WADC TECHNICAL REPORT 55-58
ASTIA DOCUMENT No. AD 97234

A STUDY OF THE EFFECTS OF NUCLEAR RADIATIONS ON ELASTOMERIC COMPOUNDS AND COMPOUNDING MATERIALS

D. L. LOUGHBOROUGH
A. E. JUVE
J. R. BEATTY
J. W. BORN

THE B. F. GOODRICH COMPANY

AUGUST 1956

MATERIALS LABORATORY
CONTRACT No. AF 33(616)-2308
PROJECT 1252

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
500 - January 1957

FOREWORD

This report was prepared at the B. F. Goodrich Company Research Center under USAF Contract No. AF 33(616)-2308. The contract was initiated under Project No. 1252, "ANPP Development Support Project," Task No. 73015, "Rubber for ANPP," and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Wallace W. Jackson acting as project engineer. This report covers the period of work from 1 January 1954 to 1 January 1955.

E. H. Rowe and A. Hawthorne of the Department of Physical Research contributed significantly to the study. Their assistance along with that of R. G. Bauman, D. J. Harmon, and F. D. Snyder of the same department and of R. H. Shearer, W. H. Showen, and L. O. Schroyer of the Department of Technical Service Research is gratefully acknowledged. Our appreciation extends further to the assistants who took an important part in the development.

The authors wish to thank B. Manowitz, O. A. Kuhl, and R. Oriez of the Fission Products Utilization Project at Brookhaven National Laboratory and O. Sisman and C. D. Bopp of the Solid State Division of Oak Ridge National Laboratory for their cooperation pertaining to this study.

ABSTRACT

Comprehensive study of the effects of nuclear radiation upon elastomeric compounds and compounding ingredients was the main purpose of the development. The work was done at the B. F. Goodrich Company Research Center. Two hundred nineteen compounds were selected for study. One hundred ninety were irradiated and tested. Stress-strain and stress relaxation measurements were made, along with special analyses of irradiation products. The investigations exhibit three principal results: (1) a catalog of stress-strain data for many elastomeric formulations has been compiled, (2) a group of inhibitors of radiation deterioration in rubber has been discovered, and (3) evidence has been gathered that the effect of Cobalt 60 gamma irradiation on rubber is different in air than in high vacuum. The rubber compounds which are most resistant to deterioration are cited by recipe.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

SECTION I. INTRODUCTION

The present contract proposed a general, comprehensive study of the effects of nuclear radiation upon elastomeric compounds and compounding materials. It also specified that work be done leading toward "the development of radiation resistant elastomers suitable for use in Air Force applications where nuclear radiation damage will be encountered." (1) Specific recommendations were made within the general framework regarding subjects for study. Such recommendations have all been incorporated into our work. In addition a number of lines of investigation not specified in but anticipated broadly and permitted by the contract were pursued.

The study of the resistance of elastomeric high polymers and their compounds to deterioration in mechanical and electrical properties by other investigators began almost as soon as nuclear reactors became available for research on such radiation damage. The studies of this nature prior to the work reported here were reviewed in both the classified and the unclassified literature. The reports in the unclassified literature are discussed in the section on the literature survey. No further reference will be made to the classified literature, because the authors of this report wish to keep it unclassified.

At the initiation of this contract no such extensive study as contemplated had been reported. The excellent research by Sisman and Bopp (2) had led the way and had provided an introduction in considerable detail. Moreover, work reported by Charlesby (3,4,5,6,7), Little (8), Hobbs, Pletcher, and Brown (9), Ryan (10), and Davidson and Geib (11) was helpful in providing a background of understanding. Against this background we have applied our various skills and experience with the results shown below.

SECTION II. PROBLEM

Just as rubber components have encountered an age of higher and higher service temperatures, so it appears that they will also be subjected to intense nuclear radiation of high energy. The problem, at least, is simple: impart satisfactory radiation resistance to each rubber without appreciable sacrificing serviceability.

Elastomers belong to the class of molecular materials, as do organic monomers. Being polymers, elastomers are in general much more sensitive to nuclear radiation deterioration, that is, to changes in physical properties due to changes in molecular structure, than are the monomers. This is because scission of a very few chemical bonds can affect the physical properties of a polymer significantly, whereas the same number of scissions would probably have a much less significant effect in the case of the monomer.

Broadly speaking, nuclear radiation can produce two initial types of effect, namely atomic displacement on the one hand and excitation and ionization on the other. The former effect is of characteristic importance in crystalline solids. The latter effect is of characteristic importance in molecular solids, particularly elastomers and elastomeric compounds. A small percent of the ionization and excitation in an elastomer is produced by the primary radiation particles and photons. Mainly, the radiation effect is produced by secondary charged particles and photons resulting from interaction of the primary radiation with the atoms of the elastomer. The ionization can lead to the formation of free radicals and to degradation resulting in unsaturation. The excitation can produce free radicals, molecular rearrangement, and unsaturation. As a result of these processes there may occur cross-linking, degradation, unsaturation, gas formation, hydrogenation, and, in the presence of oxygen or ozone, oxidation. When the elastomer or elastomeric compound contains a monomeric material or a low molecular weight polymeric material subject to polymerization, one may expect this additional process to result.

With this general understanding we proceeded with a limited attack upon the problem.

SECTION III. LITERATURE SURVEY

The first step was to learn what similar studies had already been made. Slater (12) critically reviewed the whole field of nuclear radiation effects on materials of all classes from both the experimental and the theoretical point of view. His report was written during the summer of 1949. Though little emphasis is given to molecular solids, the article illuminates the general subject very well, particularly as concerns the various "carriers" of nuclear radiant energy and their modes of energy transfer within solid media. Several direct quotations from Slater's article are pertinent:

(a) "The important types of radiation for producing damage in metals and semi-conductors are neutrons on the one hand and charged heavy particles on the other; the remaining sorts of radiation, photons or gamma radiation and electrons, produce very little damage, except in insulators and chemical compounds, and mesons are not yet available in sufficient numbers for their damage to be of practical interest, though it would presumably be intermediate in effect between that produced by electrons and protons." Ibid, page 244.

(b) "The effect of the neutron on collision, then, is to produce either a recoil atom having large energy (often tens or hundreds of thousands of volts), or a recoil atom resulting from transmutation or fission. These recoil atoms in most cases will be charged, having left some of their electrons behind in the collision." "This being the case, the study of neutron radiation damage is not different in principle from that produced directly by charged heavy particles: either by protons, deuterons, or alpha-particles from cyclotrons, or by fission fragments." Ibid, page 244.

(c) "A fast ion passing through matter can have two quite different effects on the atoms it strikes. In the first place, it can make an elastic collision, giving kinetic energy to the recoil atom." "---- the incident particle can excite or ionize the electrons of the struck atom, resulting in an inelastic collision in which most of the energy lost by the incident particle is transferred to the removed electron, rather than to the recoil of the struck atom." Ibid, page 245.

(d) "We have already seen that radiation damage in a molecular compound is likely to be of quite a different nature from that found in most other solids: it is likely to be a result of the electronic ionization or excitation, rather than the nuclear recoils, produced by the radiation, and hence is likely to be similar whether produced by electron bombardment, gamma radiation, or heavy ions. The field of radiation damage to chemical substances is, of course, one of great richness and variety, on account of the enormous number of types of chemical substances." Ibid, page 256.

(e) "One generalization regarding organic compounds which appears to be true is that aromatic compounds seem to show less damage than aliphatic compounds, the benzene ring somehow being able to absorb considerable electronic energy without dissociation." Ibid, page 256.

It is quite apparent from the above review that few unclassified or declassified experimental results on the effects of nuclear radiations on elastomers had been reported before mid-1949. Two applications of radiation to elastomeric materials prior to this merit comment. In 1927 Newton (13) found that bombardment of crude natural rubber with high speed electrons produces a product similar in physical properties to the same rubber cured by the usual chemical means. A cathode tube operating at 1 milliampere and 250 thousand volts was the source of high-speed electrons. The exposure period was 20 to 25 seconds in a nitrogen atmosphere. Davidson and Geib (11) reported in 1948 their studies at Clinton National Laboratory on the effects of pile radiations on uncured elastomers, namely smoked sheet (natural rubber), butyl rubber, and polyisobutylene. They found that natural rubber increased in molecular weight whereas polyisobutylene was degraded. They concluded that free radical-initiated chain reactions involving double bonds in rubber result in a net increase in molecular weight. Studies of uncured butyl rubber, polyisobutylene, and cured butyl rubber showed no net change in unsaturation and that the degradation induced is essentially independent of the state of vulcanization of butyl rubber. In the case of cured natural rubber modulus increased while tensile strength decreased. Although noting that this is typical of severely overcured rubber stocks, they rejected the idea of conventional overcure as a description of the radiation effects.

Dienes (14) summarized the progress from the time of Slater's review of mid-1949 through March 1952. He observed, "The study of radiation effects in molecular compounds is essentially a part of the field of radiation chemistry. The primary effects will be the result of ionization with or without excitation and will be essentially the same for all types of high energy radiation." He refers to the work of Davidson and Geib (11), Sisman and Bopp (15), and Dole (16). The latter two reports deal with plastics rather than elastomers. Dole found by chemical and infrared absorption analyses that there was considerable unsaturation in vacuum-irradiated polyethylene samples, whereas oxidation was the major effect in the material irradiated in air. His work was done in the Argonne heavy water pile. Pile irradiation in air decreased the tensile strength, whereas vacuum irradiation caused essentially little change in this property. The review by Burton (17) listed by Dienes is very helpful to an understanding of radiation chemical processes.

In the open literature, then, there is little evidence of irradiation studies of elastomers through early 1952. From that time on evidence of attention to such studies increased. Charlesby and Little reported work separately in 1952, 1953, and 1954. In 1953 Sisman and Bopp published a description of their excellent work on elastomers (2). A Phoenix Project group reported briefly some irradiation studies of elastomeric materials (9) in 1953, as did Dole (16). Furthermore, Lawton, Bueche, and Balwitt published the results of some interesting work involving the irradiation of various plastics and elastomers with high energy electrons (18). Gehman and Hobbs (20) essentially repeated the data given by Hobbs, Pletcher, and Brown (9). Recently a review article by Sun (21) summarized what is known about the effects of radiation on high polymers. It is recommended to those who are unfamiliar with the subject.

SECTION IV. EXPERIMENTATION

4.1 Selection and Purchase of Radiation Source and Shield

Since the difference in the effects of energetic neutrons, protons, deuterons, alpha particles, fission fragments, electrons, x-rays, and gamma rays upon molecular solids is one of degree rather than kind, involving principally ionization and excitation in all cases, the selection of radiation source in a study of this sort can be based upon other qualifications. The two critical requirements imposed were that the radiation effect be homogeneous throughout an elastomeric sample and relatively homegeneous throughout a close-packed group of samples first of all, and second, that radiation dose be easily calculable or measurable. These requirements were met by energetic neutrons and gamma rays. Neutron irradiation posed the technical problem of induced radioactivity in the samples. We preferred to avoid this added complication; so we chose to use gamma radiation in our study.

Among the gamma ray sources available, the multicurie Cobalt 60 sources seemed best suited to our needs. We decided to employ the Brookhaven National Laboratory Cobalt 60 gamma irradiation service (22) and to complement it with a Cobalt 60 source-shield assembly purchased from the same establishment and calibrated there before shipment. The plan was to conduct the lower dose irradiations in the purchased source and to rely on the BNL gamma irradiation service for the higher dose irradiations.

Accordingly, by negotiation with BNL through Bernard Manowitz, Leader, Fission Products Utilization Project, we purchased Cobalt 60 Source Number Co 17 in Container Number 10, a cylindrical lead shield with top opening. Three photographs of the source-shield assembly in place plus a schematic diagram appear in Figure 23. To quote Otto A. Kuhl of BNL (23): "Source 17 contains 1525 grams of cobalt and is encased in 61ST6 aluminum. The dimensions of the completed source are length 13.56 inches, outer diameter 2.31 inches, and inner diameter 1.72 inches. The R/hr reading at its geometric center as of 1/16/54 is 218,000. The curie content as of that date is 550 curies." The source-shield assembly weighs about 2 tons.

4.2 Installation and Use of Source-Shield Assembly

The source-shield assembly was installed in the northeast corner of the high bay of the B. F. Goodrich Research Center on Friday, March 5, 1954. A temporary mono-rail trolley and rope-hoist system of remote handling was installed to permit immediate use. Subsequently the crane shown in Figure 23 was constructed for permanent use. The operations area was carefully monitored under all operating conditions on the day of installation. We found that the scatter radiation flux on all floor areas outside the space enclosed by the concrete block wall (see Figure 23) was less than 300 mr/wk. There are no floors between the top of the source-shield assembly and the roof 45 feet above. Access to the roof is carefully restricted, and special permission must be obtained from the health physics supervisor to go on the roof. All personnel who took part in the irradiation operations wore film badges and pocket ionization chambers. Survey meters were used for routine area monitoring.

4.3 Selection and Preparation of Elastomeric Samples

4.3.1 For obvious reasons a study of the radiation resistance of the common commercial elastomers was of immediate interest. Accordingly, the first group of elastomeric compounds comprised 55 pure gum and black rubbers (Compounds 1GEA1 through 55). The recipes of all the compounds used in the entire study appear in Appendix I.

4.3.2. The second group of compounds was chosen for a preliminary investigation of the effect of antioxidants upon radiation resistance. It included 26 recipes in which both identity and concentration of antioxidant varied (Compounds 1GEA56 through 81). It appeared at the outset from the first irradiation experiments and from reported results that radiation deterioration in stress-strain properties closely resembled that due to oxidation of the rubber. We therefore were interested in studying the results of inhibiting oxidation.

4.3.3 Group three compounds were designed to study the effect of aromatic resins upon the radiation resistance of elastomers (Compounds 1GEA84, 85, 87, 88, 89, 92, and 93). It was known that aromatic high polymers are more resistant to radiation than are aliphatic ones. It was reasoned that homogeneous incorporation of compatible aromatic resins into rubber compounds would improve resistance.

4.3.4 The fourth group of compounds permitted study of rubber materials having non-sulfur cures (Compounds 1GEA94 through 108). It had been suggested that the sulfur present in sulfur-cured rubber has an inhibiting effect upon radiation deterioration. This approach was aimed at investigating the suggestion.

4.3.5 The fifth group of compounds was selected for an intensive study of antioxidants in inhibiting radiation effects (Compounds 1GEA109 through 148). Two masterbatch natural rubber stocks were used, one a pure gum and the other a black rubber (Compounds 1GEA109 and 129, respectively). One principal group of antioxidants included highly aromatic amines and hydroquinones. The other principal group contained proven antioxidants.

4.3.6 Group six compounds permitted study of the effect on radiation resistance of 13 different fillers, each compound having 10 square meters of surface area of filler per gram of rubber. The purpose was to exclude surface area as a variable in investigating filler effect. Certain chemical reactions are sensitive to surface characteristics such as this. (See Compounds 1GEA149 through 162.)

4.3.7 The seventh group, like the sixth, set up a study of compounds having 20 percent filler by volume. The same fillers were used as in the last case (Compounds 1GEA163 through 173). Whereas in the last case the various fillers had the same surface area per gram of rubber, in this case except for zinc oxide and whiting they have the same concentration by weight. This permitted study of another facet of the influence of fillers on radiation effects.

4.3.8 In the eighth group we investigated the effect of varying the volume percent of four fillers in Masterbatch 1GEA149 (Compounds 1GEA174 through 194). Compounds having 0, 5, 10, 20, and 30 percent filler by volume were included.

4.3.9 The ninth group comprised latex rubbers, cured and uncured (Compounds 1GEA195 through 198).

4.3.10 The tenth group was devised to study the effect of pH of the rubber upon its radiation resistance (Compounds 1GEA199 through 201).

4.3.11 Group eleven comprised four assorted special recipes (Compounds 1GEA202 through 205). Two of these were designed to investigate the influence of very high carbon black loadings, and the other two contained two special antioxidants.

4.3.12 The final group of compounds contained large loadings of heavy metal fillers contained in both a pure gum and a black natural rubber stock (Compounds 1GEA206 through 219). These heavy metal fillers are included as possible gamma ray attenuating materials. Our purpose was to learn what effect they had on the physical properties of irradiated rubber.

4.4 Irradiation of Elastomeric Compounds

4.4.1 The flux at the geometric center of Cobalt 60 Source Number Co 17 was 218 thousand roentgens per hour on 16 January 1954, as measured at Brookhaven National Laboratory before its shipment. Allowing for radioactive decay based on a 5.3-year half-life, we have used this flux figure in calculating the applied radiation doses which the elastomeric samples received in said source. We have made no direct dosimetry measurements but rather have accepted the aforementioned value. We recognize the desirability of precise dosimetry measurements and have taken steps in that direction. A thorough dosimetry study has begun. We have delayed dosimetry because we were concerned at the lack of general agreement on the merit of the various methods and because we were most interested in the fluxes at highly localized positions. The dosimetry glass developed under the supervision of Schulman (24) and now marketed by Corning Glass Works promises to permit the type of dose measurements which we require.

4.4.2 In addition to concern regarding dosimetry we were interested in the variation in gamma-ray flux as a function of distance from the geometric center of the source in all directions. In the absence of dosimetry measurements Dr. R. A. Harrington of the Physical Research Laboratory made a mathematical investigation of the gamma-ray flux variation with position inside the Cobalt-60 source cylinder. His report appears below in direct quotation.

"Let N = the number of gamma photons (γ) per second from entire source
h = height of cylinder
b = average radius = 1/4 (I.D. + O.D.)
d = wall thickness
Φ = total radiation flux in γ/cm^2 sec of a point inside the cylinder having distances r from the axis and Z_1, Z_2 from the cylinder ends.
s = source strength per unit volume = $\frac{N}{2\pi bdh}$

"Assume the source strength is constant over the volume of the cylinder. Then each element of volume dV emits sdV rays per second.

"Neglecting absorption, the γ-flux at distance R from the volume element is $\frac{sdV}{4\pi R^2}$. The flux at a point P can be found by integrating over the volume of the cylinder, taking R as the variable distance from the point to the volume element.

"Choosing cylindrical coordinates in which ρ is the distance from the axis, θ is an angle measured at the axis, and z in the projection of distance R on the axis, the volume element

$$dV = \rho\, d\rho\, d\theta\, dz$$

and the distance is given by

$$R^2 = z^2 + \rho^2 + r^2 - 2\rho r \cos\theta$$

The total flux at point P is then given by

$$\Phi = \int_{\rho=b-\frac{d}{2}}^{\rho=b+\frac{d}{2}} \int_{z=-Z_1}^{Z_2} \int_{\theta=-\pi}^{\pi} \frac{s\rho\, d\rho\, d\theta\, dz}{4\,(z^2+\rho^2+r^2-2\rho r\cos\theta}$$

"This integral reduces to

$$\Phi = \frac{s}{2} \int_{b-\frac{d}{2}}^{b+\frac{d}{2}} \frac{\rho}{\rho+r} \left[\mathrm{tn}^{-1} \left(\frac{Z_2}{\rho-r} \Big/ \frac{2\sqrt{\rho r}}{\rho+r} \right) + \mathrm{tn}^{-1} \left(\frac{Z_1}{\rho-r} \Big/ \frac{2\sqrt{\rho r}}{\rho+r} \right) \right] d\rho$$

in which $\mathrm{tn}^{-1}(\chi \mid k)$ is an elliptic integral of the first kind. It is convenient to deal with this by first solving the problem for an infinite cylinder and then introducing end corrections, as follows:

$$\Phi \approx \underbrace{s \int_{b - \frac{d}{2}}^{b + d/2} \frac{\rho}{\rho + r} K\left(\frac{2\sqrt{\rho r}}{\rho + r}\right) d\rho}_{\text{(infinite cylinder solution)}} - \underbrace{\frac{sd}{2} \left[\tan^{-1} \frac{b}{Z_1} + \tan^{-1} \frac{b}{Z_2}\right]}_{\text{(end corrections)}}$$

"Here K is the complete elliptic integral. The above expression is approximately correct for a point within the cylinder and farther than one mean radius from either end. The integration was done numerically, using K-values from a table (27). On the axis ($r=o$), K is equal to $\frac{\pi}{2}$, and $\Phi = \frac{\pi}{2}$ sd minus end corrections.

"Results: The values of Φ for the proposed cylinder for the present project can be found from Fig. 1. The numerical values C from the curves have to be multiplied by $\frac{N}{2 \pi hb}$ to give the flux Φ."

4.4.3 A preliminary irradiation of pure gum natural rubber, Compound 1GEA10, was run in order to select the series of radiation doses which would best detail the effects of Cobalt-60 gamma radiation upon elastomeric samples. Natural rubber appeared to possess at least as much inherent resistance to radiation damage as any elastomer, judging from the work of others. Since our main purpose was to study the influence of various types of compounding ingredients upon the radiation resistance of elastomers, as well as to discover the characteristic stability of the elastomers themselves in pure gum recipes, we chose Compound 1GEA10 advisedly. To be really interesting an elastomer in cured pure gum form must exhibit greater resistance than natural rubber to radiation or, in some other compounded form, must be superior to natural rubber compounded with similar ingredients. As shown in Table I and Figure 3, a series of radiation doses was selected covering a range from no physical change to minimum tensile strength for pure gum natural rubber. Essentially this series of doses was used throughout the irradiation study for each compound, namely 1×10^6, 5×10^6, 1×10^7, 2.5×10^7, 3.5×10^7, 5×10^7, and 7×10^7 roentgens.

4.4.4 The comprehensive program which was planned required the greatest efficiency in the use of irradiation facilities. This meant that the practical maximum number of samples should be irradiated each time. Therefore, we used small samples of standardized size, measuring 0.25 inches wide, 2.75 inches long, and approximately 0.025 inches thick. The samples were died from a sheet, wrapped in thin aliminum foil, and packed in cylindrical aluminum cans for gamma irradiation. In general 12 such sample strips per compound were included at each irradiation dose.

Consequently, approximately 15 thousand sample strips were irradiated, over half of which were tested subsequently. The sample strips represented the 219 elastomeric compounds shown in Appendix I.

4.4.5 The samples were given radiation doses through 2.5 x 10^7 roentgens in Cobalt-60 Source Number Co 17 at the B. F. Goodrich Research Center. They received the remaining three higher radiation doses at the gamma radiation facility at Brookhaven National Laboratory (22).

4.5 Physical Testing of Samples

4.5.1 Three sets of physical measurements were performed on the gamma-irradiated samples: tensile strength-elongation, one hundred percent modulus, and stress relaxation during 22 hours. Tensile strength and elongation values were measured with the Electrographic Stress-Strain Machine developed by Mr. F. D. Snyder of the Physical Research Laboratory. This machine was designed specifically for the stress-strain testing of rectangular small elastomeric samples and has been carefully calibrated against the Standard Scott Testing Machine, Model L-6, which has the A.S.T.M. designation D-412-51P. Stress relaxation was measured with an instrument designed according to standard principles by Dr. M. L. Dannis of the same laboratory. The one hundred percent modulus valves were obtained in a standard manner also. The irradiated sample strips were held at one hundred percent elongation for one minute at which time the force required to maintain the extension was recorded.

4.5.2 In addition to the above tests, which were made after conclusion of the irradiation and which provided the bulk of the experimental data, we ran tests during the course of gamma irradiation. The irradiations were interrupted only long enough to permit taking physical measurements. Usually an interruption lasted about five minutes and was considered to have an insignificant effect on the results. Experiment supported this belief. These tests were all stress-relaxation studies. Measurements were made in vacuum and in air of both continuous and intermittent stress relaxation. A special instrument called a Dipsometer, which was developed by Dr. M. L. Dannis and Mr. R. C. Brainard of the Physical Research Laboratory, was used throughout the stress relaxation study. This instrument is small and compact. It could be sealed inside a glass tube small enough to fit inside Cobalt-60 Source Number Co 17 and so permitted irradiation of instrument and sample together.

4.5.3 Control physical measurements of unirradiated samples were made in all the studies. In the case of the studies involving measurements after completion of irradiation, identical measurements were made on unirradiated samples of the same compounds. For the stress relaxation studies during irradiation, control studies were made in the same manner on unirradiated samples with the same compounding history.

4.6 Investigation of Special Physical Methods of Analysis

4.6.1 We sought methods of studying the changes in chemical structure of the elastomeric compounds which resulted from irradiation with gamma rays. Under the complex circumstances chemical analysis did not seem particularly promising for detailing structural changes. When more stress relaxation data have been obtained, we expect to acquire some information of this type by calculation of change in molecular weight between cross-links in the elastomeric compound. However, infrared absorption analysis was a potential approach to direct study of just such structural changes. Mr. A. Hawthorne produced thin films of pure gum natural rubber, Compound 1GEA10, mounted and cured on aluminum rings used in infrared spectrophotometric work. The sample films were irradiated on the rings. In this first trial of the method x-radiation was used in place of gamma radiation for speed. In future studies any source of radiation can be used without changing the technique. Since the films were only several mils thick the x-radiation effects should be approximately uniform throughout the sample. The atmosphere can be controlled in this approach and in the first trial was lamp-grade nitrogen.

4.6.2 Whereas the infrared technique of analysis was direct, the second special method, which involved the mass spectrometer, was indirect. We proposed to collect the volatile irradiation products from various irradiated elastomeric compounds and identify the products by analysis with the mass spectrometer. The samples, which were in the form of small strips as described above, were wrapped in aluminum foil and sealed in individual glass tubes in air at atmospheric pressure. The tubes were designed with break-seals for easy sampling. After the desired irradiation, the tubes were placed in the sample system of the mass spectrometer. The seal was broken, and all the products which were volatile at 10^5 mm. Hg pressure were analyzed. This analytical approach shows considerable promise, but some minor difficulty of internal standardization must be overcome for reliable quantitative analysis.

5. Discussion of Results

5.1 Dr. Harrington's calculations show that there is a significant change in flux as the position inside Cobalt 60 Source Co 17 varies. However, this variation in flux is relatively small for radial distances of 0.65 inches or less from the axis. The samples were no farther from the axis in any part. The maximum variation in any given plane perpendicular to the axis would be 16 percent. In a plane parallel to the axis the maximum variation would be less than 90 percent. Figure 1 illustrates the variations. Figure 2 shows the rate of radioactive decay of Cobalt 60 and indicates the decrease in flux in Source Co 17 through 30 December 1954. A 13 percent decrease has occurred to the present date since 16 January 1954. Corrections were applied for radioactive decay in all the results. Within experimental error the position of samples of pure gum natural rubber in Source Co 17 had little effect upon stress-strain properties.

5.2 As shown in Figure 3 a Cobalt 60 gamma ray dose of 7 x 10^7 roentgens diminishes the tensile strength of pure gum natural rubber to 7 percent of the original value, which corresponds closely to completion of the first phase of discomposition. This compound has been used over the dose range indicated as a standard for behavior comparison. Figure 4 contains the data for tensile strength and elongation which appear in Figure 3 as well as a second set, and it delineates the corresponding change in 100 percent modulus. Table I presents the data upon which the latter two figures are based.

5.3 Table II states the results of the infrared absorption analysis of x-irradiated Compound 1GEA10. The absorbing structure shown is responsible for a characteristic peak in the infrared absorption spectrum at a wave length of 11.95 microns. The height of this peak indicates directly the degree of ethylenic unsaturation. No effect appeared until the sample had received a calculated dose of 10^8 roentgens in a nitrogen atmosphere after which the degree of unsaturation decreased markedly. Considering that this dose is calculated and is due to x-radiation of little-known energy spectrum, the correlation of results with gamma ray-induced physical changes is good. The first major significant changes in the stress-strain properties of Compound 1GEA10 after gamma irradiation appear for doses between 10^7 and 10^8 roentgens. Since the infrared absorption of other structural groups can be studied by the same technique, this general approach can be used to study a variety of changes in elastomeric samples as a function of radiation dose. Therefore, such a study merits further attention.

5.4 The figures in Table III represent the results of a study of the effects of irradiation of certain elastomeric gum stocks in vacuum. Such a study was of interest because of the hypothesis that accelerated oxidation accounts for a significant part of deterioration of elastomeric compounds during irradiation. The variation in 100 percent modulus with radiation dose for the compounds in the latter table is shown in Figures 5 through 16. Figures 5 through 14 are semi-log graphs. Figures 15 and 16 are linear coordinate plots of the curves in Figures 10 and 14, respectively. They are included to clarify the rate of deterioration with dose. Figures 5 and 6 show that, if the 100 percent modulus values were expressed as percent of the original, the changes as a function of dose in vacuum would be about the same for Neoprene GN and Neoprene W. The curves for change in air are almost identical as they stand. In both cases the rate of increase in modulus is greater in air than in vacuum. As shown in Figures 7, 8, and 9, there is very little difference between the changes in air and in vacuum as a function of gamma irradiation of Hycar OR-15, natural rubber smoked sheet, and GR-S pure gum stocks. These are also the most resistant of the simple pure gum stocks toward radiation damage. The radiation-induced changes in 100 percent modulus are shown for both pure gum and black compounds of separate blends of GR-S and of smoked sheet with Hycar HH, a brominated butyl rubber which is more compatible than ordinary butyl rubber. The Hycar HH does indeed delay radiation change.

The Hycar HH - GR-S pure gum stock required ten times the radiation dose to produce change as did the pure gum GR-S stock. The Hycar HH-smoked sheet stock required 50 times as large a dose as did pure gum smoked sheet stock. The incorporation of Hycar HH in a natural rubber stock reduced the initial modulus markedly. However, Hycar HH had little effect upon the initial 100 percent modulus of pure gum GR-S. The addition of carbon black to the Hycar HH blends had little effect upon the improved resistance except at high doses, when the rate of change with dose was greater for the black gum stocks. It is clear that Hycar HH helps to resist change in 100 percent modulus and has in general a slightly beneficial effect on other stress-strain properties. Addition of black does not interfere with the beneficial effect of Hycar HH upon the moduli of the latter stocks but does prevent even the slight improvement in resistance as concerns the other stress-strain properties. A peroxide-cured pure gum natural rubber was unique. The modulus decreased appreciably both in vacuum and air during irradiation and subsequently increased, as shown in Figure 14.

5.5 Table 4 presents the stress-strain data, namely tensile strength, ultimate elongation, and 100 percent modulus, for the majority of the 219 elastomeric compounds whose recipes appear in Appendix I. The samples were irradiated and tested as described above. Where values have been omitted, it is for one of four reasons: (1) the samples were so altered by irradiation that they could not be tested, (2) there was insufficient stock to permit preparation of enough samples, (3) the samples broke before values could be read, or (4) parallel studies made it undesirable to test several of the compounds. Wherever sample breakage prevented obtaining a value, the word "broke" appears in the table. Where one of the first two reasons applied, dashes indicate the absence of suitable samples.

5.5.1 The gum stock group showed results of mixed quality. In general the pure gum compounds had mediocre to poor resistance to radiation change. Hycar OR-15, GR-S, smoked sheet, and possibly polybutadiene pure gums are exceptions. The Hycar OR-15 and smoked sheet compounds were the most interesting, retaining a good share of their original serviceability (Compounds 1GEA5 and 32, respectively). The blended pure gum stocks, which contain a high polymer in addition to the elastomer, had improved resistance. The GR-S - Goodrite Resin 50 gum stock (Compound 1GEA23) showed essentially no change after receiving a dose of 7 x 10^7 roentgens. The Hycar-Durez resin compound (Compound 1GEA33) actually improved in tensile strength during irradiation while showing small change in ultimate elongation and 100 percent modulus. Moreover, the latter blend maintains a higher tensile strength than and about as good an elongation as the original Hycar gum (Compound 1GEA5). The smoked sheet - Hycar HH pure gum (Compound 1GEA37) shows excellent retention of all measured properties. The corresponding GR-S - Hycar HH stock had good resistance to radiation-induced change.

The black stocks in general showed somewhat better resistance than their pure gum counterparts. In particular, smoked sheet black stock (Compound 1GEA21) displayed good retention of properties, especially of tensile strength. The GR-S black stock (Compound 1GEA34) had fair resistance. The Hycar HH was less effective in this case in preventing changes in the smoked sheet and GR-S properties, although little change in modulus resulted during irradiation.

Of the new elastomers studied, namely the carbolasts and the polyurethanes, several appear to be interesting and to merit further research. A direct correlation was found in the latter group between phenyl content and radiation resistance. Since these are experimental stocks, some difficulties of cure were to be expected, and the initial properties of Compounds 1GEA16 and 17 should have been much better than those observed. The retention of the initial properties is excellent, amounting to 90 percent or better, though the poor initial properties make the conclusions tentative. The most interesting Carbolasts are Carbolast B (Compounds 1GEA40 and 41) and Carbolast C (Compounds 1GEA43, 45, and 46). They retain their tensile strengths very well and their ultimate elongations fairly well.

5.5.2 The next phase of our study dealt with antioxidants and led to surprising and gratifying results. The various antioxidants were included in the research program because earlier work suggested that accelerated oxidation was important in the overall radiation effect. It was found that they imparted a striking resistance to radiation damage to the rubber compounds. The surprising fact is that the order of effectiveness of these inhibitors of radiation-induced discomposition is not the same as their order of effectiveness as antioxidants. Also, they are effective at inhibiting damage in natural rubber compounds, whereas irradiation of such compounds without inhibitor in vacuum produced much the same deterioration as in air. This strongly suggests that the agents in this group exert a protective effect which does not necessarily have anything to do with antioxidant activity. Subject to further study and development, it would seem that this constitutes an important new discovery.

Tables 5 and 6 give the experimental data for the various damage inhibitors in pure gum and black recipes, respectively. Also included are four special products: Tenamene, Universal Oil Products Inhibitor Number 2237-290, and two experimental antioxidants. The most resistant elastomeric compounds in this study are Compounds 1GEA80 and 81, based on natural rubber and low temperature GR-S respectively. Both the Tenamene and TMTD are considered to contribute to the improved resistance.

5.5.3 None of the loading pigments had any significant inhibiting effect, as is shown by the data for Compounds 1GEA150 through 194, inclusive, with the possible exception of several of the carbon blacks and Silene in the 20 percent by volume series.

5.5.4 The uncured latex rubbers had relatively poor resistance to deterioration. The GR-S latex was still a rubber after a dose of 7 x 10^7

roentgens, but this could not be said of the uncured natural rubber latex. The cured GR-S latex had fair resistance, retaining 41 percent of its original tensile strength and 69 percent of its ultimate elongation after 7 x 10^7 roentgens dose.

5.5.5 The pH of the rubber compound apparently had little influence on radiation resistance, although poor cure in two of the three cases could have masked any effect.

5.5.6 The elastomeric compounds having large loadings of heavy metal fillers were generally uninteresting. Only lead sulfide and titanium hydride in the pure gum series and titanium hydride in the black gum showed any merit.

5.6 It was recognized early in this study that one of the most effective approaches to a fundamental understanding of molecular changes in elastomeric compounds during nuclear irradiation would be the measurement of stress relaxation as a function of radiation dose. Equipment was available both for measurement of stress relaxation after completion of irradiation and for measurement during the course of the exposure.

Table 7 shows the effect of gamma radiation on continuous stress relaxation in 36 elastomeric compounds. The measurements were made after 22 hours relaxation at 50 percent elongation. Continuous stress relaxation indicates among other things bond scission within the elastomeric material. The table shows the relative stress relaxation at 50 percent elongation as a function of radiation dose. The data indicate to what degree the elastomeric compound deteriorated during irradiation. Among the compounds in the table smoked sheet pure gum (Compound 1GEA10), black stocks of smoked sheet (1GEA21), Hycar OS-10 (1GEA22), polybutadiene (1GEA25), Neoprene GN (1GEA26), and Neoprene W (1GEA27), and the black blend of GR-S and Goodrite Resin 50 all appear to withstand structural deterioration through radiation doses of 7 x 10^7 roentgens. Figures 17 through 20 present the data graphically for a number of these compounds. Figure 17 compares Neoprene GN (1GEA2) and Neoprene W (1GEA3) pure gums. Figure 18 involves Hycar OR-15 (1GEA5), Hypalon S-2 (1GEA6), smoked sheet (1GEA10), and GR-S (1GEA12) gum stocks. Figure 19 indicates the effect of carbon black upon the stress relaxation of polybutadiene compounds with irradiation. The black has a moderating influence. The effect of Goodrite Resin 50 on GR-S is shown in Figure 20. The increasing trend observed in the GR-S black stock is eventually reserved by the presence of the resin. The larger black loading in the case of the GR-S - Goodrite Resin 50 stock may have contributed also.

More detailed studies were made of pure gum natural rubber (1GEA10) during the course of irradiation without disturbing the samples, as described above in Section IV. Table 8 gives the experimental data for the stress relaxation of pure gum natural rubber (1GEA10) in vacuum during irradiation in Cobalt 60 Source Co 17. The flux of the source ranged from 2.0 x 10^5 to 1.9 x 10^5 roentgens per hour during the period in which these several tests were run. Table 9 compares the data for continuous stress relaxation of pure gum natural rubber during irradiation. The vacuum was better than 10^{-5} mm. Hg in all cases. In the former case two independent continuous stress relaxation tests in vacuum are compared with one intermittent stress relaxation test in vacuum, all three during irradiation. A continuous stress relaxation measurement in vacuum without irradiation served as a control. Figure 21 illustrates the comparative effects of gamma radiation. Between measurements in the intermittent stress relaxation study cross-linking could occur which would immediately affect a subsequent measurement of stress. This explains the fact that all of the points for the intermittent stress curve are for S/So greater than one. The curve indicates that a net cross-linking effect occurs throughout the dose range. In the case of continuous stress relaxation during irradiation cross-linking could also occur, but it would have no immediate effect upon the stress. Since the sample is necessarily under extension at the time of any cross-linking event and since the cross-link cannot be formed in a condition of tension but must be relaxed, the cross-links might have an ultimate effect in retarding stress relaxation but could not produce a significant short-term effect. In other words, to a first approximation the continuous stress relaxation during irradiation is a measure of the bond scission or degradation which occurs, and the like intermittent stress relaxation is a measure of the combined cross-linking and degradation. After corrections based on unirradiated controls have been applied to obtain solely the effects produced by nuclear radiation, the progress of cross-linking and degradation as distinct and separate processes can be followed. This should provide new insight into the phenomena of radiation deterioration. Only the intermittent stress relaxation control study remains before this unified investigation is completed for pure gum natural rubber. Figure 22 shows clearly that the deterioration of the latter rubber is quite different in air than in vacuum, during gamma irradiation. The degradation of the elastomeric compound proceeds much faster in air. Table 9 collects the data upon which Figure 22 is based.

SECTION VI. SUMMARY AND CONCLUSIONS

The year's study has been mainly comprehensive and designed to provide engineering information regarding the effect of nuclear radiation upon the common elastomers and many compounds thereof, comprising over 190 different materials compounded, irradiated, tested, and evaluated. A number of more fundamental investigations were begun to aid in improving the resistance of elastomeric materials to radiation damage.

The conclusions may best be presented by enumeration:

(1) Comprehensive engineering data on stress-strain properties as a function of nuclear radiation dose have been compiled (Table 4).

(2) Natural rubber is best among the pure gum compounds; and GR-S, Hycar OR-15, Hypalon S-2, and Carbolast C have good resistance to radiation-induced change. Polyisobutylene, Hycar PA-21, and perhaps Thiokol ST have the poorest resistance in the pure gum stocks tested. The Hycar-Durez resin pure gum blend had good resistance. The pure gum blends of Hycar HH with natural rubber in one case and GR-S in the other had good resistance, but the initial tensile strengths were low.

(3) Among the black gum compounds natural rubber, GR-S, and Carbolast C had the best resistance, and Hycar OR-15 and possibly Hypalon S-2 were fair. The GR-S - Goodrite Resin 50 blend in this black gum group was good. Polyisobutylene, Thiokol ST, and Hycar PA-21 had the poorest resistance.

(4) A group of chemicals has been found which markedly inhibit radiation effects in natural rubber pure gum and black compounds. All of the inhibitors are effective, but some have remarkable effectiveness.

(5) Stress relaxation measurements in air versus in vacuum as a function of radiation dose show that there is a difference in the degree of deterioration. This conclusion was especially well documented for natural rubber pure gum.

(6) Certain special lines of research involving mass spectrometry, infrared spectrophotometry, and stress relaxation measurements of irradiated elastomeric compounds show considerable promise of providing fundamental new information regarding mechanisms of radiation damage.

(7) Several new lines of investigation appear interesting from the standpoint of evaluating and improving the radiation resistance of elastomeric compounds. Briefly, they include refined dosimetry of all nuclear radiation sources used in our studies, studies of the effects of high and low temperatures (such as encountered in air navigation) on radiation deterioration of the more resistant rubber compounds, evaluation of the effect of radiation flux magnitude and of the kind of radiation upon deterioration, extended stress relaxation measurements of elastomeric compounds besides pure gum natural rubber, and attempts to produce new elastomers with custom-made radiation resistance and compounding agents with even greater inhibiting ability than those discovered in the present study.

BIBLIOGRAPHY

(1) Air Force Contract Number AF33(616)-2308. A Study of the Effects of Radiation from Power Plants on Elastomeric Compounds and Compounding Materials.

(2) Bopp, C. D. and Sisman, O. Radiation Stability of Plastics and Elastomers. ORNL 1373, Oak Ridge National Laboratory, 23 July 1953, pp. 1-24, 52-81.

(3) Charlesby, A. "High Energy Radiation and Long-Chain Polymers" Symposium on "Utilization of Radiation from Fission Products" Held at Harwell on 23rd and 24th February 1953. Atomic Energy Research Establishment, June 1953, pp. 111-120.

(4) Charlesby, A. "The Effect of High-Energy Radiation on Long-Chain Polymers", Letter in Nature (London), Volume 171, Atomic Energy Research Establishment, 24 January 1953, p. 167.

(5) Charlesby, A. "The Cross-Linking of Rubber by Pile Radiation", Atomics, Volume 5, Atomic Energy Research Establishment, January 1954, pp. 12-21, 27.

(6) Charlesby, A. Molecular Weight Changes in the Degradation of Long-Chain Polymers, A.E.R.E. M/R 1298, Atomic Energy Research Establishment, 18 November 1953, pp. 1-11.

(7) Charlesby, A. and Hancock, N. H. "The Effect of Cross-Linking on the Elastic Modulus of Polythene", Proceedings of the Royal Society A, Volume 218, Atomic Energy Research Establishment, 25 June 1953, pp. 245-255.

(8) Little, K. "Irradiation of Linear High Polymers", Letter in Nature (London), Volume 170, Atomic Energy Research Establishment, 20 December 1952, pp. 1075-1076.

(9) Hobbs, L. M., Pletcher, D. W., and Brown, D. E. "Effects of Gamma Radiation on Rubber and on Polymerization". Utilization of the Gross Fission Products, COO-196, Engineering Research Institute, University of Michigan, September 1953, pp. 158-163.

(10) Ryan, J. W. "Effect of Gamma Radiation on Certain Rubbers and Plastics", Nucleonics, General Engineering Laboratory, General Electric Company, August 1953, pp. 13-15.

(11) Davidson, W. L. and Geib, I. G. "The Effects of Pile Bombardment on Uncured Elastomers", Journal of Applied Physics, Volume 19, the B. F. Goodrich Company, May 1948, pp. 427-433.

(12) Slater, J. C. "The Effects of Radiations on Materials", Journal of Applied Physics, Volume 22, Department of Physics, Massachusetts Institute of Technology, March 1951, pp. 237-256.

(13) Newton, E. B. Vulcanization Process by Electrons, Application Date 2 May 1933, U. S. Patent 1, 906, 402.

(14) Dienes, G. J. "Radiation Effects in Solids", Annual Review of Nuclear Science, Volume 2, Brookhaven National Laboratory, 1953, pp. 187-193, 215-216.

(15) Sisman, O. and Bopp, C. D. Physical Properties of Irradiated Plastics, ORNL 928, Oak Ridge National Laboratory, 29 June 1951, pp, 8-188.

(16) Dole, M. Army Chemical Center Symposium on Chemistry and Physics of Radiation Dosimetry, U. S. Atomic Energy Commission Document, NP-3237, 1950, pp. 120-148.

(17) Burton, M. "Radiation Chemistry", Annual Review of Physical Chemistry, Volume 1, Department of Chemistry, University of Notre Dame, 1950, pp. 113-132.

(18) Lawton, E. J., Bueche, A. M., and Balwitt, J. S. "Irradiation of Polymers by High-Energy Electrons", Letter in Nature (London), Volume 172, Knolls Research Laboratory, General Electric Company 11 July 1953, pp. 76-77.

(19) Dienes, G. J. "Effects of Nuclear Radiations on the Mechanical Properties of Solids", Journal of Applied Physics, Volume 24, Brookhaven National Laboratory, June 1953, pp. 666-674.

(20) Gehman, S. D. and Hobbs, L. M. "Changes in Elastomers Due to Radiation from Cobalt-60", Rubber World, Volume 130, Goodyear Tire and Rubber Company and University of Michigan, August 1954, pp. 643-646.

(21) Sun, K. H. "Effects of Atomic Radiation on High Polymers", Modern Plastics, Westinghouse Research Laboratories, September 1954.

(22) Gamma Irradiation Service (Description), Brookhaven National Laboratory.

(23) Correspondence, 9 February 1954, by O. A. Kuhl, Fission Products Utilization Project, Brookhaven National Laboratory, to J. W. Born, Physical Research Laboratory, B. F. Goodrich Company Research Center.

(24) Schulman, J. H., Ginther, R. J., and Klick, C. C. "Dosimetry of X-Rays and Gamma-Rays by Radio-Photo Luminescence", Journal of Applied Physics, Volume 22, Naval Research Laboratory, December 1951, pp. 1479-1487.

(25) Schulman, J. H., Shurcliff, W., Ginther, R. J., and Attix, F. H. "Radio-photoluminescence Dosimetry System of the U. S. Navy", Nucleonics, Volume 11, Metallurgy Division, Naval Research Laboratory, October 1953, pp. 52-56.

(26) Schulman, J. H. Measurement of High Doses of Co^{60} Gamma-Rays by Absorption Changes in Phosphate Glass, NRL-Memo-266, Office of Naval Research, U. S. Atomic Energy Commission, Metallurgy Division, Naval Research Laboratory, February 1954, pp. 1-23.

(27) Jahnke, E. and Emde, F. Funktionentafeln mit Formeln und Kurven, Dover Publications, 1943, p. 78.

APPENDIX I

The Complete List of Recipes of Compounds Used in the Study of the Effect of Nuclear Radiation on Elastomeric Materials

A. General Recipes:

Compound 1 GEA 1

100	Polybutadiene
1	Stearic Acid
5	Zinc Oxide
2	Sulfur
0.3	T.M.T.D.

Cures: 10' at 302°F
20' at 302°F
40' at 302°F

Compound 1GEA 2

100	Neoprene GN
1	Stearic Acid
5	Zinc Oxide
4	Magnesium Oxide
0.5	Permalux
2	Neozone A

Cures: 10' at 302°F
20' at 302°F
40' at 302°F

Compound 1 GEA 3

100	Neoprene W
0.5	Stearic Acid
5	Zinc Oxide
2	Magnesium Oxide
2	P.B.N.A.
0.5	Permalux

Cures: 10' at 302°F
20' at 302°F
40' at 302°F

Compound 1 GEA 4

100	Hycar PA-21
1	Stearic Acid
0.5	Sulfur
3	Trimene Base

Cures: 15' at 302°F
30' at 302°F
60' at 302°F

Compound 1 GEA 5

100	Hycar 1001
5	Zinc Oxide
1.5	Sulfur
1	M.B.T.S.

Cures: 15' at 302°F
30' at 302°F
60' at 302°F

Compound 1 GEA 6

100	Hypalon S-2
40	Litharge
3	Mercapto Benzothiazole
2.5	Staybelite Resin

Cures: 15' at 302°F
30' at 302°F
60' at 302°F

Compound 1 GEA 7

100	Thiokol ST
3	Stearic Acid
0.5	Zinc Oxide
1.5	G.M.F.
2	Ga-10

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 8

100	Poly FBA (already cured)

Compound 1 GEA 9

100	Silicone Rubber SE-450

Cures: 10' at 230°F
15' at 230°F
20' at 230°F

Oven Cure: 60' at 300°F

Compound 1 GEA 10

100	Smoked Sheet
1	Stearic Acid
5	Zinc Oxide
3	Sulfur
1	PBNA
0.6	Mercapto Benzothiazole

Cures: 10' at 284°F
20' at 284°F
40' at 284°F

Compound 1 GEA 11

100	Smoked Sheet
50	Durex (phenolic) resin

Cures: 10' at 284°F
20' at 284°F
40' at 284°F

Compound 1 GEA 12

100	GR-S
1.5	Stearic Acid
3.5	Zinc Oxide
2	Sulfur
1	M.B.T.S.

Cures: 15' at 302°F
30' at 302°F
60' at 302°F

Compound 1 GEA 13

100	Gr-I 50
2	Stearic Acid
5	Zinc Oxide
1.5	Sulfur
1	T.M.T.D.
0.5	Mercapto Benzothiazole

Cures: 30' at 302°F
60' at 302°F
120' at 302°F

Compound 1 GEA 14-18

These 5 compounds will be polyester urethane rubbers with varying phenylene group contents.

Compound 1 GEA 19

50	GR-S
50	Hycar HH
1.5	Stearic Acid
5	Zinc Oxide
1.5	Sulfur
0.1	D.O.T.G.
1	M.B.T.S.

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 20

100	Smoked Sheet
2.9	Di-Tertiary Butyl Peroxide

Cure: 6 hrs at 284°F

Compound 1 GEA 21

100	Smoked Sheet
1	Stearic Acid
5	Zinc Oxide
3	Sulfur
1	Mercapto Benzothiazole
1	P.B.N.A.
50	EPC Black

Cures: 20' at 284°F
40' at 284°F
80' at 284°F

Compound 1 GEA 22

100	Hycar OS-10
1.5	Stearic Acid
5	Zinc Oxide
2	Sulfur
1	M.B.T.S.

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 23

100	GR-S
50	Goodrite Resin 50
1.5	Stearic Acid
5	Zinc Oxide
2	Sulfur
1	M.B.T.S.

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 24

100	Silicone Rubber SE-550

Cures: 10' at 230°F
15' at 230°F
20' at 230°F

Oven Cure: 60' at 300°F

Compound 1 GEA 25

100	Polybutadiene
1	Stearic Acid
5	Zinc Oxide
2	Sulfur
0.3	T.M.T.D.
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 26

100	Neoprene GN
1	Stearic Acid
5	Zinc Oxide
4	Magnesium Oxide
0.5	Permalux
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 27

100	Neoprene W
0.5	Stearic Acid
5	Zinc Oxide
2	Magnesium Oxide
2	P.B.N.A.
0.5	Permalux
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 28

100	Hycar PA-21
1	Stearic Acid
0.5	Sulfur
3	Trimene Base
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 29

100	Hycar 1001
5	Zinc Oxide
1.5	Sulfur
1	M.B.T.S.
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 30

100	Hypalon S-2
40	Litharge
3	Mercapto Benzothiazole
2.5	Staybelite Resin
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 31

100	Thiokol ST
3	Stearic Acid
0.5	Zinc Oxide
1.5	G.M.F.
2	Ga-10
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 32

100	Smoked Sheet
1	Stearic Acid
5	Zinc Oxide
3	Sulfur
1	P.B.N.A.
0.6	Mercapto Benzothiazole

Cures: 20' at 284°F
40' at 284°F
80' at 284°F

Compound 1 GEA 33

100	Hycar 1001
50	Durez (phenolic) resin

Cures: 40' at 302°F
80' at 302°F
160' at 302°F

Compound 1 GEA 34

100	GR-S
3.5	Zinc Oxide
2	Sulfur
1	M.B.T.S.
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 35

100	GR-I 50
2	Stearic Acid
5	Zinc Oxide
1.5	Sulfur
1	T.M.T.D.
0.5	Mercapto Benzothiazole
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 36

100	GR-S
50	Goodrite Resin 50
1.5	Stearic Acid
5	Zinc Oxide
2	Sulfur
1	M.B.T.S.
50	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 37

50	Smoked Sheet
50	Hycar HH
1.5	Stearic Acid
5	Zinc Oxide
2	Sulfur
1	P.B.N.A.
1	M.B.T.S.
0.1	D.O.T.G.

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 38

50	Smoked Sheet
50	Hycar HH
1.5	Stearic Acid
5	Zinc Oxide
2	Sulfur
1	P.B.N.A.
1	M.B.T.S.
0.1	D.O.T.G.
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 39

50	GR-S
50	Hycar HH
1.5	Stearic Acid
5	Zinc Oxide
1.5	Sulfur
1	P.B.N.A.
1	M.B.T.S.
0.1	D.O.T.G.
20	SRF Black

Cures: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 40

100	Carbolast B
12	Zinc Oxide
4	Phthalic Anhydride

Cures: 10' at 300°F

Compound 1 GEA 41

100	Carbolast B
50	Carbon Black, E.P.C.
1.5	Stearic Acid
1.2	Santocure
1.75	Sulfur
5	Zinc Oxide

Cures: 80' at 300°F

Compound 1 GEA 42

100	Carbolast B-Sorbic Acid
8.5	Zinc Oxide
3.1	Phthalic Anhydride

Cures: 40' at 300°F

Compound 1 GEA 43

100	Carbolast C
12.73	Zinc Oxide
17.2	Stearic Acid

Cure: 20' at 260°F

Compound 1 GEA 44

100	Carbolast C
12.73	Zinc Oxide
17.2	Stearic Acid
40	Carbon Black, F.E.F.

Cure: 80' at 260°F

Compound 1 GEA 45

100	Carbolast C
0.5	Ground Sulfur
3.0	445,160
3.0	Stearic Acid
40.0	Carbon Black, F.E.F.

Cure: 80' at 260°F

Compound 1 GEA 46

100	Carbolast C
40	Carbon Black F.E.F.
10	Hexamethylenediamine Carbonate

Cure: 80' at 300°F

Compound 1 GEA 47

100	Carbolast BA
6.2	Phthalic Anhydride
17.1	Zinc Oxide

Cure: 40' at 300°F

Compound 1 GEA 48

100	Carbolast BA
50	Carbon Black, E.P.C.
2.5	D.P.G.
10	Zinc Stearate
1.5	Sulfur

Cure: 40' at 300°F

Compound 1 GEA 49

100	Carbolast BS
3.7	Phthalic Anhydride
10.7	Zinc Oxide

Cure: 30' at 307°F

Compound 1 GEA 50

100	Carbolast BS
50	Carbon Black E.P.C.
1.5	Stearic Acid
1.2	Santocure
1.75	Sulfur
5	Zinc Oxide

Cure: 80' at 300°F

Compound 1 GEA 51

100	Low Temperature G.R.S.
50	Carbon Black H.S.F.
2	Accelerator 808
1.5	Dicumyl Peroxide

Cure: 20' at 302°F
40' at 302°F
80' at 302°F

Compound 1 GEA 52

100	Low Temperature G.R.S.
2	Accelerator 808
1.5	Dicumyl Peroxide

Cure: 80' at 302°F

Compound 1 GEA 53

100	Natural Rubber
1.5	Dicumyl Peroxide

Cure: 80' at 284°F

Compound 1 GEA 54

100	Natural Rubber
2	Accelerator 808
1.5	Dicumyl Peroxide
1	Antioxidant 2246
50	Carbon Black E.P.C.

Cure: 20' at 284°F
40' at 284°F
80' at 284°F

Compound 1 GEA 55

100	Thiokol FA
10	Zinc Oxide
0.5	Stearic Acid
0.1	D.P.G.
0.3	M.B.T.S.

Cure: 30' at 302°F
60' at 302°F
120' at 302°F

Compound 1 GEA 56

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
2.5	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 57

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
5.0	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 58

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
10	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 59

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
1.2	Mercapto Benzothiazole
3	Sulfur
2.5	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 60

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
1.2	Mercapto Benzothiazole
3	Sulfur
5.0	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 61

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black E.P.C.
1.2	Mercapto Benzothiazole
3	Sulfur
10	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 62

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S
2	Sulfur
2.5	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 63

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
2	Sulfur
5.0	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 64

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
2	Sulfur
10	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 65

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
2.5	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 66

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
2.5	Universal Oil Products Inhibitor No. 2237-290

Cure: 20' at 302°F

Compound 1 GEA 67

100	Low Temperature G.R.S.
1.5	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
10	Universal Oil Products Inhibitor No. 2237-290

Cure: 80' at 302°F

Compound 1 GEA 68

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
2.5	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 69

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
5	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 70

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
1	Mercapto Benzothiazole
3	Sulfur
10	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 71

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
1	Mercapto Benzothiazole
3	Sulfur
2.5	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 72

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
1	Mercapto Benzothiazole
3	Sulfur
5.0	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 73

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
1	Mercapto Benzothiazole
3	Sulfur
10	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 74

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
2	Sulfur
2.5	Tenamene

Cure: 10' at 302°F

Compound 1 GEA 75

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
2	Sulfur
5.0	Tenamene

Cure: 10' at 302°F

Compound 1 GEA 76

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
2	Sulfur
10	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 77

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
2.5	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 78

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
5.0	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 79

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
1	M.B.T.S.
50	Carbon Black, E.P.C.
2	Sulfur
10	Tenamene

Cure: 20' at 302°F

Compound 1 GEA 80

100	Natural Rubber
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
10	Tenamene
4	T.M.T.D.

Cure: 20' at 302°F

Compound 1 GEA 81

100	Low Temperature G.R.S.
1	Stearic Acid
5	Zinc Oxide
50	Carbon Black, E.P.C.
10	Tenamene
4	T.M.T.D.

Cure: 20' at 302°F

Compound 1 GEA 84

100	Butyl Rubber GR-I 50
25	Polyethylene
5	Zinc Oxide
.5	Mercapto Benzothiazole
2.	Stearic Acid
.1	T.M.T.D.
1.5	Sulfur
50	Carbon Black E.P.C.

Cure: 80' at 302°F

Compound 1 GEA 85

50	Butyl Rubber, GR-I 50
50	Polyethylene
5	Zinc Oxide
.5	Mercapto Benzothiazole
2	Stearic Oxide
.1	T.M.T.D.
1.5	Sulfur
50	Carbon Black, E.P.C.

Cure: 80' at 302°F

Compound 1 GEA 87

100	Natural Rubber
40	2-6 Dihydroxymethyl-p-cresol

Cure: 120' at 311°F

Compound 1 GEA 88

100	Natural Rubber
40	Bakelite 3360 Resin

Cure: 30' at 311°F

Compound 1 GEA 89

100	Natural Rubber
40	Bakelite 3360 Resin
1	Heavy Magnesium Oxide

Cure: 30' at 311°F

Compound 1 GEA 92

100	Natural Rubber
30	Bakelite 3360 Resin
5	Heavy Magnesium Oxide
30	Carbon Black, E.P.C.

Cure: 30' at 311°F

Compound 1 GEA 94

100	Natural Rubber
6	M-dinitrobenzene
9	Ground Litharge

Cure: 30' at 287°F

Compound 1 GEA 96

100	Natural Rubber
5	Chloranil
10	Lead Dioxide

Cure: 90' at 287°F

Compound 1 GEA 98

100	Natural Rubber
2	G.M.F.
20	Red Lead

Cure: 60' at 287°F

Compound 1 GEA 100

100	Low Temperature G.R.S.
40	Carbon Black, E.P.C.
2	Chloranil
10	Ground Litharge

Cure: 15' at 287°F

Compound 1 GEA 93

100	Natural Rubber
50	Bakelite 3360 Resin
20	Heavy Magnesium Oxide

Cure: 30' at 311°F

Compound 1 GEA 95

100	Natural Rubber
6	M-dinitrobenzene
9	Ground Litharge
8.5	Stearic Acid

Cure: 45' at 287°F

Compound 1 GEA 97

100	Natural Rubber
5	Chloranil
10	Lead Dioxide
40	Carbon Black, E.P.C.

Cure: 20' at 287°F

Compound 1 GEA 99

100	Natural Rubber
2	G.M.F.
20	Red Lead
40	Carbon Black, E.P.C.

Cure: 30' at 307°F

Compound 1 GEA 101

100	Low Temperature G.R.S.
8	Chloranil
40	Carbon Black, E.P.C.
10	Ground Litharge

Cure: 10' at 287°F

Compound 1 GEA 102

100	Butyl Rubber, GR-I 50
60	Carbon Black, E.P.C.
5	Zinc Oxide
3	Stearic Acid
10	Red Lead
2	G.M.F.

Cure: 15' at 287°F

Compound 1 GEA 103

100	Natural Rubber
2	Trinitrobenzene
1	Aniline
150	Zinc Oxide

Cure: 30' at 287°F

Compound 1 GEA 104

100	Natural Rubber
40	Carbon Black, E.P.C.
5	M-dinitrobenzene

Cure: 15' at 287°F

Compound 1 GEA 105

100	Low Temperature G.R.S.
3	M-dinitrobenzene
40	Carbon Black, E.P.C.
5	Ground Litharge

Cure: 60' at 287°F

Compound 1 GEA 106

100	Natural Rubber
7	Diazoaminobenzene

Cure: 15' at 287°F

Compound 1 GEA 107

100	Natural Rubber
5	Diazoaminobenzene
40	Yellow Lead Chromate

Cure: 60' at 287°F

Compound 1 GEA 108

100	Low Temperature G.R.S.
4	Diazoaminobenzene
40	Carbon Black, E.P.C.
40	Yellow Lead Chromate

Cure: 90' at 287°F

B. Special Recipes

1. Effect of Antioxidants:

Master Batch 1 GEA 109

Pure Gum Stocks

100	Natural Rubber
5	Zinc Oxide
1	Stearic Acid
0.5	Mercapto Benzothiazole
2.5	Sulfur
3	Antioxidant (various)

Cure: 40' at 302°F

Master Batch 1 GEA 129

Black Stocks

100	Natural Blend
50	Carbon Black E.P.C.
5	Zinc Oxide
3	Stearic Acid
1	M.B.T.S.
3	Sulfur
3	Antioxidant (various)

Cure: 40' at 302°F

Black Recipe No.	Gum Recipe No.	Anti-Oxidants
130	110	P-Methoxyphenol
131	111	P-Dimethoxybenzene
	112	1,3-Naphthalenediol
133	113	1,5-Naphthalenediol
135	115	Phenyl-B-Napthylamine
136	116	N,N-di-B-naphthyl-p-phenylene diamine
137	117	Diphenylamine
138	118	2,5-Ditertiary butyl hydroquinone
139	119	Hydroquionone dibenzyl ether
140	120	Akroflex C
141	121	Antioxidant 2246
142	122	BLE-25
143	123	Stalite
144	124	V.D.H.
146	126	Antioxidant 3112
147	127	Prophenamine
148	128	Ionol

2. Effect of Loading Pigments:

Master Batch 1 GEA 149

100	Natural Rubber
5	Zinc Oxide
2	Stearic Acid
0.6	M.B.T.S.
3	Sulfur

Cure: 40' at 302°F

a. Variations in Fillers Having 10 Square Meters of Surface Area per Gram of Rubber:

Recipe No.	Loading Pigments	Amount
1 GEA 150	Whiting	31.2
1 GEA 151	Silene	12.5
1 GEA 152	Zinc Oxide	100
1 GEA 153	Clay	58.8
1 GEA 154	H.P.C. Black	7.6
1 GEA 155	E.P.C. Black	9.4
1 GEA 156	S.A.F. Black	7.5
1 GEA 157	H.A.F. Black	12.9
1 GEA 158	V.F.F. Black	13.2
1 GEA 159	F.F. Black	20.7
1 GEA 160	M.A.F. Black	23.3
1 GEA 161	H.M.F. Black	28.5
1 GEA 162	S.R.F. Black	42.0

b. Compounds Having 20 Percent Filler by Volume:

Recipe No.	Loading Pigments	Amount
1 GEA 163	Whiting	76.2
1 GEA 164	Silene	59.7
1 GEA 165	Zinc Oxide	159.4
1 GEA 166	H.P.C. Black	51.7
1 GEA 167	E.P.C. Black	51.7
1 GEA 168	S.A.F. Black	51.7
1 GEA 169	H.A.F. Black	51.7
1 GEA 170	V.F.F. Black	51.7
1 GEA 171	F.F. Black	51.7
1 GEA 172	H.M.F. Black	51.7
1 GEA 173	S.R.F. Black	51.7

c. Compounds Having 0, 5, 10, 20, and 30 Percent Filler by volume:

Recipe No.	Fillers	Amount	Volume Fillers
1 GEA 174	E.P.C. Black	0.0	0
1 GEA 175	"	10.9	5
1 GEA 176	"	23	10
1 GEA 177	"	36.4	15
1 GEA 178	"	51.7	20
1 GEA 179	"	88.5	30
1 GEA 180	Whiting	16.0	5
1 GEA 181	"	33.8	10
1 GEA 182	"	53.7	15
1 GEA 183	"	76.2	20
1 GEA 184	"	130.5	30
1 GEA 185	Mica	18.9	5
1 GEA 186	"	40.0	10
1 GEA 187	"	63.0	15
1 GEA 188	"	89.0	20
1 GEA 189	"	153.	30
1 GEA 190	Asbestos	15.2	5
1 GEA 191	"	32	10
1 GEA 192	"	50.5	15
1 GEA 193	"	71.5	20
1 GEA 194	"	122	30

3. Latex Rubbers, Cured and Uncured:

Compound 1 GEA 195

Natural Rubber Latex
(uncured)

Compound 1 GEA 196

GR-S Latex
(uncured)

Compound 1 GEA 197

GR-S Latex

Cured: 20' at 280°F

Compound 1 GEA 198

French Resin

Cured: Latex Rubber

4. Effect of pH of the Rubber on the Radiation Effects:

Compound 1 GEA 199

100	Natural Rubber
10	Sulfur
2.4	$Na_2 HPO_4 \cdot 12 H_2O$

(pH = 9.)

Cure: 60' at 284°F

Compound 1 GEA 200

100	Natural Rubber
10	Sulfur
1.44	KH_2PO_4

(pH = 7.)

Cure: 60' at 284°F

Compound 1 GEA 201

100	Natural Rubber
10	Sulfur
9	KH_2PO_4

(pH = 4,5)

Cure: 60' at 284°F

5. Assorted Special Recipes:

Compound 1 GEA 202

100	Natural Rubber
5	Zinc Oxide
3	Stearic Acid
3	Sulfur
1	M.B.T.S.
200	Carbon Black E.P.C.
50	Paraffin Base Oil

Cure: 60' at 284°F

Compound 1 GEA 203

100	Natural Rubber
5	Zinc Oxide
3	Stearic Acid
3	Sulfur
1	M.B.T.S.
200	H.A.F. Black
50	Paraffin Base Oil

Cure: 60' at 284°F

Compound 1 GEA 204

100	1 GEA 109 Master Recipe*
3	Experimental Antioxidant

Cure: 60' at 284°F

Compound 1 GEA 205

100	1 GEA 109*
3	Experimental antioxidant

Cure: 60' at 284°F

* Compound 1 GEA 109

100	Natural Rubber
5	Zinc Oxide
1	Stearic Acid
0.5	Mercapto Benzothiazole
2.5	Sulfur
3.0	Antioxidant

6. Effect of Heavy Metal Fillers:

Compound 1 GEA 206	Compound 1 GEA 213
Master Recipe - Pure Gums	Master Recipe - Black Stocks
100 Natural Rubber	100 Natural Rubber
5 Chloranil	5 Chloranil
10 Lead Dioxide	10 Lead Dioxide
	40 Carbon Black, E.P.C.

Cure all Compounds
40' at 302°F

Pure Gum Compound	P.H.R.	Pigment	Black Compound
207	307	Lead Oxide	214
208	253	Iron Metal Powder	215
209	252	Lead Sulfide Powder	216
210	366	Lead Metal Powder	217
211	621	Tungsten Metal Powder	218
212	122	Titanium Hydride Powder	219

APPENDIX II

GAMMA IRRADIATION SERVICE
BROOKHAVEN NATIONAL LABORATORY

In order to evaluate the feasibility of the investigation and to promote safety and efficiency in performing irradiations of materials by gamma rays at Brookhaven National Laboratory, certain information is required from the applicant. This can be supplied on the "Irradiation Request" form. The applicant must describe the study for which the irradiation is to be performed, state the names and the pertinent qualifications of the investigators, and describe the adequacy of his research facilities. The form also states necessary limitations of the responsibility assumed by Brookhaven National Laboratory in performing a service of this kind. The information given below should allow the applicant to state the nature and amount of material to be irradiated and the dosage in roentgens required per sample.

Brookhaven facilities are limited. Do not send samples until your authorization has been acknowledged.

Packaging of Samples

All samples must be submitted in suitable containers (leakproof in case of fluids) of such a size that they can easily be inserted into a cylindrical canister whose dimensions are 3.81 cm (1.5 in.) I.D. by 34.21 cm (13.5 in.). The volume available is 390 cc (23.85 in^3).

We also have special apparatus which can be used for irradiation of volumes in the order of 35 gallons.

Type of Radiation

a. Tantalum 182 - average gamma energy 1.15 mev.
b. Cobalt 60 - average gamma energy 1.23 mev.
Dose rates available upon request.

Temperature and Pressure of Irradiations

All irradiations will be conducted at room temperature and atmospheric pressure unless special arrangements are made with BNL.

Charges

a. Irradiation Charges - $5/hr for short-term irradiations, or $40. per day for long-term irradiations
b. Handling Charges - $25 per canister loading

c. The above charges do not include shipping charges to or from BNL. If more than simple repackaging of samples is required, it is preferred to have the samples delivered and picked up by an agent. Simple repackaging will be done at no additional expense.

For further details of irradiation procedure, address:

Brookhaven National Laboratory
Upton, New York
Attention: Bernard Manowitz (Telephone Patchogue 2600, Ext. 377)
or Otto A. Kuhl (Telephone Patchogue 2600, Ext. 2205)

APPENDIX III

A GLOSSARY OF COMPOUNDING AGENTS

Accelerator 808: A condensation product of butyraldehyde and aniline.
Akroflex C: 65% phenyl-alpha-naphthylamine and 35% N, N' - diphenyl - para - phenylenediamine.
Antioxidant 2246: 2,2'-methylene bis (4-methyl-6-tertiary-butylphenol).
Antioxidant 3112: A bis-phenol-alpha-styrene-isobutylene product.
Bakelite 3360 Resin: A phenolic-type resin.
BLE-25: A diphenylamine-acetone product.
Ca-10: A stabilizer of unrevealed composition.
Chloranil: Tetrachloroquinone.
D.O.T.G.: Di-ortho-tolylguanidine.
D.P.G.: Diphenylguanidine .
Durex Resin: A phenol-formaldehyde thermosetting resin.
G.M.F.: Para-quinonedioxime.
Ionol: 2,6-ditertiary-butyl-para-cresol.
M.B.T.S.: Mercaptobenzothiazyl disulfide.
Neozone A: Phenyl-alpha-naphthylamine.
P.B.N.A.: Phenyl-beta-naphthylamine.
Permalux: A di-ortho-tolylguanidine salt of dicatechol borate.
Prophenamine: 9,9-dimethylacridane.
Red Lead: Red lead oxide, Pb_3O_4.
Santocure: N-cyclohexyl-2-benzothiazole sulfenamide.
Silene: Hydrated, precipitated calcium silicate.
Stalite: Alkylated diphenylamine.
Staybelite Resin: Hydrogenated rosin.
T.M.T.D.: Tetramethylthiuram disulfide.
Trimene Base: Reaction product of ethyl chloride, formaldehyde, and ammonia.
V.D.H.: N,N'-diphenyl-para-phenylenediamine
Whiting: Calcium carbonate filler.

TABLE 1

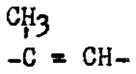
THE EFFECT OF GAMMA IRRADIATION ON PURE GUM NATURAL RUBBER

Nominal Radiation Dose (Roentgens)	Tensile Strength (psi)	Ultimate Elongation (%)	100% Modulus (psi)
0	3800	1100	88
* 0	3300	1050	88
2.2×10^5	3300	1100	91
4.4×10^5	3900	1100	90
6.5×10^5	3700	950	91
8.7×10^5	3500	1000	91
*1.0×10^6	4500	1050	98
5.0×10^6	3950	1050	93
*1.0×10^7	3500	900	100
3.7×10^7	2500	800	100
7.3×10^7	250	325	138
*1.0×10^8	100	-	-

* Data obtained in first irradiation in Co 17 source

TABLE 2

DECREASE IN UNSATURATION IN PURE GUM NATURAL RUBBER DUE TO IRRADIATION

Infrared Absorption Wave-length	Absorbing Structure
11.95	 $\overset{CH_3}{-C} = CH-$

Nominal Radiation (Roentgens)	Effect on Infrared Absorption
5×10^3	No Effect
1×10^4	" "
1×10^5	" "
1×10^6	" "
1×10^7	" "
1×10^8	Approximate 2% Decrease
1×10^9	Approximate 15% Decrease

TABLE 3

STRESS-STRAIN DATA FOR ELASTOMERIC COMPOUNDS IRRADIATED IN VACUUM

Compound	Physical Property	Nominal Gamma Radiation Dose (10^7 Roentgens)						
		0	0.01	0.1	1	3.5	5.4	7.4
1GEA2 Neoprene GN	T.S. (psi)	425	500	550	550	150	225	250
	U.E. (%)	185	230	290	280	170	110	130
	Mod (kg/cm^2)	15.3	16.9	14.9	14.8	15.2	16.3	Broke
1GEA3 Neoprene W	T.S. (psi)	765	700	465	235	150	200	Broke
	U.E. (%)	360	340	315	375	200	90	Broke
	Mod (kg/cm^2)	10.8	11.4	11.2	10.1	13.0	Broke	Broke
1GEA5 Hycar OR-15	T.S. (psi)	520	120	525	400	250	365	250
	U.E. (%)	345	325	245	295	215	190	225
	Mod (kg/cm^2)	10.8	11.0	11.3	13.9	18.9	23.1	28.8
1GEA10 Smoked Sheet	T.S. (psi)	3365	3600	3395	3650	2700	2200	1800
	U.E. (%)	930	795	765	700	595	520	450
	Mod (kg/cm^2)	6.4	6.3	6.6	7.4	8.8	9.8	10.1
1GEA12 GR-S	T.S. (psi)	600	150	535	150	150	100	200
	U.E. (%)	940	810	855	640	440	360	370
	Mod (kg/cm^2)	4.4	4.3	4.2	5.9	8.9	10.4	12.0
1GEA19 GR-S + Hycar H-H	T.S. (psi)	1000	600	365	225	235	315	235
	U.E. (%)	890	820	670	630	560	440	395
	Mod (kg/cm^2)	4.1	4.0	5.4	3.9	4.6	5.5	6.3
1GEA23 GR-S + Goodrite Resin 50	T.S. (psi)	125	100	400	150	250	200	150
	U.E. (%)	20	90	100	30	50	70	20
	Mod (kg/cm^2)	Broke	8.4	Broke	Broke	Broke	Broke	Broke
1GEA37 Smoked Sheet + Hycar HH	T.S. (psi)	700	800	800	915	475	100	225
	U.E. (%)	715	700	725	700	565	440	515
	Mod (kg/cm^2)	3.8	4.3	4.1	3.7	3.9	4.3	4.6
1GEA38 Smoked Sheet + Hycar HH + Black	T.S. (psi)	1975	2075	1400	1585	585	315	335
	U.E. (%)	540	555	40	505	410	325	320
	Mod (kg/cm^2)	8.4	8.4	8.5	8.4	8.4	9.4	9.7
1GEA39 GR-S + Black + Hycar HH	T.S. (psi)	1400	1600	1700	900	150	250	225
	U.E. (%)	890	750	640	700	440	345	260
	Mod (kg/cm^2)	5.8	5.8	5.9	5.9	7.0	7.3	8.5
1GEA53 Smoked Sheet + Dicumyl Peroxide	T.S. (psi)	2000	1400	2000	1300	350	Broke	Broke
	U.E. (%)	650	770	965	830	575	Broke	Broke
	Mod (kg/cm^2)	4.5	4.5	5.1	4.5	3.1	3.1	4.4

TABLE 4

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA1	T.S. (psi)	275	100	0	125	0	600	0	700
	U.E. (%)	415	530	0	365	0	245	0	180
	Mod.($\frac{kg}{cm^2}$)	8.37	7.3	8.1	8.6	10.5	11.0	12.6	12.8
1GEA2	T.S. (psi)	1325	1450	300	450	100	300	250	150
	U.E. (%)	625	570	300	400	180	230	240	110
	Mod.($\frac{kg}{cm^2}$)	15.3	10.6	13.2	12.1	15.2	13.8	16.8	-
1GEA3	T.S. (psi)	765	850	230	400	100	200	100	-
	U.E. (%)	360	440	440	360	170	100	90	-
	Mod.($\frac{kg}{cm^2}$)	10.8	18.4	11.1	12.9	14.8	12.1	-	-
1GEA4	T.S. (psi)	200	150	100	0	0	0	0	0
	U.E. (%)	840	400	700	0	0	0	0	0
	Mod.($\frac{kg}{cm^2}$)	2.87	3.7	2.8	4.2	2.7	4.26	-	-
1GEA5	T.S. (psi)	520	1850	600	500	600	1060	800	1080
	U.E. (%)	345	390	430	260	240	235	190	120
	Mod.($\frac{kg}{cm^2}$)	10.8	13.1	13.5	21.2	17.1	23.5	26.8	17.7
1GEA6	T.S. (psi)	2800	2150	1000	1750	1230	1570	520	625
	U.E. (%)	500	420	310	320	195	160	95	105
	Mod.($\frac{kg}{cm^2}$)	20.25	18.4	21.6	20.4	25.6	27.5	44.2	Broke
1GEA10	T.S. (psi)	3365	1000	>1000	800	3200	1500	1100	350
	U.E. (%)	930	590	>1220	580	700	710	535	310
	Mod.($\frac{kg}{cm^2}$)	6.4	6.7	6.9	7.0	8.6	8.7	8.0	9.0

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA12	T.S. (psi)	600	200	250	230	150	100	0	100
	U.E. (%)	940	840	750	440	500	400	0	380
	Mod. ($\frac{kg}{cm^2}$)	4.4	4.7	5.5	6.0	7.6	8.8	10.3	10.4
1GEA13	T.S. (psi)	1050	1000	450	0	0	0	0	0
	U.E. (%)	840	720	690	0	0	0	0	0
	Mod. ($\frac{kg}{cm^2}$)	4.83	4.43	3.6	2.6	Broke	Broke	Broke	Broke
1GEA14	T.S. (psi)	8075	6750	-	0	525	>580	0	0
	U.E. (%)	615	300	-	0	1020	>1200	0	0
	Mod. ($\frac{kg}{cm^2}$)	25.7	23.3	-	20.4	21.3	-	-	-
1GEA15	T.S. (psi)	1750	2850	-	500	0	0	0	0
	U.E. (%)	1150	710	-	960	0	0	0	0
	Mod. ($\frac{kg}{cm^2}$)	10.2	10.4	-	7.8	5.0	-	-	-
1GEA16	T.S. (psi)	160	400	-	500	400	510	890	480
	U.E. (%)	900	810	-	950	950	1055	875	870
	Mod. ($\frac{kg}{cm^2}$)	4.94	5.4	-	5.0	4.8	-	-	-
1GEA17	T.S. (psi)	2.80	ca.50	-	0	0	200	360	250
	U.E. (%)	1130	760	-	0	0	1055	1030	1015
	Mod. ($\frac{kg}{cm^2}$)	7.23	8.6	-	8.4	6.3	-	-	-
1GEA19	T.S. (psi)	1000	450	650	300	200	560	450	-
	U.E. (%)	890	690	740	900	620	760	650	-
	Mod. ($\frac{kg}{cm^2}$)	4.1	4.1	4.0	3.9	4.1	4.0	3.4	-

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA21	T.S. (psi)	3160	3750	3400	3100	3800	2650	3550	3110
	U.E. (%)	570	470	510	580	470	400	365	330
	Mod.($\frac{kg}{cm^2}$)	18.97	17.4	18.7	21.8	23.7	23.1	27.3	29.7
1GEA22	T.S. (psi)	140	400	130	500	860	200	900	350
	U.E. (%)	140	610	520	570	465	330	30	340
	Mod.($\frac{kg}{cm^2}$)	4.62	4.9	5.2	6.2	7.5	7.68	10.2	10.2
1GEA23	T.S. (psi)	125	250	100	250	550	300	150	100
	U.E. (%)	20	120	20	70	70	30	40	40
	Mod.($\frac{kg}{cm^2}$)	32.9	31.4	9.8	Broke	Broke	Broke	Broke	Broke
1GEA25	T.S. (psi)	450	750	350	650	400	330	1050	550
	U.E. (%)	460	480	350	490	280	255	190	170
	Mod.($\frac{kg}{cm^2}$)	9.7	10.1	10.8	13.2	15.7	15.2	19.0	20.7
1GEA26	T.S. (psi)	1500	2250	1900	1550	900	850	1060	600
	U.E. (%)	225	400	400	430	230	190	110	130
	Mod.($\frac{kg}{cm^2}$)	27.5	18.0	19.4	20.7	24.4	26.0	28.0	20.2
1GEA27	T.S. (psi)	1425	2600	1500	1200	1000	700	610	600
	U.E. (%)	240	400	290	300	185	160	100	75
	Mod.($\frac{kg}{cm^2}$)	18.7	15.4	16.5	15.9	20.8	25.4	Broke	Broke
1GEA28	T.S. (psi)	850	480	850	350	350	275	800	290
	U.E. (%)	570	280	500	300	240	220	140	170
	Mod.($\frac{kg}{cm^2}$)	6.01	7.1	5.5	8.6	8.6	9.7	9.62	11.8

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA29	T.S. (psi)	3150	1950	2100	1200	1400	930	1200	950
	U.E. (%)	620	360	450	240	205	215	150	110
	Mod.($\frac{kg}{cm^2}$)	14.7	15.0	17.6	19.6	26.0	29.4	47.3	37.4
1GEA31	T.S. (psi)	280	0	150	100	0	0	0	300
	U.E. (%)	270	0	200	100	0	0	0	140
	Mod.($\frac{kg}{cm^2}$)	9.96	10.9	11.7	12.9	13.3	-	-	13.1
1GEA32	T.S. (psi)	3025	2750	1700	2400	2975	2000	1560	1675
	U.E. (%)	800	1040	530	740	600	540	460	370
	Mod.($\frac{kg}{cm^2}$)	9.03	8.8	9.6	10.2	12.5	12.3	13.4	12.4
1GEA33	T.S. (psi)	2300	1300	-	2800	3000	3950	3220	3525
	U.E. (%)	230	280	-	260	210	190	160	140
	Mod.($\frac{kg}{cm^2}$)	73.3	68.8	-	80.0	98.4	109.7	> 93	-
1GEA34	T.S. (psi)	1400	2350	-	1550	1610	1350	1250	950
	U.E. (%)	880	1220	-	800	595	610	460	350
	Mod.($\frac{kg}{cm^2}$)	8.3	6.7	-	8.6	-	11.7	14.3	15.6
1GEA35	T.S. (psi)	1640	1200	500	0	0	0	0	0
	U.E. (%)	>1200	1140	1060	0	0	0	0	0
	Mod.($\frac{kg}{cm^2}$)	3.92	3.55	1.8	8.3	11.0	Broke	Broke	Broke
1GEA36	T.S. (psi)	3500	2250	2400	2600	1950	1775	2300	2350
	U.E. (%)	595	520	400	450	315	270	235	210
	Mod.($\frac{kg}{cm^2}$)	39.3	39.8	51.6	55.6	63.1	68.0	76.5	73.1

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA37	T.S. (psi)	1525	1375	1350	1200	250	400	600	500
	U.E. (%)	970	865	1060	880	940	810	800	920
	Mod. ($\frac{kg}{cm^2}$)	3.72	3.5	2.8	2.6	2.8	3.4	3.5	3.7
1GEA38	T.S. (psi)	2200	2200	1500	1500	400	600	350	300
	U.E. (%)	740	650	820	660	500	470	420	300
	Mod. ($\frac{kg}{cm^2}$)	8.59	7.6	7.7	7.4	7.0	9.2	9.5	8.0
1GEA39	T.S. (psi)	1400	1100	650	550	-	250	500	-
	U.E. (%)	890	635	430	620	-	420	440	-
	Mod. ($\frac{kg}{cm^2}$)	9.2	8.6	7.7	7.4	-	7.2	7.8	-
1GEA40	T.S. (psi)	1000	-	1800	2725	2800	1900	2225	1440
	U.E. (%)	185	-	1050	235	310	210	285	205
	Mod. ($\frac{kg}{cm^2}$)	-	-	7.7	*16.7	*25.1	-	*15.0	*35.8
1GEA41	T.S. (psi)	3700	-	3075	4150	3200	-	3600	-
	U.E. (%)	140	-	150	160	105	-	90	-
	Mod. ($\frac{kg}{cm^2}$)	-	-	60.3	8.21	*14.3	*16.6	*16.2	Broke
1GEA42	T.S. (psi)	1000	-	550	1000	850	725	800	540
	U.E. (%)	645	-	580	390	550	270	385	240
	Mod. ($\frac{kg}{cm^2}$)	-	-	5.5	4.58	*3.37	*3.57	*1.81	*9.70
1GEA43	T.S. (psi)	3410	-	2050	2725	2375	1875	-	-
	U.E. (%)	160	-	245	130	60	40	-	-
	Mod. ($\frac{kg}{cm^2}$)	-	-	5.64	7.38	Broke	Broke	Broke	Broke

* = Modulus from stress strain curve

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA45	T.S. (psi)	5150	-	875	1750	1800	1450	1720	1325
	U.E. (%)	360	-	375	350	325	205	205	175
	Mod. ($\frac{kg}{cm^2}$)	-	-	9.6	6.77	*42.2	*38.7	*69.2	*51.1
1GEA46	T.S. (psi)	1950	-	2060	2600	2600	2250	2340	-
	U.E. (%)	110	-	110	145	125	60	40	-
	Mod. ($\frac{kg}{cm^2}$)	-	-	39.3	23.8	*174.5	Broke	Broke	Broke
1GEA47	T.S. (psi)	24,550	-	35,450	5500	-	-	-	-
	U.E. (%)	365	-	320	140	-	-	-	-
	Mod. ($\frac{kg}{cm^2}$)	-	-	74.9	25.4	Broke	Broke	Broke	Broke
1GEA48	T.S. (psi)	3500	-	-	3950	4450	3300	3425	-
	U.E. (%)	410	-	-	240	220	115	125	-
	Mod. ($\frac{kg}{cm^2}$)	-	-	27.2	21.2	*116.2	*173	*170	Broke
1GEA49	T.S. (psi)	600	-	590	550	660	800	1500	600
	U.E. (%)	890	-	730	545	400	215	120	100
	Mod. ($\frac{kg}{cm^2}$)		-	6.18	*1.21	*5.75	*9.36	*75.5	*35.7
1GEA50	T.S. (psi)	9300	-	-	4650	3600	-	-	-
	U.E. (%)	140	-	-	135	80	-	-	-
	Mod. ($\frac{kg}{cm^2}$)		-	> 80	17.3	Broke	Broke	Broke	Broke
1GEA51	T.S. (psi)	3150	2700	3200	3025	[illegible]	2850	2700	2350
	U.E. (%)	320	180	330	195	215	250	240	145
	Mod. ($\frac{kg}{cm^2}$)	23.4	24.8	22.4	25.9	27.8	27.2	26.1	38.5

* = Modulus from stress strain curve

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA52	T.S. (psi)	0	0	0	0	0	0	0	0
	U.E. (%)	0	0	0	0	0	0	0	0
	Mod.($\frac{kg}{cm^2}$)	8.85	7.8	9.22	8.21	8.05	8.0	8.6	8.76
1GEA53	T.S. (psi)	2000	1000	1600	1050	0	0	150	0
	U.E. (%)	650	410	820	660	0	0	220	0
	Mod.($\frac{kg}{cm^2}$)	5.8	6.3	5.4	4.6	2.5	6.1	7.5	-
1GEA56	T.S. (psi)	2860	3660	3800	3150	2600	2550	4050	2000
	U.E. (%)	800	830	820	750	595	710	700	565
	Mod.($\frac{kg}{cm^2}$)	6.55	6.6	7.0	7.38	7.78	8.4	8.3	9.7
1GEA57	T.S. (psi)	2675	2800	2625	2800	2960	2825	3550	2525
	U.E. (%)	875	710	790	835	760	770	625	740
	Mod.($\frac{kg}{cm^2}$)	6.50	6.6	6.4	6.87	7.4	8.3	8.2	8.4
1GEA58	T.S. (psi)	780	2200	2250	2610	2780	2225	2850	2325
	U.E. (%)	660	695	690	775	685	700	660	620
	Mod.($\frac{kg}{cm^2}$)	6.59	6.3	6.4	6.77	7.17	7.8	8.3	8.3
1GEA59	T.S. (psi)	4610	3920	4100	3875	3720	3275	3450	3000
	U.E. (%)	550	530	545	490	440	435	360	320
	Mod.($\frac{kg}{cm^2}$)	23.6	24.4	25.8	23.8	28.1	34.3	36.8	41.3
1GEA60	T.S. (psi)	3250	3920	4300	3900	4400	3550	3700	3450
	U.E. (%)	635	580	580	530	550	520	435	360
	Mod.($\frac{kg}{cm^2}$)	-	21.8	22.0	25.4	27.0	28.1	33.1	33.4

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA61	T.S. (psi)	1200	3410	3725	3475	3400	3200	3325	3025
	U.E. (%)	425	565	640	565	520	520	465	440
	Mod.($\frac{kg}{cm^2}$)	18.2	19.4	20.0	21.2	22.0	24.0	25.9	27.4
1GEA62	T.S. (psi)	1500	1100	410	550	525	750	275	390
	U.E. (%)	840	860	845	845	660	765	460	490
	Mod.($\frac{kg}{cm^2}$)	5.08	5.0	5.5	6.08	7.28	8.0	8.8	10.1
1GEA63	T.S. (psi)	-	560	500	300	400	690	230	800
	U.E. (%)	-	770	1020	785	635	625	500	635
	Mod.($\frac{kg}{cm^2}$)	-	5.5	5.3	6.05	7.18	7.4	8.4	9.4
1GEA64	T.S. (psi)	-	450	450	0	300	225	600	200
	U.E. (%)	-	805	780	0	650	520	540	385
	Mod.($\frac{kg}{cm^2}$)	-	5.1	5.3	5.64	6.86	7.6	7.2	9.4
1GEA65	T.S. (psi)	-	3900	3650	3680	4125	3375	3360	3450
	U.E. (%)	-	640	555	585	550	400	435	315
	Mod.($\frac{kg}{cm^2}$)	-	17.2	17.8	20.4	26.1	28.7	30.1	37.7
1GEA66	T.S. (psi)	1200	3330	3200	3250	3360	3500	2960	2850
	U.E. (%)	450	605	585	525	450	360	435	280
	Mod.($\frac{kg}{cm^2}$)	8.16	17.6	18.5	20.6	25.1	26.8	27.9	34.3
1GEA67	T.S. (psi)	2950	1600	3130	2570	2850	3050	3000	2960
	U.E. (%)	700	570	690	625	480	500	420	380
	Mod.($\frac{kg}{cm^2}$)	14.9	13.3	15.2	17.3	19.5	20.8	24.0	20.3

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA68	T.S. (psi)	3025	3100	3600	3525	3110	2925	1320	175
	U.E. (%)	940	780	750	735	705	630	515	200
	Mod. $(\frac{kg}{cm^2})$	7.55	6.5	6.9	7.43	8.16	8.72	8.30	9.57
1GEA69	T.S. (psi)	2420	3500	2700	3370	3750	200	3425	2530
	U.E. (%)	300	725	690	720	705	240	590	500
	Mod. $(\frac{kg}{cm^2})$	24.3	7.2	7.53	7.84	8.17	6.54	8.77	9.77
1GEA71	T.S. (psi)	2050	3950	3790	4100	3975	5050	3675	3390
	U.E. (%)	420	560	535	560	520	440	400	290
	Mod. $(\frac{kg}{cm^2})$	20.7	27.2	24.6	28.2	29.6	32.9	38.0	40.0
1GEA72	T.S. (psi)	4100	4120	3900	3850	3950	3700	3900	3400
	U.E. (%)	505	600	525	585	570	645	405	370
	Mod. $(\frac{kg}{cm^2})$	27.2	26.3	24.0	26.4	27.2	33.5	35.4	38.3
1GEA73	T.S. (psi)	3550	4180	4900	3650	3750	4350	3800	3150
	U.E. (%)	600	350	515	555	550	500	420	390
	Mod. $(\frac{kg}{cm^2})$	26.0	26.8	25.8	26.1	27.2	34.1	32.0	33.7
1GEA74	T.S. (psi)	390	350	280	480	240	475	900	325
	U.E. (%)	755	845	695	770	600	485	545	340
	Mod. $(\frac{kg}{cm^2})$	5.90	5.78	6.0	6.43	7.4	8.29	8.93	9.50
1GEA75	T.S. (psi)	650	500	650	300	200	475	350	210
	U.E. (%)	780	730	740	710	610	490	440	355
	Mod. $(\frac{kg}{cm^2})$	5.82	5.55	5.9	6.4	8.0	8.46	8.70	10.22

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA76	T.S. (psi)	2365	0	500	275	0	260	275	320
	U.E. (%)	370	0	670	700	0	455	350	375
	Mod.($\frac{kg}{cm^2}$)	11.39	5.46	5.9	6.6	7.5	8.53	9.08	9.76
1GEA77	T.S. (psi)	3425	3350	3730	3800	2775	2600	2620	2775
	U.E. (%)	650	745	610	545	420	380	310	245
	Mod.($\frac{kg}{cm^2}$)	17.03	16.3	15.4	21.0	24.0	27.8	34.6	38.7
1GEA78	T.S. (psi)	3700	2675	3125	3010	3150	2980	2760	2475
	U.E. (%)	845	790	700	600	490	430	400	295
	Mod.($\frac{kg}{cm^2}$)	13.57	12.5	14.1	16.4	20.0	23.1	29.7	33.6
1GEA79	T.S. (psi)	2600	2925	3620	2930	3125	2675	2800	2375
	U.E. (%)	940	830	860	760	640	525	505	410
	Mod.($\frac{kg}{cm^2}$)	9.94	10.21	11.1	13.3	15.0	17.9	20.1	22.6
1GEA80	T.S. (psi)	3840	3500	3700	2600	2920	2850	2800	2675
	U.E. (%)	625	555	600	560	575	630	585	545
	Mod.($\frac{kg}{cm^2}$)	19.6	18.5	19.1	18.4	14.8	16.6	14.4	16.3
1GEA81	T.S. (psi)	2300	2300	2500	2475	2875	2580	2430	2825
	U.E. (%)	825	790	700	720	700	720	685	715
	Mod.($\frac{kg}{cm^2}$)	11.70	10.9	11.3	11.5	10.9	12.6	13.49	14.3
1GEA84	T.S. (psi)	-	1000	410	0	0	0	0	0
	U.E. (%)	-	545	890	330	0	255	110	0
	Mod.($\frac{kg}{cm^2}$)	-	8.22	4.17	2.16	-	-	Broke	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA85	T.S. (psi)	1550	1050	640	210	350	175	490	Broke
	U.E. (%)	595	600	465	205	80	55	35	Broke
	Mod.($\frac{kg}{cm^2}$)	33.5	34.2	31.6	26.8	Broke	Broke	Broke	Broke
1GEA88	T.S. (psi)	450	890	140	340	60	230	420	175
	U.E. (%)	710	645	365	660	635	495	140	405
	Mod.($\frac{kg}{cm^2}$)	6.95	7.26	6.67	5.15	5.33	3.3	3.2	4.9
1GEA89	T.S. (psi)	660	1000	1275	875	460	410	375	175
	U.E. (%)	425	510	530	460	420	340	225	300
	Mod.($\frac{kg}{cm^2}$)	13.1	12.52	14.2	9.80	8.24	8.7	10.5	9.6
1GEA92	T.S. (psi)	1200	1300	1225	800	725	930	925	410
	U.E. (%)	585	550	725	525	600	500	455	215
	Mod.($\frac{kg}{cm^2}$)	14.04	9.48	12.90	13.27	10.43	16.5	15.0	12.0
1GEA93	T.S. (psi)	675	675	640	410	110	90	0	0
	U.E. (%)	715	650	745	800	710	660	0	0
	Mod.($\frac{kg}{cm^2}$)	5.01	6.70	4.87	4.93	3.45	3.1	0	0
1GEA94	T.S. (psi)	950	400	760	750	350	250	325	130
	U.E. (%)	490	485	530	440	345	320	285	220
	Mod.($\frac{kg}{cm^2}$)	7.99	7.75	7.19	8.99	8.32	8.5	8.1	10.3
1GEA95	T.S. (psi)	1225	1475	975	730	620	775	575	300
	U.E. (%)	525	600	520	430	510	460	380	395
	Mod.($\frac{kg}{cm^2}$)	8.28	8.77	7.85	8.70	7.99	9.15	8.8	9.0

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA96	T.S. (psi)	200	0	300	300	0	140	175	90
	U.E. (%)	320	0	290	110	0	110	120	100
	Mod. ($\frac{kg}{cm^2}$)	9.17	8.05	7.98	9.88	11.46	Broke	17.3	Broke
1GEA97	T.S. (psi)	1900	1425	1700	1250	500	1150	1350	690
	U.E. (%)	210	200	220	170	145	100	85	50
	Mod. ($\frac{kg}{cm^2}$)	25.1	28.6	26.5	30.8	34.8	Broke	Broke	Broke
1GEA98	T.S. (psi)	225	1075	850	625	550	630	140	420
	U.E. (%)	755	735	695	660	670	470	335	430
	Mod. ($\frac{kg}{cm^2}$)	3.53	8.78	3.70	3.34	3.16	4.23	5.4	3.75
1GEA99	T.S. (psi)	-	1140	850	1300	1300	850	1650	1490
	U.E. (%)	-	370	340	305	310	265	270	220
	Mod. ($\frac{kg}{cm^2}$)	-	34.3	9.35	12.36	14.05	14.0	16.1	18.1
1GEA100	T.S. (psi)	1250	1150	1325	1310	880	1100	1220	1110
	U.E. (%)	240	175	170	190	130	120	90	115
	Mod. ($\frac{kg}{cm^2}$)	21.5	24.7	21.9	26.3	29.65	35.5	45.0	42.4
1GEA101	T.S. (psi)	1600	1575	1230	1075	1300	1090	1225	725
	U.E. (%)	160	150	155	105	150	80	100	65
	Mod. ($\frac{kg}{cm^2}$)	51.1	50.5	50.3	66.2	-	Broke	Broke	Broke
1GEA102	T.S. (psi)	1980	1300	1100	275	0	0	0	0
	U.E. (%)	390	380	430	400	0	0	0	0
	Mod. ($\frac{kg}{cm^2}$)	15.00	12.69	9.34	5.42	3.87	0	0	0

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA103	T.S. (psi)	600	1000	1050	525	590	1210	725	825
	U.E. (%)	600	610	630	530	465	470	350	305
	Mod. ($\frac{kg}{cm^2}$)	9.30	8.09	7.59	9.11	10.2	9.2	12.4	11.4
1GEA104	T.S. (psi)	2220	2030	1625	1200	1225	1500	1290	1510
	U.E. (%)	255	230	200	150	165	130	110	125
	Mod. ($\frac{kg}{cm^2}$)	32.8	27.6	32.6	31.6	36.0	42.5	30.6	53.1
1GEA105	T.S. (psi)	2100	2125	2100	2330	2600	2830	2670	2440
	U.E. (%)	790	860	850	685	645	585	540	420
	Mod. ($\frac{kg}{cm^2}$)	9.64	9.53	9.58	11.26	12.45	14.1	15.3	16.7
1GEA106	T.S. (psi)	580	550	400	125	330	1075	590	400
	U.E. (%)	960	795	970	650	940	890	860	875
	Mod. ($\frac{kg}{cm^2}$)	2.82	2.12	2.65	2.33	2.11	2.65	3.0	2.88
1GEA107	T.S. (psi)	550	375	675	800	700	580	830	200
	U.E. (%)	885	635	780	660	685	800	635	310
	Mod. ($\frac{kg}{cm^2}$)	3.37	3.65	3.69	3.24	2.60	3.7	4.3	5.4
1GEA108	T.S. (psi)	2800	2425	2300	2225	2380	3140	2230	2075
	U.E. (%)	680	570	600	500	400	280	285	205
	Mod. ($\frac{kg}{cm^2}$)	12.78	13.30	12.82	16.96	17.7	26.7	31.0	31.5
1GEA109	T.S. (psi)	3550	2210	2080	1260	75	225	0	75
	U.E. (%)	1025	1170	970	715	200	255	145	80
	Mod. ($\frac{kg}{cm^2}$)	4.95	5.52	5.74	5.71	5.94	8.7	9.0	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA110	T.S. (psi)	>1900	2950	2450	3050	2200	2950	2625	2310
	U.E. (%)	880	965	885	825	695	580	630	535
	Mod. ($\frac{kg}{cm^2}$)	5.47	5.4	5.9	6.2	7.4	8.31	8.56	10.1
1GEA111	T.S. (psi)	2500	2625	2980	1500	400	600	380	140
	U.E. (%)	1065	955	1200	830	515	370	290	135
	Mod. ($\frac{kg}{cm^2}$)	4.85	4.8	5.2	5.0	5.2	7.5	8.1	9.2
1GEA112	T.S. (psi)	2400	2550	3130	3275	3150	3100	2950	2050
	U.E. (%)	985	1010	920	855	695	645	640	500
	Mod. ($\frac{kg}{cm^2}$)	4.58	4.49	4.8	5.4	6.0	7.35	7.0	7.3
1GEA113	T.S. (psi)	1600	1575	1825	1775	1700	1975	1730	1260
	U.E. (%)	1020	890	850	770	710	650	625	555
	Mod. ($\frac{kg}{cm^2}$)	5.42	5.4	6.0	6.8	8.6	8.92	10.1	10.7
1GEA115	T.S. (psi)	1475	1525	2010	2525	2450	2075	1700	1625
	U.E. (%)	1170	915	805	800	760	770	550	560
	Mod. ($\frac{kg}{cm^2}$)	4.40	4.35	4.7	5.0	4.9	7.14	7.84	8.25
1GEA116	T.S. (psi)	2175	2425	2925	2510	2120	1900	1530	1160
	U.E. (%)	1030	935	815	920	800	680	530	485
	Mod. ($\frac{kg}{cm^2}$)	4.94	5.42	5.7	5.5	6.4	8.26	7.90	9.25
1GEA117	T.S. (psi)	2700	2275	2300	2100	1730	3050	2200	2475
	U.E. (%)	1105	1150	890	900	745	775	640	570
	Mod. ($\frac{kg}{cm^2}$)	4.19	4.5	5.0	5.0	4.4	8.12	7.55	10.23

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA118	T.S. (psi)	2575	1940	2110	2600	2500	2675	3225	2550
	U.E. (%)	1070	905	705	925	780	700	655	615
	Mod. ($\frac{kg}{cm^2}$)	4.78	4.78	5.0	5.6	6.1	7.33	9.38	9.75
1GEA119	T.S. (psi)	2580	2190	3050	2675	2250	1930	1925	1640
	U.E. (%)	930	960	780	685	630	540	380	475
	Mod. ($\frac{kg}{cm^2}$)	4.92	4.77	5.4	6.1	6.7	8.52	9.87	11.78
1GEA120	T.S. (psi)	2975	2875	2390	2550	2850	2310	2475	1550
	U.E. (%)	1120	1085	940	965	790	740	720	575
	Mod. ($\frac{kg}{cm^2}$)	4.95	4.8	5.1	5.3	5.7	6.58	7.35	8.28
1GEA121	T.S. (psi)	3150	>2600	2300	> 3100	2800	3275	2875	2160
	U.E. (%)	1045	>1200	920	870	850	700	710	490
	Mod. ($\frac{kg}{cm^2}$)	4.68	5.0	5.4	5.8	6.5	7.89	9.15	9.77
1GEA122	T.S. (psi)	2850	2700	2930	1775	2360	2575	1900	2290
	U.E. (%)	1070	1105	1080	810	590	790	645	600
	Mod. ($\frac{kg}{cm^2}$)	5.32	5.0	5.1	5.9	6.8	6.09	7.64	9.79
1GEA123	T.S. (psi)	2450	>1350	3200	1850	1500	2700	1700	1075
	U.E. (%)	1145	>1200	980	1000	765	755	685	470
	Mod. ($\frac{kg}{cm^2}$)	4.62	4.8	5.0	5.0	5.5	7.32	7.35	7.37
1GEA124	T.S. (psi)	2440	2090	2500	2425	2090	2200	390	250
	U.E. (%)	880	975	710	865	790	780	390	285
	Mod. ($\frac{kg}{cm^2}$)	5.52	5.48	5.7	6.0	7.2	7.37	8.64	9.33

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA126	T.S. (psi)	2680	>3150	2650	2900	1425	1750	2530	850
	U.E. (%)	1140	1100	920	885	755	610	600	460
	Mod.($\frac{kg}{cm^2}$)	5.11	4.76	5.2	5.5	5.8	8.7	6.1	6.7
1GEA127	T.S. (psi)	2525	2240	1425	2950	2620	1780	1425	1380
	U.E. (%)	1105	1080	820	870	845	675	605	500
	Mod.($\frac{kg}{cm^2}$)	4.65	4.62	4.77	5.3	6.1	4.3	4.9	5.1
1GEA128	T.S. (psi)	2500	2725	2650	2425	2375	3630	2450	2900
	U.E. (%)	1100	1090	815	925	855	680	665	605
	Mod.($\frac{kg}{cm^2}$)	4.85	4.66	4.83	5.6	5.9	7.1	7.2	8.8
1GEA129	T.S. (psi)	3750	3325	3000	2500	1350	1200	1125	1300
	U.E. (%)	480	540	410	300	210	125	140	115
	Mod.($\frac{kg}{cm^2}$)	24.8	26.9	29.7	34.5	37.3	41.9	46.9	57.5
1GEA130	T.S. (psi)	3380	3730	3775	3540	3300	2840	2670	2290
	U.E. (%)	480	530	540	445	365	260	265	180
	Mod.($\frac{kg}{cm^2}$)	27.5	28.6	28.1	33.4	41.2	42.4	47.6	51.2
1GEA131	T.S. (psi)	3050	3475	1430	3040	2750	2000	1875	1875
	U.E. (%)	480	485	280	430	320	180	185	140
	Mod.($\frac{kg^2}{cm}$)	19.5	27.85	29.9	34.1	40.0	43.9	47.8	47.8
1GEA133	T.S. (psi)	3630	3730	3475	3480	3475	2840	2790	2750
	U.E. (%)	535	530	500	480	430	280	280	240
	Mod.($\frac{kg^2}{cm}$)	23.7	29.7	35.1	36.6	41.7	44.1	45.4	54.1

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA135	T.S. (psi)	3650	3650	3890	4100	3400	2500	2350	1960
	U.E. (%)	520	540	550	470	425	245	255	200
	Mod.($\frac{kg}{cm^2}$)	24.1	21.0	23.8	24.6	29.5	34.1	42.3	41.1
1GEA136	T.S. (psi)	3650	3780	3500	3560	3300	2975	2575	2275
	U.E. (%)	510	490	470	485	410	275	200	230
	Mod.($\frac{kg}{cm^2}$)	23.5	25.4	27.5	31.35	33.5	43.5	38.0	42.6
1GEA137	T.S. (psi)	4150	4280	4950	4150	3040	4350	2840	2160
	U.E. (%)	505	595	520	500	360	400	300	220
	Mod.($\frac{kg}{cm^2}$)	24.5	21.3	23.6	26.3	31.7	38.0	38.2	43.5
1GEA138	T.S. (psi)	3525	3830	3900	3775	3300	3260	2400	3060
	U.E. (%)	500	540	525	555	425	355	275	260
	Mod.($\frac{kg}{cm^2}$)	26.5	24.9	23.9	27.0	33.6	35.7	33.2	42.6
1GEA139	T.S. (psi)	3280	3370	3400	3120	2830	2770	2290	1870
	U.E. (%)	460	520	440	430	335	260	210	155
	Mod.($\frac{kg}{cm^2}$)	26.9	26.8	28.7	32.1	38.7	39.6	47.1	40.3
1GEA140	T.S. (psi)	3800	3550	3440	3330	3600	3290	3000	2740
	U.E. (%)	500	515	485	535	455	340	295	240
	Mod.($\frac{kg}{cm^2}$)	24.7	23.4	24.2	27.5	30.8	32.6	37.4	41.4
1GEA141	T.S. (psi)	3900	3725	3775	3670	3900	3800	3325	2850
	U.E. (%)	580	550	560	510	520	380	355	275
	Mod.($\frac{kg}{cm^2}$)	23.3	23.1	24.9	27.9	33.2	34.7	40.2	44.6

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA142	T.S. (psi)	3850	3940	3860	3690	3690	3250	2710	3090
	U.E. (%)	640	540	630	530	395	335	260	270
	Mod.($\frac{kg}{cm^2}$)	23.5	24.2	27.0	30.1	32.9	35.1	39.2	44.3
1GEA143	T.S. (psi)	3825	3550	3510	4100	3475	3340	2440	2470
	U.E. (%)	605	460	520	550	370	355	225	240
	Mod.($\frac{kg}{cm^2}$)	24.6	24.2	24.7	26.95	34.1	33.2	45.1	40.0
1GEA144	T.S. (psi)	3350	3425	3425	3600	3240	3100	2900	2140
	U.E. (%)	560	475	460	470	435	360	310	220
	Mod.($\frac{kg}{cm^2}$)	27.7	27.7	25.6	29.8	34.2	31.4	35.7	45.1
1GEA146	T.S. (psi)	3510	3780	3930	3200	3400	3600	2300	1450
	U.E. (%)	525	510	520	525	385	345	255	150
	Mod.($\frac{kg}{cm^2}$)	23.4	21.0	26.1	25.9	34.2	35.4	34.0	40.2
1GEA147	T.S. (psi)	3975	4350	3850	3760	3450	3410	2800	2410
	U.E. (%)	625	565	530	585	465	425	320	260
	Mod.($\frac{kg}{cm^2}$)	22.9	23.8	23.6	24.7	29.9	35.2	38.2	35.5
1GEA148	T.S. (psi)	3730	4025	4600	3550	2970	3600	2375	2650
	U.E. (%)	605	580	590	470	465	405	270	325
	Mod.($\frac{kg}{cm^2}$)	25.6	24.0	25.9	26.1	34.0	35.3	40.3	35.6
1GEA149	T.S. (psi)	3350	2800	2110	110	0	110	40	75
	U.E. (%)	860	920	720	330	155	210	110	80
	Mod.($\frac{kg}{cm^2}$)	6.58	-	-	-	-	11.1	13.5	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA150	T.S. (psi)	2300	2450	1900	1030	330	550	280	0
	U.E. (%)	865	820	705	605	390	230	185	120
	Mod.($\frac{kg}{cm^2}$)	6.22	6.5	7.0	8.2	8.9	12.6	15.0	17.9
1GEA151	T.S. (psi)	1800	1975	2130	880	0	0	100	150
	U.E. (%)	925	865	810	695	0	0	165	130
	Mod.($\frac{kg}{cm^2}$)	6.13	5.8	6.2	6.2	9.3	10.9	11.2	15.6
1GEA152	T.S. (psi)	1900	1960	2075	1490	380	290	175	90
	U.E. (%)	710	720	635	550	360	155	165	120
	Mod.($\frac{kg}{cm^2}$)	10.60	11.0	12.4	13.8	17.9	21.3	23.0	27.2
1GEA153	T.S. (psi)	1350	1800	2300	1290	0	600	350	310
	U.E. (%)	620	650	645	490	0	125	115	90
	Mod.($\frac{kg}{cm^2}$)	11.37	11.8	15.2	18.3	24.6	25.8	28.2	-
1GEA154	T.S. (psi)	2025	2450	2100	1525	0	250	330	110
	U.E. (%)	840	790	720	545	0	250	190	130
	Mod.($\frac{kg}{cm^2}$)	6.57	6.6	7.5	8.1	9.9	12.0	14.4	15.5
1GEA155	T.S. (psi)	2615	2675	2775	980	500	525	600	60
	U.E. (%)	865	755	765	540	315	290	240	130
	Mod.($\frac{kg}{cm^2}$)	6.72	6.9	7.6	9.0	11.0	12.1	13.4	13.9
1GEA156	T.S. (psi)	3540	3100	2650	1470	230	425	170	250
	U.E. (%)	930	785	705	560	295	230	145	150
	Mod.($\frac{kg}{cm^2}$)	7.11	6.9	7.6	8.9	11.3	12.2	14.7	15.8

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA157	T.S. (psi)	3025	3330	2930	1150	425	375	160	300
	U.E. (%)	760	710	665	435	250	215	145	125
	Mod.($\frac{kg}{cm^2}$)	7.96	8.5	9.1	10.4	13.4	15.6	18.9	20.5
1GEA158	T.S. (psi)	3150	2950	2550	900	500	660	0	350
	U.E. (%)	780	710	640	365	285	225	145	120
	Mod.($\frac{kg}{cm^2}$)	8.18	8.6	8.7	10.3	12.5	14.0	17.6	19.9
1GEA159	T.S. (psi)	3760	3225	2790	920	500	900	300	290
	U.E. (%)	840	745	660	400	270	245	130	110
	Mod.($\frac{kg}{cm^2}$)	8.54	8.4	9.7	11.6	14.2	16.5	21.8	22.2
1GEA160	T.S. (psi)	3325	2750	2530	1530	775	850	450	375
	U.E. (%)	660	630	535	455	235	205	130	85
	Mod.($\frac{kg}{cm^2}$)	10.72	11.3	12.8	14.6	19.3	22.5	28.7	31.9
1GEA161	T.S. (psi)	3300	3075	2460	1225	800	810	310	360
	U.E. (%)	745	685	560	405	275	180	130	130
	Mod.($\frac{kg}{cm^2}$)	9.43	9.4	10.9	13.2	18.1	19.8	24.6	29.4
1GEA162	T.S. (psi)	2175	2060	1650	770	550	1000	400	520
	U.E. (%)	585	445	340	310	210	180	125	90
	Mod.($\frac{kg}{cm^2}$)	14.35	13.0	14.6	17.1	19.2	27.4	30.2	33.4
1GEA163	T.S. (psi)	1800	1680	1360	1350	1025	825	425	325
	U.E. (%)	630	630	590	540	365	305	180	85
	Mod.($\frac{kg}{cm^2}$)	9.69	10.2	11.6	15.3	19.9	21.6	26.6	28.9

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA164	T.S. (psi)	1275	1100	1580	890	475	890	875	800
	U.E. (%)	565	485	490	380	245	285	180	150
	Mod. ($\frac{kg}{cm^2}$)	11.52	12.8	15.6	17.0	21.9	25.6	28.2	29.5
1GEA165	T.S. (psi)	2040	1740	1930	1330	625	330	410	375
	U.E. (%)	650	550	590	485	365	145	150	80
	Mod. ($\frac{kg}{cm^2}$)	13.58	14.0	17.3	19.6	24.3	26.6	32.1	-
1GEA166	T.S. (psi)	2050	2600	2900	3200	2225	1500	1060	1180
	U.E. (%)	360	490	390	370	270	200	145	120
	Mod. ($\frac{kg}{cm^2}$)	21.4	20.6	22.2	25.2	34.3	32.0	32.9	34.7
1GEA167	T.S. (psi)	2800	2230	2850	2200	1200	1300	940	875
	U.E. (%)	385	390	365	275	195	145	125	110
	Mod. ($\frac{kg}{cm^2}$)	21.4	23.1	25.3	30.5	34.6	38.4	38.8	47.7
1GEA168	T.S. (psi)	1650	2350	1610	1425	1100	1220	1200	1250
	U.E. (%)	265	320	270	190	140	140	110	105
	Mod. ($\frac{kg}{cm^2}$)	22.0	26.0	27.6	34.8	39.1	39.5	44.1	Broke
1GEA169	T.S. (psi)	-	2475	2450	1925	1175	1250	1200	1125
	U.E. (%)	-	355	235	210	125	120	125	70
	Mod. ($\frac{kg}{cm^2}$)	-	26.1	29.3	32.0	39.2	50.6	Broke	Broke
1GEA170	T.S. (psi)	2425	2900	2350	2200	1150	1200	1050	750
	U.E. (%)	395	410	300	265	185	125	120	70
	Mod. ($\frac{kg}{cm^2}$)	21.5	23.0	26.1	27.0	30.2	40.0	56.4	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA171	T.S. (psi)	2830	3410	2480	2000	1300	700	1500	975
	U.E. (%)	505	570	405	310	170	135	160	120
	Mod. ($\frac{kg}{cm^2}$)	17.85	17.2	19.2	23.8	28.2	34.7	39.0	48.3
1GEA172	T.S. (psi)	2230	2300	2500	1990	940	830	925	550
	U.E. (%)	495	485	465	315	150	140	125	80
	Mod. ($\frac{kg}{cm^2}$)	14.60	16.2	18.6	23.4	26.0	36.0	41.5	49.1
1GEA173	T.S. (psi)	2325	1850	1620	1500	950	820	725	440
	U.E. (%)	425	425	360	285	200	120	120	70
	Mod. ($\frac{kg}{cm^2}$)	14.77	15.4	19.0	24.3	29.3	44.0	47.9	Broke
1GEA174	T.S. (psi)	3530	2210	2600	1600	0	100	0	0
	U.E. (%)	905	835	840	650	0	220	0	0
	Mod. ($\frac{kg}{cm^2}$)	5.70	5.56	6.18	7.17	7.82	9.8	11.0	13.7
1GEA175	T.S. (psi)	2350	2690	2325	1100	275	310	400	200
	U.E. (%)	775	695	785	490	290	205	200	130
	Mod. ($\frac{kg}{cm^2}$)	6.85	6.68	7.60	9.07	11.23	13.4	14.2	19.1
1GEA176	T.S. (psi)	2590	2700	2150	1775	675	490	825	550
	U.E. (%)	685	740	435	480	245	205	180	120
	Mod. ($\frac{kg}{cm^2}$)	9.66	9.77	10.48	13.26	15.98	18.1	19.5	27.1
1GEA177	T.S. (psi)	2130	2170	2250	2025	1110	1150	1000	950
	U.E. (%)	505	530	520	400	220	180	160	140
	Mod. ($\frac{kg}{cm^2}$)	16.04	14.32	16.64	19.8	24.2	27.8	29.9	33.4

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA178	T.S. (psi)	2250	2725	2260	2000	1440	1020	1200	1200
	U.E. (%)	370	420	355	300	200	120	135	120
	Mod.($\frac{kg}{cm^2}$)	21.3	19.4	28.1	32.5	28.7	38.6	30.2	Broke
1GEA179	T.S. (psi)	1575	1525	1580	1775	900	950	850	1000
	U.E. (%)	165	135	150	125	85	75	60	130
	Mod.($\frac{kg}{cm^2}$)	47.1	48.4	54.5	55.8	Broke	Broke	Broke	Broke
1GEA180	T.S. (psi)	2725	2000	2000	1160	350	210	225	210
	U.E. (%)	850	935	705	580	400	190	165	140
	Mod.($\frac{kg}{cm^2}$)	5.65	6.13	6.61	7.77	10.28	13.1	13.9	17.1
1GEA181	T.S. (psi)	2510	2560	1975	1560	650	500	430	480
	U.E. (%)	930	895	745	600	375	270	210	135
	Mod.($\frac{kg}{cm^2}$)	6.55	6.76	7.71	8.86	13.5	14.2	16.3	19.1
1GEA182	T.S. (psi)	2700	2550	2025	1250	800	440	500	375
	U.E. (%)	760	745	750	620	42	165	170	140
	Mod.($\frac{kg}{cm^2}$)	9.31	9.85	10.94	13.30	17.22	18.0	23.4	Broke
1GEA183	T.S. (psi)	1900	1750	1470	950	470	400	690	500
	U.E. (%)	760	790	725	590	400	205	230	125
	Mod.($\frac{kg}{cm^2}$)	8.55	9.30	11.12	15.72	19.6	17.9	23.5	29.0
1GEA184	T.S. (psi)	2025	1300	1130	1000	700	575	430	500
	U.E. (%)	605	585	530	470	30	195	110	80
	Mod.($\frac{kg}{cm^2}$)	15.58	14.55	15.97	22.6	24.2	30.2	32.2	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA185	T.S. (psi)	1550	1410	1175	125	0	170	350	310
	U.E. (%)	770	745	660	300	0	120	100	80
	Mod. ($\frac{kg}{cm^2}$)	11.49	12.26	13.53	14.78	-	Broke	21.7	Broke
1GEA186	T.S. (psi)	1710	1725	1560	750	300	150	180	325
	U.E. (%)	610	585	620	510	150	65	75	50
	Mod. ($\frac{kg}{cm^2}$)	21.6	21.5	22.1	22.0	21.1	Broke	Broke	Broke
1GEA187	T.S. (psi)	1450	1125	900	510	275	330	500	475
	U.E. (%)	405	420	410	345	90	65	40	30
	Mod. ($\frac{kg}{cm^2}$)	30.6	29.1	31.15	31.1	Broke	Broke	Broke	Broke
1GEA188	T.S. (psi)	900	850	725	575	330	390	500	500
	U.E. (%)	240	240	190	130	50	45	25	20
	Mod. ($\frac{kg}{cm^2}$)	38.5	32.5	40.45	34.6	Broke	Broke	Broke	Broke
1GEA189	T.S. (psi)	550	825	630	525	700	725	600	0
	U.E. (%)	50	50	40	20	40	5	0	0
	Mod. ($\frac{kg}{cm^2}$)	Broke	Broke	Broke	Broke	Broke	Broke	Broke	Broke
1GEA190	T.S. (psi)	275	370	360	235	175	200	75	75
	U.E. (%)	395	225	580	230	135	75	70	55
	Mod. ($\frac{kg}{cm^2}$)	12.0	13.05	16.29	16.13	19.11	Broke	Broke	Broke
1GEA191	T.S. (psi)	550	400	500	200	525	325	400	450
	U.E. (%)	345	260	70	185	30	40	30	40
	Mod. ($\frac{kg}{cm^2}$)	15.62	17.1	Broke	Broke	Broke	Broke	Broke	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA192	T.S. (psi)	500	700	360	540	275	300	275	450
	U.E. (%)	100	25	200	85	180	55	15	60
	Mod. ($\frac{kg}{cm^2}$)	19.9	26.1	32.5	Broke	Broke	Broke	Broke	Broke
1GEA193	T.S. (psi)	1050	1075	600	775	800	800	700	1150
	U.E. (%)	30	40	10	15	20	10	10	20
	Mod. ($\frac{kg}{cm^2}$)	Broke	Broke	Broke	Broke	Broke	Broke	Broke	Broke
1GEA194	T.S. (psi)	400	1000	350	1225	0	1000	1350	1525
	U.E. (%)	95	20	80	10	0	0	0	0
	Mod. ($\frac{kg}{cm^2}$)	Broke	Broke	Broke	Broke	Broke	Broke	Broke	Broke
1GEA195	T.S. (psi)	720	150	>500	>500	0	0	0	0
	U.E. (%)	>1200	>1200	>1200	>1200	810	0	0	0
	Mod. ($\frac{kg}{cm^2}$)	2.79	-	-	-	-	-	-	-
1GEA196	T.S. (psi)	1560	>1000	>1300	>1000	1675	1075	>800	>800
	U.E. (%)	1090	>1200	>1200	>1200	1200	1130	>1200	>1200
	Mod. ($\frac{kg}{cm^2}$)	4.35	-	-	-	-	-	-	-
1GEA197	T.S. (psi)	3100	3990	3400	>3550	400	2300	2100	1280
	U.E. (%)	1100	>1200	950	>1200	840	810	865	760
	Mod. ($\frac{kg}{cm^2}$)	-	-	-	-	-	-	-	-
1GEA198	T.S. (psi)	2900	4710	4250	3800	2350	1680	1360	150
	U.E. (%)	640	1105	635	835	780	560	545	110
	Mod. ($\frac{kg}{cm^2}$)	-	-	*15.8	*1.06	-	-	-	-

* = Modulus from stress strain curve

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA199	T.S. (psi)	2000	-	>2000	>1475	1425	1300	1300	160
	U.E. (%)	950	-	>1200	1200	840	630	560	385
	Mod. ($\frac{kg}{cm^2}$)	4.24	4.31	4.41	5.14	5.77	6.40	6.59	7.40
1GEA200	T.S. (psi)	375	1250	-	1525	-	-	1090	50
	U.E. (%)	1200	>1200	-	860	-	-	565	245
	Mod. ($\frac{kg}{cm^2}$)	3.78	3.96	4.42	4.47	5.17	5.74	6.66	8.06
1GEA201	T.S. (psi)	1360	-	-	>1175	-	0	0	150
	U.E. (%)	120	-	-	970	-	0	0	305
	Mod. ($\frac{kg}{cm^2}$)	3.43	3.23	3.69	3.73	4.72	5.9	5.7	6.7
1GEA202	T.S. (psi)	670	975	725	630	420	450	140	200
	U.E. (%)	240	235	205	210	130	95	60	55
	Mod. ($\frac{kg}{cm^2}$)	21.5	23.3	25.3	26.9	28.4	Broke	Broke	Broke
1GEA203	T.S. (psi)	1050	910	950	750	530	400	420	330
	U.E. (%)	210	200	195	140	110	75	65	65
	Mod. ($\frac{kg}{cm^2}$)	33.4	30.4	34.5	38.3	Broke	Broke	Broke	Broke
1GEA204	T.S. (psi)	3450	3300	3610	3075	1750	3050	2325	2270
	U.E. (%)	665	800	980	800	745	745	585	540
	Mod. ($\frac{kg}{cm^2}$)	6.53	6.59	6.92	7.06	7.63	7.7	8.4	8.9
1GEA205	T.S. (psi)	1240	1950	2900	1575	1460	1790	1650	1540
	U.E. (%)	775	470	530	690	350	480	340	385
	Mod. ($\frac{kg}{cm^2}$)	7.98	7.53	7.90	7.66	8.92	10.1	11.9	12.5

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA207	T.S. (psi)	530	750	600	290	450	350	280	Broke
	U.E. (%)	435	410	360	430	105	75	40	Broke
	Mod. ($\frac{kg}{cm^2}$)	6.05	12.5	6.68	10.3	33.6	Broke	Broke	Broke
1GEA208	T.S. (psi)	30	75	0	70	0	0	50	Broke
	U.E. (%)	145	155	70	110	65	50	35	Broke
	Mod. ($\frac{kg}{cm^2}$)	13.56	10.6	10.5	8.53	11.3	Broke	Broke	Broke
1GEA209	T.S. (psi)	1650	1660	1700	1450	980	825	650	600
	U.E. (%)	380	250	300	255	220	110	75	60
	Mod. ($\frac{kg}{cm^2}$)	18.10	20.3	17.5	22.4	30.0	Broke	Broke	Broke
1GEA210	T.S. (psi)	300	150	150	120	150	90	10	Broke
	U.E. (%)	105	110	185	210	80	45	70	Broke
	Mod. ($\frac{kg}{cm^2}$)	19.66	8.84	7.37	8.64	Broke	Broke	Broke	Broke
1GEA211	T.S. (psi)	300	440	450	320	190	50	90	Broke
	U.E. (%)	310	430	420	380	160	65	40	Broke
	Mod. ($\frac{kg}{cm^2}$)	9.78	8.49	7.32	10.9	13.2	Broke	Broke	Broke
1GEA212	T.S. (psi)	900	775	720	530	375	300	250	180
	U.E. (%)	495	400	390	400	270	245	190	70
	Mod. ($\frac{kg}{cm^2}$)	13.60	10.8	12.1	13.9	14.5	16.3	14.2	Broke
1GEA214	T.S. (psi)	870	920	400	550	600	275	0	Broke
	U.E. (%)	165	180	120	85	45	35	60	Broke
	Mod. ($\frac{kg}{cm^2}$)	46.9	28.2	Broke	Broke	Broke	Broke	Broke	Broke

TABLE 4, Cont'd.

The Effect of Gamma Radiation upon Stress-Strain Properties

Compound	Physical Property	Nominal Cobalt-60 Gamma Radiation Dose (10^7 Roentgens)							
		0	0.1	0.5	1	2.5	3.5	5	7
1GEA215	T.S. (psi)	300	400	200	290	325	400	420	360
	U.E. (%)	85	75	65	95	65	75	40	10
	Mod.($\frac{kg}{cm^2}$)	Broke	20.7	Broke	Broke	Broke	Broke	Broke	Broke
1GEA216	T.S. (psi)	1525	1290	1175	1110	975	Broke	Broke	Broke
	U.E. (%)	110	85	70	70	45	Broke	Broke	Broke
	Mod.($\frac{kg}{cm^2}$)	Broke	Broke	Broke	Broke	Broke	Broke	Broke	Broke
1GEA217	T.S. (psi)	860	700	760	690	300	350	225	Broke
	U.E. (%)	225	190	235	220	100	80	40	Broke
	Mod.($\frac{kg}{cm^2}$)	19.26	14.9	11.7	21.0	17.5	Broke	Broke	Broke
1GEA218	T.S. (psi)	475	650	490	610	500	425	340	Broke
	U.E. (%)	220	205	185	160	130	90	80	Broke
	Mod.($\frac{kg}{cm^2}$)	16.88	18.3	10.4	23.7	19.6	30.0	Broke	Broke
1GEA219	T.S. (psi)	-	1120	1120	1030	1140	975	740	450
	U.E. (%)	-	260	240	255	185	205	160	70
	Mod.($\frac{kg}{cm^2}$)	-	24.5	17.8	26.3	29.4	33.9	28.5	Broke
	T.S. (psi)								
	U.E. (%)								
	Mod.($\frac{kg}{cm^2}$)								
	T.S. (psi)								
	U.E. (%)								
	Mod.($\frac{kg}{cm^2}$)								

TABLE 5

The Effect of Antioxidants upon Radiation Resistance of Rubbers

(Pure Gum Compounds)

Compound 1GEA	Initial Test Radiation Dose: None			Final Test Radiation Dose: 70 Mr			Comparison Percent of Initial		
	TS (psi)	UE (%)	MOD ($\frac{kg}{cm^2}$)	TS (psi)	UE (%)	MOD ($\frac{kg}{cm^2}$)	TS (%)	UE (%)	MOD (%)
56	2860	800	6.4	2000	565	9.7	70	71	152
68	3025	940	7.6	175	200	9.6	6	21	126
109	3550	1025	5.0	75	80	*	2	8	–
110	1900	880	5.5	2300	535	10.1	121	61	184
111	2500	1065	4.8	140	135	9.2	6	13	192
112	2400	985	4.6	2050	500	7.3	86	51	159
113	1600	1020	5.4	1260	555	10.7	79	54	198
115	1475	1170	4.4	1625	560	8.2	110	48	186
116	2175	1030	4.9	1160	485	9.2	53	47	188
117	2700	1105	4.2	2475	570	10.2	92	52	243
118	2575	1070	4.8	2550	615	9.8	99	58	204
119	2580	930	4.9	1640	475	11.8	40	51	241
120	2975	1120	5.0	1550	575	11.3	52	51	226
121	3150	1045	4.7	2160	490	9.8	69	47	208
122	2850	1070	5.3	2290	600	9.8	80	56	185
123	2450	1145	4.6	1075	470	7.4	44	41	161
124	2440	880	5.5	250	285	9.3	10	32	169
126	2680	1140	5.1	850	460	6.7	32	40	131
127	2525	1105	4.6	1380	500	5.1	55	45	111
128	2500	1100	4.8	2900	605	8.8	116	55	183
204	3450	665	6.5	2270	540	8.9	66	81	137
205	1240	775	8.0	1540	385	12.5	124	50	156

* Sample Broke

TABLE 6

The Effect of Antioxidants upon Radiation Resistance of Rubbers

(Black Compounds)

Compound 1GEA	Initial Test Radiation Dose: None			Final Test Radiation Dose: 70 Mr			Comparison Percent of Initial		
	TS (psi)	UE (%)	MOD ($\frac{kg}{cm^2}$)	TS (psi)	UE (%)	MOD ($\frac{kg}{cm^2}$)	TS (%)	UE (%)	MOD (%)
59	4610	550	23.6	3000	320	41.3	65	58	175
71	3950	560	27.2	3390	290	40.0	86	52	147
80*	3840	625	19.6	2675	545	16.3	70	87	83
81*	2300	825	11.7	2825	715	14.3	123	87	122
129	3750	480	24.8	1300	115	57.5	35	31	232
130	3380	480	27.5	2290	180	51.2	68	38	186
131	3050	480	19.5	1875	140	47.8	62	29	245
133	3630	535	23.7	2750	240	54.1	76	45	228
135	3650	520	24.1	1960	200	41.1	54	38	171
136	3650	510	23.5	2275	230	42.6	62	38	181
137	4150	505	24.5	2160	220	43.5	52	44	181
138	3525	500	26.5	3060	260	42.6	87	52	161
139	3280	460	26.9	1870	155	40.3	57	34	150
140	3800	500	24.7	2740	240	41.4	72	48	167
141	3900	580	23.3	2850	275	44.6	73	47	192
142	3850	640	23.5	3090	270	44.3	80	42	188
143	3825	605	24.6	2470	240	40.0	64	40	163
144	3350	560	27.7	2140	220	45.1	64	39	163
146	3510	525	23.4	1450	150	40.2	41	29	172
147	3975	625	22.9	2410	260	35.5	61	42	155
148	3730	605	25.6	2650	325	35.6	71	54	139

* These compounds contain four times as much antioxidant as do the others.

TABLE 7

The Effect of Gamma Radiation on Continuous Stress Relaxation in Elastomeric Compounds

Compound Number 1GEA	Relative Stress (S/So) after Four Radiation Doses (Roentgens) after 22 Hours Relaxation						
	1 x 10^6	5 x 10^6	1 x 10^7	2.5 x 10^7	3.7 x 10^7	5.5 x 10^7	7.4 x 10^7
1	0.87	0.85	0.91	0.92	0.94	0.95	0.96
2	0.82	0.82	0.82	0.83	0.82	broke	broke
3	0.64	0.75	0.79	0.77	0.80	0.88	broke
4	too soft	0.83	0.91	broke	0.93	broke	too soft
5	0.93	0.93	0.95	0.95	0.98	0.97	broke
6	0.58	0.65	0.69	0.67	0.76	broke	0.81
10	0.96	0.95	0.94	0.92	0.89	0.88	0.93
12	0.69	0.77	0.83	0.88	0.91	0.91	broke
13	0.93	0.90	0.85	-	too soft	too soft	too soft
19	0.76	too soft	0.79	0.81	0.78	0.84	-
21	0.87	0.80	0.83	0.82	0.85	0.83	0.84
22	0.73	0.75	0.82	0.82	0.88	0.89	0.88
23	0.50	0.49	0.57	broke	broke	broke	broke
25	0.89	0.90	0.91	0.93	0.92	0.93	0.92
26	0.81	0.79	0.79	0.78	0.81	0.83	0.76
27	0.80	0.79	0.77	0.78	0.78	0.81	0.79
28	0.90	0.83	0.91	0.87	0.88	0.89	broke
29	0.87	0.89	0.91	0.94	0.95	0.95	broke
31	0.90	broke	broke	broke	broke	0.92	broke
32	0.93	0.92	0.93	0.90	0.91	0.89	0.89
33	0.69	-	0.70	0.80	*	*	*
34	0.74	-	0.85	0.88	0.90	0.94	0.94
35	0.69	0.54	too soft	-	too soft	too soft	too soft
36	0.68	0.74	0.68	0.68	0.73	0.67	0.70

* Stress too high to be measured on machine (greater than 64.5 kg/cm^2).

TABLE 8

Stress Relaxation of Pure Gum Natural Rubber in a Vacuum During Co^{60} Gamma Irradiation (Flux = 2×10^5 R/Hr)

First Test Continuous Relaxation			Second Test Continuous Relaxation			Third Test Intermittent Relaxation		
Time (min)	Stress (g)	$\frac{S_t}{S_o}$	Time (min)	Stress (g)	$\frac{S_t}{S_o}$	Time (min)	Stress (g)	$\frac{S_t}{S_o}$
0	262.3	1.00	0	261.5	1.00	0	218	1.00
60	253.6	0.97	65	253.2	0.97	57	240	1.10
120	252.4	0.96	118	250.1	0.96	122	235	1.08
240	241.7	0.92	200	247.2	0.95	267	238	1.09
380	232.3	0.89	301	244.2	0.94	552	254	1.17
1313	214.2	0.82	394	240.1	0.92	1357	242	1.10
5719	165.4	0.63	1385	211.4	0.81	1597	246	1.12
7067	158.1	0.60	1823	202.0	0.77	2715	242	1.10
8465	149.8	0.57	2794	186.2	0.71	4210	232	1.06
9877	145.5	0.56	3253	177.9	0.68	8573	228	1.05
11,274	140.2	0.53	4223	170.6	0.65	9895	232	1.06
15,607	133.9	0.51	6117	156.8	0.60	11,325	228	1.04
18,439	128.5	0.49	9977	138.5	0.53	13,061	228	1.04
21,306	126.3	0.49	12,957	133.1	0.51	14,513	222	1.02
			21,677	115.7	0.44	18,807	220	1.01
						21,687	218	1.00
						24,545	217	1.00
						32,895	213	0.98

TABLE 9

Stress Relaxation of Pure Gum Natural Rubber During Co^{60} Gamma Irradiation (Flux = 2 x 10^5 R/Hr)

Fourth Test Irradiation in Air			Control Test Irradiation in Vacuum		
Time (min)	Stress (g)	$\frac{S_t}{S_o}$	Time (min)	Stress (g)	$\frac{S_t}{S_o}$
0	234	1.00	0	203.5	1.00
31	236	1.00	10	199.0	0.98
65	232	0.99	23	198.2	0.98
124	230	0.98	50	198.2	0.98
255	233	1.00	120	196.2	0.96
367	226	0.96	260	196.2	0.96
451	224	0.95	480	194.2	0.95
769	219	0.94	1400	194.2	0.95
1379	208	0.89	1920	192.8	0.95
1665	202	0.86	15,840	187.8	0.92
1865	198	0.85	22,040	186.0	0.91
5697	130	0.56	28,880	186.0	0.91
7145	105	0.45	37,600	184.0	0.90
9018	83	0.36			
11,817	48	0.20			
15,897	9	0.04			
17,526	Broke	Broke			

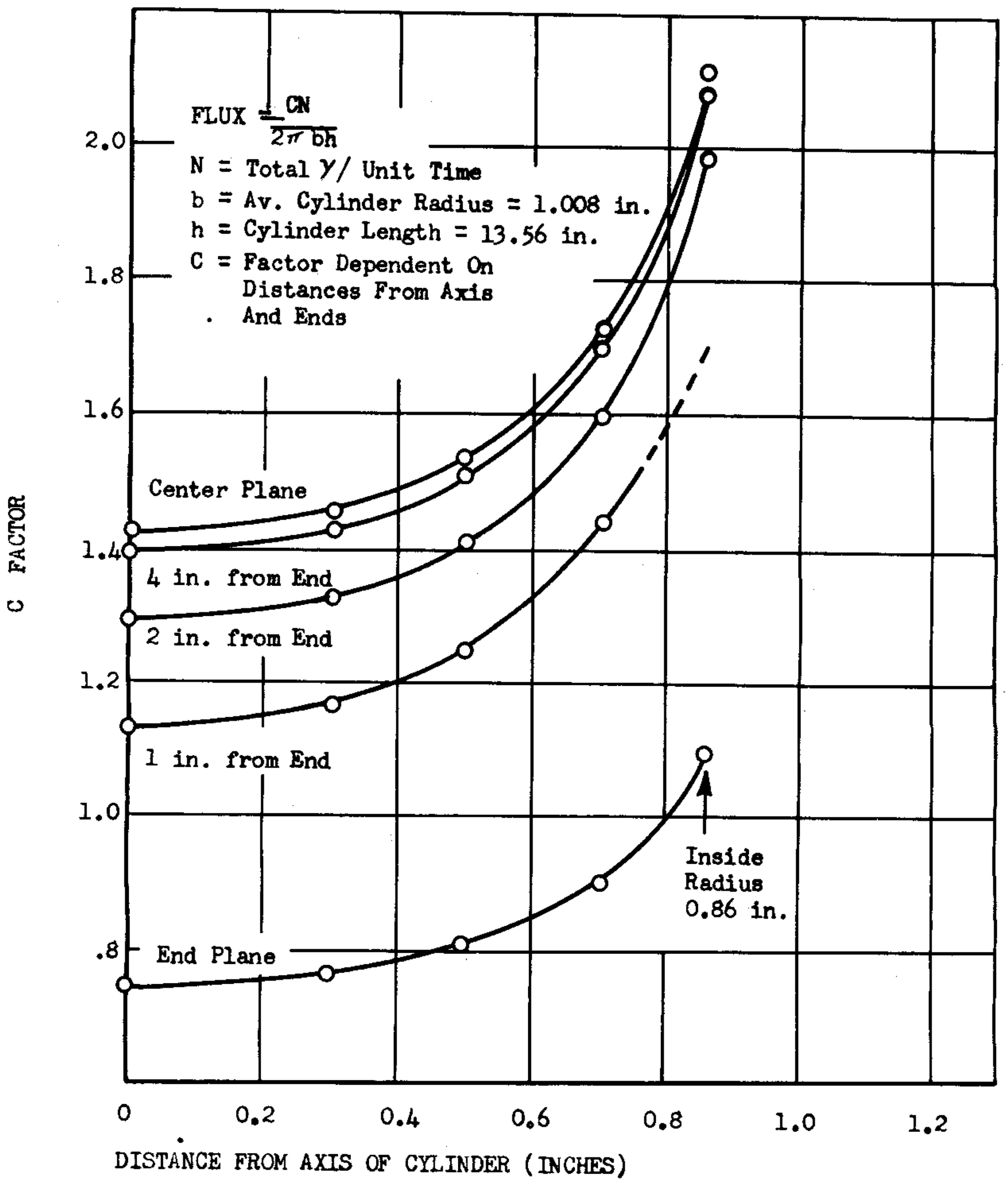


Figure 1

RADIATION FLUX VARIATION WITH POSITION
INSIDE COBALT 60 SOURCE Co 17

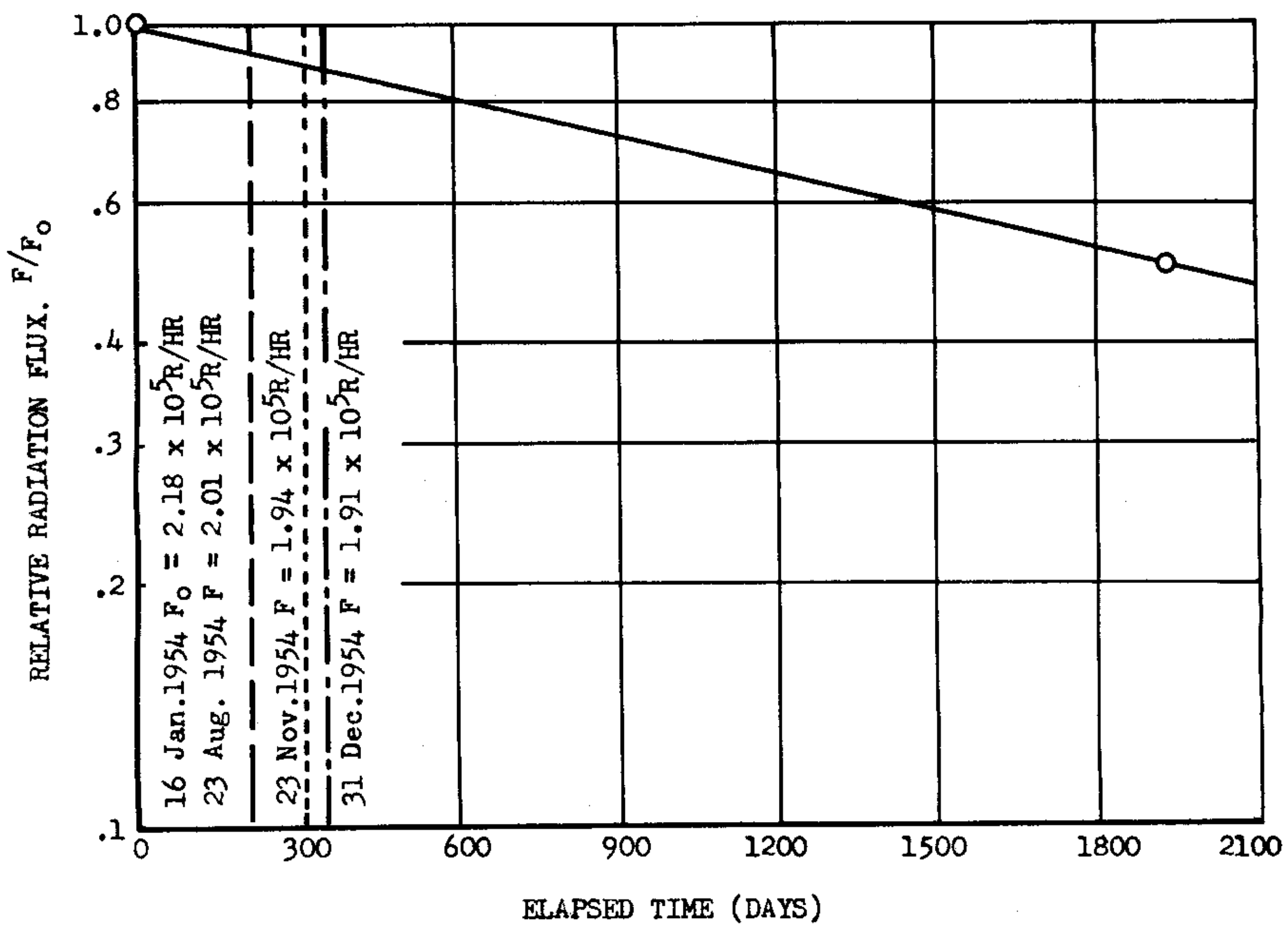


Figure 2

RADIOACTIVE DECAY RATE OF COBALT 60 SOURCE Co17

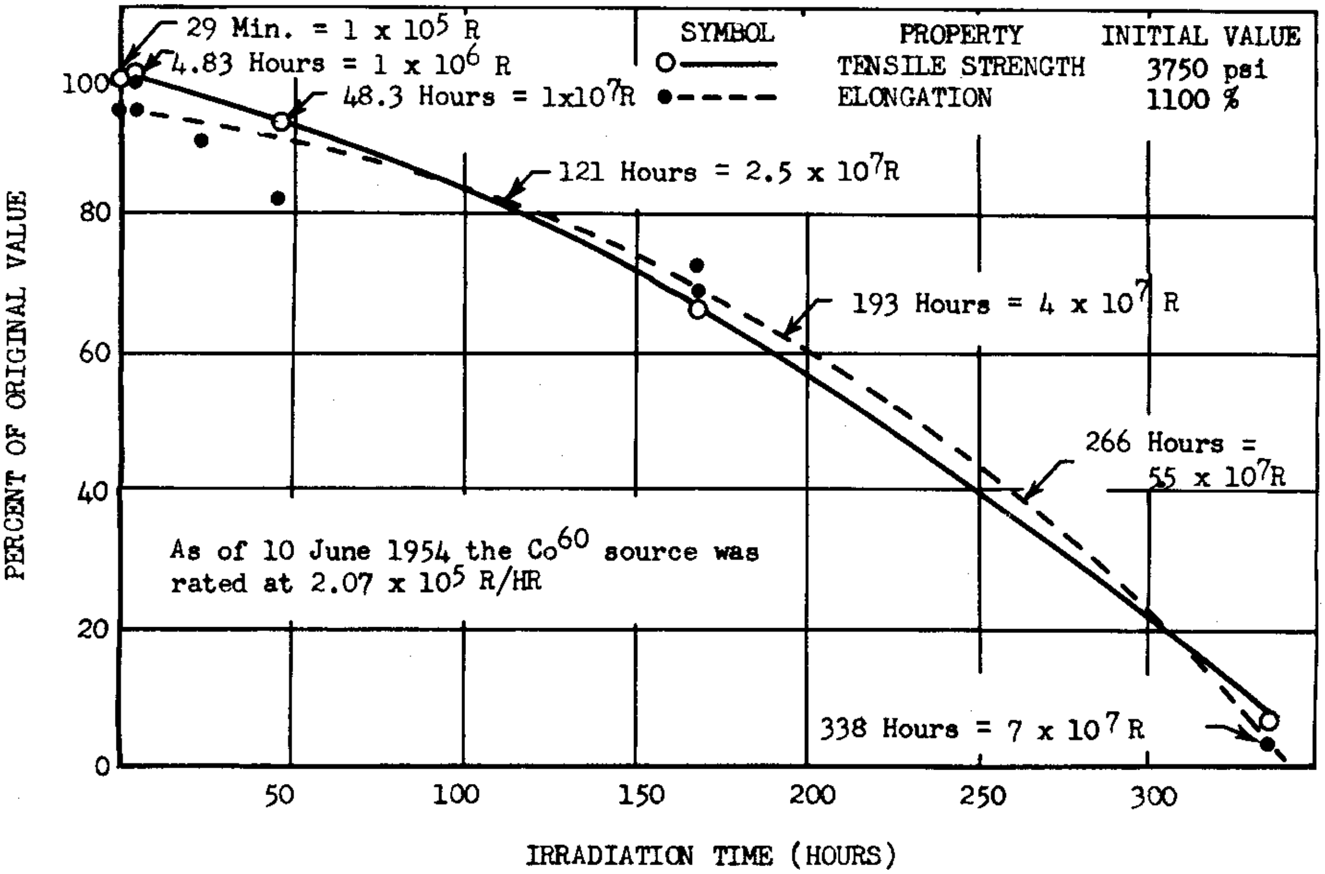


Figure 3

CHANGES IN STRESS-STRAIN PROPERTIES OF PURE GUM NATURAL RUBBER WITH GAMMA RADIATION DOSE (COMPOUND 1GEA10)

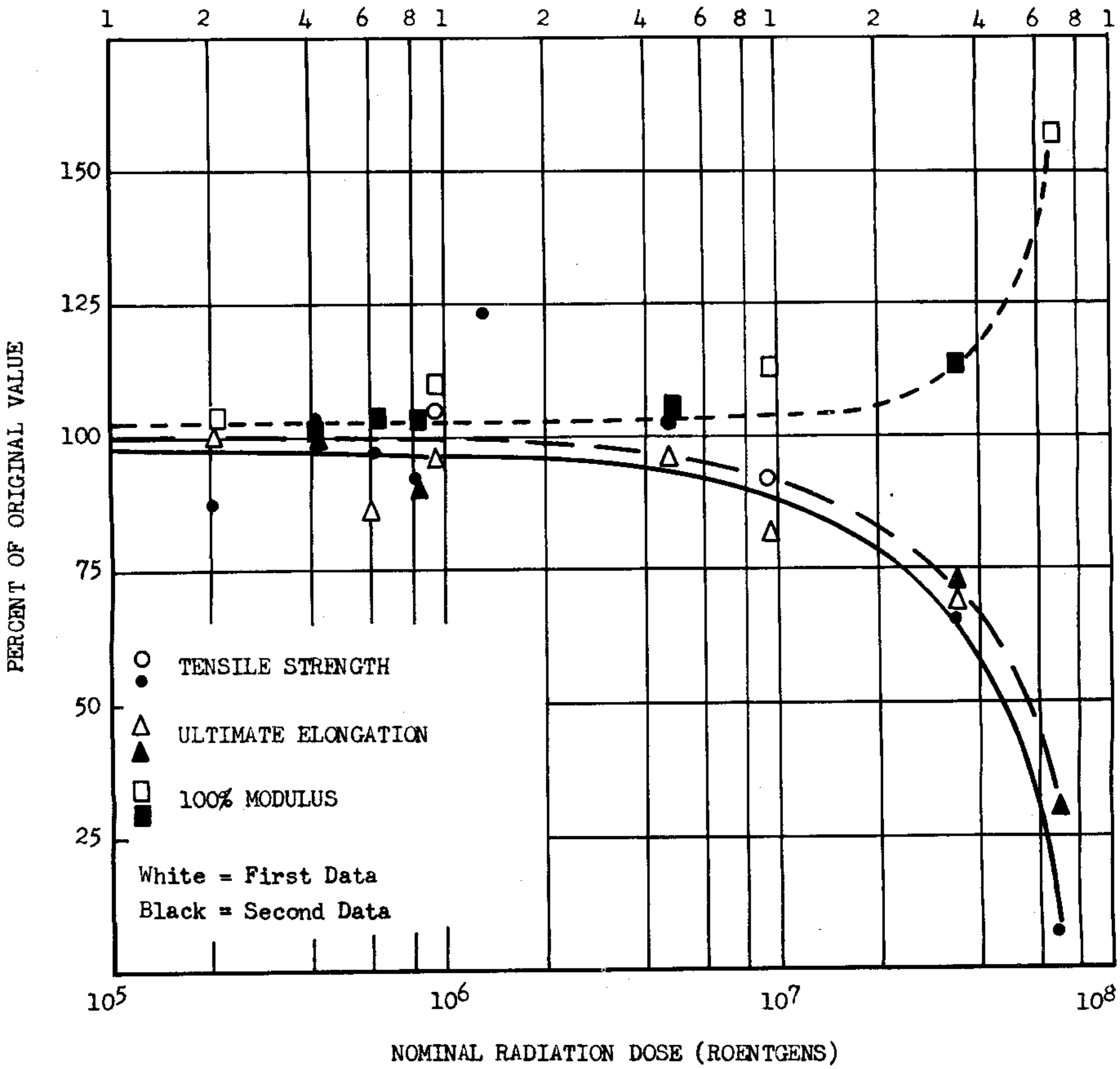


Figure 4

CHANGE IN STRESS-STRAIN VALUES
WITH IRRADIATION DOSE (COMPOUND 1GEA10)

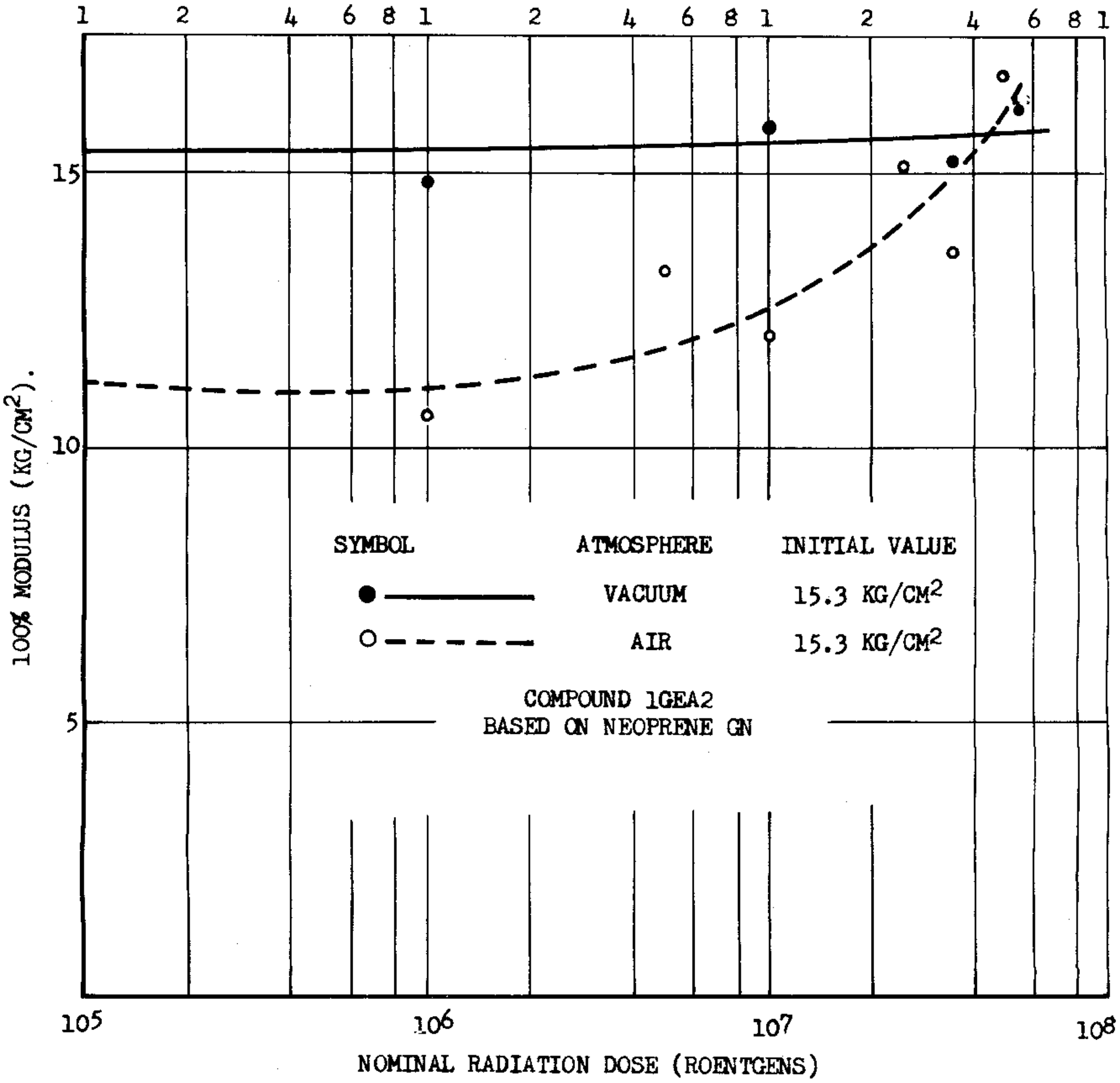


Figure 5

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA2 BASED ON NEOPRENE GN

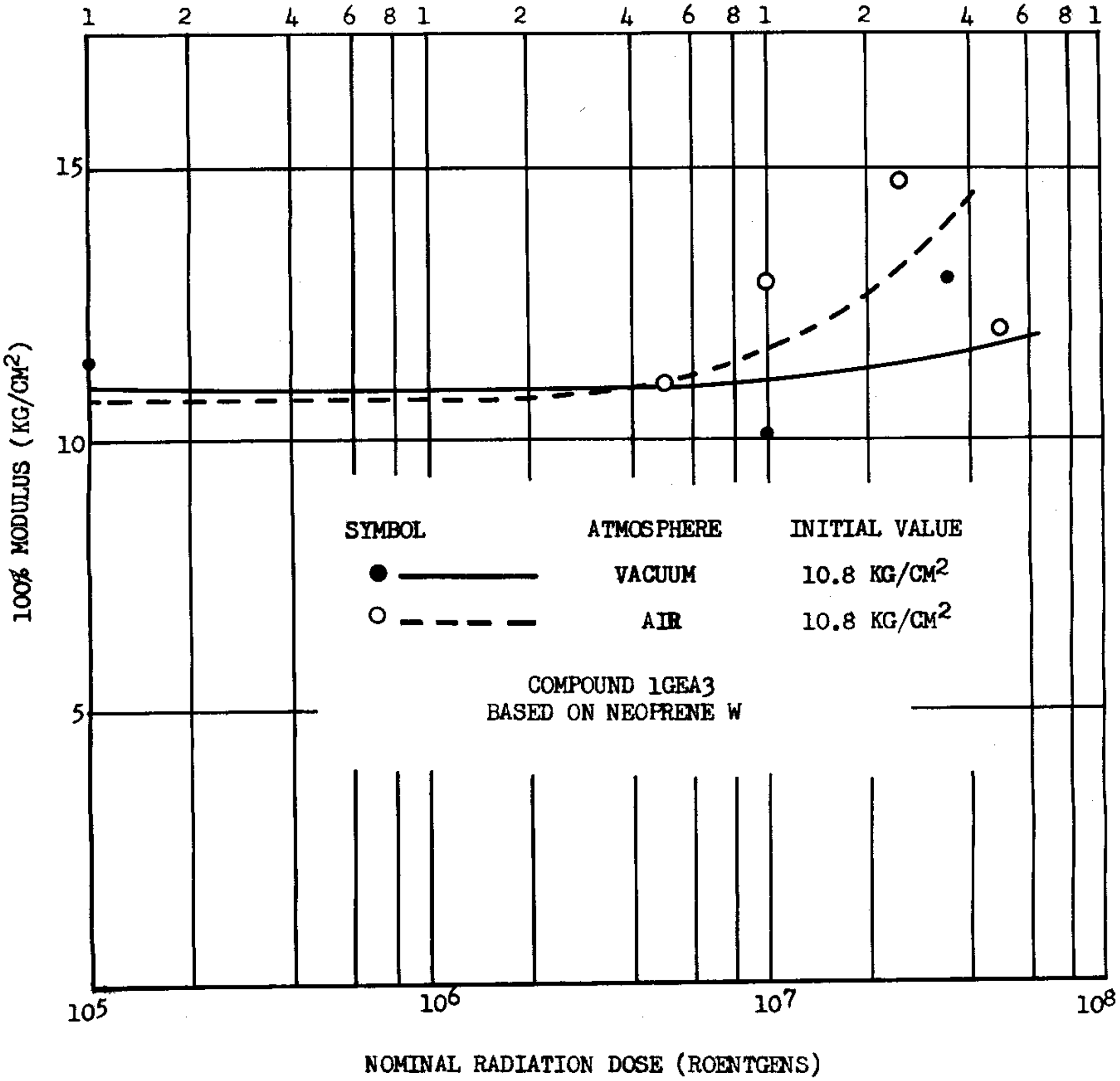


Figure 6

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA3 BASED ON NEOPRENE W

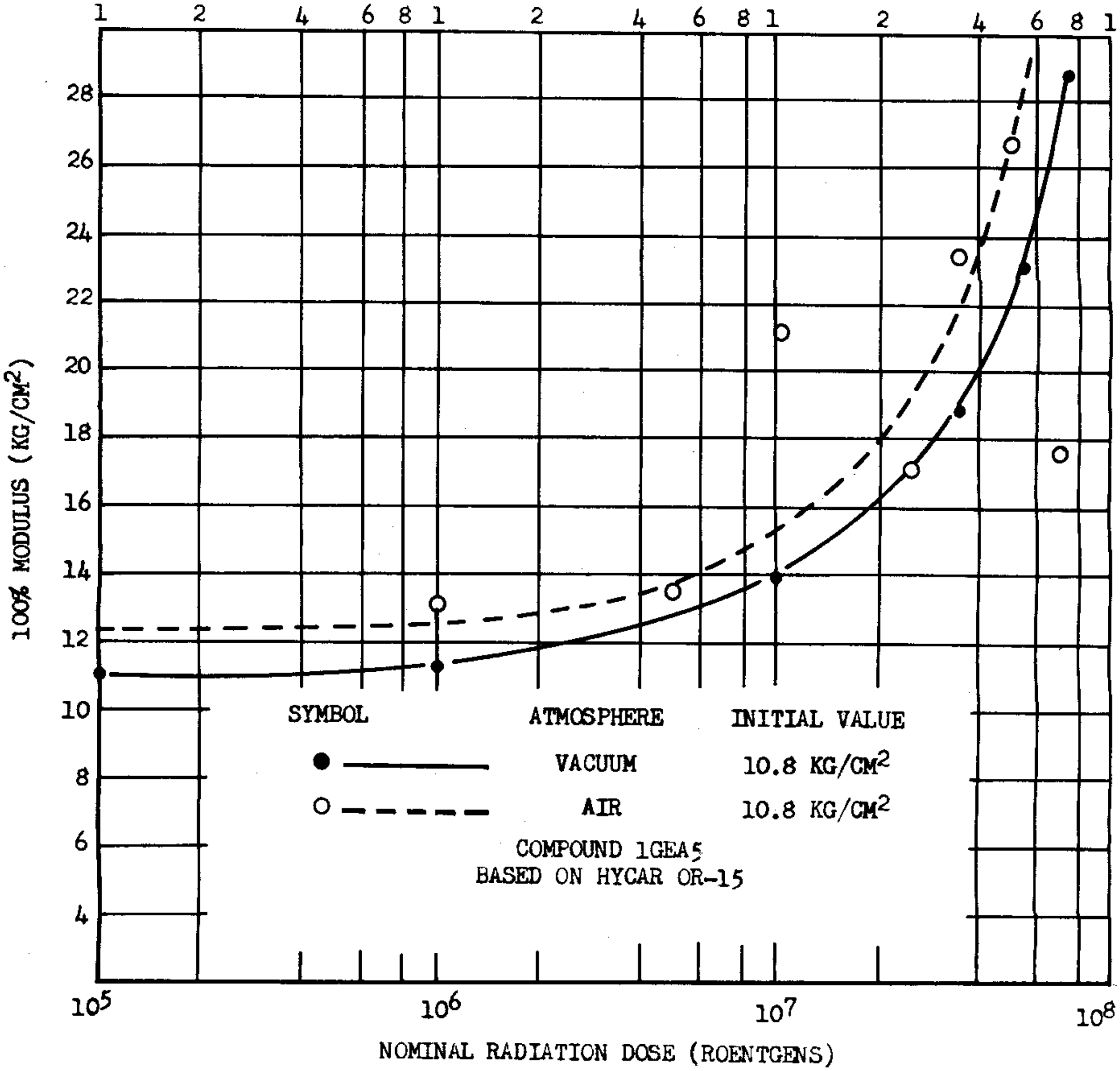


Figure 7

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA5 BASED ON HYCAR OR-15

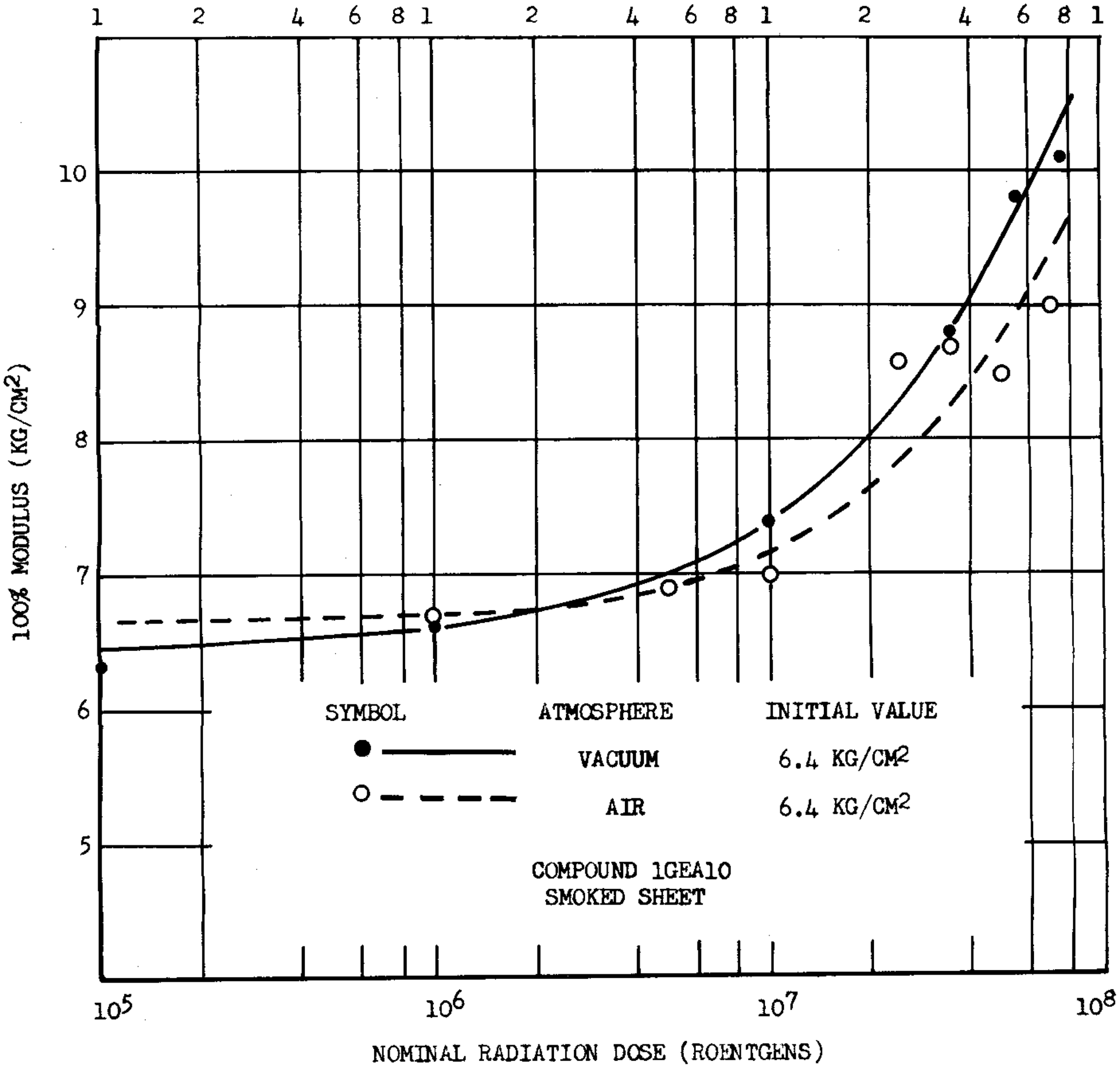


Figure 8

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA10 SMOKED SHEET

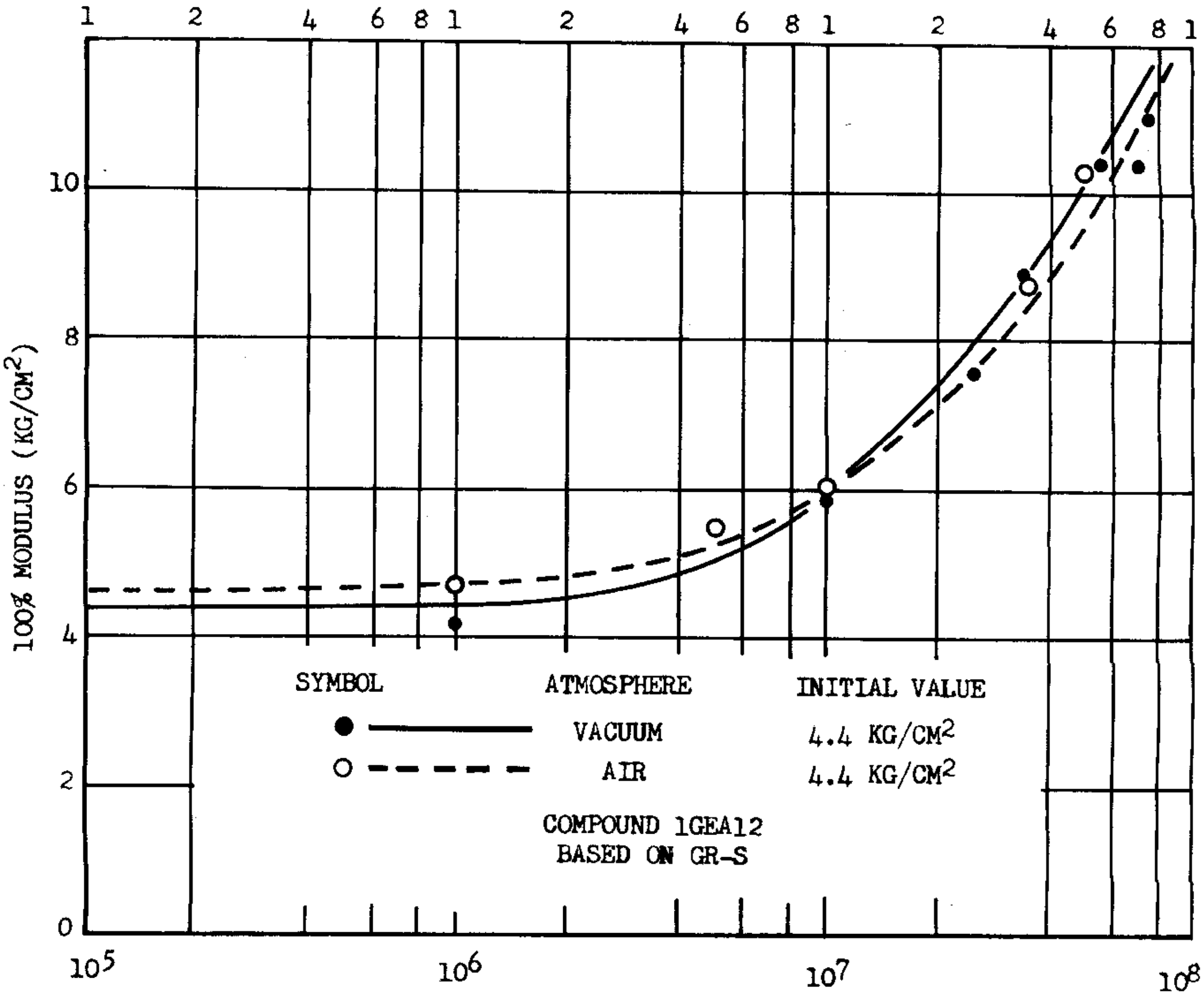


Figure 9

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA12 BASED ON GR-S

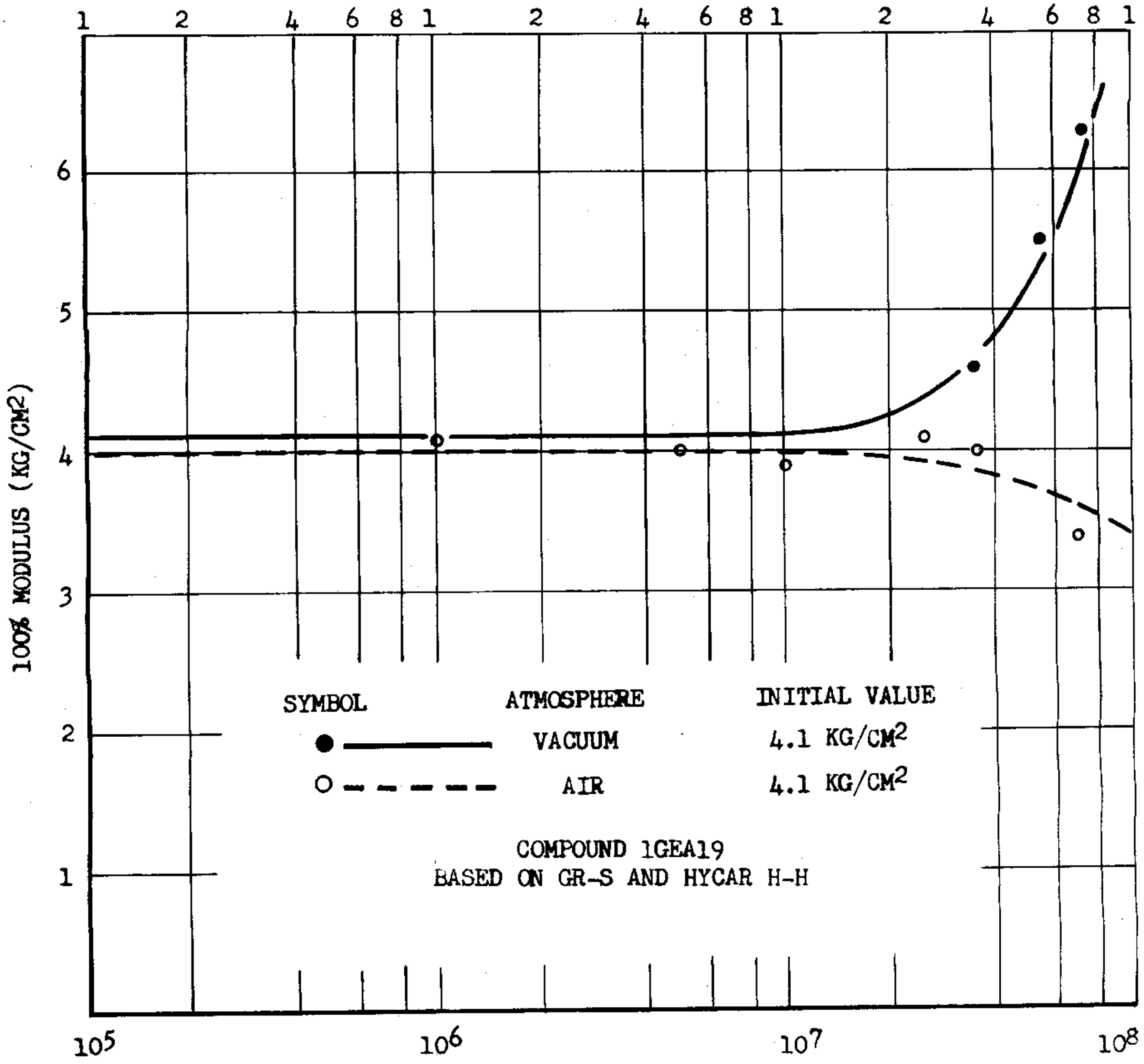


Figure 10

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA19 BASED ON GR - S AND HYCAR H-H

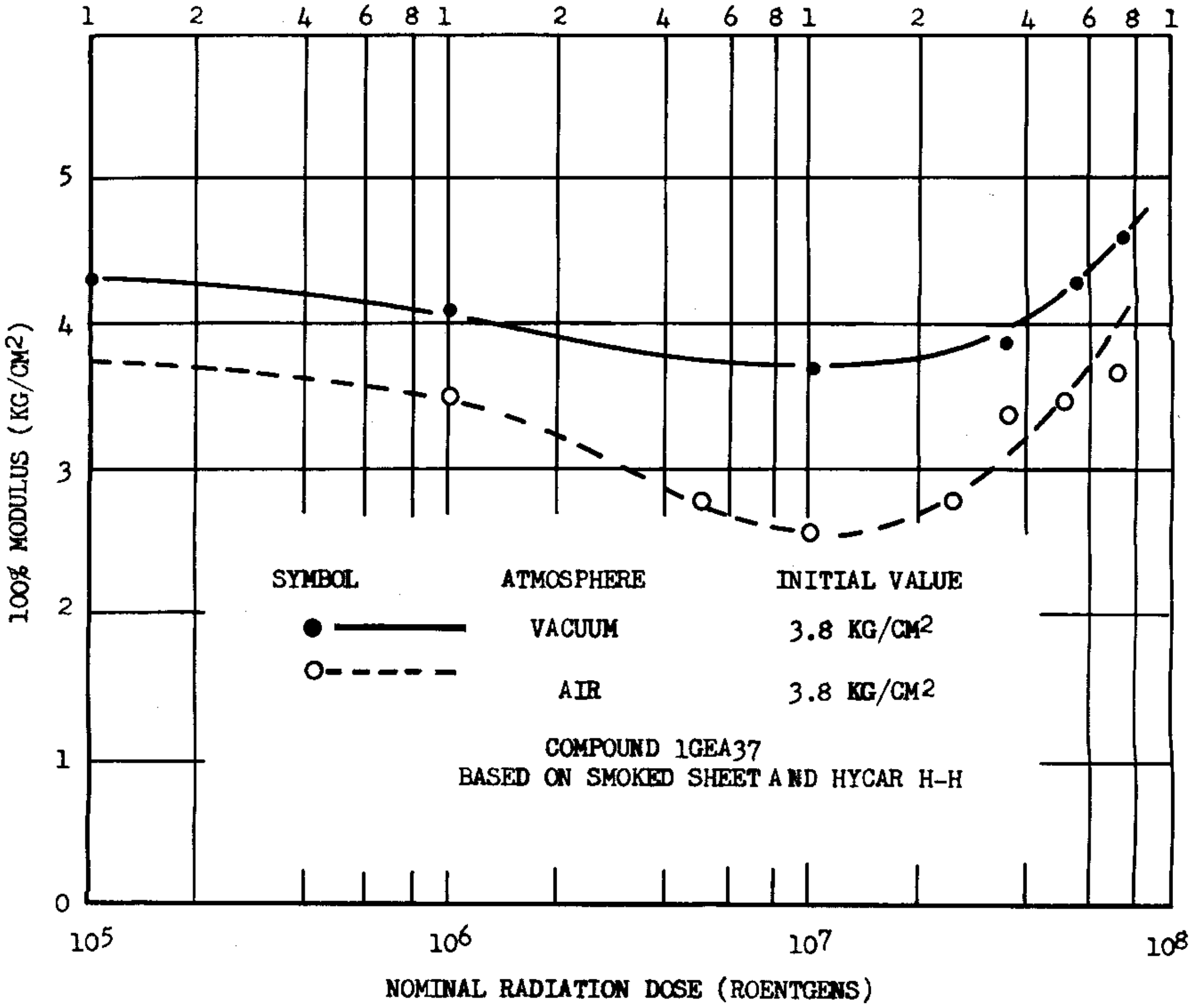


Figure 11

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA37 BASED ON SMOKED SHEET AND HYCAR H-H

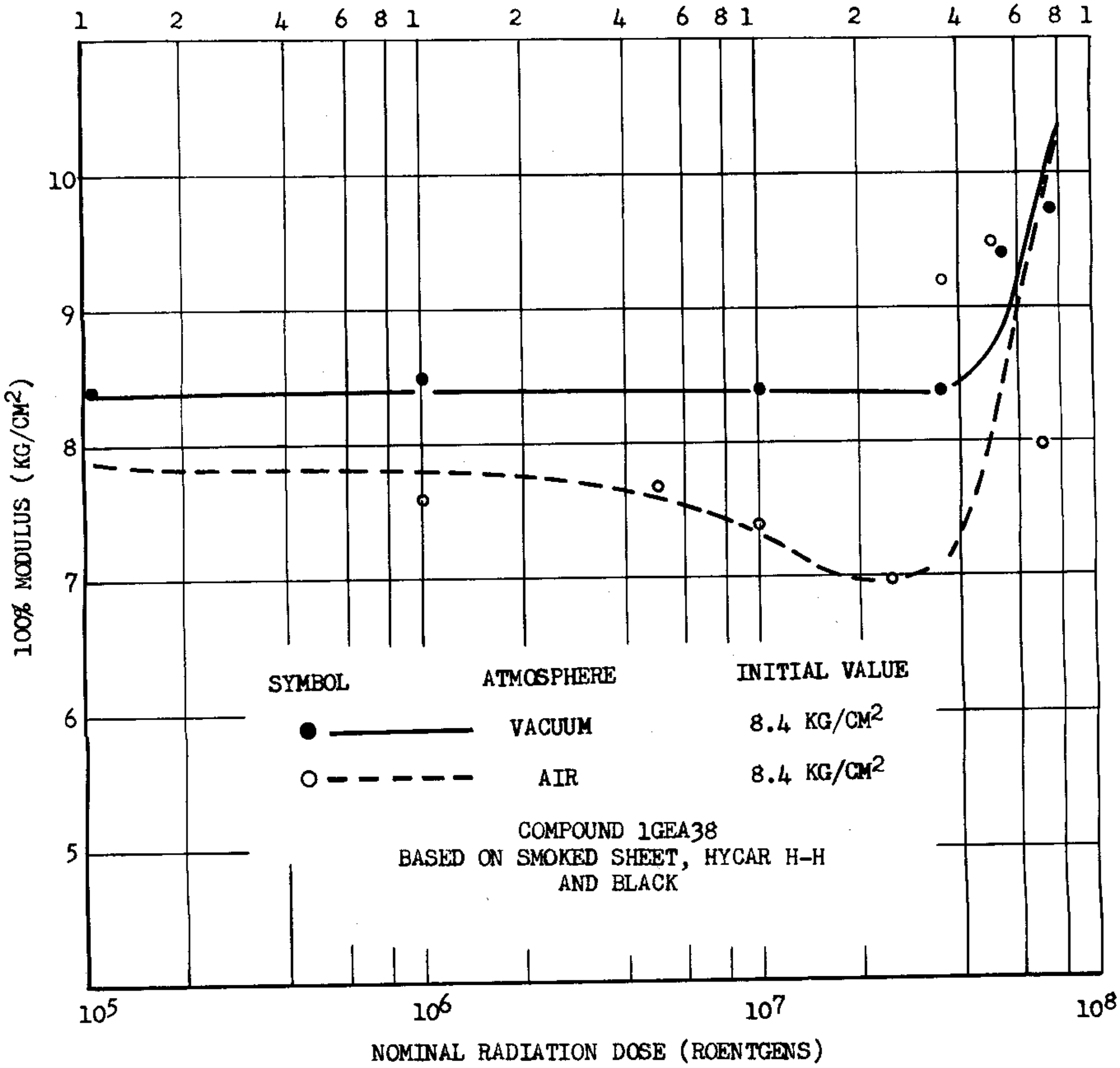


Figure 12

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA38 BASED ON SMOKED SHEET, HYCAR H-H
AND BLACK

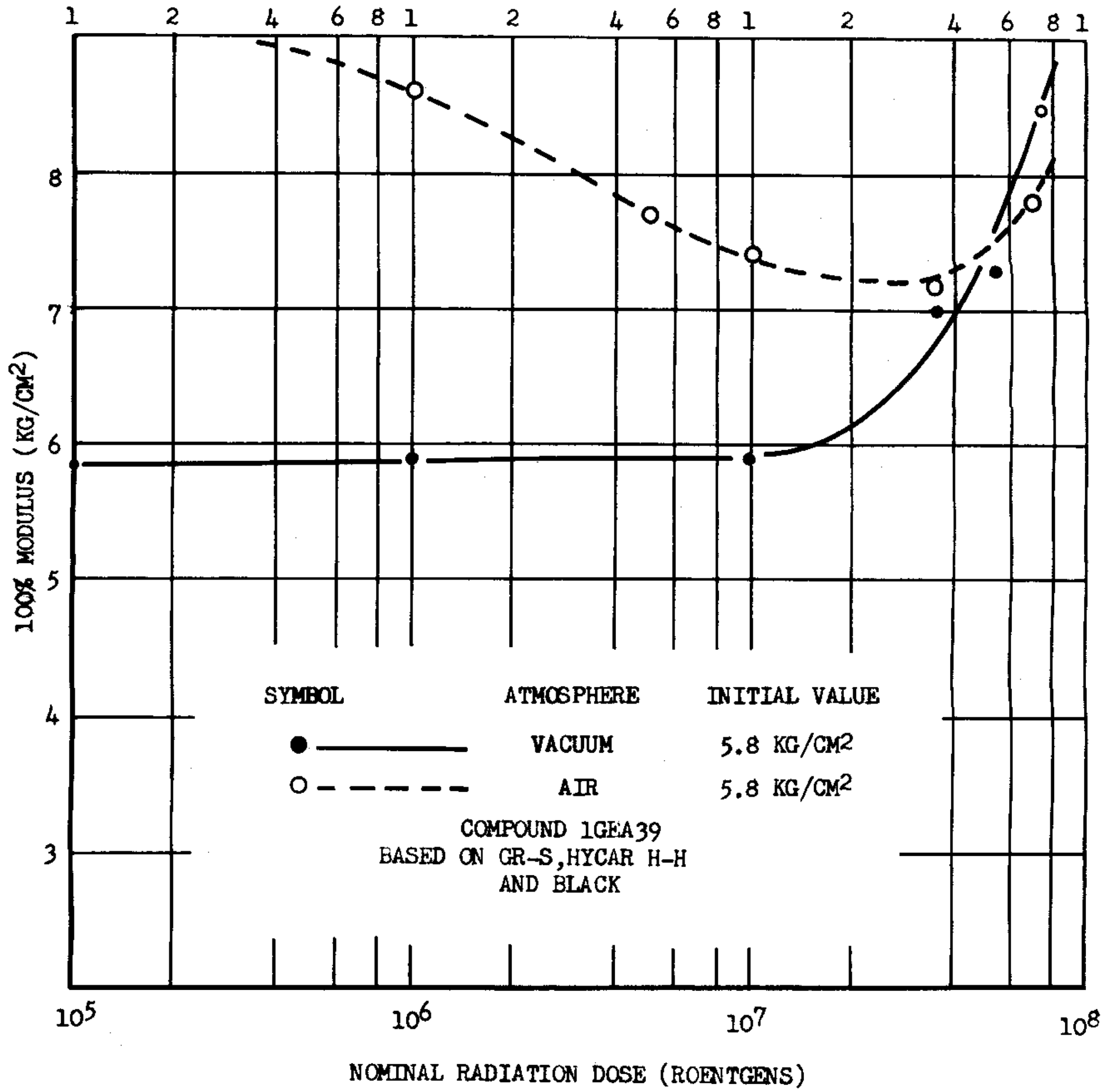


Figure 13

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA39 BASED ON GR-S, HYCAR H-H AND BLACK

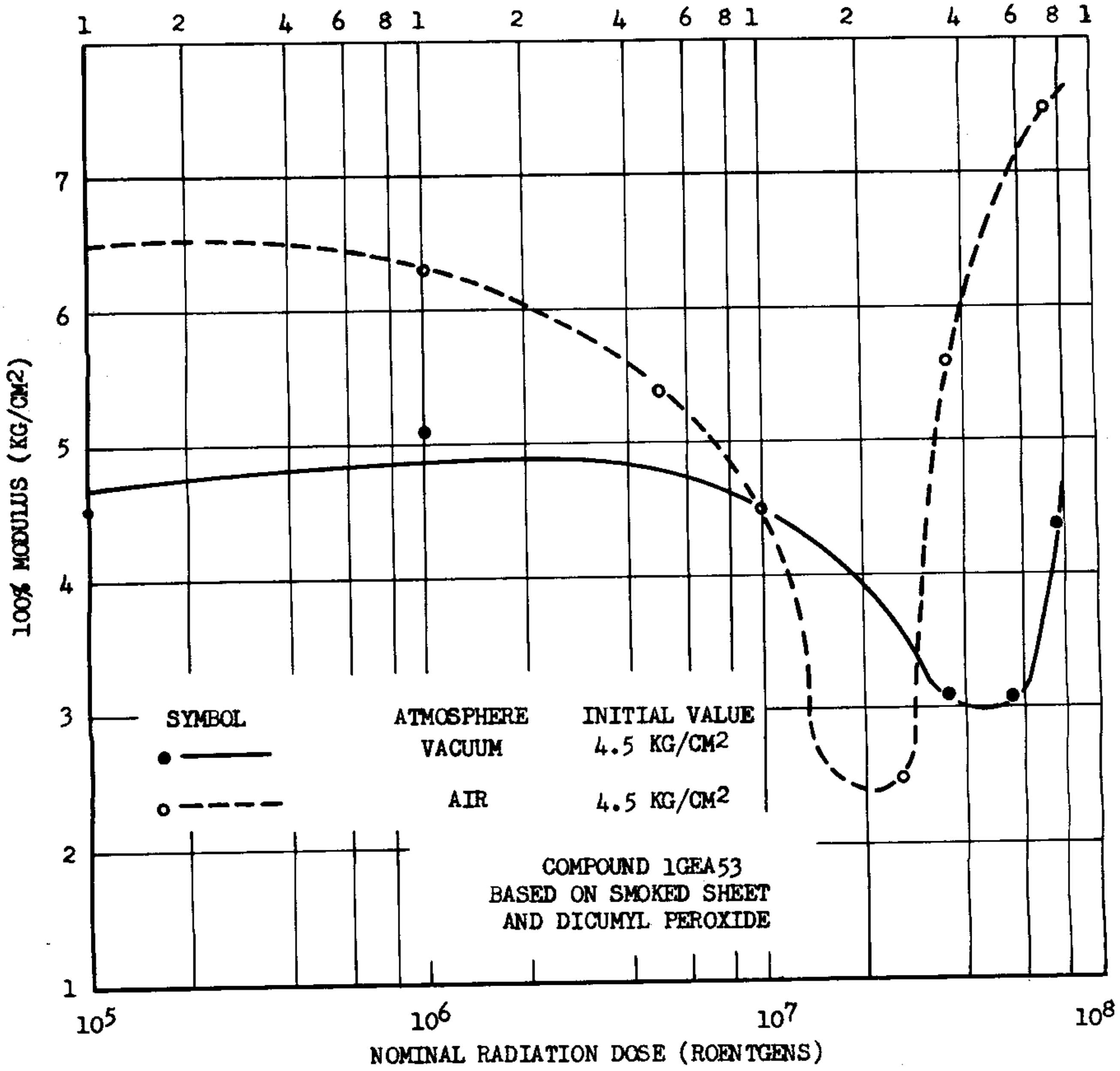
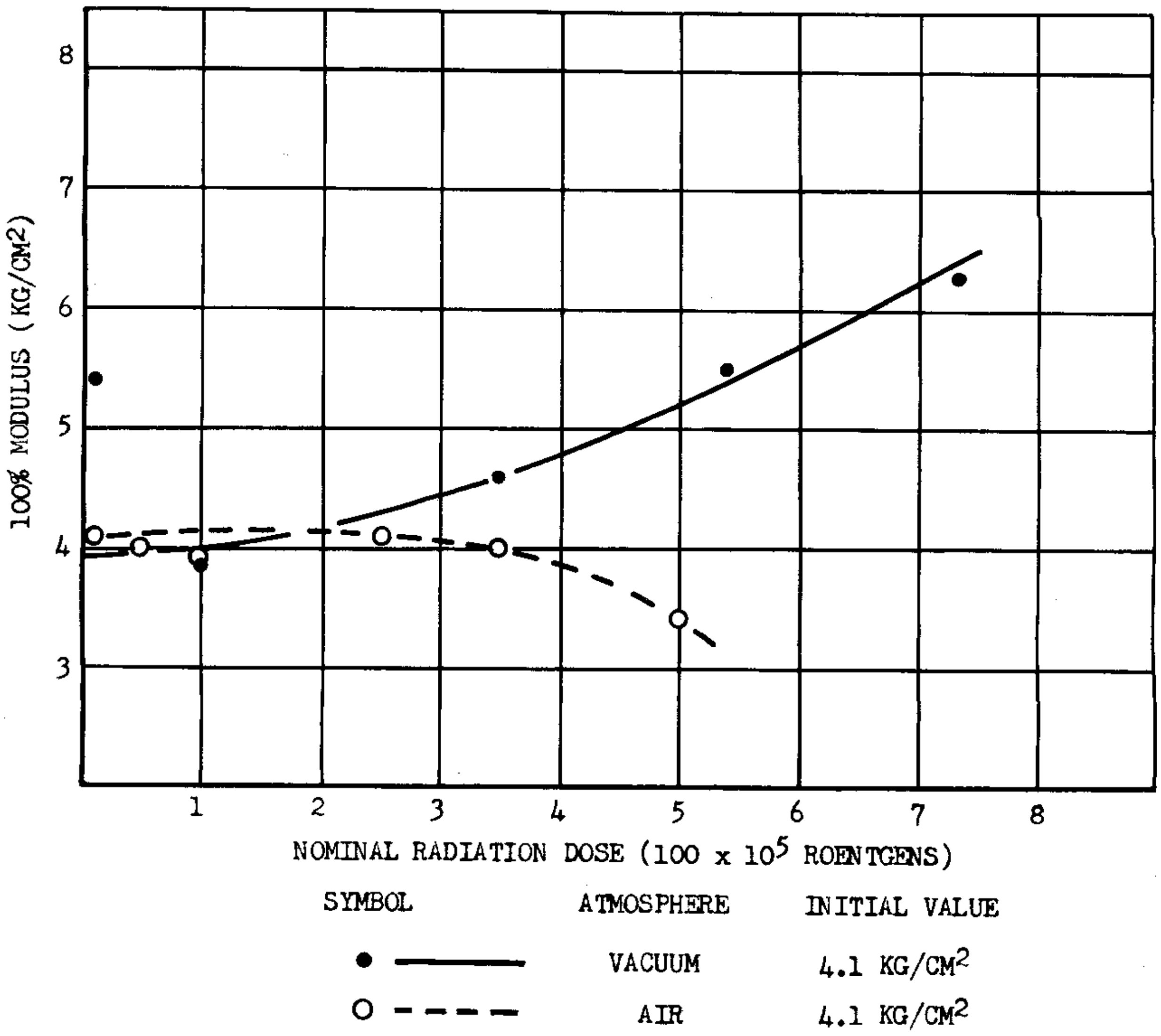


Figure 14

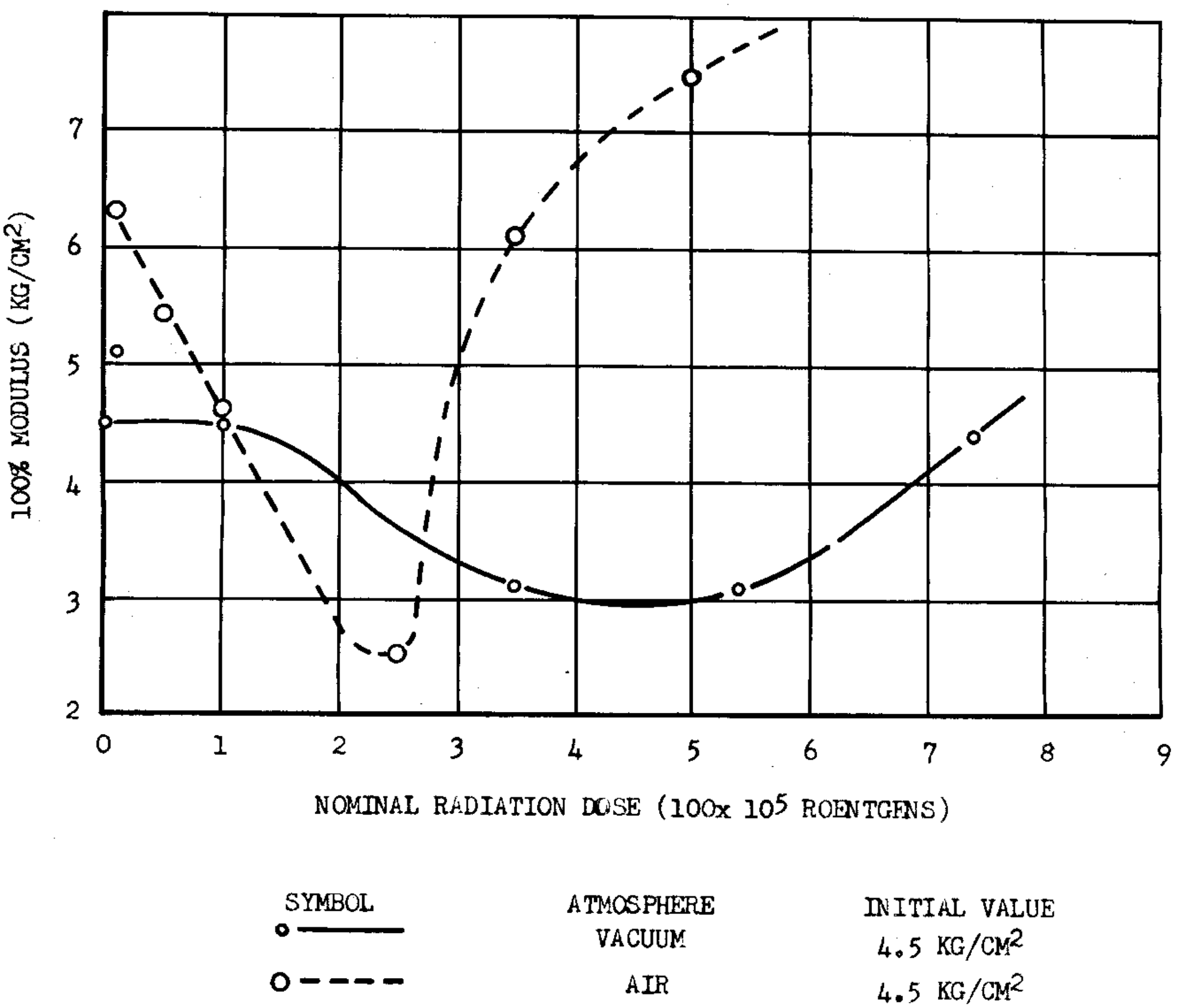
100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA53 BASED ON SMOKED SHEET AND DICUMYL PEROXIDE



COMPOUND 1GEA19
BASED ON GR-S AND HYCAR HH

Figure 15

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA19 BASED ON GR-S AND HYCAR HH



COMPOUND 1GEA53
BASED ON SMOKED SHEET
AND DICYMYL PEROXIDE

Figure 16

100% MODULUS vs. RADIATION DOSE
COMPOUND 1GEA53 BASED ON SMOKED SHEET AND DICUMYL PEROXIDE

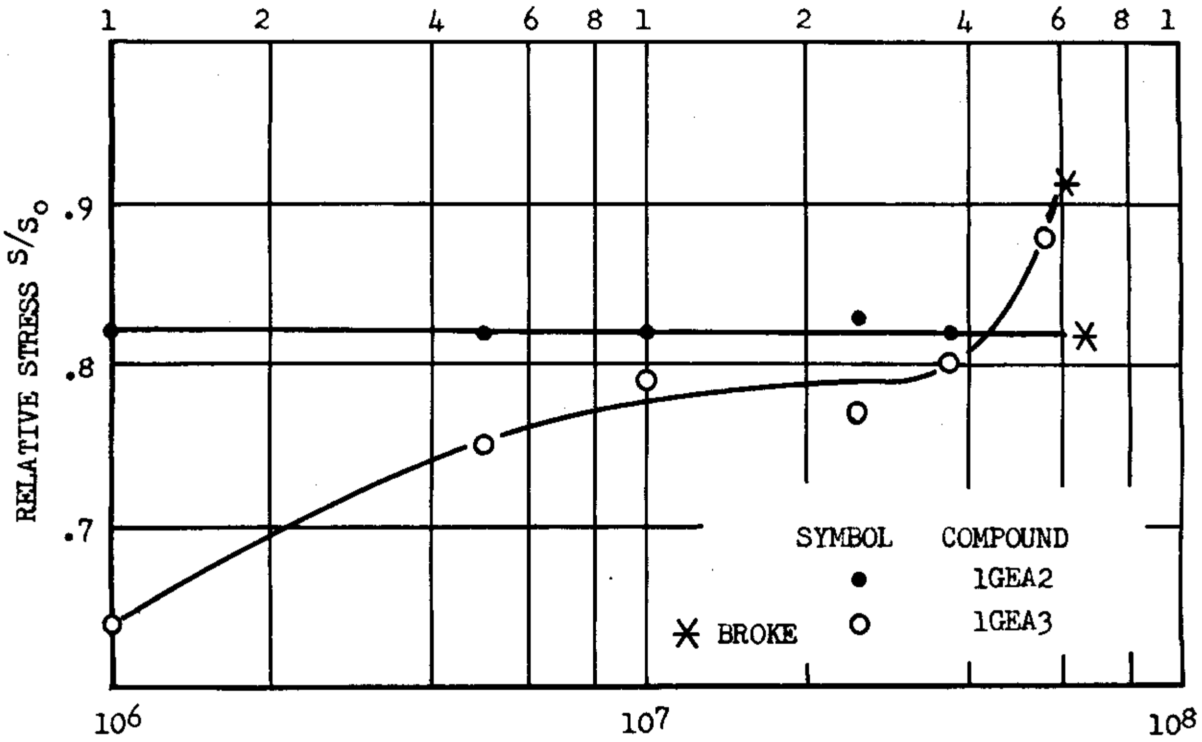


Figure 17

THE EFFECT OF GAMMA RADIATION ON
CONTINUOUS STRESS RELAXATION OF
NEOPRENE COMPOUNDS.

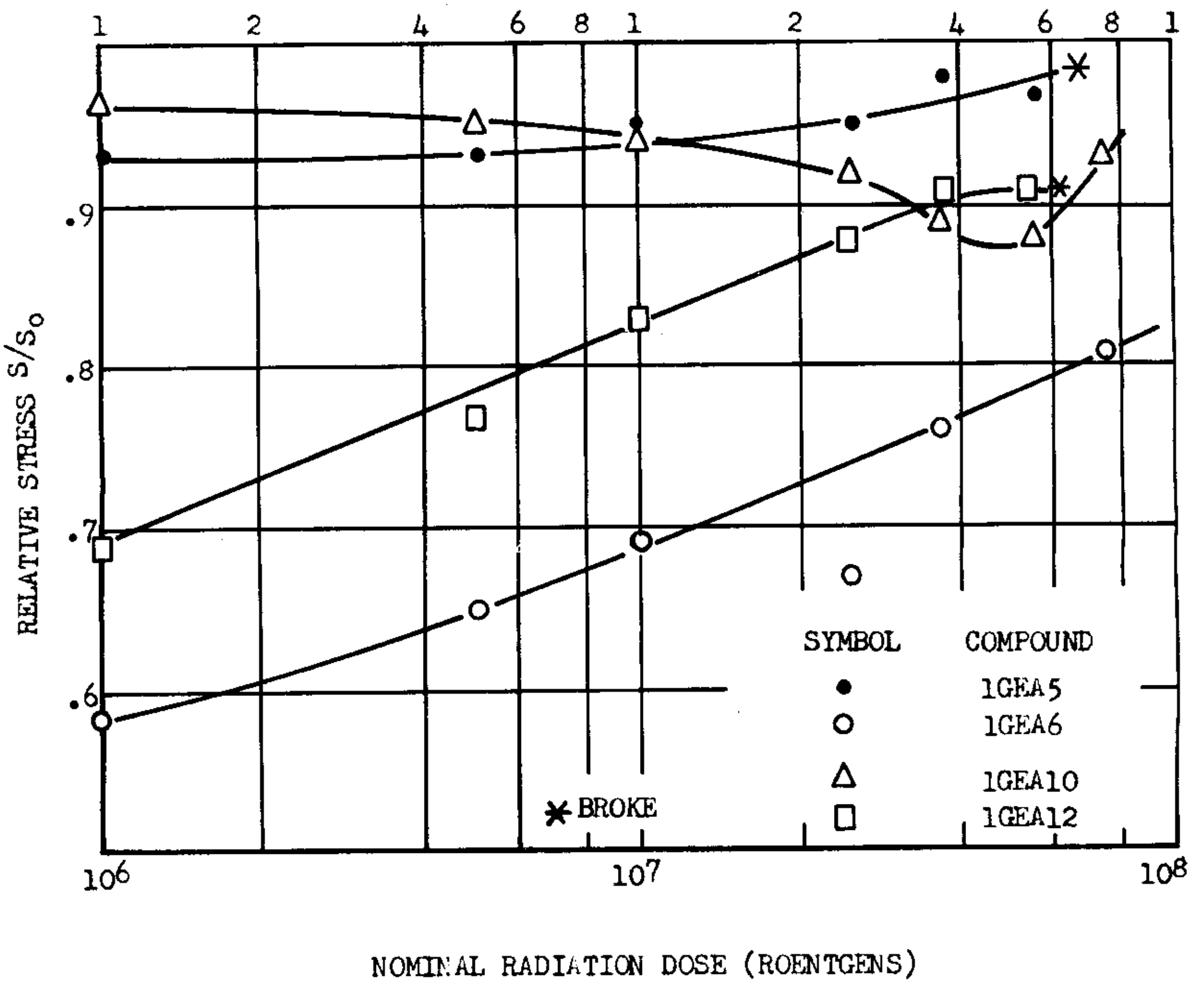


Figure 18

THE EFFECT OF GAMMA RADIATION ON
CONTINUOUS STRESS RELAXATION IN
ELASTOMERIC COMPOUNDS.

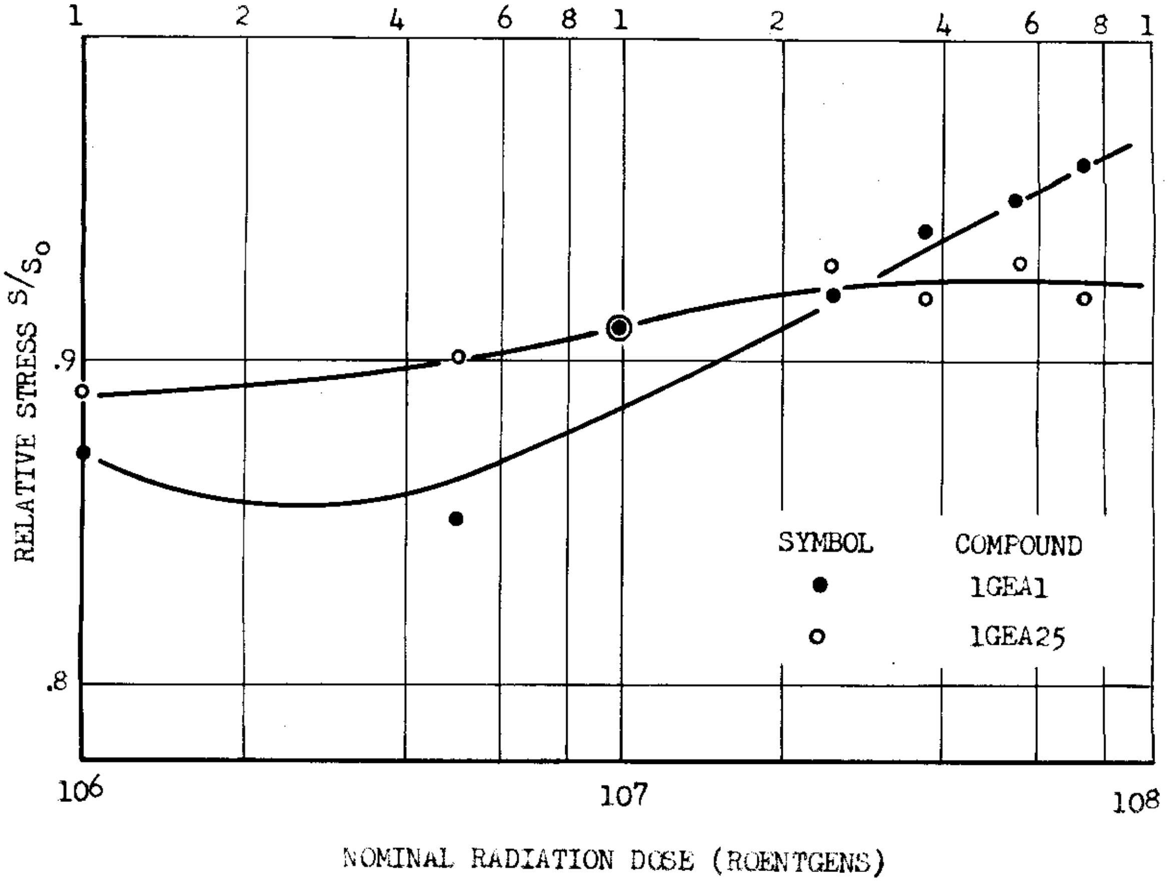


Figure 19

THE EFFECT OF CARBON BLACK ON CONTINUOUS STRESS RELAXATION OF POLYBUTADIENE WITH IRRADIATION.

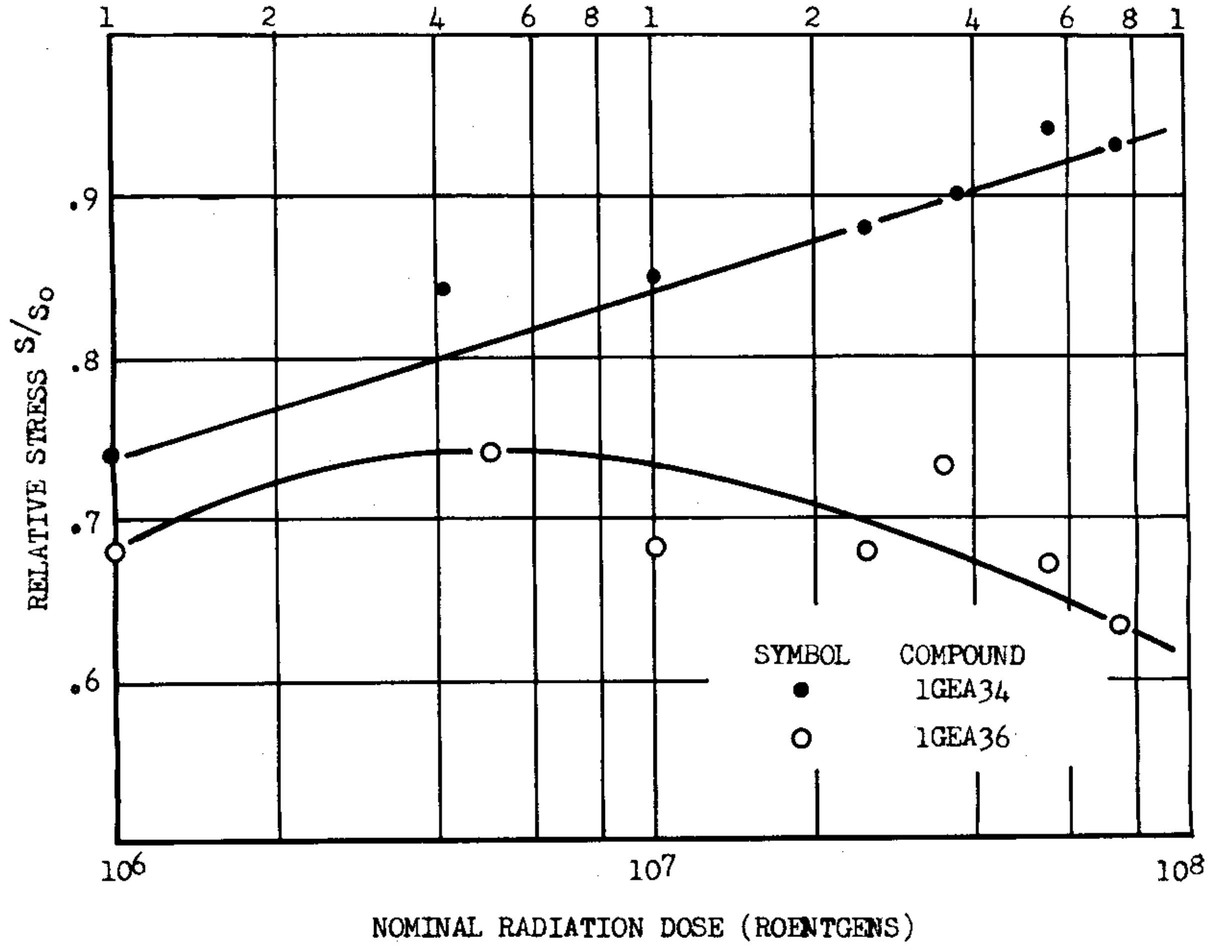


Figure 20

THE EFFECT OF GOODRITE RESIN 50 ON CONTINUOUS STRESS RELAXATION OF GR-S WITH IRRADIATION.

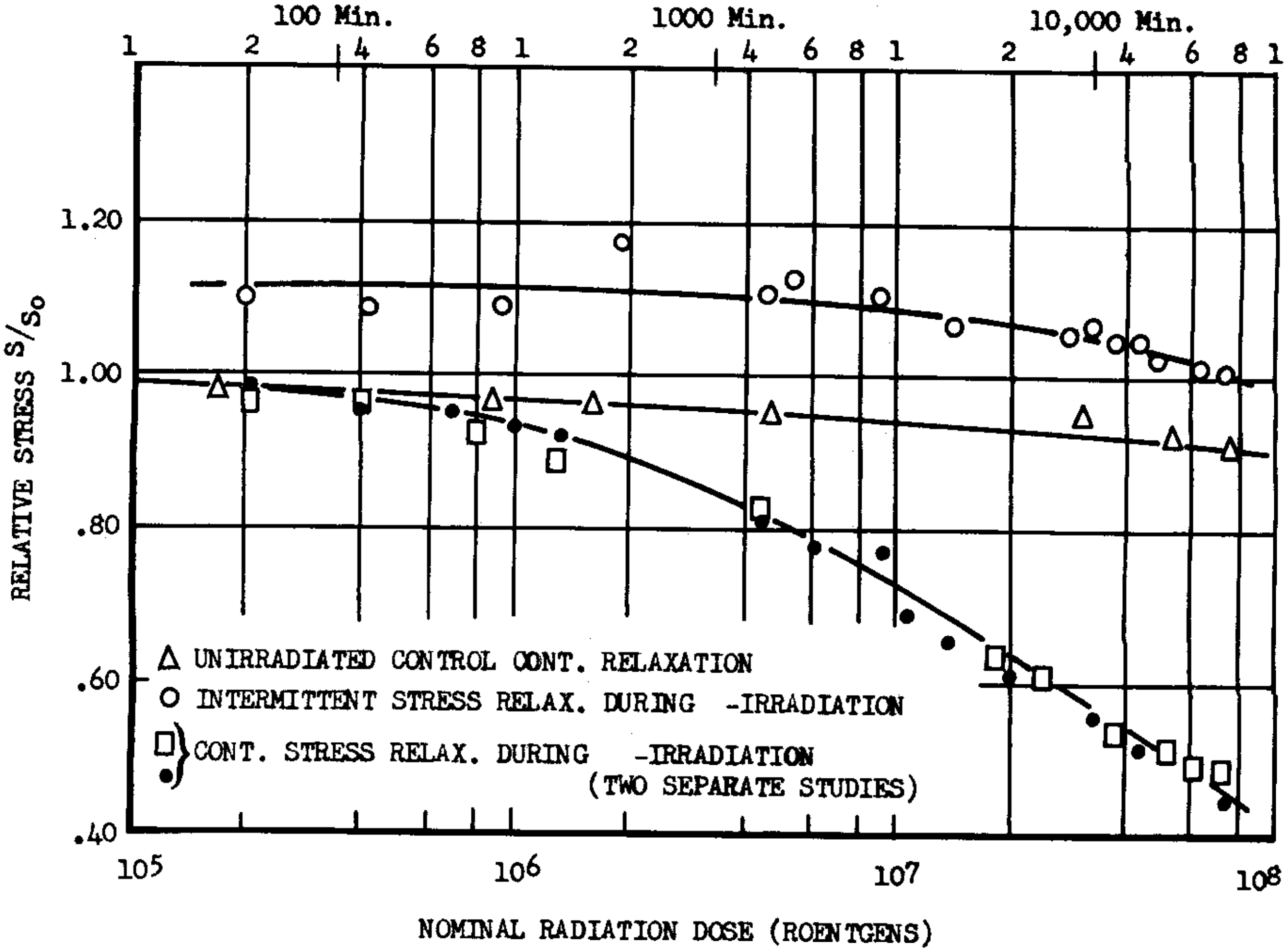


Figure 21

STRESS RELAXATION OF PURE GUM NATURAL RUBBER (COMPOUND 1GEA10) IN A VACUUM

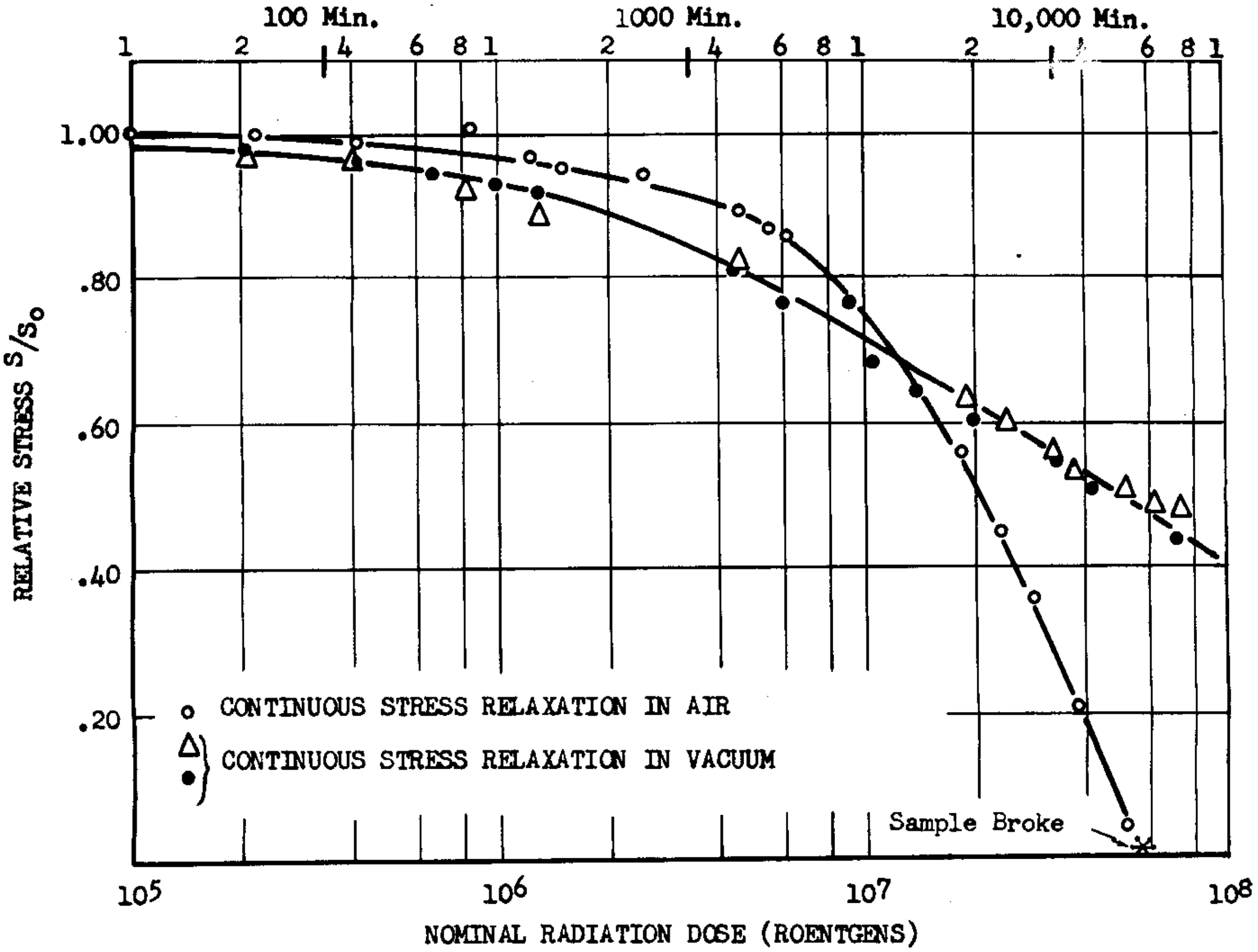
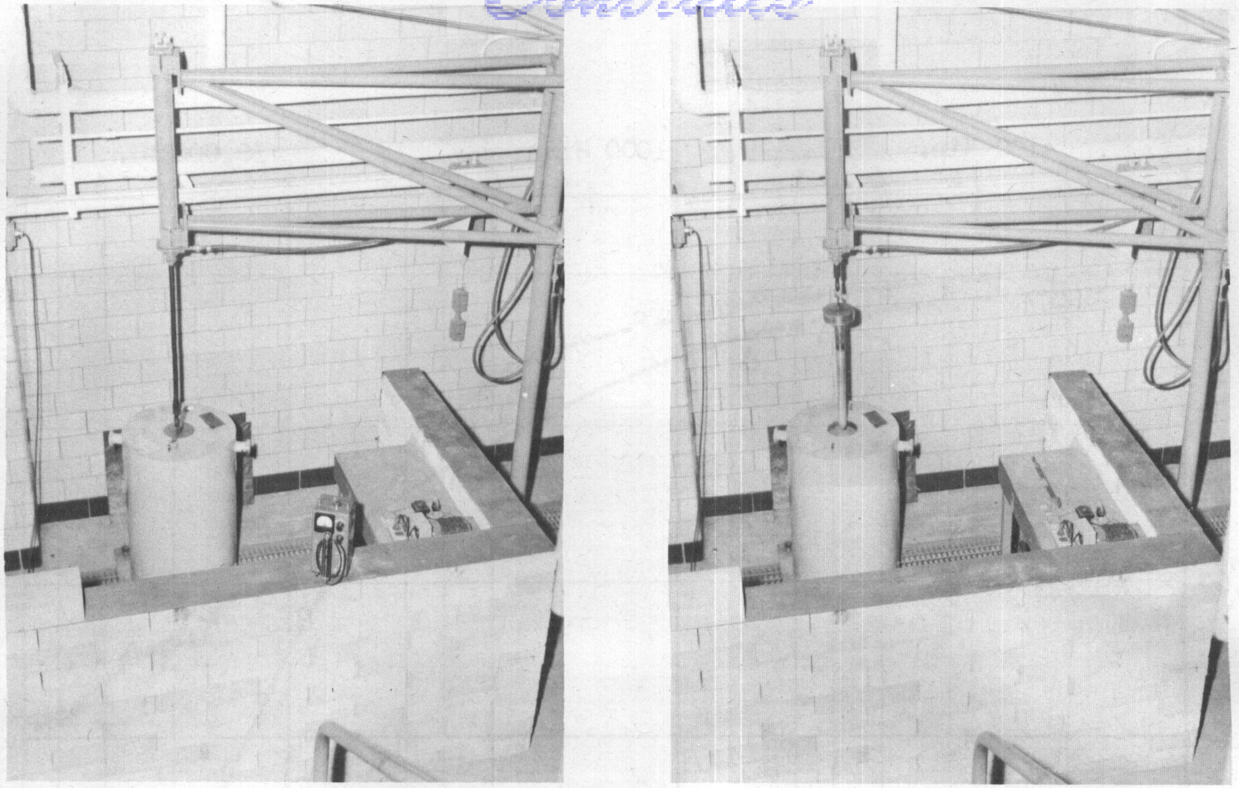


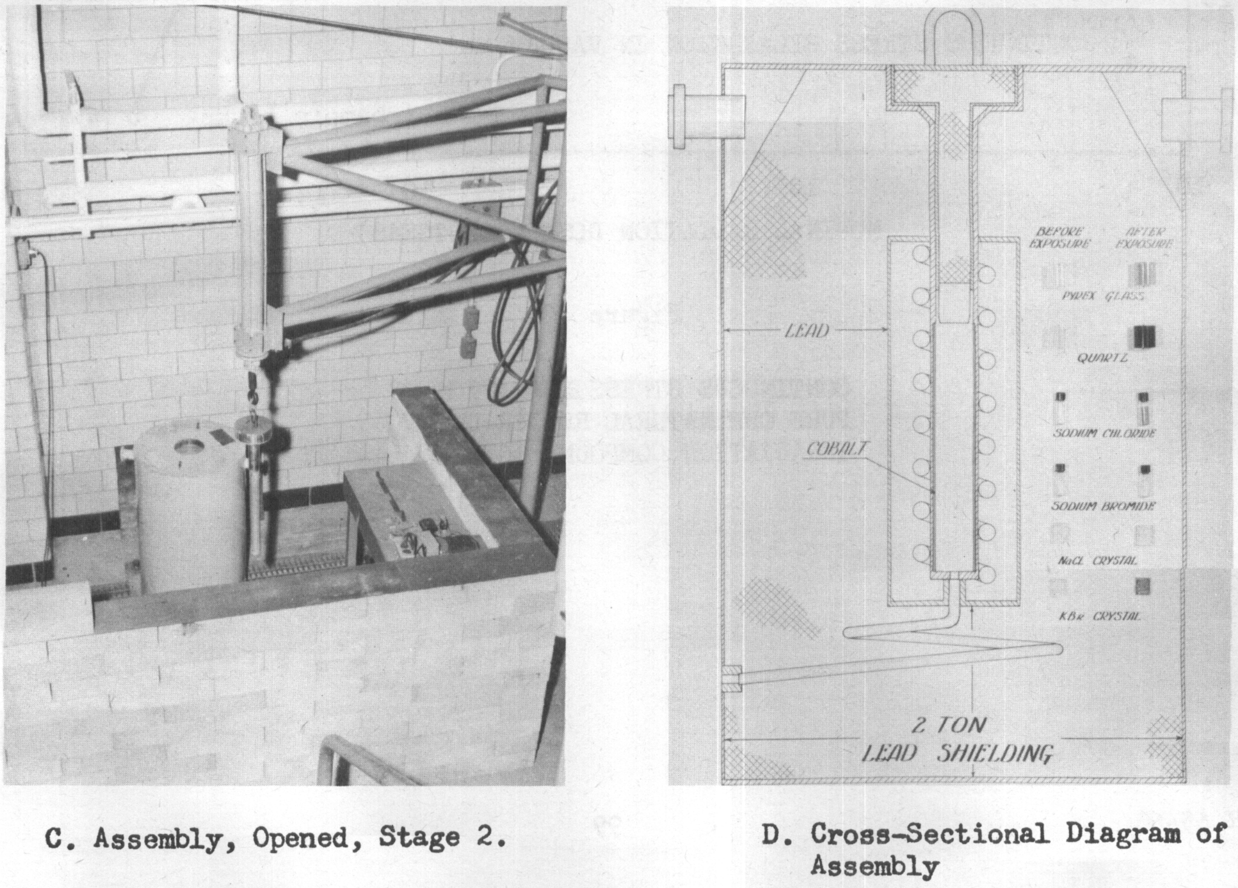
Figure 22

CONTINUOUS STRESS RELAXATION OF
PURE GUM NATURAL RUBBER DURING
IRRADIATION COMPOUND 1GEA10



A. Source-Shield Assembly, Closed

B. Assembly, Opened, Stage 1.



C. Assembly, Opened, Stage 2.

D. Cross-Sectional Diagram of Assembly

Figure 23. Cobalt 60 Source-Shield Assembly