ANL-6347
Radiation Effects on
Materials
(TID-4500, 16th Ed.)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois

THE PERFORMANCE OF A MOTOR, A SWITCH, AND TWO
TYPES OF PRESSURE PICKUP IN A HIGH-GAMMA-FLUX
ENVIRONMENT

by

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Metallurgy Program 1.5.4

June 1961

Operated by The University of Chicago
under
Contract W-31-109-eng-38

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THE PERFORMANCE OF A MOTOR, A SWITCH, AND TWO TYPES OF PRESSURE PICKUP IN A HIGH-GAMMA-FLUX ENVIRONMENT

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ABSTRACT

The design of equipment to be employed in the EBR-II Fuel Cycle Facility has been influenced by expected levels (10^5 to 10^7 r/hr) of radioactivity which limit the use of components utilizing organic materials of construction. In some instances, however, it is highly desirable to use transducers, switches, and motors to control and sense certain operations. To determine the effects of gamma radiation upon such components, two test assemblies were irradiated in the ANL Gamma Irradiation Facility at levels of 1.50×10^5 to 2.10×10^6 rad/hr to a total dose of 1.0×10^9 rad. The components tested were a motor, a strain-gauge pressure pickup, a quartz pressure pickup, and a high-temperature switch. The electrical output from the transducers was monitored at frequent intervals throughout the test period.

The performances of the strain-gauge pickup and snap switch were highly satisfactory over the test period. The quartz pickup, however, exhibited a sensitivity to radiation which rendered it ineffective for use in such an environment. Radiation damage to the motor was manifest as degradation of insulation, and evaporation and condensation of some of the products of degradation upon the walls of the test containment shell. As a result, the motor lost power, indicating a need for insulation more resistant to gamma radiation. Radiation damage to paints, varnish, grease, and conventional insulations was noted, but the extent of this effect was not considered detrimental to the test.

INTRODUCTION

The design of equipment employed in the EBR-II Fuel Cycle Facility is limited by the environment resulting from refining and refabrication of spent fuel elements. Since a relatively short fuel-cooling period is anticipated, high levels of gamma radiation will be encountered in the cell

areas. The expected levels of radioactivity, 10^4 to 10^7 r/hr, will degrade known elastomers and polymers to such an extent that they are ineffectual as long-lived materials of construction.⁽²⁾ Furthermore, the argon cell atmosphere, which will be limited to low concentrations of water vapor and oxygen, of the order of 50 ppm, imposes an additional restriction upon equipment design by precluding the use of carbon for brush materials in electric motors or as one member of a wear couple.^(3,4)

The limitations upon equipment design have been circumvented by the use of pneumatics to operate units of process equipment. There are, however, areas of interest where the use of mechanical linkages or pressure impulses are impractical. Such a condition exists in an inspection stage where length, weight, extent of internal porosity, and diameter of refabricated fuel pins are determined, as well as in a leak detector station where the integrity of a girth weld is checked.

A previous report⁽⁵⁾ dealt with the components and instrumentation required as auxiliaries to a balance and an eddy current porosity gauge and their performance in a high-gamma-flux environment. This report deals similarly with components required for the measurement of the diameter of a fuel pin over its entire length and the determination of faulty welds at the restrainer end of fuel rods.

COMPONENTS AND MATERIALS TESTED

The outside diameter of a refabrication EBR-II fuel pin is measured by passing the fuel pin, at a predetermined rate, through the throat of a pneumatic jet ring gauge. This inspection operation, as envisioned for hot cell operation, will be powered by an electric motor. Because limited life is expected from a motor utilizing carbon brushes,⁽⁶⁾ and as a result of the findings of a previous investigation,⁽⁵⁾ an hysteresis synchronous motor with class H insulation was selected. The fuel pin is advanced through the ring gauge by a motor-driven, recirculating ball screw. Argon gas at regulated pressure is supplied to three jets on the periphery of the gauge throat. Variations in pin diameter are reflected as changes in back pressure which are sensed by a pressure transducer. After a fuel pin has traversed the diameter gauge, a switch reverses the motor and the feeding device is returned to accept another pin.

The EBR-II Mark I fuel rod consists of a fuel pin which is enclosed in, and sodium-bonded to, a stainless steel jacket. The final closure is made by welding the top of a restrainer plug into the jacket tube, and the integrity of the weld is checked by leak detection. Leak detection involves inserting the top of the fuel rod into a tightly sealed chamber. A metered volume of gas at high pressure is admitted to the chamber, and leakage

through the weld results in pressure decay from the chamber into the void spaces within the fuel rod. The decay of pressure is sensed by a pressure transducer.

The reliability of the electrical components to be employed in the above schemes are dependent primarily upon their life expectancy in an environment which includes gamma-radiation intensity in excess of 10^6 r/hr. For this reason it was felt that a test to simulate performance in the radiation environment was required. The components tested were:

1. Motor - Electric Indicator Company, Inc., Type ALH-541 hysteresis synchronous motor, class H insulation
2. Switch - Micro Switch, Model 1 HT 1, High Temperature
3. Pressure Pickups
 - a. Consolidated Electrodynamics Corp., Type 4-316A
 - b. Kistler Instrument Corp., Model 701.

The testing program was carried out in two phases. Figures 1 and 2 are photographs of the test apparatus which was designed to ascertain the reliability of the units in question.

Figure 1

Test Apparatus for Determination of Effects of Gamma Radiation upon a Motor, Pressure Pickup, and Switch

Figure 2

Test Apparatus for Determination of Effects of
Gamma Radiation upon Two Pressure Pickups

The test setup shown in Figure 1 was employed to determine long-term radiation effects upon the motor, switch, and strain-gauge pressure transducer. The mechanism shown in Figure 2 was used to find the effects of varying radiation levels upon two different types of pressure transducers.

The test apparatus pictured in Figure 1 consists of a motor coupled to a reciprocating piston through a gear reducer, cam, and cam follower. Pressure pulses created by the reciprocating piston within the cylinder are monitored by a pressure pickup. The motor selected for this experiment was a Type ALH-541 hysteresis synchronous motor, manufactured by the Electric Indicator Company, Inc., chosen for its simplicity, lack of adverse wear couple,⁽³⁾ and anticipated high resistance to gamma radiation. The motor bearings were lubricated, by the manufacturer, with Calresearch No. 159 grease, which is a radiation-resistant grease developed by the California Research Corporation. Prior to mounting the motor on the base plate, the insulation on the lead wires was stripped away and steatite insulators were substituted. The insulation employed was Flex-sok Insulating Beads manufactured by the Stupakoff Ceramic and Manufacturing Company.

The motor was attached, through a coupling, to a Metron Instrument Co. Model No. 10 A 30 S speed reducer. Before mounting, the speed reducer was disassembled; rubber grease seals and fiber gaskets were removed and replaced by lead seals. It was then lubricated with Calresearch No. 159 grease. In addition, a brush application of the base oil for the Calresearch grease was applied to the shafts before reassembly of the speed reducer. The output shaft of the speed changer was attached to the yoke of a cam follower by a roll pin. Rotation of the yoke and cam follower about the cam translates the rotary motion into a reciprocating movement of the cam and attached piston. The piston was built up of spacers and cast iron rings which sealed against the polished bore of a mild steel cylinder. Before assembly, the gas cylinder and piston were coated with a thin application of molybdenum disulfide to reduce frictional resistance.

A Consolidated Electrodynamics Corp. Type 4-316A pressure pickup was piped into the cylinder at the piston head end. The pickup consisted of a metal diaphragm and unbonded strain-gauge windings connected in a four-arm bridge. Pressure against the diaphragm produces a displacement of the sensing element, which causes a change in the resistance of the active arms and results in an output which is proportional to the applied pressure.

A switch was mounted on the gas cylinder housing. This unit was a Micro Switch, Model 1 HT 1 High Temperature "HT" switch which was supplied with Refrasil-insulated leads. This device was actuated by a pin which was fixed to the reciprocating member of the test apparatus. The switch was actuated twice for each revolution of the speed changer output shaft.

The test apparatus depicted in Figure 2 consists of a pressure manifold with outlets to two pressure pickups. One pickup is the CEC Type 4-316A described above. The other is a Kistler Instrument Corp. Model 701 quartz pressure pickup. The quartz pickup consists of two semicylindrical quartz transducer elements mounted as a column which resists pressure or force. The crystals are isolated from the outer surface by an end plate and a diaphragm. A force applied to the diaphragm or end plate is transferred to the crystal which generates an electrostatic charge which is proportional to the force applied.

Each test apparatus was inserted into its brass container, as shown in Figures 3 and 4. With the exception of the quartz pressure pickup, all electrical leads were soldered onto lugs of glass-insulated Fusite octal connectors. The quartz pressure pickup employed a Type BNC coaxial connector. The connectors were in turn soldered into the top of the containment shell which was soldered into the shell of the can. To eliminate the possibility of leakage, either into or from the container, and to provide

an inert atmosphere in the can, short lengths of copper tubing were soldered over holes in the top of the container and the volume was flushed with helium gas. The container was helium mass spectrometer leak tested and areas indicating leakage were repaired. After the container was found to be leak tight, it was flushed with argon gas and the final seals were made by soldering caps onto the copper tubing.

Figure 3

Enclosure for Irradiation Test Apparatus

Figure 4

Container and Urn for Pressure Pickup
Test Apparatus

INSTRUMENTATION

The instrumentation employed in these experiments provided recorded information from the change in signal of the pressure transducers, in addition to a "pip" to denote the operation of the switch. The motor temperature was monitored by a chromel-alumel thermocouple, the hot junction of which was inserted under the motor nameplate. The temperature of the motor and/or of the gas space within the test containment shell was determined at the start and end of each run and noted on the data record. The instrumentation for this study is shown in Figures 5, 6, and 7.

Figure 5

Instrumentation and Containment for Gamma Irradiation Test Apparatus

The method employed to bring the signals from the test apparatus to the amplifier-recorders is best shown in Figure 5. The lead wires between the octal connectors and the instrumentation were conventional, thermoplastic-insulated AWG #18 wire for the motor and switch. Thermocouple wires were insulated with asbestos and an overall wrap of glass braid. The CEC pressure pickup leads were thermoplastic insulated and divided into shielded pairs. The Kistler pressure pickup lead was RG-59/U coaxial cable.

To insure leak tightness, the lead wires were terminated in female octal plugs and threaded through tubulations in an irradiation urn cover, as shown in Figure 5; the wires were then pulled through 25 ft of Tygon tubing, one end of which was clamped to tubulations in the urn cover. The free ends of the lead wires terminated in appropriate jack plugs which were coupled to the recorder-amplifiers. Where gas was required, a connection between the test manifold and the tubulations in the urn cover was made with Tygon tubing suitably clamped to the tubing. Final assembly consisted of plugging the octal connectors together, inserting the test apparatus containment shell into the urn, and clamping the urn cover into place against its "O" ring gasket.

Figure 6

Block Diagram of Test Apparatus, Control and Recording Equipment for Determination of Radiation Effects upon a Motor, Switch, and Pressure Pickup

In each experiment, temperature measurements were made by measuring the emf of a thermocouple with a Model 9B Pyrotest direct-reading potentiometer. Figure 6 is a block diagram of the control and recording system employed in the determination of radiation effects upon

the units shown in Figure 1. The hysteresis synchronous motor was operated from a 115-volt, 60-cycle supply. A Sanborn strain-gauge amplifier was used as a source of 2500-cycle excitation voltage for the strain-gauge pressure pickup. When the pickup was pressurized, a signal voltage of magnitude and phase representing the magnitude and direction of the pressure pulse returned to the strain-gauge amplifier, where it was amplified and directed into the two-channel recorder. The microswitch operation was displayed on the recorder by connecting a battery in series with the switch across the input to the dc amplifier. Each operation of the switch impressed the battery voltage on the dc amplifier. The output from the amplifier was recorded on the second channel of the recorder.

Figure 7

Block Diagram of Test Apparatus, Control and Recording Equipment for Determination of Transient Radiation Effects upon Two Types of Pressure Transducers

A similar system was used for the excitation and detection instrumentation shown schematically in Figure 7. Here, however, the second channel of the recorder was employed to display the action from the quartz pressure pickup. The quartz pressure pickup was connected to a Kistler Model 654 Piezo Calibrator. This instrument employs an electrometer

tube circuit to sense the magnitude of the electrostatic charge developed on the pickup by pressure pulses. The output signal from the calibrator was connected to a Sanborn dc amplifier and the amplifier signal was displayed on the two-channel recorder.

IRRADIATION PROGRAM AND TEST PROCEDURE

The irradiation program for this investigation was carried out in the Argonne High Level Gamma Irradiation Facility. After the cover was locked onto the sample urn, the entire assembly was lowered into an irradiation rack. In the ANL Facility, it is customary to rotate the urn during irradiation to insure uniformity of irradiation and to reduce the shielding effect which one component within the urn may have upon another. In the cases considered, the sample urn was placed in a pedestal cup to prevent rotation, which could not be tolerated because of the gas and electrical leads from the urn to the recording and controlling apparatus.

The irradiation schedule for each of the tests varied during the length of the run. During an eight-hour day the urn was placed in a storage rack where the radiation levels ranged from 1.5 to 3.4×10^5 rad/hr. At night and on weekends, the samples were transferred to an irradiation rack where the levels reached 5.4×10^5 to 2.1×10^6 rad/hr. In Table I the irradiation schedule is presented for both tests.

TABLE I

Irradiation Program for Determination of Gamma-Radiation Effects upon a Motor, Switch, and Pressure Pickup, and Transient Effects upon Two Pressure Pickups

Component	Time, days	Avg Irradiation Rate, rad/hr		Total Dose, rad
		Day	Nights and Weekends	
1a Motor	13	1.84×10^5	7.32×10^5	7.43×10^8
	31	2.25×10^5	9.30×10^5	
1b Transducer & Switch	13	1.68×10^5	1.02×10^6	1.02×10^9
	31	2.97×10^5	1.28×10^6	
2 Transient Test	73	3.41×10^5	5.40×10^5	1.01×10^9
	7	1.50×10^5	2.10×10^6	

The periods of irradiation are divided into two groups because of the insertion of fresh elements in the racks. Although the motor and transducer were placed in the same container, their exposures were different because of their respective positions in the sample urn. Average rates are given because of radiation decay during the lives of the fuel elements used.

The dose rates were determined by chemical dosimetry, employing ferrous sulfate. The gamma-radiation energy spectrum for this facility varies from 0.22 to 2.5 Mev, the average being about 0.75 Mev. Although the field is essentially gamma, there is a low neutron background which was not considered pertinent to the study.

During the study of the effects of radiation upon the motor, switch and pressure pickup, the motor was operated only when a record of the output from the pressure pickup was desired. A strip record of the operation was taken at three- and four-day intervals.

The investigation of transient effects upon the two pressure pickups, however, required a more active approach. A profile of the radiation levels at various distances over an irradiation rack position was made and is shown in Figure 8.

Figure 8

Gamma Flux Profile Normal to Rack Top and Directly Over Position C-1 in Gamma Irradiation Facility, Bldg. 310, A.N.L.

When a run was desired, the sample urn was raised by one-foot increments and the manifold was pressurized. The signal from the pressure pickups was monitored at each increment of depth, and thereby at varying irradiation rates, while at constant pressure. This procedure was repeated for pressures of 0, 10, 20 and 30 psig during the entire irradiation period, and the recorder traces were analyzed for transient effects.

RESULTS

Figure 9 is a trace of the output of the strain-gauge pressure pickup and microswitch during operation under irradiation. Trace "a" is the output of the strain-gauge pressure pickup against time. The time axis is described by trace "c" upon which each "pip" represents one second of running time. The character of curve "a" is imparted by the shape of the cam and the seal between the piston and the wall of the cylinder. The plateau on the trailing edge of the cycloid is the result of backlash between the cam and the cam follower, and was repeated on all traces throughout the testing period. An analysis of the signal amplitude during the testing period revealed a gradual loss to approximately 95% of the original signal height at the end of the test period. This phenomenon may be due to radiation effects, or wear and subsequent loss of compression in the cylinder. Although the temperature of the motor varied between 26 and 60°C during testing, it appeared to have no effect upon the output signals.

Figure 9

Trace of the Output of Strain Gauge Pressure Pickup and Microswitch Operation During Irradiation

Trace "b" is the signal output from the microswitch circuit, the rise indicating the closing of the switch circuit. The character of the baseline signal is due to ambient interference picked up through the open circuit to the dc amplifier during the period between switch actuations.

The investigation of the effects of radiation transients upon the two pressure transducers revealed a sensitivity of the quartz pressure pickup to radiation. Upon being gradually lowered into the radiation field, the output from this transducer slowly fluctuated. As the urn seated in the rack, the signal fell slowly, then gradually rose until after four minutes it was over four times the value recorded for levels of less than 1 mr. During

the first three days of irradiation, the quartz transducer exhibited a tendency toward a drifting output until, after fifteen days, the output was off-scale for the instrumentation and the leads were disconnected from the calibrator. The strain-gauge transducer appeared unaffected by varying radiation levels, and this stability persisted throughout the irradiation period. The stability was reflected in reproducibility of signal for the increments of pressure applied and was uninfluenced by radiation dosage up to 10^9 rad.

At the termination of the test, the sample urns were withdrawn from the facility and the test apparatus was removed from the urn. The solder was melted away from the container and the test rig was withdrawn. The components were examined for radiation damage and, except for expected hardening of thermoplastic insulation, condensation of organic degradation products upon cold surfaces, and a general darkening and embrittlement of varnish and other organic constituents, only one condition not found in a previous report⁽⁵⁾ was discovered. The motor was found to have lost much of its power and a white powdery deposit covered the inside of the test apparatus container. A pungent odor, which was believed due to the decomposition of urea compounds, emanated from the canister. It was apparent that the deposit had been driven from the motor insulation.

CONCLUSIONS

The performances of the strain-gauge pressure pickup and micro-switch were such that they may be expected to perform satisfactorily in a high gamma-flux environment to a total dose of at least 10^9 rad. However, when the performance of the motor is compared with that of the motor reported in ANL-5988, it would appear that the Class H insulation employed, presumably a polyurethane compound, was inferior, with respect to resistance to irradiation, to the more conventional types of insulation. The sensitivity of the quartz pressure pickup to irradiation renders it useless as a transducer in such an environment, as is anticipated in the EBR-II Fuel Cycle Facility argon or air cells. The failure of the quartz transducer may be attributed to reverse current pulses and internal leakage in the coaxial cable, as observed by Clark and Hanscombe.⁽⁶⁾ Although regions of damage and failure were encountered, it is concluded that a better choice of insulations for the hysteresis synchronous motor and the use of the microswitch and strain-gauge pressure transducer selected for this test will result in satisfactory performance under the severe environmental conditions anticipated for these components.

ACKNOWLEDGEMENTS

The authors appreciate and acknowledge the contributions of Joseph F. Harast, Chemical Engineering Division, and Jon Nelson, summer employee from Purdue University, whose works were instrumental to the success of this investigation.

BIBLIOGRAPHY

1. Schraidt, J. H. et al., "Pyrometallurgical Processing: Economics and Proposed Engineering Applications," TID-7534, Book 2, p. 766, Symposium on the Reprocessing of Irradiated Fuels, Brussels, Belgium, May 20-25, 1957.
2. Collins, C. G., Stapp, W. J., Fries, R. C., and Calkins, V. P., Estimated Radiation Stability of Aircraft Components, APEX-357 (Sept 1956).
3. Moberly, L. E., and Johnson, J. L., "Wear and Friction of Carbon Brushes as a Function of Air Humidity," Proceedings of the Conference on Carbon, 1959, Pergamon Press, pp. 711-718.
4. Carson, N. J., Jr., and Morris, W. H., Testing of Potential Bearing Materials in an Argon Atmosphere of Low Humidity, ANL-5973 (Aug 1959).
5. Pokorny, G. J., and Ayer, J. E., The Performance of a Special Differential Transformer and an Eddy Current Coil in a High Gamma Flux Environment, ANL-5988 (July 1959).
6. Clark, J. W., and Hanscombe, T. D., Radiation Pulses and Electronics, Nucleonics, 18 (No. 9) 76-77 (Sept 1960).