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EFFECTS OF NUCLEAR RADIATION, CRYOGENIC TEMPERATURE, AND VACUUM ON THE ELECTRICAL PROPERTIES OF DIELECTRIC MATERIALS

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ABSTRACT

The dielectric properties of polymeric materials probably are among the most sensitive to the effects of radiation from the space environment, from nuclear power sources, or from nuclear rockets. These properties also are affected in various ways by other parameters of the space environment such as vacuum and temperature. Therefore, a combined environmental evaluation of four commonly used dielectrics was made. Some preliminary results indicate that the effect on the dielectric constant and dissipation factor of the polymers was minor for vacuum alone but of major significance for radiation alone. The cryogenic temperatures had a minor effect on the dielectric properties of silicone rubber and polytetrafluoroethylene but a direct and significant effect on the epoxy and polyurethane materials. It appeared that the effect of cryogenic temperatures may have counteracted the radiation effects in some cases. Obtaining dielectric measurements within the combined environmental simulator posed some special problems and required some novel techniques which are described.

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RESEARCH AND DEVELOPMENT OPERATIONS

PROPULSION AND VEHICLE ENGINEERING LABORATORY

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EFFECTS OF NUCLEAR RADIATION, CRYOGENIC TEMPERATURE, AND VACUUM ON THE ELECTRICAL PROPERTIES OF DIELECTRIC MATERIALS

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SUMMARY

Commonly used dielectric materials were evaluated to determine their response to environmental parameters such as neutron and gamma radiation to 1.7×10^{10} ergs-gm^{-1} (C), cryogenic temperatures to -160°C, and low pressures to 2×10^{-7} mm Hg, simultaneously. The data which were obtained included capacitance ("k"), dissipation factor ("tan σ"), and mechanical properties. The dissipation factor data are not discussed because no significant changes were measured. The electrical measuring techniques employed for obtaining valid and reproducible information from combined environmental tests are discussed, and the test equipment is described.

A preliminary evaluation is made of four dielectric materials: fluorocarbon (Teflon TFE), polyurethane (Estane 5740-1), epoxy (Epon 828/Z), and silicone (RTV 501). The results indicate that (1) low pressure alone has little or no effect on "k" where the polymers are thermally stable, (2) radiation alone increases "k", and (3) temperature in the range +70°C to -160°C has little or no effect on "k" of the silicone and fluorocarbon, but it has a direct and significant effect on the epoxy and polyurethane. The mechanical strength of the four polymers is reasonably stable when they are irradiated in vacuum at cryogenic temperatures. This statement is particularly significant for Teflon TFE, which loses almost all of its strength when irradiated in air and about half its strength when irradiated in vacuum at room temperature to the same total dose. No recommendations on the materials are possible because of the preliminary nature of the evaluation. However, improved thermal shielding techniques are suggested for reducing specimen temperatures which are increased due to absorption of nuclear radiation.

INTRODUCTION

The birth of the "Space Age" was announced spectacularly about seven years ago with the launching of the first man-made earth satellite. Since that time, considerable effort has been expended to assess quantitatively the space environment and its effect on the properties of materials. Additionally, much information has been accumulated on the effects of the onboard environment produced by the space vehicles themselves. The assessment of the environments which are imposed by space and the space vehicle and their effects on materials is by no means complete and is vitally necessary if the spacecraft is to function properly.

The factors which determine the environment or combination of environments which will be imposed on spacecraft materials are (1) the application and location of the materials in the vehicle, (2) the type of vehicle, and (3) the space mission that is assigned the vehicle. It is obvious that many materials will be exposed simultaneously to more than one unusual environmental parameter. Nuclear radiation will be common to vehicles with onboard nuclear-powered electrical generators and/or nuclear reactor-type rocket engines. The three principal environmental factors which will influence greatly the functioning of nuclear vehicle materials are (1) cryogenic temperatures inherent in the use of liquid hydrogen as the engine working fluid, (2) high intensity nuclear radiation from the reactor, and (3) the ultralow pressure (vacuum) associated with interplanetary space.

The Marshall Space Flight Center (MSFC) conceived a program to obtain engineering data on the changes produced in the physical properties of nonmetallic materials by exposure to the various combinations of cryogenic temperatures, nuclear radiation, and vacuum. The program was implemented on November 9, 1961, with the awarding of Contract NAS8-2450, entitled "Investigation of the Combined Effects of Radiation and Vacuum on Engineering Materials," to the General Dynamics Corporation, Fort Worth, Texas (GD/FW). This discussion is concerned with the portion of the program involving electrical and mechanical properties of dielectric materials. It includes a discussion of the design of the special test apparatus, the development of procedures, and the interpretation of some preliminary results.

ELECTRICAL TEST APPARATUS

The electrical test apparatus shown in FIG 1 was designed to determine the changes in capacitance and dissipation factor of solid dielectric specimens produced by simultaneous exposure to low pressure (vacuum), reduced or elevated temperatures, and radiation without removing the specimens from the specified environment.

The electrical test apparatus fits into the access port of the Vacuum-Irradiation Chamber which is described in reference 1. Vacuum tight feed-throughs for utilities, such as cryogen inlet and exhaust and coaxial signal cables, are located on the top plate of the apparatus. After insertion into the vacuum chamber, the apparatus is sealed with "Indalloy" solder O-rings that are clamped between the top plate of the test apparatus and the mounting flange of the vacuum chamber. During testing, the pressure in the system is maintained in the 10^{-7} torr range.

The principal components of the test apparatus are the cryogen shroud assembly and the test cell (FIG 1). The cryogen shroud simply is a hollow aluminum, vacuum tight cylinder, 18 inches in diameter and 24 inches high, with a 1-inch annulus to provide for the flow of the cryogen. The test cell, which is shown in detail in FIG 2, is composed of two tiers of stainless steel plates on which eight capacitor assemblies are mounted symmetrically, four on each tier. The capacitor assemblies were designed in accordance with ASTM-D150-58T, "A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials." Each capacitor consists of an insulated, positive, upper electrode; the dielectric specimen; and a negative, lower electrode which is mounted inside a guard ring. To provide good electrode contact and to prevent the specimen from moving after it is inserted between the electrodes, the upper electrode is spring loaded. Temperature is measured by means of a copper-constantan thermocouple that is encapsulated in a cavity in the negative electrode. Polyethylene insulated coaxial cables, 165 feet long, are used to transmit the electrical signals from the General Radio capacitance measuring assembly to the capacitors via a Deutsch Company, glass insulated, coaxial, high vacuum feedthrough that is mounted on the top plate of the cryogen shroud assembly. For vacuum cryogenic testing, the test cell with the specimens in the electrodes is inserted into the bottom of the cryogen shroud and rotated 15 degrees to engage the locking lugs which are attached to the inside wall of the shroud. The cell is then bolted into place. The purpose of the locking lugs is to provide not only a means of support for the test cell but a means of heat conduction from the test cell to the cryogen shroud. Cooling is obtained by radiant heat transfer from the test cell to the cold walls of the shroud in addition to the cooling obtained by the conduction of heat through the metal structure. However, it will be obvious in the results that the cooling capacity of the apparatus is inadequate for irradiation testing; therefore, it will be modified by the addition of radiation heat shields.

TEST PROCEDURES

Electrical Tests

Four environmental tests were completed on each of four different materials employing 32 specimens in the Electrical Tester. The four materials tested were (1) Epon 828/Z, a cast epoxy, low temperature, potting compound; (2) Teflon TFE, a sintered fluorocarbon sheet material; (3) Estane 5740-1, a molded polyurethane sheet material; and (4) RTV 501, a room temperature cured silicone potting compound. Electrical and mechanical data were obtained for these materials in the following environments:

(a) Normal room temperature and room pressure

(b) Vacuum and reduced temperature

(c) Vacuum, reduced temperature, and radiation

(d) Air, elevated temperature, and radiation.

Electrical Test Procedures and Conditions

The electrical test apparatus was described previously. It provided the eight capacitor assemblies and their environmental control. For each capacitor assembly, edge and stray capacitance was reduced by the guard electrode which was at floating potential. Also, for each individual capacitor assembly, the capacitance of the lead cable, connector, and feedthrough was measured and eliminated by calculation. One unattached lead cable or "dummy" cable provided a measure of the change in cable capacitance with the change in environment, and this was eliminated by calculation. Finally, the changes in capacitance due to thermal expansion and contraction of the specimens were calculated and found to be less than one-half of one percent for the maximum temperature change. Hence, the reported values of normalized dielectric constant, based on the measured and corrected capacitance values, should be reasonably free of spurious capacitances. The capacitance and dissipation factor measurements were made at 1,000 cycles per second with the General Radio Model 716-C capacitance bridge and associated instruments in accordance with procedures in ASTM-D 150-58 T, "A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials."

Vacuum-Reduced Temperature Test Procedure

For the vacuum-reduced temperature or unirradiated control test, the electrical test apparatus was evacuated to 10^{-3} torr prior to starting the flow of liquid nitrogen (LN_2) into the shroud. Then, the shroud was filled with LN_2, and the tester was pressurized to 10^{-1} torr with helium exchange gas. The exchange gas was required to facilitate heat conduction from the inner test cell to the outer LN_2-cooled shroud. After the specimens attained a temperature of approximately -165°C, the system pressure was reduced to 4×10^{-6} torr. Measurements were made of the capacitance and dissipation factor of each specimen at this temperature and pressure and during the subsequent increase in temperature.

Irradiation Test Procedures

Three irradiations of the Electrical Tester were made: one with the specimens at room conditions exposed to the atmosphere and two with the specimens cooled and exposed to a pressure of 2×10^{-7} torr. The standard radiation dosimetry measurements are described in reference 1. The irradiation in air was made with the tester placed on a pallet located in the north irradiation position. The instrumentation for monitoring the thermocouples and capacitors was located in the control room and was connected to the tester by shielded cables which were 165 feet long. The reactor was brought to the selected power level, and the tester was irradiated for a specified time period. To make electrical measurements without interference, the reactor was retracted at the end of each period. After each set of electrical measurements was completed, the reactor was brought to the selected power level again, and the tester was irradiated for an additional period of time. This cyclic process of irradiation, reactor retraction, and data acquisition was continued until the specimens had been irradiated to the desired total dose.

In the two vacuum-cryogenic irradiations, a similar operating procedure was used with the following exceptions: the electrical tester apparatus was placed in the vacuum chamber, and liquid nitrogen was used in the shroud. Therefore, it was necessary to allow time for the specimens to cool to the desired temperature prior to commencing the irradiation. Again, as in the control test, helium gas at a pressure of 10^{-1} torr was used to facilitate specimen cool-down. After cool-down, the system was evacuated to 3×10^{-7} torr and irradiated according to the established cyclic procedure.

It was not practical to maintain constant temperature during irradiation; therefore, specimen temperatures were monitored continuously. The temperature histories of the specimens were plotted with the normalized dielectric constant data to compare these inter-related variables during irradiation. The variation in specimen temperature was due to absorption of radiated energy which generated heat in the specimen at a greater rate than that which could be thermally radiated or conducted to the shroud. During the air irradiation, the specimen temperatures became excessive, and the irradiation was interrupted to allow the specimens to cool.

Post Exposure Mechanical Test Procedures

Mechanical tests were made on the specimens after the electrical tests had been completed to aid in the evaluation of the absorbed radiation damage. Unirradiated control specimens were supplied from the same batch of material. The electrical test specimens of RTV 501 silicone resin and Estane 5740-1 polyurethane resin retained sufficient flexibility after the irradiation to be cut into miniature tensile specimens. The tensile tests were made at normal room temperature and pressure in an Instron testing machine. The gauge length was 1 inch; the cross-section was approximately 1/8 inch by 1/8 inch; the testing speed was 20 inches per minute.

The electrical test specimens of Teflon TFE and Epon 828/Z epoxy resin appeared to be more fragile after the irradiation tests, and it was feared that they might shatter when die-cut. Therefore, a disc or plate-type flexural bending test was made on the uncut electrical test specimens. This test provided values of biaxial flexural strength and modulus from a load-deflection curve. The flexural test was made at normal room temperature and pressure in an Instron testing machine. The disc specimen was supported by a 4-inch diameter cylinder. The load was applied on the center of the disc by a 1/2-inch diameter sphere at a rate of 0.05 inch per minute.

RESULTS

Results of Vacuum-Reduced Temperature Test

The data obtained in the vacuum-reduced temperature (unirradiated control) test were normalized to the standard room temperature, atmospheric pressure values of the dielectric constant. The results are tabulated in Tables I - IV and are plotted in FIG 3 in terms of the normalized values of the dielectric constant (K_n). No dissipation factor data are given because no significant changes in this property were measured for the four materials tested. Estane 5740-1 polyurethane showed the greatest change in K_n, a decrease of approximately 50% at -140°C. Epon 828/Z epoxy showed a reduction in K_n of 34% at -160°C. However, Teflon TFE and RTV 501 silicone showed no significant change in K_n down to -160°C.

Results of Irradiation Tests

The data obtained from the irradiation tests are tabulated in Tables I - IV and are plotted in FIG 4 - 7. For all four materials, the dielectric constant was increased because of irradiation in air. Three materials, Epon 828/Z, Estane 5740-1, and RTV 501, showed significant increases in K_n of approximately 22% when irradiated to a total integrated dose of approximately 1.5×10^{10} ergs-gm^{-1} (C). Teflon TFE responded peculiarly in an unexplainable manner, decreasing and increasing for a total change of 38% in K_n during irradiation in air up to 1.24×10^{10} ergs-gm^{-1} (C). Some preliminary generalizations which agree with previously stated trends can be based on the foregoing data. Vacuum alone has little or no effect on the dielectric constant of well stabilized materials such as those considered in this study. Radiation tends to increase the dielectric constant, and reduced temperature tends to decrease it.

In the vacuum-reduced temperature-irradiation tests, some interesting speculations arose. For instance, would it be possible to counteract the radiation effects on dielectric constant at cryogenic temperatures due to the decrease in the mobility of the ions formed and/or due to the increased hindrance to molecular rotation and polarization? If so, radiation damage might be avoided in electrical insulation on space vehicles by judicious placement of cables close to the cryogenic fuel tanks and lines. Unfortunately, a constant cryogenic temperature could not be maintained in the vacuum-reduced temperature-cryogenic test because irradiated energy was absorbed faster than heat could be expelled by the apparatus at reasonable dose rates. However, the data were evaluated at points of comparable temperature. From elevated temperatures to -100°C, the irradiated specimens had significantly (greater than 10%) higher dielectric constants than unirradiated specimens. At -160°C, the lowest temperature attained in these tests, both irradiated and unirradiated specimens had the same dielectric constant except for Estane 5740-1 polyurethane, which was highly temperature sensitive. Therefore, it appears that the speculation concerning the counteraction of radiation damage at cryogenic temperatures may have merit. Further testing with better control of conditions is required.

Results of Mechanical Tests

As stated previously, mechanical tests were made on the specimens after the electrical tests had been completed to aid in the evaluation of the absorbed radiation damage. A standard tensile test was made on the more flexible materials, RTV 501 silicone and Estane 5740-1 polyurethane. A plate flexural test was made on the stiffer materials, Teflon TFE and Epon 828/Z epoxy.

The tensile data are shown in Tables V and VI and FIG 7 and 8. RTV 501 silicone changed very little in average tensile strength when irradiated in vacuum at reduced temperatures. However, the increased range of the tensile strength value indicated that some molecular rearrangement took place. When RTV 501 was irradiated in air, the average tensile strength decreased about 20%, indicating, perhaps, that some chain scission occurred. Interestingly, the increase in dielectric constant, or polarizability, at the same conditions may indicate that additional end groups were free to rotate. Therefore, the tensile strength and dielectric constant trends were compatible, and the RTV 501 silicone material was comparatively stable at the conditions employed.

The tensile strength of Estane 5740-1 polyurethane (FIG 9) degraded about 30% when irradiated in vacuum at cryogenic temperatures and degraded about 60% when irradiated in air, which indicated a chain scission process. However, the elongation remained unchanged in the former case but degraded only 30% from the initial value in the latter case, thus indicating a high molecular mobility or low internal friction. The high dielectric constant and temperature dependence of dielectric constant may well be attributed to the same mobility of molecular structure. Although this material would not be recommended for its dielectric properties, it would be recommended highly for its retention of elongation at the conditions employed.

It is well known that Teflon TFE degrades to zero strength when irradiated to 10^{10} ergs-gm^{-1} (C) in air and degrades to about half of its initial strength when irradiated to the same level in vacuum. The plate flexural test data shown in FIG 10 indicate almost zero flex strength for the specimens irradiated in air but little or no degradation for the specimens irradiated in vacuum at reduced temperatures. Since a complex stress pattern is applied to the specimen in the plate flexural test, these data probably are conservative when compared to uniaxial stress data. Therefore, it is suggested that Teflon is stable and that the radiation damage reaction is inhibited when Teflon is irradiated at cryogenic temperatures in vacuum to at least 8.6×10^{9} ergs-gm^{-1} (C).

Finally, Epon 828/Z epoxy potting compound exhibited very little change in the plate flexural test due to the different environmental exposures according to the curves in FIG 11. No flex strength could be measured for any condition. The complex flex modulus increased about 10% from the control value when irradiated in vacuum, indicating some additional curing. In the same manner, the flex strength decreased about 10% when irradiated in air, indicating some scission of the higher molecular weight species. Epon 828/Z is mechanically stable when exposed to the conditions employed in this study.

CONCLUSIONS

The following preliminary conclusions were based on the results of this study:

1. Vacuum alone had little or no effect on dielectric constant, "k", or dissipation factor, tangent σ, of well stabilized polymers such as epoxy, silicone, polyurethane, and polytetrafluoroethylene.

2. Radiation alone increased dielectric constant of the polymers evaluated.

3. Temperature in the range -160°C to +70°C had a direct effect on "k" of polyurethane and epoxy resin. It had little or no effect on "k" of silicone resin or polytetrafluoroethylene.

4. There may well be a low critical temperature where radiation damage to the electrical properties of polymers is counteracted or frozen due to decreased ionic mobility and to hindrance of molecular rotation. According to preliminary data, the low critical temperature appears to be about -160°C.

5. The mechanical strength of Epon 828/Z epoxy, Teflon TFE, and RTV 501 silicone resin was reasonably stable when irradiated in vacuum at cryogenic temperatures. This statement is particularly significant for Teflon, which loses almost all of its strength when irradiated in air and about half its strength when irradiated in vacuum to the same total dose. The tensile strength and dielectric constant of Estane 5740-1 polyurethane were somewhat sensitive to temperature and radiation, but ultimate elongation was more stable than that of most other resins.

REFERENCE

1. Kerlin, E. E. and Smith, E. T.; Investigation of Combined Effects of Radiation and Vacuum and of Radiation and Cryotemperatures on Engineering Materials, Annual Report, November 9, 1962 to April 30, 1964, Volume I: Radiation-Vacuum Tests, General Dynamics/Fort Worth Report FZK-188-1.

TABLE I

DIELECTRIC PROPERTY CHANGES DUE TO ENVIRONMENT FOR EPON 828/Z EPOXY

Initial Dielectric Constant, K_1 = 4.5

INTEGRATED DOSE (ergs-gm^{-1} C)	PRESSURE (torr)	TEMPERATURE (°C)	K_n*
VACUUM - REDUCED TEMPERATURE TESTS			
0	4×10^{-6}	+20	1.00
0	4×10^{-6}	0	0.99
0	4×10^{-6}	-20	0.96
0	4×10^{-6}	-40	0.93
0	4×10^{-6}	-60	0.87
0	4×10^{-6}	-100	0.76
0	4×10^{-6}	-140	0.74
0	4×10^{-6}	-160	0.73
0			
AIR IRRADIATION TEST			
0	760	+26	1.00
1.5×10^{7}	760	33	0.98
9.5×10^{7}	760	36	0.97
3.9×10^{8}	760	60	0.96
7.0×10^{8}	760	74	0.98
1.3×10^{9}	760	46	1.04
6.4×10^{9}	760	48	1.10
1.75×10^{10}	760	55	1.20
VACUUM-REDUCED TEMPERATURE-IRRADIATION TEST			
0	2×10^{-7}	-166	0.73
2.5×10^{7}	2×10^{-7}	-158	0.73
1.0×10^{8}	2×10^{-7}	-151	0.73
3.25×10^{8}	2×10^{-7}	-112	0.85
6.25×10^{8}	2×10^{-7}	-70	0.95
3.03×10^{9}	2×10^{-7}	-5	1.08
1.38×10^{10}	2×10^{-7}	+10	1.10

*K_n is the dielectric constant normalized to the initial room temperature, atmospheric pressure, unirradiated value for the average of two specimens.

TABLE II

DIELECTRIC PROPERTY CHANGES DUE TO ENVIRONMENT FOR TEFLON TFE

Initial Dielectric Constant, K_1 = 2.0

INTEGRATED DOSE (ergs-gm^{-1} C)	PRESSURE (torr)	TEMPERATURE (°C)	K_n*
VACUUM - REDUCED TEMPERATURE TESTS			
0	4×10^{-6}	+20	1.00
0	4×10^{-6}	0	1.00
0	4×10^{-6}	-20	1.00
0	4×10^{-6}	-40	1.00
0	4×10^{-6}	-60	1.00
0	4×10^{-6}	-80	0.99
0	4×10^{-6}	-100	0.99
0	4×10^{-6}	-120	0.99
0	4×10^{-6}	-160	0.99
AIR IRRADIATION TEST			
0	760	26	1.00
1.5×10^{7}	760	33	0.78
9.5×10^{7}	760	37	0.76
3.9×10^{8}	760	62	0.68
7.0×10^{8}	760	75	0.70
1.3×10^{9}	760	47	1.00
6.4×10^{9}	760	48	1.01
1.24×10^{10}	760	52	1.06
VACUUM-REDUCED TEMPERATURE-IRRADIATION TESTS			
0	2×10^{-7}	0	0
2.5×10^{7}	2×10^{-7}	-147	0.99
1.0×10^{8}	2×10^{-7}	-142	0.99
3.25×10^{8}	2×10^{-7}	-139	0.99
6.25×10^{8}	2×10^{-7}	-111	2.09
3.03×10^{9}	2×10^{-7}	-94	1.09
9.32×10^{9}	2×10^{-7}	-5	1.10

*K_n is the dielectric constant normalized to the initial room temperature, atmospheric pressure, unirradiated value for the average of two specimens.

TABLE III

DIELECTRIC PROPERTY CHANGES DUE TO ENVIRONMENT FOR ESTANE 5740-1 POLYURETHANE

Initial Dielectric Constant, K_1 = 7.5

INTEGRATED DOSE (ergs-gm^{-1} C)	PRESSURE (torr)	TEMPERATURE (°C)	K_n*
VACUUM-REDUCED TEMPERATURE TESTS			
0	4×10^{-6}	20	1.00
0	4×10^{-6}	0	0.99
0	4×10^{-6}	-20	0.86
0	4×10^{-6}	-40	0.73
0	4×10^{-6}	-60	0.62
0	4×10^{-6}	-100	0.57
0	4×10^{-6}	-140	0.50
AIR IRRADIATION TEST			
0	760	28	1.00
1.6×10^{7}	760	36	1.00
9.8×10^{7}	760	44	1.00
4.0×10^{8}	760	93	1.08
7.2×10^{8}	760	100	1.12
1.7×10^{9}	760	58	1.15
6.6×10^{9}	760	65	1.18
1.07×10^{10}	760	75	1.22
VACUUM-REDUCED TEMPERATURE-IRRADIATION TESTS			
0	2×10^{-7}	-161	0.50
2.6×10^{7}	2×10^{-7}	-156	0.61
1.04×10^{8}	2×10^{-7}	-152	0.70
3.35×10^{8}	2×10^{-7}	-109	0.79
6.7×10^{8}	2×10^{-7}	-96	0.84
3.1×10^{9}	2×10^{-7}	-5	0.90
7.2×10^{9}	2×10^{-7}	0	1.06

*K_n is the dielectric constant normalized to the initial room temperature, atmospheric pressure, unirradiated value for the average of two specimens.

TABLE IV

DIELECTRIC PROPERTY CHANGES DUE TO ENVIRONMENT FOR RTV 501 SILICONE

Initial Dielectric Constant, K_1 = 3.5

INTEGRATED DOSE (ergs-gm^{-1} C)	PRESSURE (torr)	TEMPERATURE (°C)	K_n*
VACUUM-REDUCED TEMPERATURE TESTS			
0	4×10^{-6}	20	1.00
0	4×10^{-6}	0	1.00
0	4×10^{-6}	-20	1.00
0	4×10^{-6}	-40	0.98
0	4×10^{-6}	-60	0.98
0	4×10^{-6}	-80	0.98
0	4×10^{-6}	-100	0.98
0	4×10^{-6}	-120	0.98
0	4×10^{-6}	-140	0.98
0	4×10^{-6}	-160	0.98
AIR IRRADIATION TESTS			
0	760	28	1.00
1.6×10^7	760	32	1.00
9.8×10^7	760	37	1.06
4.0×10^8	760	70	1.11
7.2×10^8	760	96	1.18
1.5×10^9	760	64	1.18
6.6×10^9	760	64	1.20
1.67×10^{10}	760	70	1.22
VACUUM-REDUCED TEMPERATURE-IRRADIATION TESTS			
0	2×10^7	-166	0.98
2.6×10^7	2×10^7	-164	0.98
1.04×10^8	2×10^7	-153	0.98
3.35×10^8	2×10^7	-107	1.08
6.7×10^8	2×10^7	-76	1.08
3.1×10^9	2×10^7	+10	1.18
1.05×10^{10}	2×10^7	+35	1.23

* K_n is the dielectric constant normalized to the initial room temperature, atmospheric pressure, unirradiated value for the average of two specimens.

TABLE V

TENSILE PROPERTIES OF RTV 501 SILICONE RESIN

CONTROLS		CRYO-VAC-RAD				AMBIENT-AIR-RAD			
		1.2×10^{10} $\frac{ergs}{gm(C)}$		1.7×10^{10} $\frac{ergs}{gm(C)}$		1.2×10^{10} $\frac{ergs}{gm(C)}$		1.7×10^{10} $\frac{ergs}{gm(C)}$	
TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %
476	-	613	90	508	70	220	20	-	-
530	210	573	80	366	30	396	35	489	80
533	205	644	95	472	45	505	70	481	80
470	180	571	60	500	80	509	95	-	-
493	190	616	75	469	50	518	90	324	40
546	180	504	70	380	-	549	95	238	30
538	180	625	95	400	50	445	80	445	60
545	180	574	100	404	20	350	50	420	60
521	170	270	40	423	40	468	70	327	45
546	200	590	70	384	50	509	90	388	50

	CONTROLS MAX	AVG	MIN	CRYO 1.2 MAX	AVG	MIN	CRYO 1.7 MAX	AVG	MIN	AMB 1.2 MAX	AVG	MIN	AMB 1.7 MAX	AVG	MIN
TEN STR PSI	546	520	470	644	560	270	508	430	366	549	445	220	489	390	238
ULT EL %	210	190	170	100	80	40	80	50	20	95	70	20	80	55	30

TABLE VI

TENSILE PROPERTIES OF ESTANE 5740-1 POLYURETHANE

CONTROLS		CRYO-VAC-RAD 6.9×10^9 $\frac{ergs}{gm(C)}$		CRYO-VAC-RAD 3.8×10^9 $\frac{ergs}{gm(C)}$		AMBIENT-AIR-RAD 6.9×10^9 $\frac{ergs}{gm(C)}$		AMBIENT-AIR-RAD 3.8×10^9 $\frac{ergs}{gm(C)}$	
TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %	TEN STR PSI	ULT EL %
-	-	3205	515	3174	595	1640	350	1460	355
4722	540	3442	520	2943	525	1314	260	1920	440
-	-	3365	520	3395	535	1529	300	2015	455
4766	575	3615	560	3551	625	2872	515	1729	350
-	-	3103	520	3224	575	2431	430	1444	360
5270	590	3442	550	3324	580	2514	475	2371	400
4595	580	3495	530	3596	595	3028	550	1575	370
4926	570	3571	550	3229	565	1785	375	2538	470
3375	550	3524	590	3222	570	1518	310	2615	470
5682	575	3774	580	3944	590	1194	225	2321	505
5455	-	3204	527	3271	580	1586	315	1806	390
-	-	-	-	-	-	2099	400	-	-

	CONTROLS MAX	AVG	MIN	CRYO 6.9 MAX	AVG	MIN	CRYO 3.8 MAX	AVG	MIN	AMB 6.9 MAX	AVG	MIN	AMB 3.8 MAX	AVG	MIN
TEN STR PSI	5622	4850	3375	3774	3430	3103	3944	3350	2943	3028	1960	1194	2615	1980	1444
ULT EL %	590	570	540	590	540	515	625	575	525	550	375	225	505	415	350

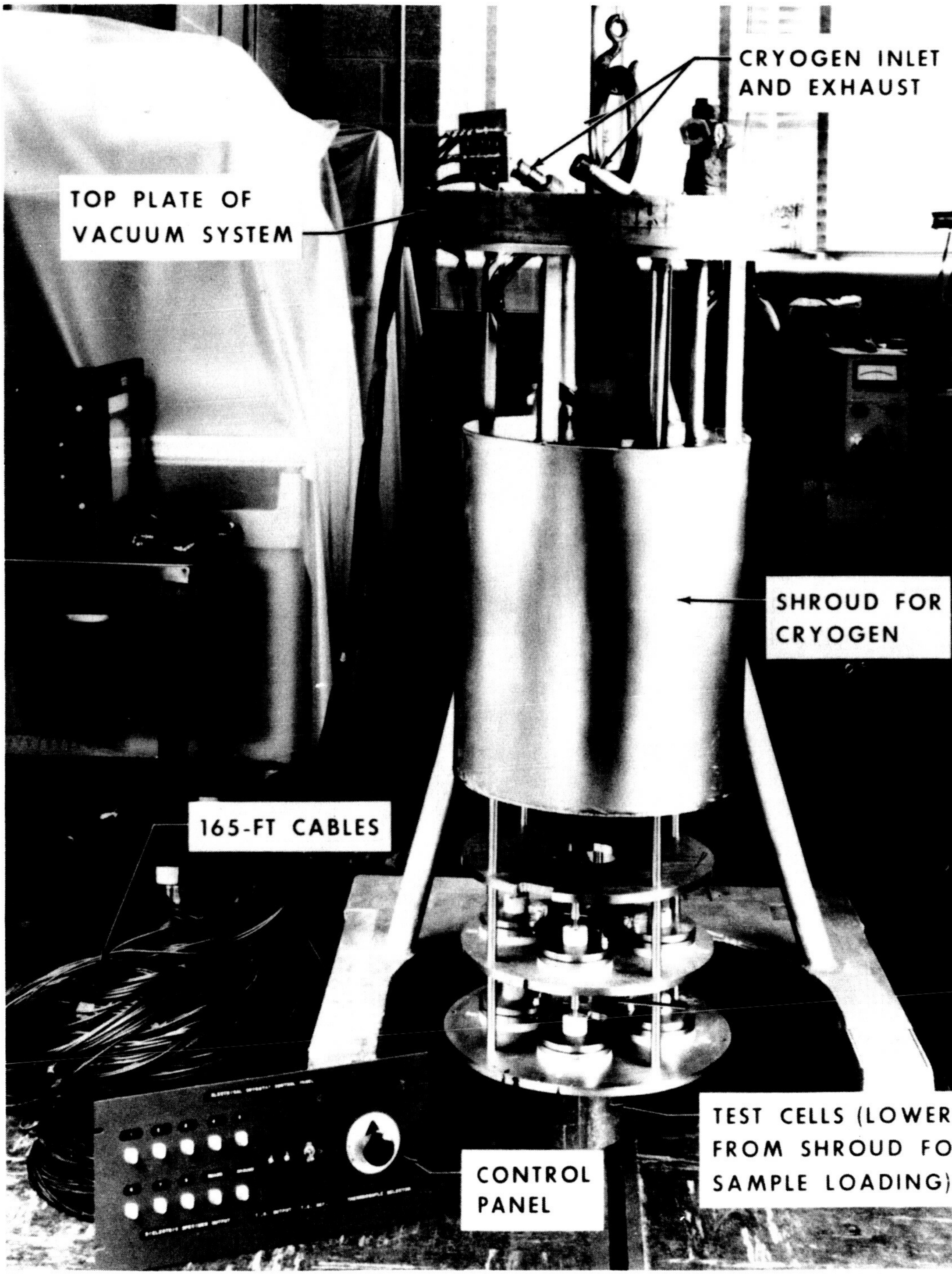


FIGURE 1. ELECTRICAL TESTER OPEN FOR SAMPLE INSTALLATION

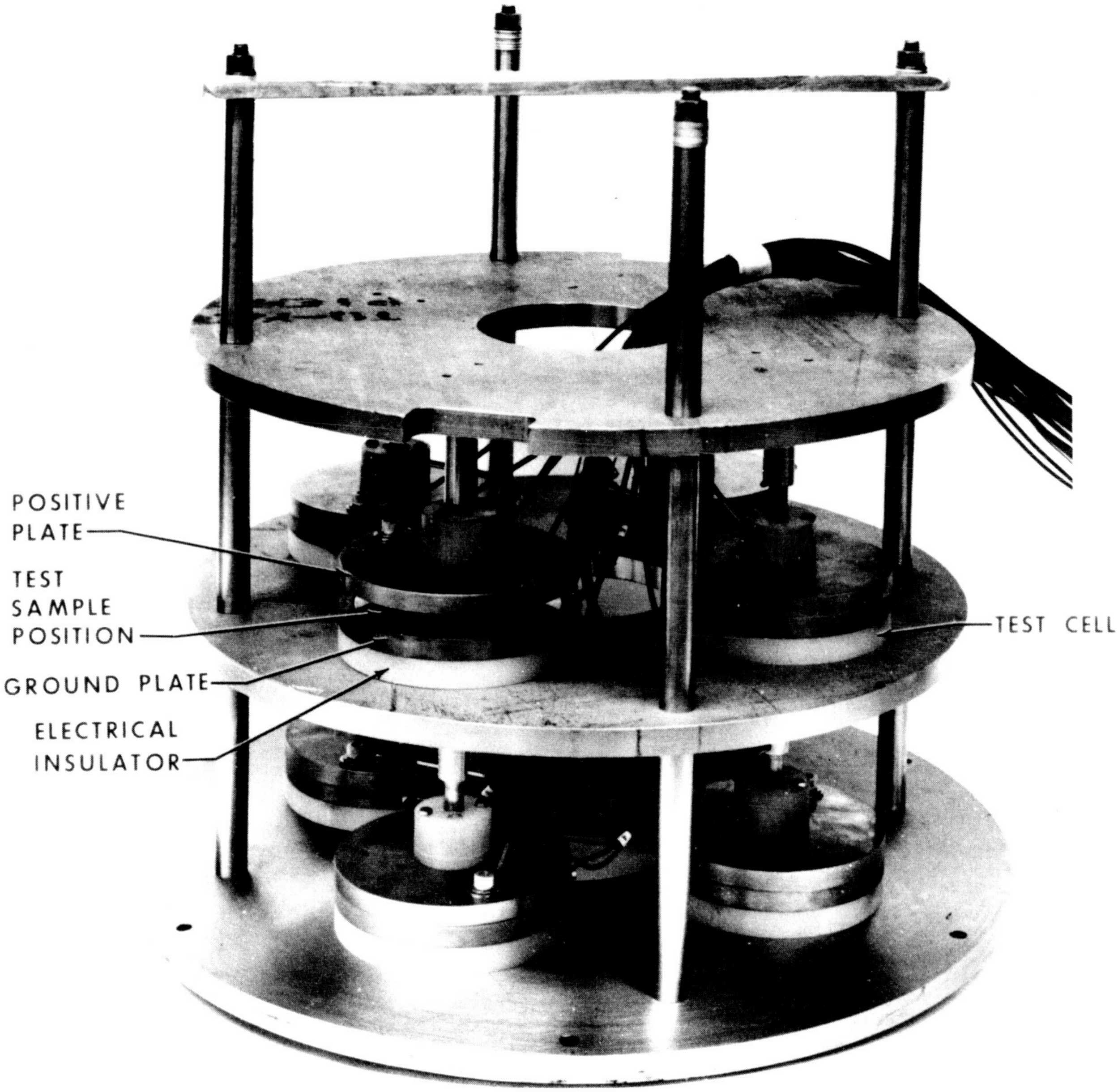


FIGURE 2. TEST CELL ARRANGEMENT OF ELECTRICAL TESTER

FIGURE 3 NORMALIZED DIELECTRIC CONSTANT, K_n, VS TEMPERATURE FOR EPON 828/Z, TEFLON TFE, ESTANE 5740, AND RTV 501

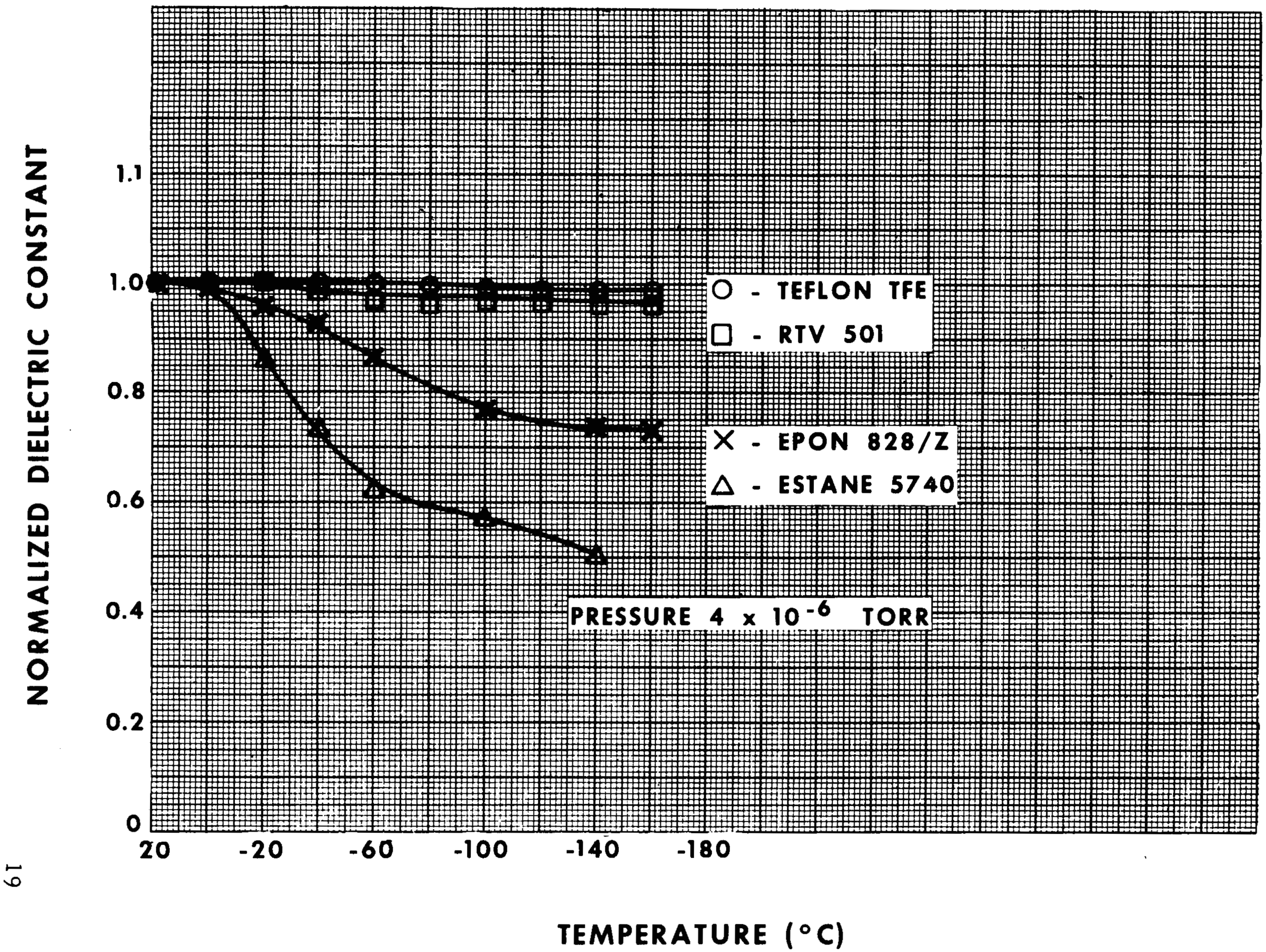


FIGURE 4 NORMALIZED DIELECTRIC CONSTANT, K_n, OF EPON 828/Z AS A FUNCTION OF INTEGRATED GAMMA DOSE AND TEMPERATURE

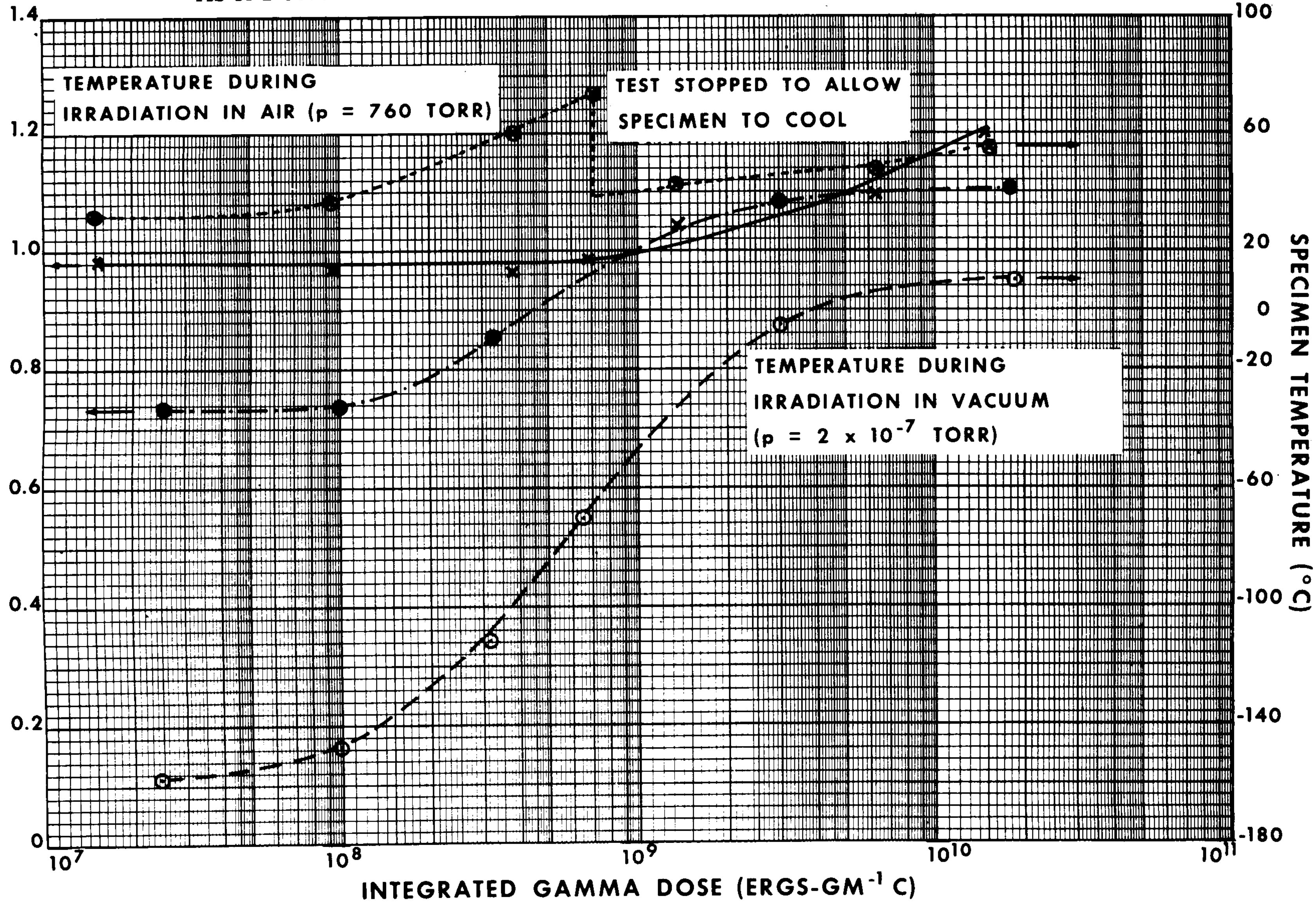


FIGURE 5 NORMALIZED DIELECTRIC CONSTANT, K_n, OF TEFLON TFE AS A FUNCTION OF INTEGRATED GAMMA DOSE AND TEMPERATURE

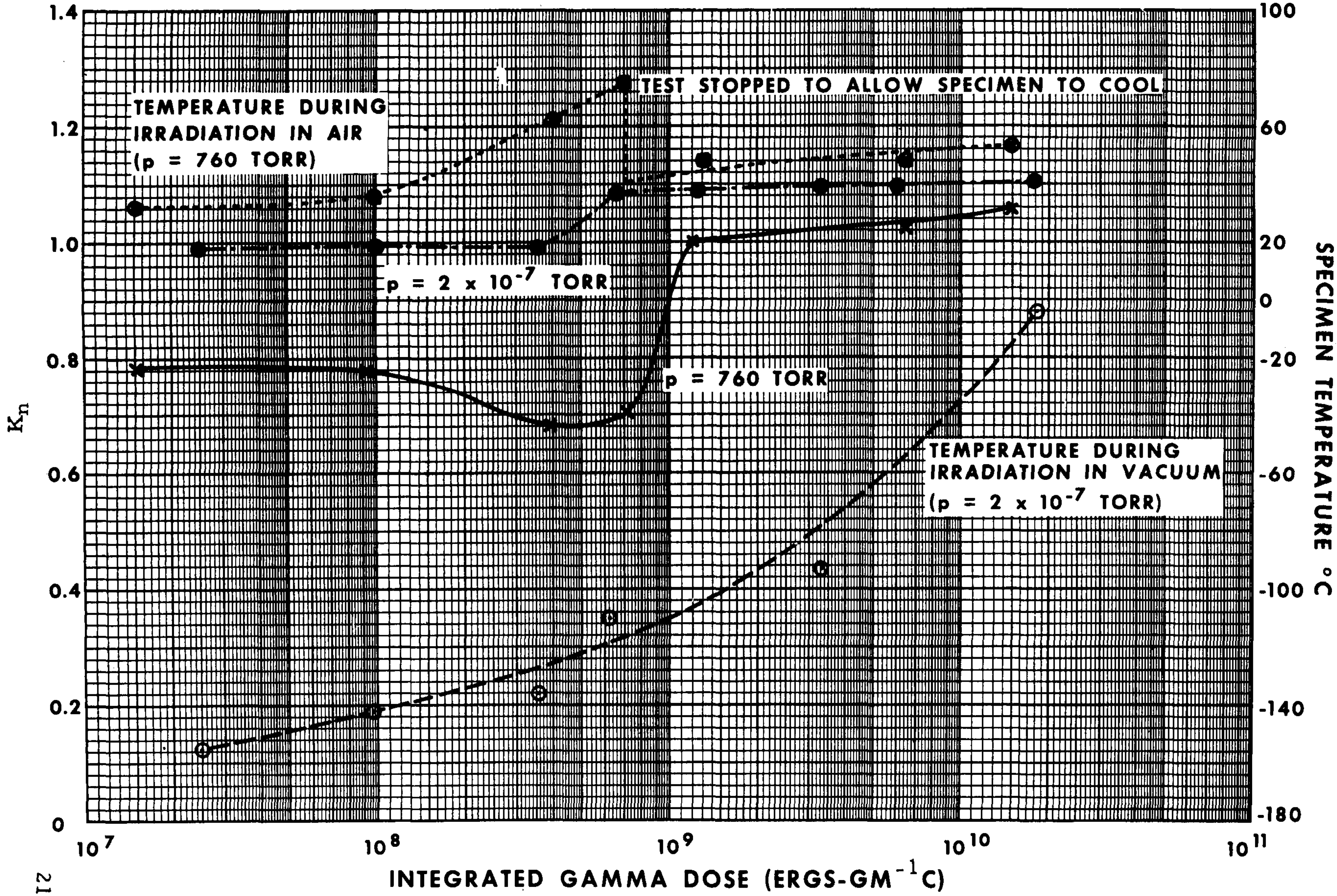


FIGURE 6 NORMALIZED DIELECTRIC CONSTANT, K_n, OF ESTANE 5740 AS A FUNCTION OF INTEGRATED GAMMA DOSE AND TEMPERATURE

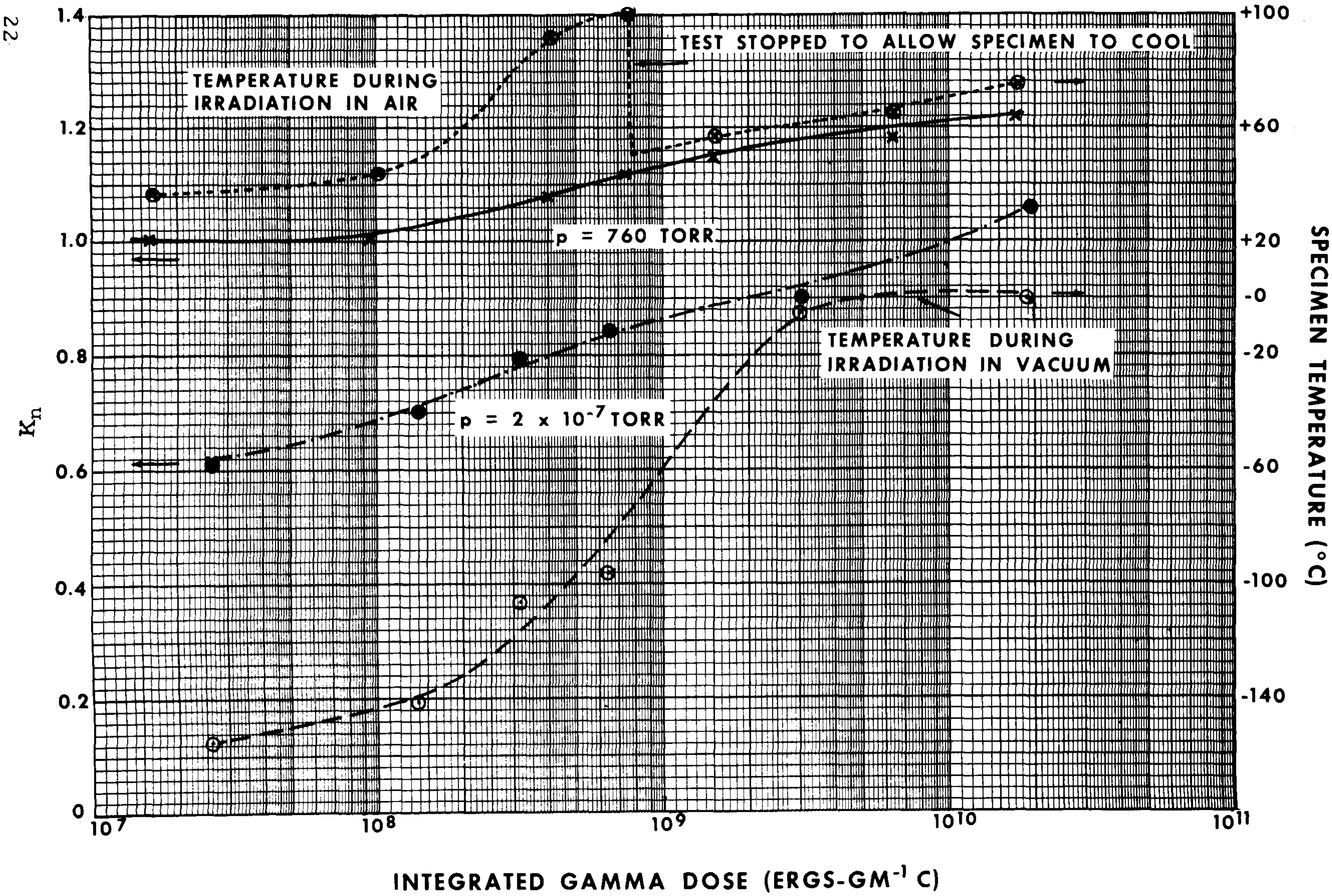
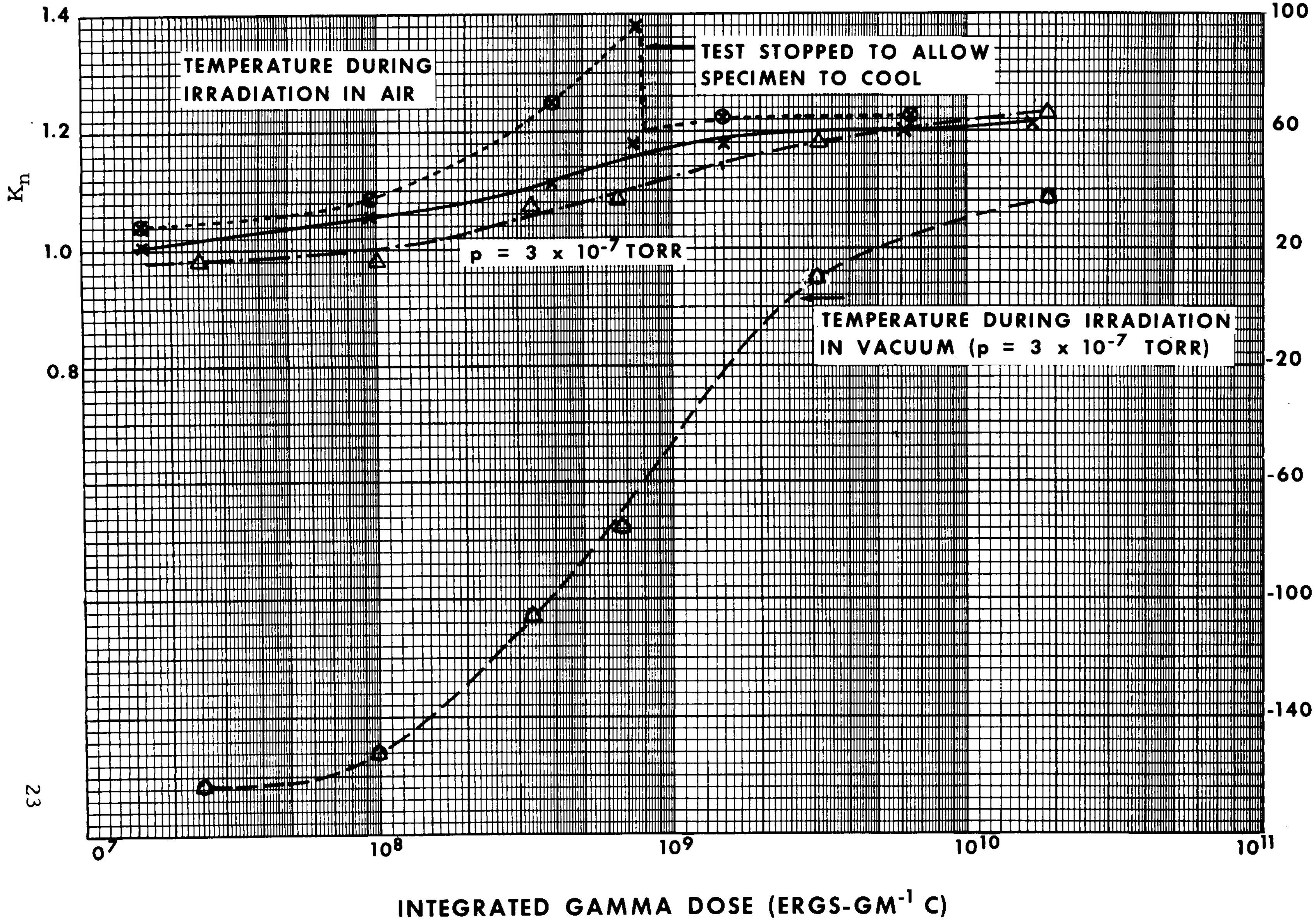


FIGURE 7 NORMALIZED DIELECTRIC CONSTANT, K_n, VS INTEGRATED GAMMA DOSE AND TEMPERATURE FOR RTV 501



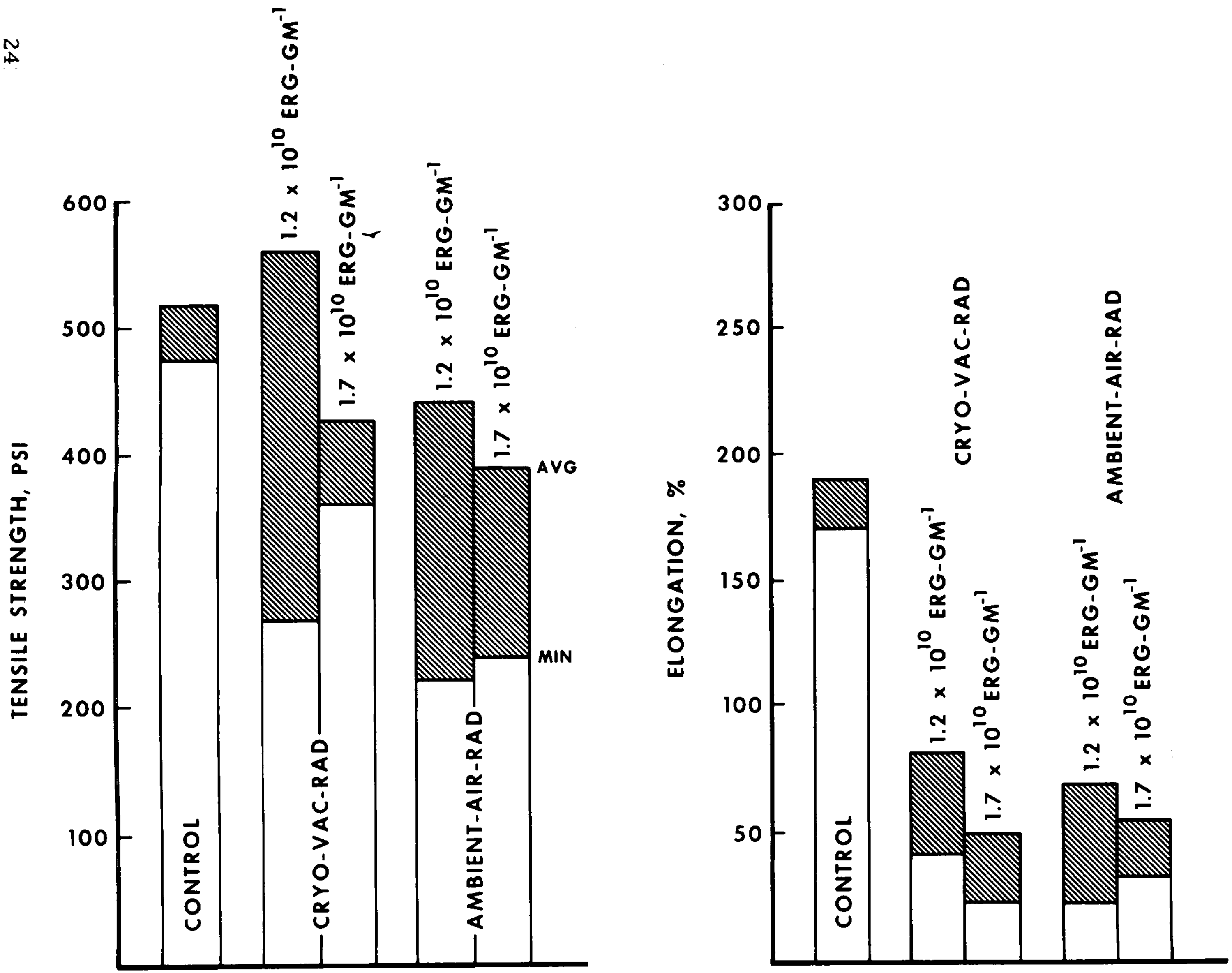


FIGURE 8 TENSILE PROPERTIES OF RTV 501 SILICONE RESIN

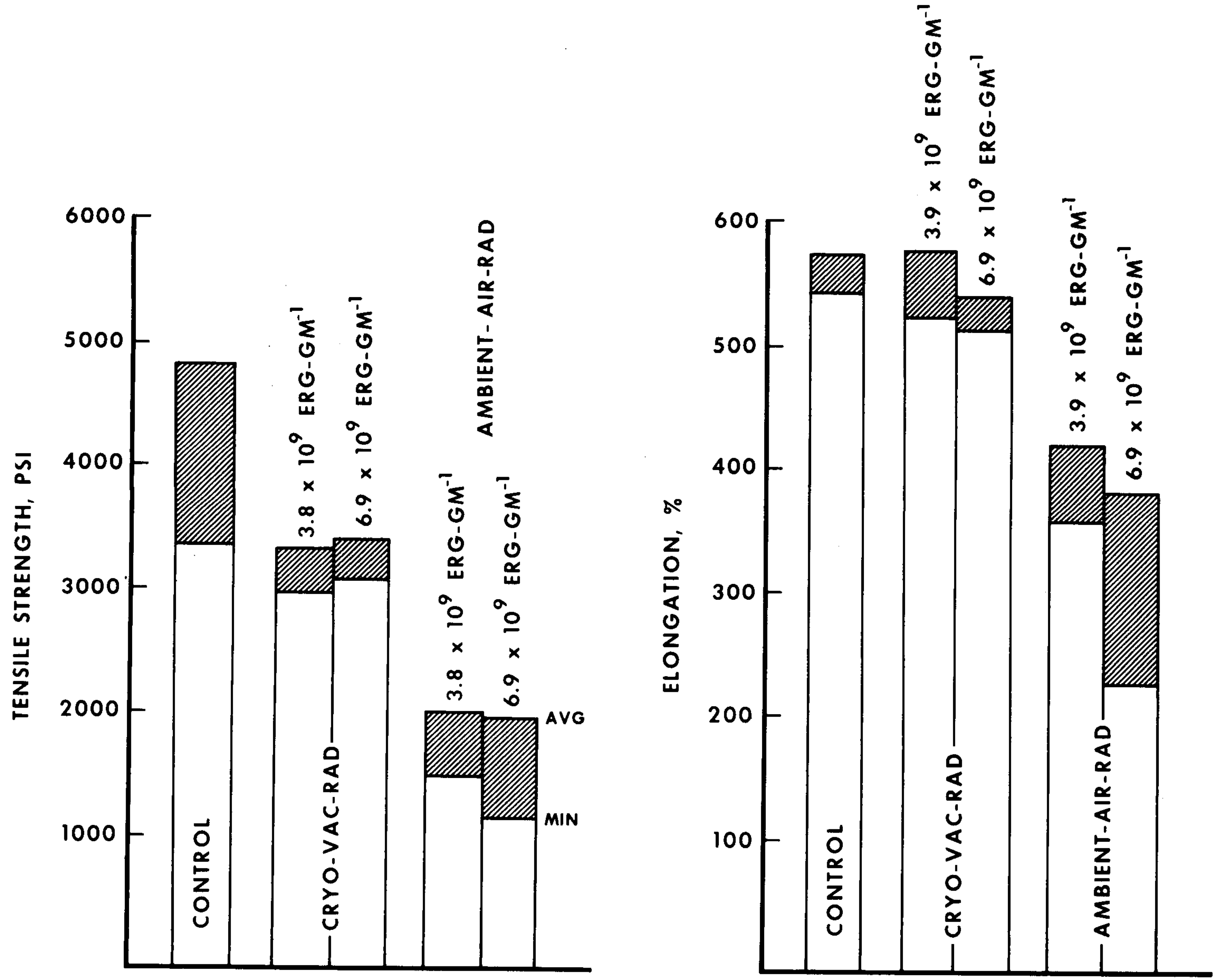


FIGURE 9 TENSILE PROPERTIES OF ESTANE 5740-1 POLYURETHANE

FIGURE 10 TEFLON TFE IRRADIATED SEPTEMBER 5, 1963 IN DIELECTRIC TESTER

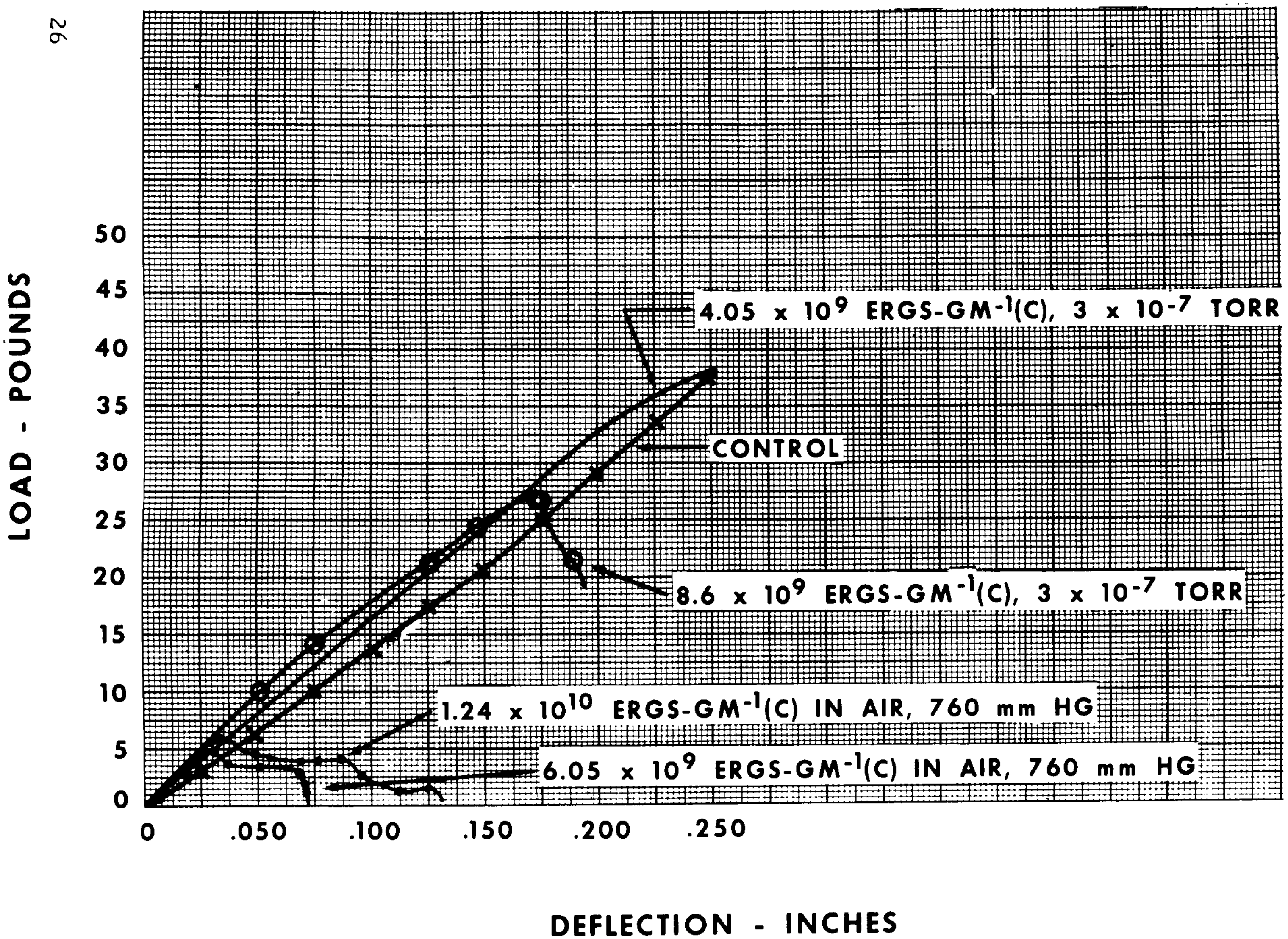
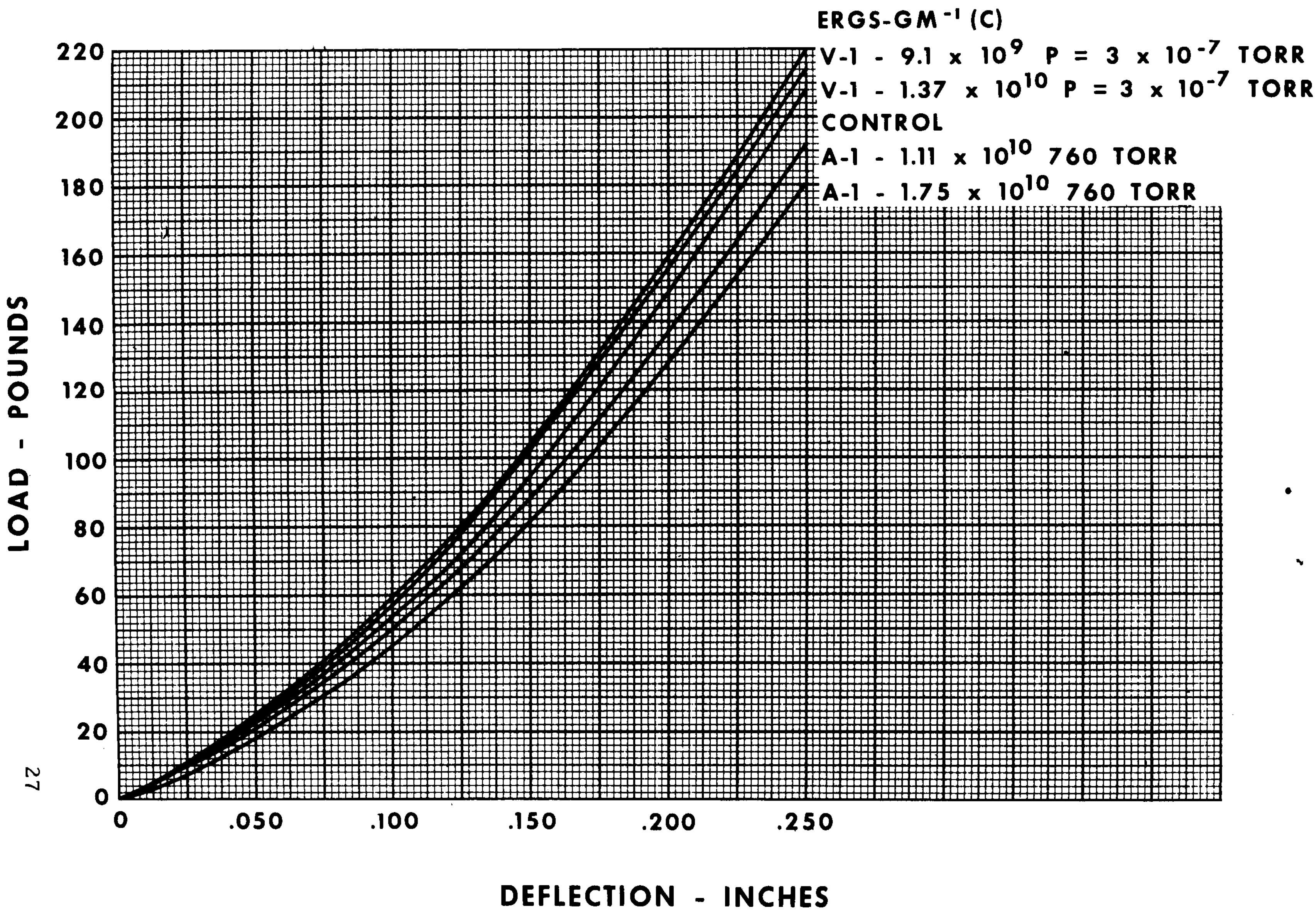


FIGURE 11 EPON 828/Z IRRADIATED SEPTEMBER 5, 1963 IN DIELECTRIC TESTER



March 30, 1965 APPROVAL TM X-53230

EFFECTS OF NUCLEAR RADIATION, CRYOGENIC TEMPERATURE, AND VACUUM ON THE ELECTRICAL PROPERTIES OF DIELECTRIC MATERIALS

By

R. L. Gause and E. C. McKannan

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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