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ABSTRACT

A delay-line fission counter with a sensitivity of about 8 counts sec^{-1} / neutrons sec^{-1} cm^{-2} (cps/nv), capable of operating at 550°C (830 K), has been built and is being tested. The counter consists of 19 coaxial, cylindrical electrode pairs within a common shell, connected inductively to form a double-ended delay line, with two sensing cables. The counter's materials are predominantly Inconel and high-purity aluminum oxide, with a total of 9.9 g of uranium oxide coated on the facing surfaces of the electrodes. The counter has been evacuated and processed at temperatures as high as 550°C at which temperature it has a dc insulation resistance of about 30,000 Ω. Its bakeout and insulation resistance behavior is similar to that found in the much smaller high-temperature fission counter, the FC3-HT-2, which has recently completed 2 years of irradiation in the EBR-2, except that the HTHSFC insulation resistance is about 50 times lower. The HTHSFC has been filled with a 90% A + 10% N_2 counting gas mixture, and integral bias curves have been obtained at room temperature. Further testing of its performance at higher temperatures and its long-term aging and subsequent irradiation testing are being planned.

I. FABRICATION

A high-sensitivity fission counter was designed by ORNL to meet the source range flux monitoring requirements of the Advanced Liquid Metal Reactor (ALMR)[1]. This detector must be installed in the sodium-filled vessel, operate at a temperature of about 500 to 550°C, provide sufficient sensitivity to monitor the initial loading of the reactor core, and be qualified for a year's service under normal operating conditions. Its design is based on innovative features used previously in the ultra-high sensitivity fission counter (UHSFC) built for the Clinch River Breeder Reactor Plant project and on the design, fabrication, and testing of a low-sensitivity high-temperature fission counter, the FC-3-HT-2, built at ORNL[2] and tested for two years in the EBR-2 neutron irradiation test facility.

Procedures and details of the fabrication of the HTHSFC are contained in "High-Temperature High-Sensitivity Fission Counter (HTHSFC) Fabrication and Assembly Plan," by J. A. Williams, C. A. Hahs, and R. L. Shepard, currently available only in software (MacFlow) form. The principal flow sheet is shown in Fig. 1. Additional sheets provide procedures, materials lists, inspection and testing requirements, standards, and other details.

The overall mechanical design of the HTHSFC is shown in Fig. 2. A detailed cross-sectional view of one electrode pair is shown in Fig. 3. The counter was fabricated and assembled at ORNL, using cables provided by Westinghouse-Hanford and electrodes that were coated with uranium oxide by Reuter-Stokes, Inc. The significant design features of the HTHSFC are (1) an inductively coupled, delay-line configuration, (2) integral hot-end seals on the two cables, (3) a ruggedized close-packed cylindrical electrode configuration, and (4) an all-Inconel construction, except for the high-purity alumina insulators.

A major fabrication problem, undertaken by Reuter-Stokes, was the deposition and suitable adhesion of a 2-mg/cm^2 coating of uranium oxide on the Inconel electrodes. The procedure developed and performed by Reuter-Stokes is proprietary with them.

2. TESTING

It became evident in initial high-temperature testing of the evacuated, assembled counter that several important fabrication procedures had not been accomplished adequately when the counter's dc insulation resistance dropped to about 3000 Ω at 550°C (830 K). These inadequate procedures involved the cleaning of Inconel parts by electropolishing and the vacuum baking of the uranium oxide-coated electrodes.

Measurements of the counter's dc insulation resistance provided a means for monitoring its condition during evacuation and baking operations. The insulation resistance was determined by measuring the current drawn from a 500 V dc power supply connected across the electrodes.

Following 2 months of vacuum baking, the assembled counter was opened and contamination of insulator surfaces was observed. Two of the 19 electrode pairs that showed very low insulation resistance were bypassed. The reassembled counter was then reevacuated and heated to temperatures as high as 500°C in the succeeding 4 months. During this second bakeout period,

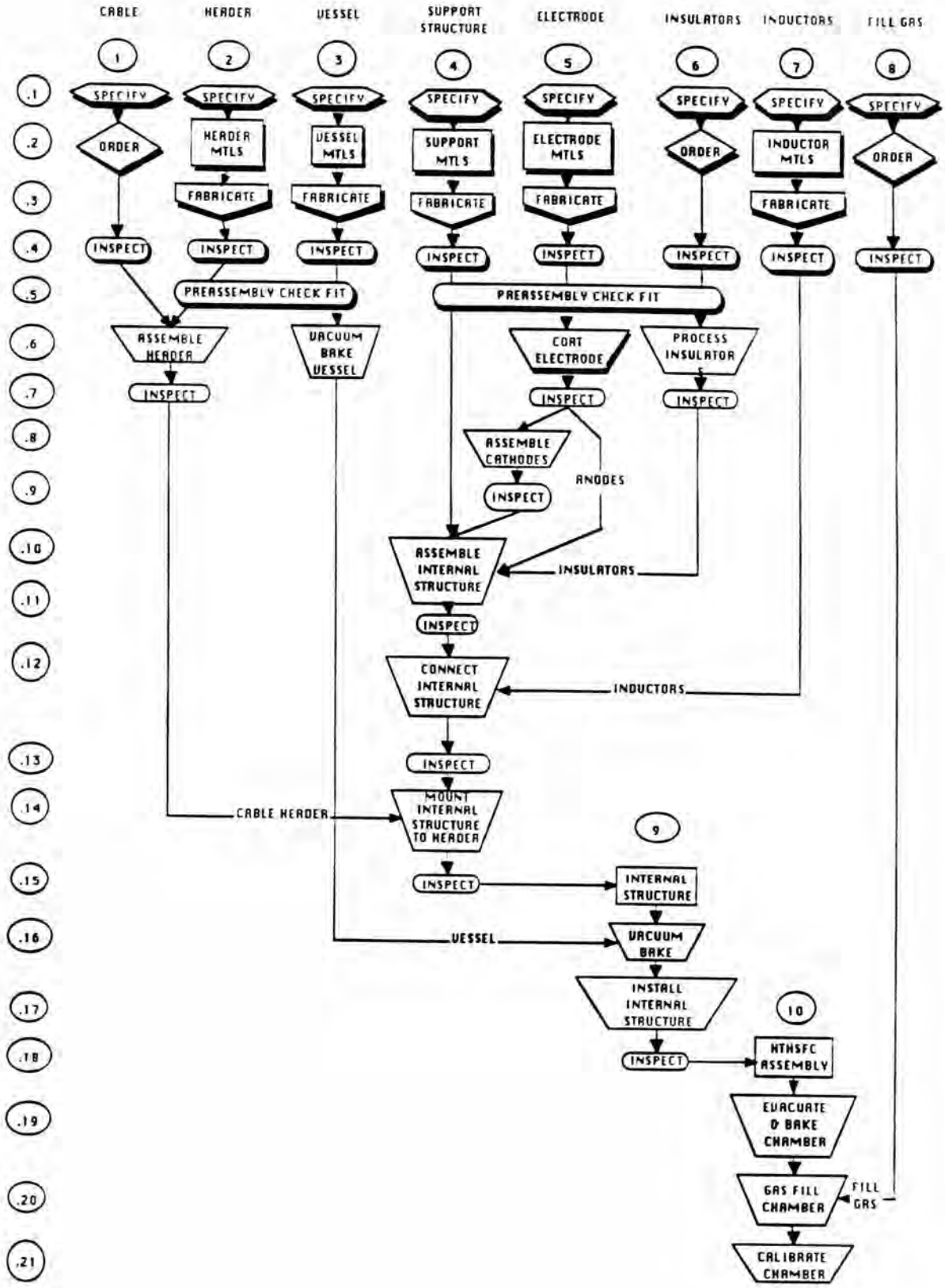
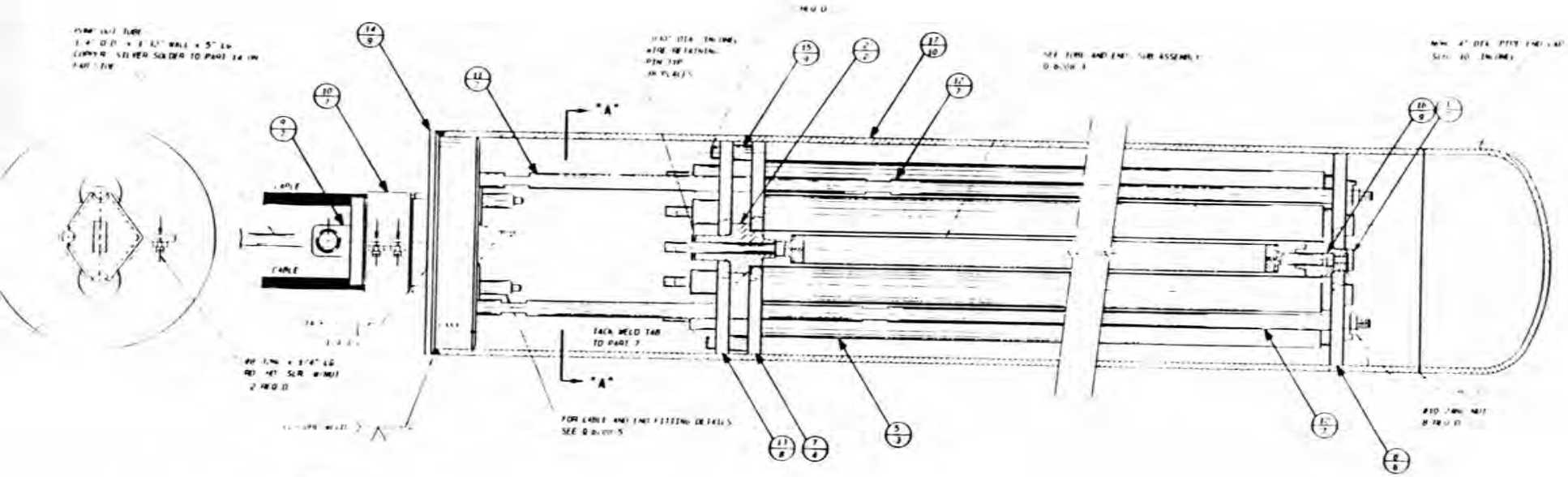
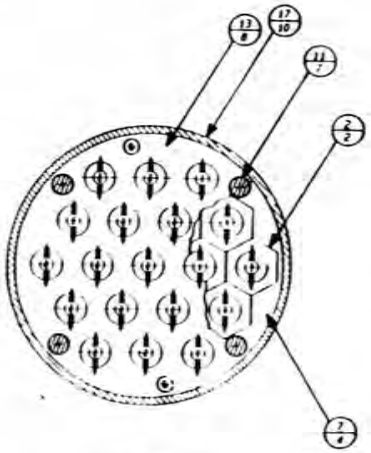


Fig. 1. Fabrication plan for the HTHSFC.





OD: 4.5 in.
LENGTH: 30 in.
MATERIAL: Inconel 600
MAX DESIGN TEMPERATURE: 600°C
SENSITIVITY: 8 cps/nv

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Fig. 2. Assembly drawing for the HTHSFC

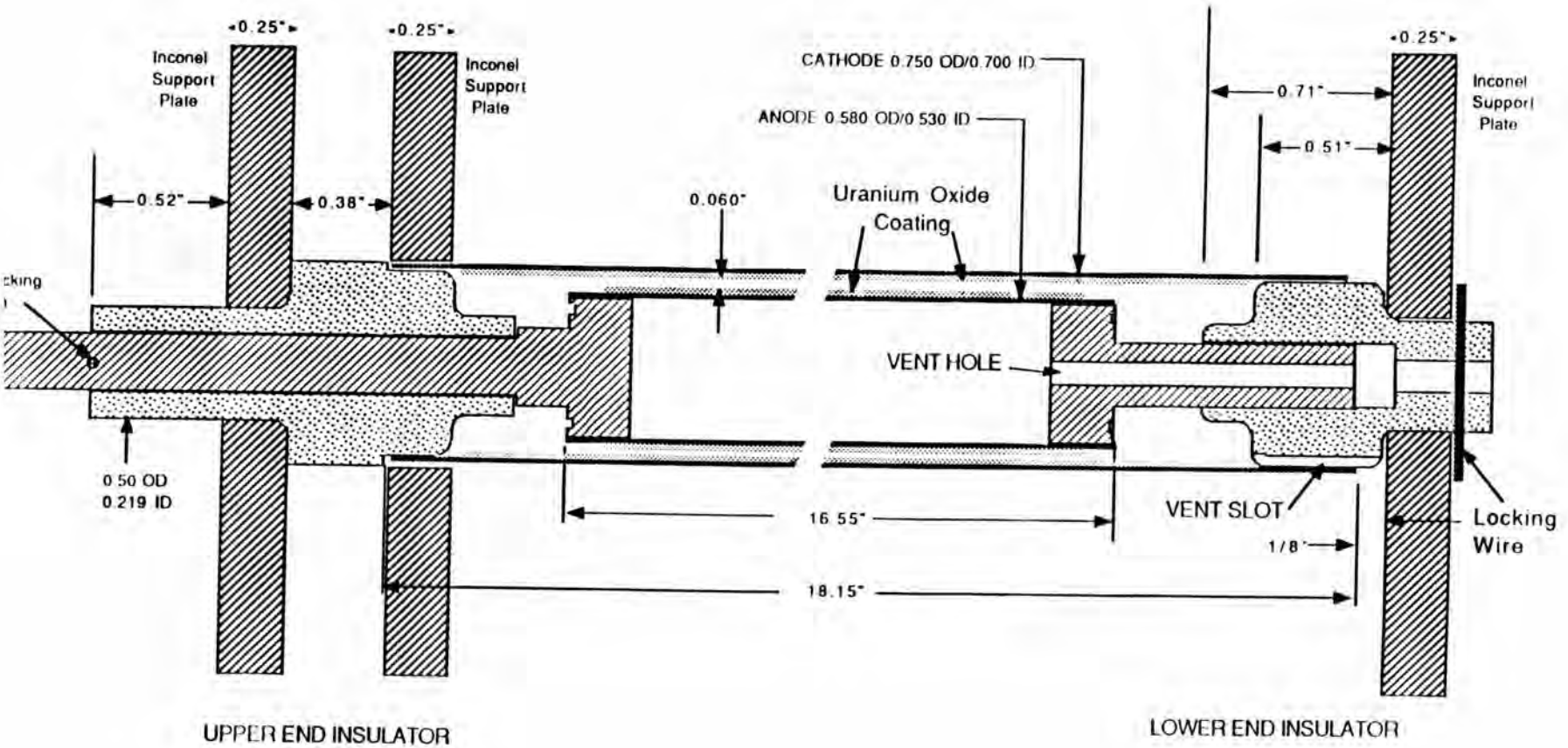

Fig. 3. Detail drawing of HTHSFC individual electrode pair.

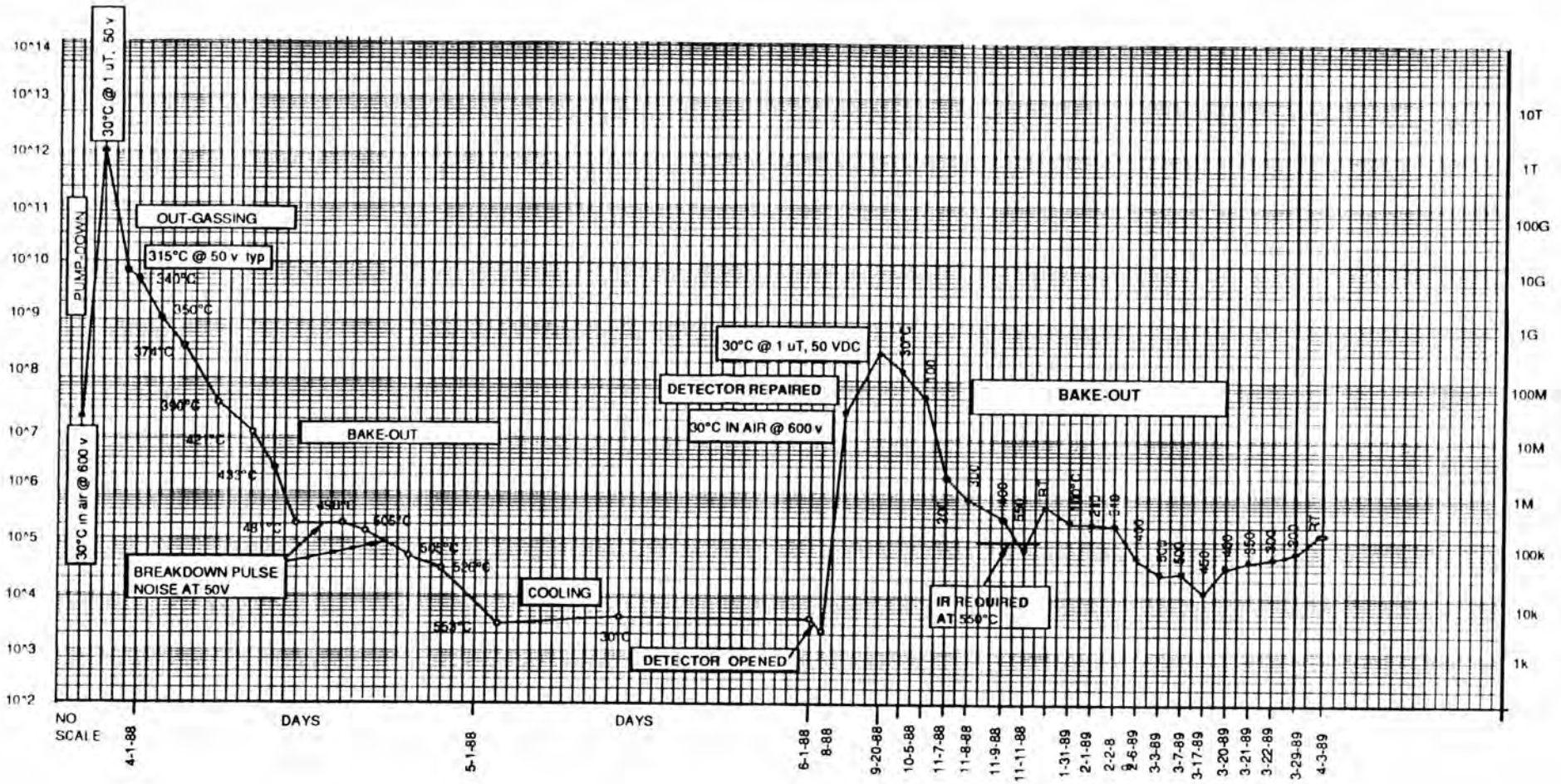

Fig. 4. HTHSFC insulation resistance chronology.

the counter again displayed low dc insulation resistance, ranging from 100,000 to 300,000 Ω at room temperature to about 25,000 Ω at 500°C. A chronology of vacuum baking and dc insulation resistance measurements on the HTHSFC is shown in Fig. 4. While the final dc insulation resistance, measured with 500 V applied between the electrodes, is rather low, no additional breakdown noise is evident in the counter, even at high temperatures.

A similar bakeout dc insulation resistance chronology is shown in Fig. 5 for the smaller FC-3-HT-2. A comparison of these two charts shows that the initial resistance of the two counters differed by about two orders of magnitude, and the final resistance, after vacuum baking, differed by about a factor of 50. This difference in resistance is comparable to the difference in insulator conduction paths in the two high-temperature counter designs. To show this comparison, the dc insulation resistance of the two counters is plotted in Fig. 6 as a function of the reciprocal absolute temperature for initial bakeout, and for the FC-3 with counting gas filling and the HTHSFC during its final vacuum bakeout. The slopes and offsets of the two pairs of curves suggest that the lower IR of the HTHSFC is more likely a characteristic of its design (insulator paths) rather than a result of contamination.

Integral bias curves were obtained for the HTHSFC at room temperature after a preliminary heating to 200°C and filling with counting gas in April 1988, before the extensive vacuum baking shown in Fig. 4. These curves are shown in Fig. 7. A plutonium-beryllium (Pu-B) neutron source placed in a fixed position against the surface of the HTHSFC and pulse count rates were measured at various discriminator voltage levels. The curve labeled "neutron" includes not ony the pulses from neutrons, but also from the noise contribution of the counter and the amplifiers, and from the contribution of alpha pulses generated by the ^{234}U in the electrode coating. In the absence of the neutron source, a second curve, labeled "alphas," shows the contribution of noise and alphas. With the bias voltage removed from the counter, a curve labeled "noise" shows the inherent noise in the detector and the amplifiers.

Integral bias curves obtained recently for the HTHSFC at room temperature following its vacuum bakeout are likewise shown in Fig. 8. As in the previous figure, the detector was filled with 90% A-10% N_2 counting gas, a bias voltage of 500 V was applied, and the Pu-Be source was placed against the surface of the counter. Differences between the two integral bias curves (Figs. 7 and 8) are due to the differences in the gain of the measuring system, which displaces all curves horizontally. If the two figures are superimposed and shifted horizontally so that the

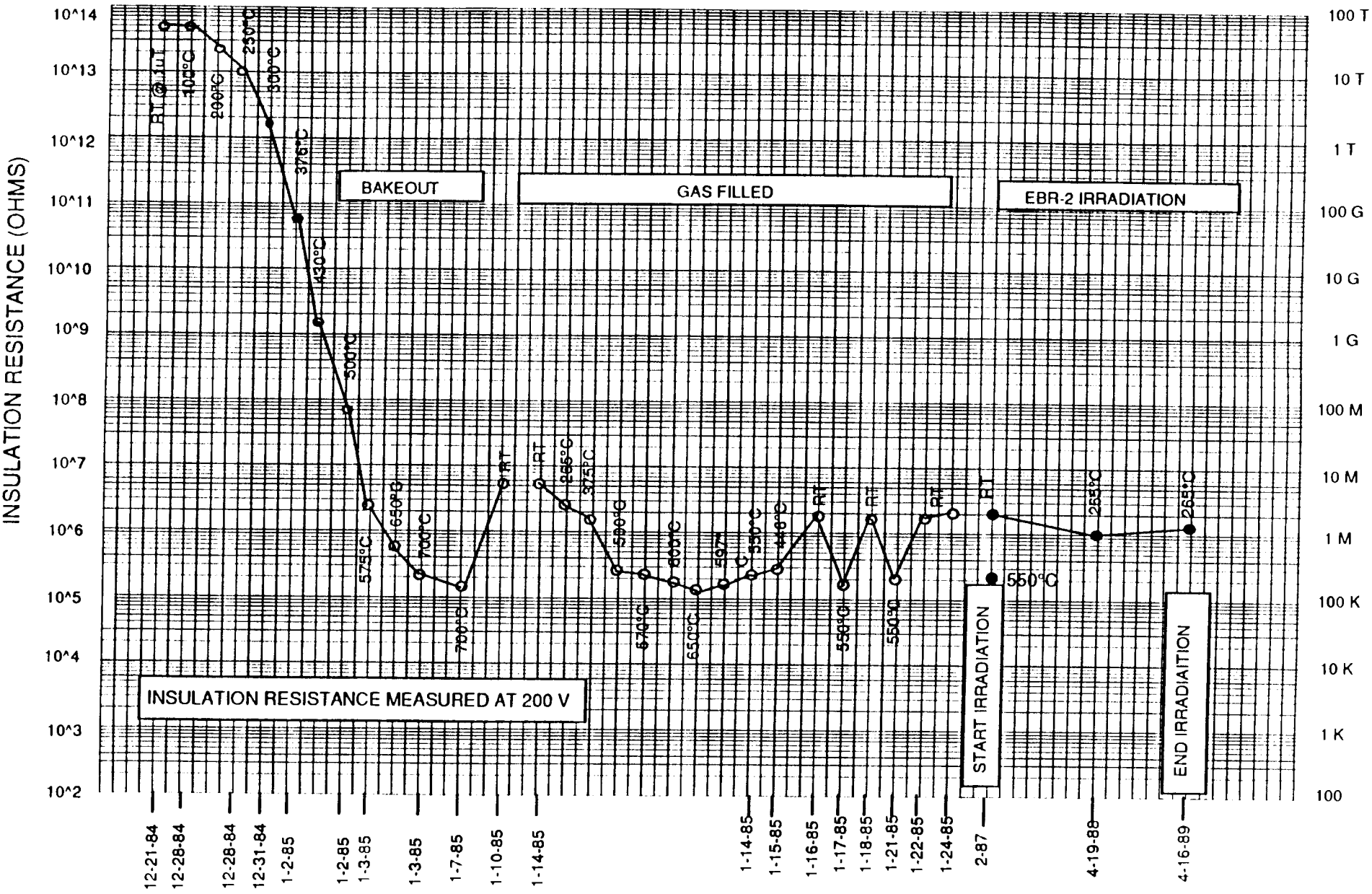

Fig. 5. FC3HT-2 insulation resistance chronology.

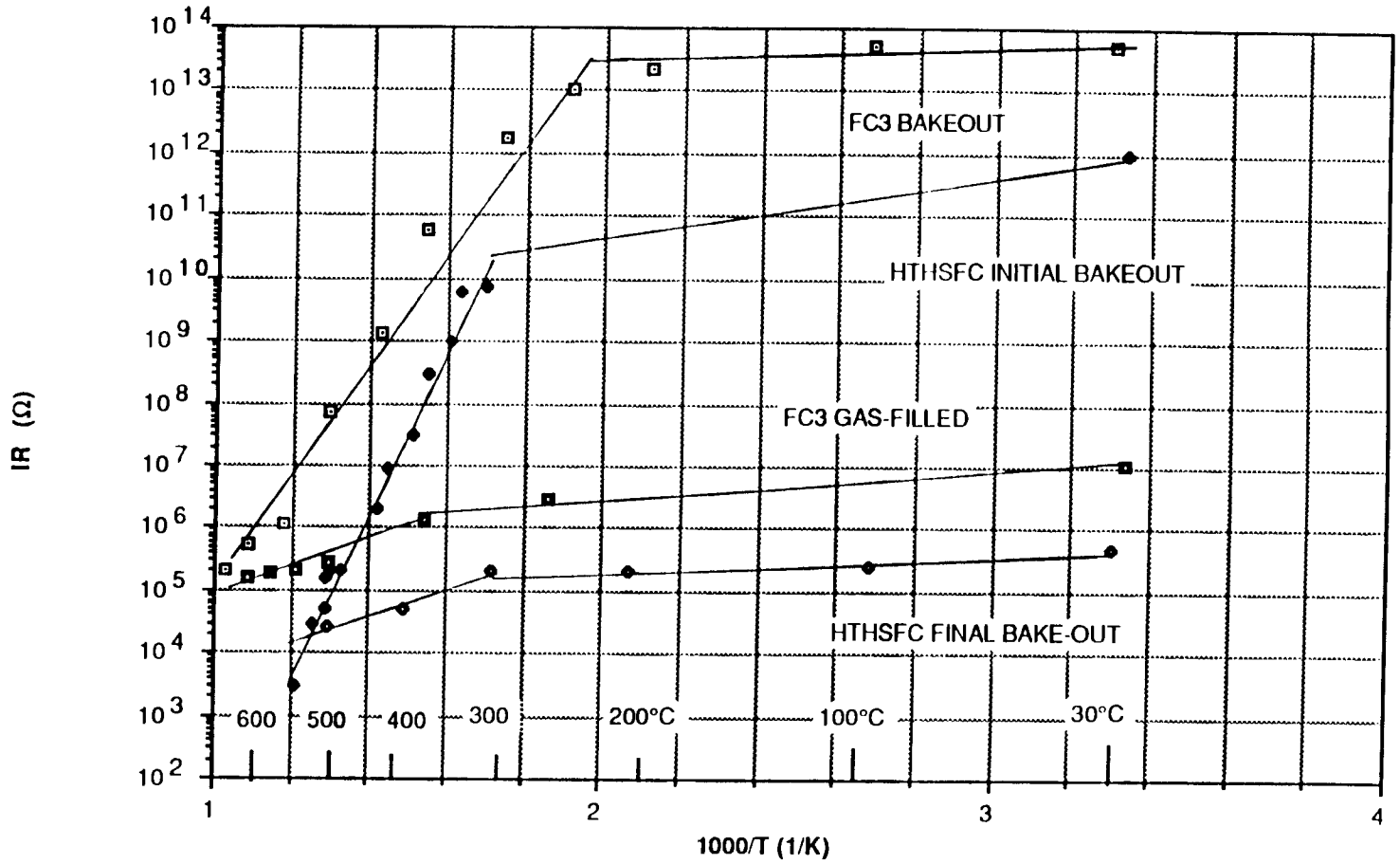

Fig. 6. Insulation resistance of the HTHSFC and the FC3HT-2.

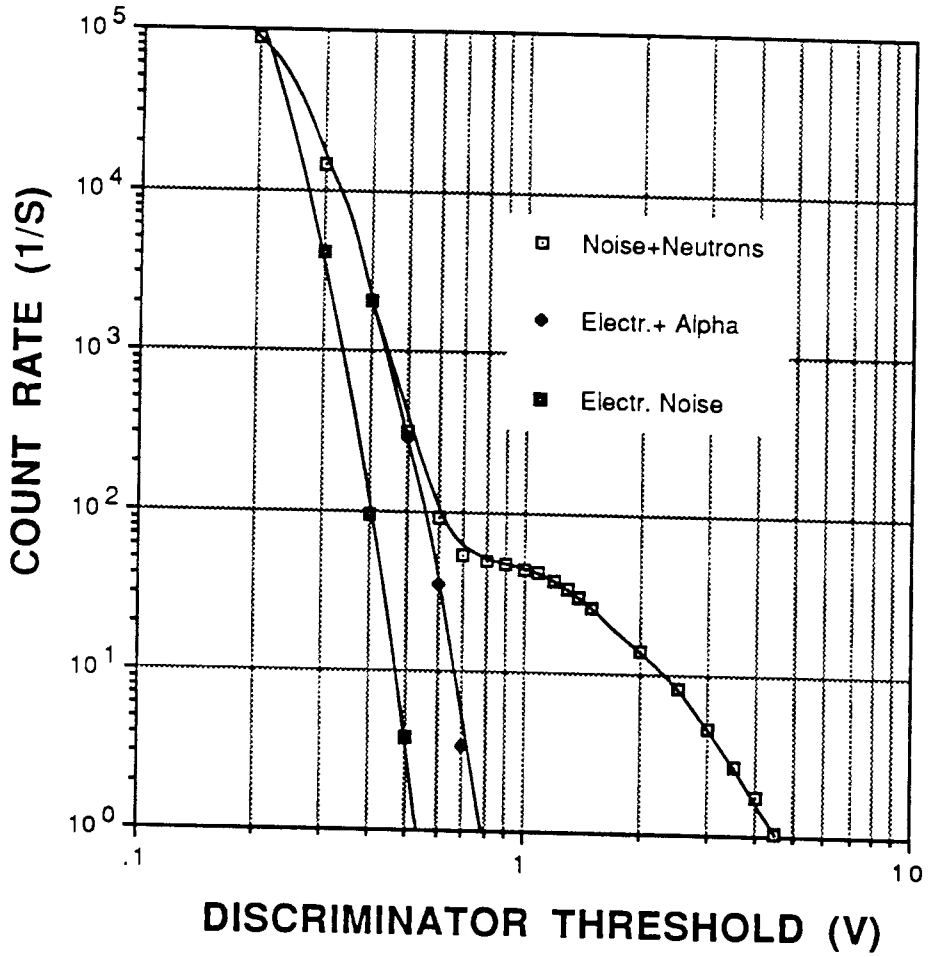

Fig. 7. Integral bias curves for the HTHSFC before vacuum baking.

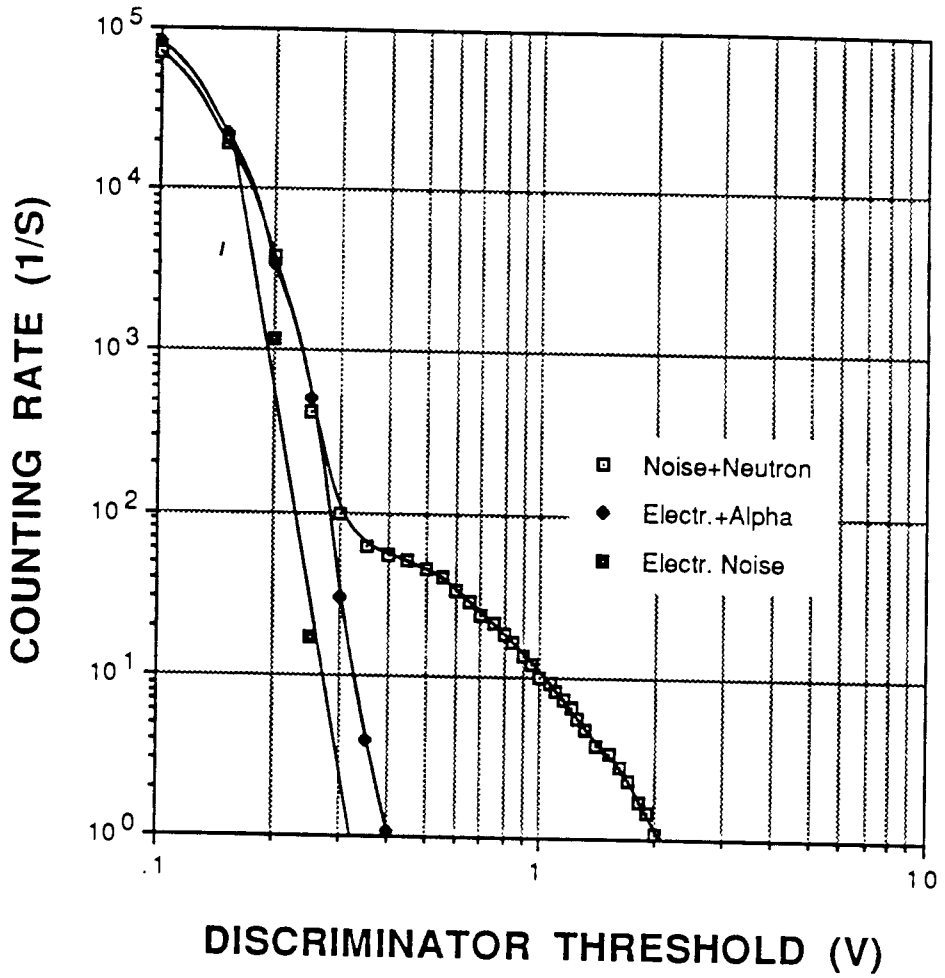

Fig. 8 Integral bias curves for the HTHSFC after vacuum baking

electronic noise curves coincide, the alpha curves and neutron curves are similar for the two cases, but lower in Fig. 8, because of reduced counter sensitivity caused by the bypassing of two electrodes which showed low IR when the counter was repaired in June 1988. If the figures are shifted so that the alpha curves coincide, the neutron curves then coincide nearly perfectly, showing that the counting efficiency of the HTHSFC was not affected by vacuum baking. Thus at room temperature, the HTHSFC shows adequate neutron counting capability and a neutron count rate at least two orders of magnitude greater than the noise plus alpha count rate, obtainable at discriminator voltages greater than 0.5 V using this calibration source.

When the gain of the measuring equipment is realigned, additional measurements will be made to determine whether there may have been a significant increase in the detector noise. Calibration of the Pu-Be neutron source strength is required to obtain a numerical value for the counter's sensitivity, which strength is equal in the two episodes shown in Figs. 7 and 8. Finally, these integral bias and sensitivity measurements will be repeated at temperatures up to 550°C.

A display of the counting rates of individual electrodes in the HTHSFC was obtained during the tests in April 1988 using a time-delay time-interval analyzer. The pattern provided by this measurement is shown in Fig. 9. Electrode No. 13 showed low counting rates in the April 1988 measurements and in fact, was one of the two electrodes bypassed in the reassembly of the HTHSFC. When that measuring circuit (now being repaired) becomes available, a similar time-based trace will be obtained for the HTHSFC, which may show other anomalies in electrode sensitivity.

3. PLANNED TESTING

1. Characterization of the performance and the calibration of the HTHSFC at room temperature will be completed. These tests include the determination of the counter's sensitivity (using a neutron source of known strength) and a time-based display of individual electrode counting rates.

2. Characterization and calibration of the HTHSFC will be extended to operating temperatures as high as 550°C.

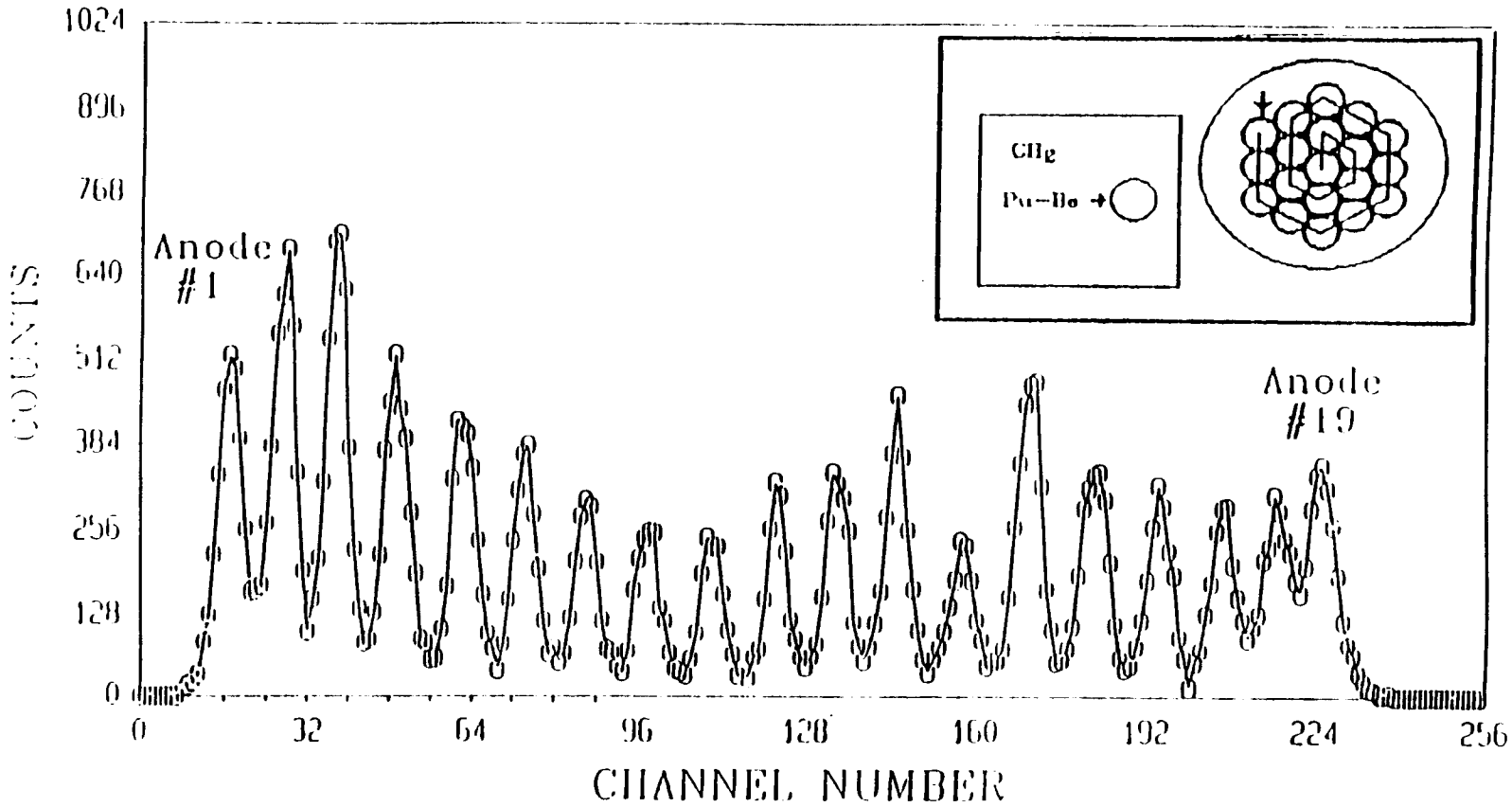

Fig. 9. Time interval analyzer trace for the HTHSFC.

3. A long-term aging test of 6 to 12 months duration will be undertaken in the laboratory (prior to its irradiation in a test facility) to determine the stability of the dc insulation resistance and the neutron counting sensitivity.

4. The HTHSFC will be installed in the Neutron Irradiation Test Facility at the EBR-2 and irradiated for 2 years at 550°C in a neutron flux of about 10^{14} nv. During this qualification test, the wide-range single-mode counting system, also being developed under this program, will be used to monitor the performance of the HTHSFC.

5. If the HTHSFC fails during the preirradiation testing, we would then propose to disassemble the counter, examine the condition of the coated electrodes, possibly vacuum bake the electrodes, and reassemble the counter with new insulators. It does not now appear that this procedure is required.

4. CONCLUSIONS

1. From measurements made with the HTHSFC at room temperature, the sensitivity of the HTHSFC appears to be close to its design goal of 8 cps/nv. The reduced sensitivity ia apparently due to the two bypassed electrodes, which had to be disconnected because of their low IR.

2. The dc insulation resistance of the HTHSFC is comparable to that IR which would be expected from a comparison to the FC-3-HT-2 and, while low, does not present any insurmountable problems. A high-voltage power supply with ~ 50 mA current capacity at voltages up to 500 V dc will be required to operate the detector at high temperature.

3. There may be adverse indications when the detector is operated in the counting mode at higher temperatures, and the time-delay counting rate distribution may show evidence of distortion of the interelectrode gaps due to stress relief of the coated cylindrical electrodes.

4. In the absence of any adverse findings, the HTHSFC should be subjected to long term (6- to 12- month) aging at 550°C and then sent to the EBR-2 for the planned 2-year high-temperature fast-neutron irradiation testing.

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2. W. T. Clay, J. T. De Lorenzo, V. K. Pare`, and G. C. Guerrant, " ORNL Fission Counter FC-3 Quality Assurance Report, Vol. 1: Fission Counter Development," ORNL/TM-5725 (March 1977)

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