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IMPEDANCE OF COMMERCIAL LECLANCHÉ DRY CELLS AND BATTERIES

RALPH J. BRODD AND HAROLD J. DEWANE

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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An extensive study of the impedance characteristics of the most commonly used sizes of commercial Leclanché type dry cells and batteries has been made through the frequency range of 50 to 50,000 cycles. Changes in impedance due to aging and use were determined. Open-circuit voltages and flash currents were measured, and capacities determined on standard tests in an effort to find a possible correlation between any of those three parameters and residual capacity. Data obtained are displayed in tabular form and on Argand diagrams.

1. Introduction

This note presents results of studies of the impedance of Leclanché dry cells and batteries of various make, size, type, and condition. By condition is meant the age or the amount of electrical capacity remaining in the cells or batteries either after storage or after electrical discharge. Three sizes of cylindrical cells, AA, C, and D and various sizes of flat-cell 45-volt "B" batteries were used in the studies. Dimensions of the cells and batteries are given in the tables referred to later. Impedance measurements were made on the cells prior to and after their discharge on various standard tests [1][1]; in fact, the measurements were made in conjunction with the qualification tests of dry cells and batteries which are conducted annually at the National Bureau of Standards. Impedance measurements were also made on cells and batteries prior to and after a specified period of storage at 21°C.*

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[1] Figures in brackets indicate literature references at the end of this paper.

* Initial tests were made after cells and batteries were stored at 21°C for approximately one week.

2. Impedance Measurements

The impedance was calculated from measurements of the internal resistance and the capacitive reactance of the cells and batteries. These latter quantities were measured by a substitution method using a Wien bridge, as described by Grover [2] and Vinal [3], and shown schematically in figure 1. R_1 was a variable non-inductive resistor, graduated in 0.01-ohm steps, covering a range up to 11,111.1 ohms in six decades. Capacitor C_1 consisted of two capacitors in parallel, continuously variable from 50 pf to 1.111 μf and served to compensate for the capacitance of the cell or battery under study. R_2 and C_2 were a fixed precision resistor and capacitor, respectively, and were selected to cover a range of R and C found for the cells or batteries under study. For single cells R_2 and C_2 were, respectively, 100 ohms and 1μf. R_3 and R_4 were 1000-precision ac resistors. Detector D was a tunable amplifier having a sensitivity of 5 μv for a 10 per cent deflection of full scale. The oscillator was a wide-range type activated by 60-cycle ac and was coupled to the bridge by an isolation transformer, and had a range of 5 cps to 600 kc. Its frequency was monitored by an electronic counter. The bridge was initially balanced with a thick, short copper bar, then with the cell or battery under study. This procedure was repeated at ten frequencies, namely, 50, 100, 200, and 500 cps and 1, 2, 5, 10, 20, and 50 kc. All measurements were made at ambient room temperature which was about 26°C.

The resistances and capacitances were calibrated by the Resistance and Reactance Section. To calibrate the Wien bridge a calibrated capacitor and a calibrated resistor were placed in the unknown positions and their values determined on balancing of the bridge. Results for a 1.0-ohm resistor and a 10 μf capacitor follow for several frequencies:

Frequency	Resistance		Capacitance	
	Standard (DC calibration)	Measured	Standard	Measured
cycles/second	ohms	ohms	μf	μf
60	0.99943	0.998	10.5577	10.5497
100	0.99943	1.002	10.5501	10.5409
400	0.99943	0.999	10.5258	10.5166
1000	0.99943	0.999	10.5088	10.5011
20000	0.99943	1.000	10.74	10.7778

Measured values generally agreed with calibrated values within 0.1 per cent; therefore, residuals in the bridge arms were insignificant for the purpose.

The resistance, R, and the capacitive reactance, X_c, were obtained at each frequency from

$$R = R_i - R_f \quad (1)$$

$$X_c = \frac{1}{\omega}\left[\frac{1}{C_i} - \frac{1}{C_f}\right] \quad (2)$$

where C = capacitance, $\omega = 2\pi f$ where f is the frequency in cycles per second (cps), and _i_ and _f_ refer to the initial (with bar) and final (with cell) balances. From these, the impedance, Z, is obtained from

$$Z = \sqrt{R^2 + X_c^2} \quad (3)$$

3. Standard Service Tests

The resistance, capacitive reactance, and impedance were not only determined for new and aged cells but for cells after they had been discharged on one of the following standard tests [1]:

3.1 General-Purpose 4-ohm Intermittent Test (4Ω).

Each cell is discharged through a resistance of 4 ohms for 5-minute periods at 24-hour intervals. The test is continued until the closed-circuit voltage of the cell falls below 0.75 volt. The service is reported as the number of minutes of discharge before the cell voltage falls below 0.75 volt.

3.2 General-Purpose 2.25-ohm Intermittent Test (2.25Ω).

Each cell is discharged through a resistance of 2.25 ohms for 5-minute periods at 24-hour intervals. The test is continued until the closed-circuit voltage of the cell falls below 0.65 volt. The service is reported as the number of minutes of discharge before the cell voltage falls below 0.65 volt.

3.3 Light-Industrial Flashlight-Cell Test (LIF).

Each cell is discharged through a resistance of 4 ohms for 4-minute periods, beginning at hourly intervals for 8 consecutive hours each day, with 16-hour rest periods intervening. The test in continued until the closed-circuit voltage of the cell falls below 0.90 volt. The service is reported as the number of minutes of discharge before the cell voltage first falls below 1.10 volts and then below 0.90 volt.

3.4 Heavy-Industrial Flashlight-Cell Test (HIF).

Each cell is discharged through a resistance of 4 ohms for 4-minute periods, beginning at 15-minute intervals, for 8 consecutive hours each day, with 16-hour rest periods intervening. The test is continued until the closed-circuit voltage of the cell falls below 0.90 volt. The service is reported as the number of minutes of discharge before the cell voltage first falls below 1.10 volts and then below 0.90 volt.

Prior to and at times during the tests the open-circuit voltage of the cells or batteries was measured with a voltmeter having a resistance of 1,000 ohms per volt. Also, the short-circuit current of the cells was measured with a critically-damped ammeter having a resistance, with the leads, of 0.01 ohm. The impedance of the cells or batteries was measured on the day following or on the day preceding the standard discharge test.

3.5 Test and Storage Conditions

"Initial" tests intended to show the condition of fresh batteries shall be started within 30 days of the receipt of the batteries by the testing agency.

"Delayed" tests are intended to measure the keeping quality of cells and batteries. Cells and batteries for delayed test shall be stored on open-circuit at a temperature of 70 ± 2°F (21°C) for the time specified. The storage time specified shall be measured from the time at which the batteries were received by the testing agency.

The standard temperature for tests is 70 ± 2°F (21°C) unless otherwise specified.

4. Results

Results obtained on fresh (or new) and discharged (on standard tests) AA-size general-purpose, C-size general-purpose, D-size general-purpose, and D-size industrial Leclanche dry cells, and on 45-volt Leclanche dry batteries of various make are given in tables 1 to 5, inclusive. In each case the results are the average of the number of cells listed in the table heading. In tables 1 to 4, inclusive, the condition of the cell at the time of the impedance measurements is listed in the next to the last column. The number given in the last column of these tables refers to the diagrams discussed below. For fresh cells the values of the open-circuit voltage (OCV) and the short-circuit current (SCC) are given. For the various discharge tests the number of minutes obtained on the discharge is listed; this is the service obtained from the cell before the final impedance measurements were made. When more than one discharge test was made on a particular brand of cell, the second or third test was made on a similar cell chosen from the same production lot. Inspection of the data shows clearly that there are no clear-cut correlations between output and internal resistance, impedance, open-circuit voltage, or short-circuit current. In table 6 a summary is given where the data, for any one cell size or type, are listed in order of increasing values for the internal resistance. One would expect that the output would decrease, within any one group, as one goes down the table; instead, no such tread is evident.

The data of table 5 refer to 45-volt batteries of 30 cells in series. Since it was not possible to complete the measurements of the batteries, whether simultaneously or within a short period of time, the batteries had an age ranging from 1 to 4 months at the time of the impedance measurement. Batteries F100 (brand 6) and F100 (brand 7) were discharged on the 2500-radio "B" battery test as described in reference [1]. In this test each 22.5-volt battery unit is discharged through a resistance of 2,500 ohms for a continuous period of 4 hours daily, with the intervals between successive discharge periods being not less than 16 hours. The test is continued until the closed-circuit voltage falls below 15 volts per 22.5 volt unit. On this test, batteries F100 (brand 6) and F100 (brand 7), although their internal impedances differed by a considerable amount (82.7 per cent at 1000 cps), gave nearly the same service, viz., 559 and 595 hours, respectively. Here again the lack of a correlation between cell output and internal impedance is evident.

The impedance is a function of the frequency and decreases as the frequency is increased, approaching a constant value in the limit. At the higher frequencies the impedance tends to have the characteristics of a resistive element; this tendency begins at about 1,000 cps. At the lower frequencies the capacitance of the electrode-electrolyte interface comes into play.

In table 7 the effect of aging on the impedance is summarized. The data given are in percentage changes which occur during a 6-month or a 3-month aging period at 21°C. Aging does not change the impedance much at the higher frequencies, above 1,000 cps where the impedance has the characteristics of a resistive element. Above and including the frequency of 1,000 cps, the average increase in impedance is only 3.0 per cent for C-size cells, 2.4 per cent of D-size general-purpose cells, and 4.8 per cent for D-size industrial cells. Below 1,000 cps, aging increases the impedance considerably and a progressively higher amount as the frequency is decreased. The increase in the impedance at the lower frequencies is a manifestation of an increase in the resistance at the electrode-electrolyte interface.

In table 8 the effects of various types of discharges on the impedance are summarized, likewise in percentage changes. As is the case for aging, different phenomena are seen to occur above and below a frequency of about 1,000 cps. At the higher frequencies the percentage change in impedance is nearly constant with frequency and is quite large. This change in impedance is not related to the output given by the cells, as was shown above in table 6 for frequencies of 1,000 cps. At the lower frequencies the percentage changes, in general, were of lower magnitude showing that the resistive element at the electrode-electrolyte interface is decreased during or as a result of electrical discharge. This decrease was so large in some cases that the percentage changes were negative. Increase in electrode capacitance during discharge would also contribute to a lowering of the electrode impedance.

In figures 2 to 52, inclusive, Argand diagrams are given for the various cells having the condition listed in the next to the last column of tables 1 to 4, inclusive. In these diagrams the capacitive reactance, X_c, is plotted against the resistance, R, where each point corresponds to one definite frequency in cycles per second and is so labeled. The vector from the origin to where the curve (at the left) cuts the R axis gives the resistive component of the impedance which is frequency independent whereas the vector from the origin to a point on the curve gives the total impedance. The angle the vector makes with the real axis is the phase angle for that frequency.

4.1 AA-Size Cells (Penlite Size).

Argand diagrams for new (fresh or undischarged) AA-size Leclanché cells of 4 different manufacturers are shown in figures 2, 4, 6, and 8, respectively; the corresponding diagrams after the cells were discharged on the general-purpose 4-ohm intermittent test are shown, respectively, in figures 3, 5, 7, and 9. In the first group of figures (No. 6 excepted) the open-circuit voltage (OCV), short-circuit or flash current (SCC), and performance on test (PT) are given. The units for OCV, SCC, and PT are, respectively, volts, amperes, and minutes. These figures show that cells of the same size (AA) but of different manufacture exhibit widely different impedance characteristics not only when new and undischarged but also after discharge on the same test procedure. Furthermore, none of the cells exhibit a semi-circle with the abscissa, which is a necessary result if simple relaxation processes as a function of frequency prevail in the electrode processes [4].

4.2 C-Size Cells.

Argand diagrams for new (fresh or undischarged) C-size Leclanché cells of 4 different manufacturers are shown in figures 10, 13, 16, and 19, respectively; the corresponding diagrams for the respective cells after they were stored for 6 months are given in figures 11, 14, 17, and 20, respectively. In the first group of figures OCV, SCC, and PT mean the same as above. The figures also show the wide difference in the impedance of cells of the same size (C) but of different manufacture. Here, however, the difference is not as marked as for AA-size cells and the diagrams approximate a semi-circle much more closely. After the cells were discharged on the general-purpose 4-ohm intermittent test they exhibited, respectively, the impedance shown in figures 12, 15, 18, and 21.

4.3 D-Size General-Purpose Cells.

Argand diagrams for D-size general-purpose Leclanché cells of 5 different manufacture when new, after 6-month storage, after discharge on the light-industrial test, 2.25-ohm test, and the general-purpose 4-ohm test are shown in the corresponding figures as listed below:

Brand	New	6-month	LIF	2.25-ohm	4-ohm
1	22	23	24	25	26
2	27	28	29	30	-
3	31	-	32	-	-
4	33	34	-	35	-
5	36	37	38	39	40
6	41	42	43	44	45

Here again, we see the wide difference in the impedance of cells of the same size but of different manufacture. In some cases the Argand diagrams approach a semi-circle in shape; in other cases a semi-circle would become complete only at very low frequencies, if at all.

4.4 D-Size Industrial Cells.

Argand diagrams for D-size industrial Leclanché cells of 2 different manufacture when new, after 3-month storage, after discharge on the light-industrial test, and after the heavy-industrial test are shown in the corresponding figures as listed below:

Brand	New	3-month	LIF	HIF
1	46	47	48	-
2	49	50	51	52

As with D-size general-purpose cells the diagrams are different for cells of different make. Again, semi-circles are approximated.

5. General Considerations

In the above it has been shown that the impedance of Leclanché dry cells of different make, size, type, and condition varies widely, not only at a particular frequency, but as a function of frequency. In some cases the impedance tends toward a maximum at a particular frequency and then decreases as the frequency is lowered. In other cases, the impedance tends to increase, as the frequency is lowered. The over-all characteristics of the Leclanché cell depend on the type of cell construction and since this is not known and frequently cannot be ascertained no correlation of impedance with cell construction is possible here. Even so, relative changes that occur in the impedance of Leclanché cells on storage or on electrical discharge may be followed by the method described here.

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6. References

[1] "Specification for Dry Cells and Batteries", Natl, Bur. Standards Handbook 71, December 29, 1959; American Standards Association Standard C18.1-1959; UDC 621.352.7.

[2] F. W. Grover, Bull. Natl. Bur. Standards 3, 378(1907).

[3] G. W. Vinal, "Storage Batteries", 4th Ed., p. 328, John Wiley and Sons, New York, N. Y., 1955.

Table 1. Impedance Data on AA-size General-purpose Leclanché Dry Cells; Average of 3 Cells in Each Case.

[AA Cells: diameter, 17/32 inch; can height, 1 7/8 inches]

Brand	Resistance, capacitive reactance, and impedance	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Condition of Cell	Figure Number
	R, ohm	0.955	0.546	0.410	0.349	0.330	0.316	0.307	0.300	0.296	0.289	Fresh	
1	X_c, ohm	2.174	1.165	.617	.268	.147	.079	.038	.024	.016	.011	OCV = 1.65v	2
	Z, ohm	2.375	1.287	.741	.440	.361	.326	.309	.301	.296	.289	SCC = 3.7 amp	
	R, ohm	1.517	1.207	1.069	0.952	0.836	0.722	0.593	0.530	0.491	0.461	After 4-Ω	
1	X_c, ohm	1.089	0.673	.432	.297	.268	.237	.173	.127	.090	.058	GP* test	3
	Z, ohm	1.867	1.382	1.153	.997	.878	.760	.618	.545	.499	.465	min = 148	
	R, ohm	1.077	0.738	0.519	0.393	0.361	0.344	0.332	0.325	0.320	0.314	Fresh	
2	X_c, ohm	0.561	.513	.362	.180	.104	.061	.032	.022	.016	.011	OCV = 1.56v	4
	Z, ohm	1.214	0.899	.633	.432	.376	.349	.334	.332	.320	.314	SCC = 3.5 amp	
	R, ohm	0.897	0.850	0.797	0.747	0.722	0.705	0.684	0.670	0.669	0.656	After 4-Ω	
2	X_c, ohm	.103	.103	.093	.070	.053	.041	.032	.028	.027	.022	GP* test	5
	Z, ohm	.903	.856	.802	.750	.724	.706	.685	.671	.670	.656	min = 144	
	R, ohm	1.449	0.722	0.447	0.324	0.292	0.273	0.262	0.255	0.251	0.245	Fresh	
3	X_c, ohm	2.082	1.273	.709	.318	.175	.094	.045	.026	.016	.009	OCV = 1.56v	6
	Z, ohm	2.537	1.464	.838	.454	.340	.288	.266	.256	.252	.245	SCC = 4.1 amp	
	R, ohm	1.572	1.418	1.245	1.138	1.107	1.075	1.036	1.011	1.000	0.969	After 4-Ω	
3	X_c, ohm	0.331	0.327	0.265	0.162	0.111	0.079	0.057	0.049	0.044	0.043	GP* test	7
	Z, ohm	1.606	1.455	1.273	1.149	1.113	1.078	1.038	1.012	1.001	0.970	min = 102	
	R, ohm	1.396	0.702	0.388	0.237	0.199	0.193	0.188	0.184	0.183	0.177	Fresh	
4	X_c, ohm	1.239	.951	.577	.269	.146	.076	.034	.019	.011	.005	OCV = 1.62v	8
	Z, ohm	1.867	1.182	.695	.359	.247	.207	.191	.185	.183	.177	SCC = 6.1 amp	
	R, ohm	1.339	1.078	0.999	0.931	0.864	0.842	0.773	0.714	0.657	0.634	After 4-Ω	
4	X_c, ohm	0.615	0.448	.262	.153	.092	.067	.038	.033	.022	.028	GP* test	9
	Z, ohm	1.474	1.168	1.033	.943	.869	.845	.774	.715	.657	.635	min = 128	

* - GP = general purpose

Table 2. Impedance Data on C-size General-purpose Leclanché Dry Cells; Average of 3 Cells in Each Case.
[C Cells: diameter, 15/16 inch; can height 1 13/16 inches]

Brand	Resistance, capacitive reactance, and impedance	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Condition of Cell	Figure Number
	R, ohm	0.509	0.487	0.356	0.297	0.259	0.237	0.224	0.218	0.215	0.213	Fresh	
1	X_c, ohm	.035	.048	.067	.074	.059	.038	.020	.013	.008	.004	OCV = 1.60v	10
	Z, ohm	.510	.489	.362	.306	.266	.240	.225	.219	.215	.213	SCC = 5.4 amp	
	R, ohm	0.638	0.586	0.437	0.307	0.262	0.246	0.233	0.229	0.226	0.225	After 6-	
1	X_c, ohm	.136	.186	.198	.139	.086	.052	.026	.016	.009	.005	month	11
	Z, ohm	.652	.615	.480	.337	.276	.251	.234	.230	.226	.225	aging	
	R, ohm	1.396	1.296	1.148	1.006	0.931	0.871	0.803	0.785	0.774	0.742	After 4-Ω	
1	X_c, ohm	0.212	0.242	0.243	0.204	.156	.117	.076	.068	.058	.050	GP* test	12
	Z, ohm	1.412	1.319	1.174	1.026	.944	.879	.807	.788	.776	.744	min = 430	
	R, ohm	0.521	0.501	0.476	0.414	0.374	0.343	0.320	0.306	0.301	0.291	Fresh	
2	X_c, ohm	.031	.046	.068	.082	.070	.054	.037	.027	.019	.011	OCV = 1.56v	13
	Z, ohm	.522	.503	.481	.422	.381	.347	.322	.307	.302	.291	SCC = 3.8 amp	
	R, ohm	0.869	0.682	0.513	0.404	0.365	0.344	0.323	0.309	0.303	0.293	After 6-	
2	X_c, ohm	.317	.365	.246	.145	.094	.063	.040	.029	.021	.013	month	14
	Z, ohm	.925	.774	.569	.429	.377	.350	.326	.310	.304	.293	aging	
	R, ohm	1.172	1.108	1.056	1.052	0.980	0.933	0.898	0.880	0.865	0.852	After 4-Ω	
2	X_c, ohm	0.102	0.116	0.113	0.093	.079	.062	.047	.041	.038	.035	GP* test	15
	Z, ohm	1.177	1.114	1.062	1.056	.983	.935	.899	.881	.866	.852	min = 406	
	R, ohm	0.876	0.778	0.617	0.387	0.305	0.260	0.236	0.228	0.225	0.223	Fresh	
3	X_c, ohm	.159	.238	.286	.240	.164	.095	.048	.026	.014	.006	OCV = 1.61v	16
	Z, ohm	.890	.814	.680	.455	.346	.277	.241	.229	.225	.223	SCC = 5.3 amp	
	R, ohm	1.521	0.971	0.545	0.341	0.289	0.268	0.253	0.247	0.247	0.244	After 6-	
3	X_c, ohm	0.964	.862	.596	.296	.167	.094	.044	.024	.012	.006	month	17
	Z, ohm	1.801	1.298	.808	.452	.334	.284	.257	.248	.247	.244	aging	
	R, ohm	1.143	1.081	1.011	0.969	0.953	0.935	0.925	0.923	0.909	0.898	After 4-Ω	
3	X_c, ohm	0.141	0.125	0.098	.061	.044	.032	.024	.022	.020	.021	GP* test	18
	Z, ohm	1.152	1.089	1.016	.971	.954	.936	.925	.923	.909	.898	min = 420	
	R, ohm	0.625	0.547	0.457	0.376	0.336	0.331	0.323	0.317	0.313	0.308	Fresh	
4	X_c, ohm	.110	.147	.148	.098	.064	.040	.021	.015	.011	.009	OCV = 1.59v	19
	Z, ohm	.635	.566	.480	.389	.342	.333	.324	.317	.313	.308	SCC = 4.0 amp	
	R, ohm	0.754	0.625	0.480	0.382	0.350	0.335	0.323	0.318	0.316	0.310	After 6-	
4	X_c, ohm	.213	.219	.201	.121	.075	.045	.025	.017	.012	.008	month	20
	Z, ohm	.784	.662	.520	.401	.358	.338	.324	.319	.316	.310	aging	
	R, ohm	1.550	1.494	1.465	1.406	1.372	1.345	1.315	1.303	1.277	1.251	After 4-Ω	
4	X_c, ohm	.024	.066	.072	.075	.071	.061	.051	.047	.043	.044	GP* test	21
	Z, ohm	1.550	1.495	1.467	1.408	1.374	1.346	1.316	1.304	1.278	1.252	min = 462	

* - GP = general purpose

Table 3. Impedance Data on D-size General-purpose Leclanche Dry Cells; Average of 9 Cells in Each Case

[D Cells: diameter, 1 1/4 inches; can height, 2 1/4 inches]

Brand	Resistance, capacitive reactance, and impedance	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Condition of Cell	Figure Number
	R, ohm	0.246	0.238	0.232	0.211	0.189	0.174	0.160	0.153	0.151	0.151	Fresh	
1	X_c, ohm	.007	.015	.023	.034	.035	.028	.015	.011	.007	.004	OCV = 1.58v	22
	Z, ohm	.246	.238	.233	.214	.192	.176	.161	.153	.151	.151	SCC = 7.1 amp	
	R, ohm	0.262	0.251	0.239	0.206	0.191	0.165	0.163	0.159	0.159	0.154	After 6-	
1	X_c, ohm	.014	.022	.034	.049	.036	.026	.015	.010	.007	.003	month	23
	Z, ohm	.262	.252	.241	.212	.194	.167	.164	.159	.159	.154	aging	
	R, ohm	0.719	0.690	0.658	0.602	0.565	0.526	0.482	0.461	0.452	0.448	After	
1	X_c, ohm	.065	.066	.072	.084	.087	.077	.059	.046	.033	.022	LIF[a]	24
	Z, ohm	.722	.693	.662	.608	.572	.532	.486	.463	.453	.449		
	R, ohm	1.180	1.149	1.109	1.043	0.963	0.833	0.794	0.753	0.718	0.693	After 2.25-Ω	
1	X_c, ohm	.034	.085	0.106	0.138	.154	.147	.116	.088	.065	.047	GP* test[b]	25
	Z, ohm	1.180	1.153	1.114	1.052	.975	.845	.802	.758	.721	.695	min = 444	
	R, ohm	1.253	1.224	1.192	1.115	1.032	0.938	0.826	0.772	0.742	0.713	After 4-Ω	
1	X_c, ohm	.068	.083	0.106	0.119	0.179	.179	.139	.102	.116	.046	GP* test	26
	Z, ohm	1.255	1.227	1.197	1.121	1.047	.955	.838	.779	.751	.714	min = 584	
	R, ohm	0.330	0.303	0.263	0.214	0.196	0.183	0.171	0.164	0.159	0.155	Fresh	
2	X_c, ohm	.045	.064	.068	.053	.038	.028	.018	.013	.008	.004	OCV = 1.56v	27
	Z, ohm	.333	.336	.272	.220	.199	.185	.172	.165	.159	.155	SCC = 6.9 amp	
	R, ohm	0.458	0.343	0.259	0.212	0.195	0.184	0.174	0.170	0.165	0.165	After 6-	
2	X_c, ohm	.177	.166	.124	.070	.046	.031	.020	.014	.010	.005	month	28
	Z, ohm	.491	.381	.287	.223	.200	.187	.175	.171	.165	.165	aging	
	R, ohm	0.328	0.319	0.298	0.284	0.276	0.273	0.270	0.267	0.265	0.259	After	
2	X_c, ohm	.029	.033	.029	.019	.014	.007	.007	.005	.004	.002	LIF[a]	29
	Z, ohm	.329	.321	.299	.285	.276	.273	.271	.267	.265	.259	min = 642	
	R, ohm	0.756	0.708	0.675	0.650	0.635	0.633	0.625	0.622	0.617	0.613	After 2.25-Ω	
2	X_c, ohm	.087	.072	.058	.040	.032	.026	.020	.015	.013	.010	GP* test	30
	Z, ohm	.761	.712	.678	.651	.636	.634	.625	.622	.617	.613	min = 533	
	R, ohm	0.335	0.314	0.241	0.238	0.224	0.207	0.184	0.181	0.180	0.175	Fresh	
3_1	X_c, ohm	.006	.005	.011	.021	.028	.030	.022	.015	.010	.008	OCV = 1.68v	31
	Z, ohm	.335	.314	.241	.239	.226	.209	.185	.182	.180	.175	SCC = 7.3 amp	
	R, ohm	0.639	0.608	0.561	0.507	0.482	0.468	0.460	0.455	0.449	0.444	After	
3_1	X_c, ohm	.056	.075	.082	.064	.044	.029	.016	.011	.009	.008	LIF[a]	32
	Z, ohm	.641	.613	.567	.511	.484	.469	.460	.455	.449	.444	min = 693	
	R, ohm	0.975	0.755	0.502	0.298	0.233	0.212	0.194	0.190	0.188	0.188	Fresh	
3_2	X_c, ohm	.310	.409	.377	.230	.135	.077	.036	.020	.011	.005	OCV = 1.61v	33
	Z, ohm	1.023	.859	.628	.376	.269	.225	.197	.191	.188	.188	SCC = 6.5 amp	

Table 3. (CONTINUED)

Brand	Resistance, capacitive reactance, and impedance	50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Condition of Cell	Figure Number
		Frequency, Cycles per Second											
	R, ohm	1.255	0.663	0.383	0.258	0.229	0.215	0.205	0.204	0.201	0.201	After 6-	
3_2	X_c, ohm	1.275	.910	.522	.239	.131	.073	.035	.018	.011	.005	month	34
	Z, ohm	1.789	1.126	.647	.352	.264	.227	.208	.205	.201	.201	aging	
	R, ohm	0.882	0.792	0.720	0.676	0.655	0.636	0.620	0.607	0.605	0.592	After 2.25-Ω	
3_2	X_c, ohm	.184	.157	.119	.073	.054	.040	.029	.025	.023	.021	GP* test	35
	Z, ohm	.901	.807	.729	.680	.657	.637	.621	.607	.605	.592	min = 538	
	R, ohm	0.401	0.354	0.307	0.241	0.208	0.193	0.185	0.181	0.178	0.175	Fresh	
4	X_c, ohm	.049	.077	.090	.074	.051	.034	.017	.011	.007	.005	OCV = 1.63v	36
	Z, ohm	.404	.362	.320	.252	.214	.196	.186	.181	.178	.175	SCC = 6.9 amp	
	R, ohm	0.438	0.378	0.306	0.243	0.215	0.203	0.194	0.190	0.189	0.183	After 6-	
4	X_c, ohm	.095	.121	.115	.075	.053	.033	.018	.012	.009	.006	month	37
	Z, ohm	.448	.397	.327	.254	.221	.206	.195	.190	.189	.183	aging	
	R, ohm	0.556	0.531	0.501	0.459	0.434	0.423	0.408	0.404	0.397	0.390	After	
4	X_c, ohm	.038	.056	.060	.057	.044	.032	.021	.016	.012	.008	LIF[a]	38
	Z, ohm	.557	.534	.505	.463	.436	..424	.409	.404	.397	.390	min = 695	
	R, ohm	0.993	0.966	0.947	0.911	0.878	0.855	0.819	0.794	0.775	0.751	After 2.25-Ω	
4	X_c, ohm	.051	.061	.054	.060	.061	.059	.055	.051	.046	.033	GP* test	39
	Z, ohm	.995	.968	.949	.913	.880	.857	.821	.796	.776	.752	min = 497	
	R, ohm	1.130	1.099	1.064	0.994	0.938	0.884	0.829	0.797	0.768	0.736	After 4-Ω	
4	X_c, ohm	.080	.102	.101	.110	.110	.102	.086	.073	.062	.052	GP* test	40
	Z, ohm	1.133	1.104	1.069	1.000	.945	.890	.834	.803	.770	.738	min = 758	
	R, ohm	0.696	0.314	0.271	0.204	0.180	0.166	0.153	0.149	0.145	0.141	Fresh	
5	X_c, ohm	.546	.415	.247	.128	.077	.047	.026	.017	.012	.010	OCV = 1.62v	41
	Z, ohm	.885	.520	.366	.241	.196	.172	.155	.150	.146	.141	SCC = 7.1 amp	
	R, ohm	0.478	0.313	0.240	0.190	0.182	0.155	0.154	0.150	0.148	0.142	After 6-	
5	X_c, ohm	.399	.265	.165	.088	.056	.036	.020	.014	.010	.008	month	42
	Z, ohm	.623	.410	.291	.209	.190	.159	.155	.151	.148	.142	aging	
	R, ohm	0.431	0.349	0.307	0.286	0.278	0.276	0.271	0.268	0.260	0.257	After	
5	X_c, ohm	.194	.137	.085	.044	.028	.019	.013	.010	.009	.009	LIF[a]	43
	Z, ohm	.473	.375	.319	.289	.279	.277	.271	.268	.260	.257	min = 823	
	R, ohm	---	1.707	1.526	1.401	1.350	1.315	1.275	1.246	1.219	1.182	After 2.25-Ω	
5	X_c, ohm	---	0.583	0.387	0.221	0.151	0.109	0.082	0.073	0.069	0.073	GP* test	44
	Z, ohm	---	1.804	1.574	1.418	1.358	1.319	1.277	1.248	1.221	1.184	min = 526	
	R, ohm	1.319	1.219	1.162	1.118	1.090	1.073	1.046	1.033	1.014	---	After 4-Ω	
5	X_c, ohm	0.354	0.230	0.151	0.093	0.068	0.053	0.045	0.043	0.043	---	GP* test	45
	Z, ohm	1.365	1.240	1.172	1.122	1.092	1.074	1.047	1.034	1.015	---	min = 904	

* - GP = general purpose

a - to a 0.9-volt cutoff

b - when more than one test, results were obtained on separate cells within same production lot

3_1 and 3_2 were of different production lots

Table 4. Impedance Data on D-size Industrial Leclanche Dry Cells; Average of 6 Cells in Each Case.
[D Cells: diameter, 1 1/4 inches; can height, 2 1/4 inches]

Brand	Resistance, capacitive reactance, and impedance	50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Condition of Cell	Figure Number
		Frequency, Cycles per Second											
	R, ohm	0.314	0.301	0.285	0.254	0.231	0.219	0.207	0.199	0.196	0.191	Fresh	
1	X_c, ohm	.018	.028	.036	.040	.034	.026	.018	.013	.007	.006	OCV = 1.62v	46
	Z, ohm	.315	.302	.287	.257	.234	.220	.208	.199	.196	.191	SCC = 6.8 amp	
	R, ohm	0.377	0.348	0.307	0.262	0.242	0.225	0.217	0.211	0.207	0.203	After 3-	
1	X_c, ohm	.053	.061	.071	.057	.041	.028	.019	.014	.011	.008	month	47
	Z, ohm	.381	.353	.315	.268	.245	.227	.218	.211	.207	.203	aging	
	R, ohm	1.319	1.266	1.200	1.079	0.972	0.873	0.778	0.732	0.700	0.663	After	
1	X_c, ohm	0.119	0.140	0.162	0.195	.199	.172	.124	.095	.072	.053	LIF[a]	48
	Z, ohm	1.324	1.274	1.211	1.097	.992	.890	.788	.738	.704	.665	min = 913	
	R, ohm	0.363	0.336	0.294	0.242	0.222	0.208	0.197	0.192	0.187	0.183	Fresh	
2	X_c, ohm	.045	.066	.073	.057	.041	.028	.016	.012	.007	.005	OCV = 1.66v	49
	Z, ohm	.366	.342	.303	.249	.226	.210	.198	.192	.187	.183	SCC = 6.7 amp	
	R, ohm	0.506	0.368	0.286	0.243	0.229	0.214	0.207	0.200	0.198	0.194	After 3-	
2	X_c, ohm	.230	.203	.138	.072	.047	.030	.020	.014	.009	.005	month	50
	Z, ohm	.556	.420	.318	.253	.233	.216	.208	.200	.198	.194	aging	
	R, ohm	0.584	0.547	0.516	0.478	0.459	0.449	0.435	0.429	0.419	0.418	After	
2	X_c, ohm	.072	.065	.060	.044	.035	.027	.020	.014	.010	.005	LIF[a]	51
	Z, ohm	.589	.551	.519	.480	.460	.450	.435	.429	.419	.418	min = 891	
	R, ohm	---	0.466	0.427	0.401	0.385	0.374	0.367	0.361	0.356	0.347	After	
2	X_c, ohm	---	.093	.070	.041	.031	.023	.017	.013	.008	.009	HIF[a,b]	52
	Z, ohm	---	.475	.433	.403	.386	.375	.367	.361	.356	.349	min = 775	

a - to a 0.9-volt cutoff

b - obtained on similar cells within same production lot

Table 5. Impedance Data on 45-volt Leclanché Dry Batteries; Average of Either 2 or 3 Batteries in Each Case. [Composed of Flat Cells of Various Sizes*; all Batteries 1 to 4 Months Old]

Brand	Resistance, capacitive reactance, and impedance	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Cell Size
	R, ohms	672.90	627.93	564.46	463.33	396.19	346.47	302.59	277.36	256.95	--	
6	X_c, ohms	105.46	133.45	143.79	143.68	124.49	98.00	72.57	56.87	41.51	--	F20
	Z, ohms	681.11	641.95	582.48	485.10	415.29	360.06	311.17	282.95	260.28	--	
	R, ohms	375.00	224.89	154.78	106.38	82.48	73.24	62.86	57.76	54.04	50.23	
6	X_c, ohms	491.59	336.87	204.33	106.47	65.69	40.95	22.90	15.41	10.83	7.44	F40
	Z, ohms	618.29	405.04	256.33	150.51	105.44	83.91	66.90	59.78	55.11	50.78	
	R, ohms	131.51	89.37	58.08	35.34	27.36	22.79	18.95	16.86	15.17	13.52	
6	X_c, ohms	85.21	74.44	55.88	32.30	20.58	13.26	8.00	5.70	4.13	2.60	F60[a]
	Z, ohms	156.70	116.31	80.60	47.88	34.23	26.37	20.57	17.80	15.72	13.77	
	R, ohms	65.07	47.37	32.40	19.50	14.87	12.63	10.91	9.94	9.16	8.35	
6	X_c, ohms	31.75	31.39	26.33	16.59	10.49	6.54	3.79	2.72	1.95	1.13	F95[b]
	Z, ohms	72.40	56.83	41.75	25.60	18.20	14.22	11.55	10.30	9.37	8.54	
	R, ohms	46.47	41.82	38.04	33.65	30.54	27.59	24.14	21.92	19.98	17.49	
6	X_c, ohms	0.85	4.11	5.87	6.55	6.59	6.19	5.43	4.80	4.15	3.22	F100
	Z, ohms	46.48	42.02	38.49	34.28	31.24	28.28	24.74	22.44	20.41	17.78	
	R, ohms	331.33	222.29	161.03	136.17	128.24	123.60	120.38	118.75	116.82	114.84	
7	X_c, ohms	356.90	236.90	136.68	62.72	36.35	20.48	10.43	6.97	5.38	4.86	F20
	Z, ohms	486.99	324.86	211.21	149.92	133.29	125.28	120.83	118.96	116.94	114.94	
	R, ohms	166.50	107.63	81.02	66.97	61.57	57.12	53.08	50.81	48.74	45.47	
7	X_c, ohms	256.63	148.75	79.27	40.88	24.67	15.94	9.48	7.12	5.93	4.94	F30
	Z, ohms	348.29	183.60	113.35	78.46	66.33	59.30	53.92	50.10	49.10	45.74	
	R, ohms	85.29	57.43	46.87	41.00	38.63	37.14	35.68	34.63	33.54	31.98	
7	X_c, ohms	78.60	48.54	28.22	14.11	8.63	5.53	3.67	3.13	2.91	2.88	F60
	Z, ohms	115.99	75.19	54.71	43.36	39.58	37.55	35.87	34.77	33.67	32.11	
	R, ohms	37.80	27.00	21.17	16.91	14.92	13.66	12.62	12.02	11.48	10.73	
7	X_c, ohms	13.59	12.77	9.75	6.34	4.49	3.09	2.04	1.67	1.46	1.34	F95
	Z, ohms	40.17	29.87	23.30	18.06	15.58	14.00	12.78	12.14	11.57	10.81	
	R, ohms	30.53	22.27	18.38	15.47	14.49	13.89	13.20	12.68	12.12	11.34	
7	X_c, ohms	6.84	8.17	6.01	3.61	2.45	1.79	1.41	1.33	1.29	1.25	F100
	Z, ohms	31.29	23.72	19.34	15.89	14.70	14.00	13.27	12.75	12.19	11.41	

*

Cell size	Length, inches	Width, inches	Thickness, inches
F20	15/16	17/32	0.11
F30	1 1/4	27/32	.13
F40	1 1/4	27/32	.21
F60	1 1/4	1 1/4	.15
F95**	2 3/8	1 3/4	.28
F100	2 3/8	1 25/32	.41

** new size not included in NBS Handbook 71 [1]

a - cylindrical AA-size cells

b - cylindrical B-size cells; B cells have a diameter of 3/4 inch and a can height of 2 1/8 inches.

Table 6. Comparison of Output with Internal Resistance, Impedance, Open-circuit Voltage, and Short-circuit Current

[In increasing order for internal resistance within cell size]

Cell	R* ohm	Z* ohm	OCV volts	SCC amperes	Test No. 1 minutes	Test No. 2 minutes	Test No. 3 minutes
AA4	0.199	0.247	1.62	6.1	128	---	---
AA3	.292	.340	1.56	4.1	102	---	---
AA1	.330	.361	1.65	3.7	148	---	---
AA2	.361	.376	1.61	3.5	144	---	---
C1	0.259	0.266	1.60	5.4	430	---	---
C3	.305	.346	1.61	5.3	420	---	---
C4	.336	.342	1.59	4.0	462	---	---
C2	.374	.381	1.56	3.8	406	---	---
D5	0.180	0.196	1.62	7.1	904	526[b]	823
D1	.189	.192	1.58	7.1	584	444	---
D4	.208	.214	1.63	6.9	758	497	695
D2	0.196	0.199	1.56	6.9	---	533	642
$D3_1$	.224	.226	1.68	7.3	---	---	693
$D3_2$	.233	.269	1.61	6.5	---	538	---
D2[a]	0.222	0.226	1.66	6.7	---	---	891
D1[a]	.231	.234	1.62	6.8	---	---	913

* - at 1000 cps

a - industrial type cell

b - when more than one test, results were obtained on a separate cells within same production lot.

Table 7. Effect of Aging on the Impedance of Leclanché Dry Cells, Given in Percentage Change

[Period of Aging - 6 Months]

Brand	Size and Type of Cell	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000
1	C-general purpose	27.8	25.8	32.6	10.1	3.8	4.6	4.0	5.0	5.1	5.6
2	C-general purpose	77.2	53.9	18.3	1.7	-1.0	0.9	1.2	1.0	0.7	0.7
3	C-general purpose	102.4	59.5	18.8	-0.7	-3.5	2.5	6.6	8.3	9.8	9.4
4	C-general purpose	23.5	17.0	8.3	3.1	4.7	1.5	0	0.6	1.0	0.6
1	D-general purpose	6.5	5.9	3.4	-0.9	1.0	-5.1	1.9	3.9	5.3	2.0
2	D-general purpose	47.4	13.4	5.5	1.4	0.5	1.1	1.7	3.6	3.8	6.5
3_2	D-general purpose	74.9	31.1	3.0	-6.4	-1.9	0.9	5.6	7.3	6.9	6.9
4	D-general purpose	10.9	9.7	2.2	0.8	3.3	5.1	4.8	5.0	6.2	4.6
5	D-general purpose	-29.7	-21.2	-20.5	-13.3	-3.1	-7.6	0	0.7	1.4	0.7
1[a]	D-industrial	21.0	16.9	9.8	4.3	4.7	3.2	4.8	6.0	5.6	6.3
2[a]	D-industrial	51.9	22.8	5.0	1.6	3.1	2.9	5.1	4.2	5.9	6.0

a - aged 3 months.

Table 8. Effect of Various Types of Discharge on the Impedance of Leclanché Dry Cells, given in Percentage Change

Brand	Size of Cell*	Frequency, Cycles per Second 50	100	200	500	1,000	2,000	5,000	10,000	20,000	50,000	Minutes on Discharge
		General-purpose 4-ohm Intermittent Test										
1	AA	-21	7	56	127	143	133	100	81	69	61	148
2	AA	-26	-5	27	74	93	102	105	102	109	109	144
3	AA	-37	-1	52	151	227	274	290	295	297	296	102
4	AA	-21	-1	49	163	252	308	305	286	259	259	128
1	C	177	170	224	235	255	266	259	260	261	249	430
2	C	125	121	121	150	158	169	179	187	187	193	406
3	C	29	34	49	113	176	238	283	303	304	303	420
4	C	144	164	206	262	302	304	306	311	308	306	462
1	D	410	416	414	424	445	442	420	409	397	373	584
4	D	180	205	234	297	342	354	348	344	333	322	758
5	D	54	138	220	366	457	524	575	589	595	---	904
		General-purpose 2.25-ohm Intermittent Test										
1	D	380	384	378	392	408	380	398	395	377	360	444
2	D	129	112	149	196	220	243	263	277	288	295	533
3_2	D	-12	-6	16	81	144	183	215	218	222	215	538
4	D	146	167	197	262	311	337	341	340	336	330	497
5	D	---	247	330	488	593	667	724	732	736	740	526
		Light-industrial Flashlight-cell Test (LIF)										
1	D	193	191	184	184	197	202	202	202	200	196	---
2	D	-1	-4	10	30	39	48	58	62	67	67	642
3_1	D	91	95	135	114	114	124	149	150	149	154	693
4	D	38	45	58	84	104	116	120	123	123	123	695
5	D	-47	-28	-13	20	42	61	75	79	78	82	823
1	D[a]	320	322	322	327	324	305	279	271	259	248	913
2	D[a]	61	61	71	93	104	114	120	123	124	128	891
		Heavy-industrial Flashlight-cell Test (HIF)										
2	D[a]	---	39	43	62	71	79	85	88	90	91	775

* - All cells were of the general-purpose type except those marked with a superscript a.

a - Industrial type cells.

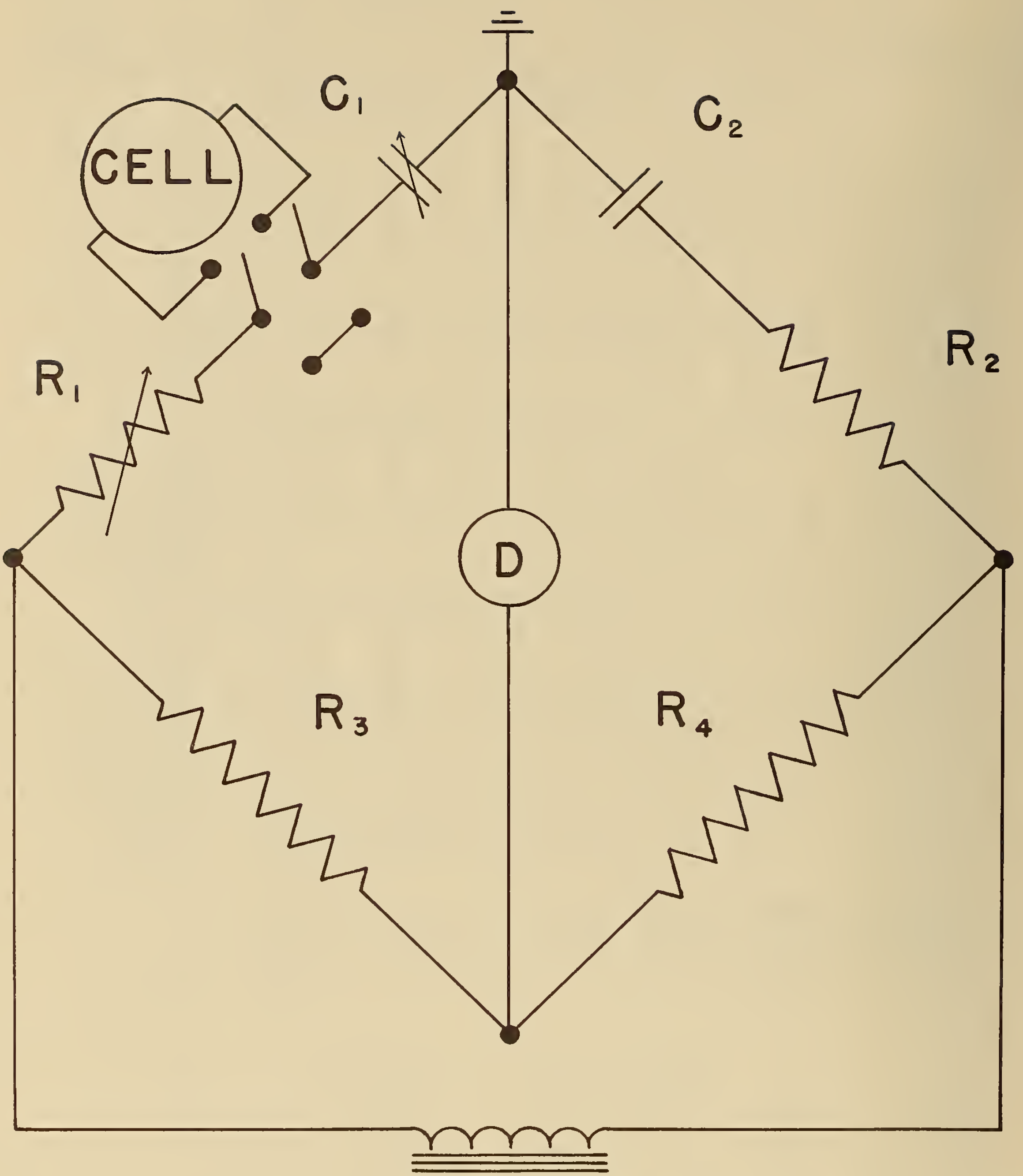

FIG. 1 WIEN IMPEDANCE BRIDGE CIRCUIT

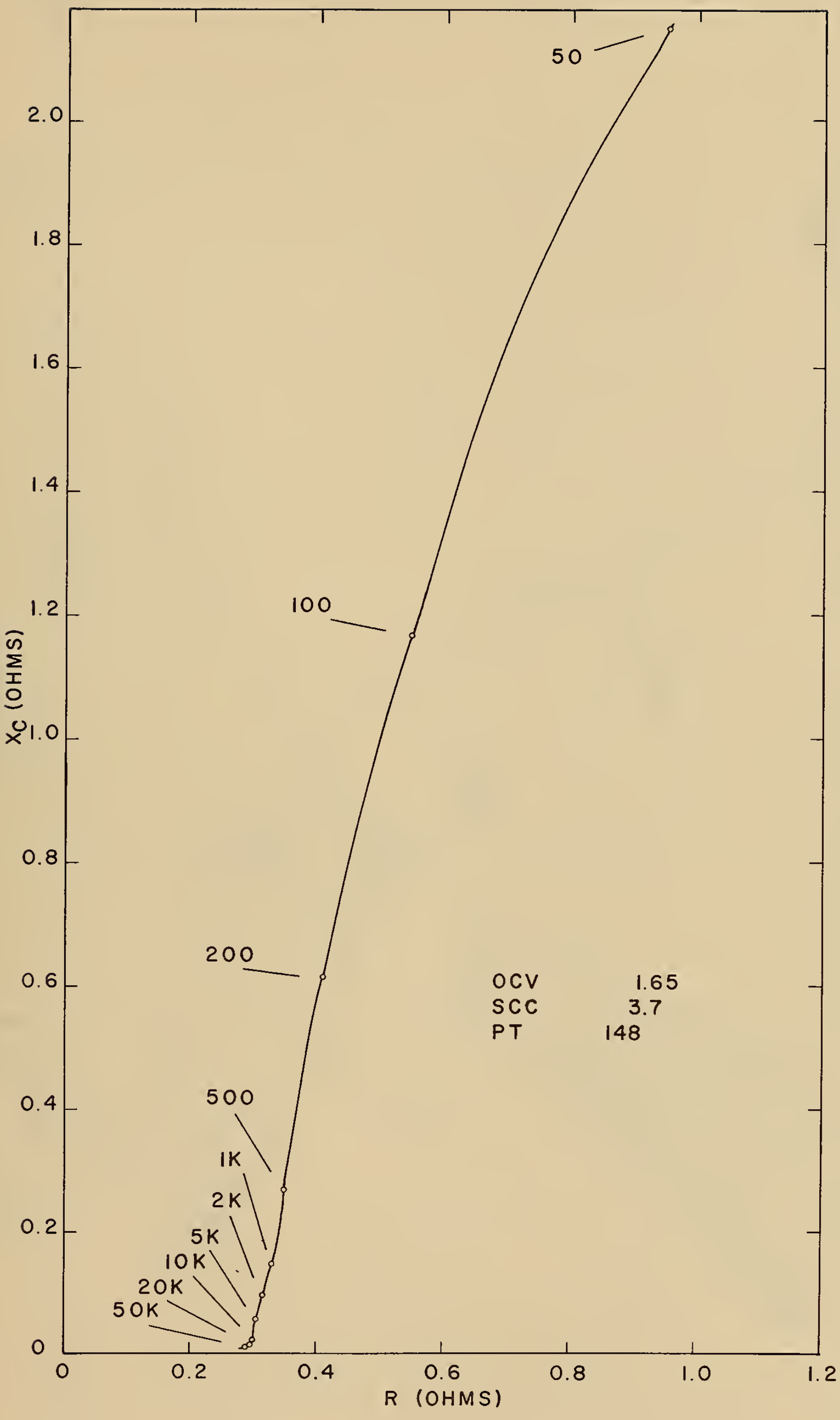

FIG. 2 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 1 BEFORE DISCHARGE

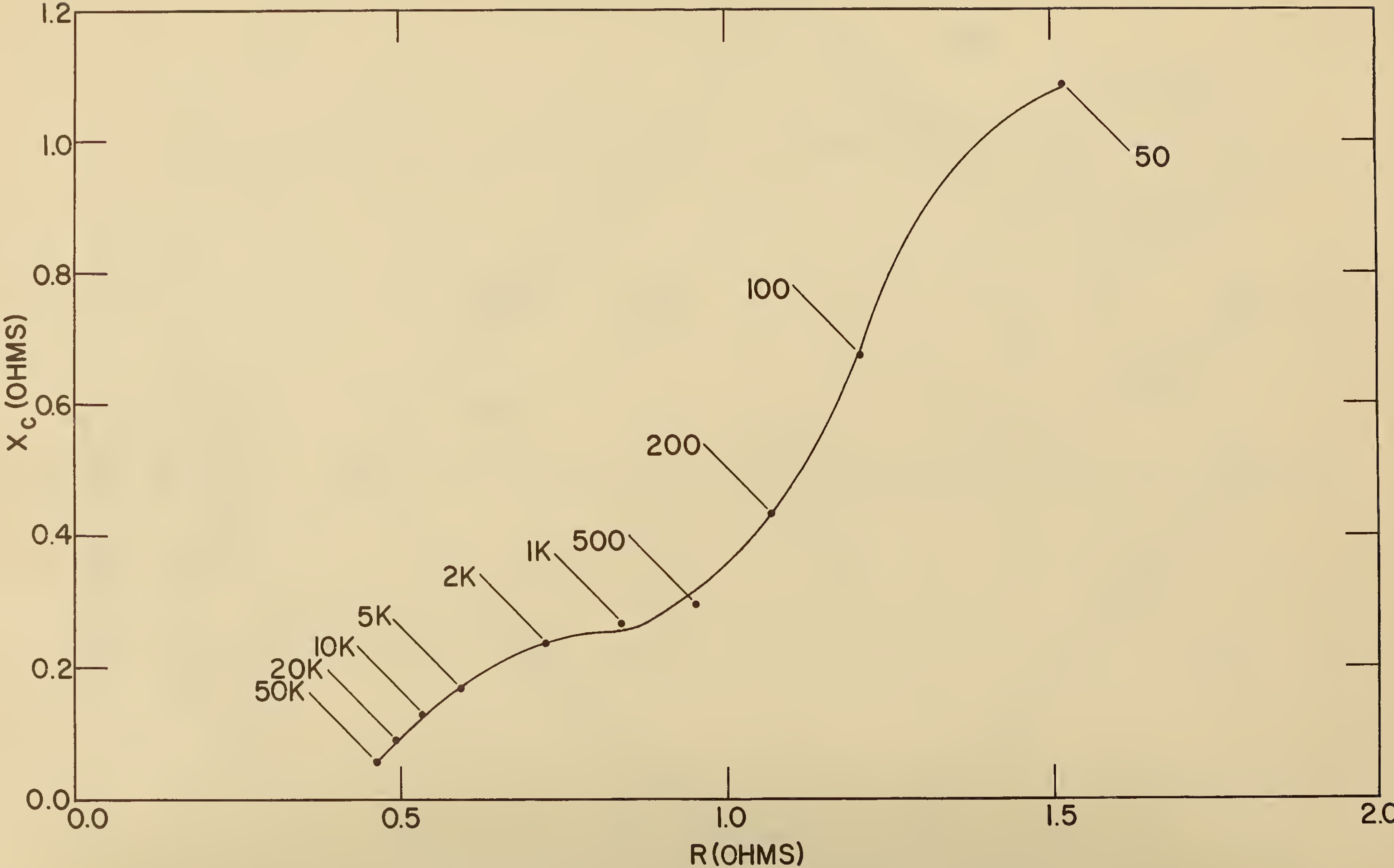

FIG. 3 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 1 AFTER 4-OHM TEST

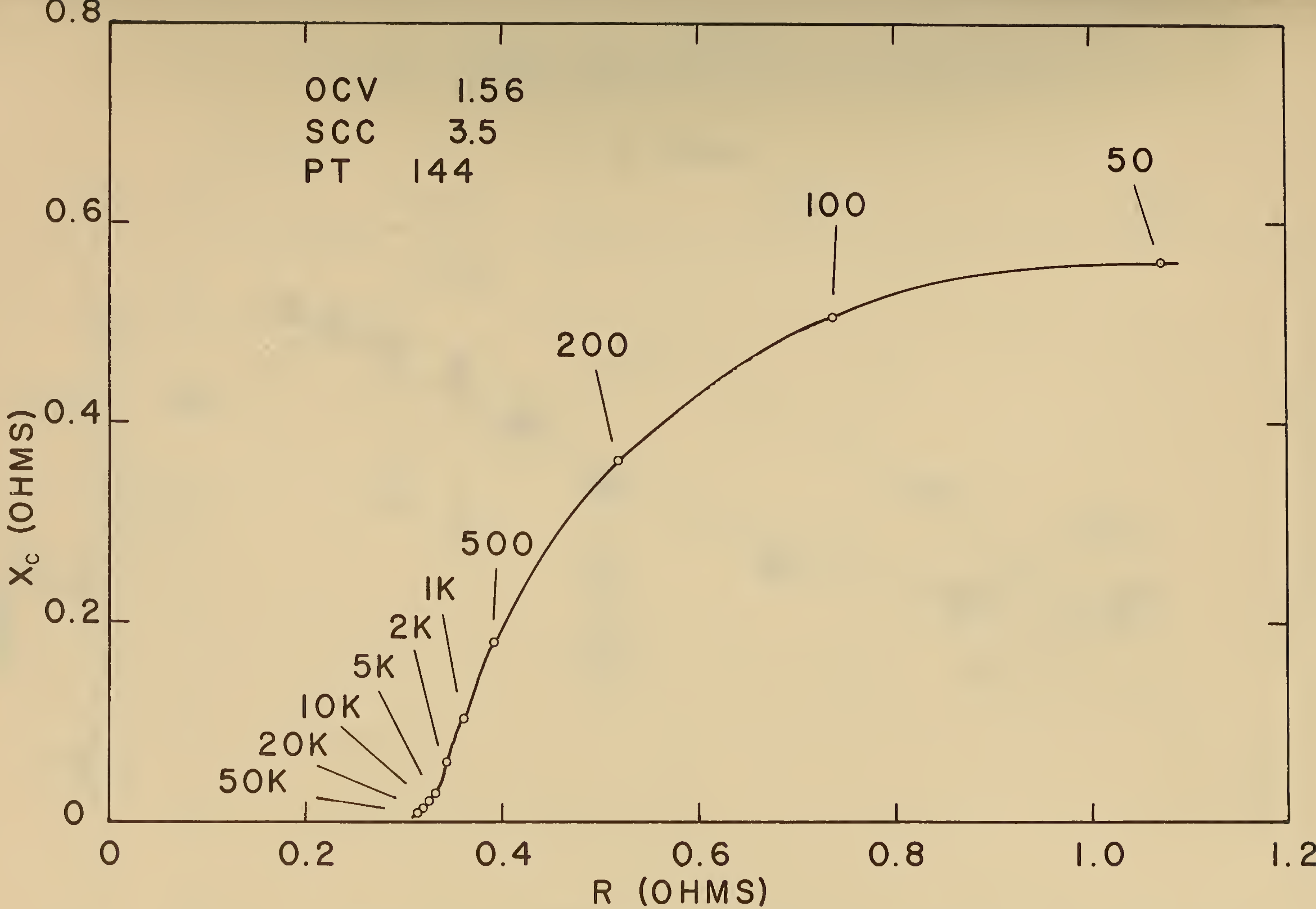

FIG. 4 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 2 BEFORE DISCHARGE

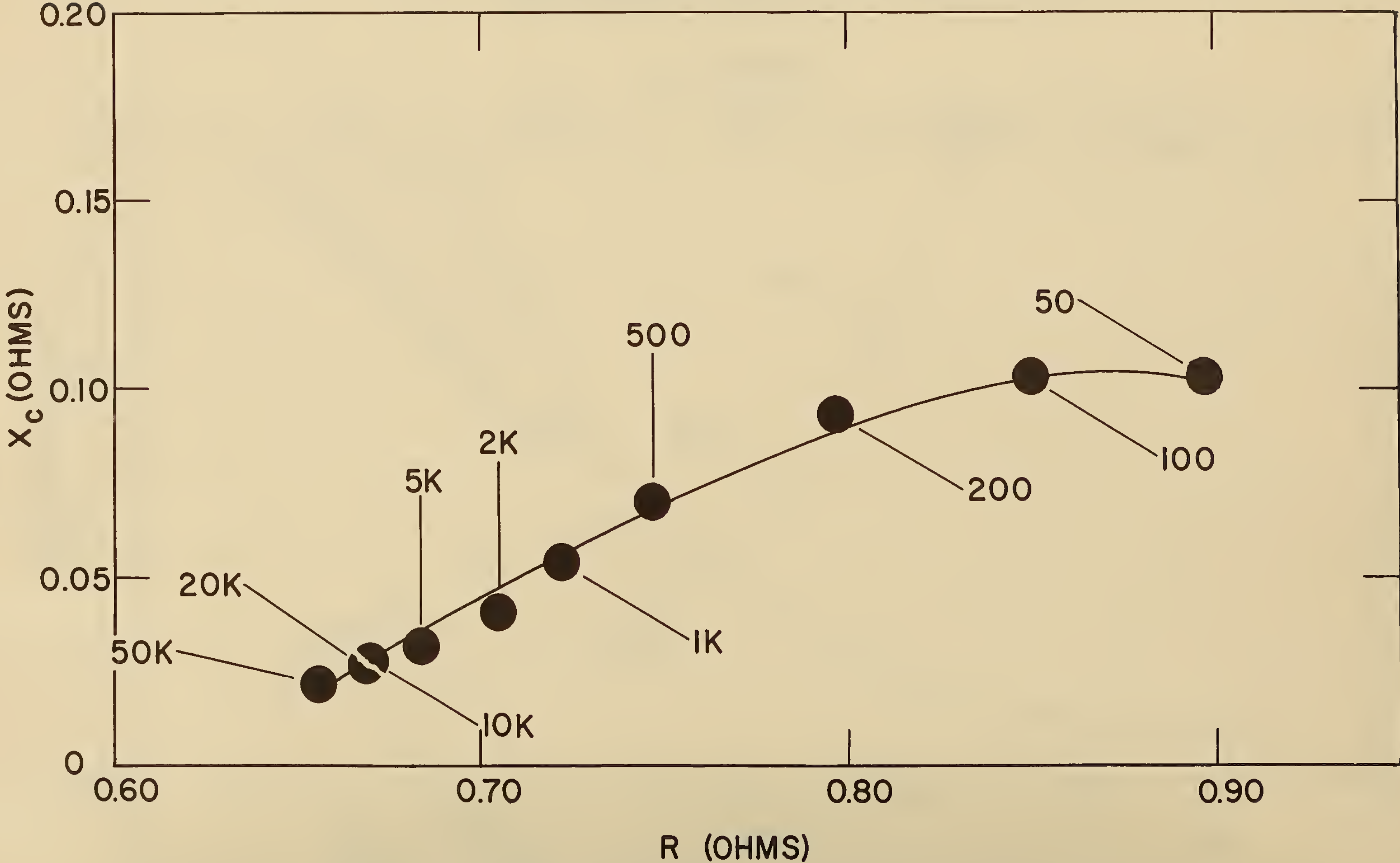

FIG. 5 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 2 AFTER 4-OHM TEST

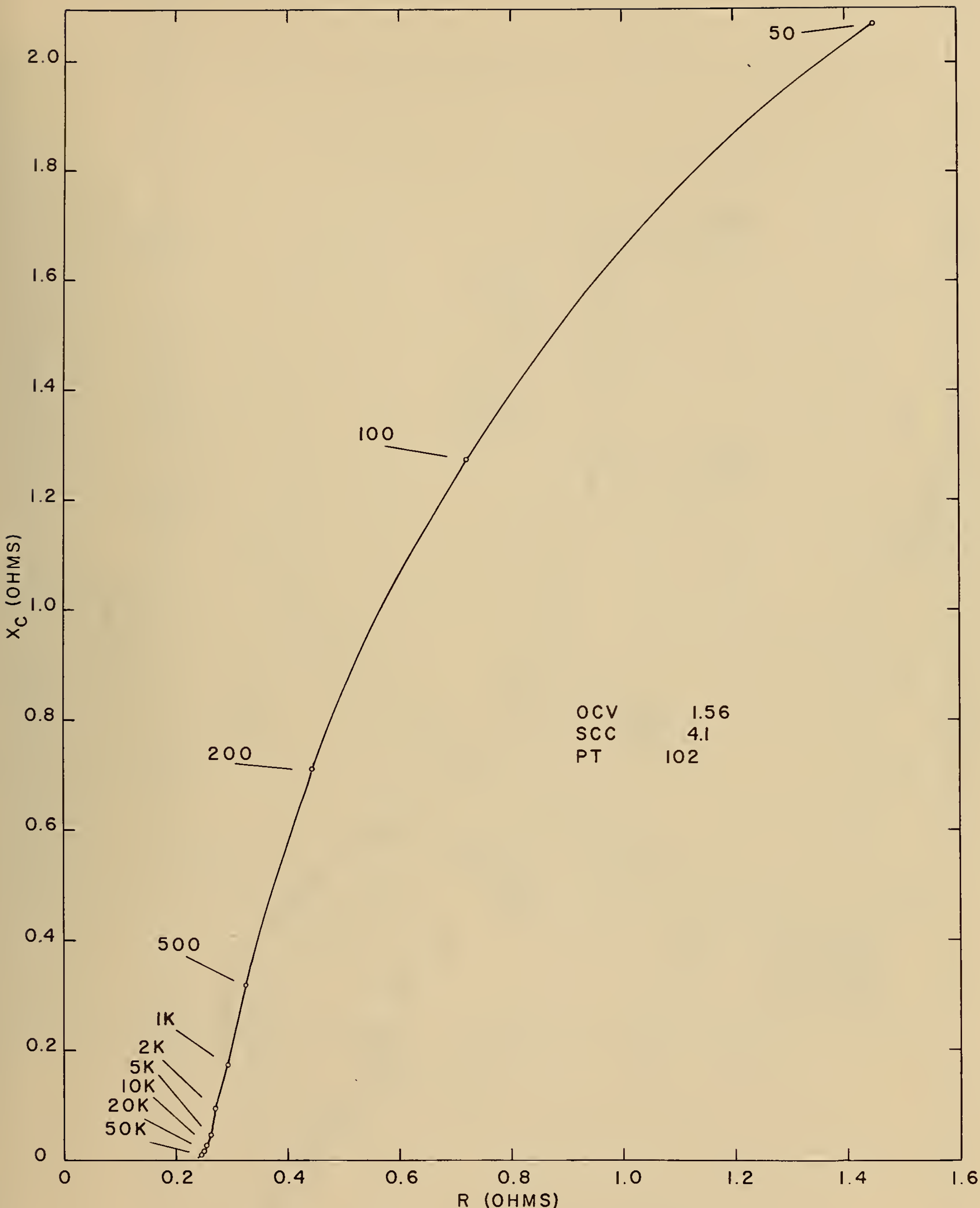

FIG. 6 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 3 BEFORE DISCHARGE

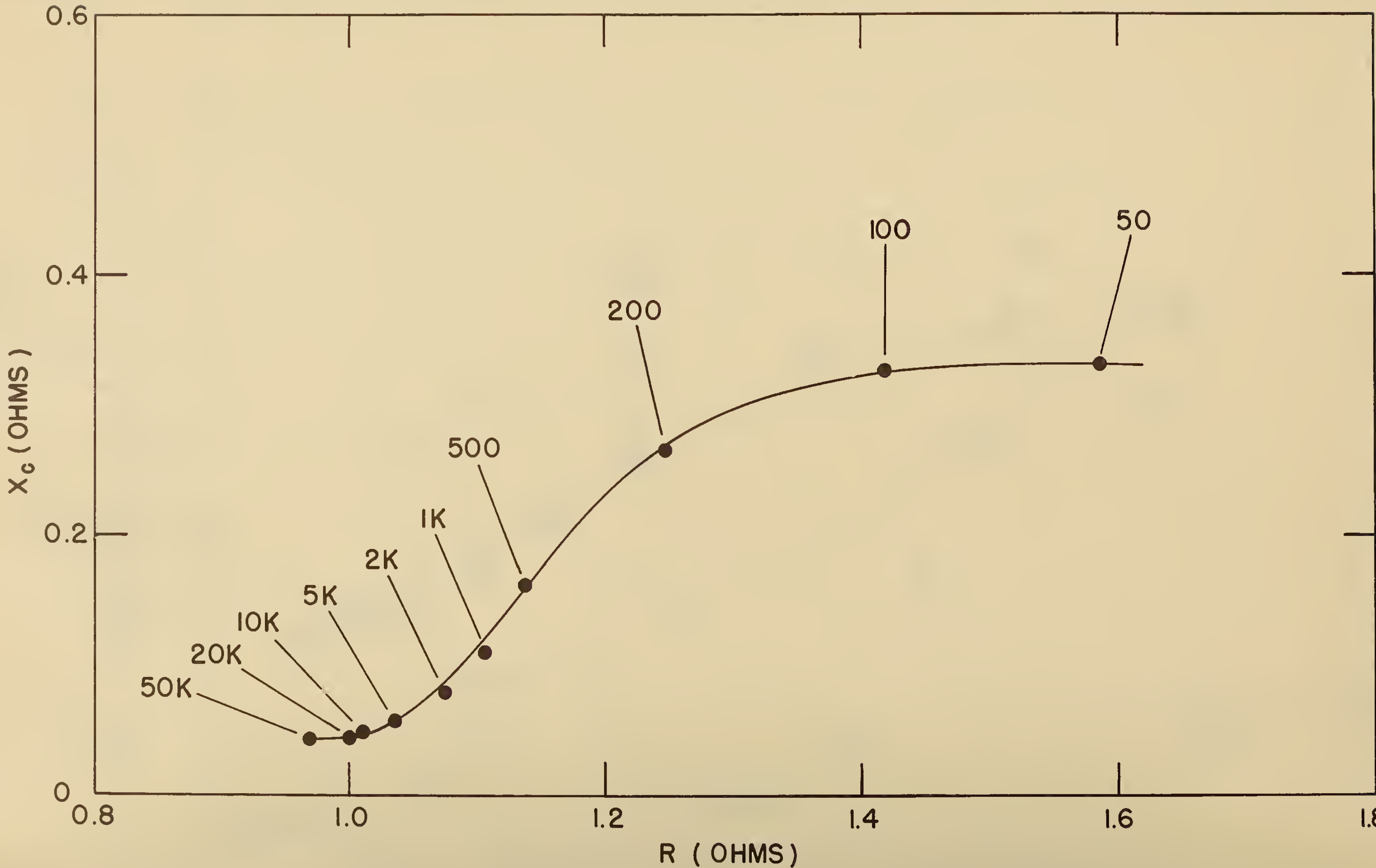

FIG. 7 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 3 AFTER 4-OHM TEST

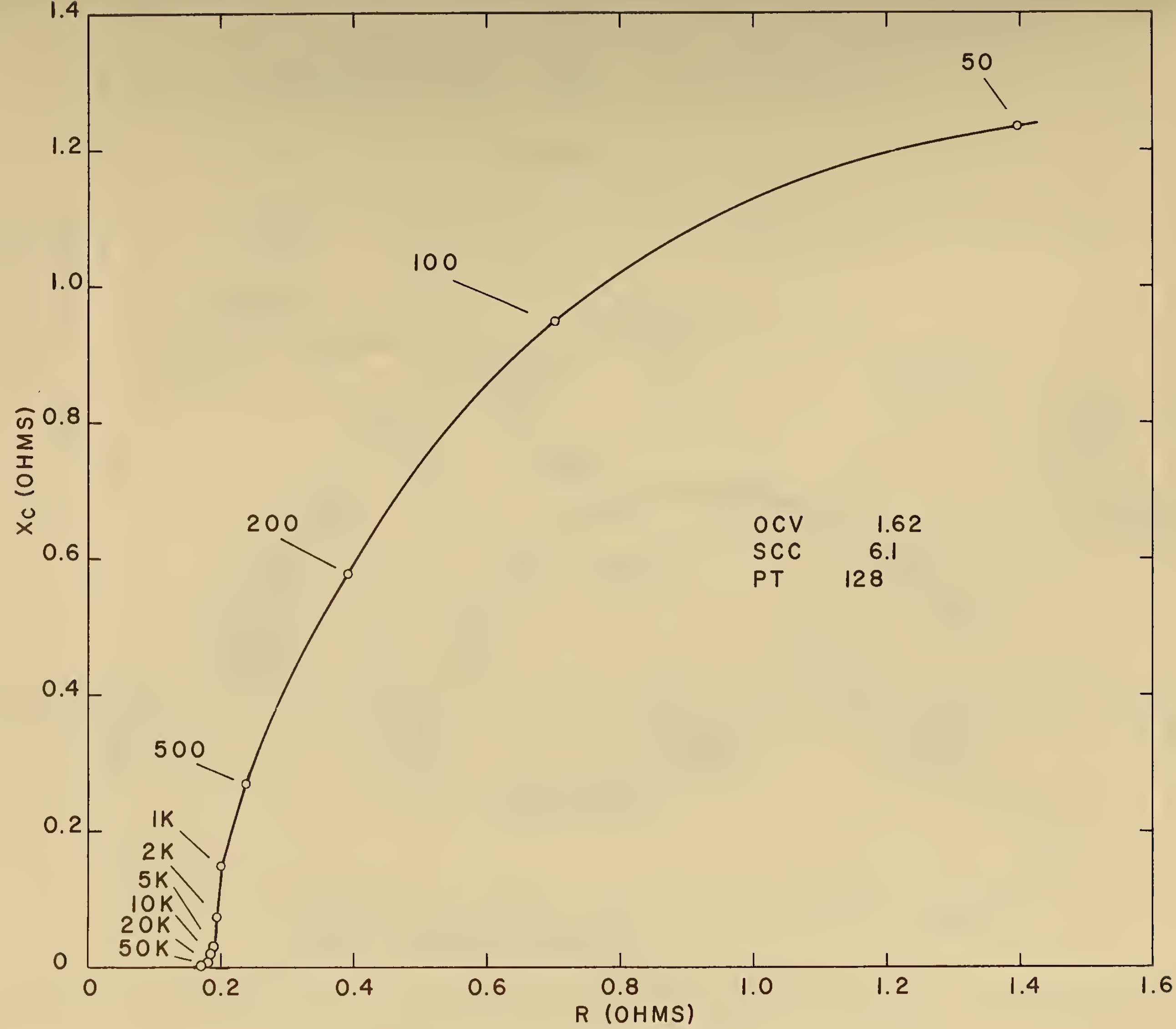

FIG. 8 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 4 BEFORE DISCHARGE

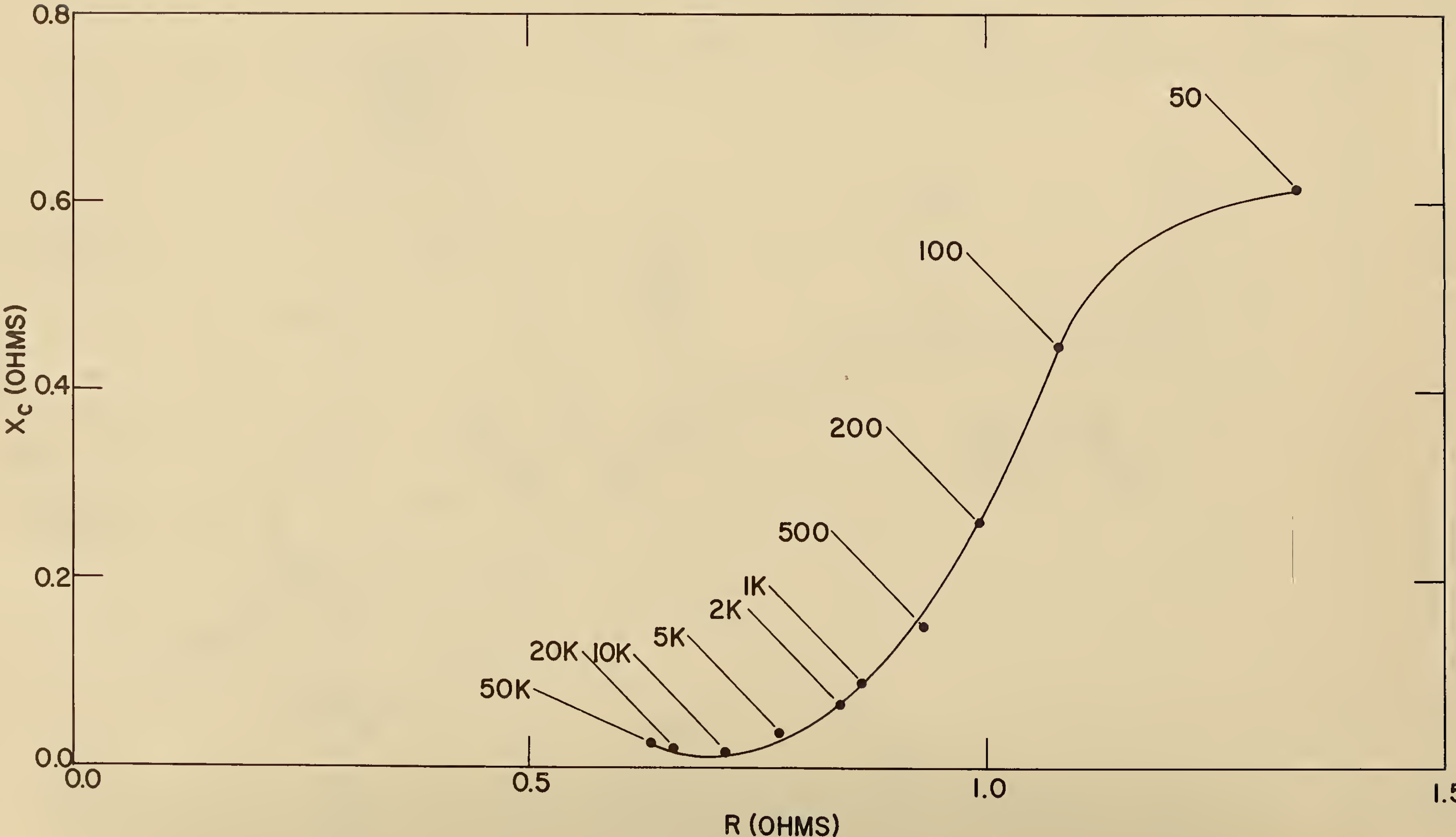

FIG. 9 RESISTANCE-REACTANCE CURVE OF AA-SIZE CELLS OF BRAND 4 AFTER 4-OHM TEST

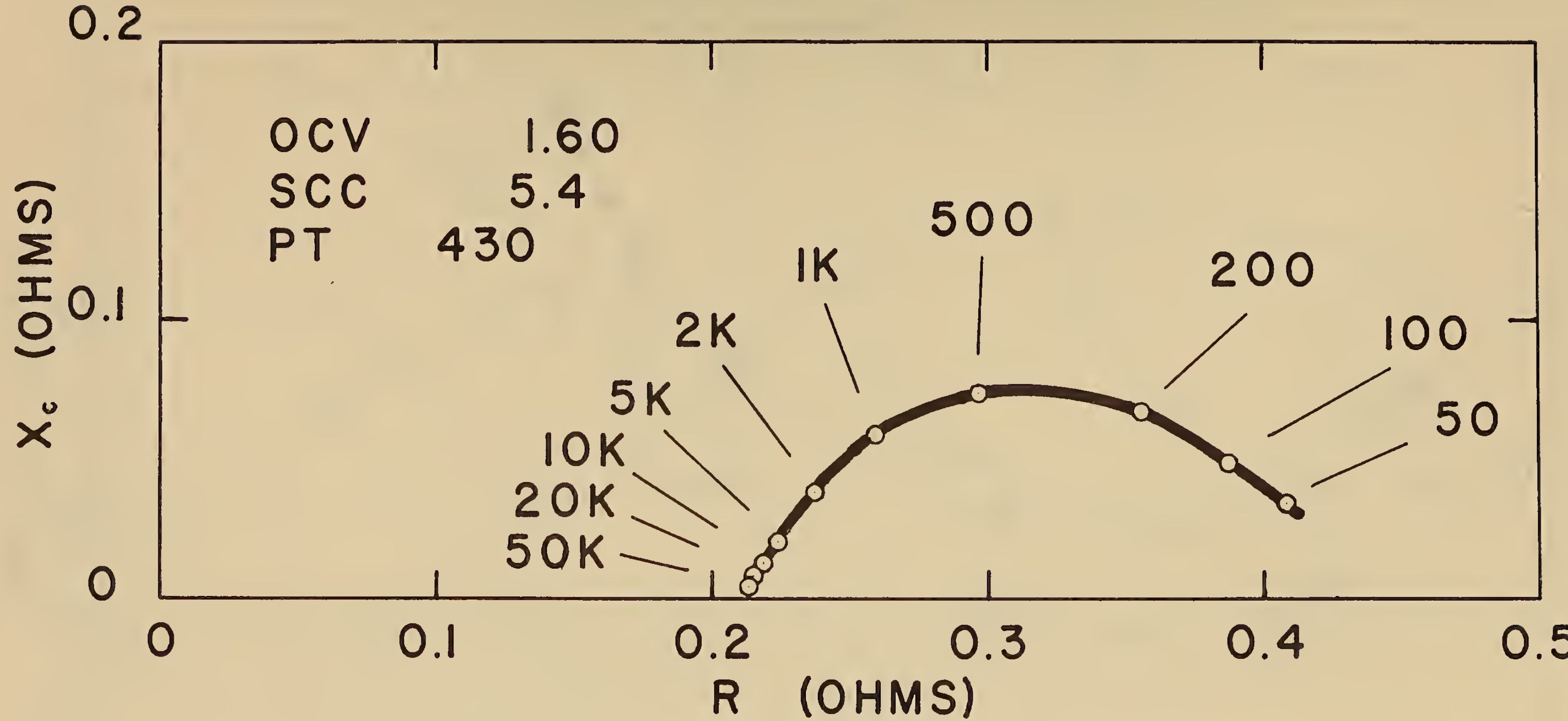

FIG. 10 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 1 BEFORE DISCHARGE

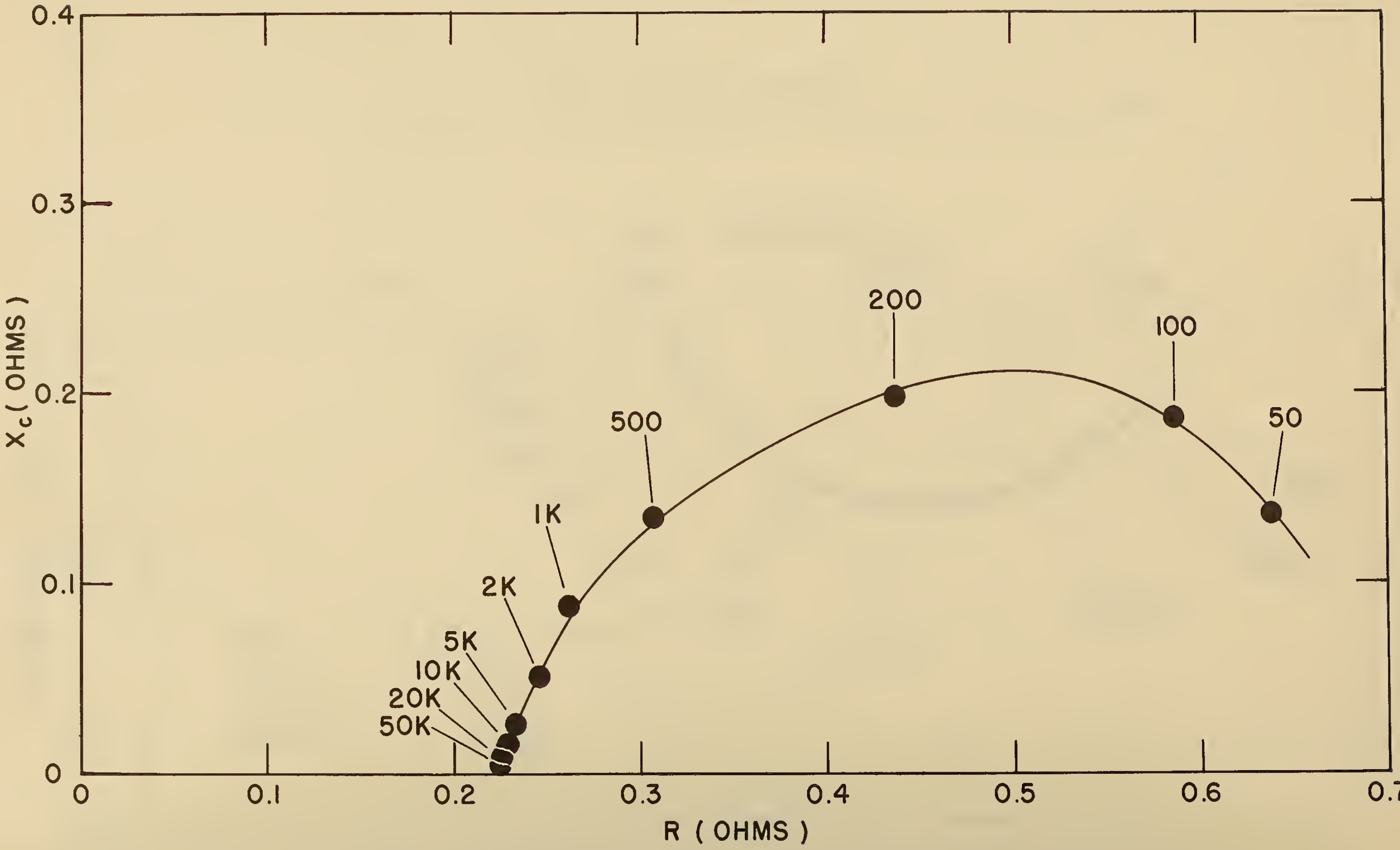

FIG. 11 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 1 AFTER 6 MONTHS STORAGE

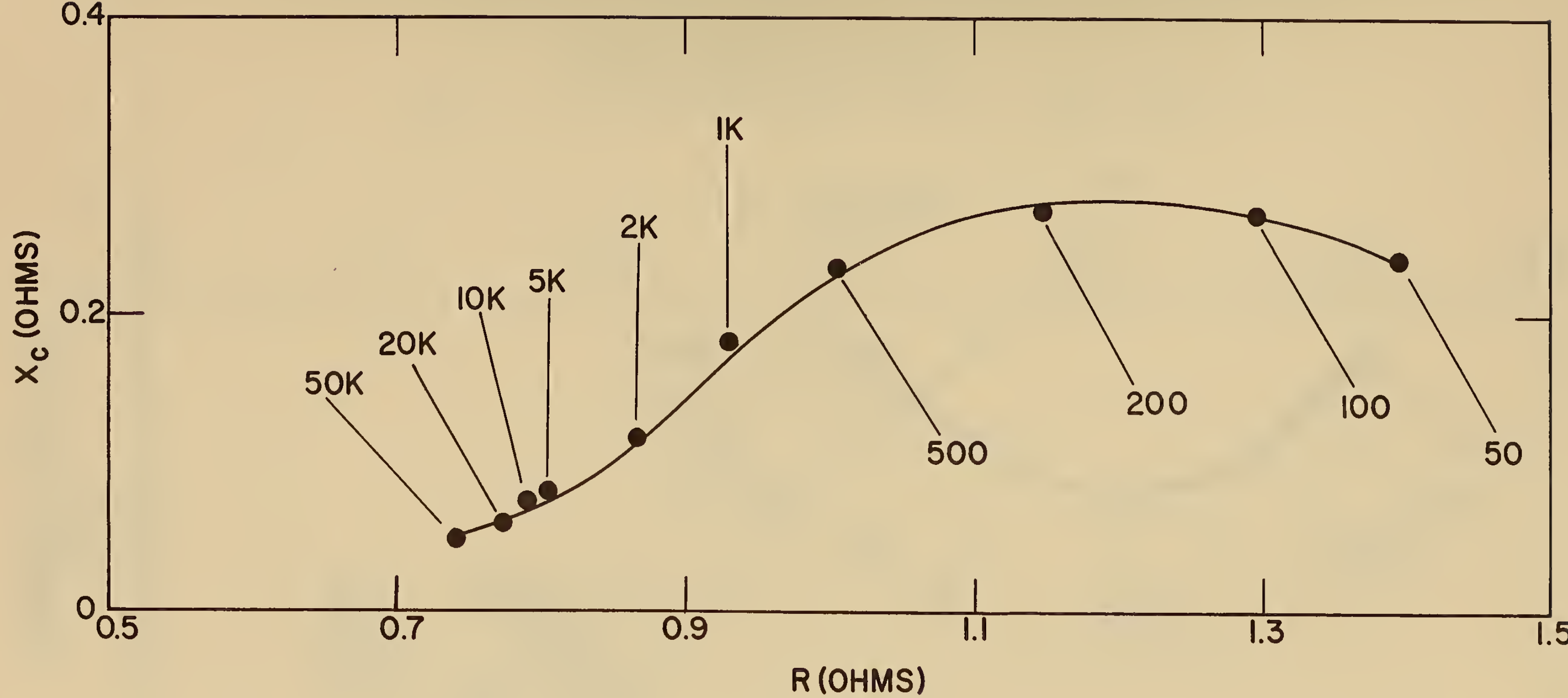

FIG. 12 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 1 AFTER 4-OHM TEST

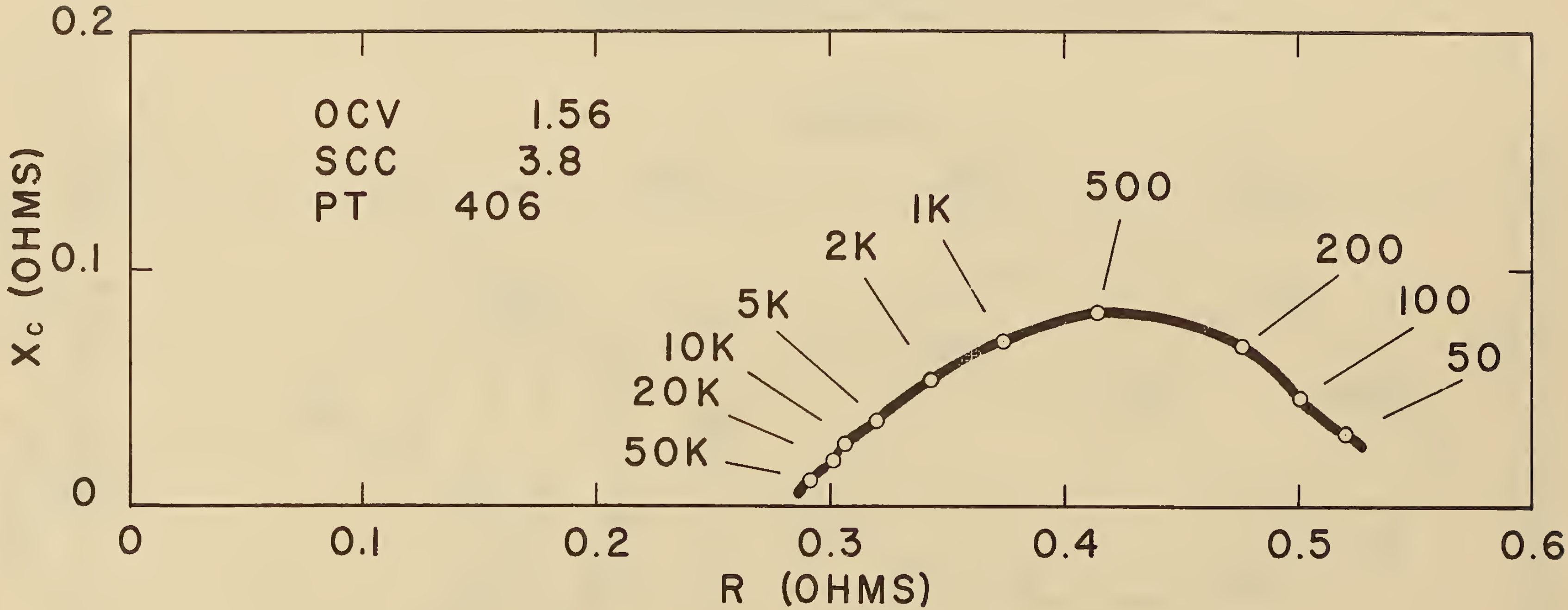

FIG. 13 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 2 BEFORE DISCHARGE

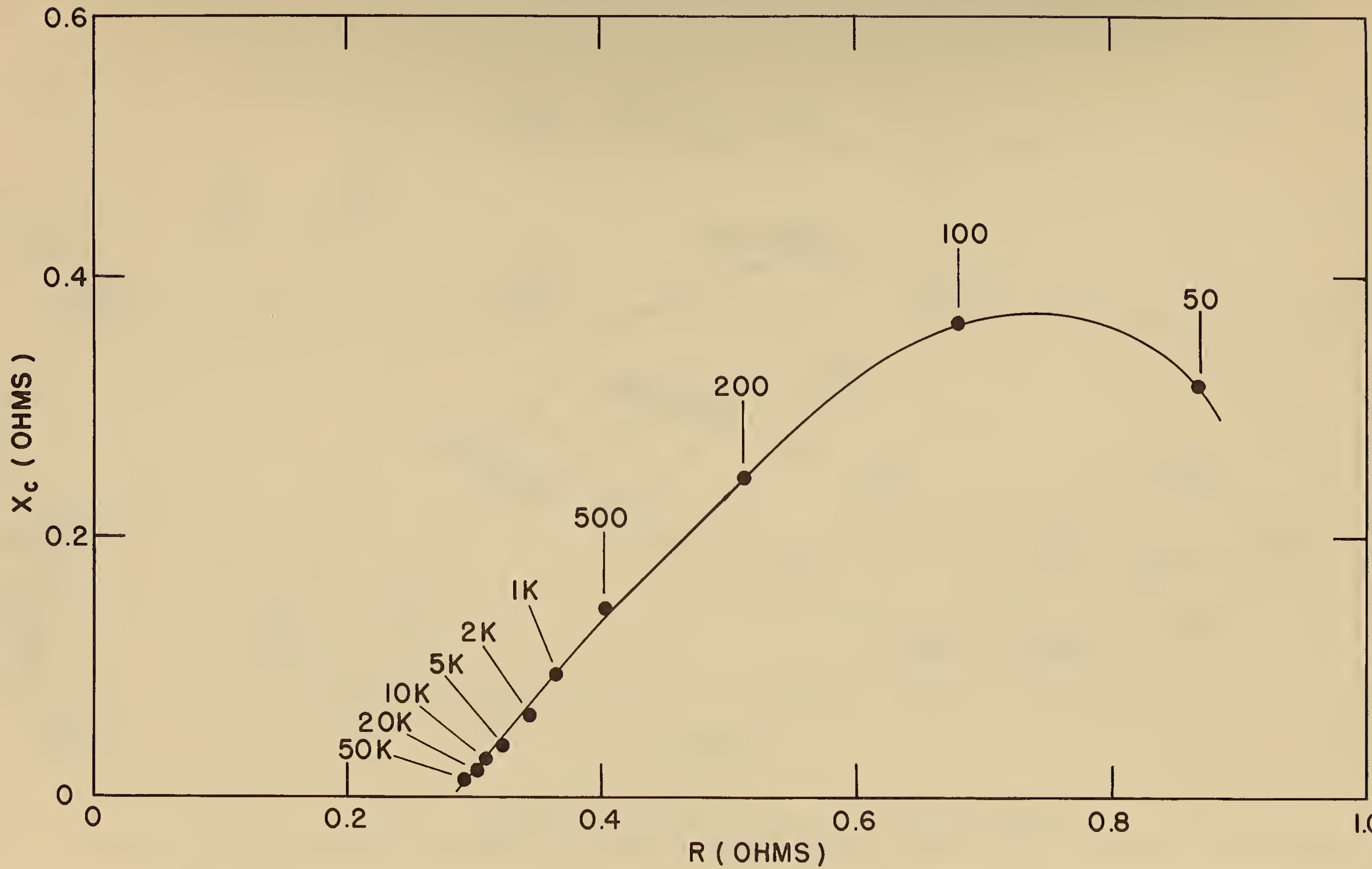

FIG. 14 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 2 AFTER 6 MONTHS STORAGE

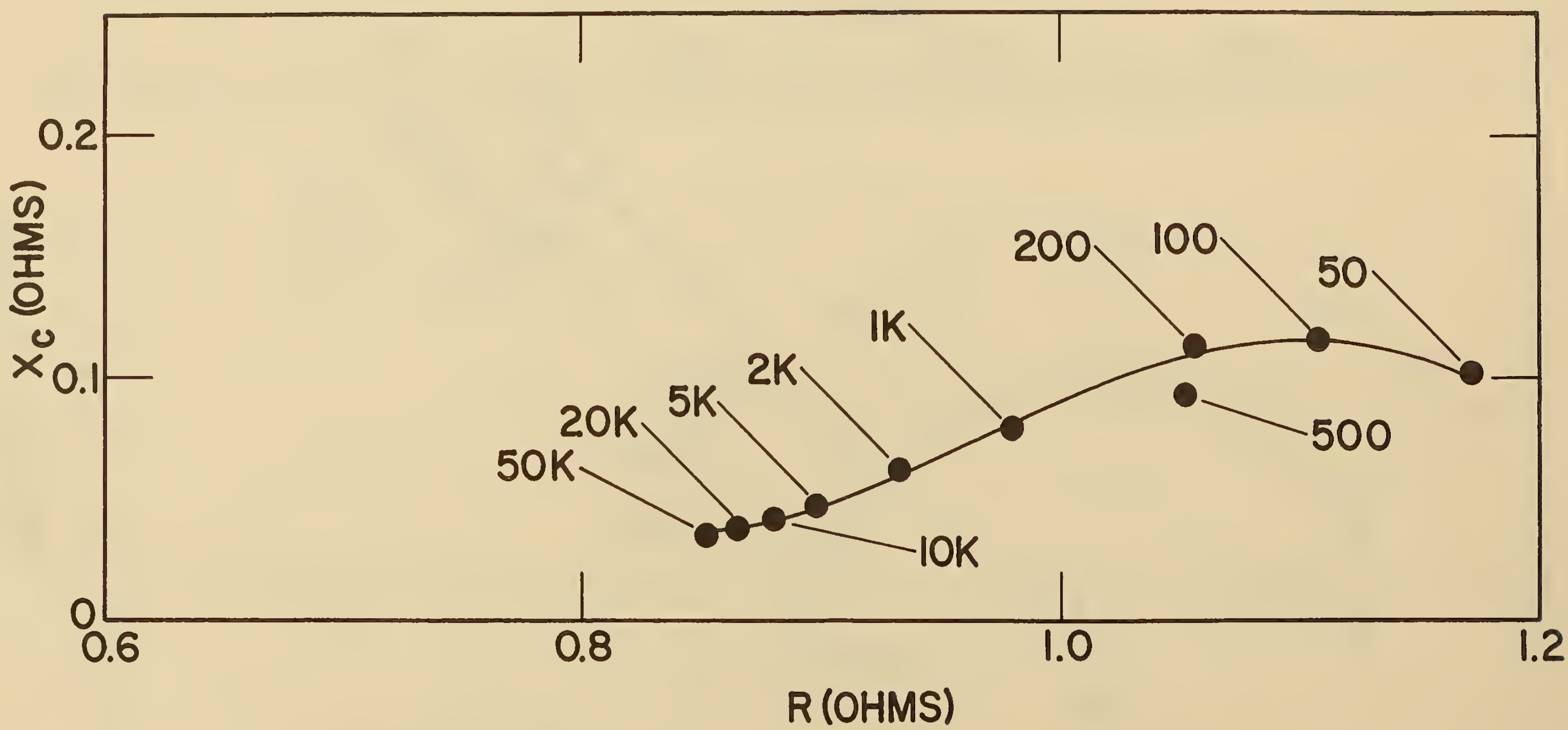

FIG. 15 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 2 AFTER 4-OHM TEST

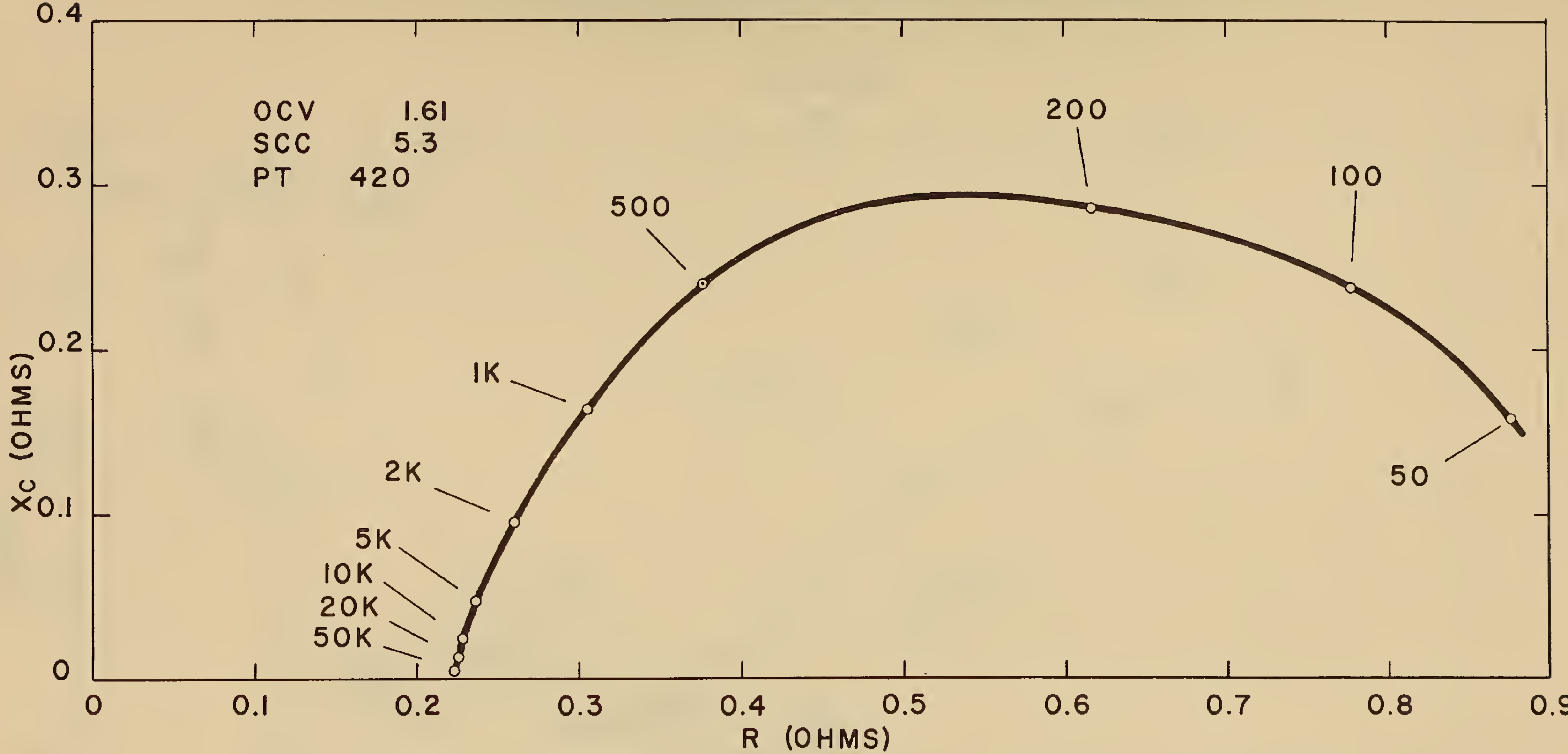

FIG. 16 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 3 BEFORE DISCHARGE

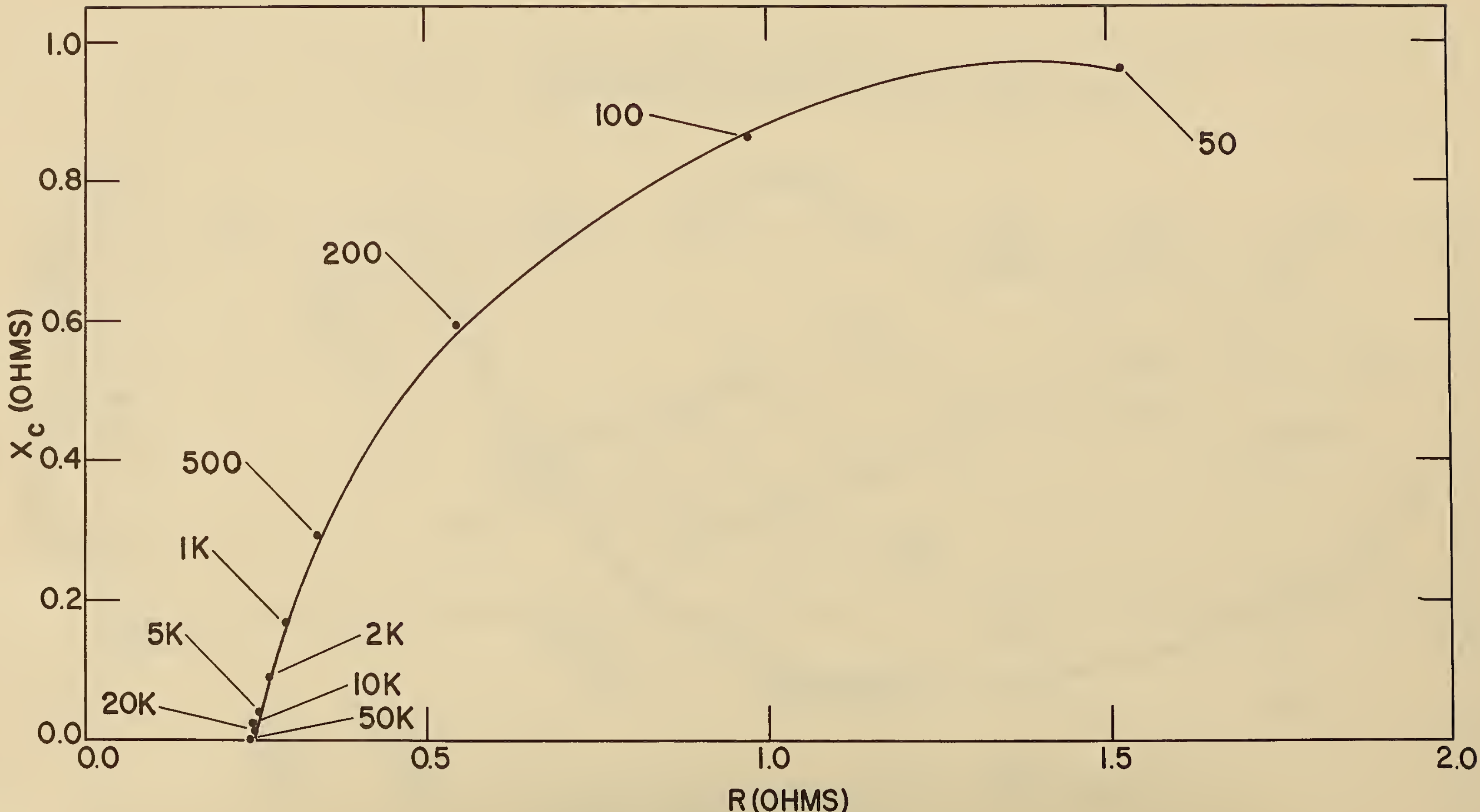

FIG. 17 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 3 AFTER 6 MONTHS STORAGE

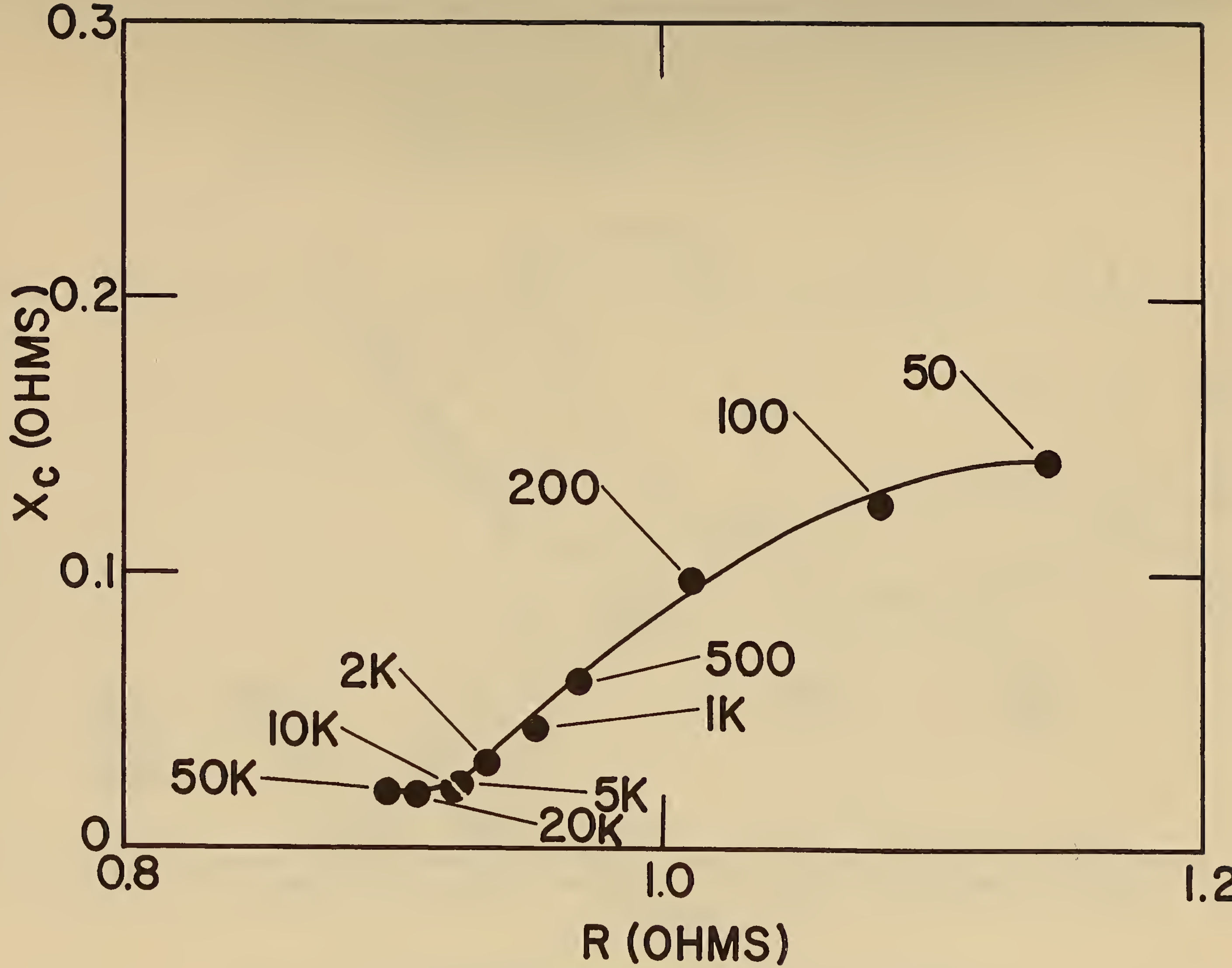

FIG. 18 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 3 AFTER 4-OHM TEST

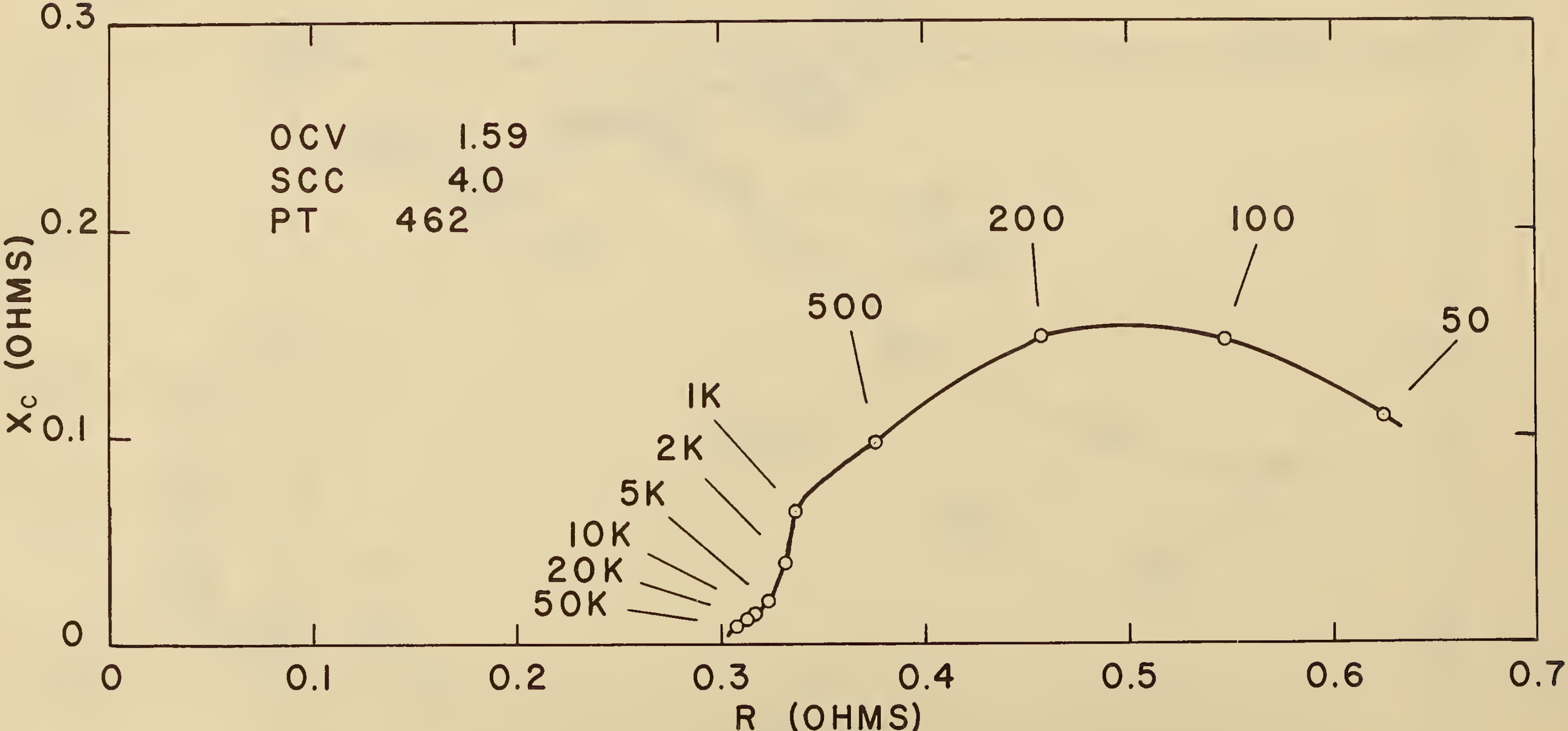

FIG. 19 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 4 BEFORE DISCHARGE

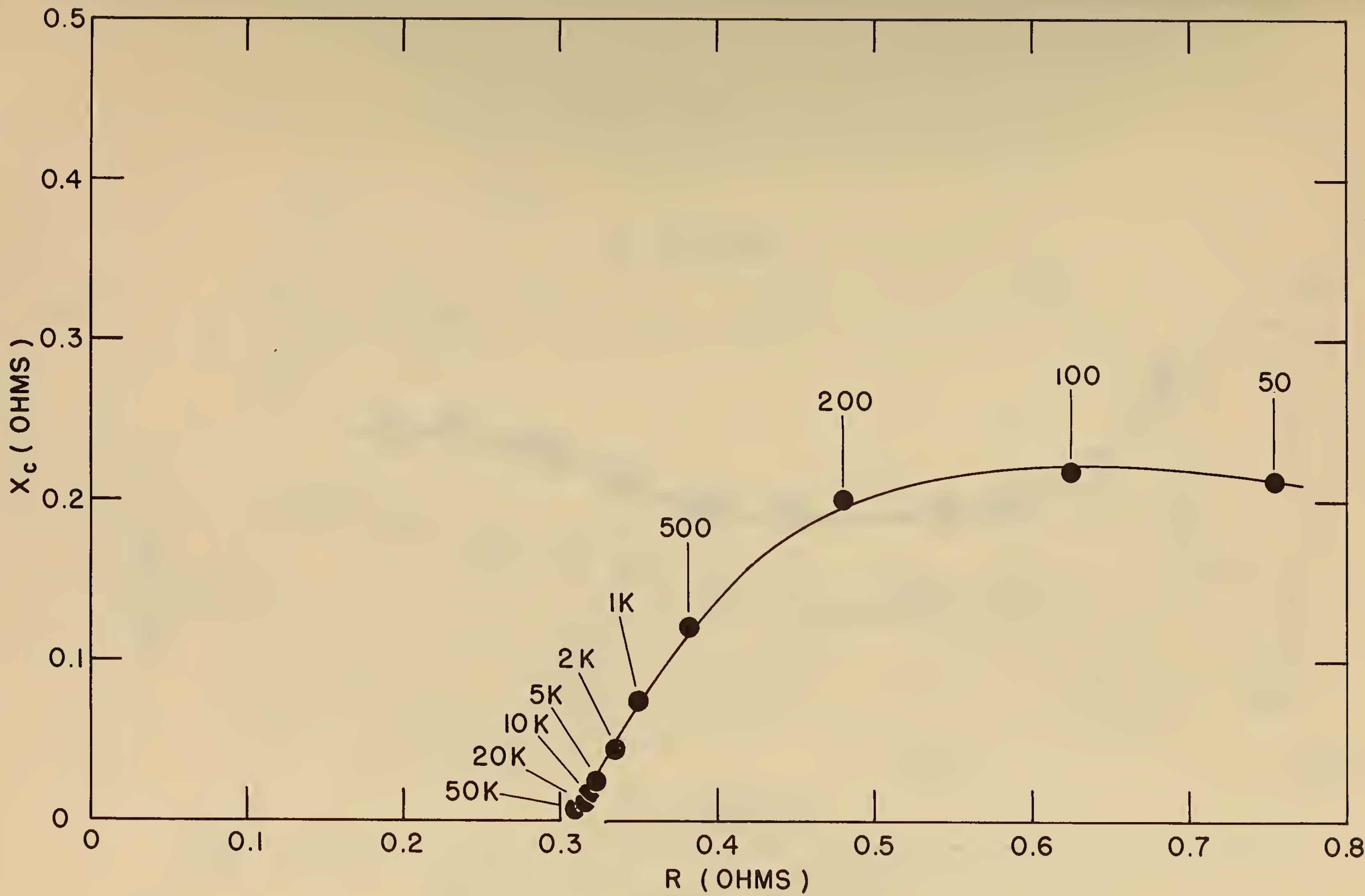

FIG. 20 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 4 AFTER 6 MONTHS STORAGE

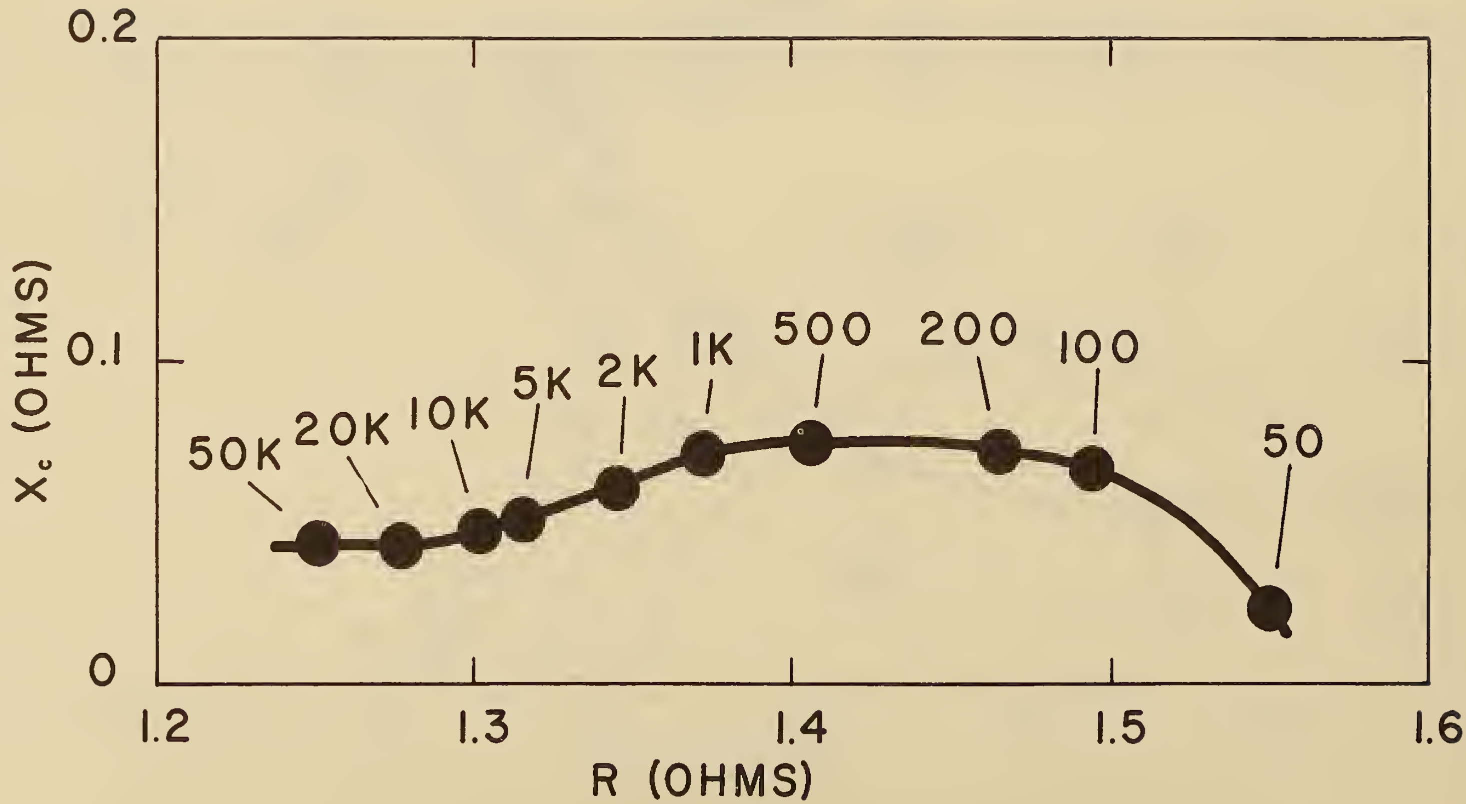

FIG. 21 RESISTANCE-REACTANCE CURVE OF C-SIZE CELLS OF BRAND 4 AFTER 4-OHM TEST

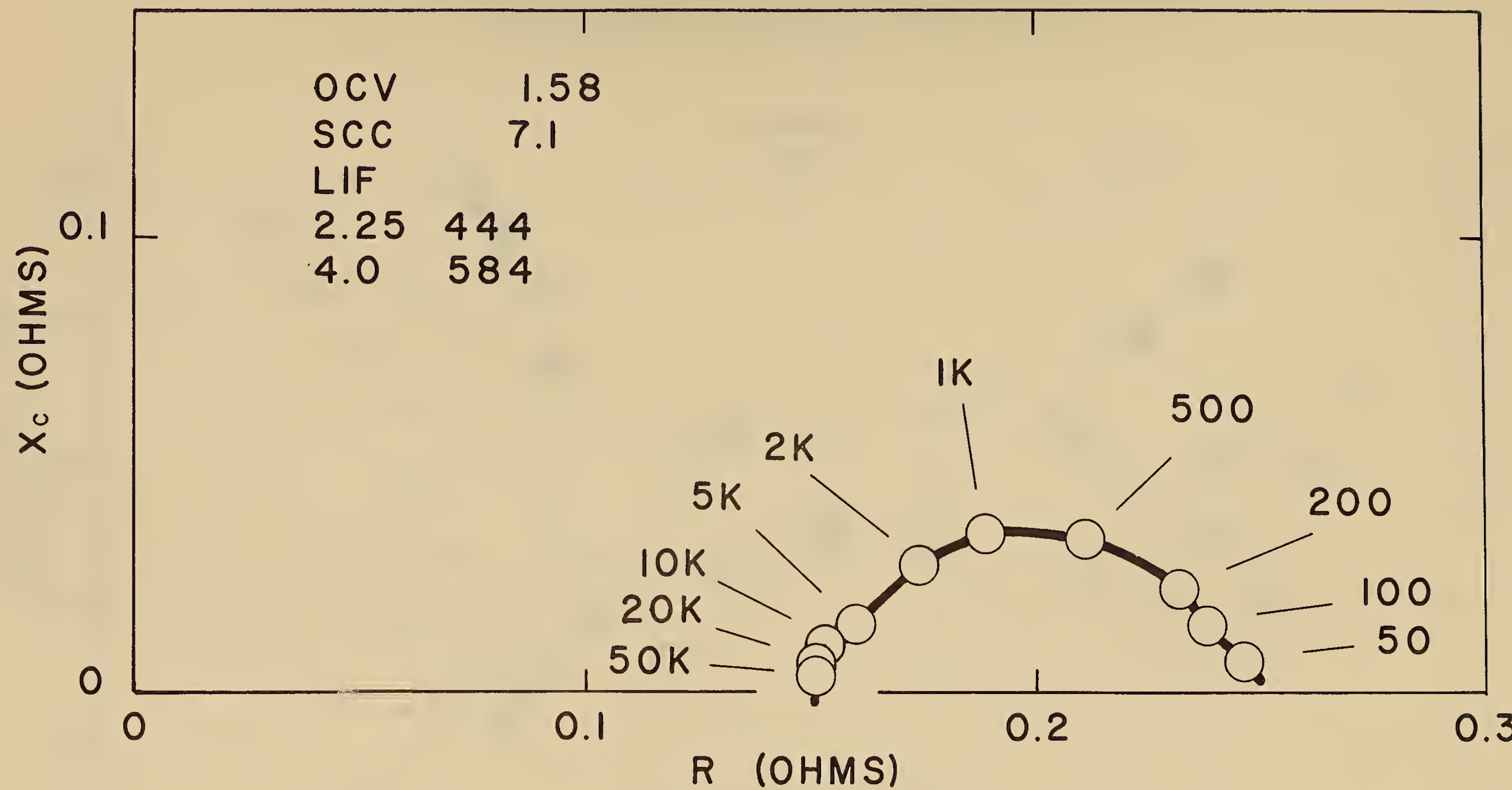

FIG. 22 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 1 BEFORE DISCHARGE

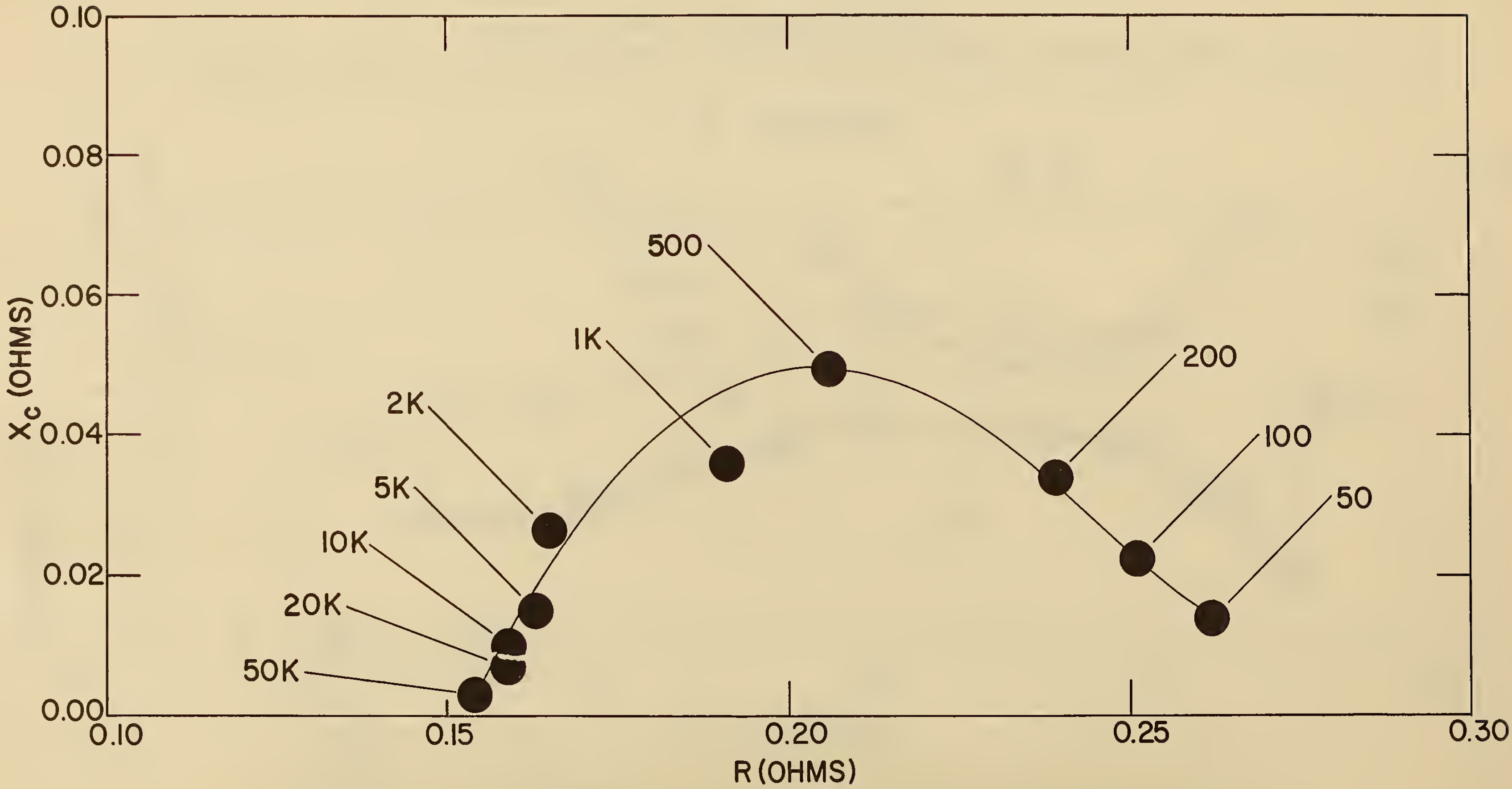

FIG. 23 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 1 AFTER SIX MONTHS STORAGE

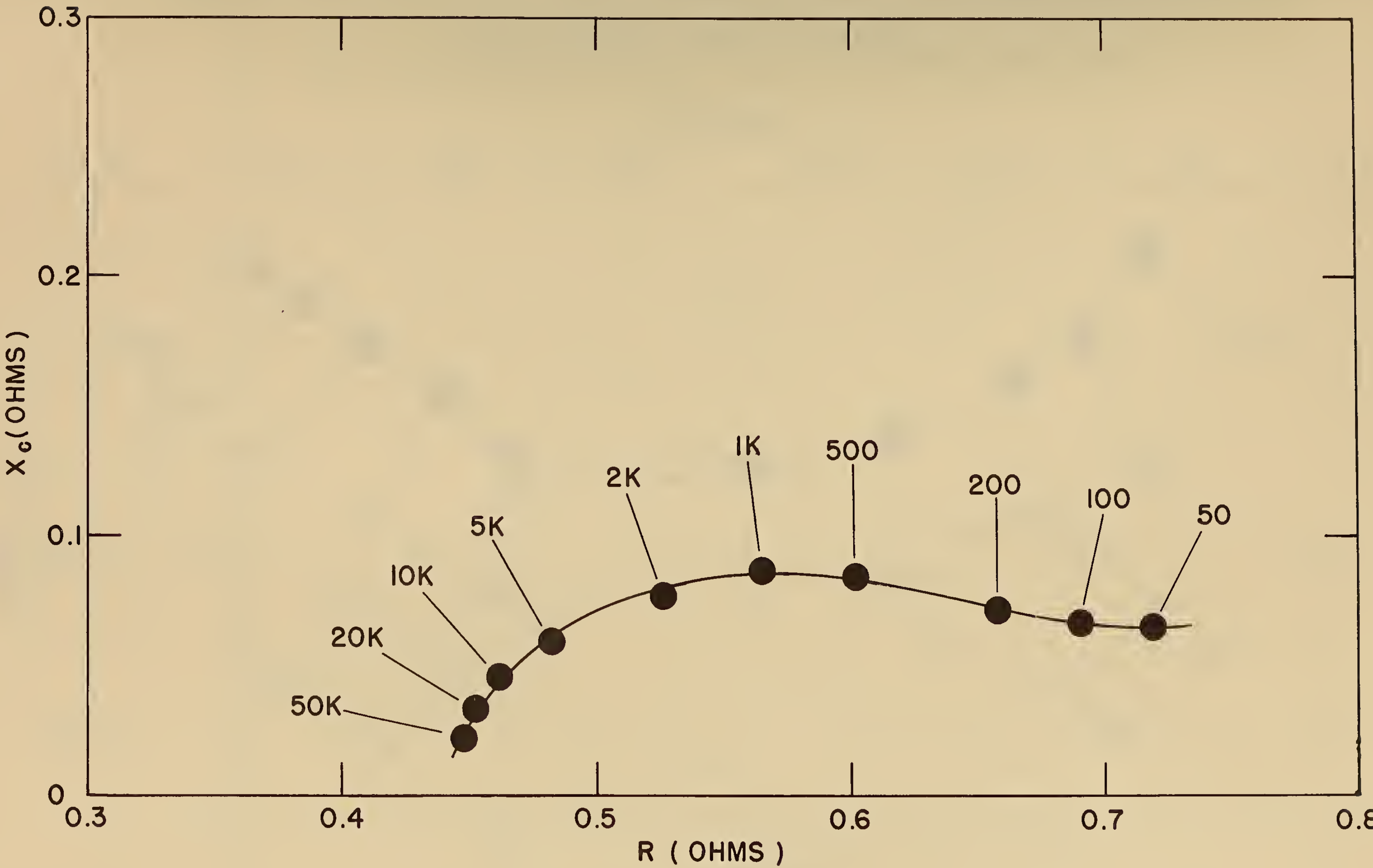

FIG. 24 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 1 AFTER LIF TEST

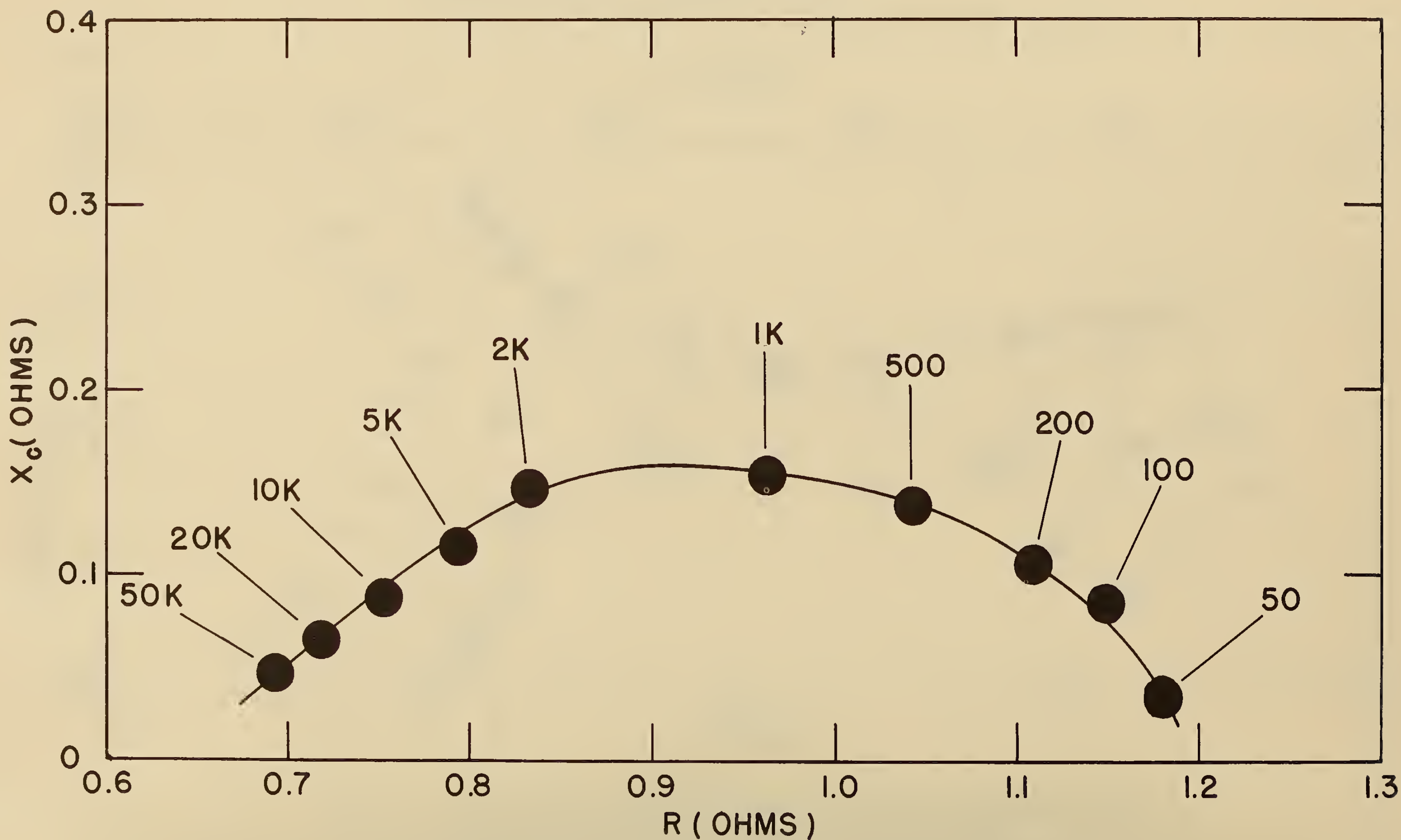

FIG. 25 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 1 AFTER 2.25-OHM TEST

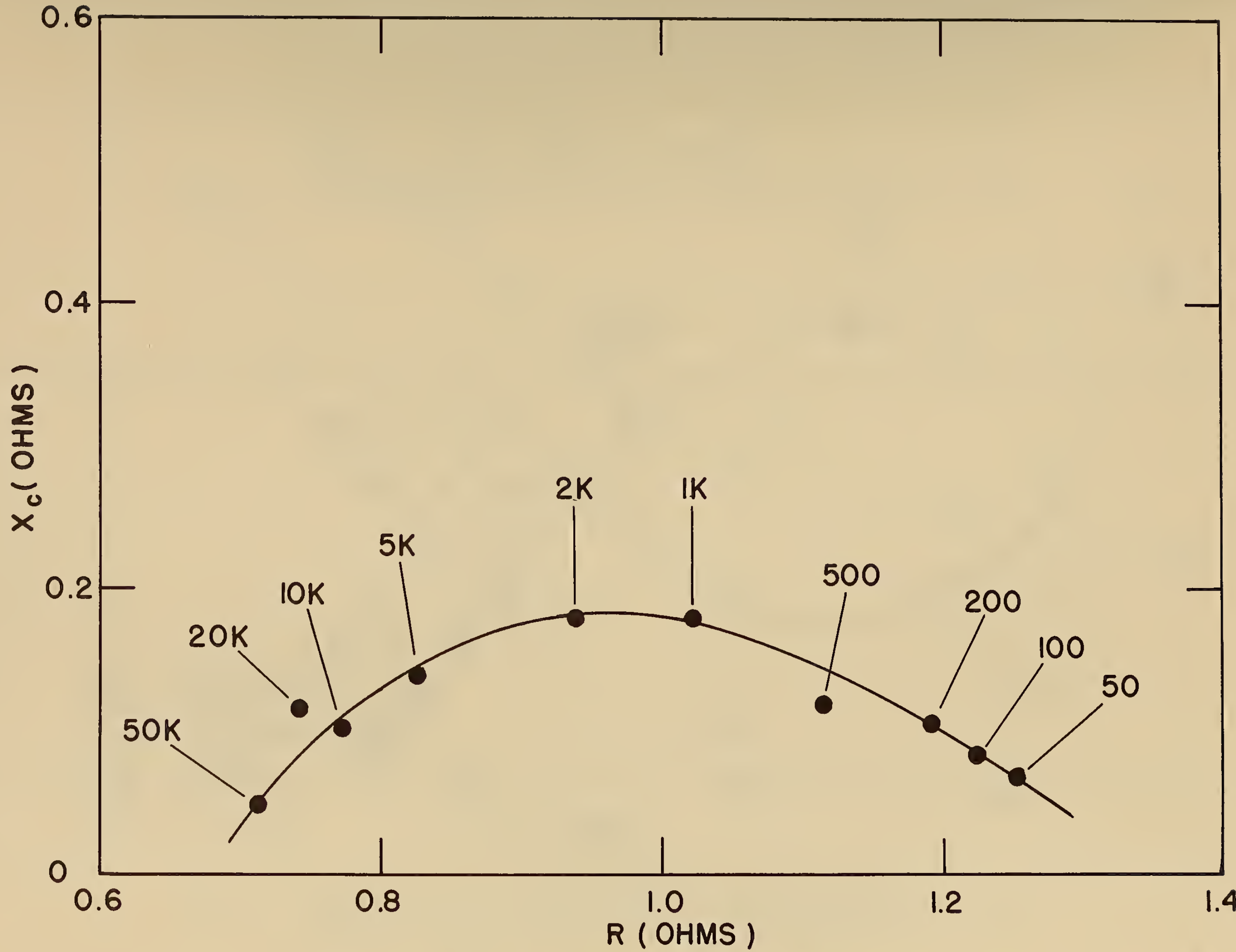

FIG. 26 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 1 AFTER 4-OHM TEST

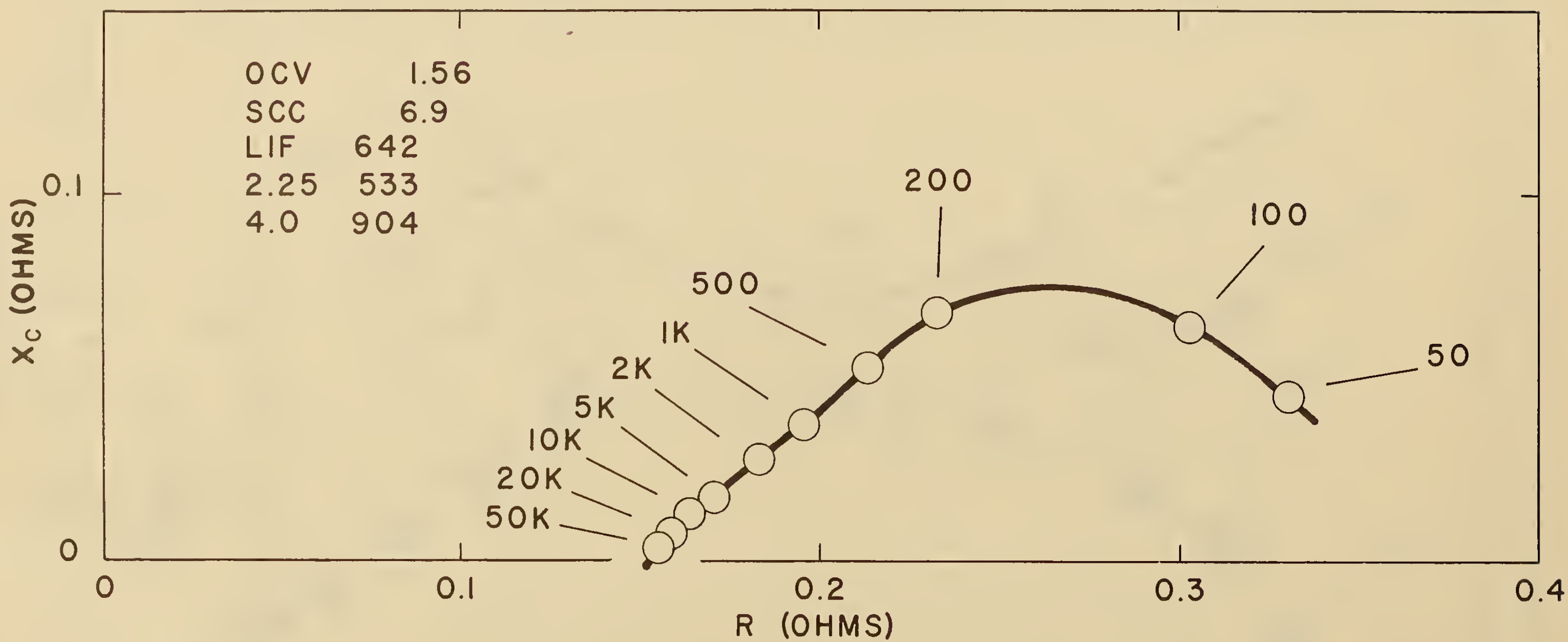

FIG. 27 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 2 BEFORE DISCHARGE

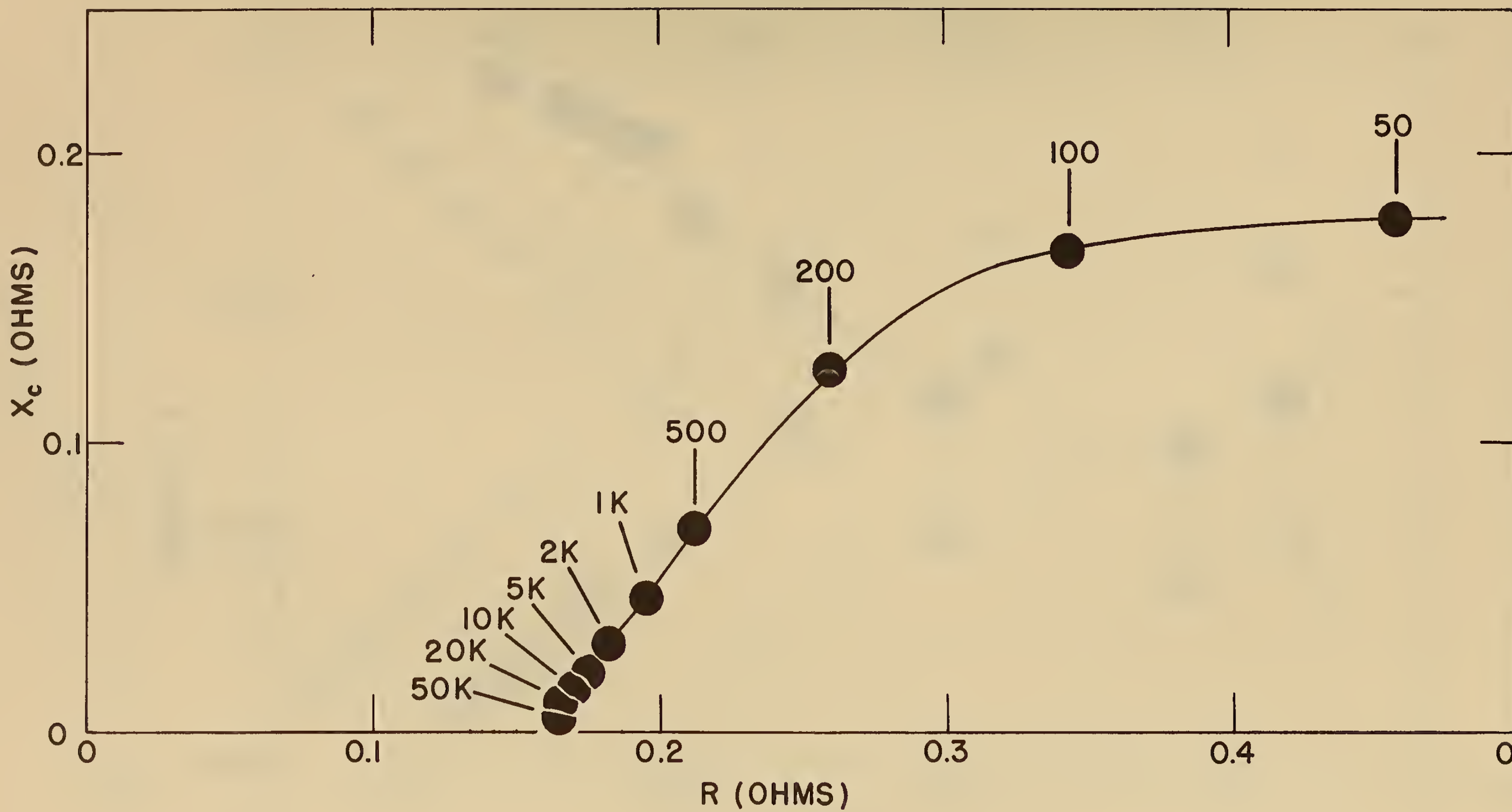

FIG. 28 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 2 AFTER SIX MONTHS STORAGE

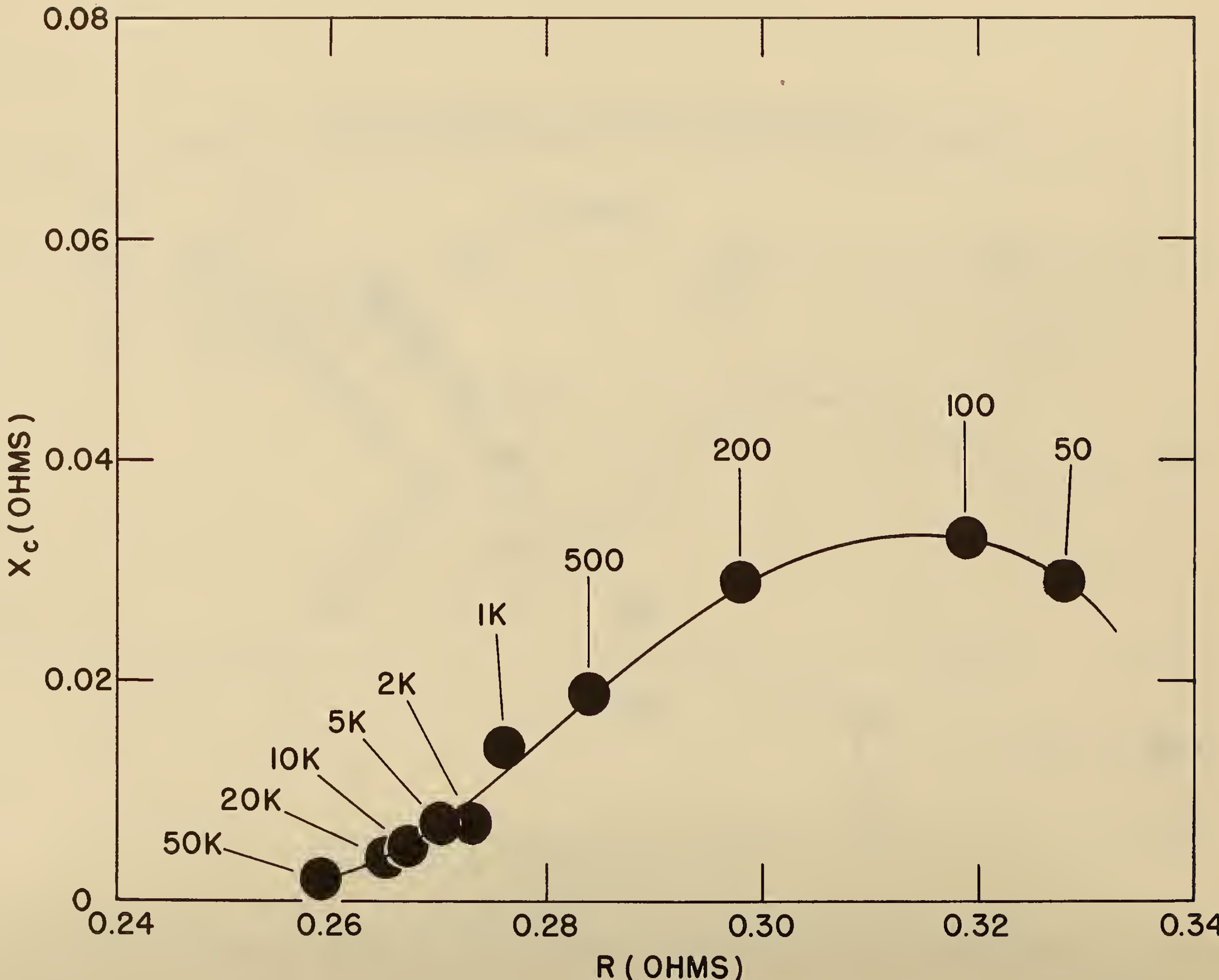

FIG. 29 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 2 AFTER LIF TEST

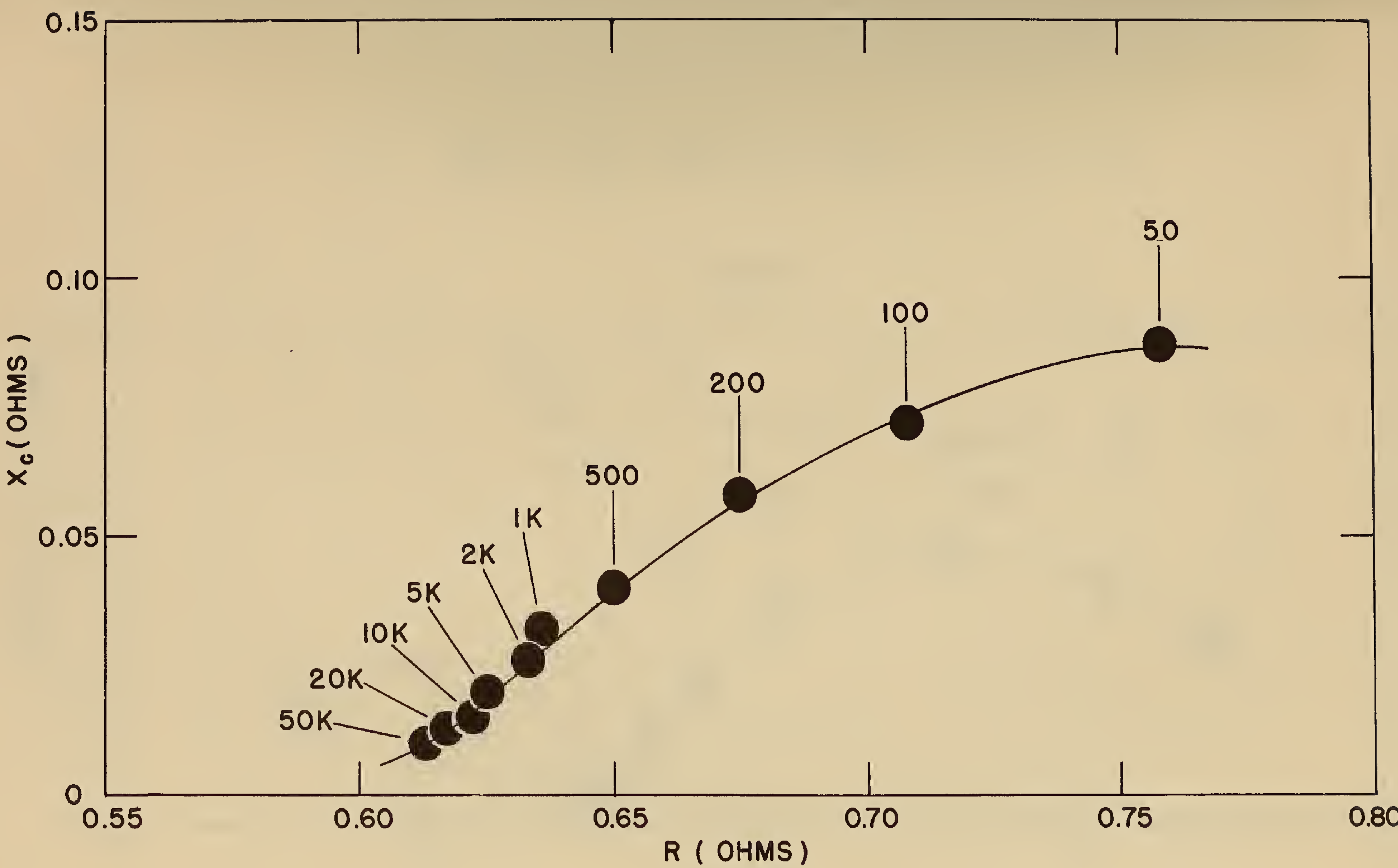

FIG. 30 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 2 AFTER 2.25-OHM TEST

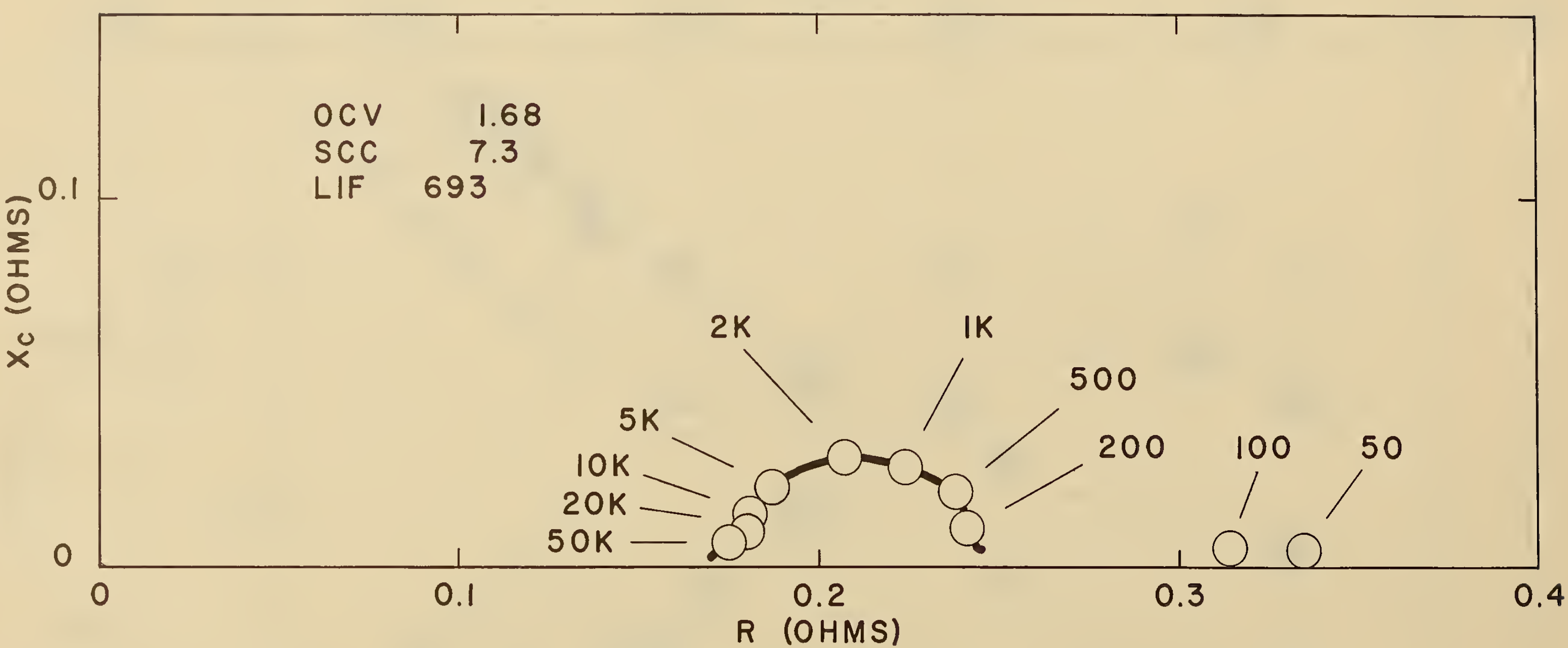

FIG. 31 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 3 BEFORE DISCHARGE

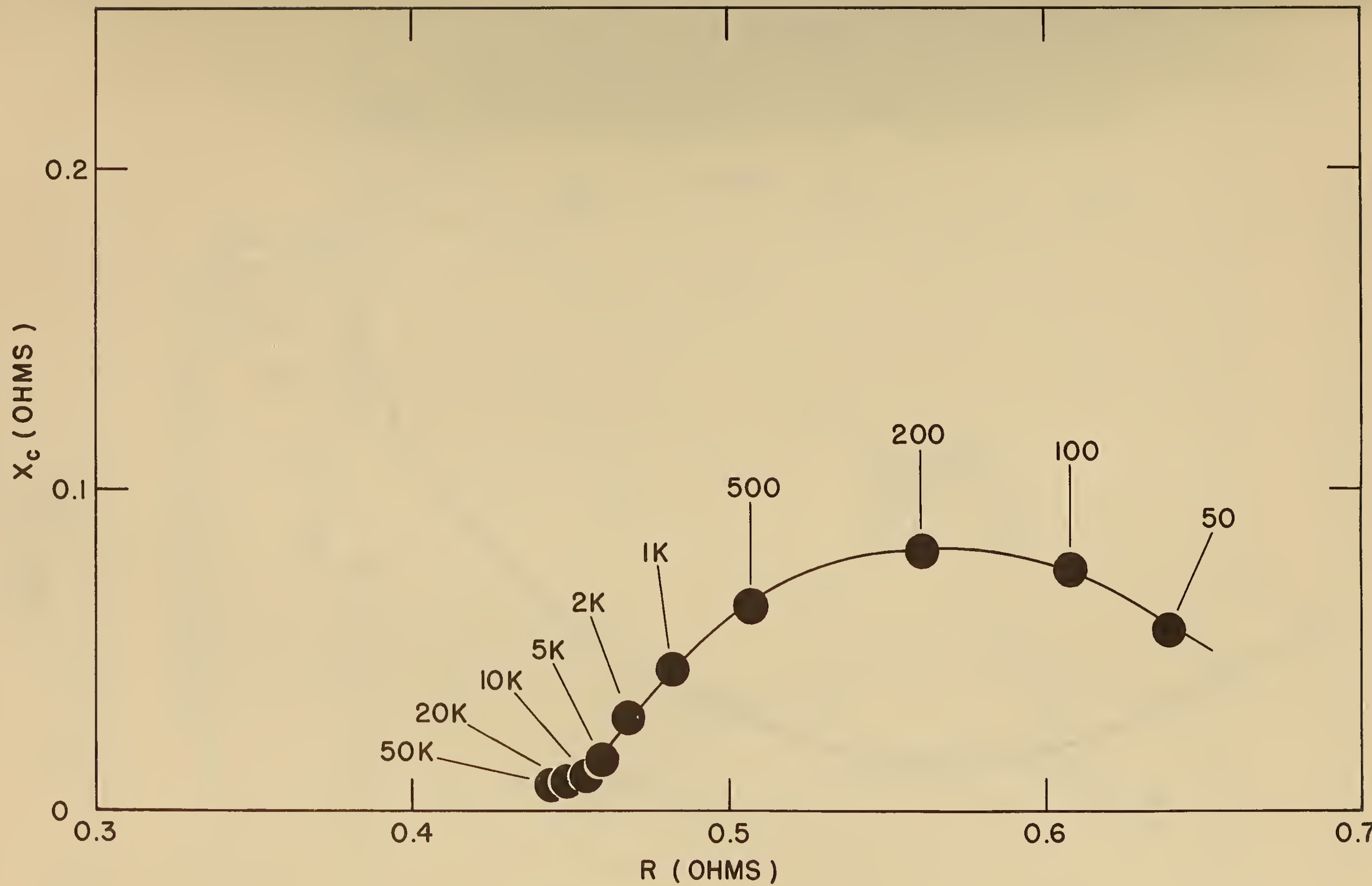

FIG. 32 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 3 AFTER LIF TEST

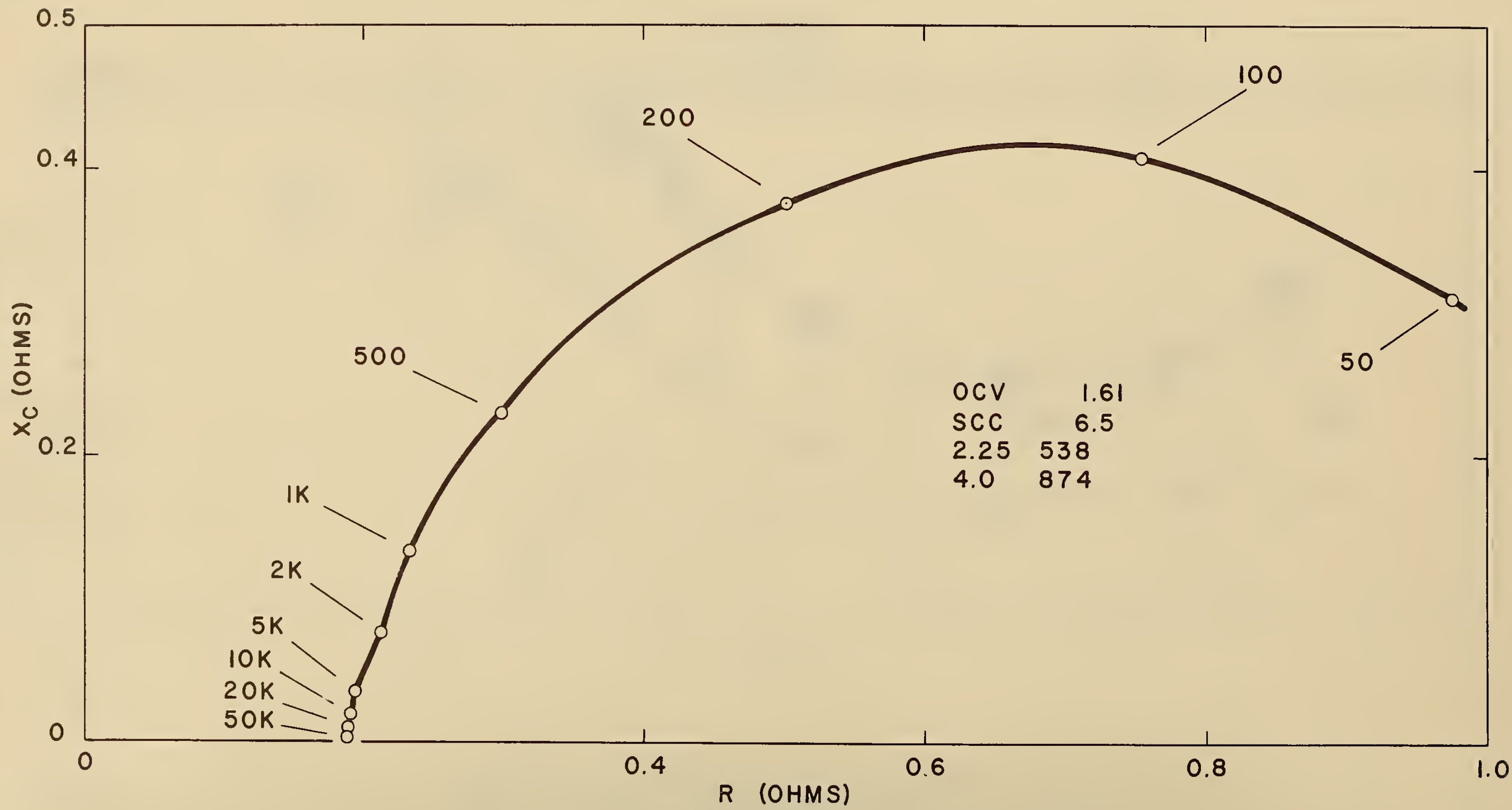

FIG. 33 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 4 BEFORE DISCHARGE

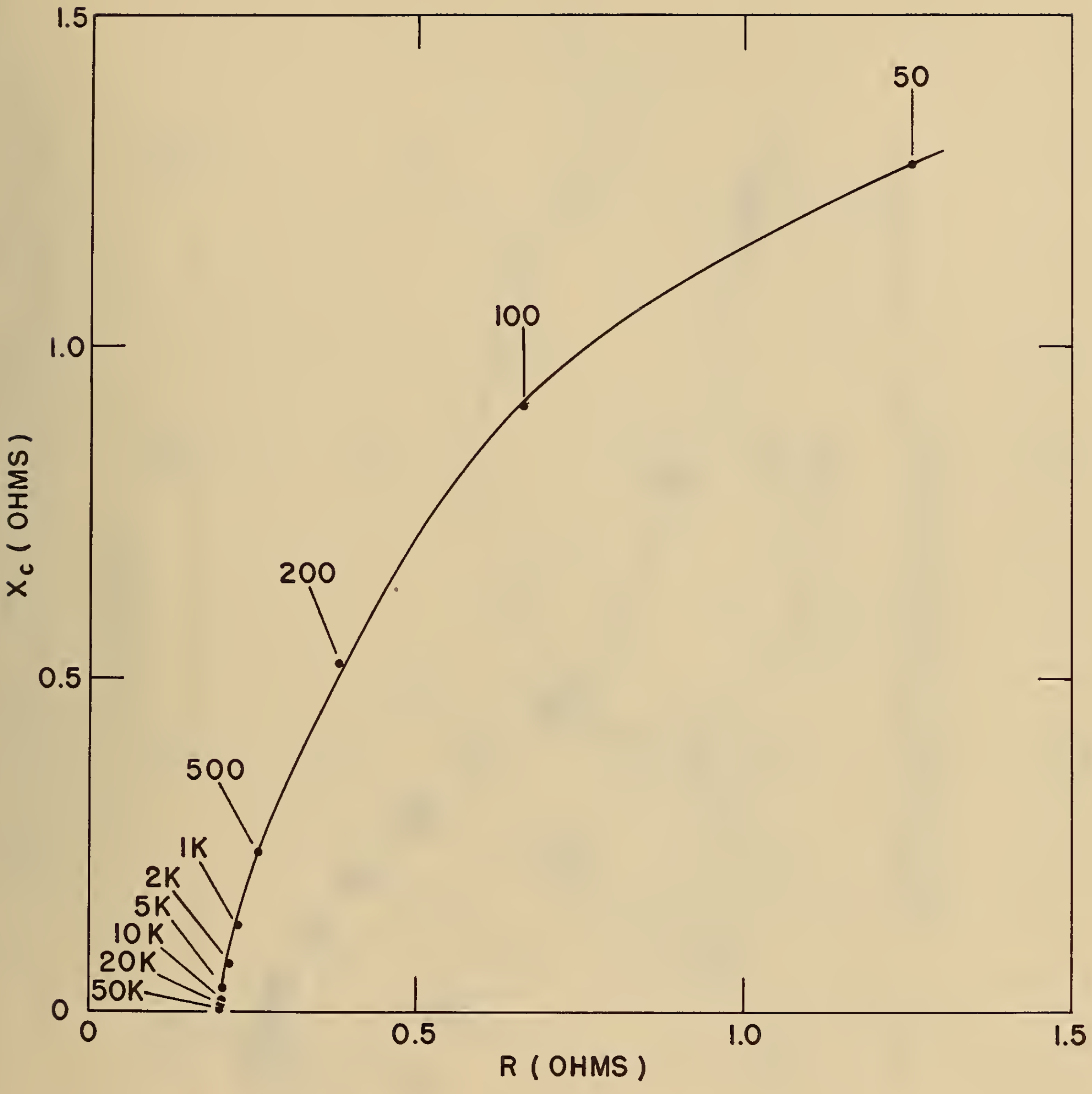

FIG. 34 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 4 AFTER SIX MONTHS STORAGE

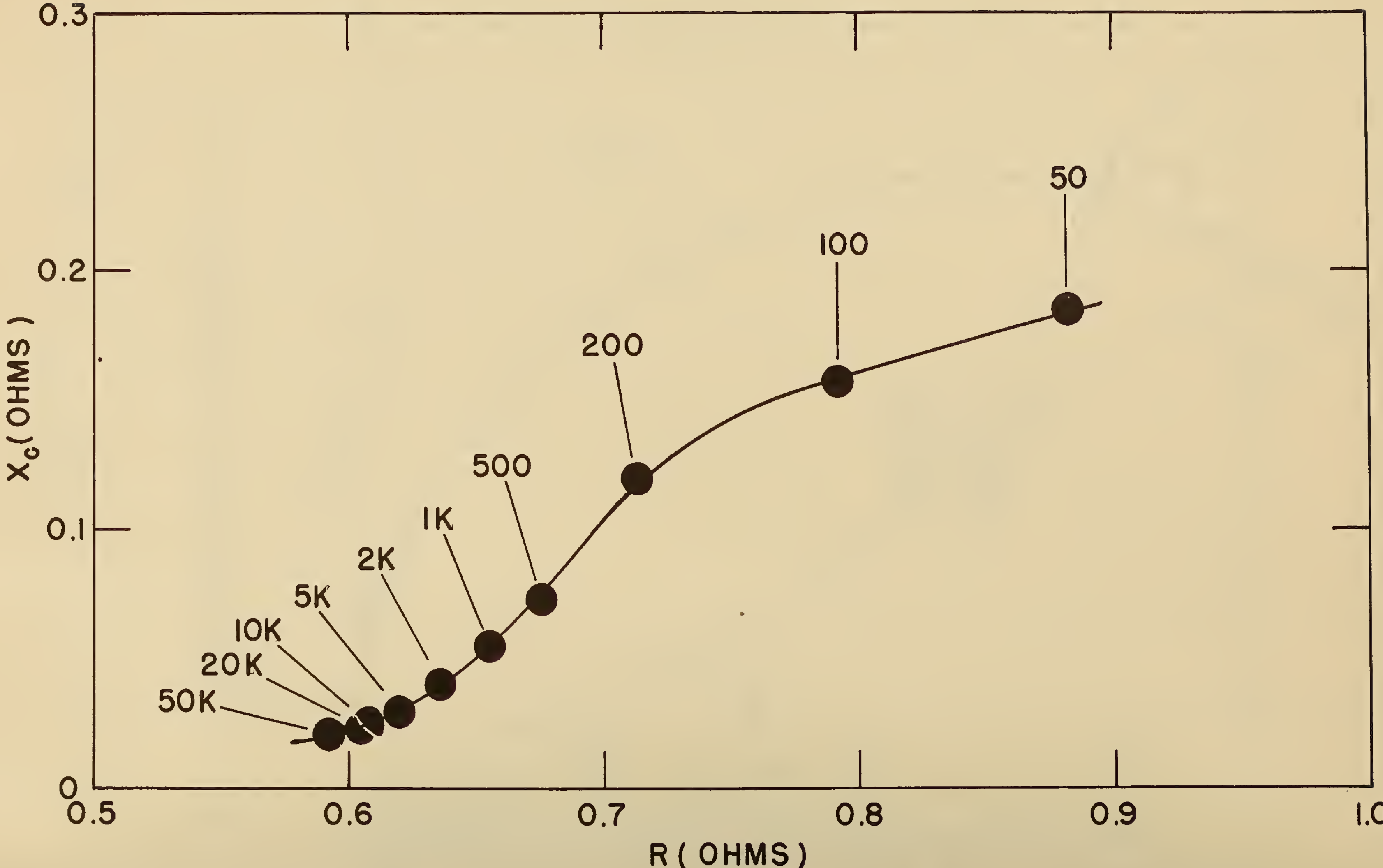

FIG. 35 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 4 AFTER 2.25-OHM TEST

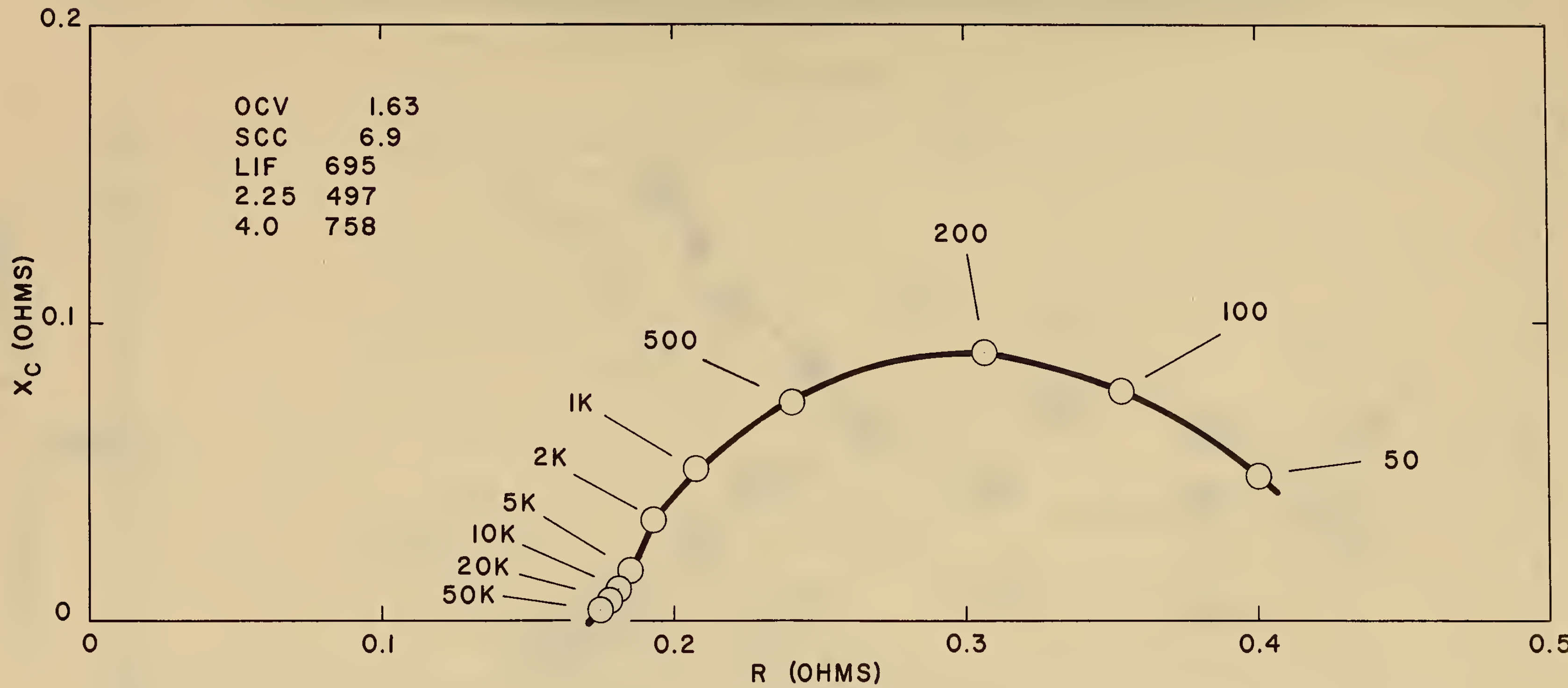

FIG. 36 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 5 BEFORE DISCHARGE

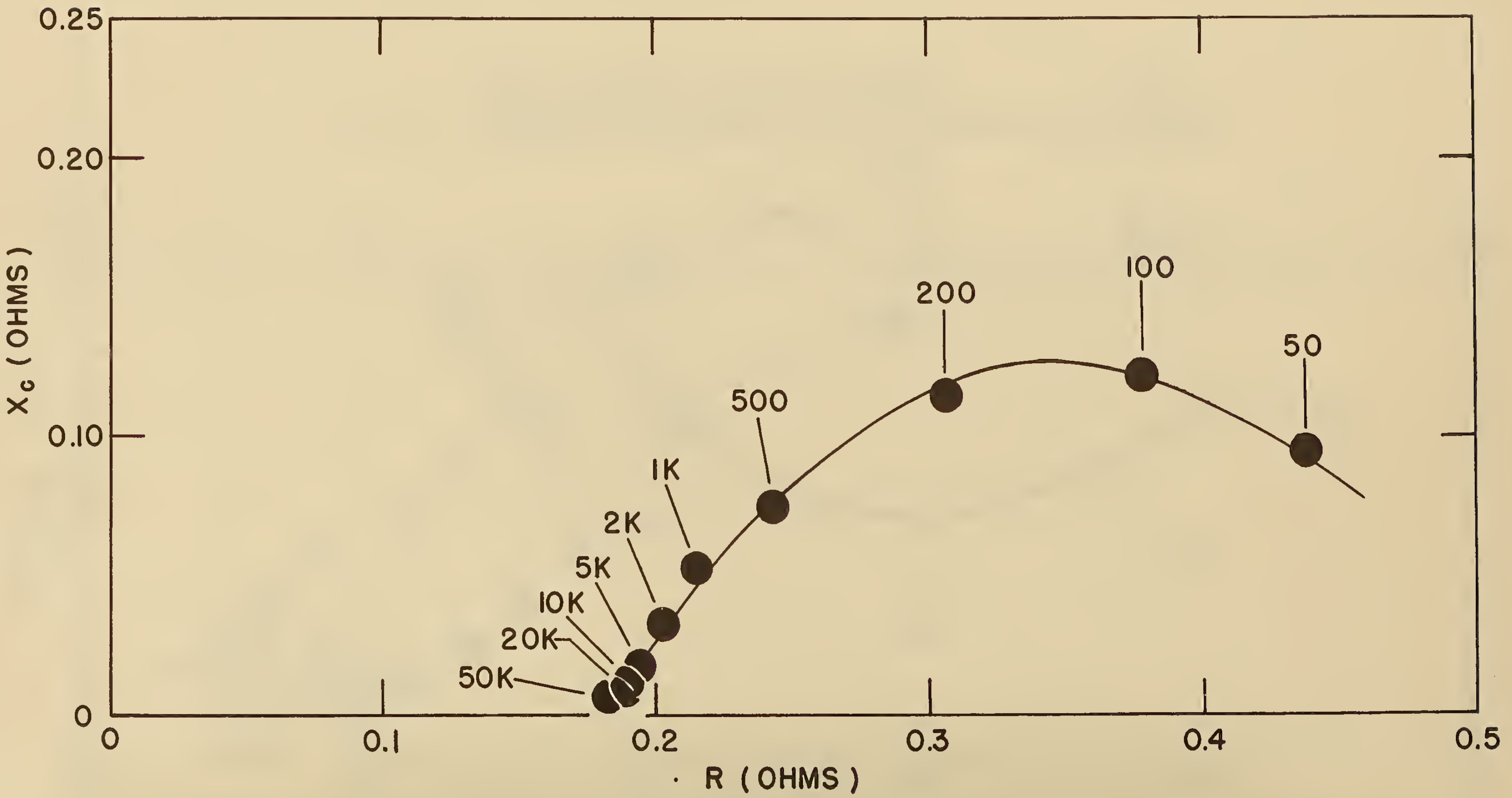

FIG. 37 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 5 AFTER 6 MONTHS STORAGE

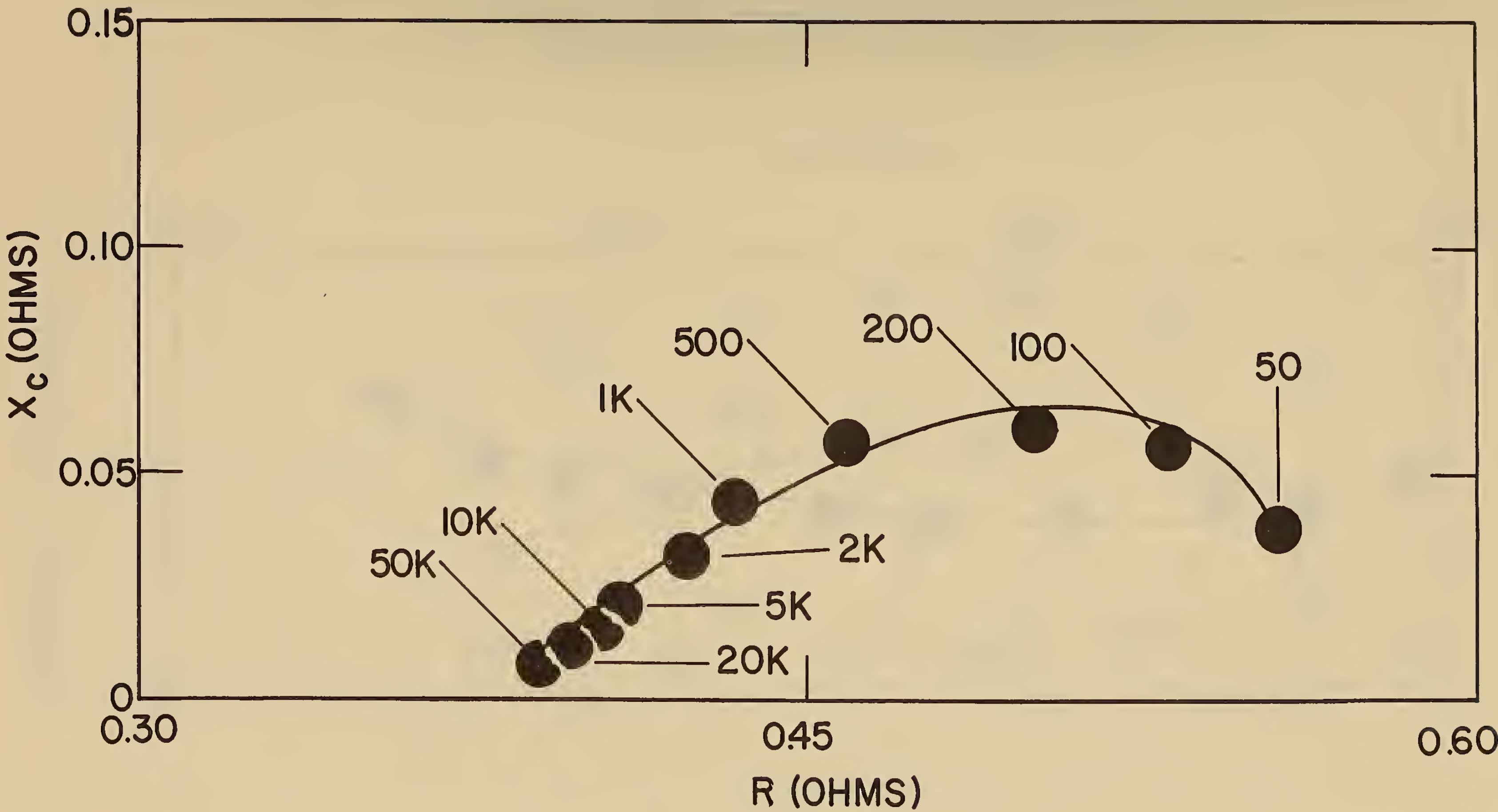

FIG. 38 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 5 AFTER LIF TEST

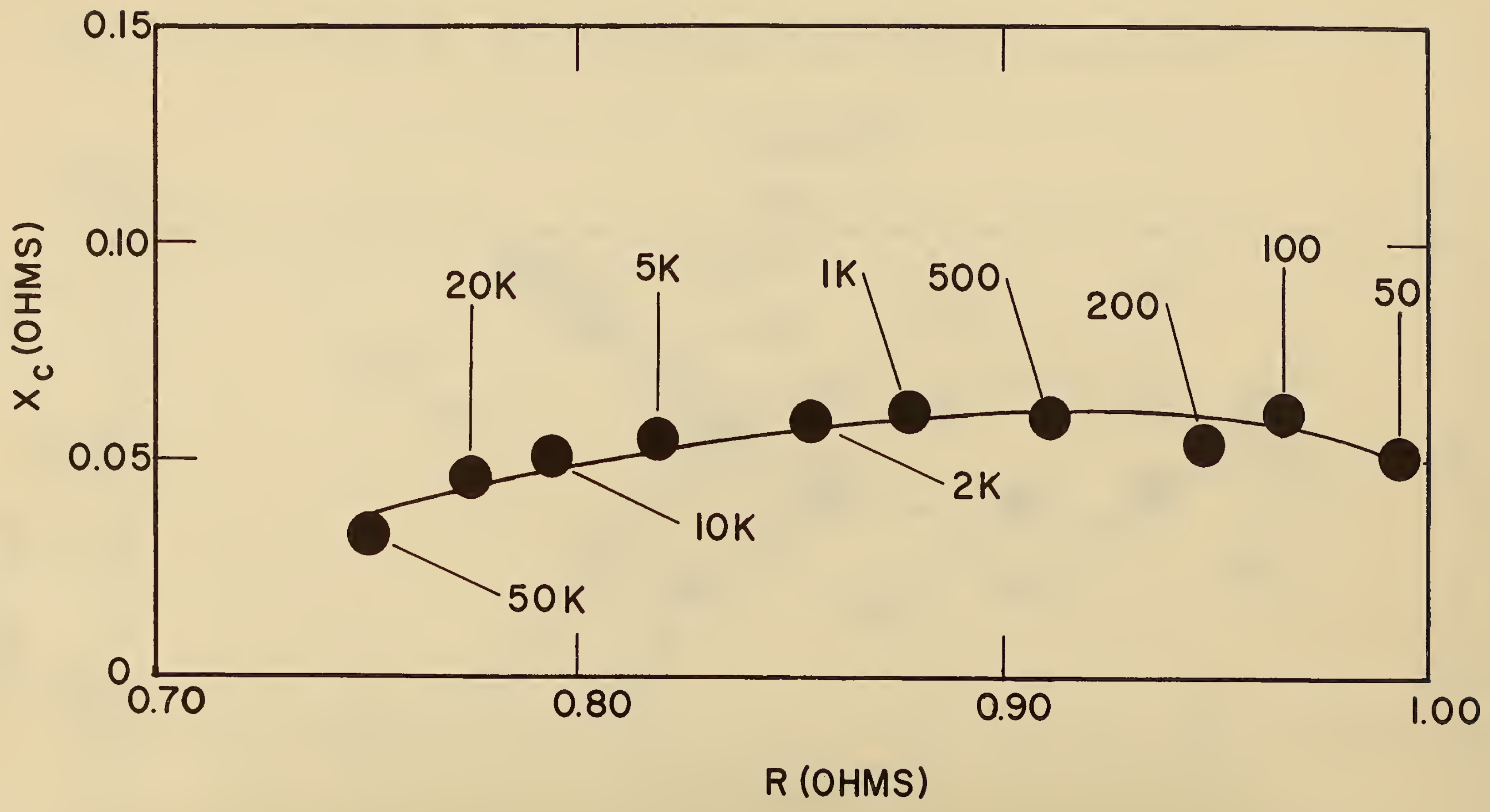

FIG. 39 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 5 AFTER 2.25-OHM TEST

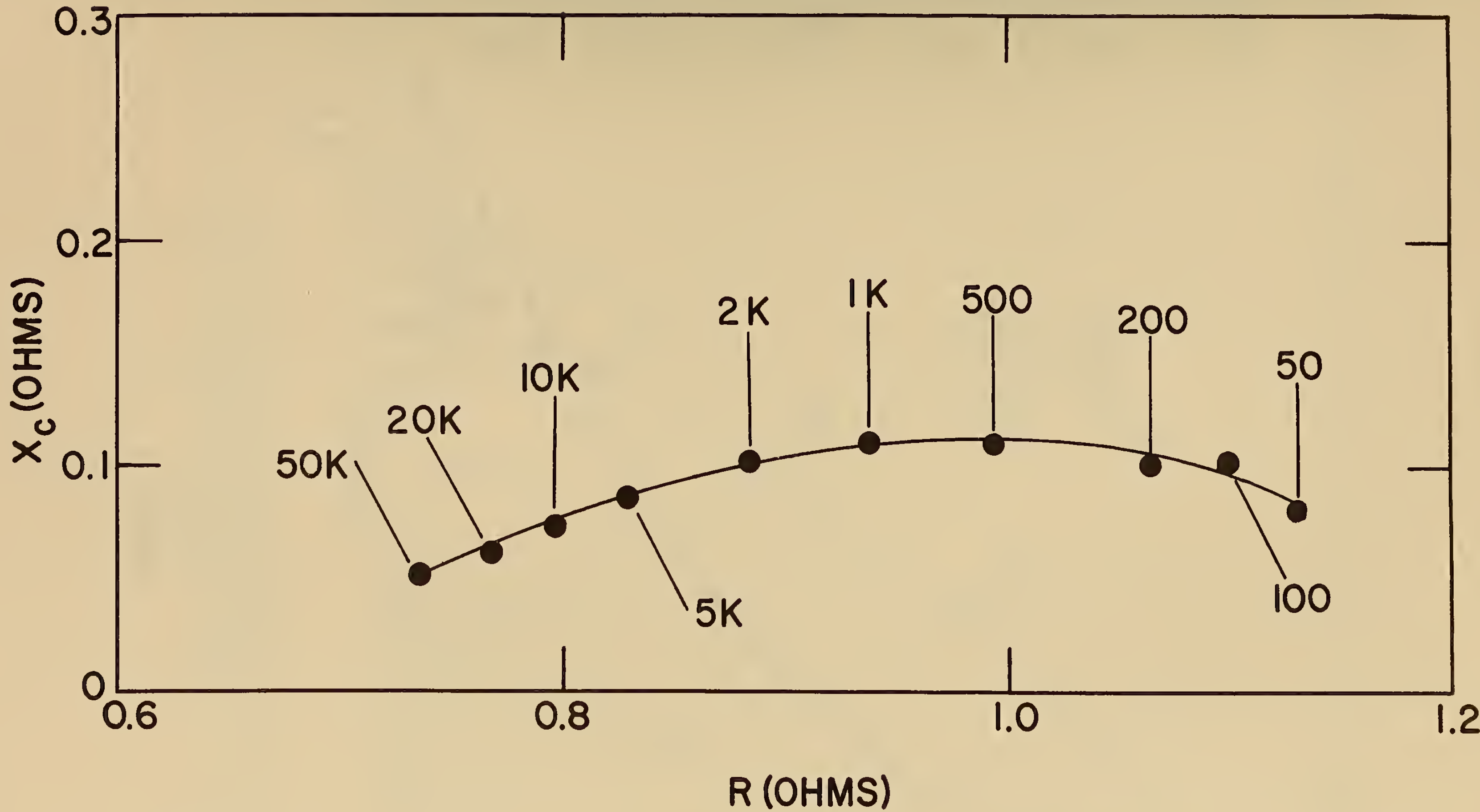

FIG. 40 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 5 AFTER 4-OHM TEST

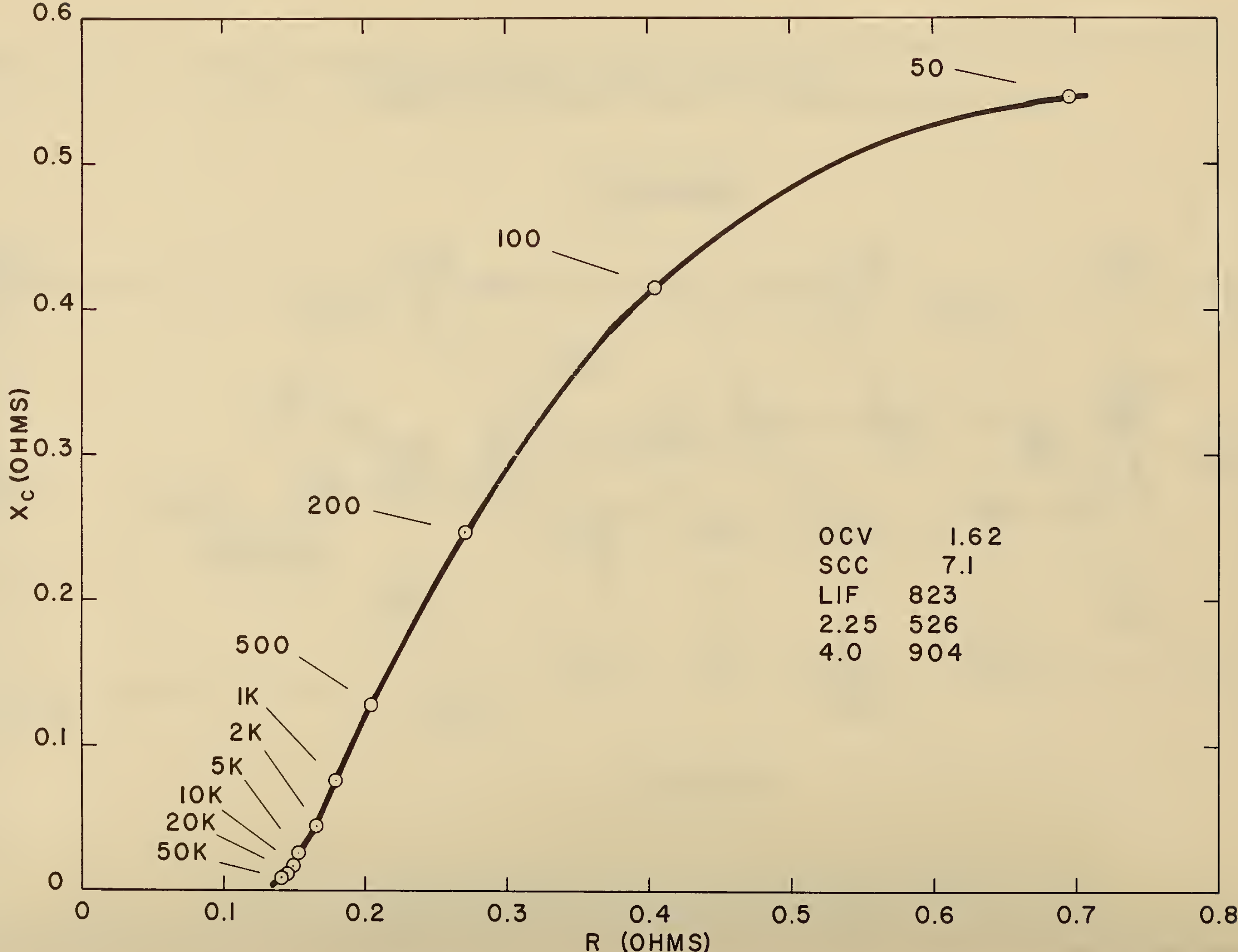

FIG. 41 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 6 BEFORE DISCHARGE

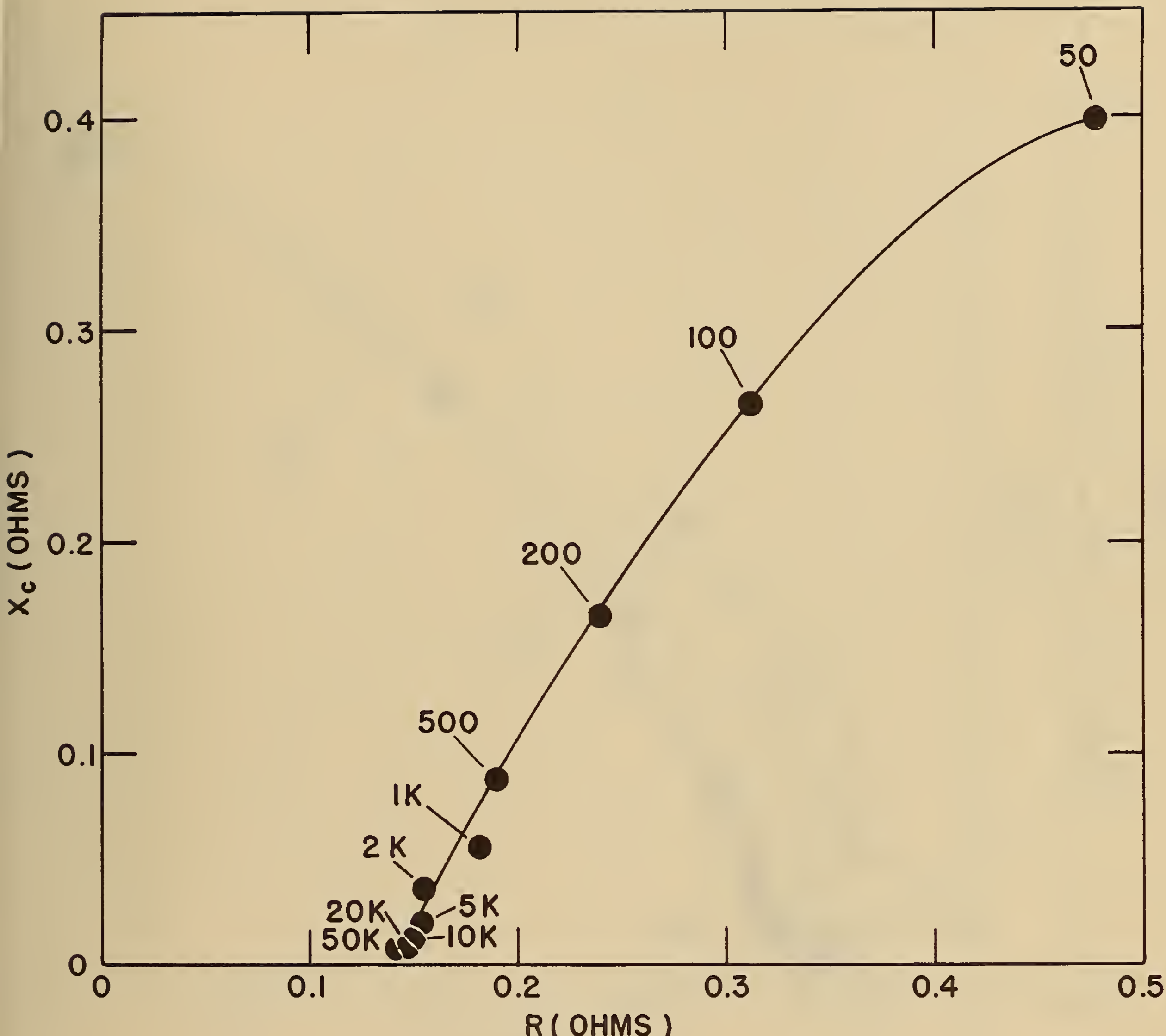

FIG. 42 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 6 AFTER 6 MONTHS STORAGE

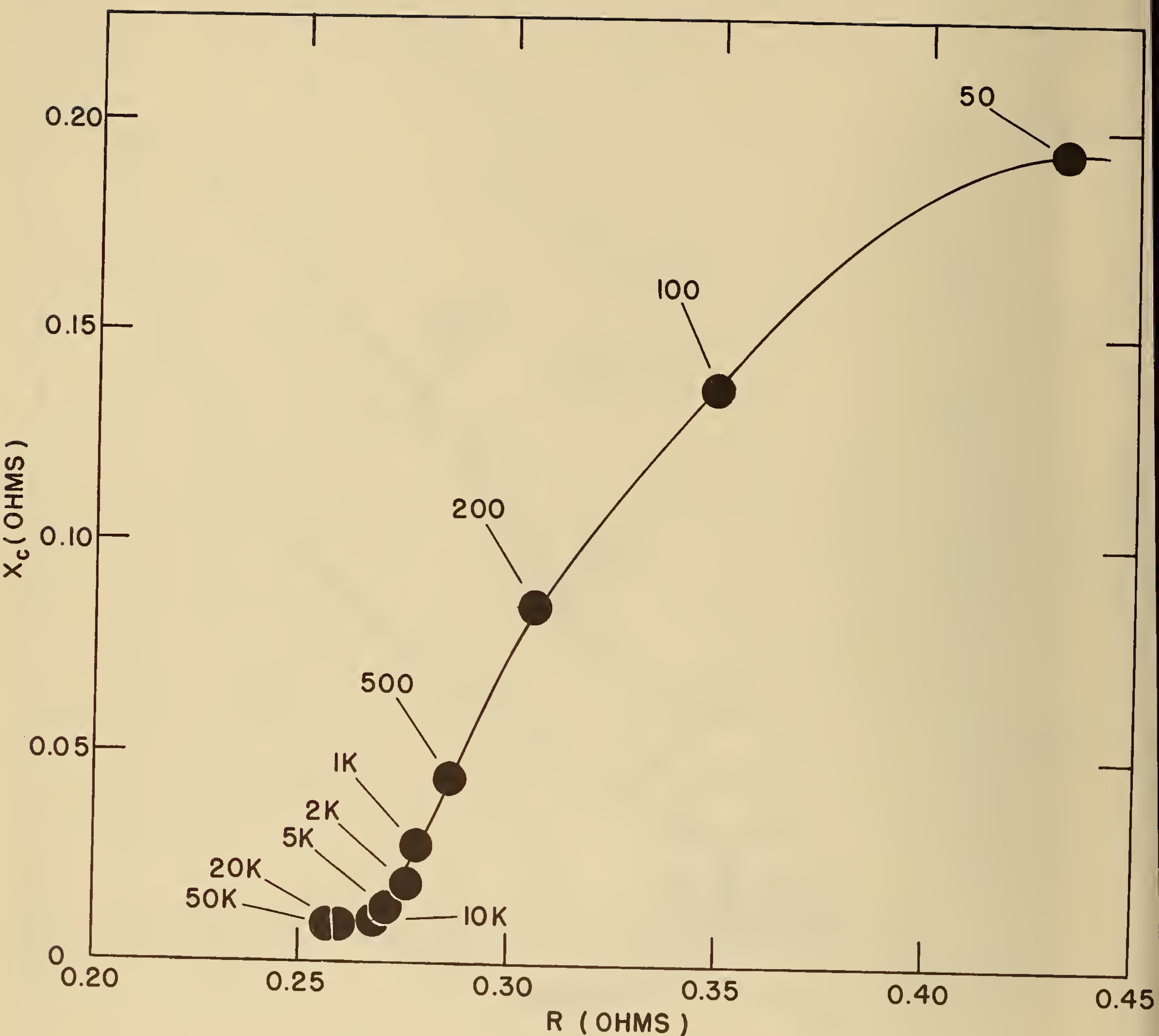

FIG. 43 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 6 AFTER LIF TEST

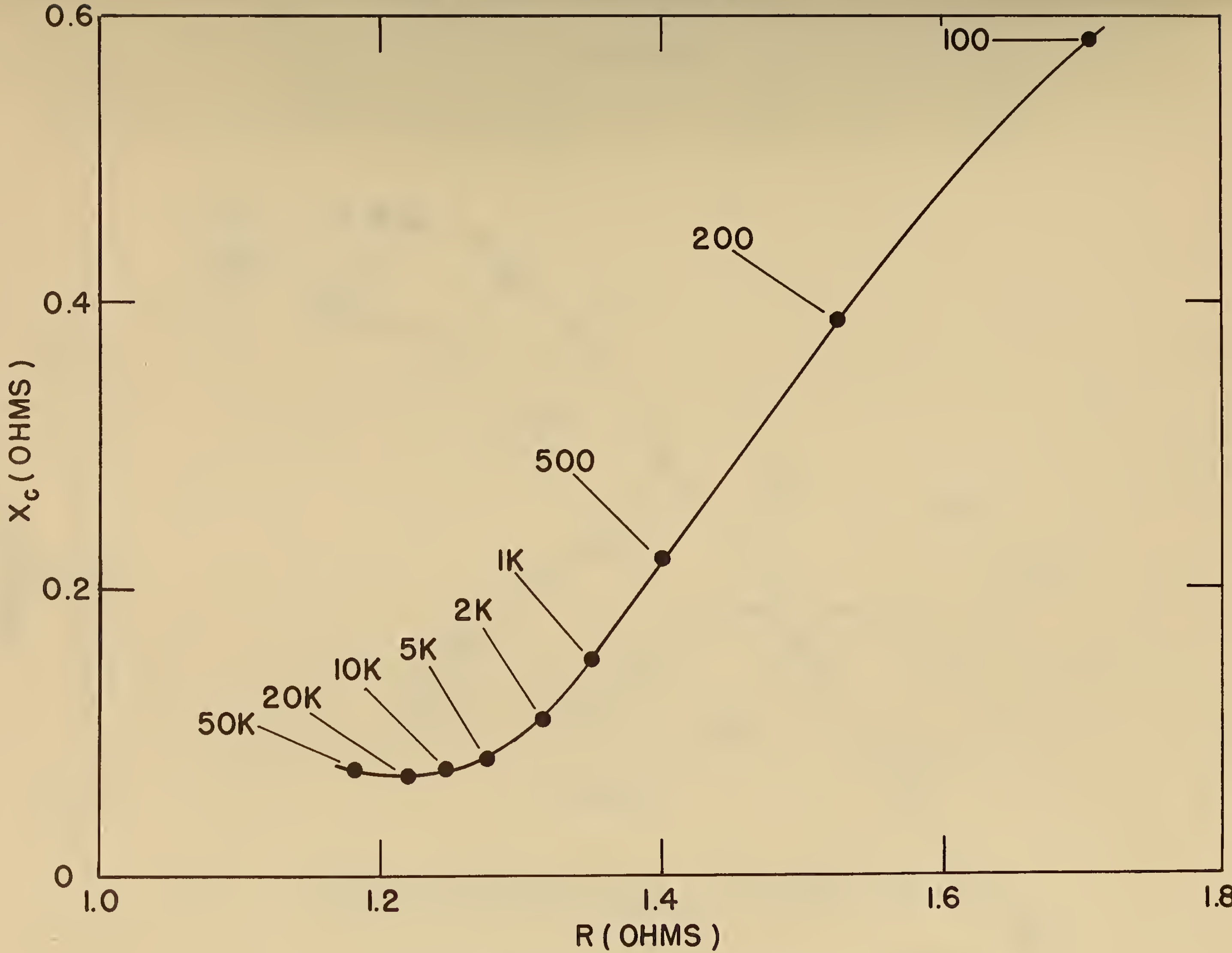

FIG. 44 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 6 AFTER 2.25-OHM TEST

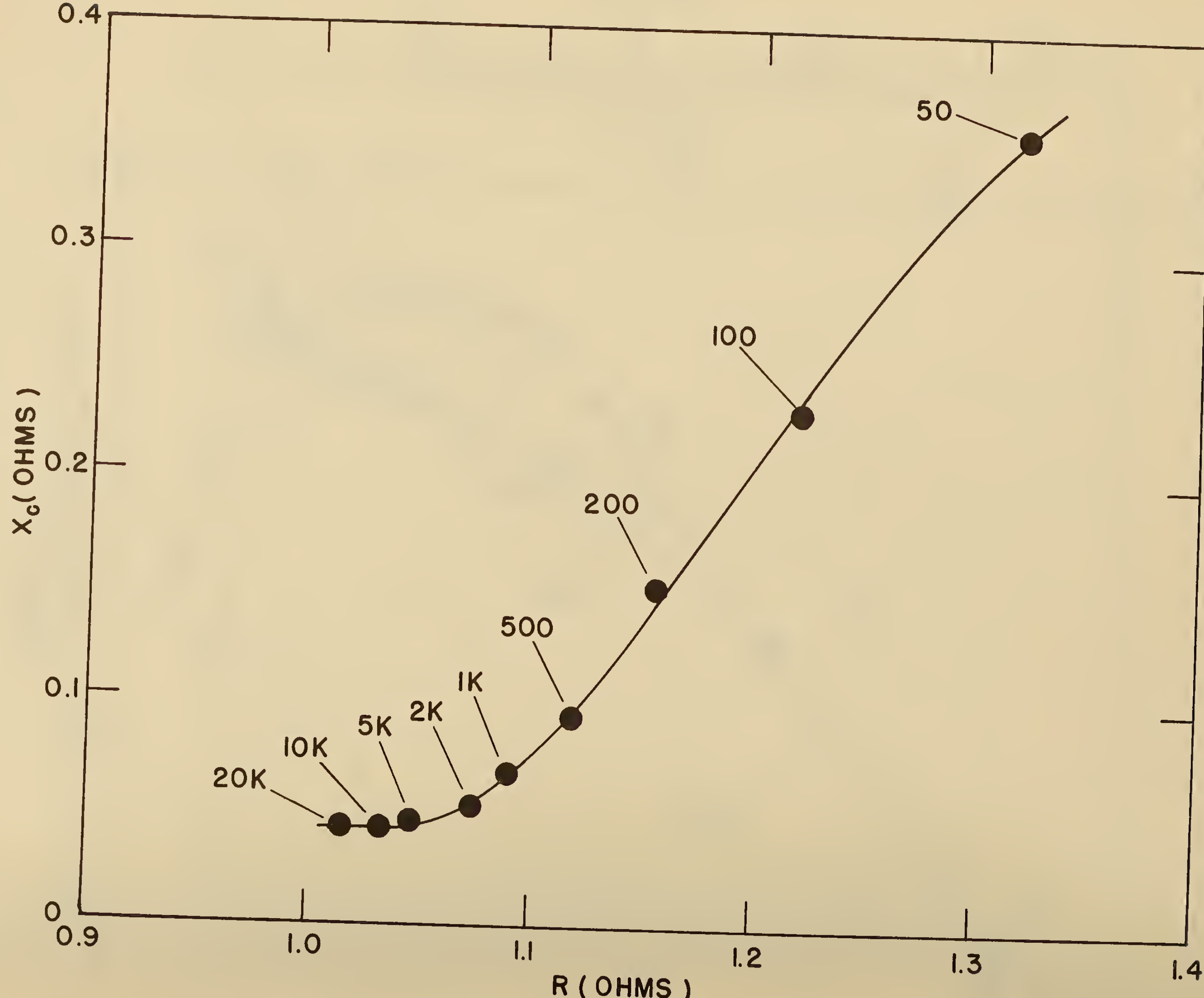

FIG. 45 RESISTANCE-REACTANCE CURVE OF GENERAL-PURPOSE D-SIZE CELLS OF BRAND 6 AFTER 4-OHM TEST

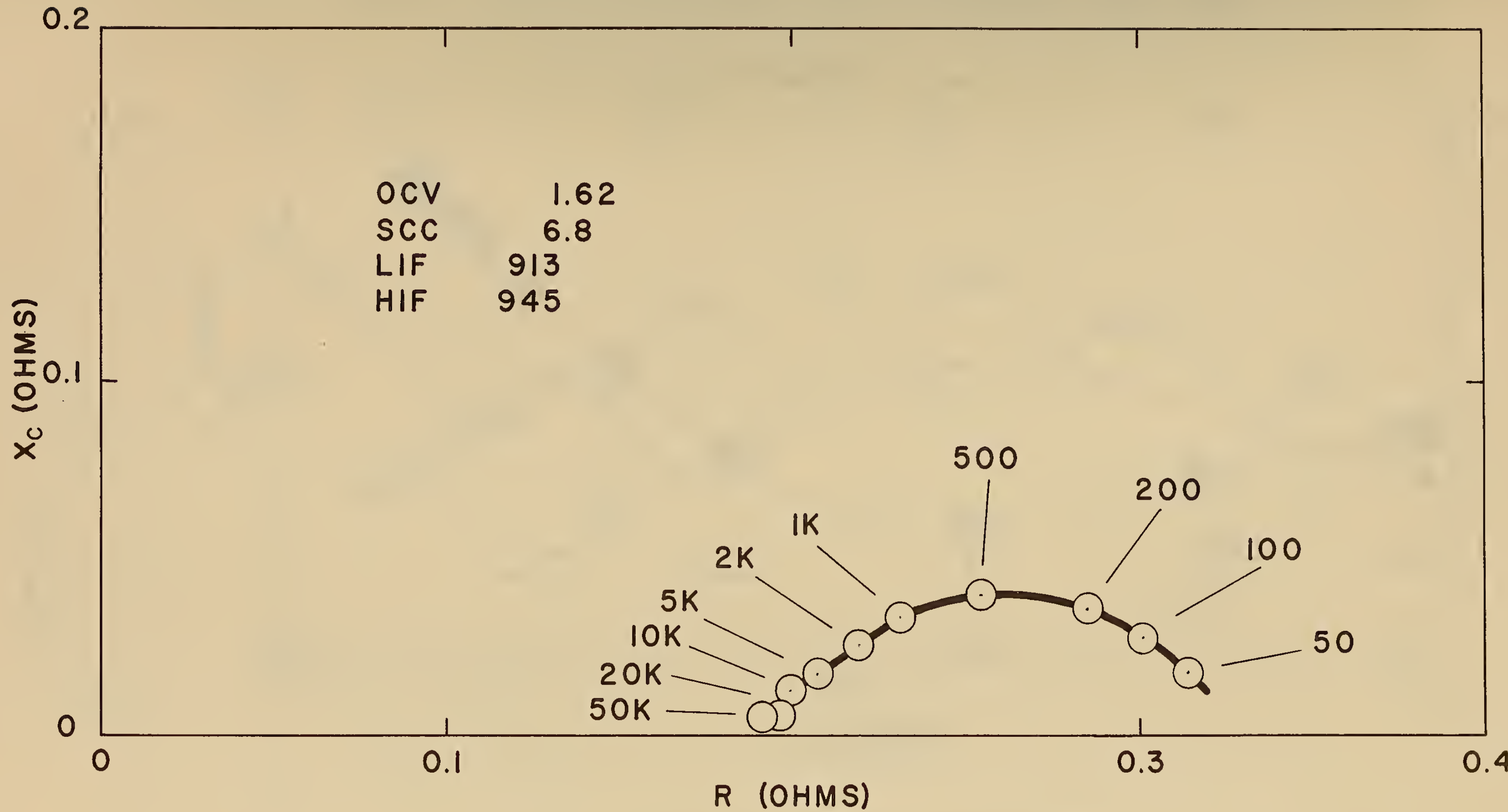

FIG. 46 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 1 BEFORE DISCHARGE

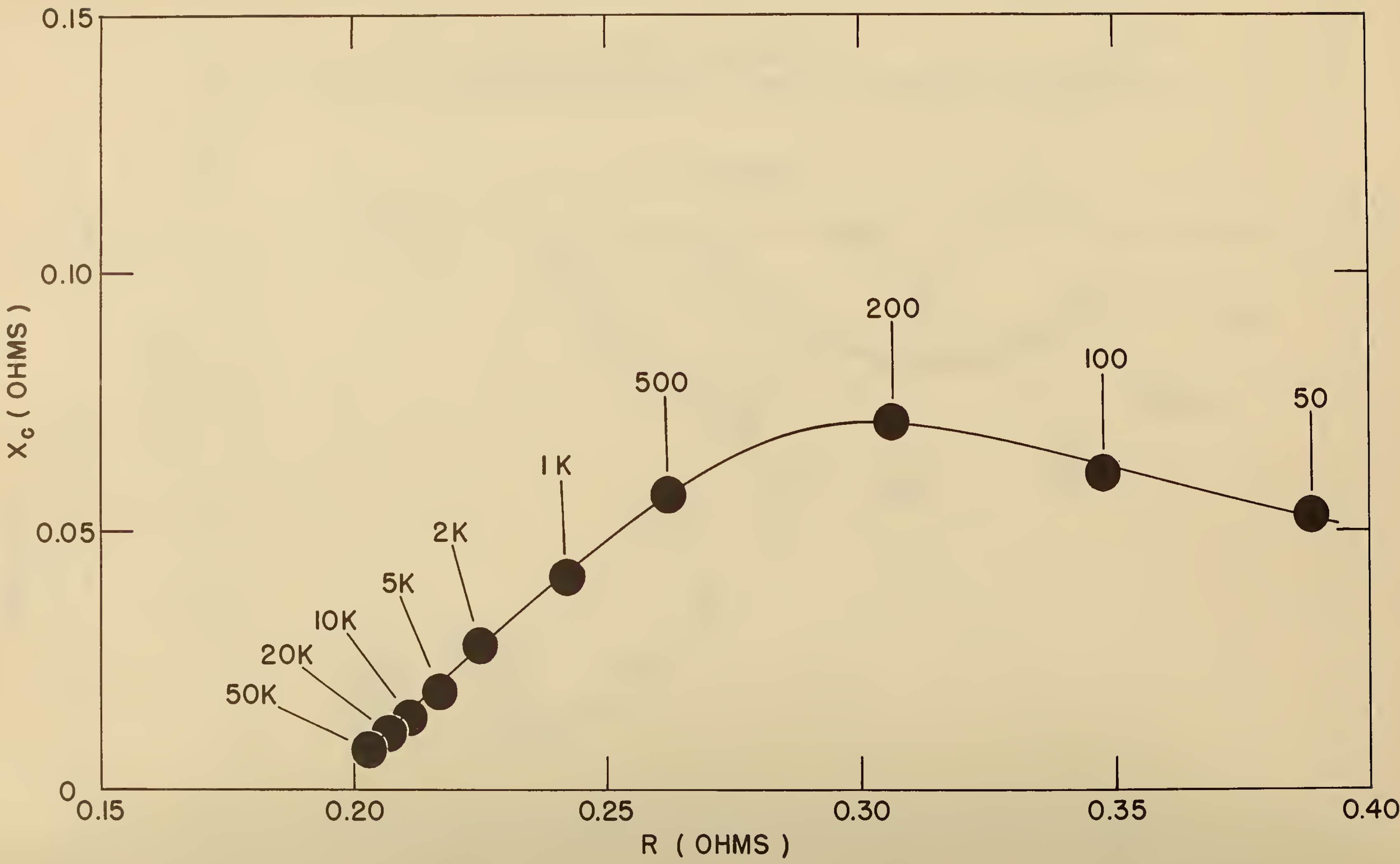

FIG. 47 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 1 AFTER 3 MONTHS STORAGE

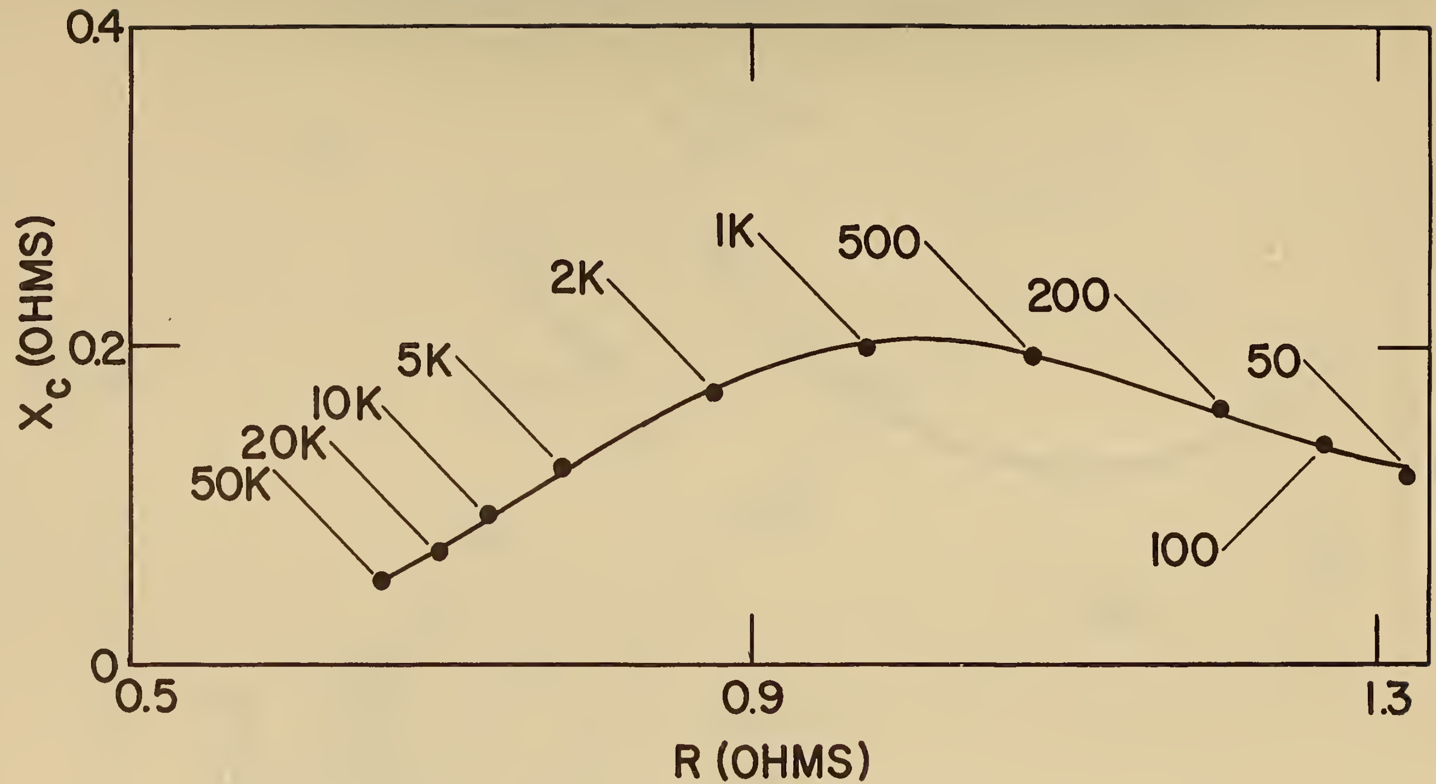

FIG. 48 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 1 AFTER LIF TEST

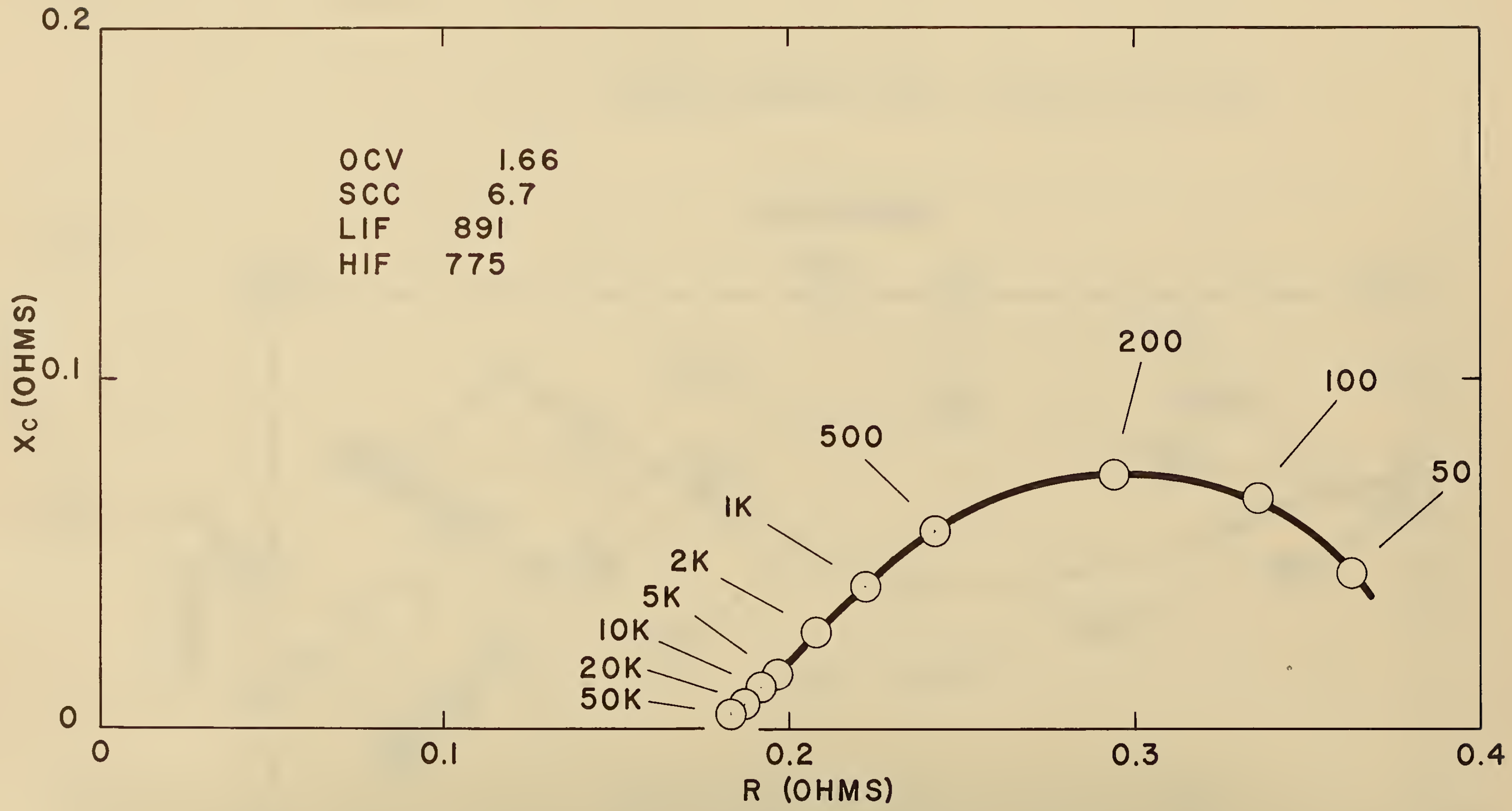

FIG. 49 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 2 BEFORE DISCHARGE

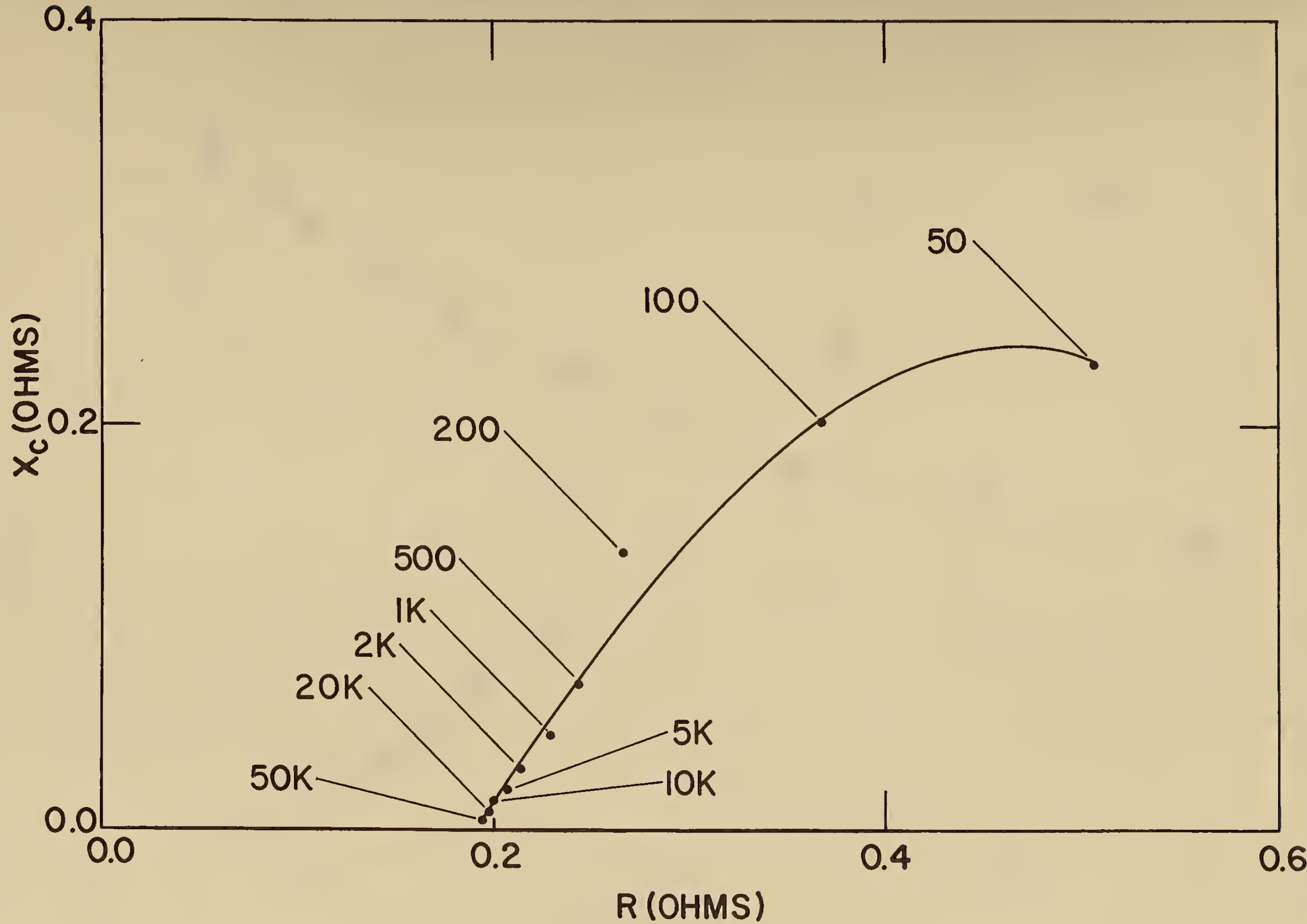

FIG. 50 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 2 AFTER 6 MONTHS STORAGE

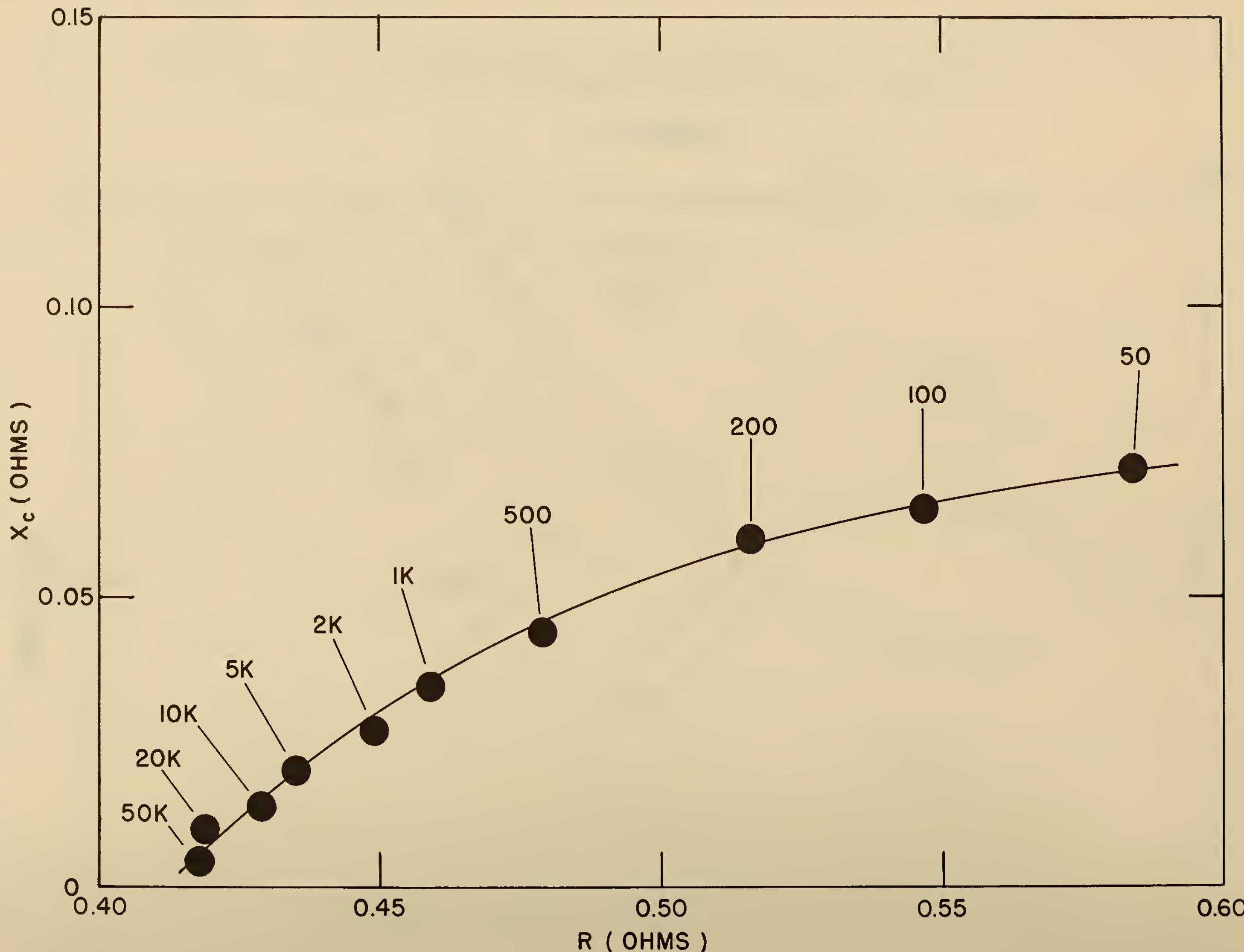

FIG. 51 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 2 AFTER LIF TEST

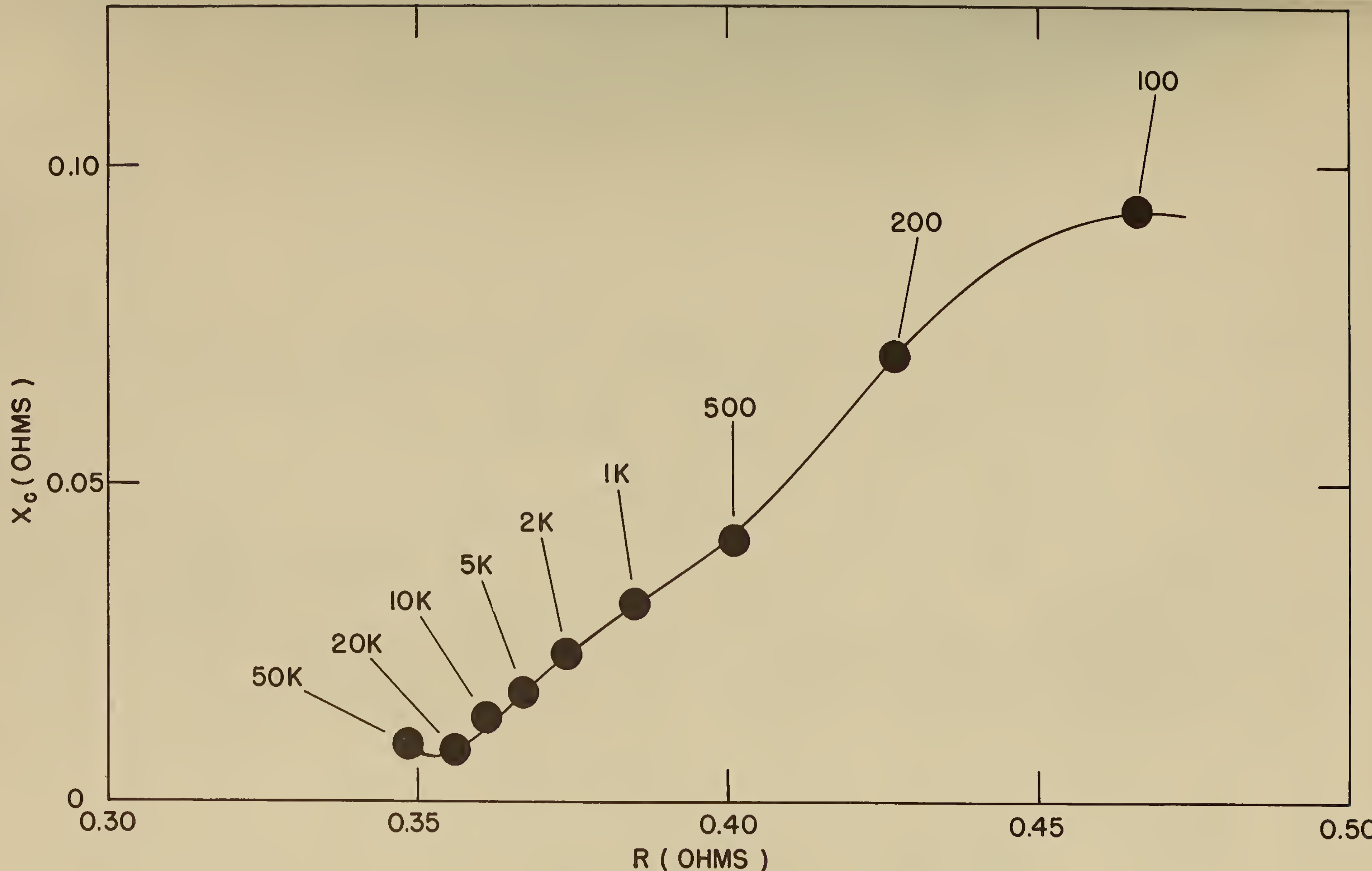

FIG. 52 RESISTANCE-REACTANCE CURVE OF INDUSTRIAL D-SIZE CELLS OF BRAND 2 AFTER HIF TEST

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U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage. Absolute Electrical Measurements.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

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Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Rescarch. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

Joint Institute for Laboratory Astrophysics - NBS Group (Univ. of Colo.).

NBS