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RADIATION DAMAGE OF MATERIALS ENGINEERING HANDBOOK PART II: A GUIDE TO THE USE OF ELASTOMERS

M. H. Van de Voorde

28 November 1966

DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

REPORT

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V. d. Voorde M.

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November 28, 1966

RADIATION DAMAGE OF MATERIALS

ENGINEERING HANDBOOK

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M.H. Van de Voorde

Part II: A Guide to the Use of Elastomers

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PART II : A GUIDE TO THE USE OF ELASTOMERS

A GUIDE TO THE USE OF ELASTOMERS

Introduction

Selecting an engineering elastomer for application in today's chemistry takes a lot of the design engineer's time. Direct guidance is needed for choosing the best material for real life application.

Because of the current use of elastomers in nuclear radiation environments, it is believed that the attached data may be useful in answering some of the questions which arise in the selection of elastomers for use in nuclear equipment.

This report contains:

- A guide to the general properties of elastomers, and
- A summary of unclassified data available in the technical literature on the subject of the effects on elastomers of nuclear radiation.

At present the majority of the available irradiation data are those obtained in γ - sources and nuclear reactors, particularly by the ORNL graphite reactor. In the application of this information to equipment designed for use in particle accelerators, these data should be considered only as reasonable estimates since the fields of irradiation around accelerators and reactors are quite different.

In many instances the only available information is concerned with structural characteristics, such as tensile strength, rather than with electrical data. In general, if properties, such as tensile strength show large variations, it would be reasonable to expect that the electrical properties will also vary.

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None of the data listed in this report was taken during irradiation. While some of the mechanical properties may differ little if measured during exposure, the volume resistivity can be significantly different.

The unit of radiation used in this report is the rad; one rad is equivalent to the absorption of 100 ergs of energy per gramme of material.

The radiation field inside the ORNL graphite reactor is:

1.1×10^{12} thermal neutrons/cm^2 sec.
1.4×10^{11} neutrons (≥ 0.1 Mev)/cm^2 sec.
6.7×10^{10} neutrons (≥ 0.5 Mev)/cm^2 sec.
4.2×10^{10} neutrons (≥ 1.0 Mev)/cm^2 sec.
$\sim 5 \times 10^{10}$ γ - rays (1 Mev)/cm^2 sec.

The dose rate is 10^6 to 10^7 rads/hr.

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EXPLANATION OF TABLES AND FIGURES

Table 1 represents the chemical resistance, physical and mechanical properties of the most common elastomers. As in plastics new elastomers are created by varying the composition, e.g. fillers and processing techniques. The data in the table are given only for pure gums.

Table 2 is a selection guide to aid the choice of material for a given application.

The effect of nuclear radiation on volume resistivity of the commonest elastomers are given in Table 3.

Table 4 gives values for the total gas evolvedfrom irridiated samples of 0,2 to 0,5 gramme weight.

The radiation stability of some elastomers at temperatures above 85°C is summarized in Table 5.

Table 6 represents the popular name, chemical designation and trade names of elastomers.

Fig. 1 shows the relative radiation resistance of elastomers. It should be mentioned that this Figure reflects only resistance to radiation and that a consideration of other parameters (fillers, antirads, etc.) could change the order in which the material are ranked.

Figs. 2 - 37 show the mechanical property changes effected by radiation in a variety of commercially available polymers.

TABLE 1: GENERAL PROPERTIES OF ELASTOMERS (GENERAL BIBLIOGRAPHY I 56)

Properties \ Popular Name	Acrylics	Butyl	Ethylene Propylene	Fluoroelastor			Heypalon	Natural Rubber
				Vinylidene Fluoride Hexofluoropropylene	Fluorosilicone	Polytrifluorochloro-ethylene		
Specific gravity	1.09	0.90	0.86	-	1.4	1.85	1.18	0.93
Minimum Service Temperature, (°C)	-19	-46	-50	-46	-68	-50	-40	-50
Maximum Service Temperature, (°C)	175	150	150	232	200	200	160	80
Dielectric strength Kv/mm	5	6 -20	16 -30	12 -24	12 -24	12 -24	16 -30	8
Volume resistivity (Ohm-cm)	$10^{10}-10^{12}$	$10^{12}-10^{14}$	$10^{12}-10^{14}$	$>10^{14}$	$10^{12}-10^{14}$	$>10^{14}$	$10^{11}-10^{14}$	$>10^{14}$
Dielectric constant 60 cps 1.000 cps	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10
Tensile strength (kg/cm^2)	18-28	175-210	140-238	140	70	25-42	250-280	175-245
Elongation (%)	450-750	750-950	400-600	>350	200	500-800	600	750-850
Hardness (Durometer)	A40-A90	A40-A90	A30-A90	A60-A90	A50-A60	A45	A45-A90	A30-A90
Compression set (%)	5	7.2	1.5 - 3	<2	<2	<2	3 - 5	13
Strain at 28 kg/cm^2 (%)	36	31	-	-	-	-	-	30
Abrasion resistance	Good	Good	Good	-	Poor	-	Excellent	Excellent
Water resistance	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Excellent
Oil resistance (Aliphatic hydro-carbons; kerosine-gasoline etc.)	Excellent	Poor	Poor	Excellent	Excellent	Excellent	Good	Poor
Ozone resistance	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Poor
Permeability to gas	Low	Very Low	Low	Low	Low-Medium	Very Low	Low	Low

Properties \ Popular Name	Neoprene	Nitrile	Polybutadiene	Polyisoprene-synthetic	Polysulfide	Polyurethane	SBR	Silicone
Specific gravity	1.25	1.00	0.91	0.93	1.35	1.25	0.94	1.1-1.6
Minimum Service Temperature, (°C)	-40	-50	-100	-45	-50	-54	-50	-11
Maximum Service Temperature, (°C)	115	120	95	80	120	115	80	240
Dielectric strength Kv/mm	12	6 -22	6 -22	6 -22	6 -22	> 10	6 22	12 -24
Volume resistivity (Ohm-cm)	10^{10}-5x10^{12}	10^{10}-10^{12}	~10^{14}	>10^{14}	10^{8}-10^{10}	10^{8}-5x10^{10}	>10^{14}	10^{12}-10^{15}
Dielectric constant 60 cps 1.000 cps	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10	3- 3.5 7-10
Tensile strength (kg/cm²)	210-280	35-63	14-70	70-140	>70	>350	14-21	42-91
Elongation (%)	800-900	450-700	400-1.000	-	450-650	540-750	400-600	100-500
Hardness (Durometer)	A40-A95	A40-A95	A40-A90	A40-A80	A40-A85	A35-A100	A40-A90	A30-A90
Compression set (%)	5 - 9	6 - 9	4 - 6	6	8 - 11	1.5 - 3	2 - 5	~1.5
Strain at 28 kg/cm² (%)	31	25	-	-	28	-	28	3.4
Abrasion resistance	Good	Good	Excellent	Excellent	Poor	Excellent	Good	Poor
Water resistance	Good	Excellent	Excellent	Excellent	Good	Good	Excellent	Good
Oil resistance (Aliphatic hydro-carbons; kerosine-gasoline etc.)	Good	Excellent	Poor	Poor	Excellent	Excellent	Poor	Poor
Ozone resistance	Excellent	Poor	Poor	Poor	Excellent	Excellent	Poor	Excellent
Permeability to gas	Low	Low	Low	Very Low	Very Low	Very Low	Low	High

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TABLE 2 ELASTOMER SELECTION GUIDE (General Bibliography p.56)

Secondary Requirement	Primary Requirement					
	Hardness	Resilience	Tensile strength	Compression Set	Abrasion Resistance	Tear Resistance
Hardness	---	1. Natural Rubber 2. Polyurethane 3. Neoprene 4. Synthetic rubber 5. Polybutadiene	1. Polyurethane 2. Natural rubber 3. Neoprene	1. Polyurethane 2. Natural Rubber 3. Synthetic rubber 4. S B R	1. Polyurethane 2. S B R 3. Natural rubber	1. Polyurethane 2. Natural rubber 3. Polybutadiene 4. Butyl
Resilience	1. Polyurethane 2. Natural rubber 3. Neoprene	---	1. Polyurethane 2. Natural rubber 3. Neoprene	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Polyurethane	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene 5. Polyurethane	1. Natural rubber 2. Polyurethane 3. Synthetic rubber 4. Polybutadiene 5. Neoprene
Tensile strength	1. Polyurethane 2. Natural rubber 3. S B R 4. Butyl	1. Polyurethane 2. Natural rubber 3. Neoprene	---	1. Polyurethane 2. Natural Rubber 3. Synthetic rubber 4. Polybutadiene	1. Polyurethane 2. Natural rubber 3. Neoprene	1. Polyurethane 2. Natural rubber 3. Neoprene
Compression Set	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Polybutadiene	1. Synthetic rubber 2. Natural rubber 3. Polybutadiene 4. Neoprene	1. Synthetic rubber 2. Natural rubber 3. Polybutadiene 4. Polyurethane	---	1. S B R 2. Natural rubber 3. Neoprene 4. Polyurethane	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Polybutadiene 5. Neoprene
Abrasion resistance	1. Polyurethane 2. Natural rubber 3. S B R 4. Butyl	1. Natural rubber 2. Polybutadiene 3. Neoprene 4. Polyurethane 5. Synthetic rubber	1. Polyurethane 2. Natural rubber 3. Neoprene	1. Polyurethane 2. Natural rubber 3. Synthetic rubber 4. Polybutadiene 5. S B R	---	1. Polyurethane 2. Natural rubber 3. Synthetic rubber 4. S B R 5. Nitrile
Tear resistance	1. Polyurethane 2. Natural rubber 3. S B R 4. Butyl	1. Polyurethane 2. Natural rubber 3. Synthetic rubber 4. Polybutadiene 5. Neoprene	1. Polyurethane 2. Natural rubber 3. Neoprene	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene	1. Polyurethane 2. Natural rubber 3. Synthetic rubber 4. S B R 5. Polybutadiene	---

Secondary Requirement	Primary Requirement					
	Heat resistance	Low temperature resistance	Electrical resistance	Oil resistance	Permeability to gases	Chemical resistanc
Hardness	1. Butyl 2. Hypalon 3. Ethylene propylene 4. Acrylics 5. Fluoro	1. Silicone 2. Natural rubber 3. S B R	1. Natural rubber 2. S B R 3. Butyl 4. Ethylene Propylene	1. Polyurethane 2. Nitrile 3. Acrylics 4. Fluoro	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Polybutadiene 5. Neoprene	1. S B R 2. Natural rubber 3. Ethylene Propyle
Resilience	1. Butyl 2. Ethylene Propylene 3. Silicone 4. Hypalon 5. Acrylics	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. S B R 5. Ethylene Propylene	1. Polyurethane 2. Nitrile 3. Thiokol 4. Acrylics 5. Fluoro	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene 5. Polyurethane	1. Natural rubber 2. S B R 3. Polybutadiene
Tensile strength	1. Ethylene Propylene 2. Fluoro 3. Butyl 4. Hypalon	1. Natural rubber 2. S B R 3. Neoprene	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Butyl 5. Polybutadiene	1. Polyurethane 2. Nitrile 3. Fluoro	1. Polyurethane 2. Synthetic rubber 3. Polybutadiene 4. Natural rubber 5. Neoprene	1. Polyurethane 2. Polybutadiene 3. Neoprene
Compression Set	1. Nitrile 2. Butyl 3. Ethylene Propylene 4. Silicone	1. S B R 2. Natural rubber 3. Synthetic rubber 4. Polybutadiene	1. Natural rubber 2. Synthetic rubber 3. Ethylene Propylene 4. Neoprene	1. Polyurethane 2. Fluoro 3. Nitrile 4. Neoprene	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Ethylene Propylene 5. Polyurethane	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Hypalon 5. Polybutadiene
Abrasion resistance	1. Butyl 2. Ethylene Propylene 3. Hypalon 4. Acrylics 5. Fluoro	1. Polyurethane 2. S B R 3. Polybutadiene 4. Natural rubber 5. Neoprene	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Polybutadiene 5. Butyl	1. Nitrile 2. Polyurethane 3. Acrylics 4. Neoprene	1. Polyurethane 2. Synthetic rubber 3. Polybutadiene 4. Natural rubber	1. Butyl 2. S B R 3. Natural rubber 4. Neoprene
Tear resistance	1. Butyl 2. Hypalon 3. Acrylics	1. Natural rubber 2. Polyurethane 3. Polybutadiene	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Butyl 5. Polybutadiene	1. Polyurethane 2. Nitrile 3. Acrylics 4. Neoprene 5. Hypalon	1. Polyurethane 2. Butyl 3. Thiokol 4. Natural rubber	1. Synthetic rubber 2. Natural rubber 3. Hypalon 4. Neoprene

Secondary Requirement	Primary Requirement					
	Heat resistance	Low temperature resistance	Electrical resistance	Oil resistance	Permeability to gases	Chemical resistance
Heat resistance	---	1. Nitrile 2. Natural rubber 3. Neoprene 4. Hypalon	1. Butyl 2. Ethylene Propylene 3. Silicone 4. Natural rubber 5. Synthetic rubber	1. Fluoro 2. Acrylics 3. Nitrile 4. Polyurethane 5. Thiokol	1. Butyl 2. Hypalon 3. Ethylene Propylene	1. Butyl 2. Hypalon 3. S B R 4. Polybutadiene
Low temperature resistance	1. Silicone 2. Ethylene Propylene 3. Hypalon	---	1. Ethylene Propylene 2. S B R 3. Synthetic rubber 4. Natural rubber 5. Polybutadiene	1. Nitrile 2. Neoprene 3. Thiokol 4. Fluoro	1. Silicone 2. Hypalon 3. Polybutadiene 4. Natural rubber	1. Polybutadiene 2. Natural rubber 3. S B R
Electrical resistance	1. Butyl 2. Ethylene Propylene 3. Silicone 4. Hypalon 5. Acrylics	1. Natural rubber 2. S B R 3. Ethylene Propylene	---	1. Thiokol 2. Polyurethane 3. Acrylics 4. Fluoro 5. Hypalon	1. Butyl 2. Natural rubber 3. S B R 4. Silicone 5. Polyurethane	1. Hypalon 2. Natural rubber 3. Silicone
Oil resistance	1. Acrylics 2. Fluoro 3. Hypalon 4. Nitrile 5. Thiokol	1. Nitrile 2. Neoprene 3. Thiokol	1. Thiokol 2. Polyurethane 3. Acrylics 4. Fluoro 5. Hypalon	---	1. Thiokol 2. Nitrile	1. Nitrile 2. Neoprene 3. Hypalon
Permeability to gases	1. Ethylene Propylene 2. Polyurethane 3. Fluoro 4. Hypalon	1. Ethylene Propylene 2. Natural rubber 3. Neoprene 4. Butyl	1. Butyl 2. Ethylene Propylene 3. Natural rubber 4. S B R	1. Polyurethane 2. Nitrile 3. Neoprene 4. Fluoro 5. Hypalon	---	1. Butyl 2. Natural rubber 3. Hypalon
Chemical resistance	1. Ethylene Propylene 2. Butyl 3. Hypalon 4. Nitrile	1. Ethylene Propylene 2. S B R 3. Natural rubber	1. Ethylene Propylene 2. S B R 3. Natural rubber 4. Polybutadiene 5. Natural rubber	1. Nitrile 2. Polyurethane 3. Acrylics 4. Neoprene 5. Hypalon	1. Butyl 2. Ethylene Propylene 3. Hypalon	---

Secondary Requirement	Primary Requirement					
	Hardness	Resilience	Tensile strength	Compression Set	Abrasion Resistance	Tear resistanc
Heat resistance	1. Butyl 2. Polyurethane 3. Natural rubber 4. S B R	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene 5. Polyurethane	1. Polyurethane 2. Natural rubber 3. Ethylene Propylene 4. Fluoro	1. Nitrile 2. S B R 3. Ethylene Propylene	1. Polyurethane 2. Natural rubber 3. Synthetic rubber 4. S B R 5. Polybutadiene	1. Polyurethane 2. Natural rubbe 3. Butyl 4. Hypalon 5. Acrylics
Low temperature resistance	1. Ethylene Propylene 2. S B R 3. Polybutadiene	1. Polybutadiene 2. Neoprene 3. Polyurethane	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene 5. Nitrile	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. S B R	1. S B R 2. Polybutadiene 3. Neoprene 4. Polyurethane	1. Natural rubbe 2. Polybutadiene 3. Neoprene 4. Polyurethane
Electrical resistance	1. Natural rubber 2. Butyl 3. S B R 4. Polyurethane	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene 5. Polyurethane	1. Natural rubber 2. Polyurethane 3. Neoprene	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. S B R	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. S B R 5. Neoprene	1. Natural rubbe 2. Polyurethane 3. Butyl 4. S B R 5. Synthetic rub
Oil resistance	1. Polyurethane 2. Hypalon 3. Nitrile 4. Acrylics 5. Fluoro	1. Polyurethane 2. Neoprene 3. Nitrile 4. Thiokol 5. Acrylics	1. Polyurethane 2. Nitrile 3. Fluoro 4. Neoprene	1. Nitrile 2. Neoprene 3. Fluoro	1. Neoprene 2. Polyurethane 3. Neoprene 4. Acrylics	1. Polyurethane 2. Nitrile 3. Acrylic 4. Neoprene 5. Hypalon
Permeability to gases	1. Butyl 2. S B R 3. Natural rubber 4. Synthetic rubber	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. Neoprene	1. Butyl 2. Natural rubber 3. Polybutadiene 4. S B R	1. S B R 2. Ethylene Propylene 3. Butyl	1. Natural rubber 2. Synthetic rubber 3. Polybutadiene 4. S B R 5. Polyurethane	1. Natural rubbe 2. Synthetic rubl 3. Polybutadiene 4. Polyurethane 5. Neoprene
Chemical resistance	1. S B R 2. Natural rubber 3. Polybutadiene	1. Natural rubber 2. Polybutadiene 3. Synthetic rubber 4. Neoprene	1. Natural rubber 2. Neoprene 3. S B R	1. Natural rubber 2. Synthetic rubber 3. S B R 4. Polybutadiene	1. S B R 2. Synthetic rubber 3. Butyl 4. Polybutadiene 5. Polyurethane	1. Natural rubbe 2. S B R 3. Polybutadiene 4. Neoprene 5. Polyurethane

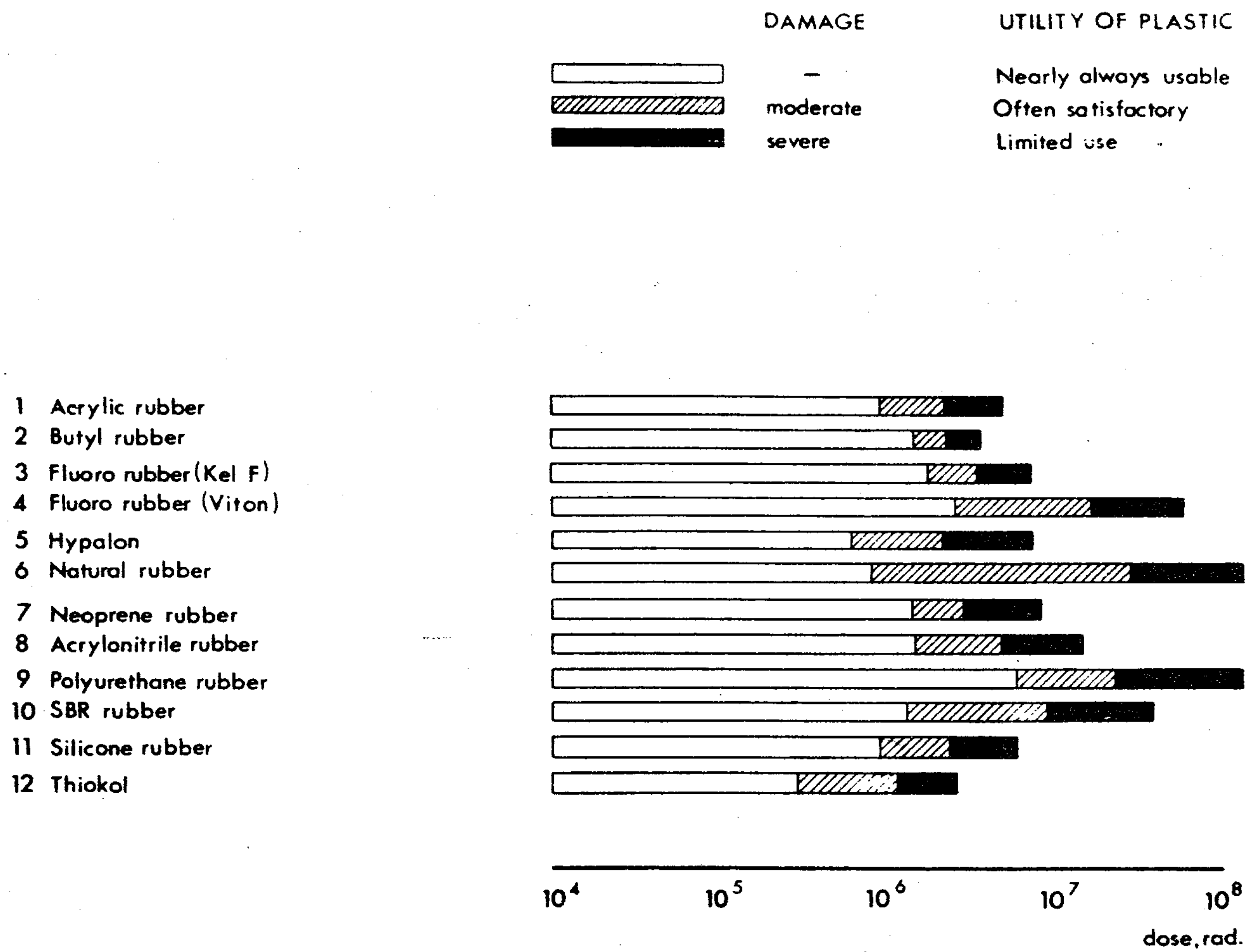
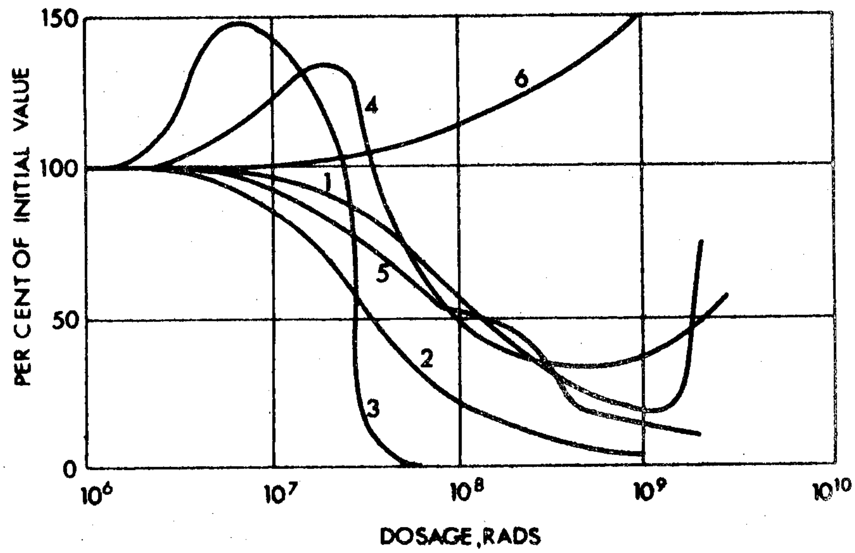


Fig.1 OVER-ALL RELATIVE RADIATION STABILITY OF ELASTOMERS (1,2,3)

Acrylic Elastomer



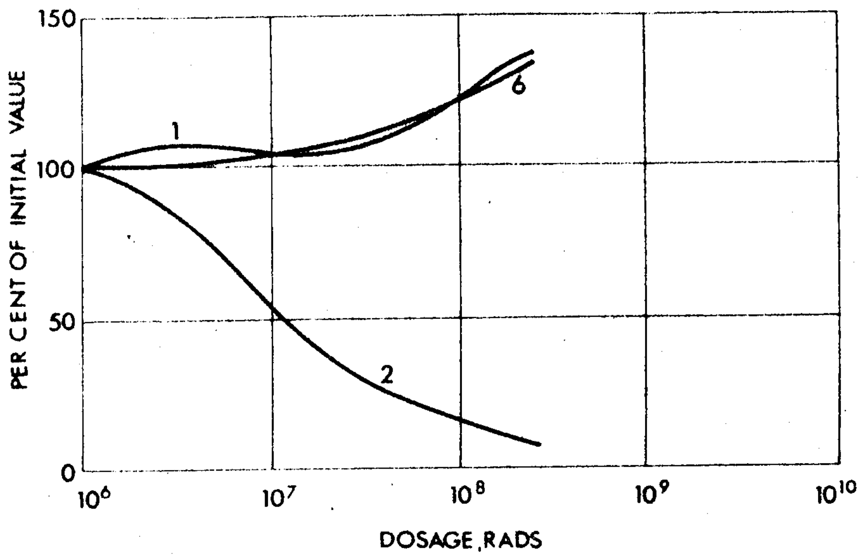
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	140kg/cm^2
2 ELONGATION	230%
3 SET AT BREAK	10%
4 COMPRESSION SET	5%
5 STRAIN AT 28kg/cm^2	36%
6 DUROMETER HARDNESS	60

HYCAR PA-21-"COPOLYMER OF 90% BUTYL ACRYLATE AND 100% ACRYLONITRILE" (4,5)

B.F.Goodrich Chemical Co

Fig. 2

Acrylic Elastomer



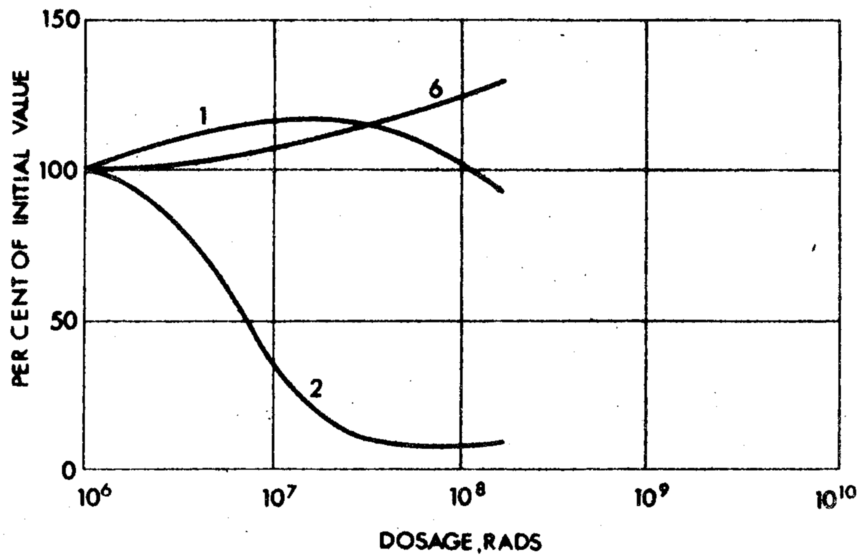
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	110 kg/cm^2
2 ELONGATION	545%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	70

ACRYLON EA-5 – "COPOLYMER OF 95% ETHYL ACRYLATE AND 5% ACRYLONITRILE" (6)

Borden Chemical C^o^

Fig. 3

Acrylic Elastomer (4,5,6,7)



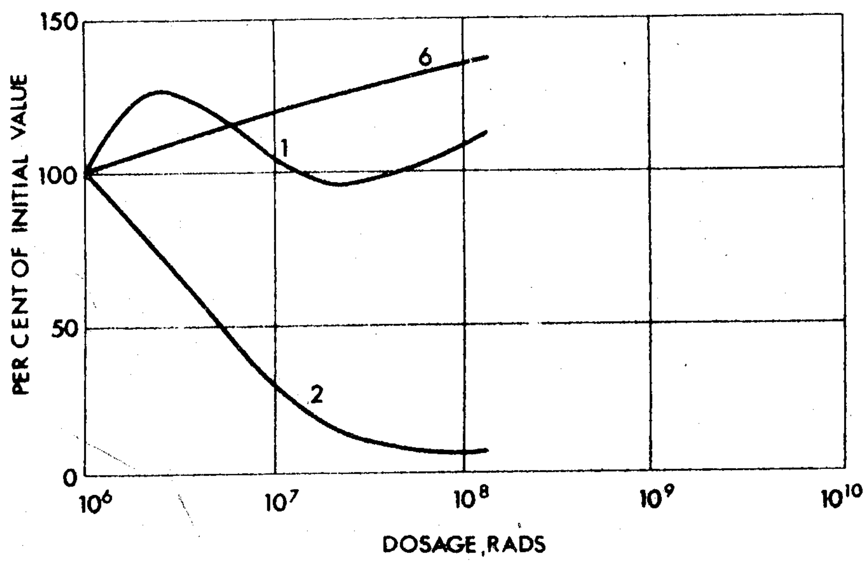
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	95 kg/cm^2
2 ELONGATION	505%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	70

PR 1203-70 - "NOT KNOWN" (6,7,8)

Precision Rubber Products Co

Fig. 4

Acrylic Elastomer (4,5,6,7)



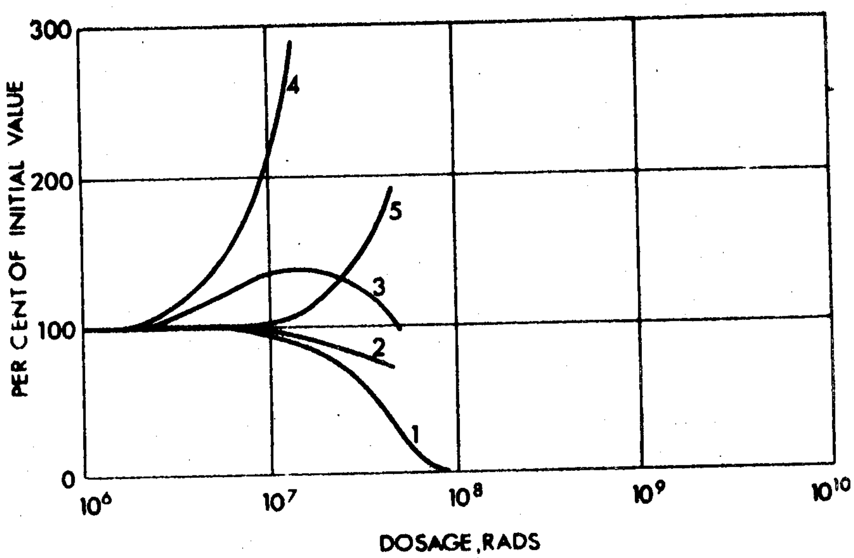
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	68 kg/cm2
2 ELONGATION	275%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm2	–
6 DUROMETER HARDNESS	68

VYRAM - "NOT KNOWN" (6,8)

Monsanto Chemical C°

Fig. 5

Butyl Elastomer

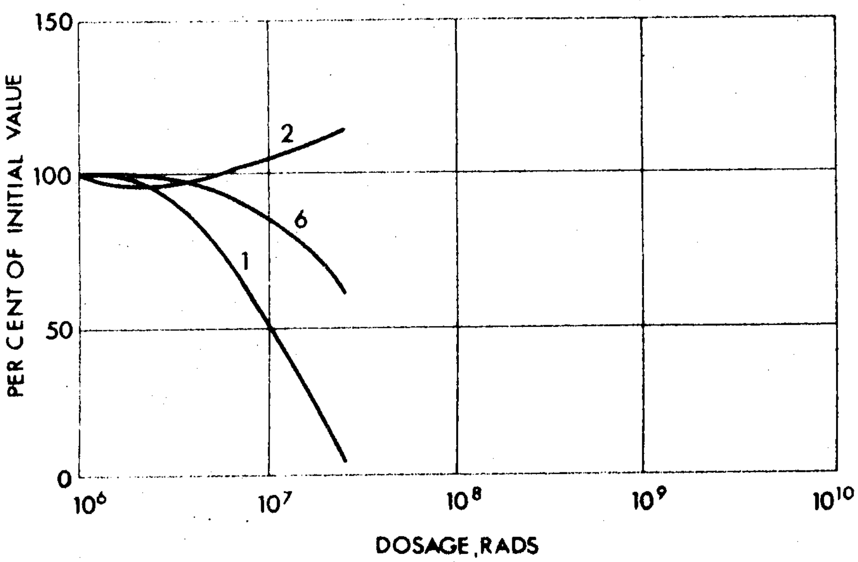


PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	77 kg/cm^2
2 ELONGATION	525%
3 SET AT BREAK	35%
4 COMPRESSION SET	72%
5 STRAIN AT 28 kg/cm^2	31%

GR-150-"ISOBUTYLENE - DIENE COPOLYMER" (4,5)

Fig. 6

Butyl Elastomer



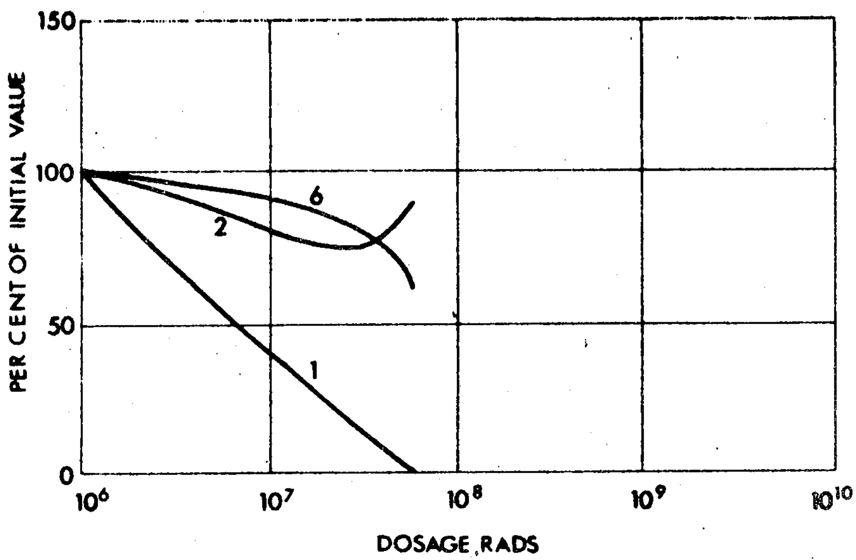
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	105 kg/cm^2
2 ELONGATION	440%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	71

PR 907-70-"NOT KNOWN" (1,8,9)

Precision Rubber Products C°

Fig. 7

Butyl Elastomer



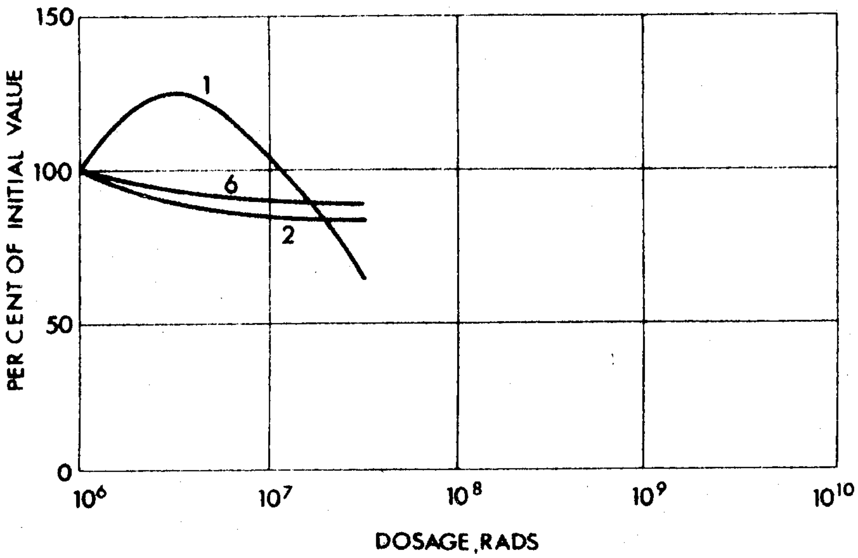
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	150 kg/cm²
2 ELONGATION	345 %
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm²	–
6 DUROMETER HARDNESS	73

HYCAR 2002-"BUTYL-RUBBER BROMINATED TO APPROXIMATELY 3%"
(1,8,9)

B. F. Goodrich Chemical C°

Fig. 8

Fluoro Elastomer



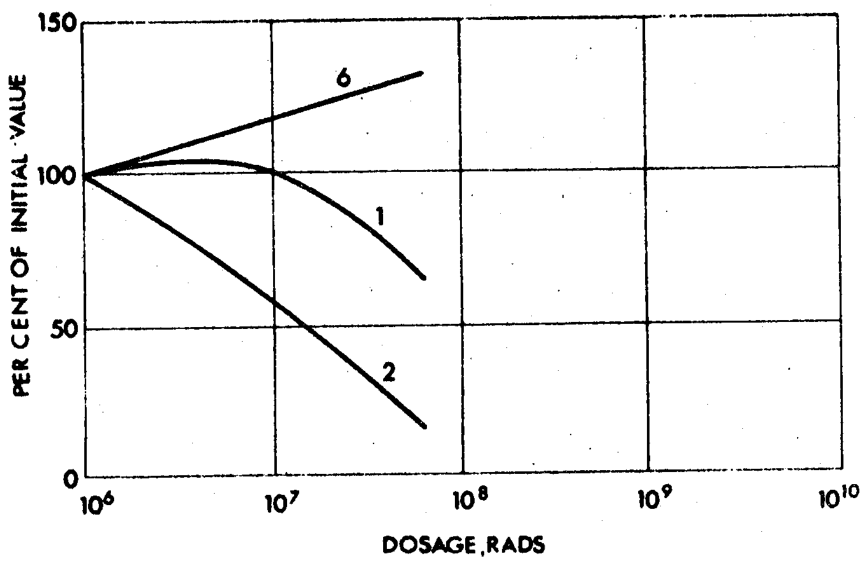
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	77 kg/cm^2
2 ELONGATION	640%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	75

KEL-F ELASTOMER-"COPOLYMER OF TRIFLUOROCHLOROETHYLENE AND VINYLIDENE FLUORIDE" (10,13)

Fig. 9

Minnesota Mining & Mfg C°

Fluoro Elastomer



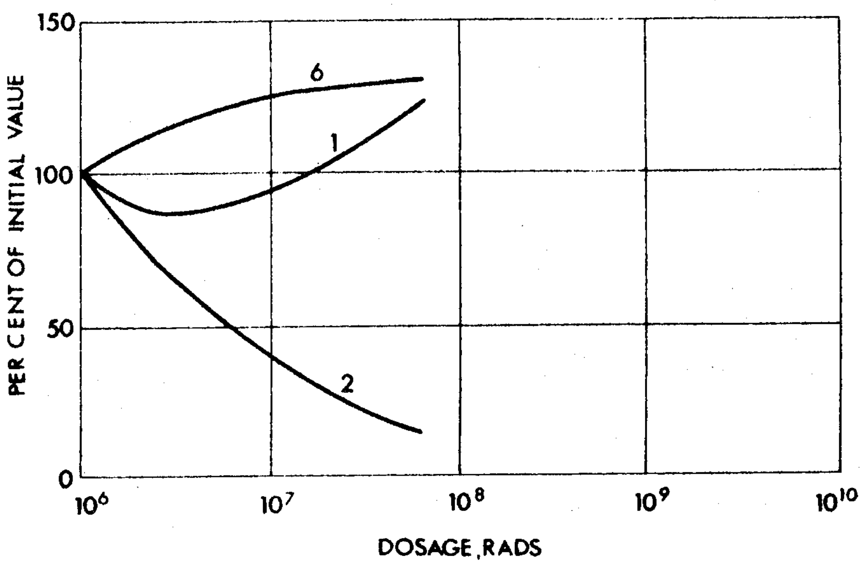
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	84 kg/cm^2
2 ELONGATION	150%
3 SET AT BREAK	-
4 COMPRESSION SET	-
5 STRAIN AT 28 kg/cm^2	-
6 DUROMETER HARDNESS	71

3M-1F4 - "POLYMER OF 1,1 DIHYDROPERFLUOROBUTYL ACRYLATE" (13,16)

Fig. 10

Minnesota Mining & Mfg C°

Fluoro Elastomer



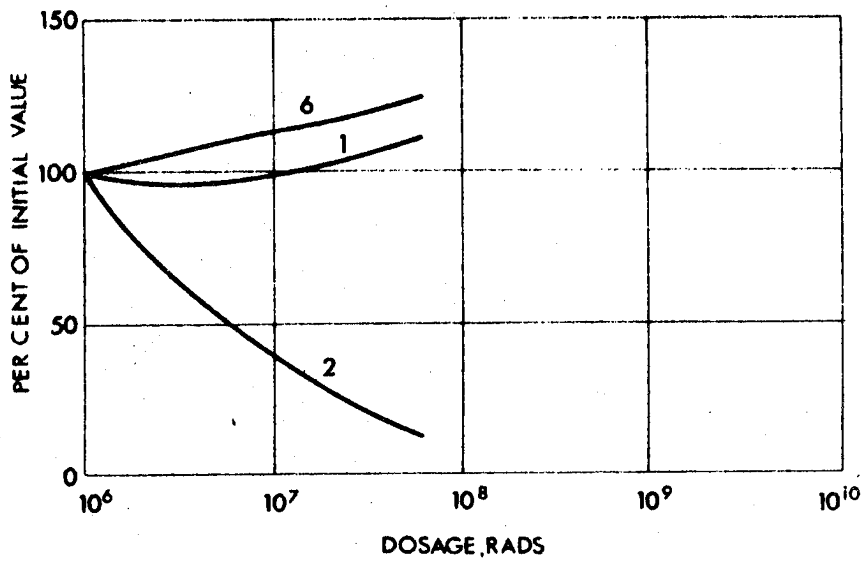
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	140 kg/cm^2
2 ELONGATION	275 %
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	77

VITON - "COPOLYMER OF VINYLIDENE FLUORIDE AND HEXAFLUOROPROPYLENE" (10,11,12,14,15,16)

Fig. 11

E.I. du Pont de Nemours C°

Fluoro Elastomer



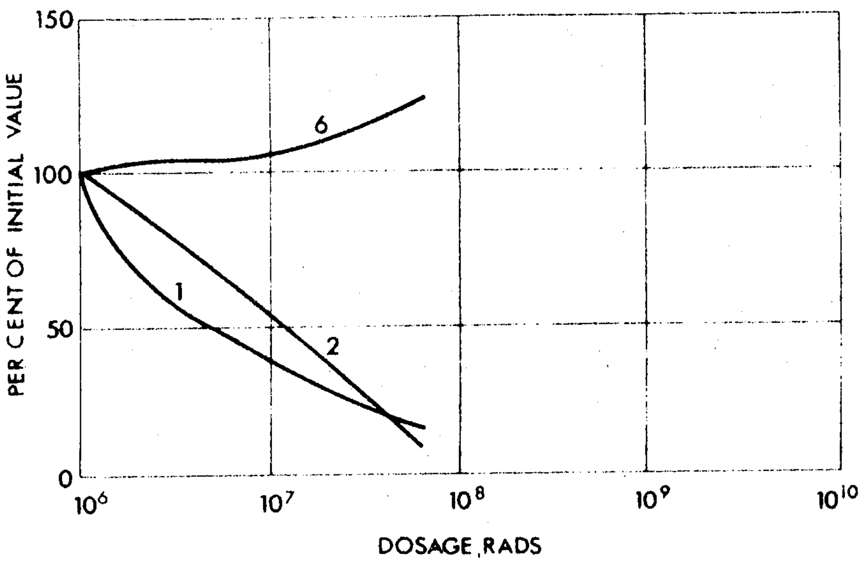
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	135 kg/cm^2
2 ELONGATION	250%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	75

PR 1700 - X7 - "COPOLYMER OF VINYLIDENE FLUORIDE AND HEXAFLUOROPROPYLENE" (11,12,14,16)

Fig.12

Precision Rubber Products Co

Fluoro Elastomer



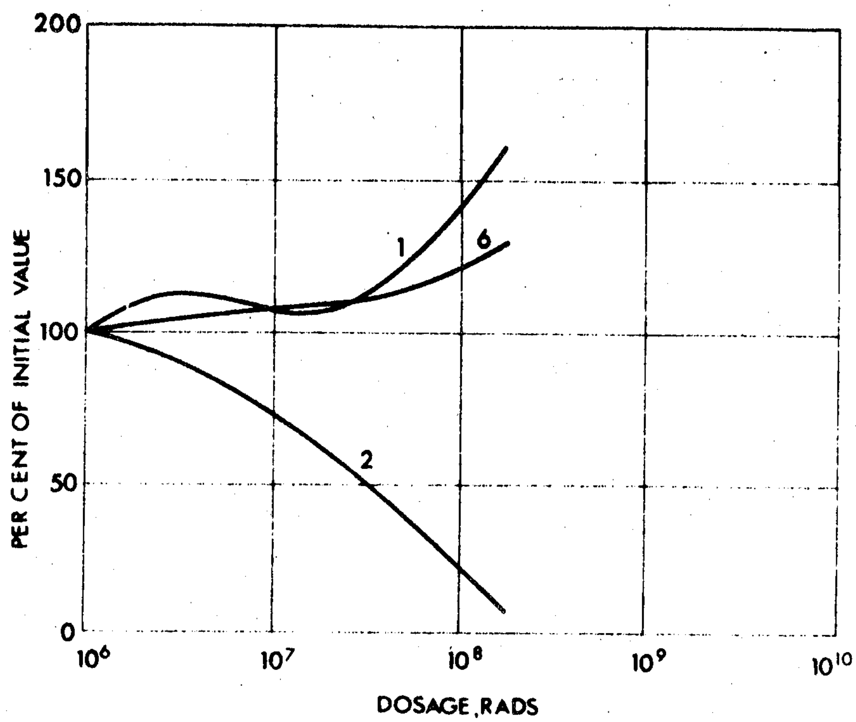
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	980 kg/cm^2
2 ELONGATION	220%
3 SET AT BREAK	-
4 COMPRESSION SET	-
5 STRAIN AT 28kg/cm^2	-
6 DUROMETER HARDNESS	59

SILASTIC LS 53 - "FLUORO SILICONE" (10,13,16)

Fig. 13

Dow Corning C^o

Hypalon Elastomer



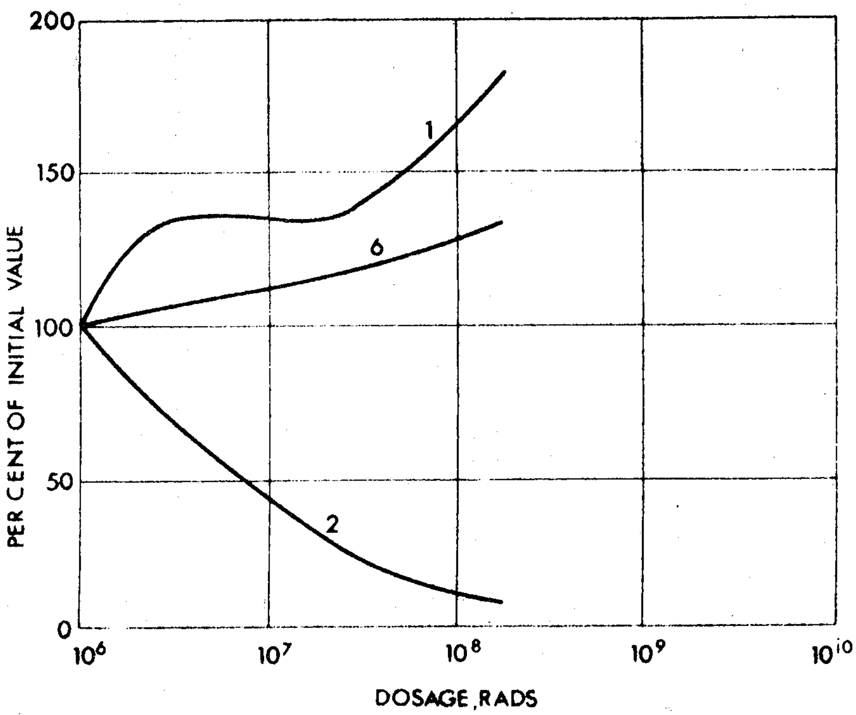
	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	140 kg/cm2
2	ELONGATION	440%
3	SET AT BREAK	–
4	COMPRESSION SET	–
5	STRAIN AT 28kg/cm2	–
6	DUROMETER HARDNESS	75

HYPALON HW-B8-"NOT KNOWN" (4.6.8.11.17.18)

Fig.14

E. I. du Pont de Nemours C°

Hypalon Elastomer



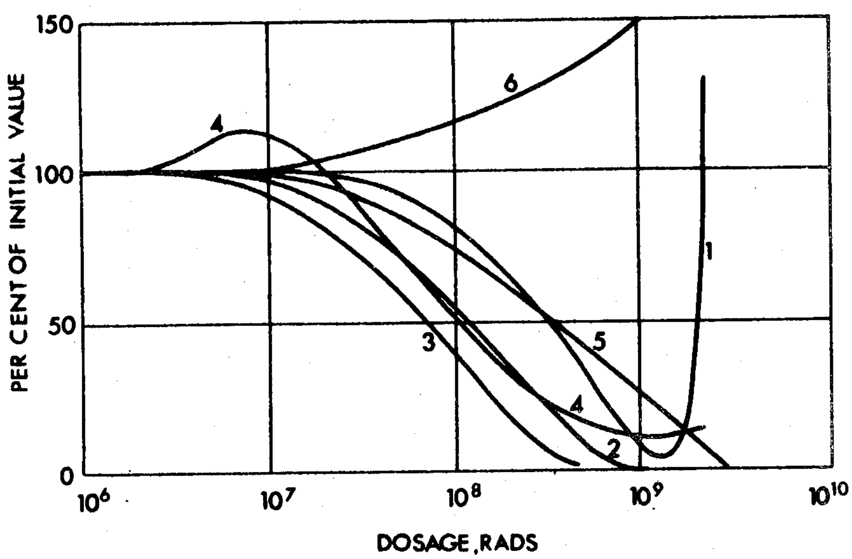
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	126 kg/cm^2
2 ELONGATION	225%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	75

PR 1401-70- "NOT KNOWN "(4,6,11,17,18)

Fig.15

Precision Rubber Products C°

Natural Elastomer

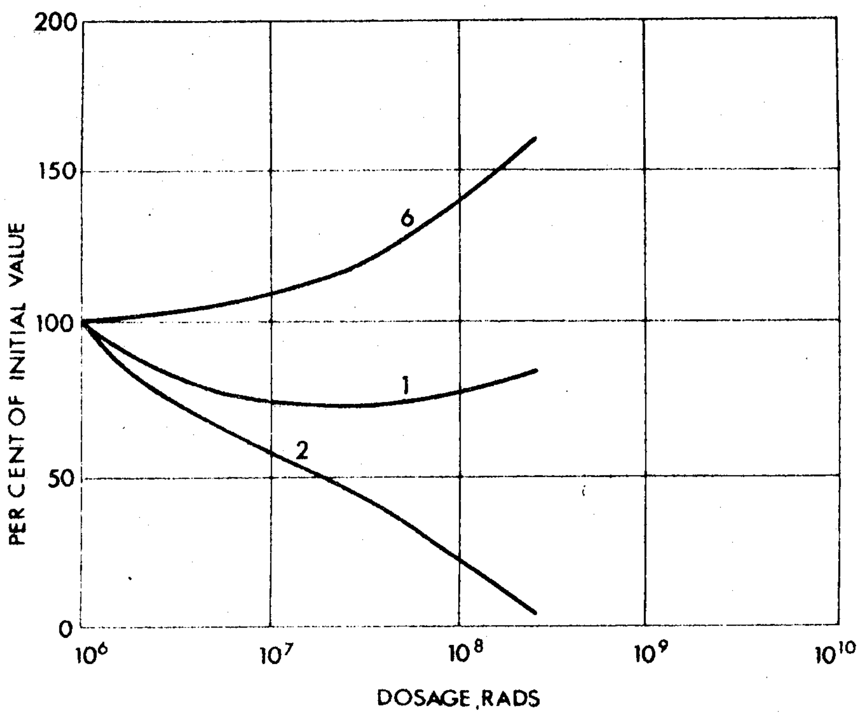


	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	182 kg/cm^2
2	ELONGATION	420%
3	SET AT BREAK	32%
4	COMPRESSION SET	13%
5	STRAIN AT 28kg/cm^2	30%
6	DUROMETER HARDNESS	60

NATURAL RUBBER – "POLYISOPRENE" (4,5,8,9,19,20,21,22,23)

Fig. 16

Natural Elastomer



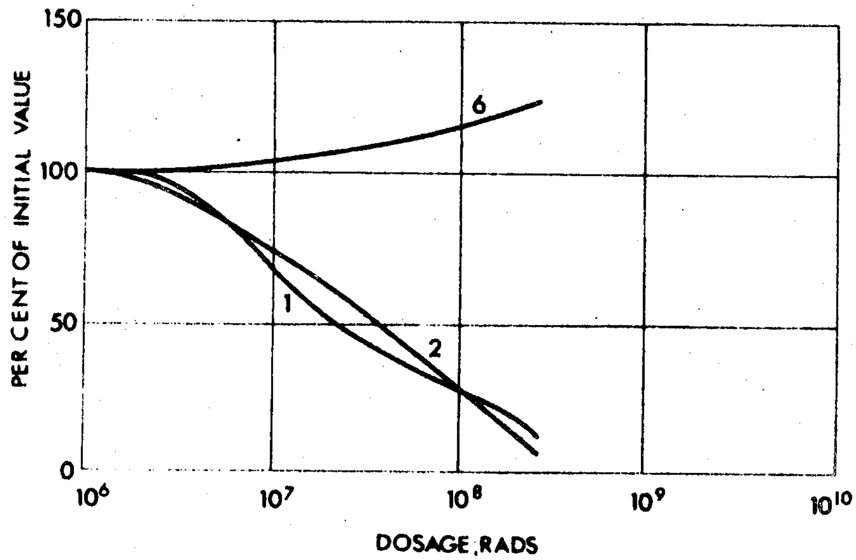
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	28 kg/cm²
2 ELONGATION	200%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm²	–
6 DUROMETER HARDNESS	54

HW - B14 - "SMOKED SHEET" (1,8,9)

Hanford Rubber C°

Fig. 17

Natural Elastomer



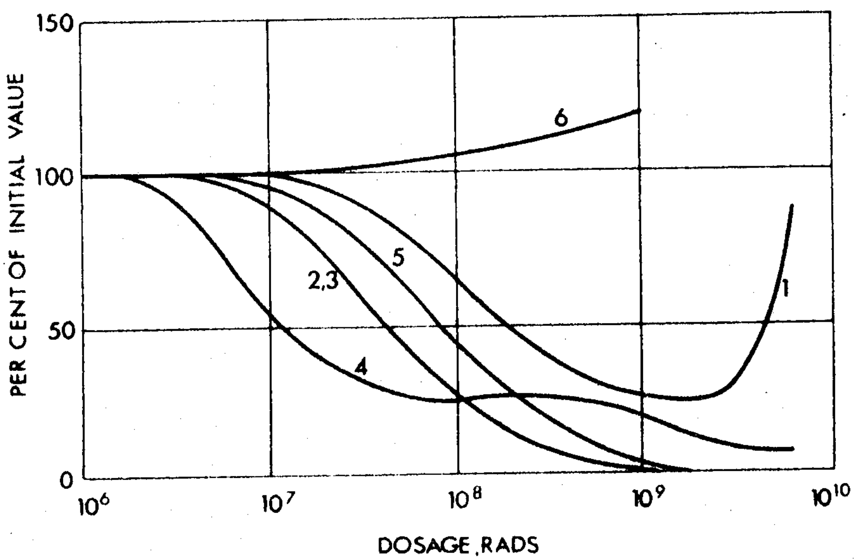
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	260 kg/cm2
2 ELONGATION	560%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm2	–
6 DUROMETER HARDNESS	69

TK 1/1 –"GRAFT POLYMER OF STYRENE AND NATURAL RUBBER "(1,8,9)

Natural Rubber Bureau

Fig. 18

Neoprene Elastomer



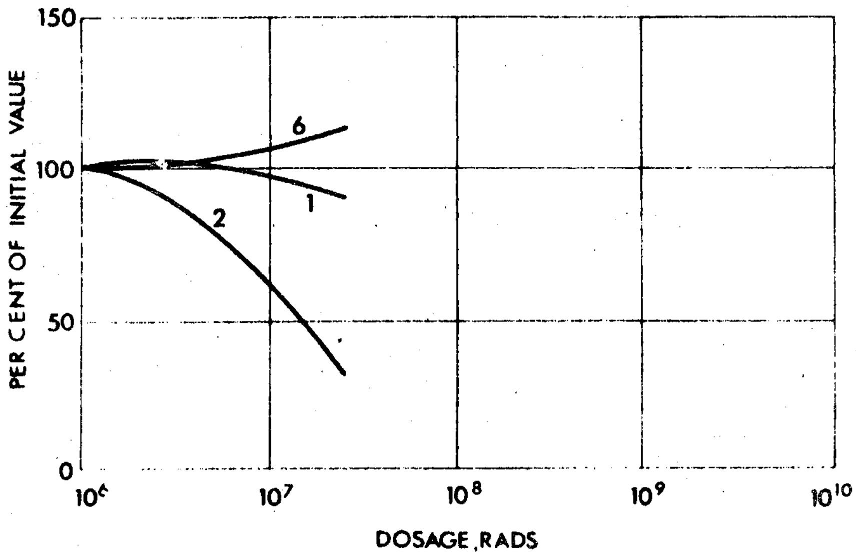
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	203kg/cm
2 ELONGATION	450%
3 SET AT BREAK	6%
4 COMPRESSION SET	9%
5 STRAIN AT 28kg/cm	31%
6 DUROMETER HARDNESS	80

NEOPRENE A 109 D-73 - "NEOPRENE TYPE W POLYMER USED"
(4,5,8,9,16,24)

E.I. Du Pont de Nemours Co

Fig. 19

Neoprene Elastomer



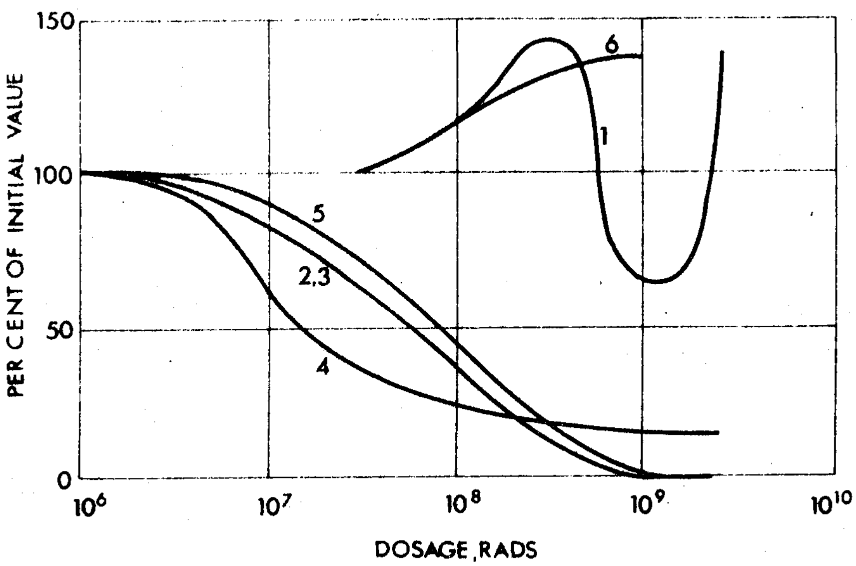
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	190 kg/cm^2
2 ELONGATION	290%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	72

P.R. 227-70- "NOT KNOWN" (8,16,23,24,25)

Precision Rubber Products C°

Fig. 20

Nitrile Elastomer



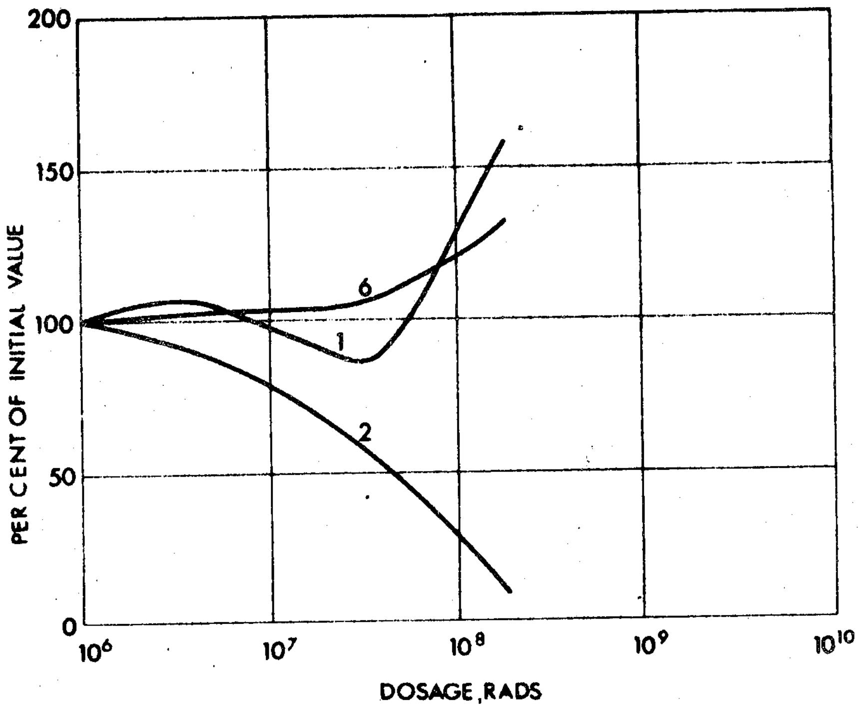
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	133kg/cm^2
2 ELONGATION	250%
3 SET AT BREAK	3 %
4 COMPRESSION SET	9,5%
5 STRAIN AT 28kg/cm^2	25%
6 DUROMETER HARDNESS	75

HYCAR OR-15 -"COPOLYMER OF BUTADIENE AND ACRYLONITRILE" (4,5,6,8,26 27)

B. F. Goodrich Chemical C°.

Fig 21

Nitrile Rubber



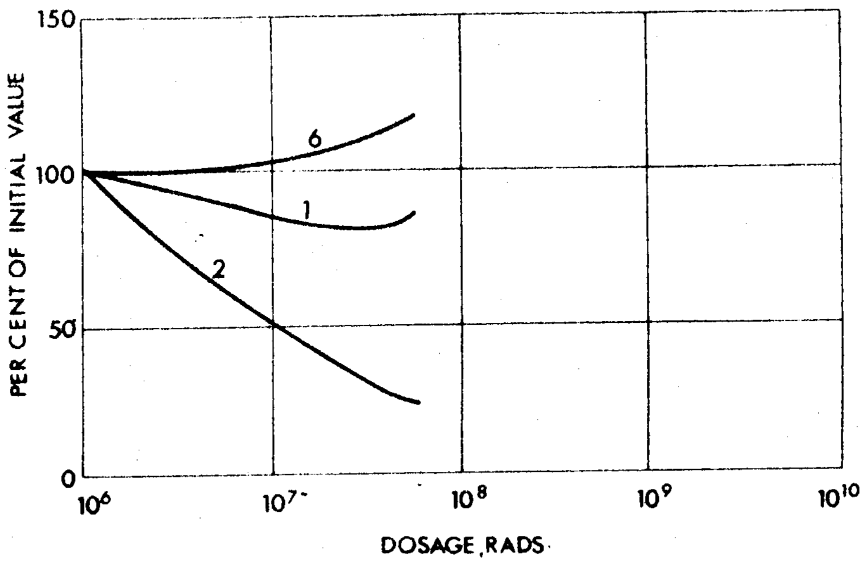
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	140 kg/cm^2
2 ELONGATION	255%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	75

PR 122-70 -"COPOLYMER OF BUTADIENE AND ACRYLONITRILE BASED ON HYCAR 1.042" (11, 26, 28, 29)

Precision Rubber Products C°.

Fig. 22

Nitrile Elastomer



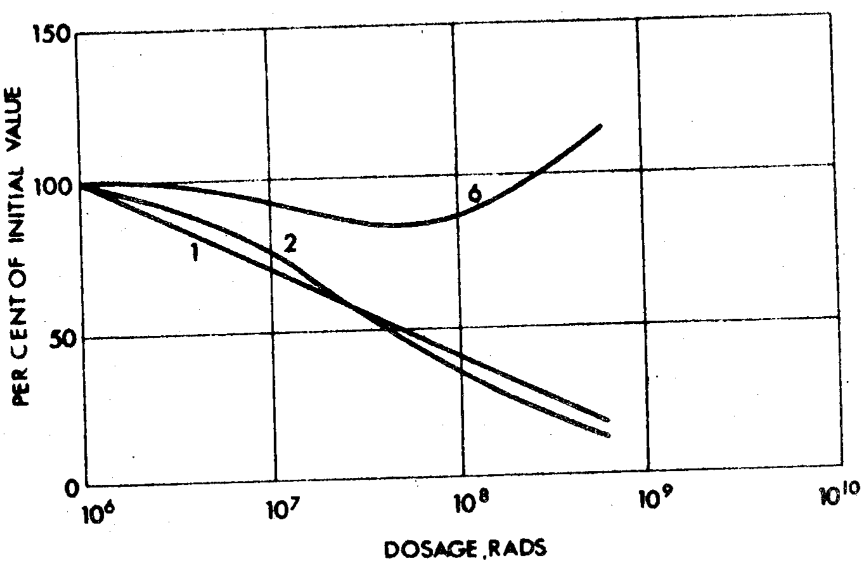
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	175 kg/cm^2
2 ELONGATION	500%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	72

PARKER 46-101 - "COPOLYMER OF BUTADIENE AND ACRYLONITRILE BASED ON PARACRIL 35" (11, 25, 26, 28, 29)

Parker Appliance Co

Fig. 23

Polyurethane Elastomer



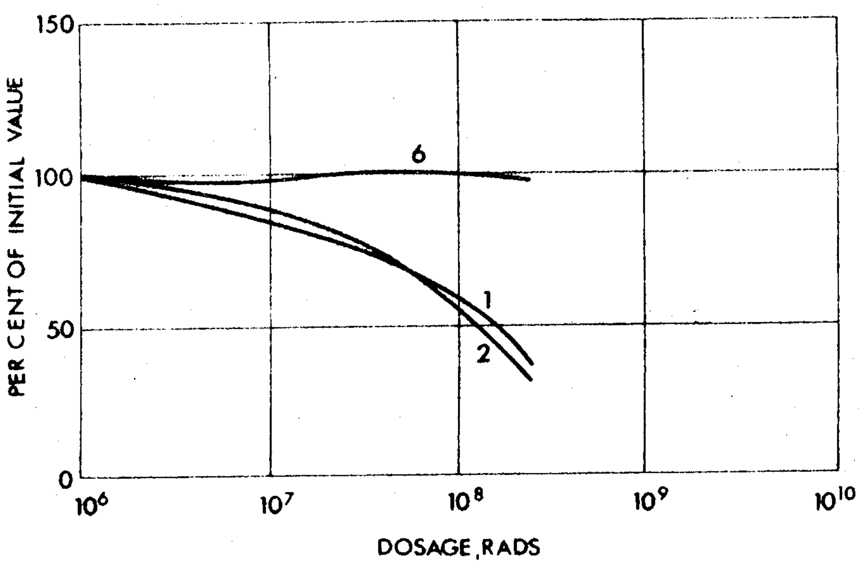
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	300 kg/cm²
2 ELONGATION	530 %
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm²	–
6 DUROMETER HARDNESS	62

ADIPRENE C-1- "NOT KNOWN" (13, 20, 30, 31)

Fig. 24

E.I. du Pont de Nemours Co

Polyurethane Elastomer



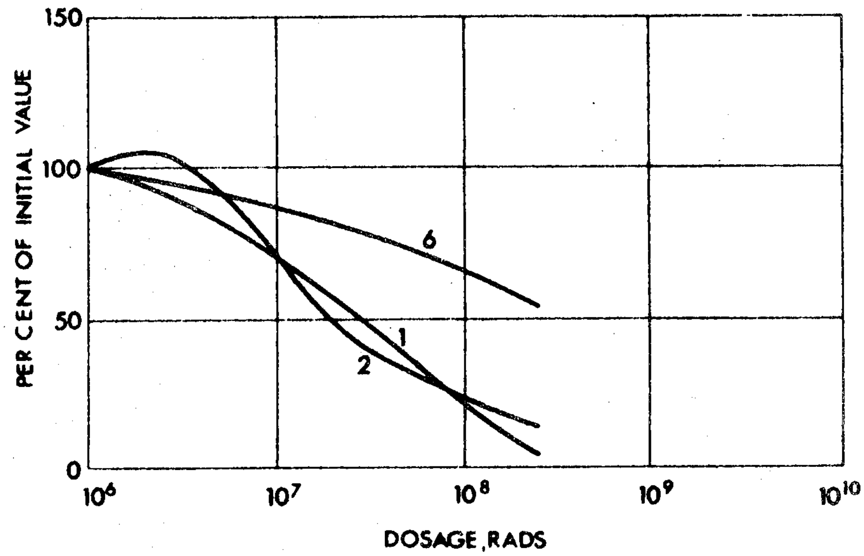
	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	220 kg/cm2
2	ELONGATION	540 %
3	SET AT BREAK	–
4	COMPRESSION SET	–
5	STRAIN AT 28kg/cm2	–
6	DUROMETER HARDNESS	77

PR 631-70- "NOT KNOWN" (13,20,30,31)

Fig. 25

Precision Rubber Products Co

Polyurethane Elastomer



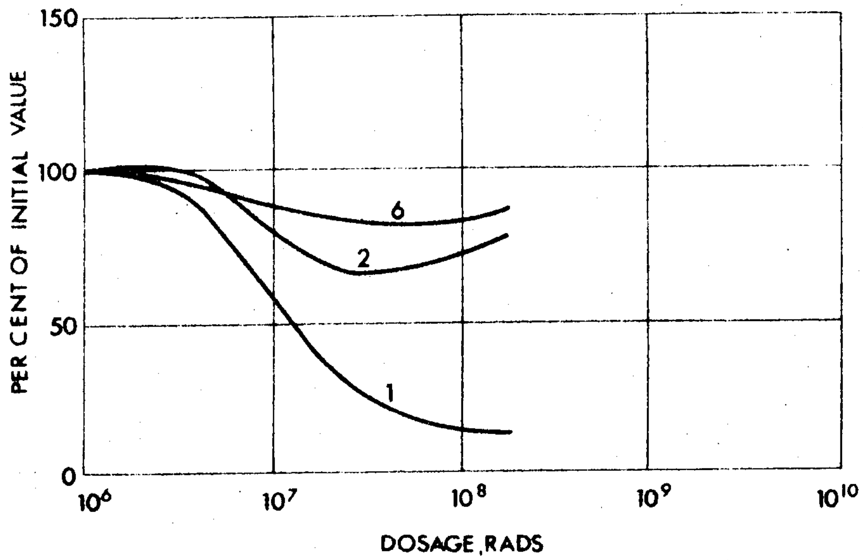
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	280 kg/cm^2
2 ELONGATION	500%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28 kg/cm^2	–
6 DUROMETER HARDNESS	70

GENTHANE S - "NOT KNOWN" (13,30,31)

Fig. 26

The General Tire and Rubber C°

Polyurethane Elastomer



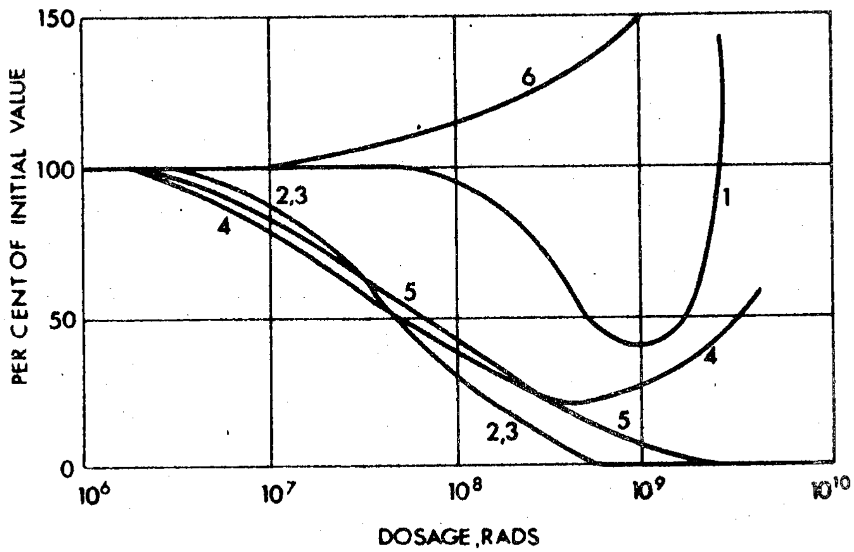
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	280 kg/cm^2
2 ELONGATION	690%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	69

CHEMIGUM XSL- "NOT KNOWN" (13,30)

Fig. 27

Goodyear Tire & Rubber Co.

SBR Elastomer



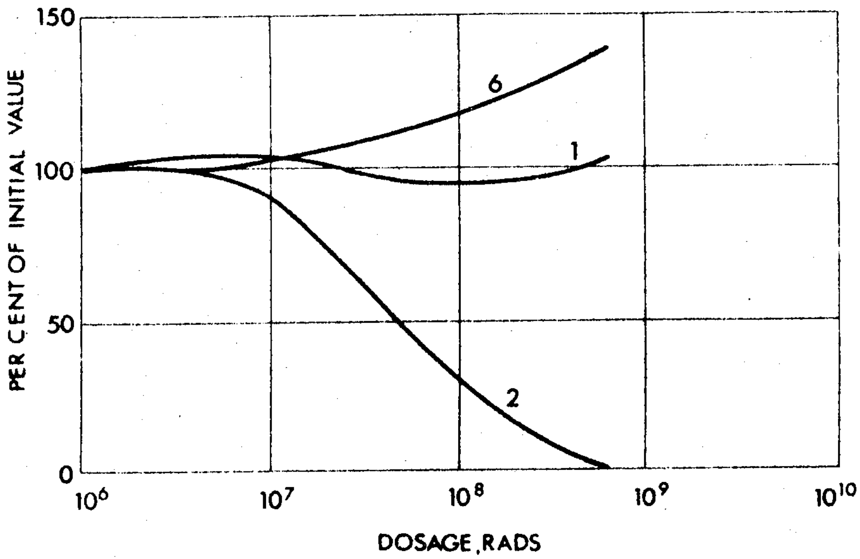
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	119kg/cm^2
2 ELONGATION	270%
3 SET AT BREAK	5%
4 COMPRESSION SET	4,7%
5 STRAIN AT 28kg/cm^2	28%
6 DUROMETER HARDNESS	60

BUNA S: "STYRENE BUTADIENE COPOLYMER" (4,5,8,26,27,32)

Fig. 28

Bayer A.G.

SBR Elastomer



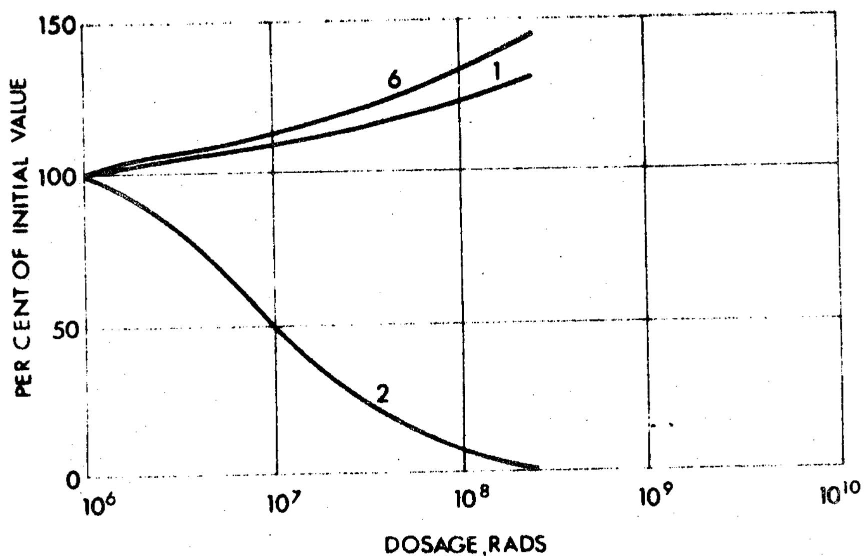
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	140kg/cm^2
2 ELONGATION	355%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	73

PR-408-70-"COPOLYMER OF BUTADIENE AND STYRENE" (4,6,33)

Fig. 29

Precision Rubber Products C°

SBR Elastomer



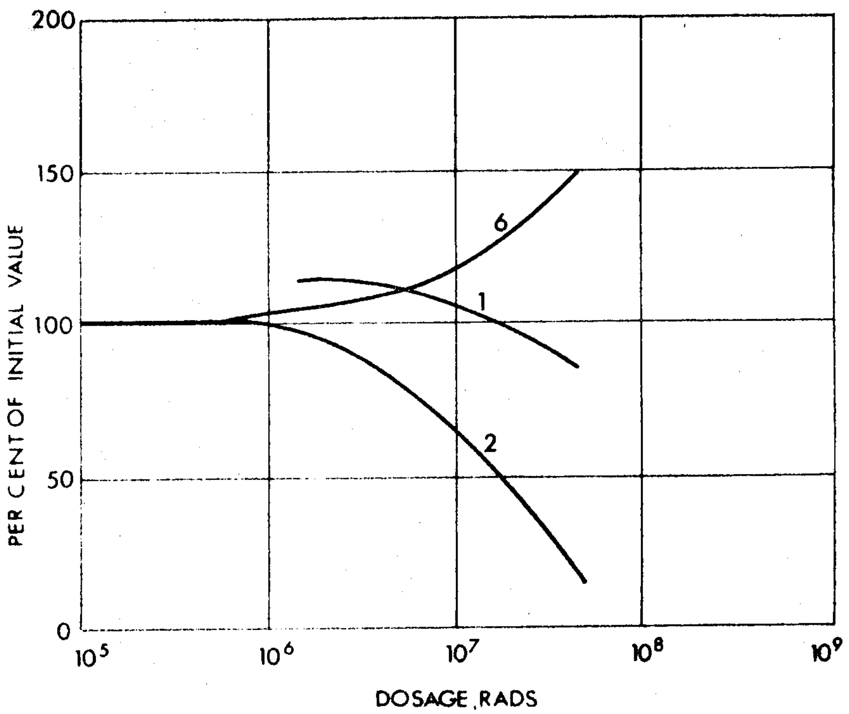
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	150 kg/cm^2
2 ELONGATION	435%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	69

HYCAR-2001 - "COPOLYMER OF BUTADIENE AND STYRENE "(4,6,33)

Fig. 30

B. F. Goodrich Chemical Co

Silicone Elastomer



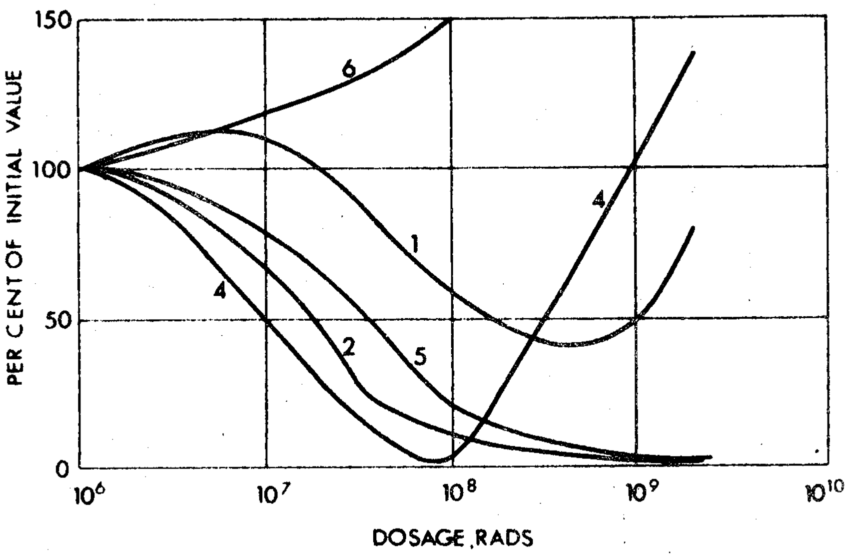
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	52 kg/cm²
2 ELONGATION	140%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm²	–
6 DUROMETER HARDNESS	54

SE 750 - "METHYL VINYL SILOXANE" (5,8,13,33,34,36)

Fig. 31

General Electric C°

Silicone Elastomer



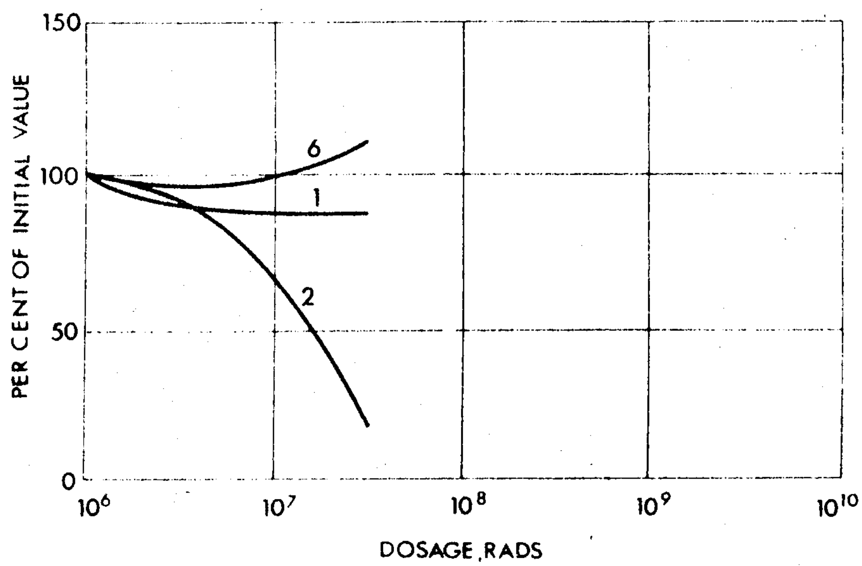
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	36 kg/cm^2
2 ELONGATION	95%
3 SET AT BREAK	—
4 COMPRESSION SET	1,4%
5 STRAIN AT 28kg/cm^2	3,4%
6 DUROMETER HARDNESS	60

SILASTIC - 7170: "DIMETHYL SILOXANE" (4,5,8,26,35)

Fig. 32

Dow Corning C°

Silicone Elastomer



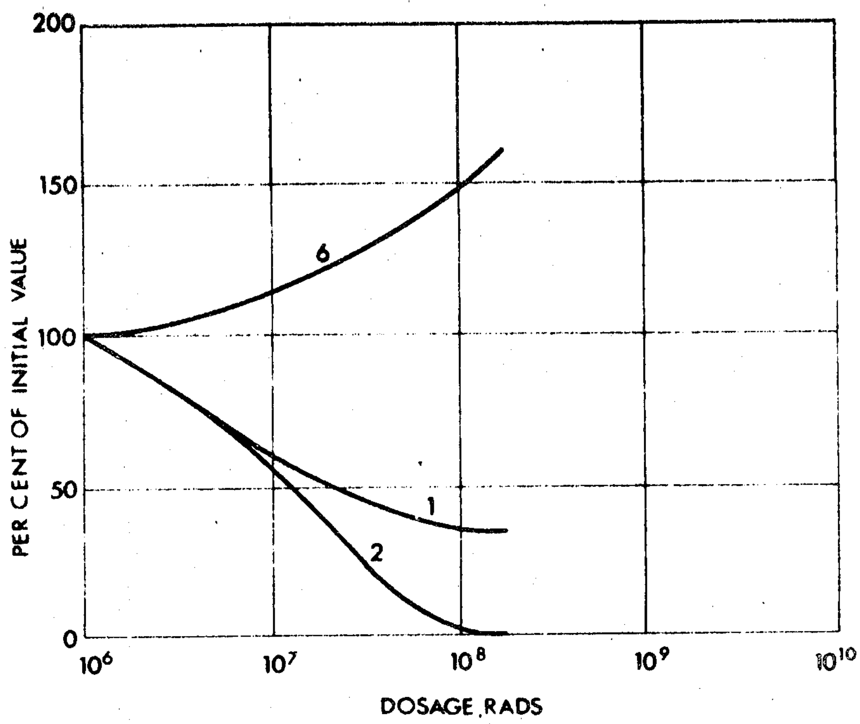
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	64 kg/cm^2
2 ELONGATION	375%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	78

77-018 - "DIMETHYL - SILOXANE" (13,34)

Fig. 33

Parker Appliance C°

Silicone Elastomer



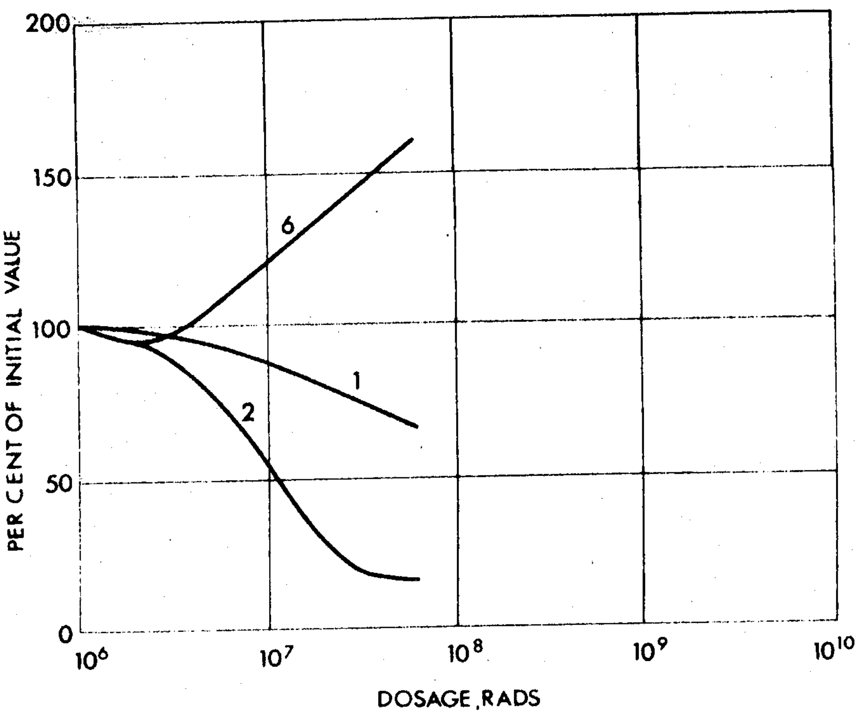
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	102 kg/cm^2
2 ELONGATION	560%
3 SET AT BREAK	-
4 COMPRESSION SET	-
5 STRAIN AT 28kg/cm^2	-
6 DUROMETER HARDNESS	63

COHRLASTIC HT-666 -"METHYL-PHENYL-VINYL-SILOXANE" (13, 34)

Fig. 34

Connecticut Hard Rubber Co

Silicone Elastomer



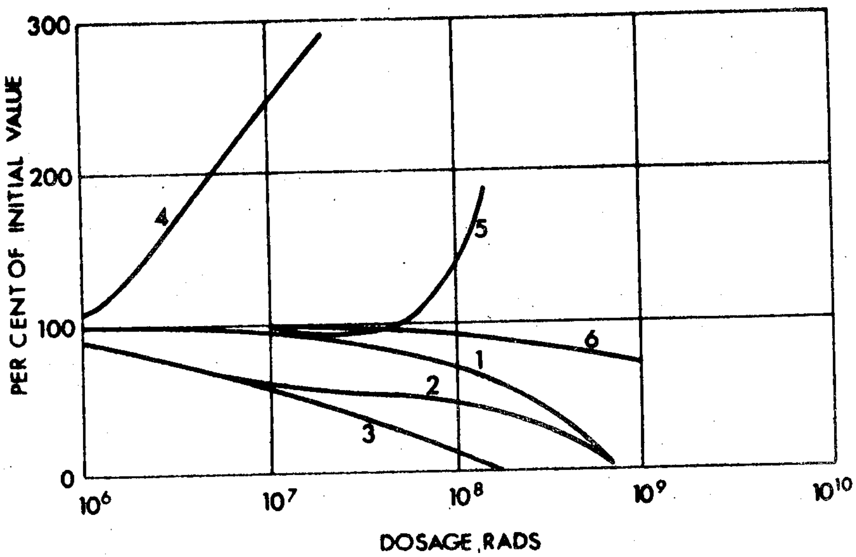
PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	56 kg/cm²
2 ELONGATION	330%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm²	–
6 DUROMETER HARDNESS	52

Y-1668 - "METHYL - PHENYL - SILOXANE" (13,34)

Fig. 35

Union Carbide & Carbon

Thiokol Elastomer



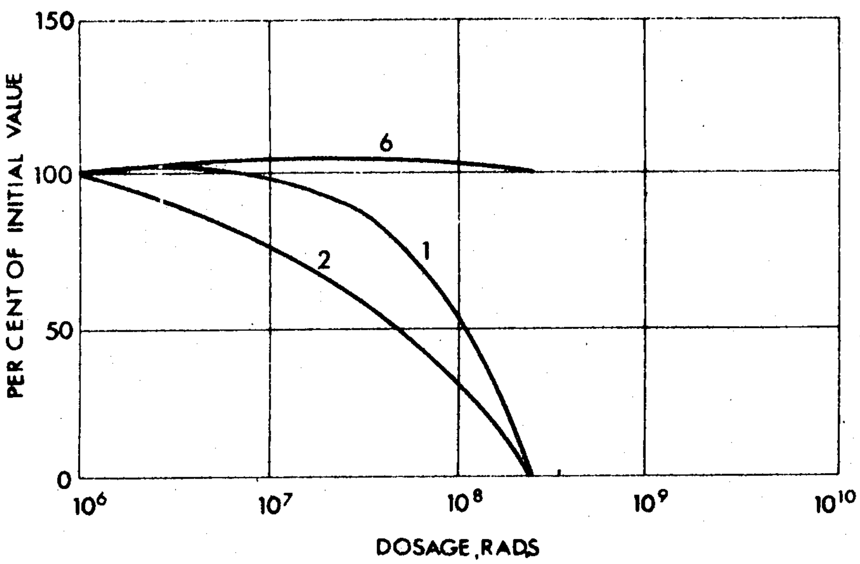
	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	56kg/cm^2
2	ELONGATION	162%
3	SET AT BREAK	3%
4	COMPRESSION SET	9%
5	STRAIN AT 28kg/cm^2	26%
6	DUROMETER HARDNESS	78

THIOKOL ST "ORGANIC POLYSULFIDE" (1, 4, 5, 8, 11, 14, 37, 38)

Thiokol Chemical C°

Fig. 36

Thiokol Elastomer



PROPERTY	INITIAL VALUE
1 TENSILE STRENGTH	70 kg/cm^2
2 ELONGATION	220%
3 SET AT BREAK	–
4 COMPRESSION SET	–
5 STRAIN AT 28kg/cm^2	–
6 DUROMETER HARDNESS	71

PR 1000-70-"NOT KNOWN" (1,4,14,25)

Precision Rubber Products Co

Fig. 37

TABLE 3 : EFFECT OF RADIATION ON VOLUME RESISTIVITY (4) (8) (26)

Material	Radiation type and energy in Mev	Dose rate rad/h $\times 10^{-7}$ **	Total dosage $\times 10^{7}$ in rad	Volume Resistivity (ohm - cm) Before irradiations	Volume Resistivity (ohm - cm) After irradiations
Acrylics (Hycar PA 21)	Pile	-	0	6×10^{11}	-
			15		10^{11}
			35		3×10^{10}
			70		5×10^{10}
Butyl	Pile	-	0	10^{12}	-
			15		10^{13}
Hypalon (Hypalon S 2)	Pile	-	0	6×10^{13}	-
			20		4×10^{12}
			35		2×10^{13}
			70		2×10^{13}

The pile fluxes are :

1.1×10^{12} thermal neutrons/cm^2. sec
1.4×10^{11} neutrons/cm^2. sec with energies above 0.1 Mev
6.7×10^{10} neutrons/cm^2. sec with energies above 0.5 Mev
4.2×10^{10} neutrons/cm^2. sec with energies above 1 Mev
5×10^{11} protons (γ.rays)/cm^2. sec with average energy of 1 Mev

** Irradiation in the pile took place at an equivalent rate of 10^6 to 10^7 rad/h

Material	Radiation Type and energy in Mev	Dose rate rad/h x 10^{-7}	Total dosage r x 10^{-7} in rad	Volume Resistivity (ohm-cm)			
				Before irradiations	After irradiations	Recovery on standing	
						Time, hours	Final Resistivity
Natural rubber (Okolite 313)	2.0 e^-	3.63	2.1	4.4×10^{14}	1.1×10^{14}	1.5	1.7×10^{14}
						5.5	3.0×10^{14}
						22	2.4×10^{14}
		3.54	4.1	4.4×10^{14}	7×10^{14}	6	3.7×10^{14}
	2.5 X	-	3.2	4.4×10^{14}	1.2×10^{14}	22	2.9×10^{14}
	Pile	-	0	$>10^{14}$	-		
			15		10^{14}		
			70		10^{12}		
(Okolite-Okoprene)	2.2 γ	0.36	1.3	6.7×10^{12}	5.6×10^{12}		
		0.21	0.33		5.8×10^{12}		
		0.06	0.33		5.8×10^{12}		
(Rubber 5.C13 B1)	2.0 e^-	3.5	2.1	1.6×10^{14}	2.5×10^{14}	22	2.4×10^{14}
			4.1		3.9×10^{14}	23	2.4×10^{14}
	3.0 X	0.6	3.1		1.6×10^{14}	20	3.6×10^{14}
Neoprene (Okoprene	2.0 e^-	4.65	2.1	8.0×10^{10}	6.8×10^{10}	168	8.5×10^{10}
		4.52	4.1		6.1×10^{10}	166	7.0×10^{10}
	2.5 X	-			6.6×10^{10}	22	7.6×10^{10}
(Neoprene)	2.0 e^-	5.7	3.2	4×10^{12}	8.9×10^{11}		
			4.1		1×10^{11}		
	Pile	-	0	2×10^{11}	-		
			100		2×10^{10}		
			200		10^{10}		
(Neoprene gray)	2.0 e^-	-	3.2	4×10^{12}	8.9×10^{11}	2.2	1.9×10^{12}
						19	1.6×10^{12}
	2.0 e^-	-	4.1	4×10^{12}	1×10^{12}	183	2.3×10^{12}
	2.5 X	-	3.1		3.5×10^{12}	22	4.7×10^{12}

Material	Radiation type and energy in MeV Rad. Type Energy	Dose rate rad/hr $x\ 10^{-7}$ Dose rate	Total dosage $x\ 10^{-7}$ in rad Dose	Volume Resistivity (ohm-cm) Before irradiation	 After irradiation
Nitrile (Royalite)	Pile		10	10^{12}	10^{10}
Polybutadiene	Pile		0	10^{14}	
			15		10^{14}
			30		10^{10}
			70		10^{9}
Polyurethane (Vulcallon)	Pile		0	$3x10^{8}$	
			10		$3x10^{8}$
			100		$3x10^{8}$
			300		$3x10^{8}$
SBR (Pliostuf)	Pile		0,5	10^{14}	10^{8}
Silicone (Silastic 250)	Pile		0	$>10^{14}$	
			15		10^{14}
			30		10^{12}
			70		10^{14}
Thiokol	Pile		0	$10^{8}-10^{10}$	
			15		10^{10}
			30		10^{9}
			70		10^{7}

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TABLE 4

GASEVOLUTION * (4)(8)(26)(39)(40)

Material - Elastomer	Gas Evolved - ml/g at 10^9 Rads
Acrylics	28
Butyl	13
Natural Rubber	7
Neoprene	2-4
Nitrile	5-10
Polybutadiene	5
Polyisoprene (synthetic)	10
Polyisobutylene	17-20
Polysulfide	6
S.B.R.	4
Silicone	20

* The gasevolution was measured from samples of 0.2 to 0.5 gramme.

TABLE 5

Radiation Stability of Elastomers at Temperatures above 85°C (41)

Material - Elastomer	Temperature °C	Max. dose (electrical) Rads.	Max. dose (Mechanical) Rads.
Butyl	85	5×10^8	5×10^7
Natural Rubber	85	8×10^8	10^8
Neoprene	100	1.5×10^9	5×10^8
Polyisobutylene	85	5×10^8	5×10^7
Silicone	125	2×10^9	5×10^7

TABLE 6

E L A S T O M E R S

Popular Name	Chemical Designation	Trade Names
Acrylics	Polyacrylate	Acrylon Angus HR, SH Cyanocryl Hycar Lactoprene Paracril OHT Precision Acrylics Thiacril Vyram
Butyl - GRI	Isobutylene - Isoprene	Bucar Butyl Enjay Butyl Hycar I.I. Rubber Petro-Tex Butyl Polysar Butyl Precision Butyl Vistanex MM
EPR	Ethylene Propylene	Angus KR APK C 23 Dutral N Enjay EPR Nordel Olethene Royalene
Fluoroelastomers	Vinylidene Fluoride Hexafluoropropylene	Angus VA,SV Fluorel Precision Fluoro Viton
	Fluoro Silicone	Silastic LS 53 Precision Fluoro Silicone
	Trifluorochloro-ethylene- vinylidene-fluoride	Kel F
Hypalon	Chlorosulphonated polyethylene	Angus HH Hypalon Precision Hypalon

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TABLE 6 (Continued)

Popular Name	Chemical Designation	Trade Names
Natural Rubber	Natural Polyisoprene	Coral DPR Natsyn Okolite Shell Isoprene Trans P.R.
Neoprene GR-M	Chloroprene	Angus G Neoprene Precision Neoprene Okoprene Per unan C Sovprene U.S. Rubber Neoprene
Nitrile; Buna N; G.R.A.; N.B.R.	Acrylonitrile - Buta- diene	Angus DS, WR, FR,LR,E,P. Butacril Butraprene Chemigum Chemivic FR-N Herecrol Hycar OR Parker Nitrile Perbunan Polysar Krynao Precision Nitrile Royalite Tylac
Polybutadiene; Buna; S.K.A.	Butadiene	Ameripol CB B R Rubber Budene Cisdene Diene Duradene Duragen Polysar Tacktene S.K.B. Texus Synpol EBR Trans 4 or cis 4

TABLE 6 (Continued)

Popular Name	Chemical Designation	Trade Name
Polyisoprene synthetic	Synthetic Polyisoprene	Ameripol SN Coral DPR Natsyn Philprene Shell IR Trans PIP Cariflex
Polyurethane	Diisocyanate-polyester or polyether	Adiprene Chemigum XSL Conathene Cyanoprene Desmodur Desmolin Disogrin Elastocast Elastothane Estane Genthane Guidfoam Mearthane Microvon Multrathane Polyvon Precision Urethane Roylar Solithane Texin Vulcaprene
SBR, Buna S, GRS; SKB.	Styrene-Butadiene	Ameripol Angus R.G. ASRC Polymers Butaprene S Carbonix Cariflex Chemigum IV Copo Darex Duradene Flosbrene FR-S Gen-Flow Gentro Hycar OS, E, TT

TABLE 6 (continued)

Popular Name	Chemical Designation	Trade Name
SBR, Buna S, GRS; SKB. (Continued)	Styrene - Butadiene	Krylene Kryflex Navgapol Naugatex Philprene Plioflex Pliolite S Pliotuf Polysar S S Polymers Solprene Synpol Tylac
Silicone	Polysiloxane	Angus SIL. SIS Arcosil Cohrlastic Fairprene General Electric SE HW Parker Silicone Rhodorsils Silastene Silastic Siloprene Union Carbide K.Y.
Thiokol GR-P	Organic Polysulfide	Alkylene Polysulfide F.A. Polysulfide rubber Perduren Precision Thiokol S.T. Polysulfide rubber Thioplasts Vulcaplas
Vinylpyridine	Butadiene - 2 - methyl 5 vinyl pyridine	Philprene

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