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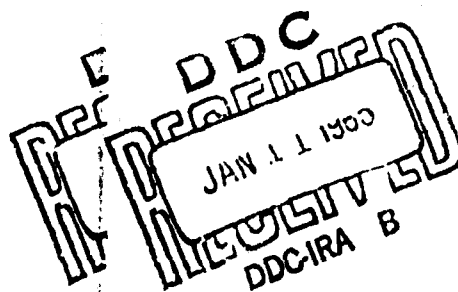
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REC PENC Report No. 21 (Addendum)

August 31, 1964

CATALOGED BY DDC
AS AD No. 454056

**THE EFFECT OF NUCLEAR RADIATION ON
ELASTOMERIC AND PLASTIC COMPONENTS
AND MATERIALS**



**RADIATION EFFECTS INFORMATION CENTER
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Addendum Report on

**THE EFFECT OF NUCLEAR RADIATION ON
ELASTOMERIC AND PLASTIC COMPONENTS
AND MATERIALS**

by

N. J. Broadway and S. Palinchak

to

**RESEARCH TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND**

**RADIATION EFFECTS INFORMATION CENTER
Battelle Memorial Institute
Columbus, Ohio 43201**

ABSTRACT

This report is an addendum to REIC Report No. 21 and presents the state of the art of the effects of nuclear radiation on elastomeric and plastic components and materials from 1961 to the present.

The mechanism of radiation damage and the effects of radiation in various environments are briefly discussed. Data summarizing the radiation-effects information on specific components and on the various types of elastomers and plastics are presented in detail. Areas in which additional work is needed are indicated. Radiation polymerization or vulcanization are not covered in this report.

The report is intended to be sufficiently inclusive to make it valuable as a reference guide relative to radiation effects under varying conditions of temperature and vacuum on elastomeric and plastic components and materials.

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THE EFFECT OF NUCLEAR RADIATION ON ELASTOMERIC
AND PLASTIC COMPONENTS AND MATERIALS
(ADDENDUM REPORT)

SUMMARY AND CONCLUSIONS

There is a widespread interest in polymeric materials which may be used in aerospace applications. There is an increasing demand for information on the behavior of these materials in a radiation environment (nuclear, ultraviolet and particle radiation), in a high vacuum, and at extreme temperatures. This is reflected in the amount and types of publications which have become available since the publication of REIC Report No. 21 on "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials". The amount of data which has become available since 1961 is somewhat limited, although both the quality and scope have improved. The trend, noted in Report No. 21, of testing components in the environments to be encountered in actual operation has increased. Data on the behavior of polymers in a radiation-vacuum-extreme temperature environment have become available. Because of the difficulties in obtaining data of this type, the amount is still limited. However, it is encouraging to see the progress in this direction.

In general, materials having a high degree of cure, high molecular weight, good heat resistance, and little or no plasticizer or other volatile additive show promise for use in this environment. In some cases, the radiation resistance of a material is improved in vacuum because of the lack of oxygen which is generally the major contributing factor to polymer deterioration.

Polyimide and phosphonitrilic chloride polymers have been reported as having improved radiation stability over presently used polymers and merit consideration for further development and application in end items. O-rings manufactured from rubber compositions containing antirads have shown improved service life in a radiation environment, although this improvement still falls short of the requirements for many applications. Several structural adhesives and laminates have been found to be satisfactory in radiation exposures at cryogenic temperatures. These include polyurethane, epoxy and modified epoxy, phenolic, and polyester materials.

In this addendum report, a brief summary of the effects of radiation and other known environmental conditions is given for end items and materials. A comparison of the relative resistance is provided by Figures 1 through 4 and Tables 1 and 2, which show the stability of the various elastomers and plastics to gamma radiation as well as noting the general effects of vacuum and ultraviolet radiation on these materials. At the present time, data are not sufficient to definitely establish the life of a particular material for all conditions of exposure, but the data do give guidelines which will help to determine the proper use of various types of polymeric materials.

In general, the vacuum environment has not proven to be too severe. Most of the polymeric materials have not been too seriously affected by this environment and have maintained satisfactory properties. Several plastic materials have shown promise for use at cryogenic temperatures. In most cases, the effects of nuclear radiation under

Electric Insulation

Silicon - glass mica
 Silicone, filled
 Teflon, in air
 Teflon, in fluid
 Dialyl phthalate, glass filled

Seals

Viton A or Silicone
 In air
 In oil
 Nitrile rubber
 Neoprene rubber

Sealants

Viton A, in air
 Silicone, in air
 Thiokol, in fuel
 Neoprene, in air
 Nitrile, in air
 Viton B, in air

O-Rings

Viton A, in oil
 Natural rubber

Tires, with antiradLaminates

Phenol
 Room temperature
 500 F
 Phenolic, irradiated and
 tested at 500 F
 Epoxy
 Room temperature
 500 F
 Silicone
 Room temperature
 500 F
 Polyester
 Room temperature
 500 F

Adhesive

422J
 Room temperature
 500 F

Potting Compounds

Epoxy
 Room temperature
 Silicone
 Room temperature
 400 F

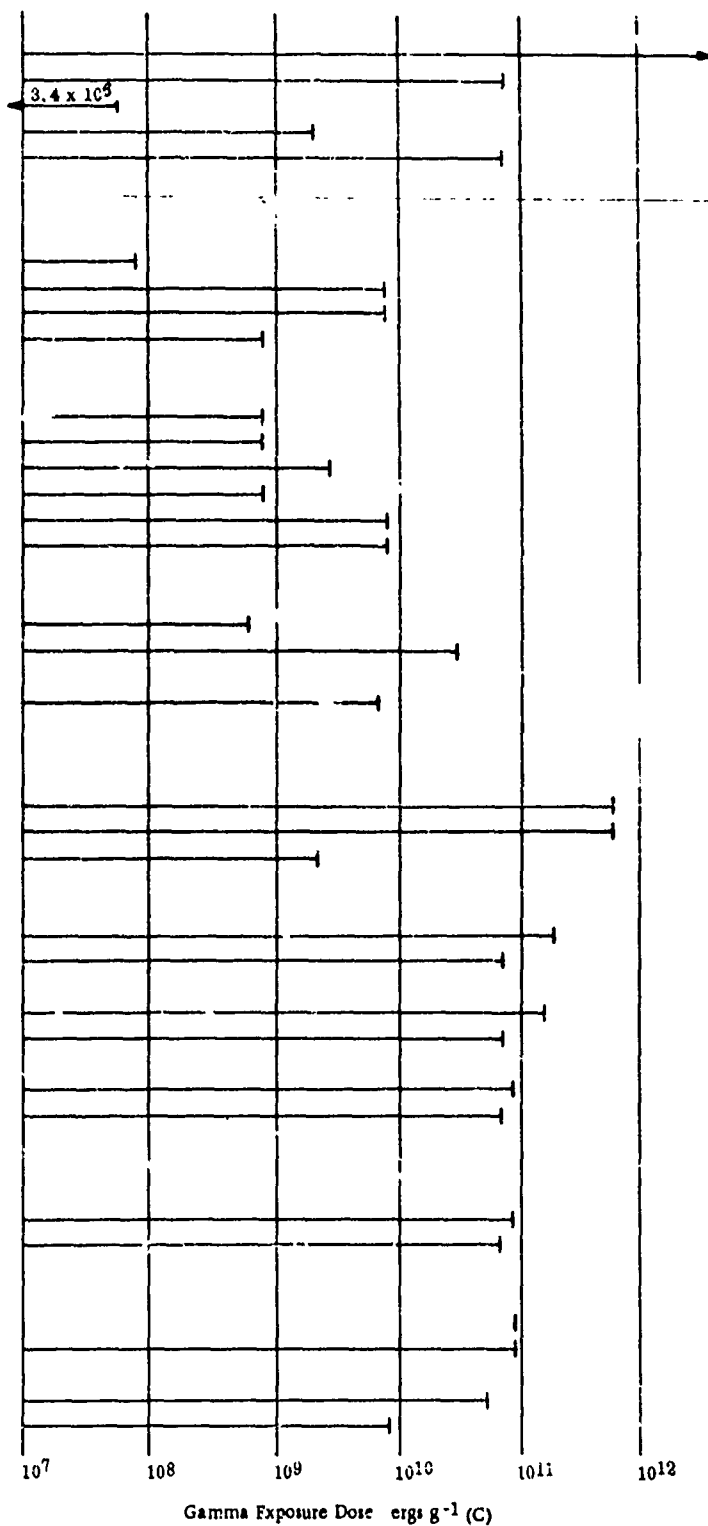


FIGURE 1. MAXIMUM RADIATION EXPOSURE OF VARIOUS COMPONENTS FOR RETENTION OF USEFUL PROPERTIES

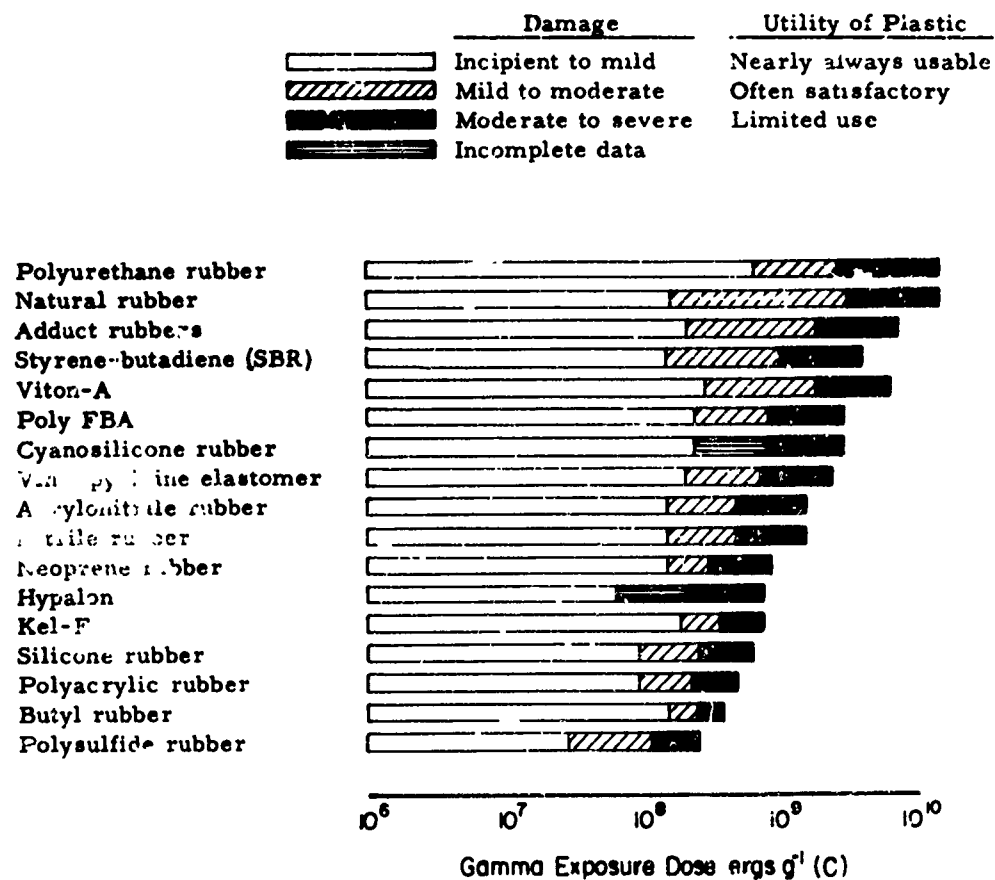
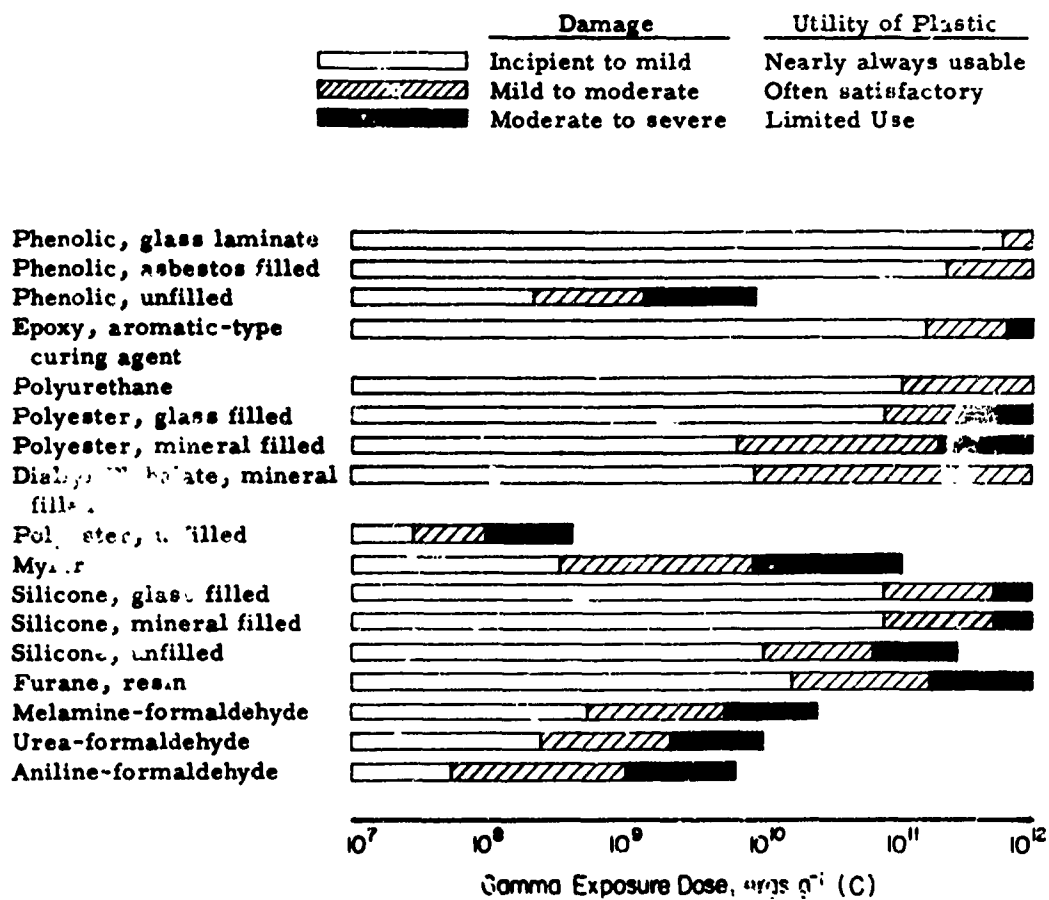


FIGURE 2. RELATIVE RADIATION STABILITY OF ELASTOMERS



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FIGURE 3. RELATIVE RADIATION STABILITY OF THERMOSETTING RESINS

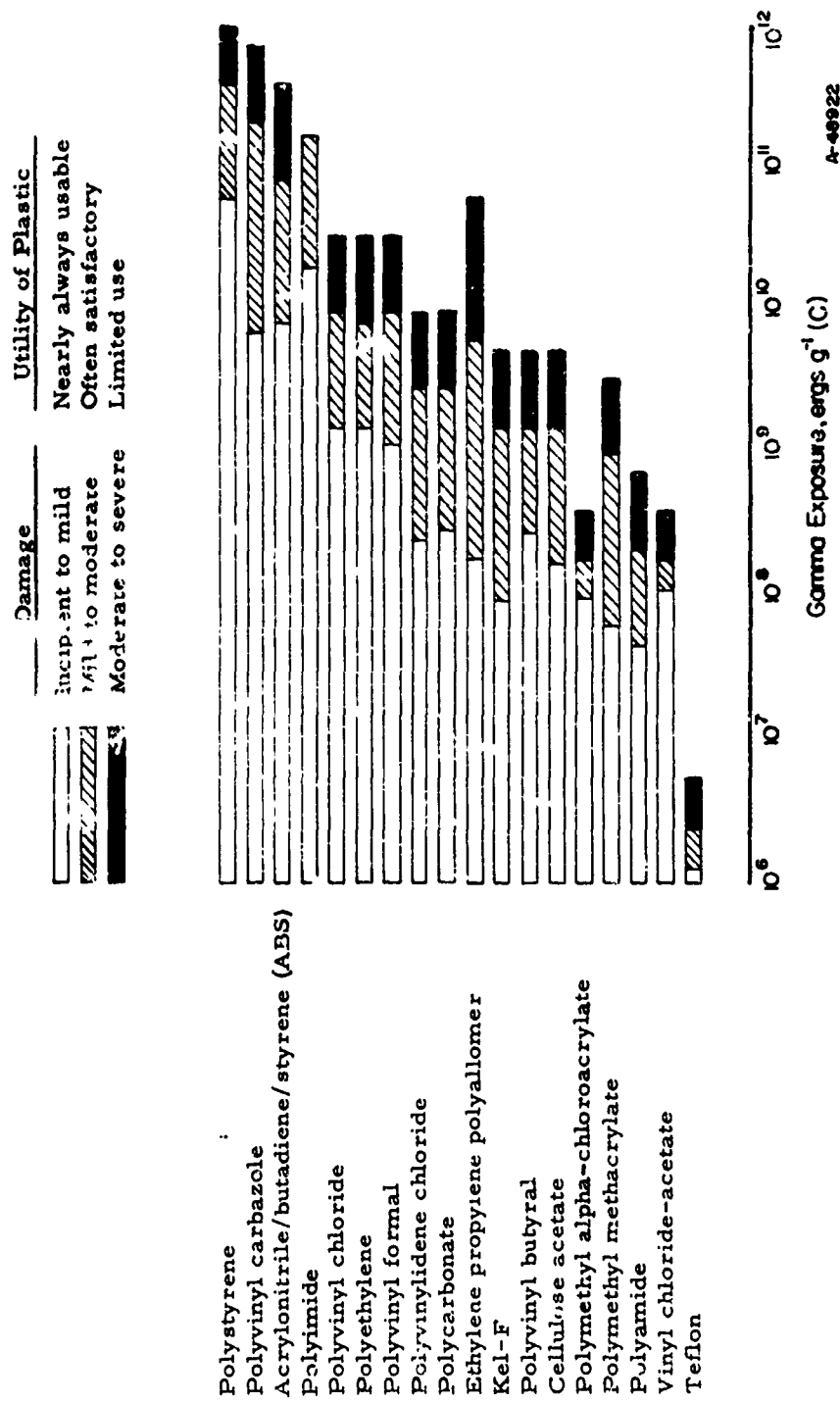


FIGURE 4. RELATIVE RADIATION RESISTANCE OF THERMOPLASTIC RESINS

TABLE 1. EFFECT OF VACUUM ON RADIATION STABILITY OF POLYMERS

Polymer	Effect of Vacuum ^(a)
Plastics	
Diallyl phthalate	No significant effect
Epoxy	No significant effect
Mylar	Improves stability
Polyamide (nylon)	No significant effect
Polycarbonate	Slight improvement
Polyethylene	Improves stability
Polyvinyl chloride	Decreases stability
Silicone	Improves stability
Teflon	Improves stability substantially
Kynar (polyvinylidene fluoride)	No significant effect
Tedlar (polyvinyl fluoride)	No significant effect
Kel-F (trifluoromonochloroethylene)	Improves stability
Elastomers	
Polyacrylic	No significant effect
Butyl	No significant effect
Hypalon (chlorosulfonated polyethylene)	Decreases stability
Neoprene	No significant effect (conflicting data)
Nitrile	Decreases stability
Polysulfide	No significant effect
Polyurethane	No significant effect
Silicone	No significant effect
Viton A	Improves stability

(a) These effects are on general and individual compositions may behave differently.

TABLE 2. EFFECT OF ULTRAVIOLET RADIATION ON POLYMER STABILITY

Polymer	Effect of Ultraviolet Energy
Plastics	
Mylar	Decreases tensile strength and elongation
Polyamide (nylon)	No significant effect
Polymethyl methacrylate	Surface discoloration and crazing
Polyethylene	Embrittlement
Polypropylene	Embrittlement
Polyimide	No significant effect
Polystyrene	Yellows
Plasticized polyvinyl chloride	Develops tacky and discolored surface
Teflon	No significant effect
Elastomers	
Butyl	Increases tensile strength and elongation
Hypalon (chlorosulfonated polyethylene)	No significant effect
Neoprene	Increases tensile strength, decreases elongation
Nitrile	Decreases tensile strength and elongation
Styrene-butadiene (SBR)	Decreases tensile strength and elongation
Silicone	Surface crazing
Viton A	No significant effect

these combined environments are not any more serious than under atmospheric conditions as far as usefulness in various components is concerned. Some materials such as Teflon have shown better properties in these combined environments. However, it remains a matter of proper compounding and curing and individual study to determine the applicability of the various materials for a particular component use.

Recommendations

- (1) The recommendations made in REIC Report No. 21 are still applicable. Although some steps have been made to secure the data recommended in that report, there is still need for more work in these areas.
- (2) More data are needed on the amount of damage which may be accrued by elastomeric and plastic materials before failure occurs in the operation of the fabricated component. Information is needed on minimum strength requirements before an item is considered inoperable.
- (3) Many of the experimental space flights have been successful and in many of these there has been good use made of polymeric materials. One of the more useful and relatively inexpensive pieces of information which would be of extremely great value would be an accurate and complete compilation of the elastomeric and plastic materials including trade names and specific compositions which have proved successful in these space missions. In cases where these data are of a proprietary nature, sufficient information should be made available so that designers of future vehicles and components can be made aware of the availability of these materials.
- (4) Continued work is needed in fundamental studies leading to new and improved polymers having greater resistance to radiation damage.

INTRODUCTION

This report is the first addendum to REIC Report No. 21, "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials" and summarizes data published during the period April 30, 1961, and April 30, 1964, on radiation effects in polymeric components and materials. It also includes effects of vacuum, ultraviolet radiation, and extreme temperatures, where these data are available.

There has been a noticeable decrease in the volume of publications during the period covered in this report. This has been due in part to the amount of information which had been collected previously and to the scope of this earlier information. However, part of the reason for the lack of new information is due to a cutback in the rate of effort and to a change in the overall objectives and philosophy of both Government and industry. There is still a need for work to be continued on determining the effects of radiation at high exposures, the effects of exposure rate on components, high-impulse effects, and the mechanisms of degradation of various elastomers and plastics. In this last area, the amount of degradation which can be tolerated in various component parts before failure in operation needs to be determined.

Because of the interest in space vehicles, the greater portion of the present work being done is concerned with the effects of combined environments such as vacuum and radiation and elevated and cryogenic temperatures and radiation. Because of the interest in space environments, data on the effects of vacuum and temperature are included in this report which do not refer directly to radiation stability. However, it is believed that these data will help to impart an understanding of the effects of radiation in space.

A few new polymers have been developed which are of interest both with respect to their properties and to their possible applications in a space-radiation environment. These are discussed under the individual polymeric materials.

Elastomers and plastics for which no new information was found are not included in this report and the reader is referred to REIC Report No. 21. In this addendum report, components are discussed, followed by the elastomers and then the plastics, arranged alphabetically.

It is often necessary in dealing with radiation exposures to convert from one unit of radiation exposure to another, particularly when comparing various reports. Table 3 lists the conversion factors which have been used by the REIC in making the necessary conversions.

To permit comparison of data from various sources, reported in a variety of units, it is frequently necessary for the REIC to convert to the units recommended in this memorandum. In many cases, insufficient information is presented to permit an accurate conversion. Of the conversion factors listed below, those marked with an asterisk have been adopted by the REIC to be used in such instances. The values are approximately correct for hydrocarbons, assuming an average energy of 1 Mev for the radiations. These values should be used with caution and only in cases where information is not available on materials composition and energy distribution of the radiation to permit an accurate conversion.

TABLE 3. CONVERSION FACTORS

To Convert	To	Multiply By
Rads	ergs g ⁻¹	100
Ev g ⁻¹ (C)	ergs g ⁻¹ (C)	1.6 x 10 ⁻¹²
Roentgen	ergs g ⁻¹ (C)	87.1
Rep	ergs g ⁻¹ (C)	84.6
Rad (tissue)	ergs g ⁻¹ (C)	90.9
Rad (water)	ergs g ⁻¹ (C)	90.0
Mev cm ⁻² (a)	ergs g ⁻¹ (C)	4.5 x 10 ⁻⁸
Photons cm ⁻² (a)	ergs g ⁻¹ (C)	4.5 x 10 ⁻⁸
Photons cm ⁻² (a)	rep	5 x 10 ⁻¹⁰
Rep hr ⁻¹ (a)	n cm ⁻² sec ⁻¹ (b)	7.1 x 10 ⁴
Rad (C) hr ⁻¹ (a)	n cm ⁻² sec ⁻¹ (b)	1.17 x 10 ⁵
Rem hr ⁻¹ (a)	n cm ⁻² sec ⁻¹ (b)	8.3 x 10 ³
(nv ₀)	rad (C) hr ⁻¹	4.58 x 10 ⁻⁶
n cm ⁻² (a, b)	rads (C)	4.17 x 10 ⁻⁹
n cm ⁻² (a, b)	ergs g ⁻¹ (C)	4.17 x 10 ⁻⁷
(nv ₀)	rads (C)	1.06 x 10 ⁻⁹
(nv ₀)	ergs g ⁻¹ (C)	1.06 x 10 ⁻⁷

(a) Assumed average energy of 1 Mev.

(b) The term n cm⁻² sec⁻¹ may appear as nv and the term n cm⁻² may frequently appear as nvt although the terminology is not strictly correct unless the "v" value is specified.

COMPONENTS

Adhesives

Adhesives are available which maintain shear strengths to a gamma exposure of 10^{10} to 10^{11} ergs g^{-1} (C) at room temperature. An epoxy-phenolic adhesive retained excellent shear strength after irradiation at 350 F to an exposure of 10^{11} ergs g^{-1} (C).

In order to retain useful strengths of adhesives as long as possible, it was recommended that adhesive thicknesses of 10 mils or better be used.

In general, vacuum is not harmful to adhesives, but there are exceptions. Tensile shear strengths of several adhesives either remained the same or increased when samples were exposed to a temperature of 200 C in a vacuum. Oxidation appears to be an important factor in the degradation of adhesives at high temperatures. Vacuum irradiation produced no detectable changes or only minor changes in the lap-shear strength of adhesives tested by various investigators.

Information is available on the effects of radiation at various temperatures in air for several adhesives. In general, these maintained their shear strength to a gamma exposure of 10^{10} ergs g^{-1} (C). Studies with structural adhesives have emphasized their stability in space environments, and several are commercially available that are serviceable under the vacuum and temperature conditions encountered in space. However, care must be exercised in choosing adhesives since some compositions may be adversely affected by vacuum. In the use of transparent adhesives for bonding transparent materials, such as polymethyl methacrylate, ultraviolet radiation is a factor to be considered.

Effects of Nuclear Radiation

Hexcell 422-J (epoxy-phenolic) adhesive was tested in the form of lap-shear specimens at room temperature and at elevated temperatures⁽¹⁾. Shear-strength tests were conducted at laboratory temperature (75 F) for samples irradiated at ambient temperatures (110 to 130 F) and at 350 F for the samples irradiated at elevated temperatures. Shear strengths of the samples irradiated at ambient temperature to gamma exposures up to 1.7×10^{11} ergs g^{-1} (C) were not greatly different from the shear strength of the control samples. Samples irradiated at 250 F and 310 F to 6.8×10^{10} ergs g^{-1} (C) and 2.2×10^{11} ergs g^{-1} (C), respectively, stored for 7 days at 350 F and then tested at 350 F, lost approximately 15 per cent and 10 per cent of their shear strength. The control (unirradiated) samples under similar test conditions lost approximately 70 per cent of their shear strength. Apparently heat alone affected the lap-shear strength to a much greater degree than the combined radiation-heat environment. At temperatures above 310 F, the effects of heat alone and heat plus radiation [6×10^{10} ergs g^{-1} (C)] were about equivalent. The shear strength of specimens, both control and irradiated, exposed to 450 F decreased from 2500 psi to about 800 psi. Data are shown in Table 4.

(1) References appear on page 117.

TABLE 4. SHEAR STRENGTH OF ADHESIVE: 422-J LAP-SHEAR SPECIMENS⁽¹⁾

Gamma, ergs g ⁻¹ (C)	Neutron n cm ⁻² (E>2.9 Mev)	Irradiation		Storage		Test Temperature, F	Shear Strength ^(a) , psi
		Temperature, F	Time, hr	Temperature, F	Time, Days		
Control		--	--	75	--	75	2,490/51/16
Control		--	--	75	--	350	2,490/102/8
Control	2.2 x 10 ¹⁵	110	33	--	--	75	2,568/160/20
Control	2.5 x 10 ¹⁰	110	33	--	--	75	2,782/123/20
Control	1.0 x 10 ¹⁶	140	33	--	--	75	2,742/171/20
Control	9.1 x 10 ¹⁰	140	33	--	--	75	2,506/137/20
Control	5.9 x 10 ¹⁵	250	33	350	7	350	794/88/20
Control	6.8 x 10 ¹⁰	250	31	350	7	350	2,240/150/16
Control	6.8 x 10 ¹⁰	250	31	350	8	350	1,937/151/4
Control	2.4 x 10 ¹⁶	310	31	350	7	350	216/36/20
Control	2.2 x 10 ¹¹	310	31	350	7	350	2,406/159/3
Control	2.2 x 10 ¹¹	310	31	350	8	350	1,853/52/7
Control	5.2 x 10 ¹⁵	--	--	--	--	75	2,542/195/10
Control	1.7 x 10 ¹⁶	120	55	--	--	75	2,881/199/20
Control	6.0 x 10 ¹⁰	130	55	--	--	75	2,590/180/20
Control	7.2 x 10 ¹⁵	450	55	--	--	450	1,450/136/9
Control	6.0 x 10 ¹⁰	445	55	--	--	450	1,280/74/9
Control	7.2 x 10 ¹⁵	445	55	450	7	450	920/93/10
Control	6.0 x 10 ¹⁰	445	55	450	7	450	209/78/10

(a) Data are given as $\bar{x}$ /S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

The effect of gamma radiation on four adhesives was studied by McCurdy and Rambosek(2). Included were:

EC-1469	A modified epoxy-based adhesive
AF-31	An elastomer-phenolic film adhesive
AF-32	An elastomer-phenolic film adhesive
EC-1639	A modified phenolic adhesive

All of these adhesives are relatively rigid and are used primarily for metal-to-metal bonding. The effects of radiation on overlap shear strengths and on peel strengths in air at room and at elevated temperatures were determined. Also, the effect of adhesive film thickness was studied. In each case, the adhesive seemed to benefit slightly from the additional crosslinking resulting from low doses of irradiation. However, degradation began at an exposure of 5 to 6×10^{10} ergs g^{-1} (C). The principal effect of the high exposure [8 to 9×10^{10} ergs g^{-1} (C)] was embrittlement.

Figure 5 shows the effect of radiation on the bond performance over a wide temperature range. In most cases the high-temperature performance fell off in a way which paralleled the room-temperature performance. EC-1469 maintained its properties to about 6×10^{10} ergs g^{-1} (C), while EC-1639 was relatively unaffected at an exposure of 9×10^{10} ergs g^{-1} (C). The elastomer-phenolic films, AF-31 and AF-32, were affected by radiation to a greater extent than were the other adhesives. These rubber-modified films maintained their performance at room temperature up to 4×10^{10} ergs g^{-1} (C), but at elevated temperatures, both fell below the MIL-A 5090D, Type II specifications after about 10^{10} ergs g^{-1} (C).

The three elastomer phenolic films varied somewhat in flexibility and, therefore, in the amount of peel strength at room temperature. The most rigid, AF-31, showed the best retention of peel strength when subjected to radiation, but all three adhesives deteriorated to about the same over-all value after 9×10^{10} ergs g^{-1} (C). It was thought that some gas formed at the interface.

To determine the effect of adhesive thickness, four bonds were made which varied in thickness from 1.2 mils to 16.1 mils. Peel strength varied from 10 to 30 pounds per inch width. However, under irradiation, all the adhesives lost strength rather rapidly; and at very high doses, there was little significant difference in peel strengths. The absolute peel strengths were such, however, that the use of adhesive thicknesses of 10 mils or greater was recommended to retain a useful strength as long as possible. Loss of peel strength was due to embrittlement and, to some extent, to degradation of the adhesive.

McCurdy and Rambosek also tested three composite adhesives for use in bonding honeycomb sandwich structures to metal surfaces. The composite consisted of a flexible adhesive to provide good peel strength at the metal interface and a rigid adhesive to provide wetting and filleting of the honeycomb core structure. One of the adhesive systems checked consisted of an EC-1469 epoxy coating on an AF-102 nitrile-phenolic film. The other two composites, AF-200/1593 and AF-202/1593 were not identified as to chemical type. The investigators found that radiation had an extremely detrimental effect on the properties of the rigid adhesive. Peel strength deteriorated rapidly with failure in the fillet area. With high dosage, fillets spalled badly, leaving a relatively clean core surface. It was concluded that these composite adhesive films would not be suitable for high radiation areas in honeycomb sandwich structures where high peel strength is important. Where beam structural strength is a more important function, these adhesives will perform up to 3 to 4×10^{10} ergs g^{-1} (C) exposure dose.

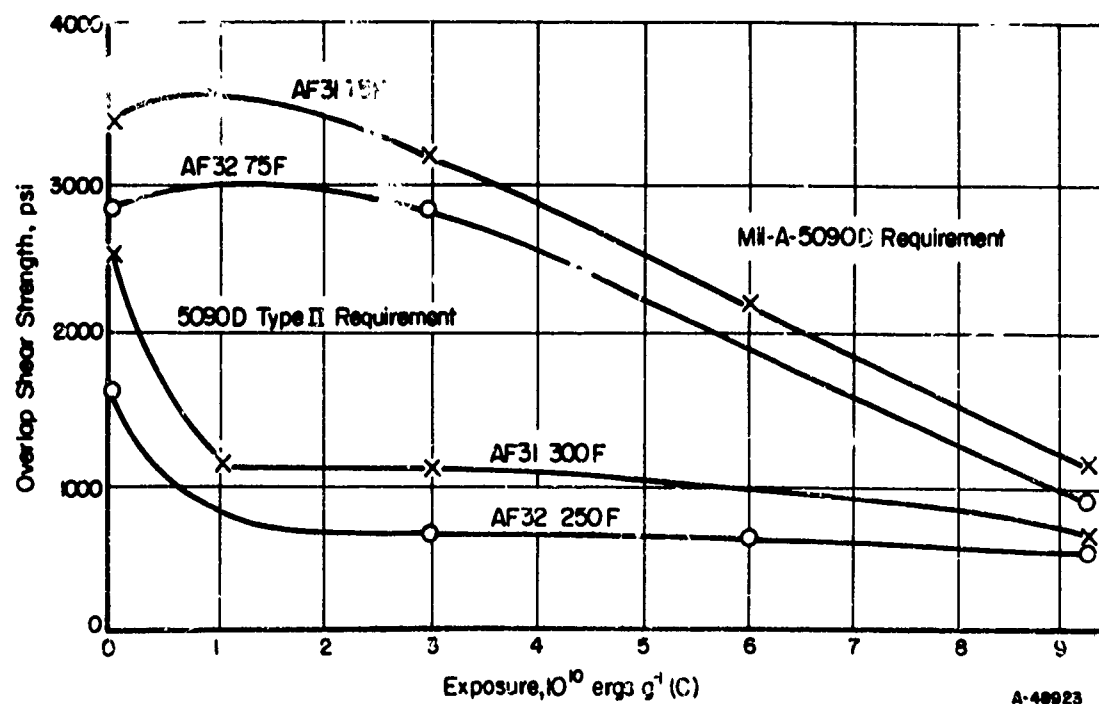
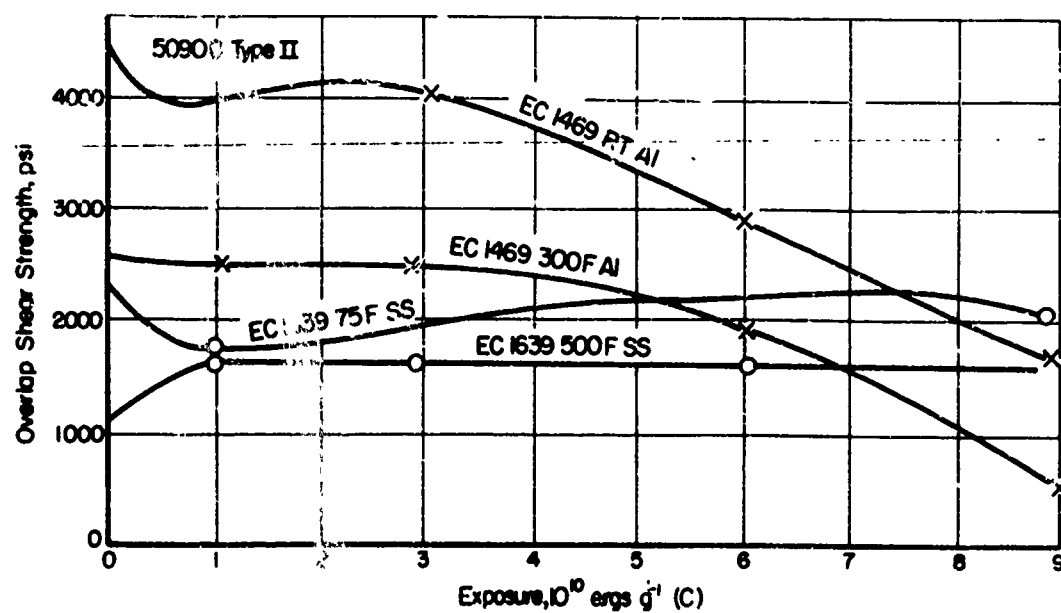


FIGURE 5. EFFECT OF RADIATION ON BOND PERFORMANCE AT VARIOUS TEMPERATURES⁽²⁾

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Figure 6 shows the difference in performance of the same three adhesive systems under bending loads. It was found that the relatively rigid high-density system EC-1469/AF-102 maintained its performance over the whole range of irradiation. The two composite films, AF-200/1593 and AF-202/1593, deteriorated after an exposure of $3 \pm 4 \times 10^{10}$ ergs g^{-1} (C), but not quite so fast in the beam structure requirement as they did in the peel test. Failure again was in adhesion to the core.

In an applications test, Litton Systems found that Epon VI did not prove satisfactory for use as an adhesive for bonding a metal spring when the bond was subjected to a radiation exposure of 1×10^{11} ergs g^{-1} (C) and a temperature of about 45 C(3). The adhesive appeared to lack dimensional stability, a movement of 1 to 10 mils being sufficient to seriously degrade performance.

Effects of Vacuum and Nuclear Radiation

Podlaseck and Suhorsky(4) and Blackmon, Clauss, and associates(5) reported data on the volatilization of adhesives in a vacuum and in a vacuum-radiation environment. In order to determine the extent of bond weakening of epoxy, epoxy-phenolic, epoxy-polyamide, and silicone adhesives, long-term exposures up to 1100 hours at 93 to 121 C were carried out in vacuum. The samples were exposed to a vacuum of 10^{-6} torr and a temperature of 200 F for 865 hours, followed by an exposure to 250 F and 10^{-6} torr for 312 hours. With the exception of one modified phenolic, supported adhesive film Aerobond 422, the adhesives were stable in these test environments. The samples were then exposed to 3.4×10^9 ergs g^{-1} (C) in air, followed by exposure to vacuum at temperatures of 200 F and 300 F, and finally to a cycling (10 cycles) over a temperature range of -80 F to 200 F. As can be seen in Table 5, there was an increase in leakage rate of several of the adhesives after exposure to radiation. However, additional exposure to vacuum and elevated temperatures decreased these leakage rates. It is believed by Blackmon and associates that the gamma radiation induced crosslinking, depolymerization, and chain scission so that low-molecular-weight fragments (e.g., hydrogen, carbon monoxide, carbon dioxide, and methane) were liberated and produced porosity in the glue line. Subsequent exposure to vacuum and elevated temperature permitted flow in the polymers and sealed up the pores.

Kerlin and Smith(6,7) tested structural adhesives for shear strength under combined temperature, radiation, and vacuum environment. Data were included for the following adhesives:

<u>Adhesive</u>	<u>Type</u>	<u>Adhesive</u>	<u>Type</u>
Shell 929	Epoxy	HT-421	Epoxy phenolic
Shell 934	Epoxy	Epon 422 J	Epoxy phenolic
Epon VIII	Epoxy	Metlbond 4021	Nitrile phenolic
Narmco A	Modified epoxy	Scotchweld AF-6	Nitrile phenolic
FM-1000	Epoxy polyamide	FM-47	Vinyl phenolic
Metlbond 406	Epoxy polyamide	APCO 1252 (formerly	Polyurethane
Metlbond 408	Vinyl epoxy polyamide	Hexcel 1252)	
Metlbond 302	Epoxy phenolic	Narmco C	Polyurethane

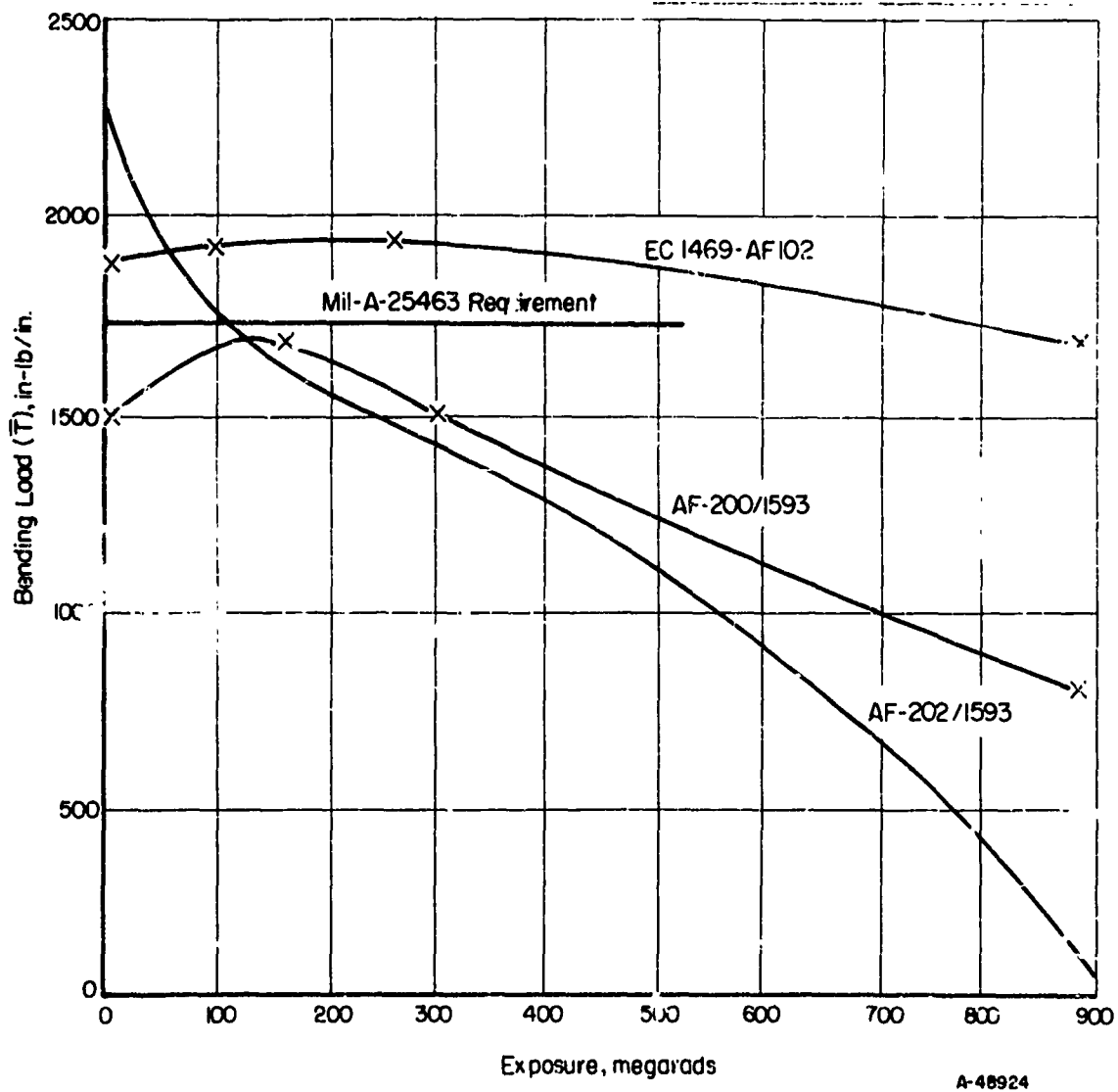


FIGURE 6. EFFECT OF RADIATION ON HONEYCOMB BEAM FLEXURE⁽³⁾

TABLE 5. RESULTS OF EXPOSURE TESTS ON ADHESIVES TO VACUUM, FLUORATED TEMPERATURE, AND HIGH-ENERGY RADIATION (4, 5)

Adhesive	Chemical Type	Form	After Exposure of 865 Hours at 200 F Plus 312 Hours at 250 F and 10^{-6} mm Hg	Leak Rate, cc/sec (Measured With Helium Leak Detector)		
				After Additional Exposure to 3.4×10^7 Roentgens of Gamma Radiation From Co-60 Source in Air	After Additional Exposure of 50 Hours at 250 F and 50 Hours at 300 F at 10^{-6} mm Hg	After Temperature Cycling at -80 to 200 F (10 Cycles)
Aerobond 422	Epoxy phenolic	Supported film	2×10^{-5}	4.7×10^{-6}	5×10^{-7}	2×10^{-6}
HT-424	Epoxy phenolic	Supported film	Large(a) 10^{-6} (b)	Too large to measure	Too large to measure	--
HT-424-F	Epoxy phenolic	Primer only	10^{-6}	2×10^{-5}	4×10^{-7}	1.3×10^{-6}
EC-1648	Epoxy polyamide	2-pt liquid	10^{-6}	9×10^{-6}	4×10^{-7}	3×10^{-7}
EC-1386	Epoxy	1-pt liquid	10^{-6}	4×10^{-6}	2×10^{-7}	1.3×10^{-6}
Epon 901/B-1	Epoxy	2-pt liquid	10^{-6}	1.4×10^{-7}	2×10^{-7}	2×10^{-6}
Epon 8/A	Epoxy	2-pt liquid	10^{-6}	2.3×10^{-7}	5×10^{-7}	7.5×10^{-7}
A-1	Epoxy	2-pt liquid	10^{-6}	2×10^{-5}	2.5×10^{-7}	9×10^{-7}
Q3-0079	Silicone	1-pt liquid	10^{-6}	1.5×10^{-7}	5×10^{-8}	4.5×10^{-6}

(a) Leak in specimen bonded with HT-424 was detected after the first 21 hours of exposure. This may have been due to a poor seal rather than to the adhesive itself.

(b) Values taken from The Stability of Organic Materials in Vacuum. (4)

The adhesives were irradiated in vacuum to various gamma exposure doses and tested in air after the irradiation in vacuum had been completed. According to Kerlin, the data show that vacuum irradiation produced no detectable change in the lap-shear strength of FM-1000, Metlbond 406, and Epon 422 J. Also, only minor changes were found for Shell 934, HT-424, and APCO 1252. Metlbond 408 decreased 78 per cent in lap-shear strength, Epon VIII and Shell 929 decreased by 12 per cent, and FM-47 decreased by approximately 42 per cent. Metlbond 3021 decreased by 25 per cent while Narmco C decreased by 48 per cent in shear strengths. (In air, Narmco C lost practically all shear strength when irradiated.) Narmco A increased by 16 per cent in shear strength when irradiated in vacuum. Data are given in Table 6.

Two adhesives, FM-1000 (epoxy polyamide) and Metlbond 302 (epoxy phenolic), were tested for ultimate shear strength in vacuum immediately after irradiation (this was described as a dynamic test). The average ultimate shear strength of the test specimens showed a significant increasing trend from the control tests, through the static irradiation (air) tests, to the dynamic irradiation tests (Table A-1 in Appendix A). This is attributed to a greater rate of crosslinking of the polymer relative to chain scission by oxygen during irradiation. At the lower partial pressures of oxygen in the higher vacuum, the rate of oxygen-induced chain scission is decreased and the relative rate of radiation-induced crosslinking is increased, leading to increased stiffness and strength of the polymers.

Gray, et al., (8) irradiated lap-shear specimens prepared with epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported epoxy-film adhesives. These were irradiated in air and in vacuum (10^{-6} torr) to a gamma exposure of 10^9 ergs g^{-1} (C) at a temperature of 100 F maximum. The specimens were then tested for shear strength at a temperature of -300 F. In all cases, loss in shear strength was small and the original strength of the adhesive bond specimens could be considered for the design of parts to be subjected to the above conditions.

DeWitt, Podlaseck, and Suhorsky(9) reported on adhesives FM-47, a polyvinyl butyral-phenolic adhesive, and HT-424, an epoxy-phenolic exposed to vacuum and elevated temperature. FM-47, after exposure for 3-1/2 hours at 250 F in a vacuum of 4.2×10^{-4} torr, decreased in peel strength by 13 per cent and in shear strength by 7.1 per cent. HT-424, after exposure to 450 F for 4 hours in a vacuum having an ultimate pressure of 5.9×10^{-4} torr, showed a 14.0 per cent decrease in peel strength and 0.6 per cent in shear strength. There was no change in color of the temperature-vacuum exposed samples. Both of these adhesives were evaluated as supported films, the adhesive being coated on an open-weave glass fabric.

Levine(10) noted that oxidation is an important factor in the degradation of adhesives at high temperatures, and he studied adhesive performance in nitrogen. He found that in this environment, serious degradation did not begin with epoxy-phenolic or phenolic adhesives even after an exposure to 600 F for almost 190 hours. Data are shown in Figure 7.

Kerlin(6) reported work done at the George C. Marshall Space Flight Center on the effect of a temperature of 200 C in air and in vacuum on several adhesives. These included:

TABLE 6. AVERAGE ULTIMATE SHEAR STRENGTHS OF ADHESIVES BEFORE AND AFTER IRRADIATION (6, 7)

Adhesive	Type	Shear Strength Before irradiation, psi	Irradiation dose, ergs g ⁻¹ (C)	Shear Strength After Irradiation in Air, psi	Irradiation in Vacuum, ergs g ⁻¹ (C)	Shear Strength After Irradiation in Vacuum, psi
Shell 929	Epoxy	2264	3.9 x 10 ¹⁰	2510	2.9 x 10 ¹⁰	1973
Shell 934	Epoxy	2562	3.9 x 10 ¹⁰	2840	2.9 x 10 ¹⁰	2320
Epon VIII	Epoxy	2361	--	--	1.7 x 10 ¹⁰	2072
FM-1000	Epoxy polyamide	6065	--	--	1.7 x 10 ¹⁰	6121
		6283	3.9 x 10 ¹⁰	6086	2.9 x 10 ¹⁰	6117
Methylbond 406	Epoxy polyamide	4873	1.1 x 10 ¹⁰	5940	--	--
			4.9 x 10 ¹⁰	752	--	--
HT-424	Epoxy phenolic	3605	3.9 x 10 ¹⁰	2599	2.9 x 10 ¹⁰	3303
Epon 422 J	Epoxy phenolic	2362	--	--	3.9 x 10 ¹⁰	2452
Narmco A	Modified epoxy	415	3.9 x 10 ¹⁰	3634	2.9 x 10 ¹⁰	4959
Methylbond 408	Modified vinyl epoxy nylon	4083	--	--	3.9 x 10 ¹⁰	896
FM-47	Vinyl phenolic	4315	3.9 x 10 ¹⁰	3716	3.9 x 10 ¹⁰	2561
		4180	--	--	3.9 x 10 ¹⁰	2415
Methylbond 4021	Nitrile phenolic	4370	3.9 x 10 ¹⁰	3234	2.9 x 10 ¹⁰	3250
AF-6	Nitrile phenolic	2578	--	--	3.9 x 10 ¹⁰	2410
APCO 1252	Polyurethane	2743	3.9 x 10 ¹⁰	3262(a)	2.9 x 10 ¹⁰	3181
Narmco C	Polyurethane	883	3.9 x 10 ¹⁰	90.8	2.9 x 10 ¹⁰	454

(a) At a radiation exposure of 1×10^{10} ergs g⁻¹ (C) shear strength given as 3416 and 4212 in two different tests. At a radiation dose of 6×10^{10} ergs g⁻¹ (C), shear strength was 5028 psi.

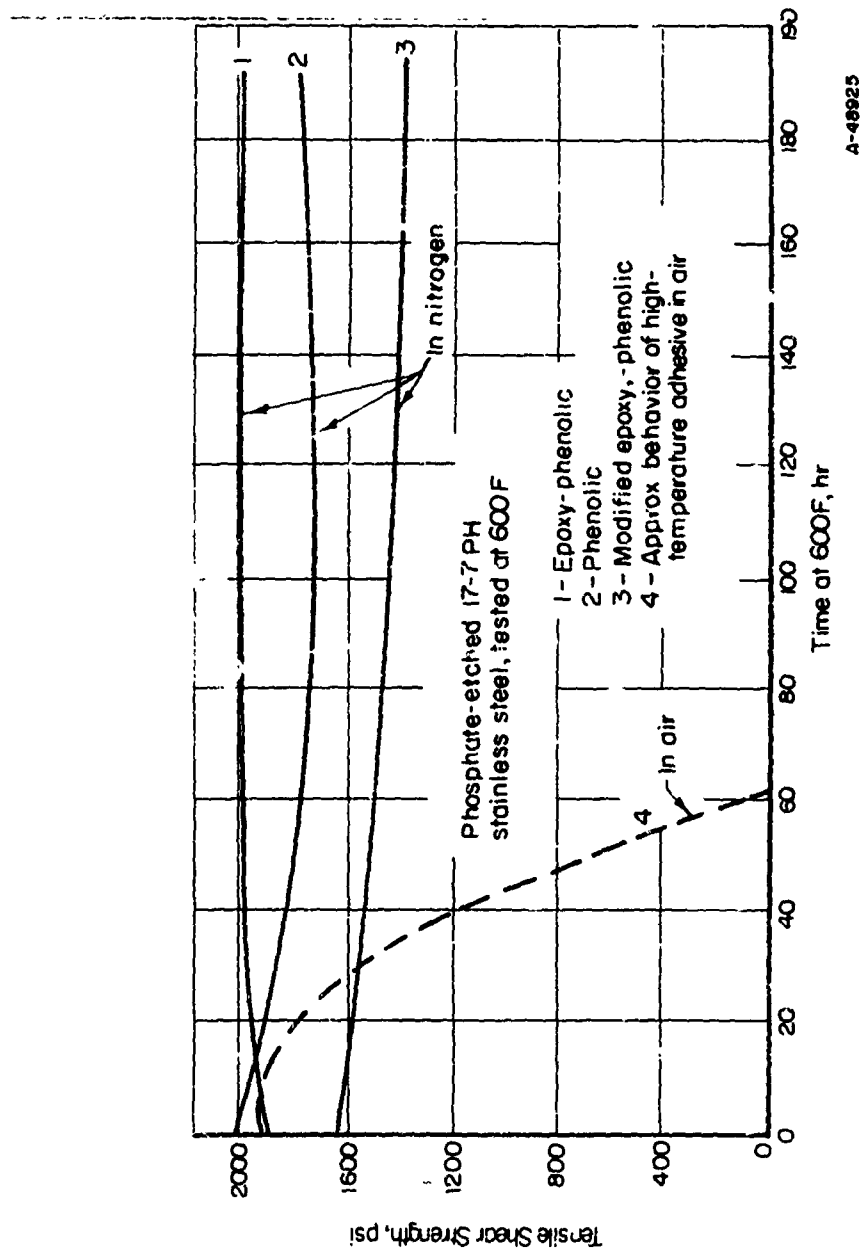


FIGURE 7. EFFECT OF HEAT AGING ON TENSILE SHEAR STRENGTH OF FIVE ADHESIVE BONDS IN NITROGEN VS APPROXIMATE BEHAVIOR IN AIR(10)

<u>Adhesive</u>	<u>Type</u>	<u>Adhesive</u>	<u>Type</u>
Epon VIII	Epoxy	FM-47	Vinyl phenolic
Metlbond 406-1	Epoxy polyamide	Metlbond 302A	Epoxy phenolic
FM-1000	Epoxy polyamide	AF-6	Nitrile phenolic
Epon 422 J	Epoxy phenolic	Metlbond 408	Modified vinyl epoxy nylon

Tensile shear strength of these adhesives either remained the same or increased when samples were exposed to a temperature of 200 C in a vacuum. In most cases, exposure in air to 200 C for the same period of time, 24 hours, caused a decrease in tensile shear strength. The exceptions to this were FM-1000, AF-6, and Metlbond 408. With FM-1000, shear strength increased both in air and in vacuum at the higher temperature, although the increase was greater in vacuum than in air. Data on the AF-6 and Metlbond 408 were incomplete, so no conclusions could be drawn. However, it was evident that these adhesives would withstand elevated temperatures better in a vacuum than in air.

Effects of Nuclear Radiation and Cryogenic Temperatures

Five classes of adhesives were selected for evaluation at cryogenic temperatures on the basis of promising high lap-shear strengths at -65 F and 75 F. (11) These were not subjected to radiation. Lap-shear specimens were tested at -423 F, -320 F, -100 F, and 75 F, utilizing epoxy-nylon adhesives (Metlbond 406, AF-40, and FM-1000), nitrile-phenolic adhesives (Metlbond 4041 and AF-32), epoxy-polyamide adhesives (Resbond No. 4 and Narmco 3135), an epoxy-phenolic adhesive (Metlbond 302-A), and a polyurethane adhesive (APCO 1219). Selection of adherends for testing was based on the anticipated use of these materials in future missiles and spacecraft, the prevalent use of some of these materials in the Atlas and Centaur, and the promising cryogenic properties of the base materials. The adherends utilized were 0.020-inch EFH 301 CRES (stainless steel), 0.064-inch 2024-T3 bare aluminum, 0.020-inch A-110-AT titanium, 0.125-inch Conolon 506 (phenolic-glass fiber laminate) and 0.125-inch Conolon 527 (polyester-glass fiber laminate). Butt-tensile tests were conducted with 3/4-inch-round stock Type 321 stainless steel and AF-40 epoxy-nylon adhesive.

The epoxy-nylon adhesives resulted in the higher lap-shear strengths with all adherends over the entire temperature range of -423 F to 78 F. Values obtained at -423 F are more than 100 per cent higher than any previously reported values for similar tests. The nitrile-phenolic adhesive gave excellent results over the temperature range of -320 F to 78 F but strength values dropped off sharply at -423 F. The epoxy-phenolic adhesives gave uniform results over the complete temperature range. These results were significantly lower than the epoxy-nylon and nitrile-phenolic adhesives at -320 F, 100 F, and 78 F. At -423 F the epoxy-phenolic is superior to the nitrile-phenolics. Room-temperature-cured adhesives are generally inferior to those that are heat cured. Of the three room-temperature-cured adhesives tested, the polyurethane gave higher lap-shear strengths than the epoxy-polyamides with an aluminum adherend and approximately the same strengths with stainless steel adherends. All the adhesives tested had their highest lap-shear strengths at -100 F.

Gray, et al., (8) irradiated in vacuum at ambient temperature specimens prepared with epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported

epoxy-film adhesives and tested them at -300 F for ultimate shear strength. Results are shown in Appendix A, Figure A-1. The test results indicated that the cryogenic temperature-vacuum environment had no effect on lap-shear strength. Gray noted that specimens prepared with epoxy-phenolic, glass-supported epoxy film, and vinyl-phenolic appeared to be only slightly affected by vacuum. The effect was small enough that the original strength of the adhesive-bonded specimens could be considered in the design of parts for the above conditions. Epoxy and nitro-phenolic-adhesive-bonded specimens showed no indication of deterioration.

Yasui(12, 13) irradiated one polyurethane-adhesive-bonded and three epoxy-adhesive-bonded test specimens immersed in liquid nitrogen. They were then tested at liquid-nitrogen temperatures. Yasui found no effects of irradiation on single lap-shear or flatwise ultimate strengths for these materials. Data are shown in Figures A-2 and A-3. Narmco 3135, 3M 1469/1968, and Lefkowitz 109 are epoxy adhesives while APCO 1219 is a film-forming polyurethane polymer.

Coatings

When nuclear reactors are used in spacecraft, gamma radiation may be present in large quantities and may become an important design consideration. However, for exposure to the normal elements of the space environment, nuclear radiation does not appear to be so severe a problem as ultraviolet flux.

Several coatings have shown negligible change in α/ϵ ratios as a result of exposure to 10^6 rads (C) of cobalt-60 gamma radiation.

Zinc sulfide in a silicone resin vehicle has afforded a very good combination of infrared emission and long service life, in spite of the fact that considerable discoloration developed under ultraviolet irradiation. Zinc sulfide in an acrylic coating matrix also has shown good promise.

Organic coatings were originally used solely for corrosion protection and decoration. Today, coatings used for temperature-control materials, have to survive and function reliably on, and within, spacecraft in a totally new environment. When using coatings in thin films, the optical and physical changes resulting from long exposure to high vacuum, intense ultraviolet radiation, and variable temperatures have to be considered.

Coatings having selective properties can be used to control radiant heat transfer by control of three basic optical properties: (1) reflectance, (2) absorptance, and (3) emittance. (14) In most practical systems, a balance between these three conditions will be used to obtain the desired temperatures as illustrated in Table 7.

Present-day coatings for spacecraft are designed to rely upon passive radiation techniques in which the desired average critical temperature is achieved by properly balancing the absorptivity of the surfaces for solar radiation (α) with their emissivity for infrared radiation (ϵ).

Organic coatings are virtually all very absorptive in the infrared and hence have high emittance. Such a surface is the most stable and efficient to use for long heating periods. The short-wavelength absorption can be readily varied by pigmentation with

TABLE 7. VEHICLE TEMPERATURE CONTROL⁽¹⁴⁾

Coating	Solar			Temperature, F	
	Reflection	Absorption	Emissance	Sphere	Striped Sphere
White	0.82	0.18	0.95	-135	-20
White plus carbon black	0.47	0.53	0.95	-30	32
Flat black	0.03	0.97	0.95	45	85
Flat black plus aluminum	0.05	0.95	0.80	65	120

TABLE 8. ORGANIC MATERIAL RADIATIVE PROPERTIES⁽¹⁴⁾

Organic Material	α	ϵ	α/ϵ Ratio
White (30% PV zinc sulfide) silicone	0.31	0.77	0.40
Gray silicone	0.53	0.95	0.55
Leafing aluminum in silicone	0.32	0.33	0.98
White lead carbonate (30% PV) silicone	0.46	0.46	1.0
Dull black (vinyl phenolic)	0.93	0.84	1.1

organic and inorganic materials. The organic coatings will have α/ϵ ratios of 1 or less and can be used to give cool or cold surfaces in space (Table 8). It is obvious that the reflectance and absorptance of the pigmented coating varies with the pigment. A leafing aluminum pigment is the most efficient reflector of ultraviolet energy. Several white pigments are superior to leafing aluminum in the visible and near-infrared spectral regions, but are inferior to it as a reflector of ultraviolet energy. Of the nonleafing pigments, basic white lead carbonate is superior to all others in reflecting ultraviolet energy. The white lead pigmented coatings lose much of their efficiency as ultraviolet reflectors when exposed to the simulated space environment. In other regions of the spectrum, zinc sulfide is an excellent reflector of visible and near infrared energy. Other paint formulations use rutile, carbon black, red iron oxide, and chrome oxide green in various amounts as pigments, depending on the α/ϵ ratio desired.

The ultraviolet spectrum of the sun ranges from about 100 A to 4000 A. Virtually all the energy below 3000 A and most of the energy between 3000 and 4000 A is filtered out by the earth's atmosphere. As a result, coatings may absorb 10 to 100 times as much ultraviolet light above the atmosphere as on the surface of the ground on a clear day. Thus, ultraviolet light is definitely a serious radiation problem.

Intense radiation is the second major element of the space environment and can be divided into two broad classes; electromagnetic and particulate. The electromagnetic component of cosmic radiation has low intensity and is rather inconsequential as far as coatings are concerned. When nuclear reactors are used in spacecraft, gamma radiation of high energy may be present in large quantity and can become an important consideration.

The penetration of ionizing radiation in high doses on organic thin films will also result in physical, chemical, and optical changes. However, for exposure to all elements of the space environment, nuclear radiation is not so severe a problem area when compared to ultraviolet flux.

Effects of Nuclear Radiation

General Dynamics⁽¹⁵⁾ and Lockheed Missiles and Space Company⁽¹⁶⁾ are currently engaged in determining the effects of nuclear radiation on the optical characteristics of thermal coatings. This work is presently in progress and only limited data are available. Preliminary results indicate that negligible change in the α/ϵ was experienced by the materials listed below as a result of exposure to 10^9 ergs g^{-1} (C) of cobalt-60 gamma radiation.

Kemacryl White Lacquer No. M49WC17 (Sherwin-Williams)

Kemacryl Black Lacquer No. M49BC12 (Sherwin-Williams)

Leafing aluminum pigment in Kemacryl acrylic vehicle (Sherwin-Williams)

Nonleafing aluminum pigment in Kemacryl acrylic vehicle (Sherwin-Williams)

Fuller 517-W-1 Gloss White Silicone (W. P. Fuller Co.)

Fuller 517-B-2 Flat Black Silicone (W. P. Fuller Co.)

Fuller 172-A-1 Aluminum Silicone (W. P. Fuller Co.)

Fuller 171-A-152 Aluminum Silicone (W. P. Fuller Co.)

Dull Black Micobond L6X962 (Midland Industrial Finisher Co.)

LMSC White Silicate Paint on Al 1100 aluminum alloy

The irradiations are to continue to 10^{11} ergs g^{-1} (C) gamma radiation and to other types of penetrating radiation.

Effects of Ultraviolet Radiation

Fulk and Herr(17) determined the weight loss in vacuum of a number of polymeric materials used in spacecraft. Compositions of the materials are listed in Table 9 while a typical weight loss-versus-time curve is shown in Figure 8. Fulk points out that the "total weight loss until stationary state" and the "time to reach stationary state" are important characteristics of each material. These values should be taken into account when selecting materials for vacuum and/or spacecraft use. Figure 9 shows typical curves for a number of good points.

Carroll(18) reported on the evaluation of materials used on early Mariner spacecraft. The results of screening tests on paints and nonpaint "whites" are listed in Appendix A, Tables A-2, A-3, and A-4, and Figure A-4. The values of initial weight indicated in Table A-4 and Figure A-4 are nominal values for the materials. The aluminumized F&P 1101 showed the least degradation of the materials tested and is the logical choice for the top of the heat shield. For rigid paintable surfaces, either ZW60 or ZW60 zero side paints (Table A-4) are recommended.

Effects of Ultraviolet Radiation and Vacuum

Wahl, et al.,(19) and co-workers studied the effects of various combinations of ultraviolet radiations (2500 to 7000 Å), moderate temperature (290 F), vacuum pressure ($9.0 \pm 7.0 \times 10^{-6}$ torr), and atmospheric pressure (750 ± 20 torr) on a commercial white polyurethane enamel manufactured by Lowe Brothers Paint Company. This enamel consisted of two parts, No. LH-2392 enamel and No. LH-2393 hardener, which were mixed in equal volumes just prior to use. The coating lost weight and changed color from white to light brown. Total spectral reflectance measurements indicated that the absorptivity increased as the ultraviolet radiation intensity and exposure time increased. It was predicted that the long-time, close temperature control of a space vehicle would not be successful using this polyurethane coating.

Clauss, et al.,(20) and Gaumer, et al.,(21) at Lockheed investigated the effect of ultraviolet radiation and vacuum on temperature-control surfaces. For electronic equipment aboard spacecraft to function properly, their temperatures must be maintained within a range of approximately 0 to 60 C. At the present time, white paints are largely used as solar reflectors, but their α/ϵ ratio is about 0.27 and is not low enough for many practical applications, such as attaining low temperature for infrared sensors to operate efficiently. Solar reflectors with an α/ϵ ratio not greater than 0.1 are needed. Table A-5 shows the α/ϵ ratios of a group of representative materials

TABLE 9. SAMPLE COMPOSITION(17)

Material	Manufacturer	Composition
EPO Enamel	Kohler-McLister Paint Co.	Epoxy Paint No. 705-W-132A
606 Line	Kohler-McLister Paint Co.	Alkyd Paint (industrial type)
606 White Line	Kohler-McLister Paint Co.	Alkyd Paint No. 606-W-135
BBRC "Satellite White" Paint (63 W)	Ball Brothers Research Corporation	Satellite Paint having an ϵ of .85 and α/ϵ of .27-.30
BBRC "One" Paint (80 U)	Ball Brothers Research Corporation	Satellite Paint having a α/ϵ ratio of 1 $\left(\frac{.42}{.42}\right)$

Fuller 172-A-1 Aluminum Silicone (W. P. Fuller Co.)

Fuller 171-A-152 Aluminum Silicone (W. P. Fuller Co.)

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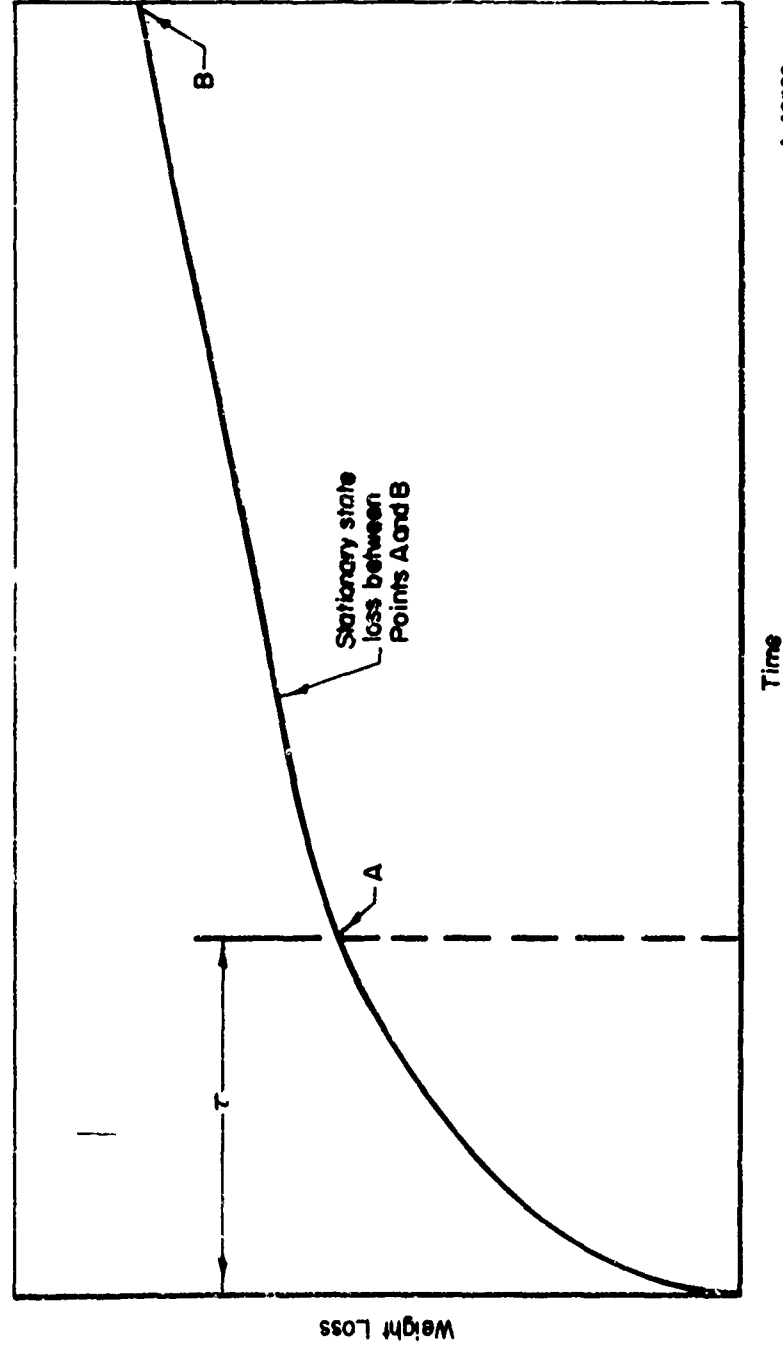
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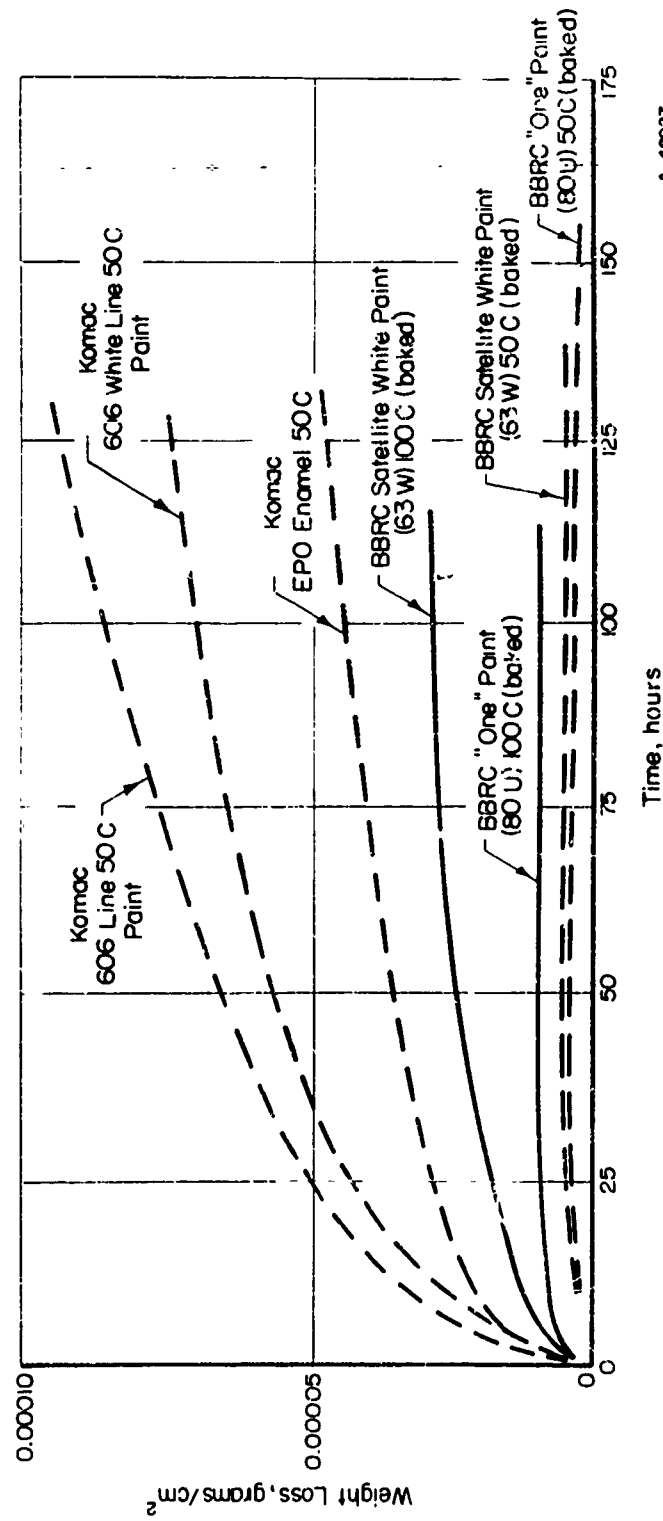
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606 Line	Kohler-McLister Paint Co.	Alkyd Paint (industrial type)
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BBRC "Satellite White" Paint (63 W)	Ball Brothers Research Corporation	Satellite Paint having an ϵ of .85 and α/ϵ of .27-.30
BBRC "One" Paint (80 U)	Ball Brothers Research Corporation	Satellite Paint having α/ϵ ratio of 1 ($\frac{.42}{.42}$)



A-46826

Time

FIGURE 8. CHARACTERISTIC WEIGHT LOSS VERSUS TIME - A TYPICAL, WEIGHT LOSS VERSUS TIME CURVE FOR A POLYMERIC MATERIAL IN VACUUM(17)



A-48927

FIGURE 9. PAINTS - WEIGHT LOSS IN VACUUM (PRESSURE $< 5 \times 10^{-6}$ mm Hg) CURVES FOR A NUMBER OF PAINTS AT 50 AND 100 C(11)

evaluated. The types of surfaces exposed as well as the results of exposure tests are summarized in Table A-6. The designation of the commercial coatings are listed in Table A-7, the compositions of the laboratory-prepared paints are listed in Table A-8. The acrylic-base paints were more resistant to visible yellowing than either the epoxy or silicone-base paints. For many of the organic-base paints, there was an increase of approximately 50 per cent in solar absorptivity (α), while the infrared emissivity (ϵ) remained constant. This 50 per cent increase in the α/ϵ ratio of a surface at room temperature would result in an increase of 57 F in temperature.

Alexander, et al., (22) studied the effect of very-short-wavelength radiation (1150 to 2000 Å) on polymeric films. The percentage weight losses of various coating materials are shown in Figure 10.

Miller and co-workers (23) at Armour Research Foundation tested the stability of white coatings in simulated space environment (approximately 10^{-6} torr vacuum, temperature varying from 150 to 275 F). The results indicated that all synthetic oxide pigments, except zinc oxide, darken appreciably in 100 equivalent solar hours; natural mineral pigments proved more stable. Among the organic binders, a silicone-type material appeared the most promising. Typical results are shown in Table A-9.

The weight loss through volatilization of pigmented coatings after exposure to a simulated space atmosphere for 100 hours (ultraviolet radiation in vacuum of 1×10^{-5} torr) was determined by Cowling. (24) The results are shown in Table A-10.

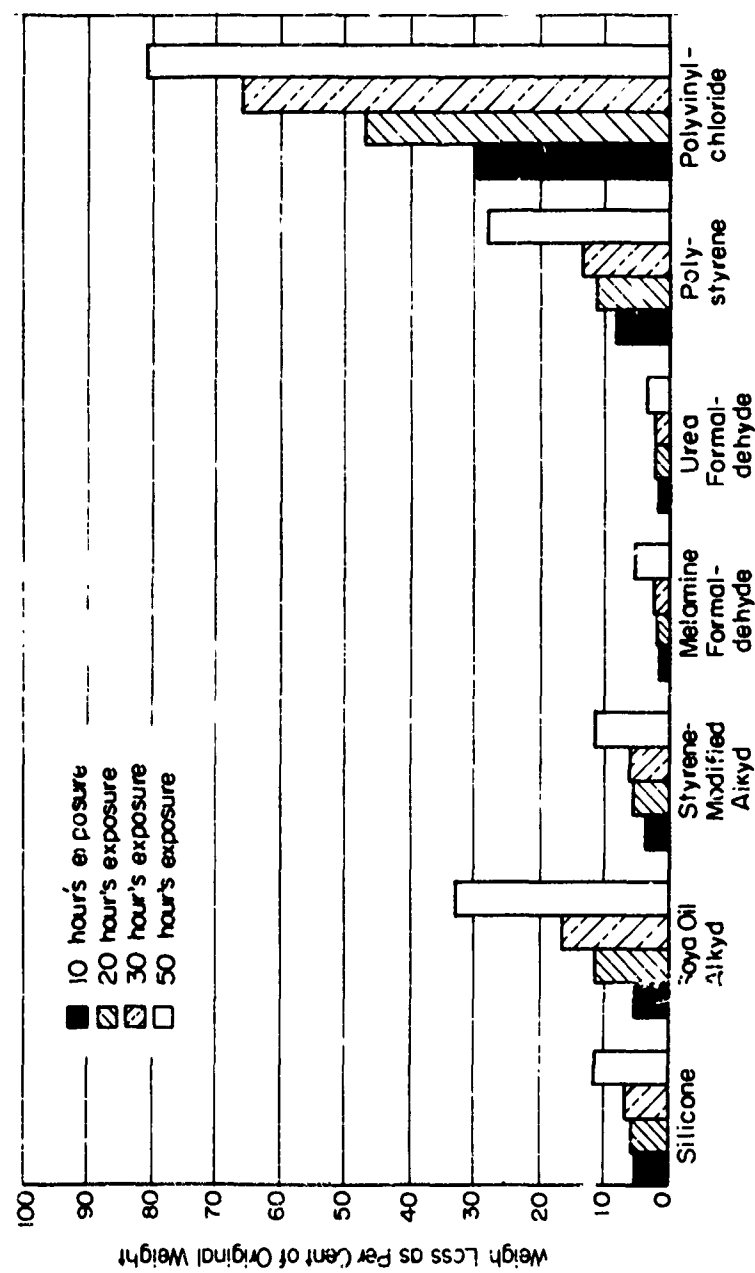
Effects of Ultraviolet Absorbers

Hormann (25) exposed tailored coatings, some of which contained ultraviolet absorbers such as:

- (1) 2, 2'-4,4' tetrahydroxybenzophenone (D50)
- (2) Dibenzoylresorcinol (DBR)
- (3) 2-hydroxybenzoylferrocene (HB₁)
- (4) 2-hydroxy-4-methoxy-2'-trifluoromethyl benzophenone (DR1)

to ultraviolet and vacuum. He found that a flat white titanium dioxide-pigmented silicone-alkyd coating showed good vacuum-thermal and ultraviolet-radiation stability. A wide range of α/ϵ values (0.20-0.85) based on this coating was available for various temperature-control conditions. Dispersion of an ultraviolet absorber in a clear film over the basic coating exhibited a protective action in reducing the weight loss through 500 F and in reducing $\Delta\alpha$ at 300, 400, and 500 F.

The black-leaving-aluminum system would provide high α/ϵ values (0.90 to 1.40) due to decreased emittance values with increased leaving-aluminum content. Hormann also indicated that above 400 F, polyurethane systems are inadequate in a vacuum-thermal environment.



A-48328

FIGURE 10. EFFECTS OF NEAR ULTRAVIOLET IRRADIATION ON POLYMER FILMS UNDER NORMAL ATMOSPHERIC CONDITIONS(22)

Field, Cowling, and Noonan(26) found zinc sulfide (Cryptone 800 produced by the New Jersey Zinc Company) in a silicone vehicle afforded a very good combination of infrared emission and long service life, in spite of the fact that considerable discoloration developed under ultraviolet irradiation. Zinc sulfide in an acrylic coating matrix (Acryloid A-10, Rohm & Haas) also showed good promise. In at least one instance, the acrylic formulation proved superior to all the silicone formulations.

Electrical Insulation

Insulation materials such as glass-diallyl phthalate, Formvar wire coating, Silicone DC 997 varnish, polystyrene coil dope, and polyolefin wire insulation have been satisfactory in room-temperature tests to an exposure of 10^{11} ergs g^{-1} (C).

A number of phenolic circuit boards tested have shown no deterioration at 10^{10} ergs g^{-1} (C).

In general, the effects on electrical properties of irradiation of electrical insulation in air and in vacuum are similar.

Polyimide film (Du Pont H-Film) shows excellent temperature and radiation stability in air and in vacuum to at least 10^{10} ergs g^{-1} (C).

In general, permanent changes in electrical properties of polymeric materials with irradiation are minor and the life of the insulation depends upon its resistance to mechanical damage. However, transient effects due to exposure in a radiation flux may cause difficulty. The discussion in this section is limited to the physical properties of some of the more recent insulating materials which have been investigated. A more comprehensive discussion of electrical effects will be found in REIC Report No. 36, "The Effect of Nuclear Radiation on Electronic Components Including Semiconductor Devices", which is being published concurrently with this report.

Data have been obtained on Tedlar (polyvinyl fluoride), Kynar (polyvinylidene fluoride), and H-film (polyimide), some of the newer films which have appeared on the market. Also, limited data on effects of vacuum and radiation, and extreme temperatures and radiation have been collected.

Effects of Nuclear Radiation

Kaufman and Gardner(27) determined the performance characteristics of resistors, capacitors, and insulating materials used for printed-circuit boards or electrical connectors in a nuclear environment. At an exposure of 1×10^{11} ergs g^{-1} (C) [1.67×10^{16} n/cm² ($E_n > 2.9$ Mev)], glass-diallyl phthalate was the most suitable material tested as an insulating material for connectors. Melamine, silicone rubber, and phenolic were rated second best because of some degradation in their mechanical properties.

Several laminates were tested for use as circuit-board insulation. Silicone-resin-impregnated Fiberglas was satisfactory as an insulation at an exposure of approximately

10^{11} erg g^{-1} (C), but the copper circuit could not be adequately bonded to this material. Only slight discoloration of the circuit board occurred owing to irradiation. A phenolic circuit board, 181 Volan A glass fiber impregnated with CTL-91D was exposed to 10^{10} ergs g^{-1} (C) [2.5×10^{15} n/cm² ($E_n > 2.9$ Mev)]. No evidence could be found of any discoloration, warping, or blistering, and the copper circuit remained firmly bonded to the board.

Koehler and Pefnay⁽²⁸⁾ reported polyethylene, Zytel Nylon 33, and polyvinyl chloride as satisfactory insulation materials to an exposure of 10^{10} ergs g^{-1} (C) in air when dry. Litton Systems, Inc.,⁽³⁾ in work to secure data on the performance of subsystem components and hardware, exposed an LPR-10 drum to the neutron and gamma flux of General Dynamics Ground Test Reactor (GTR). Exposure was to an integrated neutron and gamma exposure of 1.3×10^{16} nvt and 1×10^{11} ergs g^{-1} (C) at a temperature of 30 C to 60 C. The specimens were at 45 C during the greater portion of the time. Polymeric materials which were found satisfactory included silicone glass insulation, Formvar magnet-wire coating, Silicone DC 997 varnish, Raychem polyolefin lead-wire insulation, polystyrene coil dope, and mineral filled diallyl phthalate (for the terminal block).

Effects of Elevated Temperature and Radiation

Campbell⁽²⁹⁾ studied the effect of combined heat and radiation on several magnet-wire-insulation materials, including polyvinyl formal, polyester, silicone, and fluorocarbon enamel and varnishes. He found that the normal service life of some materials was increased by as much as 800 per cent in a combined radiation and thermal environment. He attributes this to a balancing of the chain-scission and crosslinking mechanisms. Tables 10 and 11 show a comparison of the service life of several insulation coatings in a thermal environment and that in a radiation-thermal environment. Radiation exposures varied from 1.8×10^6 ergs g^{-1} (C) hr^{-1} (2×10^4 roentgens hr^{-1}) to 1.6×10^8 ergs g^{-1} (C) hr^{-1} (1.77×10^6 roentgens hr^{-1}).

The normal service life at 160 C of polyvinyl formal was extended by 870 per cent when the material was in a combined thermal-radiation environment as compared with the life in a thermal environment. Several other materials exhibited longer service life in the combined environment. Improvement ranged from 162 per cent for the combination of silicone enamel and silicone varnish at 240 C to 780 per cent for that of a polyester enamel and oil-modified phenolic varnish at 200 C. On the other hand, polytetrafluoroethylene enamel retained less than 1 per cent of its normal service life at 270 C when in a radiation field.

Effects of Vacuum and Radiation

General Dynamics^(6,7) irradiated in air and in vacuum electrical insulation materials designated as DC-7-170 (silicone), Geon 2046 and Geon 8800 (polyvinyl chloride), Estane 5740X1 (polyurethane), Kynar (polyvinylidene fluoride), Kel-F-81 (polytrifluoroethylene), Duroid (a Fiberglas-reinforced Teflon), and Mylar (polyester). Physical properties were determined before and after irradiation and the data are shown in Table A-11.

TABLE 10. EFFECTS OF GAMMA RADIATION ON THERMAL LIFE OF MAGNET-WIRE INSULATION (29)

Insulation Material		Exposure Environment										
		(A)				(B)				(C)		
		Thermal Aging; No Irradiation				Thermal Aging Following Irradiation [Aging Temperature as in (A)]				Combined Environment [Aging Temperature as in (A); Exposure Rate as in (B)]		
Enamel	Varnish	Aging Temperature, C	Average Life, hr	Exposure Rate, mr/hr	Total Exposure, mr	Average Life, hr	Per Cent of Thermal Life	Total Exposure, mr	Average Life, hr	Per Cent of Thermal Life		
Polyvinyl formal	None	180	230	0.5	210	244	87	281	562	100		
Polyvinyl formal	None	130	634	0.5				2750	5507	870		
Polyester	Oil-modified phenolic	200	3,163	0.02	125	2640	84	25	126.4	10		
Silicone	Silicone	240	253	0.5	12.5	315	89	286		16.2		
Modified polyester	Oil-modified phenolic	200	655	0.2	125	722	110	1020	1122	84		
Polytetra- fluoroethylene	Silicone	270	10,000	0.02	25	0	0	1.2	60	0.6		
Polytetra- fluoroethylene	None	270	10,000	0.02				1.0	53	0.9		
Modified silicone	None	240	500	0.5				154	307	61		

TABLE 11. RESULTS OF COMBINED ENVIRONMENT EXPOSURES IN PROGRESS(29)

Insulation Material		Exposure Temperature,	Normal Thermal Aging Life,	Exposure Rate,	Exposure Time at End of Limited Test Period,	Per Cent of Normal Thermal Life at End of Limited Test Period(a)
Enamel	Varnish	C	hr	mr/hr	hr	
Polyethyl-formal	None	200	190	0.5	288	200
Polyvinyl-formal	None	180	280	0.04	1862	665
Aromatic polyimide	None	300	940	0.5	2650	282
Polyester	Oil-modified phenolic	200	500	0.5	2793	112
Polytetra-fluoroethylene	None	13	>10,000	0.02	1882	<100

(a) Results not final; aging process being continued.

Silicone DC-7-170 increased in tensile strength 144 per cent, while elongation decreased 83.5 per cent when subjected to a nuclear-radiation exposure of 9×10^9 ergs g^{-1} (C) in vacuum. Average weight loss was 0.2 per cent. The color changed from a light cream to a dark brown during the vacuum irradiation. Mechanical properties were more severely affected by the vacuum irradiation than by air irradiation.

Kel F became very brittle with vacuum irradiation [exposure of 10^{10} ergs g^{-1} (C)], one specimen breaking during removal from the vacuum chamber. Weight loss was 0.29 per cent. When irradiated in air to 8×10^9 ergs g^{-1} (C), the specimens crumbled. For polyvinyl chloride (Geon 2046 and Geon 8800), changes were somewhat greater in a vacuum-radiation environment than in an air-radiation environment. At approximately 10^{10} ergs g^{-1} (C), changes in tensile strength were 20 to 30 per cent in vacuum and 5 to 15 per cent in air. Also, elongation decreased by 55 to 75 per cent in air and 80 to 85 per cent in vacuum. Kynar (polyvinylidene fluoride) increased in tensile strength by about 20 per cent when irradiated in air to an exposure of approximately 10^9 ergs g^{-1} (C). In vacuum, the increase was negligible. Change in elongation was greater in vacuum than in air, although there was little change in this property.

Polyurethane and Duroid are less affected by irradiation exposure of 10^9 ergs g^{-1} (C) in vacuum than in air. Mylar increased in tensile strength, but decreased in elongation when irradiated in vacuum. No significant weight loss was noted. This material appears satisfactory for applications in a vacuum-gamma radiation environment to 10^{10} ergs g^{-1} (C). However, it is susceptible to ultraviolet radiation damage.

Kerlin and Smith(6,7) also investigated the physical properties of several dielectric materials when irradiated in air and in a vacuum (10^{-6} to 10^{-7} torr). These included Marlex 6002 (high-density polyethylene), Teflon TFE, Tedlar (polyvinyl fluoride), and H-film (polyimide). Data are given in Table A-12. The polyimide film showed the

highest tensile strength and the greatest stability to radiation both in air and in a vacuum. After 3×10^{10} ergs g^{-1} (C) exposure, tensile strength dropped only from 19,470 psi to 17,903 psi when irradiated in air and to 18,877 psi when irradiated in vacuum. Elongation decreased from 128 per cent to 83 per cent when irradiated in air and to 105 per cent when irradiated in vacuum. Tedlar also showed good stability to radiation both in air and in vacuum when irradiated to an exposure of 10^9 ergs g^{-1} (C).

Effects of Cryogenic Temperatures and Radiation

Mylar C was irradiated at liquid-nitrogen and liquid-hydrogen temperatures.⁽³⁰⁾ At cryogenic temperatures, there was an increase in tensile strength and a decrease in elongation. At the liquid-nitrogen temperature, gamma irradiation decreased the tensile strength, but not below the original value at room temperature.

The polyimide film, HT-1, was also irradiated at liquid-hydrogen and liquid-nitrogen temperatures.⁽³⁰⁾ Tensile strength of the polyimide film increased and elongation decreased at this temperature, but the effect of radiation up to 10^{10} ergs g^{-1} (C) was very slight.

Laminates

Combined effects of radiation and vacuum [10^{10} ergs g^{-1} (C) and 10^{-7} torr] have shown no deleterious effects on the strength of various tested laminates except those prepared with Paraplex P-43 and Silicone DC-2104 resins. These decreased in tensile strength when subjected to exposures higher than 10^{10} ergs g^{-1} (C).

Dynalam (glass fiber-phosphonitrilic chloride polymer) shows promise for use at 450 F and an exposure of 6×10^{10} ergs g^{-1} (C).

Epoxy, polyester, phenolic, melamine, and silicone laminates have been investigated as to their behavior in a radiation environment. These do not appear to be adversely affected by nuclear-radiation exposure of 10^{10} ergs g^{-1} (C) and ultraviolet exposures of 2 pyrons for 500 hours (1 pyron = $1 \text{ cal/cm}^2/\text{min}$). The polyesters were found to be the more sensitive to ultraviolet irradiation, but may be improved with the incorporation of ultraviolet stabilizers. Phenolics appear to be least sensitive to ultraviolet exposure. Epoxy laminates show improved strengths when tested in a vacuum environment. Present information would indicate that cryogenic temperatures will not be a serious problem with structural laminates.

Effects of Nuclear Radiation

Laminates called Dynalam consisting of 181 glass cloth (A-1100 finish) impregnated with AP-Resin-XHU (a phosphonitrilic chloride polymer) were irradiated for 55 hours at an ambient temperature (120 to 130 F) and at 450 F.⁽¹⁾ Some of these laminates contained an unspecified curing agent and some contained no curing agent. All of them showed excellent radiation stability. The tensile strength of samples irradiated in air at 130 F to an exposure of 1.7×10^{11} ergs g^{-1} (C) and tested at room

temperature did not change more than 5 per cent. The tensile strength of samples irradiated at 450 F to an exposure of 6×10^{10} ergs g⁻¹ (C) and tested at room temperature did not change appreciably. This was true for both laminates containing a curing agent and for those with no curing agent. Data are given in Appendix A, Table A-13.

Effects of Vacuum and Nuclear Radiation

DeWitt, Podlaseck, and Suhorsky⁽⁹⁾ exposed samples in a vacuum of 10^{-4} to 10^{-5} torr to a temperature of 250 F to 400 F for a 7-hour period. Materials investigated and test results are shown in Table A-14 in Appendix A. Only the phenolic 91 LD-Fiberglas laminate was significantly affected by the vacuum exposure. The compression strength of this material increased by 36.5 per cent. Wahl⁽¹⁹⁾ conditioned specimens of polyester (P-43), epoxy (Epon 815), and phenolic (91 LD) laminates for 2 hours in an air-circulating oven. After being cooled in a desiccator and weighed, the samples were placed in a vacuum oven for 1000 hours. After 6 hours, pressure was 7.2×10^{-6} torr; after 100 hours, it was down to 6×10^{-7} torr, and at the end of 1000 hours the pressure was down to 3×10^{-7} torr. Temperature ranged from 78 to 80 F. After 1000 hours, the samples were reweighed. In all cases loss of weight was less than 0.1 per cent. Data are given in Table 12.

TABLE 12. WEIGHT LOSS OF LAMINATES EXPOSED TO HIGH VACUUM FOR 1000 HOURS⁽¹⁹⁾

Material	Polyester		Phenolic		Epoxy	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
Original weight, grams	13.4794	13.6450	15.1660	14.6489	14.1908	14.0576
Weight after exposure, grams	13.4771	13.6408	15.1526	14.6352	14.1908	14.0570
Loss in Weight						
Grams	0.0023	0.0042	0.0134	0.0117	0.0	0.0
Per Cent	0.02	0.03	0.09	0.08	0.0	0.0

Boundy⁽³¹⁾ reports the per cent weight loss at a pressure of 10^{-6} torr and exposure temperatures of 75, 150, and 300 F after periods of 1, 4, and 7 days. Data are given in Table 13.

TABLE 13. WEIGHT LOSS FOR LAMINATES UNDER VACUUM-THERMAL CONDITIONS⁽³¹⁾

(Pressure, 10^6 mm Hg)

Materials	Weight Loss, per cent								
	Temperature, 75 F			Temperature, 150 F			Temperature, 300 F		
	Time, days			Time, days			Time, days		
	1	5	8	1	4	7	1	4	7
Epoxy glass fiber	0.03	0.06	0.06	0.09	0.30	0.33	0.31	0.56	0.62
Phenolic glass fiber	0.11	0.24	0.29	0.24	0.48	0.55	0.91	1.25	1.32
Phenolic cotton	0.41	0.95	1.14	0.93	1.32	1.36	1.84	1.83	1.89

The epoxy has a lower weight loss than the phenolics. It is believed that part of the weight loss of phenolics is due to the release of water formed during polymerization and which has remained in the laminate.

Podlaseck and Suhorsky(4,32) show that the effect of vacuum on weight loss of polymers is to decrease the equilibrium weight-loss rate at elevated temperatures. They state that since the weight-loss rate is proportional to the degradation rate, the implication is that the normal rate of degradation observed in air can be considered to consist of two modes: (1) an oxidative degradation which is dependent on the partial pressure of oxygen or water vapor available to the specimen, and (2) a pure thermal degradation which is independent of the surrounding environment. A vacuum does not appear to alter the equilibrium weight-loss behavior of the unmodified crosslinked-resin system used, but seems only to provide an inert environment at temperatures where oxygen increases degradation. Nitrogen and helium can afford the same protection as a good vacuum.

Because the rate of weight-loss increase, with increasing temperature, is less in vacuum than in air, the upper temperature limit for the use of many plastics may actually be increased for extended space exposures in radiation-protected areas.

Gray, et al.,(8) determined the tensile strength of several laminates after exposure to radiation and/or vacuum. Table A-15 lists the materials tested, and Figure A-5 shows the effect of vacuum, radiation, and combined environment on these materials. It may be seen from Figure A-5 that, except for the epoxy glass-fiber material (Scotchply 1000-76, Minnesota Mining and Manufacturing), there was little effect of these environments on the laminates. With the Scotchply materials, the combined radiation [10^9 ergs g^{-1} (C)] and vacuum (10^{-6} torr) environment increased tensile strength; whereas either factor alone slightly decreased this property.

Kerlin and Smith(7,33) tested nine glass-fabric laminates and one honeycomb laminate for effects of radiation-vacuum environment. These included Mobiloy AH-81, CTL-91-LD, and Conolon 506 (phenolic), Paraplex P-43 and Selectron 5003 (polyester), DC-2104 and DC-2106 (silicone), Epon 828 (epoxy), and HRP Honeycomb (phenolic). Tests indicated that the combined effects of radiation and vacuum [approximately 10^{10} ergs g^{-1} (C) and 10^{-7} torr] have no deleterious effect on the strength of the laminates except for P-43 and DC-2104. Paraplex P-43 lost tensile strength rapidly after 10^{10} ergs g^{-1} (C). At an exposure of 3.1×10^{10} ergs g^{-1} (C) in vacuum, tensile strength decreased by approximately 20 per cent as compared with a loss of 6 per cent when irradiated in air to 3.9×10^{10} ergs g^{-1} (C). Similarly, the tensile strength of Silicone DC-2104 decreased after an exposure of 10^{10} ergs g^{-1} (C) in vacuum. At 2.9×10^{10} ergs g^{-1} (C), tensile strength decreased by 15 per cent. In air, no loss was observed at an exposure of 3.9×10^{10} ergs g^{-1} (C). See Tables A-16 through A-19.

Effects of Nuclear Radiation and Cryogenic Temperature

Yasui(13) irradiated two phenolic-impregnated glass-cloth laminates (Sinwave and Hexcel) in liquid hydrogen to an exposure of 3.2×10^8 to 2.1×10^9 ergs g^{-1} (C). Tensile strength and tear strength were determined while samples were immersed in liquid nitrogen. Exposure to 2×10^9 ergs g^{-1} (C) in liquid nitrogen produced no significant effect on the tensile and tear strengths of either material. Data are given in Figures A-6 and A-7.

Two laminates prepared by Lockheed-Georgia Company for possible hydrogen barriers also were evaluated. Laminate I consisted of two plies of Epon 820-resin-impregnated 116 Fiberglas cloth laminated to 1 ply of aluminized polyester film with the aluminum forming one exterior surface. Radiation results indicate that the strength properties of the material were not significantly affected by exposure to 2.6×10^9 ergs g^{-1} (C). The same radiation exposure produced no statistically significant effects on Laminate II which consisted of one ply of 181 Fiberglas cloth impregnated with ERL 2795/2870 epoxy resin and coated with six thin layers of Elastathane M-50.

Gray, et al., (8) irradiated phenolic, polyester, epoxy, and silicone laminates in air and in vacuum (10^{-6} torr for 2 weeks) to an exposure of 10^9 ergs g^{-1} (C). These were then tested at a temperature of -300 F. Data are shown in Figures A-8 to A-11 (also compare with Figure A-5). According to Gray, the environmental conditioning improved the strength of epoxy with unidirectional glass fibers and phenolic with glass fabric. However, phenolic with high-silica fabric exhibited a slight degradation in ultimate strength. No trend of improvement or degradation due to environmental exposure was found for the remaining materials.

Kerlin and Smith (7) irradiated Conolon 506 (phenolic) and Paraplex P-43 (polyester) at liquid-nitrogen and liquid-hydrogen temperatures to a gamma exposure of 6×10^{10} ergs g^{-1} (C). No significant change in ultimate tensile strength occurred at the liquid-nitrogen temperature. Although tensile strength increased somewhat at the liquid-hydrogen temperature, this was believed to be due to chemical reactions between the ionized hydrogen and components of the adhesive rather than to the lower temperature.

Effects of Vacuum and Ultraviolet Radiation

Wahl, et al., (34, 35, 19) exposed three types of laminates to ultraviolet radiation in vacuum. These included glass-reinforced polyester P-43, epoxy Epon 815, and phenolic CTL-91 LD. The ultraviolet source was either an Osram HBO-109 high-pressure quartz-mercury lamp or Osram HBO-100 W/2 mercury lamp which produce ultraviolet and visible radiation from below 2500 to about 7000 Å.

No significant degradation of the laminates occurred when exposed to radiation of 2 pyrons ($2 \text{ cal/cm}^2/\text{min}$) for periods up to 500 hours. To determine the relative effect of exposure to vacuum and varying intensities of ultraviolet radiation for greater lengths of time, further tests were conducted at 2, 3, 4, 5, and 6 pyrons.

Examination of the specimens after exposure to vacuum and ultraviolet radiation, of 2 and 3 pyrons intensity, for periods of 125 hours showed that the transparent polyester and epoxy laminates became opalescent and the surface facing the radiation became brown. This was not observed with the phenolic laminates since they were relatively dark brown and opaque before exposure. With greater exposure to ultraviolet, the polyester and epoxy laminates became more charred and blistered. The phenolics did not char even with 4, 5, and 6 pyrons of ultraviolet. Compressive and flexural strength data are given in Tables A-20 and A-21.

In summary, Wahl found that pressure showed little or no influence on flexural modulus except with polyester at moderate temperature in the presence of ultraviolet radiation. In all cases, higher temperatures decreased flexural strength. The extent of the influence is greatest with epoxy and least with phenolic. It is greatest in the presence of vacuum without radiation, and least in the presence of radiation at 1 atmosphere of pressure. The presence of radiation generally decreased strength. The effect was most pronounced with polyester at room temperature with 1 atmosphere of pressure. Wahl states that heat or ultraviolet alone, or combined, have the greatest influence on strength properties of the three types of laminates and it is important to separate these environmental elements when determining their effect on plastic materials.

Initial work would indicate that incorporation of an ultraviolet absorber in the polyester resin would be effective in reducing degradation due to vacuum ultraviolet. Tables A-22 through A-24 show the ultraviolet absorbers tried, weight loss, and flexural strengths of laminates after exposure.

Potting Compounds

Potting compounds are available that maintain good dielectric-constant, dissipation-factor, and volume-resistivity measurements before, during, and after irradiation to an exposure of about 10^{11} ergs g^{-1} (C).

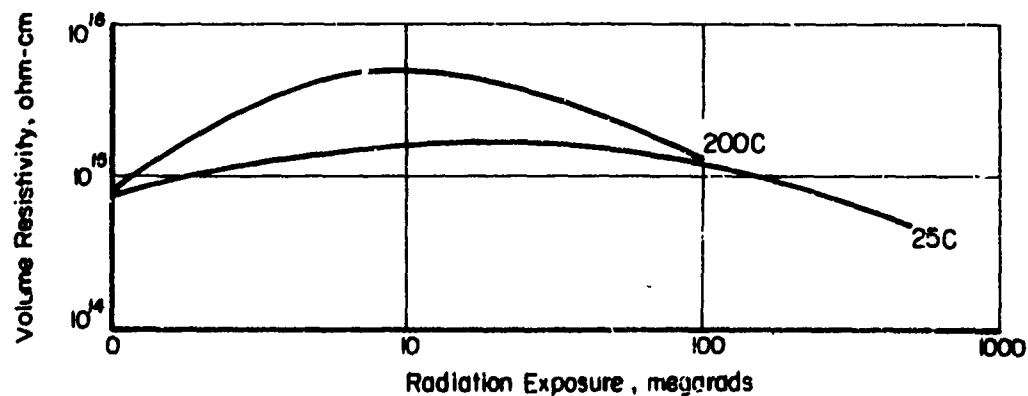
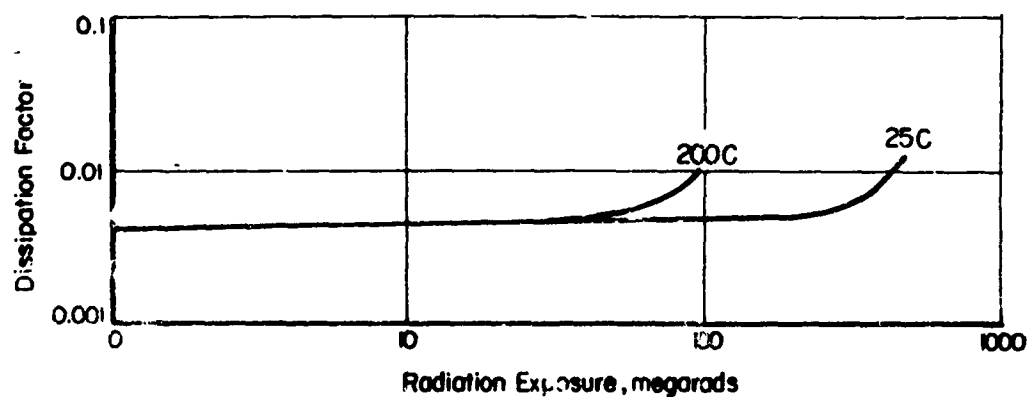
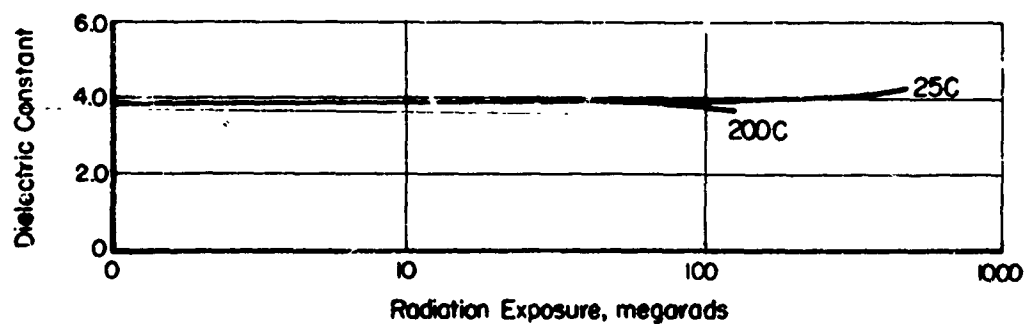
For potting compounds to be used in a vacuum-radiation environment, a higher temperature cure is preferred to a room temperature cure. Solvent systems are generally not satisfactory because they tend to be gaseous as a result of entrapped solvent; this leads to porosity.

Potting compounds have been found satisfactory for use in vacuum at 170 F to a gamma exposure of 10^{10} ergs g^{-1} (C).

Effects of Gamma Radiation

According to Dexter and Curtindale⁽³⁶⁾ Dow Corning R-7521 (silicone resin) combined with inorganic fillers such as silica sand or zirconium orthosilicate showed no apparent degradation of physical properties after irradiation exposures of 5×10^{10} ergs g^{-1} (C) (500 megarads) at 23 C or after 10^{10} ergs g^{-1} (C) and 2650 hours at 200 C. Because of its outstanding thermal endurance and radiation resistance, this system is considered an ideal potting material for such equipment as canned motor pumps and reactor-control-rod drives. Figure 11 shows the effects of combined heat and radiation on the electrical properties of R-7521 silicone resin.

Several potting compounds were investigated by Armstrong.⁽³⁷⁾ These included:



A-48929

FIGURE 11. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICA SAND IMPREGNATED WITH DOW CORNING SOLVENTLESS SILICONE RESIN R-7521⁽³⁶⁾

Scotchcast No. 3
 Stycast 2651 MM
 RTV-501
 Epon 828/D
 Insulating Lacquer 1162 A/B
 12-007
 Stayfoam AA402
 EG 758 T
 Scotchcast Foam Resin No. 603

Minnesota Mining and Manufacturing Co.
 Emerson and Cuming
 Dow Corning
 Shell Chemical Co.
 Dennis Chemical Co.
 Hysol Corp.
 American Latex
 Mica Corp.
 Minnesota Mining and Manufacturing Co.

Insulation resistance measurements were taken before, during, and after irradiation. Resistances of the samples were found to be dependent on the exposure [exposure rates varied from approximately 10^4 ergs g^{-1} (C) hr^{-1} to 10^8 ergs g^{-1} (C) hr^{-1}]. The greatest change occurred in the Mica reference sample; the potting materials served to decrease the rate effects in the other samples. RTV-501 showed an appreciable change in insulation resistances at the higher exposure rates, as did Dennis Insulating Lacquer 1162 and American Latex Stayfoam AA-402.

Bendix Corporation measured dielectric constant, dissipation factor, and volume resistivity before, during, and after irradiation of seven types of epoxy resins. (38) Exposure was about 10^{11} ergs g^{-1} (C) or 1.1×10^{16} nvft. Of the seven tested, five were considered as stable potting and insulating materials at the exposure of the test. These included:

Maraset 622-E
 K 447-M
 Lish 420 A
 Scotchcast 5
 Scotchcast 212

Effects of Radiation and Vacuum

Cure is an important factor with potting compounds subjected to the radiation and vacuum conditions of a space environment. A higher-temperature cure is preferred to a room-temperature cure. Solvent systems are generally not satisfactory as they tend to dissolve the insulation of imbedded wire and retain residual solvent which leads to porosity.

Blackmon, et al., (5) determined the effect of vacuum (10^{-7} torr) and radiation on a number of potting compounds at a temperature of 170 F. Some of the materials were exposed to 10^{10} ergs g^{-1} (C) gamma radiation in air. Table 14 summarizes the overall performance of the materials. No large changes in hardness or dielectric constant resulted. The greatest variations were in weight loss and, consequently, dimensional stability. Two of the materials, Epocast 202/9615 and Hysol 12-007 A/B were satisfactory on exposure to vacuum and gamma radiation. According to Clauss⁽³⁹⁾, the Hysol showed excellent stability, but cure shrinkage was greater than 2 per cent and shrinkage during exposure to vacuum at 170 F was 4.5 per cent. Three materials that were found satisfactory after exposure to vacuum at 170 F were not subjected to radiation exposure. These included a polyurethane, PRC 1535 A/B (Products Research Company), a silicone elastomer, DC 502/501 (Dow Corning Corp.), and an epoxy-polyamide, Epibond 1210/9615 (Furane Plastics Co.).

TABLE 14. ENCAPSULATING MATERIALS(39)

Material Designation	Type	Manufacturer
Satisfactory After Both Types of Exposure		
EPOCAST 202/9615	Epoxy-polyamide	Furane Plastics Co.
HYSOL 12-007 A/B	Epoxy (flexible)	Hysol, Inc.
Satisfactory After Vacuum-Temperature Exposure (no radiation exposure)		
PRC 1535 A/B	Polyurethane	Products Research Co.
DC 502/501	Silicone (elastomer)	Dow-Corning Corp.
EPICOND 1210/9615	Epoxy-polyamide	Furane Plastics Co.
Unsatisfactory		
DENNIS 1152	Epoxy (solvent system)	Dennis Chemical Co.
PRC 1201-Q	Polysulfide	Products Research Co.
ECCOSEAL HI-Q	Polystyrene (solvent system)	Emerson and Cuming, Inc.
EPON 828/D	Epoxy	Shell Chemical Co.
HYSOL 3X	Epoxy (filled)	Hysol, Inc.

Vacuum-Temperature Exposure: 48 hours at room temperature followed by 96 hours at 170 F in a vacuum of 10-5 torr

Radiation Exposure: 10⁸ roentgens total gamma dose in air at room temperature at a dose rate of 10⁶ r/hr

Kerlin and Smith^(6,7) studied the effect of radiation and vacuum on several silicone and epoxy potting compounds. These included:

Epon 828/Z	Epoxy
Silicone DC-R7521	Silicone
Scotchcast 212	Epoxy
RTV-501	Silicone
RTV-60	Silicone elastomer
EC-2273	Fluorinated elastomer

The ultimate compressive strength of Epon 828/Z increased approximately 6 per cent when subjected to a radiation exposure of 10^{10} ergs g^{-1} (C) at a pressure of 2×10^{-6} torr. This change is not considered to be significant. There was no change in the weight of the material and its color changed from amber to dark brown. Silicone DC-R7521 did not change significantly in weight or compressive strength at a radiation exposure of 9×10^9 ergs g^{-1} (C) and a pressure of 2×10^{-6} torr, but changed from a straw color to dark brown. Data are given in Table A-25 in Appendix A.

RTV-60, a silicone elastomer, was exposed to radiation under static and dynamic conditions. The compressive strength was found to increase for a deflection of 0.02 inch after an exposure of 8.6×10^9 ergs g^{-1} (C) in vacuum. Samples exposed under dynamic conditions required a 76 per cent increase in load to compress them 0.02 inch. Statically exposed samples tested several weeks later required a 386 per cent increase in load. A load of 1549 psi was required to compress the static irradiated sample 25 per cent as compared to a value of 203 psi for the control, a change of 660 per cent. Data are given in Table A-26 and Table 15.

The irradiation in air of Scotchcast 212 (epoxy) and EC-2273 (a fluorinated elastomer) had little effect on their properties. Irradiation in vacuum caused compressive strength of the Scotchcast to increase by almost 50 per cent. A small increase was noted for EC 2273. With RTV-501 silicone, radiation both in air and in vacuum increased compressive strength. However, in vacuum, the increase was more noticeable. Data are given in Table A-27.

Seals, O-Rings, and Gaskets

Elastomers which have shown promise for use as seals, O-rings or gaskets for use in a radiation environment include natural rubber, SBR, nitrile rubber, some polyurethanes, neoprene, Viton A and B, and silicone elastomers.

For temperatures above 300 F, Viton A, Kel-F, nitrile rubber, and silicone elastomers may be considered.

Elastomers which have shown promise when irradiated to 10^{10} ergs g^{-1} (C) at room temperature include natural, SBR, nitrile, neoprene (if not immersed in water), and some polyurethane rubbers.

At elevated temperatures, the most radiation-resistant elastomers appeared to be satisfactory to 10^9 ergs g^{-1} (C).

The addition of antirads improved somewhat the stability of nitrile, neoprene, SBR, and natural rubbers. The antirads increased service life by about one order of magnitude.

TABLE 15. EFFECT OF NUCLEAR RADIATION IN VACUUM ON POTTING COMPOUNDS (25)

Category	Trade Name	Gamma Dose [ergs./gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Potting Compounds	Epon 828/Z	1.0×10^{10}	2×10^{-6}	Compression disks	Ultimate compressive strength Weight change	+ 0.3
	DC R-7521	9.0×10^9	2×10^{-6}	Compression disks	Ultimate compressive strength Weight change	
	RTV-60	8.6×10^9	3×10^{-7}	Compression disks	Compressive strength at 25% Compressive strength at 0.02 inch Weight change	+

Nitrile rubber is not seriously affected by radiation either in air or in vacuum to an exposure of 10^9 ergs g^{-1} (C). At 10^{10} ergs g^{-1} (C), the effect of irradiation is about the same in air as in vacuum. Irradiation of neoprene to 10^9 ergs g^{-1} (C) has about the same effect in vacuum as in air. Radiation effects on Viton-B appeared to be similar whether irradiated in air or in vacuum.

Effects of Nuclear Radiation

Morris and Caggegi⁽⁴⁰⁾ investigated 24 rubber vulcanizates and 93 antirads in an effort to develop rubber gaskets which would be resistant to nuclear radiation. The vulcanizates were exposed to a gamma exposure of 10^{10} ergs g^{-1} (C) at a temperature of 75 F. Elastomers examined included natural, styrene-butadiene, acrylonitrile, acrylic, neoprene, vinylpyridine, polyurethane, silicone, fluorinated silicone, and Viton-A. Using compression set as the criterion for behavior as a gasket material, the elastomers which were the most satisfactory were natural rubber, styrene-butadiene containing 23.5 per cent styrene polymerized at 41 F (Synpol 1500), and nitrile rubber (Hycar 1072). It was found that the resistance to gamma irradiation of styrene-butadiene rubber was improved if it was cured with dicumyl peroxide instead of sulfur.

Genthane S, a polyurethane, was rated as one of the best vulcanizates, but Adiprene C, also a polyurethane, was questionable. Some of the specimens of the latter including the control, hot-compression set, and irradiated samples, shattered while compressed. Apparently, the strength of this vulcanizate was marginal. Silicone vulcanizates had a high compression set before irradiation and showed large decreases in Moiré indentation* after irradiation. Irradiation caused the Philprene VF-25, Viton A-H, and Stastic LS-53 specimens to corrode the aluminum plates holding them in compression.

Table 16 shows the compression set and the decrease of Moiré indentation of several vulcanizates after irradiation. The figures given are the differences between the irradiated values and the original values.

The radiation resistance of the vulcanized rubbers with respect to compression set can be improved by compounding with certain antioxidants, antiozonants, or with certain chemicals containing aromatic rings or condensed ring structures. These are discussed in the section on antirads.

In studies to determine the extent to which antirads can protect O-rings, Born and Associates⁽⁴¹⁾ investigated the effect of the more promising antirads in nitrile, nitrile/styrene-butadiene (90/10), neoprene, and Viton-A premium-quality compounds used currently in commercial O-ring seal production. They found that on the basis of absolute postirradiation property values as well as per cent retention of initial values, the nitrile rubber compound (NBR) plus 5 phr of Stabilite-FLX was the most promising all-around candidate rubber compound of this group for O-ring seals for radiation service. This formulation is compounded by Precision Rubber Products Corporation.

*Moiré indentation is the depth of penetration of a 0.125-inch hemispherical indenter into the sample with a 1000-gram weight resting on the indenter. Readings are taken after 1 minute and are expressed in hundredths of a millimeter. This test utilizes the Moiré Indentometer Model 650-2, but otherwise it is the same test as ASTM D231-56, "Indentation of Rubber by Means of the Pusey and Jones Plastometer".

TABLE 16. CHANGE IN COMPRESSION SET AND MAST INDENTATION OF ELASTOMERS DUE TO GAMMA RADIATION(40)

Rubber	Compression Set due to Radiation, %	Decrease of Mast(a) Indentation due to Radiation
Adiprene C	55	12
Silastic S2048	59	174
Silicone W96	71	185
Synpol 1500	74	41
Philprene VP-25	77	62
Natural	78	42
Genthane S	79	26
Hycar 1071	79	55
Hycar 1041	80	49
Hycar 1042	80	39
Hycar 2001	81	51
Hycar 1001	82	43
Synpol 1000	82	46
Naugapol 1504	83	45
Synpol 8000	83	42
Naugapol 1023	84	57
Hycar 1002	84	43
Hycar 1043	84	48
Neoprene WRT	85	59
Hycar 1014	88	61
Hycar 4021	89	63
Silastic LS-53	98	97
Viton A-HV	100	44

(a) Mast indentation is the depth of penetration of a 0.125-inch hemispherical indenter into the sample with a 1000-gram weight resting on the indenter. Readings are taken after 1 minute and are expressed in hundredths of a millimeter. This test utilizes the Mast Indentometer Model 650-2, but otherwise it is the same test as ASTM D531-56, "Indentation of Rubber by Means of the Pusey and Jones Plastometer".

General Dynamics⁽¹⁾ irradiated four O-ring formulations manufactured by Precision Rubber Products Corporation (PRP). Three of the formulations were developed in a cooperative program by B. F. Goodrich Co. and PRP to develop radiation-resistant O-ring compounds. The fourth was a standard PRP Viton-B formulation. Data were given for a neoprene rubber containing 5 parts Antiox 4010 and for Viton B. These materials when irradiated at 375 F in air and in fluid maintained considerable tensile strength and elongation. Data are given in Table 17.

Lewis⁽¹⁵⁾ at General Dynamics irradiated an SBR rubber and a nitrile rubber composition developed by Goodrich and Precision Rubber Products Companies. Both contained an antirad to improve radiation resistance. These compositions appeared to be serviceable to a radiation exposure of 10^{10} ergs g^{-1} (C). (See Tables 18 and 19.)

TABLE 17. ULTIMATE PROPERTIES OF PRECISION RUBBER PRODUCTS CORPORATION O-RING COMPOUNDS 2277 SPECIAL AND 19007(1)

Compound	Exposure		Irradiation Time and Temperature, hr/°F	Medium	Tensile Strength(a), psi		Ultimate Elongations(a), %	
	Gamma, ergs g ⁻¹ (C)	Neutron, n cm ⁻² (E>2.9 Mev)			No. 222 O-Rings	Tensile Specimens	No. 222 O-Rings	Tensile Specimens
2277 Special (neoprene containing 5 phr Axiolox 4010)	Controls	Controls	5/75	Air	2638/140/5	2795/233/2	372/23/5	523/-/1
	1.2 x 10 ⁹	2.3 x 10 ¹⁴	5/75	Air	2339/158/5	264,146/3	287/14/5	362/11/3
	Controls	Controls	5/375	Air	1499/234/3	1379/102/3	180/21/3	144/8/2
	9.1 x 10 ⁸	1.1 x 10 ¹⁴	5/375	Air	788/80/5	1075/15/3	65/5/5	69/3/3
	Controls	Controls	5/75	Oxalite 8515	2584/82/3	2672/174/3	338/11/3	430/54/3
	1.2 x 10 ⁹	2.3 x 10 ¹⁴	5/75	Oxalite 8515	1771/216/5	2389/110/3	227/23/5	323/14/3
19007 (Viton-B)	Controls	Controls	5/375	Oxalite 8515	1631/87/3	1880/146/3	213/8/3	284/8/3
	9.1 x 10 ⁸	1.1 x 10 ¹⁴	5/375	Oxalite 8515	1247/454/5	2145/203/3	142/28/5	212/17/3
	Controls	Controls	5/75	Air	1984/89/3	2021/135/3	254/23/3	305/1.2/3
	1.2 x 10 ⁹	2.3 x 10 ¹⁴	5/75	Air	2041/181/3	2149/312/3	141/5/3	143/12/3
	Controls	Controls	5/375	Air	2024/57/3	2061/159/3	254/8/3	282/20/3
	1.1 x 10 ⁹	2.9 x 10 ¹⁴	5/375	Air	1131/72/3	1285/55/3	146/5/3	191/7/3
4P3E (fluid-mixed isomers of phenoxyphe- nyl ether)	Controls	Controls	5/75	4P3E fluid(b)	1973/44/3	1951/116/3	256/4/3	293/35/3
	1.2 x 10 ⁹	2.9 x 10 ¹⁴	5/75	4P3E fluid	1937/180/5	2319/154/3	136/7/5	171/9/3
	Controls	Controls	5/375	4P3E fluid	1863/141/3	2005/181/3	269/10/3	307/34/3
	1.1 x 10 ⁹	2.9 x 10 ¹⁴	5/375	4P3E fluid	1818/19/4	1844/176/3	164/8/4	187/14/3

(1) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of n individual observations estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) 4P3E - fluid-mixed isomers of phenoxyphe-nyl ether.

TABLE 18. SUMMARY OF EFFECT OF IRRADIATION AT AMBIENT TEMPERATURE ON PPC-O-RING COMPOUND 1387(15)

Gamma Exposure, $\text{ergs g}^{-1} (\text{C})$	Specific Gravity at 25 C		Specific Gravim. at 25 C		Compression Set (%),	Hardness, Shore A		Tensile Strength (d), psi	Ultimate Elongation, %
	Before	After (a)	Before	After (b)		Before	After		
0					5.63	70.2	70.4	2704.8	342.3
4.9×10^8	1.250	1.252	1.251	1.243	16.96	70.2	71.4	2512.3	300.7
1.8×10^9	1.249	1.253	1.251	1.249	36.91	70.4	71.0	2621.4	290.7
3.6×10^9	1.249	1.254	1.251	1.245	55.19	70.2	73.2	2809.1	266.7
1.2×10^{10}	1.250	1.258	1.252	1.255	82.96	69.6	82.6	3206.8	164.0
3.5×10^{10}	1.250	1.267	1.253	1.257	94.44	70.6	92.4	4128.3	64.0
1.6×10^{11}	1.244	1.293	1.254	1.280	--	--	--	6018.7	(c)

(a) After irradiation in air.

(b) After irradiation in ASTM No. 3 oil. Total oil soak time, 171 hours.

(c) Total time in compression for all specimens, 310 hours.

(d) Tensile values are average for 15 samples; all others are average for 5 samples.

(e) Broke immediately; elongation could not be measured.

TABLE 19. SUMMARY OF EFFECT OF IRRADIATION AT AMBIENT TEMPERATURE ON PRPC
O-RING COMPOUND 4387(15)

Gamma Exposure, ergs g ⁻¹ (C)	Specific Gravity at 25 C		Compression Set(a), %	Hardness, Shore A		Tensile Strength(b), psi	Ultimate Elongation, %
	Before	After		Before	After		
0			9.04			1890.6	449.3
4.9 x 10 ⁸	1.164	1.172	14.42	64.6	64.4	2014.1	453.3
1.8 x 10 ⁹	1.166	1.173	27.88	65.0	65.0	2003.2	427.3
3.6 x 10 ⁹	1.165	1.157	43.26	65.0	67.4	1811.2	339.4
1.2 x 10 ¹⁰	1.162	1.160	74.95	65.0	75.6	1779.7	209.3
3.6 x 10 ¹⁰	1.163	1.184	89.77	64.8	86.4	1749.2	65.5
1.6 x 10 ¹¹	1.160	1.211	--	--	--	3601.8	18.3

(a) Total time in compression for all specimens, 310 hours.

(b) Tensile values are average for 15 samples; all others are average for 5 samples.

Koehler and Pefhany⁽²⁸⁾ tested a gaging system for reactor pressure tubes designed to measure diameter, surface defects, wall thickness, and straightness in a defuelled, drained channel during periods of reactor shutdown. The ultrasonic crystal used to trace the wall contour required a water coupling to the tube wall and, therefore, some of the O-rings were wet or immersed in water during the testing of the gaging system. As a result, some of the O-ring materials were tested wet and some dry, depending on the location. The neoprene O-rings were found to be satisfactory to a radiation exposure of approximately 10^{10} ergs g^{-1} (C) both wet and dry. Although the O-rings had hardened, they were considered satisfactory for this application. Silicone rubber O-rings (Armet Green and Grey, and Linear White) and a white Teflon O-ring were considered satisfactory when dry, but they hardened considerably when wet.

Effects of Vacuum and Nuclear Radiation

Gamma-radiation effects were determined by subjecting components containing the seals to nuclear radiation. Solenoid valves, check valves, relief valves, actuators, ball valves, and regulators were subjected to 2 weeks in a vacuum with the temperature cycled daily from -175 to $+50$ C. They were then subjected to radiation exposure in air and finally to a repetition of the vacuum exposure. Although the effects of environment on the seals in these components were not given directly and are not strictly comparable, it would appear that neoprene, Viton-A, Kel-F, and some Teflon seals were satisfactory. Butyl rubber, nitrile rubber, and other Teflon seals were adversely affected and thus were not satisfactory.

Elastomer sealing materials within a solenoid changed in hardness or size, thereby increasing the mechanical forces required to actuate the valve. This is illustrative of the type problems encountered. Leakage rates of components with elastomer seals and seats generally increased as a result of the combined environmental exposure testing.

Kerlin and Smith^(6,7) evaluated Viton-B, nitrile rubber, neoprene, and natural rubber as O-rings. These materials were subjected to nuclear-radiation exposure and to vacuum. Data are given in Tables A-28 through A-31, Appendix A. Table A-28 shows the data for O-rings which were irradiated in vacuum or in air and tested in air. These were described as being static tests. Tables A-29 and A-30 contain data for materials irradiated in vacuum and tested in vacuum. These were described as being dynamic tests.

Examination of Table A-28 will show that nitrile rubber (Parker Compound 66-581) is not seriously affected by radiation either in air or vacuum to an exposure of 10^9 ergs g^{-1} (C). At 10^{10} ergs g^{-1} (C), the effect of irradiation is about the same whether or not air is present. When tensile strength was determined in a vacuum (dynamic tests, Table A-29), it appeared somewhat lower than when tested in air (static tests). Weight loss was approximately 1 per cent (Table A-31).

Tensile strength and elongation of natural rubber O-rings changed considerably when irradiated in vacuum to 9×10^9 ergs g^{-1} (C). However, up to 5×10^9 ergs g^{-1} (C), there was little difference between irradiation in air and in vacuum. No significant change in weight occurred.

Irradiation to an exposure of 10^9 ergs g^{-1} (C) had practically no effect on neoprene either in air or in vacuum. Dynamic tests (tests in vacuum) showed little difference from the tests in air (see Tables A-28 and A-29).

Radiation effects on Viton-B appeared to be similar whether irradiated in air or in vacuum. Elongation decreased considerably after 10^9 ergs g^{-1} (C) (compare Tables A-28 and A-30).

A nitrile rubber containing an antirad (PRP 737-70) showed better tensile strength when irradiated in air than in vacuum. After 10^9 ergs g^{-1} (C), elongation decreased considerably in air. No comparable data for vacuum were given.

All of these materials except Viton-B showed good stability to radiation both in air and in vacuum to about 10^9 ergs g^{-1} (C), but above that exposure, changes in physical properties were large. Viton-B showed considerable change at 10^9 ergs g^{-1} (C). At the highest exposures, natural and nitrile rubber appeared to be damaged more by exposure to gamma radiation in vacuum than exposure in air. Neoprene and Viton-B were not tested to sufficiently high radiation levels in vacuum to determine the effect of vacuum on gamma-radiation damage.

Wahl and Robinson⁽³⁵⁾ exposed several elastomeric seals to a gamma exposure of 5×10^6 ergs g^{-1} (C) in a vacuum (2×10^{-6} torr at beginning of exposure and 9×10^{-6} torr at end of exposure) and measured weight and Durometer hardness changes. Samples remained in vacuum condition for 1 week following the radiation exposure before they were tested. No gross physical property changes of the seals were observed. Data are given in Table A-32.

Gray⁽⁸⁾ determined the effect of radiation and vacuum exposure on the compressive and tensile strength of Fluorobestos, a mixture of Teflon and random asbestos fibers. The results of these tests, shown in Table A-33, indicate that the material would still remain useful as a gasket material after radiation exposure of 10^9 ergs g^{-1} (C) in vacuum.

Gray, et al.,⁽⁸⁾ investigated the performance of seals and gaskets to determine both design and material limitations, particularly those for unlubricated vacuum service. The studies consisted of performance tests and the determination of leak rates in static and dynamic operations. Tests included both rotational and reciprocating motion. Leakage rates were measured by means of a helium leak detector connected to the interior of the seal test container. The vacuum level was maintained below 10^{-6} torr except in case of seals for which leakage rates were too high to maintain the vacuum.

All seals were dusted with molybdenum disulfide before installation. Elastomers examined for use as seals in reciprocating engines included neoprene, silicone, Viton-A, nitrile (Buna N), and Butyl rubbers. Also tested were Kel-F, polyethylene, and polyvinyl chloride. Materials tested for rotating seals were silicone rubber, Viton-A, Kel-F elastomer, Teflon, and Kel-F. Leakage rates and pertinent comments on wear and abrasion effects are shown in Table A-34 in Appendix A.

Polyethylene and silicone rubber were the most effective seals for reciprocating service. Leak rates were very low, 5×10^{-5} standard cubic centimeters of helium gas, after test durations of 30 minutes. It was found that a dry lubricant such as molybdenum

disulfide improved performance. Silicone rubber and Viton-A proved to be good materials for rotational motion. Again, small amounts of dry lubricants were beneficial. Seal positioning and loading were found to be critical, and have to be carefully designed.

Teflon was particularly ineffective because of its relatively rigid, inflexible properties. The material wore rapidly since it was not as porous as the elastomers and would not accept a surface coating of lubricant such as molybdenum disulfide to reduce friction and wear. Gray points out that self-lubricating properties of a material apparently do not increase its life when operated as a dynamic vacuum seal.

Abrasion and tearing were major problems. Many of the seals were turned and split after a few minutes' operation. Viton-A was an example of this mode of failure.

Static seal tests were conducted on the same elastomers used for the dynamic tests. Seals were loaded to obtain the deflections and contact pressures recommended by the manufacturers. Leak rates were measured before and after operation. Data are given in Table A-34. Some seals such as silicone rubber exhibited a reduced leak rate for static sealing after being subjected to dynamic operation.

Polyethylene and polyvinyl chloride (Vinylite) in an O-ring configuration were very effective in static applications. These materials as well as the remainder of the elastomers tested were not appreciably affected by a 2-week vacuum exposure at 1×10^{-7} torr.

In another study of sealants for space environment, Farkass and Barry⁽¹²⁾ screened seven elastomer materials for use as O-ring-type door seals. These were studied from the standpoint of outgassing and leakage rates in a high vacuum environment. Again, a radiation environment was not considered in these studies. Butyl rubber, Viton-A, neoprene, and Buna-N were roughly comparable in combined gas load (leakage plus outgassing) during the screening tests, with preference in the order named. Natural rubber was eliminated because of excessive physical damage, and Teflon was rejected because of permanent deformation. Silicone O-rings were substantially poorer in combined leakage and outgassing, although the outgassing studies rated the silicones as lowest in actual outgassing with Butyl, Viton-A, and neoprene in descending order of merit. The degree of compression of the O-rings was found to be an important factor and the effect of compression was approximately the same for all the materials tested.

The effect of temperature was explored in the range from 25 C to 100 C. Helium leak rate increased, at first, with increase in temperature for all the elastomers studied. However, different elastomers reacted differently to long exposure at 100 C. The leak rate of the silicones ultimately decreased by a hundredfold, but the deformation made it impossible to re-use the O-ring. Butyl rubber is not deformed by prolonged heating and the leak rate remains at the level initially reached. Neoprene and Viton-A performed in a manner intermediate to these two extremes.

Tables 20, 21, and 22 show the air leak rates of the better elastomers at 25 C and at 100 C, as well as the permeability and effect of loading on the air leakage rates.

TABLE 20. AIR LEAK RATE OF ELASTOMER COMPOUNDS^{(42)(a)}

Compound	Leak Rate - std cc air / inch/year	
	0 C	100 C
Silicone (Compound 76-128)	2.2	3.6
Silicone (Compound 77-018)	2.1	3.6
Neoprene	0.03	0.29
Viton-A	0.022	0.44
Butyl	<0.001	0.37

(a) Elastomer was loaded by four clamps with 40 foot-pounds torque on each clamp in addition to atmospheric pressure.

TABLE 21. COMPARISON OF REAL AIR LEAK RATES OF ELASTOMERS AS MEASURED EXPERIMENTALLY AND AS CALCULATED FROM PERMEABILITY VALUE⁽⁴²⁾

Material	Permeability ^(a) , std cc/(cm ²)(cm)(atm)(sec)	Leak Rate at 100 C, std cc air/inch/year	
		Calculated	Experimental ^(b)
Viton-A	8.8×10^{-8}	0.36	0.44
Neoprene	7.0×10^{-8}	0.29	0.29
Silicone (Compound 6-128)	450×10^{-8}	18.40	3.60
Silicone (Compound 77-018)	Ditto		
Butyl	3.2×10^{-8}	0.13	0.37

(a) Obtained from WADC Technical Report 56-331, References 20-23, cm² refers to thickness of material.

(b) The clamp torque was approximately 40 foot-pounds during these measurements.

TABLE 22. RELATION OF AIR LEAK RATE OF GASKET MATERIAL TO LOADING⁽⁴²⁾

Torque on Clamps, ft-lb	Air Leak Rate, std cc air/inch/year			
	Neoprene	Silicone	Butyl ^(a)	Viton-A
0 (atmospheric pressure)	1.28	10.0	<0.001	1.1
10	0.22	4.0	<0.001	0.2
20	0.09	2.8	<0.001	0.08
30	0.03	2.4	<0.001	0.04
40 (normal operating torque)	0.03	2.2	<0.001	0.022
60	0.03	2.2	<0.001	0.02
80	0.03	2.0	<0.001	0.02
100	0.018	1.6	<0.001	0.01
150	0.002	1.4	<0.001	0.01

(a) It should be pointed out that, in the case of a pressurized container subjected to space environment, the atmospheric pressure would not ordinarily be acting to compress the rubber sealant material. Therefore, the conclusion that an adequate seal can be constructed employing the action of atmospheric pressure on a flanged door using a Butyl O-ring gasket should not be too hastily drawn from these figures.

Thermal Insulation (Foamed Materials)

Polyurethane foamed materials appeared stable when irradiated to 5×10^8 to 1×10^9 ergs g^{-1} (C) in air and in vacuum. At cryogenic temperatures, the approximate threshold point for compressive resistance was an exposure of about 5×10^9 ergs g^{-1} (C). The radiation threshold at cryogenic temperatures for a polystyrene thermal insulation was about 5×10^9 ergs g^{-1} (C).

Two polyurethane foamed materials manufactured by Chemical Plastics Research Company were irradiated in vacuum at General Dynamics and tested for compression strength at 25 per cent deflection in air and in vacuum. (7) After a radiation exposure of 10^9 ergs g^{-1} (C), compression strength of CPR-20 did not change when tested in air (100 psi to 99 psi). When tested in vacuum to a radiation exposure of 5×10^8 ergs g^{-1} (C), compression strength for 25 per cent deflection increased to 124.5 psi. With the second material, CPR-1021-2, compression strength at 25 per cent deflection again did not change significantly when tested in air after being irradiated in vacuum to 5×10^8 ergs g^{-1} (C) gamma exposure. Values were 33 psi and 29.8 psi before and after irradiation, respectively. When tested in vacuum, after the same radiation exposure, compression strength increased to 49.4 psi.

Stayfoam AA 402, also a polyurethane thermal insulation material was irradiated at cryogenic temperatures. (43) There appeared to be an approximate threshold point for compressive resistance of this material at an exposure of about 5×10^9 ergs g^{-1} (C).

Styrofoam 22, a polystyrene thermal insulation, showed a radiation threshold of 2 to 5×10^9 ergs g^{-1} (C) at cryogenic temperatures.

ELASTOMERS

Radiation data relative to elastomeric materials since the publication of REIC Report No. 21 have resulted primarily from radiation studies of end items and components of operational equipment. Efforts to develop new and improved materials have met with only limited success, and, as a result, these studies have been cut back. Data on the effect of extreme temperatures and of vacuum with radiation are included in this report. Many of the data have been presented in the discussion of various components, but information of general significance is included under the several types of elastomers. For information on those elastomers for which no additional pertinent data have been received, the reader is referred to REIC Report No. 21, September 1, 1961.

Elastomers are among the most sensitive to environment of any of the materials considered for equipment to be used in space. (44) Vulcanizates containing plasticizers, oils, and other compounding ingredients are more apt to be affected adversely by space environments than are polymers without these additives. However, for applications such as seals or gaskets, there are few other materials which may be used satisfactorily. As a result, work is continuing in such areas to develop satisfactory seal materials.

Polyacrylic Rubber

Radiation stability of acrylic rubbers is slightly inferior to those of nitrile and neoprene rubbers. An exposure of 10^9 ergs $g^{-1}(C)$ will effect an overall change in physical properties of 25 per cent.

Hycar 4021 exposed to 400 F for 5 days in vacuum retained appreciable strength, although elongation decreased considerably.

No additional radiation-effects data were received since issuance of REIC Report No. 21. However, some information on the effect of vacuum was noted. Hycar 4021 exposed to 400 F for 5 days in vacuum retained appreciable strength, although elongation decreased considerably. (45) Compound formulations and values of the properties tested are given in Tables B-1 and B-2 in Appendix B. These data are included to help in design of parts for space, since, in general, radiation deterioration in air is greater than that in vacuum.

Butyl Rubber

Butyl rubber has probably the least radiation stability of any of the common synthetic rubbers. Twenty-five per cent damage is reached for tensile strength and elongation at about 10^9 ergs $g^{-1}(C)$.

Ultraviolet radiation in vacuum caused an increase in tensile strength of about 10 to 15 per cent. Elongation decreased 10 to 25 per cent.

No additional data on effects of radiation on butyl rubber were received. Data on the effects of vacuum and temperature are given below. DeWitt(9) found Butyl rubbers

K-121 and K-1330 increased in hardness, decreased in elongation, and only slightly changed (7 per cent) in tensile strength when exposed to vacuum (10^{-4} to 10^{-5} torr) and elevated temperature (250 to 300 F).

Snyder⁽⁴⁶⁾ exposed Butyl rubber to ultraviolet in vacuum (1×10^{-5} torr) for 24, 96, and 312 hours. In each case, tensile strength increased from about 10 to 15 per cent. Elongation decreased from 10 to 25 per cent. Data are given in Table B-3.

Chlorobutyl, Chlorobutyl-Chloroprene Blends

An attempt was made to achieve a balanced radiation resistance by maintaining a balanced crosslinking/scission reaction. These chlorobutyl-chloroprene blends were a step in this direction, but did not produce the needed improvement.

Chlorobutyl elastomer has, because of its chlorination, additional crosslinking sites. It was felt that gamma radiation could cause crosslinking at these sites and counteract the chain/scission reactions of regular Butyl compounds. For this study Heitz and coworkers⁽⁴⁷⁾ selected polychloroprene as the blending elastomer because of its widespread use as a seal material. Results are given in Tables B-4 through B-7 in Appendix B.

After an initial stiffening period, the scission reaction became predominant in the chlorobutyl compound (suggesting a threshold exposure of about 10^9 ergs $g^{-1}(C)$ for scission similar to the one for crosslinking in other polymers). The scission effect seemed to be more predominant in air than in vacuum. The specimen surfaces decomposed to a sticky-tacky condition. Combined radiation prevented the formation of this tacky surface, but that this was purely a surface condition was indicated by a study of the other physical properties.

Increasing the polychloroprene content of the blends increased the tendency for crosslinking as indicated particularly by modulus changes and the lack of surface decomposition except in spots on the clamped ends, and the compound (158-62) containing 75 parts chloroprene to 25 parts chlorobutyl exhibited no surface decomposition at all.

The heat encountered, coupled with the ultraviolet radiation, makes the discussion of combined radiation difficult, but it was felt that blending compounds might be a good way to achieve a balanced radiation resistance, by maintaining a balanced crosslinking/scission reaction without adversely affecting the vacuum stability.

Chlorosulfonated Polyethylene (Hypalon)

Hypalon 30 showed good stress-strain properties up to a radiation exposure of 3.1×10^9 ergs $g^{-1}(C)$.

The addition of 3.3 parts hydroquinone improved the radiation resistance of a base compound. Also, aromatic plasticizers such as Kenflex A improve stability.

In general, the effect of gamma radiation in vacuum is more severe than that of radiation in air.

Hypalon 30 as tested by Wattier, Newell, and Morgan⁽⁴⁸⁾ showed good stress-strain properties up to an exposure of 3.1×10^9 ergs $\text{g}^{-1}(\text{C})$, after which all properties tested except ultimate strength underwent considerable change. Data are given in Table 23.

TABLE 23. ENGINEERING PROPERTIES^(a) OF HYPALON 30 ELASTOMER VERSUS RADIATION⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm^{-2} ($E > 0.33 \text{ Mev}$) ^(b) Gamma Exposure (G) ergs $\text{g}^{-1}(\text{C})$ ^(b)	Modulus at 100% Elongation, psi	Ultimate Strength, psi	Ultimate Elongation, %	Compression Set, %	Slope of Load - Deflection Curve, lb/in.
Control	1184/8.7/5	2769/3.4/5	212/8.1/5	32.7/7.3/3	2947/2.4/3
N 2.3×10^{13} G 5.1×10^7	1392/5.4/5	2945/2.8/4	208/4.7/4		
N 1.4×10^{14} G 1.8×10^8				35.2/4.4/3	3293/3.6/3
N 8×10^{14} G 8×10^8				45.2/3.7/4	3600/3.8/4
N 1.2×10^{15} G 3.1×10^9	1610/3.2/4	2688/7.3/4	175/ /4		
N 5.5 to 7.0×10^{15} G 1.1 to 1.4×10^{10}		2864/9.8/5	88/12 /5	83.2/6.3/2	7680/3.7/2

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculation of $\bar{x}$ and S.D.

(b) Ambient radiation temperature; test temperature 80 F.

The effects of filler level, antirad, and curing time on the radiation resistance of chlorosulfonated polyethylenes were examined by Heitz.⁽⁴⁷⁾ Addition of 3.3 parts hydroquinone (13-62) improved radiation resistance of the base compound (130-62). Decreased cure time of this formulation produced a compound (132-62) with a lower radiation resistance rating (i.e., greater property changes) than the control compound. (See Appendix B, Tables B-8 through B-13.) Increasing the carbon black content (132-62) lowered the rating, but a test of this compound after addition of an antirad (138-62) indicated an improvement.

It was noted the antirad compound cured for 120 minutes and the compounds with the higher level of carbon black showed an initial decrease in modulus, indicating a possible threshold exposure for crosslinking to become predominant. This "threshold" effect was masked by further curing of the material. In any event, crosslinking was increased as the exposure time was increased.

In general, the effect of straight gamma radiation in vacuum was more severe than that of radiation in air. The changes produced by the addition of ultraviolet radiation were mixed insofar as physical-property changes were concerned. The specimen showed a marked increase in weight gain during air irradiation as opposed to vacuum irradiation, indicating a strong oxidation reaction. The mixed radiation increased the weight gain in the vacuum condition and decreased the gains in air.

It must be noted that it was impossible to separate the effects of heat aging from the desired effects of the ultraviolet radiation, and the evaluation of the mixed gamma-ultraviolet radiation effects is colored by this fact.

Fluorocarbon Rubbers

Viton-A reaches threshold damage in air at a gamma exposure of 5×10^8 ergs $\text{g}^{-1}(\text{C})$, and 25 per cent damage at 6×10^9 ergs $\text{g}^{-1}(\text{C})$. This rubber possesses poor radiation stability when irradiated in air at temperatures higher than about 250 F. However, it can be used at 400 F when irradiated to an exposure of 10^9 ergs $\text{g}^{-1}(\text{C})$ in jet turbine oil.

In vacuum there was no significant change in tensile strength at an exposure of 10^{10} ergs $\text{g}^{-1}(\text{C})$ at room temperature.

Viton-B irradiated in bis-phenoxy-phenyl ether at 400 F at an exposure of 10^{10} ergs $\text{g}^{-1}(\text{C})$ showed excellent retention of tensile strength but a decrease of 50 per cent in elongation.

Kel-F is damaged by 25 per cent at 6×10^8 ergs $\text{g}^{-1}(\text{C})$ in air. It is stable in silicate ester fluids at room temperature to 10^{10} ergs $\text{g}^{-1}(\text{C})$.

Fluorobutyl acrylate elastomer increases about 40 per cent in tensile strength and 20 per cent in hardness but decreases in elongation by 70 per cent when irradiated in air to an exposure of 10^{10} ergs $\text{g}^{-1}(\text{C})$.

According to Kerlin⁽⁶⁾ there were wide variations in physical properties of control samples of Viton-A. However, it would appear that, at gamma exposures of 1.6×10^{10} ergs $\text{g}^{-1}(\text{C})$ in vacuum, there was no significant change in tensile strength. On the other hand, when Viton-A was irradiated in air, there was an increase in tensile strength of 39 per cent. Vacuum did not appear to make a difference in the change in elongation due to radiation exposure. Weight loss was 1.2 per cent with a vacuum-nuclear radiation exposure of 1.6×10^{10} ergs $\text{g}^{-1}(\text{C})$. DeWitt, et al.,⁽¹¹⁾ found that a vacuum of 5.5×10^{-4} torr and a temperature of 400 F for 6-1/2 hours caused only a slight decrease in tensile strength and elongation of Viton-A and practically no change in hardness. (See Tables B-14 and B-15, Appendix B.)

Podlaseck and Suhorsky⁽⁴⁾ measured the change in permeability of Viton-A after exposures to vacuum and ultraviolet for periods of up to 2 weeks. The results (Figure B-1) showed that there were no significant changes. Equilibrium weight loss at 177 C for Viton-A was given by Podlaseck as 20 grams/sq cm/sec $\times 10^{10}$ for a pressure of 10^{-5} torr.

Ossefort and Ruby⁽⁴⁵⁾ found that a Viton-B vulcanizate showed better properties when subjected to 600 F in vacuum for 5 days than when exposed to the same temperature in air. However, tensile strength had decreased from 2610 psi to 620 psi. At 500 F, tensile strength had decreased only to 2140 psi. Data are given in Table B-16.

Heitz and coworkers⁽⁴⁷⁾ studied the effect of the amount and type of filler with Viton-A. They found that increasing the amount of carbon black increased the amount of change induced in the physical properties by exposure to irradiation. The compound containing GPF (152-62) rated slightly lower than the compound containing MT black (151-62), but the pattern of difference was not consistent between them.

Examination of the data in Tables B-17 through B-20 shows that crosslinking, as evidenced by increases in modulus and hardness and decreases in ultimate elongation, started immediately and continued increasing as the exposure time increased.

Radiation in air produced greater changes than radiation in vacuum for all compounds. At low carbon black levels, the combined gamma-ultraviolet radiation produced greater changes than did straight gamma radiation, but the situation was reversed for the higher-carbon-black-content compounds.

The heat effects present in the combined gamma-ultraviolet radiation conditions again made evaluation of the effects of ultraviolet irradiation difficult. However, the heat resistance of the fluoroelastomers provided some help in separating the heat and ultraviolet effects, by minimizing the effects of heat on the elastomers.

Nitrile Rubber

Further work is needed to confirm reported results on the effect of radiation in vacuum because of conflicting data. For example, nitrile rubber appears to be less radiation stable in vacuum than in air. In air at 10^{10} ergs $g^{-1}(C)$ exposure, tensile strength increased from 2459 psi to 3512 psi. In vacuum, tensile strength at 10^9 ergs $g^{-1}(C)$ decreased from 2630 psi to 203 psi.

On the other hand, some nitrile rubber O-rings were not seriously affected by radiation either in air or in vacuum to an exposure of 10^9 ergs $g^{-1}(C)$. At 10^{10} ergs $g^{-1}(C)$, the effect of radiation was about the same whether or not air was present. When tensile strength was determined in a vacuum after irradiation, it appeared somewhat lower than when tested in air after being irradiated in a vacuum.

Additional work on nitrile rubber has included studies of the effects of vacuum, and nuclear radiation and vacuum, and some additional work on the effects of antirads. The latter is discussed in the section on antirads.

Bonanni⁽⁴⁹⁾ irradiated Buna N rubber to an exposure of 7.9×10^7 ergs $g^{-1}(C)$ in air, in a closed atmosphere, and in vacuum (5×10^{-5} torr). The per cent change in weight was negligible in each case. In an ampule containing approximately 7 cubic centimeters of air sealed under atmospheric conditions, the degradation of Buna N as a result of gamma irradiation was more severe than that in an open atmospheric condition. The average tensile strength was lower at an exposure of 7.2×10^8 ergs $g^{-1}(C)$, and at 7.9×10^9 ergs $g^{-1}(C)$ tensile strength was about two-thirds that of the samples exposed to gamma irradiation in an open atmosphere. In a vacuum, Buna N lost more

than 50 per cent of its tensile strength after exposure to 7.9×10^9 ergs $\text{g}^{-1}(\text{C})$. The per cent elongation followed a straight-line degradation, but with a lower per cent elongation value in vacuum than in air. The value in a closed atmosphere was again intermediate. Thus, nitrile rubber appeared to be less satisfactory when irradiated in a vacuum than when irradiated in air. Data are shown in Figures 12 and 13.

Kerlin⁽⁶⁾ found that air produced a harder and more brittle material with Buna N (RA 30760), while vacuum irradiation produced a weak, tacky, ductile material. After exposure to 10^{10} ergs $\text{g}^{-1}(\text{C})$ in air, tensile strength increased from 2459 psi to 3512 psi, while after exposure to 10^9 ergs $\text{g}^{-1}(\text{C})$ in vacuum, tensile strength decreased from 2630 psi to 203 psi. Data are shown in Tables B-21 and B-22 in Appendix B. No weight loss occurred at a vacuum-gamma radiation dose of 7×10^9 ergs $\text{g}^{-1}(\text{C})$. (See also discussion on nitrile rubber under seals, O-rings, and gaskets.)

DeWitt, et al.,⁽⁹⁾ studied the effect of vacuum (1.2×10^{-3} torr) and temperature (300 F) on several nitrile elastomers. He found that vacuum exposure increased hardness and decreased elongation, but that tensile data were widely scattered and inconclusive.

Ossefort and Ruby⁽⁴⁵⁾ exposed plasticized and unplasticized nitrile rubber compounds to vacuum and elevated temperatures. Properties were not seriously affected after 5 days' exposure at 300 F in vacuum. Data are given in Table B-23.

Polychloroprene (Neoprene)

Tensile strength of neoprene varies depending on the type of polymer, cure, and additives, but in general, tensile strength decreases to a radiation exposure of 4.3 to 8.7×10^9 ergs $\text{g}^{-1}(\text{C})$ and then increases with increasing radiation. Twenty-five per cent change occurs at about 10^9 to 5×10^9 ergs $\text{g}^{-1}(\text{C})$. Elongation decreases with increased radiation exposure; while hardness does not change to an absorbed radiation of 4.5×10^9 ergs $\text{g}^{-1}(\text{C})$.

Reports on the effect of vacuum and radiation on neoprene are conflicting. Some tests have shown improvement in properties in vacuum and others have shown less radiation resistance in vacuum for neoprene. No doubt, the type of neoprene, the filler, compounding materials, and cure affect the stability of the rubber in vacuum.

Data obtained on the effects of radiation on neoprene rubber in vacuum as compared with radiation in air are conflicting. Kerlin⁽⁶⁾ irradiated a neoprene rubber (type not specified) in vacuum and in air and the data show the rubber to be very sensitive to vacuum-gamma radiation. At an exposure of approximately 1.9×10^9 ergs $\text{g}^{-1}(\text{C})$, tensile strength for the vacuum-irradiated samples decreased from 3134 psi to 191 psi; in air the decrease was from 3297 to 2769 psi. The decrease in elongation was of the same order of magnitude in both cases. Weight loss was not considered significant. Data are shown in Tables B-24 and B-25 in Appendix B.

On the other hand, Bonanni⁽⁴⁹⁾ irradiated a neoprene rubber to 7.9×10^9 ergs $\text{g}^{-1}(\text{C})$ and found little difference between the effect of radiation in vacuum, in air, and in a sealed atmospheric environment. Data are shown graphically in Figures 14 and 15. Heitz, et al.,⁽⁴⁷⁾ found that room-temperature irradiation in air generally produced somewhat greater changes than room temperature irradiation in vacuum, although the

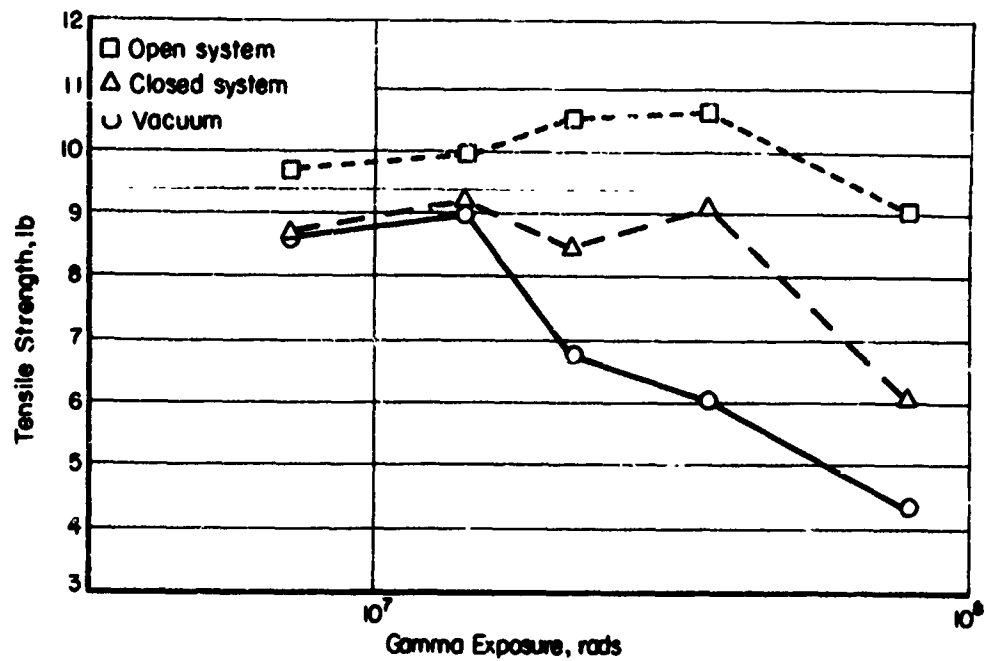
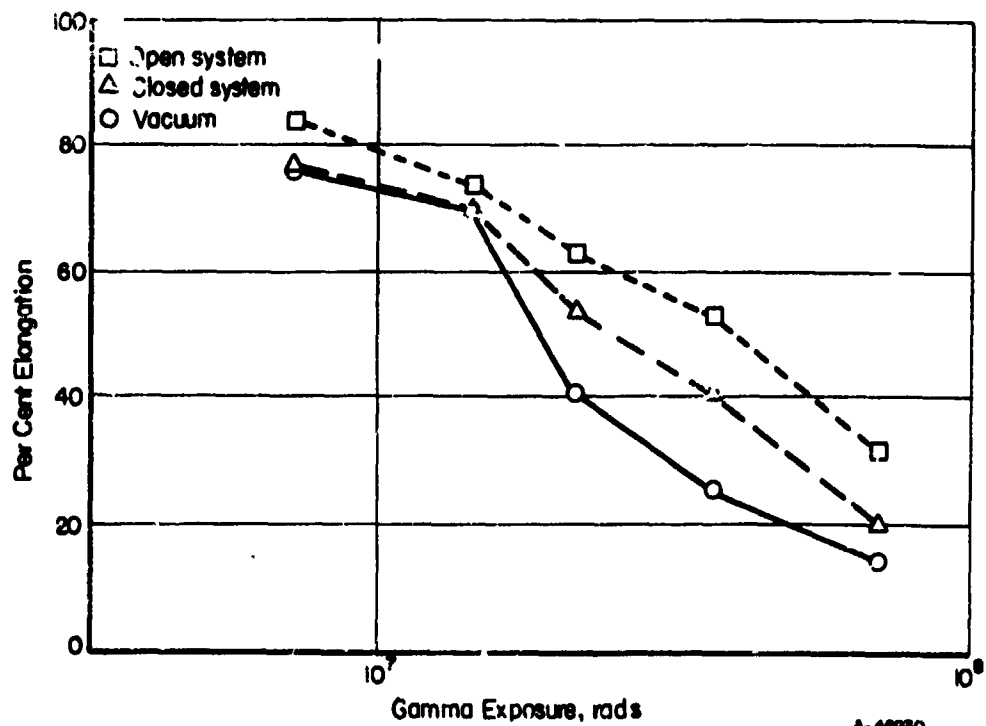


FIGURE 12. TENSILE STRENGTH VERSUS GAMMA EXPOSURE (Buna N)⁽⁴⁹⁾



A-48880

FIGURE 13. PER CENT ELONGATION VERSUS GAMMA EXPOSURE (Buna N)⁽⁴⁹⁾

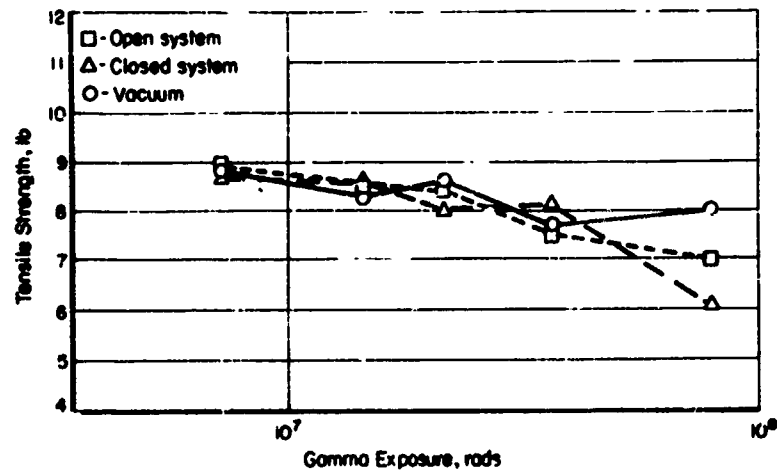
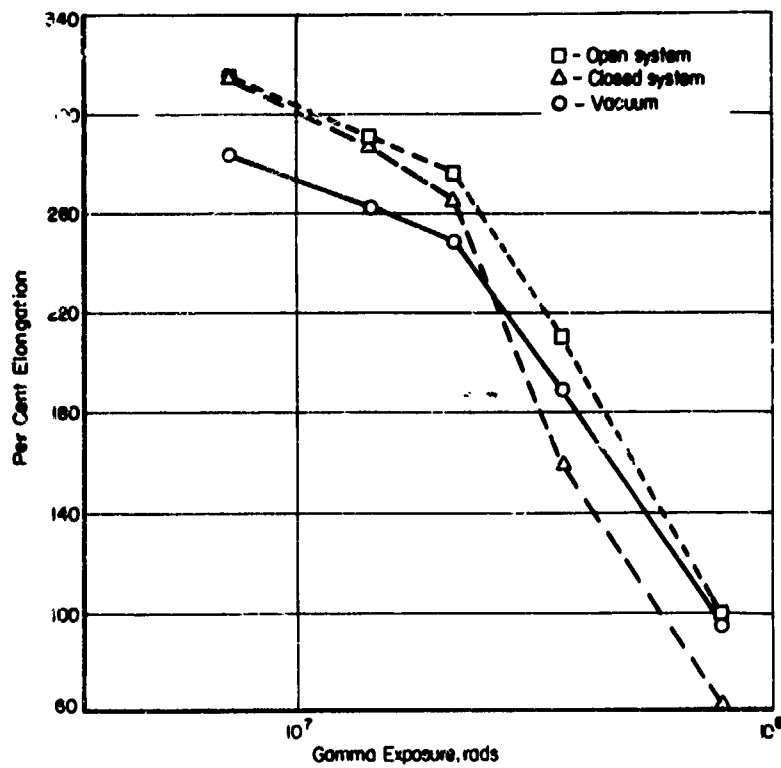


FIGURE 14. TENSILE STRENGTH VERSUS GAMMA EXPOSURE (Neoprene)⁽⁴⁹⁾



A-40031

FIGURE 15. PER CENT ELONGATION VERSUS GAMMA EXPOSURE (Neoprene)⁽⁴⁹⁾

differences were in general not large. There was one exception in which Neoprene WRT having 35 parts of SKF carbon black showed a much greater change in tensile strength in air than in vacuum (see Table 24).

TABLE 24. EFFECT OF GAMMA RADIATION AND VACUUM ON NEOPRENE WRT COMPOUNDS AT ROOM TEMPERATURE⁽⁴⁷⁾

Compound	Description	Radiation Exposure, ergs g ⁻¹ (C)	Tensile Strength, psi		Elongation, per cent	
			Irradiated in Air	Irradiated in Vacuum	Irradiated in Air	Irradiated in Vacuum
138-62	35 parts SRF carbon black	None	2303		537	
		3.6×10^9	579		23	
		1.3×10^9		2140		77
139-62	35 parts SRF carbon black, 2 % hydroquinone	None	2149		516	
		3.6×10^9	1016		70	
		4.3×10^9		1367		123
140-62	35 parts SRF carbon black, 5 % hydroquinone	None	1835		517	
		3.6×10^9	1063		93	
		4.3×10^9		1243		123
159-62	50 parts HAF carbon black; cured 40 min at 293 F	None	2654		287	
		3.6×10^9	898		27	
		--		--		--
161-62	50 parts HAF carbon black; cured 20 min at 293 F	None	1651		437	
		4.3×10^9	2116		53	
		4.3×10^9		1864		47

The reasons for the conflicting data are not known, but could be due to the types of neoprene studied, differences in compounding, and cure. No definite conclusions on the relative effect of radiation in vacuum and radiation in air can be made at this time.

Wattier, Newell, and Morgan⁽⁴⁸⁾ studied postirradiation effects on three neoprene elastomers. They reported tensile data for specimens irradiated at 75 F and stored at 75 F and at -20 F for 1, 4, 11, and 29 days before testing. Data are given in Tables 25 and 26. Postirradiation changes were noted in two of the three neoprenes. In the Kirkhill and Rubbercraft neoprenes (60 mils thick), a postirradiation decrease in tensile strength with time occurred with room-temperature storage. There were no detectable postirradiation effects in the special O-ring formulation of neoprene (78 mils thick) by Parco. When neoprene is stored in an oxidizing atmosphere, postirradiation changes probably will be more noticeable in thin samples than in thick ones due to the time for diffusion of the oxygen through the rubber.

TABLE 25. TENSILE PROPERTIES^(a) OF NEOPRENE RUBBERS AND BUNA-N VERSUS POSTIRRADIATION STORAGE TIME⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (> 2.9 Mev)(b)		Neoprene Rubber (K Inhibitor)(b)				Neoprene Rubber (Rubber-ra)(b)			
		Miniature, 60 Mil Thick, 75 F(C)		ASTM, 60 Mil Thick, 75 F(C)		Miniature, 60-Mil Thick, 75 F(C)		ASTM, 61 Mil Thick, 75 F(C)	
		Ultimate, psi		Ultimate, psi		Ultimate, psi		Ultimate, psi	
		Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation
Control	1	1830/2.3/8	1805/4.9/9	1780/4.6/12	2940/5.4/9	1850/5/9	2210/2.8/12	1980/2.6/9	
N 1.5 x 10 ¹⁵									
G 7 x 10 ⁹	1	1405/4.9/5		1350/8.3/5	1600/11/5	1450/12/5	1430/9.9/4	1350/11/5	
N 2.5 x 10 ¹⁵									
G 1 x 10 ¹⁰	1	1725/14/4		1670/12/4	1585/8.6/4	1505/7.4/4	1354/13/5	1320/6.9/5	
N 5 x 10 ¹⁵									
G 2 x 10 ¹⁰	1	3355/12/4	3654/4.2/5	4030/5.1/4	2925/13/4	2610/6.3/4	3460/5.1/4	2620/3.6/3	
	5	3650/5.2/4	3859/9.1/5	3760/8.3/4	3038/12/4	2550/3.3/5	3080/12/4	2654/5.7/5	
	9	3145/11/4	3760/5.3/5	3440/10/5	2344/9.7/5	2515/17/4	2820/2.8/4	2060/3.4/5	
	35	2930/5.8/4	3675/8.3/5	3085/4.6/4	2640/9.3/5	1590/17/4	2515/3.3/4	2750/7.2/4	
		Neoprene Rubber (K Inhibitor)(b)				Buna-N Rubber(b)			
		Miniature, 60 Mil Thick, 75 F(C)		ASTM, 60 Mil Thick, 75 F(C)		Miniature, 60 Mil Thick, 75 F(C)		ASTM, 61 Mil Thick, 75 F(C)	
		Ultimate, psi		Ultimate, psi		Ultimate, psi		Ultimate, psi	
		Elongation, %		Elongation, %		Elongation, %		Elongation, %	
Control	1	1961/4.8/10	267/9.5/10	1832/6.5/8	242/6.1/7	1362(d)	263(d)	1307(d)	223(d)
	4	735/2.2/10	268/8.1/10	1830/2.1/9	72.1/9				
	11	303/5.6/10	277/7.9/9	1845/1.3/9	249/1.5/7				
	29	1357/2.9/10	245/2.9/8	1870/1.3/8	247/2.2/8				
N 1 x 10 ¹⁵									
G 8.7 x 10 ⁹	1	2280/11/6	9/35/6	4800/6/7	5.6/6.7/7	4050/	17/	3430/	18/
	4	2090/7.8/9	10/4.2/8	4016/5.4/10	5.6/12/10	4360/	17/	3350/	19/
	11	1968/22/9	14/19/9	3040/8.2/9	7.6/18/9	4861/	16/	3480/	20/
	29	1550/14/6	13/19/8	2636/7/10	5/10	4752/	15/	3280/	20/

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of samples used in calculating $\bar{x}$ and S.D.

(b) Radiation temperature and test temperature, 75 F.

(c) Storage temperature.

(d) Individual values not available; average obtained from 4 to 8 samples.

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(c) Storage temperature.

(d) Individual values not available; average obtained from 4 to 8 samples.

TABLE 26. TENSILE PROPERTIES^(a) OF NEOPRENE VERSUS POSTIRRADIATION STORAGE TIME⁽⁴⁸⁾

Integrated Neutron Flux (N), $n\text{ cm}^{-2}$ ($E > 2.9\text{ Mev}$)(b)	Gamma Exposure (G), ergs $\text{g}^{-1}(\text{C})(b)$	Days Tested After Irradiation	Neoprene (Parco 3046-60)(b)				Ultimate Elongation, %
			Modulus, psi		Tensile		
			At 25% Elongation	At 50% Elongation	At 100% Elongation	Strength, psi	
Control		1	141/16 /5	262/8.7/5	539/17 /5	2375/4.8/5	334/2.7/5
		3	151/8.1/7	254/7.7/7	545/8.9/7	2058/5.2/7	324/8.7/7
		10	170/15 /10	277/17 /10	532/17 /10	2005/6.7/10	321/10 /10
		34	154/11 /9	265/9.9/9	511/8.7/9	2223/4.5/9	330/4 /9
N 1.9×10^{15} G 1.2×10^{10}		1	920/32 /5	2066/30 /5		2150/18 /5	56/13 /5
		3	826/38 /5	1818/5 /5		2071/15 /5	52/17 /5
		10	664/20 /5	1872/20 /5		2291/8.9/5	55/20 /5
		34	785/6 /5	1820/25 /5		1926/24 /5	51/4.8/5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation, storage, and test temperature, 75 F.

Hcitz⁽⁴⁷⁾ studied the effect of cure, antirad (hydroquinone), and carbon-black type and level on neoprene. Addition of 2.0 parts of the antirad (Formulation 139-62, see Tables B-26 through B-31) decreased the radiation induced physical changes in air by about 20 per cent, and an increase in the level of 5.0 parts decreased the changes by about 30 per cent. However, changing from 35 parts of SRF black to 50 parts HAF black (159-62) decreased the changes to a greater extent.

In general, the reaction was predominantly crosslinking and the crosslinking increased markedly with increases in dosage. Room-temperature irradiation in air generally produced greater changes than room-temperature radiation in vacuum, but the situation was generally reversed in the combined nuclear radiation-ultraviolet radiation exposures. The specimens seemed to gain weight during exposure, particularly after air exposure, and this increase was even more marked by the addition of ultraviolet irradiation and heat.

Snyder⁽⁴⁶⁾ exposed neoprene to ultraviolet radiation in vacuum. Exposure was at 80 and 155 F for 24, 96, and 312 hours. Ultraviolet caused tensile strength to increase and elongation to decrease. Values are given in Table B-32.

Data have also been reported for the effect of vacuum and elevated temperatures without exposure to radiation. DeWitt⁽⁹⁾ found that vacuum exposure of 5×10^{-4} torr and a temperature of 300 F for 3 hours caused an increase in tensile strength and hardness and a decrease in elongation (see Table B-15).

Ossefort and Ruby⁽⁴⁵⁾ showed the effect of exposure to elevated temperatures and vacuum. Data are given in Table B-33. Both plasticized and unplasticized materials were tested. Samples were oven-aged for the same temperature exposures for comparison. In general, properties did not change significantly up to 212 F. At 300 F, and 5-day exposure, tensile strength decreased by approximately 25 per cent. However, properties had not changed to such an extent as to affect serviceability for most applications.

Styrene-Butadiene (SBR)

Styrene-butadiene rubber (SBR) commonly called GR-S resists radiation better than most of the common synthetic rubbers, but is not equal to natural rubber in radiation resistance. Threshold damage is reached at 2×10^8 ergs $g^{-1}(C)$, and 25 per cent damage is accrued at 1×10^9 ergs $g^{-1}(C)$.

No data on the effect of radiation and vacuum were reported. At elevated temperatures, tensile strength is better in vacuum (no radiation) than in air.

Data on radiation effects on SBR rubber included the effects of some antirads and are discussed in the section on antirads. Ossefort and Ruby⁽⁴⁵⁾ examined the effect of vacuum and elevated temperature on SBR vulcanizates with and without an antiozonant. Specimens with antiozonant lost their ozone resistance after exposure to vacuum at either room or elevated temperature. The antiozonant no doubt sublimed under vacuum and so was removed from the vulcanizate. Data are given in Table B-34, Appendix B.

Polysulfides

Polysulfide rubbers have poor radiation stability. An exposure of 10^8 ergs $g^{-1}(C)$ in air is sufficient to damage Thiokol ST seriously. However, it retains its elongation to a greater extent than do most elastomers. After an exposure of 10^{10} ergs $g^{-1}(C)$, both Thiokol ST and FA retained considerable elongation. Thiokol materials can be used for applications where flexibility is required without any great strength.

Differences in the effects of radiation in air and in vacuum are not marked.

Heitz, et al.,⁽⁴⁷⁾ studied the effect of gamma radiation, vacuum, and ultraviolet on polysulfide elastomers. These were vendor compounded, and the only known variation was the type of curing agent. One dichromate-cured compound (154-62), one lead peroxide-cured compound (155-62), and two manganese dioxide-cured compounds (146-62 and 167-62) were tested. Data are given in Appendix B, Tables B-35 through B-39.

The main observable difference between the curing agents was in the inferior heat resistance of the lead peroxide-cured compound (155-62) compared with that of the other three, although all compounds were affected by heat.

The primary reaction when irradiated was chain scission, and this grew more marked as the exposure was increased. In the case of the lead peroxide and manganese dioxide cures, this was indicated by decreases in modulus and hardness. The dichromate cure, however, produced slight increases in modulus along with slight decreases in hardness, indicating a possibility of a more balanced crosslinking/chain scission reaction.

The atmosphere effect (i.e., radiation in air versus vacuum) did not appear to be marked. Evaluation of the effects of ultraviolet irradiation was rendered impossible by the heat which accompanied the radiation and the heat sensitivity of the compounds.

Wattier, Newell, and Morgan⁽⁴⁸⁾ examined Thiokol ST rubber for postirradiation effects. There was evidence for some recovery of tensile strength. Materials tested for 1, 3, 10, and 34 days after being irradiated to 1.1×10^{10} ergs $g^{-1}(C)$ increased in tensile strength (see Table B-40).

Polyurethane Rubber

Polyurethane rubber is one of the more radiation-resistant elastomers. It is damaged by 25 per cent at an exposure of about 4×10^9 ergs $g^{-1}(C)$. Hardness is unaffected even at 8.7×10^{10} ergs $g^{-1}(C)$.

Irradiation in vacuum has about the same effect as irradiation in air. The effects of combined radiation and temperature up to 260 F are approximately the same as for radiation alone with respect to tensile strength. Elongation is greater at the elevated temperatures.

Cure and filler are important considerations in determining radiation stability of polyurethane rubbers.

Polyurethane rubber is recognized as being one of the more radiation-resistant elastomers. Born and associates⁽⁴¹⁾ found Estane VC cured with 1 phr DiCup (dicumyl peroxide) to be the most radiation-resistant compound tested. It required an exposure of 5.5×10^9 ergs $g^{-1}(C)$ to induce 50 per cent net compression set. On the other hand, Adiprene C, a carbon-black-reinforced sulfur-cured polyurethane, showed poor radiation resistance. Thus cure and filler are important considerations in determining radiation stability. Born indicated that the type of crosslink appeared to play an important role in the radiation resistance of the different polyurethanes. Also, spatial arrangements of the polymer chains, the degree of aromaticity, and the polymer main-chain composition were important factors in the radiation resistance of the polyurethane.

Effects of Temperature and Radiation

Wattier, Newell, and Morgan⁽⁴⁸⁾ irradiated fifteen commercial polyurethane elastomers and studied the effect of postirradiation storage time on some of these and the effect of elevated temperature on others. In general, their findings substantiated the fact that polyurethane rubbers are among the most radiation resistant of the elastomers. Ultimate tensile strength and elongation of all the elastomers decreased at the highest radiation doses. No major postirradiation effects are evident in their data and for most of the elastomers a temperature of 260 F did not seriously affect tensile strength of either the irradiated or nonirradiated samples. Elongation was greater for the samples irradiated at 260 F than for those irradiated at 80 F. In both cases, the test temperature was at 80 F. A summary of the polyurethanes studied and the results of radiation are shown in Table 27. Data for the individual elastomers are given in Tables B-41 through B-50 in Appendix B.

Seilon R-80T, a polyurethane elastomer produced by Seiberling Rubber Co., was irradiated at 80 F and at 250 F to a gamma exposure of 9.4×10^{10} ergs $g^{-1}(C)$ at the lower temperature and 8×10^{10} ergs $g^{-1}(C)$ at the higher temperature.⁽¹⁵⁾ Preliminary observations indicate that this elastomer has excellent radiation resistance. However, the original hardness of the materials before irradiation was about 96, Shore A, which is higher than is desirable for most applications. Data are given in Table 28.

A flexible polyurethane foam, a blown polyether urethane produced by General Foam Co., was also irradiated at 75 F and 250 F. Data are given in Table 29. It can be seen that at the lower temperature, compression set at 50 per cent deflection increased from 8 per cent to 20 per cent at 10^9 ergs $g^{-1}(C)$, to 95 per cent at 8.3×10^9 ergs $g^{-1}(C)$, and 100 per cent at 2.8×10^{10} ergs $g^{-1}(C)$. At the highest dose, 9.4×10^{10} ergs $g^{-1}(C)$, the material adhered to the plates. At 250 F, compression set of the unirradiated material was 103 per cent and irradiation did not change this value. However, at an exposure of 8×10^{10} ergs $g^{-1}(C)$, shrinkage and sticking to the plates again was encountered.

Effects of Radiation and Vacuum

Golden and Hazell⁽⁵⁰⁾ determined the effect of high energy radiation in air and in vacuum on polyurethane rubber. He found that tensile strength and elongation were steadily reduced by electron radiation. The effect is more marked in vacuum than in air. In vacuum, complete loss of strength of Vulkollan Grade 2018/40 (hardness 60 ± 5) was caused by an exposure of 10^{10} ergs $g^{-1}(C)$.

TABLE 27. EFFECT OF RADIATION AND TEMPERATURE ON POLYURETHANE ELASTOMERS

Polyurethane	Temperature of Irradiation, F	Exposure Dose(a), ergs g ⁻¹ (C)	Test Temperature, F	Tensile Strength, psi	Elongation, per cent
Genthane S (General Tire)	75	None	75	2360	468
	75	3.7×10^{10}	75	386	63
3109-B-13 (Du Pont)	75	None	75	4745	434
	75	2.1×10^{10}	75	3325	128
Disogrin 1-DSA- 6865	75	None	75	7222	666
	75	2.2×10^{10}	75	899	56
Disogrin 1-DSA- 4250	75	None	75	4688	583
	75	2.2×10^{10}	75	2574	77
Adiprene L (Du Pont) 12 Phr MOCA Cure: 3 hr at 100 C	80	None	80	5346	390
		7×10^{10}	80	1679	75
	260	None	80	5542	420
		5.4×10^9	80	1513	299
Adiprene L-167 18 hr MOCA Cure: 1 hr at 100 C	80	None	80	5949	328
		7×10^{10}	80	2650	63
	260	None	80	6013	358
		5.4×10^9	80	3111	326
Adiprene L-167 5.8 Phr 1,4 Butanediol 1 Phr Trimethylpropyl Cure: 4 hr at 140 C	80	None	80	1002	452
		7×10^{10}	80	604	69
	260	None	80	1361	499
		5.4×10^9	80	575	465
Genthane S-1	80	None	80	5564	589
		7×10^{10}	80	906	26
	260	None	80	5697	614
		1.9×10^{10}	80	1218	138
Genthane S-2	80	None	80	2932	598
		7×10^{10}	80	692	25
	260	None	80	3008	622
		1.9×10^{10}	80	888	165
General Tire Type R	80	None	80	4102	596
		7×10^{10}	80	890	29
	260	None	80	4160	609
		1.9×10^{10}	80	992	139

TABLE 27. (Continued)

Polyurethane	Temperature of Irradiation, F	Exposure Dose ^(a) , ergs g ⁻¹ (C)	Test Temperature, F	Tensile Strength, psi	Elongation, per cent
Disogrin 1-DSA-6365	80	None	80	4989	685
		7×10^{10}	80	830	36
	260	None	80	4345	676
		1.9×10^{10}	80	1260	278
Disogrin 1-DSA-7560	80	None	80	5254	718
		7×10^{10}	80	850	35
	260	None	80	--	--
		1.9×10^{10}	80	1474	362
Disogrin 1-DSA-9250	80	None	80	5544	578
		7×10^{10}	80	2424	27
	260	None	80	4585	566
		1.9×10^{10}	80	2285	247
Disogrin 2-DSA-8445	80	None	80	(5418) ^(b)	645
		7×10^{10}	80	1050	47
	260	None	80	5082	555
		1.9×10^{10}	80	--	--
Disogrin 2-DSA-9840	80	None	80	5661	563
		7×10^{10}	80	2585	56
	260	None	80	5917	599
		1.9×10^{10}	80	2524	330
Disogrin 3-DSA-8050	80	None	80	(5759) ^(b)	(588) ^(b)
		7×10^{10}	80	1075	44
	260	None	80	--	--
		1.9×10^{10}	80	--	--
Disogrin 3-DSA-9045	80	None	80	3407	598
		7×10^{10}	80	2472	49
	260	None	80	2928	616
		1.9×10^{10}	80	2071	313

(a) Control specimens were subjected to the same nonnuclear environment and test procedures as the irradiated ones.

(b) Numbers in parentheses are values from equivalent test.

TABLE 28. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON SEILON UR-80T (POLYURETHANE ELASTOMER)(15)

Gamma Exposure, ergs g ⁻¹ (C)	Temperature Treatment, F/hr	Specific Gravity at 25 C		Compression Set, %	Hardness, Shore A		Tensile Strength, psi	Ultimate Elongation, %
		Before	After		Before	After		
0	75/67			73.8			4648.4	623.8
3.2 x 10 ⁸	75/2	1.225	1.238	64.4	96.5	96.7	4454.0	597.7
1.2 x 10 ⁹	75/2	1.223	1.254	72.8	96.5	96.0	4062.0	580.0
2.7 x 10 ⁹	75/6.7	1.225	1.239	84.2	96.7	97.0	3413.2	523.8
8.3 x 10 ⁹	75/6.7	1.225	1.232	91.9	97.0	97.2	2698.2	432.1
2.8 x 10 ¹⁰	75/67	1.227	1.240	93.6	97.0	98.0	1931.7	116.5
9.4 x 10 ¹⁰	75/67	1.226	1.234	94.5	96.5	92.5	1967.8	42.1
0	210/2	1.226	1.217	100.4	96.3	89.0	4175.9	606.6
2.7 x 10 ⁸	210/2	1.225	1.237	99.3	96.5	96.3	4150.9	582.1
9.7 x 10 ⁸	210/2	1.224	1.235	101.2	97.0	96.5	3431.8	512.7
0	240/6.7	--	--	101.6	96.0	91.2	--	--
2.5 x 10 ⁹	240/6.7	1.225	1.225	102.8	96.5	96.3	3023.9	492.2
1.1 x 10 ¹⁰	250/6.7	1.229	1.211	114.8	96.5	93.8	2648.0	414.0
0	250/70	--	--	105.1	96.0	92.0	--	--
2.4 x 10 ¹⁰	250/67	1.226	1.195	107.5	96.0	78.2	1542.3	123.9
8.0 x 10 ¹⁰	250/67	1.226	1.225	106.7	95.8	84.8	1751.2	50.5

(a) Total time in compression for all specimens, 312 hours.

(b) Tensile values are average for 15 samples; all others are average for 5 samples.

TABLE 29. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON FLEXIBLE POLYURETHANE FOAM (BLOWN POLYETHER URETHANE, GENERAL FOAM CO.)⁽¹⁵⁾

Gamma Exposure, ergs g ⁻¹ (C)	Temperature Treatment, F/hr	Density, lb/ft ³	Compression Set(a), %	Compression Deflection(b) psi
0	75/67	2.65	7.67	0.500
3.2 x 10 ⁸	75/2	2.57	4.70	0.565
1.2 x 10 ⁹	75/2	2.75	19.42	0.535
2.7 x 10 ⁹	75/6.7	2.62	77.39	0.466
8. x 10 ⁹	75/6.7	2.51	95.99	0.340
.8 x 10 ¹⁰	75/67	2.67	100.34	0.171
1.4 x 10 ¹⁰	75/67	2.86	(c)	0.034
0	210/2	2.36	69.33	0.591
2.7 x 10 ⁸	210/2	2.50	77.37	0.602
9.7 x 10 ⁸	210/2	2.46	82.23	0.542
0	240/6.7	2.30	99.69	0.638
2.9 x 10 ⁹	240/6.7	2.48	99.02	0.525
1.1 x 10 ¹⁰	240/6.7	2.59	100.33	0.407
0	250/67	2.33	103.29	0.764
2.4 x 10 ¹⁰	250/67	2.64	102.66	0.330
8.0 x 10 ¹⁰	250/67	3.14	100.0(c)	0.223

(a) Compressed to 50 per cent deflection during irradiation and for time period of 312 hours. Average of 6 samples.

(b) Load required for 25 per cent compression of 1-sq.-in.-specimen area. Average of 6 samples.

(c) Highest exposure groups adhered to plates. Some could not be removed. Also shrank in size.

Modulus was not greatly affected by radiation. Swelling measurements indicated that a greater degree of crosslinking occurred during irradiation in vacuum than in air. Specimens showed no loss of transparency after irradiation, but the pale amber color was considerably intensified at the higher doses. No voids or bubbles were formed. Data are shown in Figures B-2 to B-5.

Heitz, et al.,⁽⁴⁷⁾ examined a polyurethane vulcanizate for stability to nuclear radiation and ultraviolet radiation in air and in vacuum. He found that the samples underwent an initial crosslinking period after which chain scission was more predominant. The difference between air and vacuum irradiation appeared very small. The weight changes were also small in view of the extensive degradation of some of the specimens. Regarding its resistance to gamma radiation alone, Heitz found that it compared with the best of the silicones evaluated. Data are given in Table B-51.

DeWitt, et al.,⁽⁹⁾ tested Adiprene L and C for effects of exposure to vacuum and elevated temperatures (200 and 300 F for L and C, respectively). He found either no change or an increase in tensile strength, hardness, and elongation. Vacuum pressure obtained with Adiprene L would suggest that quite a bit of outgassing occurred.

Ossefort and Ruby⁽⁴⁵⁾ found that 5 days' exposure to vacuum at 200 F did not significantly affect tensile strength, although elongation decreased about 50 per cent. Hardness increased from 56 to 80. Exposure to the same temperature in air decreased tensile strength by almost 65 per cent, but did not change hardness. Data are given in Table B-52.

Effects of Radiation and Fluid Immersion

Wattier, Newell, and Morgan⁽⁴⁸⁾ irradiated four polyurethane elastomers while immersed in selected fluids. Those included:

Mil-L 7808	A phenoxy phenyl ether
4P3E	A diester oil
Oronite 8515	A nonpetroleum-base hydraulic fluid

Samples were immersed for approximately 1 month prior to irradiation and soaked for 2 months after irradiation. Data obtained were of a preliminary nature only, and no conclusions were drawn except that irradiation in 4P3E fluid appeared to cause more degradation than irradiation in the other fluids used. Data are shown in Tables B-53 through B-56.

Silicone Rubbers

The tensile strength of silicone rubber increases with irradiation in air up to an exposure of approximately 10^9 ergs $g^{-1}(C)$, then it rapidly decreases. Elongation is the property most affected by radiation. Most silicones retain 50 per cent elongation after exposure to 5×10^9 ergs $g^{-1}(C)$ at room temperature, 10^9 ergs $g^{-1}(C)$ at 150 C, and 5×10^8 ergs $g^{-1}(C)$ at 200 C.

Nitrile silicone retained useful properties when irradiated in fluids such as Oronite 8515, MIL-L-7808, and JP-4 fuel to an exposure of 10^{10} ergs $g^{-1}(C)$.

Changes in tensile properties of silicone elastomers due to vacuum irradiation (gamma) are, in general, equivalent to or somewhat greater than the changes induced by irradiation in air.

Vacuum exposure to 600 F for 5 days had no appreciable effect on tensile strength of silicon elastomers, although exposure in air reduced this property by about 50 per cent. Elongation was not greatly affected.

The surface of silicone rubber shows crazing and discoloration on exposure to ultraviolet radiation.

Radiation-effects data have been obtained on the following types of commercially available silicone rubbers: dimethyl, methyl phenyl, methyl vinyl, methyl phenyl vinyl, methyl trifluoropropyl, and nitrile siloxanes. Of these, the nitrile and methyl phenyl silicone vulcanizates suffer the least damage when exposed to gamma radiation in air while the methyl trifluoropropyl type experiences the greatest damage. The methyl vinyl and methyl phenyl vinyl silicones are intermediate with respect to radiation stability. REIC Report No. 21 gives more detailed information regarding these types. Additional information covered in this addendum includes effect of temperature and gamma radiation-vacuum and gamma radiation, and some data on the effect of ultraviolet radiation.

Effects of Radiation and Temperature

Wattier, Newell, and Morgan⁽⁴⁸⁾ irradiated six silicone elastomers at -65 F, 80 F, and 350 F. The materials were stored at the same temperatures until testing. Testing was at -65 F, 80 F, and 300 F. Table 30 shows the changes in ultimate strength due to irradiation at the three temperatures. Additional tensile data are presented in Appendix B, Tables B-57 through B-63, for the control and irradiated specimens. An examination of these tables will show that all silicone rubbers tested gave evidence of extensive crosslinking, even when irradiated at -65 F. Ultimate strength increased with exposure to a certain point, generally about 10^9 ergs $g^{-1}(C)$, and then decreased with increasing exposure. This decrease appeared to be quite rapid above 10^9 ergs $g^{-1}(C)$, as shown by comparing the above tables with Tables B-64 through B-67. The increase in tensile strength was considered to be a continuation of the crosslinking that was not fully completed by the usual curing process and the decrease was attributed to chain cleavage. Tear strength decreased with increasing dose. It may be noted that the tensile properties were sensitive to the test temperature, tensile strength decreasing considerably at the 300 F temperature.

Two silicone rubbers, a methyl phenyl vinyl type (DC-916) and a nitrile silicone (NSR-X5602), were cycled under compression during radiation. A nitrile elastomer (Hycar 1001) was also tested for comparison. Data on the number of cycles and the compressive strengths are given in Table B-68. The cycling of the material was found to have an effect on the nitrile silicone and the nitrile rubber. Compression set for NSR-X5602 and Hycar 1001 was less for the cycled-compressed environment than for the static-compressed environment. No difference was found for DC-916.

Dexter and Curtindale at Dow Corning Corporation⁽³⁶⁾ determined the combined effects of gamma radiation and high temperatures on the electrical and physical properties of liquid, semisolid, elastomeric, and resinous silicones. These tests indicated that many silicone dielectrics exhibit appreciable resistance to changes in

properties induced by exposure to gamma radiation at temperatures ranging from 150 C to 200 C.

These investigators state that the tensile strength of silicone rubbers, e.g., Silastic 1602, was unaffected by irradiation at room temperature and at 150 C to 10^{10} ergs $g^{-1}(C)$, while irradiation at 200 C decreased tensile strength (see Figure B-5). In all cases, hardness of the silicone elastomers increased with dose, the rate of increase being greater at elevated temperatures. Ultimate elongation is the property most affected by irradiation. Most silicone elastomers retain 50 per cent elongation after exposures of 5×10^9 ergs $g^{-1}(C)$ at room temperature, 10^9 ergs $g^{-1}(C)$ at 150 C, and 5×10^8 ergs $g^{-1}(C)$ at 200 C. Dexter and Curtindale state that an experimental radiation-resistant stock retained 50 per cent elongation after 9×10^9 ergs $g^{-1}(C)$ and 340 hours at 200 C, indicating a life in radiation fields 15 times greater than that of conventional silicone elastomers.

Electrical properties examined by these investigators included dielectric constant, dissipation factor, volume resistivity, and electric strength. The increase in dielectric constant of silicone elastomers irradiated at high temperatures was found to be less than that of the same materials irradiated at room temperature. The increase was of such magnitude as to cause only a slight change in the operating characteristics of the materials. Dissipation factor was affected in a similar manner, but did not change sufficiently to affect its operation in electrical equipment. Radiation exposure either at room temperature or high temperature did not significantly affect the volume resistivity or electric strength of the silicone elastomers at these exposures [10^{10} ergs $g^{-1}(C)$]. The effect of radiation at 25 C, 150 C, and 200 C on the electrical properties of Silastic 1602 are shown in Figure B-7.

Effects of Radiation and Fluid Immersion

A nitrile silicone (General Electric NSR-S5602) was tested by Wattier, Newell, and Morgan⁽⁴⁸⁾ in a combination of fluid, temperature, and irradiation environments. Specimens tested in fluids were immersed for approximately 7 days prior to irradiation and 30 days after irradiation. Samples were then tested within 4 hours after removal from the fluid. Data are given in Tables B-66 and B-67. Degradation of the silicone was noted in fluid MIL-L-7808, as indicated by the decrease in stress at 50 per cent elongation with exposure. Irradiations in Oronite 8515 and air resulted in an increase in stress at 50 per cent elongation with increasing exposure up to the maximum given [about 10^9 ergs $g^{-1}(C)$]. There did not appear to be any major difference between the tensile values obtained for the samples irradiated at 260 F and those irradiated at 80 F. Tests were run only at 80 F for JP-4 fuel immersion. In all cases, the nitrile silicone appeared to retain usable properties when immersed in these fluids after a radiation dose of 10^{10} ergs $g^{-1}(C)$.

Effects of Radiation and Vacuum

Silicone elastomers have been subjected to vacuum at room and at elevated temperatures. In general, outgassing and equilibrium-weight-loss rates are relatively low and properties are not seriously affected. According to Jaffe and Rittenhouse⁽⁵¹⁾, the temperature for 10 per cent weight loss per year in vacuum for silicone rubber is 200 C

TABLE 30. EFFECT OF NUCLEAR RADIATION AND TEMPERATURE ON TENSILE STRENGTH OF SILICONE ELASTOMERS⁽⁴⁸⁾

Silicone	Chemical Type	Temperature of Irradiation and Testing ^(a) , F	Gamm. Exposure, ergs g ⁻¹ (C)	Tensile Strength, psi
DC-80	Methyl vinyl	-65	0	1303
			1.1×10^9	1238
		80	0	1057
			7×10^8	1117
		300	0	538
			1.6×10^9	631
SE-361	Methyl vinyl	-65	0	1050
			1.1×10^9	1354
		80	0	967
			1.6×10^9	953
		300	0	541
			1.6×10^9	611
DC-675	Methyl phenyl vinyl	-65	0	1090
			7×10^8	944
			1.1×10^9	1109
		80	0	992
			1.6×10^9	936
		300	0	533
DC-916	Methyl phenyl vinyl	-65	0	(1589)
			1.1×10^9	404
		80	0	1504
			1.6×10^9	1182
		300	0	489
			1.3×10^8	772
			1.6×10^9	322
			1.1×10^9	611

TABLE 30. (Continued)

Silicone	Chemical Type	Temperature of irradiation and Testing ^(a) , F	Gamma Exposure, ergs g ⁻¹ (C)	Tensile Strength, psi
SE-551	Methyl phenyl	-65	0	1404
			7×10^8	1515
			1.1×10^9	1259
		80	0	976
			7×10^8	1078
			1.6×10^9	883
		300	0	416
			1.6×10^9	544
LS-53	Methyl trifluoropropyl	-65	0	2052
			1.1×10^9	1076
		80	0	1289
			1.6×10^9	514
		300	0	472
			1.6×10^9	243

^(a) Samples tested at 300 F were irradiated and stored at 350 F.

(400 F). Podlaseck and Suhorsky⁽⁴⁾ give the following data for equilibrium-weight-loss rates:

Temperature, C	Pressure, torr	Equilibrium Weight Loss Rate, $\frac{g}{(cm^2)(sec)}$
177	760	3.9
	5×10^{-2}	2
	10^{-5}	ND
204	760	46.8
	5×10^{-2}	9.6
	1.6×10^{-2}	
	10^{-5}	
232	760	74.9
	9.5×10^{-1}	11.3
	6×10^{-2}	7.2
	10^{-5}	5.7

Outgassing rates as given by these investigators⁽⁴⁾ are shown in Table 31. In general, these rates are low, and silicones are useful in vacuum environment. In areas where outgassing and possible recondensation may present problems, such as on optical surfaces and electrical contacts, silicones may be preferred over other elastomers and plastic materials. Although silicone rubber has a relatively high permeability rate, loss of gas from pressurized vehicles due to permeability is so small that it may be disregarded in most cases.

TABLE 31. OUTGASSING RATES OF SILICONE ELASTOMERS⁽⁴⁾

Elastomer	Outgassing Rate, $\frac{\text{torr-liters}}{\text{sq. cm} \times 10^7}$		
	After 1 Hr	After 24 Hr	After 24 Hr
Silicone rubber (Wacker R50)	70	17	--
Silicone rubber (Wacker R80)	180	44	--
Silicone rubber (24 hours, 95 per cent humidity)	230	46	--
Silicone rubber (outgassed + 24 hours dry N ₂)	13	--	--
Silastic	25	6	--
Silicone rubber	94	21	--
Silastic X6145C	25	5.6	--
Silastic 8-104 (red, 62 durometer)	12	3.7	--
Silastic 80 (white, cured 24 hours at 480 F, 74 durometer)	28	6.0	--
Silastic 50 (white, 55 durometer)	30	6.4	--
Silastic 67-163 (red, 61 durometer)	19	5.4	--
Silicone (red)	--	--	0.44
Silicone (green)	--	--	0.44

Boundy⁽³¹⁾ listed the weight loss of several silicones after exposure to temperatures of 105 F and 300 F at a pressure of 10^{-6} torr after a period of 7 days. Values are

given in Table B-69. Per cent weight loss was in the order of 1.5 per cent. Boundy noted that an appreciable decrease in vacuum weight loss was noted when the rubber was postcured, especially if the postcure temperature was higher than the use temperature.

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Fulk and Horr⁽¹⁷⁾ reported the stationary-state weight-loss rate at 50 C for several silicone rubbers as well as the weight loss occurring before they reached a stationary state. Data are given in Table B-70. Stationary-state values were of the order of magnitude of 10^{-5} g/sq cm/hr. Weight loss to reach stationary state varied from 4.2 to 5.8×10^{-3} g/sq cm for the elastomers. In general, a steady-state weight loss was reached in 44 to 68 hours.

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Ossefort and Ruby⁽⁴⁵⁾ exposed 2 methyl vinyl silicone rubbers to temperatures from 400 to 700 F. Vacuum exposure to 500 F for 5 days had no appreciable effect on tensile strength, although on exposure in air, this property was reduced by about 50 per cent. Elongation was not greatly affected in vacuum exposure. Weight losses were higher at these temperatures but this was also true in oven aged samples. One of the silicones maintained almost 50 per cent of its tensile strength when exposed to 700 F in vacuum. In air at this temperature, samples were too brittle to be tested. Data are given in Table B-71. In general, the effect of elevated temperatures was greater in air than in vacuum.

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Heitz and coworkers⁽⁴⁷⁾ irradiated silicone elastomers in air and in vacuum with gamma radiation. They found that atmospheric conditions as compared with vacuum environment did not cause many significant differences in radiation effects on these materials. Where such differences did occur, gamma radiation in vacuum produced greater crosslinking in the dimethyl, dimethyl phenyl, and dimethyl vinyl types than radiation in air. The reverse was true of the methyl phenyl vinyl compound tested. Tables B-72 through B-85 show the effect of radiation in air and in vacuum on tensile strength, 100 per cent modulus, ultimate elongation, hardness, and weight change for six types of elastomers. The values after 100 hours of radiation are compared for these rubbers in Table 32. It may be seen that changes in properties due to gamma radiation in vacuum were, in general, equivalent to or somewhat greater than those in air.

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These data are in general agreement with the findings of McGarvey⁽⁵²⁾ who studied the effects of radiation in air, oxygen, argon, and vacuum on various silicone elastomers and found that the media had little influence on the vulcanizate's physical properties at the exposures employed [10^{10} ergs $\text{g}^{-1}(\text{C})$].

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Heitz indicated that room-temperature vulcanizing compounds as a class, with one exception, were the most radiation resistant of the silicones. However, it should be pointed out that tensile strength of these materials was lower than that of the high-temperature-cured materials (see Table 32).

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Effects of Ultraviolet Radiation

Podlaseck and Suhorsky⁽⁴⁾ investigated the effect of ultraviolet and vacuum at 26 C and 53 C on the permeability of silicone rubber. No significant changes in the permeability rates were found, but the silicone rubber showed surface crazing as a result of the ultraviolet exposure. Ultraviolet exposure was equivalent to approximately 1300 hours of solar radiation for the samples tested at 53 C and about 24 hours for the samples tested at 26 C.

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TABLE 32. EFFECT OF GAMMA RADIATION AND VACUUM ON SILICONE ELASTOMERS⁽⁴⁷⁾

Compound	Curing Data	Nominal Irradiated Conditions ^(a)	Gamma Expos re, ergs g ⁻¹ (C)	Tensile Strength		100 Per Cent Modulus		Ultimate Elongation		Hardness		Weight Change, mg
				Psi	Chg. (b)	Psi	Chg. (b)	Per Cent	Chg. (b)	Duro A	Chg. (b)	
106-62 Dimethyl	Postcured 12 hr at 480 F	As cured Gamma, air Gamma, vacuum	None 3.4 x 10 ⁹ 6.2 x 10 ⁹	1010 106 600	-9 -51	193 1016 --	-426(c) +564	387 120 47	-69 -88	58 78 74	+20 +16	+2 +33
105-62 Dimethyl	Press cured 5 min at 240 F Postcured 24 hr at 480 F	As cured Gamma, air Gamma, vacuum	None 3.4 x 10 ⁹ 6.2 x 10 ⁹	819 1210 1010	+48 +28	-- -- --	+205(c) +298(c)	62 30 20	-52 -68	83 87 92	+4 +8	-- +1 +6
39-62 Dimethyl vinyl	Postcured 24 hr at 410 F	As cured Gamma, air Gamma, vacuum	None 4.1 x 10 ⁹ 4.9 x 10 ⁹	731 838 787	+15 +7.6	449 -- --	+196(c) +150(c)	210 57 63	-63 -70	67 81 73	+14 +6	-- +2 +4
107-62 Dimethyl vinyl	Postcured 24 hr at 480 F	As cured Gamma, air Gamma, vacuum	3.4 x 10 ⁹ 6.2 x 10 ⁹	859 926 655	+7.8 -24	523 -- --	+164(c) +213(c)	150 67 40	-55 -73	64 75 80	+11 +16	+3 +1
111-62 Dimethyl vinyl	Postcured 24 hr at 480 F	As cured Gamma, air Gamma, vacuum	3.4 x 10 ⁹ 6.2 x 10 ⁹	1029 1151 816	+12 -21	415 -- --	+345(c) +318(c)	227 63 47	-72 -79	73 -- 87	+10 -- +4	-- +4 +4
1-9-62 Methyl phenyl vinyl	Postcured 4 hr at 480 F	As cured Gamma, air Gamma, vacuum	3.4 x 10 ⁹ 6.2 x 10 ⁹	1473 302 774	-32 -48	229 -- --	+337 +404(c)	500 30 67	-82 -87	62 76 78	+14 +16	+3 +3
56-62 Dimethyl phenyl	Press cured 10 min at 250 F Postcured 3 hr at 400 F	As cured Gamma, air Gamma, vacuum	3.4 x 10 ⁹ 6.2 x 10 ⁹	1169 692 660	-41 -41	208 737 --	+254 +323(c)	403 93 75	-77 -82	50 67 76	+17 +26	+6 0
58-62 Dimethyl phenyl	Press cured 10 min at 250 F Postcured 24 hr at 480 F	As cured Gamma, air Gamma, vacuum	3.4 x 10 ⁹ 6.2 x 10 ⁹	1147 742 777	-35 -32	117 -- --	+424(c) +458(c)	383 80 75	-80 -81	53 70 76	+17 +23	+5 +2

TABLE 32. (Continued)

Compound	Curing Data	Nominal Irradiated Conditions(a)	Gamma Exposure, ergs g ⁻¹ (c)	Tensile St.		100 Per Cent Modulus		Ultimate Elongation		Hardness		Weight Change, % (b)	
				Pa. Co.	St. Chg. (b)	Pa. Co.	Chg. (b)	Per Cent	Chg. (b)	Duro A	Chg. (b)		
110-62 Methyl trifluoro propyl	Postcured 16 hr at 300 F	As cured Gamma, air Gamma, vacuum	1.46 4.1 x 10 ⁹ 6.2 x 10 ⁹	374 374 382	-72 -72		371		243 67 67	-72 -72	62 73 72	+11 +10	-8 -8
120-62 Dimethyl	Room-temperature- vulcanized silicone	As cured Gamma, air Gamma, vacuum	674 688 573		+2.1 -15		503		147 70 57	-52 -61	62 72 75	+11 +12	+2
147-62 Dimethyl	RTV, 95 parts com- pound, 4 parts curing agent	As cured Gamma, air Gamma, vacuum	282 211 541		-25 +92		203		167 23 60	-86 -64	51 68 73	+17 +22	-8 -18
148-62 Dimethyl	RTV, 100 parts com- pound, 0.5 parts Thermoline T-12	As cured Gamma, air Gamma, vacuum	409 329 315		-20 -23		232		143 80 77	-44 -48	54 60 65	+6 +11	-5 -2
149-62 Dimethyl	RTV, low density 100 parts rxn; sand, 10 parts accelerator	As used Gamma, air Gamma, vacuum	266 211 288		-21 +8.3				90 47 60	-48 -33	64 73 75	+9 +11	+18 -2

(a) Samples irradiated for 100 hours at 70 F.

(b) From as-cured value.

(c) Value found by extrapolation.

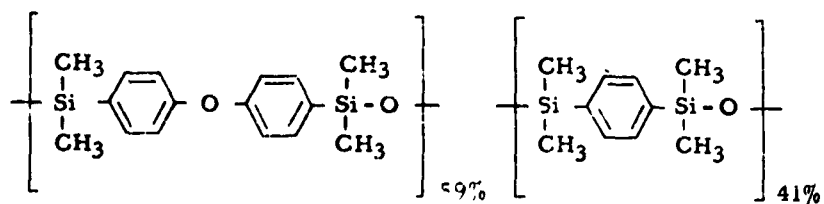
Heitz(47) found that combined radiation (gamma and ultraviolet) caused more crosslinking than straight gamma radiation, the differences ranging from slight to marked. The evaluation of this, however, is complicated by the fact that the ultraviolet radiation was accompanied by high temperatures. Since heating in vacuum causes chain scission of silicone compounds, and it was not possible to cool the specimens to room temperature, Heitz acknowledges that a straightforward evaluation of the changes caused only by the ultraviolet radiation was very difficult. However, specimens exposed to ultraviolet light showed a marked discoloration of the surfaces toward the lamp, thus indicating an ultraviolet-radiation-induced reaction. Data are given in Tables B-72 through B-85.

Studies to Improve Radiation Stability

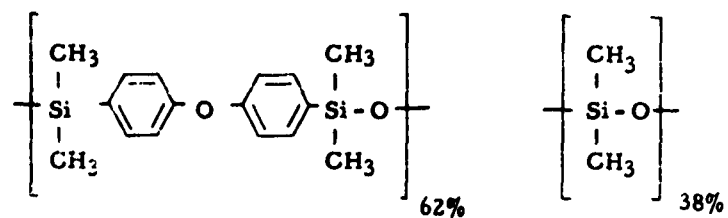
The incorporation of arylene groups in the backbone structure of the silicone molecule appears to be promising for improved radiation resistance. Ossefort(53) and McGarvey(52) at Rock Island Arsenal studied the thermal and radiation stability of arylene-modified siloxanes prepared by Union Carbide Corporation. On the basis of this work, it appears that the incorporation of arylene structures in the main chain does not contribute to their thermal stability or to their elevated-temperature properties. However, aryl-ether aryl and aryl-ether dimethyl silicones were found to possess significantly better initial physical properties than did the conventional silicones and were significantly better than any of the commercial types evaluated with respect to radiation stability. Figure 16 shows the chemical structure of the arylene-modified materials. The aryl-ether aryl vulcanizate retained some useful properties at exposure up to 3×10^{10} e.g. (C) in both vacuum and in air. Figure 17 shows a comparison of the effect of gamma radiation on ultimate elongation of these materials as compared with those of methyl phenyl silicone and dimethyl silicone. Following is a comparison of the effect of radiation on the several types of silicone rubbers as found by McGarvey.

<u>Radiation Resistance</u>	<u>Elongation After Exposure of 5×10^9 ergs g⁻¹(C)</u>	<u>Type of Silicone</u>
Good	>50% of initial value	Aryl-ether aryl Aryl-ether dimethyl
Fair	<50%, >20% of initial value	Nitrile Aryl dimethyl Methylphenyl Methylphenylvinyl Methylvinyl
Poor	<20% of initial value	Methyltrifluoropropyl

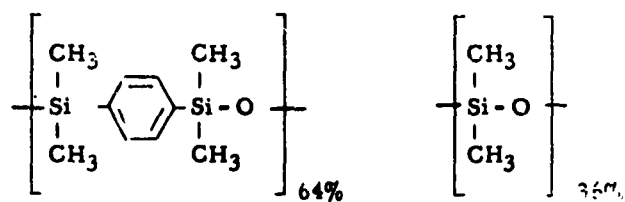
It was also determined that the physical properties of the arylene-modified silicones cured by gamma radiation were equal to or better than those obtained with a peroxide-type cure. A dose of approximately 10 megarads produced optimum cures in the aryl dimethyl and the aryl-ether aryl silicones, and about 15 megarads produced the optimum cure for the aryl-ether dimethyl type.



Aryl-Ether Aryl



Aryl-Ether Dimethyl



Aryl Dimethyl

FIGURE 16. ARYLENE-MODIFIED SILICONES

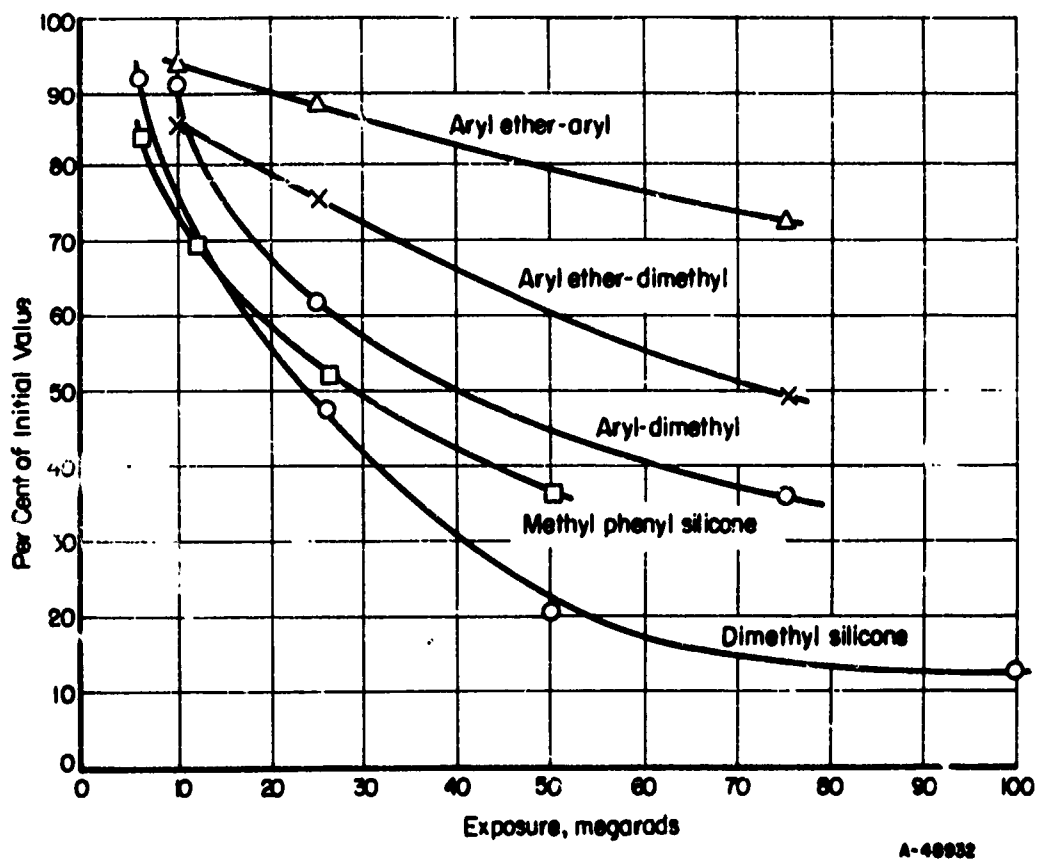
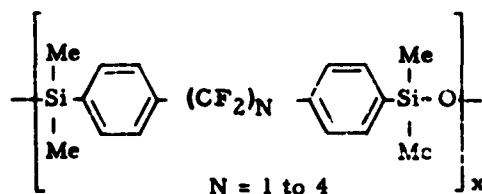


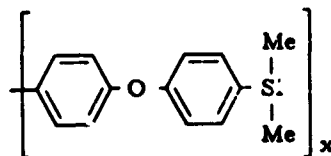
FIGURE 17. EFFECT OF GAMMA RADIATION ON THE ULTIMATE ELONGATION OF VARIOUS SILOXANES

ON

Two other phases of the program included the preparation of arylene-modified siloxanes connected by perfluoromethylene groups (Stanford Research Institute) and the preparation of arylene-modified silcarbanes (Yarsiey Research Laboratories, London). The structures of these materials are indicated in Figure 18. Data on these modifications are not yet available.



Fluorinated-Arylene-Modified Polysiloxane



Arylene-Modified Silcarbanes

FIGURE 18. SILOXANE AND SILCARBANE POLYMERS

Antirads

A considerable amount of work has been performed to improve radiation resistance of polymers by using antirads. Work has been done on the investigation of antirads at Mare Island Naval Shipyard and at Rock Island Arsenal. Morris and Caggegi at the naval shipyard investigated 93 antirads in an effort to develop rubber gaskets which would be resistant to nuclear radiation, and McGarvey at the arsenal evaluated approximately 200 potential antirads to determine the best one for low-acrylonitrile-content nitrile (NBR) rubber.

Morris and Caggegi⁽⁴⁰⁾ were interested in improving the compression-set properties of gaskets. They found that improvement could be obtained by compounding with certain antioxidants, antiozonants, or with certain chemicals containing aromatic rings or condensed ring structures. Akroflex C, AgeRite HP, and Santoflex GP were among the best antioxidants for improving the radiation stability of Synpol 1500 (SBR). Those antioxidants having the best antirad properties were derivatives of p-phenylene diamine, phenyl naphthylamine, or a blend of these chemicals.

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Some of the antirads which were good in Synpol 1500 were among the best also in Hycar 1072 (nitrile rubber). Examples were Wingstay 100, Akroflex C, Akroflex CD, and AgeRite HP. Antirads which were not outstanding in Synpol 1500 but which were quite good in Hycar 1072 and Hycar 1041 were Santovar A, Ionol, and Deenax. All of these are phenolic derivatives.

Vulcanizates were further improved in radiation resistance when both an anti-oxidant and a plasticizer with an aromatic ring structure were incorporated in the rubber stocks. Five parts of Thermoflex A and 10 parts of dibenzyl phthalate lowered compression set of Synpol 1500 from 74 per cent to 48 per cent after irradiation. It was necessary to compound stocks with more carbon black to maintain the Shore hardness of the plasticized vulcanizates within the range of 65 to 75.

Naphthalene was a plasticizer which was particularly effective in combination with an antirad for nitrile rubber (Hycar 1072). AgeRite Hipar (5 part) and Naphthalene (10 parts) gave a vulcanizate with a compression set of 53 per cent after irradiation. Compression set of irradiated vulcanizates of Hycar 1072 without these additives was 80 per cent and that for Hycar 1072 with AgeRite Hipar was 65 per cent.

Acridine, pyrene, and fluoranthene were other plasticizers which provided improved radiation with antirads in Synpol 1500. Acridine was also outstanding with antirads in Hycar 1072. These antirads are listed, with the chemical composition and name of the supplier, in Tables 33 and 34.

McGarvey⁽⁵⁴⁾ evaluated antirads on the basis of per cent of initial NBS strain and Shore A values after an exposure of 5×10^9 ergs $\text{g}^{-1}(\text{C})$. The compounds whose vulcanizates met the following requirements after irradiation were judged to possess significant antirad activity:

NBS strain, 50 per cent, >50 per cent of initial value
 Ultimate elongation, 200 per cent, >50 per cent of initial value
 Ultimate tensile strength, >2000 psi.

Table 35 lists the 12 best antirads arranged in descending order according to their antirad activity. From this table it can be seen that several aromatic nitro compounds function as inhibitors of radiation damage in NBR rubber. In particular, 2,2-diphenyl 1-picrylhydrazyl (DPPH) and 1,1-diphenyl-2-picrylhydrazine (DPPH₂) appear to be the most efficient antirads. The mechanism of their protective action was attributed to their function as radiation-stabilized scavengers for free radicals produced by high-energy radiation. It is not known how DPPH and DPPH₂ may attach to the free radicals produced in the NBR vulcanizate.

The antirad activity of DPPH₂ present at a concentration of 5 phr was also investigated in SBR, Butyl rubber, and natural rubber. A significant antirad activity was exhibited in only the SBR vulcanizate, as can be seen from Table 36.

TABLE 33. ANTIRADS FOR STYRENE-BUTADIENE (SBR) RUBBER⁽⁴⁰⁾

Name	Chemical Composition (Supplier's Description)	Supplier
<u>Antioxidants and Antiozonants</u>		
Akioflex C	Diphenyl-p-phenylenediamine + phenyl-alpha-naphthylamine	E. I. du Pont de Nemours & Co.
AgeRite HP	Phenyl-beta-naphthylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
Santoflex GP	N-Cyclohexyl-N'-phenyl-p- phenylenediamine	Monsanto Chemical Co.
Wingst 100	Alkyl aryl amine	Goodyear Tire and Rubber Co.
Akroflex CD	Diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
Thermoflex A	Di-p-methoxydiphenylamine + diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
<u>Plasticizers</u>		
Dibenzyl phthalate	Dibenzyl phthalate	Eastman Chemical Products
<u>Miscellaneous</u>		
Acridine	Acridine	Eastman Chemical Products
Pyrene	Pyrene	Reilly Tar & Chemical Corp.
Fluoranthene	Fluoranthene	Reilly Tar & Chemical Corp.

TABLE 34. ANTIRADS FOR NITRILE RUBBER

Name	Chemical Composition (Supplier's Description)	Supplier
<u>Antioxidants and Antiozonants</u>		
Wingstay 100	Alkyl aryl amine	Goodyear Tire and Rubber Co.
Akroflex C	Diphenyl-p-phenylenediamine + phenyl-alpha-naphthylamine	E. I. du Pont de Nemours & Co.
Akroflex CD	Diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
AgeRite	Phenyl-beta-naphthylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
Santoar A	2,5-di-tertiary-amyl hydroquinone	Monsanto Chemical Co.
Ionol	2,6-Di-tert-butyl-4-methyl phenol	Shell Chemical Corp.
Deenax	2,6 Di-tert-butyl-4-methyl phenol	Enjay Chemical Co.
AgeRite Hipar	Phenyl-beta-naphthylamine + isopropoxy diphenylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
<u>Miscellaneous</u>		
Naphthalene	Naphthalene	Reilly Tar & Chemical Corp.
Acridine	Acridine	Eastman Chemical Products

TABLE 35. EVALUATION OF THE BEST ANTIRADS IN NBR

Additive (5 Phr Polymer)	Per Cent of Original Property After 5 x 10 ⁷ Rads			
	Tensile	Elongation	Hardness, Shore A	Strain, NBS
None (Control)	92	33	116	34
2,2-Diphenyl-1-picrylhydrazyl	109	61	104	58
1,1-Diphenyl-2-picrylhydrazine	98	63	108	55
N,N'-Diphenyl paraphenylenediamine	82	51	110	55
1-Fluoro-2,4-dinitrobenzene	113	70	114	57
5-Nitro-1-naphthylamine	100	58	110	54
p-Phenylazoaniline	95	53	114	54
4-Phenylazodiphenylamine	91	51	112	53
2-Nitrodiphenylamine	97	51	112	52
Phenothiazine	93	51	115	52
p-Nitrobenzylamine	97	52	118	52
p-Nitrobenzhydrazide	92	51	112	51
p-Nitrophenylhydrazine	113	60	113	50

TABLE 36. EVALUATION OF DPPH₂ IN VARIOUS ELASTOMERS

Polymer	Additive	Per Cent of Original Property After 5 x 10 ⁷ Rads			
		Tensile	Elongation	Hardness, Shore A	Strain, NBS
SBR	None	98	55	117	51
"	DPPH ₂	112	84	108	65
Butyl	None	4	71	59	--
"	DPPH ₂	4	70	66	--
Natural	None	86	67	112	64
"	DPPH ₂	80	71	106	78

PLASTICS

As was true with elastomers, most of the data collected on plastics since the publication of REIC Report No. 21 have been in connection with the materials used in various components for space vehicles or missiles. Effects of combined environments such as vacuum and radiation have been investigated. Most of this work was discussed in the section on components. However, those plastics for which new information was obtained are discussed alphabetically in this section.

Three new polymers have been developed that look promising with respect to radiation stability. These are the polyimides, poly n-vinyl carbazole, and the phosphonitrilic chlorides. More work needs to be done with these materials before it will be possible to determine their suitability for specific applications. Ultraviolet radiation is important in the use of plastics and deterioration can be serious under certain conditions of exposure.

Acrylics

Polymethyl methacrylate (Lucite or Plexiglas) is unaffected by gamma radiation to an exposure of 8.2×10^7 ergs $g^{-1}(C)$, but tensile strength and elongation are decreased by 25 per cent at an exposure of 1.1×10^9 ergs $g^{-1}(C)$. Physical properties deteriorate quite rapidly above that amount of radiation. Above 10^9 ergs $g^{-1}(C)$ of absorbed radiation, polymethyl methacrylate becomes very brittle.

Information on acrylic polymers shows that work has been done on the effects of vacuum, temperature, and ultraviolet (UV) radiation on Plexiglas (methylmethacrylate) and on acrylic coatings. Data for the latter are presented in the section on coatings, and the information on the plastic is given here.

Effect of Ultraviolet Radiation

Wahl and Robinson⁽³⁵⁾ observed the effects of ultraviolet radiation (2 pyrons) and vacuum ($6.0 \pm 3 \times 10^{-6}$ torr) for periods of 100 hours. Properties observed were surface and color changes, spectral transmission, luminous transmittance, and haze. Hardness, loss in weight, and changes in chemical structure after irradiation were also determined. Data are given in Table 37. Also included for comparison is Selectron 400, a heat-resistant polyester, transparent glazing material. Wahl stated that the plastics irradiated in a vacuum became slightly translucent and the haze measurements are of questionable value.

After vacuum exposure alone, Plexiglas 55 and Selectron 400 specimens lost less than 0.8 per cent in weight and there was no measurable change in Barcol hardness. With ultraviolet and vacuum, Plexiglas lost less than 2 per cent in weight and hardness decreased slightly. Selectron 400 showed no significant weight loss but a considerable increase in hardness. The irradiated Selectron 400 became very brittle and shattered when indented with the Barcol hardness tester. The surface of the plastics turned brown.

TABLE 37. PROPERTIES OF VACUUM-IRRADIATED TRANSPARENT GLAZING MATERIALS BEFORE AND AFTER 100-HOUR EXPOSURE⁽³⁵⁾

Material	Haze, per cent		Parallel Light Transmission, per cent		Weight Loss, per cent After	Barcol Hardness	
	Before Exposure	After Exposure	Before	After		Before	After
Selectron 400	6.2	74.8	89.3	22.3	0.22	14	52
Plexiglas 55	4.8	68.7	90.9	20.0	1.89	58	54
Stretched Plexiglas 55	6.9	70.0	89.2	5.0	1.80	59	54

Versluys, et al.,⁽⁵⁵⁾ also irradiated Plexiglas in vacuum with ultraviolet. Data are shown in Table C-1 of Appendix C. The outgassing was believed to be adsorbed nitrogen since the dissolved gas was found to be of mass 28. No discoloration was observed.

Ringwood⁽⁵⁶⁾ states that polymethyl methacrylate tends to unzip or depolymerize in a vacuum of 10^{-8} torr at ambient temperatures under exposure to rays shorter than $3800 \text{ \AA}$. In space this effect is accelerated by the increase in temperature in the plastic caused by the absorption of infrared rays. Surface discoloration and crazing have been observed under the same ultraviolet exposure but at higher pressures (10^{-6} torr) when tested in a chamber maintained at 72 F .

Temperatures at which there is 10 per cent weight loss per year are 40 to 150 C (100 to 300 F) for methylacrylate, and 100 to 200 C (220 to 390 F) for methylmethacrylate in vacuum. An acrylate (MIL-P-5425) showed 0.3 per cent weight loss on disciccation, an additional 0.03 per cent on vacuum exposure, and maintained 0.15 per cent (net weight loss) after re-exposure to air⁽⁵⁷⁾.

Acrylonitrile

Wilcox, et al.,⁽⁵⁸⁾ irradiated Acrilan in nitrogen with monochromatic light and irradiated samples with a G30T8 lamp in nitrogen and in a vacuum. Data are included in Tables C-2 and C-3. The shorter wavelengths produce greater changes in the tensile strength per joule of incident energy than the longer wavelengths produce. Tensile strength is degraded about 1.5 times as fast in nitrogen as in a vacuum. Jaffe and Rittenhouse⁽⁵¹⁾ give 20 C (240 F) as the temperature for 10 per cent weight loss per year for acrylonitrile polymer.

Acrylonitrile/Butadiene/Styrene Terpolymer (ABS)

At room temperature, Kralastic MV (an ABS polymer) increased in tensile strength when irradiated to a gamma exposure of $2.8 \times 10^{10} \text{ ergs g}^{-1}(\text{C})$. At $9.4 \times 10^{10} \text{ ergs g}^{-1}(\text{C})$, tensile strength decreased by 30 per cent. At 250 F , the polymer lost two-thirds of its tensile strength at an exposure of $8 \times 10^{10} \text{ ergs g}^{-1}(\text{C})$.

Lewis⁽¹⁵⁾ determined the effects of irradiation on two types of ABS polymers at 75 F and at 250 F. These materials were Kralastic MV and Kralastic SRA plastics. At 75 F, both materials increased in tensile strength when irradiated to an exposure of 2.3×10^{10} ergs $g^{-1}(C)$. At 9.4×10^{10} ergs $g^{-1}(C)$, tensile strength decreased by approximately 30 per cent of the original. The MV material increased in tensile strength from 3730 psi to a maximum of 5070 psi and then decreased to 2140 psi. The tensile strength of SRA material increased from 4730 psi to 6330 psi and then decreased to 2820 psi. In both cases, hardness increased with increasing radiation exposure. At elevated temperatures this change takes place more rapidly, and at 250 F Kralastic MV, non-irradiated, has a tensile strength of 3670 psi, while after irradiation to an exposure of 8×10^{10} ergs $g^{-1}(C)$ at 250 F tensile strength decreased to 1230 psi. Under the same conditions, the SRA material decreased from 4350 psi to 875 psi. Hardness of both materials increased with increasing radiation at the elevated temperatures in approximately the same fashion as it did when irradiated at room temperature.

Cellulose Acetate

Cellulose polymers are among the polymers least resistant to radiation damage. At an exposure of 1.9×10^9 ergs $g^{-1}(C)$, cellulose acetate has deteriorated by 25 per cent.

Weight-loss data for cellulose acetate and cellulose acetate butyrate only were found. Riehl⁽⁵⁷⁾ indicates that neither material lost weight in 24 hours in vacuum after first coming to constant weight in a desiccator.

Diallyl Phthalate

Diallyl phthalate has shown excellent radiation stability. For example, a case molded from diallyl phthalate Type FS80 which is flameproof and long-glass-fiber filled was exposed to 4.3×10^{16} nvt [the equivalent of 1.3×10^{10} ergs $g^{-1}(C)$]. The radiation resistance of this case was considered very good.⁽³⁸⁾ Also, coil forms, insulators, and standoffs were relatively unaffected at an exposure of 6.2×10^{12} ergs $g^{-1}(C)$.

Although there are changes in electrical properties such as dielectric constant, dissipation factor, and volume resistance while exposed to a radiation flux, recovery of these properties after exposure is very good. Electrical leakage resistance of diallyl phthalate connectors was reduced to 0.1 of the initial value at an integrated exposure of 8.8×10^{12} ergs $g^{-1}(C)$. The connectors were removed from the radiation field and within 15 minutes, leakage resistance had returned to the original value.^(59,60) Table 38 shows the change in leakage resistance with exposure.

The effect of vacuum and temperature on diallyl phthalate was studied by Podlaseck and Suhorsky⁽⁴⁾ and Fulk and Horr⁽¹⁷⁾. Data are presented in Tables C-4 and C-5. The effect of temperature on weight loss in air and in vacuum is shown in Figure 19. Diallyl phthalate has a very low equilibrium outgassing rate at moderate temperature similar to those of epoxies and polyesters. But like these, the initial rates are considerably higher than those for fluorocarbons, silicones, and Mylar.

TABLE 58. LEAKAGE RESISTANCE OF DIALLYL PHTHALATE CONNECTORS IN PILE - DYNAMIC TESTING⁽⁶⁰⁾

Radiation Exposure, n cm ⁻² (E _n > 2.9 Mev)	Leakage Resistance ^(a) , megohms at 55 C
None	56
1.68 x 10 ¹⁴	36
5.04 x 10 ¹⁴	41
1.34 x 10 ¹⁵	33
2.27 x 10 ¹⁵	12.5
3.36 x 10 ¹⁵	6.8
5.12 x 10 ¹⁵	5.8
6.47 x 10 ¹⁵	5.2
9.24 x 10 ¹⁵	5.9
9.58 x 10 ¹⁵	5.1
1.31 x 10 ¹⁶	6.2
1.43 x 10 ¹⁶	6.8
1.67 x 10 ¹⁶	6.8
Scram + 2 min	17.5
Scram + 22 min	40
Scram + 42 min	58
Scram + 237 min	90
Scram + 24 hours	110

(a) initial leakage measurement before installation = 4000 megohms at room conditions;
baseline leakage resistance = 56 megohms at 55 C.

Epoxy Resins

Epoxy resins are above average for plastics in radiation resistance, having withstood gamma exposures to 9.5×10^{10} ergs g⁻¹(C) without appreciable deterioration.

Aromatic-type curing agents provide the best irradiation resistance.

Epoxy resins have low-weight-loss equilibrium constants, although initial outgassing is somewhat greater.

Epoxy resins are considered for use in space applications primarily for laminates, adhesives, encapsulating or potting materials, and coatings. In general, epoxy resins have low-weight-loss equilibrium constants, although initial outgassing is somewhat greater. In this latter respect it is inferior to the fluorocarbons and silicone but superior to the phenolics.

Equilibrium-weight loss data⁽¹⁸⁾ are given in Table C-4. A comparison of the initial rates of weight loss of several materials as given by Gloria et al.,⁽⁶¹⁾ are shown in Figure C-1. Weight losses were also obtained by Fulk⁽¹⁷⁾ and are given in Table B-70.

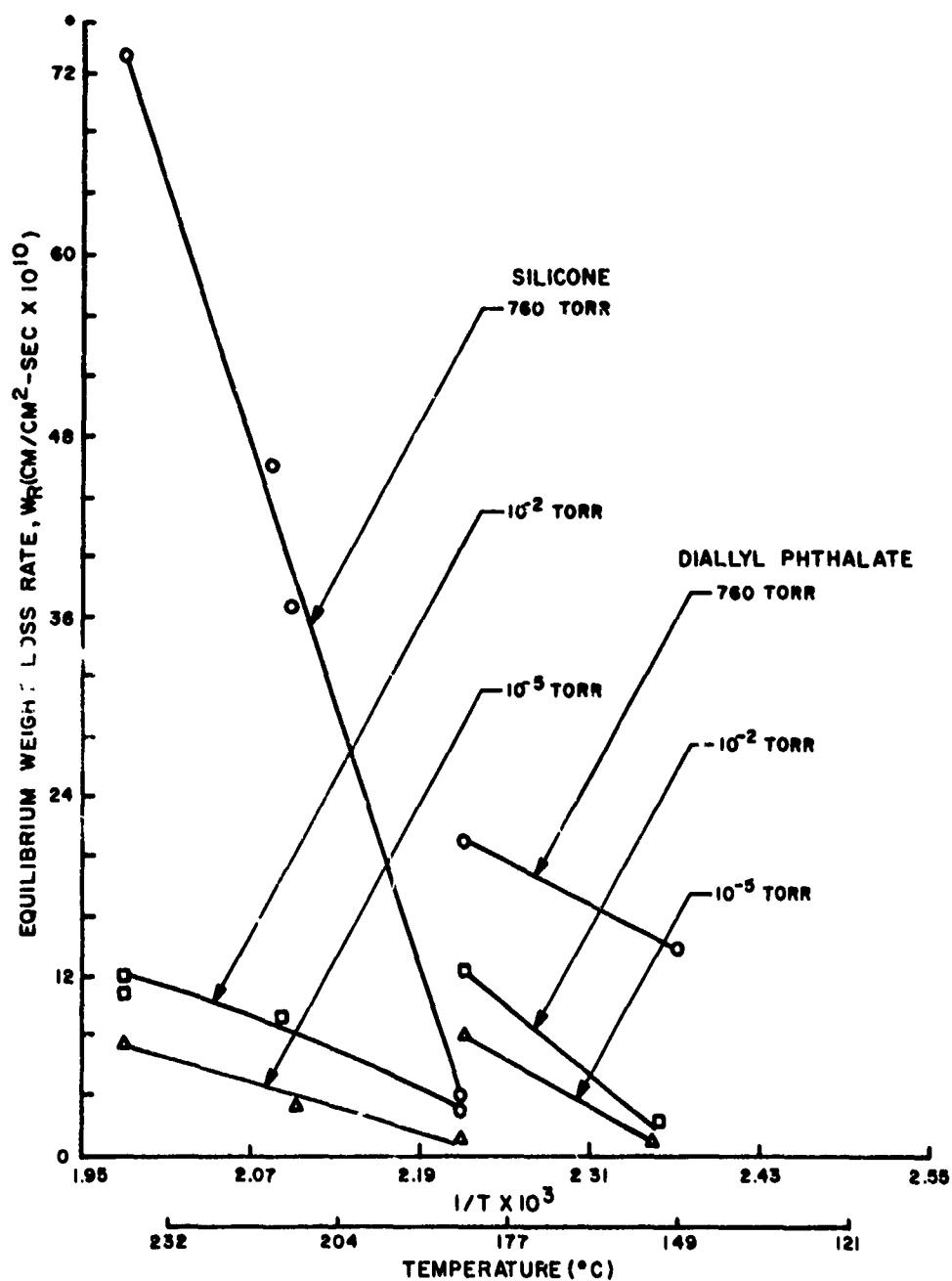


FIGURE 19. EFFECT OF TEMPERATURE ON WEIGHT LOSS IN AIR AND IN VACUUM⁽⁴⁾

At cryogenic temperatures, epoxies have the highest flexural strength, with phenolics and polyesters following in that order. (8)

Fluorocarbons

Teflon FEP 100 (a copolymer of hexafluoropropene and tetrafluoroethylene) is considerably more radiation resistant in air than is Teflon TFE (tetrafluoroethylene). Threshold damage for Teflon TFE in air occurs at 1.7×10^6 ergs $\text{g}^{-1}(\text{C})$, and 25 per cent damage is accrued at an exposure of 3.4×10^6 ergs $\text{g}^{-1}(\text{C})$.

In vacuum, tensile strength of Teflon TFE is satisfactory to 8×10^9 ergs $\text{g}^{-1}(\text{C})$.

Fiberglass reinforced Teflon retained 40 per cent of tensile strength and some flexibility at 1.2×10^{10} ergs $\text{g}^{-1}(\text{C})$ in air.

Tedlar (polyvinyl fluoride) as a 4-mil film showed good radiation resistance to an exposure of 10^{10} ergs $\text{g}^{-1}(\text{C})$, but decomposed and gave off a considerable quantity of HCl above that exposure.

Kynar (polyvinylidene fluoride) shows excellent retention of tensile strength when irradiated in air and in vacuum to 10^9 ergs $\text{g}^{-1}(\text{C})$.

Kynar is reported to have excellent resistance to ultraviolet radiation.

Fluorocarbons with their excellent temperature and chemical resistance and with good to excellent electrical characteristics are of great interest for space applications. Fluorocarbons for which information is available include Teflon TFE (polytetrafluoroethylene), Teflon FEP (a copolymer of hexafluoropropene and tetrafluoroethylene), Kel-F (chlorotrifluoropropylene), Tedlar (polyvinyl fluoride), and Kynar (polyvinylidene fluoride).

Teflon is probably the best illustration of the importance of considering all factors of space environment in determining the behavior of a material in space. Teflon has poor radiation resistance in air and originally this was believed to preclude its use for space applications. However, in an oxygen-free atmosphere (as in a vacuum) its radiation resistance is improved by about two orders of magnitude. It is being used successfully for many applications in satellites and numerous studies have been made to determine the behavior of this material in space. The following data show the results of these efforts. Most of the work has been with Teflon TFE, Teflon FEP and Kel-F. Limited data are available on Kynar and Tedlar. Comparative properties of the first three materials in air are shown in Table C-6, Appendix C.

Effects of Nuclear Radiation

In order to determine differences in radiation resistance among fluorocarbon polymers, Wattier, Newell, and Morgan⁽⁴⁸⁾ studied the radiation resistance of Teflon TFE, Teflon FEP 100, and Tedlar. They found that Teflon FEP 100 had considerably more radiation resistance in air than the standard TFE of the same thickness. Teflon FEP also shows greater stability in the absence of air, as can be noted in its radiation

resistance when immersed in Cronite 8515 or in helium. Fiberglass-reinforced Teflon showed good radiation resistance. This material retained some of its flexibility as well as 40 per cent of its tensile strength at a radiation exposure of 1.2×10^{10} ergs $\text{g}^{-1}(\text{C})$. Data are given in Tables C-7 through C-9.

Tedlar film decomposed and gave off a considerable quantity of HCl during irradiation. Radiation resistance of the 0.004-inch film was quite good up to an exposure of 1.0 to 1.4×10^{10} ergs $\text{g}^{-1}(\text{C})$. Data are included in Table C-10.

Effects of Nuclear Radiation and Vacuum

Golden and Hazell⁽⁵⁰⁾ irradiated Teflon in vacuum (10^{-6} torr). No change in color or opacity occurred at doses less than 1.3×10^{10} ergs $\text{g}^{-1}(\text{C})$, but above this dose, disks and film disintegrated. Polymers which had received a high radiation dose had a sharp melting point (327 C) and gave a clear colorless melt, whereas unirradiated material showed no visible change up to 400 C. Highly irradiated material evolved gas at and above the melting point.

Variation of tensile properties with increasing radiation dose are shown in Figure C-2. Table C-11 shows values as given by Shoffner⁽⁶²⁾. It may be seen in Figure C-2 that tensile strength equivalent to that of unirradiated material is maintained up to an irradiation exposure of 8×10^9 ergs $\text{g}^{-1}(\text{C})$. At higher exposures, the tensile strength, although somewhat erratic, is greatly decreased and at 1.2×10^{10} ergs $\text{g}^{-1}(\text{C})$ is reduced to a negligible value. However, elongation is reduced from 200 per cent for the unirradiated material to a few per cent after an exposure of 4×10^9 ergs $\text{g}^{-1}(\text{C})$. Thus degradation reduces the extensibility before appreciably reducing tensile strength. Infrared spectrographs of unirradiated samples and of those irradiated in air and in vacuum have been made.⁽⁸²⁾ Table C-12 shows the differences in unirradiated and irradiated samples.

Kerlin^(6,7) irradiated Teflon TFE and Kel-F in vacuum (2.5×10^{-7} torr) and tested the specimens while in vacuum (described as dynamic tests). The same polymers were irradiated in vacuum and in air and the tensile strength and ultimate elongation determined in air (described as static tests). Data are given in Tables C-13 and C-14. The difference between the effects of irradiation in vacuum and in air on ultimate strength and elongation can be seen in these tables. Although not strictly comparable, the ultimate strength and elongation appear to be greater when the materials are irradiated in vacuum than when irradiated in air. With Kel-F, tensile strength is greater than that for Teflon, and neither irradiation in vacuum and nor irradiation in air seriously affects tensile properties.

It may be noted that Teflon FEP shows better radiation stability in air than does TFE, but the improvement in vacuum is minor.

The effects of radiation on Duroid 5600, a glass-fiber-reinforced Teflon, and unfilled Teflon are similar. Kynar and Tedlar both show excellent retention of tensile strength and elongation when irradiated in air and in vacuum (see Table C-15). According to Kerlin, Kynar does not have low-temperature properties as good as those of Teflon. It has, however, excellent resistance to ultraviolet radiation.

The following data show the effect of vacuum and temperature with no irradiation. At 100 C, and after 100 hours exposure to a pressure of 10^{-7} torr, the weight loss of TFE resin was found by Jolley and Reed⁽⁶³⁾ to be 0.04 per cent and that of FEP resin was 0.08 per cent. No comparable data were found for Kel-F. However, Bringer⁽⁶⁴⁾ compares the outgassing of Kel-F and Teflon. He states that significant weight loss for Kel-F begins to occur at about 250 C, and for Teflon at about 350 C. Outgassing rate for Teflon at 25 C is 1.6×10^{-7} torr-liters/(sec)(sq cm). This compares with a value of 3.7×10^{-7} torr-liters/(sec)(sq cm) for aluminum. The rate of outgassing of Teflon TFE and FEP decreases with time. This is also true for Kel-F. Table C-16 gives the mole per cent and identity of evolved gases for Teflon TFE at 71, 180, and 200 C.

Analyses of gases evolved from vacuum outgassing of Teflon have indicated that no degradation of Teflon resins or of their properties occurs in high-vacuum service at room temperature. Tubing of Teflon in use in the vacuum systems (10^{-6} to 5×10^{-9} torr) of the Bendix Mass Spectrometer for more than 5 years has given no mass-spectrum-analysis evidence of outgassing or breakdown of the Teflon tubing.

Buckley and Johnson⁽⁶⁵⁾ conducted experiments to determine the effects of vacuum on friction and wear for three polymers, including Teflon (PTFE) and Kel-F (PCFE). Both friction and wear for unfilled PTFE and PCFE in vacuum were nearly the same and were high. In general, the wear mechanism of the two polymers sliding on stainless steel surfaces was one of an abrasion process. It was found that heat generated at the sliding interface was transferred to the wear particles abraded from the polymer and adhering to the metal surface. This increased surface temperatures and caused surface degradation of the particles.

Buckley determined the influence of fillers on the wear of Teflon and Kel-F in vacuum. Fillers used for these studies included glass fiber, molybdenum disulfide, copper, silver, and graphite. The addition of glass fibers and copper powder markedly improved the friction and wear characteristics for PTFE. Molybdenum disulfide offered essentially no improvement. It is believed that improvement came as a result of dissipation of frictional heat. The effect of fillers can be seen in Figure C-3.

Decomposition products were studied for PTFE. With unfilled polymer, the principal products of decomposition were the heavier-molecular-weight fragments of the polymer unit. With glass-filled compositions, the principal decomposition product was fluorine. Copper-filled Teflon gave very small concentrations of decomposition products.

As a matter of comparison, Buckley found the friction and wear characteristics of a polyimide resin to be superior to those of Teflon TFE in vacuum. This polyimide was stable to 500 F.

Effects of Cryogenic Temperatures

The utility of Kel-F and Teflon at cryogenic temperatures has been proven in practice by their extensive use in connection with liquid oxygen (-325 F) and liquid hydrogen (-425 F)⁽⁶⁴⁾. The plastics retain some degree of ductility at these temperatures. Figure C-4 shows the tensile behavior of the fluorocarbon plastics in the subzero regions. According to Vickers⁽⁶⁶⁾, FEP has an impact strength of 2.0 ft-lb/in. while Kel-F (medium crystallinity) has an impact value of 1.25 ft-lb/in. Elongation of FEP is four times as great as that for Kel-F at -420 F. On the other hand, Bringer⁽⁶⁴⁾, measuring

thermal contraction between room temperature and liquid-oxygen or -hydrogen temperature, found that Teflon contracts roughly twice as much as Kel-F. (See Figure C-5).

Kel-F was irradiated (nuclear) at cryogenic temperatures by Yasui⁽¹³⁾. At radiation exposures to 2.6×10^9 ergs $g^{-1}(C)$, the Kel-F 2-mil film was not significantly affected by irradiation in liquid nitrogen (see Figure C-6).

Effects of X-Ray and Vacuum

Low-frequency loss properties of TFE polymers are drastically affected by X-ray irradiation.⁽⁶³⁾ High-frequency loss properties are considerably less affected. Increases in dielectric constant and dissipation factor depend on the ambient oxygen concentration during exposure and recovery.

The dielectric constant and dissipation factor of Teflon FEP resins are unaffected by X-ray irradiation in vacuum for measured frequencies of 50 cps to 100 kcps.

Figure C-7 shows the effect of X-ray irradiation in air and in vacuum on dissipation factor of Teflon. Recovery characteristics are shown in Figure C-8. Changes in dielectric constant are shown in Figure C-9. In the case of FEP, dissipation factor and dielectric constant were unaffected by X-ray irradiation in vacuum (Figures C-10 and C-11), although physical and optical property changes were evident.

Measurements of electrical properties made during irradiation without removal from oxygen are given by Bringer⁽⁶⁴⁾. A comparison of the effects of X-ray irradiation on the dissipation factor of PTFE in both air and in vacuum are given in Figure C-12.

Effects of Ultraviolet and Vacuum

Wilcox, et al.,⁽⁵⁸⁾ irradiated Teflon with monochromatic light in nitrogen and with a G30T8 lamp in nitrogen and in vacuum. Data are given in Tables C-17 and C-18. The shorter wavelengths are more damaging than the longer wavelengths. Ultraviolet produces greater changes in elongation than in tensile strength; irradiation in a vacuum is approximately 14 times as severe as that in nitrogen.

Phenolic Resins

Unfilled phenolics stand fairly low in radiation resistance, 25 per cent damage being accrued at an absorbed dose of 10^9 ergs $g^{-1}(C)$. When irradiated, they swell, become very brittle, and tend to crumble.

The addition of fillers, particularly mineral fillers, increases the stability of phenolics. Phenol-formaldehyde with asbestos filler (Havag 41) shows excellent radiation stability, being one of the more radiation-resistant plastics. It is unaffected by a radiation exposure of 3.9×10^{10} ergs $g^{-1}(C)$ and is damaged by 25 per cent at an exposure of 3.9×10^{11} ergs $g^{-1}(C)$.

Phenolic laminates irradiated to an exposure of 2×10^9 ergs $\text{g}^{-1}(\text{C})$ at temperatures of 600, 700, 800, and 900 F showed flexural-strength values equivalent to or higher than those for laminates heated to these temperatures with no irradiation.

Redeker and Van Sickle⁽⁶⁷⁾ studied the effect of radiation on phenolic-model compounds in a fundamental approach to determine basic chemical reactions involved. They found that the ring-connecting methylene bridges were most easily broken when ortho to a hydroxy group. The hydrogen-oxygen bond appeared to be the most labile to radiolysis, followed closely by the carbon-oxygen bond. Their work suggested that, for radiation environmental applications, as many para links should be used in the polymer as is possible. The work also suggests that incorporation of polyhydroxybenzenes or naphthalenes into resins as a means of providing energy sinks or dissipators for the absorbed radiation is desirable.

Phosphonitrilic Chloride Polymers

Glass-cloth laminates with this resin showed excellent stability at 455 F and a exposure of 6×10^{10} ergs $\text{g}^{-1}(\text{C})$.

A blend of this resin and acrylonitrile showed excellent tensile strength when irradiated in air to 10^{11} ergs $\text{g}^{-1}(\text{C})$. However, elongation decreased to about 25 per cent when the blend was irradiated to 2.5×10^{10} ergs $\text{g}^{-1}(\text{C})$. Elongation decreased from 138 per cent to 94 per cent when heated to 110 F for 33 hours with no irradiation.

General Dynamics⁽¹⁾ developed a resin which is a derivative of phosphonitrilic chloride and which is designated as AP-Resin-XHU. The resin contains a number of unreacted polar groups (hydroxyphenyl) which can be reacted with selected curing agents and monomeric or polymeric materials containing reactive constituents. Blends of this resin with phenolics, polyesters, epoxies, polyamides, and many elastomers can be prepared. The cured resin or resin-polymer blends are reported to have flame resistance, high heat stability, high structural strength, and excellent environmental resistance.

Several of the phosphonitrilic chloride polymeric blends were irradiated both at room temperature and at elevated temperatures. A blend of the AP-Resin XHU and acrylonitrile was prepared and irradiated in air, and immersed in 5P4E polyphenyl ether (Monsanto OS-124) at temperatures ranging from 75 to 340 F. Data for this material are shown in Table 39.

In general, exposure of the blend to elevated temperatures and radiation resulted in an increase in tensile strength, elastic modulus (compression), and hardness. However, elongation decreased from 138 per cent to 94 per cent when the blend was heated to 110 F for 33 hours with no irradiation. When irradiated to 2.5×10^{10} ergs $\text{g}^{-1}(\text{C})$ in air at this same temperature, elongation decreased to 26 per cent. Elongation was 50 per cent when the material was immersed in the polyphenyl ether for 33 hours at 110 F with no irradiation. After irradiation to 2.1×10^{10} ergs $\text{g}^{-1}(\text{C})$ in the oil at 110 F (33 hours), elongation was 30 per cent. Glass-cloth laminates of this resin showed excellent radiation stability at 455 F to an exposure of 6×10^{10} ergs $\text{g}^{-1}(\text{C})$. Data are included in the section on laminates.

TABLE 39. PROPERTIES OF A BLEND OF AP-K⁵, N-XHU AND ACRYLONITRILE POLYMER(1)

Exposure		Medium: Temp, F; Cycle; and Time, hr	Strength(a), psi	Ultimate Elongation(a), %	Elastic Modulus (Compression)(a), psi	Hardness(a), Shore D
Gamma, ergs g ⁻¹ (C)	Neutron n cm ⁻² (E > 2.9 Mev)					
Control		Air, 75, --, --	2,219/30/8	138/5.5/7	48,041/5,578/3	65.9/1.4/5
Control		Air, 110, II, 33	2,242/163/5	94/5.6/5	52,467/1,162/3	73.8/0.9/5
2.5 x 10 ¹⁰	2.2 x 10 ¹⁵	Air, 110, II, 33	4,760/132/5	26/2.5/5	75,031/1,743/3	67.1/1.9/5
Control		Air, 150, I, 33	2,599/243/5	76/9.7/4	57,913/1,395/3	85.4/0.4/5
9.1 x 10 ¹⁰	1.0 x 10 ¹⁶	Air, 150, I, 33	8,067/1,230/5	1.1/1/5	124,943/2,905/3	68.1/0.8/5
Control		Oil, 110, II, 33	2,481/55/5	50/12/5	56,614/2,105/2	62.5/1.3/5
2.1 x 10 ¹⁰	2.1 x 10 ¹⁵	Oil, 110, II, 33	4,772/216/5	30.6/1.8/3	77,870/2,615/3	65.6/2.1/5
Control		Oil, 200, III, 33	2,824/257/5	35/5.6/5	45,253/698/2	73.9/2.1/5
7.5 x 10 ¹⁰	1.0 x 10 ¹⁶	Oil, 200, III, 33	6,839/555/5	3/1/4	101,659/1,162/3	88/1.1/5
Control		Air, 240, IV, 31(b)	6,321/1,597/2	0	133,791/6,974/3	34.8/1.9/5
6.8 x 10 ¹⁰	5.9 x 10 ¹⁵	Air, 240, IV, 31(b)	2,538/1,027/4	0	95,096/2,324/3	89.6/1.6/5
Control		Air, 310, VI, 31(b)	3,023/237/5	0	129,199/1,162/3	90.8/1.6/4
2.2 x 10 ¹¹	2.4 x 10 ¹⁶	Air, 310, VI, 31(b)	1,798/723/5	0	125,920/11,621/3	76.9/1.6/4
Control		Oil, 270, V, 31(b)	2,490/467/4	0	51,467/2,350/3	65.7/2/5
5.2 x 10 ¹⁰	5.1 x 10 ¹⁵	Oil, 270, V, 31(b)	5,623/322/5	8.4/1.3/5	49,181/2,324/3	79.0/2.1/5
Control		Oil, 340, VII, 31(b)	2,720/1,016/3	0	59,353/2,905/3	78.9/2.1/5
1.7 x 10 ¹¹	2.4 x 10 ¹⁶	Oil, 340, VII, 31(b)	3,962/668/5	0	104,671/3,487/3	

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = a range value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Tensile specimens sagged and bent during the 14-day storage at 350 F; consequently, the data for these samples are of doubtful validity.

Polyacetal

No radiation data were found for this polymer. Podlaseck and Suhorsky⁽⁴⁾ gave the equilibrium-weight-loss rate for Delrin 500 and Delrin 507 (carbon-black-filled 500); see Table C-4 in Appendix C. Values were also given by Fulk⁽¹⁷⁾ in Table B-70 (Appendix B). These were the only data found for this polymer.

Polyamide (Nylon)

Nylon, tested in sheet form, reaches threshold damage at an absorbed radiation of 8.6×10^7 ergs $g^{-1}(C)$ and 25 per cent damage at 4.7×10^8 ergs $g^{-1}(C)$. Its tensile strength increases with radiation, reaching 25 per cent increase at 10^{11} ergs $g^{-1}(C)$.

Nylon fiber was reported to have lost more than 50 per cent of its original strength at an exposure of 8.5×10^8 ergs $g^{-1}(C)$.

The service life of nylon in air can be increased by the use of antirads or antioidants.

Nylon shows good heat stability in vacuum.

Koehler and Pefhany⁽²⁸⁾ reported that nylon (Zytel 33), when irradiated to 2×10^{10} ergs $g^{-1}(C)$ in a dry atmosphere was satisfactory and could be used in a gaging system for reactor pressure tubes designed to measure surface defects during periods of reactor shutdown. A nylon ring used in this equipment was also satisfactory, although its color changed to a brown.

Although the following data are not concerned with the effects of nuclear radiation, they are of interest with respect to space applications. These include weight-loss data in vacuum, and the effect of thermal radiation, ultraviolet, and the effect of fillers on lubrication properties of nylon in vacuum.

The stability of nylon in space environments will vary according to the processing of the material. However, in general, nylon is useful under space conditions. Podlaseck and Suhorsky⁽⁴⁾ give the equilibrium-weight-loss rate as follows:

Material	Temperature, C	Pressure, torr	Equilibrium-Weight- Loss Rate, $g/(sq\ cm)(sec) \times 10^{10}$
Nylon (Zytel 105) (carbon-black-filled 101)	50	5×10^{-6}	0.33
	100	5×10^{-6}	3.3
Nylon (Zytel 31) (electrical grade nylon)	50	5×10^{-6}	0.89
	100	5×10^{-6}	3.3
Nylon (Zytel 101) (standard grade nylon)	50	5×10^{-6}	0.94
	100	5×10^{-6}	4.2

Jaffe and Rittenhouse⁽⁵¹⁾ give the temperature for 10 per cent weight loss per year for nylon in high vacuum as 30 to 210 C (80 to 410 F). He indicates nylons show high decomposition rates in vacuum. However, Riehl⁽⁵⁷⁾ states that nylon lost 0.05 per cent weight on desiccation and 0.01 per cent more on vacuum exposure. It returned to its original weight (<0.001 per cent difference) on re-exposure to air. He thus claims that vacuum exposure served only to provide more drastic desiccation.

Boundy⁽³¹⁾ reported the weight loss of Nylon-101 in vacuum (10^{-6} torr) at 75, 150, and 300 F. Even at 300 F, the weight loss was only about 0.63 per cent (see Figure 20).

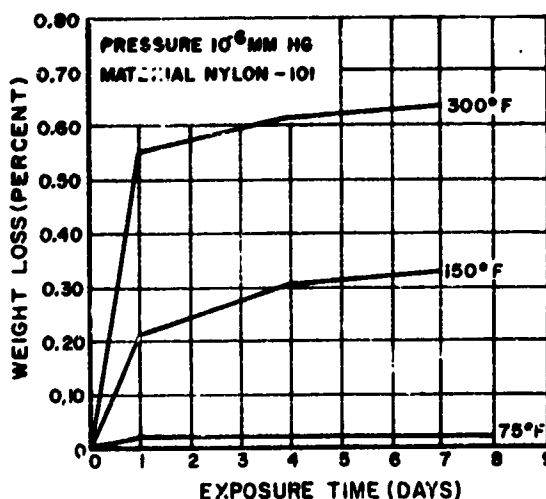


FIGURE 20. PER CENT WEIGHT LOSS VERSUS TIME AT 10^{-6} TORR AND VARIOUS TEMPERATURES FOR NYLON⁽³¹⁾

Hargreaves⁽⁶⁸⁾ exposed Nylon 66 to thermal radiation in vacuum. Results are given in Table C-19 in Appendix C. He found that heat and vacuum (10^{-5} torr) decreased the over-all transmission in the 220 to 330 mμ range. The effect of heat and vacuum is, first, to induce crosslinking but later, to induce chain scission. However, less than 2 per cent of the chemical structures are affected. Thermal radiation in the range of 180 to 275 C has no significant effect on the melting point. Specimens heated to 275 C darkened, fused, and were insoluble in a calcium chloride-methyl alcohol solvent. The fiber was brittle and useless as such, but the basic structure was unchanged.

Wilcox, et al.,⁽⁵⁸⁾ found that changes in tensile strength of nylon were produced twice as fast by ultraviolet in nitrogen as in a vacuum (see Tables C-20 and C-21). Blackmon⁽⁵⁾ states that nylon irradiated in a vacuum (10^{-7} torr) with ultraviolet for 91 hours shows very slight discoloration, and retains good tear and tensile strengths.

Because of its stability in vacuum, and because of its use as bearings which need no lubrication, nylon has been examined for use as a dry lubricant for space applications. Bowen⁽⁶⁹⁾ determined the wear of nylon materials containing various fillers. Tests were run at rubbing velocities of 40 and 230 ft/min. at temperatures of 86 F and 160 F. The load on the test block was 3 pounds (150 psi for a 2-mm scar width). The atmosphere was nitrogen. The nylon which did not contain a lubricant filler was unsatisfactory; it

was considered better with 40 per cent MoS_2 filler (Nylasint 144) than with 20 per cent carbon-graphite (even though the friction is higher because of the expected poor lubricating qualities of graphite in a space environment). Outgassing tests, however, indicated that Teflon would be more acceptable than the nylon.

Polycarbonates

Lexan retained strength and toughness after an exposure of 8×10^9 ergs $\text{g}^{-1}(\text{C})$, but these properties decreased rapidly after 9×10^9 ergs $\text{g}^{-1}(\text{C})$. It can probably be considered as useful to 10^{10} ergs $\text{g}^{-1}(\text{C})$.

Radiation resistance of Lexan in vacuum is only slightly better than that in air.

At 300 F, polycarbonates are superior to nylon with respect to vacuum-thermal stability.

Polycarbonates have excellent impact strength and dimensional stability and resist thermal-oxidative degradation up to 150 C. They are reasonably good with respect to radiation resistance. (70) Lexan (General Electric polycarbonate) retained most of its original strength and toughness after irradiation to 8×10^9 ergs $\text{g}^{-1}(\text{C})$. However, in another investigation, a sample irradiated in air⁽¹¹⁾ was found to have lost all tensile strength at an exposure of 2.9×10^{10} ergs $\text{g}^{-1}(\text{C})$. Oxidation is relatively minor below an exposure of 8.8×10^9 ergs $\text{g}^{-1}(\text{C})$. Merlon polycarbonate irradiated at 75 F to a dose of 3.5×10^{10} ergs $\text{g}^{-1}(\text{C})$ in air showed no appreciable change in hardness. Its ultimate strength decreased from 8590 psi to 2070 psi. At 10^{10} ergs $\text{g}^{-1}(\text{C})$, elongation decreased from 104 per cent to 54 per cent. At an exposure of 2×10^{11} ergs $\text{g}^{-1}(\text{C})$, the material was too brittle to determine these properties. Thus it would appear that these materials would be satisfactory to an exposure of about 10^{10} ergs $\text{g}^{-1}(\text{C})$, but that properties begin to fall off considerably above that exposure.

Samples irradiated in vacuum were very brittle after an exposure of 8.8×10^{10} ergs $\text{g}^{-1}(\text{C})$. Giberson⁽⁷¹⁾ states that it is possible that less than this exposure dose would be required to obtain this degradation. Evidently the radiation stability of this polymer in vacuum is just slightly better than its stability in air. Giberson concluded that degradation of polycarbonates in an irradiation field occurs by a chain-scission mechanism.

Moulton and associates⁽⁷²⁾ studying the effect of X-ray irradiation on the optical, electron paramagnetic resonance, and diffusion properties of Lexan found that X-ray irradiation induced cross linking rather than degradation of the polymer.

Jaffe and Rittenhouse⁽⁵¹⁾ give 180 C (350 F) as the temperature for 10 per cent weight loss per year in vacuum, but indicate that the basis for this value is not too reliable. Gloria, et al.,⁽⁶¹⁾ tested Lexan in vacuum and found its initial weight loss to be similar to that of Teflon. There was no apparent change in physical appearance up to its heat-distortion temperature. The initial rates of weight loss of Lexan, epoxy, nylon-phenolic, and silica-phenolic were found to increase significantly with decreasing material thickness, indicating that the diffusion of the reaction products through the bulk of the material was a controlling factor in the weight-loss process of these materials.

Boudry⁽³¹⁾ determined the weight loss of polycarbonate resin in a vacuum (10^{-6} torr) at 75, 150, and 300 F. Data are shown in Figure 21. At the higher temperatures, polycarbonate is markedly superior to nylon as far as vacuum-thermal stability is concerned.

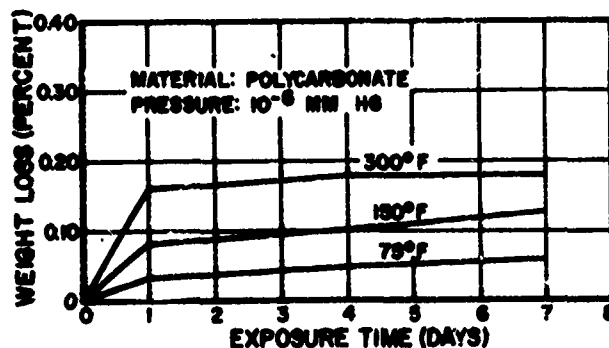


FIGURE 21. PER CENT WEIGHT LOSS VERSUS TIME AT 10^{-6} TORR AND VARIOUS TEMPERATURES FOR POLYCARBONATE⁽³¹⁾

Polyesters

Unfilled polyesters have poor radiation stability, hardening and developing small cracks under irradiation. Their properties begin to change at approximately 10^7 to 10^8 ergs g^{-1} (C).

Oriented films appear to have greater stability than the random polymer. Mylar (polyethylene terephthalate) has been reported as reaching threshold damage at an exposure of 4.4×10^8 ergs g^{-1} (C) and 25 per cent damage at about 8.7×10^9 ergs g^{-1} (C).

Irradiation of Mylar in vacuum to 8.7×10^9 ergs g^{-1} (C) produced the same damage as 4.4×10^9 ergs g^{-1} (C) in air.

Mylar is unaffected during thermal aging up to 200 C (392 F) by irradiation, except at levels above 10^{10} ergs g^{-1} (C).

When exposed to ultraviolet in a vacuum, Mylar decreases in tensile strength and elongation.

Polyesters are used in laminates and in coatings and are covered in those sections of this report. Matacek⁽⁷³⁾ reported on work in which cumulative stepwise weight losses were obtained. One of the resins tested was unfilled Paraplex P-43 polyester. After exposure to 400 F and a vacuum of 4×10^{-5} torr for 24 hours, the polyester had lost 20 per cent in weight, and testing of this material was discontinued. Luperco ATC had been used as the catalyst, and it has been shown that benzoyl peroxide can cause depolymerization under proper conditions. This and the fact that no filler was present may have been part of the reason for the high weight loss.

Polyethylene Terephthalate (Mylar)

Kerlin and Smith⁽⁷⁾ irradiated Mylar A and Mylar C in air and in vacuum. Although earlier tests had shown irradiation to be less damaging in vacuum than in air (particularly with a 3-mil film), later results (see Table C-22 in Appendix C) would indicate that there is little difference between irradiation in air and in vacuum.

Yasui⁽¹³⁾ irradiated Mylar film, aluminized Mylar, and several Mylar laminates at cryogenic temperatures. There were no significant effects on these materials. Data are shown in Figures C-13 to C-15.

Mylar capacitors were tested for performance characteristics in a nuclear-radiation field at Bendix Systems Division of Bendix Corporation⁽³⁸⁾ and at Litton Industries⁽²⁷⁾. The results of the tests at Bendix indicated that film capacitors were well suited for use in radiation environments, at least up to an exposure of approximately 10^{10} ergs g^{-1} (C) (about 10^{15} nvt). Capacitance and dissipation factor were little affected by irradiation. Leakage resistance was reduced during irradiation whenever the reactor was at power, but no permanent changes in leakage resistance were observed. The capacitors became slightly radioactive during the irradiation; this activity was sufficiently small to indicate that these capacitors do not present a serious handling problem when used in radiation environments with thermal-neutron shielding. Litton Industries, on the other hand, found that the Mylar film-foil capacitors suffered permanent degradation in insulation resistance, i. e., their insulation resistance showed negligible recovery 24 hours after removal from the environment. The exposure was 10^{11} ergs g^{-1} (C) (10^{16} r cm⁻², $E_n > 2.9$ Mev). Also, it was shown that the electrical properties of capacitors made from the same dielectric material but by different manufacturers differed considerably from one another.

Mylar has been found to have extremely low outgassing rates at room temperature, similar in this respect to fluorocarbons and silicones. Riehl⁽⁵⁷⁾ tested the stability of Mylar under high vacuum (Table C-23). Plain and aluminum-vapor-coated Mylar films were exposed to various temperatures at a pressure of 10^{-5} to 10^{-6} torr for a duration of 72 hours. It was found that Mylar, with or without an aluminum coating, exhibited only a slight loss in flexibility after exposure to the test conditions at room temperature. At 100 C, under the same conditions of pressure and time, weight losses were appreciable. Both coated and uncoated films warped and/or wrinkled, and all samples suffered appreciable losses in flexibility. Similar tests at 150 C produced increased weight losses and distortion.

Effects of Ultraviolet Radiation

Versluys, et al.,⁽⁵⁵⁾ subjected Mylar to ultraviolet radiation at 10^{-8} torr to a dose of 50 hours of insolation in the 1300 to 1850 Å band and 565 hours in the 1100 to 1300 band. Weight loss was 0.2 ± 0.2 per cent. Vacuum exposure alone gave 0.3 ± 0.3 per cent. The released gas was analyzed by means of a mass spectrometer and found to be nitrogen, which was assumed to be adsorbed to the Mylar

Table C-24 shows the effect of vacuum and combined vacuum and ultraviolet on Mylar aluminized on one side, as determined by Snyder⁽⁴⁷⁾. Ultraviolet (770 hours' exposure) caused a decrease of 43 per cent in tensile strength and a decrease of

88 per cent in ultimate elongation. Table C-25 shows the effect of ultraviolet and vacuum on the tensile strength at butt-seamed areas using Mylar tape with various adhesives.

Wilcox, et al.,⁽⁵⁸⁾ irradiated Mylar in nitrogen and in vacuum with ultraviolet (Tables C-20 and C-21). Elongation decreased faster for samples irradiated in nitrogen than it did for samples irradiated in a vacuum. Also, tensile strength was less affected in vacuum than in nitrogen.

Blackmon, et al.,⁽⁵⁾ also reported the effects of ultraviolet and vacuum on Mylar, both metalized and nonmetalized. After 91 hours at 80 F and 10^{-7} torr, there was no change in the aluminized Mylar. The uncoated 5-mil material turned brown and disintegrated on handling.

In summary, Mylar has low outgassing in a vacuum at room temperature. However, elevated temperatures and, particularly, ultraviolet adversely affect weight loss and tensile properties.

Polyethylene

Polyethylene is unaffected by radiation to an absorbed radiation of 1.9×10^9 ergs g^{-1} (C), and accrues 25 per cent damage at 9.3×10^9 ergs g^{-1} (C). Tensile strength increases at first, but at approximately 1.1×10^{10} ergs g^{-1} (C), it begins to decrease, and is 25 per cent lower than the initial value at approximately 10^{12} ergs g^{-1} (C).

Polyethylene is subject to oxidation when irradiated. As a result it is more stable in vacuum than in air.

Kerlin and Smith⁽⁷⁾ found that Marlex 6002, a high-density polyethylene, irradiated in air to an exposure of 10^9 ergs g^{-1} (C) decreased in elongation from 907 per cent to 14 per cent. However, in vacuum, the decrease was only to 675 per cent. Tensile strength increased both in air and in vacuum but the increase was slightly higher in vacuum. Data are shown in Appendix C, Table C-26.

Gray, et al.,⁽⁸⁾ found polyethylene, along with silicone rubber, to be the most effective seal for reciprocating service in a vacuum environment. Leak rates were very low (5×10^{-5} standard cubic centimeters of helium gas per second) after test durations of 30 minutes. Gray suggests that a dry lubricant such as molybdenum disulfide should be used to obtain good results. Polyethylene and Vinylite (polyvinyl chloride), in an O-ring configuration, were also effective in static sealing applications. They were not appreciably affected by 2-week vacuum exposures at 1×10^{-7} torr.

Jaffe and Rittenhouse⁽⁵¹⁾ list polyethylene and polypropylene as exhibiting good-to-excellent behavior in high vacuum. Fulk⁽¹⁷⁾ determined the equilibrium-weight-loss rate for irradiated polyolefins (probably polyethylene). Values are given in Table B-70 (Appendix B).

Versluys, et al.,⁽⁵⁵⁾ studied the effect of ultraviolet on polyethylene and noted that weight loss in vacuum with no irradiation was 0.3 ± 0.2 per cent, but when irradiated, no weight loss was observed. The exposure did not change the appearance of the

polymer. The exposure of the sample was equivalent to 28 hours of insolation in the 1300 to 1850 Å band and 1975 hours in the 1100-1300 Å band.

Wilcox, et al., (58) irradiated polyethylene with ultraviolet light in nitrogen and in vacuum. A wavelength of 244 mμ was more damaging than the 314 or 369 mμ. Also, changes in tensile strength were produced about three times faster in nitrogen than in a vacuum (see Table C-20).

Polypropylene

Polypropylene has been found to be inferior to polyethylene in radiation resistance. At an exposure of 8.7×10^9 ergs g⁻¹ (C), it has become brittle and lost all of its elongation and most of its tensile strength.

Sauer (74) in his studies of the effects of gamma irradiation on the dynamic mechanical properties of various polymers has shown that crosslinking efficiencies of polypropylene are from one and one-half to two times greater for quenched isotactic polypropylene samples than for annealed specimens.

Polyallomers

Irradiated to an exposure of 9.4×10^{10} ergs g⁻¹ (C) at 75 F, a propylene-ethylene polyallomer retained only 25 per cent of its tensile strength. Above 2.8×10^{10} ergs g⁻¹ (C), hardness decreased and the material became very tacky. Elongation decreased considerably between 3×10^8 ergs g⁻¹ (C) and 10^9 ergs g⁻¹ (C).

These materials are defined as crystalline thermoplastic polymers produced from two or more different monomers. These are not copolymers in the usual sense, nor are they blends, but are more like block polymers. One of the more interesting of these is the propylene-ethylene polyallomer. This polymer exhibits many of the best properties of both high-density polyethylene and crystalline polypropylene. Propylene-ethylene polyallomers are superior to the linear polyethylene in flow characteristics, softening point, hardness, stress-crack resistance, and mold shrinkage. They overcome the most serious property deficiencies of crystalline polypropylene, offering lower brittleness temperatures, higher impact strengths, and less notch sensitivity. However, the polyallomers retain the desirable built-in hinge effect that is exhibited by crystalline polypropylene. Polyallomers in many respects are as easy to mold as crystalline polypropylene and easier to mold than linear polyethylene.

In wire covering and cable jacketing, the propylene-ethylene polyallomers offer a good balance of impact strength, elongation, stress-crack resistance, and low-temperature toughness while retaining the desirable electrical properties of the other polyolefins.

Lewis (15) irradiated a propylene-ethylene polyallomer at room temperature and at temperatures of 205 to 250 F. When the material was irradiated to 9.4×10^{10} ergs g⁻¹ (C) at 75 F, tensile strength decreased from 4380 psi to 1100 psi. Above 2.8×10^{10} ergs g⁻¹ (C), hardness decreased and the material became very tacky. Elongation

decreased considerably between 3×10^8 and 10^9 ergs g^{-1} (C). At 250 F, after irradiation to an exposure of 2.4×10^{10} ergs g^{-1} (C), the specimens were stuck to the foil wrapper and tore easily. At 200 F, tensile strength decreased from 4390 psi to 1300 psi at an exposure of 2.9×10^9 ergs g^{-1} (C) while elongation decreased from 688 per cent to 34 per cent at an exposure of 9.7×10^8 ergs g^{-1} (C). Data are shown in Table 40.

TABLE 40. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON PROPYLENE-ETHYLENE POLYALLOMER (CRYSTALLINE POLYMER) (EASTMAN)(a)(15)

Gamma Exposure, ergs g^{-1} (C)	Temp, F	Hardness(b), Shore D	Yield Strength(a), psi	Tensile Strength(a), psi	Ultimate Elongation(a), %
0	75	63.9	3280/123/15	4380/482/15	770/60/15
3.2×10^8	80	67.1	3460/84/15	4050/493/15	771/63/15
1.2×10^9	80	69.5		3470/171/15	20/5.7/15
2.7×10^9	75	70.3		2850/79/14	5
8.3×10^9	75	71.6		2130/122/15	2-3
2.8×10^{10}	75	64.7		2880/100/15	22/5/15
9.4×10^{10}	75	35.4(c)		1100/75/13	30/9.0/13
0	250	69.7	3300/44/15	4390/196/15	688/40/15
2.7×10^8	205	68.9	3330/62/14	3100/469/15	687/22/11
9.7×10^8	205	68.7		3360/93/15	34/12/15
2.9×10^9	230	69.4		1300/135/14	Small
1.1×10^{10}	235	63.1		1400/135/15	5
2.4×10^{10}	245	(d)			(e)
8.0×10^{10}	248	(d)			(e)

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Average of 30 measurements.

(c) Very tacky.

(d) Too tacky to measure.

(e) Specimens were stuck to foil wrapper and tore easily.

Polyimide

Nomex yarn (Fiber HT-1) was reported to be unaffected to an exposure of 3.3×10^{10} ergs g^{-1} (C).

At 500 F and 1.4×10^9 ergs g^{-1} (C) gamma exposure, the yarn retained 45 per cent of its elongation and 62 per cent of its tensile strength.

Polyimide fiber [HT-1 (Du Pont Nomex yarn)] has approximately the same strength characteristics as nylon, with greatly increased resistance to heat and gamma irradiation. (75) There are no melt-flow characteristics below 750 F. It does not have the objectionable melt-drop characteristics of nylon. Its strength is unaffected by exposure to 3.3×10^{10} ergs g^{-1} (C) gamma irradiation. No practical solvents for this yarn are known at present.

McGrath⁽⁷⁶⁾ irradiated Nomex yarns at 100, 400, 500, and 600 F. These were then oven aged for 2 hours. The natural yarn and two-color sealed yarns were irradiated, the colors used being International Orange and Olive Green. Strength and elongation properties are given in Tables C-27 through C-34 in Appendix C. It may be noted in Tables C-30 and C-33 that the natural yarn when irradiated at 500 F to an exposure of 1.4×10^9 ergs g^{-1} (C) retained 45 per cent of its elongation and 62 per cent of its strength. Variations between the dyed yarns and the natural yarns were believed to be due to a variation in the yarns and twist of the yarns rather than to the color process.

Stephenson, et al.,⁽⁷⁷⁾ irradiated polyimide fibers [HT-1 (Du Pont)], polybenzimidazole, and thiazole polymer (Southern Research Institute). During ultraviolet irradiation of HT-1, no volatile products were detected. No differences in degradation were noted between irradiations in air, nitrogen, or vacuum (10^{-3} and 10^{-6} torr) (see Figure C-16). Exposure to energy at a wavelength of 369 m μ caused greater deterioration than that at 244 or 314 m μ . Irradiation of polybenzimidazole fibers with 253.7 m μ light from the G30T8 lamp produced greater deterioration of tensile properties in oxygen than in nitrogen or in vacuum (see Figure C-17). Irradiation in nitrogen produced effects in elongation that were intermediate between those produced by irradiation in oxygen and in vacuum.

Fibers of a thiazole polymer appeared not to be affected differently in nitrogen, oxygen, and vacuum. As shown in Figure C-18, no loss of tensile strength due to X-ray irradiation was apparent, but some decrease in elongation was noted.

Du Pont "H" film, considered for use as a hydrogen barrier, was irradiated (nuclear) while immersed in liquid nitrogen.⁽¹³⁾ Tensile and tear strengths of 2-mil sheet were similar to those of 2-mil Mylar. These properties were not significantly affected by exposure to 2×10^9 ergs g^{-1} (C). Data are shown in Figure C-19. Radiation did not affect hydrogen permeability.

Mathes⁽⁷⁸⁾ evaluated wire insulation for cryogenic applications after thermal aging in air and vacuum and after moisture exposure. Among the materials examined were HML (a heavy aromatic polyimide enamel), HML asbestos [a polyimide solution (ML) coated, felted asbestos], and Glass/ML [a polyimide solution (Du Pont ML) coated glass fiber insulation]. These were also examined at cryogenic temperatures. The advantages of the ML material is that it has the greatest flexibility at cryogenic temperatures, excellent thermal stability, mechanical toughness, and no measurable thermal cut-through. Its disadvantages are that it is available only as a relatively thin film coating and it is somewhat sensitive to moisture. Evaluation of coated wires consisted of repeated mandrel flexibility tests in liquid hydrogen. Figures C-20 and C-21 give a comparison of breakdown voltage in air, vacuum, and liquid nitrogen. Voltage breakdown of HML is not significantly affected by thermal aging, even at 250 C.

Buckley and Johnson⁽⁶⁵⁾ investigated the usefulness of polyimide resins as lubricants in the space environment. To determine relative stability in a vacuum, some evaporation studies were conducted in vacuum to 10^{-8} torr and at ambient temperatures to 875 F. Data are shown in Figure C-22. Evaporation rate was less than 10^{-10} g/(sq cm)(sec) from ambient temperatures to 500 F. Above 500 F, the polyimide began to lose weight at an appreciable rate, and at 875 F, the rate was too high to follow with the recorder.

Friction and wear studies were conducted in vacuum (10^9 torr) with polyimides sliding both on metals and on themselves. Although friction for polyimides on Type 440 C stainless steel was relatively low, wear to the polyimide rider was somewhat high (Figure C-23). However, the wear for the polyimide is only one-fifteenth that obtained with Teflon, and the friction is also lower.

With polyimide sliding on itself, the friction was higher than with polyimide on stainless steel, but wear was 1/500th that of the polyimide on metal (Figure C-24).

A 15 per cent graphite-filled polyimide composition was also examined in friction and wear studies. The presence of graphite in the polyimide did not improve its lubricating characteristics; relatively high friction and wear were obtained.

Suess and Neff⁽⁷⁹⁾ examined six insulated wires for use in a space environment. One of these was "Suroc" FEP w/corona etched, bonded "ML polyimide" manufactured by Supernant Wires; another was Teflon FEP and "H" film laminated into tape and helically wrapped. On the basis of weight loss, dissipation factor, dielectric constant, capacitance, and abrasion resistance, the best selection appeared to be an extruded Teflon and the FEP-ML coated wire. However, he found that the FEP-ML coating was quite sensitive to ultraviolet degradation.

Polystyrene

Polystyrene is one of the most radiation resistant of all polymers. Its threshold degradation at an exposure of 10^{10} ergs g^{-1} (C) and 25 per cent damage at greater than 10^{11} ergs g^{-1} (C).

Exposures of 10^{12} ergs g^{-1} (C) are required in a vacuum to produce significant change in its infrared spectra.

Polystyrene film was not affected at 75 F by an exposure of 8×10^9 ergs g^{-1} (C). At 9.4×10^{10} ergs g^{-1} (C), it retained 54 per cent of its initial tensile strength.

Lewis⁽¹⁵⁾ irradiated polystyrene film at 75 F to an exposure of 9.4×10^{10} ergs g^{-1} (C). Tensile strength did not change appreciably until after an exposure of 8×10^9 ergs g^{-1} (C). At an exposure of 9.4×10^{10} ergs g^{-1} (C), the polystyrene retained 54 per cent of its initial tensile strength. Ultimate elongation decreased from 6.5 per cent to 3.2 per cent (see Table 41).

TABLE 41. EFFECT OF IRRADIATION ON TENSILE PROPERTIES OF POLYSTYRENE FILM⁽¹⁵⁾

Exposure, ergs g^{-1} (C)	Temp, F	Tensile Strength ^(a) , psi	Ultimate Elongation ^(a) , %
0	75	1120/40/15	6.5/0.29/15
3.2×10^8	75	1130/32/14	6.8/0.44/14
1.2×10^9	75	1090/28/15	6.3/0.46/15
2.7×10^9	75	1090/37/15	6.4/0.32/15
8.3×10^9	75	1080/45/15	6.3/0.40/15
2.8×10^{10}	75	976/102/15	5.3/0.49/15
9.4×10^{10}	75	512/52/15	3.2/0.25/15

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

Riehl⁽⁵⁷⁾ found that high-impact polystyrene lost only moisture in vacuum at room temperature and at 50 C. At 100 C, sustained weight loss occurred.

Versluys, et al.,⁽⁵⁵⁾ tested Trycite-1000 film (Dow polystyrene film - 1 mil) for weight loss after exposure to vacuum and to X-ray in vacuum. Weight loss in both cases was 0.1 per cent. The exposure did not cause a change in appearance. Insolation was for 128 hours for the 1300 to 1850 Å band and 3500 hours for 1100 to 1300 Å band.

Blackmon, et al., and Clauss^(5,39) determined the effect of elevated temperature on plastic potting compounds. Eccoseal HI-Q, a polystyrene-solvent system, showed no visible effects after room-temperature vacuum exposure, but vigorous bubbling and outgassing resulted at 170 F in vacuum (10^{-7} torr). This was probably due to the trapped solvent.

Polyurethane

A polyurethane foam sandwich sample showed no reduction in mechanical properties up to 10^{11} ergs g^{-1} (C), the largest exposure to which the sample was subjected.

The compressive strength of a polyurethane thermal insulation appeared higher when irradiated in vacuum than when irradiated in air.

Kerlin and Smith⁽⁷⁾ irradiated two polyurethane thermal-insulation materials in air and in vacuum. These were tested for compression strength. Irradiation at an exposure of 5×10^8 to 10^9 ergs g^{-1} (C) did not seriously affect this property. Compressive strength when tested in a vacuum appeared somewhat higher. Data are given in Table C-35, Appendix C.

The effect of nuclear-radiation exposure at cryogenic temperatures was examined on four polyurethane foams by Yasui.⁽¹³⁾ The materials were Magnolia Foam, Marfoam, CPR 20-3 Foam, and Douglas Insulation. Data are given in Figures C-25 to C-28. There was no statistically significant difference between the controls and irradiated specimens of Magnolia Foam or Marfoam. CPR-20-3 increased about 39 per cent in shear strength in the anisotropic direction. Yasui attributes this to the fact that the individual cells within the foam were elongated in this direction and were mutually parallel. Radiation did not affect compressive properties.

Matacek⁽⁸⁰⁾ investigated the effect of humidity during cure on a polyurethane resin (Multron R-10/Mondur C) with respect to weight loss in vacuum. The materials cured at high humidity had a greater weight loss when exposed to elevated temperatures in vacuum than those cured at low humidity.

Clauss and Blackmon, et al.,^(5,39) in their investigations of encapsulating materials, found PRC 1535A/B satisfactory after vacuum-temperature exposure. The material was not irradiated, but on the basis of its radiation stability in air, it would be anticipated as being satisfactory in the combined radiation-vacuum-temperature environment. They stated that it had a high mold shrinkage and turned slightly brown after 170 F aging. They rated it as appearing satisfactory as an encapsulant.

Poly n-Vinyl Carbazole

There was no appreciable change when Grinlan F plastic was irradiated to 2×10^{11} ergs g^{-1} (C) at room temperature.

Grinlan F plastic (poly n-vinyl carbazole)⁽¹⁵⁾ showed extremely good radiation resistance at room temperature. When the material was irradiated to an exposure of 2×10^{11} ergs g^{-1} (C), there was no appreciable change in hardness, specific gravity, or tensile strength. Values for the last property were 2900 psi and 2590 psi before and after irradiation, respectively. Data are shown in Table 42.

TABLE 42. SUMMARY OF EFFECTS OF IRRADIATION ON GRINLAN F
(POLY N-VINYL CARBAZOLE) PLASTIC⁽¹⁵⁾

Gamma Exposure, ergs g^{-1} (C)	Temp, F	Specific Gravity at 25 C	Hardness(a), Shore D	Tensile Strength(b), psi
0	75	1.185	91.5	2900/206/15
4.9×10^8	75	1.187	88.8	2630/448/14
1.8×10^9	75	1.187	89.8	2700/421/15
3.6×10^9	50	1.186	88.2	2690/371/15
1.1×10^{10}	50	1.188	89.4	2660/324/15
3.5×10^{10}	50	1.188	88.9	2830/132/14
2.0×10^{11}	70	1.188	91.3	2590/274/14

(a) Average of 30 measurements.

(b) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

Silicones

Silicone resins, used for laminates, coatings, and insulating materials, are not seriously degraded at exposures to 10^9 or 10^{10} ergs g^{-1} (C) and, with the proper filler, are satisfactory to 10^{11} ergs g^{-1} (C).

The stability of silicones to radiation depends upon their structure. The presence of phenyl groups in the silicone chain increases radiation stability, while the presence of methyl groups increases flexibility.

Dexter and Curtindale⁽³⁶⁾ investigated the combined effects of temperature and radiation on silicones. Samples were irradiated at temperatures of 150 and 200 C. Electrical and physical properties were measured 24 hours or longer after removal from the radiation source. Since time constants of the decay of transient effects on silicones are less than 10 minutes and stable properties are attained within 1 hour, transient effects were not considered in this work. Electrical properties were measured at room temperature and in some cases at elevated temperatures. Materials evaluated included:

Silicone Fluids

Dow Corning 200 Fluid, 20 centistokes
 Dow Corning 200 Fluid, 1000 centistokes
 Dow Corning 510 Fluid
 Dow Corning 710 Fluid
 Sylgard 51 Dielectric Gel

Dimethylpolysiloxane
 Dimethylpolysiloxane
 Phenylmethylpolysiloxane
 Phenylmethylpolysiloxane
 Dimethylpolysiloxane

Silicone Compounds

Dow Corning 4 Compound
 Dow Corning 5 Compound

Silica-filled dimethyl silicone
 Silica-filled phenylmethyl silicone

Silicone Elastomer

Silastic 1602

Silicone Resins

Dow Corning R-7521
 Dow Corning 980
 Dow Corning Sylgard 182

Solventless resin
 Impregnating varnish
 Solventless resin

Silica sand or zirconium
 orthosilicate filled
 Glass cloth filled
 No filler

In general the effect of the elevated temperature was to decrease the radiation resistance of the material by approximately 50 per cent. Electrical properties of the silicone fluids did not change significantly during exposure to radiation and high temperature. (150 to 200 C). Their usefulness is limited by their increase in viscosity. Effects of temperature and radiation on electrical and physical properties of silicone fluids are shown in Figures C-29 and C-30 in Appendix C.

Silicone insulating compounds are used as sealing materials in electronic apparatus and as a water-repellant surface coating for ceramic insulators. The phenylmethyl based compounds gelled after a radiation exposure of 4×10^9 ergs g^{-1} (C) [40 megarads] at room temperature, 2×10^9 ergs g^{-1} (C) at 150 C, or 10^9 ergs g^{-1} (C) at 200 C. The expected life of a dimethyl based compound is about one-half of this. Electrically, neither compound was significantly affected by radiation doses in excess of the gelation dose. Data are shown in Figures C-31 and C-32.

Silastic 1602 is discussed in the section on silicone elastomers, while R-7521 is included in the discussion on potting compounds. Data on the effects of temperature and radiation on the various silicones are shown graphically in Figures C-29 to C-37.

Silicone resins are also used in laminates, coatings and seals. As such, they are discussed under those headings in this report. According to Jaffe and Rittenhouse⁽⁵¹⁾, the temperature for 10 per cent weight loss per year in vacuum for methyl phenyl silicone resins is greater than 380 C (710 F). Jaffe lists silicone resins along with Teflon, polyethylene, polypropylene, and Mylar as showing good-to-excellent behavior in high vacuum. Podlaseck and Suhorsky⁽⁴⁾ show the equilibrium weight loss for silicones at elevated temperatures (see Table C-4). At atmospheric pressure, these losses appear high, but in a vacuum they are considerably lower and within a usable range.

Vinyl Polymers

Polyvinyl chloride (PVC) is equivalent to polyethylene in its radiation stability. Its properties begin to change at a radiation exposure of 1.9×10^9 ergs g^{-1} (C), while it is damaged by 25 per cent at an exposure of 1.1×10^{10} ergs g^{-1} (C).

Tensile strength of PVC is not affected until it is given a radiation dose higher than that which affects polyethylene. However the tensile strength of PVC decreases more rapidly than that of polyethylene, whereas its elongation decreases less rapidly than that of polyethylene.

The liberation of hydrogen chloride when PVC is irradiated makes this material unsuitable for many applications in a nuclear environment.

Aitken and associates⁽⁸¹⁾ investigated the effect of plasticizer, filler, and stabilizer on the radiation resistance of polyvinyl chloride. Two levels of radiation exposure were used, 10^{10} ergs g^{-1} (C) and 2×10^{10} ergs g^{-1} (C). The polymer used for this study was Geon 101. Fillers were carbon black (Vulcan black XXX), precipitated whiting (97 per cent $CaCO_3$, 99.98 per cent passes 200 mesh), china clay (Stockalite), anatase titanium dioxide (Tiona G), and rutile titanium dioxide (Runa R. G.). Plasticizers studied were tritolyl phosphate (TTP), Reoplex 100 (a sebacate polyester used in formulations which require maximum extraction resistance), and dioctyl sebacate. Stabilizers included white lead paste ground in DOP (dioctyl phthalate) in a ratio of 7:1 by weight and used at a level of 8 parts per hundred parts of polymer, and "Stabilizer Mixture", a nonlead mixture normally designed to confer thermal stability to PVC formulations. This mixture consisted of:

<u>Material</u>	<u>Parts by Weight</u>
Organic tin (Stanclore DBTL)	1.2
Organic cadmium (Ferroclere 202)	0.4
Epoxidized oil (Ferroclere 900)	1.0

The mixture was used at a level of 2.6 parts per hundred parts of polymer.

Plasticizer-polymer ratios of 35/65 and 45/55 by weight were used. Levels of filler were 10 per cent and 20 per cent by weight of the total (plasticizer plus polymer).

None of the interactions reached the level of significance in changes of tensile strength. However, on the basis of elongation and tensile values before and after radiation, the following conclusions were reached:

(1) Plasticizer Type and Content

Tritolyl phosphate showed the least degradation; the average drop in elongation was only 8 per cent after 1×10^{10} ergs g^{-1} (C) and 25 per cent after 2×10^{10} ergs g^{-1} (C). Reoplex 100 lost 36 per cent and 59 per cent, respectively, under the same radiation exposures. Only dioctyl sebacate (DOS) showed a decrease in tensile strength.

Tri-xylyl phosphate has been shown to be identical in radiation stability to tri-tolyl phosphate.

Plasticizer content may be adjusted to suit the requirements of the formulation. For a given plasticizer, the decrease in elongation was independent of the plasticizer concentration. (Note that plasticizer ratios used were 35/65 and 45/55 parts by weight of plasticizer and polymer.)

(2) Filler type and content

No filler gave a better resistance to the degradative effect of radiation than was obtained in the absence of filler, but china clay and titanium dioxide (anatase) gave compounds that were no worse than those without filler, whether judged on the basis of actual elongation after exposure or on the basis of retention of initial elongation. Carbon black gave a very low initial elongation which was well retained. Whiting is very poor in retention of elongation and shared with carbon black the lowest actual elongation after exposure.

Addition of filler produced a small proportional diminution of the initial elongation, and the average effect of exposure to radiation was proportional to this initial elongation and independent of the filler content (zero to 20 per cent filler).

(3) Stabilizer

With Reoplex 100 plasticizer, stabilizer Mixture X is to be preferred; with tritolyl phosphate there was no difference between the two stabilizers.

(4) Color stability

With respect to color only, the best filler was anatase titanium dioxide, the best plasticizer was DOS, the best stabilizer was Mixture X. The best individual formulation was DOS with anatase titanium dioxide and stabilizer Mixture X.

Specimens containing precipitated whiting were almost as good as those with titanium dioxide. One effect observed was that the wire staples holding the specimens to the card were rusted and corroded in nearly all the specimens except those containing whiting. There was very little exudation.

Versluys, et al., (55) found no weight loss in a 2-mil polyvinyl chloride film after exposure to a vacuum of 10^{-8} torr for 8 hours at ambient temperature. No weight loss was observed after exposure to ultraviolet for a total insolation of 120 hours in the 1300 to 1850 Å band and 2140 hours in the 1100 to 1300 Å band.

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Blackmon, et al., (5) exposed pigmented polyvinyl fluoride and polyvinyl chloride to ultraviolet for 96 hours in a vacuum of 3×10^{-7} torr at 80 F. The fluoride film darkened slightly, but no appreciable change in flexibility or tear strength was noted. The film retained an excellent appearance. The PVC film, however, turned brown, and voids and blisters from exuded plasticizer became evident. The film had a poor appearance.

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Matacek⁽⁷³⁾ in his report on studies to determine the vacuum volatility of organic resins indicated that VMCH, a vinylchloride-acetate copolymer, lost 60 per cent of its weight when exposed to a temperature of 300 F for 24 hours. Polyvinyl butyral (Vinylite XYHL) lost 40 per cent of its weight. This temperature is, of course, high for these materials, but this would show their limitations for space applications.

REFERENCES

Components

- (1) "NARF Final Progress Report", General Dynamics/Fort Worth, Nuclear Aerospace Research Facility, Fort Worth, Texas, NARF-62-18P, FZK-9-184, Final Progress Report, October 1, 1961 - September 30, 1962, AF 33(657)-7201, 375 pp.
- (2) McCurdy, R. M., and Rambosek, G. M., "The Effect of Gamma Radiation on Structural Adhesive Joints", Minnesota Mining & Manufacturing Company, Adhesives, Coatings & Sealers Division, March 20, 1962, paper presented at the National Symposium on The Effects of Space Environment on Materials, St. Louis, Missouri, May 7-9, 1962, 12 pp.
- (3) Kaufman, A. B., Newhoff, H. R., and Gaz, R. A., "LPR-10 Drum Performance in a Nuclear Environment", Litton Systems, Inc., Guidance and Control Systems Division, Woodland Hills, California, 27 pp.
- (4) Podlaseck, S., and Suhorsky, J., "The Stability of Organic Materials in Vacuum", 1963 Proceedings of the Institute of Environmental Sciences, Annual Technical Meeting, Los Angeles, California, April 17-19, 1963, pp 593-603.
- (5) Blackmon, P. H., Clauss, F. J., Ledger, G. E., and Mauri, R. E., "Materials Examination Under High Vacuum and Other Satellite Environmental Conditions", Lockheed Missiles and Space Company, Sunnyvale, California, LMSC-3-77-61-23, January, 1962, AF 04(647)-787, 40 pp.
- (6) Kerlin, E. E., "Investigation of Combined Effects of Radiation and Vacuum and of Radiation and Cryotemperatures on Engineering Materials. Volume I. Radiation-Vacuum Tests", General Dynamics/Fort Worth, Fort Worth, Texas, FZK-161-1, January 5, 1963, Annual Report, November 9, 1961 - November 8, 1962, NAS8-2450, 340 pp.
- (7) Kerlin, E. E., and Smith, E. T., "Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials", General Dynamics/Fort Worth, Fort Worth, Texas, FZK-172, September 30, 1963, Quarterly Progress Report, June 1 - August 31, 1963, NAS8-2450, 121 pp.
- (8) Gray, P. D., Cornelius, G. K., O'Donnell, J. D., and Howard, W. W., "Rockets in Space Environment. Volume I. The Experimental Program", Aerojet-General Corporation, Azusa, California, RTD-TDR-63-1050, February 1963, Final Report, AF 04(611)-7441, 150 pp.
- (9) DeWitt, E. A., Podlaseck, S., and Suhorsky, J., "Effect of Low Pressure at Elevated Temperatures on Space Vehicle Materials", The Martin Company, Baltimore, Maryland, M-RM-29, March 1959, Research Memorandum, 42 pp.
- (10) Levine, H. H., "Recent Developments in High Temperature Adhesives", paper presented at the Adhesives Symposium, Picatinny Arsenal, Dover, New Jersey, September 27-28, 1961.

- (11) Chafey, J. E., "Compilation of Materials Research Data", General Dynamics/Astronautics, San Diego, California, GD-AE-62-0060, September, 1961, Summary Report No. 1, Phase II, March 1 - September 1, 1961, AF 33(616)-6213, 20 pp.
- (12) Yasui, G., "RIFT Radiation Effects Program Irradiation No. 1 and 2 - Cryogenic Insulation Materials", Lockheed Missiles and Space Company, Sunnyvale, California, NSP-63-35, May 7, 1963, NAS8-5600, 50 pp.
- (13) Yasui, G., "Thermal Insulation Material Tests (Cryogenic)", RIFT Nuclear Engineering Report, Lockheed Aircraft Corporation, Lockheed-Georgia Company, Marietta, Georgia, ER-6512, September 10, 1963, pp 37-69.
- (14) Weaver, J. H., and Jacobs, C., "Coatings for Temperature Control in Space Vehicles", paper presented at Materials Symposium, Phoenix, Arizona, September 13-15, 1961, ASD-TR-61-322, July, 1961, pp 456-468.
- (15) Lewis, J. H., "Second Quarterly Status Letter January 1 - March 31, 1964", General Dynamics/Fort Worth, Fort Worth, Texas, NARF '64, April 16, 1964, AF 29(601)-6213, 150 pp.
- (16) Matthews, C. O., and Finch, W. L., "Report on the LMSC Spacecraft Materials Reliability Program", Lockheed Missiles and Space Company, Sunnyvale, California, May 7, 1962, AF 04(647)-787, 71 pp.
- (17) Ball, G. M., and Horr, K. S., "Sublimation of Some Polymeric Materials in Vacuum", Ball Brothers Research Corporation, Boulder, Colorado, TN-62-118, September 10, 1962, 26 pp.
- (18) Carroll, W. F., "Development of Stable Temperature Control Surfaces for Spacecraft", California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California, JPL-TR-32-340, November 20, 1962, Progress Report No. 1, NAS 7-100, 17 pp.
- (19) Wahl, N. E., Lapp, R. R., and Haas, F. C., "The Effects of High Vacuum and Ultraviolet Radiation on Nonmetallic Materials", Cornell Aeronautical Laboratories, Incorporated, Buffalo, New York, WADD-TR-60-125, Pt. II, June 1962, February 1, 1960 - April 1, 1961, AF 33(616)-6267, 73 pp. es,
- (20) Clauss, F. J., Mauri, R. E., Smith, E. C., and Drake, S., "Evaluating the Behavior of Materials Under Space Conditions", 1961 Proceedings of the Institute of Environmental Sciences, National Meeting, Washington, D. C., April 5-7, 1961, pp 475-488. 1,
- (21) Gaumer, R. E., Clauss, F. J., Sibert, M. E., and Shaw, C. C., "Materials Effects in Spacecraft Thermal Control", paper presented at the ASD Conference on Coatings for the Aerospace Environment, Dayton, Ohio, November 9-10, 1960, WADD-TR-60-773, July 1961, pp 117-136.
- (22) Alexander, A. L., et al., "The Ultraviolet Degradation of Organic Coatings", U. S. Naval Research Laboratory, Washington, D. C., WADD-TR-60-703, Part II, November 1960, October 1, 1958 - April 1, 1959, AF 33(616)-59-21, 14 pp. II,

- (23) Miller, C. D., Rechter, H. L., and Tomkins, E. H., "Highly Reflecting Coatings for the Space Environment", paper presented at the National Symposium on the Effects of Space Environment on Materials, St. Louis, Missouri, May 7-9, 1962, 21 pp. m
- (24) Cowling, J. E., Alexander, A. L., and Noonan, F. N., "The Design of Organic Coatings for Use in the Space Environment" paper presented at the ASD Conference on Coatings for the Aerospace Environment, Dayton, Ohio, November 9-10, 1960, WADD-TR-60-773, July, 1961, pp 17-37. c
- (25) Hormann, H. H., "Improved Organic Coatings for Temperature Control in a Space Environment", Aeronautical Systems Division, Nonmetallic Materials Laboratory, Wright-Patterson Air Force Base, Ohio, ASD-TDR-62-917, 1963, 54 pp.
- (26) Field, D. E., Cowling, J. E., and Noonan, F. M., "The Properties of Paints as Affected by Ultraviolet Radiation in a Vacuum - Part II", U. S. Naval Research Laboratory, Chemistry Division, Washington, D. C., NRL-5737, March 8, 1962, Interim Report, 28 pp. as
1
2,
- (27) Kaufman, A. B., and Gardner, L. B., "Passive Components in a Hypernuclear Environment", Litton Systems, Incorporated, Woodland Hills, California, ASD-TN-61-99, August 1961, Technical Note, AF 33(600)-41452, 27 pp. .
.
- (28) Koehler, H. P., and Pefhany, J., "Irradiation Test on Electrical and Mechanical Components for a Gauging System for Reactor Pressure Tubes", A. V. Roe Canada Limited, Orenda Engines Division, Malton, Ontario, Canada, AECL-1627, OEL-Nuclear-56, February 9, 1962, 25 pp. cal
7,
- (29) Campbell, F. J., "Effects of Combined Thermal and Nuclear Radiation Environments on Magnet Wire Insulation", Report of NRL Progress, August, 1963, pp 1-5. 1-
1-5.
- (30) Smith, E. T., "Investigation of Combined Effects of Radiation and Vacuum and of Radiation and Cryotemperatures on Engineering Materials", General Dynamics/Fort Worth, Fort Worth, Texas, FZK-161-2, Annual Report, November 9, 1961 - November 8, 1962, NAS8-2450, January 5, 1963, 260 pp. of
/
1 -
- (31) Boundy, R. A., "Spacecraft Applications of Polymeric Materials", paper presented at the 18th Annual Meeting of the Reinforced Plastics Division, SPI, Chicago, Illinois (1963). nted
- (32) Podlaseck, S., Suhorsky, J., and Fisher, A., "The Behavior of Organic Materials at Elevated Temperatures in a Vacuum", paper presented at the 9th National Symposium of the American Vacuum Society, Los Angeles, California, October 31 - November 2, 1963, 14 pp. ials
- (33) Kerlin, E. E., and Smith, E. T., "Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials", General Dynamics/Fort Worth, Nuclear Aerospace Research Facility, Fort Worth, Texas, FZK-167, June 28, 1963, Quarterly Progress Report, March 1 - May 31, 1963, NAS8-2450, 77 pp. ons
,"
rth,

- (34) Wahl, N. E., and Lapp, R. R., "The Effects of High Vacuum and Ultraviolet Radiation on Plastic Materials", Cornell Aeronautical Laboratory, Incorporated, Buffalo, New York, WADD-TR-60-125, June 1960, February, 1959 - February, 1960, AF 33(616)-6267, 71 pp.
- (35) Wahl, N. E., and Robinson, J. V., "The Effects of High Vacuum and Radiation on Polymeric Materials", paper presented at the National Symposium on the Effects of Space Environment on Materials, St. Louis, Missouri, May 7-9, 1962, 28 pp. :cts
- (36) Dexter, J. F., and Curtindale, E. C., "The Effects of Gamma Radiation at Elevated Temperatures on Silicone Dielectrics", paper presented at the AIEE Summer General Meeting, Denver, Colorado, June 18-22, 1962, 25 pp.
- (37) Armstrong, E. L., "Results of Irradiation Tests on Electronics Parts and Modules Conducted at the Vallecitos Atomic Laboratory", Lockheed Missiles and Space Company, Sunnyvale, California, SS-840-T62-6, LMSC-A054870, August 27, 1962, AF 04(695)-136, 13 pp. les 62,
- (38) "M&TC System Study", Bendix Corporation, Systems Division, Ann Arbor, Michigan, BSR-371, December, 1960, Final Report, Volume I, Part II, AF 33(600)-35026.
- (39) Clauss, F. J., "Materials and Components in Space Environments", paper presented at the Institute of the Aerospace Sciences 31st Annual Meeting, New York, New York, January 21-23, 1963, IAS Paper No. 63-58, 38 pp. ,
- (40) "Development of Rubber Gaskets Which are Resistant to Nuclear Radiation", Mare Island Naval Shipyard, Rubber Laboratory, Vallejo, California, Report No. 149-4, February 28, 1961, Final Report, Project No. NS-033-200. re -4,
- (41) Born, J. W., "Nuclear Radiation Resistant Polymers and Polymeric Compounds", B. F. Goodrich Company, Research Center, Brecksville, Ohio, WADC-TR-55-58, Part VII, March, 1962, Technical Documentary Report, April 1, 1960 - May 31, 1961, AF 33(616)-7491, 205 pp. 3", 38,
- (42) Farkas, I., and Barry, E. J., "Study of Sealants for Space Environments", National Research Corporation, Cambridge, Massachusetts, Summary Report, December 4, 1959 - December 20, 1960, DA-19-020-506-ORD-5097, 44 pp.
- (43) Smith, E. T., "Investigation of Combined Effects of Radiation and Vacuum on of Radiation and Cryotemperatures on Engineering Materials", General Dynamics/ Fort Worth, Nuclear Aerospace Research Facility, Fort Worth, Texas, FZK-161-2, January 5, 1963, Annual Report, November 9, 1961 - November 8, 1962, NAS8-2450, 260 pp. 61-2,

Elastomers

- (44) Gibbs, W. E., Griffin, W. R., and Spain, R. G., "Elastomers", paper presented at the Materials Symposium, Phoenix, Arizona, September 13-15, 1961. ted

- (45) Ossefort, Z. T., and Ruby, J. D., "The Effects of a Simulated Space Environment on the Properties of Elastomers", Rock Island Arsenal Laboratory, RIA-61-1999, May 15, 1961, 9 pp.
- (46) Snyder, C. E., and Cross, W. B., "Theoretical and Experimental Evaluation of Polymeric Materials for Use in a Space Environment", paper presented at the ASD Conference on Coatings for the Aerospace Environment, Dayton, Ohio, November 9-10, 1960, WADD-TR-60-773, July 1961, pp 75-91.
- (47) Heitz, R. M., Hunter, R. W., and D'Anna, P. J., "Research on Elastomeric and Compliant Materials for Aerospace Sealants", Northrop Space Laboratories, Hawthorne, California, ASD-TDR-62-709, January, 1963, AF 33(616)-8258, 157 pp.
- (48) Wattier, J. B., Newell, L. M., and Morgan, L. L., "Effects of Reactor Radiation on the Engineering Properties of Elastomers and Plastics", General Dynamics/Fort Worth, Nuclear Aerospace Research Facility, Fort Worth, Texas, NARF-62-5T, FZK-9-174, June, 1962, AF 33(657)-7201, 115 pp.
- (49) Bonanni, A. P., and Cassola, C. A., "The Effects of Gamma Irradiation and High Vacuum on Polymeric Materials", Naval Air Engineering Center, Philadelphia, Pennsylvania, NAEC-AML-1712, August 20, 1963, Partial Report.
- (50) Golden, J. H., and Hazell, E. A., "The Effect of High Energy Radiation on Plastics and Rubbers. Part 3. Polyurethane Rubber", Explosives Research and Development Establishment, Essex, England, E. R. D. E. TM 16/M/60, January, 1961, 3 pp.
- (51) Affee, L. D., and Rittenhouse, J. B., "Behavior of Materials in Space Environments", ARS J., 32, 320-346 (March, 1962).
- (52) McGarvey, J. W., "The Effects of Radiation on Silicone Rubbers", Rock Island Arsenal, Rock Island, Illinois, RIA-61-2379, June 13, 1961, Technical Report, 18 pp.
- (53) Ossefort, Z. T., "Heat and Radiation Resistant Arylene Modified Polysiloxanes", Proceedings of the Sixth Joint Army-Navy-Air Force Conference on Elastomer Research and Development, Boston, Massachusetts, October 18-20, 1960, Volume 2, pp 612-626.
- (54) "Elastomer Research and Development", Seventh Joint Army-Navy-Air Force Conference on Elastomer Research and Development, Office of Naval Research, Department of the Navy, Washington, D. C., ONR-13, Volume 1, October 22-24, 1962, 276 pp.

Plastics

- (55) Versluys, W., Beecher, N., Accardo, C., Herzog, R., and Warneck, P., "Ultraviolet Effects on Space Vehicle Operation in Ultra-High Vacuum Environment", National Research Corporation, Cambridge, Massachusetts, AEDC-TDR-62-17, January, 1962, March 22 - September 22, 1961, AF 40(600)-906, 118 pp.

- (56) Ringwood, A. F., "Behavior of Plastics in Space Environment", Modern Plastics, 41 (5), 173 (January, 1964). ics,
- (57) Riehl, W. A., "Considerations on the Evaporation of Materials in Vacuum", American Institute of Chemical Engineers, Chemical Engineering Progress Symposium Series No. 40, 59 (40), 103-117 (1963).
- (58) Wilcox, W. S., Stephenson, C. V., Lacey, J. C., Jr., and Moses, B. C., "Deterioration of Textile Materials by Ultraviolet Light", Southern Research Institute, Birmingham, Alabama, WADD-TR-60-510, October, 1960, May 1, 1959 - July 31, 1960, AF 33(616)-6565, 146 pp.
- (59) "NGL Platform Nuclear Radiation Program", Litton Systems, Incorporated, Beverly Hills, California, BH-59-3461.10, October 10, 1960, 2nd Bimonthly Report, July 23 - September 23, 1960, AF 33(600)-41452.
- (60) Kaufman, A. B., and Gardner, L. B., "NGL Platform Nuclear Radiation Program Volume I - Research and Analytical Data Section", Litton Systems, Incorporated, Flight Control Laboratory, Woodland Hills, California, ASD-TR-61-511, January, 1962, Final Report, AF 33(600)-41452, 312 pp. ram ed,
- (61) Gloria, H. R., Stewart, W. J., and Savin, R. C., "Initial Weight Loss of Plastics in a Vacuum at Temperatures from 80 to 500 F", NASA, Ames Research Center, Moffett Field, California, NASA-TN-D-1329, December, 1962, 20 pp. stics r,
- (62) Shoffner, J. P., "Effects of Radiation on Teflon Resins in Space", J. of Teflon, 2 (1), 6-7 (January, 1961). on
- (63) Jolley, C. E., and Reed, J. C., "The Effects of Space Environments on Insulation of Teflon, TFE and FEP Resins", paper presented at the Eleventh Annual Signal Corps Wire and Cable Symposium, Asbury Park, New Jersey, November 28-30, 1962, 20 pp. tion al 0,
- (64) Bringer, R. P., "Fluorocarbon Plastics Under the Influence of Unusual Environmental Conditions", paper presented at the National Symposium on The Effects of Space Environment on Materials, St. Louis, Missouri, May 7-9, 1962, 22 pp. on- of
- (65) Buckley, D. H., and Johnson, R. L., "Friction, Wear, and Decomposition Mechanisms for Various Polymer Compositions in Vacuum to 10^{-9} Millimeter of Mercury", NASA, Lewis Research Center, Cleveland, Ohio, NASA-TN-D-2073, December, 1963, 30 pp. of 3,
- (66) Vickers, D. L., "Teflon in Cryogenic and Storable Propellants", E. I. du Pont de Nemours and Company, Incorporated. it
- (67) Redeker, H. E., and Van Sickle, D. E., "Radiation of Selected Polymers and Model Compounds", Stanford Research Institute, Menlo Park, California, April 30, 1961, Summary Technical Report No. 1, April 1, 1960 - April 1, 1961, DA-04-200-ORD-1056, 46 pp. 061,

- (68) Hargreaves, G., "Molecular Changes in Polyamide and Elastomeric Polymers Due to Nuclear, Ultraviolet and Thermal Radiation", Naval Air Material Center, Aeronautical Materials Laboratory, Philadelphia, Pennsylvania, December 15, 1961, Fourth Progress Report, June 16 - December 15, 1961, NAMC-AML (16)-R360FR101, 25 pp.
- (69) Bowen, P. H., "Lubrication of Bearings and Gears in Aerospace Environmental Facilities", Westinghouse Electric Corporation, Research Laboratories, Pittsburgh, Pennsylvania, AEDC-TDR-63-166, July, 1963, AF 40(600)-915, 135 pp.
- (70) Turner, J. O., Plastics in Nuclear Engineering, Reinhold Publishing Corporation, New York, New York (June, 1961). on,
- (71) Giberson, R. C., "Gamma-Radiation Effects on Polycarbonate Resin", Modern Plastics, 39 (8), 146-228 (April, 1962).
- (72) "Spectroscopic Studies of Irradiation Damaged Solids", University of Alabama, Department of Physics, Final Technical Report, DA-01-009-ORD-561.
- (73) Matecek, G. F., "Vacuum Volatility of Organic Resins", Wright Air Development Center, Materials Laboratory, Wright Patterson Air Force Base, Ohio, WADC-TR-59-268, September, 1959, 32 pp. nt
- (74) Sauer, J. A., "Effect of Radiation on Dynamic Properties of High Polymers", Pennsylvania State University, Physics Department, University Park, Pennsylvania, July 1, 1961, Progress Report, July 1, 1960 - June 30, 1961, AF(30-1) 1858. ania,
- (75) Hargreaves, G., "Molecular Changes in Polyamide and Elastomeric Polymers Due to Nuclear, Ultraviolet and Thermal Radiation", U. S. Naval Air Material Center, Aeronautical Materials Laboratory, Philadelphia, Pennsylvania, June 15, 1962, Fifth Progress Report, December 16, 1961, - June 15, 1962, 10 pp.
- (76) McGrath, J. C., "Thermal and Gamma Radiation Behavior of Dyed Nomex Yarns", Air Force Systems Command, Research and Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, ML-TTR-64-77, April, 1964, Technical Documentary Report, March - November, 1963, May, 1961, 16 pp. s", 7,
- (77) Stephenson, C. V., Wilcox, W. S., Crenshaw, H. T., Hancock, H. L., and Dismukes, E. B., "Deterioration of Fibrous Materials by Ultraviolet Light", Southern Research Institute, Birmingham, Alabama, ASD-TDR-63-57, February, 1963, Annual Report No. 3, December 15, 1961 - December 15, 1962, AF 33(616)-7701, 22 pp. 2,
- (78) Mathes, K. N., "Development of Low Temperature Dielectric Coatings for Electrical Conductors", General Electric Company, Missile and Space Vehicle Department, Philadelphia, Pennsylvania, NASA-CR-51332, July 15, 1963, Annual Summary and Quarterly Report No. 8, NAS8-2442, 69 pp.

- (79) Suess, R. H., and Neff, G. R., "Evaluation of Insulated Wire for Space Environment", Ardel Corporation, Report No. 05132-4, February 7, 1963, Final Report, 49 pp. al
- (80) Matecek, G. F., "Vacuum Volatility of Organic Coatings", paper presented at the First Symposium, Surface Effects on Spacecraft Materials, Palo Alto, California, May 12-13, 1959, pp 263-283. the
ia,
- (81) Aitken, I. D., Wells, H., and Williamson, I., "The Degradation of Plasticized PVC Compositions Under High Level Gamma Radiation, Part 2", Atomic Energy Research Establishment, England Division, Harwell, England, AERE-R-3381, 45 pp. l
sy
- (82) Golden, J. H., and Hazell, E. A., "The Effect of High Energy Radiation on Plastics and Rubbers. Part 1. Polytetrafluoroethylene", Explosive Research and Development Establishment, Essex, England, E. R. D. E. 21/R/60, November, 1960. and

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APPENDIX A

COMPONENTS

TABLE A-1. TEST ENVIRONMENT AND RESULTS FOR HIGH-FORCE DYNAMIC-
TEST MATERIALS: STRUCTURAL ADHESIVES⁽⁶⁾

Material and Type of Test	Radiation Exposure				Ultimate Shear Strength, psi	Temperature		Pressure	
	Gamma [ergs/gm(C)]	Thermal	Neutrons (n/cm ²) E>2.9 Mev	E>8.1 Mev		Avg. F	Fig. No. (e)	Avg. (e) (torr)	Fig. No. (e)
FM-1000	0	0	0	0	6302 6117 6004 5946 5955 <u>6065/153^a</u>	77	-	760	-
(control specimens)									
High- Force Tester	1.1(10)	1.82(14)	1.83(15)	7.0(13)	6050 6096 6525 4830 4977 <u>5696/774</u>	157	D-16	3x10 ⁻¹	4.2
(vacuum irradiation)									
High- Force Test	1.9(10)	5.1(14)	4.15(15)	1.7(14)	7016 6897 7689 7760 <u>7340/419</u>	-	-	5(-6)	4.3
(vacuum irradiation)									
Instron Tester	9.5(9)	1.34(14)	1.51(15)	5.95(13)	6082 6200 5900 6185 6442 <u>6162/233</u>	207	D-16	3x10 ⁻¹	4.2
(vacuum irradiation)									
Metlbond 302 (epoxy phenolic)	0	0	0	0	2323 2510 2570 2526 <u>2482/125^a</u>	77	-	760	-
(control specimens)									
High- Force Tester	1.6(10)	1.0(14)	2.33(15)	8.8(13)	2984 2938 2949 2777 2640 2856 <u>2856/139</u>	157 ^h	D-16	3x10 ⁻¹	4.2
(vacuum irradiation)									
High- Force Tester	2.05(10)	4.57(14)	4.32(15)	1.98(14)	3613 3680 3310 3497 3455 <u>3511/150</u>	-	-	5(-6)	4.3
(vacuum irradiation)									

TABLE A-1. (Concluded)

Material and Type of Test	Radiation Exposure				Ultimate Shear Strength, psi	Temperature		Pressure		g g(e)
	Gamma [ergs/gm(c)]	Neutrons Thermal E>2.9 Mev	Neutrons E>0.1 Mev	n/cm ²		Avg. F	Fig. No.	Avg. (torr)	Fig. No.	
Metlbond 302 (epoxy phenol- ic)	9.15(9)	1.34(14)	1.51(15)	5.95(13)	2586 2415 2355	207 ^b	D-16	3x10 ⁻¹	4.2	.2
Instren Tester					2536 2643					
					2507/140					

(a) Average value/standard deviation on an individual basis.

(b) Estimated value based on temperature of FM-1000.

(c) Figures given in reference 6.

TABLE A-2. SCREENING TESTS, PAINTS(18)

Test No.	Vehicle	Pigment	Manufacturer or Designation	Original Approximate a_p (a)	Change in a_p (b)		Extended (c)
					11 Hours	22 - 25 Hours	
1	Acrylic	Rutile-Talc	Sherwin Williams Kenacryl M-49 MC-17	≈ 0.29	0.028	0.760 to 0.085	
2		Rutile	Fuller 8093 Insignia White 171-M-522	≈ 0.22	0.049	0.068 to 0.112	
3	Polyurethane	Rutile (r)	M-1 Laminar X-500 White M-1	≈ 0.22	-	>0.20	
4	Silicone	Rutile	JPL Compounded JW 40	≈ 0.21	0.018	0.030 to 0.049	See Fig. 6
5		Zinc Sulfide	ZR 40	≈ 0.25	0.028	0.032 to 0.040	See Fig. 4, 6
6		Zirconium Oxide	ZR 40 ZR 60 ZEDA 50 ZEDA 75	≈ 0.20 <0.20 <0.20 <0.20	- - - -	0.15 0.12 0.19 0.15	
7	Acrylic						

(a) a_p Values listed only to indicate general range of value, no attempt was made to accurately measure as for those materials which degraded severely.

(b) Ultraviolet exposure at approximately 10 suns in vacuum.

(c) Figure given in Reference 18.

TABLE A-3. SCREENING TESTS, NON-PAINT "WHITES" (19)

System	Original Approximate	Change in		Remarks
		22 - 24 Hours (b)	48 Hours (c)	
(1) Anodized high purity aluminum	≈ 0.25	0 to 0.021	0.045 to 0.072	
(2) Al ₂ O ₃ Tile (Gladding McBean and Company)	≈ 0.25	>0.15	-	
(3) "Scotchcal" 3650 white ps (Minn. Mining and Mfg. Co. - white pigmented vinyl tape)	≈ 0.25	>0.10	-	
(4) Tedlar 30 wh (Du Pont - white pigmented polyvinyl fluoride film)	≈ 0.25	>0.15	-	
	≈ 0.25	0.078(b)	-	
(5) Tedlar - aluminized clear film (Du Pont - polyvinyl fluoride film)	≈ 0.25	0.088	-	
	≈ 0.25	0.047	-	
(6) Teflon - TFE aluminized clear film (Du Pont - polytetrafluoroethylene film)	≈ 0.40	0.0352	-	"milky" film, high initial α_s
	≈ 0.40	0.0160	-	
(7) Teflon FEP - aluminized clear film (Du Pont - fluorinated ethylene-propylene)	≈ 0.25	0.065	-	
	≈ 0.25	0.117	-	
	≈ 0.25	0	-	
	≈ 0.25	0 to 0.013	0.015 to 0.019	

(a) Values listed to indicate general range of values.

(b) Ultraviolet exposure time of approximately 10 suns in vacuum.

(c) 20-hr exposure.

TABLE A-4. OPTICAL PROPERTIES OF BEST MATERIALS
TESTED(18)

Material	Initial Properties		At Termination of 3 Months Venus Mission		K
	α_s	$\epsilon_{300\text{ K}}$	α_s (a)	$\epsilon_{300\text{ K}}$	
Zinc sulfide-silicon ZW 40	0.26	0.90	0.24	0.90	0
Zinc sulfide-silicon ZW 60	0.21	0.91	0.29	0.91	1
Aluminized FEP teflon (Type "A", 5 mil	0.26	0.84	0.31	0.84	4

(a) These values represent the maximum degradation that test data indicate may occur during a 3-month Venus mission.

(b) No significant change in $\epsilon_{300\text{ K}}$ was found for any materials due to UV exposure.

TABLE A-5. REPRESENTATIVE MATERIAL RADIATIVE PROPERTIES(24)

Material	α	ϵ	α/ϵ Ratios
Metals			
Aluminum 6061 alloy			
As received	0.41	0.04	10.3
Machine polished and degreased	0.35	0.04	8.8
Sandblasted, 120 size grit	0.60	0.41	1.5
Aluminum 2024 alloy			
As received	0.27	0.02	13.5
Machine polished and degreased	0.31	0.06	5.2
CMU Beryllium alloy			
Rolled plate, chem. milled	0.48	0.11	4.4
Rolled plate, chem. milled, chem. polished	0.50	0.09	5.6
Gold			
Vacuum deposit gold on aluminum	0.24	0.04	6.0
Vacuum deposit gold on buffed titanium	0.33	0.05	6.6
Nickel			
Electroless nickel	0.45	0.17	2.6
Special surfaces on metals	0.63	0.66	0.95
Dow 17 on magnesium	0.53-0.72	0.50-0.82	0.95
Foils and adhesive-backed metals			
Fascat chrome aluminized mylar film	0.25	0.09	2.8
Bright gold foil	0.29	0.23	1.3

TABLE A-5. (Concluded)

Material	α	ϵ	α/ϵ Ratios
Paints (according to vehicle)			
Vinyl (phenolic)			
Dull black Micabond	0.93	0.84	1.1
Epoxy			
Skyspar (untinted white)	0.26	0.86	0.3
Silicone			
Fuller gloss white silicone	0.30	0.81	0.37
Fuller flat black silicone	0.89	0.81	1.1
Fuller aluminum silicone	0.23	0.20	1.2
Acrylic			
Kemacryl lacquer (white)	0.26	0.75	0.35
Kemacryl lacquer (black)	0.94	0.83	1.1
Miscellaneous			
Silica oxide			
5 mils of silica on magnesium	0.21	0.83	0.25
Adhesive-backed dielectrics			
Scotchc.1 (white) on aluminum	0.24	0.83	0.29
Ceramics			
Cermet (ceramic containing sintered metal)	0.65	0.58	1.1

ϵ = total hemispherical emissivity at 500° R

α = solar absorptivity, extraterrestrial

Values listed are averages of several determinations. Accuracy of the tabulated values is variable, but usually reliable to 10 per cent, except for very low emissivities.

TABLE A-6. RESULTS OF EXPOSURE OF COATING MATERIALS TO ULTRAVIOLET RADIATION AND VACUUM(24)

Test No.	Exposure Time (hr)	Material(1)	Substrate	Visible Changes	Measured Radiation Characteristics			
					a	Before	a	After
1	46	White Skyspar enamel, A	Dow 15 treated magnesium alloy	yellowed	0.25	0.85	0.37	0.87
		Gloss white silicone	Dow 15 treated magnesium alloy	slight yellowing	0.290	0.83	0.293	0.82
2	80	White Skyspar enamel, A (2 samples)	Dow 17 treated magnesium alloy	yellowish brown	0.22-0.23	0.82-0.85	0.39	0.82
		White Kemacryl lacquer	Dow 17 treated magnesium alloy	very slight yellowing	0.26	0.73	0.33	0.78
		Black Kemacryl lacquer	Dow 17 treated magnesium alloy	very slight change	0.94	0.81	0.92	0.79
		Aluminum silicone paint (2 samples)	Bare, untreated magnesium alloy	slight crackling	0.21-0.22	0.20-0.19	0.30-0.33	0.23-0.27
3	26	White Skyspar enamel, B	Dow 17 treated magnesium alloy	yellowish brown	0.24	0.83	0.37	0.85
		Gloss white silicone (2 samples)	Bare, untreated magnesium alloy	yellowish brown	0.27-0.33	0.83	0.30-0.35	-
		Gloss white silicone	Dow 15 treated magnesium alloy	yellowish brown	0.30	0.81	0.34	0.78
		White Kemacryl lacquer (2 samples)	Dow 17 treated magnesium alloy	very little change	0.27	0.73	0.32	0.76
		White Kemacryl lacquer (20 times intensity)	Dow 17 treated magnesium alloy	very little change	0.27	0.73	0.35	0.75
4	12	White Skyspar enamel, B (2 samples)	Dow 15 treated magnesium alloy	yellowish brown	0.26	0.86	0.31	0.84
		Gloss silicone white	Bare, untreated magnesium alloy	yellowish brown	0.30	0.81	0.29	0.83
		Sicon white, A	Dow 15 treated magnesium alloy	yellowish brown	0.25	0.83	0.33	0.83
		Dow 15 finish on magnesium (2 samples)	—	no change	0.23-0.17	0.06-0.07	0.28	0.07-0.08
		Dow 15 finish on magnesium (20 times intensity)	—	no change	0.18	0.09	0.30	0.14

TABLE A-6. (Concluded)

Test Exposure No.	Time	Material ⁽¹⁾	Substrate	Visible Changes	Measured Radiation Characteristics			
					Before		After	
					a	ϵ	a	ϵ
5	100	Gloss white silicone (2 samples)	Bare, untreated magnesium alloy	yellowish brown	0.30	0.81	0.33	0.84
		Sicon white, A	Dow 15 treated magnesium alloy	yellowish brown	0.26	0.84	0.37	0.83
		White Kenacryl lacquer (2 samples)	Dow 17 treated magnesium alloy	no change	0.26	0.74	0.35-0.32	0.76
		White Skyspar enamel, B	Bare, untreated magnesium alloy	yellowish brown	0.26	0.86	0.36	0.82
		Sicon white, (20 times intensity)	Dow 17 treated magnesium alloy	very dark brown	0.31	0.83	0.60	0.83
6	127	Unpigmented silicone resin	Dow 17 treated magnesium alloy	slight yellowing	—	—	—	—
		Barium titanate pigment, silicone resin	Dow 17 treated magnesium alloy	yellowed	—	—	0.34	0.84
		Strontium zirconate pigment, silicone resin	Dow 17 treated magnesium alloy	severe yellowing	—	—	0.47	0.85
		Zircon pigment, silicone resin	Dow 17 treated magnesium alloy	severe yellowing	—	—	0.45	0.85

Note: Intensity of ultraviolet radiation was six times solar ultraviolet intensity in space, except as noted.
 Vacuum generally improved with time during each test, beginning at about 8×10^{-6} mm Hg and ending at about 1×10^{-6} .

(1) Tests No. 1 through 5 are commercial paints; No. 6 are laboratory-prepared paints.

TABLE A-7. COMMERCIAL MATERIALS EXPOSED TO ULTRAVIOLET RADIATION
AND VACUUM (24)

Material	Manufacturer and Designation	Vehicle	Pigment
White Kemacryl laquer	Sherwin Williams, M49WC17	Acrylic resin	50 per cent TiO_2 , 50 per cent talc
Black Kemacryl laquer	Sherwin Williams, M49BC12	Acrylic resin	Carbon black
White Skyspar enamel, A	Andrew Brown, SA-8818	Epoxy resin	TiO_2 , tinted
White Skyspar enamel, B	Andrew Brown, A423-SA9185	Epoxy resin	TiO_2 , untinted
Gloss white silicone	H. P. Fuller, 517-W-i	Silicone resin	TiO_2 , untinted
Sicon white, A	Midland Industrial Finishes Co., 7X1153	Silicone	TiO_2 , tinted
Sicon white, B	Midland Industrial Finishes Co., 7X1120	Silicone	TiO_2 , tinted
Aluminum silicone paint	H. B. Fuller, 171-A-152	Silicone	Aluminum
Dow 15 bright metal finish	Dow Chemical Company	Chemical treatment; no vehicle or pigment	

TABLE A-8. LABORATORY-PREPARED PAINTS EXPOSED TO ULTRAVIOLET
RADIATION AND VACUUM(2.)

Coating Composition (parts by weight)	Curing Cycle
146 parts sodium silicate K 356 parts zircon 890 parts water	0.5 hr 20° C, 1 hr 110° C, 2 hr 150° C, 1.5 hr 250° C, 1 hr 400° C
120 parts silicone resin 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts barium titanate 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts strontium zirconate 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts zircon 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
100 parts sodium silicate K 57 parts Aquablack B 50 parts water	88 hr 20° C, 1 hr 65° C, 1 hr 110° C, 2 hr 150° C
142 parts sodium silicate L 356 parts zircon 890 parts water	0.5 hr 20° C, 1 hr 110° C, 2 hr 150° C, 1.5 hr 250° C, 1 hr 400° C

Sodium silicate D has $\text{Na}_2\text{O}:\text{SiO}_2$ ratio of 1:2.00; sodium silicate K, 1:2.90
Silicone resin was Dow Corning No. 805

TABLE A-9. COLOR CHANGES OF ORGANIC COATINGS IN SIMULATED SOLAR RADIATION (23)

Vehicle	Pigment	Weight Ratio (solids) Vehicle/Pigment	Exposure, h n-hours	Reflectivity ¹ , % at		
				380 mμ	440 mμ	700 mμ
Leonite 201-S	ZrO	1:08:4	0	33.0	93.8	96.5
			74	26.2	76.5	93.7
Leonite 201-S	ZnS	1:08:4	0	60.5	86.4	89.6
			74	52.5	78.5	88.3
Kel-F 800	ZnO	1:5	0	65.0	87.5	90.5
			108	38.0	47.0	57.5
Kynar	ZnO	1:5	0	36.0	84.0	90.0
			108	30.0	64.0	81.0
Exon 461	ZnS	1:4	0	63.0	86.0	89.0
			108	25.5	38.0	64.5
Viton A	ZnO	1:4	0	31.0	88.0	94.0
			108	26.0	68.0	87.5
RTV-11 Silicone	ZnO	1:1	0	26.0	91.0	92.0
			108	26.0	86.0	91.5
LTV-402 Silicone	ZnO	1:5	0	31.5	94.0	95.5
			108	31.0	93.0	94.5
Silicone 806 A	ZnO	1:5:1	0	24.0	86.5	84.0
			108	12.5	46.0	79.0
Silicone 806 A	ZnO	1:4:1	0	26.0	89.0	87.5
			108	17.0	56.0	83.5

¹ Relative to MgO

Leonite 201-S: A silicone-epoxy-acrylic resin supplied by Leon Chemical Industries.

It was cured for 1/2 hour at 125° C.

Kel-F 800: Copolymer of Kel-F and vinylidene fluoride.

Exon 461: Copolymer of vinyl chloride and trifluorochloroethylene

(Firestone Plastics Co.)

Kynar: Vinylidene fluoride homopolymer (Pennsalt Chemicals Corp.)

Viton A: Linear copolymer of vinylidene fluoride and hexafluoropropylene (Du Pont)

LTV-402 Silicone: Liquid dimethylpolysiloxane supplied by G.E.

RTV-11 Silicone: A silica-reinforced dimethylpolysiloxane liquid supplied with CaO and

CaCO₃ fillers by G.E. a catalyst (Thermitite-12) is required for a cure

at room temperature.

TABLE A-10. PHYSICAL EVALUATION OF COATINGS BEFORE AND AFTER ULTRAVIOLET IRRADIATION IN A VACUUM OF 1×10^{-5} mm Hg (24)

Coating Formulation	Test Period, (hr)	Flexibility - Bend at					Adhesion (a)	Color	Weight Loss, (%)	Quality - Remarks
		1/4 inch	1/8 inch	1/16 inch	1/32 inch	1/64 inch				
Phenylmethyl silicone (unpigmented)	0 100	S U	S U	S U	S U	S U	E G	Colorless Amber	- 0.63	Tough and flexible Hard - brittle
Leafing aluminum in silicone	0 100	S S	S S	S S	S S	S S	G G	Metallic Metallic	- 0.08	Tough and flexible Tough and flexible
Zinc sulfide (30% PV in silicone) (b)	0 100	U S	U S	U S	U S	U S	E E	White Slight yellow	- 0.05	Cracks on bending -id
Antimony oxide	0	S	S	S	S	S	E	White	-	Hard and slightly brittle
(30% PV in silicone)	100	S	S	S	S	S	E	Slight yellow	1.27	Hard and brittle
Calcium carbonate (30% PV in silicone)	0 100	S S	S S	S S	S S	S S	E E	Grayish Dark amber	- 0.34	Tough and flexible Hard and slightly brittle
China clay (30% PV in silicone)	0 100	S S	S S	S S	S S	S S	G G	Dark gray Dark amber	- 0.80	Tough and flexible Tough and flexible
Basic white lead carbonate	0	S	S	S	S	S	E	White	-	Hard and slightly brittle
(30% PV in silicone)	100	S	S	S	S	S	G	Slight yellow	2.92	Hard and slightly brittle
Basic white lead carbonate (40% PV in silicone)	0 105	U U	U U	U U	U U	U U	G G	White White	- 0.89	Hard and brittle Hard and brittle
Butyl methacrylate (unpigmented)	0 105	S S	S S	S S	S S	S S	G G	Colorless Amber	- 62%	Soft Brittle
Basic white lead carbonate (40% PV in butyl methacrylate)	0 105	S S	S S	S S	S S	S S	G G	White White	- 4.26	Slightly brittle Slightly brittle
Butylated urea formaldehyde (unpigmented)	0 105	S U	S U	S U	S U	S U	G G	Colorless Amber	- 14.6	Hard and flexible Hard and brittle
Basic white lead carbonate (40% PV in urea formaldehyde)	0 105	U U	U U	U U	U U	U U	G G	White White	- 5.81	Brittle Brittle

(a) Et: excellent, G: good, S: satisfactory, U: unsatisfactory.

(b) PV: pigment-volume ratio.

(c) Slight surface cracks not extending through the coating.

TABLE A-11. TEST ENVIRONMENT AND RESULTS (F STATIC TEST: ELECTRICAL INSULATION(6,7)

Material Trade Name	Gamma [rads] gm(C)	Radiation Exposure		Time Until Test, days	Sample We. Original, gm	Tensile Strength* (psi)			Ultimate Elonga- tion, percent		Temp- ature Avg., °F	Press. Avg., torr
		Thermal	Neutron			at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Percent		
Mylar C (1 mil) (polyester)	0	0	0	0	—	—	20300	Broken in Jaws	24500	70	77	760
		(control specimens) for vacuum test							28000/1369	55		
Batch 1	1.3(9)	6.4(12)	1.5(13)	5.8(11)	0.1218	—	—	—	22800	85	80	5(-6)
		(vacuum irradiation)			0.1201	—	—	—	16400	15		
					0.1194	—	—	—	21300	75		
					0.0012	—	—	—	18677/753	—		
5.4(9)	9.2(13)	9.8(13)	3.7(12)		0.1191	—	—	—	17300	40	80	5(-6)
	(vacuum irradiation)				0.1189	—	—	—	13800	70		
					0.1125	—	—	—	12500	—		
					0.1191	—	—	—	20300	80		
									17225/3768	57/23.6		
Mylar C (1 mil) (polyester)	0	0	0	0	—	—	—	—	17400	47.2	77	760
	(control specimens) for air test								17700	52.5		
Batch 2	4.9(9)	—	1.3(17)	—	—	—	—	—	17600	49.7		
	(air irradiation)								45000	64		76
									38000	54		
									36000	64		
8.0(9)	—	2.2(15)	—	—	—	—	—	—	16500	34.6	—	70
	(air irradiation)								15500	32.4		
									18500	50.5		
									16800	42		
DC 7-170 (silicone)	0	0	0	0	—	—	—	—	788	70	77	760
	(control specimens)								703	71		
									642	62		
									748	97		
									743	95		
									716	—		
									723/57.6	79/15.0		
9.03(9)	2.9(14)	1.4(15)	5.1(13)		3.8522	—	—	—	1690	10	112**	2(-6)
	(vacuum irradiation)				3.6466	—	—	—	1890	16		
					3.7556	—	—	—	1715	13		
									1765/118	13/3.5		
0	0	0	0	0	—	—	—	—	847	80	—	—
	(control specimens)								420	100		
									355	100		
									414	100		
									584	60		
									200	90		
									264	90		
									343/90	57/16		

TABLE A-11. (Continued)

Material Trade Name		Radiation Exposure		Time Until Test, days	Sample Weight		Tensile Strength (psi)		Elongation		Ultimate Temperature		
		Gamma [rads/ gm/Ci]	Neutron (n/cm ²) Thermal E>2.9 Mev D>8.1 Mev days		Original, gm	Change gr	at %	at 100%	at 50%	at 100%	Ultimate percent	Avg. °F	
Kal-F-31 (fluorocarbon)													
0	0	0 (control specimens)	0	—	—	—	—	3670	3990	4660	5240	15, 77 760	
1.47(10)	3.4(14)	2.1(15) (vacuum irradiation)	7.8(13)	20.9974 21.2226 20.2352	-0.0415 -0.0606 Broken	—	—	—	—	—	40	<1 115** 2(-6)	
5.5(9)	—	1.08(15) (air irradiation)	—	—	—	—	—	—	—	—	1568/3	0.58	
8(9)	—	2.2(15) (air irradiation)	—	—	—	—	—	—	—	—	Specimen crushed	—	
Mylar (10 ml) (polyester)													
0	0	0 (control specimens)	0	—	—	—	—	13000	13000	15900	16000	103 77 760	
2.42(10)	3.7(14); 2.2(15) (vacuum irradiation)	8.4(13)	—	1.2589 1.2578 1.2690	-0.0002 0.0000 -0.0009	—	—	—	—	—	17700 14000	<2 <2	118** 2(-6)
Mylar A (3 ml) (polyester)													
0	0	0 (control specimens)	0	—	—	—	—	20650 20850 19833 20037 20037	18330 15180 17300 17800 17900/500	Broken in Jaws	23650 24350 22167 22133 23076/107	85 70 75 78.9	77 760
1.3(9)	5.8(12) 1.5(13) (vacuum irradiation)	6.1(11)	—	1.2455 1.2643 1.2533 1.2477	+0.0003 +0.0007 -0.0000 +0.0004	—	—	—	—	—	51600 56700 66000 64400 59675/5934	80 105 135 135 114/26.7	82 5(-6)
7.0(9)	8.1(12) 6.1(13) (vacuum irradiation)	3.1(12)	—	1.2389 1.2632 1.2368 1.2668	+0.0007 +0.0005 +0.0003 +0.0002	—	—	—	—	—	60000 62667 56300 57052/4869	130 145 110 113/29.1	82 5(-6)

TABLE A-11. (Continued)

[illegible]

TABLE A-11. (Continued)

Material Trade Name	Gross Weight, gm	Time Test, days	Radiation Exposure Neutron (n/cm ²) Thermal D>2.9 Mev D>8.1 Mev	Sav. Wt. Change, Original, gm	Tensile Strength (psi)		Ultimate Elongation, percent	Temper- ature, °F	Presur- Avg., torr
					at 2%	at 50% Elongation			
Gen 2046 Elastomer Div C Specimen	0	0	0 (control specimen)	—	846	1171	2934	295	—
					849	1246	3223	190	—
					844	1252	2921	140	—
					1000	1146	2560	260	—
					849	1151	2722	285	—
					766/236	1282/139	2841	300/67	—
6.8(8)	2.4(13)	1.2(14)	4.9(12) (air irradiation)	—	665	1139	2539	—	—
					572	1173	2553	330	—
					516	1148	2574	330	—
					669	1139	2570	320	—
					607/66	1137/21	2559/23	320/15	—
6.0(9)	1.26(15)	1.6	(air irradiation)	—	855	1244	2561	170	—
					824	1246	2556	172	—
					714	1178	2409	172	—
					736	919	2375	170	—
					740	1122	2375	169	—
					767/79	1137/145	2456/71	169/16	—
1.07(10)	1.9(14)	2.3(15)	8.2(13) (air irradiation)	—	875	1483	2695	130	—
					870	1485	2690	135	—
					714	1281	2620	130	—
					692	1175	2579	130	—
					712	1345	2659	130	—
					794/77	1222	2702	130	—
					1323/124	2000/79	2659/51	134/4	—
3.9(8)	2.0(13)	5.8(13)	2.4(12) (vacuum irradiation)	—	1008	1411	2941	315	4(-7)
					1.003	1192	2900	316	—
					1.0741	1295	3060	315	—
					1.6627	1273	3022	300	—
					3.5968	1230	2870	325	—
					855/104	1239/94	2497/55	325/20	—
1.3(10)	1.2(15)	2.0()	9.8(13) (vacuum irradiation)	—	1174	1875	2941	80	8(-7)
					1.2141	1334	2920	60	—
					1.2116	2078	2422	70	—
					1.117	1989	2360	55	—
					1.0985	2034/2	2360/14	66/12	—
Gen 8800 Elastomer Div C Specimen	0	0	0 (control specimen)	—	1071	1714	3289	270	—
					1746	2077	2930	—	—
					1641	2132	2966	315	—
					1577	1995	2851	300	—
					1577	2169	2924	300	—
					1552	2018	2874	300	—
					1351/307	2352/153.3	2956/173.0	297/15.7	—

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure		Time Up-ell Test, days	Sample Weigh- Original, gm	Change gm	Tensile Strengths (psi)			Ultimate Elongation percent	Ultimate Elonga- tion, in.	Temp- ature °F	Pres- sure, atm.
	Thermal D ₂ 9 Mev D ₂ 1 Mev	Neutron (c/cm ²)				25% Elongation	50% Elongation	100% Elongation				
6.8(8)	2.4(13)	1.2(14) (air irradiation)	10	—	—	—	—	—	1669	0.42	86	—
									1666	0.36		
									1546	0.34		
									1359	0.27		
									1618	0.37		
									1599/297	0.35/0.09		
1.36(9)	1.8(13)	2.5(14) (air irradiation)	10	—	—	—	—	—	1542	0.34	86	—
									1546	0.37		
									1569/51	0.35/0.06		
1.8(8)	8.4(12)	1.8(13) (vacuum irradiation)	6	23.3102	+0.053	—	—	—	8001	0.50	80	1.7(-7)
				23.8511	+0.017				8881	0.74		
				23.0900	+0.037				1977	0.37		
				23.8446	+0.0105				8666	0.63		
				23.8812	+0.0090				2115	0.60		
									2072/100	0.68/0.07		
4.2(8)	1.9(13)	4.5(13) (vacuum irradiation)	6	22.9025	-0.0033	—	—	—	2843	0.65	90	4(-7)
				22.8774	-0.0076				8880	0.75		
				23.8973	-0.0088				1950	0.86		
				22.9133	-0.0098				2243	0.77		
				23.7812	-0.0093				2115	0.75		
									2214/101	0.75/0.09		
8.8(8)	2.8(13)	1.7(14) (vacuum irradiation)	6	23.0949	-0.0060	—	—	—	2216	0.66	90	4(-7)
				22.9676	-0.0040				2568	0.50		
				23.9630	-0.0077				2551	0.78		
				23.7785	-0.0056				2351	0.73		
				24.0815	-0.0043				2115	0.61		
									2250/95	0.70/0.18		
Kymex	0	0	0	—	—	—	—	—	4000	—	—	—
		(control specimens)							5133	—		
									4285	—		
									6167	10		
									5900	5		
									7000	10		
									5900	10		
									5900/2109	8.75/2.12		
0	0	0	0	—	—	—	—	—	7000	300	—	—
		(vacuum deho)										
6.5(7)	3.5(12)	1.4(13) (air irradiation)	13	—	—	—	—	—	5167	10	80	—
									6000	10		
									6167	5		
									7447	10		
									5033	80		
									5987/575	127/7.1		

TABLE A-11. (continued)

Material Trade Name	Gamma Ergs/ gm(Ci)	Radiation Exposure		Time Test, days	Sample Wt., Original, gm	Tensile Strength (psi)		Ultimate Elonga- tion, percent	Temper- ature Avg., °F	Press- ure, torr
		Thermal E>2.9 Mev E>8.1 Mev	Neutron E>2.9 Mev E>8.1 Mev			at 25% Elongation	at 50% Elongation			
1.07(10)	1.5(14)	2.3(15)	8.2(14)	16	—	844	993	1103	2625	300
						769	1020	1291	3120	592
						753	942	1106	2540	292
						735	944	1108	2621	298
						777/47	984/33	1224	2668/127	298/8
3.9(12)	2.8(14)	6.1(15)	2.6(14)	16	—	668	1237	1907	247	120
						1027	1449	—	247	115
						829	1164	1542	2565	135
						885	1170	1770	2360	128
						893/85	1185	1770	2360	128
9.1(8)	2.8(13)	1.4(14)	6.0(12)	—	1.6393	731	914	1111	5499	552
					1.6330	615	976	1161	5496	555
					1.7473	769	894	1092	5591	550
					1.7386	760	900	1080	5596	550
					1.7353	749	900	1105	5590	550
					1.7353	773/36	921/35	1110/35	5521/342	550/22
1.3(10)	1.2(15)	2.0(15)	9.8(12)	6	1.7587	657	960	1644	3420	205
					1.6095	556	927	1483	3770	245
					1.7386	723	1112	1710	3770	245
					1.7584	572	976	1594	3571	230
					1.7684	642/72	1068/82	1625/98	3707/255	231/19
2.6(10)	4.86(14)	4.36(15)	2.09(14)	10	1.7709	565	1412	—	2545	35
					1.6673	667	1359	—	2842	60
					1.7740	855	1641	—	3065	40
					1.7357	1091	2369	—	3195	70
					1.7511	592	1500	—	3319	30
					1.7511	754/226	1097/434	—	2981/341	81/9
0	0	0	0	0	—	—	—	—	2919	0.82
					—	—	—	—	2492	0.91
					—	—	—	—	2262	0.79
					—	—	—	—	2167	0.69
					—	—	—	—	2316	0.94
					—	—	—	—	2291/140	0.83/1.11
1.5(8)	3.3(12)	3.0(13)	1.1(12)	10	—	—	—	—	2193	0.46
					—	—	—	—	1596	0.47
					—	—	—	—	1800	0.41
					—	—	—	—	1972	0.64
					—	—	—	—	1890	0.53
					—	—	—	—	1890/257	0.53/1.10

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure		Time Until Test, days	Sample Weight: Original, Change, at 21 gm gr		Tensile Strength (psi) at 50° at 100° Elongation		Ultimate Elongation, Percent		Ultimate Temper- ature, °F		Pres- sure, Avg., torr
	Gamma (rads/	Neutron (n/cm ²) Thermal > 2.9 Mev > 8.1 Mev										
1.5(8)	3.3(12)	3.0(13)	1.1(12)	13	--	--	--	--	5850 6117 5833 6367 5950 1423/225	10 10 10 5 10 9/2.24	80	--
1.36(9)	1.8(12)	2.5(14)	9.5(12)	13	--	--	--	--	6367 6200 8233 7333 5833 6793/982	10 10 5 5 10 6/2.74	92	--
6.2(7)	4.5(12)	6.3(12)	2.8(12)	9	1.7303 1.5895 1.6308 1.4761 1.5320	0.0030 -0.0002 +0.0015 +0.0002 +0.0006	--	--	6550 5185 5417 5417 5167 5587/543	5 20 15 10 15 16.25/6.77	80	1.7(-7)
1.8(8)	8.4(12)	1.85(13)	7.6(11)	8	1.5288 1.5462 1.5446 1.5016 1.5072	+0.0019 +0.0031 +0.0084 +0.0080 +0.0085	--	--	5283 4581 5667 6000 5811 5363/429	15 5 5 -- 10 8.75/4.80	80	1.7(-7)
9.4(8)	2.8(13)	5.5(14)	5.6(12)	10	--	--	--	--	5667 5333 5250 6117 5800 5033/359	10 -- 10 10 -- 10/0	90	1.7(-7)

* Values given as: average value/standard deviation on an individual basis.

** Estimated value based on temperature of natural rubber.

*** Average value/standard deviation on an individual basis.

Tested under atmospheric conditions.

**** Data point not used in average

TABLE A-12. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS: DIELECTRIC MATERIALS(6,7)

Material Trade Name	Gamma [ergs/ gm(G)]	Radiation Exposure		Time Until Test, days	Sample Orig. Wt., gm	Change, gm	Tensile Strengths (psi)			Ultimate Elonga- tion, percent	Temper- ature Avg., °F	Press. Avg., torr
		Thermal D-2.9 Mev D-8.1 Mev	Neutron (n/cm ²)				at 25% Elongation	at 50% Elongation	at 100% Elongation			
Marlex 6002 (14 mil)	0	0	0	0	—	—	3000	2714	2714	4071	785	—
		(control specimen)					3685	2571	2357	2571	1100	—
							3643	3014	2961	3243	775	—
							3507	2943	2907	3481	640	—
							3700	3107	2843	3086	860	—
							3414	2941	2884	3289	860	—
							3714	3114	2914	3521	910	—
							3685/284	2887/198	2837/217	3776/60	907/120	—
1.5(8)	3.3(12)	3.0(13)	1.1(12)	14	—	—	—	—	—	4286	80	—
		(air irradiation)					—	—	—	4071	—	—
							—	—	—	3613	—	—
							3571	3071	2571	3643	—	—
							3371	3071	2571	4071/191	—	—
1.36(9)	1.8(13)	2.5(14)	9.5(12)	14	—	—	—	—	—	4307	82	—
		(air irradiation)					—	—	—	4079	15	—
							—	—	—	4057	20	—
							—	—	—	3933	5	—
							—	—	—	4097	10	—
							—	—	—	4087/135	14/6	—
1.8(8)	8.4(12)	1.85(13)	7.6(11)	8	1.3795	+0.0008	3214	3464	—	4356	720	1.7(-7)
		(vacuum irradiation)			1.3150	+0.0007	2929	—	—	4286	975	—
					1.2319	+0.0001	3289	—	—	4307	1030	—
					1.2232	+0.0004	3457	2714	—	3664	690	—
					1.3605	+0.0002	4407	3087	—	4250	885	—
							3507/552	3087	—	4197/169	808/142	—
4.5(8)	2.95(12)	5.45(13)	2.1(12)	10	1.3427	+0.0005	3571	3000	—	4429	800	4(-7)
		(vacuum irradiation)			1.3551	+0.0005	4071	—	—	4500	—	—
					1.3462	+0.0003	3786	3071	—	4464	430	—
					1.3441	+0.0004	4143	3486	—	4393	837	—
					1.3169	+0.0003	3786	2857	—	4014	715	—
							3871/246	3054/184	—	4207/183	711/198	—
9.4(8)	2.8(13)	1.6(14)	6.0(12)	10	1.2586	+0.0012	3714	3071	—	3679	725	4(-7)
		(vacuum irradiation)			1.2871	+0.0012	—	—	—	—	—	—
					1.2490	+0.0007	4071	3143	—	4214	640	—
					1.3087	+0.0008	—	—	—	—	—	—
					1.3116	+0.0010	4214	2857	—	4429	660	—
							4700/885	3087/169	—	4307/143	675/50	—
Reaction 778 (10 mil)	0	0	0	0	—	—	1563	2109	2209	3572	255	—
		(control specimen)					—	2318	2590	3845	260	—
							—	2036	2263	3418	240	—
							—	2136	—	533	230	—
							1800/111	2150/137	—	4009/894.0	271/42.5	—

TABLE A-12. (Continued)

Material Trade Name	Radiation Exposure		Time Until Test, days	Sample Weight, Original, Char c. gm	Tensile Strength (psi)			Ultimate Elongation, percent	Temperature, °F	Pressure, Avg., torr
	Gamma [ergs/ cm ²]	Neutron [n/cm ²] Thermal >2.9 Mev >8.1 Mev			at 5% Elongation	at 10% Elongation	at 10% Elongation			
6.5(7)	3.5(12)	1.4(13)	6.0(11)	11	---	---	---	30	80	---
	(air irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
1.5(8)	3.3(12)	3.0(13)	1.1(12)	11	---	---	---	60/17.0	80	---
	(air irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
6.8(8)	2.4(13)	1.2(14)	4.9(12)	x	Too brittle to test			30/6.5		
7.5(7)	4.6(12)	5.2(12)	2.35(11)	9	2.2805 2.2113 2.1813 2.2462 2.2907	-0.0012 -0.0005 -0.0003 -0.0009 -0.0003	1772 1765 1768 1770 1772	30 35 40 45 50	80	1.7(-7)
	(vacuum irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
9.1(7)	7.8(12)	1.7(12)	7.0(11)	9	2.2188 2.2187 2.2885 2.1411 2.3958	+0.0003 +0.0003 -0.0001 +0.0008 0.0000	1772 1765 1768 1770 1772	30 35 40 45 50	80	1.7(-7)
	(vacuum irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
1.68(8)	1.7(12)	1.9(13)		10	---	---	---	100/20.8	85	2.3(-7)
	(vacuum irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
4.45(8)	1.95(13)	5.45(13)	2.1(12)	10	2.2441 2.3956 2.2721 2.3678 2.3678	-0.0009 -0.0005 -0.0006 -0.0002 -0.0003	1772 1765 1768 1770 1772	30 35 40 45 50	90	4(-7)
	(vacuum irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
5.06(8)	8.31(12)	6.9(13)	2.77(12)	9	---	---	---	100/20.8	87	2.5(-7)
	(vacuum irradiation)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	
Reaction Type (40 m.l.) Dye A Specimen	0	0	0	0	---	---	---	100/20.8	---	---
	(control specimens)							1772 1765 1768 1770 1772 1773	30 35 40 45 50 55	

TABLE A-12 (Continued)

[illegible]

TABLE A-1. (Continued)

Material Gamma Trade Name	Radiation Exposure		Time Until Test, days	Sample Weight Original, gm	Change gm	Tensile Strength (psi)			Elongation, percent		Temperature, °F	
	Gamma [ergs/gm(C)]	Neutron [D>2.9 Mev D>8.1 Mev]				at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Final	Avg., °F	Pres., torr
6.8(8)	2.4(13)	1.2(14)	16	4.9(12)	—	2000	2040	2030	2300	140	82	—
						1950	2000	2000	2250	220	—	—
						1900	1950	1970	2250	140	—	—
7.5(7)	4.6(12)	5.2(12)	9	2.35(11)	—	1950/49	1980/45	1945/38.5	2245/49.5	177.5/43.5	—	—
						2050	2100	2160	3000	365	80	1.7(-7)
						2050	2100	2160	4020	430	—	—
1.8(8)	8.4(12)	1.05(13)	9	7.6(11)	—	2050	2100	2160	3780	360	—	—
						2050	2100	2160	3780	360	—	—
						2050	2100	2160	3780	360	—	—
4.45(8)	1.95(13)	5.45(13)	10	2.1(12)	—	1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—
						1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—
						1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—
1.5(8)	3.3(12)	3.0(13)	16	4.9(12)	—	1860	1869	1845	2102	300	80	—
						1796/74	1834/40	1868/91	2191/90	313/11	—	—
						1796/74	1834/40	1868/91	2191/90	313/11	—	—
5.8(8)	2.4(13)	1.2(14)	16	4.9(12)	—	2065	2085	2065	2276	120	82	—
						1904	1928	1657	1928	100	—	—
						1913	1913	1913	1913	55	—	—
4.45(8)	1.95(13)	5.45(13)	10	2.1(12)	—	1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—
						1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—
						1940/129	1960/125	1970/117.0	3445/336.2	349.5/34.2	—	—

TABLE A-12. (Continued)

Material Trade Name	Radiation Exposure		Time Until Test, days	Specimen Weight Change, Original, gm		Tensile Strength (psi) at 25% Elongation		Tensile Strength (psi) at 50% Elongation		Ultimate Elongation, percent	Temperature, °F	Pressure, Avg., torr
	Gamma [Mr(Ci)]	Neutron (n/cm ²) Thermal E>2.9 Mev E<8.1 Mev		Original, gm	Change, gm	at 25% Elongation	at 50% Elongation	Ultimate Elongation	Ultimate Elongation			
9.1(7)	7.8(12)	1.7(13)	7.0(11)	5.452	+0.0007	1896	1933	1933	2852	320	80	1.7(-7)
				5.414	+0.0014	1941	1975	1975	2858	315		
				5.432	+0.0031	1908	1956	1956	2884	345		
				5.382	+0.0082	1908	1932	1932	2894	310		
				5.475	-0.0039	1896	1933	1933	2877	310		
										1908/28		
3.9(8)	1.9(13)	4.4(13)	1.7(12)	5.388	-0.0007	1849	1867	1867	231	330	90	4(-7)
				5.387	+0.0004	1893	1902	1902	235	315		
				5.407	-0.0015	1917	1941	1941	2487	155		
				5.461	-0.0005	1893	1932	1932	2394	336		
				5.452	-0.0006	1870	1892	1892	2389	310		
										1884/25		
1.5(8)	3.3(12)	3.0(13)	1.1(12)	5900	—	5900	—	—	283	—	—	—
				5790	—	5790	—	—	287	—		
				5790	—	5790	—	—	276	—		
				6000	—	6000	—	—	255	—		
				5790	—	5790	—	—	250	—		
										5930/107		
1.36(9)	1.8(13)	2.5(14)	9.5(14)	5400	—	5400	—	—	255	—	80	—
				5730	—	5730	—	—	250	—		
				5730	—	5730	—	—	260	—		
				5400	—	5400	—	—	250	—		
				5400	—	5400	—	—	250	—		
										5477/172		
9.1(7)	7.8(12)	1.7(13)	7.0(11)	5900	—	5900	—	—	190	—	80	1.7(-7)
				5790	—	5790	—	—	225	—		
				5790	—	5790	—	—	260	—		
				5400	—	5400	—	—	250	—		
				5400	—	5400	—	—	250	—		
										5470/125		
9.1(7)	7.8(12)	1.7(13)	7.0(11)	6000	+0.0004	6000	6500	6500	10000	260	80	1.7(-7)
				6240	+0.0003	6240	—	—	7500	—		
				6000	+0.0009	6000	—	—	17400	285		
				6000	+0.0002	6000	—	—	2650	280		
				6000	+0.0004	6000	—	—	2650	280		
										6100/150		
4.45(8)	1.95(13)	5.45(13)	2.1(12)	5900	-0.0008	5900	—	—	225	—	90	4(-7)
				5900	+0.0003	5900	—	—	225	—		
				5900	+0.0003	5900	—	—	240	—		
				5900	+0.0003	5900	—	—	240	—		
				5900	+0.0002	5900	—	—	240	—		
										6100/170		

TABLE A-12. (Continued)

Material Trade Name	Radiation Exposure		Time Until Test, days	Sample Weights		Tensile Strengths (psi)		Ultimate Elongation, percent	Temperature At Test, °F	Press. Avg., torr
	Gamma [ergs/ gm(G)]	Neutron (n/cm ²)		Original, gm	Change, gm	at 25% Elongation	at 100% Elongation			
1.5(8)	3.3(12)	3.0(13)	1.1(12)	13					80	-
	(air irradiation)					1515 1422 1393 1362 1310 1280/74	1334 1376 1393 1472 1477 1447/38	2482 2493 2633 2463 2707 2715/105	410 360 390 400 410 384/21	
1.36(9)	1.8(13)	2.5(14)	9.5(12)	13					88	-
	(air irradiation)					1658 1606 1626 1632 1613 1637/22	1711 1616 1616 1701 1685 1674/31	2139 1770 1944 2327 2404 2361/765	270 230 250 290 290 266/26	
1.07(1)	1.9(14)	2.3(15)	0.2(13)	16					100	-
						2100 — 8094 2077/27	— — 8094 2077/27	2100 2114 1970 2090 2084/22	25 30 25 31 27/6	
1.8(8)	8.4(12)	1.05(13)	7.6(11)	8					80	1.7(-7)
	(vacuum irradiation)					1473 1673 1700 1715 1513 1657/50	1673 1693 1700 1702 1618 1674/35	2744 2644 2496 2885 2723 2746/167	400 400 370 400 381 393/13	
8.8(9)	2.8(13)	1.7(14)	6.4(12)	7					90	4(-7)
	(vacuum irradiation)					1722 3.2368 3.0910 3.1378 3.3332 1679/31	1736 1680 1743 1654 1693 1699/38	2646 2643 2802 2893 2748 2700/189	325 315 322 322 315 324/9	
1.3(10)	1.2(15)	2.0(15)	9.8(13)	6					160	9(-7)
	(vacuum irradiation)					1807 — 1800 — 1800 1800/4	— — 1800 — 1800 1800/4	2115 2106 2053 2101 2100 2099/29	35 65 50 45 45 48/13	
Reflex 775 (no mil)	0	0	0	0					77	760
	(control specimen)					1683 1690 1660 1678/17.7 1694/34.8	1683 1690 1660 1678/17.7 1694/34.8	— 1881 1915 273 V/254 273 V/254	— 290 315 302/22.1**	

TABLE A (Continued)

Material Gamma		Radiation Exposure		Time	Sample Weights		Tensile Strengths (psi)		Ultimate		Tempor-
Trade	[e.g./	Neutron		Test,	Original,	Final	at 50%	at 100%	Elonga-	percent	ature
Name	gm(Ci)]	Thermal E		days	gm	gm	Elongation	Elongation	Ultimate		°F
		2.9(13)	8.0(11)		8.7099	-0.0003	—	—	1564	15	60
		(vacuum irradiation)			8.7756	+0.0012	—	—	1512	5	
					8.8495	0.0000	—	—	1519/49.0	11.7/5.9	
					9.0502	-0.0001	—	—	—	—	
Teflon TFE	0	0	0	0	1630	1630	1750	1970	2230	155	77
(10 mil)		(control specimens)			1690	1690	1840	2050	2130	116	
		August 1962			1670	1670	1800	1930	2120	139	
					1665/29.1	1798/43.7	1890	1930	2230	148	
					1665/29.1	1798/43.7	1890	1930	2202/7.7	143/18.0	
0	0	0	0	0	1620	1620	1800	—	2240	160	—
		(control specimens)			1590	1590	1800	2110	2210	125	
		February 1963			1780	1780	1950	2160	2300	130	
					1660/118	1850/86.6	1950/62.1	2145/62.1	2250/53.2	130/20.7	
0	0	0	0	0	2.1280	+0.0002	—	—	—	—	77
		(vacuum controls)			2.0628	+0.0002	1660	1820	2180	130	1(-6)
		February 1963			2.0423	+0.0038	1711	1875	2260	132	
					2.1156	+0.0011	1680	1870	2280	131	
					2.1127	+0.0004	1660	1850	2260	130	
					—	—	1663/53.3	1854/26.7	2235/48.6	130/8.3	
1.7(9)	6.5(12)	1.3(13)	7.3(11)		2.1373	-0.0023	—	—	1300	2	80000
		(vacuum irradiation)			2.1178	0.0000	—	—	1250	3	c(-6)
					2.1397	-0.0002	—	—	—	—	
					2.0991	+0.0032	—	—	—	—	
Teflon loc	0	0	0	0	1690	—	1750	1775	1275/44.3	2.5/0.69	77
(40 mil)		(control specimens)			1725	—	1770	1800	2106	283	
					1725	—	1770	1800	1910	235	
					1713/20.7	1763/11.8	1770	1800	2165	288	
					—	—	1793/17.7	1800	2061/151	262/28.4	
8.6(9)	3.7 (4)	3 (15)	4.6 (13)		8.2465	-0.0250	—	—	1307	2	110
		(vacuum irradiation)			8.1375	-0.0187	—	—	1311	1	5(-7)
					8.1265	-0.0197	—	—	1224/73.6	1.5/0.69	
Marlex 6002	0	0	0	0	—	—	—	—	1343	> (800) none	77
(poly-		(control specimens)			—	—	—	—	3857	> (800) none	
ethylene)					—	—	—	—	3269	> (800) none	
					—	—	—	—	3214	> (800) none	
					—	—	—	—	3571	1060	
					—	—	—	—	3520	350	
					—	—	—	—	3941/234	1305/97.5	

TABLE A-12. (Continued)

Material Trade Time	Radiation Exposure		Time Until Test, days	Sample Weights Original, Change, gm	Tensile Strengths (psi)			Ultimate Elonga- tion, percent	Temper- ature Avg., °F	Press. Avg., atm
	Gamma (rads/cm ²)	Neutron (n/cm ²)			at 25% Elongation	at 50% Elongation	at 100% Elongation			
Teflon	1.1(10)	3.6(14)	2.3(15)	5.5(13)	1.2836 1.2832 1.2748	-	-	9489 5500 5405/126	50 75 55/20.7	5(-7)
	0	0	0	0	-	6050 6100 6250 6375 6590 6333/176	6700 6800 7500 7200 7000/472	170 100 100 90 110/44.7	114	760
	1.3(9)	6.1(12)	1.55(13)	5.95(11)	0.3060 0.3060 0.3067 0.3095 0.3092	-	-	7650 8150 8100 7800 7925/283	90 105 105 105 101/7.3	5(-6)
Teflon	5.2(9)	0.6	9.1(13)	3.4(12)	0.2814 0.2872 0.2810 0.3050	-	-	7900 6800 9000 7500 7600/1028	90 70 100 75 84/15.5	5(-6)
	0	0	0	0	-	-	-	-	-	-
	1.3(9)	6.1(12)	1.55(13)	5.95(11)	0.3060 0.3060 0.3067 0.3095 0.3092	-	-	7650 8150 8100 7800 7925/283	90 105 105 105 101/7.3	5(-6)

* Values given: ± average value/standard deviation on an individual basis.

** Average value/standard deviation on an individual basis.

*** Estimated value based on temperature of Teflon (40 mil)

**** The elongation was greater than 800 percent but was not the ultimate, since the original gage length selected for this specimen was so large and resulted in an insufficient amount of total crosshead travel required to break the specimen. This did not effect the maximum strength, however, since this value is obtained when the specimen yields.

***** Specimen broke in jaws.

Tested under atmospheric conditions.

TABLE A-13. TENSILE STRENGTH OF DYNALAM LAMINATES⁽¹⁾

Type*	Exposure		Irrad. Temp, F	Tensile Strength**, psi		
	Gamma, ergs g ⁻¹ (C)	Neutron, n cm ⁻² (E>2.9)		Sheet 1	Sheet 2	
A	Controls	Controls	75	39,411/4,528/6	31,163/2,453/8	/8
A	5.6 x 10 ¹⁰	5.2 x 10 ¹⁵	120	36,894/6,650/5	29,372/2,261/5	/5
A	1.7 x 10 ¹¹	1.7 x 10 ¹⁶	130	38,317/3,082/5	29,559/1,258/5	/5
A	Controls	Controls	450	21,157/7,724/5	20,441/5,226/5	/5
A	5.6 x 10 ¹⁰	7.2 x 10 ¹⁵	455	28,160/3,494/5	22,600/1,826/5	/5
B	Controls	Controls	75	40,073/8,633/5	32,080/4,173/3	/3
B	5.6 x 10 ¹⁰	5.2 x 10 ¹⁵	120	44,047/4,184/4	32,706/4,870/5	/5
B	1.7 x 10 ¹¹	1.7 x 10 ¹⁶	130	41,297/11,674/4	31,563/3,502/5	/5
B	Controls	Controls	450	30,822/2,988/3	21,962/2,735/5	/5
B	6.0 x 10 ¹⁰	7.2 x 10 ¹⁵	455	30,684/4,995/4	21,252/3,953/5	/5

*A - with curing agent

B - without curing agent.

**Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

TABLE A-14. EFFECT OF TEMPERATURE AND VACUUM ON LAMINATES (9)

Laminate	Test Conditions	Tests	Test Result	Comments
1. Epon 828, Het anhydride cured, fiberglass cloth	Temperature 400 F Pressure 8.3×10^{-5} Time at pressure 6 hours	Wet compression test at room temperature	2.6% Increase in compression strength	--
2. Polyester, 181 glass cloth with Volan A finish	Temperature 250 F Pressure 1.0×10^{-4} Time at pressure 6 hours	Ditto	8-4% Increase	--
3. Phenolic 91LD, 181 glass cloth with Volan A finish	Temperature 400 F Pressure 4.5×10^{-4} Time at pressure 4-5 hours	"	36.5% Increase	--
4. Silicone phenolic 37-9X, 181 glass cloth with Volan A finish	Temperature 400 F Pressure 4.4×10^{-4} Time at pressure 6 hours	"	9.6% Increase	Compression data widely scattered
5. Epon X131, on 181 glass cloth with Volan A finish	Temperature 400 F Pressure 2.2×10^{-4} Time at pressure 6 hours	"	No significant change	--
6. Silicone R 7141 asbestos	Temperature 400 F Pressure 6.5×10^{-5} Time at pressure 2.5 hours	"	3.7% Increase	Compression data widely scattered
7. DC 2105 Silicone asbestos RPI	Temperature 400 F Pressure 1.1×10^{-4} Time at pressure 6.5 hours	"	4.1% Decrease	Compression data widely scattered
8. Melamine Ali00, 181 glass cloth with Volan A	Temperature 400 F Pressure 9.6×10^{-5} Time at pressure 6 hours	"	5.2% Decrease	Ditto
9. Phenolic 41KPD, asbestos	Temperature 400 F Pressure 4.3×10^{-4} Time at pressure 5.5 hours	"	6.1% Increase	"

TABLE A-15. COMPOSITION OF PLASTIC TEST SPECIMENS (7)

Specimen	Description	Material Trade Name	Manufacturer
1	Epoxy with unidirectional glass fibers	Scotchply 1009-26	3M Company
2	Phenolic with glass fabric - lengthwise	Type 143 glass fabric, SC 1008 resin	Coast Mfg.
3	Phenolic with high-silica fabric	Refrasil fabric, SC 1008 resin	Western Backing
4	Phenolic with asbestos felt - random	40 RPD asbestos, Plyophen 5900 resin	U.S. Polymeric
5	Phenolic with graphite fabric!	Graphite fabric, SC 1008 resin	Coast Mfg.
6	Phenolic with chopped glass fibers - random	Molding Compound OPX-197	Fiberite
7	Phenolic with chopped glass fibers - random	Molding Compound MX-2625	Fiberite
8	Phenolic with chopped graphite fabric random	Molding Compound MX-4551	Fiberite
9	Phenyl-silane with glass fabric	Type 181 glass fabric, SC 1013 resin	Monsanto
10	Epoxy with glass fabric	Type 181 glass fabric, E-787 resin	U.S. Polymeric

TABLE A-16. SUMMARY OF PROPERTIES, CHANGES FOR MATERIALS IRRADIATED
IN VACUUM AND AIR AND TESTED IN AIR(6)

Category	Material Trade Name	Gamma Exposure, ergs/gm(C)	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Structural Laminates	Silicone DC-2106	4.5×10^{10}	5×10^{-7}	Tensile (ASTM-D-638- 58I, Type I)	Ultimate tensile strength Ultimate elongation Weight Change	0 0 -0.19
	CTL-91-LD (phenolic)	4.5×10^{10}	5×10^{-7}	Tensile (ASTM-D-638- 58I, Type I)	Ultimate tensile strength Ultimate elongation Weight change	0 0 -0.60
	Epon 828 (epoxy)	8.6×10^9	3×10^{-1}	Tensile, modified (ASTM-D-638-58I Type I)	Ultimate tensile strength Ultimate elongation	0 0
		7.5×10^9	3×10^{-7}	Straight flexural specimens	Ultimate flexural strength Ultimate deflection Weight change	0 0 0
	Conolon 506 (phenolic)	9.7×10^9	3×10^{-1}	Tensile, modified (ASTM-D-638-58I, Type I)	Ultimate tensile strength Ultimate elongation	0 0
	Mobiloy AH-81 (phenolic)	1.7×10^{10}	5×10^{-7}	Straight tensile specimens	Ultimate tensile strength	-15.6

TABLE A-17. SUMMARY OF PROPERTY CHANGES FOR MATERIALS IRRADIATED AND TESTED IN VACUUM (6)

Category	Material Trade Name	Gamma Exposure [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Adhesive	FM-1000 (epoxy polyamide)	1.1×10^{10}	3×10^{-6}	Lap shear, modified	Ultimate shear strength	0
		1.9×10^{10}	5×10^{-6}	Lap shear, modified	Ultimate shear strength	+21
	MB-302 (epoxy phenolic)	1.6×10^{10}	3×10^{-6}	Lap shear, modified	Ultimate shear strength	+15
		2.1×10^{10}	5×10^{-6}	Lap shear, modified	Ultimate shear strength	+41.5
Structural Laminate	Canolon 506 (phenolic)	1.3×10^{10}	3×10^{-6}	Tensile, modified (ASTM-D-638-S8T)	Ultimate tensile strength	+29.6
		2.0×10^{10}	5×10^{-6}	Tensile, modified (ASTM-D-638-S8T)	Ultimate elongation	+50
	Epon 828/A (epoxy)	1.4×10^{10}	3×10^{-6}	Tensile, modified (ASTM-D-638-S8T)	Ultimate tensile strength	+55
		2.0×10^{10}	5×10^{-6}	Tensile, modified (ASTM-D-638-S8T)	Ultimate tensile strength	+48
Sea:	Viton F (PP 19007)	9.0×10^9	3×10^{-7}	O-Rings	Ultimate tensile strength	+7
					Ultimate elongation	-79
	RTV-60 (silicone)	8.6×10^9	3×10^{-7}	Compression disks	Compressive strength at 0.02-inch deflection	+76
					Compressive strength at 25% deflection	+30
Potting Compound	Stafoam AA-402 (polyurethane)	8.9×10^9	3×10^{-7}	Compression disks	Ultimate compressive strength	+22
Thermal Insulation					Weight change	-2.0

TABLE A-18. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS:
STRUCTURAL PLASTICATES

Material Trade Name	Radiation Exposure		Time Until Test, days	Sample Weight		Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressing Average, torr
	Gamma [ergs/gm(C)]	Neutrons (n/cm ²) Thermal E>2.9 Mev E<8.1 Mev		Original, grams	Change, grams				
Mobiloy 81-4H7 (phenolic)	0	0 (control specimens)	0	-	-	60666 41245 38717 <u>34123</u> 49238/10757	1.96 1.46 1.30 <u>1.60</u> 1.60/0.32	-	-
	6.0(9)	- (air irradiation)	14	-	-	60082 45238 46746 38716 <u>41122</u> 46381/9186	1.75 1.44 1.37 1.75 <u>1.30</u> 1.32/0.19	100	-
	1.07(10)	1.9(14) (air irradiation)	14	-	-	49705 59153 43082 39289 <u>56672</u> 49380/8340	1.53 1.86 1.36 1.18 <u>1.75</u> 1.54/0.29	100	-
	3.9(10)	2.8(14) (air irradiation)	14	-	-	47199 54313 50329 50385 <u>34615</u> 47368/8469	1.57 1.81 1.56 1.61 <u>1.02</u> 1.51/0.34	100	-
	4.1(9)	6.4(13) (vacuum irradiation)	6	15.1895 15.2567 14.8518 14.1000 14.62.1	-0.0300 -0.0261 -0.0206 -0.0231 -0.0275	47750 58373 55652 60949 <u>56568</u> 55938/5075	1.37 1.77 1.71 1.88 <u>1.44</u> 1.63/0.22	160	8(-7)

TABLE 18. (Continued)

Material Trade Name	Radiation Exposure		Time Unit, days	Sample Weight		Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, ° F	Pressure Average, torr
	Gamma [ergs/gm(C)]	Neutrons (n/cm ²) Thermal E>2.9 Mev E8.1 Mev		Original, grams	Change, grams				
1.4(10)	9.5(14) (vacuum irradiation)	1.8(15) 7.4(13)	6	15.0600	-0.0241	61167	1.50	160	8(-7)
				14.5719	-0.0287	57673	1.63		
3.1(10)	2.87(14) (vacuum irradiation)	7.87(15)	13	14.6645	-0.0218	58771	1.29		
				14.6314	-0.0194	60832	1.61		
				14.7718	-0.0272	55264	1.54		
				15.2639	-0.0151	58741/2538	1.51/0.15		
				14.6430	+0.0077	39535	1.05	200	5(-7)
Paraplex P-43 (polyester)	0 (control specimens)	0	0	14.3558	+0.0101	46400	1.50		
				14.5942	+0.0079	--	--		
				14.9385	+0.0103	41016	1.19		
						42317/4055	1.25/0.27		
						37925	1.61		
						35042	1.78		
						38738	1.78		
						38529	1.94		
						37638	2.02		
						43650	2.15		
6.0(9)	1.26(15) (air irradiation)	8.2(13)	15	41117	1.75	41117	1.75		
				40140		40140	2.17		
				40815		40815	1.75		
				39173/2767		39173/2767	1.88/0.18		
				36322		36322	1.77	100	
1.07(10)	1.9(14) (air irradiation)	2.3(15)	15	35611		35611	1.75		
				26891		26891	1.45		
				32941/5571		32941/5571	1.66/0.19		
				40862		40862	1.87	100	
				39299		39299	1.95		
				25049		25049	1.10		
				36370		36370	1.61		
				35445/7587		35445/7587	1.63/0.41		

TABLE A-18. (Continued)

Material Trace Name	Radiation Exposure		Time Until Test, days	Sample Weight		Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressure Average, torr
	Gamma [ergs/cm(C)]	Neutrons (n/cm ²)		Original, grams	Change, grams				
DC-2104 (silicone)	3.9(10)	2.8(14) (air irradiation)	15	-	-	36103 36114 36075 36099 <u>36773, 1324</u>	1.89 1.79 1.73 1.80 <u>1.80/0.08</u>	100	-
	4.1(9)	6.4(13) (vacuum irradiation)	6	14.5953 14.5378 14.5011 13.7559	-0.0119 -0.0143 -0.012 -0.0142	40348 40898 40126 49698 <u>42768/4652</u>	1.88 1.92 2.00 1.94 <u>1.94/0.06</u>	160	8(-7)
	1.4(10)	9.4(14) (vacuum irradiation)	0	14.0466 13.5526 14.7077 14.8699	-0.0278 -0.0252 -0.0401 -0.0368	40523 43224 39366 39311 <u>40356/2338</u>	1.65 2.06 1.96 1.86 <u>1.88/0.17</u>	160	8(-7)
	3.1(10)	2.7(14) (vacuum irradiation)	12	14.8013 12.9719 14.8986 13.7477	-0.1001 -0.0735 -0.1199 -0.1060	31250 35871 28908 31603 <u>31908/3384</u>	1.52 1.54 1.44 1.62 <u>1.53/0.09</u>	200	6(-7)
DC-2104 (silicone)	0	0 (control specimens)	-	-	-	16399 21626 23210 17848 17989 <u>19406/2945</u>	0.94 1.17 1.11 1.10 0.93 <u>1.05/0.10</u>	-	-

TABLE A-19. (Continued)

Material Trade Name	Radiation Exposure		Time Until Test, day	Sample Weight Change, grams	Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressure Average, torr
	Gamma ergr/gm(C)	Neutrons(a/cm ²) Thermal E>2.9 Mev E>8.1 Mev						
DC-2104 (silicone)	6.0(9)	-	14	-	17562 17594 21192 20131 <u>20044</u> <u>20515/3668</u>	0.95 0.89 1.09 1.07 <u>1.17</u> <u>1.05/1.15</u>	100	-
	1.07(10)	1.9(14) (air irradiation)	14	-	19352 20645 19789 18707 <u>18622</u> <u>19423/870</u>	1.02 1.07 1.04 1.05 <u>0.91</u> <u>1.02/0.07</u>	100	-
	3.9(10)	2.8(14) (air irradiation)	14	-	19737 22795 21080 19768 <u>20290</u> <u>20734/1313</u>	1.16 1.19 1.23 1.15 <u>1.12</u> <u>1.17/0.05</u>	100	-
	3.8(9)	-	6	19.8010 13.4341 13.8041 20.3603 20.1233	22243 19512 19073 23438 21229 <u>21099/1877</u>	1.19 1.50 1.34 1.25 <u>1.14</u> <u>1.28/0.15</u>	160	8(-7)
	1.4(10)	9.4(14) (vacuum irradiation)	6	20.0366 20.3746 20.3654 20.3454 19.9027	-0.0691 -0.0450 -0.0459 -0.0416 -0.0658	1.17 1.21 1.21 1.17 <u>1.25</u> <u>1.28/0.03</u>	160	8(-7)
	2.85(10)	3.88(14) (vacuum irradiation)	12	20.3202 19.4871 20.4845 20.1397 20.3301	-0.2352 -0.2169 -0.2492 -0.2480 -0.2487	0.98 1.10 1.14 0.97 <u>1.11</u> <u>1.06/0.07</u>	200	6(-7)

TABLE A-18. (Continued)

Material Trade Name	Radiation Exposure			Time Test, days	Sample Weight Original, grams	Change, grams	Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressure Average, torr
	Gamma [ergs/gm(C)]	Neutrons (n/cm ²)								
		Thermal E<2.9 Mev	E>2.9 Mev E>8.1 Mev							
Selectron 5003 (polyester)	0	0	0	-	-	-	45524	1.93	-	-
		(control sr					45768	1.52		
							50593	2.13		
							42829	2.28		
							45429/3800	1.99/0.32		
6.0(9)		-	1.26(15) (air irradiation)	14	-	-	50444	1.84	100	-
							51102	2.04		
							48217	1.63		
							46602	1.84		
							42661	1.84		
1.07(10)		1.9(14)	2.3(15) (air irradiation)	14	-	-	47805/3629	1.86/0.18	100	-
							35878	1.43		
							41609	1.64		
							48819	2.00		
							40637	1.78		
3.9(10)							42452	1.60		
		2.8(14)	6.1(15) (air irradiation)	14	-	-	41879/5564	1.39/0.25		
							41767	1.86	100	-
							50020	1.90		
							43998	1.84		
7.2(9)							48033	1.62		
		1.29(14)	6.55(14) (vacuum irradiation)	15	-	-	45256	1.71		
							45815/3548	1.79/0.12		
							52038	2.02	130	1(-3)
							55585	2.13		
							56102	2.19		
							47905	1.62		
							51655	2.29		
							52657/3524	2.05/0.29		

TABLE A-18. (Concluded)

Trade Name	Radiation Exposure		Time Until Test, days	Sample Weight Original, Change, grams	Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressure Average, torr
	Gamma ergs/gm(C)	Neutrons (n/cm ²) Thermal E>2.9 Mev E>8.1 Mev						
Selectron 5003 (polyester)	1.05(10)	1.32(14)	5.90(13)	-	51918	2.36	150	1(-3)
		(vacuum irradiation)			46924	1.45		
					42609	2.03		
					44120	2.09		
					44930	1.94		
					46080/4002	1.97/0.39		
	2.85(10)	3.89(14)	2.09(14)	-	45782	1.83	200	6(-7)
		(vacuum irradiation)			50814	2.03		
					40864	1.96		
					42293	1.96		
					44176	1.81		
					44786/4278	1.92/0.09		

Tested under atmospheric conditions.

(a) Values given as average value/standard deviation on an individual basis.

TABLE A-19. TEST ENVIRONMENTS AND RESULT OF STATIC TESTS:
STRUCTURAL LAMINATES(7)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure		Time Until Test, days	Compressive Strength at 25% Elongation, psi	Compressive Elongation, a per cent	Temperature Average, °F	Pressure Average, torr
		Thermal	Neutrons (0/cm ²) E>2.9 Mev E>8.1 Mev					
Honeycomb HRP (phenolic)	0	0 (control specimens)	0	-	303 302 276 330 303/26	422 438 418 441 427/16	-	-
	6.0(9)	- (air irradiation)	1.26(15)	23	-	431 494 456 460/37	100	-
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	23	-	606 567 606 531 378/36	100	-
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	23	-	582 625 544 462 468 536/27	100	-
	5.9(9)	1.18(14) (vacuum irradiation)	6.56(14)	23	280 352 282 305/43	424 447 422 431/15	150	1(-3)

TABLE A-12. (Concluded)

Material Trade Name	Radiation Exposure		Time U-til Test, days	Compressive Strength at 25% Elongation, psi	Compressive Elongation, per cent	Temperature Average °F	Pressure Average torr
	Gamma ergs/g.m(C)	Neutrons (n/cm ²) Thermal E>2.9 Mev E>0.1 Mev					
Honeycomb HRP (phenolic)	1.05(10)	1.32(14) (vacuum irradiation)	5.9(13)	23	456 433 <u>446/22</u>	150	1(-3)
	2.85(10)	3.88(14) (vacuum irradiation)	2.09(14)	22	483 410 <u>482</u> 458/43	200	6(-7)

Tested under atmospheric conditions.

(a) Values given as average value/standard deviation on an individual basis.

TABLE A-20. FLEXURAL STRENGTH OF LAMINATES AFTER
EXPOSURE TO VACUUM AND VARIED INTENSITY (35)
OF ULTRAVIOLET RADIATION³⁵

Radiation Falling on Specimens, pyrons	Time of Exposure, hours	Average* Ultimate Flexural Strength, psi	Average* Flexural Modulus x 10 ⁶ , psi
<u>Polyester P-43 Laminate</u>			
Control	0	59,300	2.4
2	125	61,800	2.6
3	125	64,400	2.8
4	25	50,100	2.5
5	3	24,200	-
6	3	--	-
<u>Epoxy Epon 815 Laminate</u>			
0	0	84,400	3.8
2	125	84,700	3.8
3	125	84,000	3.8
4	25	57,600	3.5
5	3	39,800	-
6	3	--	-
<u>Phenolic CTI.-91 Laminate</u>			
0	0	68,900	3.6
2	125	61,700	3.6
3	125	56,700	3.5
4	25	49,500	3.0
5	3	57,100	3.2
6	3	--	-

* Average of four specimens.

TABLE A-21. COMPRESSIVE STRENGTH OF LAMINATES
AFTER EXPOSURE TO VACUUM AND VARIED
INTENSITY OF ULTRAVIOLET RADIATION³⁵

Radiation Falling on Specimens, pyrns	Time of Exposure, hours	Average* Compressive Strength, psi	Average* Compressive Modulus x 10 ⁶ , psi
<u>Polyester P-43 Laminate</u>			
Control	0	40,900	3.1
2	125	47,300	3.1
3	125	51,900	3.2
4	25	40,800	3.1
5	3	39,900	3.1
6	3	--	-
<u>Epoxy Epon 815 Laminate</u>			
0	0	53,900	3.5
2	125	48,400	3.5
3	125	51,300	3.5
4	25	43,000	3.4
5	3	44,200	3.4
6	3	--	-
<u>Phenolic CTL-91 Laminate</u>			
0	0	44,800	3.5
2	125	39,400	3.5
3	125	39,300	3.5
4	25	31,500	3.4
5	3	32,600	3.4
6	3	--	-

* Average of four specimens.

TABLE A-22. LAMINATE PANELS COMPARED WITH ULTRAVIOLET ABSORBERS (19)

Panel	Reinforcement	Resin	Catalyst	Ultraviolet		Laminate Thickness	Resin Yellowing Due to UV Absorber	Appearance of Panel
				Absorber by Weight Based on Resin	Absorber by Weight Based on Resin			
UV I	12 plies 181-172	Paraplex P-444A	1% B.P.	None added	None added	0.105	None	Opaque
UV II	12 plies 181-172	P-43	1% B.P.	0.5% Cyasorb UV9	0.5% Cyasorb UV9	0.109	None	Transparent
UV III	12 plies 181-172	P-43	1% B.P.	0.5% Cyasorb UV24	0.5% Cyasorb UV24	0.112	Slight	Transparent
UV IV	12 plies 181-172	P-43	1% B.P.	Geigy Tunuvin P CH-497 0.5%	Geigy Tunuvin P CH-497 0.5%	0.112	Slight	Transparent
UV V	12 plies 181-172	P-43	1% B.P.	Dicarboxy-ferrocene 0.1%	Dicarboxy-ferrocene 0.1%	0.110	Decided yellowing	Opaque

TABLE A-23. PERCENTAGE LOSS IN WEIGHT OF POLYESTER LAMINATES
CONTAINING ULTRAVIOLET-ABSORBING AGENTS(19)

Panel	Control	Ultimate Flexural Strength* After Indicated Exposure, psi					
		2 pyrens 100 hours	2 pyrens 200 hours	3 pyrens 100 hours	3 pyrens 125 hours	6 pyrens 6 hours	6 pyrens 6 hours
UV I	61,000	70,400	72,500	72,500	72,800		56,700
UV II	78,800	81,400	82,500	79,500	80,500		72,300
UV III	72,400	76,400	80,900	73,200	67,300		69,300
UV IV	77,700	81,200	81,800	77,500	72,100		71,700
UV V	67,100	79,500	74,300	71,400	74,600		60,900

* Average of five specimens.

TABLE A-24. SUMMARY OF ULTIMATE FLEXURAL STRENGTHS OF POLY-
ESTER LAMINATES CONTAINING ULTRAVIOLET-ABSORBING
AGENTS (19)

Panel	Weight Loss* for Indicated Exposure, per cent					
	2 pyrons 100 hours 287°F max	2 pyrons 200 hours 292°F max	3 pyrons 100 hours 302°F max	3 pyrons 125 hours 305°F max	6 pyrons 6 hours 428°F max	
UV I	0.63	0.95	1.38	1.51	9.70	
UV II	0.35	0.43	0.57	0.86	7.62	
UV III	0.31	0.38	0.57	0.89	7.49	
UV IV	0.31	0.40	0.60	0.95	7.49	
UV V	1.15	1.93	2.16	2.71	8.75	

* Average of five specimens.

TABLE A-25. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: POTTING COMPOUNDS(6)

Material	Radiation Exposure			Sample Weight		Ultimate Compressive Strength, psi	Temperature Average (°F)	Pressure Average (torr)
	Gamma [ergs/gm(C)]	Thermal	Neutrons (n/cm ²) E>2.9 Mev E>8.1 Mev	Original gm	Change, gm			
DC R-7521 (silicone)	0	0	0 (Control specimens)	-	-	23424	77	760
						<u>22940</u>		
						23162/429		
	9.03(9)	4.3(14) 1.4(15) (Vacuum irradiation)	5.1(13)	8.5021 7.6400 7.7806	+0.0011 +0.0010 +0.0009	24103 20791 <u>17339</u>	117	2(-6)
Epon 828/z (epoxy)						20811/3877		
	0	0	0 (Control specimens)	-	-	19811	77	760
						<u>19621</u>		
						19716/168		
	1.0(10)	3.1(14) 1.6(15) (Vacuum irradiation)	5.8(13)	9.8382 9.8654 9.8658	-0.0102 -0.0086 -0.0037	20833 20892 <u>20849</u>	116	2(-6)
						20858/35		

TABLE A-26. TEST ENVIRONMENT AND RESULT : FOR LOW-FORCE DYNAMIC-TEST MATERIALS:
POTTING COMPOUNDS(6)

Material and Test Equipment	Radiation Exposure			Sample Weight		Compressive Strength,		Temperature Average (°F)	Pressure Average (torr)	
	Gamma [ergs/gm(C)]	Neutrons (n/cm ²)		Original, gm	Change, gm	0.02 Inch Deflection	At 25 Per Cent Deflection			
		Thermal	E>2.9 Mev							E>8.1 Mev
RTV-60 (silicone)										
Instron Tester	0	0	0	(Control specimens)	-	-	22.5	218	77	760
							21	200		
							20	210		
							19	185		
							22	198		
							20.9/1.4	202.2/12.5(a)		
Low-Force Tester	0	0	0	(Control specimens)	-	-	41	-	77	760
Low-Force Tester	8.6(9)	1.5(.14)	1.4(15)	5.4(13) (Vacuum irradiation)	-	-	72.5	-	170	3(-7)
Instron Tester	3.6(9)	1.5(.14)	1.4(15)	5.4(13) (Vacuum irradiation)	11.8049	-0.0715	96	1508	167	3(-7)
					12.2921	-0.0789	109	1590		
							102/9.5	1549/71.8		

(a) Average value/standard deviation on an individual basis.

TABLE A-27. TEST ENVIRONMENT AND RESULTS OF STATIC TESTS: POTTING COMPOUNDS
(COMPRESSION BUTTONS)(7)

Material Trade Name	Gamma [rads/ gm(C)]	Radiation Exposure		Time Until Test, days	Sample Weights		Yield, psi	Crushing Load, lb	Compression Strength, psi	Strength At 25 percent Compression, psi	Temperature	
		Thermal	Neutron		Original, gm	Change, gm					Avg., F	Avg., torr
Scotchcast												
212	0	0	0	0								
Epoxy												
6.8(8)		2.4(13)	1.2(14)	4.9(12)			9,091	2,740	13,955		32	-
		(Air irradiation)	(Control specimens)				9,091/x	2,740	13,955			
1.36(9)		1.8(13)	2.5(14)	9.5(12)			9,473	2,500	12,732		82	-
		(Air irradiation)	(Air irradiation)				9,829	2,435	12,401			
3.9(10)		2.8(14)	6.1(15)	5.90(13)			10,033	2,350	11,968		100	-
		(Air irradiation)	(Air irradiation)				9,718/331	2,428/85	12,357/651			
4.7(8)		2.0(13)	4(13)	2.4(12)			-	3,010	14,330		90	-(-7)
		(Vacuum irradiation)	(Vacuum irradiation)				6,998	1,550	11,968			
9.4(8)		2.8(13)	5.5(14)	5.6(12)			8,538	3,000	15,171/2981		90	-(-7)
		(Vacuum irradiation)	(Vacuum irradiation)				3,607	2,190	12,681			
2.65(10)		3.08(14)	5.1(15)	2.09(14)			3,938	3,050	15,533		200	6(-7)
		(Vacuum irradiation)	(Vacuum irradiation)				3,913	2,350	11,968			
							2,244	2,290	11,663			
							3,487	2,480	12,631			
							8,574/274	2,532/327	12,695/1684			
							3,422	2,070	10,942			
							3,671	2,150	14,136			
							3,575	2,760	14,057			
							9,537/124	2,439/335	12,421/1707			
							17,851	3,120	17,851			
							17,545	3,250	17,545			
							17,643	3,180	17,698			
							17,628	3,352	18,557			
							17,658/149	3,448/353	18,163/977			
Durock D-133	0	0	0	0								
3.9(10)		2.8(14)	5.1(15)	2.6(14)								
		(Air irradiation)	(Air irradiation)									
											21,390 3,068* <u>24,458</u> 24,116/2232	
											30,429 34,722 <u>33,459</u> 32,670/2035	

TABLE A-27. (Continued)

Material Gamma Trade Name	Radiation Exposure		Time Until Test, days	Sample Wt. Original, gm	Size, gm	Compression on Crushing Yield, lb	Compression Strength, psi	Strength At 25 percent Compression, psi	Temperature, Avg. F	Press Avg. torr
	Thermal	Neutron								
3.42(12)	4.07(14)	7.56(15) 2.70(14) (Vacuum irradiation)	24	21.1543 21.0721 21.1106	-0.0004 -0.0015 -0.0011	--	--	6.3134 17.677 17.694 17.151/622	200	6(-)
RTV-50L Silicone	0	0 (Control specimens)	-					134 126 138 113/8	-	-
1.5(8)	3.3(12)	3.0(13) 1.1(12) (Air irradiation)	15					124 119 117 125 121/4	80	-
1.35(9)	1.8(13)	2.5(14) 9.5(12) (Vacuum irradiation)	15					197.5 125 200 160.5 126/19	62	
1.8(8)	8.4(12)	1.05(13) 7.6(11) (Vacuum irradiation)	8	9.0581 8.9502 9.0108 8.9517	-0.0562 -0.0604 -0.0591 -0.0558			148 144 147 146 146/2	62	1.7(-)
4.7(3)	2.0(13)	6.4(13) 2.4(12) (Vacuum irradiation)	9	9.0669 9.0227 9.0087 8.9402	-0.0521 -0.0525 -0.0517 -0.0556			154 153.5 154.5 157 159/5	90	4(-)
9.4(8)	2.8(13)	1.5(14) 5.6(12) (Vacuum irradiation)	12	9.0601 8.9892 8.9049 8.9633	-0.0553 -0.0553 -0.0545 -0.0561			181.5 170 170 172 174/6	90	4(-)
SC273 Proprietary	0	0 (Control specimens)	-					457 457 430 419 417/8		

TABLE A-27. (Continued)

Material Gamma Trade Name	Gamma Ergs/ gm(C ₁)	Radiation Exposure		Time Until Test, days	Sample Weights		Crushing Load, lb	Compression Strength, psi	Strength At 25 Percent Compression, psi	Temp- ature Avg. F	Press Avg. tonf
		Neutron (n/cm ²)	Thermal >2.9 Mev D>8.1 Mev		Test, Original, gm	Change, gm					
1-5(8)		3-3(12)	3-0(13) (Air Irradiation)	1-1(12)	15				458 463 460 748/10	80	—
1-36(9)		1-8(13)	2-5(14) (Air Irradiation)	9-5(12)	15				453 460 438 457 440/20	82	—
6-0(9)		—	1-26(1,2) (Vacuum Irradiation)	—	15				537 527 540 549 531/16	100	
1-8(8)		8-4(12)	1-85(13) (Vacuum Irradiation)	7-6(11)	8	10.3397 10.3580 10.3657 10.3776	+0.0194 +0.0178 +0.0172 +0.0175		— 470 445 437 448/24	80	1.1(-7)
9-4(8)		2-8(13)	1-5(14) (Vacuum Irradiation)	5-6(12)	12	10.3455 10.4134 10.4224 10.0136	+0.0024 +0.0099 +0.0086 +0.0081		477 627 627 367/39	90	4.1(-)
5-9(9)		1-12(14)	6-23(14)	—	12	10.4031 10.3368 10.3043 10.0084	-0.0023 -0.0048 -0.0116 -0.0071		515 548 581 531/13	166	—

* Values not included in calculating average and standard deviation.
Tested under atmospheric conditions.

TABLE A-28. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: SEALS (6.7)

Material Trade Name	Gamma Ergs/ EmC	Radiation Exposure		Time Int'l Test, Days	Sample Weight		Tensile Strength (a)		Ultimate Elonga- tion, percent	Temper- ature		Press. Avg., torr
		Thermal D-2, c-Mev D-8	Net Dose (cm ²)		Original, gm	Gr-8	at 25%	at 50%		°F		
Butter Compound 66-501 (Butter-8) O-rings	0	0 (control specimens)	0	0	—	—	—	—	1349 1322 1355 1307 1331/26.7	487 480 493 478 493/15.5	77	760
8.06(9)	2.8(14)	1.2(15)	4.5(13)	—	1.945	—	1155	—	1805	76	112(b)	2(-6)
		(vacuum irradiation)			1.908	—	1200	—	1965	87		
					1.667	—	1150	—	1690	70		
							122/25.0	1128/91.2	1887/162	78/10.0		
3.2(9)		4.7(14)		—	—	—	—	—	1530/3.8(3)	246/1.8/3	—	—
		(air irradiation)										
1.1(10)		1.8(15)		—	—	—	—	—	2077/9.1/4	104/13/4		
		(air irradiation)										
Butter Compound 66-501 (Butter-8) Tensile Specimens	0	0 (control specimens)	0	—	—	—	183	238	1440	412	77	760
					—	—	192	285	1331	408		
					—	—	174	267	1423	425		
					—	—	152	250	1350	415		
					—	—	176.5/23.8	260/22.8	347.2/62.7	515/8.2		
8.06(9)	2.8(14)	1.2(15)	4.5(13)	—	4.5873	—	820	—	1598	55	112(b)	2(-6)
		(vacuum irradiation)			4.9499	—	860	—	1740	62		
					4.5546	—	782	—	1855	70		
					—	—	827/46.1	—	1728/158	22/8.9		
Butter Compound 66-501 (Butter-8) O-rings	0	0 (control specimens)	0	—	—	—	139	198	1339	477	—	—
					—	—	122	188	1290	472		
					—	—	142	209	1355	448		
					—	—	135	205	1386	468		
					—	—	139	201	1381	486		
					—	—	119	208	1330	486		
					—	—	136/8	202/8	1550/41	470/16		
1.5(8)	3.3(12)	3.0(13)	1.1(12)	11	—	—	149	214	1368	463	80	—
		(air irradiation)			—	—	149	214	1359	457		
					—	—	149	214	1355	434		
					—	—	149	214	1318	441		
					—	—	149	214	1314	418		
					—	—	169/0	214/0	1343/23	413/19		
1.36(9)	1.8(13)	2.5(14)	9.5(12)	11	—	—	182	264	1588	409	82	—
		(air irradiation)			—	—	182	264	1595	365		
					—	—	182	264	1551	402		
					—	—	165	251	1437	349		
					—	—	158	246	1572	388		
					—	—	167/10	256/7	1531/65	385/28		

TABLE A-2 Continued)

Material Trade Name	Gamma Dose/ hr(Ci)	Radiation Exposure		Time Until Test, days	Sample Wt., Original, gm	Change, gm	Tensile Strength (psi)			Ultimate Elonga- tion, percent	Temper- ature Avg., °F	Press- ure Avg., torr	
		Thermal	Neutron				at 25% Elongation	at 50% Elongation	at 100% Elongation				
Natural Rubber Compound RA3560 (O-ring)	7.5(7)	4.6(12) (vacuum irradiation)	5.2(12) (vacuum irradiation)	2.35(11)	1.1744	-0.0036	149	214	330	1370	80	1.7(-7)	
					1.1721	-0.0026	149	214	330	1366	80	1.7(-7)	
					1.1673	-0.0037	149	214	314	1355	80	1.7(-7)	
					1.1695	-0.0032	149	214	347	1341	80	1.7(-7)	
	1.8(8)	8.4(12)	1.85(13) (vacuum irradiation)	7.6(11)	1.1731	-0.0029	149	214	330	1357	80	1.7(-7)	
					1.1751	-0.0024	149	214	330	1367	80	1.7(-7)	
					1.1741	-0.0019	158	228	347	1339	80	1.7(-7)	
					1.1759	-0.0018	149	224	350	1366	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1783	-0.0021	149	218	350	1355	80	1.7(-7)	
					1.1771	-0.0016	145	221	350	1344	80	1.7(-7)	
1.1751					-0.0024	149	221	347	1357	80	1.7(-7)		
1.1672					-0.0029	158	238	379	1339	80	1.7(-7)		
Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80	1.7(-7)	
	1.1672					-0.0029	158	238	379	1339	80	1.7(-7)	
	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
	Natural Rubber Compound RA3560 (O-ring)	9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
1.1775						-0.0026	149	231	353	1344	80	1.7(-7)	
1.1672						-0.0029	158	238	379	1339	80	1.7(-7)	
9.1(8)		2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)	
					1.1600	-0.0012	149	231	353	1344	80	1.7(-7)	
					1.1775	-0.0026	149	231	353	1344	80	1.7(-7)	
					1.1672	-0.0029	158	238	379	1339	80	1.7(-7)	
Natural Rubber Compound RA3560 (O-ring)		9.1(8)	2.8(13)	1.6(14) (vacuum irradiation)	6.0(12)	1.1660	-0.0027	149	231	353	1344	80	1.7(-7)
						1.1600	-0.0012	149	231	353	1344	80	1.7(-7)
	1.1775					-0.0026	149	231	353	1344	80		

TABLE A-28. (Continued)

Material Trade Name	Gamma Ergs/ gm(C)	Radiation Exposure		Time Until Test, Days	Sample Weights		Tensile Strength (a) (psi)			Ultimate Elonga- tion, Percent	Temper- ature	
		Thermal D-2 gm(C)	Neutron (a/cm ²) D-8 1 Mev		Original, gm	Change, gm	at 25% Elongation	at 50% Elongation	at 100% Elongation		Avg. °F	Press. torr
Natural Rubber O-rings MA3560	0	0	0	0	—	—	91	132	258	1905	—	—
							91	139	236	1903		
							85	130	249	1893		
							85	133	230	1744		
							91	133	230	1744		
							91	136	236	1721		
							91	139	245	1721		
							91	145	242	1732		
							90/2	139/1	239/13	1796/108		
										1776/138		
6.8(8)	2.4(13)	1.2(14)	4.9(12)	11	—	—	100	167	261	1760	82	—
							91	152	258	1721		
							91	152	258	1693		
							97	152	258	1910		
							97	152	258	1565		
							95/4	155/6	259/1	1776/138		
6.0(9)	1.25(15)	1.25(15)	1.25(15)	16	—	—	136	236	467	1239	82	—
							136	242	449	1480		
							136	236	455	1521		
							142	236	449	1560		
							145	242	470	1767		
							139/4	238/3	458/9	1513/227		
4.45(8)	1.95(13)	5.45(13)	2.1(12)	7	1.0282	-0.0112	97	164	273	1605	90	—
					1.0270	-0.0108	94	157	266	1755		
					1.0289	-0.0107	91	164	285	1780		
					1.0194	-0.0107	100	167	288	1780		
					1.0233	-0.0102	96/4	162/5	278/11	1733/85		
9.1(8)	2.3(13)	6.6(14)	6.0(12)	7	1.0212	-0.0115	112	176	303	1797	90	4(-7)
					1.0198	-0.0115	112	167	288	1865		
					1.0206	-0.0102	106	167	279	1815		
					1.0217	-0.0126	112	176	309	1965		
					1.0264	-0.0120	112	177	288	1830		
							111/3	177/13	293/13	1864/72		
4.1(9)	6.4(13)	3.7(14)	1.6(13)	8	1.0267	-0.0177	151	242	445	1665	160	9(-7)
					1.0251	-0.0187	136	239	424	1765		
					1.0279	-0.0200	139	239	421	1739		
					1.0286	-0.0204	227	227	409	1222		
					1.0317	-0.0191	206	206	384	1605		
							13-1	289/15	419/22	1599/308		

TABLE A 9. (Continued)

Material Trade Name	Gamma Dose/ Gm(C)	Radiation Exposure		Time Unit: Test, Days	Sample Weight Original	Change	Tensile Strength (psi)		Ultimate Elongation, Percent	Temperature Average, °F	Pressure Average, torr
							at 25% Elongation	at 100% Elongation			
Neoprene O-rings PR2277	0	0	0	0	—	—	104	306	85	2875	—
							174	291	261	2840	—
							174	276	221	2521	—
							167	274	221	2601	—
							154	266	208	2440	—
							151	250	185	2270	—
							157/13	285/16	530/39	2551/140	294/15
1.5(8)	3.3(12)	3.0(13)	1.1(12)	11	—	—	167	264	185	2873	—
		(air irradiation)					167	276	252	2873	—
							161	264	255	2682	—
							184	280	275	2275	—
							175/7	278/10	521/29	2580/376	304/51
1.36(9)	1.0(13)	2.5(14)	9.5(12)	11	—	—	151	264	152	2641	—
		(air irradiation)					201	335	669	2523	—
							211	342	659	2339	—
							211	352	669	2820	—
							201	335	669	1840	—
							193/26	330/29	646/50	2431/421	250/43
1.8(8)	8.4(12)	1.05(13)	7.1(11)	9	1.3162	-0.0049	184	291	562	2815	104
		(vacuum irradiation)			1.3351	-0.0037	167	274	519	2960	152
					1.3273	-0.0050	171	294	569	2760	310
					1.3210	-0.0053	167	301	585	2694	292
					1.3224	-0.0045	167	280	519	2535	110
							172/7	289/12	551/28	2753/183	314/26
4.45(8)	1.95(13)	5.45(13)	2.1(12)	7	1.3270	-0.0054	201	318	619	2341	—
		(vacuum irradiation)			1.3211	-0.0052	167	291	575	2810	298
					1.3351	-0.0056	171	311	569	2519	279
					1.3254	-0.0048	164	301	603	2571	264
					1.3290	-0.0046	159	218	585	2348	256
							187/15	308/12	590/21	2514/207	274/18
9.1(8)	2.2(13)	1.6(14)	6.0(12)	7	1.3285	-0.0050	184	318	619	2678	276
		(vacuum irradiation)			1.3302	-0.0050	184	308	569	2543	332
					1.3388	-0.0054	194	335	652	2571	253
					1.3261	-0.0048	201	335	635	2864	267
					1.3273	-0.0053	184	318	619	2341	256
							186/7	323/12	616/36	2556/194	276/34
Viton B O-rings PR15007	0	0	0	0	—	—	177	287	253	2010	280
		(control specimens)					177	315	605	1999	261
							167	280	560	1835	259
							156/11	295/17	576/25	1894/228	256/28

TABLE A-40. (Continued)

Material Trade Name	Gamma [ergs/ cm(C)]	Radiation Exposure		Time Unil Test.	Sample Orig. g	Tensile Strength (psi)			Ultimate Elonga- tion, percent	Temper- ature Avg., °F	Press- ure Avg., torr
		Thermal D-2 9 Mev D-8.1 Mev	Neutron (n/cm ²)			Elongation at 25%	Elongation at 50%	Elongation at 100%			
1(9) (estimated)		(air irradiation)		13	—	280	524	1294	1825	137	105
						260	559	1311	1888	140	—
						266	534	1303	1538	115	—
5(9) (estimated)		(air irradiation)		13	—	273	552	1336	1860	126	—
						283	544	1339	1566	122	—
						276/7	551/30	1318/19	1735/150	128/11	—
3.1(8) (estimated)		(air irradiation)		8	—	1224	—	—	2028	44	125
						1182	—	—	1444	45	—
						1189	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
3.1(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—
5.08(8) (estimated)		(air irradiation)		8	—	1187	—	—	2028	44	125
						1187	—	—	1444	45	—
						1187	—	—	1444	44	—

TABLE A 22. (Concluded)

Material Trade Name	Gamma [rads/ gm(C)]	Radiation Exposure		Time Until Test, days	Sample Wt. g. Original C gm	Tensile Strength (s) (psi)			Ultimate Elonga- tion, percent	Tempe- ature Avg. °F	Press- ure Avg. torr
		Neutron (n/cm ²)	Thermal D-2.9 Mev D-8.1 Mev			at 25% Elongation	at 50% Elongation	at 100% Elongation			
3.1(8)	6.98(12)	3.98(13)	1.56(12)	8	—	196	273	909	176	85	2.5(-7)
						186	340	915	196		
						186	340	881	133		
						186	356	915	204		
5.08(8)	8.31(12)	6.98(13)	2.77(12)	8	—	196	356	909	176	87	2.5(-7)
						190/4	376/14	915/29	177/31		
						220	424	1032	184		
						220	389	983	189		
		(vacuum irradiation)				186	389	949	186		
						196	407	1016	151		
						230	389	966	173		
						212/19	400/15	988/36	177/31		

(a) Values given as: average value/standard deviation on an individual basis.

(b) Estimated value based on similar temperatures of natural rubber.

(c) Average value/standard deviation on an individual basis/number of specimens

Tested under atmospheric conditions.

TABLE A-29. LOW-FORCE DYNAMIC TEST RESULTS(6)

Material and Test Equipment	Gamma rays/eq(C)	Radiation Exposure		Machine Crosshead Speed (in./min.)	Tensile Strength (psi)				Ultimate Elongation, per cent	Temperature, Average, $^{\circ}$ F	Pressure, Average, Curt
		Thermal	Neutrons (n/cm ²)		at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate			
Viton 2 (RPP 1900) Instron Tester	0	0	0 (control specimens) September 1962	0	330 288 330 322 316/20	495 429 495 496 476/32	925 834 890 883 883/45	1302 1305 1334 1365 1312 1334/27	107 116 159 157 157 157/4.9(a)	77	760
Low-Force Instron Tester	9.0(9)	1.4(14)	1.7(15) (vacuum irradiation) September 1962	6.75(13)	0.5	—	—	1451 1398 1437 1429/27.5	34 31.5 34 33.2/2.44	167	3(-7)
Instron Tester	9.0(9)	1.4(14)	1.7(15) (vacuum irradiation) September 1962	6.7(15)	0.5	—	—	1180 918 1049/144	19.8 17.1 18.5/2.4	167	3(-7)
Instron Tester	0	0	0 (control specimens) January 1962	0	20.0	—	—	1984/4.5/3	294/3.1/3	—	—
Instron Tester	1.2(9)	2.3(14)	(air irradiation) January 1962	20.0	20.0	—	—	2047/8.9/3	141/3.8/3	—	—
Instron Tester	0	0	0 (control specimens) October 1962	0	20.0	—	—	1710 1405 1650 1585 1607/96	183 124 165 165 166/13	—	—

(a) Average value/standard deviation on an individual basis/number of specimens.

TABLE A-30. LOW-FORCE DYNAMIC TEST RESULTS(6)

Material Trade Name	Gross wt./ sq. (c)	Radiation Exposure		Nastle Strength (c) (psi)		Ultimate Elongation (b) pc. cent	Temperature Average, ° F	Pressure Average, psf
		Thermal	D-2.9 Mr	D-2.9 Mr	D-2.9 Mr			
				at 25% Elongation	at 50% Elongation	Ultimate (b)		
Run I. April 24, 1963								
Beam B O-rings	1.68(8)	1.7(12) (vacuum irradiation)	--	93 93.5/2	159 175 122/5	285 317 284/7	85	2.3(-7)
Beam B O-rings	1.68(8)	1.7(12) (vacuum irradiation)	--	110 125/13	210 200 205/9	455 326 476/56	85	3.3(-7)
Run II. June 4, 1963								
Beam B O-rings	5.08(8)	8.1(12) (vacuum irradiation)	2.77(12)	110 125 123/14	200 205 205/6	347 356 360/18	87	2.5(-7)
Beam B O-rings	5.08(8)	8.3(12) (vacuum irradiation)	2.77(12)	195 173 185/50	333 300 317/89	560 500 530/53	87	2.5(-7)

(a) Values given as: average value/standard deviation on an individual basis.

(b) Not reached in test.

TABLE A-31. EFFECT OF NUCLEAR RADIATION ON SEALS, STATIC TESTS(8)

Category	Trade Name	Gamma Dose [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Seals	Natural Rubber	0	1 x 10 ⁻⁶	O-Rings	Ultimate tensile strength	0
		Vacuum Controls			Ultimate elongation	0
		9.0 x 10 ⁹	2 x 10 ⁻⁶	O-Rings	Weight change	+1
					Ultimate tensile strength	-48
	Viton B PRP 19007	9.0 x 10 ⁹	3 x 10 ⁻⁷	O-Rings	Ultimate elongation	-75
					Weight change	0
	Parker Compound 66-581 (Buna N)	8.1 x 10 ⁹	2 x 10 ⁻⁶	O-Rings	Ultimate tensile strength	-21
					Ultimate elongation	-88
		8.1 x 10 ⁹	2 x 10 ⁻⁶	O-Rings	Ultimate shear strength	+37
					Ultimate elongation	-85
		8.1 x 10 ⁹	2 x 10 ⁻⁶	Tensile (ASTM-D-412- 51F, Die C)	Weight change	-1.27
					Ultimate tensile strength	+25
		3.2 x 10 ⁹	Air Irrad.	O-Rings	Ultimate elongation	-85
					Weight change	-1.32
		1.1 x 10 ¹⁰	Air Irrad.	O-Rings	Ultimate tensile strength	+15
					Ultimate elongation	-50
	Viton B PRP 19007	9.0 x 10 ⁹	3 x 10 ⁻⁷	O-Rings	Ultimate tensile strength	+56
					Ultimate elongation	-79.5
					Ultimate tensile strength	+7
					Ultimate elongation	-79

TABLE A-32. EFFECT OF VACUUM AND GAMMA RADIATION
ON SEALS⁽³⁵⁾

Specimen No.	Code	Weight Change, percent	Change in Shore Durometer Hardness
1A	Alleghany Plastic	-.01	-
B	Teflon X	0	-
2A	TDXE 121 No. 72	1.08	-2
B	Acrylonitrile	1.06	-1
3A	50% Teflon	-.01	-3
B	Loaded XIT351	-.04	-3
4A	TDXE-35 No. 74	1.16	-10
B	Acrylonitrile	1.10	-7
5A	Rubber	-.85	-9
B	366 YV	-.85	-4
6A	En-Jay Butyl	-.09	+2
B	XI 351	-.09	+2
7A	Rubber	0	-14
B	524A	0	-7
8A	Linear	0	-1
B	Copolymer XP-9-13	0	-1
9A	Parker	1.00	-10
B	B-496-7	1.00	-
10A	Rubber	1.00	+2
B	524A	1.00	+4
11A	Neoprene	-.53	0
B	No. 74 Compound	1.007	0
12A	Neoprene	1.009	0
B	No. 72 Compound	1.007	0
13A	Rubber	-.86	+1
B	366 YV	-.79	+2

TABLE A-33. FLUOROBESTOS TEST DATA^{(a)(8)}

I. Compression Tests (Federal Test Method 601-3331)

Specimen No.	Compressibility, percent	Recovery, percent
Control Test		
1	800.0	94.6
2	590.0	91.5
3	325.0	95.4
4	1,150.0	91.3
Average	716.2	92.2
Irradiated Specimens [10 ⁹ erg/g(C)]		
1	331.8	95.9
2	657.1	93.5
3	500.0	95.0
4	940.0	93.6
Average	607.2	94.5

II Tensile Tests (Strain Rate = 0.1 in./min)

Specimen No.	Elastic Limit, psi	Elongation in 1 in., percent	Hardness, Shore B	0.2% Offset Yield Strength, psi	Ultimate Stress, psi
Control Test					
1	2,156	2.0	93.0	1,927	2,226
2	1,847	8.0	92.0	1,667	1,964
3	2,053	2.0	92.0	1,681	2,257
4	1,982	6.0	89.0	1,429	2,300
Average	2,009	4.5	91.5	1,676	2,206
Irradiated Specimens [10 ⁹ erg/g(C)]					
1	495	0	86.0	542	554
2	957	2.0	85.0	1,081	1,106
3	1,005	4.0	86.0	1,130	1,176
4	1,058	3.0	86.0	1,128	1,222
Average ^(b)	1,007	3.0	85.7	1,113	1,168

(a) All specimens 0.07-inch thick (nominal).

(b) Data from Specimen No. 1 not included in average. Specimen defective.

TABLE A-34. TESTS WITH ELASTOMER SEALS⁽⁸⁾

Seal Type	Sample No.	Test Duration	Static Leakage (std cc He/sec)	Dynamic Leakage (std cc He/sec)
<u>Reciprocating Seals</u>				
Neoprene	1	Start	0.80	0.20
		30 min	2.40	1.00
	2	Start	0.54	0.24
		30 min	0.95	0.08
	3	Start	0.22	0.045
		30 min	0.0095	0.014
Silicone Rubber	1	Start	0.19	0.38
		30 min	0.26	0.33
	2	Start	0.87	1.50
		10 min (test stopped, leakage rate greater than 10 std cc/sec)		
	3	Start	2.50	3.40
		30 min	4.90	4.30
Viton A	1	Start	1.40	0.60
		40 min	0.02	0.20
	2	Start	0.35	0.65
		30 min	0.13	0.17
	3	Start	0.0001	0.20
		35 min	0.50	0.10
Kel-F	1	Start	1.00	0.12
		20 min (seal failure)	-	-
	2	Start	0.31	0.07
		10 min (seal failure)	-	-
	3	Start	0.10	0.14
		10 min (seal failure)	-	-
Buna N	1	Start	0.36	0.03
		30 min	0.10	0.032

TABLE A-34. (Continued)

Seal Type	Sample No.	Test Duration	Static Leakage (std cc He/sec)	Dynamic Leakage (std cc He/sec)
<u>Reciprocating Seals</u>				
Buna N	2	Start	0.55	0.040
		30 min	0.10	0.15
	3	Start	0.32	0.24
		30 min	0.10	0.18
Butyl	1	Start	0.80	0.28
		30 min	0.02	0.06
	2	Start	0.22	0.20
		30 min	0.038	0.038
	3	Start	0.004	0.03
		30 min	0.47	0.50
Polyethylene	1	Start	0.0001	0.005
		30 min	0.0001	0.012
	2	Start	0.0001	0.004
		30 min	0.002	0.01
	3	Start	0.2	0.10
		30 min	0.0001	0.005
Vinylite	1	Start	0.0090	0.20
		30 min	0.0040	0.60
	2	Start	0.0010	0.01
		30 min	0.0010	0.02
	3	Start	0.0010	0.03
		30 min	0.0010	0.01
<u>Rotating Seals</u>				
Kel-F	1	Start	0.28	0.50
		30 min	0.30	1.00
	2	Start	0.26	0.48
		30 min (seal destroyed by wear and abrasion)		0.16

TABLE A-34. (Concluded)

<u>Seal Type</u>	<u>Sample No.</u>	<u>Time Duration</u>	<u>Static Leakage (std cc He/sec)</u>	<u>Dynamic Leakage (std cc He/sec)</u>
<u>Rotating Seals</u>				
Kel-F	3	Start	0.34	0.38
		30 min (seal destroyed by wear and abrasion)	-	-
Silicone Rubber	1	Start	0.044	0.06
		30 min	0.35	0.80
	2	Start	0.15	0.26
		30 min	0.25	0.54
	3	Start	1.00	1.00
		30 min	0.28	0.02
Viton-A	1	Start	0.14	0.03
		30 min	0.01	0.02
	2	Start	0.032	0.10
		30 min	0.016	0.019
	3	Start	0.10	0.22
		30 min	0.008	0.02
Kel-F Elastomer	1	Start	0.28	0.50
		30 min	0.30	1.0
	2	Start	0.34	0.38
		30 min	(a)	(a)
	3	Start	0.26	0.48
		30 min	(a)	(a)
Teflon	1 & 2	Start	0.1	(a)
		30 min	(a)	(a)

(a) Leakage excessive.

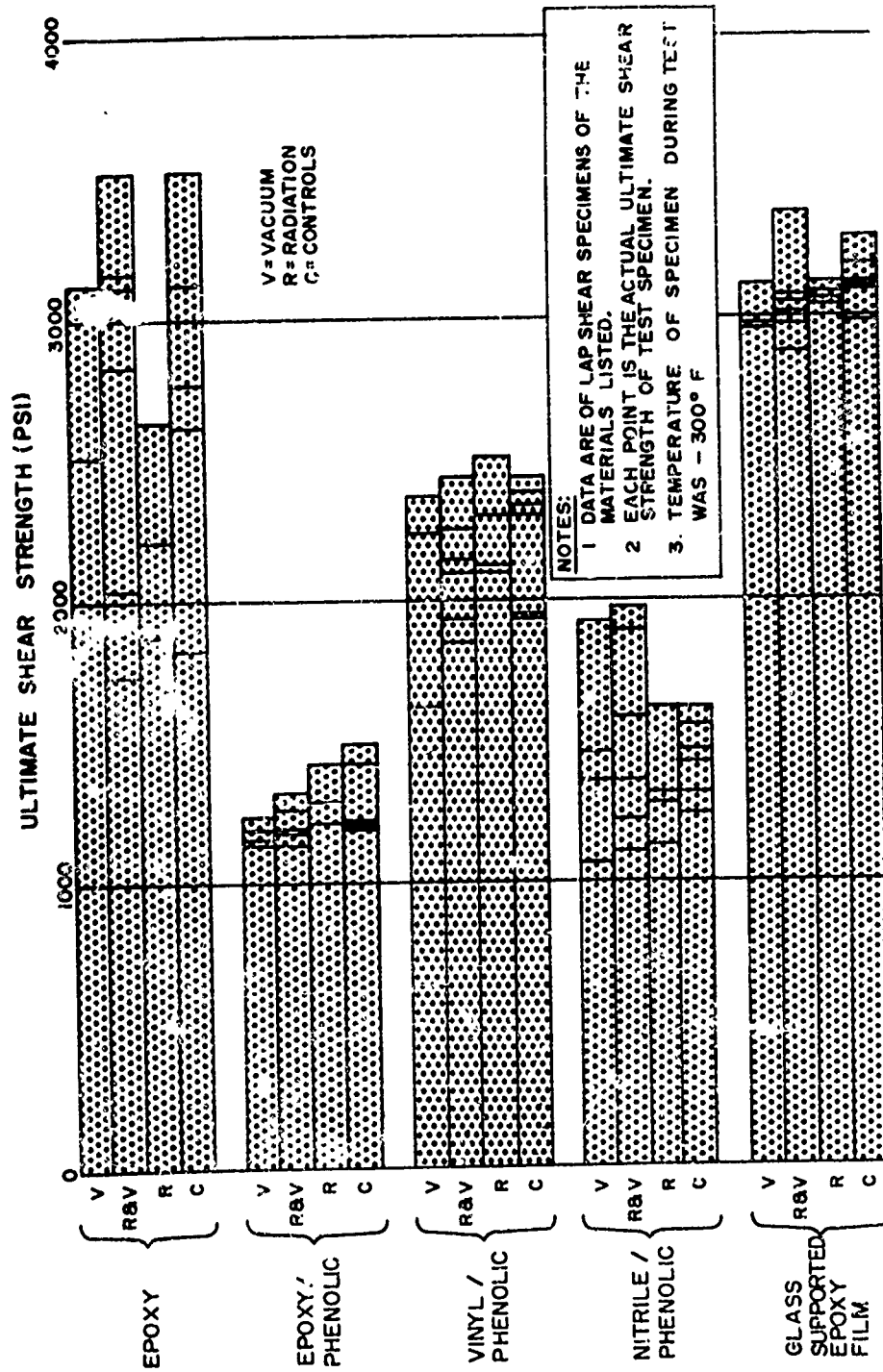


FIGURE A-1. COMBINED PARAMETER MATERIALS TESTS(8)

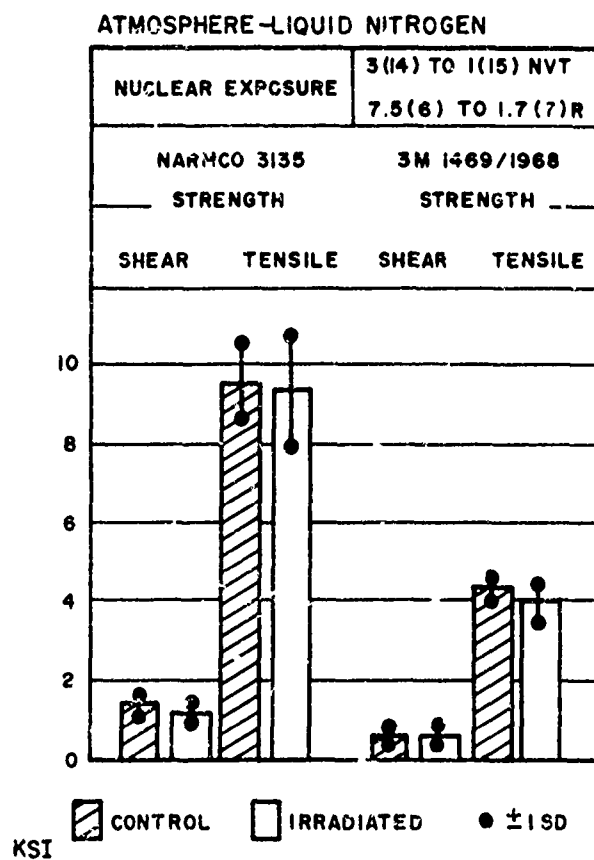


FIGURE A-2. RADIATION EFFECTS ON NARMCO 3135 AND 3M 1469/1968 ADHESIVES⁽¹³⁾

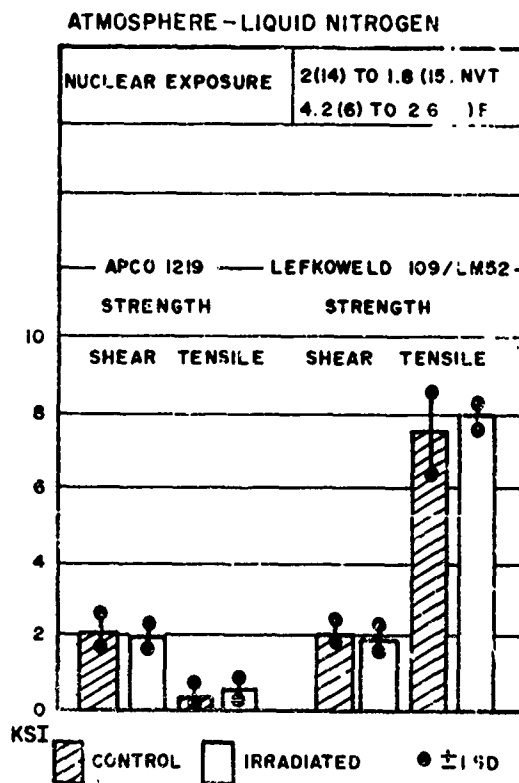


FIGURE A-3. RADIATION EFFECTS ON APCO 1219 AND LEFKOWELD 109/LM52 ADHESIVES⁽¹³⁾

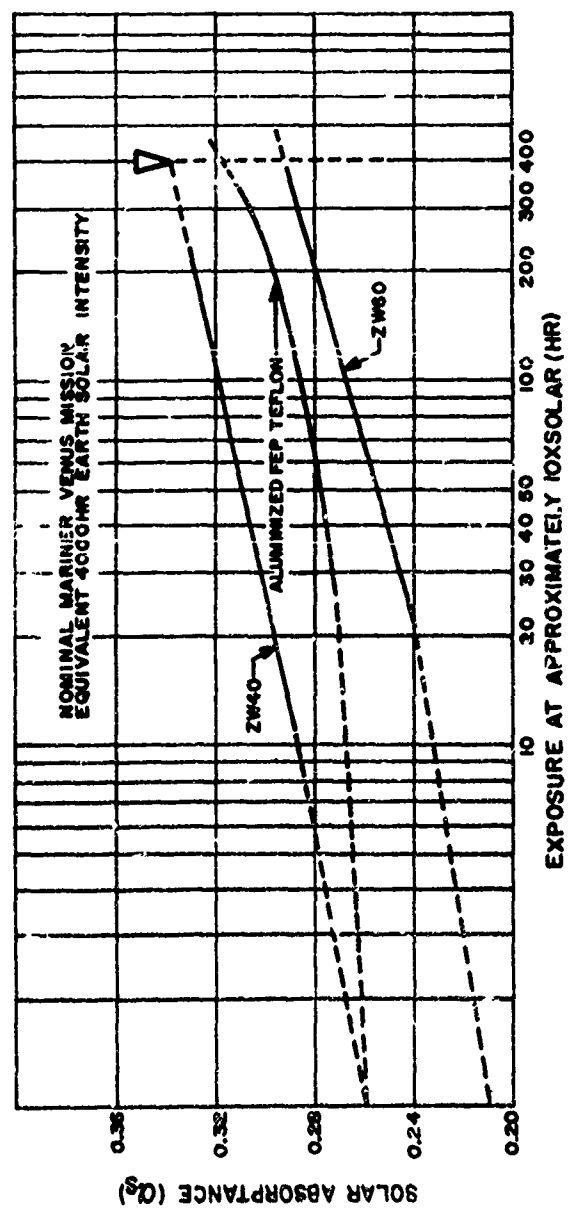


FIGURE A-4. ULTRAVIOLET DEGRADATION IN VACUUM, SPACECRAFT "WHITE" SURFACES(18)

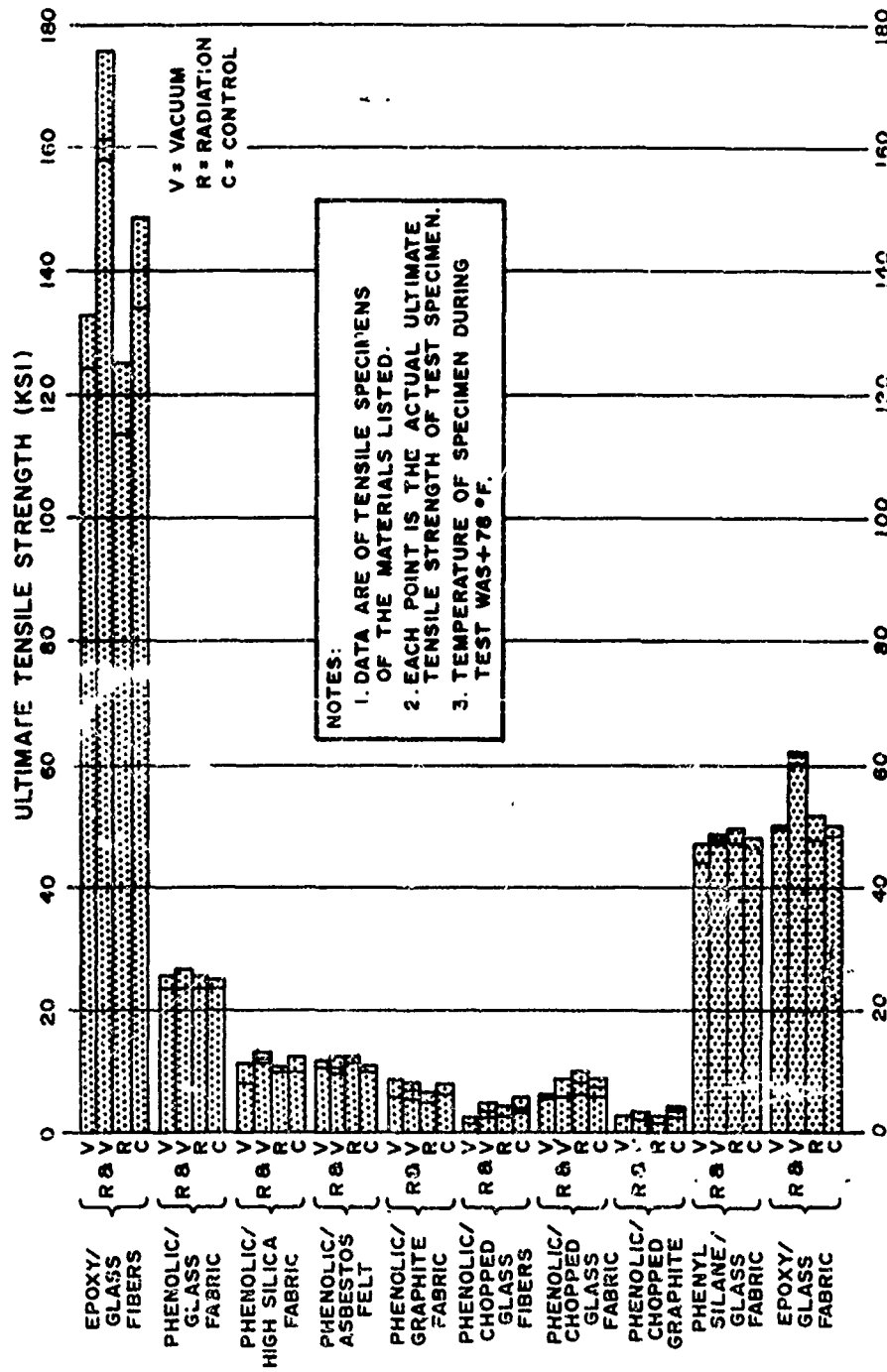


FIGURE A-5. COMBINED PARAMETER MATERIALS TEST(8)

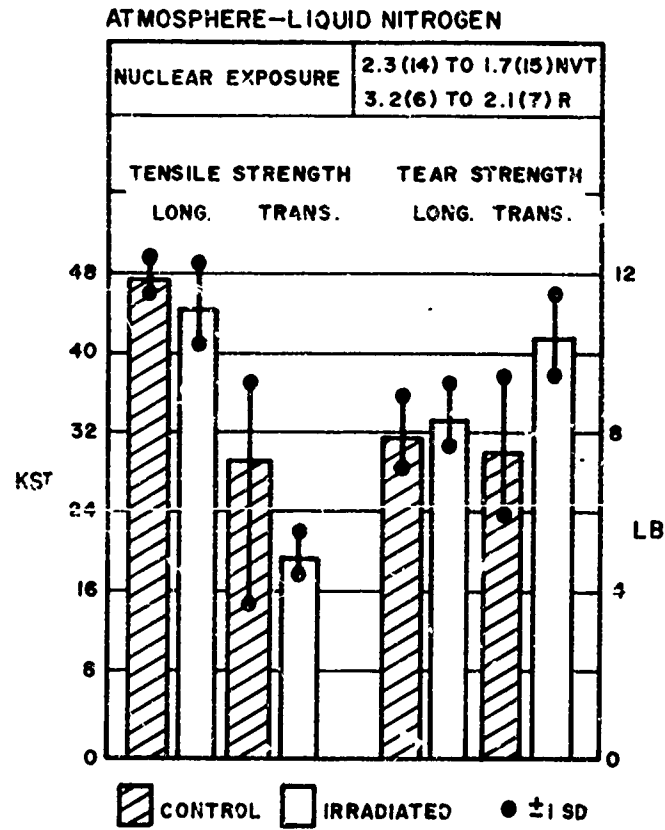
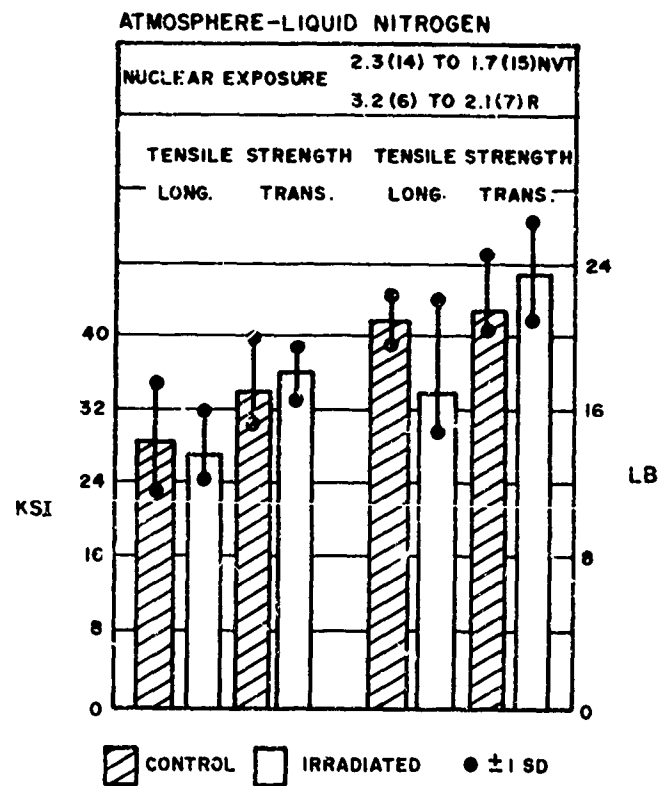


FIGURE A-6. RADIATION EFFECTS ON SINEWAVE LAMINATE⁽¹³⁾

FIGURE A-7. RADIATION EFFECTS ON HEXCEL LAMINATE⁽¹³⁾

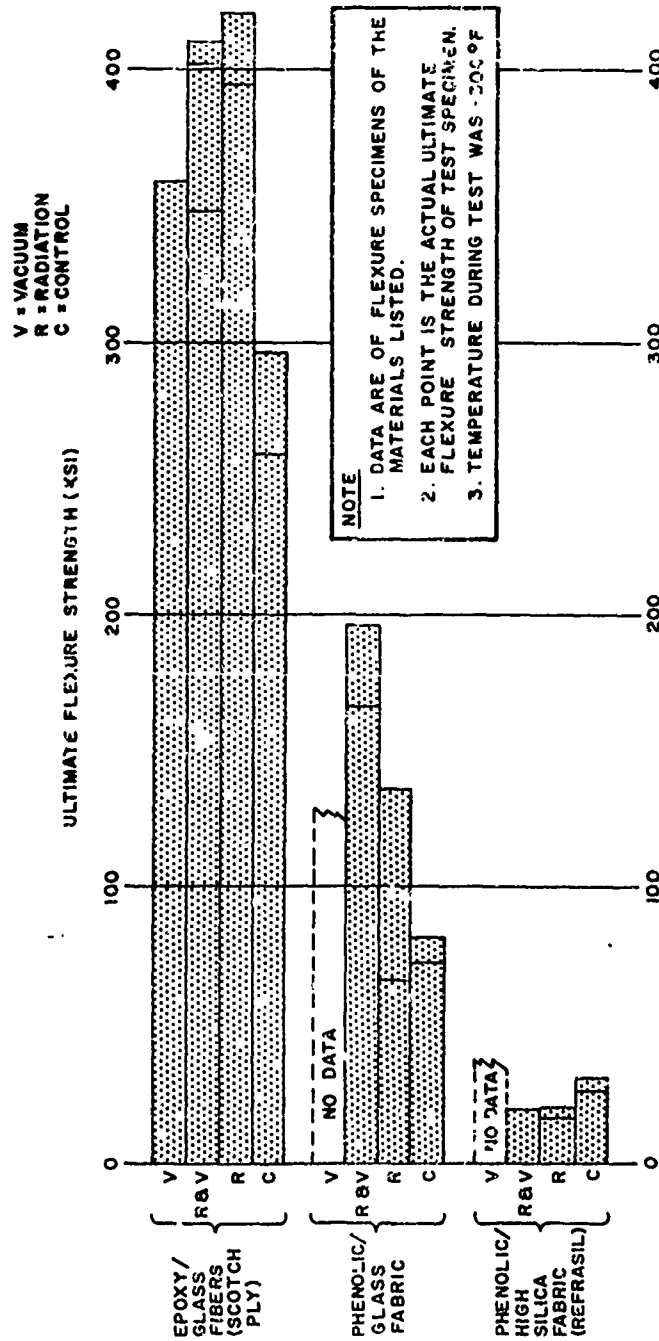


FIGURE A-8. COMBINED PARAMETER MATERIALS TESTS(8)

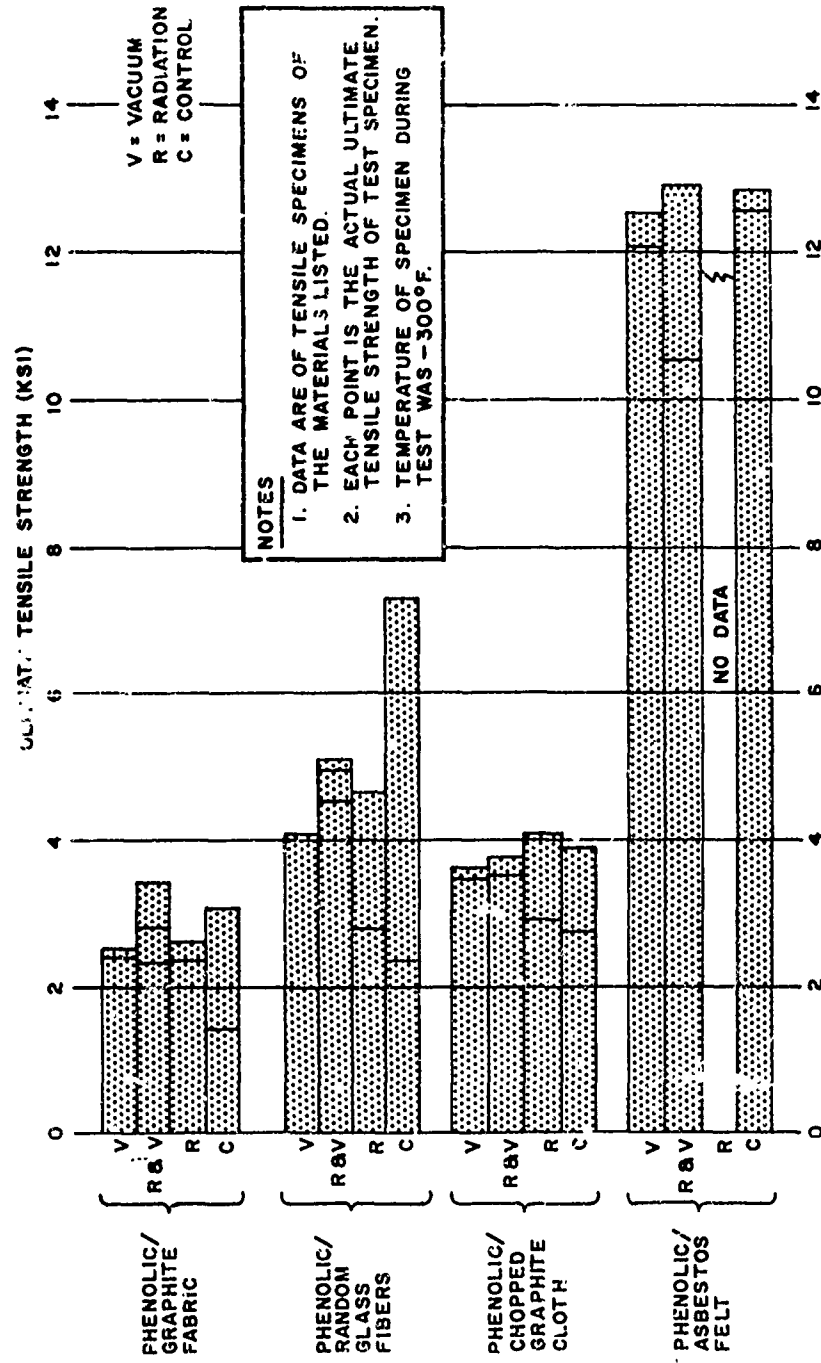


FIGURE A-2. COMBINED PARAMETERED MATERIALS TESTS(8)

NOTES:

1. THE MATERIAL TESTED WAS THE LISTED RESINS IN A GLASS FABRIC LAMINATE SYSTEM.
2. EACH POINT IS ACTUAL ULTIMATE STRENGTH OF TEST SPECIMEN.
3. TEMPERATURE OF SPECIMEN DURING TEST WAS 300 °F

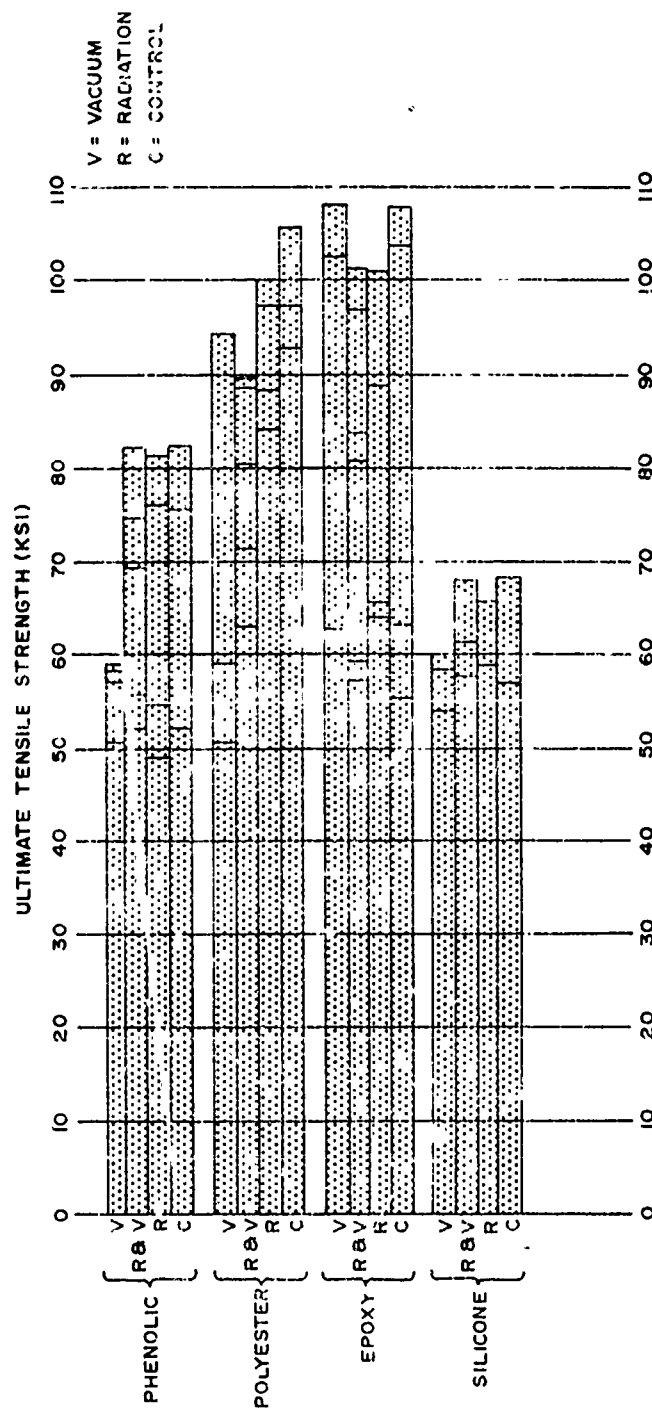


FIGURE A-16. COMBINED PARADIGMS MATERIALS TESTS(8)

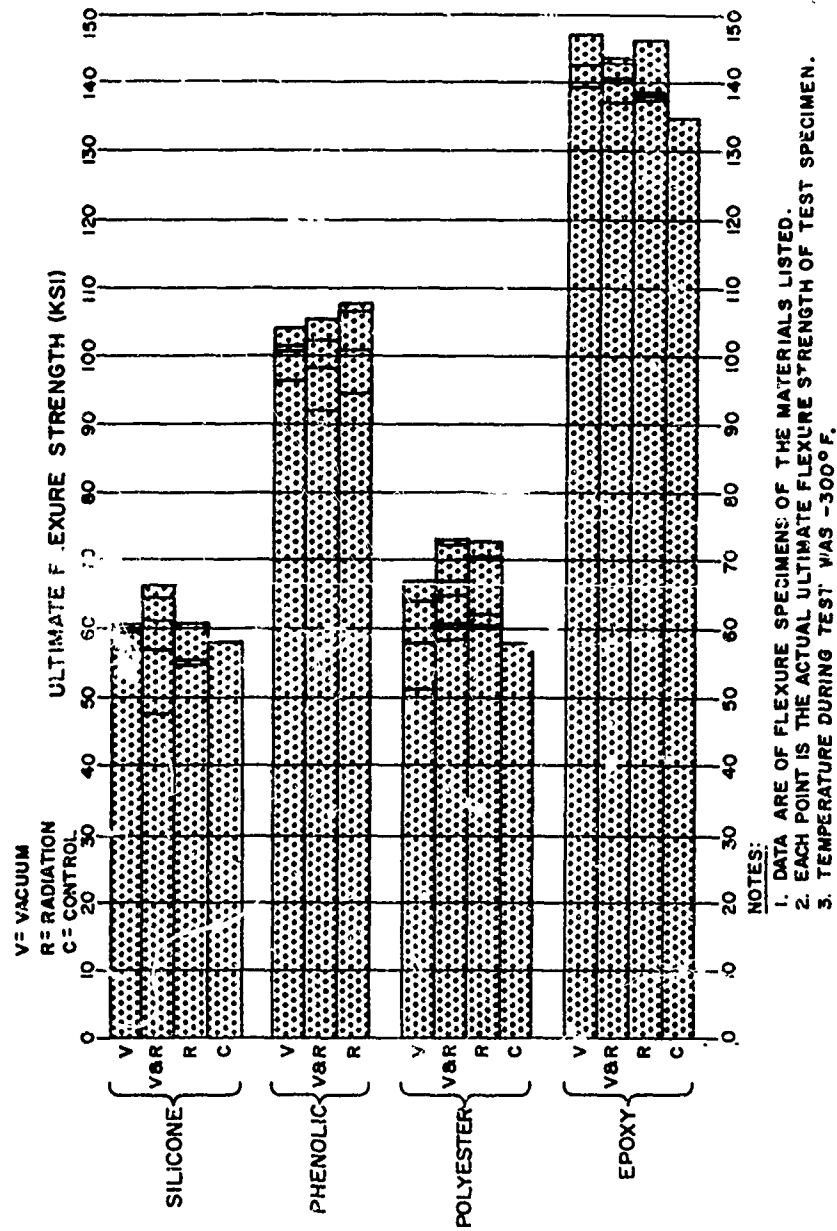


FIGURE A-11. COMBINED PARAMETER MATERIALS TESTS(8)

APPENDIX B

ELASTOMERS

Table B-1. COMPOUND FORMULATIONS^{a,b}

Compounding Ingredient	Parts by Weight								
	S119	S119B	N126	M72E	Z72	FCT Z83	Z69	Z84	FCT Z83
SBR 1500	150	150							
Paracril 18-80			100	100					
Neoprene WRT				100	100				
Centhane S									
Hycar 4021					100				
SE33 (methyl vinyl siloxane)									
Linde W96 (methyl vinyl siloxane)									
Viton B								100	100
Zinc Oxide	3	3	5	5					100
Stearic Acid	2	2	1.5	1.5	0.2				
Magnesium Oxide									
Sulfur	1.75	1.75	1.5	1.5	4	4			15
Altax			1.5	1.5		0.5			1
Santocure	1.0	1.0							
Trimene Base									
Cadox TS Paste									
Cadox SG Paste									
LD 214								1.3	1.6
Neozone D	1	1		2					3
Heliozone		1							
U. O. P. 88		3							
Agerite Rosin D	1	1							
Di Cup 40 C									
NA-22									
SRF Carbon Black				0.5					
MAF Carbon Black				20					
MT Carbon Black			60						
Hi Sil 303				30					20

Table B-1. (Concluded)

Compounding Ingredient	Parts by Weight						
	S119	S119B	N128	N128E	M72	M72E	Z72 Z74F .84 FCT Z83
Santocel CS							40
Red Iron Oxide							2
Diocetyl Sebacate			20				
Triocetyl Phosphate					20		
HAF Carbon Black						30	
TOTAL PARTS	159.75	163.75	169.5	189.5	158	178	138.2 137.5 151.3 143.6 138

All compounds were cured for 30 minutes at 307°F except as follows:

Z69FCT - Press cured 20 minutes at 307°F; post cured 24 hours at 300°F in air oven.

Z84 - Press cured 10 minutes at 240°F; post cured 24 hours at 480°F in air oven.

Z83 - Press cured 30 minutes at 307°F; step cured in oven for one hour each at 212°, 250°, 300°, and 350°F; post cured 24 hours at 400°F in air oven.

Table B-2. EXPOSURE OF A POLYESTER ELASTOMER TO HIGH VACUUM AT VARIOUS TEMPERATURES⁴⁵

Property Measured	Original	Exposed to Vacuum of			
		7.8 x 10 ⁻⁶ mm Hg for 5 Days at Room Temperature	400 F. Vacuum of 1.9 x 10 ⁻⁵ mm Hg for 5 Days	500 F. Vacuum of 1.4 x 10 ⁻⁵ mm Hg for 5 Days	600 F. Vacuum of 1.7 x 10 ⁻⁵ mm Hg for 5 Days
		Air Oven for 5 Days	Air Oven for 5 Days	Air Oven for 5 Days	Air Oven for 5 Days
Mycel 402 (274F)					
Tensile strength, psi	1420	1610	810		
Modulus, psi at 200 % E.	520	830	--		
Elongation, %	350	310	30		
Hardness, Shore A	58	56	89		
Strain, % E. at 400 psi	152	111	Broke		
Change in weight, %	—	-0.6	-8.6	-13.5	

to
little
test

Table B-3. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON ELASTOMERS⁴⁶*

Material	Type of Exposure**	Temperature, F	Exposure Time, hour	Weight Change, per cent	Tensile Strength		Change, per cent	Breaking Elongation		Change, per cent
					Before Exposure, psi	After Exposure, psi		Before Exposure, in./in.	After Exposure, in./in.	
Butyl	Vacuum	80	24	+ 0.10	2315	2616	+13.0	0.880	0.820	- 6.8
	Vacuum	80	96	+ 0.22	2315	2420	+ 4.5	0.880	0.845	- 4.0
	Vacuum	80	312	+ 0.09	2315	2441	+ 5.4	0.830	0.805	- 3.5
	Vacuum and ultraviolet	155	24	- 1.59	2315	2572	+11.1	0.880	0.790	-10.2
	Vacuum and ultraviolet	155	96	- 4.04	2315	2626	+13.4	0.880	0.755	-14.2
	Vacuum and ultraviolet	155	312	- 4.04	2315	2710	+17.1	0.880	0.650	-26.1

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* Values are averages of two specimens.

** Maximum vacuum pressures on the order of 1×10^{-5} mm Hg.

B-4

Table B-4. RECIPES AND CURE SCHEDULES OF THE CHLOROBUTYL,
CHLOROBUTYL-POLYCHLOROPRENE BLENDS AND
CHLOROPRENES, USED IN THE IRRADIATION STUDIES⁴⁷

Compound Data - Chlorobutyl, Chlorobutyl-Polychloroprene Blends and Chloroprene

	Compound 156-62	Compound 157-62	Compound 158-62	Compound 159-62
Recipe, parts by weight				
Chlorobutyl HT-10-66	100	50	25	—
Neoprene WRT	—	50	75	100
EAF black	50	50	50	50
ZnO	—	5	5	5
Stearic acid	1	1	1	1
Tetramethyl thiuram disulfide	1	1	1	—
Benzothiazyl sulfide	—	2	2	—
MgO	0.5	2.5	3.25	8
Cure Schedule				
Cure time, min.	40	40	40	40
Cure temperature, F	307	307	307	293

Table B-5. PHYSICAL PROPERTIES OF COMPOUND 156-6247
Base Elastomer-Chlorobutyl, Type HT-10-66

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)	Dur. A	Cng.(1)		
As-cured		0	1494		223		500		62			
1. Y, Vac. 16 hrs., 70 F	1	6.4 x 10 ⁶	1371	- 8	374	+68	243	-51	63	+ 1	+ 2	2
2. Y, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	582	-61	267	+20	187	-63	55	- 7	+ 2	3
3. Y+ UV, Vac.(2) 16 hrs., 95 F	14	5.7 x 10 ⁶	1127	-25	309	+39	273	-45	63	+ 1	- 2	1
4. Y, Vac.(3) 100 hrs., 70 F	16	5.0 x 10 ⁷	524	-65	269	+20	167	-67	57	- 15	-13	4
5. Y, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	539	-64	285	+28	163	-67	50	-12	+ 2	5
6. Y+ UV, Air(2) 100 hrs., 200 F	18	5.0 x 10 ⁷	128	-91	92	-59	140	-72	52	-10	- 9	6

Table B-5. Concluded)

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Combined radiation intended.

Time effect: Reaction is predominantly scission as noted by the decrease of hardness with time and of modulus after an initial increase.

Atmosphere effect: The scission seems to be slightly greater than crosslinking in air than in vacuo as indicated by hardness change.

Type irradiation effect: The specimens exposed to the combined radiation conditions did not show the surface decomposition that the straight gamma exposure specimens did.

Observations:

Condition 1, soft surfaces on specimens.

Condition 2, surface depolymerization to a tacky condition.

Condition 3, smoky discoloration on face toward lamp-tacky free surface.

Condition 4, surface depolymerization to a tacky condition.

Condition 5, surface depolymerization to a tacky condition.

Condition 6, iridescent discoloration on face toward lamp-tacky free surface.
Specimens had lost elasticity.

Table B-6. PHYSICAL PROPERTIES OF COMPOUND 157-62 47

Base Elastomer-Chlorobutyl Polychloroprene Blend
Type-Chlorobutyl HT-10-66, Neoprene WRT (50:50)

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength		100 % Modulus		Ultimate Elongation		Hardness Duro A Chg. (1)	Weight Change mg.	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)			
As-cured		0	1452		334		433		70		
1. V, Vac. 16 hrs., 70 F	13	6.4 x 10 ⁶	2058	+42	646	+ 93	223	-49	72 + 2	+2	1
2. V, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	963	-34	--	+350(3)	60	-86	82 +12	+8	4
3. V, Vac. (2) 16 hrs., 95 F	15	5.7 x 10 ⁶	987	-32	--	+102(3)	93	-79	75 + 5	Nil	2
4. V, Vac. (4) 100 hrs., 70 F	16	5.0 x 10 ⁷	850	-42	--	+248(3)	73	-83	83 +13	+8	3
5. V, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	1145	-21	--	+411(3)	67	-85	81 +11	+9	5
6. V + UV, Air (2) 100 hrs., 200 F	18	5.0 x 10 ⁷	148	-90	--	+450(3)	10	-98	86 +16	-7	6

Table B- (Concluded)

- (1) From as-cured value.
- (2) Measured temperatures are uncertain.
- (3) Value found by extrapolation.
- (4) Combined radiation intended.

Time effect: Cross-linking is the predominant reaction and is in proportion to the exposure time as was shown by comparison of Conditions 1 and 2.

Atmosphere effect: The reactions were similar in air as shown by comparison of the property changes in Conditions 2, 4, and 5.

Type irradiation effect: Comparison of 1 and 3, and 5 and 6 showed slightly more cross-linking induced by the combined radiation than by straight gamma.

Observations: Condition 2, tabs of specimens had tacky spots on protected ends. Condition 3, smoky brown discoloration of face toward lamp. Condition 4, tabs of specimens had tacky spots on protected ends. Condition 5, tabs of specimens had tacky spots on protected ends. Condition 6, iridescent discoloration on face toward UV lamp. Slight blistering of specimens. No specimens broke before test.

Table B-7. PHYSICAL PROPERTIES OF COMPOUND 158-6247
 Base Elastomer-Chlorobutyl-Polychloroprene Blend
 Type-Chlorobutyl HT-10-66, Neoprene WRT (25:75)

Nominal Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation %	Hardness Duro A Chg. (1)	Weight Change mg	Rating
As-cured		0	2144	420	383	72		
1. Y, Vac. 16 hrs., 70 F	13	6.4 x 10 ⁶	1023	332	217	-43	+4	1
2. Y, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	1343	--	+578(3)	-88	+14	5
3. Y + UV, Vac.(2) 16 hrs., 95 F	15	5.7 x 10 ⁶	1415	--	+350(3)	-80	+6	2
4. Y, Vac.(4) 100 hrs., 70 F	16	5.0 x 10 ⁷	1168	--	+340(3)	-84	+14	3
5. Y, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	1542	--	+672(3)	-88	+14	6
6. Y + UV, Air(2) 100 hrs., 200 F	18	5.0 x 10 ⁷	1052	--	+402(3)	-87	+17	4

Table B -7. (Concluded)

- (1) From as-cured value.
- (2) Measured temperatures are uncertain.
- (3) Value found by extrapolation.
- (4) Combined radiation intended.

Time effect: The compound showed an initial softening due to scission (by decrease in 100 per cent modulus condition), but this was balanced by cross-linking as shown by the hardness increase and the cross-linking became predominant as exposure time increased.

Atmosphere effect: Radiation in air apparently produced more cross-linking than radiation in vacuo as shown by comparison of Conditions 2, 4, and 5.

Type irradiation effect: Combined radiation in vacuo produced more cross-linking than straight gamma radiation (Condition 3 vs. 1), but examination of Conditions 5 and 6 revealed mixed changes in properties.

Table B-8. RECIPES AND CURE SCHEDULES OF THE CHLOROSULFONATED POLYETHYLENES USED IN THE IRRADIATION STUDIES⁴⁷

Compound Data - Chlorosulfonated Polyethylenes

	Compound 130-62	Compound 131-62	Compound 132-62	Compound 134-62	Compound 136-62
	Resins, parts by weight				
Hypalon 40	100	100	100	100	100
SP-2 black	20	20	20	40	40
Rosin	2.5	2.5	2.5	2.5	2.5
Tetron A	1.0	1.0	1.0	1.0	1.0
MgO	30	30	30	30	30
Hydroquinone	—	3.3	3.3	—	4
	Cure Schedule				
Cure time, min	40	120	10	40	120
Cure temperature, F	293	293	293	293	293

Table B-9. PHYSICAL PROPERTIES OF COMPOUND 130-6247

Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		Modulus		Elongation		Hardness Duro A Chg.(1)	Weight Change mg.	Rating	
			psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)				
As-cured		0	3235		941		277		80			
1. Y, Vac. 16 hrs., 70 F	3	7.8 x 10 ⁶	3475	+ 7.4	1373	+ 45	280	+ 1.1	82	+ 2	+ 18	2
2. Y, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	2590	-20	2267	+141	110	-60	82	+ 2	+ 19	6
3. Y + UV Vac.(2) 16 hrs., 190 F	12	6.4 x 10 ⁶	2253	-30	1275	+ 36	167	-40	85	+ 5	+ 27	3
4. Y + UV Vac.(2) 100 hrs, 250 F	10	6.1 x 10 ⁷	3192	- 1.3	3265	+247	100	-64	85	+ 5	+ 10	7
5. Y, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	3062	- 5.3	2126	+126	130	-53	91	+11	+145	4
6. Y + UV Air(2) 100 hrs., 250 F	9	3.8 x 10 ⁷	2977	- 8.0	2208	+135	120	-57	85	+ 5	+ 80	5
7. Y, Air 16 hrs., 70 F	3A	5.7 x 10 ⁶	2362	-27	1005	+ 6.8	243	-12	85	+ 3	+ 21	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

Table B-9. (Concluded)

Time effect: The basic effect was cross-linking, increasing with exposure time.

Atmosphere effect: The modulus increase was greater in vacuo than in air. Tensile changes were mixed as were the changes in ultimate elongation. The specimens gained weight, markedly so in air. The effect of the UV was to increase the vacuum exposure weight gain and decrease the size of the weight gain in air.

Type irradiation effect: After 16 hours the mixed radiation in vacuo showed a greater effect on hardness, ultimate elongation and tensile, and a lesser effect on modulus than straight gamma in vacuo. After 100 hours the mixed radiation effect on tensile was less, the effect on modulus and hardness greater, and the effect on elongation the same as for straight gamma. In air the results were similar for mixed and straight gamma radiation.

Observations: Condition 2, specimens broke out of or close to end of reduced section. Condition 3, slight discoloration of face toward UV lamp. Condition 4, very slight discoloration of face toward UV lamp. Condition 7, very slight discoloration of face toward UV lamp.

Table B-10. PHYSICAL PROPERTIES OF COMPOUND 131-6247
Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose, r.	Tensile Strength, psi	Chg. (1)	psi	Modulus, psi	Chg. (1)	Ultimate Elongation, %	Chg. (1)	Hardness, Duro A Chg. (1)	Weight Change mg.	Rating
As-cured		0	3063		1001		330		84			
1. γ, Vac. 16 hrs., 70 F	3	7.8 x 10 ⁶	3022	-1.3	1404	+40	257	-22	+2		+22	2
2. γ, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	3316	+9.7	2002	+100	205	-38	+2		+14	4
3. γ + UV Vac. (2) 16 hrs., 190 F	12	6.4 x 10 ⁶	3195	+4.3	1374	+37	213	-36		84	+20	3
4. γ + UV Vac. (2) 100 hrs., 250 F	10	6.1 x 10 ⁷	3099	+1.1		141(3)	93	-71		84	-7	6
5. γ, Air 100 hrs., 70 F	8	1.1 x 10 ⁷	2994	-0.9	2534	+80	127	-62	+6		+147	4
6. γ + UV Air (2) 100 hrs., 250 F	9	3.8 x 10 ⁷	3849	+26	2867	+104	140	-46	+4		+95	5
7. γ, Air 16 hrs., 70 F	3A	5.7 x 10 ⁶	3151	+2.9	976	-2.5	363	+10	+1		+30	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-10. (Concluded)

Time effect: The radiation effects, essentially cross-linking, grow more severe as the exposure time is increased (Condition 1 vs. 2).

Atmosphere effect: Except for elongation change at 100 hours the gamma radiation effects were more severe in vacuo than in air. In combined radiation the effect was mixed, the increase in 100 per cent modulus and decrease in ultimate elongation being greater in vacuo and the increase in tensile strength and hardness being greater in air. Most specimens gained weight markedly in air. The effect of UV was to increase the weight gains in vacuum exposure and decrease the weight gains in air.

Type irradiation effect: The difference between the effects of combined radiation and straight gamma radiation were inconsistent.

Observations: Condition 4, moderate discoloration on face toward UV lamp. Condition 5, very slight discoloration. Condition 6, very slight discoloration on face toward UV lamp. Condition 7, slight iridescence on face of specimens.

Table B-11. PHYSICAL PROPERTIES OF COMPOUND 132-62¹⁷
Base Elastomer - Chlorosulfonated Po., Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Modulus		100 % Modulus psi	Ultimate		Hardness Duro A Chg.(1)	Weight Change mg.	Rating
			Strength psi	% Chg.(1)		Elongation % Chg.(1)	% Chg.(1)			
As-cured		0	3312		878	330		82		
1. V, Vac. 16 hrs., 70 F	3	7.8 x 10 ⁶	3274	- 1.2	1514 + 72	223	-32	83 +1	+20	1
2. V, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	3425	+ 3.7	2155 +145	170	-48	85 +3	+18	3
3. V + UV, Vac.(2) 16 hrs., 190 F	12	6.4 x 10 ⁶	3112	- 5.8	1644 + 87	167	-49	85 +3	+18	2
4. V + UV, Vac.(2) 100 hrs., 250 F	10	6.1 x 10 ⁷	2617	-21	-- +462(3)	53	-84	83 +1	- 3	6
5. V, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	2558	-22	2364 +169	113	-66	91 +9	+30	4
6. V + UV, Air(2) 100 hrs., 250 F	9	3.8 x 10 ⁷	3120	- 5.5	2677 +205	114	-66	85 +3	+79	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-11. (Concluded)

<u>Time effect:</u>	Cross-linking in vacuo became more severe as exposure time increased (Conditions 1 vs. 2 and 3 vs. 4).
<u>Atmosphere effect:</u>	Air exposure was more severe than vacuo in gamma radiation but the reverse was true in mixed radiation (Conditions 2 vs. 5 and 3 vs. 6). Most specimens gained weight. The weight gain was markedly more pronounced in air than vacuo and was decreased by the addition of UV radiation and heat.
<u>Type of radiation effect:</u>	Mixed radiation produces more cross-linking than gamma radiation and the effect is more pronounced in vacuo than in air (Conditions 2 vs. 4 and 5 vs. 6).
<u>Observations:</u>	Condition 3, discoloration on face toward UV lamp. Condition 4, slight discoloration on face toward UV lamp. Condition 6, discoloration on face toward UV lamp.

Table B-12. PHYSICAL PROPERTIES OF COMPOUND 134-62-47
Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile psi	Elongation % Chg. (1)	Modulus 100% psi Chg. (1)	Ultimate Elongation % Chg. (1)	Hardness Duro A Chg. (1)	Weight Change mg.	Rating		
As-cured		0	3190		1567	207	88				
1. V, Vac. 16 hrs., 70 F	3	7.8 x 10 ⁶	3372	+ 4.1	2567	+ 64	143	-30	-1	+ 18	1
2. V, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	3414	+ 7.0	—	+150(3)	87	-58	+1	- 15	5
3. V + UV, Vac. (2) 16 hrs., 190 F	12	6.4 x 10 ⁶	1938	-29	—	+ 30(3)	95	-54	Nil	+ 19	2
4. V + UV, Vac. (2) 100 hrs., 250 F	10	6.1 x 10 ⁷	3108	- 2.6	—	+231(3)	60	-71	+1	+ 6	7
5. V, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	3553	+11	—	+183	80	-44	+6	+117	6
6. V + UV, Air (2) 100 hrs., 250 F	9	3.8 x 10 ⁷	3692	+16	—	+125(3)	83	-56	+3	+ 62	4
7. V, Air 16 hrs., 70 F	3A	5.7 x 10 ⁶	900	-72	796	- 48	110	-48	Nil	+ 19	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-12. (Concluded)

Time effect:

The compound when irradiated in vacuo underwent an increase in tensile and modulus and decrease in elongation with time. In air it passed through an initial period which in the modulus and tensile strength decreased as well as the elongation. This indicated a period of chain scission.

Atmosphere effect: The reaction produced by exposure in vacuo was, in general, more severe than that in air. The reaction in vacuo, at all periods, and air, for long periods, seemed to be predominantly cross-linkage although the material irradiated in air underwent an initial chain scission period. The weight changes were greater in air than in vacuo and were decreased by the addition of the UV radiation.

Type irradiation effect: The difference in effect between combined radiation and gamma radiation was inconsistent.

Observations: None

Table B-13. PHYSICAL PROPERTIES OF COMPOUND 136-62¹
 Base Elastomer - Chlorosulfonated Polyethylene: Type - Hypalon 40⁴⁷

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation % Chg. (2)	Hardness Duro A Chg. (2)	Weight Change mg.	Rating
As-cured		0	3400	1785	210			
7. v, Air 16 hrs., 70 F	3A	5.7 x 10 ⁶	1217	789	-56	203	-3.3	+26

(1) Although lack of time permitted exposure of this compound to only one condition, it was included to show the effect of the addition of antirac (to compound 134-62).

(2) From as-cured value.

Table B-14. ELASTOMERS TESTED FOR EFFECTS OF
HIGH TEMPERATURES IN A VACUUM⁹

Elastomers

Silicone (DC 651, 916, 2071), a polysiloxane high polymer useful over the temperature range of -130°F to 500°F.

Adiprene ("L" and "C"), a urethane polymer useful over the temperature range of -65°F to 175°F.

Buna N, an acrylonitrile-butadiene polymer useful over temperature range of -60°F to 200°F.

Butyl (K-121 and K-1330), an isobutylene isoprene polymer useful over temperature range of -70°F to 250°F.

Neoprene, a chloroprene polymer useful over the temperature range of -60°F to 200°F.

Viton A-U-74, a copolymer of vinylidene fluoride and hexafluoropropylene useful over the temperature range of -47°F to 500°F.

Silicon sponge, closed cell recommended for use from -100°F to 480°F.

Table B-15. EFFECT OF LOW PRESSURE AND HIGH TEMPERATURES ON SPACE VEHICLE ELASTOMERS

Material	Conditions	Sample Size & No.	Property	Result	Comments
Silicone DC 2071	Temperature 450 F Ultimate pressure 6×10^{-4} mm Time at pressure 3 hours	3 Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) No significant change in tensile strength b) No change in hardness c) 18.4% Decrease in elongation	The test results for the silicone rubbers were very widely scattered and varied demonstrating a need for large sample lots to indicate more conclusively any trends in physical-property change.
Silicone DC 916	Temperature 450 F Ultimate pressure 1.2×10^{-4} Time at pressure 4-1/2 hours	2 Standard tensile specimens	Same as above	a) Test void - results widely variant b) 2% Increase in hardness c) 4.2% Decrease in elongation	Ditto
Silicone DC 651	Temperature 450 F Ultimate pressure 1.2×10^{-4} Time at pressure 4-1/2 hours	2 Standard tensile specimens	Same as above	a) No significant change in tensile strength b) No change in hardness c) 10.2% Decrease in elongation	"
Buna-N	Temperature 300 F Ultimate pressure 1.2×10^{-3} Time at pressure 5 hours	3 Standard tensile specimens	Same as above	a) Tensile tests inconclusive b) 13.5% Increase in hardness c) 7.6% Decrease in elongation	Hardness and elongation differences consistent tensile data widely scatter.
Neoprene	Temperature 300 F Ultimate pressure 5×10^{-4} Time at pressure 3 hours	3 Standard tensile specimens	Same as above	a) 34.2% Increase in tensile strength b) 23% Increase in hardness c) 6.8% Decrease in elongation	Tensile, hardness, and elongation changes consistent.
Adiprene	Temperature 200 F Ultimate pressure 1.1×10^{-2} Time at pressure 5 hours	3 Standard tensile specimens	Same as above	a) No significant change in tensile strength b) No change in hardness c) 7.2% Increase in elongation	Poor ultimate pressure obtained; rerun of additional samples necessary.
Silicone Sponge MCI 4546-GR.42	Temperature 450 F Ultimate pressure 8×10^{-5} Time at pressure 3-1/2 hours	3 Specimens $2 \times 2 \times 3$ "	a) Compression deflection b) Water absorption	a) Test results inconclusive	
Adiprene C	Temperature 300 F Ultimate pressure $9/2 \times 10^{-4}$ Time at pressure 6 hours	Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) Decrease of 37.7% in tensile strength b) 8.3% Increase in hardness c) No significant change in elongation	Tensile and hardness data consistent.

Table B-15. (Concluded)

Material	Test Data				Comments
	Conditions	Sample Size & No.	Property	Result	
Butyl K-1210	Temperature Ultimate pressure 8.4 x 10 ⁻⁴ Time at pressure 5.5 hours	6 Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) 7.7% Decrease in tensile strength b) 1.9% Increase in hardness c) 11.9% Decrease in elongation	Yellowish condensate observed in cold trap. Elongation data consistent tensile strength data scattered.
Viton A U-74	Temperature Ultimate pressure 5.5 x 10 ⁻⁴ Time at pressure 6.5 hours	2 Standard tensile specimens	Same as above	a) 12.3% Decrease in tensile strength b) 1.4% Increase in hardness c) 5.5% Decrease in elongation	Insufficient samples for significant results.
Butyl K-1330	Temperature Ultimate pressure 2.5 x 10 ⁻⁴ Time at pressure 5 hours	6 Standard tensile specimens	Same as above	a) 7.3% Increase in tensile strength b) 7.7% Increase in hardness c) 6.5% Decrease in elongation	Elongation data consistent tensile data scattered.

Table B-16. EXPOSURE OF VITON-B TO HIGH VACUUM AT VARIOUS TEMPERATURES 45

Property Measured	Original	Temperature	Exposed to			600 F		
			Vacuum of 7.8 x 10 ⁻⁶ mm Hg for 5 Days at Room			400 F		
						Vacuum of 1.9 x 10 ⁻⁵ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.4 x 10 ⁻⁵ mm Hg for 5 Days
								Air Oven for 5 Days
Tensile strength, psi	2610	2630		2270	620	220	620	220
Modulus, psi at 200 per cent elongation	1300	1030		1000	520	---	570	---
Elongation, per cent	320	340		370	410	110	240	110
Hardness, Shore A	74	72		64	75	83	77	83
Strain, per cent elongation at 400 psi	107	96		125	171	Broke	123	Broke
Change in weight, per cent	---	-0.06		-1.1	-6.8	-18.8	-5.5	-18.8

Table B-17. RECIPES AND CURE SCHEDULES OF THE FLUOROELASTOMERS (VITON A) USED IN THE IRRADIATION STUDIES⁴⁷

Compound Data - Fluoroelastomer

	Compound 150-62	Compound 151-62	Compound 152-62
	<u>Recipe, parts by weight</u>		
Viton A	100	100	100
MT black	25	60	—
GPF black	—	—	60
MgO	15	15	15
HMDAC	1.5	1.5	1.25

Cure Schedule

All compounds were press cured for 30 minutes at 300 F, and post cured for 28 hours at 400 F.

Table B-18. PHYSICAL PROPERTIES OF COMPOUND 150-6247
Base Elastomer - Fluorocelastomer, A Copolymer of
Vinylidene Fluoride and Hexafluoropropylene

Type - Viton A

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus psi	Ultimate		Hardness Duro A Chg. (1)	Weight Change mg.	Rating
			psi	% Chg. (1)		%	% Elongation			
As-cured		0	1835		1446	123		88		
2. V, Vac. 100 hrs., 70 F	14	6.1×10^7	1299	-29	-- +199(3)	30	-76	93	+1	3
3. V + UV, Vac. (2) 16 hrs., 95 F	15	5.7×10^6	1512	-18	-- + 35(3)	77	-37	88	Nil	1
4. V, Vac. (4) 100 hrs., 70 F	16	5.0×10^7	1946	+ 6.0	-- + 92(3)	67	-46	91	+3	2
5. V, Air 100 hrs., 70 F	17	6.1×10^7	1600	-13	-- +381(3)	23	-81	88	Nil	5
6. V + UV, Air (2) 100 hrs., 200 F	18	5.0×10^7	1461	-20	-- +304(3)	25	-72	91	+3	4

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-18. Concluded)

Time effect: Cross-linking increases with the increase in radiation dosage.

Atmosphere effect: Irradiation in air caused more cross-linking than in vacuo.
Weight changes were generally insignificant.

Type irradiation effect: Combined irradiation caused more cross-linking than straight gamma radiation.

Observations: Condition 3, brownish to smoky grey discoloration on face toward UV lamp. Condition 6, iridescent discoloration of face toward UV lamp.

Table B-19. PHYSICAL PROPERTIES OF COMPOUND 151-62 47
Base Elastomer - Fluoroelastomer A Copolymer of Vinylidene
Fluoride and Hexafluoropropylene

Type - Viton A

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation %	Hardness Duro A Chg. (1)	Weight Change mg.	Rating
As-cured		0	1867	696	177	78		
1. Y, Vac. 16 hrs., 70 F	13	6.4×10^6	1833	+106	113	-36	+3	2
2. Y, Vac. 100 hrs., 70 F	14	6.1×10^7	2010	—	+345(3)	-63	+2	5
3. Y + UV, Vac. (2) 16 hrs., 95 F	15	5.7×10^6	2168	1333	+92	-23	+1	1
4. Y, Vac. (4) 100 hrs., 70 F	16	5.0×10^7	1658	—	+258(3)	-62	Nil	4
5. Y, Air 100 hrs., 70 F	17	6.1×10^7	1977	—	+374(3)	-66	+4	6
6. Y + UV, Air (2) 100 hrs., 200 F	18	5.1×10^7	1738	—	+235(3)	-41	-4	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table 1 (Concluded)

Time effect: Cross-linking starts immediately and becomes more severe as exposure time is increased (Condition 1 vs. 2).

Atmosphere effect: At room temperature the changes produced by air exposure are somewhat greater than those produced by vacuo exposure. The situation is reversed at the elevated temperature of the combined irradiation. The weight gains are not large enough to be significant.

Type irradiation effect: Combined irradiation produces less cross-linking than straight gamma radiation as particularly shown in the 100 per cent modulus figures (Condition 1 vs. 3 and 5 vs. 6).

Observations: Condition 3, brownish discoloration on face toward lamp. Condition 6, iridescent coloration on face toward UV lamp.

Table B-20. PHYSICAL PROPERTIES OF COMPOUND 152-6247
Base Elastomer - Fluoroclastom, A Copolymer of Vinylidene
Fluoride and hexafluoropropylene

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus psi	Ultimate Elongation % Chg. (1)	Hardness		Weight Change mg.	Rating
			Strength psi	% Chg. (1)			Duro A	Chg. (1)		
As-cured		0	1300			90	95			
1. V, Vac. 16 hrs., 70 F	13	6.4 x 10 ⁶	1884	+ 45	+146(3)	53	94	-1	+5	2
2. V, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	2459	+ 83	+153(3)	30	96	+1	+6	3
3. V + UV, Vac. (2) 16 hrs., 95 F	15	5.7 x 10 ⁶	1670	+ 28	+ 83(3)	63	93	-2	-1	1
4. V, Vac. (4) 100 hrs., 70 F	16	5.0 x 10 ⁷	2321	+ 79	+222(3)	50	95	Nil	+2	4
5. V, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	2593	+100	+495(3)	30	95	Nil	+3	5
6. V + UV, Air (2) 100 hrs., 200 F	18	5.0 x 10 ⁷	2048	+ 65	+610(3)	20	95	Nil	-3	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-20. (Concluded)

Time effect: The cross-linking effect caused by radiation was increased by increased exposure time.

Atmosphere effect: Examination of Condition 2 and 5 reveals that greater cross-linking took place in air rather than in vacuo. Weight changes were small and generally gains. The effect of ultraviolet was to decrease the weight gains or cause small losses (Conditions 3 and 6).

Type irradiation effect: Combined radiation caused less cross-linking in vacuo as evidenced by the effect on the tensile strength and modulus (Condition 1 vs. 3). The reverse was true in air as shown by changes in modulus and 100 per cent elongation (Condition 5 vs. 3).

Observations: Condition 3, shiny brownish yellow discoloration on face toward UV lamp. Condition 6, iridescent discoloration with smoky deposit on face toward UV lamp.

Material Trade Name	Dose/ Gy (C)	Radiation Exposure		Sample Weight Original, Change, gm	at 2% Elongation		at 50% Elongation		at 100% Elongation		Ultimate Elonga- tion, per cent	Temperature Average, No. (a) (F)	Pressure Average, (torr) No. (c)
		Thermal	Fast		Thermal	Fast	Thermal	Fast					
Buna E (RA30760)	0	0	0 (control specimens) August 1962	--	99 103 101 101	137 141 134 140	170 185 168 173	2511 2679 2598 2732	2130 2130 2130 2130	690 680 670 700	77	--	760
1.7(9)	6.5(12)	1.9(13)	7.3(11) (vacuum irradiation) August 1962	-8288 +0.0020 3.8104 +0.0080 3.8688 +0.0012 3.9216 +0.0012	(b) 14 14 13	(b) 21 20 20	(b) -- 3 --	(b) 137 207 201	(b) 2130 2130 2130	(b) 690 660 650	80	D-8	5(-6)
7.0(9)	8.1(12)	8.7(13)	3.1(12) (vacuum irradiation) August 1962	3.8052 +0.0004 3.9793 +0.0014 3.8966 +0.0006	25 -- 22 22	46 -- 38 38	87 -- 81 80/9.4	212 195 210 189/15.5	180 200 200/23.6	180	80	D-8	5(-6)
0	0	0	0 (control specimens) February 1963	--	138 142 140 142	193 161 168 156	-- 239 228 210	-- 2583 2447 2034	-- 672 660 680	--	--	--	--
0	0	0	0 (vacuum controls) February 1963	3.8951 +0.0020 3.8763 -0.0025 3.8334 -0.0025 3.8295 -0.0028 3.8063 -0.0026	-- 133 112 141 149	177 167 157 180	221 222 214 230	2553 2400 2646 2710	2355 2400 2646 2710	690 635 650 570	--	--	--
0	0	0	0 (control specimens) May 1962	--	129/14.1	169/17.9	221/6.9	2868/309	652/40.8	--	--	--	--
1.87(9)	(air irradiation)			--	109/11.4	160/6.4/5	211/8.6/5	2459/496/5	643/51.5*	--	--	--	--
2.06(10)	(air irradiation)			--	159/30/5	2880/25/5	348/12/5	2274/630/5	391/67/5	--	--	--	--
				--	1177/129/4	1999/52/4	3495/233/4	3512, 206/5	100/4.9/4	--	--	--	--

 σ^2 = variance/second deviation on an individual basis/number of sam. σ^2

(a) Average value/standard deviation on all 11 values

(c) Applies to the original reference.

Table B-22. CHANGES IN PROPERTIES OF NITRILE RUBBER IRRADIATED IN VACUUM AND IN AIR⁶

Category	Trade Name	Gamma Dose [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Elastomers	Buna N (RA 30760)	0	1 x 10 ⁻⁶	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	0
		Vacuum Controls			Ultimate elongation	0
					Weight change	0
		1.7 x 10 ⁹	5 x 10 ⁻⁶	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-91.5
					Ultimate elongation	-34.3
					Weight change	0
		7.0 x 10 ⁹	5 x 10 ⁻⁶	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-92
					Ultimate elongation	-71
					Weight change	0
		1.9 x 10 ⁹	Air irradiated	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-11.6
					Ultimate elongation	-39
		2.1 x 10 ¹⁰	Air irradiated	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	+43
					Ultimate elongation	-84.5

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Table B-23. EXPOSURE OF NITRILE RUBBER VULCANIZATES TO HIGH VACUUM
AT VARIOUS TEMPERATURES

Property Measured	Original	Exposed to					300 F		
		158 F		212 F		Vacuum of 2.1 x 10 ⁻⁶ mm Hg for 5 Days			
		Vacuum of 10 ⁻⁵ mm Hg for 56 Days	at Room Temperature	Vacuum of 8 x 10 ⁻⁵ mm Hg; for 7 Days	Air Oven for 7 Days			Vacuum of 7.8 x 10 ⁻⁶ mm Hg for 5 Days	Air Oven for 5 Days
(1)									
<u>Unplasticized Compound (N128)</u>									
Tensile strength, psi	2680	2470	2670	2710	2910	2830	2270		
Modulus, psi at 200 per cent elongation	1980	—	—	—	—	—	—		
Elongation, per cent	260	230	235	255	230	230	170		
Hardness, Shore A	72	74	75	75	72	74	79		
Strain, per cent elongation at 400 psi	82	82	72	63	75	70	55		
Low temperature flexibility, ASTM D1043, T ₂₀₀ , F	-28	-29	-31	-29	—	—	-25		
Weight change, per cent	—	+1.2	-0.5	—	-2.6	-0.8	-2.8		
							-3.2		

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Table B-25. (Continued)

Property Measured	Original Temperature	Vacuum of 10-5 mm Hg for 56 Days at Room Temperature	Vacuum of 10-5 mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8 x 10-6 mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2.1 x 10-6 mm Hg for 5 Days	Air Oven for 5 Days
(1)								
Plasticized Compound (N128E)								
Tensile strength, psi	1370	1480	2020	1580	2160	1330	1790	Too brittle to test
Modulus, psi at 300 per cent elongation	850	840	1290	950	1870	1460	--	Too brittle to test
Elongation, per cent	410	430	325	340	330	360	210	Too brittle to test
Hardness, Shore A	57	55	66	59	68	56	76	Too brittle to test
Strain, per cent elongation at 400 psi	209	200	141	206	124	116	79	Too brittle to test
Low temperature flexibility, ASTM D1043, T200, F	-56	-55	-36	-55	--	--	-31	Too brittle to test
Weight change, per cent	--	+0.2	-9.1	--	-9.3	-1.9	-10.2	-9.0
(1) See Table A-1 for formulation.								
per cent	--	+0.2	-9.1	--	-9.3	-1.9	-10.2	-9.0
(1) See Table A-1 for formulation.								

TABLE B-24. TEST ENVIRONMENT AND RESULT. OF STATIC TEST: NEOPRENE RUBBER

Material Trade Name	Radiation Exposure		Sample Weight Original, Change, gm	Tensile Strength (a) (psi)		Temperature		Ultimate Elonga- tion, percent	Pressure Average, Figure (torr) No. (c)		
	Gamma [ergs/ gm(C)]	Neutrons (n/cm ²) Thermal E>2.9 Mev E>8.1 Mev		at 25% Elongation	at 50% Elongation	at 100% Elongation	Average, Figure (F)			No. (c)	
Neoprene (B24350)	0	0	—	135	233	415	3306	445	77	—	760
		(control specimens)		141	222	384	3182	450			
		(for vacuum test)		131	222	37	3005	430			
				—	227	—	2876	330			
				139/9.2	222/5.3	384/36.0	3134/227	425			
				139/9.2	222/5.3	384/36.0	3134/227	426/25.6			
1.9(9)	6.7(12)	2.9(13)	8.0(11)	—	28	—	237	260	80	D-7	5(-6)
	(vacuum irradiation)			+0.0093	21	32	158	190			
	August 1962			+0.0100	18	33	197	220			
				+0.0170	18	36	172	200			
				19/1.5	32/3.9	65/3.0	191/38.1	218/34.0			
5.4(9)	9.2(12)	9.8(14)	3.7(12)	—	75	—	115	115	80	D-7	5(-6)
	(vacuum irradiation)			+0.0470	30	76	130	80			
	August 1962			+0.0365	29	66	147	115			
				+0.0361	35	72	142	80			
				+0.0276	31/2.9	72/4.9	134/15.5	98/17.0			
0	0	0	0	—	153/12.9/5	220/3.6/5	392/18.9/4	3297/244/5	454/29.6/5	—	—
	(control specimens)										
	May 1962										
1.8(9)	(air irradiation)			—	186/24.9/5	316/26.2/1	628/46.4/5	2769/224/5	265/21.5/5	—	—
	May 1962										
2.06(10)	(air irradiation)			—	—	—	—	203/40/5	35/6.4/5	—	—

(a) Average value/standard deviation on an individual basis/number of samples.

(b) No tensile values were obtained for this specimen.

(c) Applies to the original reference.

TABLE B-25. CHANGES IN PROPERTIES OF ELASTOMERS IRRADIATED IN VACUUM AND IN AIR⁽⁶⁾

Category	Trade Name	Gamma Exposure, ergs g ⁻¹ (c)	Vacuum, torr	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Elastomers	Neoprene (RA 24160)	1.9 x 10 ⁹	5 x 10 ⁻⁶	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength Ultimate elongation Weight change	-94 -49 0
		5.4 x 10 ⁹	5 x 10 ⁻⁶	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength Ultimate elongation Weight change	-96 -77 0

Table B-26. RECIPES AND CURE SCHEDULES OF THE
POLYCHLOROPRENES USED IN THE
IRRADIATION STUDIES⁴⁷

Compound Data - Polychloroprenes

	Compound 138-62	Compound 139-62	Compound 140-62	Compound 159-62	Compound 161-62
Recipe, parts by weight					
Neoprene WRT	100	100	100	100	100
SRF black	35	35	35	—	—
HAF black	—	—	—	50	50
Ca ²⁺	5	5	5	5	5
Stearic acid	1	1	1	1	1
MgO	4	4	4	8	8
Hydroquinone	—	2.0	5.0	—	—
Tetramethyl thiuram disulfide	—	—	—	1	1
Benzothiazyl sulfide	—	—	—	2	2
Cure Schedule					
Cure time, min.	40	40	40	40	20
Cure temperature, F	293	293	293	293	293

Table B-27. PHYSICAL PROPERTIES OF COMPOUND 138-6247
Base Elastomer - Polychloroprene, Type - Neoprene WRT

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		Modulus		Ultimate		Hardness Durometer A Chg. (1)	Weight Change %	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	% Elongation	% Chg. (1)			
As-cured		0	2303		187		537		60		
1. V, Vac. 16 hrs., 70 F	3	7.8×10^6	2731	+ 29	340	+ 189	247	- 54	69 + 9	+10	1
2. V, Vac. 100 hrs., 70 F	4	4.9×10^7	2140	- 7	---	+ 1385(3)	77	- 86	84 +24	+21	5
3. V + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	855	- 64	---	+ 408(3)	90	- 83	75 +15	+16	2
4. V + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	1700	- 26	---	+ 2356(3)	37	- 93	88 +28	+10	6
5. V, Air 100 hrs., 70 F	8	4.1×10^7	579	- 75	---	+ 1245(3)	23	- 96	88 +28	+67	4
6. V + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	1265	- 45	---	+ 1007(3)	57	- 89	86 +26	+53	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table C-27. (Continued)

Time effect: The cross linking began immediately and increased very much with increase in exposure time. This was shown by the behavior of all properties checked (Conditions 1 vs. 2 and 3 vs. 4), except the tensile strength.

Atmosphere effect: Irradiation in air produced a greater change in tensile strength than radiation in vacuo. The difference in change was greater after at room temperature than at the elevated temperature of the combined irradiation conditions. The modulus change was somewhat greater in vacuo than air at room temperatures and very much greater at the elevated temperature of combined radiation. Hardness and elongation changes were mixed. All specimens gained weight, markedly so in air.

Type irradiation effect: In vacuo the combined radiation effects were markedly more severe than the straight gamma radiation. The combined radiation in air was apparently less severe than straight gamma radiation.

Observations: Condition 4, slight discoloration on face toward UV lamp. Condition 5, slight discoloration of specimens, whitish deposit on protected tabs. Condition 6, discoloration on face toward UV lamp.

Table B-28. PHYSICAL PROPERTIES OF COMPOUND 139-62⁴⁷
Base Elastomer - Polychloroprene, Type - Neoprene WRT

Specimen	Temp., F.	Modulus, psi	Strain, % Chg. (1)	Stress, psi	Modulus, psi	Strain, % Chg. (1)	Ultimate Elongation, % Chg. (1)	Hardness, Duro A Chg. (1)	Weight Change, mg.	Rating
As-cured	0	2149	224	516	68					
1. V, Vac., 16 hrs., 70 F	3	1.5×10^6	2110	-13	461	+106	260	-50	+1	+5
2. V, Vac., 100 hrs., 70 F	4	4.9×10^7	1357	-36	933	+317	123	-75	+4	+11
3. V + UV, Vac. (2), 100 hrs., 190 F	12	6.4×10^6	1394	-35	592	+16	167	-61	+3	+10
4. V + UV, Vac. (2), 100 hrs., 250 F	10	6.1×10^7	965	-55	—	+978(3)	40	-93	+5	Nil
5. V, Air, 100 hrs., 70 F	8	4.1×10^7	1016	-53	—	+827(3)	70	-86	+6	+72
6. V + UV, Air (2), 100 hrs., 250 F	9	3.8×10^7	1109	-48	—	+586(3)	63	-88	+5	5
7. V, Air, 16 hrs., 70 F	3A	1.7×10^6	2526	+18	495	+121	290	-14	+2	+13

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

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Table B-23. (Concluded)

Time effect:

The cross-linking began immediately with exposure and increased markedly as exposure time increased. This was shown by the behavior of the 100 per cent modulus, ultimate elongation, and hardness changes (1 vs. 2, 3 vs. 4, and 7 vs. 5).

Atmosphere effect: During short periods of irradiation (Condition 1 vs. 7), irradiation in air produced slightly greater changes in the physical properties than irradiation in vacuo. This difference became more marked as the irradiation time was increased. However, during combined irradiation (Condition 4 and 5), the effect was reversed and irradiation in vacuo produced greater changes than irradiation in air. All conditions showed an increase in ultimate elongation and modulus being produced by irradiation in air and by combined radiation.

Type irradiation effect: The combined radiation produced more severe effects in vacuo than the straight gamma radiation (Conditions 1 vs. 3 and 2 vs. 4). In air the differences were slight but larger changes were produced by straight gamma in tensile strength and modulus and very slightly larger changes were produced in the ultimate elongation by combined radiation.

Observations: Condition 4, discoloration of specimens on face toward ultraviolet lamp. Condition 5, slight discoloration of specimens. Condition 6, slight discoloration of specimens.

Table B-29. PHYSICAL PROPERTIES OF COMPOUND 100-6247

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Base Elastomer - Polychloroprene		5. Type Neoprene WRT		Ultimate Elongation % Chg. (1)	Hardness Dure A Chg. (1)	Weight Change mg.	Ratios
			Can No.	Base Elastomer Polychloroprene	Base Elastomer Polychloroprene	Base Elastomer Polychloroprene				
As-cured		0	1835	239	317	71				
1. V, Vac. 16 hrs., 70 F	3	7.8 x 10 ⁶	2330	+27	491	+105	283	-46	-2	+4
2. V, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	1243	-32	871	+263	123	-76	+6	+11
3. V + UV, 16 hrs., 100 F	12	6.4 x 10 ⁶	1097	-40	606	+154	163	-69	+2	+3
4. V + UV, 100 hrs., 250 F	10	6.1 x 10 ⁷	884	-52	--	+900(3)	37	-93	+12	+12
5. V, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	1063	-42	1116(4)	+367	93(4)	-83	+3	+5
6. V + UV, Air(2) 100 hrs., 250 F	9	3.8 x 10 ⁷	940	-48	--	+642(3)	53	-90	+9	+24
7. V, Air 16 hrs., 70 F	3A	5.7 x 10 ⁶	2271	+24	449	+88	317	-39	71	+12

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Two specimens had an ultimate elongation equal to 100 percent.

Table B-79 (Continued)

Time effect: The effect of time was to increase the amount of cross-linking caused by the initial exposures. Even though 16 hour gamma + vacuum (Condition 1) shows a slight hardness drop, the reaction at all times was predominantly cross-linking.

Atmosphere effect: The changes caused by sixteen hours exposure in vacuum were somewhat greater for the same period in air (Condition 1 vs. 7). By 100 hours exposure (Condition 2 vs. 5), the situation was reversed and markedly so. At the elevated temperature of the combined irradiation (Condition 4 vs. 6), the vacuum exposure caused greater change than air exposure. Most of the specimens gained weight. The gain in weight was greater in air than in vacuum and was decreased by the addition of the combined irradiation.

Type irradiation effect: Combined irradiation caused more cross-linking in all properties examined (Condition 1 vs. 3, 2 vs. 4 and 5 vs. 6) than equivalent exposure time in straight gamma.

Observations: Condition 4, moderate discoloration on face toward ultraviolet lamp. Condition 5, slight discoloration of specimens. Condition 6, slight discoloration of specimens.

Table B-30. PHYSICAL PROPERTIES OF COMPOUND 159-6247
Base Elastomer - Polychloroprene Type - Neoprene WRF

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg. (1)	Modulus psi	Modulus % Chg. (1)	Ultimate Elongation % Chg. (1)	Hardness Duro A Chg. (1)	Weight Change mg.	Rating
As-cured		0	2654		496		387	74		
1.										
2.										
3. v + UV, Vac. (2) 16 hrs., 190 F	12	6.4 x 10 ⁶	1406	-47	--	+ 155(3)	93	-76	+15	2
4. v + UV, Vac. (2) 100 hrs., 250 F	10	6.1 x 10 ⁷	2131	-20	--	+1768(3)	23	-34	+2	5
5. v, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	698	-66	--	+ 570(3)	27	-93	+71	4
6. v + UV, Air (2) 100 hrs., 250 F	9	3.8 x 10 ⁷	1811	-32	--	+ 540(3)	57	-85	+16	3
7. v, Air 16 hrs., 70 F	4A	5.7 x 10 ⁶	3055	+15	882	+ 78	250	-35	+1	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-30. (Concluded)

Time effect: Increase of exposure markedly increased the effect of cross-linking for all conditions checked (7 vs. 5 and 3 vs. 4).

Atmosphere effect: Air exposure at elevated temperature had less effect on all properties (except tensile) checked (Condition 4 vs. 6). All specimens gained weight, more in air than in vacuo, and the effect of the combined radiation was to lessen the weight gain.

Type irradiation effect: Combined radiation in air (Condition 6) produced less cross-linking than straight gamma radiation for the same condition.

Observations: Condition 3, slight purplish discoloration on face toward UV lamp. Condition 4, purplish discoloration on face toward UV lamp. Condition 5, slight discoloration of specimens, whitish discoloration of protected ends of tabs. Condition 6, brownish discoloration on face toward UV lamp. Condition 7, slight discoloration of specimen.

Table B-31. PHYSICAL PROPERTIES OF COMPOUND 16.1-62 INDUCED BY EXPOSURE TO
THE DIFFERENT IRRADIATION CONDITIONS⁴⁷

Base Elastomer - Polychloroprene, Type - Neoprene WRT										
Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Elongation % Chg. (1)	Modulus psi	Modulus % Chg. (1)	Ultimate Elongation % Chg. (1)	Hardness Duro A Chg. (1)	Weight Change mg	Rating
As-cured		0	1651		376		437	72		
1. V, Vac. 16 hrs., 70 F	13	6.4 x 10 ⁶	3176	+92	723 + 91		277 -37	77 + 5	+ 8	1
2. V, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	1864	+13	— + 949(3)		47 -89	91 +19	+20	4
3. V + UV, Vac. ⁽²⁾ 16 hrs., 95 F	15	5.7 x 10 ⁶	1991	+21	1800 + 376		110 -74	80 + 8	+ 2	2
4. V, Vac. ⁽⁴⁾ 100 hrs., 70 F	16	5.0 x 10 ⁷	1812	+ 9.7	— + 615(3)		67 -85	91 +19	+18	3
5. V, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	2116	+28	— + 956(3)		53 -91	90 +18	+24	5
6. V + UV, Air ⁽²⁾ 100 hrs., 200 F	18	5.0 x 10 ⁷	1950	+18	— + 1810(3)		27 -94	92 +20	+14	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-31. (continued)

Time effect: Cross-linking as evidenced by increase in modulus and hardness and decrease in elongation was initially marked and increased greatly with time (Condition 1 vs. 2).

Atmosphere effect: There were slightly larger increases in air radiation as compared to vacuo radiation in all properties except hardness (Condition 2 vs. 5). Weight increases were greater in air than in vacuo, and the addition of UV radiation decreased the weight gains.

Type irradiation effect: The combined radiation reduced markedly the amount of cross-linking as compared to that produced by straight gamma radiation (Conditions 1 vs. 3 and 5 vs. 6).

Observations: Condition 3, smoky brown discoloration on face toward UV lamp. Condition 6, purplish discoloration on both faces of specimens.

Table B-32. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET
RADIATION ON ELASTIC PROPERTIES (46)

Material	Type of Exposure**	Temperature (°F)	Exposure Time (hour)	Weight Change (per cent)	Tensile Strength			Breaking Elongation		
					Before Exposure (psi)	After Exposure (psi)	Change (per cent)	Before Exposure (in./in.)	After Exposure (in./in.)	Change (per cent)
Neoprene	Vacuum	80	24	+ 0.04	2288	2378	+ 3.9	0.515	0.525	+ 1.9
	Vacuum	80	96	- 0.14	2288	2306	+ 0.6	0.515	0.532	+ 3.3
	Vacuum	80	312	- 0.93	2286	2286	- 0.1	0.515	0.518	- 0.6
Vacuum and ultraviolet	Vacuum and ultraviolet	155	24	- 3.27	2288	2658	+ 16.2	0.515	0.518	- 16.9
	Vacuum and ultraviolet	155	96	- 5.93	2288	2566	+ 12.2	0.515	0.302	- 41.3
	Vacuum and ultraviolet	155	312	- 5.95	2288	2858	+ 25.0	0.515	0.305	- 35.0

* Values are averages of two specimens.

** Maximum vacuum pressure: on the order of 1×10^{-5} mm Hg.

Table B-33. EXPOSURE OF NEOPRENE VULCANIZATES TO HIGH VACUUM
AT VARIOUS TEMPERATURES (45)

Property Measured	Original Temperature	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature				Exposed to Vacuum of 2×10^{-6} mm Hg for 5 Days			
		100 F		212 F		300 F		300 F	
		Vacuum of 10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days
<u>Unlagged Compound (M72)</u>									
Tensile strength, psi	2490	2150	2170	2300	2460	2500	1860	--	--
Modulus, psi at 300 per cent elongation	2010	1950	2110	2030	2300	2060	--	--	--
Elongation, per cent	350	330	315	325	310	340	210	--	--
Hardness, Shore A	62	61	63	63	59	61	70	--	--
Strain, per cent elongation at 400 psi	119	122	123	113	109	94	70	--	--
Low temperature flexibility, ASTM D1043, T200, F	-27	-28	-29	-28	-28	--	-27	--	--
Weight change, per cent	--	+0.2	-0.9	--	-2.1	-1.0	-4.3	-14.7	--

Table B-33. (Continued)

Property Measured	Original Temperature	Exposed to Vacuum of 10 ⁻⁵ mm Hg for 56 Days at Room Temperature			158 F		212 F		300 F	
		Vacuum of 8 x 10 ⁻⁵ mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8 x 10 ⁻⁶ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2 x 10 ⁻⁶ mm Hg for 5 Days	Air Oven for 5 Days			
<u>Plasticized Compound (M23)</u>										
Tensile strength, psi	2010	2070	2110	2050	2120	2170	1660	Too brittle to test		
Modulus, psi at 300 per cent elongation	1100	1180	1220	1250	1710	1310	—	Too brittle to test	55	
Elongation, per cent	380	375	340	340	330	380	220	Too brittle to test		
Hardness, Shore A	52	54	59	55	60	50	63	Too brittle to test		
Strain, per cent elongation at 400 psi	173	180	160	187	137	116	100	Too brittle to test		
Low temperature flexibility, ASTM D1043, T ₂₀₀ F	-54	-44	-33	-54	—	—	-30	Too brittle to test		
Weight change, per cent	—	-4.7	-9.5	—	-8.0	-2.2	-8.6		-18.6	

Table B-34. EXPOSURE OF SBR VULCANIZATES TO HIGH VACUUM AT VARIOUS TEMPERATURES⁴⁵

Property Measured	Original Temperature	Exposed to Vacuum of 10 ⁻⁵				Compound Containing No Antiozonant (S119) ⁽¹⁾				Compound Containing Antiozonant (S119B) ⁽¹⁾			
		mm Hg for 56 Days at Room Temperature for 7 Days		Vacuum of 8 x 10 ⁻⁵ mm Hg for 7 Days		Air Oven for 7 Days		Vacuum of 7.8 x 10 ⁻⁶ mm Hg for 5 Days		Air Oven for 5 Days		Vacuum of 2.1 x 10 ⁻⁶ mm Hg for 5 Days	
		56 Days at Room Temperature for 7 Days	56 Days at Room Temperature for 7 Days	8 x 10 ⁻⁵ mm Hg for 7 Days	8 x 10 ⁻⁵ mm Hg for 7 Days	Air Oven for 7 Days	Air Oven for 7 Days	7.8 x 10 ⁻⁶ mm Hg for 5 Days	7.8 x 10 ⁻⁶ mm Hg for 5 Days	Air Oven for 5 Days	Air Oven for 5 Days	2.1 x 10 ⁻⁶ mm Hg for 5 Days	2.1 x 10 ⁻⁶ mm Hg for 5 Days
Tensile Strength, psi	3590	3440	3180	343	2980							2570	--
Modulus, psi at 300% E	1650	1780	2220	2040	--			--	--			--	--
Elongation, percent	530	490	380	430	390			320	390			220	--
Hardness, Shore A	67	67	70	70	74			73	74			75	--
Strain, percent E at 400 psi	120	116	92	--	154			169	154			65	--
Low Temperature Flexibility, ASTM D1043, T ₉₀ , F	-42	-41	-42	-38	--			--	--			-38	--
Ozone Resistance, time to first crack, 50 pphm, loop specimen	2 hrs	2 hrs	2 hrs	2 hrs	2 hrs			2 hrs	2 hrs			2 hrs	--
Weight Change, percent	--	-0.3	-1.4	--	-1.4			-1.4	-1.1			-3.1	-1.4
Compound Containing Antiozonant (S119B) ⁽¹⁾													
Tensile Strength, psi	3240	3040	3250	53.0	3370			3590	3370			2900	Too brittle to test
Modulus, psi at 300% E	1220	1380	1930	1650	2600			--	2600			--	Too brittle to test
Elongation, percent	605	540	480	540	400			410	400			260	Too brittle to test
Hardness, Shore A	65	66	68	68	75			62	75			76	Too brittle to test
Strain, percent E at 400 psi	141	148	122	--	89			92	89			66	Too brittle to test
Low Temperature Flexibility, ASTM D1043, T ₉₀ , F	-41	-39	-39	-37	--			--	--			-36	Too brittle to test
Ozone Resistance, time to first crack, 50 pphm, loop specimen	No cracks 90 days	2 hrs	1 day	1 day	2 hrs			2 hrs	2 hrs			2 hrs	Too brittle to test
Weight Change, percent	--	-0.9	-2.6	--	-2.8			-2.8	-1.1			-4.2	-2.1

(1) See Table A-1 for formulation.

Table B-35. CURE SCHEDULES OF THE POLYSULFIDES
USED IN THE IRRADIATION STUDIES⁴⁷

Compound	Curing Data	Recipe, Parts	
		Base Compound	Accelerator
146-62	MnO ₂ Cured	100	10
154-62	Dichromate Cured	7.5	1.0
155-62	Pb-peroxide Cured	100	10
167-62	MnO ₂ Cured	100	10

All compounds above were cured at room temperature for at least one week before exposure.

Table B-36. PHYSICAL PROPERTIES OF COMPOUND 146-6247
Base Elastomer - Polysulfide, Type MnO₂ Cured

Nominal Irradiated Condition	Can No.	Cure Days	Tensile		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A (% (1)		
As-cured		0	449		229		377		62		
2. γ, Vac. 100 hrs., 70 F	4	4.9 x 10 ⁷	352	-22	191	-33	287	-24	59	-3	-40
3. γ + UV, Vac. (2) 16 hrs., 190 F	12	6.4 x 10 ⁶	350	-22	191	-17	420	+11	61	-1	-22
4. γ + UV, Vac. (2) 100 hrs., 250 F	10	6.1 x 10 ⁷	241	-46	—	+163 (3)	40	-89	64	+2	-80
5. γ, Air 100 hrs., 70 F	8	4.1 x 10 ⁷	377	-24	198	-14	283	-25	59	+3	-6
6. γ + UV, Air (2) 100 hrs., 250 F	9	3 x 10 ⁷	295	-34	287	+25	130	-66	54	+2	-70
7. γ, Air 16 hrs., 70 F	3A	1.7 x 10 ⁶	378	-15	222	-3.0	443	+17	64	+2	-3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table 2-36. (Concluded)

Time effect: In combined radiation in vacuum, the tensile strength was not affected greatly by time. The 100 per cent modulus increased markedly, hardness increased slightly, and the ultimate elongation dropped markedly as exposure time increased. In straight gamma in air, the four physical properties did not vary significantly as exposure time increased.

Atmosphere effect: The compound apparently reacted about the same in vacuum and in air. All specimens lost weight, markedly so in the case of combined radiation.

Type irradiation effect: The combined radiation at 100 hours in air and vacuum showed cross-linking and the straight gamma radiation at 100 hours in air and vacuum showed scission.

Observations: Condition 2, slight darkening (brown cast). Condition 3, moderate darkening on face toward UV lamp--slight on back face. Condition 4, heavy blackening on face toward UV lamp--moderate on other face. Condition 5, moderate discoloration, (brown) occlusion in break. Condition 6, specimens were more heavily blackened on one end indicating uneven exposure--slight to moderate darkening on back faces. Condition 7, slight darkening (brown cast) soot on specimens.

Table B-37. PHYSICAL PROPERTIES OF COMPOUND 154-62⁴⁷
Base Elastomer - Polysulfide, Type - Dichromate Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation % Chg. (1)	Hardness Duro A Chg. (1)	Weight Change mg.	Rating
As-cured		0	387	329	160	74		
1. v, Vac. 16 hrs., 70 F	13	6.4×10^6	469	+ 21	+ 1.9	- 1	-13	4(5)
2. v, Vac. 100 hrs., 70 F	14	6.1×10^7	419	+ 8.3	- 4.4	- 2	-18	1(5)
3. v + UV, Vac. (2) 10 hrs., 95 F	15	5.7×10^6	155	-	+ 57(3)	- 9	-27	5
4. v, Vac. (4) 100 hrs., 70 F	16	5.0×10^7	399	+ 3.1	-19	- 2	- 2	2
5. v, Air 100 hrs., 70 F	17	6.1×10^7	423	+ 15	-10	- 4	-15	3
6. v + UV, Air (2) 100 hrs., 200 F	18	5.0×10^7	167	-	+ 54(3)	-14	-25	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

(5) The reasons for the apparently reversed ratings are discussed in the st section of Part C, Phase III, Reference 47.

Table B-17 (Concluded)

Time effect: In vacuum and straight gamma radiation the physical properties were not markedly affected by time with the exception of the tensile strength which was affected to some degree. The initial increase in modulus, followed by decreasing values (from the initial increase), would indicate an initial period of cross-linking, followed by predominant scission.

Atmosphere effect: There was slightly greater reaction caused by radiation in air than in vacuo. All specimens lost weight and the weight loss was greater in the case of combined scission.

Type irradiation effect: All four physical properties are markedly affected. The observations made in the case of irradiation Condition 6 could explain the sharp decrease of elongation and sharp increase of 100 per cent modulus as follows: the compound was probably decomposed by the high temperature giving gas formation and charring which rendered the specimen weak. Irradiation effects of most conditions indicated scission.

Observations: Condition 3, marked darkening on both faces. Condition 6, heavy blackening on face toward UV lamp. Moderate discoloration on other face. Some swelling on face toward UV lamp. Hardness 55 on one end and 65 on the other end of specimens.

Table B-38. PHYSICAL PROPERTIES OF COMPOUND 155-6247
Base Elastomer - Polysulfide, Type - Lead Peroxide Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus psi	Ultimate Elongation		Hardness Duro A	Weight Change mg.	Rating
			Strength psi	% Chg. (1)		% Chg. (1)	% Chg. (1)			
As-cured		0	412		108		520	55		
1. Y, Vac. 16 hrs., 70 F	13	6.4×10^5	312	-24	133	-21	510	-1.9	-3	1
2. Y, Vac. 100 hrs., 70 F	14	6.1×10^7	298	-28	131	-22	363	-30	-3	3
3. Y + UV, Vac. ⁽²⁾ 16 hrs., 95 F	15	5.7×10^6	101	-76	—	+501(3)	10	-98	-3	4
4. Y, Vac. ⁽⁴⁾ 100 hrs., 70 F	16	5.0×10^7	302	-27	154	-8.2	310	-40	M11	2
5. Y, Air 100 hrs., 70 F	17	5.1×10^7	291	-29	155	-7.7	303	-42	-1	3
6. Y + UV, Air ⁽²⁾ 100 hrs., 200 F	18	5.3×10^7	—	—	—	—	—	—	—	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation and temperature.

Table B-38. (Concluded)

Time effect: In Conditions 1 and 2 the over-all physical properties were not affected greatly by time. Both conditions indicated scission.

Atmosphere effect: Straight gamma radiation 100 hours showed no appreciable changes in physical properties. All specimens lost weight and in the one case of combined radiation where the specimens were weighable, the loss was quite marked.

Time irradiation effect: The combined radiations, with elevated temperatures, weakened the compound which apparently underwent scission. Straight gamma also showed scission but no temperature effect.

Observations: Condition 1, slight greying on specimens. Less residual "set" after tensile test than unaged. Condition 2, moderate greying of specimens. Still less residual set after tensile test. Condition 3, specimens blushed and shriveled. Condition 4, bleaching of specimens. Condition 5, specimens markedly "greyed". Condition 6, specimens decomposed and charred.

Table B-39. PHYSICAL PROPERTIES OF COMPOUND 167-5247
Base Elastomer - Polysulfide, Type - MnO₂ Cured

Nominal Irradiated Condition	Can No.	Comm. Dose r.	Tensile Strength psi % Chg. (1)	100 % Modulus psi % Chg. (1)	Ultimate Elongation % % Chg. (1)	Hardness Duro A Chg. (1)	Weight Change %	Rating
As-cured		0	479	184	483	59		
1. γ, Vac. 16 hrs., 70 F	13	6.4 x 10 ⁶	453	- 3.3	200 + 8.9	490 + 1.5	57 -2	- 6 1
2. γ, Vac. 100 hrs., 70 F	14	6.1 x 10 ⁷	406	-15	148 - 29	520 + 7.7	54 -5	- 5 2
3. γ + UV, Vac. (2) 16 hrs., 95 F	15	2.7 x 10 ⁶	335	-30	153 - 17	365 -25	58 -1	-15 5
4. γ, Vac. (4) 100 hrs., 70 F	16	5.0 x 10 ⁷	360	-25	142 - 23	493 + 2.1	54 -5	-22 3
5. γ, Air 100 hrs., 70 F	17	6.1 x 10 ⁷	409	-15	145 - 22	583 +21	55 -4	- 1 4
6. γ + UV, Air 100 hrs., 200 F	18	5.0 x 10 ⁷	153	-68	-- +748(3)	10 -99	60 +1	-86 6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-39. (Concluded)

Time effect: Time in Conditions 1 and 2 did not affect appreciably the physical properties.

Atmosphere effect: Conditions 2 and 5 showed no marked change in physical properties.
All specimens lost weight, more so in the case of the combined radiations.

Type irradiation effect: Conditions 5 and 6 underwent scission, but apparently the data for Condition 6 were mainly affected by the high temperature. Conditions 3 and 1 indicated scission and combined radiation, with the high temperature. Conditions 3 and 1 indicated scission and combined radiation, with the help of a high temperature, weakened the compound even further as indicated by a marked decrease of the tensile strength, 100 per cent modulus, and elongation.

Observations: Condition 2, specimens bonded to case and to one another. Condition 3, smoky brown discoloration on face of specimen. Condition 6, surface browning and hardening, large amount of blistering on two specimens.

TABLE B-40. ELASTOMERS - TENSILE PROPERTIES(a) OF THIOKOL ST
VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N), n cm ⁻² (b) (E > 2.9 Mev)(b) Gamma Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Modulus (c), psi				Ultimate (c), psi	Ultimate Elongation (c), %
		At 25%		At 50%			
		Elongation		Elongation			
Control	1	131/15	/4	193/10	/7	142/6.2/7	281/ 6.6/7
	3	144/	7.5/8	204/	6.5/8	916/2.4/8	275/ 5.7/8
	10	132/	4.9/9	183/	7.8/9	800/7.3/9	313/21 /9
	34	141/	7 /10	210/	/10	825/9.3/10	265/13 /10
N 1.5 x 10 ¹⁵ G 1.1 x 10 ¹⁹	1	95/12	/5	157/12	/5	472/8.6/5	138/ 7.7/5
	3	120/14	/5	186/18	/5	498/3.6/5	146/11 /5
	10	143/	7.9/5	245/	8.3/5	508/1.3/5	123/13 /5
	4	147/	7.2/5	231/	9.8/5	624/6.1/5	138/ 7.7/5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-41. ELASTOMERS - TENSILE PROPERTIES(a) OF PU 3109B AND PU 6865
VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N), n cm ⁻² (E > 2.9 Mev)(b) Gamma Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Modulus (c), psi				Ultimate (c), psi	Ultimate Elongation (c), %
		At 25%		At 50%			
		Elongation		Elongation			
PU-3109B							
Control	1	890/10 /4		1107/5.4/4	1414/12 /4	4296/3.9/4	460/11 /4
	3	944/2.8/8		1199/2.8/8	1550/1.7/8	4276/6.8/8	463/1.8/8
	10	1013/4.5/7		1278/4.5/7	1625/4.3/7	5016/13 /7	450/8.2/7
	34	983/4.4/8		1200/5.4/8	1459/7 /8	4745/12 /8	434/6.4/8
N 4.7 x 10 ¹⁵ G 2.10 x 10 ¹⁰	2	1220/12 /5		1598/3.4/5	2624/9.6/5	3221/4.9/5	145/21 /5
	3	1409/11 /5		1957/4.1/5	2910/6.3/5	3390/12 /5	125/19 /5
	10	1775/4.2/5		2415/11 /5	3344/24 /5	3529/13 /5	106/59 /5
	34	1300/6.1/5		1870/4 /5	2823/3.8/5	3325/2.8/5	123/9.5/5
PU 6865							
Control	1	229/15 /8		358/5.7/8	708/2.9/8	7739/8.5/8	616/5.7/8
	3	267/8.6/6		434/5.3/6	754/6 /6	7365/7.1/6	669/3.4/6
	10	270/13 /7		470/4.6/7	762/2.9/7	6955/12 /7	666/3.8/7
	34	253/25 /7		409/13 /7	638/3.4/7	7222/5.3/7	
N 3.4 x 10 ¹⁵ G.2.2 x 10 ¹⁰	1	309/16 /5		744/25 /5		922/18 /5	39/26 /5
	3	343/5.2/3		858/12 /3		963/8.8/3	58/26 /3
	10	315/8 /5		759/14 /5		973/10 /5	57/5.7/5
	34	320/27 /5		756/13 /5		899/	56/18 /5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-42. ELASTOMERS - TENSILE PROPERTIES(a) OF PU-GENTHANE-S
VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N) n cm ⁻² (E > 2.9 Mev)(b)	Gamma Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	Modulus (c), psi			Ultimate Elongation (c), psi	Ultimate Elongation (c), %
			At 25%		At 100%		
			Elongation	Elongation			
Control		1	108 / 3	163 / 3	345/5.6/8	2499/15 /8	457/8.7/8
		3	106/3.9/5	148/8.2/5	309/11 /5	2476/11 /5	486/6.7/5
		10	98/12 /7	147/11 /7	297/12 /7	2463/9.1/7	490/9.1/7
		34	101/9.5/8	151/7.9/8	298/6.4/8	2360/4 /8	468/3.6/8
N 5.7 x 10 ¹⁵							
G 3.7 x 10 ¹⁰							
		1	136/36 /2	380/38 /2		495/8 /4	55/28 /4
		3	92/38 /5	246/26 /5		432/16 /5	61/9.3/5
		10	116/14 /5	287/15 /5		463/18 /5	69/12 /5
		4	88/30 /4	264/5 /4		386/13 /4	63/12 /4

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-43. ELASTOMERS - TENSILE PROPERTIES^(a) OF PU-4250
VERSUS POSTIRRADIATION STORAGE TIME⁽⁴⁸⁾

Integrated Neutron Flux (N), $n\text{ cm}^{-2}$ ($E > 2.9\text{ Mev}$)(b) Gamma Exposure (G), ergs g^{-1} (C)(b)	Days Tested After Irradiation	Modulus (c), psi		At 100% Elongation	Ultimate (c), psi	Ultimate Elongation (c), %
		At 25% Elongation	At 50% Elongation			
Control	1	1184/3.1/5	1397/3.6/5	1835/2.7/5	5251/5.5/5	583/6.8/5
	3	1219/1.5/5	1536/3.6/5	1945/3.8/5	4657/5.4/5	478/3.4/5
	10	1125/9.1/8	1479/4.1/8	1922/1.6/8	4575/3.6/8	549/2.8/8
	34	1088/17/8	1450/4.1/8	1775/3.5/8	4638/10/8	583/4.7/8
N 3.4×10^{15}						
G 2.2×10^{10}	1	1241/3/5	1904/11/5		2689/1.9/5	84/22/5
	3	1466/8.3/5	2233/8.3/5		2814/8.4/5	77/25/5
	10	1226/7.4/5	2227/6.7/5		2764/5.9/5	79/21/5
	34	1489/14/5	2066/13/5		2574/3.9/5	77/14/5

(a) Data are given as $\bar{x}/\text{S.D.}/n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from: the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-44. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF DUPONT ADIPRENE L
VERSUS TEMPERATURE AND LINE DILATION(48)

Integrated Neutron Flux (N), $n\text{ cm}^{-2}$ ($E > 2.9\text{ Mev}$) Gamma Exposure (G), $\text{ergs g}^{-1}\text{ (C)(b)}$	Irradiation Temp, F	Modulus(b), psi		Ultimate(b), psi	Ultimate Elongation(b), %
		At 100% Elongation	At 200% Elongation		
Control	80	970/4.3/10	1416/3.1/10	4065/8.4/10	433/13 /10
N 2.5×10^{13} G 5.2×10^7	175	1030/1.3/5	1460/2.4/5	4251/23 /5	404/2.2/5
N 2.9×10^{13} G 6×10^7	75	1013/2 /5	1432/5.1/3	4869/6.8/3	420/4.6/4
N 3.9×10^{13} G 6.5×10^7	-45	1028/2.6/5	1432/1.5/5	4661/8.9/4	433/4.5/4
N 1×10^{16} G 1.4×10^{10}	75			1562/6.3/4	142/6.9/4
Control	80 60	1282/1.7/10 1182/1.5/10	1798/2.8/10 1623/1.8/10	5346/6.3/9 5542/8.1/10	390/1.7/9 420/3.1/10
N 1.2×10^{15} G 2×10^9	80	1263/4.3/5	1831/2.5/5	5055/10 /3	393/8.2/5
N 1.8×10^{15} G 5.4×10^9	260	921/5.7/4	1214/4 /4	1513/1.6/5	299/8.6/5
N 4.5×10^{16} G 7×10^{10}	80			1679/21 /5	75/26 /5

(a) Data are given as $\bar{x}/\text{S.D.}/n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(b) Test temperature 80 F.

TABLE B-45. POLYURETHANE RUFFERS - TENSILE PROPERTIES^(a) OF DUPONT L-187
VERSUS TEMPERATURE AND RADIATION^(b)

Integrated Neutron Flux (N), $n\text{ cm}^{-2}$ ($E > 0.33\text{ Mev}$) Gamma Exposure (G), $\text{ergs g}^{-1}\text{ (C)}$	Irradiation Temp, F	DuPont L-187(a)(b)				DuPont L-187(b)(b)			
		Modulus, psi		Ultimate, psi	Ultimate Elongation, %	Modulus, psi		Ultimate, psi	Ultimate Elongation, %
		At 100% Elongation	At 200% Elongation			At 100% Elongation	At 200% Elongation		
Control	80	1777/2.9/10	2514/2.6/10	5414/7.5/10	348/4.8/9	233/6.2/8	300/7.4/9	1825/12/7	584/4.4/7
N 2.5×10^{13} G 5.2×10^7	175	1713/4.6/5	2534/2.3/5	6492/10/5	360/3.6/5	248/15/3	348/15/3	1596/23/3	550/14/3
N 2.9×10^{13} G 8×10^7	75	1685/5.7/5	2560/1.8/5	6433/3.2/5	336/2.6/5	231/1.9/4	312/7.2/4	2804/85/4	527/7.9/3
N 3.9×10^{13} G 6.5×10^7	-45	1793/5.5/5	2680/4.9/5	5688/14/5	366/5.9/5	257/28/5	284/22/3	1140/39/4	527/7.9/3
N 1×10^{16} G 1.4×10^{10}	75	2054/4.4/4		3331/16/4	217/8.2/3	120/1.2/4	196/15/4	579/18/5	383/14/5
Control	80	2085/1.5/10	3014/3/9	5949/8.3/9	328/4.1/9	252/10/10	343/11/10	1002/7/7	455/7.4/7
	260	2080/2.3/10	2903/2.2/10	6013/11/10	358/5/10	219/8.5/10	303/8.9/10	1361/13/10	493/7.2/10
N 1.2×10^{15} G 2×10^9	80	2131/0.2/5	3197/1.6/5	4857/9.3/5	290/8/5	213/4/5	305/12/5	1899/7/4	480/6.8/4
N 1.8×10^{15} G 5.4×10^9	260	1766/1/5	2160/2.5/5	3111/3.4/5	326/6.3/5	120/6.4/5	173/9.7/5	575/18/4	465/2.6/4
N 4.5×10^{16} G 7×10^{10}	80			2850/6.3/4	63/7.6/4			604/9.4/5	69/9.4/5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observations estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-16. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF DISOGRIN 3DSA 8050 AND 3DSA 9047 VERSUS TEMPERATURE AND IRRADIATION DOSE

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev)	Gamma Exposure (G) ergs g ⁻¹ (C)	Irradiation Temp. F	Disogrin 3DSA 8050(b)				Disogrin 3DSA 9045(b)			
			Modulus, psi		Ultimate Elongation, %		Modulus, psi		Ultimate Elongation, %	
			At 100% Elongation	At 200% Elongation	Ultimate		At 100% Elongation	At 200% Elongation	Ultimate	
Control		80	625/4.9/9	876/6.1/8	5759/11.4/10	588/3.3/10	1446/3.8/9	1790/4.2/3	3597/15 /10	6 3/9.2/8
N 2.5 x 10 ¹³										
G 5.2 x 10 ¹		175	602/6.3/5	852/5.4/5	5129/10 /5	652/3.3/5	1475/4.3/5	1834/4.2/4	3384/8.2/5	678/5.7/5
N 2.9 x 10 ¹³										
G 6 x 10 ⁷		75	629/4.3/4	888/4.1/4	5703/3.8/4	580/6.1/3	1838/13 /5	2058/8.7/5	4058/12 /5	632/2.7/5
N 3.9 x 10 ¹³										
G 6.5 x 10 ⁷		-45	573/4.1/5	822/1.3/4	5822/6.3/5	614/2.1/5	1398/3.1/5	1832/2.7/5	3872/7.7/5	632/2.7/5
N 1 x 10 ¹⁶										
G 1.4 x 10 ¹⁰		75	719/8.8/4	1094/9.9/4	2088/10 /4	333/12 /4	1454/8 /5	1596/7.7/5	130/9.9/5	
Control		80	632/2.3/10	890/2.2/10			1504/2.2/10	1963/3.8/10	3407/7.2/10	598/6.5/10
N 5.3 x 10 ¹⁵		280	621/3.9/10	882/5.1/10			1344/2.8/10	1703/3.8/10	2928/6.7/10	616/3.4/10
G 1.3 x 10 ¹⁰										
N 2.7 x 10 ¹⁵		-65	641/2.4/5	838/2.2/4	2881/11 /3	682/2.2/3	1416/5.3/2	1565/ /1	1541/6.9/5	293/31 /4
G 1.5 x 10 ¹⁰										
N 8.5 x 10 ¹⁵		80	72 /3.3/5	1130/2.2/5	2537/4.9/4	375/1.3/4	1529/1.2/5	1698/6.2/5	1929/5.8/3	348/4.2/3
G 1.9 x 10 ¹⁰										
N 4.5 x 10 ¹⁶		280					1435/13 /5	1688/4.7/3	2071/15 /4	313/3.8/3
G 7 x 10 ¹⁰										
		80			1075/12 /5	11/15 /5			172/11 /4	49/20 /4

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-47. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF DISOGRIN 2DSA 8445 AND 2DSA 9840
VERSUS TEMPERATURE AND IRRADIATION (b)

Integrated Neutron Flux (N) n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp. F	Disogrin 2DSA 8445(b)				Disogrin 2DSA 9840(b)			
		Modulus, psi		Ultimate Elongation, %		Modulus, psi		Ultimate Elongation, %	
		At 100% Elongation	At 200% Elongation	Ultimate, psi		At 100% Elongation	At 200% Elongation	Ultimate, psi	
Control	80	604/2.1/10	844/3.2/10	5418/2.8/10	586/3.5/3	1494/8.3/10	1876/7.2/10	5477/9	582/7.8/10
N 2.5 x 10 ¹³ G 5.2 x 10 ⁷	175	576/2.8/5	852/3.2/5	5505/7.5/4	585/3.4/5	1415/7.1/5	1788/6.9/5	5489/5.1/5	542/6.4/5
N 2.9 x 10 ¹³ G 6 x 10 ⁷	75	625/3 /5	862/3.9/5	5571/6.3/5	582/6.1/5	1493/8.4/5	1842/3.6/5	5751/12 /5	568/8.6/4
N 3.9 x 10 ¹³ G 6.5 x 10 ⁷	-45	534/3.1/5	836/2.3/5	5198/3.8/5	564/5.3/5	1406/8.2/5	1794/9.6/5	5632/13/5	574/3.7/5
N 1.7 x 10 ¹³ G 1.4 x 10 ¹⁰	75	808/5 /4	852/25 /3	1951/8.3/4	341/2.9/4	1637/7.6/5	1904/7.4/5	3274/18 /5	394/9.8/5
Control	280	952/4.2/10 589/1.4/10	915/3.5/10 786/3.3/10	5082/ /1	645/3.7/7 555/ /1	1558/5.1/10 1535/5.1/10	1905/3.4/10 1898/4.8/9	5661/15 /9 5917/7.3/10	563/4.2/9 599/6.5/3
N 5.3 x 10 ¹⁵ G 1.3 x 10 ¹⁰	-65	655/8.3/5	832/8 /5	2907/9.3/5	672/7.7/5	1502/13 /5	1728/15 /5	3205/17 /5	616/7.7/5
N 6.7 x 10 ¹⁵ G 1.5 x 10 ¹⁰	80	745/4.2/4	1053/3 /4	2825/22 /5	377/8.6/5	1859/3.7/4	2212/4.5/4	3418/11 /5	346/7.5/5
N 8.5 x 10 ¹⁵ G 1.9 x 10 ¹⁰	280					1627/22 /5		2524/17 /4	330/14 /5
N 4.5 x 10 ¹⁶ G 7 x 10 ¹⁰	80			1050/35 /5	1000 /5			2585/12 /5	56/7.7/5

(a) Data are given as $\bar{x}/s.d./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 60 F.

TABLE B-48. POLYURETHANE RUBBERS - TENSILE PROPERTIES^(a) OF DISOGRIN IDSA 7560 AND IDSA 9250
VERSUS TEMPERATURE AND IRRADIATION^(b)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp. F	Disogrin IDSA 7560(b)				Disogrin IDSA 9250(b)			
		Modulus, psi		Ultimate Elongation, %		Modulus, psi		Ultimate Elongation, %	
		At 100% Elongation	At 200% Elongation	Ultimate, psi		At 100% Elongation	At 200% Elongation	Ultimate, psi	
Control	80	548/3.1/9	826/12 /2	4743/8.5/9	599/4.3/9	1781/4.3/9	2446/4.4/10	4646/9.1/10	538/8.5/10
N 2.5 x 10 ¹³ G 5.2 x 10 ⁷	175	463/3.6/4	826/6.4/5	4743/9.7/2	715/1.2/2	1735/2.7/5	2478/2.4/5	4691/10 /5	556/15 /5
N 2.9 x 10 ¹³ G 6 x 10 ⁷	75	483/16 /5	820/5.2/5	5292/7.5/2	670/ /1	1734/3.5/5	2384/2.6/5	4809/8.9/4	533/4.6/4
N 3.9 x 10 ¹³ G 6.5 x 10 ⁷	-45	546.7/6/5	820/6 /5	4327/20 /5	670/9 /5	1780/4.5/5	2470/26 /5	4621/8.3/5	566/14 /5
N 1 x 10 ¹⁵ G 1.4 x 10 ¹⁰	75	745/6.7/5		1133/4.2/5	178/7.3/5	2074/2.4/5		2384/3 /5	178/2.4/5
Control	80	523/5.8/10	884/6.1/10	5254/11 /7	718/3.4/10	1891/3 /10	2484/6 /10	5544/13 /10	573/3.9/10
	260	459/4.5/10	776/7.6/10			1804/3 /10	2441/2.7/10	4585/12 /9	586/3.6/9
N 5.3 x 10 ¹⁵ G 1.3 x 10 ¹⁰	-65	674/8.2/5	921/6.2/5	2477/9.8/5	677/5.7/5	1745/3 /5	2105/3.8/5	2969/14 /4	503/5.1/5
N 6.7 x 10 ¹⁵ G 1.5 x 10 ¹⁰	80	1166/17 /2	1415/ /1	1541/13 /5	257/31 /3			2936/7.5/5	164/1.3/5
N 8.5 x 10 ¹⁵ G 1.9 x 10 ¹⁰	260	466/5.3/4		1474/15 /4	362/3.4/4	1773/4.9/5		2285/5.6/5	247/11 /5
N 4.5 x 10 ¹⁶ G 7 x 10 ¹⁰	80			850/12 /5	55/18 /5			2426/14 /5	27/32 /5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Test temperature 80 F.

TABLE B-49. POLYURETHANE RUBBERS - TENSILE PROPERTIES^(a) OF GENERAL TIRE POLYURETHANE TYPE R AND DISOGRIN IDSA 6865 VERSUS TEMPERATURE AND RADIATION^(b)

Integrated Neutron Flux (N), a cm ⁻² (E > 0.33 Mev)	Irradiation Temp. F	Gamma Exposure (G), ergs g ⁻¹ (C)	General Tire Polyurethane Type R ^(c)				Disogrin IDSA 6865 ^(b)			
			Modulus, psi		Elongation, %		Modulus, psi		Elongation, %	
			At 100% Elongation	At 200% Elongation	Ultimate, psi	Ultimate, %	At 100% Elongation	At 200% Elongation	Ultimate, psi	Ultimate, %
Control	80		301/6.6/10	700/9.5/10	3900/15 /10	557/7.6/10	673/5 /10	1134/7.4/10	5198/19 /9	704/2.4/9
N 2.5 x 10 ¹³ G 5.2 x 10 ⁷	175		317/2.9/5	718/6.6/5	3523/8.1/5	522/4.1/5	658/9.9/5	1078/3.4/5	5216/ /1	
N 2.9 x 10 ¹³ G 6 x 10 ⁷	75		338/9.9/5	734/11 /5	3982/6.2/5	532/3.1/5	711/7.7/5	1190/5.2/5	5931/4.2/5	666/3.2/5
N 3.9 x 10 ¹³ G 6.5 x 10 ⁷	-45		319/5.9/5	744/3.2/5	3469/20 /5	528/13 /5	669/4.8/5	1166/9.4/5	5056/15 /5	708/3.4/5
N 1 x 10 ¹⁶ G 1.4 x 10 ¹⁰	75		293/8.2/5	880/6.4/5	1187/10 /5	258/2.4/3	770/7.5/5	1344/11 /5	1344/11 /5	914/10 /5
Control	80		313/6.2/10	736/3.8/10	4102/7 /10	596/4.4/10	683/8.7/10	1115/9.1/10	4989/7 /6	685/4.3/5
	260		242/11 /8	727/9.3/10	4160/7.9/10	609/6.4/10	862/5 /10	1090/3.2/10	4345/18 /7	816/9.6/5
N 5.3 x 10 ¹⁵ G 1.3 x 10 ¹⁰	-65		190/5.4/5	462/5.4/5	1741/5.6/5	468/18 /5	773/8.1/5	1132/4.1/5	2896/13 /5	588/8.4/5
N 6.7 x 10 ¹⁵ G 1.5 x 10 ¹⁰			472/9.7/5		1265/18 /5	274/3.6/4	1158/7.1/2		1410/4.5/5	140/9.2/5
N 8.5 x 10 ¹⁵ G 1.9 x 10 ¹⁰	260		571/8.1/5		992/16 /5	139/17 /5	572/5 7/5	884/8.1/4	1260/6.2/5	278/3.9/5
N 4.5 x 10 ¹⁶ G 7 x 10 ¹⁰	80				890/7.8/5	87/4/5			830/13 /5	36/24 /5

(a) Data are given as $\bar{x}$ /S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Test temperature 80 F.

TABLE B-50. POLYURETHANE RUBBERS - TENSILE PROPERTIES^(a) OF GENTHANE S-1 AND S-2 VERSUS TEMPERATURE AND RADIATION⁽⁴⁸⁾

Integrated Neutron Flux (N), $n \text{ cm}^{-2}$ ($E > 0.33 \text{ Mev}$) Gamma Exposure (G), $\text{ergs g}^{-1} \text{ (C)}$	Irradiation Temp, F	Gentane S-1(b)				Gentane S-2(b)			
		Modulus, psi		Ultimate Elongation, %		Modulus, psi		Ultimate Elongation, %	
		At 100% Elongation	At 200% Elongation	At 100% Elongation	At 200% Elongation	At 100% Elongation	At 200% Elongation	At 100% Elongation	At 200% Elongation
Control	80	329/11 / 10	810/6.3/10	5740/4 / 10	557/2.9/10	325/17 / 0	900/6.6/10	3109/6.4/10	537/4.8/10
N 2.5×10^{13} G 5.2×10^7	175	320/11 / 4	876/5.5/5	5470/6.4/5	550/6.2/4	303/8.4/5	970/6.4/5	2845/6.1/5	528/4.1/5
N 2.9×10^{13} G 6×10^7	75	315/4 / 4	770/9.5/5	5637/16 / 5	544/8.7/5	300/8.5/5	840/5 / 5	3230/7.3/5	554/3.4/5
N 3.9×10^{13} G 6.5×10^7	-45	327/5 / 5	816/4.8/5	5588/1.8/4	565/13 / 4	338/4.8/5	936/9.5/5	3023/3.7/5	578/11 / 5
N 1×10^{16} G 1.4×10^{10}	75	251/19 / 4	800/10 / 4	1830/4.1/4	320/3 / 4	228/6.5/4	546/9.3/4	748/7.9/4	
Control	80	330/5.7/10	818/4.2/10	5564/7.4/10	589/5 / 10	278/9.4/10	813/5.9/10	2932/5.7/10	598/6 / 10
	260	294/8.1/10	862/2.8/10	5637/4.4/10	614/2.7/10	263/8.8/10	848/5.9/10	3008/4.3/10	622/3.4/10
N 5.3×10^{15} G 1.3×10^{10}	-65	192/7.4/4	640/6.9/4	2234/14 / 5	406/11 / 5	305/11 / 5	858/4.6/5	1571/1.6/5	359/8.1/4
N 6.7×10^{15} G 1.5×10^{10}	80	4 / 6.5/5		1736/16 / 5	216/8 / 5	307/2.9/5		1068/1.4/5	256/6.7/5
N 8.5×10^{15} G 1.9×10^{10}	260	628/6.3/5		1218/14 / 5	138/7.2/4	445/10 / 5		888/12 / 4	165/10 / 4
N 4.5×10^{16} G 7×10^{10}	80			906/14 / 5	26/9.4/5			692/9.8/5	25/17 / 5

(a) Data are given as $\bar{x}/\text{S.D.}/n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

Table B-51. PHYSICAL PROPERTIES OF WYJOUND 160-62⁴⁷
Base Elastomer - Polyurethane

Radical Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Elongation % Chg.(1)	Modulus psi	Modulus Elongation % Chg.(1)	Ultimate Tensile Strength psi	Ultimate Elongation % Chg.(1)	Hardness Duro A Chg.(1)	Weight Change mg. Rating
As-cured		0	2084		335		660		68	
1. γ , Vac. 16 hrs., 70 F	13	6.4×10^6	996	-52	373	+12	427	-35	73	+5
2. γ , Vac. 100 hrs., 70 F	14	6.1×10^7	820	-61	365	+9	340	-48	71	+3
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	640 118	-69 -94	350 51	+4.5 -85	290 350	-56 -46	70 70	+2 +2
4. γ , Vac.(3) 100 hrs., 70 F	16	5.0×10^7	764	-63	328	-2.1	333	-50	72	+4
5. γ , Air 100 hrs., 70 F	17	6.1×10^7	1012	-51	344	+2.7	390	-41	70	+2
6. γ + UV, Air(2) 100 hrs., 250 F	18	5.7×10^7	--	--	--	--	--	--	73	+5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Combined radiation intended

Table B-51. (Concluded)

Time effect: The samples underwent an initial cross-linking period after which chain scission was more predominant (Condition 1 vs. 2).

Atmosphere effect: The difference between air and vacuo irradiation appeared very small. The weight changes were also small, in view of the extensive degradation of some of the specimens.

Type irradiation effect: The effect of combined radiation was very greatly masked by the effect of the heat accompanying the desired ultraviolet radiation.

Observations: Condition 3, one specimen (upper) was covered with an iridescent discoloration on face toward UV lamp. Two specimens (lower) appeared to have partially melted and rehardened on that face. Condition 6, iridescent discoloration glazed surface with fine cracks on face toward UV lamp. All irradiated specimens exhibited a slight "tacky" condition on their edges and the broken ends.

Table B-62. EXPOSURE OF POLYURETHANE VULCANIZATE (Z72)¹ TO HIGH VACUUM
AT VARIOUS TEMPERATURES^{4,5}

Property Measured	Original Temperature	Exposed to			Vacuum of			Vacuum of		
		158 F			212 F			300 F		
		Vacuum of 10 ⁻⁵ mm Hg for 56 Days at Room Temperature			Vacuum of 7.8 x 10 ⁻⁶ mm Hg for 5 Days			Vacuum of 2.1 x 10 ⁻⁶ mm Hg for 5 Days		
		Air Oven for 7 Days			Air Oven for 5 Days			Air Oven for 5 Days		
Tensile strength, psi		3250	3370	3470	3100	3360	3250	3540	1220	
Modulus, psi at 300 per cent elongation		715	760	950	760	925	810	1960	945	
Elongation, per cent		715	675	650	625	615	710	385	350	
Hardness, Shore A		56	60	62	58	58	58	80	56	
Strain, per cent elongation at 400 psi		219	205	188	214	195	175	89	160	
Low temperature flexibility, ASTM D1043, 200° F		-40	-38	-38	-37	—	—	-28	—	
Weight change, per cent		—	-0.4	-1.9	—	-2.1	-1.5	-2.7	-2.0	

Parts by Weight

Compounding Ingredient

Genthan S	100
Stearic Acid	0.2
Magnesium Oxide	4
DiCup 40 C	4
MAF Carbon Black	30
	138.2

Magnesium Oxide	4
DiCup 40 C	4
MAF Carbon Black	30
	138.2

TABLE B-53. FLUID SOAK IRRADIATION - EFFECTS ON TENSILE PROPERTIES^(a) OF GENTHANE S-1 AND BUTADIENE-ACRYLONITRILE⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (E > 0.35 Mcv) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp, F	MIL-L-7808(b)		4F3E(b)		Oronite 8515(b)	
		Modulus at 100% Elongation, psi	Ultimate, psi	Modulus at 50% Elongation, psi	Ultimate, psi	Modulus at 100% Elongation, psi	Ultimate, psi
<u>Gentane S-1 (Polyurethane)(c)</u>							
Control(d)							
N 1.2-1.6 x 10 ¹⁴ G 3.0-3.3 x 10 ⁸	80	131/4 /5	2616/12/5	176/9.8/5	2122/4.5/5		
N 1.3-1.4 x 10 ¹⁵ G 2.1-2.2 x 10 ⁹	80					217/4 /5	3598/16 /5
N 1.1 x 10 ¹⁵ G 2.8 x 10 ⁹	80			82/11/5	1988/15 /4		
<u>Nitrile (Butadiene-Acrylonitrile)(c)</u>							
Control(d)							
N 1.1-1.6 x 10 ¹⁴ G 3.0-3.3 x 10 ⁸	80	257/21/5	3110/12/4	273/10 /5	1570/22 /4	464/11/5	2946/15 /5
N 1.3-1.4 x 10 ¹⁵ G 2.1-2.2 x 10 ⁹	80					598/14/5	2562/7.3/5
N 1.1 x 10 ¹⁵ G 2.8 x 10 ⁹	80			186/17/5	2036/14 /5		
N 9.3 x 10 ¹⁵ G 1.3 x 10 ¹⁰	350					559/15 /5	

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Immersion media.

(c) Test temperature 80 F.

(d) Control data lost.

TABLE 3-56. FLUID SOAK IRRADIATION - KIRK HILL MIL-R-68855 AND DU PONT LD-234(48)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp, F	Kirkhill MIL-R-68855(b)				Du Pont LD-234(b)	
		MIL-L-7808(C)		4P3E(C)		4P3E(C)	
		Modulus at 100% Elongation, psi	Ultimate, psi	Modulus at 50% Elongation, psi	Modulus at 100% Elongation, psi	Modulus at 100% Elongation, psi	Ultimate, psi
Control(d)							
N 1.2-1.6 x 10 ¹⁴ G 3.0-3.3 x 10 ⁸	80	445/2.5/5	1008/7.5/5		534/20/4	1225/5.7/4	
N 1.3-1.4 x 10 ¹⁵ G 2.1-2.2 x 10 ⁹	80 350				223/20/5	791/2/6	183/8.6/6
N 1. x 10 ¹⁵ G 2.8 x 10 ⁹	80			88/12/5		425/9.7/4	

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

(d) Control data not reported.

TABLE E-57. SILICONE RUBBERS - TENSILE PROPERTIES OF DC-80 VERSUS TEMPERATURE AND RADIATION(48)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation and Storage Temp. F	DC-80 (Methyl Vinyl)					
		-65 F(°)			80 F(°)		
		Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate, psi	Modulus at 50% Elongation, psi	Ultimate, psi	Modulus at 50% Elongation, psi
Control	-65	417/4.3/5	1303/5.5/5	1155/8.8/5	303/2.8/5	369/8.8/4	300 F(°)
	80			1057/8.7/5	321/5.0/5	317/10 /5	Ultimate, psi
	350			1209/3.4/5		325/3 5/5	286/11 /8
N 8.2 x 10 ¹³ G 8 x 10 ⁷	-65	410/4 /5	1288/13 /5				555/15 /5
	80						
	350						
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ³	-65						
	80						
	350						
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	-65						
	80						
	350						
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65						
	80						
	350						
N 1.0-1.3 x 10 ¹⁵ G 1.5/1.7 x 10 ⁹	-65						
	80						
	350						

(a) Data are given as $\bar{x}/s.d./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature.

TABLE B-58. SILICONE RUBBERS - TENSILE PROPERTIES(a) AT -65, -50, -35, -20, -5, 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180, 195, 210, 225, 240, 255, 270, 285, 300 F(b)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mcv) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation and Storage Temp, F	-65 F(b)				DC-75 (Methyl Phenyl Vinyl)				300 F(b)	
		Modulus at 50%		Ultimate, psi		50% Elongation, psi		Ultimate, psi		Modulus at 50% Elongation, psi	
		Elongation, psi	psi	Elongation, psi	psi	Elongation, psi	psi	Elongation, psi	psi	Elongation, psi	psi
Control	-65	322/5.8/5	1090/8 /5	212/5.9/5	901/4.8/5	324/15 /5	324/15 /5	212/5.4/10	533/12 /9		
	80			288/2.4/5	392/3.5/5	335/3.9/5	335/3.9/5				
	350				931/7.8/5	308/7.7/5	308/7.7/5				
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	383/5.4/5	1005/7.8/5					264/4.2/5	481/13 /5		
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	80			205/12 /5	968/3.8/5	325/5.3/5	325/5.3/5	208/5.2/5	559/12 /5		
	350				703/18 /5	218/11 /4	218/11 /4	227/7.2/5	450/17 /5		
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	-65	646/2.8/5	944/14 /5	287/11 /5	888/3.5/5	180/8.4/5	180/8.4/5	293/6.9/5	581/10.4/5		
	80							207/4 /5	574/11 /5		
	350										
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65	153/10 /5	1109/6.3/5	334/7.2/5	878/8.4/5	152/9.9/5	152/9.9/5	547/5.4/5	603/4.4/5		
	80			510/0.6/5	938/8.7/5	136/16 /5	136/16 /5	378/6.2/5	503/4.5/4		
	350				998/10 /5	38/17 /5	38/17 /5				
N 1.0-1.3 x 10 ¹⁵ G 1.5-1.7 x 10 ⁹	80										
	350										

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of $\bar{x}$, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature.

TABLE B-59. SILICONE RUBBERS - TENSILE PROPERTIES^(a) OF DC-916 VERSUS TEMPERATURE AND IRRADIATION⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation and Storage Temp, F	DC-916 (Methyl Phenyl Vinyl)				
		-85 F(b)		80 F(b)		300 F(b)
		Modulus at 50% Elongation, psi	Ultimate psi	Modulus at 50% Elongation, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi
Control	-65	145/5.5/5				
	80			109/2.8/5	508/3.9/10	
	350			148/11/5		123/1.4/10 489/15/10
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	362/3/5				
	80					
	350			104/13/4	584/3/5	655/7.7/5
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	-65					
	80					
	350					658/7.9/5 772/11/5
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	-65	246/0.6/5	1802/1.5/5			
	80			150/4.6/5	455/3.3/5	160/6.7/5 171/8.0/5 517/11/5 145/11/5
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65					
	80					
	350	359/7.7/5	1404/4.7/5	237/9.3/5	382/3.6/5	312/9.4/5 449/6.5/5 611/7.0/5
N 1.0-1.3 x 10 ¹⁵ G 1.5-1.7 x 10 ⁹	-65					
	80					
	350					461/16/5 322/24/5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature.

TABLE B-60. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF SE-361 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation and Storage Temp, F	SE-361 (Methyl Vinyl)					
		-65 F(b)		80 F(b)		300 F(b)	
		Modulus at 50% Elongation, psi	Ultimate, psi	Modulus at 50% Elongation, psi	Ultimate, psi	Modulus at 50% Elongation, psi	Ultimate, psi
Control	-65	231/21 /5	1050/11 /5	269/23 /5	950/5.9/5	136/3.7/4	
	80			228/18 /5	967/3.1/5	128/6.8/5	
	350			313/19 /5	974/6.9/5	126/9.7/4	481/20 /9
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	417/23 /5	1284/6.4/5				547/18 /5
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	80			343/19 /5	983/10 /5	109/12 /5	644/3 /5
	350			235/9.3/5	875/9 /5	121/7.8/5	571/4.5/5
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	-65						
	80	752/19 /5	1239/19 /5	430/28 /5	977/5.6/5	380/15 /5	613/15.9/5
	350		1354/1.8/5			505/13 /5	86/11 /5
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65						
	350				349/2 /5	637/18 /5	740/12 /5
N 1.0-1.3 x 10 ¹⁵ G 1.5-1.7 x 10 ⁹	80						
	350				953/8.1/5	83/7.8/5	651/20 /5
					711/2.4/5	32/40 /5	711/10 /5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observations estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature.

TABLE B-61. SILICONE RUBBERS - TENSILE PROPERTIES^(a) OF SE-551 VERSUS TEMPERATURE AND IRRADIATION⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation and Storage Temp, F	SE-551 (Methyl Phenyl)							
		-65 F(b)		80 F(b)		300 F(b)			
		Modulus at 50% Elongation, psi	Ultimate psi	Modulus at 50% Elongation, psi	Ultimate psi	Modulus at 50% Elongation, psi	Ultimate psi	Modulus at 50% Elongation, psi	Ultimate psi
Control	-65	128/1.5/5	1464/ /1	85/5.1/5	955/18 /5	384/14 /5			
	80			109/4.4/5	976/20 /5	431/7.5/5			
	350				1096/4.7/5	398/5.4/5	116/17 /8	416/15 /10	
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	127/12 /5					125/7.4/5	555/6.9/5	
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	80			118/14 /5	948/5.8/5	480/5.2/5	147/7.9/5	487/11 /5	
	350				928/15 /5	277/12 /5	148/9.1/5	452/15.8/5	
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	45								
	80	289/7 /5	1515/8.6/5	182/3.8/5	1078/9.2/5	288/12 /5	219/9.8/5	530/6.7/5	458/25 /5
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65								
	350	535/6.1/5	1253/3.1/5	229/6.2/5	1088/7.5/5	184/15 /5	398/8.6/5	577/15 /5	
N 1.0-1.3 x 10 ¹⁵ G 1.5-1.7 x 10 ⁹	80			245/13 /5	883/8.5 /5	177/21 /5	373/9.2/5	477/13 /5	
	350				808/10 /5	75/3 /4		544/15 /5	

(a) Data are given as $\bar{X}/S.D./n$, where $\bar{X}$ = average value, S.D. = standard deviation of the individual observation estimated from the range, and n = number of specimens used in calculating $\bar{X}$ and S.D.

(b) Test temperature.

TABLE B-62. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF LS-53 VERSUS TEMPERATURE AND IRRADIATION(b)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.03 Mev) Gamma Exposure (G), crs g ⁻¹ (C)	Irradiation and Storage Temp. F	LS-53(b)				
		Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi	Ultimate, psi
Control	-65 80 350	361/5.5/5	2055/2.4/5	2-2/3 /5 249/4.7/5	1924/3.2/5 1253/12 /5 1354/3.4/5	217/5.4/5 253/8.5/5 237/0.9/5
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	436/2.7/5	2094/3.1/5		214/17 /5	543/6.1/4
N 1.1 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	30 350			233/3.2/5 263/6.5/5	1169/1.3/5 853/11 /5	238/1.8/5 174/13 /4
N 4.7-5.3 x 10 ¹⁴ G 6.3-8.3 x 10 ⁸	-65 80	882/6.4/5	1783/6.1/5	333/4 /5	751/6.5/5	120/5.4/5
N 0.7-1.0 x 10 ¹⁵ G 1.1 x 10 ⁹	-65 350	717/1.5 /5	1076/6.1/5		313/11 /5 318/6.3/2	307/4.3/5 327/8.4/5
N 1.0-1.3 x 10 ¹⁵ G 1.5-1.7 x 10 ⁹	80 350				71/3.5/4	273/3.7/5 328/27 /5
					514/13 /5 482/17 /5	74/17 /4 20/32 /5
						307/14 /5 243/20 /5

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-63. SILICONE RUBBERS - TEAR STRENGTH (a) v. RSUS IRRADIATION AND TEMPERATURE (48)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), crgs g ⁻¹ (C)	Irradiation and Storage Temp. F	Tear Strength, lb/in.				
		DC-80(b)	DC-975(b)	DC-916(b)	SE 381(b)	SE 551(b)
Control	80	101/12 /5	120/20 /5	242/19 /5	27/14 /5	110/18 /5
N 6.2 x 10 ¹³ G 8 x 10 ⁷	-65	89/11 /5	121/13 /5	204/14 /5	29/14 /5	95/3.8 /2
N 6 x 10 ¹³ G 1.3 x 10 ⁸	-65	76/20 /5	98/13 /5	156/15 /5	24/36 /5	75/7.1 /4
	80	67/7.7 /5	78/11 /5	5/16 /5	20/8.6 /4	67/17 /4
N 1 x 10 ¹⁴ G 1.3 x 10 ⁸	350	13/30 /4	86/15 /5	158/4 /4	22/27 /5	64/4 /5
N 1.1 x 10 ¹⁴ G 1.4 x 10 ⁸	80	92/17 /5	95/7.7 /5	179/8.9 /5	25 /5	86/9.1 /4
N 2.8 x 10 ¹⁴ G 3.5 x 10 ⁸	-65	69/8.1 /4	64/11 /5	151/18 /5	28/35 /5	63/16 /5
	80	66/11 /5	80/9.1 /5	186/18 /5	20/8.6 /5	50/15 /5
N 1 x 10 ¹⁵ G 1.1 x 10 ⁹	65	9/19 /5		115/11 /4	31/22 /5	53/18 /4
N 1 x 10 ¹⁵ G 1.5 x 10 ⁹	30	11/24 /5	25/7.8 /4	181/12 /5	17/18 /5	70/12 /5
N 1.3 x 10 ⁹ G 1.7 x 10 ⁹	350	3/43 /5	4/22 /5	38/21 /4	6/7.2 /5	21/6.2 /5
						7/6.9 /4

(a) Data are given as $\bar{x}/(S.D./n)$, where $\bar{x}$ = average value, S.D. = standard deviation, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-64. SILICONE RUBBERS - TENSILE AND SHEAR PROPERTIES^(a) OF DC-918 AND SE-555 VERSUS IRRADIATION⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (b) (E > 0.33 Mev)(b) Gamma Exposure (G), ergs g ⁻¹ (C)(b)	Days Tested After Irradiation	DC-918 (Methyl Phenyl Vinyl)(-)				SE-555 (Methyl Phenyl Vinyl)(c)			
		Ultimate, psi	Elongation, %	Compression Set, %	Tear Strength, lb/in.	Ultimate, psi	Elongation, %	Compression Set, %	Tear Strength, lb/in.
Control	14	1504/4.7/10	508/3.9/10	12.9/8.8/8	185/4.3/10	1840/8/10	631/2.8/10	25/4.8/8	285/3.5/9
	25	1589/7.8/8	524/4.7/8			1580/14/7	496/7.5/7		
N 3 x 10 ¹⁵ G 6.5 x 10 ⁹	14	283/9.3/10	12/14/10	109/6.2/6	14.7/27/10	547/17/10	28/12/10	113/3.5/8	20/28/10
	21	311/9.1/8	19/19/8			557/15/8	51/21/8		
N 5.5 x 10 ¹⁵ G 1.2 x 10 ¹⁰	25	260/13/10	10/10	112/3.9/8	10/23/10	482/10/10	32/11/10	112/3.2/8	14/24/10
	32	331/11.2/8	15/8			514/9.9/8	31/21/8		

- (a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
 (b) Irradiation temperature 80 F.
 (c) Test temperature 80 F.

TABLE B-65. ELASTOMERS - TENSILE PROPERTIES OF DC-916 VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.29 Mev)(b)	Days Tested After Irradiation	DC-916 (Methyl Phenyl Vinyl)(c)				
		Modulus, psi		Ultimate, psi		Ultimate Elongation, %
		At 100% Elongation	At 200% Elongation	At 300% Elongation	At 300% Elongation	
Control	2	184/5.2/8	343/4.1/8	122/7.8/5	494/7	7/8
N 7.2 x 10 ¹³ G 4.7 x 10 ⁸	2	234/6.8/5	450/8.7/5	1201/5.9/5	408/3.2/5	
	5	219/7.3/5	463/12/4	1070/5.9/5	378/9.9/5	
	11	242/3.1/4	483/12/4	1282/13/4	391/2.4/4	
	30	229/5.7/5	466/6.2/5	1155/6.6/5	392/8.7/5	
N 2.4 x 10 ¹⁴ G 1.3 x 10 ⁹	2	481/7.8/5	804/2.7/5	183/2.2/5		
	5	513/8.6/5	764/5.8/5	146/8.9/5		
	11	555/6.3/5	773/7/5	142/9.2/5		
	30	493/14/5	780/7.2/5	158/6.7/5		

(a) Data are given as $\bar{x}$ /S. D., u, where $\bar{x}$ = average value, S. D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S. D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-66. NITRILE-SILICONE RUBBER NSR-X5802 - ENGINEERING TEST PROPERTIES^(a) VERSUS IRRADIATION TEMPERATURE AND IMMERSION MEDIA (AIR AND JP4 FUEL)⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mcv) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp. F	NSR-X		2 (Nitrile Silicone) ^(b)		JP 4 Fuel ^(c)	
		Air (C)		50%		50%	
		Modulus at 50% Elongation, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi	Slope of Load Deflection Curve, lb/in.	Modulus at 50% Elongation, psi	Ultimate Elongation, %
Control	80	144/2.1/5 148/10 /8	978/9.2/5 994/7.2/8	270/5.9/6 280/5.7/8	14.5/9.1/8 18.2/5.9/6	134/11/5 314/11 /5	102/8.4/5
N 0.9-1.1 x 10 ¹² C 1.3-1.6 x 10 ⁸	-65 80 260	182/7.1/10	1027/7.4/10	231/8.4/10	31.4/5 /4 27.7/6.8/4 53.9/2.7/4	1280/1.5/4 1250/6.2/4 1690/3.4/4	
N 7.0-7.7 x 10 ¹⁴ C 8 x 10 ⁸	-65 80	208/6.4/5	778/9.9/5	184/2.7/5	65.6/7.8/4 62.7/4.3/4	2190/3.8/4 2280/3.9/4	
N 1.5 x 10 ¹⁵ G 1.2 x 10 ⁹	260	545/ /1	778/9.9/5	69/3.5/5	99 /2.5/1	5563/1.3/4	
N 5.0-9.0 x 10 ¹⁵ G 1.1-1.3 x 10 ¹⁰	-65 80 260		545/12 /9 118/13 /9 103/23 /8	16/22 /8 16/22 /8 103/23 /8	95 /2.1/4 100 /6.3/4 108 /2.7/4	11,525/3.4/4 12,350/12 /4 13,375/13 /4	250/9.4/8 53/10 /5
N 4.5 x 10 ¹⁶ G 7 x 10 ¹⁰	80		221/14 /7	<5/ /8			

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of $\bar{x}$, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

(c) Immersion media.

TABLE B-87. NITRILE-SILICONE RUBBER NSR-X5802 - ENG. L. BRING TEST PROPERTIES(a) VERSUS IRRADIATION TEMPERATURE AND IMMERSION MEDIA (ORONITE 8515 AND MIL-L-7808)(48)

Integrated Neutron Flux (N), $n \text{ cm}^{-2}$ ($E > 0.33 \text{ Mev}$) Gamma Exposure (G), $\text{ergs g}^{-1} \text{ (C)}$	Irradiation Temp. F	NSR-X5802 (Nitrile Silicone)(b)					
		Oronite 8515(c)			MIL-L-7808(c)		
		Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %
Control	80	122/9.9/5	547/7.4/5	183/5.9/5	110 /20 /5	410/12/5	146/12 /4
	280	123/12 /5	554/16 /5	178/12 /5	115 /10 /5	390/12/5	153/14 /5
N 0.9-1.1 x 10 ¹³ G 1.3-1.6 x 10 ⁸	80	156/8.1/10	449/8 /10	133/6.1/10	80 /9.7/9	256/16/10	150/6.5/10
	280	160/16 /9	489/11 /10	138/5.9/10	78.5/13 /8	278/10/10	151/11 /10
N 7.0-7.7 x 10 ¹⁴ G 8 x 10 ⁸	30	201/4.7/5	506/4.3/5	117/3.7/5	97 /14 /5	134/18/5	122/7.3/3
N 1.3 x 10 ¹⁵ G 1.3 x 10 ⁹	280	191/18 /5	383/5.7/4	85/6.9/3			
N 5.0-8.0 x 10 ¹⁶ G 1.1-1.3 x 10 ¹⁰	80		320/24 /8	23/15 /8			

(a) Data are given as $\bar{x}/s, D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observations estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

TABLE B-68. COMPRESSION CYCLING OF ELASTOMERS^(a) DURING IRRADIATION⁴⁸

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) ^(b)	Gamma Exposure (G), ergs g ⁻¹ (C) ^(b)	Irradiation Time, hr	Noncycled		Noncycled Compressed Load- Deflection, lb/in.	Compression Set, %	Cycled Compressed ^(c)	
			Uncompressed	Load- Deflection, lb/in.			Load- Deflection, lb/in.	Compression Set, %
			Load- Deflection, lb/in.	Load- Deflection, lb/in.			Compression Set, %	Compression Set, %
<u>NSR-X5602^(d)</u>								
Control			1337/9 /3	1230/4.8/8	16.4/16.4/8	1333/1.8/3	1.2/16 /3	
N 2 x 10 ¹⁴								
G 4 x 10 ⁸		1	2000/3.9/4	1470/6.6/4	48.1/11 /4	1627/2.9/3	27.2/18 /3	
		3	2040/5.7/4	1410/6.9/4	48.8/4.5 /4	1600/4.4/3	11.9/ /1	
<u>Hycar 1001^(d)</u>								
Control			1720/2.8/3	1785/3.3/8	13.3/14 /4	1750/2.1/3	01-14	
N 3.8 x 10 ¹⁴								
G 4.8 x 10 ⁸		1	1990/2.9/4	2070/5.4/4	40.1/3.8 /4	1820/7.8/3	13.3/14/2	
		3	1890/0 /4	2.60/2.3/4	51.4/9 /4	1930/1 /3		
<u>DC-916^(d)</u>								
Control			1544/2.3/4	1663/4.4/4	24.5/27.6/4	1675/2.7/2	15.3/ .1/2	
3 x 10 ¹⁴								
G 3.3 x 10 ⁸		1	2056/7.1/4	2431/9 /4	54 /11 /4			
N 2.8 x 10 ¹⁴								
G 4.2 x 10 ⁸		3	1968/6.2/4	2363/6.2/4	51.1/12 /4			
N 4 x 10 ¹⁴								
G 4.5 x 10 ⁸						2275/3.8/2	54.6/1.2/2	
N 3.3 x 10 ¹⁴								
G 5.3 x 10 ⁸		3				2450/7.3/2	43.3/1.6/2	

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Ambient radiation temperature.

(c) Number of cycles are as follows:

Material	Power Level	Number of Cycles			Total
		Before Irradiation	During Irradiation	After Irradiation	
NSR-X5602	Control				14,000
	3000 kw, 1 hr	8,600	4,460	920	13,980
	1000 kw, 1 hr	920	11,680	900	11,700
Hycar 1001	Control				10,800
	3000 kw, 1 hr	3,600	3,600	3,600	10,800
	1000 kw, 3 hr	900	10,800	--	11,700
DC-916	Control				5,400
	3000 kw, 1 hr	900	3,600	900	5,400
	1000 kw, 3 hr	9,900	10,800	900	12,600
	Control				12,600

(d) Test temperature, 80 F.

Table B-69. PERCENT WEIGHT LOSS FOR SILICONE RUBBER UNDER
VACUUM-THERMAL CONDITIONS³¹

Silicone Rubber and Manufacturer	Weight Loss, percent							
	Temperature 105°F				Temperature, 300°F			
	Time, days				Time, days			
	1	4	7	10	1	4	7	10
RTV 891, Dow Corning Corp.	0.50	0.68	0.74	-	1.49	1.73	1.80	-
Silicone, Lord Mfg. Co.	0.32	0.40	0.43	0.43	0.70	0.93	1.02	1.07
RTV-60, General Electric Co.	-	-	-	-	1.05	1.30	1.36	-
PR-1930-1/2, Products Research								
Ambient temperature cure	0.79	0.91	0.97	-	1.64	1.86	1.96	-
Post cured 6 hours, 300°F	0.14	0.19	0.25	-	0.77	1.00	1.12	-
Silicone Rubber, Nylon Reinforced Irvington Division, MMM Co.	0.58	0.79	0.86	-	1.48	1.71	1.78	-

Pressure 10⁻⁶

TABLE B-70. WEIGHT LOSS IN VACUUM, PRESSURE $< 5 \times 10^{-6}$ mm Hg(17)

Material	Composition	Total Weight Loss to Stationary State (grams/cm ²)		Time to Stationary State (hours)		Stationary State Weight Loss Rate (grams/cm ² /hour)	
		50 C	100 C	50 C	100 C	50 C	100 C
Polyolefin							
Irradiated polyolefin Wire insulation (Rayolin N 102E)	Radiation cross-linked polymers with additives	8.5-11 x 10 ⁻⁵		138		4.7-7.3 x 10 ⁻⁸	
Irradiated polyolefin Shrinkable tubing Type RHF RT 201	Radiation cross-linked polymers with additives	4.6 x 10 ⁻⁵	4.3 x 10 ⁻⁴	138	144	6.5 x 10 ⁻⁸	3.8 x 10 ⁻⁷
Irradiated polyolefin Experimental type	Radiation cross-linked polymers with additives	1.1 x 10 ⁻⁴	3.5-4.0 x 10 ⁻³	138	191	1.7-3.4 x 10 ⁻⁷	8.0-8.3 x 10 ⁻⁶
Nylon							
Zytel 101	Standard grade nylon	2.8 x 10 ⁻⁴	7.5 x 10 ⁻⁴	188	104	3.4 x 10 ⁻⁷	1.5 x 10 ⁻⁵
Zytel 31	Electrical grade nylon	2.2 x 10 ⁻⁴	6.3 x 10 ⁻⁴	141	104	3.2 x 10 ⁻⁷	1.2 x 10 ⁻⁶
Zytel 105	Carbon black filled 101	1.6 x 10 ⁻⁴	6.3 x 10 ⁻⁴	141	104	1.2 x 10 ⁻⁷	1.2 x 10 ⁻⁶
Polycetal							
Delrin 500	Standard grade resin	3.0 x 10 ⁻⁴	5.3 x 10 ⁻⁴	168	104	2.0 x 10 ⁻⁷	2.0 x 10 ⁻⁶
Delrin 507	Carbon black filled resin	3.6 x 10 ⁻⁴	5.6 x 10 ⁻⁴	188	104	5.0 x 10 ⁻⁷	1.6 x 10 ⁻⁶
Diallyl Phthalate (DAP)							
FS-5	Meta form, short glass fiber filled	2.6 x 10 ⁻⁴	6.5 x 10 ⁻⁴	55	88	1.5 x 10 ⁻⁶	1.1 x 10 ⁻⁶
3-2-530	Meta form, long glass fiber filled	1.1 x 10 ⁻⁴	4.2 x 10 ⁻⁴	55	88	6.3 x 10 ⁻⁷	1.2 x 10 ⁻⁶

TABLE 1. (Continued)

Material	Composition	Total Weight Loss to Stationary State (grams/cm ²)		Time to Stationary State (hours)		Stationary State Weight Loss Rate (grams/cm ² /hour)	
		50 C	100 C	50 C	100 C	50 C	100 C
52-01	Ortho form, short glass fiber filled	1.3×10^{-4}	3.1×10^{-4}	55	64	7.3×10^{-7}	1.6×10^{-6}
1-530	Ortho form, long glass fiber filled	1.0×10^{-4}	4.1×10^{-6}	55	64	8.0×10^{-7}	1.2×10^{-6}
1-503	Ortho form, orlon filled	1.2×10^{-4}	5.1×10^{-4}	55	88	8.4×10^{-7}	1.1×10^{-6}
Epoxy							
Epiall 1288 epoxy molding compound	Epoxy molding compound, glass fiber filled	3.9×10^{-5}	4.2×10^{-4}	55	64	1.6×10^{-7}	6.6×10^{-7}
Epiall 1459 epoxy molding compound	Epoxy molding compound, mineral filled	3.8×10^{-5}	1.5×10^{-4}	55	64	2.6×10^{-7}	4.7×10^{-7}
Devcon F epoxy (room temperature cure)	Aluminum filled (80 per cent by weight) epoxy	7.0×10^{-4}	1.0×10^{-3}	25	28	9.1×10^{-7}	1.8×10^{-6}
Armstrong epoxy (room temperature cure)	Unmodified polyamid cured epoxy system	1.8×10^{-4}	1.4×10^{-3}	25	28	3.8×10^{-6}	6.4×10^{-5}
Permacel epoxy type PRH 102 (cured 3 hours at 60 C)	Three parts variable flexibility epoxy	3.2×10^{-4}	2.3×10^{-3}	25	28	6.3×10^{-6}	2.9×10^{-5}
Permacel epoxy type PR 3935 (room temperature cure)	Modified, polyamid cured epoxy system	7.1×10^{-4}	4.0×10^{-3}	25	28	9.8×10^{-6}	$3.7-4.1 \times 10^{-5}$
Permacel epoxy (type PRH 102) (room temp- erature cure)	Three parts variable flexibility epoxy	6.6×10^{-4}	3.4×10^{-3}	25	28	1.0×10^{-5}	3.4×10^{-5}

TABLE B-70. (Continued)

Material	Compositior	Total Weight Loss to Stationary State (grams/cm ²)		Time to Stationary State (hours)		Stationary State Weight Loss Rate (grams/cm ² /hour)	
		50 C	100 C	50 C	100 C	50 C	100 C
<u>Phenolic Laminates</u>							
Phenolic laminate grade XX natural	Phenolic laminate, paper filler	1.4-1.5 x 10 ⁻³	3.5 x 10 ⁻³	138	161	3.7-4.4 x 10 ⁻⁶	8.9 x 10 ⁻⁶
Phenolic laminate grade LB 103	Phenolic laminate, cotton fabric MeS ₂ impregnated	3.7-3.8 x 10 ⁻³	5.7-5.8 x 10 ⁻³	138	161	3.9-4.2 x 10 ⁻⁶	3.2-3.4 x 10 ⁻⁵
Phenolic laminate grade LBB natural	Phenolic laminate, cotton fabric	2.3-2.3 x 10 ⁻³	4.6-4.8 x 10 ⁻³	138	161	4.8-5.1 x 10 ⁻⁶	3.8-4.3 x 10 ⁻⁶
<u>Silicones</u>							
Dow RTV 521 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	4.5 x 10 ⁻³		68		1.6 x 10 ⁻⁵	
Dow RTV 503 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	4.2 x 10 ⁻³		68		2.3 x 10 ⁻⁵	
GE RTV 40 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	5.0 x 10 ⁻³		68		2.7 x 10 ⁻⁵	
GE RTV 60 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	5.3 x 10 ⁻³		68		2.8 x 10 ⁻⁵	

TABLE B-79 (Continued)

Material	Composition	Total Weight Loss to Stationary State (grams/cm ²)		Time to Stationary State (hours)		Stationary State Weight Loss Rate (grams/cm ² /hour)
		50 C	100 C	50 C	100 C	
Dow RTV 501 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and Fe ₂ O ₃)	5.8 x 10 ⁻³		58		3.7 x 10 ⁻⁵
GE RTV 11 silicone rubber (room tem- perature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	4.1 x 10 ⁻³		44		3.7 x 10 ⁻⁵
GE LTV 602 silicone potting compound (cured 16 hours at 100 C)	Clear silicone potting compound	1.2 x 10 ⁻²		44		1.0 x 10 ⁻⁴
Dow RTV 5313-5314 silicone potting compound (room temperature cure)	Cross-linked silicone resins with various fillers (CaCO ₃ , SiO ₂ , and FeO ₂)	4.3 x 10 ⁻²		68		3.8 x 10 ⁻⁴

Table B-71. EXPOSURE OF SILICONE ELASTOMERS TO HIGH VACUUM AT VARIOUS TEMPERATURES⁹

Property Measured	Original Temperature	400°F			500°F			600°F			700°F		
		Exposed to Vacuum of 7.8 x 10 ⁻⁴ mm Hg for 5 days at Room Temperature	Vacuum of 1.9 x 10 ⁻³ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.4 x 10 ⁻³ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.7 x 10 ⁻³ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 3.1 x 10 ⁻³ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 3.1 x 10 ⁻³ mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 3.1 x 10 ⁻³ mm Hg for 5 Days
Tensile Strength, psi	710	740	770	Silicone SE 33 (Z84) (1)	550	690	400	700	390	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Modulus, psi at 100% E	110	110	130		390	590	100	240	-	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Elongation, percent	260	250	230		190	210	190	230	110	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Hardness, Shore A	48	46	51		44	53	42	56	81	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Strain, percent E at 200 psi	98	96	89		100	73	110	Broke	Broke	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Change in weight, percent	-	-0.7	-1.8		-0.4	-3.2	-2.7	-10.3	-20.3	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Silicone W96 (Z69 FCI) (1)													
Tensile Strength, psi	740	640	680		660	700	330	600	370	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Modulus, psi at 100% E	375	310	570		440	470	-	360	-	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Elongation, percent	220	210	130		160	160	80	150	40	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Hardness, Shore A	7	77	78		80	78	83	74	82	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Strain, percent E at 200 psi	19	19	17		17	14	21	46	-	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test
Change in weight, percent	-	-0.1	-1.6		-2.0	-3.0	-5.7	-14.7	-14.7	Too brittle to test	Too brittle to test	Too brittle to test	Too brittle to test

(1) See Table B-1 for formulation.

Table B-72. PRESS AND POST CURE SCHEDULES OF THE SILICONES USED IN THE IRRADIATION STUDIES 47

Compound	Curing Data
39-62	Conductive silicone; post cure 24 hours at 410°F
56-62	Press cure 10 minutes at 250°F; post cure 3 hours at 400°F
58-62	Press cure 10 minutes at 250°F; post cure 24 hours at 480°F
105-62	Press cure 5 minutes at 240°F; post cure 24 hours at 480°F
106-62	Post cure 12 hours at 480°F
107-62	Post cure 24 hours at 480°F
109-62	Post cure 4 hours at 480°F
110-62	Post cure 16 hours at 300°F
111-62	Post cure 24 hours at 480°F
120-62	Room temperature vulcanizing silicone
147-62 ^(a)	Room temperature vulcanizing silicone
148-62 ^(b)	Room temperature vulcanizing silicone
149-62 ^(c)	Low-density room-temperature vulcanizing silicone

(a) 96 parts compound, 4 parts curing agent

(b) 100 parts compound, 0.5 parts Thermolite T-12

(c) 100 parts compound, 10 parts accelerator

Table B-73. PHYSICAL PROPERTIES OF COMPOUND 105-6247

Base Elastomer - Silicone. Type - Dimethyl

Base Elastomer - Silicone - Type 2000-1										
Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus psi	Ultimate Elongation %	Hardness		Weight Change mg.	Rating
			Strength psi	% Chg. (1)			Duro A	Chg. (1)		
As-cured		0	819			62		83		
1. V, Vac. 16 hrs., 70 F	1A	5.7 x 10 ⁶	836	+ 2.1	- 9.6(3)	70	+13	84	+1	1
2. V, Vac. 100 hrs., 70 F	2	6.2 x 10 ⁷	1050	+28	+238(3)	20	-68	92	+9	6
3. V, Vac. (4) 16 hrs., 70 F	11	6.4 x 10 ⁶	806	- 1.6	+ 65(3)	37	-40	85	+2	3
4. V + UV, Vac. (2) 100 hrs., 335 F	7	6.1 x 10 ⁷	1250	+53	+250(3)	27	-46	91	+8	5
5. V, Air 100 hrs., 70 F	5	3.4 x 10 ⁷	1210	+43	+205(3)	30	-52	87	+4	4
6. V, Air (4) 100 hrs., 70 F	6	3.8 x 10 ⁷	1012	+24	+350(3)	17	-3	86	+3	7
7. V, Air 16 hrs., 70 F	1	1.5 x 10 ⁶	794	- 3.1	- 16(3)	72	+16	85	+2	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-73. (continued)

Time effect: This compound showed a slight tendency toward chain scission at 16 hours in Conditions 1 and 7. Cross-linking predominated as exposure time increased. Comparison of Conditions 1 and 7 with 3 showed a possible "threshold dose" after which cross-linking becomes predominant.

Atmosphere effect: Differences were slight between radiation in air and vacuo. This compound showed initial scission in both air and vacuo at low dosages. Weight changes were not significant.

Type irradiation effect: The tensile strength was increased by combined irradiation. The 100 per cent modulus and ultimate elongation changes were decreased, and the hardness change remained the same in a comparison of Conditions 4 and 2.

Observations: Condition 4, grey-brown discoloration on face toward UV lamp.
Condition 6, brown stains on specimens.

Table B-74. PHYSICAL PROPERTIES OF COMPOUND 106-624:7

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gauss Dose r.	Tensile		100 % Modulus		Ultimate Elongation		Hardness Change		Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A Chg. (1)	eg.	
As-cured		0	1216		193		387		58		
1. V, Vac. 16 hrs., 70 F	1A	5.7×10^6	1270	+ 4.4	180	- 6.8	410	+ 5.9	54	- 4	1
2. V, Vac. 100 hrs., 70 F	2	6.2×10^7	600	-51	—	+664(3)	17	-88	74	+16	5
3. V, Vac. 16 hrs., 70 F	11	6.4×10^6	1110	- 8.3	385	+100	230	-41	61	+ 3	3
4. v + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	288	-76	—	+894(3)	13	-97	82	+24	6
5. V, Air 130 hrs., 70 F	5	3.4×10^7	1106	- 9.0	1016	+426	120	-62	78	+20	4
5. V, Air(4) 100 hrs., 70 F	6	3.8×10^7	466	-62	—	+355(3)	53	-86	78	+20	4
7. V, Air 16 hrs., 70 F	1	7.5×10^6	1333	+ 9.6	334	+ 73	260	-33	61	+ 3	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

B-102

Table 1, -74. (Concluded)

Time effect: Time effects were pronounced for all properties. This compound apparently undergoes an initial period of chain scission in vacuo (Condition 1).

Atmosphere effect: The cross-linking was more pronounced in vacuo than in air except during the sixteen hour period (Condition 1) where the specimens exposed in vacuo apparently underwent a slight amount of scission. Specimen weight changes were insignificant.

Type irradiation effect: Combined radiation was more severe than straight gamma radiation, as evident from larger changes in all properties.

Observation: Condition 4, discoloration on face toward UV lamp.

Table B-75. PHYSICAL PROPERTIES OF COMPOUND 120-6247

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A Chg. (1)			
As-cured		0	674		503		147		62			
1. Y, Vac. 16 hrs., 70 F	1A	5.7×10^6	623	- 7.6	584	+ 16	123	-16	63	+ 1	---	1
2. Y, Vac. 100 hrs., 70 F	2A	5.0×10^7	573	-15	---	+100(3)	57	-61	75	+13	---	4
3. Y, Vac. (4) 16 hrs., 70 F	11	6.4×10^6	599	-11	582	+ 16	103	-30	65	+ 3	-2	2
4. Y + UV, Vac. (2) 100 hrs., 115 F	7	6.1×10^7	601	-11	---	+139(3)	50	-66	76	+14	-6	6
5. Y, Air 100 hrs., 70 F	5	3.4×10^7	686	+ 2.1	---	+ 95(3)	70	-52	72	+10	+2	3
6. Y, Air (4) 100 hrs., 70 F	6	3.8×10^7	637	- 5.5	---	+139(3)	53	-64	75	+13	+5	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

B-104

Table D-75. Concluded)

Time effect: The compound does not show the "threshold" effect apparent in other compounds. The cross-linking increased with exposure time.

Atmosphere effect: There was little apparent difference due to atmosphere. The compound showed slight weight gains in air and slight losses in vacuum.

Type irradiation effect: There was little difference in properties produced by combined and straight gamma radiation as evident from comparison of Conditions 2 and 4.

Observation: Condition 4, slight darkening on both faces of specimens.

Table B-76. PHYSICAL PROPERTIES OF COMPOUND 147-62⁴⁷
Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation %	Hardness Duro A	Weight Change mg.	Rating
As-cured		0	282	203	167	51		
1. Y, Vac. 16 hrs., 70 F	1A	5.7 x 10 ⁶	396	+40	113	-32	57	+6
2. Y, Vac. 100 hrs., 70 F	2	6.2 x 10 ⁷	541	+92	60	-64	73	+22
3. Y, Vac. 16 hrs., 70 F	11	6.4 x 10 ⁶	350	+24	100	-40	61	+10
4. Y + UV, Vac. ⁽²⁾ 100 hrs., 335 F	7	6.1 x 10 ⁷	409	+45	37	-77	74	+23
5. Y, Air 100 hrs., 70 F	5	3.4 x 10 ⁷	211	-25	23	-86	68	+17
6. Y + UV, Air ⁽⁴⁾ 100 hrs., 70 F	6	3.8 x 10 ⁷	489	+73	57	-66	71	+20

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-76. (Concluded)

Time effect: Radiation effects became more severe with increasing exposure. This compound did not show the "threshold" effect apparent in other compounds.

Atmosphere effect: The radiation effects were similar in vacuo and air, except for tensile strength during straight gamma radiation, which showed a marked increase in vacuo versus a marked decrease in air. Straight gamma radiation in vacuo produced slightly greater changes in hardness than in air, and combined radiation in vacuo produced greater changes in modulus, elongation, and hardness than in air. The compound showed a consistent weight loss, greater in vacuo than in air.

Type irradiation effect: The effect of combined radiation appeared to be slightly greater than that of straight gamma radiation.

Observation: Condition 4, moderate browning on face toward UV lamp.

Table B-77. PHYSICAL PROPERTIES OF COMPOUND 148-62 47
Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiation Condition	Can No.	Gamma Dose r.	Tensile Strength		100 % Modulus psi	Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg.		%	% Chg.	Duro A	Chg.		
As-cured		0	409		232	143		54			
1. Y, Vac. 16 hrs., 70 F	1A	5.7×10^6	347	-15	289	+24	113	-21	+1	--	1
2. Y, Vac. 100 hrs., 70 F	2	6.2×10^7	315	-23	--	+76(3)	77	-46	+11	-2	4
3. Y, Vac. (4) 16 hrs., 70 F	11	6.4×10^6	331	-19	297	+28	110	-23	+3	-3	2
4. Y + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^7	71	-83	--	+206(3)	10	-93	+14	--	6
5. Y, Air 100 hrs., 70 F	5	7.4×10^7	329	-20	--	+77(3)	80	-44	+6	-5	3
6. Y, Air (4) 100 hrs., 70 F	6	3.8×10^7	321	-22	--	+106(3)	67	-53	+10	-3	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

(4) Combined radiation intended.

Table B-77. (Concluded)

Time effect: The radiation effects became more severe with increasing exposure time. This compound exhibited increasing cross-linking with exposure time.

Atmosphere effect: There was little difference between specimens exposed in air and vacuo. The specimens showed a slight weight loss for all conditions.

Type irradiation effect: The combined radiation was markedly more severe than straight gamma radiation for all properties compared in Conditions 2 and 4.

Observation: Condition 4, specimens darkened on face toward laser. Two specimens broke in handling prior to test.

Table B-78. PHYSICAL PROPERTIES OF COMPOUND 149-6247
Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A Chg. (1)			
As-cured		0	266				90		64			
1. γ , Vac. 16 hrs., 70 F	1A	5.7×10^6	209	-21	—	- 3.4(3)	73	-19	70	+ 6	—	1
1'. γ , Vac. 16 hrs., 70 F	3	7.8×10^6	211	-18	—	+ 47(3)	50	-44	65	+ 1	- 3	3
2. γ , Vac. 100 hrs., 70 F	4	4.2×10^7	288	+ 8.3	—	+ 62(3)	60	-33	75	+11	- 2	3
3. γ + UV, Vac. (b) 16 hrs., 70 F	11	6.4×10^6	248	- 6.8	—	+ 39(3)	60	-33	70	+ 6	- 1	2
4. γ + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^7	136	-49	—	+130(3)	20	-78	79	+15	-12	6
5. γ , Air 100 hrs., 70 F	5	3.4×10^7	211	-21	—	+ 52(3)	47	-48	73	+ 9	+18	4
6. γ , Air (4) 100 hrs., 70 F	6	3.8×10^7	272	+ 2.2	—	+ 84(3)	50	-44	75	+11	+ 4	5

(1) From as-cured value.

(2) Measured temperatures are $\pm 1^\circ$ F.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table E 13. (Concluded)

Time effect: Three canisters in this series had the same nominal gamma radiation for 16 hours in vacuo. Comparison of these showed the possibility of a "threshold" dosage required to start cross-linking since the exposure showing the tendency toward scission (decrease in modulus) had the lowest of the three recorded dosages. As the dosage increased, the apparent cross-linking increased.

Atmosphere effect: Examination of the effect of air and vacuo irradiation on mechanical properties did not show sufficient consistent differences to state that one was more severe than the other. The specimens gained weight in air and lost it in vacuo, the loss being greater in combined radiation than in straight gamma.

Type irradiation effect: Combined radiation produced more cross-linking effects than straight gamma in all properties compared in Conditions 2 and 4.

Observations: Condition 4, moderate to heavy browning on both faces of specimens, heaviest on face toward UV lamp.

TABLE B-79. PHYSICAL PROPERTIES OF COMPOUND 111-62(47)

Base Elastomer - Silicone, Type - Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gauss Dose r.	Tensile		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)	Duro A	Chg.(1)		
As-cured		0	1029		415		227		73			
1. V, Vac. 16 hrs., 70 F	1A	5.7×10^6	1056	+ 2.6	584	+ 41	177	-22	74	+ 1	--	1
2. V, Vac. 100 hrs., 70 F	2	6.2×10^7	816	-21	--	+318(3)	47	-79	87	+14	+4	4
3. V, Vac. (4) 16 hrs., 70 F	11	6.4×10^6	809	-21	637	+ 54	130	-43	78	+ 5	+2	3
4. V + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^4	302	-71	--	+628(3)	10	-96	88	+15	+3	6
5. V, Air 100 hrs., 70 F	5	3.4×10^7	1151	+12	--	+440(3)	63	-72	--	+10	+4	4
6. V, Air (4) 100 hrs., 70 F	6	3.8×10^7	1049	+ 1.9	--	+406(3)	50	-78	85	+12	+4	5
7. V, Air 16 hrs., 70 F	1	7.5×10^6	1080	+ 4.9	699	+ 68	147	-35	75	+ 2	--	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

TABLE B-79. (Cc tinued)

Time effect: The cross-linking effect became more severe as exposure time increased. The threshold effect noted in other compounds was not apparent here.

Atmosphere effect: Effect of atmosphere was slight, but cross-linking was more pre-dominant in the air exposures than in the vacuo exposures. A slight weight increase, almost identical for each group, was noted.

Type irradiation effect: Combined radiation produced more cross-linking than gamma radiation alone.

Observation: Condition 4, marked discoloration on face toward lamp.

TABLE B-20. PHYSIC L PROPERTIES OF COMPOUND 107-82(47)

Base Elast. . . . Silicone, Type - Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 %		Ultimate		Hardness		Weight Change mg.
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A	Chg. (1)	
As-cured		0	859		523		150		64		
1. Y, Vac. 16 hrs., 70 F	1A	5.1×10^6	932 + 8.5		447	- 22	177	+18	66	+ 2	--
2. Y, Vac. 100 hrs., 70 F	2	6.2×10^7	655 -24		--	+213(3)	40	-73	80	+16	+1
3. Y, Vac. (4) 16 hrs., 70 F	11	6.4×10^6	796 - 7.3		565	+ 8.0	127	-15	66	+ 2	+2
4. Y + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^7	274 -62		--	+162(3)	20	-87	80	+13	Nil
5. Y, Air 100 hrs., 70 F	5	3.4×10^7	926 + 7.8		--	+164(3)	67	-55	75	+11	+3
6. Y, Air (4) 100 hrs., 70 F	3	3.8×10^7	760 -12		--	+191(3)	50	-67	78	+14	+4
7. Y, Air 16 hrs., 70 F	1	7.5×10^6	1001 +16		832	+ 59	123	-18	71	+ 7	--

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

Note: Continued on next page.

TABLE B-80. (Continued)

Time effect: Cross-linking increased as exposure time increased in both air and vacuo. The specimens exposed in vacuo apparently underwent scission during the 16 hour radiation period (Condition 1). A comparison of Conditions 1 and 3 showed a possible threshold value for cross-linking.

Atmosphere effect: After short-term radiation (16 hour), vacuum exposure showed pre-dominant scission and air atmosphere resulted in cross-linking. After 100 hours, both showed predominant cross-linking with the effect more severe in vacuo than in air.

Type irradiation effect: The straight gamma radiation produced comparable or slightly greater effects on the properties.

Observation: Condition 4, heavy blackening on face toward UV lamp and moderate on back face.

TABLE B-81. PHYSICAL PROPERTIES OF COMPOUND 39-62(47)

Base Elastomer - Si cone, Type - Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		100 %		Ultimate		Hardness		Weight Change mg.
			psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)	Duro A	Chg.(1)	
As-cured		0	731		449		210		67		
1. Y, Vac. 16 hrs., 70 F	3	7.8×10^6	703	- 3.8	626	+ 39	127	-39	72	+ 5	--
2. Y, Vac. 100 hrs., 70 F	4	4.9×10^7	787	+ 7.6	--	+150(3)	63	-70	73	+ 6	+4
3. Y + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	714	- 2.4	659	+ 47	113	-46	74	+ 7	-2
4. Y + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	1037	+42	--	+391(3)	47	-78	86	+19	Nil
5. Y, Air, 100 hrs., 70 F	8	4.1×10^7	838	+15	--	+196(3)	57	-63	81	+14	+2
6. Y + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	1027	+40	--	+332(3)	53	-75	83	+16	+1
7. Y, Air 16 hrs., 70 F	3	5.7×10^6	538	-26	455	+ 1.3	125	-40	69	+ 2	--

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Note: Continued on next page.

TABLE 3-81. (C ntinued)

Type effect: The tensile was not affected greatly by time. The 100 per cent modulus markedly increased, hardness increased very slightly, and the ultimate elongation dropped as exposure time increased.

Atmosphere effect: The compound apparently reacted about the same in vacuo and in air. Weight changes were erratic within the groups and the net changes were insignificant.

Type irradiation effect: Cross linking was more severe for the combined irradiation than with the gamma radiation alone, as evidenced by the substantially larger increases in modulus, tensile strength, and hardness.

Observations: Condition 4, smoky discoloration--purple and green iridescent surfaces.
Condition 6: smoked surfaces on face toward lamp. Condition 7, smoky discoloration in spots--purple iridescence.

TABLE B-32. PHYSICAL PROPERTIES OF COMPOUND 109-62(47)

Base Elastomer - Silicone, Type - Methyl Phenyl Vinyl

Original Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	100 % Modulus psi	Ultimate Elongation %	Hardness Duro A Chg. (1)	Weight Change mg.	Rating
As-cured		0	1473	229	500	62		
1. Y, Vac. 16 hrs., 70 F	1A	5.7×10^6	1591 + 8.0	255 + 11	445	-11	-4	1
2. Y, Vac. 100 hrs., 70 F	2	6.2×10^7	774 -48	-- +404(3)	67	.87	+16	6
3. Y, Vac. 16 hrs., 70 F	11	6.4×10^6	1492 + 1.3	304 + 33	403	-19	-5	2
4. Y, Vac. (2) 100 hrs., 335 F	7	6.1×10^7	281 -80	-- +622(3)	17	-97	+20	7
5. Y, Air 100 hrs., 70 F	5	3.4×10^7	902 -32	-- +337(3)	90	-82	+14	4
6. Y, Air (4) 100 hrs., 70 F	6	3.8×10^7	627 -57	-- +334(3)	63	-87	+15	5
7. Y, Air 16 hrs., 70 F		7.5×10^6	1514 + 2.7	347 + 52	380	-34	N11	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

Note: Continued on next page.

TABLE B-82. (Continued)

Time effect: The effects became markedly more severe as the exposure time was increased. This was true in both air and vacuo. The short-term exposures in vacuo showed a small drop in hardness coupled with slight increases in modulus and decreases in ultimate elongation, suggesting a balanced cross-linking-scission effect or a "threshold dose".

Atmosphere effect: At 16 hours the effect of gamma radiation in air was somewhat more severe than in vacuo. There were slight increases in weight in air indicating a small amount of oxidation.

Type irradiation effect: The combined radiation produced more cross-linking than gamma radiation alone, as evidenced by comparison of Conditions 2 and 4.

Observation: Condition 4, specimens blackened on face toward lamp. Darkened on opposite face.

TABLE B-83. PHYSICAL PROPERTIES OF COMPOUND 58-62(47)

Base Elastomer - Silicone, Type - Dimethyl Phenyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A Chg. (1)			
As-cured		0	1169		208		403		50			
1. Y, Vac. 16 hrs., 70 F	1A	5.7×10^6	899	-23	285	+ 37	227	-44	55	+ 5	---	1
2. Y, Vac. 100 hrs., 70 F	2	6.2×10^7	660	-41	---	+323(3)	75	-82	76	+26	Nil	5
3. Y, Vac. (4) 16 hrs., 70 F	1J	6.4×10^6	938	-20	334	+ 60	220	-46	57	+ 7	+ 2	2
4. Y + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^7	270	-77	---	+464(3)	23	-94	80	+30	Nil	6
5. Y, Air 100 hrs., 70 F	5	3.4×10^7	692	-43	737	+254	93	-77	67	+7	+ 6	3
6. Y, Air (4) 100 hrs., 70 F	6	3.8×10^7	429	-63	---	+289(3)	53	-84	76	+26	+17	4
7. Y, Air 16 hrs., 70 F	1	7.5×10^6	1069	- 8.6	368	+ 77	240	-41	56	+ 6	---	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

TABLE D-83. (Continue.)

Time effect: All properties were time dependent for a given irradiation condition, with the changes being significant even for the shorter time.

Atmosphere effect: Cross-linking was less in air than in vacuo, but still the pre-dominant effect. Specimens exposed to air gained some weight while those exposed in vacuo showed no change indicating a minor oxidative reaction in the air exposures.

Type irradiation effect: Combined radiation appeared to be more severe than straight gamma radiation.

Observations: Condition 2, tear strength noticeably decreased. Condition 4, blackened on face toward UV lamp.

TABLE B-84. PHYSICAL PROPERTIES OF COMPOUND 58-62(47)

Base Elastomer - Silicon. Type - Dimethyl Phenyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile		Modulus psi	100 %		Ultimate Elongation %	Hardness		Weight Change mg.
			Strength psi	% Chg. (1)		% Chg. (1)	% Chg. (1)		Duro A	Chg. (1)	
As-cured											
1. V, Vac. 16 hrs., 70 F	1A	5.7×10^6	0	1147	117	383	53				
2. V, Vac. 100 hrs., 70 F	2	6.2×10^7		743	301	200	-49		+2		2
3. V, Vac. (4) 16 hrs., 70 F	11	6.4×10^6		777	---	75	-81		+23		5
4. V + UV, Vac. (2) 100 hrs., 335 F	7	6.1×10^7		550	350	143	-64		+6		3
5. V, Air 100 hrs., 70 F	5	3.4×10^7		202	---	20	-95		+2		7
6. V, Air (4) 100 hrs., 70 F	6	3.8×10^7		742	---	80	-80		+17		4
7. V, Air 16 hrs., 70 F		7.5×10^6		635	---	63	-84		+20		6
				1181	359	240	-39		+3		1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

TABLE B-84. (Continued)

Time effect: Increase in exposure time produced marked effects on modulus, ultimate elongation, and hardness, and a somewhat irregular effect on tensile strength in both air and vacuo.

Atmosphere effect: Reaction was predominantly cross-linking whether specimens were exposed in air or vacuo. Weight changes were small and erratic.

Type irradiation effect: There was greater loss of tensile strength and slightly greater loss of elongation during combined radiation than during straight gamma radiation with other property changes being comparable.

Observation: Condition 4, specimens blackened on face toward UV lamp.

TABLE B-35. PHYSICAL PROPERTIES OF COMPOUND 110-62(47)

Base Elastomer - Silicone, Type - Methyl Trifluoro Propyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength		100 % Modulus		Ultimate Elongation		Hardness		Weight Change mg.	Rating
			psi	% Chg. (1)	psi	% Chg. (1)	%	% Chg. (1)	Duro A	Chg. (1)		
As-cured		0	1346		371		243		62			
1. Y, Vac. 16 hrs., 70 F	1A	5.7×10^6	591	-56	333	- 10	153	-37	62	N11	---	2
2. Y, Vac. 100 hrs., 70 F	2	6.2×10^7	382	-72	---	+ 54(3)	67	-72	72	+10	- 8	4
3. Y + UV, Vac. (2) 16 hrs., 190 F	12	6.4×10^6	333	-75	---	+ 3(3)	87	-64	65	+ 3	- 4	3
4. Y + UV, Vac. (2) 100 hrs., 250 F	10	6.1×10^7	304	-77	---	+ 310(3)	20	-92	78	+16	-21	6
5. Y, Air 100 hrs., 70 F	8	4.1×10^7	374	-72	---	+ 50(3)	67	-72	73	+11	- 8	4
6. Y + UV, Air (2) 100 hrs., 250 F	9	3.8×10^7	372	-72	---	+ 203(3)	33	-86	74	+12	- 5	5
7. Y, Air 16 hrs., 70 F	1	7.5×10^6	988	-27	454	+ 22	180	-25	64	+ 2	---	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Note: Continued on next page.

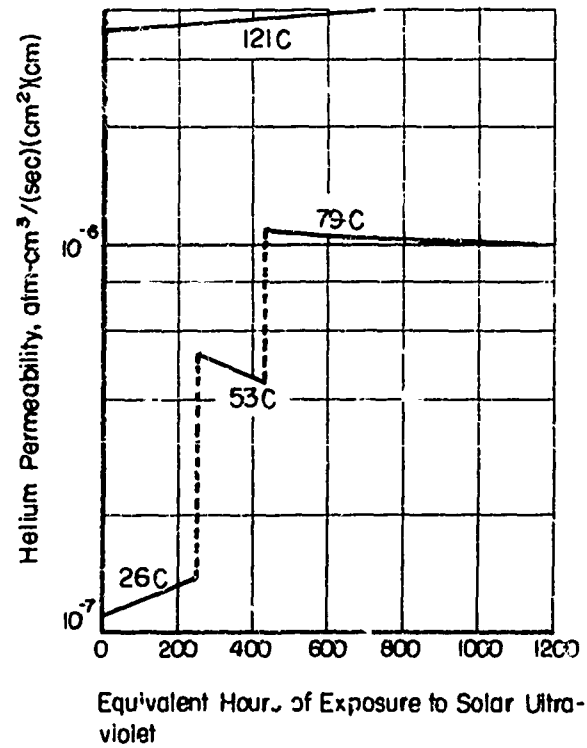
TABLE B-8c. (Continued)

Time effect: The radiation effects increased with exposure time. Short-term radiation in vacuo showed scission effects. Otherwise the reaction was predominantly cross-linking. This indicated a threshold radiation for cross-linking.

Atmosphere effect: As noted above, short-term vacuo exposure showed effect of scission as opposed to cross-linking in air; otherwise, little difference due to atmosphere was noted. The specimens all lost weight and the effect was greatest on the specimens exposed to combined radiation in vacuo.

Type irradiation effect: Combined radiation appeared to cause more cross-linking than straight gamma radiation in the three comparisons 1 and 3, 2 and 4, and 5 and 6).

Observations: Condition 4, blackened on face toward lamp. Darkened on other face. Condition 6, moderate darkening on face toward lamp. Condition 7, scum deposits on specimens.



A-48933

FIGURE B-1. CHANGE IN PERMEABILITY ON EXPOSURE TO ULTRAVIOLET RADIATION AT VARIOUS TEMPERATURE LEVELS - VITON "A"(4)

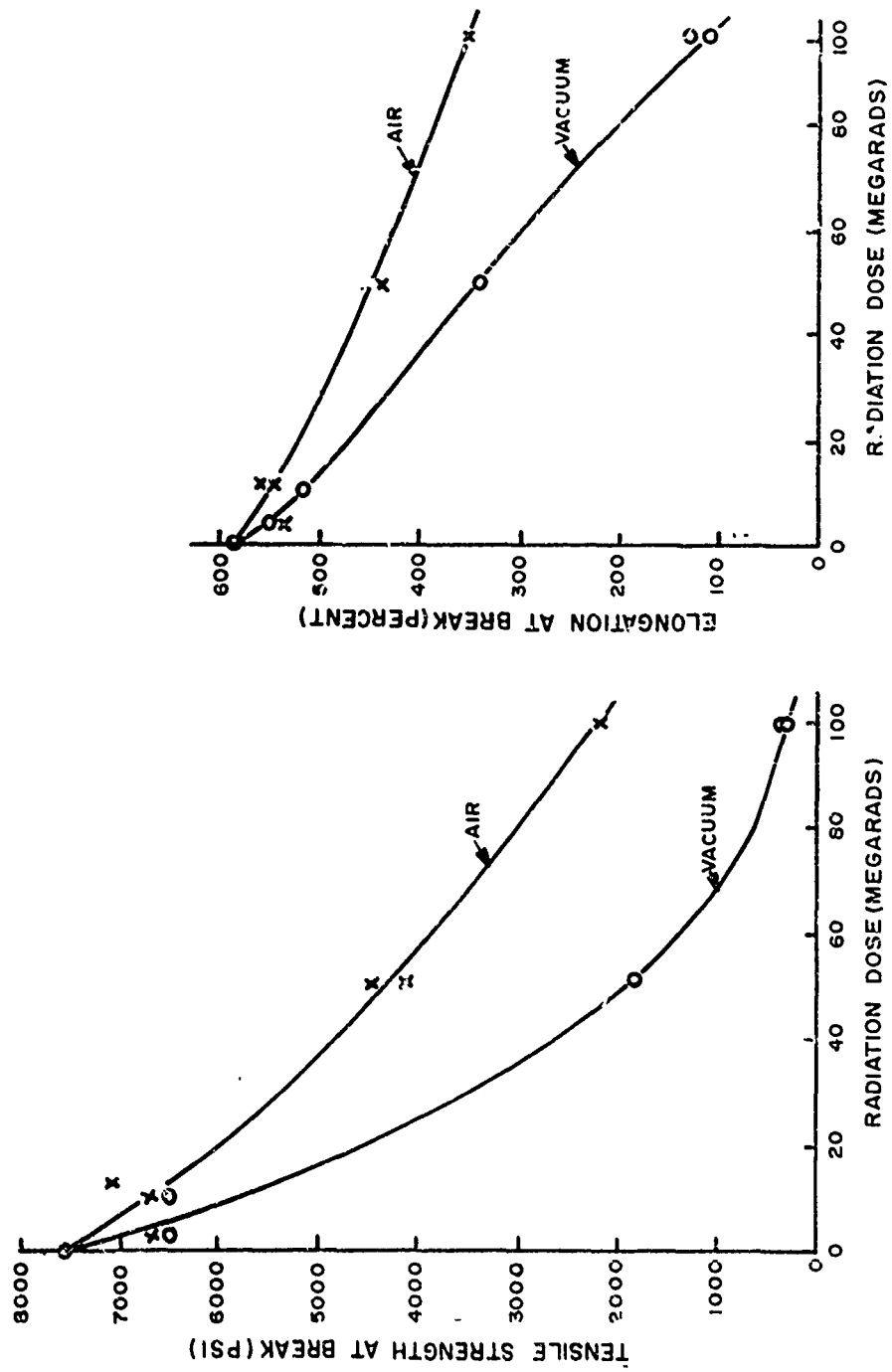


FIGURE B-2. TENSILE STRENGTH AND ELONGATION FOR POLYURETHANE IRRADIATED IN VACUUM AND IN AIR(18)

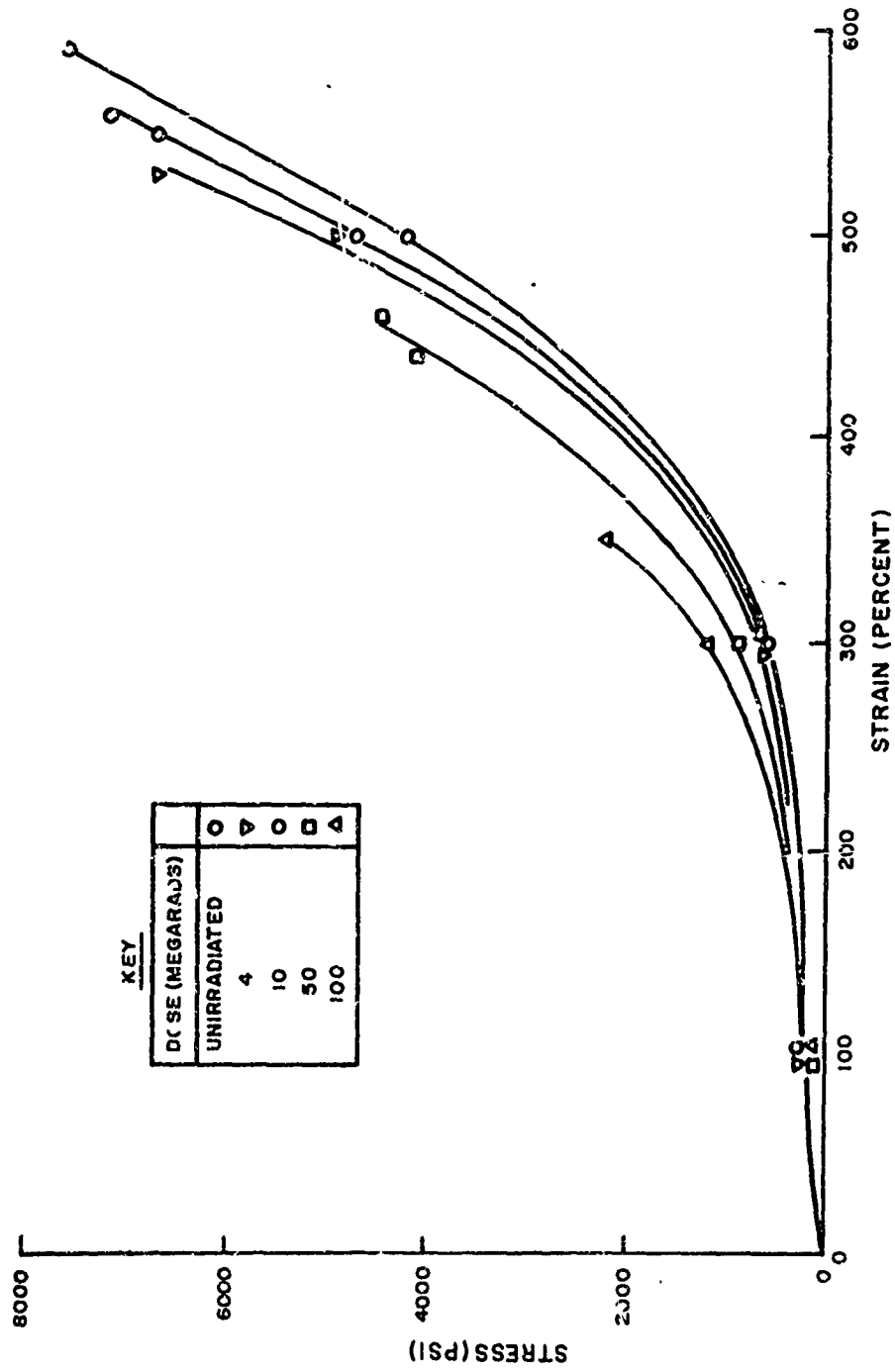


FIGURE B-3. STRESS/STRAIN CURVES FOR POLYURETHANE IRRADIATED IN AIR (50)

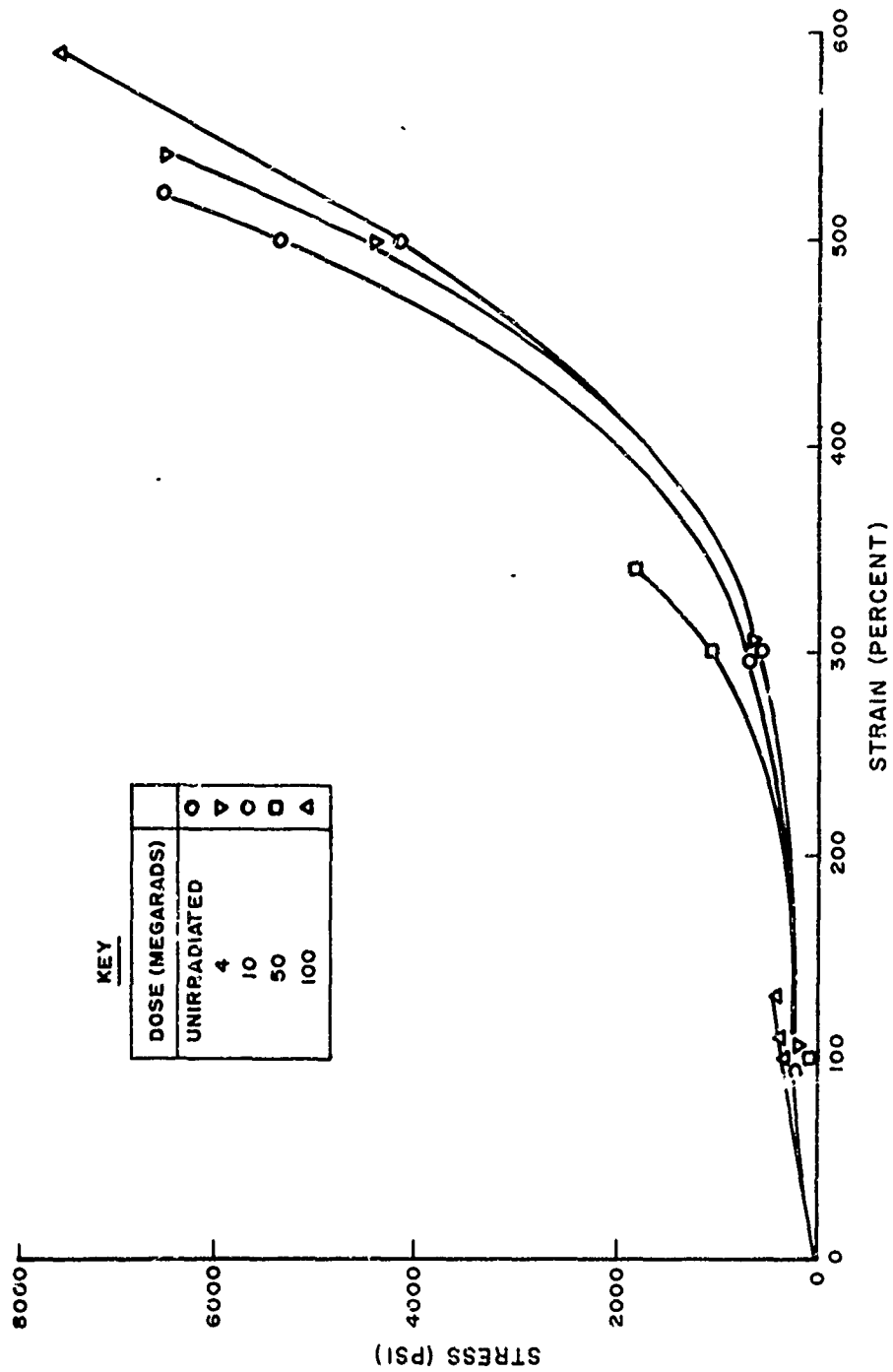


FIGURE B-4. STRESS/STRAIN CURVES FOR POLYURETHANE IRRADIATED IN VACUUM (50)

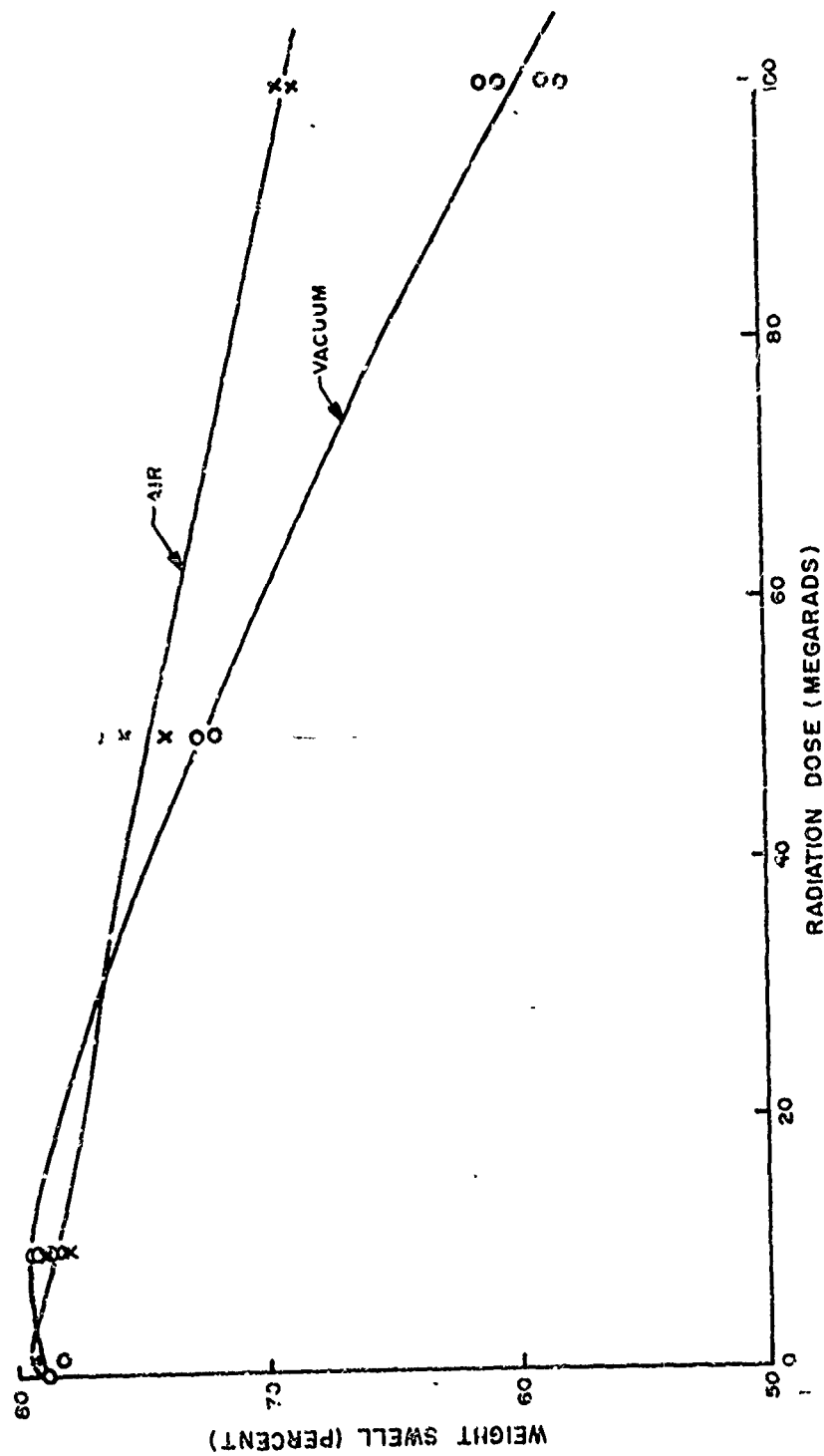
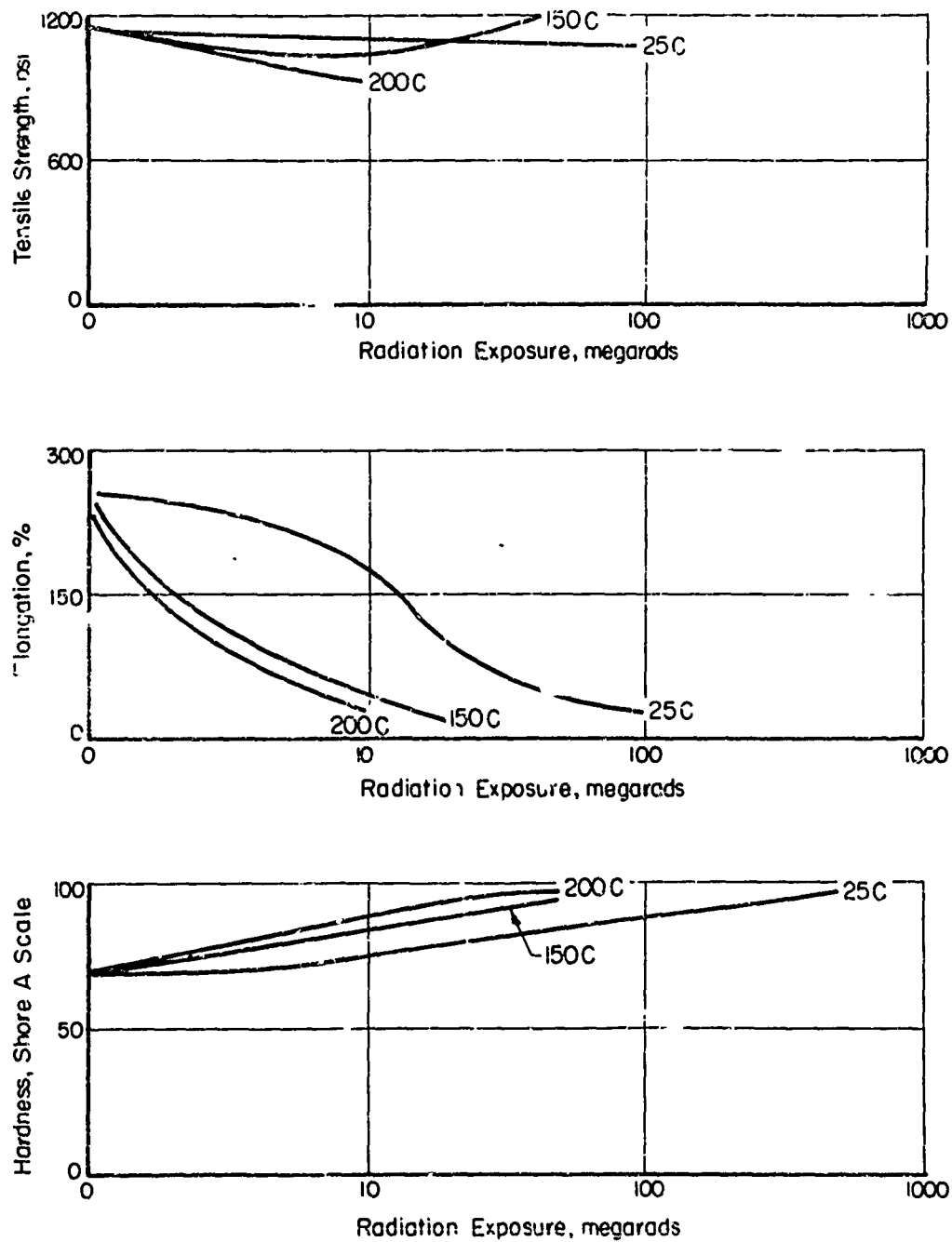
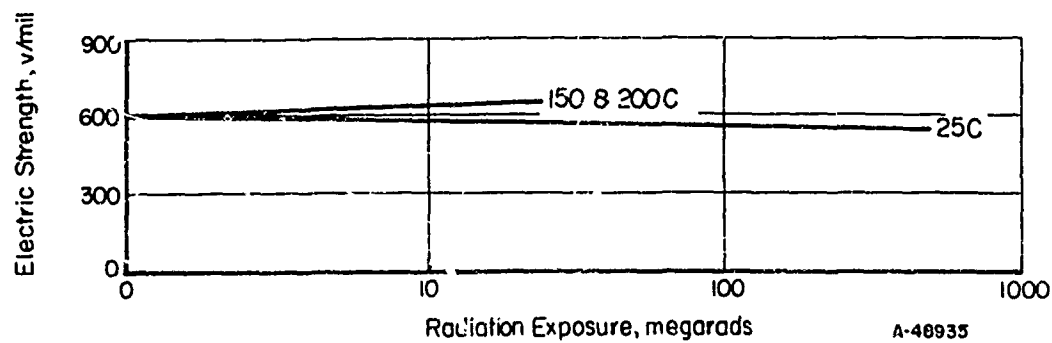
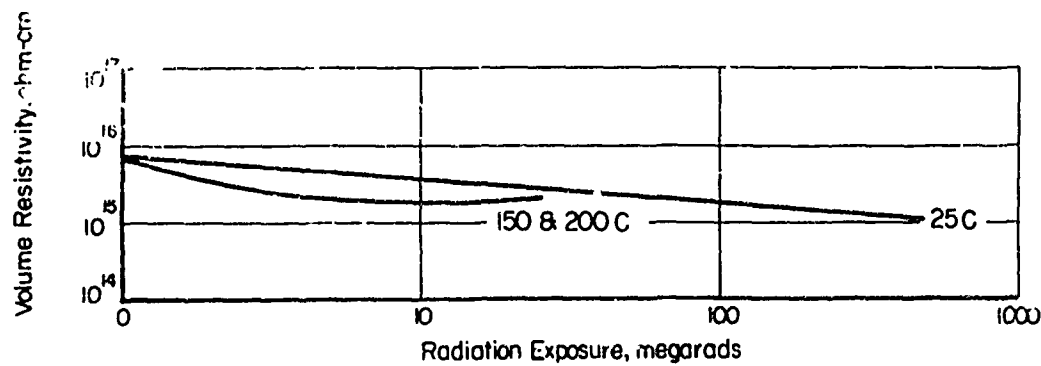
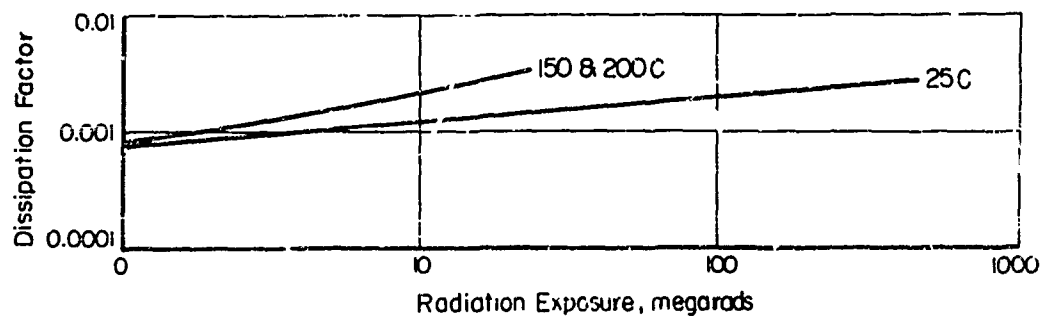
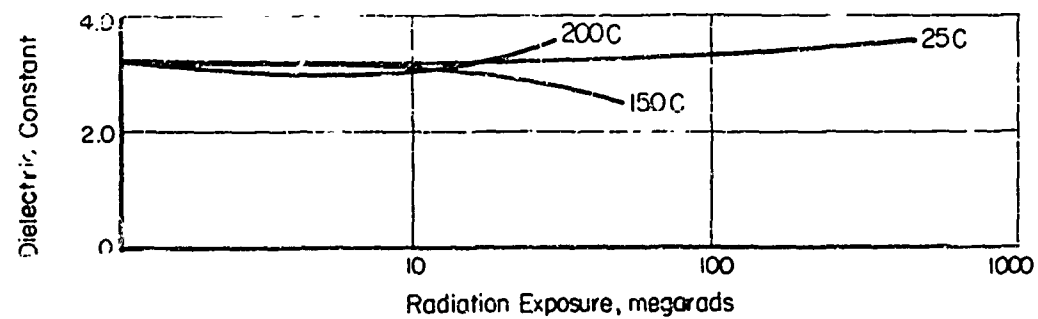


FIGURE B-5. SWELLING OF IRRADIATED POLYURETHANE SPECIMENS IN BENZENE(50)



A-48934

FIGURE B. 6. EFFECTS OF GAMMA RADIATION ON PHYSICAL PROPERTIES OF SILASTIC 1602(36)



A-48935

FIGURE B-7. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILASTIC 1602(36)

APPENDIX C

PLASTICS

TABLE C-1. EFFECT OF ULTRAVIOLET ON PLASTICS(55)

Plastics	Radiation Wavelength Band, Å	Equivalent Dose, hours		Change of Appearance	Weight Loss, %	Quantum Yield, η %	Mass of Released Material
		1300 to 1850 Å	1100 to 1300 Å				
Butyl Compound B-26	1100-1850	123	3600	None	0.14	0.16	N.M.
Epoxy Resin (Epon 828)	1100-1850	37	780	None	0.10	0.15	N.M.
Polyester (Mylar A)	1100-1850	50	565	None	0.2±0.2	0.15	28
Polyester (Mylar A)	2000-4000	--	--	None	0.3±0.3	--	23
Polyethylene (Polyfilm 601)	1100-1850	28	1975	None	0	0.27	N.M.
Polymethyl Methacrylate (Plexiglas "G") Rubbed with cotton	1100-1850	204	645	None	0.13	0.12	N.M.
Polymethyl Methacrylate (Plexiglas "G") No masking paper	1100-1850	66	186	None	0.04	0	N.M.
Polymethyl Methacrylate (Plexiglas "G") No masking paper	1100-1850	150	2200	None	0.5	0.65	28
Polystyrene (Trycite-1000)	2000-4000	--	--	None	0.5	--	28
Polystyrene (Trycite-1000)	1100-1850	128	3500	None	0.1±0.1	0	N.M.
Polystyrene (Trycite-1000)	1100-1850	29	0	None	-0.2±0.2	0	N.M.
Polyvinyl Chloride	1100-1850	130	1000	Yellow discoloration	0	0	N.M.
Polyvinyl Chloride	1100-1850	120	2140	Yellow discoloration	0	0	Not observed
Polyvinyl Chloride	1100-1850	120	2140	Yellow discoloration	0	0	Not observed

C-2

TABLE C-2. PHYSICAL PROPERTIES OF ACRILAN IRRADIATED
IN NITROGEN WITH MONOCHROMATIC LIGHT⁽⁵⁸⁾

Incident Energy, joules/cm ²	Wavelength, mμ	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, per cent
0	-	33.4	3.97	24
179	369	34.3	3.18	20
1269	369	36.0	3.37	36
2200	369	34.6	4.49	18
5644	369	33.8	3.06	48
1082	314	34.0	1.12	38
58	244	36.0	-	33
193	244	31.5	0.82	30
225	244	34.6	1.45	11.5
649	244	18.6	2.83	14

TABLE C-3. PHYSICAL PROPERTIES OF ACRILAN IRRADIATED
WITH G30T8 LAMP⁽⁵⁸⁾

Irradiation Time, hours	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, per cent

A. Irradiated in Nitrogen

0	33.8	3.97	24
24	35.4	3.51	24
90	25.4	-	16
162	23.7	3.85	19

B. Irradiated in a Vacuum

5	31.7	2.30	30
67	29.9	1.92	28
91	29.0	3.78	18
149	27.0	4.42	18

Table C-4. SUMMARY OF EQUILIBRIUM WEIGHT LOSS DATA(4)

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate (gm/cm ² /sec x 10 ¹⁰)
Phenolic	121	760	ND
	121	9.5×10^{-1}	0.4
	121	2.2×10^{-2}	0.9
	177	760	56.1
	177	9.5×10^{-1}	16.0
	177	4×10^{-2}	15.3
	177	10^{-5}	15.0
	204	760	30.1
	204	9.5×10^{-1}	8.6
	204	4.6×10^{-2}	6.5
	204	1.2×10^{-5}	6.5
Epoxy	121	760	ND
	121	9.5×10^{-1}	1.1
	121	7×10^{-2}	1.0
	177	760	11.4
	177	9.5×10^{-1}	4.7
	177	4×10^{-2}	5.0
	177	10^{-5}	4.3
	204	760	97
	204	9.5×10^{-1}	25
	204	3.6×10^{-2}	20
	204	10^{-5}	19
Teflon	149	760	ND
	204	760	ND
	204	9.5×10^{-1}	0.2
Diallyl Phthalate	149	760	12.1
	149	9.5×10^{-1}	3.5
	149	2.3×10^{-2}	2.0
	149	10^{-5}	1.1
	177	760	20.9
	177	9.5×10^{-1}	0.5
	177	1.6×10^{-2}	12.1
	177	10^{-5}	7.7
Mylar	149	760	ND
	149	10^{-5}	ND
Silicone	177	760	3.9
	177	9.5×10^{-1}	2
	177	4×10^{-2}	0.9
	177	10^{-5}	ND

TABLE C-4. (Continued)

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate ($\frac{\text{gm}}{\text{cm}^2/\text{sec}} \times 10^{10}$)
	204	760	46.8
	204	9.5×10^{-1}	9.6
	204	1.6×10^{-2}	3.5
	204	10^{-5}	7.3
	232	760	74.9
	232	9.5×10^{-1}	11.3
	232	6.0×10^{-2}	7.2
	232	10^{-5}	5.7
Viton A	177	10^{-5}	20
Irradiated polyolefin	50	5×10^{-6}	0.13-0.20
Wire insulation N)102E	100		18-2.3
Irradiated polyolefin shrinkable	50	5×10^{-6}	0.18
Tubing type RNF E-201	100	5×10^{-6}	1.1
Nylon (ZYTEL 105)	50	5×10^{-6}	0.13
	100	5×10^{-6}	0.3
Epiall 1288 molding	50	5×10^{-6}	0.44
Compound	100	5×10^{-6}	18
Irradiated polyolefin	50		0.472
Experimental type	100		22-23
Delrin 500	50	5×10^{-6}	0.56
	100		5.5
Epiall 1459 epoxy	50	5×10^{-6}	0.72
Molding compound	100		1.31
Nylon (ZYTEL 31)	50	5×10^{-6}	0.89
	100		0.3
Nylon (ZYTEL 101)	50		0.94
	100		4.2
Delrin 507	50	5×10^{-6}	1.4
	100		4.4

TABLE C-4. (Concluded)

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate (gm/cm ² /sec x 10 ¹⁰)
DAP type 3-2-530	50	5 x 10 ⁻⁶	1.75
	100		3.34
DAP type 52-01	50	5 x 10 ⁻⁶	2
	100	5 x 10 ⁻⁶	4.4
DAP type 1-530	50	5 x 10 ⁻⁶	2.2
	100		3.3
DAP type 1-503	50	5 x 10 ⁻⁶	2.3
	100		3.06
Devcon F epoxy	50	5 x 10 ⁻⁶	2.5
Room temperature cure	100		5
DAP type 3-2-5	50		4.2
	100		3.1
A. Armstrong epoxy	50		10.6
Room temperature cure	100		17.8
Phenolic laminate	50		10.3-12.2
Grade XX natural	100		24.8
Phenolic laminate	50	5 x 10 ⁻⁶	10.8-11.7
Grade LB 103	100		8.9-9.5
Phenolic laminate	50		13.3-14.4
Grade LBB natural	100		10.6-12
Epiall 1552	100	5 x 10 ⁻⁶	12.6
Molding compound			

TABLE C-5. WEIGHT LOSS IN VACUUM OF DIALLYL PHTHALATE, PRESSURE $\sim 5 \times 10^{-6}$ MM Hg⁽¹⁷⁾

Material	Composition	Total Weight Loss to Stationary State, g/cm ²		Time to Stationary State, hours		Stationary State Weight Loss Rate, g/cm ² /hour	
		50 C	100 C	50 C	100 C	50 C	100 C
F-5-5	Meta form, short-glass- fiber filled	2.6×10^{-4}	6.5×10^{-4}	55	88	1.5×10^{-6}	1.1×10^{-6}
3-2-330	Meta form long-glass- fiber filled	1.1×10^{-4}	4.2×10^{-4}	55	88	6.3×10^{-7}	1.2×10^{-6}
52-01	Ortho form, short-glass- fiber filled	1.3×10^{-4}	3.1×10^{-4}	55	64	7.3×10^{-7}	1.6×10^{-6}
1-530	Ortho form, long-glass- fiber filled	1.0×10^{-4}	4.1×10^{-4}	55	64	3.0×10^{-7}	1.2×10^{-6}
1-503	Ortho form, orlon filled	1.2×10^{-4}	5.1×10^{-4}	55	88	8.4×10^{-7}	1.1×10^{-6}

TABLE C-6. FLUOROCARBON PLASTICS -- COMPARATIVE PROPERTIES(64)

Property	PTFE	PFEP	PCTFE	
Crystalline Melting Point, C	327	285	220	
Specific Gravity	2.13-2.20	2.14-2.17	2.10-2.16	
Tensile Strength, psi	1500-3000	1500-3000	4500-5500	
Elongation, per cent	150-450	250-330	100-175	
Compressive Strength, psi				
at 0.2% offset	-	-	5500	
at 1.0% offset	600	-	7850	
at 2.0% offset	-	1400	8400	
Coefficient of Friction against steel	0.04	0.08	0.43	
Hardness, Shore D	65	55	80	
Dielectric Constant	2.10	2.10	2.59	
Dissipation Factor (1000 cps)	<0.0002	<0.0002	0.0215	
Moisture Absorption, per cent	0	0	0	
Water Vapor Transmission Rate 10 mil film, 100% R.H. at 25 C, gms/100 in ² /24 hrs/mil	-	0.310	0.030	
Maximum Recommended Service Temperature, F	500	400	390	
Chemical Resistance	Inert to most chemicals and solvents with the exception of alkali metals. Halogena- ted solvents at high tempera- tures and pressure have some effect.	Impervious to corro- sive chemicals; highly resistant to most organic solvents. Swelling may occur with some highly halogenated and aromatic compounds.		with rated inds.

TABLE C-7. FLUOROCARBON POLYMERS - TENSILE PROPERTIES(a) OF TEFLON 100 FEP AND REINFORCED TEFLON VERSUS IRRADIATION AND MIXED ENVIRONMENTS(48)

Integrated Neutron Flux (N), $n \text{ cm}^{-2}$ ($E > 0.33$)(b)	Teflon 100 FEP(c)				Reinforced Teflon(c)	
	.021 In. Thick		0.115 In. Thick		.030 In. Thick	
	Ultimate, psi	Elongation, %	Ultimate, psi	Elongation, %	Ultimate, psi	psi
Controls	2609/8.5/14	328/5.2/9	2144/8 /10	280/7.6/8	25,303/13 /7	
N 6.3×10^{13} G 1×10^8						
N 2×10^{14} G 2.5×10^8			1883/6.9/10	235/12 /8	20,458/9.5/8	
N 2.8×10^8			1808/3 /10	172/13 /10	20,264/14 /9	
N 2.5×10^{14} G 4.8×10^8	1675/0.5/5	Not brittle				
N 1.1×10^{15} G 7.4×10^8	1662/1.1/5	Not brittle				
N 7.9×10^{15} G 1.2×10^{10}		Brittle		Brittle	10,767/29 /6 (not brittle)	

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Ambient irradiation temperature.

(c) Test temperature 80 F.

TABLE C-8. FLUOROCARBON POLYMERS - TENSILE PROPERTIES(a) OF TEFLON TFE VERSUS IRRADIATION AND MIXED ENVIRONMENT. N^o S(43)

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp, F	Teflon TFE(S)			
		0.010 in. Thick		0.125 in. Thick	
		Air (c) Ultimate, psi	Oronite 8515(c) Ultimate, psi	Air (c) Ultimate, psi	Oronite 8515(c) Ultimate, psi
Control	80	2495/12 /20		2545/9.3/10	
N 1.5-1.7 x 10 ¹⁴ G 1.3-1.4 x 10 ⁸	-65 80 Ambient 275	1481/12 /20	1452/5.2/10 1590/6 /10	1217/5.1/5	1229/1.2/5
N 5.9-6.6 x 10 ¹⁴ G 0.8-1.0 x 10 ⁹	80 Ambient	888/15 /5	1396/4.6/9	1185/5.7/5	1333/1.1/5
N 5.9-6.5 x 10 ¹⁵ G 1.3-1.5 x 10 ¹⁰	80 Ambient	No measurable strength	1641/6.4/6	832/12 /4	1302/6.2/5

(a) Data are given as $\bar{x}$ /S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Irradiation media.

TABLE C-3. FLUOROCARBON POLYMERS - TENSILE PROPERTIES^(a) OF TEFLON TFE VERSUS IRRADIATION AND MIXED ENVIRONMENTS⁽⁴⁸⁾

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) ^(b) Gamma Exposure (G), rads g ⁻¹ (C)	Teflon TFE (C)									
	0.0633 in. Thick		0.011 in. Thick		0.021 in. Thick		0.041 in. Thick		0.115 in. Thick	
	Air (d) Ultimate, psi	Air (d) psi	Air (d) Ultimate, psi	Granite Ultimate, psi	Air (d) Ultimate, psi	Helium (d) Ultimate, psi	Air (d) Ultimate, psi	Air (d) Ultimate, psi	Helium (d) Ultimate, psi	Helium (d) Ultimate, psi
Control	2717/13/10		2886/4.4/6		5503/7/7		3040/6.7/10		3115/8.6/10	
N 2.8 x 10 ¹⁴ G 4.8 x 10 ⁸	1096/21/6		1371/11/10		1293/4.9/10		1197/2.2/8		1035/4.7/10	
N 4.5 x 10 ¹⁴ G 6.3 x 10 ⁸	917/18/4		1128/16/4		1171/7.6/19		1228/2.3/16		1356/2.1/19	
N 7 x 10 ¹⁴ G 1.2 x 10 ⁹	Too brittle						1571/1.8/20		887/12/8	1545/4/20
N 1.6 x 10 ¹⁵ G 2.3 x 10 ⁹			1286/15/5	1684/4.2/10						
N 5.7 x 10 ¹⁵ G 1.1 x 10 ¹⁰			Too brittle		589/22/4		581/16/14		638/20/10	
N 1 x 10 ¹⁶ G 1.7 x 10 ¹⁰							1749/2.4/20			1311/11/19
N 1.5 x 10 ¹⁶ G 2.1 x 10 ¹⁰				1490/13/4						

(a) Data are given as $\bar{x}/S.D./n$, where $\bar{x}$ = average value, S.D. = standard deviation of individual observations estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Ambient irradiation temperature.

(c) Test temperature 80 F.

TABLE C-10. TENSILE PROPERTIES^(a) OF POLYVINYL FLUORIDE FILM, VERSUS IRRADIATION, TEMPERATURE, AND IMMERSION MEDIA^{(c)(8)}

Integrated Neutron Flux (N), n cm ⁻² (E > 0.33 Mev) Gamma Exposure (G), ergs g ⁻¹ (C)	Irradiation Temp, F	Air(c)				MIL-808(c)				Oronite 8615(c)				JP4 Fuel(c)	
		Breaking		Ultimate		Breaking		Ultimate		Breaking		Ultimate		Breaking	
		Strength, lb/in.		Elongation, %		Strength, lb/in.		Elongation, %		Strength, lb/in.		Elongation, %		Strength, lb/in.	
Control	80	56.2/5	/10	74	/9.1/9	56.4/1.3/3	88	/7.7/9	53.4/4.4/10	81/11/9					
		52.3/5	/9	75.6/8.9/9		52.4/4.2/10	77.2/11/9		52.8/5.2/8	79/11/8					
N 1.5-1.8 x 10 ¹⁴ G 1.3-1.6 x 10 ⁸	-65 260	45.9/2.4/10		72.2/9.4/9											
		38.7/2.2/10		70.7/13/7											
N 0.9-1.1 x 10 ¹⁴ G 1.3-1.5 x 10 ⁸	80 260	48.8/8.4/9		80.6/11/8		46.8/3.3/8	67	/11/8							
		51/4.3/10		73/5.4/6											
N 7.0-7.7 x 10 ¹⁴ G 8.0-9.0 x 10 ⁸	-65 80 260	44.8/5/9		73/12/8											
		42.6/8.1/10		75/21/6		46.2/2.8/10	66	/11/10	44.4/2.1/10	63/8/10					
						43.5/4.7/9	56	/6.2/9							
N 1.2-1.3 x 10 ¹⁵ G 1.2-1.3 x 10 ⁹	260	34.8/1.5/9		75.6/13/9					43.8/5.6/9	56/6.8/7					
N 5.0-8.9 x 10 ¹⁵ G 1.0-1.4 x 10 ¹⁰	-65 80 260	39.0/6.9/10		34/14/7											
		37.4/7.3/10		36/9.3/8		40.1/10/10	31	/21/10	36.7/16/8	33/12/6					
		27.5/8.8/8		23/32/7		30/7.2/9	37.8/15/8		22.1/11/7	39/25/6					40.3/5/8 32/13/8
N 4.5 x 10 ¹⁵ G 7 x 10 ¹⁰	80	17.4/20/8		<5/ /3											
		Testar(b), 2 MIL Thick				Testar(b), Laminated 4-MIL Sheet = 0.150 in. Thick				Oronite 8615(c)					
		Breaking		Ultimate		Ultimate		Ultimate		Ultimate		Ultimate			
		Strength, lb/in.		Elongation, %		Tensile, psi		Elongation, %		Tensile, psi		Elongation, %			
Control	80	9.66/7.1/4		230/11/4		5744/12/15	142/14/14								
N 5.0-8.0 x 10 ¹⁵ G 1.0-1.4 x 10 ¹⁰	80 260	4.9/24/4		10/ /4		4618/18/5	16/54/5		3674/4/12	26/47/11					
N 4 x 10 ¹⁴ G 1 x 10 ⁴	Ambient	8.9/9.8/4		115/7.1/4											

(a) Data are given as $\bar{x}$ /S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

(c) Immersion media.

TABLE C-11. DESIGN FOR IRRADIATED TEFLON RESINS*(62)

	Radiation Dose,** $\times 10^8 \text{ Ergs g}^{-1}(\text{C})$	Elongation, per cent	Tensile Strength, psi	Dielectric Constant (± 0.05)
Atmosphere	0	165	3000	2.1
Atmosphere	0.1	152	1882	2.1
Atmosphere	0.5	37	1539	2.1
Atmosphere	1.0	21	1388	2.1
Atmosphere	5.0	--	1322	2.1
Vacuum (10^{-6} mm Hg)	1.0	92	2481	2.1
Vacuum (10^{-6} mm Hg)	5.0	73	1972	2.1
Vacuum (10^{-6} mm Hg)	51.0	38	1462	2.1
Vacuum (10^{-6} mm Hg)	150.0	16	800	2.1

* These data also apply to Teflon FEP resin. Actual experimental data even indicate a slight improvement in the above characteristics for this material. Radiation source was Co^{60} isotope emitting gamma rays at 1.3×10^6 rads/hour. Temperature was 25 C (77 F). Sample was 0.010-inch film of a Teflon FFE resin. Note that values for tensile strengths and elongations are known to be conservative based on current techniques of end-product fabrication.

** Conversion factors useful for determining performance expectancies for other-than gamma radiation follow: 1 rad = 1.2 roentgens; 1 rad = 1×10^{10} thermal neutrons/ cm^2 = 1×10^{10} Nvt; 1 rad = 2.8×10^3 fast neutrons/ cm^2 (2 Mev); 1 rad = 1.4×10^5 gamma protons/ cm^2 (2 Mev); 1 rad = 5.2×10^7 electrons/ cm^2 (1 Mev).

TABLE C-12. TENTATIVE ASSIGNMENTS OF INFRA-RED PEAKS⁽⁸²⁾

Infra-red Peak (cm^{-1}) Due to Irradiation in:		Tentative Assignment
Vacuum	Air	
--	3472	COOH
--	3096	COOH
--	1880 enhanced	
--	1757	COOH
1350	1350	)
		) Unsaturation?
981.8	983.7	)

TABLE C-13. LOW-FORCE DYNAMIC TEST RESULTS: RUN II, June 4, 1963(7)

Material Trade Name	Test Condi- tion	Radiation Exposure		Tensile Strength ^a (psi)			Ultimate Elonga- tion, %	Ultimate Elonga- tion, % at 100°C	Temperature Avg. (F)	Pressure Avg. (torr)		
		Gamma [ergs/ gm(C)]	Neutron [n/cm ²]	25 % Elonga- tion	50 % Elonga- tion	100 % Elonga- tion						
Teflon TFE Film 10 mil	Vacuum Irradia- tion	5.08(8)	8.31(12) 6.98(13)	2.77(12)	2090	2225	2575	2650	109.1	2.5(-7)		
					2160	2180	2350	2460	114.2			
					2065	2120	2320	2860	159.3			
					2105/56			2175/62	2415/151		2657/236	127.529.7
Kel-F-81	Vacuum Irradia- tion	5.08(8)	8.31(12) 6.98(13)	2.77(12)	Flexural Strength			---	---	---		
					Maximum							
					Fiber	Fiber	Fiber					
					Stress	Strain	Modulus					
					(psi)	in./in.	(psi)					
					12,278	0.092	135,679	---	---	---		
					9,300	0.076	137,070	---	---	---		

(a) Values given as: average value/standard deviation on an individual basis.

(b) Figures showing plotted data to be presented and listed in the annual report.

TABLE C-14. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS^(6,7)

Material Trade Name	Test Condi- tion	Radiation Exposure		Time Unbl Test, days	S. T. weight Original, gm Change, gm	Tensile Strength (psi) at 25% elongation at 100%		Ultimate Elonga- tion, percent	Temper- ature Avg., (°F)	Prags. Avg., (bars)
		Gamma [rads/] gm[²]	Neutron (n/cm ²) Thermal D-2.9 Mev D-8.1 Mev			Elongation	Ultimate			
Section TPR Air (10 mil)	0	0	0 (control specimens)	—	—	—	—	—	—	—
Al ₂	6.5(7)	3.5(12)	1.4(13) (air irradiation)	11	—	—	—	—	90	—
Air	1.5(8)	3.5(12)	3.0(13) (air irradiation)	11	—	—	—	—	60	—
Air	6.8(8)	2.4(13)	1.2(14)	2	—	—	—	—	—	—
Air	7.5(7)	4.6(14)	5.5(12) (vacuum irradiation)	7	—	—	—	—	—	—
Air	9.1(7)	7.9(12)	1.7(13) (vacuum irradiation)	9	—	—	—	—	—	—
Air	1.68(8)	1.7(12)	1.9(13) (vacuum irradiation)	10	—	—	—	—	—	—
Air	4.45(8)	1.95(13)	5.45(13) (vacuum irradiation)	10	—	—	—	—	—	—
Air	5.08(8)	8.31(12)	6.94(13) (vacuum irradiation)	9	—	—	—	—	—	—

TABLE C-14. Continued

Material Test Trade Name	Gamma [grg/cm ²]	Radiation Exposure		Time Test, Days	Sample Change, gm	Tensile Strength (psi)			Ultimate Temperature	
		Thermal D ₂ -9 Mev D ₂ -1 Mev	Neutron (n/cm ²)			at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate tension, percent	Ultimate tension, AVG., (F)
Air	6.5(7)	3.5(12) (air irradiation)	1.4(13)	16	6.0(11)	2000	2000	2130	2420	80
						2000	2000	2130	3550	370
						2000	2070	2130	2800	300
						2000	2100	2130	2100	240
Air	6.8(8)	2.4(13) (air irradiation)	1.2(14)	16	4.9(12)	2000	2000	2030	2300	140
						1950	2000	2000	1250	220
						1950	1970	1970	1250	110
						1950	1950	1950	1400	110
Air	7.5(7)	4.8(12) (vacuum irradiation)	5.2(12)	9	2.35(11)	2050	2100	2160	3600	365
						2050	2100	2160	4020	400
						2050	2100	2150	3700	380
						2050	2100	2150	3830	385
Air	1.6(5)	8.4(12) (vacuum irradiation)	1.05(13)	9	7.6(11)	2070	2150	2200	3570	365
						2070	2110	2160	3280	330
						2070	2110	2160	3280	330
						2070	2110	2160	3280	330
Air	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	10	2.1(12)	1940	2010	2070	2230	270
						1940	1990	2060	2420	240
						1940	1990	2060	3000	300
						1940	1990	2060	2120	275
Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	16	1.1(12)	1940	2010	2070	2230	270
						1940	1990	2060	2420	240
						1940	1990	2060	3000	300
						1940	1990	2060	2120	275
Air	6.8(8)	2.4(13) (air irradiation)	1.2(14)	16	4.9(12)	2000	2000	2030	2300	140
						1950	2000	2000	1250	220
						1950	1970	1970	1250	110
						1950	1950	1950	1400	110

TABLE C-1'. (Continued)

Material Trade Name	Test Condition	Radiation Exposure		Time Until Test, day	Sample Weight, gm	Tensile Strength, (psi)		Elongation, percent	Ultimate Tensile Strength, (psi)	Elongation, percent	Temperature, (F)	Pressure, (torr)
		Gamma [rads/gm(C)]	Neutron D=2.9 Mev D=8.1/cm ²			Original, (psi)	at 100% Elongation, (psi)					
Air	9-1(7)	7.8(12)	1.7(13)	7.0(11)	8	5.492 5.4134 5.4191 5.3982 5.4775	1886 1933 1933 1933 1933	1933 1933 1933 1933 1933	2952 315 315 315 315	320	60	1.7(-7)
Air	3-9(8)	1.9(13)	4.4(13)	1.7(12)	7	5.3818 5.3817 5.4215 5.4641 5.4252	1809 1809 1917 1913 1899	1887 1922 1941 1943 1899	2231 2246 2427 2294 1889	330 315 315 336 300	90	1.7(-7)
Kel-F-BL	0	0	0	0	—	4.622 4.495 — 4.221 4.377/4.219	4622 4561 4286 4221 4385/428	4558 4462 4284 4347 4375/436	5897 5619 5081 5513 6070	176 200 200 180 185	—	—
Air	0.5(7)	3.5(12)	1.4(13)	6.0(11)	14	— 4.178 4.622 4.204 4.333 4.367/4.239	— 4211 4106 4016 4111/4115	— 4275 4149 4161 4187/4179	5177 5409 5080 5219 5276/5260	15* 205 150 205 187/32	60	—
Air	1.5(8)	3.3(12)	3.0(13)	1.1(12)	14	4.166 4.175 4.157 4.313 4.367/4.239	4399 4312 4269 4337 4286/4111	4166 4344 4285 4143 4238/4167	5477 5431 5345 5231 5354/503	180 200 185 180 187/9	60	—
Air	6.8(8)	2.4(13)	1.2(14)	4.9(12)	14	3.976 3.988 4.016 3.941 4.142 3.973/3.935	3976 3988 3944 4027 3954 3797/375	— 3954 4016 4071 3943 4009/371	5276 5227 5173 5110 5249 5307/511	140* 190 210 215 200 204/12	60	—
Air	7.5(7)	4.6(12)	5.2(12)	2.3(11)	8	22.2016 22.5782 22.1667 16.6396 23.5746	4590 4590 4590 4590 4590	4590 4717 4637 4521 4481 4559/4360	5605 5610 5610 5521 5481 5605/559	104 150 170 145 182 350/34	80	1.7(-7)

TABLE C-14. (Concluded)

Material Test Trade Name	Radiation Exposure	Time	Sample Weight	Tensile Strengths (psi)			Elongation		Ultimate Tension, percent	Ultimate Temperature Avg. (F)	Press. Avg. (torr)
				Original, Change, gm	at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate Elongation			
Kcl-P-81	9.1(7) 7.8(12) 1.7(13) (vacuum irradiation)	8	22.2692	-0.0006	4405	4340	4405	202	5655	80	1.7(-7)
			22.4512	-0.0007	3841	3777	3809	168	5633		
			21.9510	-0.0040	4487	4520	4404	175**	5626		
			16.8468	-0.0010	4538	4528	4528	177	5184		
			23.5801	+0.0002	4330	4306	4367/4363	172/172	5347/108		
Air	4.5(8) 7.95(13) 5.45(13) (vacuum irradiation)	10	22.6419	-0.0008	4437	4405	4373	165	5733	90	1.7(-7)
			22.0044	-0.0068	4599	4532	4587	185	5798		
			16.7075	+0.0007	4779	4807	4779	175	5367		
			16.7083	-0.0007	4586	4552	4586	180	5436		
			23.1123	-0.0001	4448	4330	4371	200	5416		
					4437/4306	4367/4363	4376/429	184/15	5590/555		

* Values given as: average to value/standard deviation on an individual basis.

** Data point not used in average.

TABLE C-15. EFFECT OF NUCLEAR γ RADIATION ON FLUOROCARBONS (6, 7)

[illegible]

TABLE C-15 (Concluded)

Material Test Name	Gamma Dose (Mrad)	Radiation Exposure		Time Test, days	Sample Weight, Original, Change, gm	Tensile Strength, psi		Elongation, percent		Press. Avg., (torr)
		Neutron (Mrad)	Thermal (Mrad)			at 50% Elongation	at 100% Elongation	at 50% Elongation	at 100% Elongation	
Tedlar										
(2 mil) Air	0	0	(control specimen)	—	—	5900	6150	—	9900	245
						5750	5750	—	9250	227
						5750	5750	—	9650	276
						5900	6000	—	9350	255
3630/157						5900	5910/172	—	9460/322	247/23
Air	1.5(8)	3.3(12)	3.0(13) (air irradiation)	12	—	5250	5400	5750	6350	355
						5900	5400	5750	6350	350
						5400	5400	5750	6350	350
						5400	5400	5750	6350	350
3470/172						5400/125	5750/150	6350/13	8680/451	261/13
Air	1.5(9)	1.8(13)	2.5(14) (air irradiation)	12	—	5350	5350	5400	6350	190
						5400	5750	5750	6350	225
						5750	5750	5750	6350	260
						5250	5350	5400	6350	230
5400						5400	5500	6350	8000	260
5470/215						5500/172	5600/193	6350/233/50	8680/451	261/13
Air	9.1(7)	7.8(12)	1.7(13) (vacuum irradiation)	9	—	6000	6250	6900	10000	260
						6250	—	7500	—	—
						6100	5750	—	10000	285
						6250	—	9650	220	
5900						6000	6150	6350	10250	340
6100/150						6000/295	6350/2	9560/1247	271/19	—
Air	4.45(8)	1.95(13)	5.15(13) (vacuum irradiation)	8	—	—	—	—	—	225
						5800	—	—	9100	218
						6150	—	—	9650	240
						6150	—	—	9350	240
6150						6000	6350	10250	340	—
6100/267						6000/170	6350/2	9560/1247	271/19	—
Air	2.8(13)	5.1(14)	5.6(12) (vacuum irradiation)	8	—	—	5750	5900	5900	235
						6150	—	—	9100	218
						6150	—	—	9650	240
						6150	—	—	9350	240
6150						6000	6350	10250	340	—
6100/267						6000/170	6350/2	9560/1247	271/19	—

Values given are: average value/standard deviation; on an individual basis.

TABLE C-16. VACUUM DATA FROM OTHER WORK⁽⁶³⁾

Mo 1 % Gases Evolved							
	Weight of Samples, gm	Temperature, C	H ₂ O	CO ₂	N ₂	O ₂	Volume of Gas, cc/gm
Teflon TFE*	0.9010	71	12.07	--	62.51	25.42	0.0067
	0.9010	180	14.10	--	64.64	21.26	0.0164
	0.9010	200	6.28	1.78	72.88	19.06	0.0172

* Pressure at 10^{-6} mm Hg.

TABLE C 17. PHYSICAL PROPERTIES OF TEFLON FILMS IRRADIATED WITH MONOCHROMATIC LIGHT⁽⁵⁸⁾

Incident Energy, joules/cm ²	Wavelength, mμ	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ³ psi	Elongation, per cent
52.3	244	10.4	--	142
78.5	244	11.36	4.4	178
103.0	244	9.08	4.6	120
252.0	244	6.52	5.6	44

Irradiated with Nitrogen

0	-	4.02	0.0965	1164
5644	369	4.14	0.167	850
649	314	4.40	0.144	950
1180	314	3.68	0.174	745
132	244	3.68	0.0832	725
300	244	3.48	0.076	700
497	244	3.08	-	800

Each of the observations recorded was an average of two separate measurements, except for the controls, which were averages of 8-10.

TABLE C-18. PHYSICAL PROPERTIES OF TEFLON FILMS
IRRADIATED WITH A G30T8 LAMP(58)

Irradiation Time, hours	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, per cent
<u>C. Teflon Irradiated in Nitrogen</u>			
0	4.02	0.0965	1164
92	4.00	-	1086
120	3.90	0.0972	750
559	3.79	0.0968	770
<u>D. Teflon Irradiated in a Vacuum</u>			
40	3.80	0.0564	1160
68	3.46	-	-
139	3.04	0.0590	520
146	2.85	0.057	500
167	2.59	0.0510	520

TABLE C-19. TEST RESULTS - BEFORE AND AFTER THERMAL IRRADIATION(68)

Nylon 66

Sample Designation	Pre-treatment	Temperature, C	Time of Exposure, hours	Atmosphere	Physical Condition	Solvent	Concentration, g/dl	Viscosity at 30 C, cp	Relative* Viscosity	Inherent** Viscosity	Melting Point, C
0	—	—	—	—	Transparent flexible	CaCl in CH ₃ OH	2.00	73.51	2.38	0.43355	254-260
1	—	66	3	Vacuum	No change	Ditto	2.00	121.71	3.94	0.68559	251-255
2	—	66	7	Vacuum	Ditto	"	2.00	121.41	3.94	0.68559	254-258
3	—	66	24	Vacuum	"	"	2.00	105.71	3.42	0.61482	255-258
4	2 hr vac at 100	275	2	Vacuum	Fused, dark	"	Insol.	—	—	—	213-260
5	2 hr vac at 150	275	2	Vacuum	Fused, dark	"	Insol.	—	—	—	213-258
6	4 hr vac at 100	200	2	Vacuum	Yellow, slightly brittle	"	2.00	83.66	2.71	0.49848	251-254
7	4 hr vac at 66	250	2	Vacuum	Slight yellowing	"	2.00	106.91	3.46	0.62063	256-258
8	24 hr vac at 89	180	4	Vacuum	Slight yellowing	"	2.00	87.98	2.85	0.52366	254-256
9	24 hr vac at 66	180	4	Vacuum	Slight yellowing	"	2.00	93.36	3.02	0.52222	254-256

* Relative viscosity = η_r = viscosity of the solution/viscosity of the solvent.
Viscosity of the solvent CaCl₂-CH₃OH = 30.85 cp.

** Inherent viscosity = η_i = $\ln \eta_r / c$.

TABLE C-20. PHYSICAL PROPERTIES OF PLASTIC FILMS
IRRADIATED WITH MONOCHROMATIC LIGHT⁽⁵⁸⁾

Incident Energy, joules/cm ²	Wavelength, mμ	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, percent
<u>A. Polyethylene Irradiated in Nitrogen</u>				
0	-	5.52	5.90	512
179	369	7.04	2.49	270
2200	369	7.49	4.6	342
3160	369	5.77	4.62	343
475	314	5.59	4.95	290
623	314	6.28	2.25	290
1053	314	4.09	4.92	225
87	244	5.86	5.39	95
290	244	4.05	6.17	50
400	244	2.07	4.93	16
<u>A. Polyethylene Irradiated in a Vacuum</u>				
527	244	7.41	4.09	232
595	244	7.48	5.51	190
<u>B. Mylar Irradiated in Nitrogen</u>				
0	-	17.3	2.64	46
1269	369	20.1	1.32	36
3096	369	7.68	1.36	40
585	314	14.46	1.5	17
921	314	6.30	7.75	18
58	244	16.7	2.47	47
57	244	15.6	2.10	28
225	244	12.46	2.69	7
314	244	12.1	3.02	11
<u>B. Mylar Irradiated in a Vacuum</u>				
1375	244	6.56	1.42	11

TABLE C-20. (Concluded)

Incident Energy, joules/cm ²	Wavelength, mμ	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, percent
<u>C. Nylon Irradiated in Nitrogen</u>				
0	-	11.32	4.6	153
158.5	369	11.24	4.0	203
376.1	369	10.28	6.8	157
1234	369	11.6	-	133
2700	369	11.02	6.4	137
89	314	10.8	6.4	140
336	314	11.04	5.4	168
1234.4	314	11.56	6.5	133
1450	314	10.82	5.2	182

TABLE C-21. PHYSICAL PROPERTIES OF PLASTIC FILMS
IRRADIATED WITH A G30T8 LAMP(58)

Irradiation Time, hour	Tensile Strength, 10 ³ psi	Young's Modulus, 10 ⁵ psi	Elongation, percent
<u>A. Polyethylene Irradiated in Nitrogen</u>			
0	5.52	5.90	512
8	6.24	4.47	550
24	4.32	2.09	200
47	2.82	5.62	95
72	2.08	4.95	6
154	1.57	3.9	7
<u>B. Polyethylene Irradiated in Vacuum</u>			
22	6.24	5.70	520
48	4.82	5.73	270
68	5.02	7.13	100
168	3.28	3.21	8
<u>C. Teflon Irradiated in Nitrogen</u>			
0	4.02	0.0965	1164
92	4.00	--	1086
120	3.90	0.0972	750
559	3.79	0.0968	770
<u>D. Teflon Irradiated in a Vacuum</u>			
40	3.80	0.0564	1160
68	3.46	--	--
139	3.04	0.0590	520
146	2.85	0.057	500
167	2.59	0.0510	520
<u>E. Nylon Irradiated in Nitrogen</u>			
0	8.32	2.46	131
42	8.96	3.31	135
78	6.32	3.08	80
180	3.56	6.17	14

TABLE C-21. (Concluded)

<u>Irradiation Time,</u> hour	<u>Tensile Strength,</u> 10 ³ psi	<u>Young's Modulus,</u> 10 ⁵ psi	<u>Elongation,</u> percent
<u>F. Nylon Irradiated in a Vacuum</u>			
8	8.36	2.2	230
24	7.92	3.75	260
68	7.06	3.75	182
140	7.04	5.73	161
190	6.8	11.03	111
<u>G. Mylar Irradiated in Nitrogen</u>			
0	17.3	2.64	46
22	13.5	1.28	21
45	13.6	--	14
161	10.5	1.98	12
192	9.7	1.37	2
<u>H. Mylar Irradiated in a Vacuum</u>			
28	18.0	1.89	54
68	17.5	1.63	58
120	15.6	1.30	30
172	14.0	2.14	11
190	13.8	1.90	14

TABLE C-22. EFFECTS OF RADIATION ON MYLAR(7)

Material Trade Name	Test Condi- tion	Gamma Ergs/ gm(C)	Radiation Exposure		Time Until Test, days	Sample Original, gm	Weight Change, gm	Tensile Strengths (psi)			Ultimate Elonga- tion, percent	Ultimate Temp- ature Avg., (F)	Press. Avg., (torr)	
			Thermal E>2.9 Mev E>8.1 Mev	Neutron n/cm ²				at 25% Elongation						
								Elongation	Elongation	at 100% Elongation				
Mylar C	Air	0	0 (control specimens)	0	—	—	—	16,300	19,200	—	21,300	50	—	
								16,000	17,100	—	—	—	—	
								16,200	16,700	24,500	24,500	50	—	
								16,300	17,500	24,000	28,500	21	—	
Air	0.6(6)	2.4(13) (air irradiation)	1.2(14)	4.9(17)	13	—	—	16,200/159	19,580/731	24,333/295	25,706, 3-5	97/3-	—	
								15,500	17,500	21,000	23,000	—	—	
								15,200	17,500	17,300	24,500	—	—	
								14,500	16,500	—	16,000	70	—	
Air	1.36(9)	1.6(13) (air irradiation)	2.5(17)	9.5(12)	13	—	—	15,000	17,000	22,500	25,000	100	—	
								15,200/301	17,200/301	20,475/157	22,700, 421	97/2c	—	
								15,500	16,300	21,500	23,000	105	—	
								15,200	17,500	21,500	24,500	125	—	
Air	0.0(5)	—	1.20(15) (air irradiation)	—	16	—	—	15,000	—	—	16,700	35	—	
								—	—	—	18,000	60	—	
								—	—	—	20,000	70	—	
								—	—	—	—	—	—	
Mylar C	Air	4.45(6)	1.95(17) (vacuum irradiation)	5.45(13)	2.1(12)	9	—	16,300	18,600	—	19,500, 1945	57/2f	—	
								—	—	—	24,000	90	4-7)	
								16,500	19,000	—	21,000	110	—	
								16,500	18,500	22,000	27,000	160	—	
Air	9.1(8)	2.8(13) (vacuum irradiation)	1.6(14)	6.0(13)	9	—	—	16,500	19,250/729	24,000/4	25,325/224	100/2f	—	
								16,000	18,500	24,500	24,000	100	4-7)	
								16,000	19,300	—	23,000	90	—	
								16,000	19,000	—	20,000	96	—	
Mylar A	Air	5.9(9)	1.8(14) (vacuum irradiation)	6.56(14)	—	7	—	16,000	18,500	—	20,000	96	—	
								16,000	18,500	—	20,000	96	—	
								16,000	18,500	—	20,000	96	—	
								16,000	18,500	—	20,000	96	—	
Air	1.05(10)	1.32(14) (vacuum irradiation)	1.05(15)	5.9(13)	7	—	—	16,000/516	16,700/129	—	17,402, 430	97/15	—	
								—	—	—	17,600	110	160	5-7)
								—	—	—	17,500	25	—	—
								—	—	—	17,500	15	—	—
Air	1.3576	—	—	—	—	—	—	16,500	18,500	—	20,000	96	—	
								—	—	—	23,785/2514	90/5	—	—
								—	—	—	17,402	100	160	5-7)
								—	—	—	17,600	110	160	5-7)
Mylar B	Air	1.3976	—	—	—	—	—	16,000	18,500	—	20,000	96	—	
								—	—	—	23,785/2514	90/5	—	—
								—	—	—	17,402	100	160	5-7)
								—	—	—	17,600	110	160	5-7)

TABLE C-22. (Concluded)

Material Test Trade Name	Condition	Radiation Exposure		Time Until Test, days	Dry Weights		Tensile Strength* (psi)			Ultimate Temperature	
		Gamma	Neutron		Original, gm	Change, gm	at 25%	at 50%	at 100%	Ultimate	Temperature
		mr(C)	D-2.9 Mev		gm	gm	Elongation	Elongation	Elongation	percent	(F)
Mylar A	Air	0	0	0	—	—	16,300	17,000	18,000	20,500	119
		0	(control specimens)	0	—	—	16,600	17,600	19,700	22,500	132
		0	0	0	—	—	16,500	17,500	19,500	19,800	100
Air	6.8(R)	2.4(13)	1.2(14)	4.9(12)	—	—	16,500	17,200	18,600	21,800	140
		(air irradiation)	(air irradiation)		—	—	16,500	17,200	18,600	21,800	130
		0	0	0	—	—	16,500	17,200	18,600	21,800	125
Air	1.27(10)	1.9(14)	2.3(15)	8.2(13)	—	—	16,500	17,200	18,600	21,800	150
		(air irradiation)	(air irradiation)		—	—	16,500	17,200	18,600	21,800	136/12
		0	0	0	—	—	16,500	17,200	18,600	21,800	100
Air	4.45(8)	1.9(13)	5.45(13)	2.1(12)	1.4195	+0.0003	16,500	17,200	18,600	21,800	80
		(vacuum irradiation)	(vacuum irradiation)		1.4099	+0.0001	16,500	17,200	18,600	21,800	79/79
		0	0	0	1.4097	+0.0005	16,500	17,200	18,600	21,800	105
Air	1.8 04	0	0	0	1.4097	+0.0005	16,500	17,200	18,600	21,800	132
		0	0	0	1.4097	+0.0005	16,500	17,200	18,600	21,800	135
		0	0	0	1.4097	+0.0019	16,500	17,200	18,600	21,800	110
Air	1.8 04	0	0	0	1.4097	+0.0019	16,500	17,200	18,600	21,800	110
		0	0	0	1.4097	+0.0019	16,500	17,200	18,600	21,800	110
		0	0	0	1.4097	+0.0019	16,500	17,200	18,600	21,800	110

* Values given as: average value/standard deviation on an individual basis.

TABLE C-23. HIGH-VACUUM TESTING OF MYLAR PLASTIC FILM(57)

Test No. of No. Samples	Mylar Thickness, mils	Aluminum Coating Thickness, A	Aluminum Coating Application	Test Duration, hours	Temperature, C	Ultimate Vacuum, mm Hg	Weight Loss, μ g/sq cm	Remarks
1	1	3	None	72	Room	10 ⁻⁶	8.6	Apparent decrease in flexibility
1	1	1	None				14	
1	1	0.1	None				0.0	
2	1	1	Coated on one side only	72	Room	10 ⁻⁶	0.0	Apparent decrease in flexibility
1	1	250					0.0	
3	Same samples as above	250	Coated on one side only	72	100	10 ⁻⁵	20	Warping, wrinkling, and loss of flexibility
2		100					13	
2		50					17	
4	2	3	Uncoated One side* Both sides*	72	150	10 ⁻⁵	Results in- valid, due to error in weighing	Warping, wrinkling, and loss of flexibility
2		None					100.0, 113.0	
2		Coated					19, 44	
2		Coated					31, 31	
5	2	3	Uncoated One side* Both sides*	72	150	10 ⁻⁵	100.0, 113.0	Warping, wrinkling, and loss of flexibility
2		None					19, 44	
2		Coated					31, 31	

* Thickness not regulated on these samples.

TABLE C-24. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON FILMS(46)

Material	Type of Exposure*	Temperature, F	Exposure Time, hours	Weight Change, per cent	Tensile Strength		Break Elongation	
					Before Exposure, psi	After Exposure, psi	Before Exposure, in./in.	After Exposure, in./in.
Polyethylene terephthalate, aluminized one side	Vacuum	75 to 80	168	-0.02	25,200	23,600	1.08	0.96
	Vacuum	55 to 60	770	+0.04	26,200	23,000	1.414	1.039
	Vacuum and ultraviolet	85 to 95	770	+0.37	26,200	14,900	1.414	0.174
Polyvinyl fluoride, Type 20, clear	Vacuum	75 to 80	168	Not measurable	12,150	12,375	1.112	1.135
	Vacuum	55 to 60	770	+0.29	14,700	13,400	0.965	0.915
	Vacuum and ultraviolet	85 to 95	770	-1.57	14,700	10,500	0.965	0.296

* Maximum vacuum pressures on the order of 5×10^{-6} mm Hg.

TABLE C-25. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION
ON SEAMED FILMS*(46)

Exposure Time of 770 Hours

Material	Time of Exposure	Temperature, F	Weight Change, per cent	Tensile Strength	
				Before Exposure, psi	After Exposure, Change, per cent
Polyethylene terephthalate, 1 mil, aluminized one side, butt-seamed with 1/2 in. heat-sealable poly-ster-matin-coated polyethylene-terephthalate tape	Vacuum	55 to 60	0.00	22,200	22,100 -0.2
	Vacuum and ultraviolet	85 to 95	+0.24	22,200	15,600*** -29.5
Polyethylene terephthalate, 1 mil, aluminized one side, butt-seamed with 3/4-in. pressure-sensitive, silicone-adhesive-coated polyethylene-terephthalate tape	Vacuum	55 to 60	+0.06	15,000	15,100 +0.7
	Vacuum and ultraviolet	85 to 95	+0.08	15,000	15,800*** +5.3
Polyethylene terephthalate, 1 mil, aluminized one side, butt-seamed with 1/2-inch polyethylene-terephthalate tape and solvent-type adhesive	Vacuum	55 to 60	-0.57	15,600	16,900 +8.1
	Vacuum and ultraviolet	85 to 95	-1.13	15,600	8,170 -48.3
Polyethylene terephthalate, 1 mil, aluminized one side, butt-seamed with 1/2-inch polyethylene-terephthalate tape and Pliobond+ solvent-type adhesive	Vacuum	55 to 60	-0.71	19,500	21,300 +9.4
	Vacuum and ultraviolet	85 to 95	-3.23	19,500	14,700*** -24.5
Polyvinyl fluoride, 1 mil, clear, 1/16-inch lap-seamed, heat-sealable	Vacuum	55 to 60	+0.04	9,400	9,600 +2.1
	Vacuum and ultraviolet	85 to 95	-1.48	9,400	9,800 +5.0

* All values are the averages of three specimens. Tapes applied to non-luminized side.

** Maximum vacuum pressures on the order of 5 x 10⁻⁶ mm Hg.

*** Specimen failure did not occur in seam.

+ Goodyear Tire and Rubber Company adhesive.

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TABLE C-26. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS: HIGH DENSITY POLYETHYLENE (7)

[illegible]

TABLE C-27. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO ELEVATED TEMPERATURE(76)

	Tenacity, grams/denier			Strength Retained, %		
	Int.		Olive	Int.		Olive
	Natural	Orange	Green	Natural	Orange	Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 400 F	5.54	6.03	5.83	93.6	103.07	104.4
Original + 2 Hr at 500 F	5.09	5.50	4.20	85.9	94.0	75.5
Original + 2 Hr at 600 F	2.13	3.29	2.86	37.0	56.3	51.3

TABLE C-28. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO ELEVATED TEMPERATURE(76)

	Elongation, %			Elongation Retained, %		
	Int.		Olive	Int.		Olive
	Natural	Orange	Green	Natural	Orange	Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 400 F	12.3	12.6	12.0	86.6	112.5	100.0
Original + 2 Hr at 500 F	10.3	11.6	7.6	72.5	103.5	63.3
Original + 2 Hr at 600 F	2.2	5.5	3.9	15.5	49.2	32.5

TABLE C-29. STRENGTH PROPERTIES OF NOMEK YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (400 F)⁽⁷⁶⁾

	Tenacity, grams/denier			Strength Retained, %		
	Natural	Int.		Natural	Int.	
		Orange	Olive Green		Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 400 F	5.54	6.03	5.83	93.6	103.07	104.4
Gamma, 7.0×10^8 (a)	5.32	5.95	5.69	89.8	101.7	101.9
Gamma, $7.0 \times 10^8 + 2$ Hr at 400 F	6.22	6.46	5.70	105.06	110.4	102.1
Gamma, $7.0 \times 10^8/400$ F(b)	5.30	5.54	5.81	88.5	94.7	104.1
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 400 F(b)	5.40	5.82	5.51	91.4	99.5	98.8
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 500 F	4.41	5.26	2.38	74.5	89.9	42.7
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 600 F	2.56	2.87	2.38 ^(a)	43.3	49.1	42.7
Gamma, 1.4×10^9 (a)	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, $1.4 \times 10^9 + 2$ Hr at 400 F	5.58	5.98	5.58	94.3	102.2	100.0
Gamma, $1.4 \times 10^9/400$ F	4.76	5.54	3.31	80.5	94.7	59.3
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 400 F	4.02	5.04	2.98	67.9	86.2	53.4
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 500 F	5.11	4.25	2.38	86.4	77.7	42.7
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 500 F	3.47	3.73	2.92 ^(a)	58.6	63.8	52.5

(a) Normal operating temperature, approx. 100 F.

(b) F indicates gamma and temperature simultaneously + hours at F indicates oven aging.

(c) Frayed and brittle.

Note: Gamma exposure in $\text{ergs g}^{-1}(\text{C})$.TABLE C-30. STRENGTH PROPERTIES OF NOMEK YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (500 F)⁽⁷⁶⁾

	Tenacity, grams/denier			Strength Retained, %		
	Natural	Int.		Natural	Int.	
		Orange	Olive Green		Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 500 F	5.09	5.50	4.20	85.9	94.0	75.5
Gamma, 7.0×10^8	5.32	5.95	5.69	89.9	101.7	101.9
Gamma, $7.0 \times 10^8 + 2$ Hr at 500 F	4.60	4.74	2.0	77.7	81.9	35.0
Gamma, $7.0 \times 10^8/500$ F	4.68	5.0	3.14	79.1	85.5	56.3
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 400 F	4.52	4.9	2.70	76.4	83.8	49.5
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 500 F	4.34	4.8	3.30 ^(b)	73.4	82.1	60.3
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 600 F	3.43	3.69	3.13 ^(b)	57.9	63.1	56.1
Gamma, 1.4×10^9	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, $1.4 \times 10^9 + 2$ Hr at 500 F	4.43	4.33	2.69	74.8	82.6	48.2
Gamma, $1.4 \times 10^9/500$ F	3.67	4.89	4.52	62.0	83.6	81.1
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 400 F	4.24	4.72	4.06	71.6	80.7	72.8
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 500 F	4.19	4.46	4.20 ^(b)	70.8	76.1	75.3
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 600 F	3.58	3.93 ^(a)	3.55 ^(a)	60.5	67.9	63.7

(a) Frayed and brittle.

(b) Frayed.

Note: Gamma exposure in $\text{ergs g}^{-1}(\text{C})$.

TABLE C-31. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION/AND/OR ELEVATED TEMPERATURE (500 F)⁽⁷⁶⁾

	Tenacity, Grams/denier			Strength Retained, %		
	Natural	Int. Olive		Natural	Int. Olive	
		Orange	Green		Orange	Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 600 F	2.18	3.29	2.86	37.0	56.3	51.3
Gamma, 7.0×10^8	5.32	5.95	5.49	89.9	101.7	101.9
Gamma, $7.0 \times 10^8 + 2$ Hr at 600 F	2.93	3.06	2.40	49.5	52.3	43.1
Gamma, $7.0 \times 10^8/600$ F	2.77	3.54	2.31	46.8	60.6	41.6
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 400 F	2.97	3.71	3.10	50.2	63.5	55.6
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 500 F	2.75	3.12	2.50 ^(b)	46.8	53.4	44.8
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 600 F	2.09	3.04	2.65 ^(a)	35.7	51.9	47.6
Gamma, 1.4×10^9	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, $1.4 \times 10^9 + 2$ Hr at 600 F	2.74	2.74	2.54	46.2	46.8	45.5
Gamma, $1.4 \times 10^9/600$ F	2.13	1.05 ^(a)	1.05 ^(a)	36.0	17.9	18.7
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 400 F	2.07	2.22	1.77 ^(b)	34.3	37.5	31.8
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 500 F	2.30	2.35	2.12 ^(a)	38.9	40.2	38.0
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 600 F	1.89 ^(a)	2.41 ^(a)	2.15 ^(a)	31.9	41.2	38.6

(a) Frayed and brittle.

(b) Frayed.

Note: Gamma exposure in crgs g⁻¹(C).TABLE C-32. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION/AND/OR ELEVATED TEMPERATURE (400 F)⁽⁷⁶⁾

	Elongation, %			Elongation Retained, %		
	Natural	Int. Olive		Natural	Int. Olive	
		Orange	Green		Orange	Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 400 F	12.3	12.6	12.0	86.6	112.5	100.0
Gamma, 7.0×10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, $7.0 \times 10^8 + 2$ Hr at 400 F	16.2	14.9	11.5	114.1	133.0	95.8
Gamma, $7.0 \times 10^8/400$ F	11.2	12.1	12.9	78.9	108.1	107.5
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 400 F	11.8	12.2	11.6	83.1	108.9	96.5
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 500 F	7.8	10.5	2.5	54.9	93.7	20.9
Gamma, $7.0 \times 10^8/400$ F + 2 Hr at 600 F	3.3	4.2	2.8	23.3	37.5	23.3
Gamma, 1.4×10^9	15.0	12.9	13.7	100.6	115.2	114.1
Gamma, $1.4 \times 10^9 + 2$ Hr at 400 F	13.5	13.9	13.7	95.1	124.1	114.1
Gamma, $1.4 \times 10^9/400$ F	8.5	10.3	4.3	59.9	94.6	35.8
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 400 F	6.3	8.8	3.4	44.4	87.5	28.4
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 500 F	3.5	7.3	2.8	24.6	65.2	23.3
Gamma, $1.4 \times 10^9/400$ F + 2 Hr at 600 F	6.5	7.1	4.6	45.8	63.4	38.4

Note: Gamma exposure in crgs g⁻¹(C).

TABLE C-33. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (500 F)⁽⁷⁶⁾

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 500 F	10.3	11.6	7.6	72.5	103.5	63.3
Gamma, 7.0×10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, $7.0 \times 10^8 + 2$ Hr at 500 F	8.3	8.8	2.4	58.5	78.6	20.0
Gamma, $7.0 \times 10^6/500$ F	10.3	10.3	4.2	72.5	93.7	35.0
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 400 F	8.4	8.6	3.6	59.2	76.8	30.0
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 500 F	8.7	10.5	5.3	61.3	95.1	44.2
Gamma, $7.0 \times 10^8/500$ F + 2 Hr at 600 F	6.6	7.8	5.3	46.5	69.7	44.2
Gamma, 1.4×10^9	15.0	12.9	13.7	105.6	115.2	114.1
Gamma, $1.4 \times 10^9 + 2$ Hr at 500 F	8.8	10.5	3.7	61.8	95.1	30.8
Gamma, $1.4 \times 10^9/500$ F	6.4	10.8	9.6	45.1	96.4	80.8
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 400 F	8.6	11.4	7.7	60.6	101.8	62.2
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 500 F	8.8	9.9	9.6	61.8	87.5	80.8
Gamma, $1.4 \times 10^9/500$ F + 2 Hr at 600 F	7.3	11.0	9.0	44.4	98.2	75.0

Note: Gamma exposure in $\text{ergs g}^{-1}(\text{C})$.TABLE C-34. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (600 F)⁽⁷⁶⁾

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 600 F	2.2	5.5	3.9	15.5	49.1	32.5
Gamma, 7.0×10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, $7.0 \times 10^8 + 2$ Hr at 800 F	5.1	5.7	3.8	35.9	50.9	31.7
Gamma, $7.0 \times 10^6/600$ F	4.5	6.8	3.4	31.8	60.7	28.3
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 400 F	5.3	7.6	5.0	37.3	67.8	41.7
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 500 F	4.8	5.2	3.4	33.8	46.4	28.3
Gamma, $7.0 \times 10^8/600$ F + 2 Hr at 600 F	3.1	5.9	5.2	22.2	72.7	43.3
Gamma, 1.4×10^9	13.5	12.9	13.7	95.1	115.2	114.1
Gamma, $1.4 \times 10^9 + 2$ Hr at 600 F	4.3	4.2	3.8	30.3	37.5	31.7
Gamma, $1.4 \times 10^9/600$ F	3.2	6.0	1.7	22.5	53.6	14.2
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 400 F	3.9	3.9	2.6	27.5	34.2	21.7
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 500 F	4.0	4.6	3.6	28.2	41.1	30.0
Gamma, $1.4 \times 10^9/600$ F + 2 Hr at 600 F	3.6	5.1	3.6	26.8	45.5	30.0

Note: Gamma exposure in $\text{ergs g}^{-1}(\text{C})$.

TABLE C-35. TEST ENVIRONMENT AND RESULTS OF STATIC TESTS:
POLYURETHANE THERMAL INSULATION(7)

Material: Trade Name	Test Condition	Radiation Exposure		Time Until Test, days	Sample Weights		Compressive Strength at 25% Deflection, psi	Temperature Average, °F	Temperature Pressure Average, (torr)
		Gamma [ergs/gm(C)]	Neutron (n/cm ²) Thermal E>2.9 Mev E>8.1 Mev		Original, gm	Change, gm			
CPR-20 Compression Buttons	Air	0	0 (control specimens)	--	-	-	126 105 84 96 100/13	-	-
	Air	6.5(7)	3.5(12) (air irradiation)	16	-	-	123.5 86 99 85 98/21	80	-
	Air	1.5(8)	3.2(12) (air irradiation)	16	-	-	117 86 89 126 105/19	80	-
	Air	1.36(9)	1.8(13) (air irradiation)	16	-	-	89 91 91.5 124 99/17	82	-
Air	7.5(7)	4.6(12) (vacuum irradiation)	7	0.6354 0.4578 0.4738 0.4554	-0.0013 -0.0010 -0.0006 -0.0006	111 82.5 85 87.5 92/14	80	1.7(-7)	
	Air	1.8(8)	8.4(12) (vacuum irradiation)	7	0.4754 0.4724 0.4651 0.626	-0.0011 -0.0012 -0.0009 -0.0005	91.5 86 103 114 99/14	80	1.7(-7)
	Air	9.1(8)	2.8(13) (vacuum irradiation)	7	0.6451 0.4722 0.4663 0.4768	-0.0026 -0.0020 -0.0025 -0.0019	116 79.5 85 90 90/18	90	4(-7)

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TABLE C-35. (Concluded)

Material Trade Name	Test Condition	Radiation Exposure		Time Until Test, days	Sample Weights		Compressive Strength* at 25% Deflection, psi	Temperature Average, °F	Pressure Average, (torr)
		Gamma [ergs/gm(C)]	Neutron (n/cm ²) Thermal E>2.5 Mev E>8.1 Mev		Original, gm	Change, gm			
CPR-1021-2 Compression Buttons	0	0	0 (control specimens)	0	-	-	39.8	--	--
							30.8		
							31.1		
							34.5		
							31.5		
CPR-1021-2 Compression Buttons	5.08(8)	8.31(12)	6.98(13) (vacuum irradiation, low force static)	2.77(12)	-	-	39.5	87	2.5(-7)
							33.0/35.8		
							29.8		
							31.7		
							27.8		
CPR-20 Compression Buttons	5.08(8)	8.31(12)	6.98(13) (vacuum irradiation)	2.77(12)	-	-	29.8/27.3	1*	2.5(-7)
							142.5		
							120.0		
							111.0		
							124.5/18.6		
CPR-1021 Compression Buttons	5.08(8)	8.31(12)	6.98(13) (vacuum irradiation)	2.77(12)	-	-	50.6	87	2.5(-7)
							48.0		
							49.4/3.6		
							49.4/3.6		
							49.4/3.6		

* Values given as: average value/standard deviation on an individual basis.

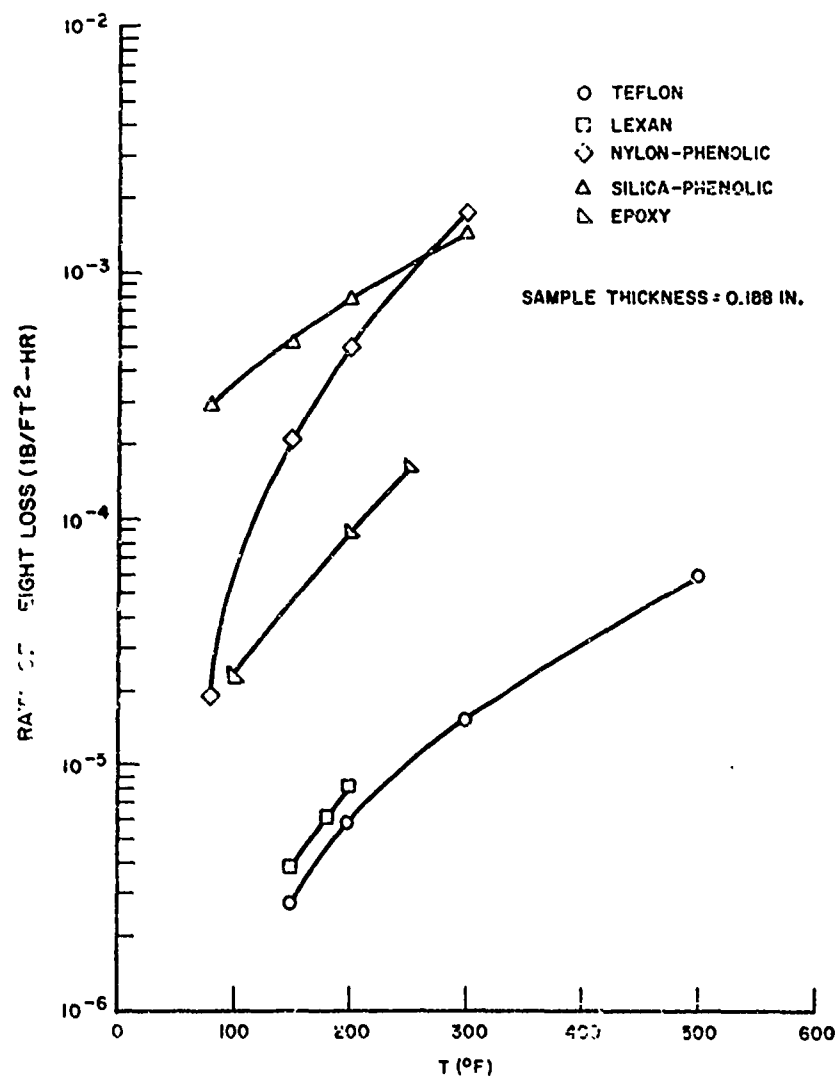


FIGURE C-1. INITIAL RATES OF WEIGHT LOSS FOR ORGANIC MATERIALS TESTED⁽⁶¹⁾

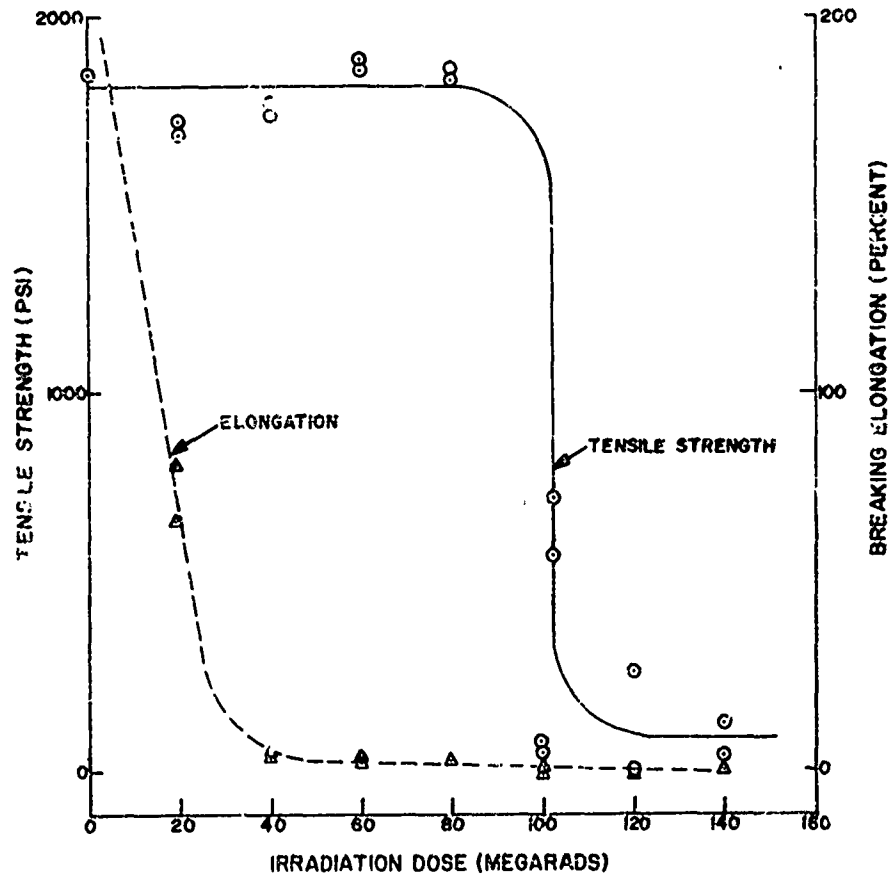


FIGURE C-2. TENSILE PROPERTIES OF IRRADIATED
POLYTETRAFLUOROETHYLENE FILM
(VACUUM = 10^{-6} mm Hg)(82)

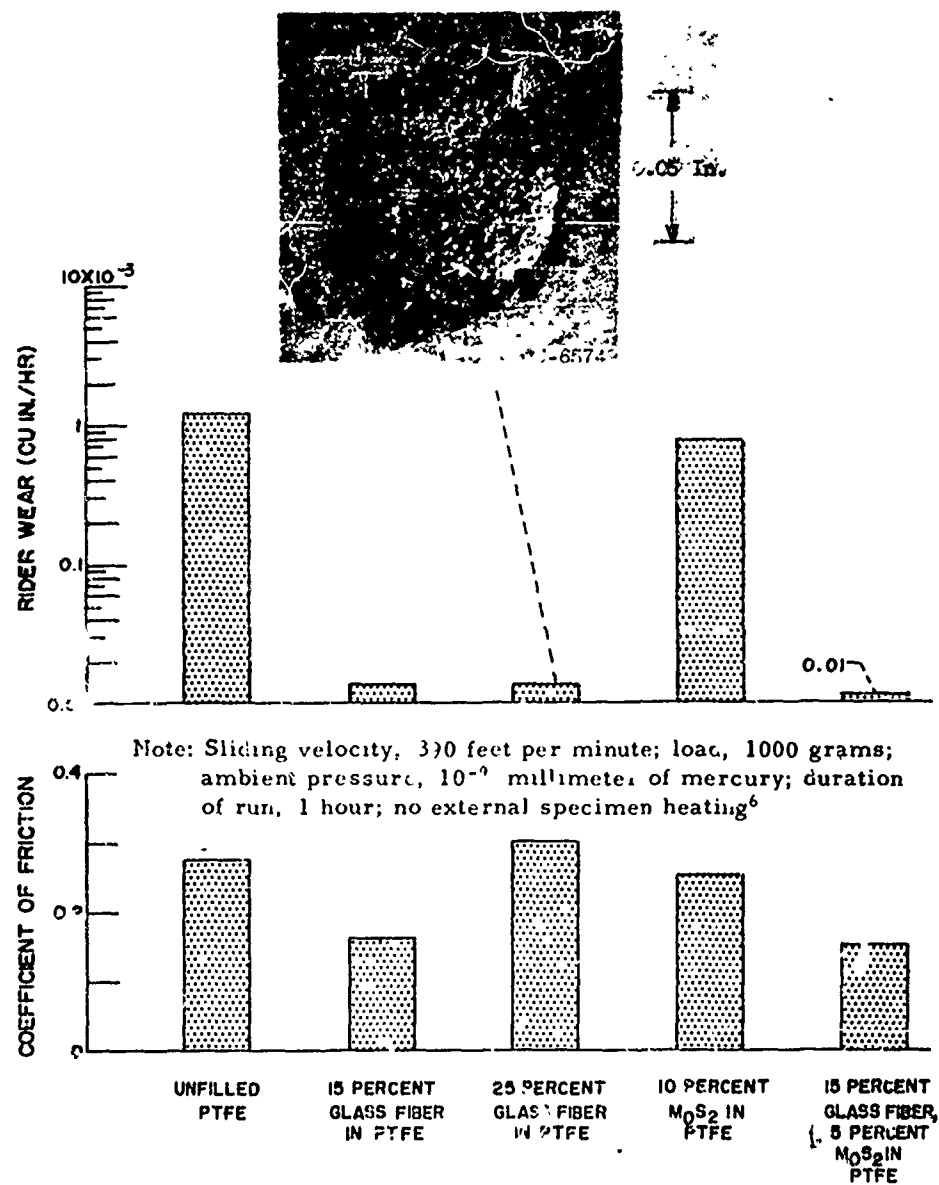


FIGURE C-3. COEFFICIENT OF FRICTION AND RIDER WEAR FOR VARIOUS POLYTETRAFLUOROETHYLENE COMPOSITIONS SLIDING ON 440-C STAINLESS STEEL IN VACUUM (10^{-9} mm Hg)

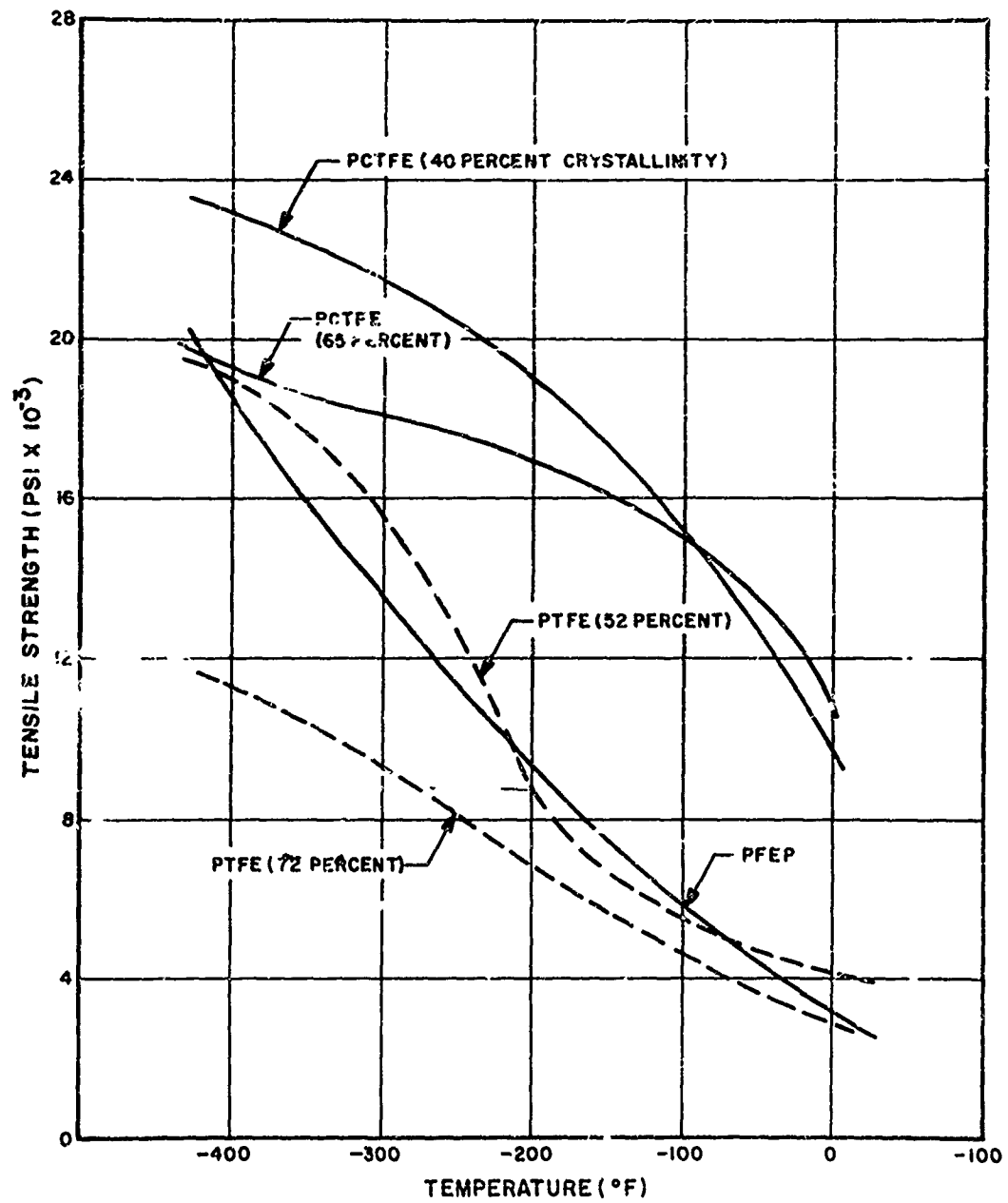


FIGURE C-4. TENSILE STRENGTH OF FLUOROCARBON PLASTICS AT CRYOGENIC TEMPERATURES(64)

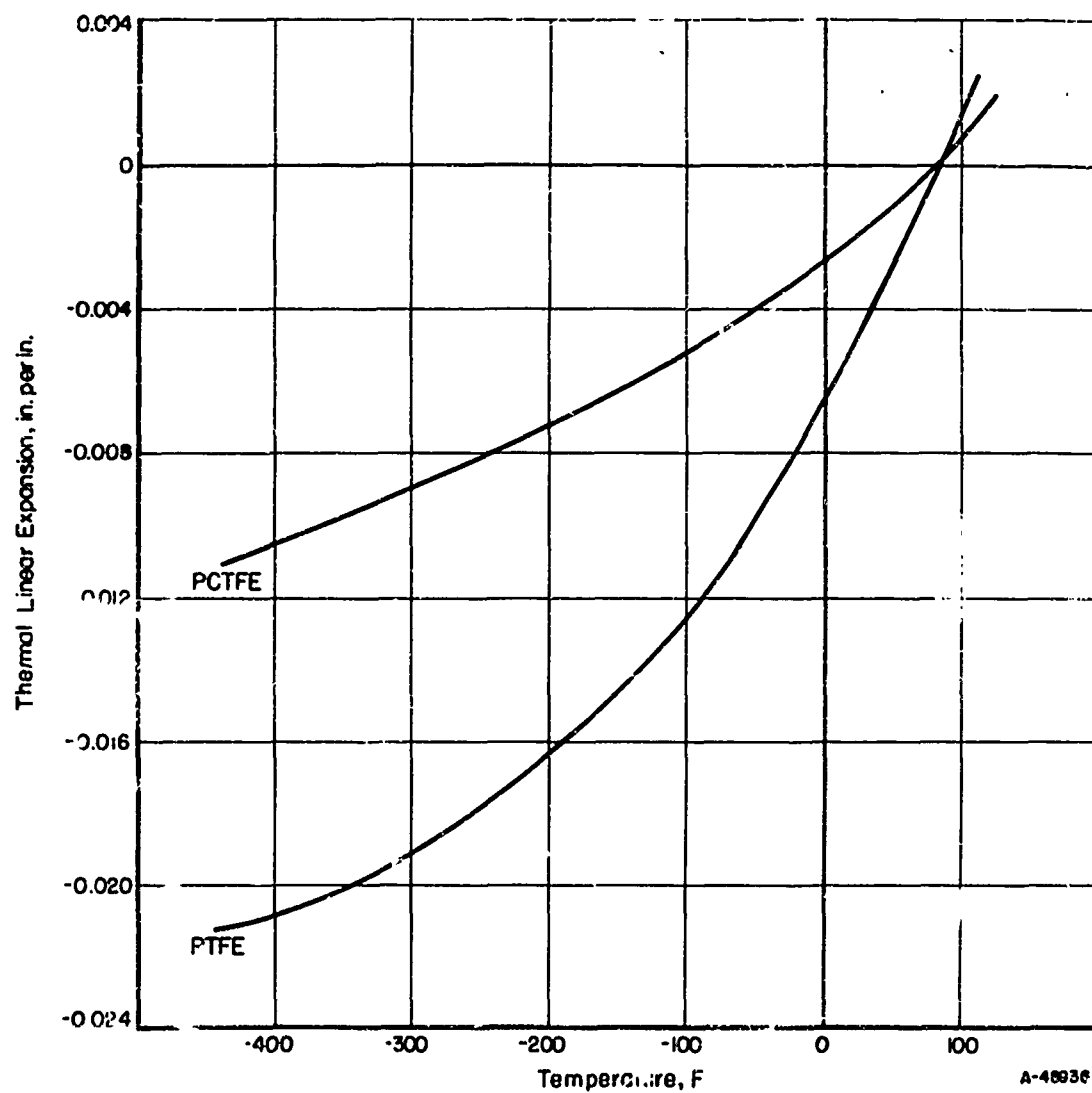


FIGURE C-5. THERMAL LINEAR EXPANSION OF PCTFE AND PTFE AT SUBZERO TEMPERATURES⁽⁶⁹⁾

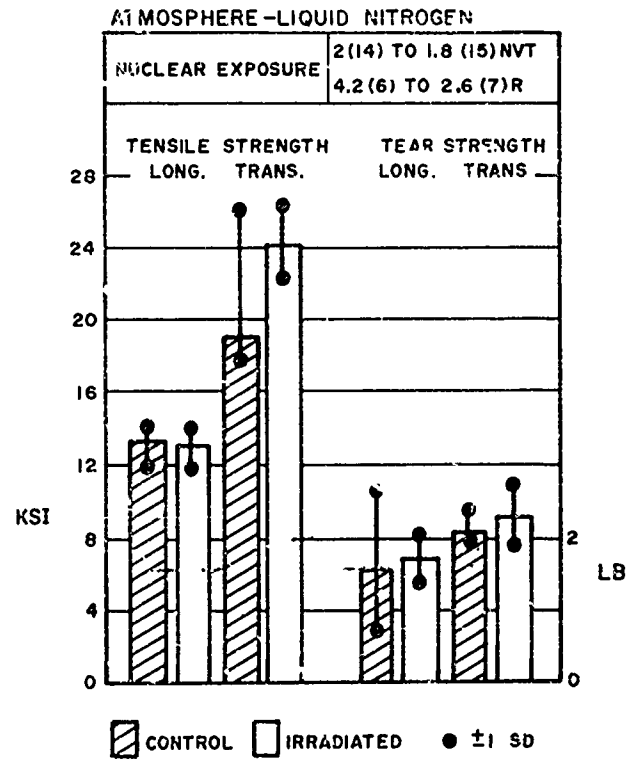


FIGURE C-6. RADIATION EFFECTS ON KEL-F FILM⁽¹³⁾

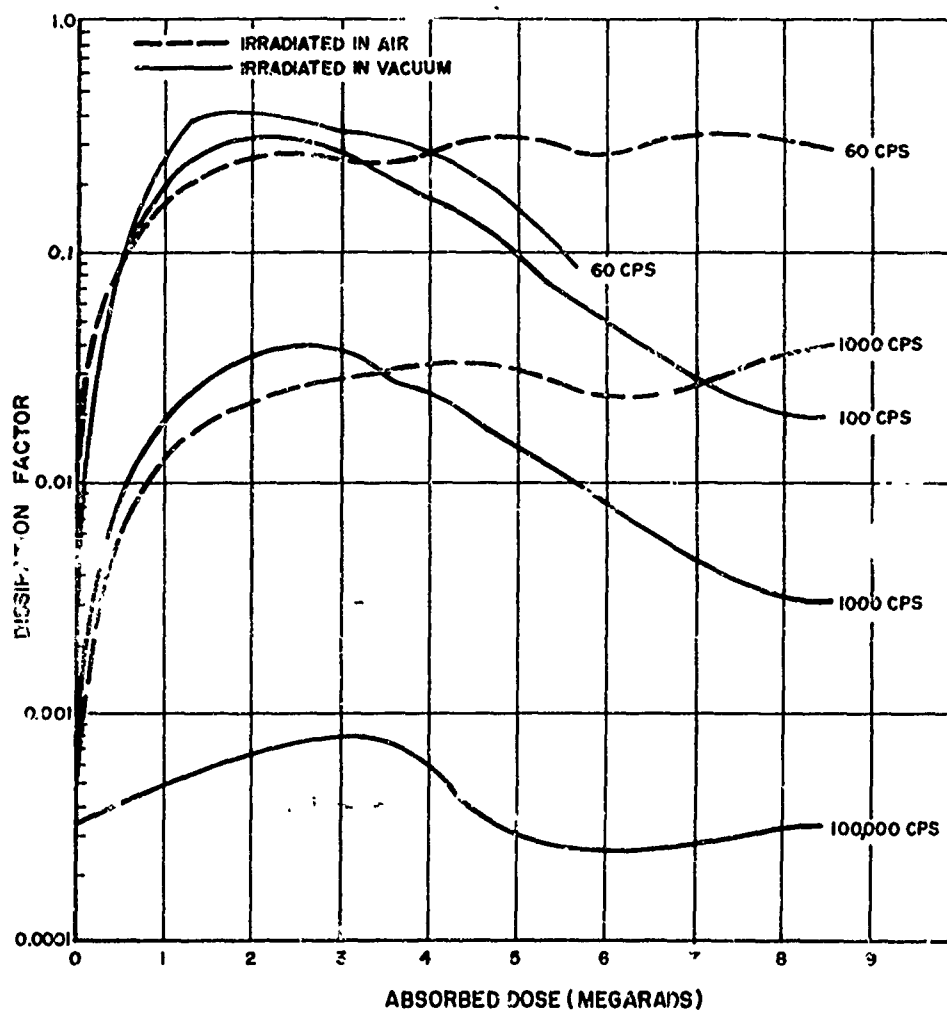


FIGURE C-7. EFFECT OF X-RAY IRRADIATION ON TFE-6
(DISSIPATION FACTOR)⁽⁶³⁾

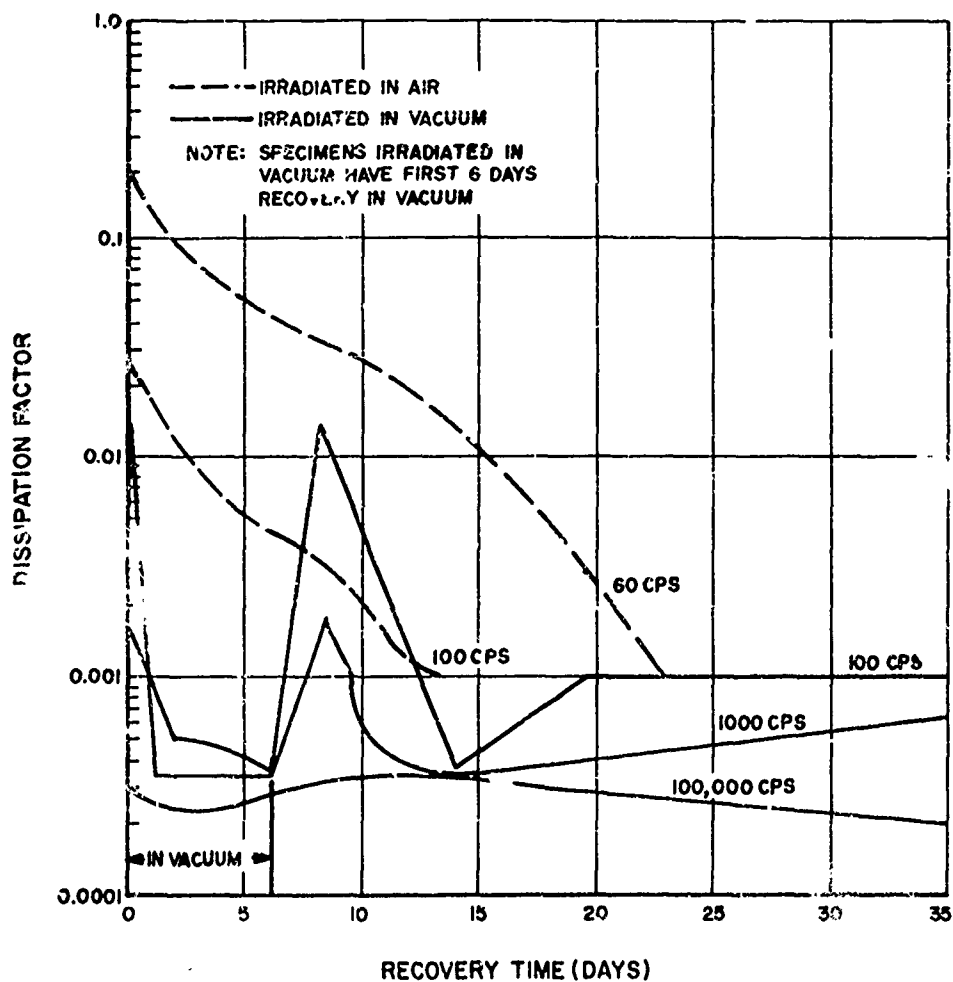


FIGURE C-8. RECOVERY CHARACTERISTICS OF TFE-6 SPECIMENS AFTER X-RAY IRRADIATION(63)

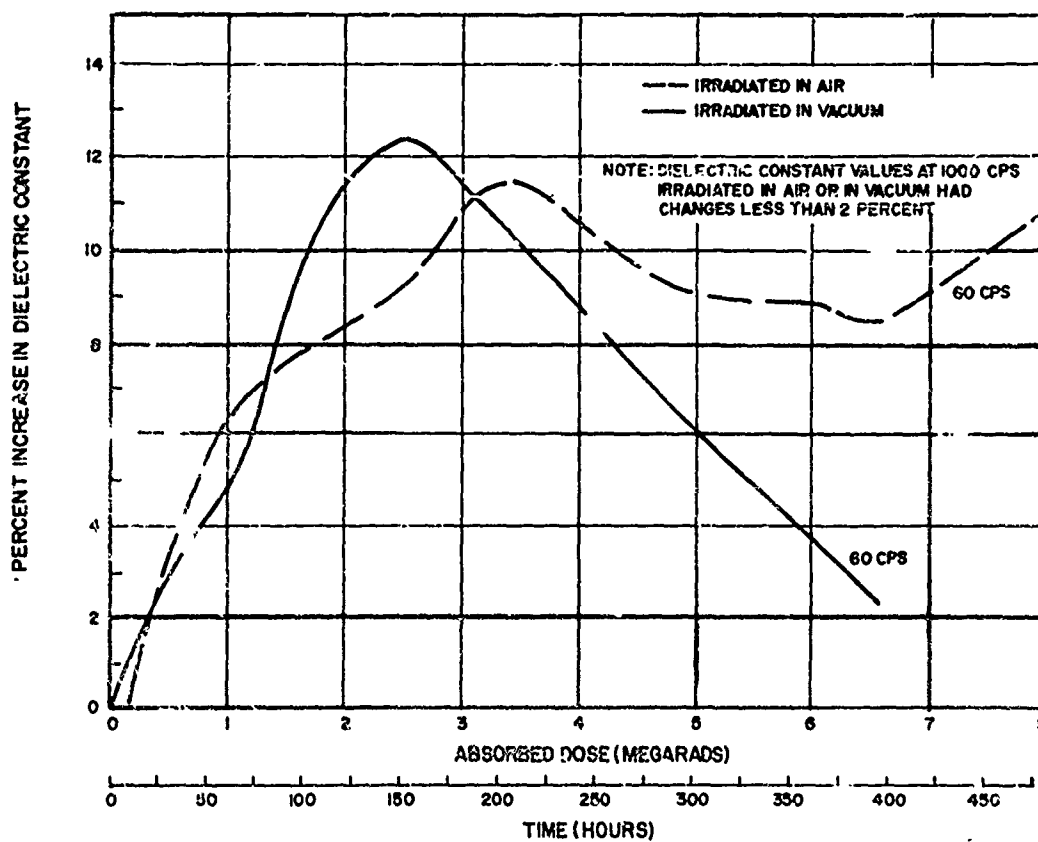


FIGURE C-9. EFFECT OF X-RAY IRRADIATION ON TFE-6
(DIELECTRIC CONSTANT)(63)

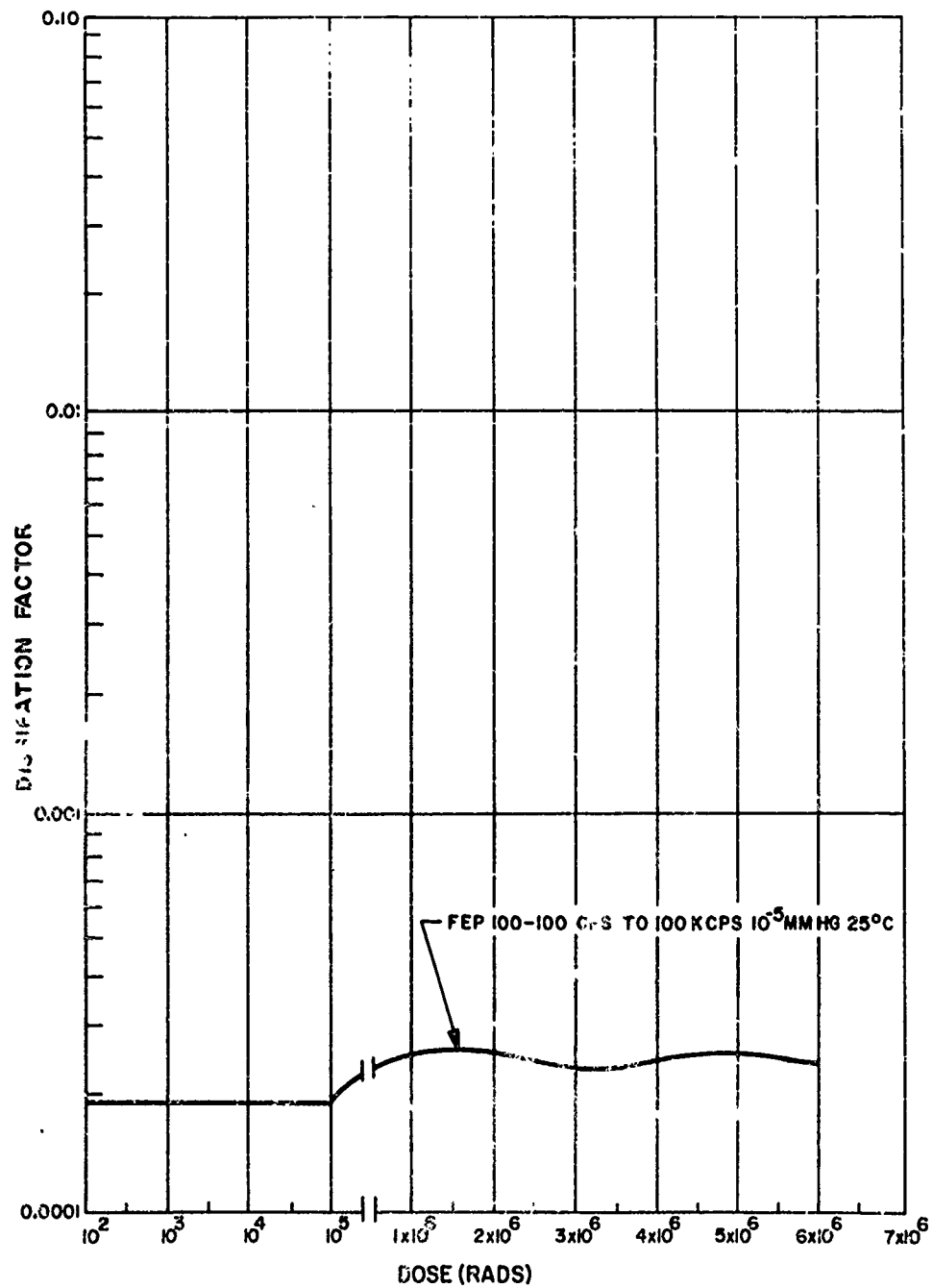


FIGURE C-10. EFFECT OF X-RAY IRRADIATION ON FEP-100
(DISSIPATION FACTOR)⁽⁶³⁾

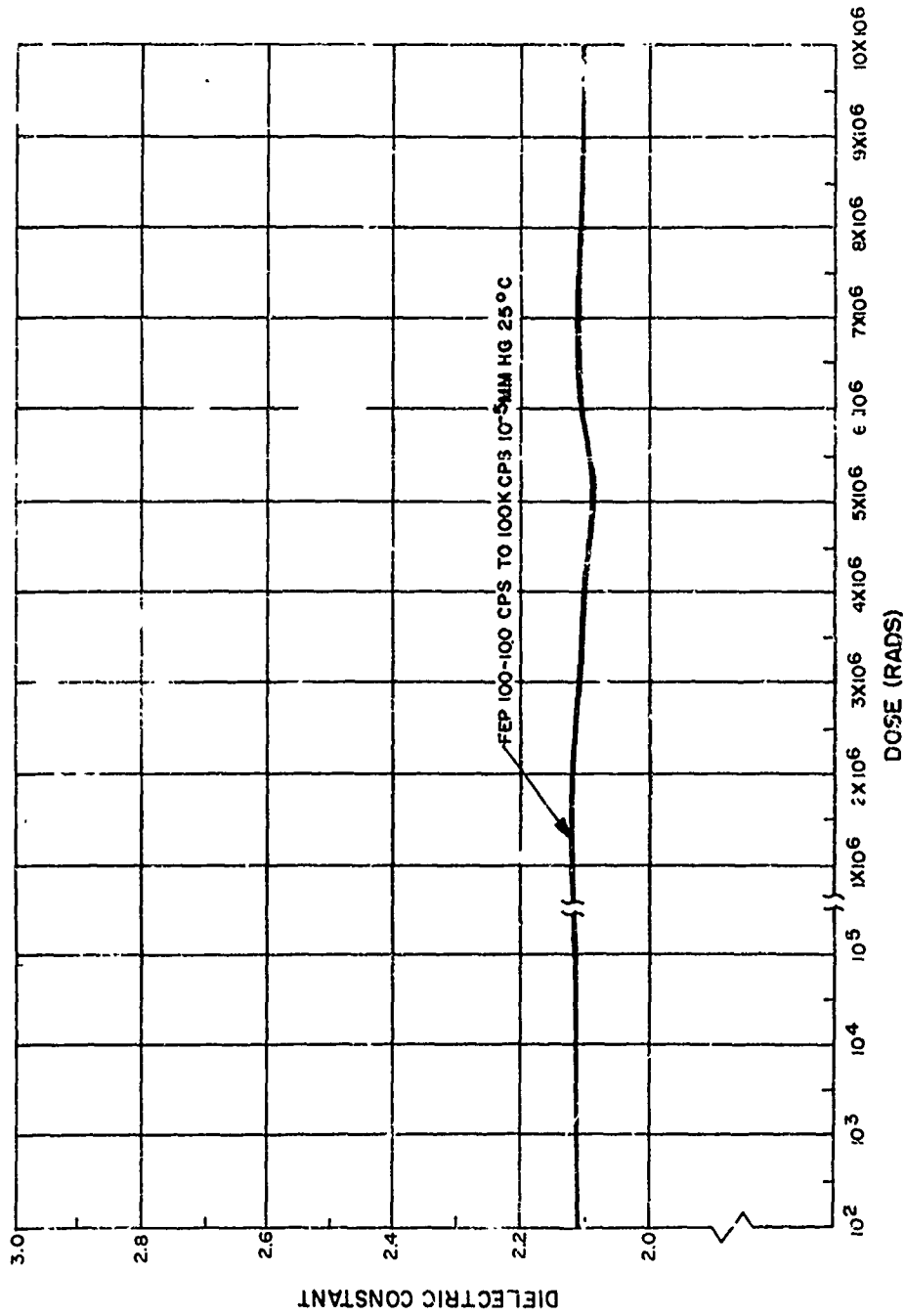


FIGURE C-11. EFFECT OF X-RAY IRRADIATION ON FEP-100 (DIELECTRIC CONSTANT) (63)

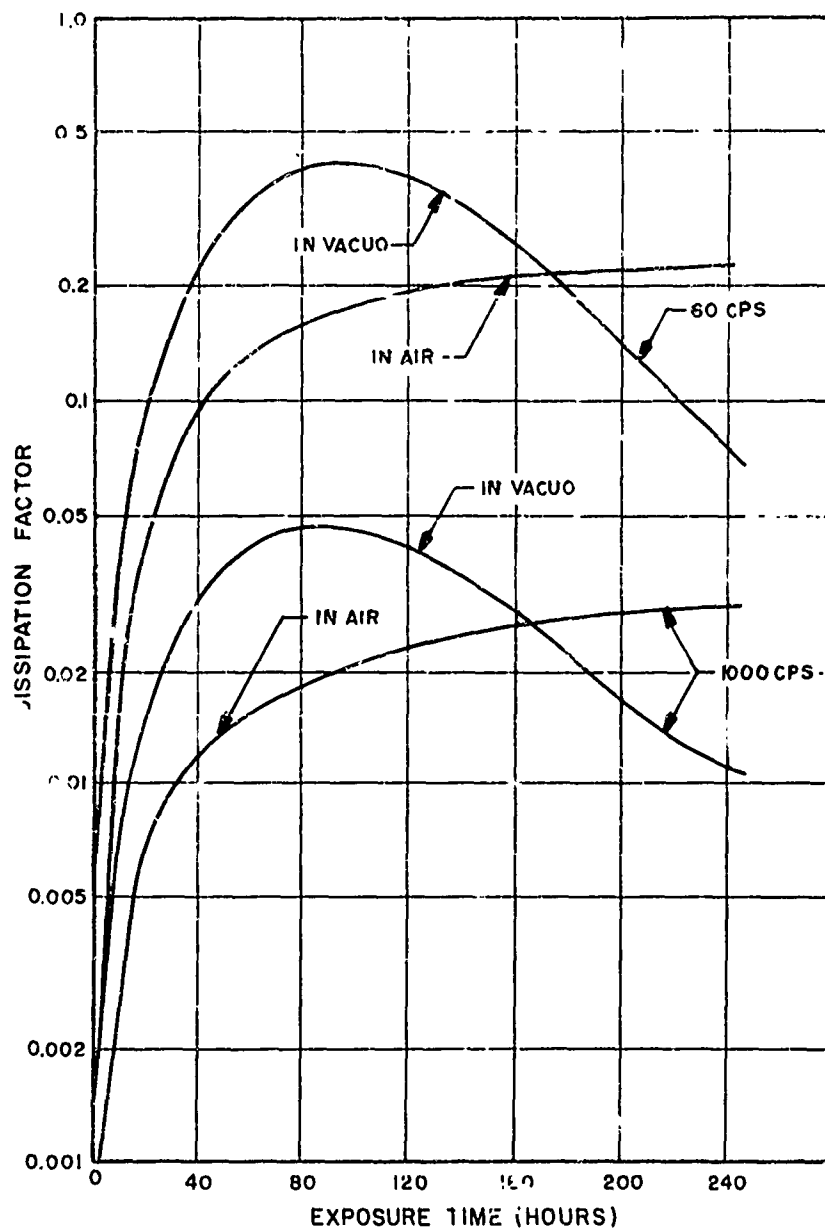


FIGURE C-12. COMPARISON OF THE EFFECTS OF X-IRRADIATION ON THE DISSIPATION FACTOR OF PTFE-6 IN VACUO (5×10^{-6} mm Hg) AND IN AIR⁽⁶⁴⁾

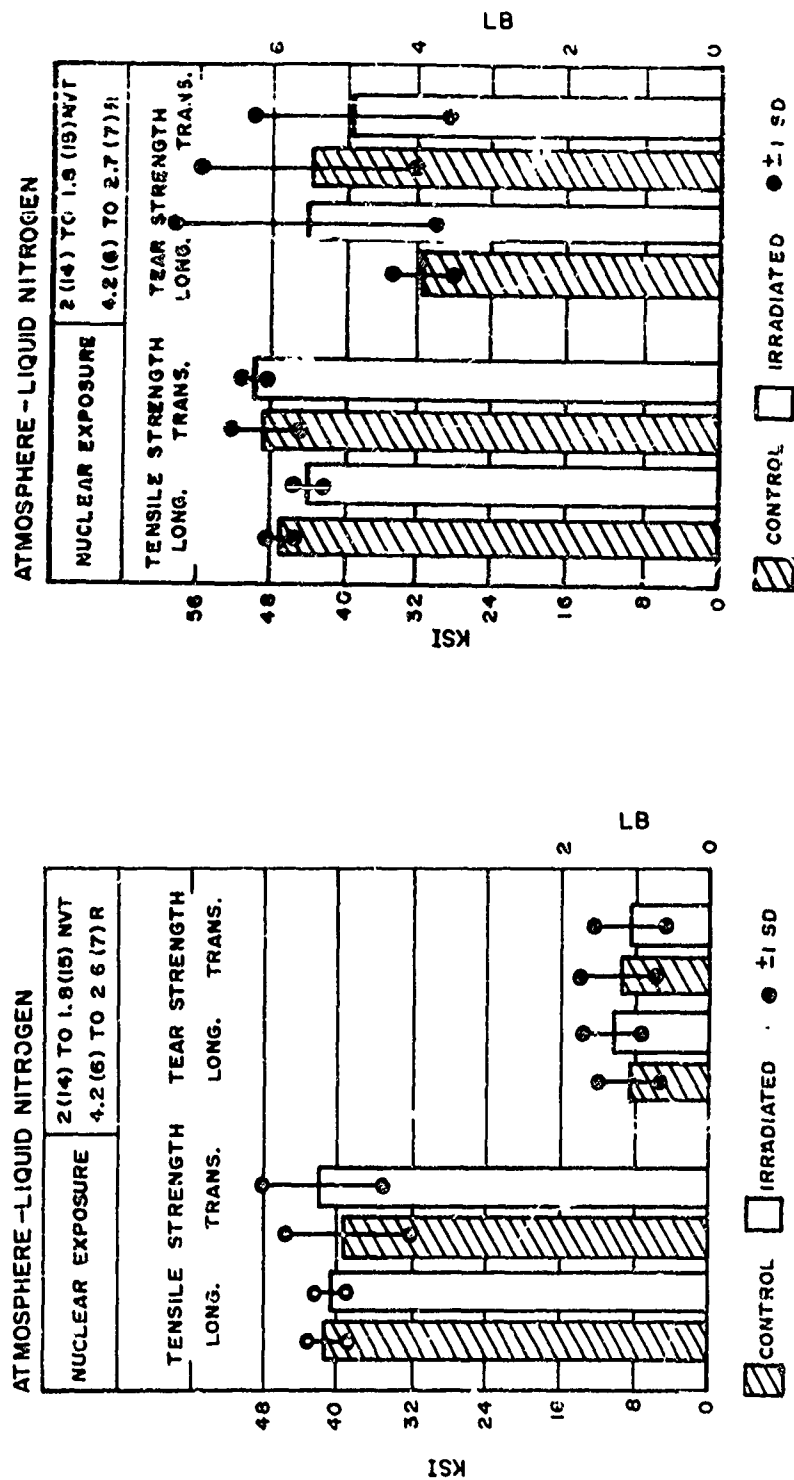


FIGURE C-13. RADIATION EFFECTS ON MYLAR FILM(13)

FIGURE C-14. RADIATION EFFECTS ON ALUMINIZED MYLAR FILM(13)

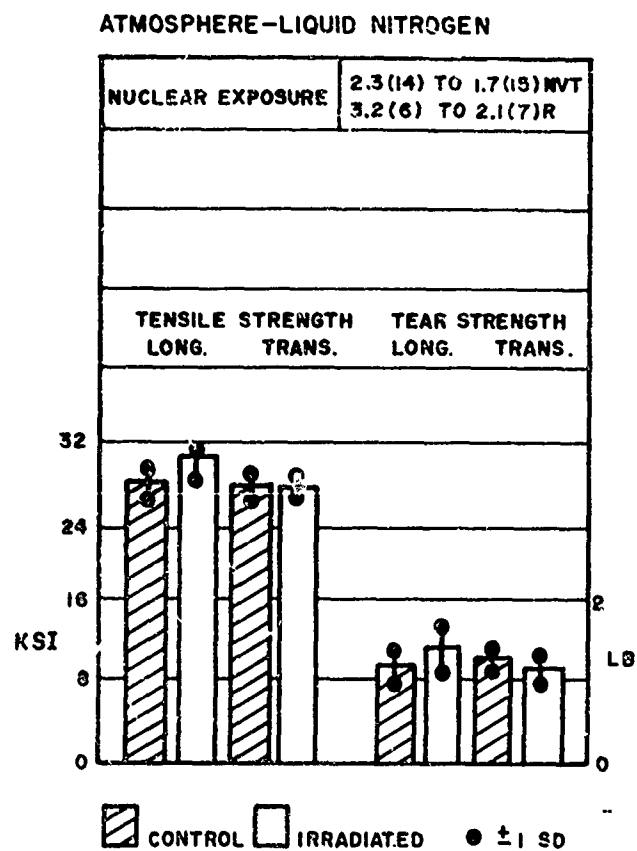


FIGURE C-15. RADIATION EFFECTS ON ALUMISEAL FILM⁽¹³⁾
(Mylar-Aluminum-Mylar Laminate)

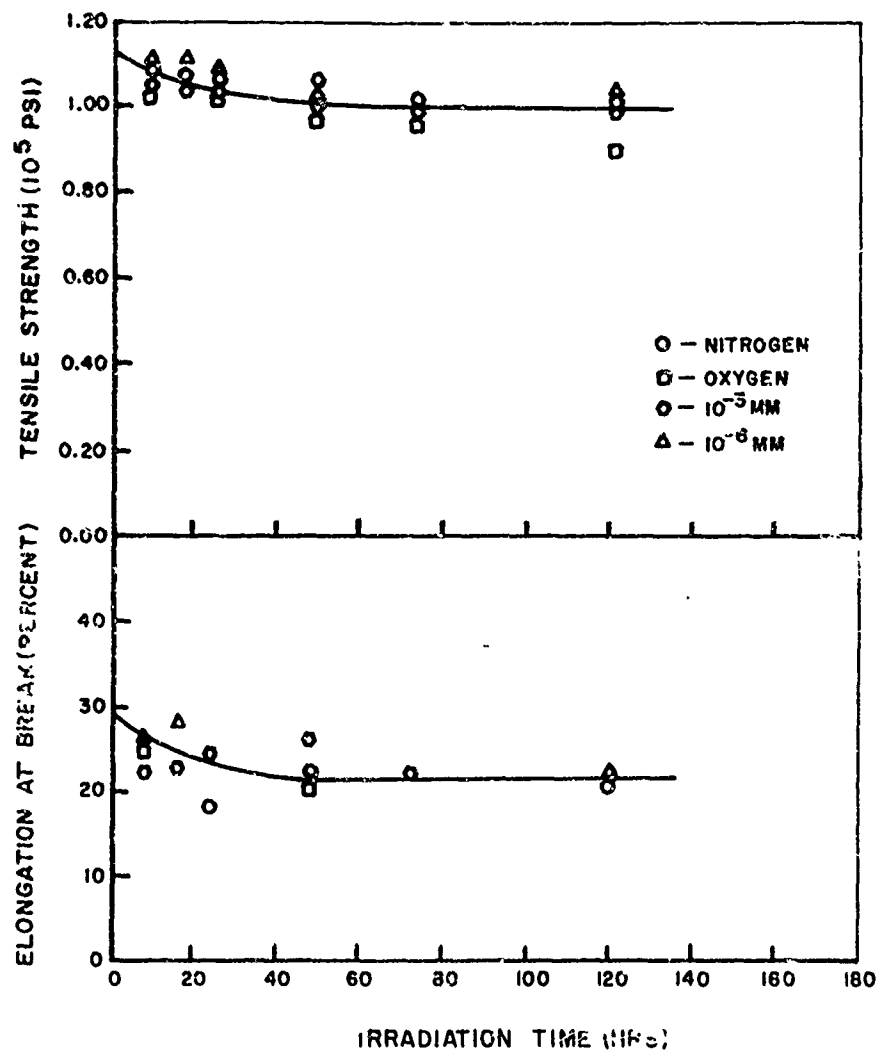


FIGURE C-16. EFFECTS ON TENSILE PROPERTIES OF HT-1 FIBERS BY IRRADIATION IN VARIOUS ENVIRONMENTS WITH 253.7 mμ LIGHT(77)

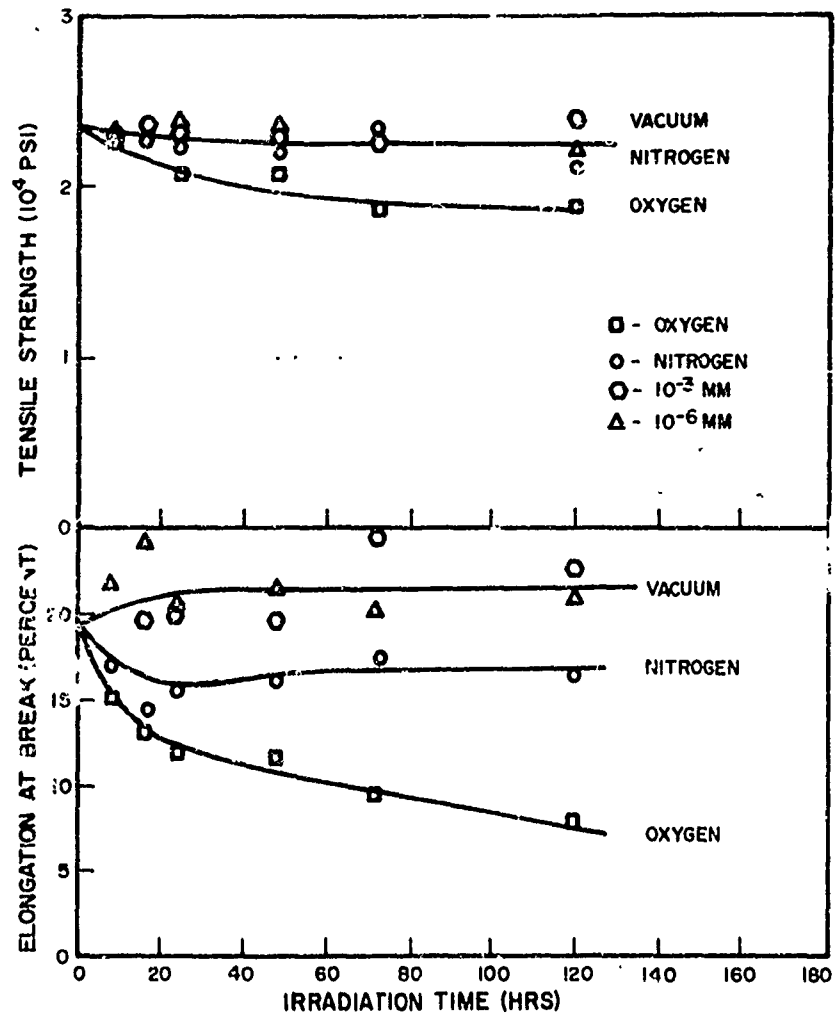


FIGURE C-17. EFFECTS ON TENSILE PROPERTIES OF POLYBENZIMIDAZOLE FIBERS BY IRRADIATION IN VARIOUS ENVIRONMENTS WITH 253.7-m μ LIGHT⁽⁷⁷⁾

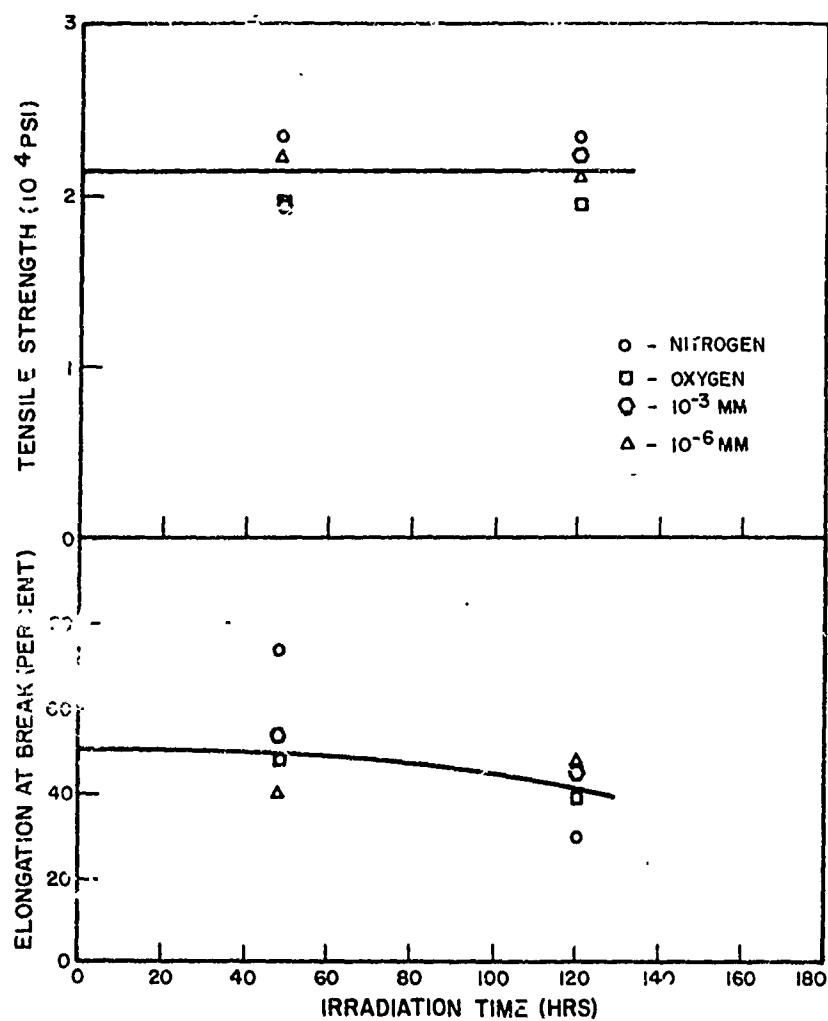


FIGURE C-18. EFFECTS ON TENSILE PROPERTIES OF FIBERS OF THIAZOLE POLYMER BY IRRADIATION IN VARIOUS ATMOSPHERES WITH 253.7-m μ LIGHT⁽⁷⁷⁾

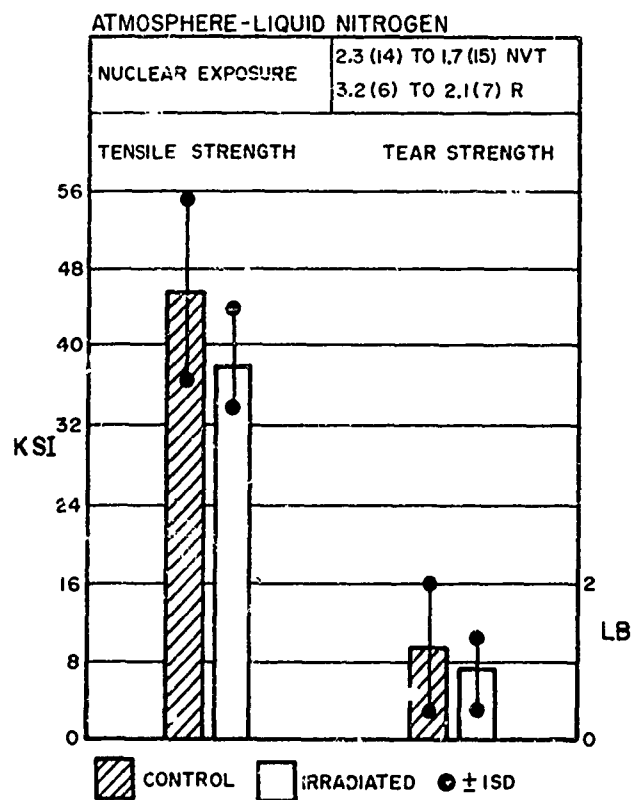


FIGURE C-19. RADIATION EFFECTS ON DUPONT "H" FILM⁽¹³⁾

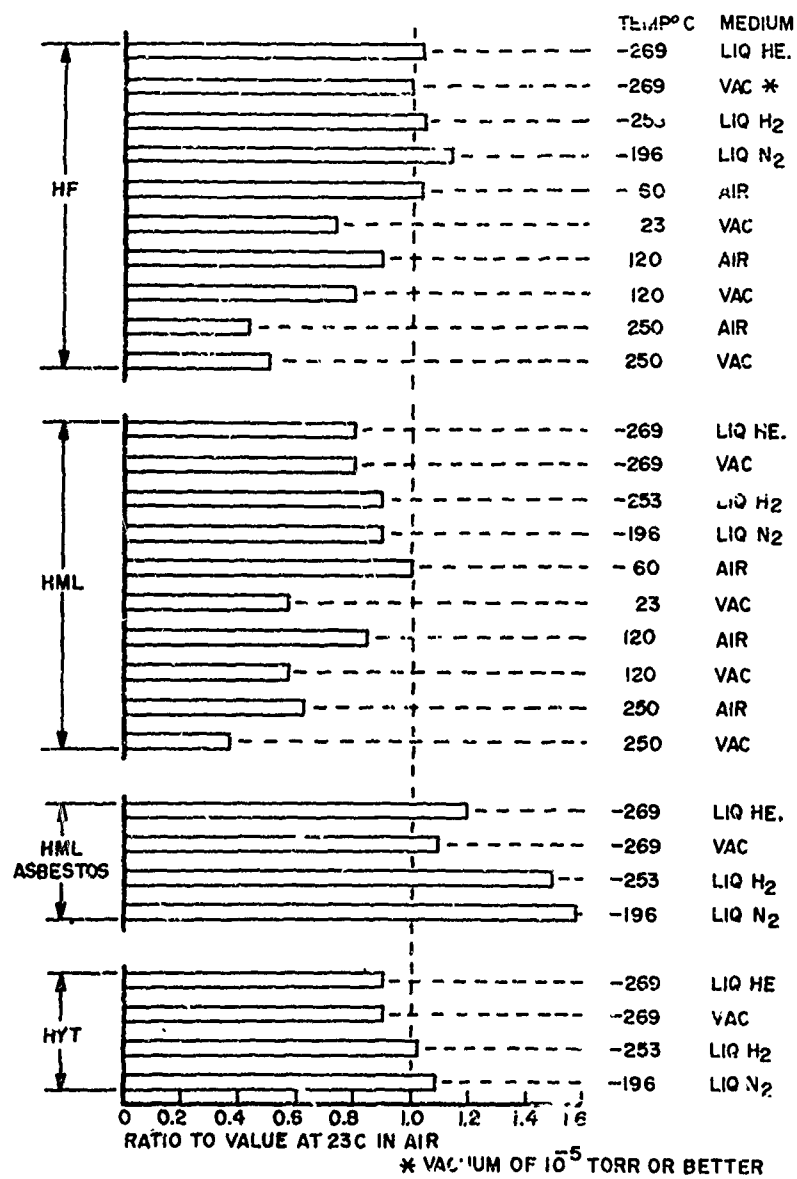


FIGURE C-20. COMPARISON OF BREAKDOWN VOLTAGE UNDER DIFFERENT TEST AMBIENTS FOR FILM-COATED WIRES⁽⁷⁸⁾

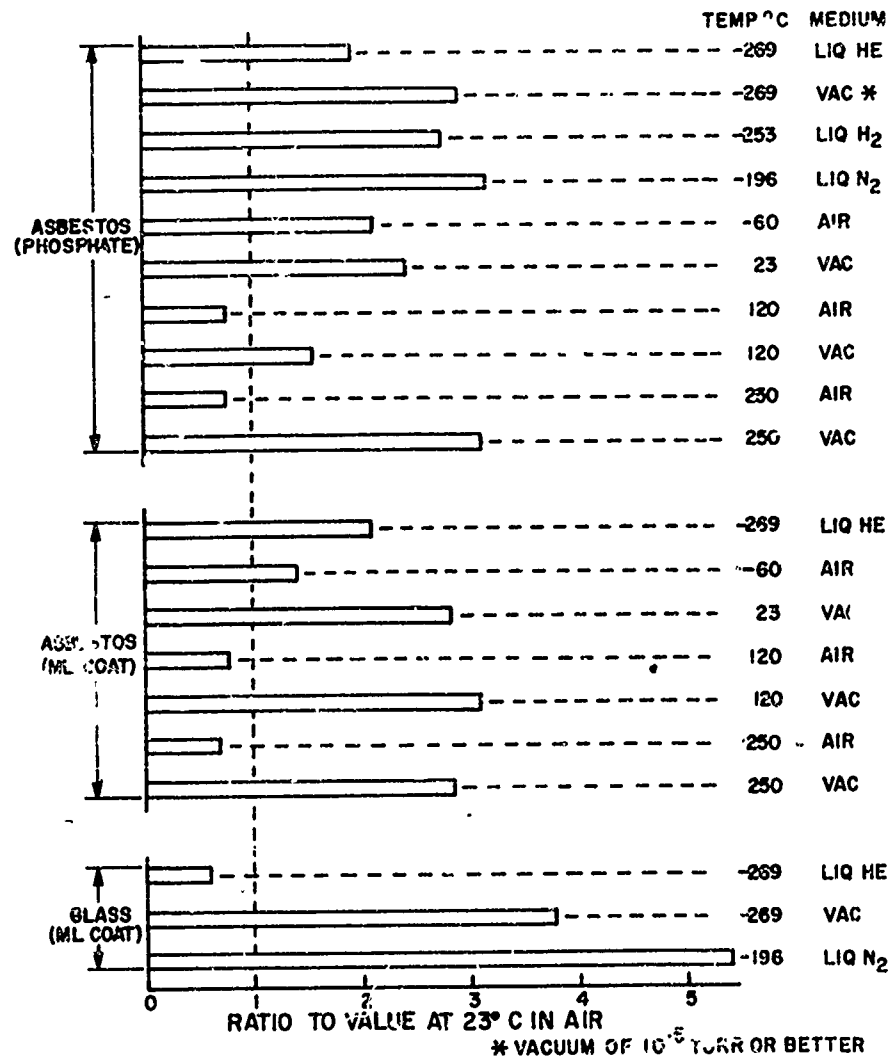


FIGURE C-21. COMPARISON OF BREAKDOWN VOLTAGE UNDER DIFFERENT TEST AMBIENTS FOR FIBROUS-COATED WIRES⁽⁷⁸⁾

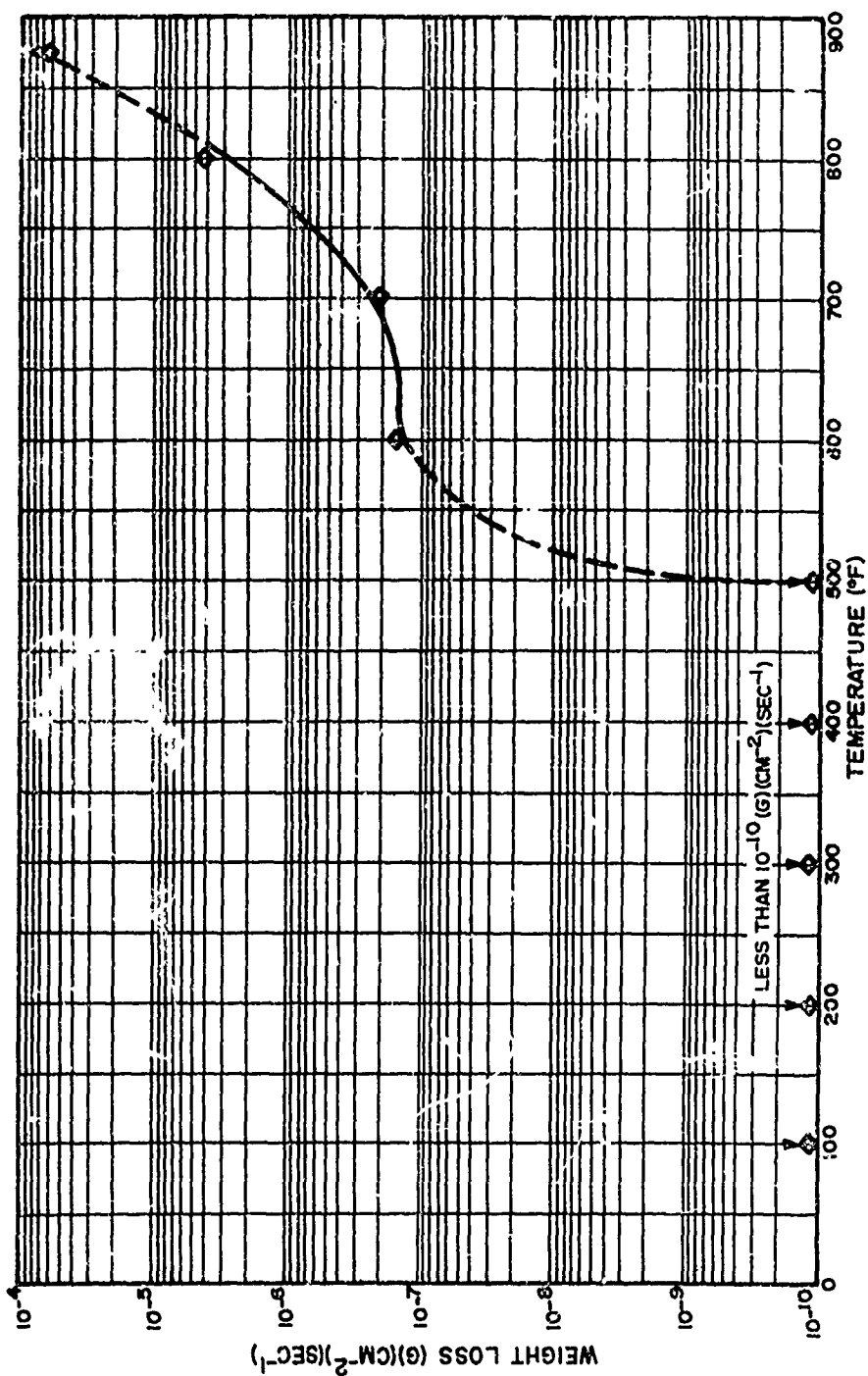


FIGURE C-22. WEIGHT LOSS OF POLYIMIDE IN VACUUM AS A FUNCTION OF SPECIMEN TEMPERATURE, AMBIENT PRESSURE, 10^{-7} TO 10^{-8} MILLIMETER OF MERCURY (65)

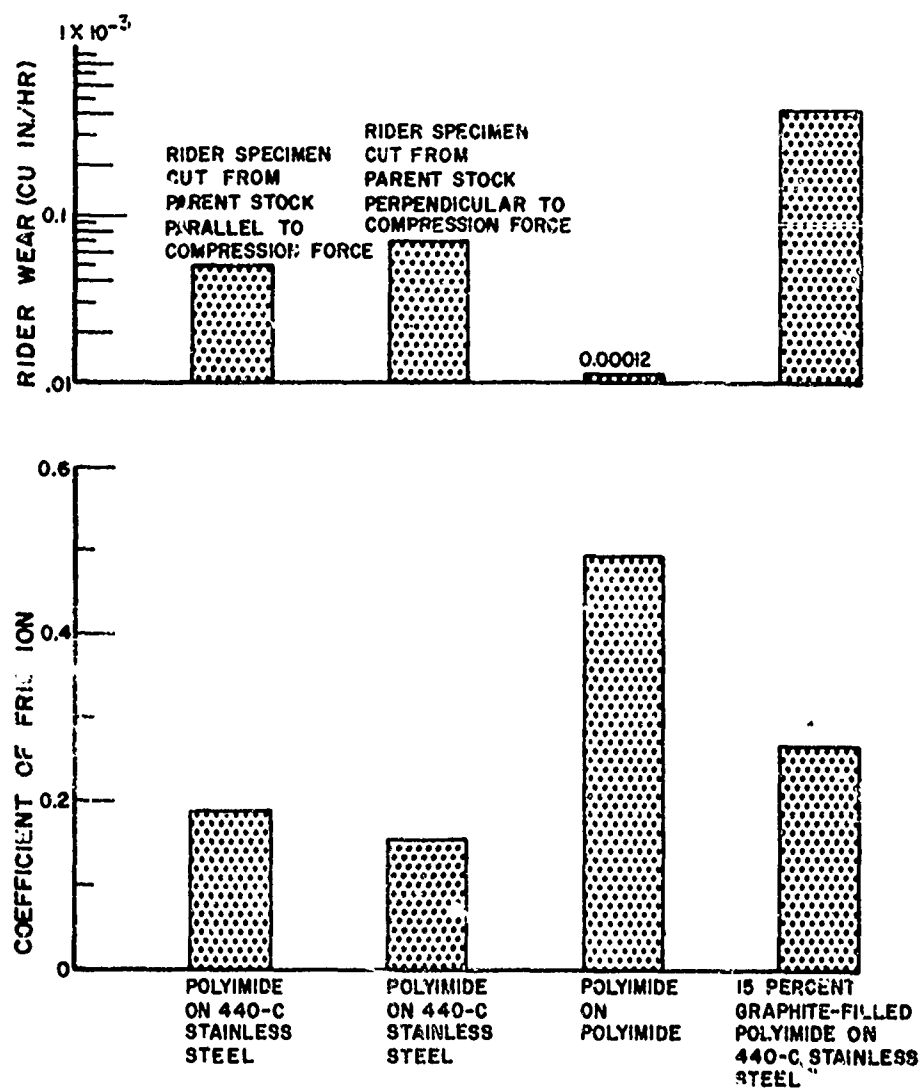


FIGURE C-23. COEFFICIENT OF FRICTION AND RIDER WEAR FOR VARIOUS MATERIAL COMBINATIONS IN VACUUM (10^{-9} mm Hg)

Note: Sliding velocity, 390 feet per minute; load, 1000 grams; duration of run, 1 hour; no external specimen heating⁽⁶⁵⁾

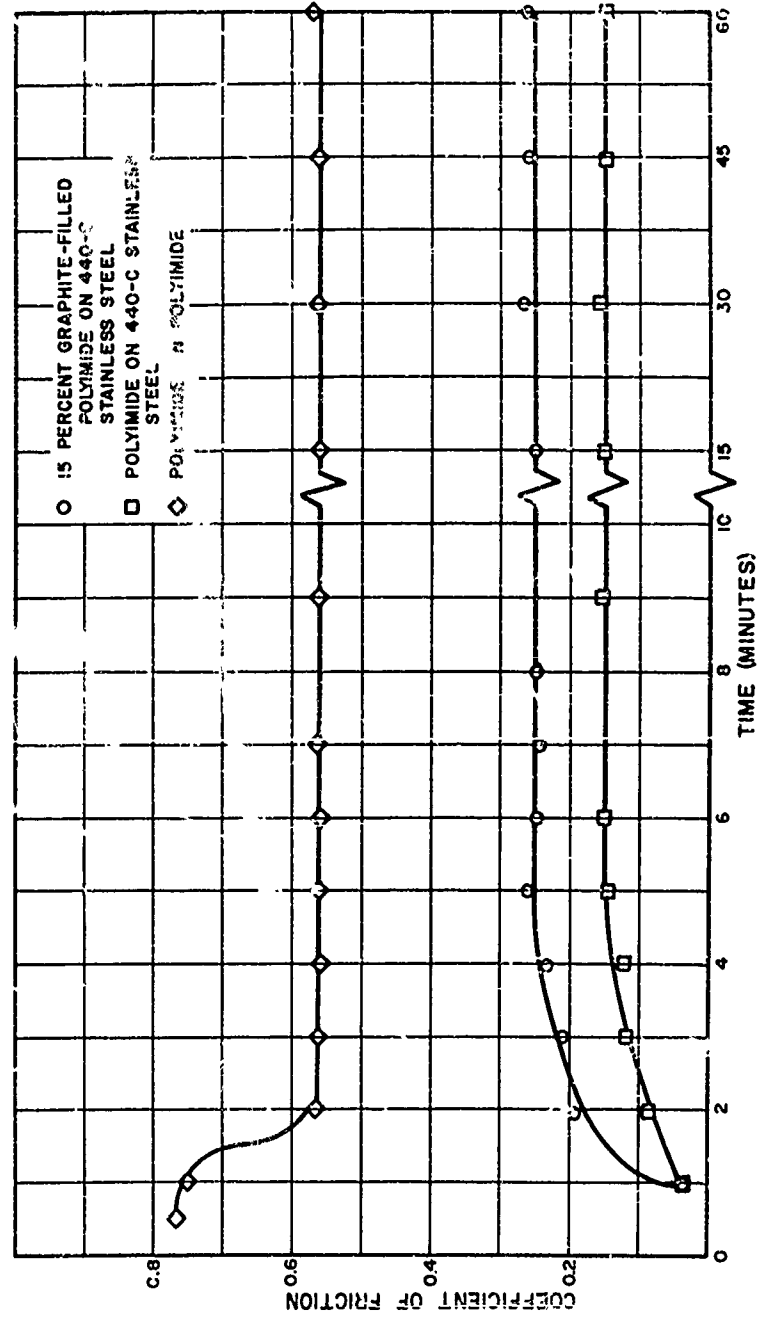
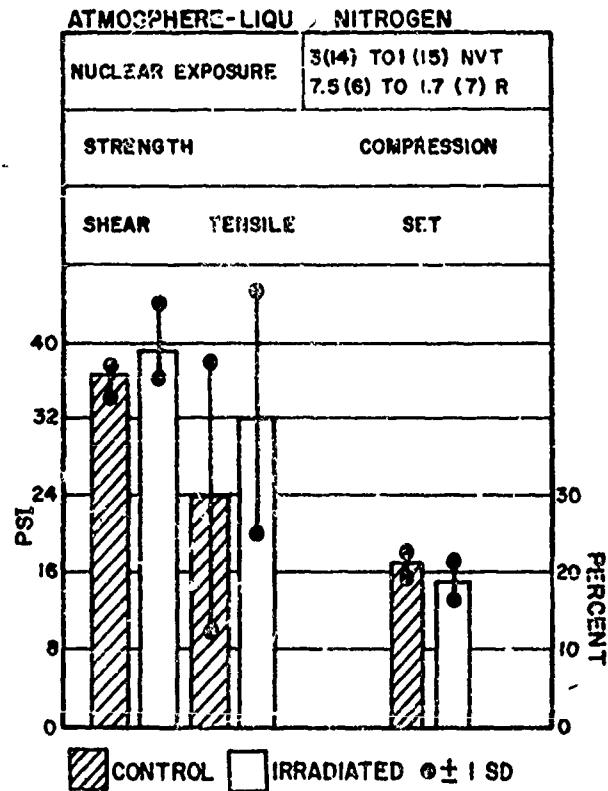


FIGURE C-24. COEFFICIENT OF FRICTION AS A FUNCTION OF TIME FOR POLYIMIDE SLIDING ON POLYIMIDE AND ON 440-C STAINLESS STEEL IN VACUUM (10^{-9} mm Hg)

Note: Sliding velocity, 390 feet per minute; load, 1000 grams; ambient pressure, 10^{-9} millimeter of mercury; no external specimen heating. (65)

FIGURE C-25. RADIATION EFFECTS ON MAGNOLIA FOAM⁽¹³⁾

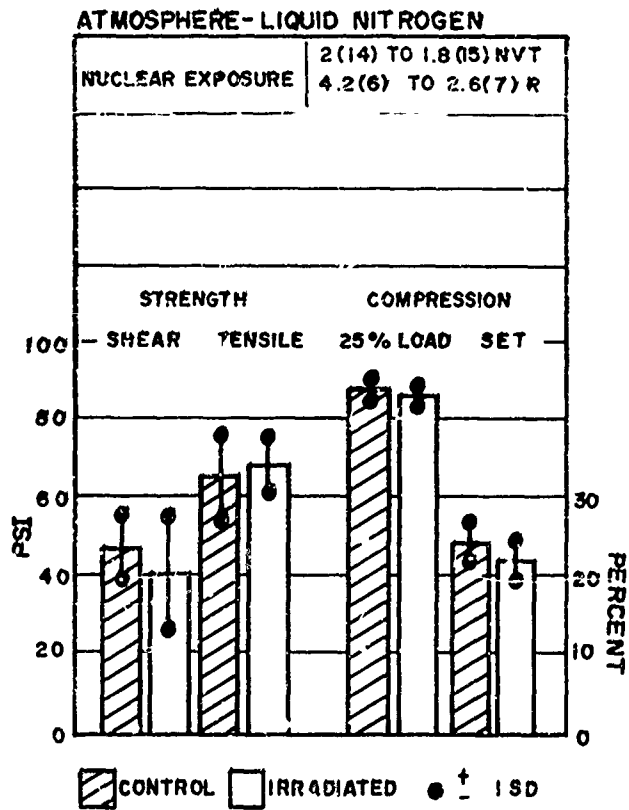


FIGURE C-26. RADIATION EFFECTS ON MARFOAM(13)

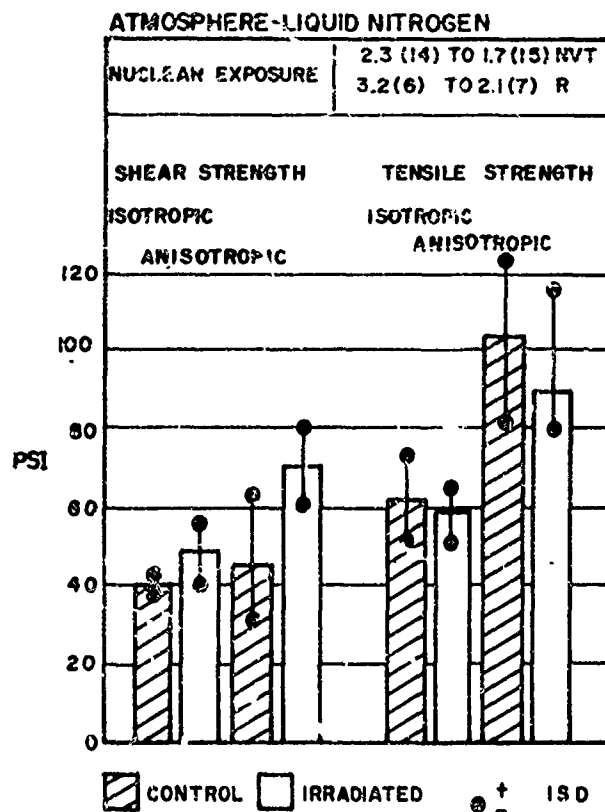


FIGURE C-27. RADIATION EFFECTS ON SHEAR AND TENSILE STRENGTHS OF CPR20-3 FOAM(13)

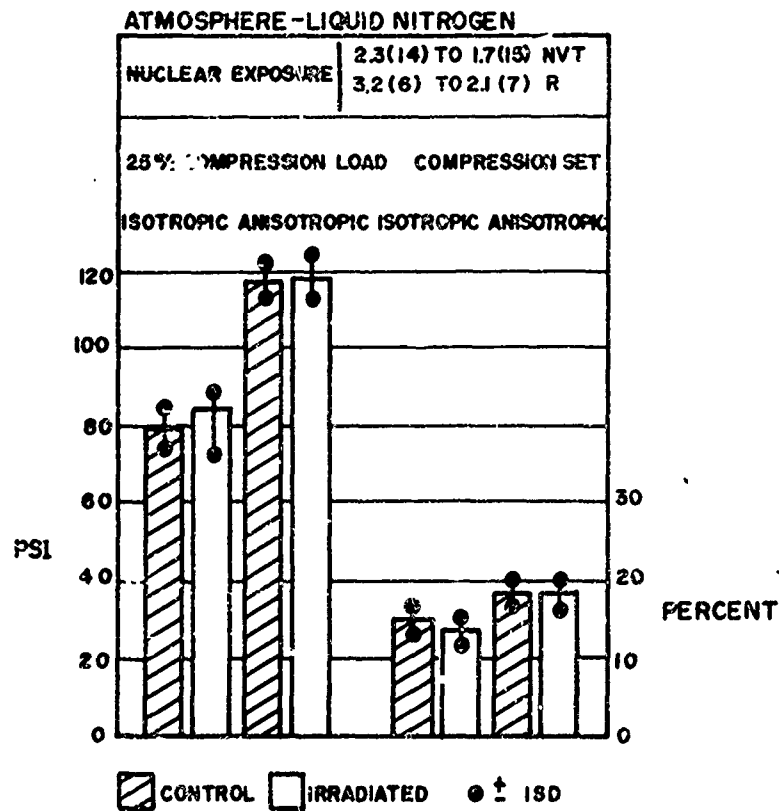


FIGURE C-26. RADIATION EFFECTS ON COMPRESSIVE PROPERTIES OF CPR20-3 FOAM⁽¹³⁾

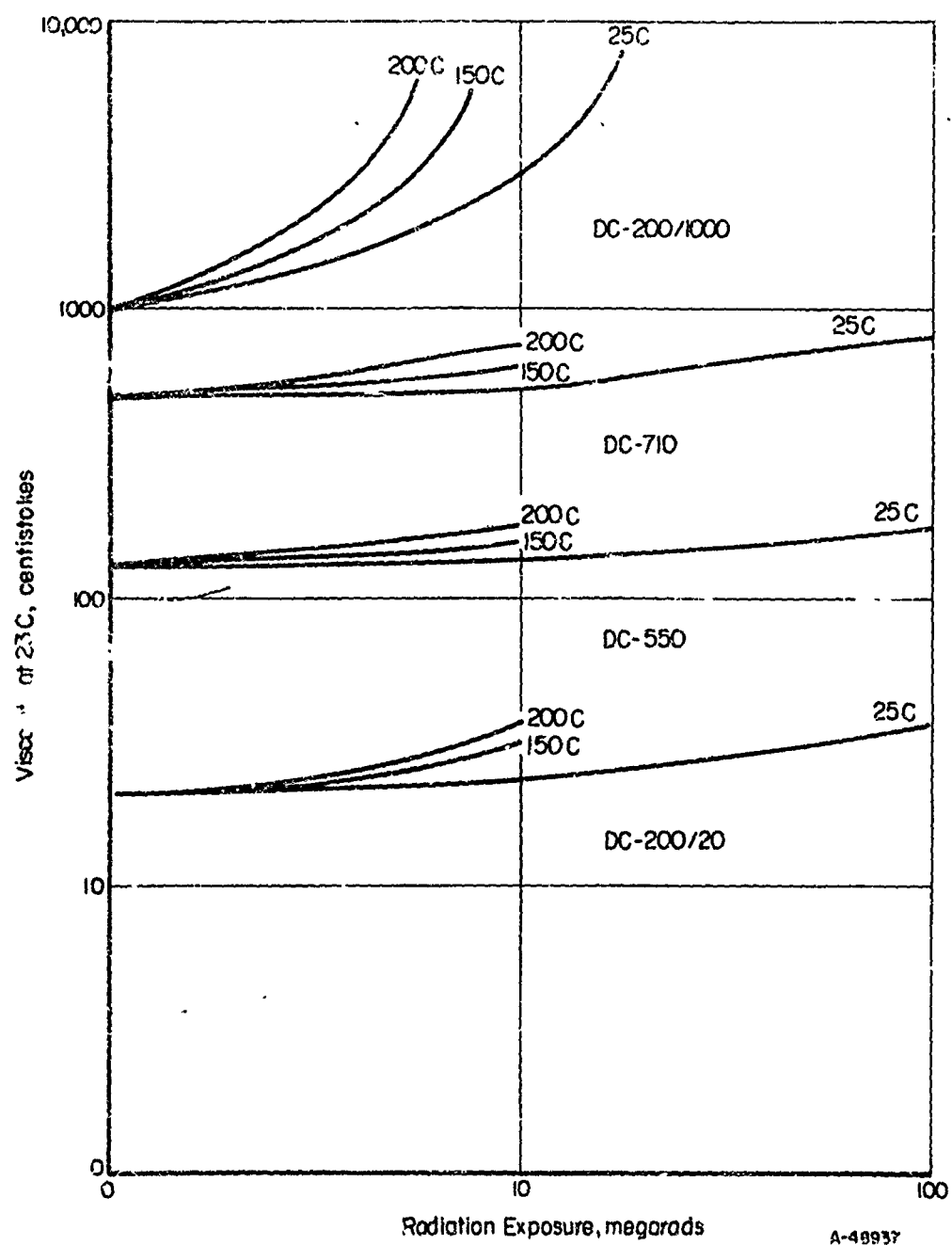
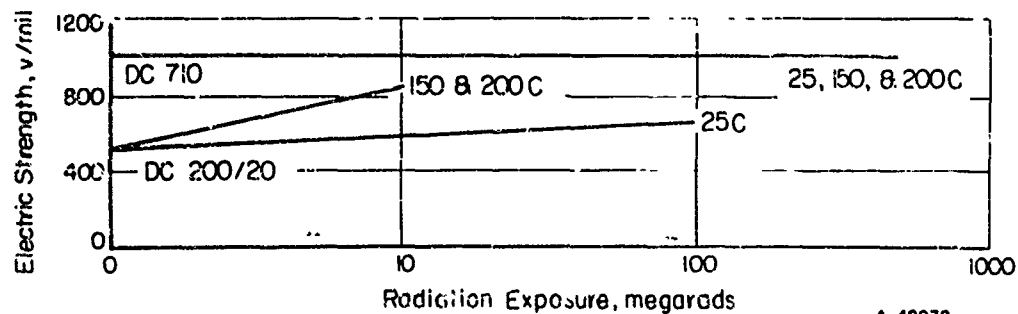
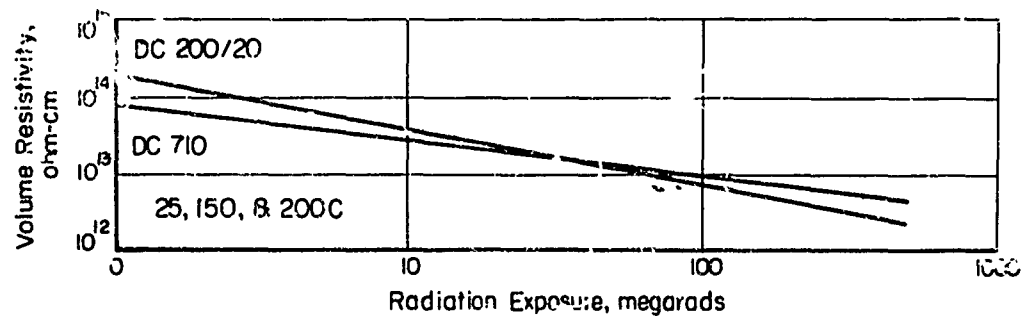
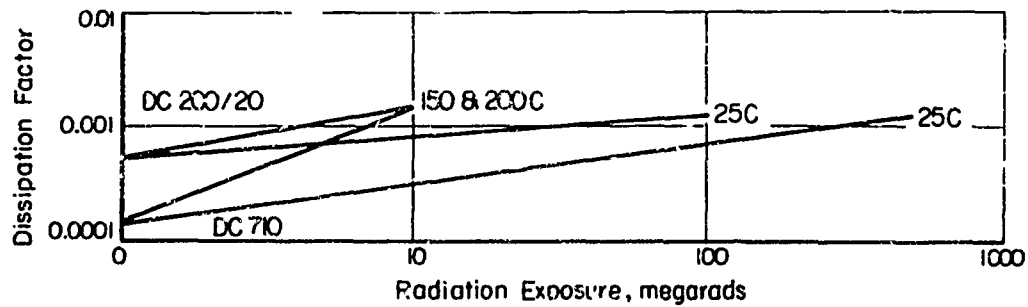
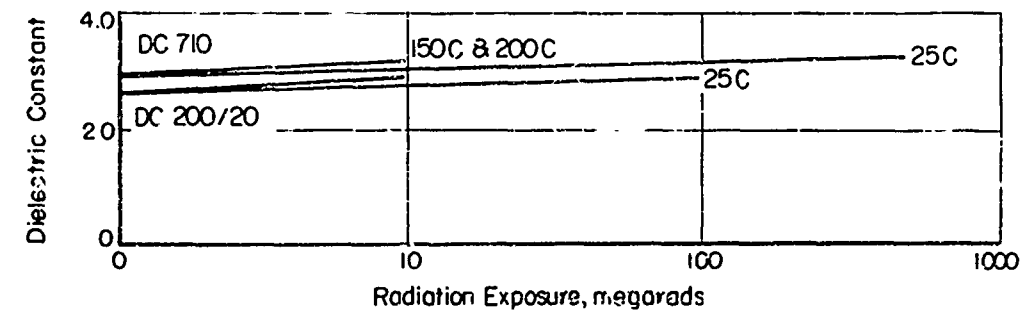
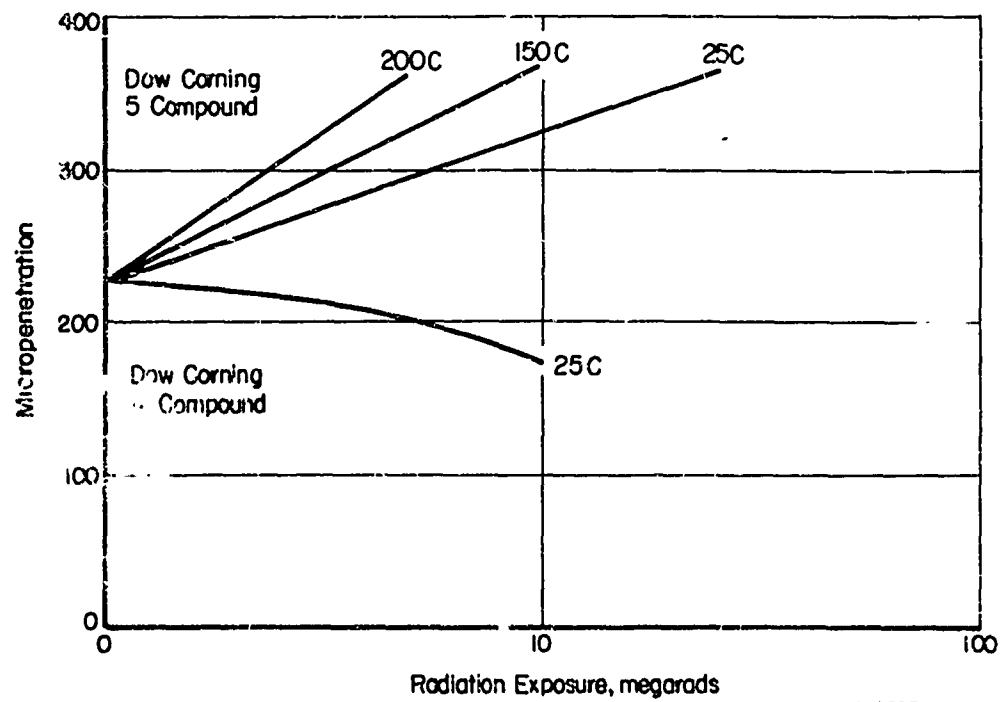


FIGURE C-29. EFFECTS OF GAMMA RADIATION ON VISCOSITY OF SILICONE FLUIDS(36)



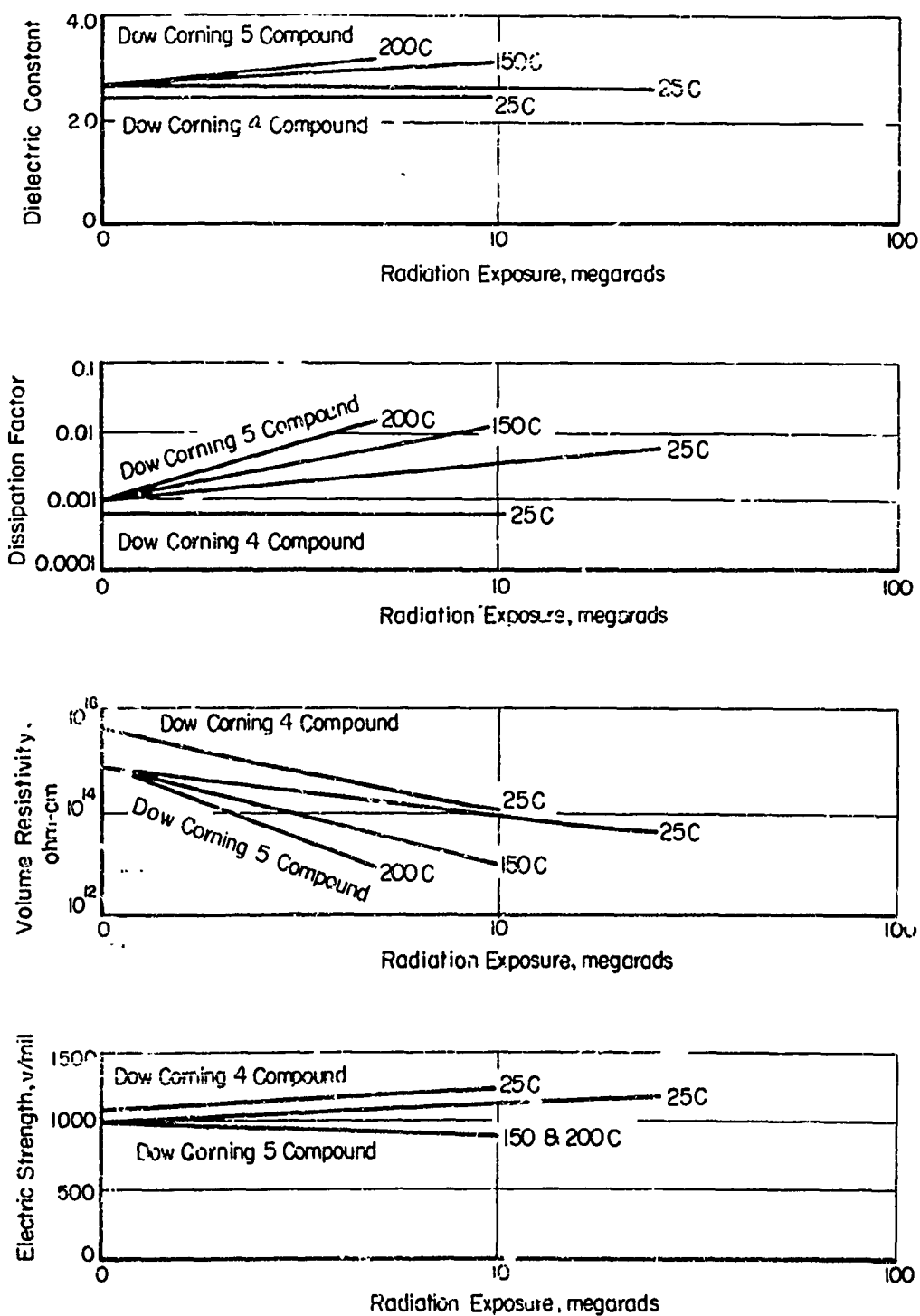
A-48938

FIGURE C-30. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICONE FLUIDS⁽³⁶⁾



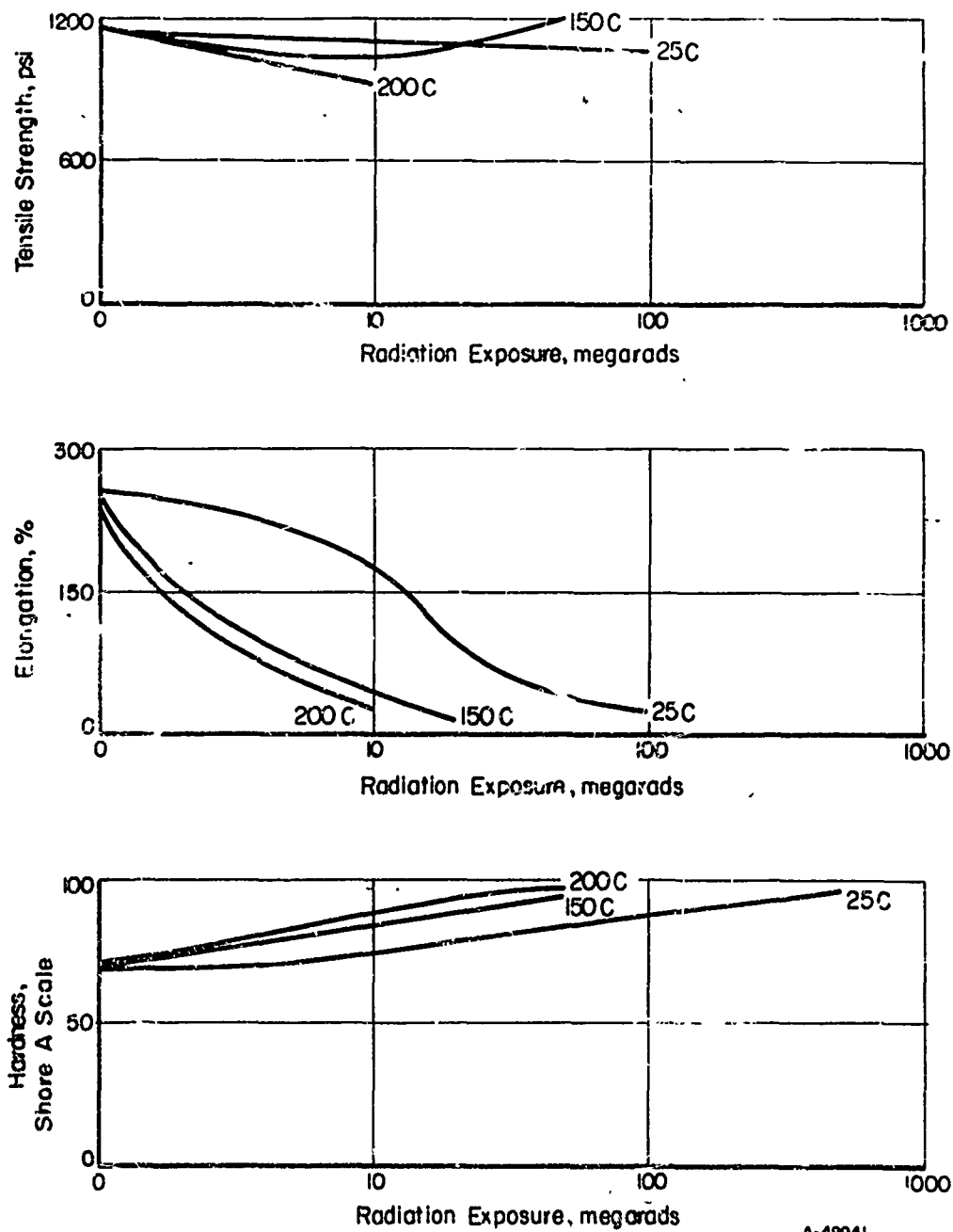
A-4893

FIGURE C-31. EFFECTS OF GAMMA RADIATION ON PENETRATION OF SILICONE COMPOUNDS⁽³⁶⁾



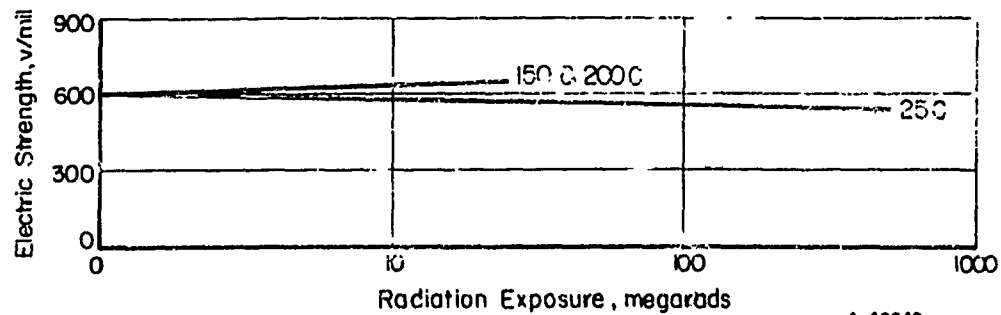
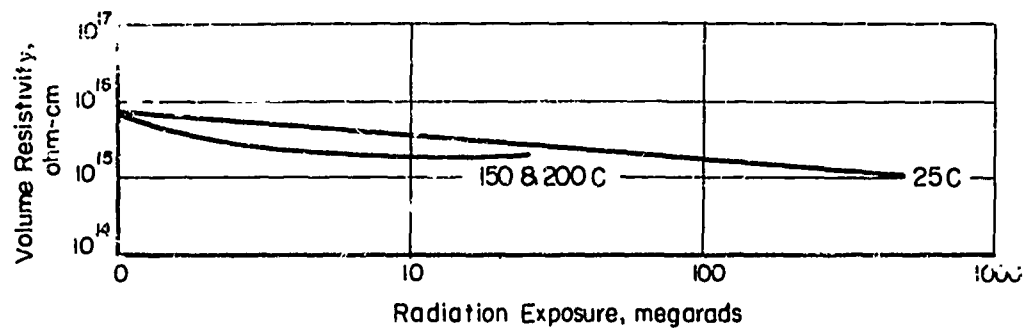
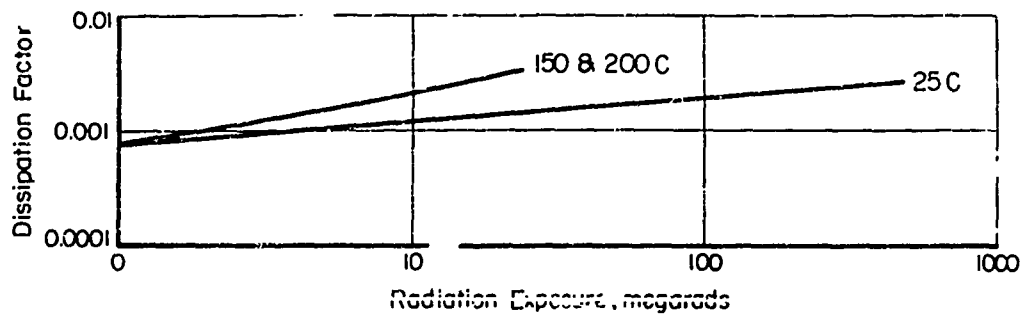
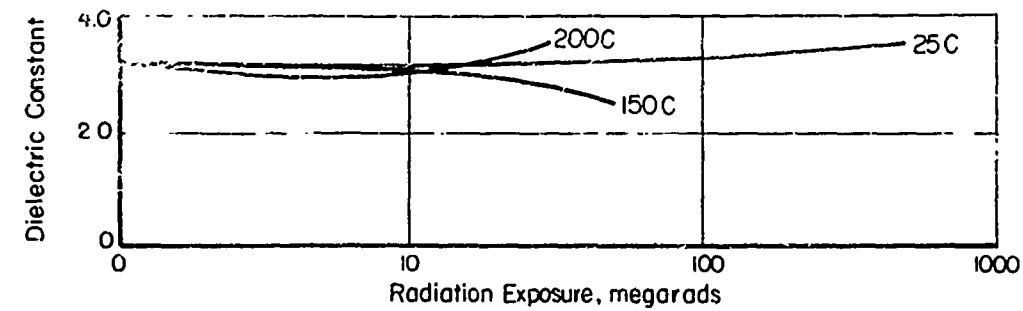
A-48940

FIGURE C-32. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICONE COMPOUNDS(36)



A-40941

FIGURE C-33. EFFECTS OF GAMMA RADIATION ON PHYSICAL PROPERTIES OF SILASTIC 1602⁽³⁶⁾



A-48942

FIGURE C-34. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILASTIC 1602(36)

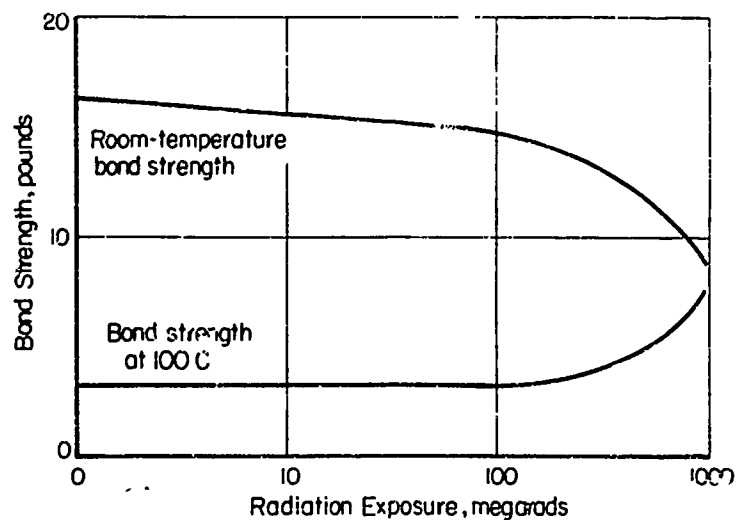
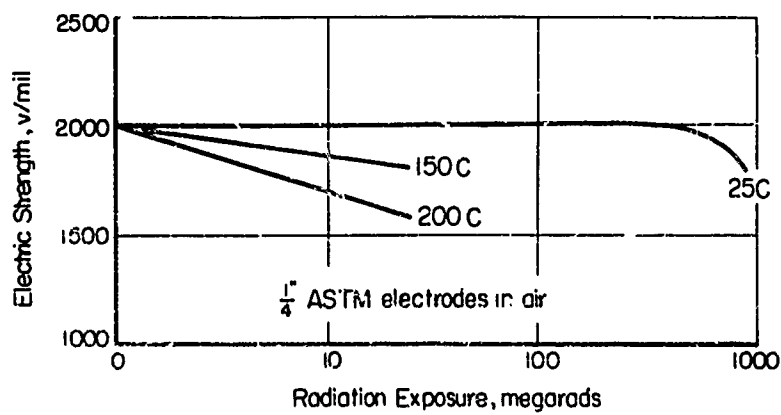
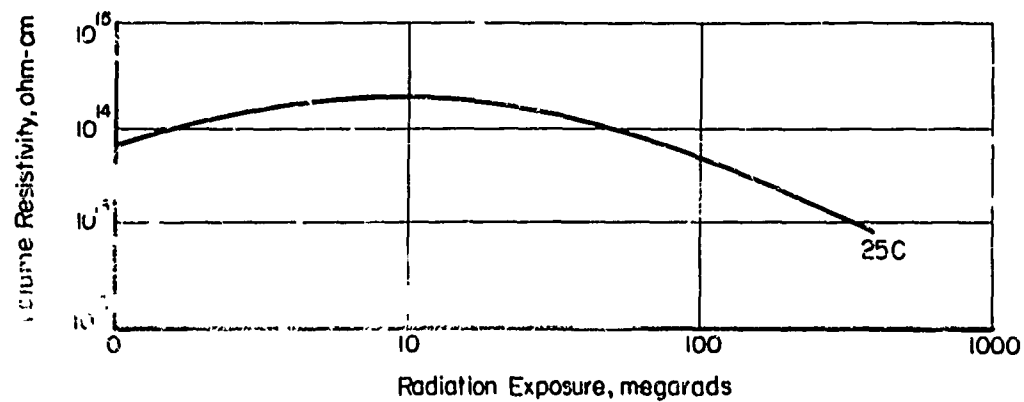
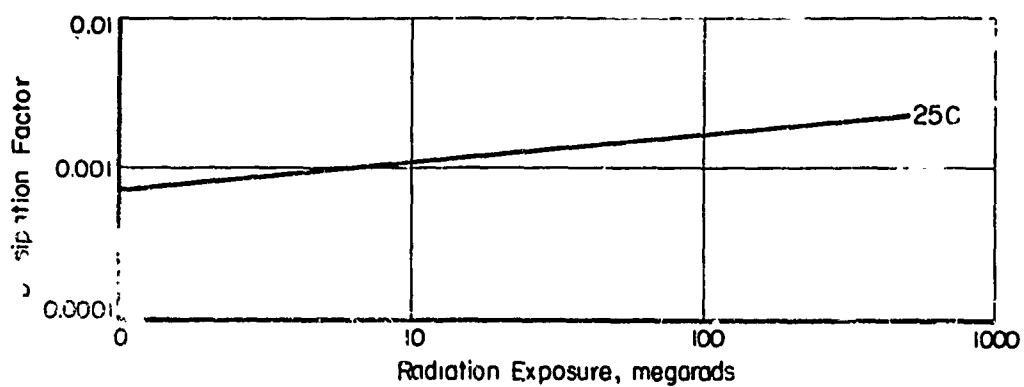
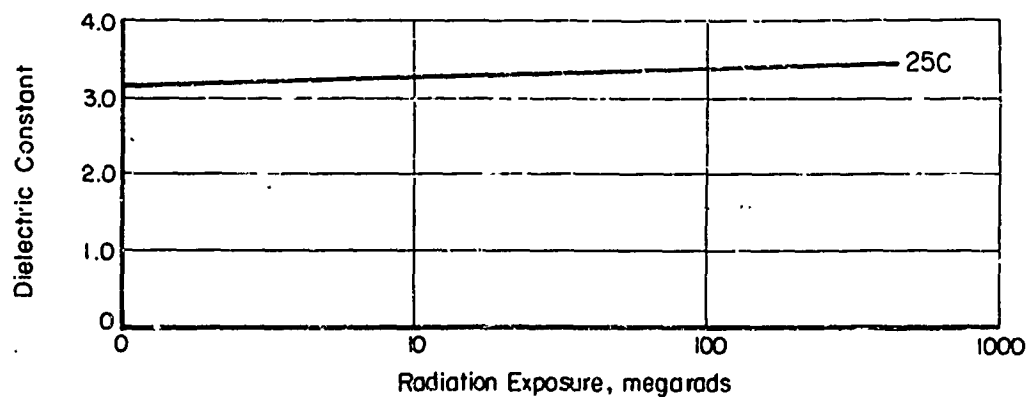


FIGURE C-35. EFFECTS OF GAMMA RADIATION ON BOND STRENGTH OF DOW CORNING 980 VARNISH⁽³⁶⁾



A-48943

FIGURE C-36. EFFECTS OF GAMMA RADIATION ON ELECTRIC STRENGTH OF DOW CORNING 980 VARNISH⁽³⁶⁾



A-48944

FIGURE C-37. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SYLGARD 182(56)

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*8	A Survey of Current Research and Developments in the Field of Dosimetry (May 31, 1958), AD 157173
6 (First Addendum)	A Survey of Current Research and Developments in the Field of Dosimetry (March 31, 1959), AD 210766
10	The Effect of Nuclear Radiation on Semiconductor Devices (April 20, 1960), AD 240433 (Supersedes Memos Nos. 4, 5, 6)
10 (First Addendum)	The Effect of Nuclear Radiation on Semiconductor Devices (July 16, 1961), AD 262081
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17	The Effect of Nuclear Radiation on Structural Adhesives (March 1, 1961), AD 258954 (Supersedes Reports Nos. 7 and 1)
18	The Effect of Nuclear Radiation on Electronic Components (June 1, 1961), AD 280303 (Supersedes Reports Nos. 9, 12, 14, and 15 and Memos Nos. 2, 7, 12, 14, and 20)
19	The Effect of Nuclear Radiation on Lubricants and Hydraulic Fluids (May 31, 1961), AD 261278 (Supersedes Report No. 4)
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Security Classification

DOCUMENT CONTROL DATA - R&D		
<i>Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified</i>		
1. ORIGINATING ACTIVITY (Corporate author) Radiation Effects Information Center Dattelle Memorial Institute Columbus, Ohio 43201		2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) State-of-the-Art 1961-1964		
5. AUTHOR(S) (Last name, first name, initial) Broadway, Norman J. and Palinchak, Stephen		
6. REPORT DATE August 31, 1964	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS 81 ?
8a. CONTRACT OR GRANT NO. AF 33(615)-1124 b. PROJECT NO. BPSN Nr. 64-6899 7381 738103 c. 64-6399 7634 d.	9a. ORIGINATOR'S REPORT NUMBER(S) REIC Report No. 21 (Addendum) 9b. OTHER REPORT NO(S) (Any other numbers that may be associated with this report)	
10. AVAILABILITY/LIMITATION NOTICES Defense Documentation Center and the Radiation Effects Information Center		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY USAF, Research and Technology Division and NASA
13. ABSTRACT This report is an addendum to REIC Report No. 21 and presents the state of the art of the effects of nuclear radiation on elastomeric and plastic components and materials from 1961 to the present. The mechanism of radiation damage and the effects of radiation in various environments are briefly discussed. Data summarizing the radiation-effects information on specific components and on the various types of elastomers and plastics are presented in detail. Areas in which additional work is needed are indicated. Radiation polymerization or vulcanization are not covered in this report. The report is intended to be sufficiently inclusive to make it valuable as a reference guide relative to radiation effects under varying conditions of temperature and vacuum on elastomeric and plastic components and materials.		

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