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TECHNICAL MEMORANDUM

ANL-CT-76-20

IRRADIATION OF MICROPHONES
IN THE EBR-II CORE

by

A. P. Gavin, T. T. Anderson and J. P. Bobis

Components Technology Division

BASE TECHNOLOGY

June 1976

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LMFBR Instrumentation and Control (UC-79m)

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ABSTRACT

Six ANL developed high temperature microphone (acoustic detectors) have been exposed in flowing sodium in the In-Core Instrument Test Facility (INCOT) in the Experimental Breeder Reactor-II (EBR-II) for seven months without any indications of serious degradation of signal output due to the exposure. The YY05 experiment (EBR-II INCOT experiment designation) was performed to obtain data which would be useful in evaluating the ability of the microphones whose active elements are lithium niobate to serve as sensors for acoustic surveillance of fast breeder reactors. The reactor was at full power for 136 days of the experiment exposure period. The microphone temperatures varied from 371°C (700°F) to 621°C (1150°F). Neutron exposure varied from 2.64×10^{22} nvt for the microphone at the elevation of the bottom of the EBR-II core to 0.24×10^{22} nvt for the microphone at the elevation of the top of an EBR-II fuel assembly. The maximum gamma dose was 5×10^{12} rads.

The electronically conditioned microphone output signals were continuously monitored and no appreciable changes were noted in sensitivity or frequency response due to exposure at high temperatures in the fast reactor core environment. Results of post irradiation recalibration of the six microphones at room temperature in a water calibrator indicated a maximum loss of sensitivity of 23%. Resistance of each of the microphones was monitored at 70 minute intervals utilizing the EBR-II data acquisition system. Although some abnormally low values were recorded during initial reactor start up only one of the six microphones exhibited resistance values lower than normally expected after the first week of exposure. The resistance of this unit remained low, i.e., 2 Kilohm at 1000°F instead of a normal 100 Kilohm at this temperature, for two of the three EBR-II runs of exposure. During the third EBR-II run the resistance of this microphone returned to normal.

The small volume (100 cc) sealed oxygen supply systems required to maintain the electrical resistance of the lithium niobate elements of the microphones functioned satisfactorily and caused no difficulty during reactor operation or during the removal process. Although it was calculated that .3 curies of tritium would have been produced by neutron bombardment of the lithium in the microphone located in the center of the core position only 15.5 microcuries were found to be present in the vent system at the end of the irradiation period.

Post irradiation examination of the lithium niobate elements from each of the microphones revealed fracturing similar to that observed in elements from a control microphone which was exposed at temperatures in the same range in a sodium filled loop. All elements exhibited discoloration in varying degrees similar to that previously observed in crystals exposed to oxygen-deficient atmospheres at elevated temperatures. The lack of any significant change in microphone response, as evidenced by output data just prior to reactor shutdown and post irradiation water calibration, indicates that neither the cracking nor oxygen starvation was sufficient to affect the ability of the microphones to produce reliable acoustic information from within the reactor core.

Comparison of piezoelectric coefficient (d_{33}) values determined by measurements made on the elements removed from the microphones after irradiation to those determined prior to their insertion into the microphones indicated no significant change in the basic sensitivity of any of the elements. Optical measurements made on these irradiated elements indicated no significant change in optical birefringence of the material due to reactor exposure, (see Appendix 7). These results establish that the loss of anisotropy (metamictization) found in previous low temperature neutron irradiations⁽¹⁾ of lithium niobate did not occur under the irradiation conditions of this experiment. As indicated in these references the major factor in the radiation resistance exhibited by the YY05 microphones is probably annealing of radiation damage at the elevated temperature of the irradiation. The temperatures at which the microphones were irradiated in this experiment are considered to be typical of those which would exist in the locations where they would be exposed in an operating LMFBR.

It is estimated that the neutron exposure received by the microphones in this experiment is equivalent to that which would be received by a microphone located six feet above the core of the Clinch River Breeder Reactor in 30 years.

1.0 Introduction

This report presents the results of an experiment conducted to evaluate the performance of ANL high temperature sodium immersible microphones in the near core environment of an operating liquid metal cooled fast breeder reactor. The experiment, designated YY05, exposed six of these microphones in the In-Core Instrument Test Facility (INCOT) in the EBR-II reactor. Their performance was evaluated by gathering data including temperature, acoustic output, resistance, neutron exposure, sensitivity before and after irradiation, as well as d_{33} piezoelectric coefficient and optical birefringence of the lithium niobate crystals before and after irradiation.

It is important to stress that this experiment was designed to evaluate the ability of the microphones to operate in the near core environment of an LMFBR and not to gather information on acoustic background noise in the EBR-II core. In fact, the configuration of the INCOT facility precluded obtaining meaningful core region acoustic background information. As described later in this report, the facility consists of several concentric tubes and a gas filled annulus which provides thermal isolation allowing the facility temperature to exceed that of the surrounding reactor core. This arrangement acoustically isolates the INCOT interior quite effectively from the reactor core. The INCOT internal temperature is controlled by adjusting the sodium flow through a valve at its inlet (bottom) end. This valve regulates sodium flow from the reactor high pressure plenum through the facility. The major portion of the sound detected by the microphones located in the facility is related to this flow.

Section 2 of the report is a description of the high temperature microphone. The microphone is an acoustic pressure sensor fabricated from high temperature materials including two lithium niobate crystals as the piezoelectric elements, arranged to approximately cancel acceleration signals.

Section 3 describes the experiment hardware and data gathering systems. A description of the EBR-II INCOT facility, included as Appendix 1, indicates the facility capabilities and constraints imposed on the YY05 experiment design. The sensor assembly which included the microphones, thermocouples, flux monitors, gamma heat susceptors, and sensor leads is described in detail. Finally, the data gathering systems are discussed. These systems provided long term data through the use of the EBR-II Data Acquisition System (DAS), manual data as a backup to the DAS and short term real time signals recorded on magnetic tape.

In Section 4 the results are presented according to the type of data obtained. These include exposure history, acoustic signals, resistance, visual examination of the lithium niobate plates; piezoelectric coefficient determinations, optical measurements, and tritium analysis.

The summary and conclusions are presented in Section 5.

2.0 The ANL High Temperature Microphone

The materials and general construction of the ANL high temperature microphones are briefly described here. Reference [2] is a comprehensive design description of the microphone. A typical unit is pictured in Fig. 1. Fig. 2 is a detailed cross sectional view of the HT-10 microphones used in this experiment. All portions of the microphone exposed to the reactor sodium are 304 stainless steel. The active elements of each microphone are two lithium niobate (LiNbO_3) discs 10 millimeters in diameter and 1 millimeter thick. These piezoelectric discs produce a charge proportional to the acoustic pressure applied to their faces. This charge varying output is transmitted through a mineral insulated signal lead and amplified using charge sensitive amplifiers to provide a voltage signal indicative of the acoustic pressure at the microphone location. The twin lead mineral insulated cable used to transmit the signal from the microphone to the reactor exterior consists of two 0.5 mm (.020 in.) thick diameter stainless steel wires with aluminum oxide insulation in a 0.5 mm (.020 in.) thick 3 mm (1/8 in.) O.D. stainless steel sheath. In the HT-10 series sensors one of the signal lead wires was grounded to the interior of the microphone case. Since no means of providing a gas tight seal for the microphone end of the cable have been developed the aluminum oxide insulation was exposed to the interior volume of the microphone. In addition to the signal cable, each microphone assembly included a 1.6 mm (1/16 in.) outside diameter by 0.5 mm (.020 in.) inside diameter stainless steel tube which connected the interior of the microphone case to an externally located oxygen reservoir. This oxygen supply which was maintained at less than atmospheric pressure was required to prevent lowering of the surface electrical resistivity of the lithium niobate crystals which occurs when they are exposed at elevated temperatures to oxygen deficient atmospheres.

Since the fast neutron reaction cross sections of the two lithium isotopes lithium 6 and lithium 7 are different, a determination of the lithium isotopic ratio present in the lithium niobate used for construction of the YY05 microphones was requested of the ANL Chemistry Division. The results of this determination (Appendix 3) confirmed that the lithium 6- lithium 7 isotopic ratio in the material used was normal for naturally occurring lithium, i.e., the lithium 6 abundance was 7.5 mole % and the lithium 7 abundance was 92.5 mole %.

Fig. 1 Closeup of High-Temperature Microphones

Fig. 2 Sectional Views of HT Microphone

3.0 Description of the YY05 Experiment

In the YY05 experiment, six of the microphones described above were tested by exposing them in the EBR-II In-Core Instrument Test Facility (INCOT) for a period of six months. Data obtained included: exposure temperature, total neutron exposure and spectra, electrical resistance, acoustic response to varying ambient noise, acoustic sensitivity of the microphones, d_{33} piezoelectric coefficient and optical birefringence of the lithium niobate crystals before and after irradiation, and tritium accumulation in the vent systems. Fig. 3 is a schematic drawing of the mechanical arrangement of the experiment. The major test parameters, i.e., neutron exposure as determined by the position in the EBR-II core, temperature, and sodium flow, were limited by the design and operating capabilities of the INCOT facility. A brief description of the facility is presented in Appendix 1 of this report. Fig. 4 is a schematic diagram of the overall INCOT arrangement.

3.1 The Sensor Bundle

The general arrangement of the six microphones with associated signal leads, vent tubes and thermocouples is illustrated in Fig. 3. Fig. 5 shows the lower portion of the assembly containing the microphones in detail. Note that microphones and associated thermocouples and vent tubes were identified as numbers 1 through 6 starting with number 1 at the lowest position. The various components of the bundle are described below.

3.1.1 Heat Source

The heat required to raise the temperature of the sodium flowing through the INCOT facility above that of the sodium in the reactor is provided by gamma heating of the materials within the facility. In order to provide sufficient heat to maintain the hottest YY05 microphone (number 3) at the desired 1175°F it was necessary to fill the greater portion of the space in the core region of the facility with stainless steel. As indicated by the drawing (Fig. 5), this was accomplished by machining individual cylindrical blocks of stainless steel with rectangular cutouts to retain the microphones and slots to accommodate the required leads and stringing these sections alternately with solid sections on two stainless steel rods. The upper ends of these rods were threaded into a solid stainless steel block at the top of the portion of the assembly containing the six microphones. See Figs. 6-8. After all leads, blocks, and microphones were positioned they were secured in place by nuts threaded on the lower end of the rods. A section of stainless steel tubing slipped over each rod above these nuts provided a convenient place to cut the rods for post irradiation disassembly.

Fig. 3 YY05 Experiment Assembly

Fig. 4 INCOT Overall Arrangement

Fig. 5 YY05 Sensor Assembly Details

Fig. 6 YY05 Sensor Assembly in Process of Assembly

Fig. 7 View of Assembled Bundle

Fig. 8 Closeup of Upper End of Sensor Assembly

(See Fig. 9). A 5/8 in. O.D shaft approximately 20 ft long, extending between the top of the microphone assembly and the INCOT terminal box, served as the main support member for the assembly.

3.1.2 Microphone Locations

Since very little information on the effects of high level neutron and gamma irradiation at high temperatures on lithium niobate was available, the microphones were positioned to give as wide a range of neutron flux and of exposure temperature as possible. Information provided by the EBR-II Experimenters Guide⁴ indicated that the neutron flux at the position of microphone number 2 (center of core) would be a factor of 300 more than that at the position of microphone number 6 located at the elevation of the top of the EBR-II fuel assemblies. Microphones Number 1 and Number 3 were positioned to be exposed to approximately equivalent neutron flux with microphone Number 1 at 750°F and Number 3 at 1175°F.

3.1.3 Thermocouples

The temperature of each microphone was monitored by a thermocouple junction located between the vent tube and the retaining block as illustrated in the cross sectional view in Fig. 3. Two additional thermocouples were positioned to monitor the temperatures at the locations of the piggyback devices described below. These chromel-alumel thermocouples were 1/16 in. O.D., stainless steel sheathed, with mineral insulation and ungrounded junctions.

3.1.4 Oxygen Supply Systems

As explained in Section 2, it was necessary to provide each microphone with a reserve supply of oxygen to maintain electrical resistance. The six 100 cc volume stainless steel oxygen reservoirs were located on the exterior of the terminal box cover as shown in Figs. 3 and 4. A short length of 1/16 in. O.D.; .020 in. I.D. stainless steel tube welded to one end of each reservoir passed through a Swagelok bulkhead fitting in the terminal box cover where it was connected to the vent tube from one of the six microphones. The reservoirs and vent tube connections are visible in Fig. 10. The spiral sections in each vent tube provided flexibility to allow the 120° rotation of the sensor assembly relative to the terminal box during operation of the INCOT flow control valve. The outlet of each reservoir was fitted with a bellows seal valve with a 1/8 in. Swagelok fitting on its outlet end. After the vent tube connections within the terminal box had been completed and checked for leak tightness each reservoir-vent tube-microphone system was evacuated through the valve and back-filled with pure oxygen to an absolute pressure of 400 mm of mercury. The valve was

Fig. 9 Closeup of Bottom of Sensor Assembly

Fig. 10 Arrangement of Experiment Leads in Terminal Box

closed and after disconnecting the filling system the valve outlet fitting was capped to provide a double seal for the reservoir outlet.

Experience with prototype units using this type of oxygen supply system indicated that in some instances there is insufficient exchange of gas between the microphone housing and the oxygen supply tank through the 20 to 30 feet of .020 in. I.D. vent tube that connects them. The main driving force for this exchange is pressure variations due to temperature fluctuations of either the microphone or the supply tank. If the temperature of both of these components remains constant, insufficient oxygen is supplied to displace gaseous oxidation products in the microphone housing. In order to provide a means of enhancing this type of circulation if normal reactor building or INCOT temperature fluctuations should prove to be insufficient, a means of periodically heating the supply tanks to approximately 200°F above ambient was provided. This heater consisted of several turns of insulated resistance wire wrapped around the perimeter of the six cans. The ends of this wire were terminated in a fixed connector which was attached to the brackets which supported the six valves on the reservoirs. Electrical power was provided through a power cord to this connector from a control panel which was located with the YY05 instrument rack in the Test Instrument Room (TIR). The maximum power available was limited to 250 watts on a 20 minute on, 100 minute off cycle. This system was to be operated only if resistance readings of one or more of the microphones dropped below a designated minimum level of 10 kOhms. Thermocouples located on the reservoir surfaces and on the terminal box cover were provided to allow continuous monitoring of the temperatures at these points. A perforated metal shield over the reservoirs and heater served to protect operating personnel from contact with the heater. After assembly of the sensor bundle at ANL/E, and again just prior to installation in the INCOT facility, a check to verify that the vent tubes were open to the microphone housings the internal volume of each unit was made. This test consisted of connecting a hypodermic syringe and a small volume pressure gauge to the vent tube and observing pressure changes in response to volume changes produced by adjusting the syringe plunger. The internal volume of each YY05 microphone determined in this manner was 2.7 ml.

3.1.5 Flux Monitors

A stainless steel capsule 0.188 in. O.D. by 3/4 in. long containing flux monitor dosimeters to establish the total neutron dose and spectrum was placed in a hole drilled in the retaining block adjacent to each microphone as shown in Fig. 5. These capsules were prepared and evaluated by the Argonne Chemical Engineering Division personnel. Since the neutron spectrum within the

EBR-II core is well documented but that above the core is not, the capsules with microphones 1, 2, and 3 did not contain as many dosimeters as those in the upper portions of the experiment. The neutron exposure is given in Section 4.1.

3.1.6 Piggyback Devices

The cylindrical holes in the spacer blocks between microphones number 1 and number 2 and between number 2 and number 3 were provided to accommodate passive piggyback monitors supplied and evaluated by the Argonne West Analysis and Test Section at EBR-II. Thermocouples numbers 7 and 8 were located to supply indications of the operating temperatures of these devices.

3.1.7 Experiment Lead Routing

The 20 experiment leads, i.e., six 1/8 in. O.D. microphone signal leads, six 1/16 in. O.D. vent tubes and eight 1/16 in. O.D. thermocouples were fastened to the support shaft with stainless steel shim stock bands TIG welded in place. At the upper end of the facility the experiment leads passed through a gas tight seal which prevented leakage of reactor cover gas into the terminal box.

The arrangement of the leads in the terminal box and the terminal box cover penetrations are illustrated in Figs. 3 and 10. The INCOT flow control valve design requires that the tube containing the sensors be free to rotate at least 120° relative to the terminal box. This freedom to rotate was provided by a transition to soft leads for the microphone signal and the thermocouples, and by making a small diameter spiral coil section in each of the 1/16 in. O.D. vent tubes before connecting them to gas tight connectors on the terminal box cover. In order to allow elevation of the INCOT facility during fuel handling, all external connections to the terminal box cover must be broken. This required that all connections be through connectors which were easily removed and replaced. The six signal leads were connected utilizing numbered, color coded BNC connectors. Two multipin connectors with chromel-alumel contacts were used for the eight thermocouples.

Also located on the outside face of the terminal box cover was a small metal "reference box" which contained reference resistors and capacitors and a thermocouple junction whose purpose was to aid in checking instrumentation system performance as described later in this report. A separate connector was required for connection of the reference components to instrument leads.

From the connectors on the INCOT terminal box, experiment signals passed through approximately 100 ft of coaxial cable to the EBR-II Test Instrument Room (TIR) located one floor below the EBR-II operating floor. The thermocouples were connected using chromel alumel extension wire.

3.2 Data Gathering Systems

Experiment data was recorded in three modes; by computer printout from the EBR-II Data Acquisition System (DAS), by readings recorded manually by the EBR-II Instrument Technicians, and by short term magnetic tape recordings.

3.2.1 Utilizing the EBR-II Data Acquisition System (DAS)

At all times that the DAS was operating it was utilized to record microphone output signals, internal resistance values and temperatures. The instrumentation used for conditioning signals to be recorded on the DAS is shown schematically in Fig. 11. The instrument rack which contained the portion of the equipment located in the TIR is pictured in Fig. 12. A multiplexing system was used to obtain periodic readings of the resistance and of output signals for each of the six microphones. The multiplexer, shown schematically on Fig. 11, sequentially switched connections between the three channels which fed data to the DAS and the seven input channels (six microphones and the reference channel). The switching period was normally 5 minutes and was controlled by a pulse signal from the DAS. The DAS supplied a printout of one value each of temperature, microphone output signal, and microphone resistance every ten minutes. This resulted in a permanent record containing complete sets of data for each of the six microphones and the reference channel at seventy minute intervals, at all times when the DAS was operating and the signal leads were connected at the INCOT terminal box.

The RMS signal channel consisted of an Endevco model 2732 charge converter, an Endevco model 2730 charge amplifier, a General Radio band pass filter and a Hewlett Packard model 3400A true RMS volt meter.

The resistance channel utilized an AC resistance monitor developed by Argonne to satisfy special requirements for measuring resistance of our microphones. Application of DC voltages to a microphone for resistance measurements results in erroneous readings due to polarization of the unit and also at high temperatures can cause crystal degradation due to electrochemical effects. For these reasons the monitor utilizes a ± 10 V, 10 hertz square wave measuring potential. In order to cover the normal resistance change of three decades over the temperature range of the experiment, the voltage output of the resistance bridge was routed through a Hewlett Packard model 7562A Log RMS volt meter to provide a

Fig. 11 Signal Routing and Conditioning Equipment for Data Recording Using EBR-II DAS

SIGNAL OUTPUT
(Hewlett Packard
RMS Voltmeter)

RESISTANCE MONITOR
(ANL Developed)

TEMPERATURE MONITOR
Doric 12pt Temperature
Indicator

T.C. REFERENCE JUNCTION
(Kay)

CHARGE SENSITIVE
AMPLIFIERS
(Endevco)

BAND PASS FILTER
(General Radio)

SIGNAL MULTIPLEXER
(Not Shown)

Fig. 12 YY05 Instrument Rack

voltage signal to the DAS which was proportional to the log of measured microphone resistance.

The 12 thermocouple signals (8 in the experiment assembly and 4 on the terminal box cover) were routed to a Kay ice point reference junction in the TIR. From the reference junction box the six microphones (TC1-6) and one reference temperature (TC9) signals were connected through the multiplexer to the DAS. The TC7 and TC8 thermocouple signals were routed directly from the reference junction to separate DAS channels to provide a temperature record for the piggyback monitors. Signals from the three thermocouples associated with the oxygen reservoir heating system (TC10, 11, and 12) were also connected to the DAS in order to provide high temperature alarm capability when the reservoir heating system was activated. In addition, all 12 thermocouple signals were connected to a 24 point Doric digital temperature indicator, which was used for manually obtained data. All signals which were to be recorded by the DAS were routed through the DAS remote data multiplexer in the TIR.

3.2.2 Manual Data

To verify that the DAS was accurately reproducing the YY05 instrument output data and to supply data at times when the DAS was not operating, manual readings of YY05 parameters were requested. The output signal and resistance of each of the six microphones and the reference channel and the temperatures indicated by each of the twelve thermocouples were recorded once a day by an EBR-II instrument technician. Readings were taken by manually cycling the multiplexer and observing the signals indicated on the appropriate instruments on the YY05 TIR instrument console (Fig. 12).

3.2.3 Magnetic Tape Recordings

Once in each of the three reactor runs during which the microphones were in the reactor, short term, continuous, wideband, magnetic tape recordings of the acoustic signals from each of the six microphones were made. At these times, the microphone signal cables were disconnected from the multiplexer input and each was connected to a charge converter and charge amplifier in the TIR. The AC output of the amplifier was routed to the tape recording equipment in the test analysis room outside the reactor containment building. The signal routing and recording and analysis equipment is shown schematically in Fig. 13.

In order to provide a changing noise source during the period of wideband recording, the INCOT flow control valve was cycled from the full open position (maximum noise) to approximately 30% open (minimum allowable flow) while the recorder was in operation. After recording each set of signals on magnetic tape,

Fig. 13 Signal Routing and Conditioning Equipment for YY05 Magnetic Tape Recording

plots were made of the log RMS signal above 2 KHz vs. time for each of the six microphones. The instrumentation used on the output side of the tape recorder is shown in Fig. 13.

4.0 Experiment Results

The exposure history, the data accumulated during the exposure period, and data relative to microphone characteristics before and after exposure, are included in the results reported in this section. To facilitate evaluation of the effects of the exposure, these results are grouped according to the parameter measured. Brief explanations of methods used to obtain the data are included in cases where they have not been described earlier in this report.

4.1 Experiment Exposure in EBR-II INCOT

The YY05 experiment was originally scheduled to remain in the reactor for one reactor run, EBR-II Run No. 75. Near the end of the run none of the microphones showed signs of failure. Since the experiment scheduled for exposure in the INCOT facility during Run 76 was not ready, an extension of the exposure period through Run 76 was requested and granted. Near the end of Run 76 the same set of conditions existed and extension through Run 77 was granted. The reactor power history during the three runs of YY05 exposure is shown in Fig. 14. The experiment was in the reactor for a total of 213 days with about thirty cycles from 0 power to full power.

4.1.1 Temperature History

Fig. 15 illustrated the temperature cycle experienced by the microphones during each of these reactor runs. The top line indicates the reactor power history during a normal run. The instructions for operation of the INCOT flow control valve, which controls the temperature in the experiment, were: when the reactor was shut down the valve was to be 100% open; after the reactor reached power, it was to be closed sufficiently to result in a temperature of 1175°F on the hottest microphone; and after a reactor scram or shutdown, it was again to be returned to the full open position. This resulted in a temperature cycle on microphone No. 3 (hottest) indicated by the lower solid line. With the valve wide open and the reactor down, the temperature was 700°F. With the reactor at power and the valve still wide open, the hottest microphone was at 800°F. With the valve closed, the planned maximum temperature was between 1150°F and 1175°F as indicated on the dotted line. Contrary to experience with previous experiments, the sodium flow through the INCOT flow control valve during the YY05 experiment was not consistent. For this reason the planned temperature distribution was maintained for only about 25% of the time that the reactor was at power. For the greater portion of the time that the reactor was at power, the experiment operated with a maximum temperature between 975°F and 1000°F. When the reactor was shut down, either by a scram or by normal shut down, with the

Fig. 14 EBR-II Power History During YY05 Irradiation

Fig. 15 Exposure Temperature of YY05 Microphone No. 3 During Typical EBR-II Power Cycle

valve still in the adjusted position, the temperature dropped to approximately 750°F and within an hour after shut down, when the valve was manually opened, it dropped back to 700°F.

Fig. 16 shows the temperature distribution within the experiment for each of these operating conditions. For thirteen percent of the total exposure time the reactor temperature was below 400°F. This was during the long shut down for reactor maintenance between the second and third reactor runs (lower line in Fig. 16). During normal shut down, about 25% of the exposure period, the experiment operated at 700°F for all microphones (2nd line). When the reactor was at power but the valve was opened, approximately 3% of the time, the temperature distribution indicated by the 3rd line resulted, the hottest microphone being microphone No. 2, operating at approximately 825°F. For the greater portion of the time that the reactor was at power, 44% of the total, the temperature distribution indicated by the fourth line was maintained, the hottest microphone, No. 3, being between 975°F and 1000°F. During approximately 17% of the total exposure time, approximate design temperature distribution was maintained, the hottest microphone operating between 1100°F and 1150°F (top line).

4.1.2 Neutron Exposure

The neutron exposure is summarized in Table 1. These values were determined from evaluation of the flux monitor capsules which accompanied the microphones (Appendix 2). The maximum neutron exposure, on microphone No. 1,* was 2.6×10^{22} nvt, and the minimum exposure was approximately 1/10 of this on microphone No. 6 at the elevation of the top end of a fuel subassembly in the EBR-II core.

Table 1 Neutron Exposure of
Microphones Irradiated in INCOT YY05

Microphone No. 1	2.64×10^{22} nvt
Microphone No. 2	2.55×10^{22} nvt
Microphone No. 3	2.24×10^{22} nvt
Microphone No. 4	$.866 \times 10^{22}$ nvt
Microphone No. 5	$.614 \times 10^{22}$ nvt
Microphone No. 6	$.246 \times 10^{22}$ nvt

* The higher fluence at M1 appears to indicate an axial flux tilt in this region of the EBR-II core.

Fig. 16 Temperature Distribution in INCOT During YY05 Irradiation

4.1.3 Gamma Exposure

Values of gamma heating rates for Runs 75, 76, and 77 at the EBR-II core center in the INCOT facility are listed in Table 2. Based on these heating rates the total gamma dose received by Mz, as the core center line, was 5.2×10^{12} R. If we assume the axial distribution of gamma heating presented in the EBR-II experimenters guide (Fig. C-13 of Ref. 4) the dose received by M1 was 3.7×10^{12} and by M3 4.3×10^{12} . However, in view of the variance of measured neutron doses as compared to those presented in the guide, the actual gamma doses may vary somewhat from these calculated values. Since gamma heating rates outside the core region of the EBR-II have not been established, no reliable estimate of gamma doses for M4, M5 and M6 could be made.

Table 2 EBR-II Gamma Dose Rate During YY05 Experiment

<u>EBR-II Run No.</u>	<u>Gamma Heat Rate (A)</u>	<u>Dose Rate R/hr.</u>
75	5.22 Watts/gram	1.9×10^9
76	5.10 Watts/gram	1.8×10^9
77	4.77 Watts/gram	1.7×10^9

(A) At core centerline in INCOT facility - Ref. 5.

4.2 Acoustic Signals

The response of the microphones to acoustic excitation was evaluated in three different ways. First, short term magnetic tape recordings of microphone signals recorded at different times during the exposure period were analyzed. Secondly, the values of RMS signal outputs recorded throughout the experiment by the DAS and manually were examined and thirdly, the microphones were calibrated in a water filled facility before and after the reactor exposure.

4.2.1 Tape Recorded Signals

Wideband recordings of the acoustic signal output of each of the six microphones were made once during each of the three reactor runs utilizing the equipment diagrammed in Fig. 13. In order to determine the response of the microphones to a changing noise level, these recordings were made while the INCOT flow control valve was cycled between the full open position and approximately 30% open. Figs. 17 and 18 summarize some of the results of these recordings. These plots show the indicated sound measured in dB re 1 bar RMS in the frequency band between 2 kHz and 40 kHz against time while the valve was being

Fig. 17 Sound Pressure Levels Sensed by YY05 Microphones During Operation of INCOT Flow-Control Valve - March 22, 1975

Fig. 18 Sound Pressure Levels Sensed by YY05 Microphones During Operation of INCOT Flow-Control Valve - June 30, 1976

cycled. The set of data in Fig. 17 was obtained near the end of the second reactor cycle, on March 22. The microphones indicated a maximum noise level when the valve was near the full open position and the sodium flow through the INCOT facility was highest. All six microphones presented almost identical output traces. Three of these are shown in the figure. At the end of the last reactor run on June 30, recordings resulting in the curves in Fig. 18 were made. The overall levels and the general response of the microphones to the changing valve position are essentially the same as those recorded in March.

4.2.2 RMS Signal Levels

Table 3 summarizes the RMS signal output of the charge amplifier for each microphone with the reactor at full power and the temperature of microphone no. 3 at approximately 1000^oF at several times during the exposure period. These values are presented to indicate relative stability throughout the exposure period and have not been adjusted for differences in sensitivity between microphones or converted to noise level equivalents. Most of the acoustic noise in INCOT is related to the sodium flowing through the facility and the best indication of this flow rate is the facility temperature. Thus, by comparing signal levels at times when M3 was at approximately the same temperature, the acoustic excitation of the microphones is assumed to be approximately equivalent.

4.2.3 Calibration in Water

The low frequency sensitivity of ANL microphones is routinely determined at room temperature by a standard procedure using a Navy type G 19 calibrator. The procedure is included as Appendix 5 of this report. The results of calibrations performed according to this procedure for each microphone before and after irradiation are summarized in Table 4. The post-irradiation remote calibration of the radioactive microphones is described below.

As explained in the INCOT facility description (Appendix 1), it was necessary to cut the leads and support shaft of the sensor assembly at a point 100 in. above its lower end in order for this section to fit in the cask used to transfer it to the EBR-II Hot Fuel Examination Facility (HFEF). Each lead was cut with wire cutters and both ends were capped to prevent possible tritium release and to prevent moisture entering the vent tubes and mineral insulated cables during the steam cleaning operation which was performed in the transfer cask prior to transfer from the cask to the HFEF hot cell.

Table 3

YY05 Microphone RMS Signal Levels
with Facility Temperature at Approximately 1000°F

RMS - Charge Amp Output - Volts

Date	Temperature of Microphone #3 °F	M1	M2	M3	M4	M5	M6
12/15	989	.30	.34	.40	.27	.16	.20
1/5	990	.27	.21	.47	.40	.29	.22
2/4	982	.36	.28	.53	.47	.39	.27
3/1	982	.38	.34	.68	.50	.50	.27
3/8	983	.38	.43	.64	.48	.47	.26
3/13	988	.44	.30	.59	.42	.50	.28
3/23	970	.45	.47	.65	.58	.53	.31
3/30	970	.48	.38	.65	.60	.55	.32
5/23	994	.40	.46	.52	.45	.45	.28
5/27	995	.38	.45	.47	.43	.46	.27
5/30	993	.38	.45	.47	*	.44	.26
6/7	992	.39	.45	.49	-	.46	.26
6/16	991	.34	.44	.48	-	.45	.24
6/25	971	.45	.54	.58	-	.45	.28
7/2	987	.38	.37	.53	-	.48	.29

* On 5/30/76 M4 was connected directly to continuous recording equipment bypassing DAS and manual recording modes.

In the hot cell the bands which retained the leads in place and the two rods which retained the stainless blocks of the assembly were cut as planned. The six microphones and associated flux monitor capsules were removed and placed in a container for transfer in a shielded cask to ANL/E for detailed examination.

Table 4 Sensitivity of YY05 Microphones
Before and After Irradiation

	Sensitivity pC/bar		Sensitivity Ratio <u>After Irradiation</u> <u>Before Irradiation</u>
	Before Exposure	After Exposure	
Microphone No. 1	1,520	1,190	.78
Microphone No. 2	1,080	830	.77
Microphone No. 3	1,480	1,380	.93
Microphone No. 4	1,630	1,420	.87
Microphone No. 5	1,690	1,600	.95
Microphone No. 6	1,330	1,240	.93

Before recalibration of the six microphones in the ANL/E hot cell it was necessary to reestablish connections to the signal leads which had been cut in the process of removing the YY05 bundle from the reactor. This was accomplished by passing the leads through a small hole in a shield plug so that a length sufficient to remove the stainless steel sheath and make electrical connections to the lead wires projected beyond the outside of the cell wall. Fig. 19 is a photograph of the projecting lead after the connector had been installed. The extension lead wire which connected this termination to the charge amplifier during calibration can be seen draped over the microphone lead.

The G19 calibrator was prepared for use in the hot cell by wrapping its exterior with cloth tape and arranging a plastic bottle as a liner to prevent contamination of the interior cavity. The performance of the unit was rechecked against a reference hydrophone after these modifications to assure that no abnormal behavior was introduced by addition of the plastic liner. Fig. 20 shows the calibrator in the hot cell with one of the YY05 microphones in the positioning fixture devised to assure standard positioning in the calibrator. Fig. 21 shows the microphone in place in the calibrator. The vent tube on the microphone

Fig. 19 Connection Used for Post Irradiation Calibration of YY05 Microphones

Fig. 20 Microphone in Holding Fixture in Front of G19 Calibrator in Hot Cell

Fig. 21 Microphone in Place in Calibrator in Hot Cell

pictured was broken at the weld to the coupling on the microphone housing during handling and was sealed with the plugged tube shown in Fig. 20. Vent tubes on other microphones extended with the signal lead out through the top of the calibrator. The charge amplifier and drive equipment for the calibrator were located outside the hot cell. An unirradiated HT microphone which had been calibrated against a reference LC10 hydrophone prior to insertion into the hot cell was used as a reference.

Resistance of the microphones varied between 6 megohms and 200 kilohms. Since several of the rubber tubes used to seal the cut ends of the cable were accidentally removed from the cable ends at various times in the transfer from the reactor to the ANL/E cave, it is probable that moisture had penetrated into the mineral insulation of the signal leads causing the abnormally low resistances. The resistance values were adequate for meaningful calibration of the microphones.

4.3 Microphone Resistance

The electrical resistance of each microphone was monitored both on the DAS and by periodic manual readings taken by the EBR-II instrument technicians.

It was important to monitor this parameter for two reasons. First, the minimum shunt resistance which the charge amplifiers can normally tolerate is 10 kilohms. The bulk resistivity of lithium niobate drops rapidly with increasing temperature such that the resistance of the elements in a typical microphone at 1200°F is 20 kilohms. The solid line in Fig. 22 illustrates the average of the resistance of several microphones as a function of temperature with ample oxygen supplied through the vent tubes. It is apparent that any appreciable drop in microphone resistance at the highest anticipated exposure temperature in the reactor would be expected to adversely affect the ability of the charge amplifier to produce a satisfactory output signal.

A second effect which causes reduced microphone resistance is apparently a surface effect which occurs when the crystals are exposed to oxygen deficient atmospheres at elevated temperatures. The effect is reversible. The microphone vent tube-oxygen reservoir systems were provided to assure that a supply of oxygen sufficient to prevent or reverse this occurrence was present. By monitoring the microphone resistance it was possible to detect changes in microphone resistance which exceed the normal decrease with increasing temperature as indicated by the solid line in Fig. 22.

Fig. 22 Pre-Irradiation Resistance of YY05 Microphones

Fig. 23 Resistance of YY05 Microphones at Beginning of First Reactor Run

The points plotted on Fig. 22 represent the individual resistances measured while the six YY05 microphones were in the conditioning furnace just prior to installation in the YY05 sensor assembly. Fig. 23 presents resistance data obtained shortly after the first reactor startup with the experiment in place. Selected data from various dates were chosen to provide readings over as wide a temperature range as possible. At this time all resistance values recorded were within the range which would be considered normal for microphones operating at these temperatures except for microphone no. 2 located in the center of the core region. An effort to alleviate the low resistance of this microphone by activating the oxygen reservoir heating system to enhance oxygen interchange between the microphone and its reservoir was unsuccessful.

Fig. 24 shows resistance data obtained on March 14 and 20, midway through the second reactor run of exposure. Again, with the exception of microphone no. 2, all values are within the normal range. Note, however, that the resistance of M2 has increased somewhat from earlier readings.

Data plotted on Fig. 25 are from readings of May 27, June 5, and June 17 near the midpoint of the third reactor run. For reasons not completely understood, after the extended reactor shutdown (20 days) during most of which time the microphones were at 600°F, the resistance of M2 did not drop to the very low values it had displayed since the start of the experiment but rather maintained the high average values plotted on this figure. At this time resistance values for all microphones were within the acceptable range.

Fig. 26 shows resistance measurements taken during the last ten days that the experiment was in the reactor. Although the resistance of microphone no. 3 was significantly below the typical line it was still well above the 10 kilohms minimum specified as acceptable for input to the charge sensitive amplifiers. All other data were within the normal range of resistance values.

4.4 Visual Examination of LiNbO_3 Plates

After completion of the post irradiation water calibration, the microphone cases were opened in the hot cell by cutting away the outer edges of one face to remove the circumferential weld with a milling machine. Since the diaphragms were tightly adhered to the platinum foil cushions which were in turn adhered to the crystal faces, it was found necessary to mill a hole completely through the diaphragm at the edge to allow insertion of tools to separate the diaphragms from the crystal surfaces. Fig. 27 shows the appearance of a typical unit after opening in this fashion. Note that the platinum foil cushion which

Fig. 24 Resistance of YY05 Microphones During Second Reactor Run

Fig. 25 Resistance of YY05 Microphones at Beginning of Third Reactor Run

Fig. 26 Resistance of YY05 Microphones Near End of Third Reactor Run

Fig. 27 Typical Microphone After Removal of One Diaphragm

was between the crystal and the inner face of the diaphragm is tightly adhered to the diaphragm face and that fragments of the crystal surface are adhered to it. This occurred on both faces of all six microphones. After removal of the alumina positioning ring it was necessary to exert considerable force to separate the crystals from the lower diaphragm surface. Fig. 28 shows the two crystals adhered to the central platinum foil electrode and supported by the electrical connection tab of the electrode after this separation was accomplished. The two lithium niobate discs of each of the six microphones, and of an unirradiated control microphone, adhered to the central electrode in this fashion.

Fig. 29 shows the outer surface of one plate from each of the six microphones and Fig. 30 shows the outer surfaces of both plates from the unirradiated control microphone. Note that all of the plates including those from the control microphone exhibit a similar degree of cracking. All of the plates displayed tints of brownish coloration to varying degrees which is typical of lithium niobate which has been exposed at high temperatures to slightly oxygen deficient atmospheres. The milky appearance of the M3 and M6 crystals is indicative of a more severe oxygen starvation. The white splotches on the surface of the crystals are areas which adhered to the platinum cushion and were dislodged when the diaphragms were separated from them.

It was found impossible to separate any pieces larger than 1 to 2 mm across from the central electrodes. As described below, it was found that pieces of this size were ample for establishing optical and piezoelectric properties of the irradiated LiNbO_3 .

4.5 Piezoelectric Coefficient (d_{33})

In order to establish the response of the active elements to applied pressure, piezoelectric coefficient (d_{33}) measurements are routinely made on all lithium niobate plates before incorporation into microphones. The procedure employed is described in Appendix 6 of this report. The tester used measures the response of only a small point on the crystal and it was determined that valid measurements could readily be made on the pieces of the plates which could be separated from the platinum foil central electrodes of the elements removed from the irradiated microphones. Since the elements were only slightly radioactive these measurements could be made by hand in a chemical hood. Values measured on the plates before incorporation into the microphone and those measured after irradiation are summarized in Table 5.

Fig. 28 Opened Microphone Showing LiNbO_3 Plates Adhering to Central Electrode

M1

M2

M3

M4

M5

M6

Fig. 29 LiNbO_3 Plates Removed from YV05 Microphones

Fig. 30 LiNbO_3 Plates Removed from Unirradiated Control Microphone

Table 5

Piezoelectric Coefficient (d_{33}) Values
for Lithium Niobate Plates from YY05 Microphones

<u>Microphone No.</u>	<u>Crystal No.</u>	d_{33}	d_{33}
		<u>Before Irradiation</u>	<u>After Irradiation</u>
1	B22	22.9	23.0
	B23	23.4	24.2
2	B15	23.2	23.1
	B5	23.2	22.4
3	B16	23.2	22.6
	B7	23.2	23.6
4	B10	22.9	22.4
	B9	23.1	23.0
5	B13	24.5	22.3
	B8	23.9	23.6
6	B12	22.8	24.0
	B6	22.3	22.3
HT9-6*	B3	23.8	24.5
	B19	23.6	

* Control microphone exposed in sodium loop at comparable temperatures and times.

4.6 Optical Measurements

Optical birefringence measurements of fragments of the irradiated lithium niobate plates were made by W. Primak. His report of this examination is included as Appendix 7 of this report. Table 6 summarizes his results.

The optical birefringence is a measure of the anisotropy of the crystal. In earlier irradiations of lithium niobate plates in CP5 at low temperature (40°C)¹ the birefringence was drastically reduced. As is indicated by the tabulated results, no significant change in this parameter occurred during the YY05 irradiation.

4.7 Tritium Accumulation

From estimated total neutron exposure and the weight of lithium in a single microphone it was calculated that a maximum of .12 CC-STP (.3 curies) of tritium would have been generated in microphone no. 2. As a safety precaution, before proceeding with removal of the experiment assembly from the reactor, a gas sample was taken from the no. 2 oxygen reservoir and analyzed for tritium content. The sampling and analysis were performed by the ANL/W analytical group using the following procedure. An evacuated 2 liter flask was attached to the outlet of the 1/8 in. valve on the no. 2 oxygen reservoir and both the flask valve and the reservoir valve were opened allowing the pressure to equilibrate in the system. Since the volume of the reservoir-vent tube-microphone housing system was about 100 ml, this procedure resulted in 95% gaseous contents of the microphone vent tube system being transferred to the flask. The contents of the flask were then passed over a CuO catalyst bed at 600°C and collected in H_2O in an ice bath. Analysis of the ^3H activity in the water indicated the presence of 15.5 μci of tritium in the total sample. The small amount of tritium activity remaining in the microphone systems caused very little difficulty in the removal operation which required that the vent tubes and mineral insulated cables be disconnected in the terminal box before removal of the sensor bundle from the reactor and that they be cut prior to transfer to the EBR-II Hot Fuel Examination Facility (HFEF) for disassembly.

Primak found no tritium activity in fluids used to wash the lithium niobate plates prior to making post-irradiation optical measurements (Appendix 7). This is contrary to results of similar measurements made on fluids used to wash plates irradiated at low temperatures in CP5.¹

Table 6 Optical Birefringence of
Crystals from YY05 Microphones

<u>Sample</u>	<u>Neutron Exposure 10²² nvt</u>	<u>Corrected Retardation</u>
YY05 unirradiated control	--	0.110
YY05 M1	2.64	0.113
YY05 M2	2.58	0.101
YY05 M4	.86	0.112
YY05 M5	.61	0.106
YY05 M6	.25	0.103
Ref. 1 unirradiated 36-day Y-cut control	--	0.119
Ref. 1 irradiated 700 days in CP5 @ 40°C (after heating at 140°C)	.009	0.0131

5.0 Summary and Conclusions

5.1 Summary

The data presented in this report show no evidence of progressive deterioration of lithium niobate based microphones of the ANL design due to seven months exposure to the high temperature, neutron-gamma environment of the EBR-II core. Data were obtained by continuously monitoring the microphone output signals and resistances during exposure, and from post irradiation calibration and evaluation of the lithium niobate elements after removal from the irradiated microphones. Exposures of from $.24 \times 10^{22}$ nvt to 2.64×10^{22} nvt at maximum temperatures of from 850°F and 1100°F had no marked effect on the RMS value of the signal output when measured at times of similar reactor and INCOT facility operating conditions, in the microphone resistances under operating conditions, in the microphone sensitivities as determined by calibration in a water filled calibrator, or in the piezoelectric (d_{33}) or optical properties (birefringence) of the lithium niobate elements of the microphones.

The many temperature cycles to which the microphones were exposed as a result of both reactor operation and INCOT valve operation are not typical of temperature conditions which will exist in a commercial LMFBR. From a structural point of view we have not observed any detrimental effects on any of our microphones due to temperature cycling. These temperature cycles do enhance the interchange of gas (oxygen and gaseous oxides) between the microphone housing and the exterior reservoirs and in this respect the conditions of this test may be less severe than the same exposure at constant temperature. Since this gas exchange can also be enhanced by cycling the temperature of the external reservoirs by use of a heating system, such as was installed in this experiment, we are confident that microphones with vent systems similar to those of this experiment could be operated in a constant temperature environment with equal success.

With two exceptions the microphone electrical resistance data as plotted in Figs. 21 through 26 fall within the range normally observed for microphones of this design when supplied with adequate oxygen and exposed to similar conditions out-of-reactor. The two exceptions noted are microphone no. 2 during the first two reactor runs and microphone no. 3 during the last reactor run. At the beginning of the experiment the resistance of M2 dropped to between 2 and 5 kilohms at 900°F compared to a normal 200 kilohms at this temperature. Although there was some improvement (6 to 8 kilohms) it remained low until the beginning of the third

reactor run when it increased to normal. While this resistance is below the 10 kilohms specified as the minimum input impedance required for satisfactory operation of the charge amplifier, we were able to obtain satisfactory signals from M2 throughout this period. Operation with such low input impedance does result in increased electrical noise in the output signal. Observations that the resistance of M2 did not decrease with increasing temperature as would be expected if the lithium niobate resistance were the controlling resistance and that no change in resistance occurred when the external oxygen reservoirs were heated to force circulation of the vent system gas indicate that the low resistance was probably due to low cable resistance and not to oxygen starvation of the lithium niobate elements.

The less severe lowering of the resistance of M3 during the last reactor run was probably due to oxygen starvation of the crystals. The resistance of M3 did drop with increasing temperature and the milky appearance of the elements removed from this unit in post irradiation examination is typical of oxygen starved lithium niobate. The oxygen reservoir heater system was not operated during this period.

The lowering of the sensitivity of the microphones as determined by water calibration (Table 4) is not considered indicative of a progressive effect which might result in continued loss of sensitivity over a longer exposure period. There is no correlation of loss of sensitivity with increased neutron dose or with exposure temperature. The post irradiation measurements were made remotely in a hot cell under conditions which were not ideal. It is possible that the differences are due, at least in part, to this inability to exactly reproduce the calibration conditions. The absence of change in the fundamental d_{33} coefficient of the lithium niobate plates is probably a more reliable indication of the lack of deterioration due to the exposure received.

Cracking of the lithium niobate plates has been observed in microphones exposed to severe temperature cycles and has no detectable effect on the microphone response. The surface crazing evident in the pictures of the plates removed from the microphones (Figs. 29 and 30) almost certainly occurred as a result of the disassembly process and is indicative of good coupling between the diaphragm and the crystal faces. The brownish discoloration which was observed in varying degrees in all of the crystals as well as the milky appearance of M3 and M6 is attributed to varying degrees of oxygen starvation. This has been verified by heating crystals with these discolorations in air for short periods and observing

the disappearance of the coloration.

5.2 Conclusions

1. It is entirely feasible to project the use of lithium niobate based immersed microphones as the primary sensors for acoustic surveillance of LMFBRs.
2. The requirements for an external, sealed, small volume, oxygen reservoir connected to the microphone housing by a small diameter (.020 in. I.D.) tube can be accommodated with little operating inconvenience or safety hazard.
3. Such vent systems will probably be required for long term reliable operation of lithium niobate based microphones under conditions which will exist in the near-core environment of a commercial LMFBR.
4. Exposure to neutron fluences up to 2.6×10^{22} nvt at maximum temperatures between 800°F and 1140°F has no appreciable effect on the fundamental piezoelectric response of the natural lithium niobate plates used in these microphones.
5. Since there was no appreciable damage to the lithium niobate elements in these microphones due to the neutron exposure, it appears that there is little to be gained by using lithium niobate which is manufactured from the Lithium 7 isotope only.
6. This experiment provides no indication of a limitation on the maximum life of this type of microphone in an LMFBR environment similar to that of the EBR-II core, i.e., no progressive deterioration with increasing neutron and gamma exposure.

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APPENDIX 1

DESCRIPTION OF EBR-II
INCOT FACILITY

Appendix 1

Description of EBR-II INCOT Facility

The EBR-II In-Core Instrument Test Facility (INCOT)

INCOT is a facility designed to enable experimental irradiations of instrument sensors and instrumented non-fissile materials specimens in the EBR-II core. It is described in detail in Reference (3) of this report. The following description has been extracted from the "GUIDE FOR IRRADIATION EXPERIMENTS IN EBR-II".

INCOT has the capability for testing instrument components such as thermocouples, resistance thermometers, flux sensors, ultrasonic sensors, acoustic sensors, flow sensors, pressure transducers, level transducers, strain gauges, cable materials, and other materials such as boron carbide, stainless steel, etc. These may be tested in a gas environment, they may be individually encapsulated in a sodium environment (or any other medium that can be contained in such capsules), or they may be tested in the primary system coolant sodium.

The test sensors must be inserted or removed when the reactor is not operating. The elevation of one sensor, or the entire group of sensors, may be varied to expose them to a wide range of neutron flux levels. The facility offers flexibility for handling a variety of sensor sizes and for meeting a range of temperature requirements. The choice of any of three basic sensor assembly models, to fit within the thimble assembly, depends on the experimental test desired.

Details of the sensor assembly (central sensor tubes) which contain the test sensors or materials are custom built according to the needs of each specific experiment, unless the preceeding sensor assembly can be utilized.

The test sensors or materials supplied by the experimenter must fit inside a 1.4 in. nominal diameter sensor tube of the sensor assembly. The test facility (Fig. 1-1) includes the thimble assembly (Fig. 1-2) installed and operated in control rod position No. 8, an elevating system to accommodate reactor fuel handling, shielded containers for handling the

Fig. 1-1 INCOT Overall Arrangement

Fig. 1-2 INCOT Thimble Assembly

irradiated components, a preheating and postirradiation check location, and general supporting facilities.

The thimble assembly is approximately 35 ft long and extends from the sensor lead terminal box (located above the rotating shield plugs) into the primary tank reactor vessel and reactor core. A special guide tube assembly, installed in control rod position No. 8 of the core, receives the thimble assembly. At the upper end of the thimble assembly, shielding slugs are located in the rotating shield plug area and a bellows seal for blanket gas is located just above the rotating shield plug.

Gamma heating is used to achieve the desired temperature, and the primary sodium coolant is utilized to regulate this temperature. The temperature operating range is dependent on the coolant flow rate and the thermal resistance between the sensor and the INCOT internal coolant sodium flow. The test sensors in Model 3, (used for the YY05 experiment) are cooled directly by sodium. The temperature rise in the thimble assembly includes heat produced above and below the core. The coolant flow can be varied from 0.6 to 40 gpm, allowing the sodium coolant temperatures to vary from 700°F to a maximum (structural thermal stress-limited) level of 1250°F.

Surrounding the flowing sodium are three concentric tubes with gas filled annulus; the inner tube (sensor tube) contains or located the flowing sodium; the outer two tubes and the gas annulus serve mainly as insulators. The sodium flow is regulated by the coolant flow control device which is located at the bottom of, and actuated by, the sensor tube. Actuation is by means of small angles of rotation of the sensor tube.

The elevating system raises and lowers the thimble assembly a total distance of approximately 80 in. to permit normal reactor fuel handling. The driving force is accomplished through twin ball bearing lead screws and gear train by a reversing-gear type motor. The insertion and removal of the sensors or thimble assembly is accomplished by a thimble

assembly handling container. Biological shielding is required around the lower portion of the handling containers.

Fig. 1-3 is a view of the top of the small rotating plug in EBR-II showing the location of exterior portions of the INCOT facility.

A facility is available in the reactor building for pre-heating INCOT assemblies before insertion in the reactor. The heated section is approximately 20 ft long with an I.D. of 3.4 in. The facility can also be used for postirradiation heated or cooled instrument checkout provided that the irradiated components can be contained in and unloaded directly from the shielded INCOT handling container. This location can be used for postirradiation comparison or calibration of test sensors when calibration means are provided by the experimenter. The test sensor bundle must be cut to a 100 in. length (or somewhat less) to fit into a special ANL transfer container. This shielded container is utilized to transport the sensor bundle through building air locks to HFEF for final disposition.

Fig. 1-3 INCOT - Facility in Control Rod Position No. 8

APPENDIX 2

EVALUATION OF FLUX MONITORS

ARGONNE NATIONAL LABORATORY CEN-1600/PROG-1.6

March 23, 1976

TO: A. P. Gavin Components Technology
FROM: R. R. Heinrich *RRH* Chemical Engineering Division
R. J. Popek *RJP*
SUBJECT: Neutron Dosimetry for High Temperature Microphones

Neutron dosimetry has been completed for the three flux and three spectral dosimeter sets associated with your high temperature microphones irradiated during Runs 75-77 in EBR-II. Saturated reaction rates were calculated based on a total irradiation time of 207.0 days at an average reactor power of 41.65 MW and were corrected for decay back to July 9, 1975, 0340 hrs (MDT), the end of the irradiation. Flux and fluence values were calculated using the measured reaction rates and the SAND-II code; in all cases, a solution of less than 5% standard deviation was obtained. These results are reported in Attachment 1 relative to their approximate reactor position.

The neutron spectra obtained from the three spectral dosimeter sets (Sets 4-6) are reported in Attachment 2. These spectra were calculated using nine reaction rates and the SAND-II code. A solution of less than 5% standard deviation was also obtained for these calculations; however, these spectra more realistically have a 10-20% total uncertainty. The differential neutron fluxes ($n/cm^2\text{-sec-MeV}$) are reported in a 29-group energy structure, ranging from 1×10^{-10} to 20 MeV.

Absolute Ge(Li) counting of the M-3 microphone has identified several prominent nuclides which are reported below.

<u>Nuclide</u>	<u>dpm at the End of Irrad.</u>
^{94}Nb	4.1×10^8
^{95}Nb	6.1×10^{10}
^{182}Ta	1.1×10^9
^{110m}Ag	1.1×10^6
^{124}Sb	2.2×10^7
^{54}Mn	1.6×10^6

If we can be of any other assistance to you, please do not hesitate to call us.

RRH/RJP:dm

cc: L. Burris (2)
F. A. Cafasso

9700 South Cass Avenue, Argonne, Illinois 60439 • Telephone 312-739-7711 • TWX 910-258-3285 • WUX LB, Argonne, Illinois

ATTACHMENT 1

Flux and Fluence Obtained from Dosimetry of High Temperature Microphones

Dosimeter Set	Approx. Reactor Position		Flux ₁₄ x 10 ¹⁴ (n/cm ² -sec)	Fluence x 10 ²¹ (n/cm ²)
	R(cm)	Z(cm)		
1	23.0	-16.0	14.7	26.4
2	23.0	- 1.1	14.4	25.8
3	23.0	15.0	12.5	22.4
4	23.0	30.9	4.83	8.63
5	23.0	46.0	3.43	6.14
6	23.0	77.1	1.37	2.45

ATTACHMENT 2

Neutron Distribution Obtained from Spectral Dosimeter Sets for High Temperature Microphones

Lower Group Energy, MeV	Differential Neutron Flux (n/cm ² -sec-MeV)		
	Set #4	Set #5	Set # 6
1.00 x 10 ⁻¹⁰	1.17 x 10 ¹⁷	1.20 x 10 ¹⁷	9.29 x 10 ¹⁶
5.04 x 10 ⁻⁶	2.48 x 10 ¹⁶	2.66 x 10 ¹⁶	2.01 x 10 ¹⁶
8.31 x 10 ⁻⁶	1.55 x 10 ¹⁶	2.05 x 10 ¹⁶	1.91 x 10 ¹⁶
1.37 x 10 ⁻⁵	9.20 x 10 ¹⁶	1.01 x 10 ¹⁷	7.06 x 10 ¹⁶
2.26 x 10 ⁻⁵	3.05 x 10 ¹⁷	2.83 x 10 ¹⁷	1.39 x 10 ¹⁷
3.72 x 10 ⁻⁵	1.33 x 10 ¹⁷	1.27 x 10 ¹⁷	6.27 x 10 ¹⁶
6.14 x 10 ⁻⁵	1.85 x 10 ¹⁶	2.32 x 10 ¹⁶	1.81 x 10 ¹⁶
1.01 x 10 ⁻⁴	1.21 x 10 ¹⁶	1.65 x 10 ¹⁶	1.10 x 10 ¹⁶
1.67 x 10 ⁻⁴	1.96 x 10 ¹⁶	1.86 x 10 ¹⁶	8.52 x 10 ¹⁵
2.75 x 10 ⁻⁴	1.64 x 10 ¹⁶	1.45 x 10 ¹⁶	6.25 x 10 ¹⁵
4.54 x 10 ⁻⁴	2.76 x 10 ¹⁶	2.78 x 10 ¹⁶	1.43 x 10 ¹⁶
7.49 x 10 ⁻⁴	1.89 x 10 ¹⁶	1.90 x 10 ¹⁶	1.03 x 10 ¹⁶
1.23 x 10 ⁻³	1.51 x 10 ¹⁶	1.48 x 10 ¹⁶	6.83 x 10 ¹⁵
2.04 x 10 ⁻³	3.03 x 10 ¹⁵	2.95 x 10 ¹⁵	1.55 x 10 ¹⁵
3.36 x 10 ⁻³	1.65 x 10 ¹⁵	1.63 x 10 ¹⁵	1.03 x 10 ¹⁵
5.53 x 10 ⁻³	1.41 x 10 ¹⁵	1.28 x 10 ¹⁵	7.98 x 10 ¹⁴
9.12 x 10 ⁻³	2.11 x 10 ¹⁵	2.01 x 10 ¹⁵	1.10 x 10 ¹⁵
1.50 x 10 ⁻²	2.51 x 10 ¹⁵	2.40 x 10 ¹⁵	1.45 x 10 ¹⁵
2.48 x 10 ⁻²	1.25 x 10 ¹⁵	1.19 x 10 ¹⁵	7.20 x 10 ¹⁴
4.09 x 10 ⁻²	9.26 x 10 ¹⁴	8.93 x 10 ¹⁴	4.86 x 10 ¹⁴
6.74 x 10 ⁻²	7.16 x 10 ¹⁴	6.92 x 10 ¹⁴	3.58 x 10 ¹⁴
1.11 x 10 ⁻¹	5.34 x 10 ¹⁴	5.06 x 10 ¹⁴	2.47 x 10 ¹⁴
1.83 x 10 ⁻¹	3.43 x 10 ¹⁴	2.95 x 10 ¹⁴	1.16 x 10 ¹⁴
3.02 x 10 ⁻¹	4.01 x 10 ¹⁴	2.44 x 10 ¹⁴	4.71 x 10 ¹³
4.98 x 10 ⁻¹	2.40 x 10 ¹⁴	1.05 x 10 ¹⁴	1.21 x 10 ¹³
8.21 x 10 ⁻¹	8.23 x 10 ¹³	2.87 x 10 ¹³	2.43 x 10 ¹²
1.35	2.41 x 10 ¹³	6.85 x 10 ¹²	3.64 x 10 ¹¹
2.23	6.34 x 10 ¹²	1.47 x 10 ¹²	4.68 x 10 ¹⁰
3.68	8.66 x 10 ¹¹	1.84 x 10 ¹¹	5.31 x 10 ⁹
6.07	3.01 x 10 ¹⁰	6.12 x 10 ⁹	1.80 x 10 ⁸

APPENDIX 3

ISOTOPIC ANALYSIS OF LITHIUM IN LiNbO_3 PLATES

ARGONNE NATIONAL LABORATORY

9700 South Cass Avenue

Argonne, Illinois 60439

REPORT ON CHEMICAL ANALYSIS

Date Received: 11/19/74

Sample: Lithium Niobate Discs

Source: A. P. Gavin

Mass Spectrometric Isotopic Analysis

YOUR NUMBER	OUR NUMBER		Ratio	Mole %	Wt %
B2	75-0393-01	Li 6	0.08080	7.48	6.48
		Li 7	1.00000	92.52	93.52
C7	-02	Li 6	0.08279	7.65	6.63
		Li 7	1.00000	92.35	93.37

Reported by: Alice Essling

Date: 03/21/75

Copies to: A. P. Gavin ✓

Analyst: AE

N. Dudey

DR

R. Meyer, AE File

APPENDIX 4

ANALYSIS OF VENT SYSTEM GAS FOR TRITIUM

ARGONNE NATIONAL LABORATORY

Idaho Division

Serial No. 85155

Cost Code: _____

ANALYTICAL SAMPLE RECORD

Date Received 7-9-75

Sample from FRR-II

Radioactive _____, High _____, Low _____, ALPHA _____ BETA _____ GAMMA _____

Analyzed by _____

Sampled by HP

Radiation Survey _____

Run No. _____

Method: Colorimetric _____, Fluorometric _____, Polarographic _____, Coulometric _____

Report to R. TOMBLISON / H. SINE

Mass Spec. _____, Radiochem. _____, Chromatographic _____, Other _____

LAB NO.	DATE HOUR	SAMPLE DESCRIPTION	ANAL. FOR	SAMPLE WEIGHT	QUAN. USED. ML.	INSTRUMENT READING				STAND WT.	YIELD DECAY CORR.	ANALYTICAL RESULTS		
						SAMPLE	BLANK	STAND	STAND + SAMPLE			UC PPM	WT. %	ATOM %
	<u>7-9-75</u> <u>0900</u>	Can No. _____												
		Material: _____												
			<u>3H</u>			<u>50379 cpm</u>			<u>eff. = .293</u>					<u>3.4 x 10⁸ d/l</u>
						<u>50 ml sample →</u>			<u>5/100 d/l →</u>					<u>15.5 uci/g</u>
		<u>Sampled with a evacuated 2 liter flask</u>												
		<u>Purged for 1 hr thru CuO @ 600 °C into H₂O in an ice bath</u>												

Mass Spec. _____

Gamma Spec. _____

Time Counted _____

Approved HP

Chart _____

Chart No. _____

Date _____ Hour _____

Date 7/9/75

APPENDIX 5

PROCEDURE FOR LOW FREQUENCY CALIBRATION OF MICROPHONES IN WATER

ANL HIGH TEMPERATURE MICROPHONE FABRICATION
PROCEDURE NO. 7

LOW FREQUENCY CALIBRATION OF MICROPHONES IN WATER

Purpose

The purpose of this procedure is to define a standard method for determining the sensitivity of Sodium Immersible Microphones relative to a secondary standard hydrophone. It is to be used to establish the sensitivity of sodium immersible microphones and to monitor the effects of various exposure tests on them.

Equipment

1. U.S. Navy Underwater Sound Reference Laboratory (USRL) Type G19 acoustic calibrator.
2. Calibrator drive and sensor read out equipment per drawing and description in Figure 1.

Related Documents

1. Instructions for USRL Type G19 calibrator dated February 1966.
2. Data sheet for calibration of acoustic sensors at low frequency in water.

Procedure

1. Check that instrument and calibrator connections are according to diagram (Fig. 1).
2. Check that instrument settings are as indicated in Table 1.
3. Brush inside walls of calibrator tank with stiff bristle brush to assure that no gas bubbles remain and check that water level is 1/2 in. below top of tank.
4. Record serial number of reference hydrophone and mount so that tip is $5\frac{1}{2} \pm \frac{1}{8}$ in. below top edge of tank and in the center of the tank.
Connect transducer cable to pC/bar input connector on relay rack.

5. Set oscillator frequency to 300 hz and adjust drive voltage to 0.50 V RMS on drive voltmeter.
6. Select signal amplifier range to give a reading of between 1 and 10 volts on output meter. Record setting on data sheet.
7. Record output meter reading at these settings.
8. Change oscillator frequency to 400 hz and adjust drive voltage to 0.50 RMS. Record output meter reading on data sheet.
9. Repeat step 8 for 450, 500, and 550 hz settings.
10. Determine hydrophone sensitivity by adding five readings and multiplying by 200 X full scale pC setting of signal amplifier as indicated on data sheet. If sensitivity varies more than 5% from hydrophone calibration value recheck all instrument settings, hydrophone location in calibrator tank, and water level, and be sure that no bubbles exist on side walls or on hydrophone. Recheck reference hydrophone sensitivity per steps 5 through 9 above. Do not proceed until sensitivity determined for reference hydrophone agrees within $\pm 5\%$ of calibration. (For reference hydrophone LC 10 serial #1596 calibration is 35,600 pC/bar, allowable range is 33,800 to 37,400 pC/bar.)
11. Disconnect reference hydrophone and remove from calibrator tank.
12. Mount microphone to be calibrated in approximate center of tank with center of diaphragm $5\frac{1}{2} \pm \frac{1}{8}$ in. below top of tank. Connect signal lead to pC/bar input connector on relay rack.
13. Proceed with calibration as in steps 5 through 9.
14. As indicated on data sheet, add five readings for each sensor and multiply by 200 X full scale pC setting on signal amplifier. Result is sensitivity of sensor in pC/bar.
15. Remove microphone from calibrator and replace calibrator cover.

DATA SHEET

FOR

LOW FREQUENCY CALIBRATION OF HIGH TEMPERATURE MICROPHONES IN WATER*

Date _____

	Type	Serial No.	Comments
Reference Hydrophone			
Sensor #1			
Sensor #2			

	Reference Hydrophone	Sensor #1	Sensor #2
Signal Amplifier (A) Full Scale Setting, pC			

Frequency Hz	SIGNAL AMPLIFIER OUTPUT VOLTS		
300			
400			
450			
500			
550			
Sum of 5 Readings			
Sum X 200 X (A) = Sensitivity in pC/bar			

Calibrated by: _____

*To be used with instructions provided in construction procedure #9, "Low Frequency Calibration of Sodium Immersible Microphones in Water".

TABLE I

Instrument Settings for Acoustic Sensor Calibration

Endevco 2730 - Charge Amplifier

<u>Control</u>	<u>Position</u>
Function	Operate
Ground	Grounded
Convertor	Internal
Filter	Out
Sensitivity Range	1-10 pC/g
Variable Sensitivity dial	5.00
Full Scale Range	As required

Oscillator

<u>Control</u>	<u>Position</u>
Frequency Range	X100
Power	on
Load	on
Frequency dial	As per procedure
Amplitude	As per procedure

Calibrator Drive Amplifier

<u>Control</u>	<u>Position</u>
Power	on

APPENDIX 6

PROCEDURE FOR INSPECTION OF LITHIUM NIOBATE DISCS

ANL HT MICROPHONE FABRICATION

PROCEDURE NO. 1

INSPECTION OF LITHIUM NIOBATE DISCS

Purpose

The purpose of this procedure is to establish the physical dimensions and piezoelectric sensitivity of lithium niobate discs received from a supplier.

Equipment

1. Dial type thickness gauge .250 in. range with .001 divisions
2. Micrometer caliper 0 - 1 inch
3. Binocular microscope 5 to 10 power
4. "D" tester - Acrotech Laboratories
5. Oscilloscope
6. Voltmeter 0 - 100 mV RMS range
7. Small forceps for handling crystals
8. Sharp pointed scribing tool
9. Felt tipped pen

Materials

1. Disposable wiping tissues
2. Ethyl alcohol (c.p.)

1. Record purchase order number, date received, and quantity received in lab notebook. Attach copy of PO, spectrographic analysis report, and any other information received from vendor with shipment to notebook page.
2. Each crystal should be contained separately in a small envelope within an individual plastic or cardboard box. If crystals are not so packaged when received they should be separated and so packaged before proceeding.
3. Mark each individual envelope and the top and bottom of each individual box with a serial number which is different for each crystal and indicative of the lot from which it was taken.
4. After marking packaging as above, no more than one crystal is to be out of its protective envelope at any given time until permanently marked.
5. Connect "D" tester and other instruments as indicated in diagram below.

6. Using reference standard crystal set tester control to obtain a reading of 80 mV on DVM.
7. With numbered side of standard crystal up, set trace on oscilloscope so that a positive peak is displayed above the center line of screen.

8. Remove standard crystal and place crystal to be checked in position in tester being sure that point of contact probe does not scratch surface of crystal.
9. If oscilloscope has a positive trace at center of screen leave crystal as is, if negative remove crystal, turn over, replace in holder and recheck for a positive trace display.
10. With felt tipped pen place a small dot on the top surface of the crystal at front edge of the crystal (edge toward operator) to establish a polarity and index mark for engraving a permanent code number on each crystal.
11. Using locating shield and guide measure "D" coefficient in five places on crystal surface as indicated below. Record readings in table in data book (see sample data sheet attached).

12. Replace crystal in its numbered protective envelope.
13. Proceed to mark and measure remaining crystals rechecking tester output with standard crystal after every five crystals measured. If setting is off more than .5 mV reset and recheck previous five crystals. (Use same location on surface of standard for all checks.)
14. Check polarity and measure "D" values for all crystals in lot.
15. Each crystal is to be permanently marked on the surface whose polarity matches that of the numbered side of the "D" tester standard. The marking is to be placed on the edge nearest the operator when the "D" values were measured. (This position was temporarily marked with ink in Step 10 above.)

16. Using binocular microscope and a needle sharp scribe of the hardest material available scribe a serial number and lot letter on each disc. Care should be taken to make markings as light as possible and still legible.
17. With dial micrometer check thickness of each disc in five places. Record average on data sheet. Note any discernable deviation from average.
18. With micrometer caliper measure diameter of each disc on two diameters approximately 90° apart and record average on data sheet.
19. Check flatness of each side of each disc and record maximum number of light bands deviation from flatness.

INFORMATION TO BE RECORDED IN DATA BOOK

P.O. # _____ Name of Manufacturer _____

Manufacturer's Identification No. for lot _____

Quantity in lot _____ Lot Letter Designation (scribed on crystals) _____

Crystal No.	"D" Value					*Thickness	Diameter	Flatness	Comments
	1	2	3	4	5	Ave.	Inches	Inches	

APPENDIX 7

OPTICAL MEASUREMENTS OF IRRADIATED LITHIUM NIOBATE PLATES

ARGONNE NATIONAL LABORATORY

April 23, 1976

To: D. L. Price

From: W. Primak *WAP*

Re: Cooperation with CT: Examination of Lithium Niobate Plates
Removed from EBR-II Microphones Tested in EBR-II

Ref: W. Primak and T. T. Anderson, "Metamictization of Lithium Niobate
by Thermal Neutrons", Nucl. Technology 28, 235 (1975)

Previous memo in this series is Primak to Price, 12/13/74

INTRODUCTION: In accordance with previous understandings with T. T. Anderson and with W. W. Managan, and at the specific request of William Carey, currently in charge of this aspects of the microphone project, lithium niobate plates removed from the microphones placed into EBR-II during runs 75-77 for a total irradiation time of 207 days were examined for the purpose of evaluating radiation damage which occurred in these plates. The specimens were transferred by A. P. Gavin who also furnished information about their radiation history, T. T. Anderson furnished information about their thermal history. A. P. Gavin also furnished material which had been heated without irradiation and information about the effects of oxygen loss. E. Monahan assisted in handling radioactive material and in taking readings of the wavelength spectrometer.

GENERAL: The plates had been mounted in pairs separated with a platinum foil and compressed with stainless steel diaphragms. All of the plates adhered to the platinum foils, and all of the plates showed the typical circular fracture patterns associated with symmetrical non uniform loading. The same fracturing existed in plates which had been placed into a high temperature loop without irradiation. It is therefore concluded that the primary cause of this fracturing is absence of load distributing plates in the microphone assembly.

The irradiated plates and platinum foils gave a dose rate under 50 mR/hour @ 1" each; hence, it was deemed safe to handle them in our hot lab facility, Rm C136. Dose rate at tongs positions were under 5 mR/hr. Dose rate outside of the hood was negligible. Washings were monitored for tritium activity; none was found.

OPTICAL MEASUREMENTS: The primary examination was measurement of optical birefringence. It is a measure of the anisotropy of the crystal. During the disordering which occurred on irradiating lithium niobate in CP-5, the birefringence could be measured to better than 1%, a much higher precision than could be obtained with any of the acoustical measurements which were made. Also it is a bulk measurement made without contact, hence there is no question of a change caused by surface deterioration.

PROCEDURE FOR BIREFRINGENCE MEASUREMENTS: The plate is placed on the stage of a petrographic microscope between crossed polarizers. The substage condenser is removed and a white light illuminator of fairly high intensity is used. A low power objective and ocular are employed, and the image is projected onto the slit of a wavelength spectrometer. The channeled spectra are measured. In the present determinations the data were fitted to a 4th degree polynomial from which a number proportional to birefringence can be calculated. The proportionality factor includes the dispersion of lithium niobate for which adequate data is not at hand. The simplest practical procedure is to compare the results with those for an unirradiated plate of known orientation. The procedure was found to work perfectly well with a small fragment (~ 1 mm), hence attempts to separate the plates from the platinum foils were abandoned.

RESULTS: Results were obtained for 8 plates. First was a plate as received from the manufacturer; second was a fragment from a plate taken from a microphone which had undergone high temperature treatment without irradiation; and fragments from 5 irradiated microphones, M6, M5, M4, M2, and M1; and last, a milky plate, heated but not irradiated was measured also. The results are given in Table I.

It appears from these results that the orientations of the plates exhibit some variation. For example, the measurements of one original plate (not given) corresponded to $41-42^\circ$ Y-cut. The measurements of the heated plate correspond to a $38-39^\circ$ Y-cut. It is obvious that no significant change in birefringence has occurred. Thus loss of anisotropy is not occurring; metamictization is not taking place.

OPACITY AND OXYGEN LOSS: The irradiated specimens developed a milky opacity which was greater the higher the irradiation temperature. The highest temperature sample, M3, was too opaque to determine the birefringence with the present equipment. According to A. P. Gavin the milkiess is associated with oxygen loss. Oxygen loss may cause a brownish coloration, or milkiess with a reddish hue, or with a white hue. The detailed circumstances associated with this variation in appearance appear to be unknown. As seen in Table I, the birefringence appears to be unaffected within the precision of the present determinations.

CONCLUSIONS: There is no evidence of a loss of anisotropy in the crystals exposed in EBR-II. To understand what this means from the point of view of radiation damage, consider Fig. 10 and Table IV in Primak and Anderson's paper on the effects found on irradiation of lithium niobate near room temperature in the thermal reactor CP-5. The fast and the thermal fluence have very different effects on lithium niobate hence the scale for presenting the radiation damage was transformed (by ad hoc calculation) to displaced atoms per atom of the solid. In CP-5 at 0.028 displaced atoms/atom, birefringence had been reduced 24%; and at 0.22 displaced atoms/atom it had been reduced 89% and piezoelectric response reduced at least 10-fold. In the present irradiations in EBR-II, the displaced atoms/atom range from 2 to 24, 2 orders of magnitude above those obtained in CP-5, and there is no indication of loss of birefringence. In high temperature ion bombardments of lithium niobate, a marked reduction in effects was noted by 500°C (to be reported separately). Lack of radiation damage in EBR-II is therefore attributed in part to the high temperature. Marked effects from the injection of gas was found in the ion bombardment experiments. Therefore, part of the high deterioration encountered in CP-5 may have been caused by the retention of tritium and helium gas formed in the fissioning of the lithium. The lithium fissioning ratio (per displaced atom/atom) is estimated as 320 times smaller in EBR-II than in CP-5 because of the low thermal flux in EBR-II.

WP:cjo

bcc: W. Carey, CT
D. Y. Smith, SSS
T. T. Anderson, CT
B. R. Frost, MSD
G. W. Cunningham, ERDA
D. K. Stevens, ERDA
W. Primak, SSS
Reading Files OTD, SSS
CF

Table I. Birefringence of EBR-II exposed lithium niobate

Item	Fluence ^a (10 ²¹ /nvt)	Irradiation Temp. ^b			Measured Retardation	Corrected Retardation	Orientation ^d (deg)
		High (27%) °C	Normal (68%) °C	Low (5%) °C			
Original	None				0.0719	0.1105	39-40
Heated	None				0.0754	0.117	38-39
A-2 ^e	None				0.0775	0.113	39-1/2
A-2 ^f	None				0.0738	0.107	41
M6	2.45	516	451	404	0.0706	0.103	
M5	6.14	544	454	707	0.0725	0.106	
M4	8.63	563	452	416	0.0764	0.112	
M2	25.8	549	484	443	0.0694	0.101	
M1	26.4	461	424	399	0.0730	0.113	

^aHeinrich and Popek to Gavin 3/23/76.

^bGavin, Andersen, and Managan, Trans. Am. Nucl. Soc., Montreal Meeting June 1976 (in press).

^cCorrected for thickness and to principle direction assuming 36° Y-cut. Not corrected for dispersion.

^dAssuming birefringence is 0.125/mm and sample is properly aligned in beam.

^eHeated, milky from oxygen loss.

^fHeated in air, clarified.