Results From The Testing Of High Temperature Neutron Detectors In A Liquid Metal Fast Breeder Reactor At Temperatures Up To 1000°F (538°C)

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RESULTS FROM THE TESTING OF HIGH TEMPERATURE NEUTRON DETECTORS IN A LIQUID METAL FAST BREEDER REACTOR AT TEMPERATURES UP TO 1000°F (538°C)*

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ABSTRACT
This paper presents a summary of results from the performance testing of two high temperature neutron fission counter-cable assemblies and a high temperature gamma compensated ionization chamber-cable assembly in a typical Liquid Metal Fast Breeder Reactor (LMFBR) nuclear environment at temperatures up to 1000°F (538°C). A brief description of the test program, instruments and facilities is also included.

INTRODUCTION
The Liquid Metal Fast Breeder Reactor (LMFBR) program has set stringent requirements on the neutron monitoring systems that are necessary to measure the core neutron flux for subcriticality, control and safety purposes. In the LMFBR, large residual gamma fluxes, that are produced by sodium, structural and core material activation, in the order of 10⁶ R/hr are foreseeable in the vicinity of the neutron sensors. Neutron monitoring systems must therefore be capable of discriminating against these large unwanted gamma signals. The design of the reactor internals usually makes it difficult to obtain a sufficient neutron flux outside the vessel to allow subcritical source range or startup detectors to produce the required minimum count rate. Low level flux monitoring (LLFM) sensors must therefore be placed in the high temperature environment of the reactor vessel and operate in the temperature range from 300°F (149°C) to 1100°F (593°C). Placing low temperature sensors in cooled thimbles, such as is done in the Experimental Breeder Reactor-II (EBR-II), becomes economically unrealistic for large plants. In vessel placement of neutron sensors require that radiation damage from large total integrated neutron doses have a negligible effect on the performance of the sensors to assure an extended life and therefore minimize their costly replacement. Retracting the sensors from a high level neutron flux to a low level neutron flux environment can extend the sensor life but poses handling and safety problems. Wide range neutron monitoring systems utilizing single, fixed position, high temperature sensors are a desirable concept. Clearly, the need exists for high temperature neutron sensors that will operate in the LMFBR in-vessel environment and specifically for fixed position, high temperature sensors that will operate in the counting, mean square voltage (MSV) and ionization current modes. Proven reliable high temperature neutron sensors for the LMFBR environment are not yet available.

Several detector manufacturers are involved in developing and supplying commercial high temperature neutron detectors. Domestic manufacturers include Reuter-Stokes Inc., Westinghouse Electric Corporation and General Electric Co. Foreign manufacturers include the British Twentieth Century Electronics Limited and The Plessey Company Limited; and the French Radiotechnique - Compelec.

The Argonne National Laboratory (ANL) Components Technology Division has been engaged in a Neutron Detector Technology development program that evaluates and qualifies prototype or commercial neutron sensors that may meet present and future requirements for LMFBR applications.

This paper presents the significant results obtained from the testing of a Reuter-Stokes Model RSN-286 and a Westinghouse Model WX-31384 fission counter-chambers; and a Westinghouse Model WX-30950 gamma compensated ionization chamber in the EBR-II Nuclear Instrument Test Facilities (NITF). A brief description of the test program, instruments and facilities is also included.

TEST PROGRAM
A typical neutron detector evaluation program consists of preliminary testing, reactor life proof-testing and post-irradiation failure analysis. The latter may not be required if the reactor testing did not produce a failure mode.

During the preliminary testing phase of the program, the electrical and nuclear specifications of the detector are checked and compared to the published values of the manufacturer. This phase of the program also establishes the pre-irradiation base data for future comparisons. In addition to the room temperature testing, the detector-cable assembly is also tested in a furnace facility at temperatures up to the maximum rated detector temperature. This testing includes a 30 day life test at the maximum test temperature that will be used in the reactor proof-testing phase of the program.

The furnace facility can heat 15 feet of the detector-cable assembly in about the same geometry as

*Work performed for the U.S. Energy Research and Development Administration.
the assembly that will be used during the reactor proof-testing. The furnace facility, along with a low level neutron source, is used to establish the electrical and low level neutron pulse counting temperature stability of the detector.

The detector gamma and neutron responses are also established during the preliminary testing phase of the program. A Co$^{60}$ gamma source, capable of producing gamma dose rates of $>10^9$ R/hr, is used to establish the gamma sensitivity of the detector and the discriminator cut-off setting. The Co$^{60}$ gamma source, in conjunction with a low level neutron source, is used to establish the gamma discrimination ratio or the ability of the sensor to detect neutrons in the presence of a gamma flux. A high level neutron source, capable of producing a thermal equivalent neutron flux of $>10^6$ n/s, is used to establish the direct current and mean square voltage neutron sensitivities. Once the electrical and nuclear characteristics of the detector are established over the same temperature range as will be studied during the reactor proof testing phase of the program, the detector is packaged for insertion into the reactor test facility.

During the reactor proof testing phase of the program, the detector is placed into one of the EBR-II instrument thimbles of the Nuclear Instrument Test Facilities (NITF). The output current, preamplifier ac signal voltage, log count rate, test temperature and numerous experimental test signals along with the output signals of selected reactor plant operating instruments are continuously monitored and recorded by a Data Acquisition System (DAS). These data, when compared with the data collected during the preliminary testing phase, establish the electrical and nuclear performance of the detector, temperature stability, long term radiation damage effects and the ability of the detector to accurately monitor the core neutron flux during all phases of reactor operation in a typical LMFBR environment. Upon completion of this phase of the evaluation program, post-irradiation room temperature testing is performed.

If the detector failed during the reactor proof testing, a failure mode analysis may be performed. The failure mode analysis may be either destructive or nondestructive in nature depending upon the type of failure indicated. The analysis may include electrical testing, detector fill gas analysis, radiography, or disassembly of the detector to examine the interconnection cable and cable seals, detector insulators, seals or electrode material coating.

NUCLEAR INSTRUMENT TEST FACILITIES (NITF)

The Nuclear Instrument Test Facilities (NITF) are the EBR-II 0-1 and J-2 instrument thimbles. Typical operating characteristics of the thimbles at core midplane are listed below for a reactor operating power of 82.5 MW.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>0-1 Thimble</th>
<th>J-2 Thimble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron flux, n/cm$^2$-sec (nv)</td>
<td>$1.5 \times 10^9$</td>
<td>$8.0 \times 10^{10}$</td>
</tr>
<tr>
<td>Gamma activity, R/hr</td>
<td>$5.5 \times 10^4$</td>
<td>$1.2 \times 10^6$</td>
</tr>
<tr>
<td>Gamma heat, W/cc of stainless steel</td>
<td>$0.001$</td>
<td>$0.02$</td>
</tr>
<tr>
<td>Temperature, °F</td>
<td>125-700</td>
<td>700-1200</td>
</tr>
<tr>
<td>°C</td>
<td>(52-371)</td>
<td>(371-649)</td>
</tr>
<tr>
<td>Test volume, in.</td>
<td>4.85</td>
<td>10 x 240</td>
</tr>
<tr>
<td>cm.</td>
<td>6.2</td>
<td>10 x 84</td>
</tr>
<tr>
<td>12.2</td>
<td>10 x 609.6</td>
<td></td>
</tr>
<tr>
<td>15.7</td>
<td>10 x 213.4</td>
<td></td>
</tr>
</tbody>
</table>

These two facilities are available at EBR-II for proof-testing sensors in a neutron and gamma flux environment at elevated temperatures.

0-1 Thimble Facility. The 0-1 instrument thimble is placed vertically outside the neutron shield. The thimble is immersed in the sodium coolant in the reactor primary tank and can maintain a temperature of about 125°F (52°C) by pulling filtered reactor building air down through the inside of the thimble insert and up through a cylindrical outside baffle to the exhaust cooling filters. The temperature of the thimble can be varied from 125°F (52°C) to 700°F (371°C) by manually throttling the amount of air flow through the thimble.

The 0-1 thimble test volume is 4.85 in. (12.3 cm) in diameter and about 20 ft (6.1 m) long. The test volume extends 1 ft (30.5 cm) below core midplane. The sensors are held in position by connecting a carriage to the bottom of the shield plug. The shield plug has one 1.5 in. (5.8 cm) ID signal conduit which is spiraled and requires the signal cables to have bend radii less than 24 in. (61 cm). A 2-in. (5.1 cm) ID conduit, normally used for cooling, is also available, if needed for cables.

The sensor package and carrier cannot be larger than 4-3/8 in. (11 cm) OD. More than one sensor can be placed end-to-end providing the total package can fit into the 4-3/8 in. (11 cm) carriage.

J-2 Thimble Facility. The J thimbles are slanted about 17° from vertical and penetrate into the neutron shield. The overall length of the thimble is 28.3 ft (8.6 m). The J-2 thimble has been modified to permit testing of sensors at temperatures from 700°F (371°C) to 1200°F (649°C). The facility design provides for the insertion of $^{60}$Co gamma sources to increase the gamma flux to 10$^6$ R/hr with the reactor shut down.

The temperature can be controlled over the range of 700°F (371°C)-1200°F (649°C) by the use of heaters which provide heat along 19.5 ft (5.9 m) of the thimble and by special cooling air to the experiment. Four independently controlled heater zones provide uniform temperature throughout the test zone. Direct current heaters are employed in order to reduce electrical noise. The sensor test volume is 6.25 in. (15.9 cm) ID and .0 ft (2.1 m) long. The remaining length is used for heating the sensor cables.
The test volume can accommodate two sensor packages side-by-side if the total diameter of both does not exceed 5.75 in. (14.6 cm). Sensor packages of diameters up to 3 in. (7.6 cm) can be placed end-to-end. Larger diameter sensor packages require spacing in order to allow the leads from the lower units to pass upward to the top of the facility. A flexible spiral-wound stainless steel electrostatic shield hose of 1.5 in. (3.8 cm) ID can be used to house the cables and leads that run from the sensor to the top of the facility.

**FISSION COUNTER TEST PLAN**

A Reuter-Stokes Model RSN-286 and a Westinghouse Model WX-31384 fission counter-chamber were tested in the EBR-II NITF 0-1 thimble facility as EBR-II designated Experiment NI-1 over the temperatures range from 125°F (52°C) to 700°F (371°C) and in the EBR-II NITF J-2 thimble facility as EBR-II designated Experiment NI-2 over the temperature range from 700°F (371°C) to 1000°F (538°C). The detectors were to be tested to evaluate their suitability for use in wide range neutron monitoring system applications at temperatures up to 1200°F (649°C).

The RSN-286 fission counter-chamber is provided with an integral, mineral insulated, triaxial cable 28 ft (8.5 m) long. The detector has a close spaced (0.004 in.) (1 mm) concentric cylinder configuration electrically isolated from the outer housing. It is coated with a 0.06 plating thickness of 1.5 mg/cm² and is filled with one atmosphere of argon.

The WX-31384 fission counter-chamber is provided with two integral, mineral insulated, coaxial cables 28 ft (8.5 m) long. The electrodes are electrically isolated from the outer housing. It is coated with a 0.03 plating thickness of 2 mg/cm² and is filled with one atmosphere of argon-1% nitrogen gas mixture.

Experiment NI-1 was initiated at 125°F (52°C) in the NITF 0-1 thimble facility with the detectors connected to charge sensitive preamplifiers and a set of test instruments. The charge sensitive preamplifier output was fed to a linear amplifier, discriminator and log count rate meter and simultaneously to a true RMS voltmeter and a picoammeter. The direct current output, pulse count rate and the mean-square-voltage (MSV) signals were recorded continuously on the EBR-II Data Acquisition System (DAS). In addition, integral bias and excitation voltage characteristics were determined automatically with the reactor shutdown, at intermediate power levels and at full power.

After the detector characteristics were determined at 700°F (371°C) in the J-2 thimble with the test instruments, the detectors were disconnected from the charge sensitive preamplifiers and test instruments and matched to commercial wide range MSV systems using charge sensitive preamplifiers. The charge sensitive preamplifier output was fed simultaneously to a source range channel (equivalent in function to the linear amplifier, discriminator and log count rate meter of the test instruments), an intermediate range MSV channel (equivalent in function to the RMS voltmeter of the test instruments), and an additional wide range channel (equivalent in function to the picoammeter of the test instruments). In addition, the wide range systems provided period and trip information.

During the wide range system operation, the signal outputs including period signals and trip indications were recorded continuously on the EBR-II DAS.

After the detectors performance with the wide range systems was established at 700°F (371°C), the detectors were remated with the test instruments. The test temperature was increased in 100°F (38°C) increments over the range from 700°F (371°C) to 1000°F (538°C). However, the test was terminated at 1000°F (538°C) due to degraded detector performance.

In the original test plan, as previously stated, the detectors were to have been tested at temperatures up to 1200°F (649°C) including an additional wide range system test at 1100°F (593°C). However, the test was terminated at 1000°F (538°C) due to degraded detector performance.

The reactor proof testing of these detectors has been completed and they were removed from the facility and placed in storage to allow the residual gamma activity to decay. A destructive failure analysis will be performed.

**COMPENSATED IONIZATION CHAMBER TEST PLAN**

A Westinghouse Model WX-30950 compensated ionization chamber (CIC) is being tested in the EBR-II NITF 0-1 thimble facility as EBR-II designated experiment NI-3 over the temperature range from 100°F (38°C) to 700°F (371°C). Saturation and compensation characteristics during reactor operation are determined automatically and the normal operating current and excitation voltages are continuously recorded by the EBR-II Data Acquisition System (DAS).

The WX-30950 (S/N 703901) CIC is supplied with three WX-30954-28 mineral insulated (MI) cables 28 ft (8.5 m) long. The CIC is designed for guard ring construction to minimize insulator leakage and for operation with a fixed, applied
compensating voltage. The sensitive area is coated with 1 mg/cm² of boron enriched in ¹⁰⁰ to 92% and is filled with one atmosphere of nitrogen.

The testing of the detector at 700°F (371°C) is at this time continuing.

FISSION COUNTER TEST RESULTS

EXPERIMENT NI-1: 0-1 THIMBLE FACILITY

The RSN-286 (S/N M402) and WX-31384 (S/N 703901) counters were tested in the EBR-II 0-1 thimble facility over the temperature range from 125°F (52°C) to 700°F (371°C) for over 7000 hours, including 1800 at 700°F (371°C). The RSN-286 detector total integrated neutron flux was -8 x 10¹⁵nvt and the gamma dose 1.5 x 10¹³R. For the WX-31384 detector, the total integrated neutron flux and gamma dose were 4.8 x 10¹⁴nvt and -1.5 x 10⁶R respectively. Little, if any, change in performance characteristics was indicated during Experiment NI-1 for the RSN-286 detector. The WX-31384 detector malfunctioned intermittently throughout the test. The malfunction was determined to be a high resistance path in the signal circuit caused by a failed weld at the interface between the detector signal electrode and the integral mineral insulated cable during a post-irradiation destructive failure mode analysis. The direct current signal was not affected by this malfunction but the pulse and MSV signals decreased in value and became erratic at times because of the connection fault and complete data at all temperatures was not obtained. Sufficient data, however, was collected to judge that either detector could be used in wide-range neutron monitoring system applications at temperatures up to at least 700°F (371°C). Both designs could also be considered as prototypes for a low level flux monitor (LLFM) with neutron counting sensitivities of between 0.1 x 0.5 cps/nv. Upon completion of Experiment NI-1, the RSN-286 detector along with a different WX-31384 fission counter were packaged for insertion into the J-2 thimble as Experiment NI-2.

EXPERIMENT NI-2: J-2 THIMBLE FACILITY

The RSN-286 (S/N M402) and WX-31384 (S/N 703902) fission counters were tested in the EBR-II J-2 thimble facility in excess of 20,000 hr at temperatures ranging from 700°F (371°C) to 1000°F (538°C). Table 1 summarizes the integrated neutron flux, gamma dose, and hours of operation accumulated by each detector.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Neutron Flux, nvt</th>
<th>Gamma Flux, R/hr</th>
<th>Time at Test Temp., hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSN-286</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/N M402</td>
<td>4.5 x 10¹⁰</td>
<td>7.9 x 10⁹</td>
<td></td>
</tr>
<tr>
<td>WX-31384</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/N 703902</td>
<td>7.9 x 10⁹</td>
<td>2.0 x 10⁵</td>
<td></td>
</tr>
</tbody>
</table>

Later and the RSN-286 detector performed satisfactorily throughout the remainder of the 700°F (371°C) test.

The RSN-286 detector had developed similar malfunctions during previous testing as had its mate RSN-286 (S/N M401). A destructive failure analysis was performed on the mate RSN-286 (S/N M401) detector and indicated that the failure was probably caused by a dendritic growth of the neutron sensitive material coating causing a low impedance path between the signal and excitation electrodes. It was determined experimentally that the low impedance could be eliminated by discharging a 48.5 F capacitor charged to 600 volts across the electrodes.

Wide Range System tests at 700°F (371°C). In the next phase of the experiment NI-2 test at 700°F (371°C), the detectors were disconnected from the test instruments and mated with wide range Mean Square Voltage (MSV) systems. The WX-31384 detector was mated with a Gulf Electronics Systems Division (GESO) Ten (10) Decade Neutron Flux Monitor and the RSN-286 detector was mated with a Milletron, Incorporated Wide Range Neutron Flux Monitor. The detectors operated with these systems for over 4700 hours at 700°F (371°C). A reactor restart monitored by these systems is shown in figures 1 and 2. The reactor had unexpectedly shut down about five hours before the time sequence shown and the restart represents detector operation in the maximum shutdown gamma flux. The full shutdown count rate on GESO system was about 20 cps while the Milletron system had about 10 cps. Sufficient overlap between the counting and MSV signals...
is indicated from both systems. Both detectors indicated acceptable wide range system performance throughout the 700°F (371°C) test except that a small amount of breakdown pulse noise (BPN) was indicated in the WX-31384 GESD system. This phase of the test accomplished a significant advance in neutron monitoring systems and provided proof of high temperature detector-MSV system compatibility.

Additional Tests at 700°F (371°C). After the Wide Range System test was completed, the detectors were remated with the test instruments and operated at 700°F (371°C) for an additional 4600 hours. A comparison of the RSN-286 detector characteristics from before and after the Wide Range System test indicated essentially unchanged performance and the performance remained essentially unchanged throughout the remainder of the 700°F (371°C) test. A comparison of the WX-31384 detector characteristics from before and after the Wide Range System test indicated a lower BPN voltage threshold in the post Wide Range System test. BPN was evident in the previous 700°F (371°C) test data at detector excitation voltage >600 volts. The BPN voltage threshold continued to decrease throughout the remainder of the 700°F (371°C) temperature. By the end of the 700°F (371°C) test temperature, BPN was evident at >400 volts. The WX-31384 detector could therefore not be operated at a low enough excitation voltage to prevent BPN and still remain saturated at the full reactor power neutron flux of <8 x 10^8nv. The BPN effects limit the detector excitation voltage to <400 volts at 700°F (371°C). With 400 volts applied, the detector is saturated in the MSV or direct current modes of operation at neutron flux levels up to <3 x 10^9nv.

Tests at 800°F (427°C) to 1000°F (538°C). In the next phase of Experiment NI-2, the test temperature was increased in 100°F (38°C) steps from 700°F (371°C) to 1000°F (538°C). The integrated neutron flux, gamma dose and hours of operation for the remaining test temperatures are summarized in Table 1.

The RSN-286 detector developed the previously described low impedance malfunction within days after each test temperature increase and periodically malfunctioned throughout most of the remainder of the test. The malfunction was corrected after each occurrence except for the final attempt at 900°F (482°C) when the low impedance could not be completely eliminated resulting in a significant leakage component in the measured direct signal output and remained throughout the remainder of the test. Sufficient data was collected, however, when the detector was not malfunctioning, to indicate acceptable performance for low level flux monitoring applications.

After the test temperature was increased to 800°F (427°C), the WX-31384 detector indicated gross voltage breakdown at excitation voltage >730 volts. Gross voltage breakdown shall be defined in this paper as a sudden increase in the measured direct current signal output up to the current limit of the detector excitation power supply. The detector continued to indicate gross breakdown throughout the remainder of the test temperature. At the end of the 1000°F (538°C) temperature test, the gross voltage threshold had decreased to <370 volts at full reactor power. Little, if any, change in the pulse counting characteristics at excitation voltages >300 volts was indicated at temperatures up to 1000°F (538°C). The test results indicate that, due to the BPN and gross voltage breakdown effects, the useful range of the detector is limited. However, since the detector is saturated at <300 volts in the pulse counting mode, acceptable operation as an in-vessel low level flux monitor was attainable at temperatures up to 1000°F (538°C).

COMPENSATED IONIZATION CHAMBER TEST RESULTS

The WX-30950 (S/N 703901) CIC is currently being tested in the EBR-II O-2 thimble facility over the temperature range from 100°F (38°C) to 700°F (371°C). Table 2 summarizes the integrated neutron flux, gamma dose and hours of operation accumulated at each test temperature.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Neutron Flux, nv</th>
<th>Gamma Flux, R/hr</th>
<th>Time at Test Temperature, hr</th>
<th>Integrated Neutron Dose, nvt</th>
<th>Gamma Dose, R</th>
</tr>
</thead>
<tbody>
<tr>
<td>WX-30950</td>
<td>1.5 x 10^9</td>
<td>&lt;5.2 x 10^4</td>
<td>4.464</td>
<td>1.248</td>
<td>&lt;6.8 x 10^8</td>
</tr>
<tr>
<td>S/N 703901</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>&lt;22,900</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Little, if any, change in performance characteristics was indicated over the range of temperatures and neutron flux when operated with a fixed gamma compensation voltage of <10 volts and a neutron excitation voltage of >600 volts. The gamma compensation voltage that is required to overcompensate the detector increases with increasing temperature. For example, the detector becomes overcompensated when a gamma compensation voltage between 30 and 40 volts is applied at 100°F (38°C) but requires a voltage of between 80 and 100 volts for overcompensation at 700°F (371°C). This effect is probably due to an increase in intrinsic leakage current at 700°F (371°C) in the signal cable cancelling some of the gamma volume current. About 5-1/2 decades of neutron flux can be monitored on a clean start up but only 1-3 decades on a restart as shown in figure 3. Improved range coverage to
A decade on a restart at all temperatures can be achieved by increasing the normal gamma compensation voltage to 40 volts. If the detector is operated at only 700°F (371°C), 80 volts would give excellent gamma compensation characteristics as shown in Figure 3.

CONCLUSIONS

Based on the results from the fission counter detector test, either detector could be suitable for fixed position in-vessel wide range MSV system or low level flux monitor applications at temperatures up to 700°F (371°C).

The type of malfunction that plagued the RSN-286 throughout this test would preclude the detector from LMFBR application. However, if the malfunction was caused by a dendritic growth of the neutron sensitive material coating as the failure model analysis of the RSN-286 (S/N M401) detector suggested, then the manufacturing process for applying the neutron sensitive material coating could be corrected and improved detector performance obtained. Except for this malfunction, the detector was usable for wide range MSV system or low level flux monitoring applications at temperatures up to 1000°F (538°C).

The WX-31384 detector neutron flux operating range is limited by the low operating excitation voltage resulting from the BPN and gross voltage breakdown effects at temperatures ~700°F (371°C). However, the detector could be operated at a low enough excitation voltage to allow operation as a low level flux monitor at temperatures up to 1000°F (538°C).

Based on the results of the compensated ionization chamber test, the WX-30950 CIC should be suitable for reliable operation at temperatures up to 700°F (371°C) when operated with a fixed gamma compensating voltage.

ACKNOWLEDGEMENTS

The material presented in this paper involves the efforts of many individuals at ANL and the EBR-II. At ANL, recognition is extended to Dr. W. C. Lipinski, Instrument and Control Section Manager, for his encouragement and support, and to V. J. Elsbergas, for his efforts on the Experiment NI-1 and the early phases of the Experiments NI-2 and NI-3 testing programs. At the EBR-II, recognition is extended to K. J. Moriarty, Maintenance Supervisor, C. B. Doe, Experiment Coordination Section, R. W. Hyndman, DAS Manager, M. R. Tuck and all the Instrumentation and Control technicians who helped keep the experiments going.
Figure 1. Reactor restart from a Gulf Electronics System Ten-Decade Neutron Monitor using a Westinghouse WX-31384 fission counter operating at 725°F in the EBR-II NIF J-2 Thimble with -600 volts excitation.
Figure 2. Reactor restart from a Hilletron Wide-Range Neutron Monitor using a Reuter-Stokes RSN-286 fission counter operating at 725°F in the EBR-I NITF J-2 Thimble with -240 volts excitation.
Figure 3. Range of coverage for a Westinghouse MX-30950 Compensated Ionization Chamber operating at 700°F in the EBR-II NITF O-1 Thimble with +600 volts on the neutron excitation volume and -10, -40 or -80 volts on the gamma compensation volume.