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GEND-INF-029

TMI-2 PRESSURE TRANSMITTER EXAMINATION PROGRAM YEAR-END REPORT: EXAMINATION AND EVALUATION OF PRESSURE TRANSMITTERS CF-1-PT3 AND CF-2-LT3

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February 1983

Published on Behalf of the GEND Group
by
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Three Mile Island Operations Office
Under DOE Contract No. AC07-76ID01570

ABSTRACT

The Department of Energy has sponsored a program to examine and evaluate selected pressure transmitters located in the TMI-2 Reactor Building during the accident in March 1979, in order to establish operational characteristics and failure modes. This report discusses the program and the results of laboratory examinations and tests performed on two transmitters removed in July 1981. This is a continuing program and more transmitters will be removed and examined in the future.

SUMMARY

This report discusses the pressure transmitter portion of the DOE-sponsored Data Acquisition Program at TMI-2. In particular, two transmitters were removed from the TMI-2 Reactor Building and evaluated in the laboratory in order to establish their operational characteristics. One unit, a Foxboro gauge pressure unit, survived the accident and subsequent handling, shipping, and storage with no apparent problems. The other unit, a Bailey differential pressure unit, apparently failed in operation at an unknown time, probably from water in the unit, and subsequently corroded so badly as to make failure analysis extremely difficult.

A compilation of information on pressure transmitters located in the Reactor Building is presented.

This is a continuing program. Further units will be removed and examined in order to determine their adequacy to perform their functions during a severe accident environment, and to identify possible failure modes. Information on the failure modes will provide guidelines for important improvements in both design and in installation procedures. Another report will be issued next fiscal year.

ACKNOWLEDGMENTS

The authors wish to thank all who participated and contributed to this report. In particular, we wish to thank L. A. Hecker and H. J. Helbert who, as "residents" of TMI, fielded many questions and requests from us in Idaho; Health Physicists W. F. Miller and R. L. Wolz who provided assistance in the radiological handling of the transmitters; R. L. Rowe, E. W. Colsen, and especially J. M. Wasylow, who provided the able hands-on testing and examination.

CONTENTS

FIGURES

TABLES

TMI-2 PRESSURE TRANSMITTER EXAMINATION PROGRAM YEAR-END REPORT: EXAMINATION AND EVALUATION OF PRESSURE TRANSMITTERS CF-1-PT3 AND CF-2-LT3

INTRODUCTION

The accident at TMI-2 has provided an opportunity to evaluate instrumentation that has been exposed to unusual conditions, i.e., direct radiation, radioactive contamination, moisture, and high humidity with elevated temperatures and pressures.

Evaluation of pressure transmitters in the TMI-2 Reactor Building is part of the Data Acquisition Program sponsored by the Department of Energy and administered by EG&G Idaho, Inc. This effort is expected to continue into next year and will include further in situ and laboratory testing and examination.

There are approximately 58 pressure-sensitive transmitters located within the TMI-2 Reactor Building. Selection of transmitters to be evaluated is based upon maximum yield of data to (a) improve qualification standards, (b) assess adequacy of existing standards, (c) improve future designs, (d) assess vulnerability of other existing plants that utilize similar equipment, and (e) better understand the TMI-2 accident itself.[1] Practical and operational limitations have compromised or limited selections. For example, certain desired transmitters have been or are inaccessible or extremely difficult to remove from containment because they were or are under water or in very high radiation fields; some are essential to safe maintenance of the plant and cannot be taken out of service.

Twenty pressure-sensitive transmitters were classified as Priority 1 sensors by the Instrumentation and Electrical Equipment Survivability Planning Group.[1] Table 1 tabulates information on 43 pressure-sensitive transmitters, including Priority 1 sensors and units typical of them. A Priority 1 classification was assigned to the following types of equipment:

TABLE 1. TMI-2 PRESSURE-SENSITIVE TRANSMITTERS

Tag Number[a]	Manufacturer	Model	Parameter	Range[b]	Elevation (ft)	LOCA Sealing	Safety Class	Priority	Required for Safe Shutdown	In situ Testing	Test Results	Removal	Post-removal Test	Test Results	Failure Mode
CF-2-LT1[c]	Bailey	BY8231X-A	Core Flood A level	0 to 14 ft	324	--	--	1	--	--	--	Approved	--	--	--
CF-2-LT2[c]	Bailey	BY8231X-A	Core Flood A level	0 to 14 ft	324	--	--	--	--	09/80	Failed	Approved	--	--	--
CF-2-LT3	Bailey	BY8231X-A	Core Flood B level	0 to 14 ft	324	--	--	1	--	07/81	--	07/23/81	05/82	Failed	Moisture
CF-2-LT4	Bailey	BY8231X-A	Core Flood B level	0 to 14 ft	324	--	--	--	--	09/80	OK	--	--	--	--
CF-1-PT1	Foxboro	E11GM-HSAD1	Core Flood A pressure	0 to 800 psig	324	--	--	1	--	--	--	Approved	--	--	--
CF-1-PT2	Foxboro	E11GM-HSAD1	Core Flood A pressure	0 to 800 psig	324	--	--	--	--	--	--	--	--	--	--
CF-1-PT3	Foxboro	E11GM-HSAD1	Core Flood B pressure	0 to 800 psig	324	--	--	1	--	09/80	OK	07/23/81	03/03/81	OK	--
CF-1-PT4	Foxboro	E11GM-HSAD1	Core Flood B pressure	0 to 800 psig	324	--	--	1	--	09/80	OK	--	--	--	--
RC-1-LT1[d]	Bailey	BY3B40X-A	Pressurizer level	0 to 400 in.	286	--	--	1	--	06/82	Low IR[e]	--	--	--	--
RC-1-LT2[d]	Bailey	BY3B40X-A	Pressurizer level	0 to 400 in.	286	--	--	1	Yes	06/82	Low IR	--	--	--	--
RC-1-LT3[d]	Bailey	BY3B40X-A	Pressurizer level	0 to 400 in.	286	--	--	1	Yes	06/82	Low IR	--	--	--	--
RC-3A-PT1	Rosemont	1152GP9A	RC pressure, narrow	1700 to 2500 psig	286	--	1E	1	--	--	--	--	--	--	--
RC-3A-PT2	Rosemont	1152GP9A	RC pressure, narrow	1700 to 2500 psig	286	--	1E	1	--	--	--	--	--	--	--
RC-3A-PT3[d]	Foxboro	E11GH-HINM2	RC pressure, wide	0 to 2500 psig	287	Yes	1E	1	Yes	--	--	--	--	--	--
RC-3A-PT4	Foxboro	E11GH-HINM2	RC pressure, wide	0 to 2500 psig	287	Yes	1E	1	Yes	--	--	--	--	--	--
RC-3A-PT5	Foxboro	E11GM-HSAE1	RC pressure, low	0 to 500 psig	287	Yes	--	--	--	--	--	--	--	--	--
RC-3B-PT1	Rosemont	1152GP9A	RC pressure, narrow	1700 to 2500 psig	287	--	1E	1	--	--	--	--	--	--	--
RC-3B-PT2	Rosemont	1152GP9A	RC pressure, narrow	1700 to 2500 psig	286	--	1E	--	--	--	--	--	--	--	--
RC-3B-PT3	Foxboro	E11GH-HINM2	RC pressure, wide	0 to 2500 psig	287	Yes	1E	--	Yes	--	--	--	--	--	--
SP-1A-LT1	Bailey	BY8241X-A	SGA full range level	0 to 600 in.	287	Yes	--	2	Yes	06/82	Low IR	--	--	--	--
SP-1A-LT2	Bailey	BY8841X-A	SGA operate range level	0 to 291.51 in.	286	Yes	--	1	Yes	06/82	Low IR	--	--	--	--
SP-1A-LT3	Bailey	BY8841X-A	SGA operate range level	0 to 291.51 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-1A-LT4	Bailey	BY8841X-A	SGA startup level	0 to 250 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-1A-LT5[f]	Bailey	BY8841X-A	SGA startup level	0 to 250 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-1B-LT1[f]	Bailey	BY8241X-A	SGB full range level	0 to 600 in.	286	--	--	2	Yes	06/82	Low IR	--	--	--	--
SP-1B-LT2[d]	Bailey	BY8841X-A	SGA operate range level	0 to 291.51 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--

TABLE 1. (continued)

Tag Number[a]	Manufacturer	Model	Parameter	Range[b]	Elevation (ft)	LOCA Sealing	Safety Class	Priority	Required for Safe Shutdown	In situ Testing	Test Results	Removal	Post-removal Test	Test Results	Failure Mode
SP-1B-LT3	Bailey	BY8B41X-A	SGB operate range level	0 to 291.51 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-1B-LT4	Bailey	BY8B41X-A	SGB startup level	0 to 250 in.	286	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-1B-LT5	Bailey	BY8B41X-A	SGB startup level	0 to 250 in.	296	Yes	--	--	Yes	06/82	Low IR	--	--	--	--
SP-6A-PT1	Foxboro	E11GM-HSAE1	SGA steam pressure	0 to 1200 psig	287	Yes	--	1	--	--	--	--	--	--	--
SP-6A-PT2	Foxboro	E11GM-HSAE1	SGA steam pressure	0 to 1200 psig	288	Yes	--	1	--	--	--	--	--	--	--
SP-6B-PT1	Foxboro	E11GM-HSAE1	SGB steam pressure	0 to 1200 psig	284	Yes	--	--	--	--	--	--	--	--	--
SP-6B-PT2	Foxboro	E11GM-HSAE1	SGB steam pressure	0 to 1200 psig	286	Yes	--	--	--	--	--	--	--	--	--
WDL-PT-1202	Foxboro	E11GM-HSAD2	Drain tank bellows	0 to 750 psig	286	--	--	1	--	--	--	--	--	--	--
WDL-PT-1211	Foxboro	E11GM-HSAA2	Drain purge discharge bellows	0 to 50 psig	286	--	--	--	--	--	--	--	--	--	--
WDL-PT-3145	Foxboro	E11GM-HSAC2	Drain purge discharge bellows	0 to 160 psig	286	Yes	--	--	--	--	--	--	--	--	--
WDL-PT-7105	Foxboro	E11GM-HFDSAC2	RC leak XFR pump	0 to 150 psig	285	--	--	--	--	--	--	--	--	--	-
WDL-PT-7106	Foxboro	E11GM-HFDSAC2	RC leak XFR pump	0 to 150 psig	285	--	--	--	--	--	--	--	--	--	--
WDL-LT-1207	Foxboro	E13DM-HSAM2	RC drain tank level	0 to 8 ft	284	--	--	--	--	--	--	--	--	--	--
WDL-LT-1316	Drexel Brooks	508-15-6	RB sump level	0 to 54 in.	282	--	--	2	--	--	--	--	--	--	--
IC-10-DPT	Bailey	BY8230X-A	CRD cool water flow	0 to 200 gpm	351	--	--	1	--	--	--	--	--	--	--
RC-14A-DPT1	Bailey	BY3X41X-A	RC flow	0 to 80 x 10^6 lb/h	286	Yes	1E	1	--	--	--	--	--	--	--
RC-14A-DPT2	Bailey	BY3X41X-A	RC flow	0 to 80 x 10^6 lb/h	286	Yes	1E	1	--	--	--	--	--	--	--

a. Explanation of letter code for tag numbers.

Initial Letters	System
CF	Core flooding
IC	Intermediate closed cooling water
RB	Reactor building
RC	Reactor coolant
SP	Secondary plant
WDL	Waste disposal--liquid

Final Letters	Function
DPT	Differential pressure transmitter
LT	Level transmitter
PT	Pressure transmitter

b. All level ranges refer to water.

c. Did not respond to known level change, 12/12/80, OOS Log.

d. Failed; RC-1-LT1 on 04/03/79; RC-1-LT2 and RC-1-LT3 on 04/27/79; RC-3A-PT3 on 05/22/79; SP-1B-LT2 on 06/19/79; OOS Log.

e. IR = insulation resistence.

f. Failed high; SP-1A-LT5 on 04/26/79; SP-1B-LT1 on 04/09/79; OOS Log.

- 1E, or potentially 1E, equipment
- Reactor control equipment
- Equipment needed to understand the accident
- Equipment thought to be especially sensitive to environment, and therefore useful for establishing margins
- Equipment having properties especially useful in assessing damage, or representative of important generic features.

Table 1 also includes manufacturer, model, range, LOCA sealing, safety classification, and status for each of the sensors listed.

As noted in the table, some in situ testing has been performed, and two transmitters have been removed. Three additional transmitters have been scheduled for removal.

As of September 1982, only two pressure transmitters have been removed from the Reactor Building. These transmitters were selected for their accessibility for removal during the early Reactor Building entries. Also, they could be removed without danger to the safe maintenance of the plant, and were representative of many transmitters in the building.

A number of pressure transmitters are still in operation at TMI-2 on a daily basis and are believed to be supplying correct information. Several are known to be inoperative, and still others are questionable. Several were under water when the water level was at about the 290-ft elevation. Electrical resistance tests of those units, subsequent to lowering of the water level, have revealed low insulation resistance of the cables and transmitters (see Table 1).

TRANSMITTER REMOVAL

Two pressure transmitters, a Foxboro E11GM type gauge pressure unit and a Bailey Meter Company BY type differential pressure unit, were removed from the TMI-2 Reactor Building in July 1981. Since the units were radioactively contaminated, they required special handling, storage, and shipping. They were placed in double plastic bags, boxed, then packed in vermiculite in metal barrels and stored on the island until shipped to the Idaho National Engineering Laboratory (INEL) in November 1981. They were again stored until examination and testing began in February 1982.

EXAMINATION

The examination of each unit will be discussed separately. Keep in mind that since the units were radioactively contaminated, special handling procedures were required, i.e., personnel were required to wear protective clothing, and work was performed in controlled areas in accordance with appropriate safe work practices.

The basic examination plan was as follows:

1. In situ testing was performed, and the assembly was removed from the Reactor Building and shipped to the laboratory.

2. The assembly was visually inspected and a record was made of any apparent discrepancies, anomalies or other pertinent observations.

3. If the unit appeared functional and in situ tests revealed no apparent discrepancies, calibration tests were performed similar to preaccident measurements (pressure versus output), duplicating as close as practicable, the preaccident calibration system. No adjustments were made. Pre- and postmeasurements were compared.

4. Where discrepancy or failure existed, the cause of discrepancy was determined through nondestructive means if possible.

5. All activities associated with the examinations were documented, and photographs taken for reference.

6. Calibration of measurement equipment was certified.

7. Data were analyzed and results were reported.

8. The unit was stored for possible future action.

As installed in TMI-2, outputs of the two transmitters were not recorded continuously with a strip chart recorder or data logger. Therefore, no permanent records exist to determine how they performed during or after the accident, or if and when they may have failed. Limited information, however, is available from technician and operator log books.

Foxboro E11GM

Designated CF-1-PT3, this unit was one of two pressure transmitters utilized to monitor pressure in Core Flood Tank B. Following is a summary of pertinent characteristics:

Manufacturer	The Foxboro Company, Foxboro, Massachusetts
Model	E11GM, Style B
Serial number	2517277
Calibration range	0 to 800 psig
Output	10 to 50 mA
Power supply requirements	63 to 95 Vdc
Capsule and body	316SS.

The transmitter was located at the 324-ft elevation, which was well above the high water mark in the Reactor Building.

The unit is a force/balance assembly and includes an electronics module in the same housing as the pressure sensor[2] (see Figure 1). In the Reactor Building, the transmitter was connected to its excitation power supply and readout circuitry (located outside the Reactor Building) through approximtely 600 ft of cabling. The readout circuitry includes a meter and alarm circuit.

No failure or degradation of the instrument was reported during or after the accident.

In situ tests of the unit were performed by Technology for Energy Corporation in September 1980,[3] and again by General Public Utilities (GPU) under the auspices of EG&G Idaho, just prior to its removal in July 1981.

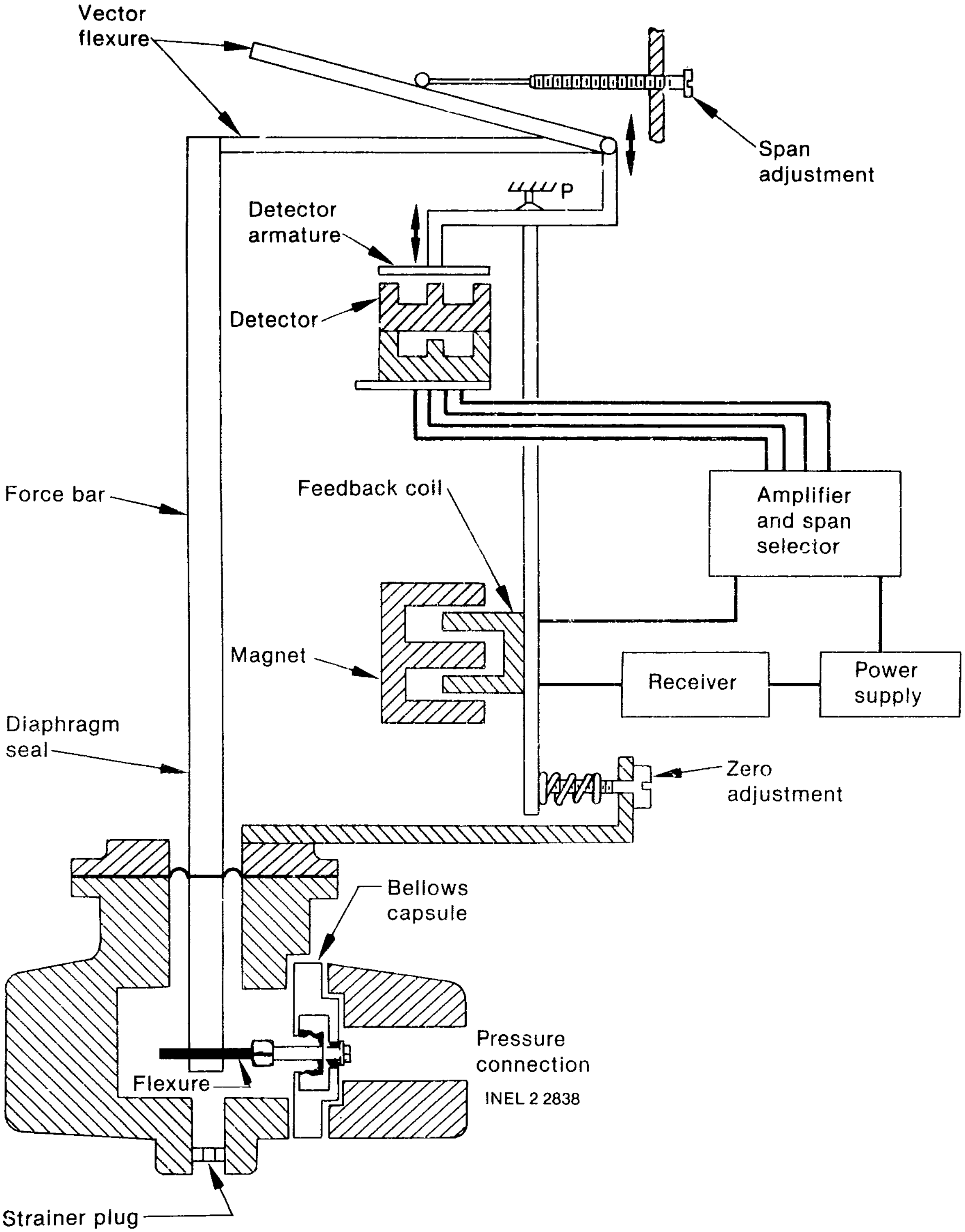

Figure 1. Foxboro E11GM pressure transmitter, functional diagram.

Note that all in situ tests were conducted from outside the Reactor Building. Access to the transmitter was not permitted, and varying the input pressure to the transmitter was not practical.

In situ tests included the following:

- Recording indicated pressures and transmitter output voltage
- Verifying calibration of readout circuitry
- Observing and photographing an oscilloscope output signal
- Performing spectral analysis of output signal
- Measuring resistance and capacitance of input/output cables
- Performing time domain reflectometry measurement of input/output cables
- Recording output signal on magnetic tape recorder for future reference.

Both sets of in situ test data indicate that the unit was probably operational. However, since pressure could not be applied, the tests could not prove that the transmitter was still in accurate calibration.

Examination of the Foxboro Unit at INEL

The unit was examined and tested in a laboratory fume-hood equipped to accept radioactively contaminated components. After unpacking, the following initial observations were made:

- Smear counts indicated about 40,000 disintegrations per minute (dpm) beta and gamma radiation ($\sim$95% beta) and the unit exhibited hot spot radiation of up to about 480 mR/h as measured by an Eberline RO-2A instrument

- The nuts and bolts holding together the flanged pressure port assembly had a heavy coating of rust; all other surfaces, painted and stainless steel, appeared fairly clean (see Figure 2).

An attempt was made to decontaminate the assembly by plugging the electrical conduit fitting and pressure port and scrubbing the assembly with a brush, using a detergent solution. Radiation measurements were reduced to 8000 dpm and 320 mR/hr. The assembly was then opened and examined:

- The interior of the sensor/electronic module assembly was clean and free of radioactive and other contaminants.

- The interior of the circular junction box was radioactively contaminated and appeared to have had water in it, as evidenced by corrosion depositions (see Figure 3). Since the junction box gasket appeared to be in good condition, it is likely that water entered the junction box through the conduit or its associated fittings. A cable seal located between the transmitter and the circular junction box probably prevented moisture from entering the transmitter itself.

The transmitter was then connected to a pressure source, power supply, load, and voltmeter as shown in Figure 4, and without making any adjustments to the transmitter, three calibration cycles of pressure versus output were run. The results of the first pressure cycle and the last known calibration test performed at TMI are given and compared in Appendix A. As can be seen, the results compare favorably, and there appears to be no significant degradation of the instrument.

Bailey Type BY

The unit, designated CF-2-LT3, was one of two differential pressure transmitters used to measure the level of Core Flood Tank B.

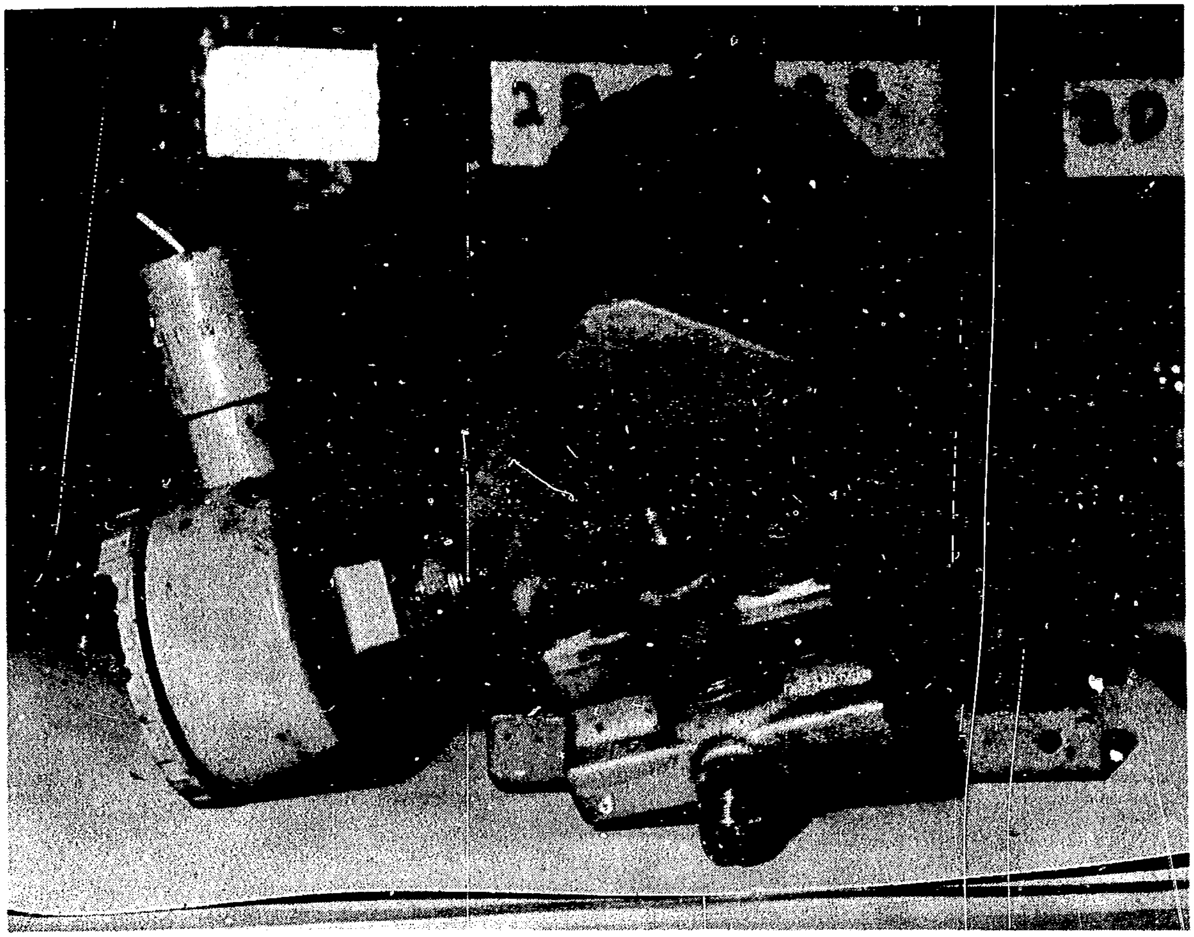

Figure 2. Photograph, Foxboro pressure transmitter.

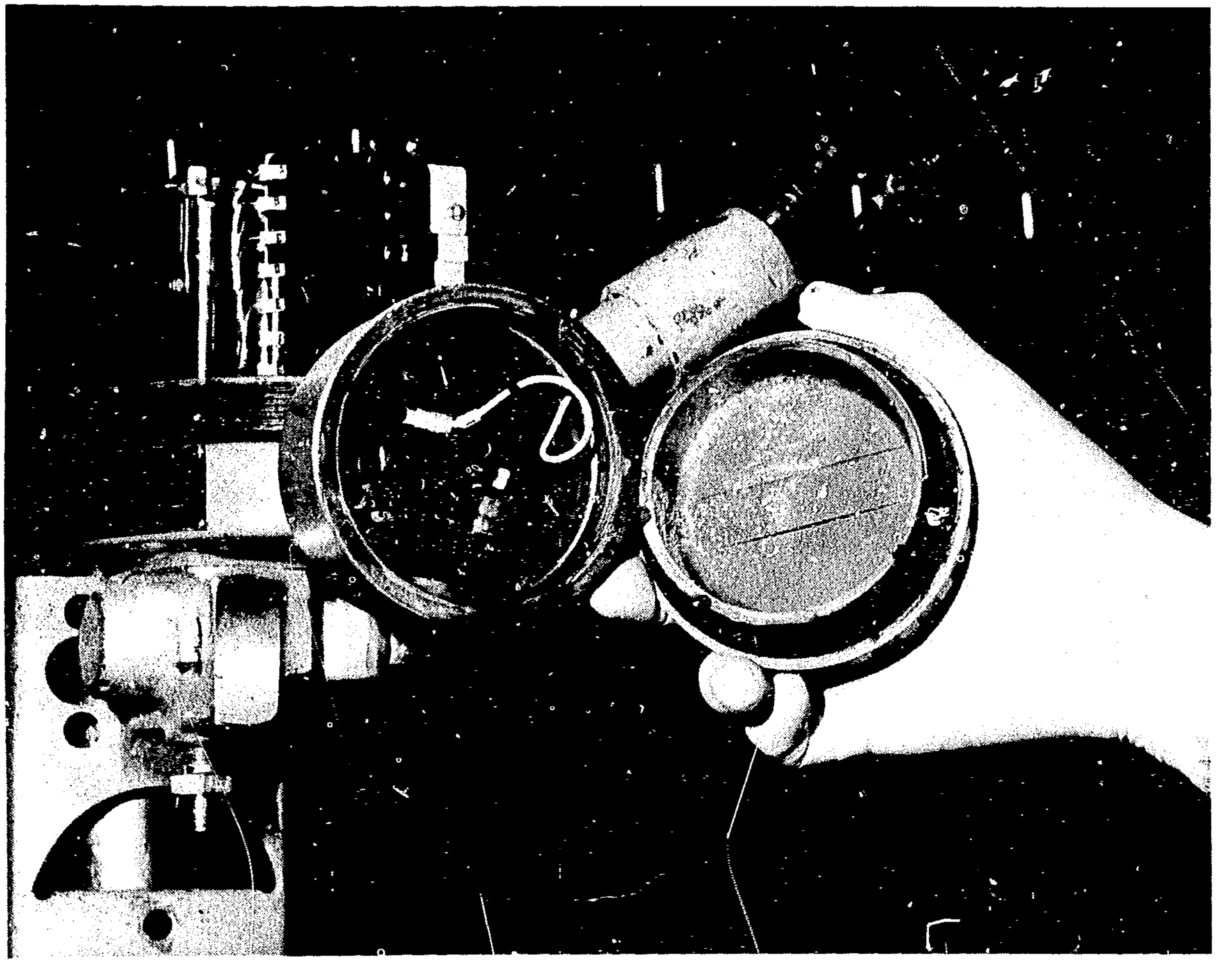

Figure 3. Photograph, Foxboro pressure transmitter.

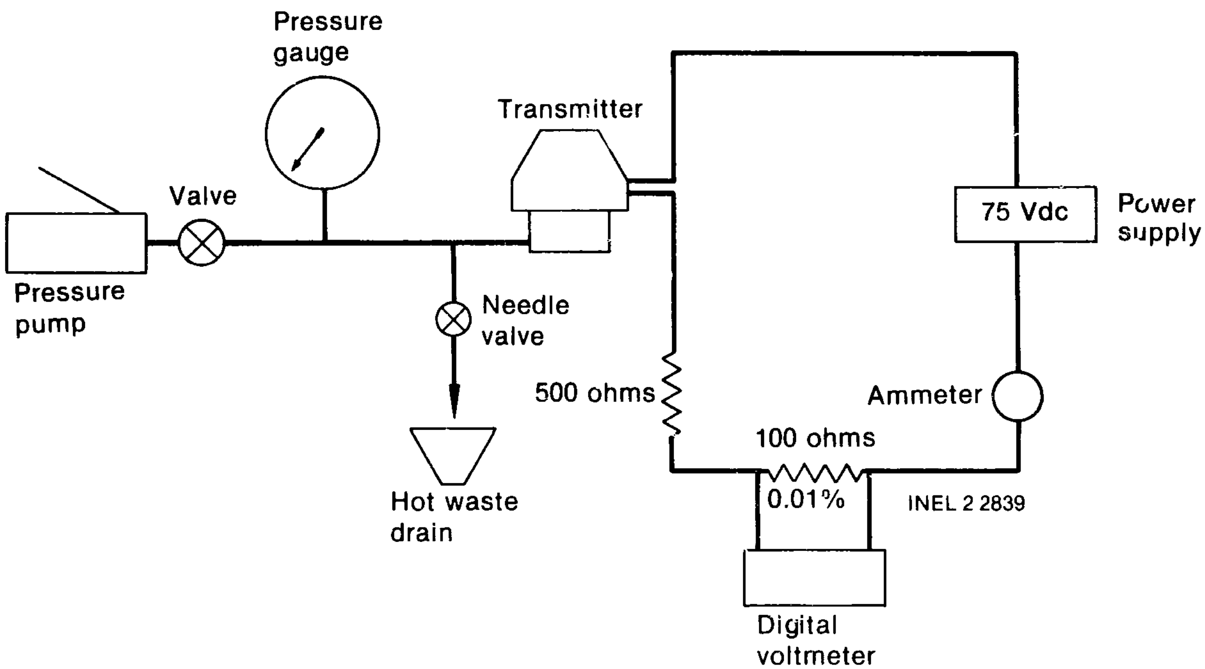

Figure 4. TMI Foxboro pressure transmitter test set up.

Following is a summary of its pertinent characteristics:

Manufacturer	Bailey Meter Company, Wickliffe, Ohio
Model	BY8231-X-A
Serial Number	721885
Calibrated Range	0 to 14 ft H_2O
Output	-10 to +10 Vdc
Power Requirements	118 V, 60 Hz.

The transmitter was also located at the 324-ft elevation.

The transmitter uses a linear variable differential transformer (LVDT) in its operation.[4] The core of the LVDT is connected to a pressure sensing bellows capsule. The electronics assembly, which includes the oscillator that provides excitation for the LVDT, is located in the transmitter assembly. Figure 5 is a block diagram of the instrument.

The out-of-service log notes that this unit and the other transmitter measuring the level of Core Flood Tank B, (CF-2-LT4) were taken out of service April 23, 1980. The log indicates that the two transmitters did not agree and that it could not be determined which, if either, was correct.

Although Technology for Energy Corporation (TEC) performed no in situ tests on this unit, they did perform in situ tests on similar units, CF-2-LT2 (level, A tank) and CF-2-LT4 (level, B tank) in September 1980.[5,6] The tests were similar to those conducted by TEC on the Foxboro unit discussed above. The conclusion based on these tests is that CF-2-LT4 was probably operating (its accuracy could not be determined) but that CF-2-LT2 was probably not operating. This conclusion is based on the fact that ripple frequencies of the LVDT excitation oscillator were observed in the output signal of CF-2-LT4 but not in the output of CF-2-LT2. A low-level ripple in the output of a system such as this would be normal to see.

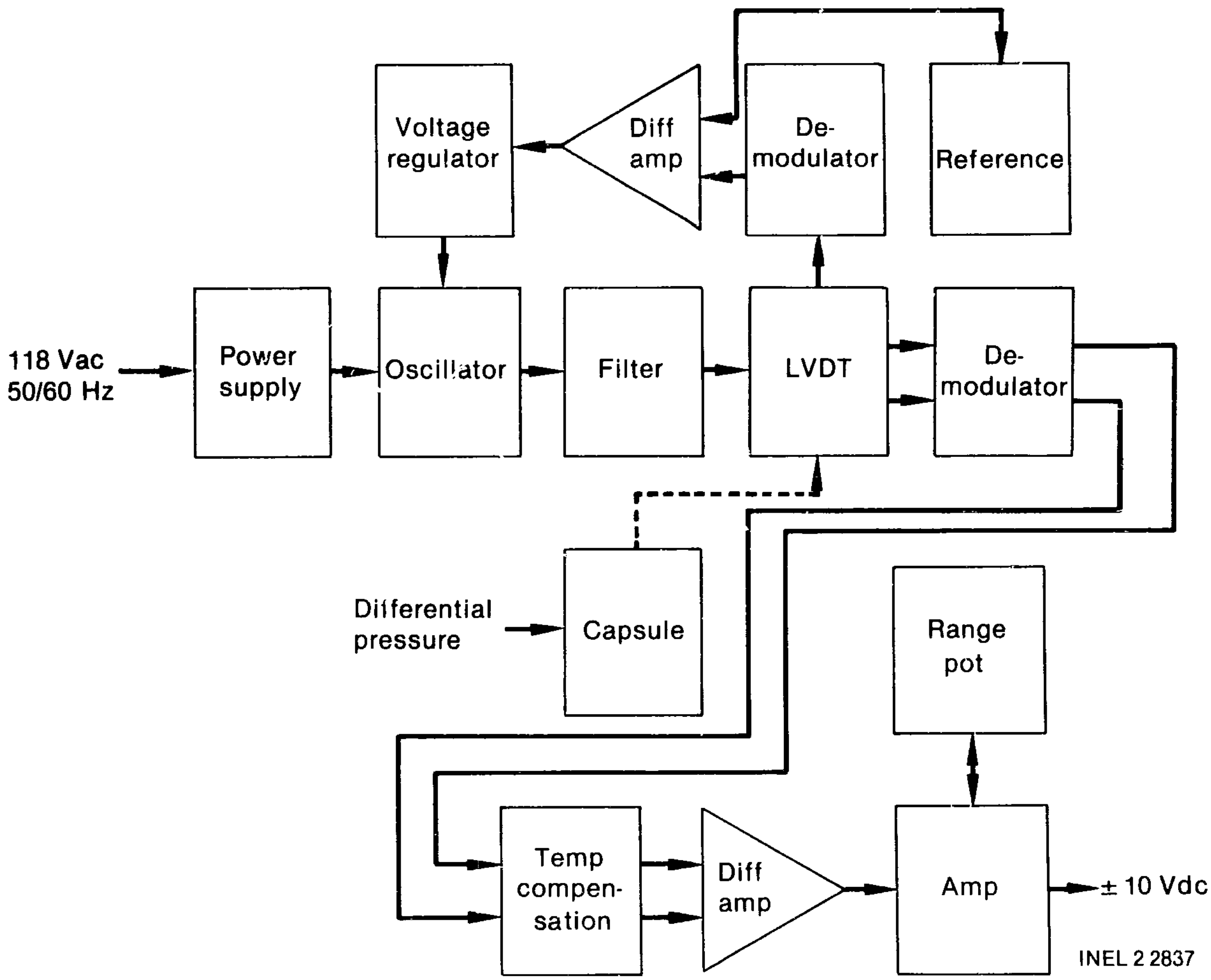

Figure 5. Block diagram of Bailey BY pressure transmitter.

In situ tests of CF-2-LT3 were performed by GPU just prior to its removal in July 1981, as with the Foxboro unit previously discussed. However, the resultant test data were incomplete, so it is not possible to determine whether the oscillator signal was present. The output voltage at that time was essentially zero (0.077 V dc), indicating a tank level of 7 ft. Unfortunately, the actual tank level at time of measurement is not known. From the limited evidence, one may deduce that the transmitter probably was not functioning at time of removal.

Examination of the Bailey at INEL

As was the Foxboro, the Bailey unit was also examined in a laboratory fume-hood. The following initial observations were made:

- Smear counts indicated about 43,000 dpm, and the unit exhibited radiation levels of about 210 mR/hr (beta and gamma). As with the Foxboro transmitter, radiation was approximately 95% beta.

- Nuts and bolts holding the fittings and assembly together had heavy coatings of rust. The main body of the assembly had a light coating of rust. Painted surfaces were fairly clean. See Figure 6.

- The side high-pressure port contained foreign material.

After initial observation, the electrical conduit fitting and pressure ports were plugged and an attempt was made to decontaminate the assembly with a brush, using a detergent solution. The resultant smear count was reduced only to about 23,000 dpm. Further scrubbing did not appear to reduce contamination appreciably.

The transmitter cover was then removed, and the following observations were made:

- There was residual moisture inside the transmitter; approximately 30 mL of water was poured out of the assembly. (The water was not a result of the attempted decontamination.)

Figure 6. Photograph, Bailey pressure transmitter, external view.

- The interior of the housing and certain components were heavily corroded, and there was an accumulation of grit-like material at the bottom (see Figure 7).
- The interior was radioactively contaminated. A smear count indicated about 300,000 dpm.

The electronic module was then removed and examined:

- Some electronic components were badly corroded; some leads were completely corroded away. (See capacitors in Figure 8.)
- A transformer, T-2 (oscillator circuit), appeared to have been badly burned (see Figure 9).
- Regulator Power Transistor Q-2 was rusted so badly it crumbled when contacted (see Figure 10).

Obviously, the unit was not capable of operating, so power was not applied to the unit.

A check of the input power fuse revealed that it was still good, though a resistance check of the input power circuit showed the circuit to be open.

In an attempt to resolve how the water entered the unit, pressure was applied to both pressure ports simultaneously to determine whether there was a leak into the housing through the capsule assembly. The results indicated that water did not enter the housing through the pressure ports. However, there was heavy leakage between the pressure port flanges and the main body. The flanges were removed and the O-rings were examined. The O-rings appeared to be made of Teflon, but it was not apparent why they leaked. No further evaluation of this leak was made.

The transmitter case gasket and the conduit junction box cover gasket were examined and found to be in good condition. It is believed that water entered the transmitter assembly through the flexible conduit or its fittings.

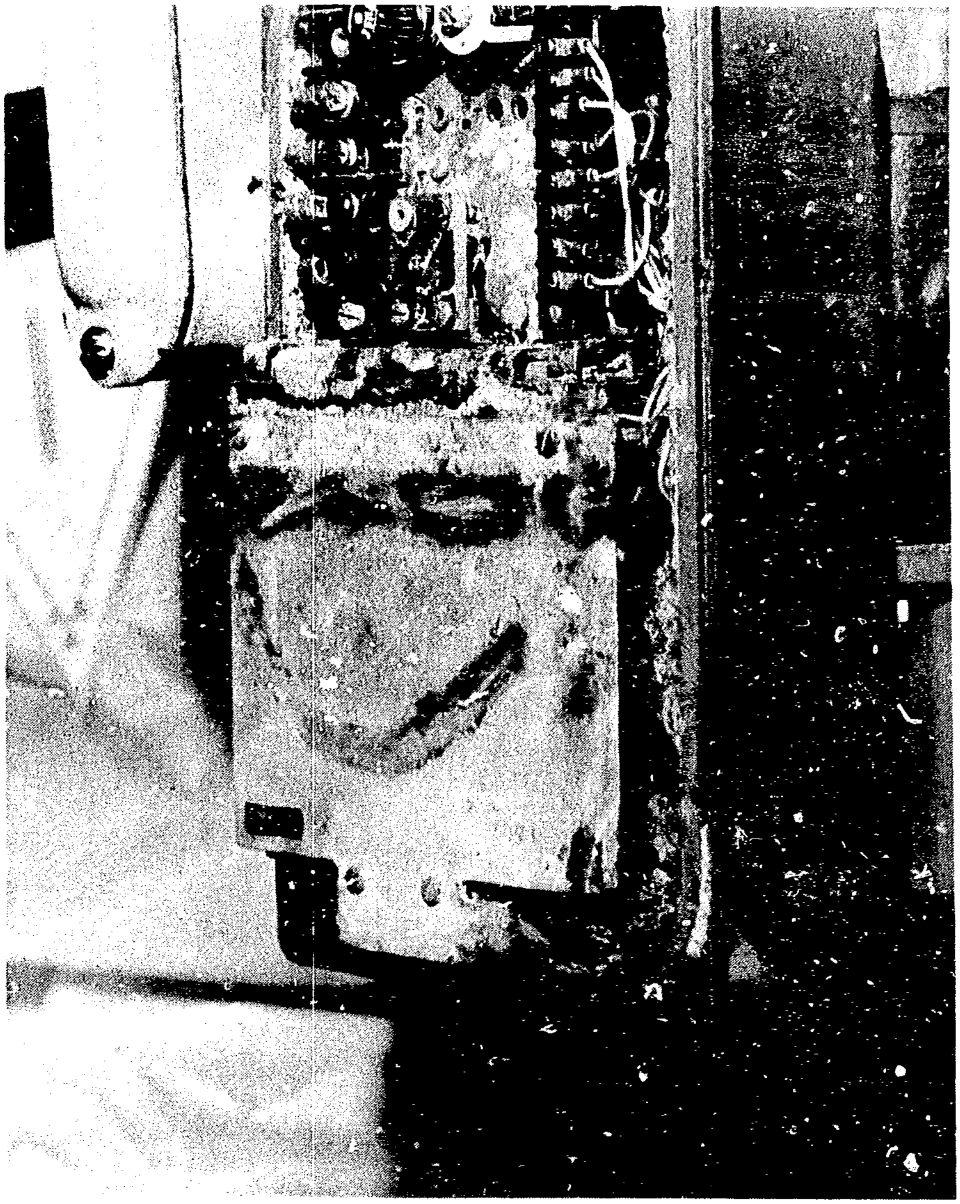

Figure 7. Photograph, Bailey pressure transmitter, internal view.

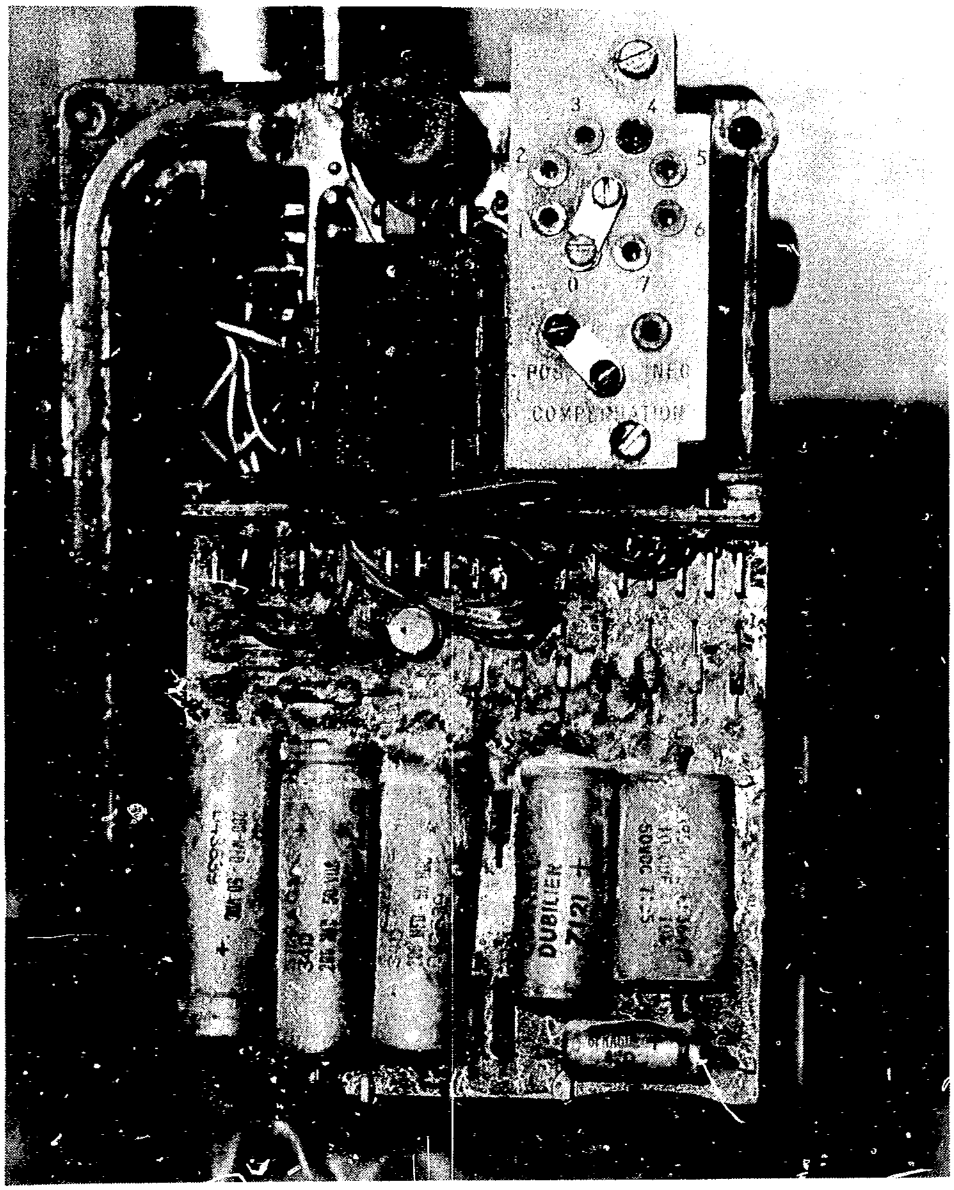

Figure 8. Photograph, Bailey pressure transmitter, circuit board, front view.

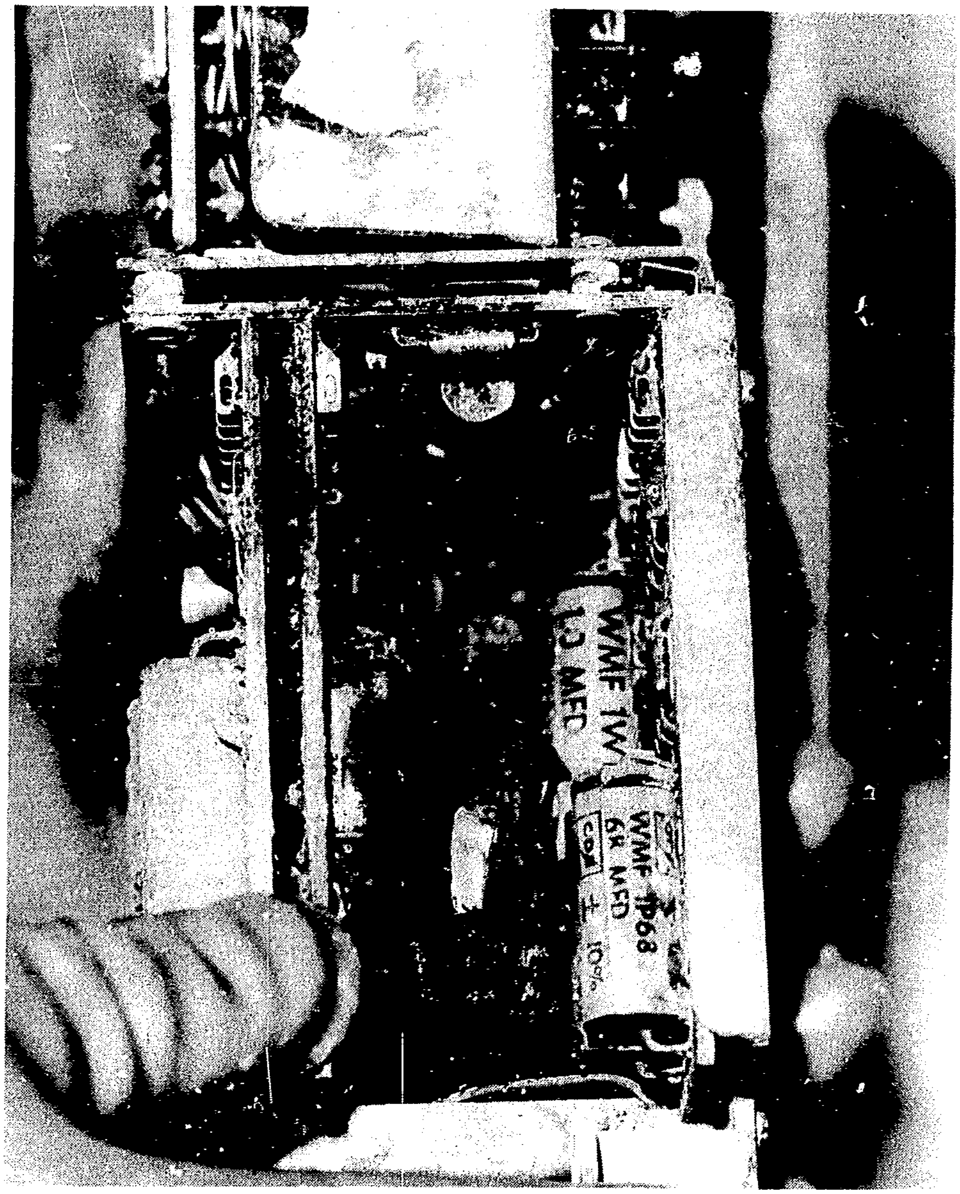

Figure 9. Photograph, Bailey pressure transmitter, circuit board, side view.

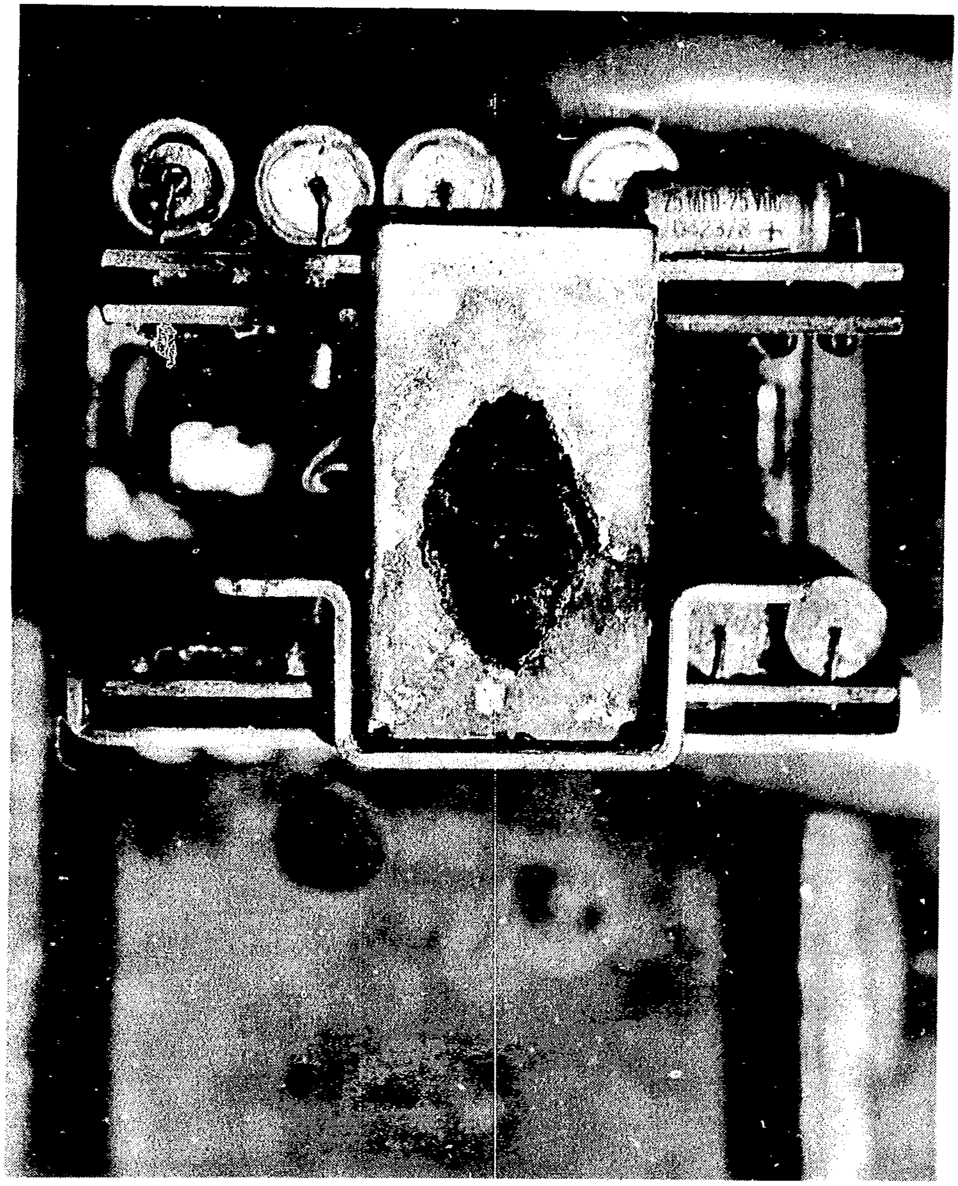

Figure 10. Photograph, Bailey pressure transmitter, circuit board, bottom view.

Spectrochemical analyses were made of the materials found in the housing and the high-pressure port. The material found in the housing was separated by colors; the results of the analysis are shown in Table 2. It is believed that this material is the result of corrosion.

TABLE 2. SPECTROCHEMICAL ANALYSIS OF LOOSE FOREIGN MATERIAL IN TMI BAILEY PRESSURE TRANSMITTER CF-2-LT3

M = MAJOR = > 5%
m = MINOR = < 5% > 0.1%
T = TRACE = (< 0.1 percent)

Foreign Material	Amount of Foreign Material in Electronics Cavity, by Color			High-Pressure Port
	Light	Brown	Dark	
Ag	T	--	T	--
Al	m	M	m	m
B	m	m	m	m-T
Be	--	--	--	--
Ca	m-T	--	--	m-T
Cd	m-T	m	T	--
Co	--	--	--	--
Cr	--	--	m-T	T-m
Cu	m	T	m	T
Fe	m	m	m-T	M
Mg	m	m	m	m
Mn	T-m	T-m	T	T
Mo	--	--	--	T-m
Na	M	m	m-T	T
Ni	T	--	T	T
Pb	m-M	T-m	T	--
Si	M	M	M	M
Sn	m	--	m-T	--
Ti	T	m-T	T	m
V	--	--	--	--
Zn	m-T	m	m-T	--
Ga	T	T	--	T
Bi	--	--	T	--
K	--	--	--	m
Sn	--	--	--	T
Zr	--	--	--	--

CONCLUSIONS

Since only two units have been removed and examined to date, one must be cautioned in drawing firm conclusions. It is expected that during this next year, after removing and examining several more units, appreciably more information will be available. However, there are several tentative conclusions that can be made.

Radiation

The Foxboro unit apparently survived the radiation field resulting from the accident. The effect of radiation on the Foxboro's accuracy during the high-radiation period could not be determined. The effect of radiation on the Bailey unit could not be determined because of subsequent moisture damage.

Transmitter Seals

It appears that the cause of failure of the Bailey unit was due to water entering the unit and shorting the electronics. The question remains, how and where did the water enter the assembly: It is known that during and following the accident, there was steam and high humidity in the building from the reactor system with a resulting rain-like atmosphere, so all components in the building were subjected to water. Since the transmitter case cover gasket and the conduit junction box gasket were inspected and found to be in good condition, and since the water was highly contaminated, it is believed that reactor water entered the transmitter through the electrical conduit or its fittings. When the water entered the conduit is not clear. Figure 11 shows what is believed to be a typical transmitter installation. Potential sources of leakage are the flexible conduit itself, the flexible conduit fittings, and the termination point of the flexible conduit (not shown) or the junction box into which the conduit terminates. As can be seen in Figure 11, there is no drip loop in the conduit. If the fitting at the conduit junction was not sealed, any water running down the outside of the conduit could enter at this point. Unfortunately, the conduit junction was disassembled during removal of the assembly, so that whether this was

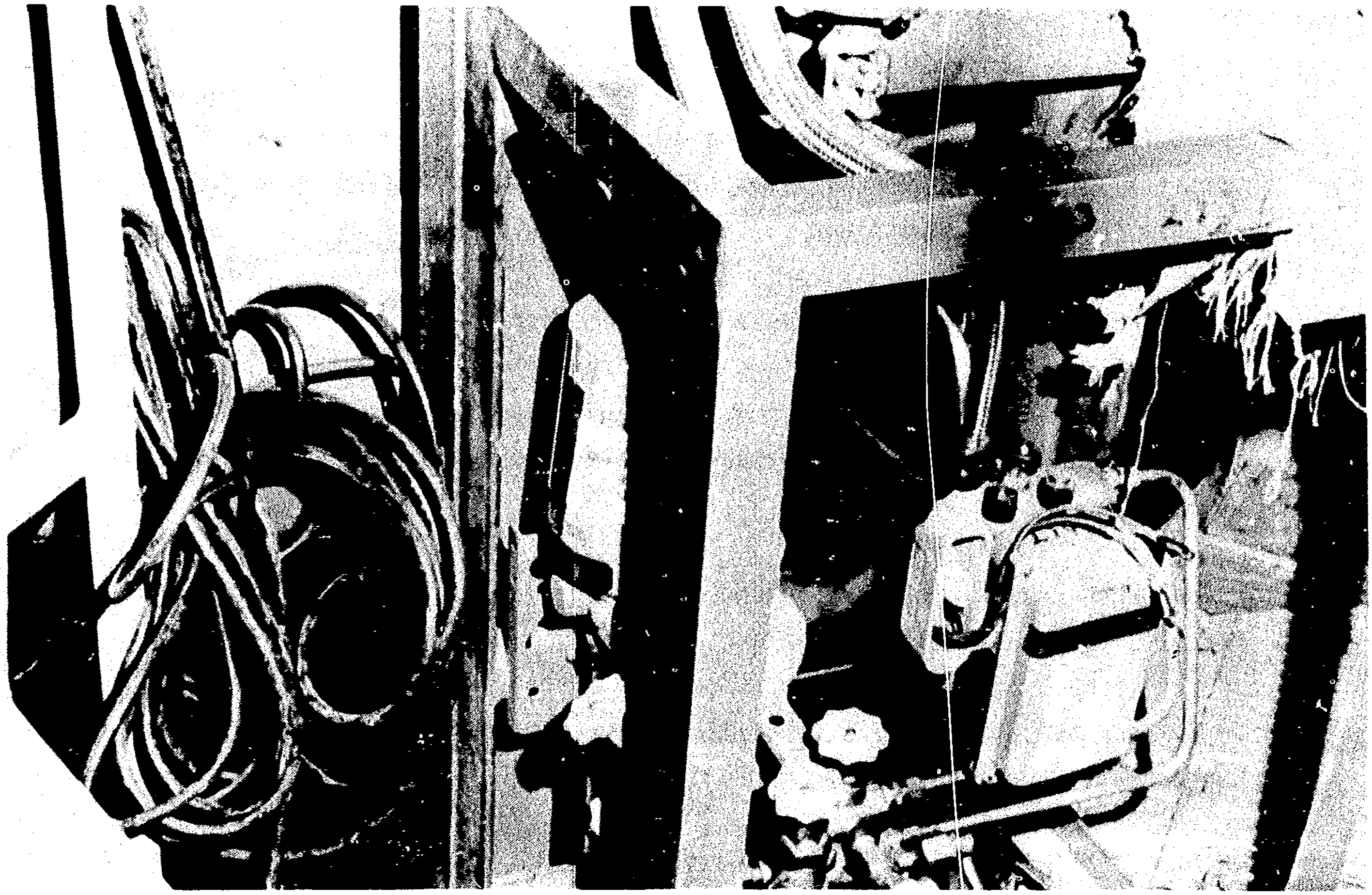

Figure 11. Photograph, typical pressure transmitter installations.

the point of leakage could not be determined. In future removals this evidence will be preserved, and more information on potential sources of leakage obtained. The Foxboro assembly appeared to have leaked in a similar manner, judging from the residue in its junction box. However, the cable seal apparently saved it from the same fate as the Bailey.

Internal contamination was observed during examination of the pressure transmitters. The contamination appeared to be via the conduit and electrical leads. This observation may indicate a significant decontamination problem in other conduits and cables in the Reactor Building.

In reviewing records, it appears that neither unit was required to be LOCA qualified, i.e., designed and fabricated to withstand a loss of coolant accident. However, it appears that the seal in the Foxboro unit was adequate to allow the unit to withstand the elevated pressure/temperature steam encountered in the accident.

Whether these units were intended, by code, regulation, or design/installation, to survive an accident such as occurred at TMI is not clear at this time. This will be the subject of further evaluation. In any case, it appears that sealing and installation systems, such as were used with the Bailey, could be improved upon.

Effects of Delays in Examination

Although the Foxboro unit did not appear to suffer from the delay in examination and testing, the Bailey unit appeared much worse than if it had been examined soon after the accident. After sitting for almost three years with water in it, the internals were so badly corroded as to have masked or destroyed evidence of its specific failure. And though specific failure may be academic in this case (it may be sufficient to say it failed because it got wet), it is indicative of problems that other investigators will face as more and more equipment is removed for evaluation. It may become increasingly difficult to obtain useful information on units not sealed against moisture.

Radiation Contamination

It was hoped at one time, to be able to readily decontaminate devices to the point that they could be easily handled and closely examined. But, though decontamination efforts were not extensive, it is clear that complete decontamination is not practical, especially for units that are also internally contaminated.

FUTURE PLANS

Future plans will involve a continued effort to meet the initially established objectives of the task. Two additional Bailey units, CF-2-LT1 and CF-2-LT2, and a Foxboro unit, CF-1-PT1, have been scheduled for removal. Data recorded in the out-of-service log indicate that both CF-2-LT1 and CF-2-LT2 did not respond to a known level change. Removal and evaluation of these units will provide the opportunity for determining if a common failure mode exists for these types of transmitters. A similar unit, CF-2-LT4, has been in situ tested and appears to be operational. Comparative evaluation of this unit and its installation with the failed units may assist in understanding the failure modes. Photographs of each transmitter will be prepared prior to removal. In addition to showing a transmitter's general condition, these photographs will provide a closeup view of the conduit, its connection to the transmitter, and its route from the unit.

An effort will be made to evaluate several of the environmentally qualified transmitters, comparing their performance with nonqualified units. Comparisons will also be made between the Class 1E and non-1E instruments. As these units become accessible, they will be removed from TMI-2 and laboratory tests will be conducted at INEL.

In situ testing will be performed to determine the operational status of the transmitters listed in Table 1. These tests will first check the condition of the cabling associated with the transmitters and then check the operational status of each transmitter. Additional in situ testing will be performed on the transmitters prior to their scheduled removal.

The laboratory tests to be performed on the removed transmitters will verify the operational condition of the functioning transmitter, including visual examination of the general condition of each transmitter. The transmitters that are determined nonfunctional will be examined and evaluated in an effort to pinpoint failure modes.

The various transmitters include semiconductors and other materials whose radiation response makes it possible to determine the total accumulated dose of radiation to which a unit was exposed. A knowledge of the total radiation seen by the various transmitters would aid in understanding possible failure modes and provide data on survival levels seen by the operational units.

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3. J. E. Jones, J. T. Smith, M. V. Mathis, Field Measurements and Interpretation of TMI-2 Instrumentation: CF-1-PT3, GEND-INF-017, Vol. I, January 1982.

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APPENDIX A

REDUCTION OF CALIBRATION DATA FROM TMI-2 PRESSURE TRANSMITTER CF-1-PT3

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REDUCTION OF CALIBRATION DATA FROM TMI-2 PRESSURE TRANSMITTER CF-1-PT3

Comparison of Calibraion Data on TMI-2 Pressure Transmitter CF-1-PT3

Pressure Transmitter CF-1-PT3 was installed to monitor the pressure of Core Flood Tank B at TMI-2. This Foxboro transmitter is a Model E11GM-HSAD1 (Serial No. 2517277). It was last calibrated October 10, 1977; the calibration data are tabulated in Table A-1. The transmitter was removed from TMI-2 on July 23, 1981, 16 months after the accident. It was then shipped to INEL for detailed evaluation. An as-received calibration was performed on the transmitter March 3, 1982 (see Table A-2). A least-squares linear regression was performed on the two sets of data. A correlation coefficient (r) of the individual data points in relation to the line fitted to these points was also calculated. A correlation coefficient of ±1 represents perfect correlation between the data points and the best fit line.

The two equations representing the best fit straight line of the 1977 and 1982 data and their corresponding correlation coefficient is shown below, where "I" represents the output current in mA of the transmitter, and "P" represents the applied pressure in psi. The linearity of each set of data referred to a least-squares fit line was also calculated.

Data (1977)

I = 0.0501232P + 10.009 mA

r = 0.9999980

Linearity = ±0.10% of span

TABLE A-1. TMI-2 CALIBRATION DATA FOR PRESSURE TRANSMITTER CF-1-PT3 (October 10, 1977, at TMI-2)

Input Pressure (psig)	Output Current[a] (mA)
0	10.05
160	18.00
320	26.04
480	34.04
640	42.08
800	50.14

a. Estimated standard deviation is 0.03mA.

TABLE A-2. EG&G IDAHO CALIBRATION DATA FOR PRESSURE TRANSMITTER CF-1-PT3 (March 3, 1982, at INEL)

Input Pressure (psig)	Output Current[a] (mA)
0	10.00
160	17.93
320	25.88
480	33.89
640	41.90
800	49.94

a. Estimated standard deviation is 0.04 mA.

Data (1982)

$I = 0.0499321P + 9.950$ mA

$r = 0.9999965$

Linearity = ±0.12% of span

The percentage change in zero shift and span occurring during the 53-month interval was calculated. The zero shifted 0.15% of span, whereas a 0.38% decrease occurred in the transmitter's sensitivity to pressure (output span). According to Jack Sears of Foxboro,[a] a typical change in transmitter output over a 6- to 12-month period is 0.5% of span. The transmitter appears to be in excellent operating condition, considering the environment to which it was subjected following the accident.

a. M. E. Yancey telecon with Jack Sears, Foxboro Company, Foxboro Massachusetts, September 23, 1982.