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IRRADIATION TEST REPORT--FOXBORO E11GM, BAILEY BY3X31A, AND FLAME RETARDANT ETHYLENE PROPYLENE INSTRUMENTATION CABLE

MASTER

Merlin E. Yancey

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

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ABSTRACT

This report summarizes the results of a test program designed to resolve whether or not pressure transmitters located on the core flood tanks at Three Mile Island Unit 2 (TMI-2) during the accident of March 28, 1979 performed within their calibration limits during the periods of high radiation. Two Foxboro transmitters and one Bailey transmitter, each with associated cabling, were subjected to irradiation at a test facility at the Idaho National Engineering Laboratory. The irradiation test was designed to simulate, as close as possible, the accident conditions experienced on the actual transmitters at TMI. The Bailey Meter Co. transmitter exhibited a definite sensitivity to total integrated dose (TID) of radiation with a 4% zero shift at 5.5×10^4 R TID and increasing to 16% at 5.4×10^6 R TID. The Foxboro units had negligible shift. The associated cabling exhibited a change in insulation resistance of -10% at 1.35×10^7 R TID.

ACKNOWLEDGMENTS

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INTRODUCTION

Seven pressure transmitters from the core flood tanks at Three Mile Island Unit 2 (TMI-2) had previously been removed and examined. These pressure transmitters included four Bailey Meter Company Model BY231XA transmitters designated CF-2-LT1, CF-2-LT2, CF-2-LT3, and CF-2-LT4 used to measure water level and three Foxboro Company Model E11GM-HSAD1 pressure transmitters, designated CF-1-PT-1, CF-1-PT3, and CF-1-PT4. Two of the Bailey units failed during or shortly after the accident as a result of water intrusion into the electronics. Both Foxboro units survived the accident in excellent condition with sensitivity shifts of 0.2 and -0.24% and zero shifts of 0.06% and 1.34%. The surviving Bailey unit had a sensitivity shift of 1.0% and a zero shift of 2.9%. These transmitters are discussed in References 1, 2, and 3. Considering the severe damage to the TMI-2 core with corresponding large releases of fission products and peak radiation levels estimated at from 1×10^4 to 2×10^5 R/h (Reference 4), a question was raised as to the accuracy of these transmitters during peak radiation levels.

This test program was therefore designed to detect changes in operational characteristics under conditions similar to the accident environment at TMI-2. The actual transmitters tested were new units and had different pressure sensitivity ranges than the units removed from TMI-2, but were electrically the same. The test was also designed to include the associated cablings to maintain circuit conditions to as close to actual conditions as possible.

TRANSMITTER AND CABLE DESCRIPTION

The transmitters evaluated as part of this test program included two Foxboro pressure transmitters and a Bailey liquid level transmitter. The input ranges of these transmitters were not the same as those of the core flood instruments; however, the amplifier assemblies were identical to those used in the core flood transmitters.

The instrumentation cables used with these transmitters was specified as type FR-15AA. Raychem Corporation manufactured the cable installed with the core flood transmitters at TMI-2, and Anaconda Industries supplied the test cable.

The electrical specifications of the three pressure transmitters and cable are shown in Tables 1 through 4.

TABLE 1. SPECIFICATIONS OF FOXBORO #1 TRANSMITTER, MODEL E11GM-HSAD1

Input range limits	100 to 1000 psi
Test range	500 psi
Supply voltage limits	30 to 95 Vdc
Test voltage	70 Vdc
Output load	500 ohms
Output current	10 to 50 mA dc
Maximum working pressure	1500 psi
Amplifier	N0143SY

TABLE 2. SPECIFICATIONS OF FOXBORO #2 TRANSMITTER, MODEL E11GM-HSAD1

Input range limits	100 to 1000 psi
Test range	500 psi
Supply voltage limits	30 to 95 Vdc
Test voltage	70 Vdc
Output load	500 ohms
Output current	10 to 50 mA dc
MWP	1500 psi
Amplifier	N0143SY

TABLE 3. SPECIFICATIONS OF BAILEY TRANSMITTER, MODEL BY3X31A

Calibration range	0 to 69.2 in. of water
Test range	69.2 in. of water
Output signal	+10 Vdc to -10 Vdc
Maximum service pressure	6000 psi
Amplifier assembly	6623040 A2 Code 002

TABLE 4. SPECIFICATIONS OF CONTROL SAMPLE CABLE FR-15AA

Conductor/wire size	2/AWG #16 Shielded
Manufacturer	Anaconda
Insulation	Flame-retardant ethylene propylene
Overall jacket	Chlorinated polyethylene
Maximum rated voltage	600 volts

IRRADIATION TEST PLAN

The objective of the irradiation test was to evaluate the performance of the transmitters and their associated cabling at various radiation dose rates and accumulated dose levels. Foxboro transmitter #1 and the Bailey transmitter had 61 and 62.5 ft respectively of FR-15AA cable attached between them and their associated instrumentation. Only a short portion of these cables were inside the canister and exposed to radiation during the testing. Foxboro transmitter #2 had a total of 309 ft of FR-15AA cable connecting it to its instrumentation. Of this length of cable, 253 ft were coiled and placed in the canister and subjected to approximately the same radiation levels as the transmitters. A control section of cable, 382.42 ft long, was also included as part of the test. This cable was installed such that both ends of the cable were accessible during the irradiation testing for measurements, with 253 ft coiled and mounted in the canister. Figure 1 shows the transmitters and cabling as mounted for the test.

With the transmitters and cabling arranged as described, it was possible to obtain data on the performance of the transmitters with and without their associated cables being irradiated. The control cable and the cable attached to the one Foxboro transmitter both had equivalent lengths that were exposed to radiation. Monitoring the control cable during the irradiation test provided baseline data on the cable's characteristics as a function of radiation.

The test data obtained on the three transmitters included calibration and response time. A 1/8-in. pressure line was used to provide an input signal to the two Foxboro transmitters and a separate 1/8-in. pressure line was used to supply an input signal to the Bailey transmitter. A set of three complete calibration cycles was obtained on each of the transmitters prior to and following irradiation. During actual irradiation, only one calibration run was obtained at the various test intervals. The transmitters response to a step input of 0 to 80% of span was also recorded at each test interval.

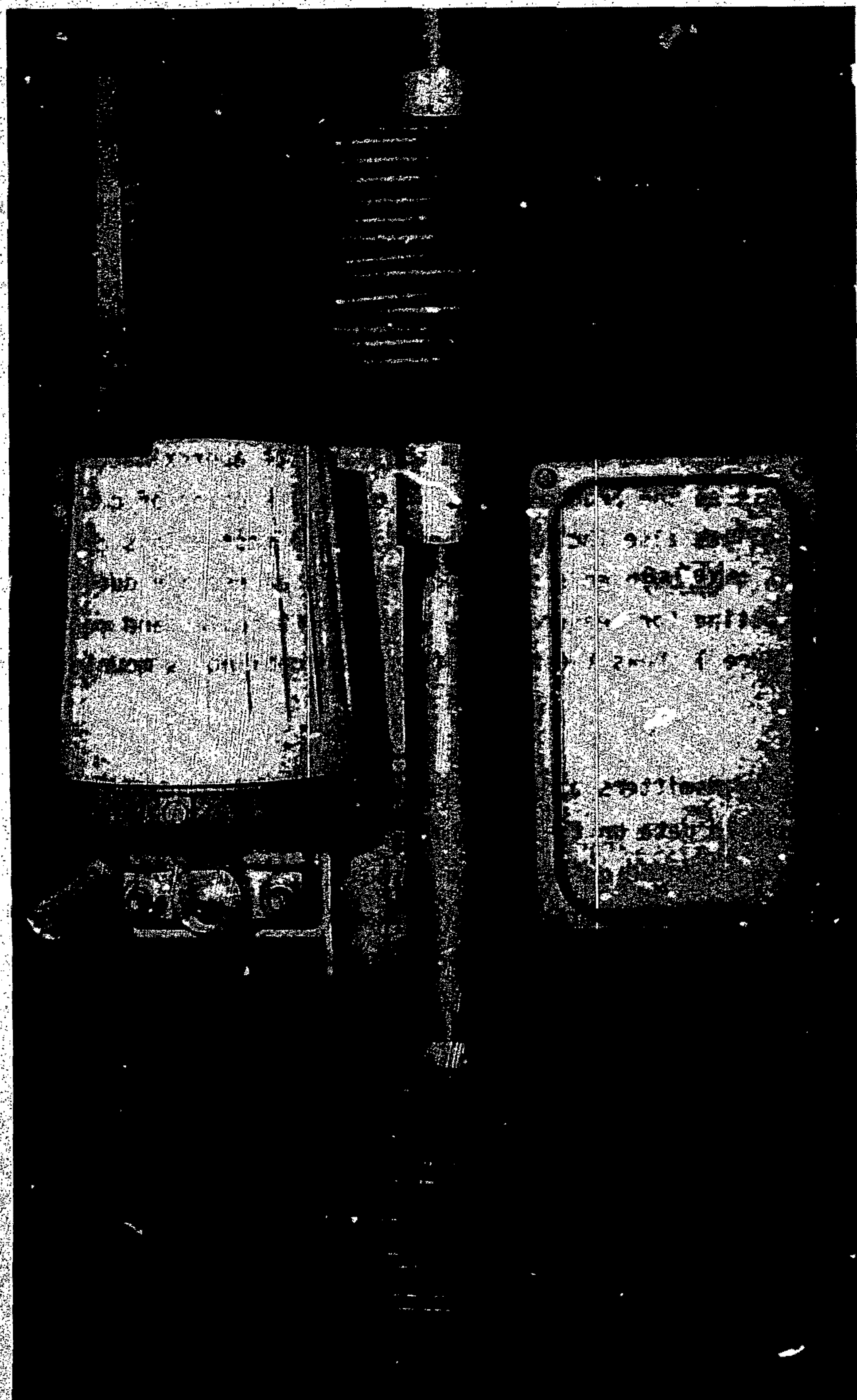

Figure 1. Transmitters and instrumentation cable in test configuration.

The cable measurements included capacitance, inductance, impedance, insulation resistance, and loop resistance. In addition to these measurements, the cable's resonant frequency was recorded and used to monitor changes in the dielectric constant of the cable insulation. Time domain reflectometry (TDR) data was also recorded prior to and during the test.

IRRADIATION TEST FACILITY

The testing program was conducted in the Advanced Test Reactor (ATR) Large Gamma Facility at the Idaho National Engineering Laboratory (INEL). This facility was designed to use fuel removed from the ATR as a source of gamma radiation. The Irradiation Test Facility included the large canister in which the transmitters and cables were mounted. This canister was approximately 48 in. high by 18 in. in diameter and was designed to be lowered into a fuel holding fixture at the bottom of the ATR canal. Figure 2 shows a cross section of the ATR Large Gamma Facility, the canister, and the three transmitters. The fuel holding fixture was designed to hold eight of the ATR fuel assemblies, thus providing a uniform radiation field to the items being irradiated.

Prior to the start of testing, three fuel loading arrangements were selected to provide the desired irradiation dose rates, and a profile of the radiation levels in the canister for each of the three fuel loadings was obtained. The cable and transmitters being tested were located in the area of the canister subjected to the maximum radiation.

The canister was designed to allow monitoring of the radiation dose rate during the irradiation test.

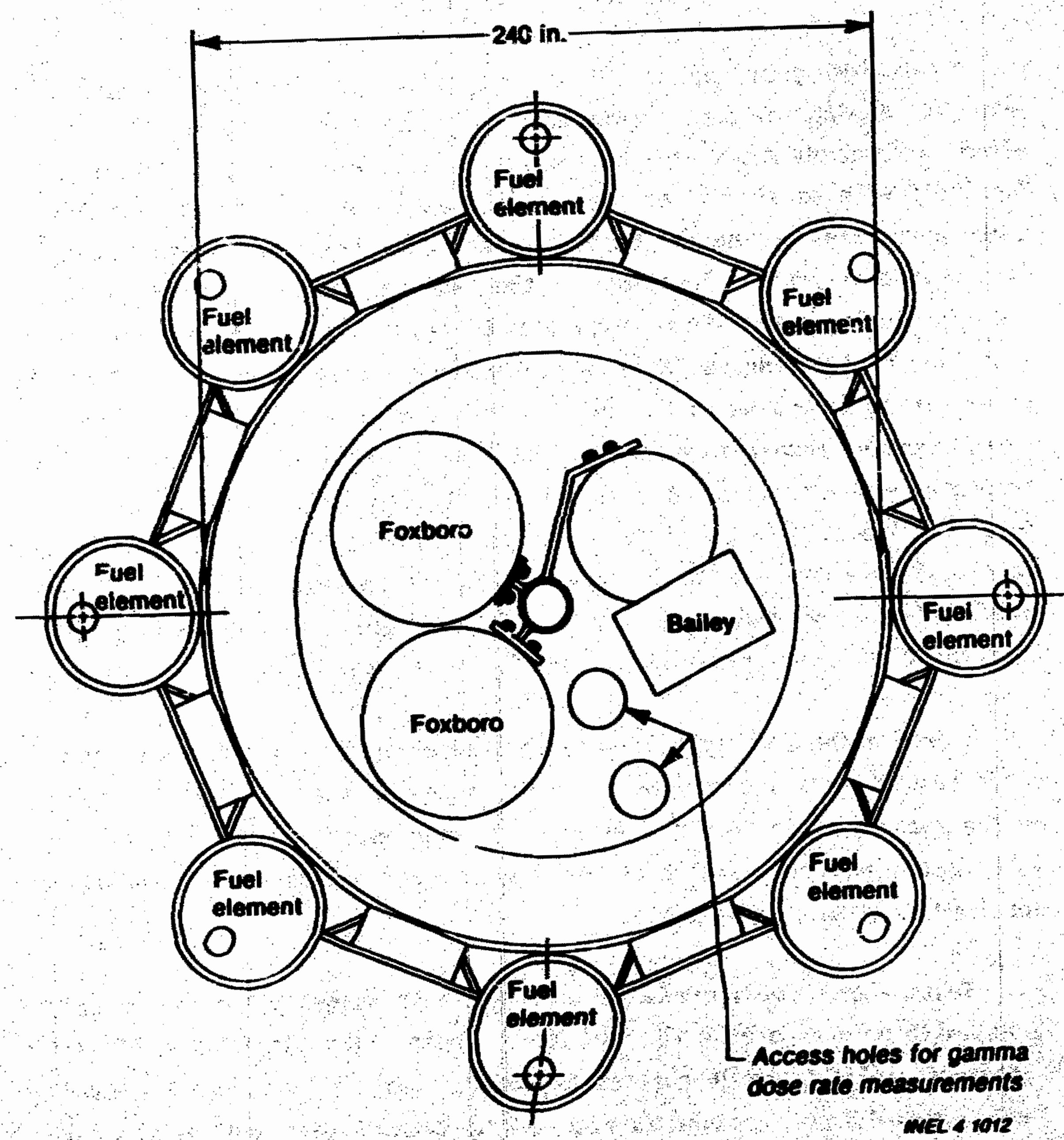

Figure 2. Cross section of ATR Large Gamma Facility showing location of canister and transmitter.

IRRADIATION MEASUREMENTS

Radiation conditions in the test canister were monitored at various intervals during the test. Both dose rate measurements and total accumulated gamma doses were measured. A Victoreen roentgen rate meter Model 510 with an air filled ionization chamber was used to monitor the gamma dose rates during the testing. The total gamma irradiation level accumulated at various locations in the canister during the test were monitored using pure lithium fluoride cut crystals. These crystals are sensitive to ionizing radiation which produce a color change in the crystal which varies according to the total absorbed dose. The dose rate and normal ambient temperature have little effect on the crystals response to the total absorbed dose. A dual beam spectrophotometer was used to determine the absorbance of the crystals. This data was then compared with data available from a set LiF crystal calibration standard which had been subjected to known radiation levels. The crystals were analyzed by the Department of Energy Radiological and Environmental Sciences Laboratory.

Thirty-eight LiF crystals were located at various locations on the three transmitters and the two coils of cables in the canister. A summary of the data obtained from the dose rate measurements and the estimated total gamma dose accumulated at the time the various sets of test data were obtained is shown in Table 5.

Tests 1 and 9 were conducted with the test assembly located in the canal with no fuel around the canister. Tests 2 through 8 had various fuel loadings yielding the dose rates as shown. Table 6 lists the average total dose of radiation received by each of the transmitters and the two coils of cables.

TABLE 5. IRRADIATION DATA

Test	Approximate Dose Rate (rads/h)	Estimated total Dose (rads)
1	None	None
2	1.0×10^4	5.5×10^4
3	1.0×10^4	1.5×10^5
4	2.5×10^5	1.1×10^6
5	2.5×10^5	2.4×10^6
6	2.5×10^5	5.4×10^6
7	3.6×10^5	8.9×10^6
8	3.6×10^5	1.3×10^7
9	None	1.3×10^7

TABLE 6. AVERAGE TOTAL ACCUMULATED DOSES

Item	Dose (rads)
Bailey	1.3×10^7
Foxboro #1	1.3×10^7
Foxboro #2	1.4×10^7
Cable-Fox #2	1.2×10^7
Cable-Control	1.2×10^7

TEST RESULTS

Transmitters

The transmitters were subjected to irradiation fields on the order of 1×10^7 rads. The three transmitters remained operational during the irradiation test, however, changes were observed in each of the transmitter's linearity and their zero and span characteristics. A least squares method was used to calculate the best fit straight line for each set of calibration data obtained during the test. Equations 1 through 3 represent the best fit straight line obtained during Test #1 for Foxboro #1, Foxboro #2, and Bailey transmitters respectively.

$$I(\text{mA dc}) = 0.08090\ P + 10.08533 \qquad (1)$$

$$I(\text{mA dc}) = 0.7972\ P + 10.02314 \qquad (2)$$

$$V(\text{V dc}) = -0.28939\ L + 10.1444 \qquad (3)$$

where "P" represent the applied pressure in psi to the Foxboro transmitters and "L" represents the liquid level applied to the Bailey transmitter in inches of water.

The zero shift that occurred for each of the transmitters during the period of irradiation is shown in Table 7. Tables 8 and 9 show the changes in span and linearity that occurred during the test.

TABLE 7. ZERO SHIFT (% OF SPAN)

Test	Foxboro #1	Foxboro #2	Bailey
2	0.21	0.20	4.09
3	0.47	0.34	7.78
4	1.04	1.11	12.51
5	1.26	1.31	14.96
6	1.45	1.43	15.97
7	1.79	1.27	15.84
8	2.26	1.47	14.62
9	1.92	1.25	12.75

TABLE 8. PERCENT CHANGE IN SENSITIVITY

Test	Foxboro #1	Foxboro #2	Bailey
2	+0.35	+0.30	-0.32
3	+0.17	+0.14	-0.76
4	-0.05	+0.15	-1.17
5	-0.73	-0.53	-0.53
6	+0.06	-1.05	-1.08
7	-0.46	-0.54	-0.87
8	+0.56	+0.39	-0.46
9	-0.49	-0.44	-0.29

TABLE 9. PERCENT CHANGE IN LINEARITY

Test	Foxboro #1	Foxboro #2	Bailey
2	0.15	0.15	0.30
3	0.08	0.10	0.15
4	0.12	0.22	0.45
5	0.10	0.18	0.55
6	0.15	0.22	0.60
7	0.10	0.62	1.50
8	0.08	0.20	1.00
9	0.10	0.20	0.20

The linearity repeatability and hysteresis for each of the transmitters was determined from the three calibration runs that were performed prior to and after the irradiation, namely during Tests #1 and #9. Tables 10 and 11 list the data for each of the transmitters before and after the irradiation.

The step response data accumulated during the irradiation is shown in Tables 12, 13, and 14. The delay between the time the input signal was applied and the transmitters output started to respond was recorded as deadtime. The time required after the input signal was applied for the transmitters output to reach 50 and 90% of its output span was also noted. Response to increasing and decreasing input signal was recorded.

A visual inspection of the internal parts of the three transmitters indicated little change in the transmitter's condition. The two Foxboro transmitters showed only a slight darkening of the amplifier's circuit board, while the insulation on the wiring in these units showed no signs of cracking upon being flexed. In the Bailey transmitter, the amplifier's circuit board and some of the capacitance on the board had darkened with irradiation and the internal wiring had become brittle. By way of comparison, the wiring in all the TMI-2 Bailey core flood transmitters was still flexible when the transmitters were examined at the INEL. This suggests that the transmitters had been subjected to a lower total gamma dose than the transmitter irradiated in this test.

Cable

The cable parameters such as capacitance, inductance, and loop resistance were affected only slightly by irradiation. The cable's loop resistance and capacitance increased less than 2% during irradiation, while inductance showed no change. Overlay plotting the TDR data obtained in the open and shorted conditions before, during, and after the test showed no detectable changes in the cables during irradiation. Time information obtained from the TDR traces on the oscilloscope were also compared and showed no changes. The cable's insulation resistance showed a decrease of approximately 10% during irradiation as indicated in Table 15.

TABLE 10. TRANSMITTER PERFORMANCE BEFORE IRRADIATION

	Foxboro #1	Foxboro #2	Bailey
Linearity	± 0.14	± 0.25	± 0.18
Repeatability	0.062	0.231	0.145
Hysteresis	0.085	0.299	0.169

TABLE 11. TRANSMITTER PERFORMANCE AFTER IRRADIATION

	Foxboro #1	Foxboro #2	Bailey
Linearity	± 0.11	± 0.21	± 0.30
Repeatability	0.066	0.067	0.384
Hysteresis	0.080	0.170	0.172

TABLE 12. STEP RESPONSE DURING IRRADIATION OF FOXBORO #1 TRANSMITTER (TIME IN SECONDS)

	Deadtime		50%		90%	
Test	Up	Down	Up	Down	Up	Down
1	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
2	0.15	0.04	0.95	0.64	1.51	1.44
3	0.17	0.05	0.96	0.61	1.54	1.43
4	0.17	0.05	1.03	0.59	1.67	1.40
5	0.17	0.05	1.05	0.59	1.70	1.44
6	0.17	0.06	1.06	0.58	1.75	1.40
7	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
8	0.16	0.05	1.11	0.57	1.82	1.45
9	0.15	0.05	1.07	0.56	1.75	1.46

a. Data not available because of a data error on the data disk used for recording.

TABLE 13. STEP RESPONSE DURING IRRADIATION OF FOXBORO #2 TRANSMITTER (TIME IN SECONDS)

	Deadtime		50%		90%	
Test	Up	Down	Up	Down	Up	Down
1	0.14	0.04	0.82	0.63	1.28	1.37
2	0.14	0.04	0.82	0.64	1.30	1.38
3	0.14	0.05	0.84	0.60	1.33	1.42
4	0.17	0.05	0.88	0.58	1.40	1.44
5	0.15	0.05	0.94	0.58	1.43	1.45
6	0.15	0.05	0.90	0.57	1.45	1.42
7	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
8	0.14	0.05	0.90	0.57	1.45	1.46
9	0.15	0.05	0.89	0.57	1.43	1.45

a. Data not available because of a data error on the data disk used for recording.

TABLE 14. STEP RESPONSE DURING IRRADIATION OF BAILEY TRANSMITTER (TIME IN SECONDS)

	Deadtime		50%		90%	
Test	Up	Down	Up	Down	Up	Down
1	0.04	0.03	0.60	0.67	1.65	1.80
2	0.04	0.04	0.60	0.75	1.61	1.90
3	0.05	0.05	0.60	0.75	1.61	1.90
4	0.03	0.04	0.60	0.78	1.58	1.95
5	0.03	0.04	0.60	0.78	1.57	1.95
6	0.04	0.07	0.60	0.66	1.57	1.78
7	0.04	0.06	0.75	0.81	1.91	1.94
8	0.06	0.07	0.60	0.85	1.56	1.95
9	0.04	0.05	0.60	0.80	1.58	1.92

TABLE 15. INSULATION RESISTANCE VERSUS IRRADIATION

Test	Total Radiation Dose (rads)	Insulation Resistance (ohms)
1	None	6.8×10^8
2	5.5×10^4	5.8×10^8
3	1.5×10^5	6.7×10^8
4	1.1×10^6	6.5×10^8
5	2.4×10^6	6.5×10^8
6	5.4×10^6	6.3×10^8
7	8.9×10^6	6.1×10^8
8	1.3×10^7	6.1×10^8
9	1.3×10^7	6.2×10^8

The cable's dielectric constant can be determined as a function of irradiation by knowing the exact length of the control cable and then determining the cables resonant frequency. During this test, a Hewlett-Packard 4192A Low Frequency Impedance Analyzer was used with a Hewlett-Packard Transmission/Reflection Kit (11652A) to determine the cable's various resonant frequencies. The cable which was not connected to any transmitter had the resonant frequencies measured for both the opened and shorted condition. The cable's dielectric constant shown in Table 16 was computed from the cable's third resonant frequency. Approximately 66% of the cable's length was irradiated with a 1% increase in dielectric constant.

The dielectric constant was also computed for the cables which were connected to the transmitters. Resonant frequency data was only available for the time periods before and after irradiation of these cables. The computed dielectric constants are shown in Table 17. Again, the increase in dielectric constant is 1%.

TABLE 16. COMPUTED DIELECTRIC CONSTANT (k) VERSUS IRRADIATION

Test	Total Radiation Dose (Rads)	Cable Condition[a] Open (k)	Cable Condition[a] Shorted (k)
1	None	2.97	2.95
2	5.5×10^4	2.98	2.96
3	1.5×10^5	2.97	2.95
4	1.1×10^6	2.99	2.97
5	2.4×10^6	3.00	2.98
6	5.4×10^6	3.00	2.98
7	8.9×10^6	3.00	2.98
8	1.3×10^7	3.00	2.99
9	1.3×10^7	3.00	2.99

a. Cable type is FR-15AA and insulation is flame retardant ethylene propylene.

TABLE 17. COMPUTED DIELECTRIC CONSTANTS (k) OF TRANSMITTER CABLES

	Cable Condition			
	Open		Shorted	
	Before Irradiation (k)	After Irradiation (k)	Before Irradiation (k)	After Irradiation (k)
Foxboro #1	2.87	2.90	2.89	2.94
Foxboro #2	3.04	3.07	3.02	3.06
Bailey	2.90	2.92	2.94	2.96

CONCLUSIONS

The three transmitters functioned without failure when subjected to a total gamma dose of 1×10^7 rads.

The two Foxboro transmitters showed slight changes in the calibration characteristics as a result of irradiation. Variations in sensitivity of approximately 1% were noted during irradiation; however, the net change in calibration at the conclusion of the test was only a 0.5% decrease in sensitivity for these transmitters. Foxboro #2 and Foxboro #1 exhibited a zero shift during irradiation of 1.5 to 2.3% of span respectively. When the fuel was removed from the area of the transmitters, the maximum zero shift in the calibration data decreased slightly for both transmitters.

The Bailey transmitter showed more changes as a result of irradiation. The calibration data for the Bailey transmitter indicated a sensitivity decrease of 1.17%, while the zero shifted about 16% of span. The final changes in the sensitivity and zero shift decreased when the fuel was removed. The visual inspection revealed that insulation on the transmitter's internal wiring had become brittle as a result of irradiation.

In comparing the response time data from before and after the irradiation for the three transmitters, a degradation of about 15% was noted for each transmitter.

The cables showed no major signs of deterioration during irradiation. The major observable change occurred in the cable's insulation resistance which showed about a 10% decrease. The cable's dielectric constant increased about 1% during irradiation. This increase in the dielectric constant appeared to be related to the total dose received since it did not change once the fuel was removed.

From a review of the data obtained on the two Foxboro transmitters, the irradiation of the cable on Foxboro #2 appeared to have little effect on the transmitters performance.

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