation Measurements

## 4.1 Purpose

A commonly used method of identifying polymer degradation is tensile/elongation testing. In these tests, we wanted to detect differences in the tensile strength and percent elongation between in-conduit samples and out-of-conduit samples to ascertain whether the conduit provided any protection from the accident environment. Samples of insulation from the inner conductors were tested. The cable's outer jacket is asbestos and is not amenable to this type of test.

Some evaluations of the cable had already been conducted in conjunction with the analysis of the dome radiation monitor.[1] As part of these evaluations, out-of-conduit samples of insulation were tested and compared to samples from the control section. In addition, samples from the control section were irradiated to various levels and then tensile/elongation-tested; a "calibration" curve was drawn, and the total dose received by the TMI-2 sample was calculated by comparison. Our work continued this effort: We attempted to detect a difference in radiation dose between the in-conduit and out-of-conduit samples to see whether the conduit provided significant beta-radiation shielding or if the jacketing and wraps were sufficient. (It should be noted that we assumed that changes in tensile strength/elongation were due primarily to radiation dose rather than to thermal or other effects.)

## 4.2 Procedures

### 4.2.1 Sample Preparation

Prior to testing, the cable samples were dissected. Care was necessary because, in addition to containing potentially hazardous materials such as asbestos and fiberglass,

the cable also was slightly contaminated with radioactive material (see Section 3.3 for decontamination information). All sample preparations were accomplished under a hood in an appropriate area for handling the materials.

First the asbestos jacketing was cut away, and then foil and mylar wraps were removed, exposing the sheathed and insulated conductors. The fiberglass sheath around each conductor's insulation was carefully filed, until the fiberglass could be removed. Then, using the special tools* shown in Figure 8, the copper conductors were pulled from the insulation, leaving samples of silicone insulation, each approximately 5 inches (12 cm) long. We were careful to maintain conductor identification numbers of the samples.

### 4.2.2 Tensile/Elongation Tests

We used an Instron Model 1130 with an extensimeter for the tensile/elongation tests. The Instron was calibrated with the appropriate weights before the tests. First we retested six samples from the out-of-conduit section of cable to ensure that our results were consistent with the previous tests.[1] Then 40 insulation samples (20 from each end) of the in-conduit section were tested, and the results were compared.

## 4.3 Results of Tensile/Elongation Testing

The data in Table 1 show that the results from our tests of the out-of-conduit insulation samples are consistent with the previous tests, for both tensile strength and percent elongation.

*The tools were made by G. Mueller for the testing described in Ref. 1.

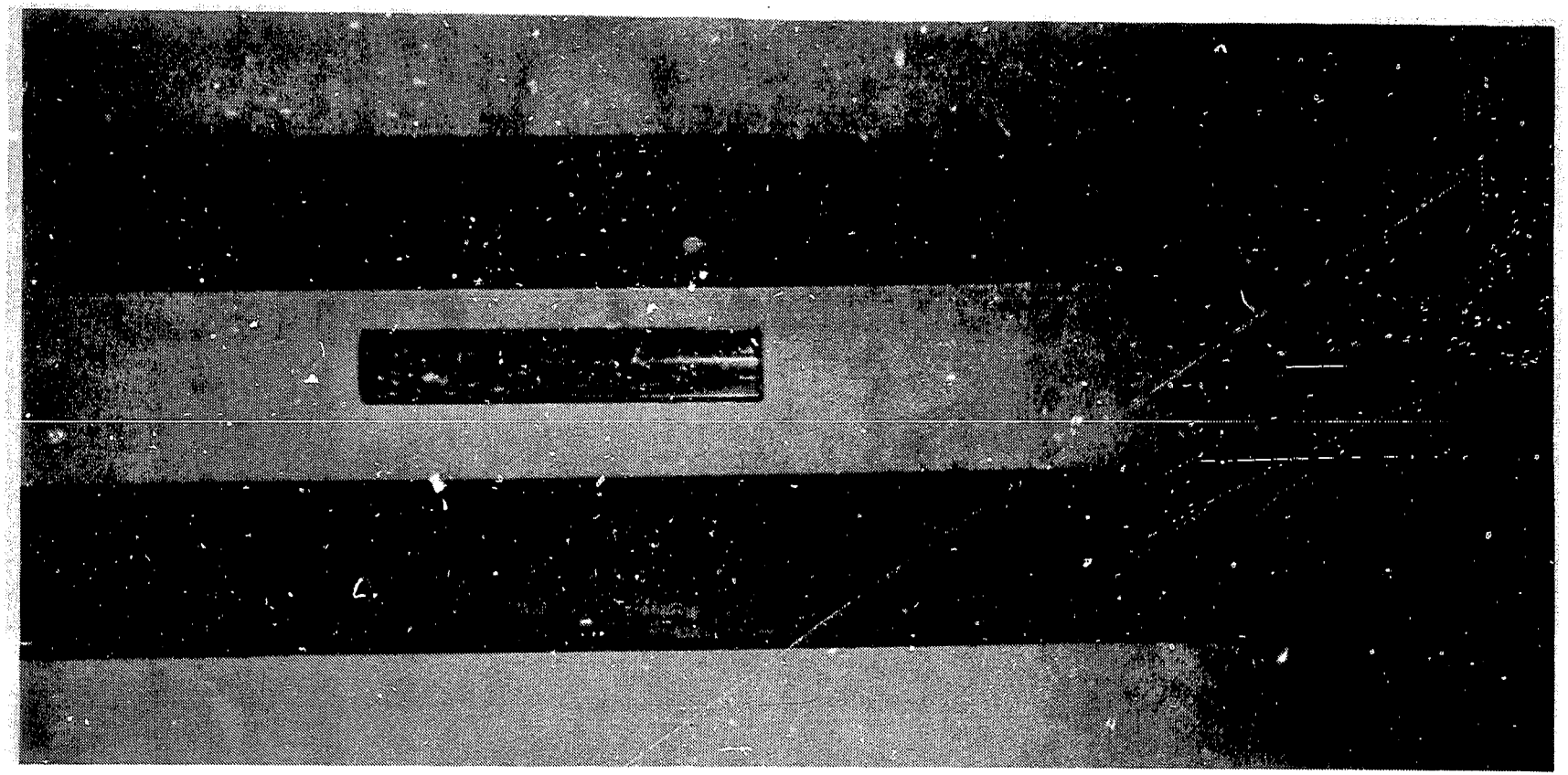

Figure 8. Tools Used To Pull Conductors from Insulation. Plastic tube kept the silicone insulation from collapsing as the wires were pulled (with pliers) through a hole on the brass plate.

Table 1

Tensile/Elongation Test Results for Out-of-Conduit Cable Samples of Silicone Insulation

| | Previous Tests | | Current Tests | |
|---|---|---|---|---|
| | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ |
| Tensile strength (lb)* | 8.47 | 0.83 | 8.12 | 0.51 |
| Percent elongation | 208.4 | 18.75 | 202.00 | 11.31 |

$\bar{x}$ = average of data

$\sigma$ = standard deviation

*Actually pounds-to-break, no cross-sectional area involved.

Table 2 compares the results from the tests of the in-conduit samples with the data for the out-of-conduit samples. The average percent elongation value is lower for the out-of-conduit cable samples. This implies that the out-of-conduit samples were more brittle (and therefore had received more radiation) than the in-conduit samples. However, from a statistical perspective, the differences in percent elongation are not significant. Therefore, definitive conclusions could not be made regarding relative radiation doses for in-conduit versus out-of-conduit cable.

For the tensile strength measurements, the average is lower for the cable samples that were out-of-conduit, implying that the out-of-conduit samples were weaker and possibly had received more radiation damage. However, the differences in tensile-strength measurements compare to the standard deviations of the data. Therefore, definitive conclusions could not be drawn from these data. Radiation doses calculated from the calibration curves were very close to the doses reported in Reference 1.

## Table 2

### Data from Tensile Strength and Percent Elongation Tests*

| Insulation from Conductor # | In-Conduit Taped End (lb/%) | In-Conduit Untaped End (lb/%) | Out-of-Conduit (lb/%) |
|---|---|---|---|
| 1 | 9.03/233 | 9.47/234 | 7.47/192 |
| 2 | 8.22/220 | 8.39/224 | 8.31/200 |
| 3 | 8.07/190 | 8.50/210 | |
| 4 | 8.34/200 | ** | |
| 5 | 8.78/210 | 9.42/223 | 7.87/200 |
| 6 | 8.51/210 | 8.62/223 | |
| 7 | 9.19/224 | 7.68/200 | |
| 8 | 7.68/194 | 9.13/230 | 8.79/220 |
| 9 | 8.66/203 | 9.25/230 | |
| 10 | 9.06/205 | 8.66/230 | |
| 11 | 9.01/220 | 7.88/225 | |
| 12 | 9.07/230 | 8.86/213 | 7.74/190 |
| 13 | 8.80/230 | 8.37/211 | |
| 14 | 8.27/212 | 8.81/223 | |
| 15 | 9.09/221 | 9.12/220 | |
| 16 | 8.68/203 | 9.38/233 | 8.55/210 |
| 17 | 8.53/210 | 7.38/182 | |
| 18 | 8.15/210 | 8.36/213 | |
| 19 | ** | 8.63/223 | |
| 20 | 8.83/220 | 7.61/193 | |
| $\bar{x}$ | 8.63/213 | 8.61/218 | 8.12/202 |
| $\sigma$ | 0.42/12.18 | 0.63/13.96 | 0.51/11.31 |

$\bar{x}$ = average of data

$\sigma$ = standard deviation

* = Does not include data for control sample or out-of-conduit sample that were recorded for work in Ref. 1.

** = Invalid data

## 5. Density Measurements

### 5.1 Purpose

When a polymer undergoes a material change, density is often a leading indicator. Because the results from the tensile tests gave a slight indication that there was a difference between the in-conduit and out-of-conduit samples, our efforts then focused on conducting density measurements using a density-gradient column. We postulated that this method might provide a more sensitive means of detecting differences between the samples.

### 5.2 Procedure

A density-gradient column was constructed with the appropriate range. Two liquids of different densities are used in density-gradient columns; the liquids are combined, mixed, and poured into a vertical column in such a way that a linear density gradient occurs over the length of the column, with increased density at the bottom. The complete procedure for constructing columns is contained in Reference 2, although we did modify the procedure by using low-speed pumps instead of stopcocks.

Figure 9 illustrates the test setup. We measured the density of silicone insulation samples* by using a calcium nitrate and water solution with a density range of roughly 1.15 to 1.30 g/cc. Representative samples of insulation from the out-of-conduit section, the control section, and both ends of the 8-m (26-ft) in-conduit section were cut into various shapes (for identification in the column). They were slowly lowered into the density-gradient column so as not to disturb the density gradient. The density-gradient

*This was the only material in the cable that was suitable for this type of test. The asbestos jacket was too fibrous and would have held bubbles.

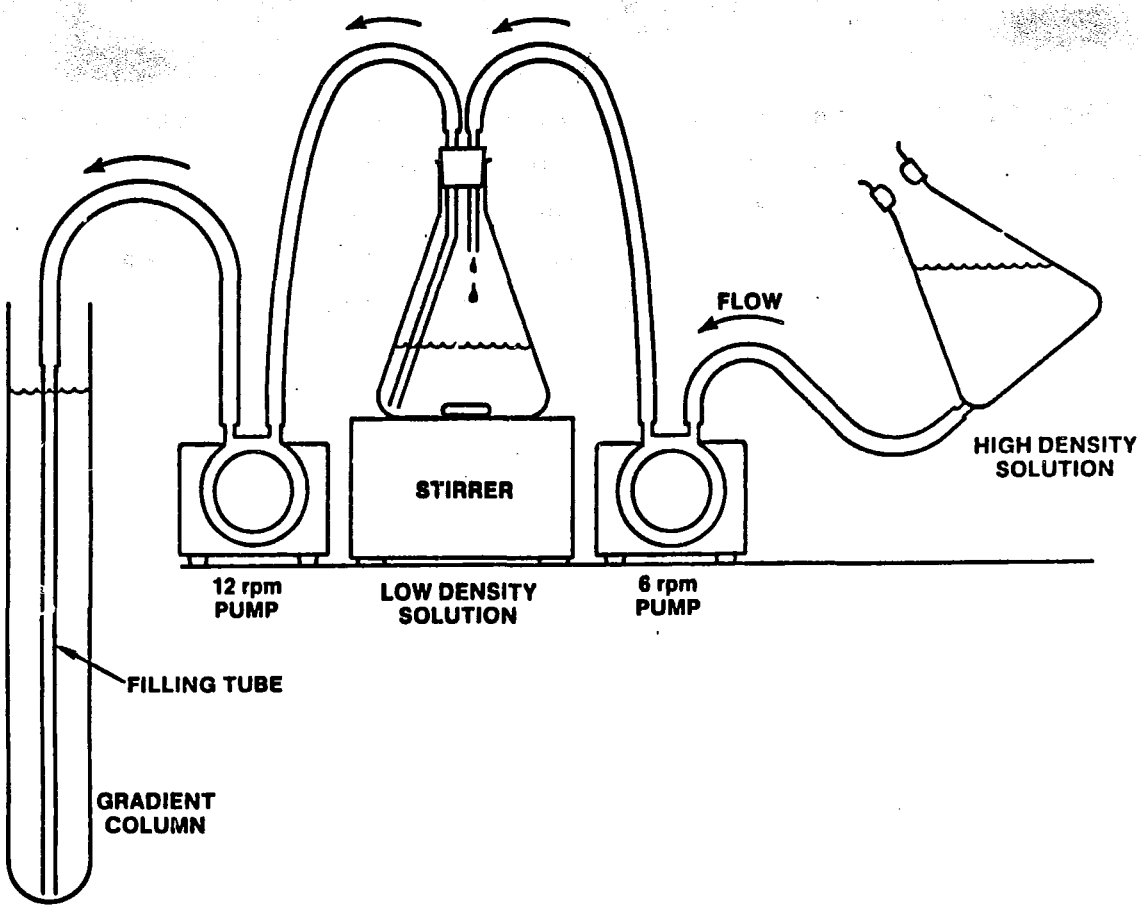


Figure 9. Schematic of Density-Gradient Setup.

column was calibrated using special floats with known densities. By observing the height at which a given sample was suspended, we could calculate its density. Various combinations of samples were examined, which included:

Set 1. Six samples of insulation from conductor #6 of the control sample. The purpose of this set was to determine the repeatability of data for supposedly identical samples.

Set 2. Samples of insulation from 14 different conductors from the control sample. The purpose of this set was to determine density consistency for insulation samples from several conductors from the same cable section.

Set 3. Samples of insulation from representative conductors for each of four cable sections: control, out-of-conduit, and both ends of the 8-m (26-ft) in-conduit section. The purpose of this set was to identify density differences in insulation samples among the cable sections.

## 5.3 Results

The samples in the first set had an average density of 1.24309 g/cc with a standard deviation of 0.0009 g/cc, indicating that the density is very consistent among samples from the same conductor.

The samples in the second set had an average density of 1.2426 g/cc, with a standard deviation of 0.0025 g/cc. Although the previous test indicated that the density was consistent for a given conductor, this test showed that density was not nearly so consistent for samples taken from different conductors. The test results on this set made it clear that it would be necessary to maintain conductor identification when comparing densities for samples from different cable sections.

Results from the third set of tests did not reveal significant changes in density among samples from different cable sections. For example, Table 3 shows results for conductor #16, which is typical of the test data obtained. The changes are so slight that they are within the error tolerance for samples from the control sample. Therefore, we concluded that there is no significant difference in densities among the various sections of cable.

Table 3

Densities Measured for Samples of Insulation from Conductor #16 (Set 3)

| Cable Section | Density, g/cc |
|---|---|
| Control | 1.24190 |
| Out-of-conduit | 1.24260 |
| In-conduit, taped end | 1.24225 |
| In-conduit, untaped end | 1.24190 |

Average = 1.24216 g/cc
Standard Deviation = 0.0003 g/cc

## 6. Chemical Element Analysis of Cable Materials

### 6.1 Exterior Jacket

Initial inspection of the in-conduit sample of the HP-R-214 dome monitor cable revealed that the exterior cable jacket contained a gray powdery substance. There was also a tan-gray crustlike substance at various points over the length of the sample. The jacket was a braided asbestos fabric that had been dyed black. A sample of the control cable did not exhibit the gray powdery substance.

Because the chemical nature of the foreign material was unknown, we investigated its elemental content using Neutron Activation Analysis (NAA). Three jacket samples were subjected to NAA and were identified as follows:

Sample A: Sample from in-conduit cable end that had been farthest from the HP-R-214 dome radiation monitor when inside containment (untaped end).

Sample B: Sample from in-conduit cable end that had been closest to the dome radiation monitor inside containment (taped end).

Sample C: Control sample from reel in storage at TMI. This sample was from the same reel as samples A and B.

Results of the NAA are given in Table 4.

Significant differences among the samples are shown in Table 5.

It is postulated that the elevated concentrations of zinc may be due to some corrosive agent (such as NaOH) in the sprays that infiltrated the conduit, leached the zinc from the galvanizing, and deposited it on the cable jacket. This might also account for the elevated levels of sodium. However, because sodium compounds are common throughout nature, the sodium may have come from the asbestos mineral deposits from which the cable jacket was manufactured. Sodium may also have been deposited by contact with bare hands during the installation of the cable.

The relatively large amount of tantalum in Sample A is of interest because tantalum is used extensively in the manufacture of nuclear reactor vessels.[3] However, the tantalum concentration in the Earth's crust averages about 2 ppm, so, in the absence of other evidence to the contrary, there is nothing unusual about the measured concentrations.[4]

Differences in uranium concentrations are not significant. Asbestos deposits can be very different, and so the mineralogy of the deposit from which the samples originated must be known before any definite conclusions can be drawn. It is not unusual to find that uranium concentrations differ by a factor of 10 in geologic samples taken only a few feet apart.[5]

Table 4

Cable Jacket Neutron-Activation Analysis Results

| Element | Element Concentration (µg/g unless noted) | | |
|---|---|---|---|
| | Sample A | Sample B | Sample C |
| Na-23* | 1.08 ± 0.03 | 1.33 ± 0.06 | 0.97 ± 0.06 |
| K-41* | 0.85 ± 0.35 | <2.1 | <2.6 |
| Ca-46* | 80 ± 5 | 81 ± 4 | 75 ± 4 |
| Sc-45 | 5.1 ± 0.2 | 5.0 ± 0.2 | 5.1 ± 0.1 |
| Cr-50 | 350 ± 11 | 360 ± 11 | 340 ± 7 |
| Fe-58* | 7.1 ± 0.7 | 7.1 ± 0.5 | 6.8 ± 0.4 |
| Co-59 | 22.4 ± 0.5 | 24 ± 2 | 22.4 ± 0.5 |
| Ni-58 | 690 ± 14 | 690 ± 55 | 700 ± 14 |
| Zn-64 | 56 ± 2 | 450 ± 9 | 23 ± 2 |
| Sr-88 | <98 | 226 ± 25 | <57 |
| Sb-121,123 | 25 ± 1 | 26 ± 1 | 19 ± 1 |
| Ba-130 | 50 ± 8 | 69 ± 28 | 53 ± 8 |
| La-139 | 2.9 ± 0.4 | 3.5 ± 0.3 | 2.8 ± 0.2 |
| Ce-140 | 8.2 ± 0.6 | 8.9 ± 0.9 | 5.9 ± 0.2 |
| Nd-146 | 2.9 ± 0.9 | <7 | 1.7 ± 0.5 |
| Sm-152 | 1.0 ± 0.2 | 1.20 ± 0.2 | 0.79 ± 0.02 |
| Eu-151 | 0.14 ± 0.03 | 0.19 ± 0.02 | 0.13 ± 0.03 |
| Tb-159 | 0.12 ± 0.01 | 0.16 ± 0.01 | 0.08 ± 0.03 |
| Yb-168,174 | <1.0 | 0.48 ± 0.10 | 0.27 ± 0.09 |
| Lu-176 | 0.05 ± 0.01 | <0.09 | 0.03 ± 0.01 |
| Hf-180 | 0.08 ± 0.06 | 0.88 ± 0.10 | 0.72 ± 0.08 |
| Ta-181 | 1.46 ± 0.03 | 0.31 ± 0.03 | 0.09 ± 0.03 |
| Th-232 | 1.3 ± 0.1 | 1.9 ± 0.3 | 0.94 ± 0.02 |
| U-238 | 2.2 ± 0.3 | 2.4 ± 0.3 | 0.31 ± 0.03 |
| Br** | 1.76 ± 0.08 | 1.02 ± 0.05 | 1.00 ± 0.05 |

*These values are in mg/g
**Br values are normalized to Sample C.

Table 5

Cable Jacket Element Concentration Differences

| Element | Element Concentration (µg/g unless noted) | | |
|---|---|---|---|
| | Sample A | Sample B | Sample C |
| Na-23* | 1.08 ± 0.03 | 1.33 ± 0.06 | 0.97 ± 0.06 |
| Zn-64 | 56 ± 2 | 450 ± 9 | 23 ± 2 |
| Sr-88 | <98 | 226 ± 25 | <57 |
| Ta-181 | 1.46 ± 0.03 | 0.31 ± 0.03 | 0.09 ± 0.03 |
| U-238 | 2.2 ± 0.3 | 2.4 ± 0.3 | 0.31 ± 0.03 |
| Br** | 1.78 ± 0.08 | 1.02 ± 0.05 | 1.00 ± 0.05 |

*Concentration in mg/g
**Concentration normalized to Sample C.

Bromine is commonly used as a fire retardant in cable insulation, and the differences in concentrations could be due to normal variations in the cable manufacturing process. Generally, the results of the NAA for bromine are inconclusive.

To investigate further the possibility that borated spray entered the conduit at TMI, three additional samples (with the same designations as the NAA samples) were tested for the presence of boron. A chemical process originally developed for the detection of germanium was used.[6] Sample A was found to have a boron concentration of 0.28 mg/g. Samples B and C showed no boron present. This indicates that borated solution from the sprays may have entered the conduit at the end farthest from the detector.

## 6.2 Interior Cable Sheaths

While individual conductor samples were being prepared for other tests, it was discovered that several of the

colored fiberglass sheaths on these individual conductors had undergone some form of bleaching. These sheath samples came from the in-conduit cable sample that was farthest from the detector. Elemental analysis was also performed on these sheath samples, using emission spectroscopy.

Four sets of samples consisting of three jackets each were examined. Sample groups for the emission spectroscopy were designated in the same manner as the samples examined in the NAA (A, B and C). A fourth group, Group D, was taken from the out-of-conduit section of the cable.

The three jacket samples in each group were taken from each of three conductors in the cable. Jacket 2 was taken from a conductor in the middle layer of the cable and was solid red in color. Jackets 8 and 16 were removed from conductors adjacent to the outer jacket of the conductor bundle. Jacket 8 was green and white; jacket 16 was green and black. Results of the emission spectroscopy are given in Table 6. Precision is within a factor of 2, and isotopic identification is not possible.

Though the uncertainty in the technique precludes definite conclusions, two interesting differences among samples are evident in the results:

Boron concentrations, as measured, are consistently higher in the Group B samples (those from the in-conduit sample closest to the detector) than in any other group. All sample groups that were installed in containment had lower measured magnesium concentrations than the control group. These findings are discussed in the next section.

Table 6

**Emission Spectroscopy Results for Fiberglass Sheaths**
**Sample Element Concentration (ppm)**

| Element | A-2 | A-8 | A-16 | B-2 | B-8 | B-16 | C-2 | C-8 | C-16 | D-2 | D-8 | D-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ca | M* | M | M | M | M | M | M | M | M | M | M | M |
| S | M | M | M | M | M | M | M | M | M | M | M | M |
| Al | M | M | M | M | M | M | M | M | M | M | M | M |
| B | 30,000 | 30,000 | 30,000 | 40,000 | 40,000 | 40,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 |
| Mg | 25,000 | 16,000 | 10,000 | 10,000 | 6,000 | 6,000 | 40,000 | 40,000 | 40,000 | 25,000 | 13,000 | 6,000 |
| Fe | 4,000 | 3,000 | 2,500 | 5,000 | 4,000 | 3,000 | 5,000 | 4,000 | 4,000 | 4,000 | 3,000 | 2,500 |
| Ti | 6,000 | 6,000 | 4,000 | 3,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 6,000 |
| Sr | 10,000 | 2,500 | 1,000 | 6,000 | 2,000 | 1,000 | 4,000 | 1,600 | 1,000 | 2,500 | 1,000 | 1,000 |
| Na | 2,500 | 1,600 | 1,600 | 1,600 | 1,600 | 1,300 | 1,600 | 1,000 | 1,600 | 1,600 | 1,000 | 1,000 |
| K | 1,000 | 1,000 | 1,000 | 600 | 500 | 500 | 600 | 500 | 600 | 1,000 | 800 | 800 |
| Ba | 250 | 400 | 600 | 150 | 400 | 600 | 150 | 400 | 600 | 150 | 400 | 600 |
| Zr | 600 | 400 | 400 | 400 | 400 | 400 | 600 | 800 | 800 | 400 | 400 | 600 |
| Cu | 100 | 200 | 60 | 40 | 60 | 60 | 60 | 100 | 150 | 50 | 50 | 50 |
| Ag | 40 | 60 | 20 | 50 | 10 | 10 | 40 | 10 | 40 | 20 | 100 | 60 |
| Li | 150 | 150 | 60 | 60 | 50 | 50 | 100 | 60 | 60 | 60 | 60 | 40 |
| Zn | 600 | ND** | ND | ND | ND | ND | 600 | ND | ND | [illegible] | ND | ND |
| Mo | ND | ND | 250 | ND | ND | ND | ND | ND | ND | ND | ND | ND |

*M indicates a major sample constituent; emission spectroscopy readings were off-scale.
**ND indicates this element was not detected; concentrations were below instrument thresholds.

## 6.3 Discussion

Because of the lack of a definitive description of the accident and postaccident environments in the TMI-2 containment, definite conclusions cannot be drawn from the results of the chemical analyses.

The detection of boron on the outer jacket of the sample that was in conduit and farthest from the detector leads to the speculation that containment sprays may have entered the conduit. A slight excess of sodium (as detected by NAA) on the same sample may also indicate spray infiltration. An even higher sodium concentration on the sample from the opposite end of the in-conduit cable section may similarly be taken to indicate that the cable was exposed to liquid from the spray system. However, this sample had no boron present on the outer jacket. The two samples were at opposite ends of a cable section that was approximately 8 m (26 ft) long.

Except for the boron and magnesium concentrations, the emission spectroscopy results are nebulous. Without further analysis beyond the scope of this work, the lower measured magnesium concentrations in the containment samples, as compared to the control samples, cannot be explained in terms of the environment to which the inside of the cable may have been exposed. Likewise, if spray infiltration is responsible for the measured higher concentration of boron, it is difficult (given the construction of the cable) to speculate on how the sprays penetrated to the cable interior when the exterior of the cable in this region did not show boron.

One possible explanation for the bleaching of the interior jacketing is that it occurred during manufacture of the cable. Related work on a control sample from the same reel showed that bleaching was present.[7]

## 7. Conclusions

The primary conclusion drawn from this work is that the accident had little effect on the cable. Although the cable looked "used" compared to the control sample, the tests provided no indication that significant material degradation took place, certainly not enough to cause concern about the cable's ability to function properly. Both the tensile/elongation tests and the density tests showed that no degradation of the silicone insulation occurred. Chemical analyses of the insulation material produced inconclusive results.

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Several material tests and chemical studies were employed to analyze the cable. These included tensile/elongation tests, density measurements, neutron-activation analysis, and emission spectroscopy. The results of all tests indicated that the accident environment had little or no effect on the cable's material properties or on the cable's ability to perform its intended function.

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