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**COMPRESSION-SET BEHAVIOR  
OF  
IRRADIATED SILICONE ELASTOMERS**

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**NUCLEAR AEROSPACE RESEARCH FACILITY**

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**NUCLEAR AEROSPACE RESEARCH FACILITY**

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**COMPRESSION-SET BEHAVIOR  
OF  
IRRADIATED SILICONE ELASTOMERS**

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## ABSTRACT

The effect of nuclear radiation (five different dose levels in the range of from  $10^8$  to  $10^{10}$  ergs/gm(C)) on the compression-set behavior of three types of silicone elastomers (SE-551, SE-361, and DC-675) was examined. During the irradiation, the samples were compressed at constant strain in an air environment. The observed postirradiation percent compression set after an accumulated dose is described by an empirically derived equation.

The ratio of the number of network chains at equilibrium with the unstrained thickness to the number of network chains at equilibrium with the applied strain rapidly decreases with dose.

The Shore-A hardness of these elastomers was observed to increase with dose. Within the dose region investigated, the hardness attained after an accumulated dose can be expressed by an empirically derived equation.

## REPORT SUMMARY

Compression set buttons of three types of silicone elastomers (SE-361, SE-551, and DC-675) were irradiated to five different dose levels in the range of from  $10^8$  to  $10^{10}$  ergs/gm(C) in the GD/FW Ground Test Reactor. During irradiation the samples were compressed at constant deflection in an air environment. Experimental data are given for percent compression set and Shore A hardness changes as a function of radiation dose. It was found that the compression set could be described by the equation

$$S_D = S_m \exp \left\{ -\alpha D^{-n} \right\}$$

where  $S_D$  = percent compression set at dose  $D$  [ergs/gm(C)],

$S_m$  = percent compression set  $D \longrightarrow$ , and

$\alpha, n$  = material parameters (the values calculated for  $\alpha$ : 0.322, 0.478, and 0.250; and for  $n$ : 0.671, 0.822, and 0.905 for SE-361, SE-551, and DC-675, respectively.)

This equation was also applied with good results to data from the B. F. Goodrich Research Center for radiation-induced compression set for different types of elastomers.

According to the concept of Andrews, Tobolsky and Hansen, two principal species of network chains are postulated for a polymer network relaxing under compression: (1) chains that are at equilibrium when the sample is in its undeformed state,  $N_0$ , and (2) chains formed by the agency of radiation that are at equilibrium in the strained state,  $N_\alpha$ . It can be shown

that the network chain ratio  $\zeta = N_0/N_\alpha$  is given by

$$\zeta = \frac{(t_\alpha/t_s) - (t_s/t_\alpha)^2}{(t_s/t_0)^2 - (t_0/t_s)}$$

where  $t_0$  = original thickness of sample,

$t_\alpha$  = thickness to which sample is compressed, and

$t_s$  = thickness of sample after release from compression.

The quantity  $\zeta$  rapidly decays with dose, and at very high doses it tends asymptotically toward a small negative value, indicating that chain species other than those postulated become operative.

Finally, the observed Shore A hardness can be expressed by the relation

$$H_D = H_0 (D/D_0)^c \text{ for } D \geq D_0$$

where  $H_D$  = hardness attained after dose  $D$  [ergs/gm(C)],

$H_0$  = hardness of the unirradiated sample,

$D_0$  = virtual dose, i.e., the extrapolated inflection point at which the sample's hardness begins to change, and

$c$  = material parameter.

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## I. INTRODUCTION

Compression set can be defined as the deformation permanently remaining in a specimen after it has been subjected to a compressive stress for a specified period of time. Since the compression-set process is sensitive to chain scission and crosslinking reactions, and since high-energy radiation can produce both these reactions, the study of compression set in elastomers provides a good method of determining their radiation resistance.

In the present investigation, the compression-set behavior of three silicone elastomers was studied as a function of radiation dose. Previous experimental data on this behavior were mostly obtained over too narrow a dose range. This made it difficult to develop predictive relationships for the entire course of radiation-induced compression set.

The principal objective of this study was to gain data on compression-set behavior of silicone elastomers over an extended range of dose and, if possible, to derive quantitative relationships describing this behavior. Empirical expressions of this sort have been reported in the literature (Refs. 1 and 2). They are particularly useful for comparative and predictive purposes.

An additional endeavor of this investigation was to deduce from the experimental results certain information about the underlying molecular processes by employing the concepts of the theory of rubberlike elasticity.

## II. EXPERIMENTAL METHOD

### 2.1 Sample Preparation

Three different types of polysiloxane elastomers, (General Electric SE-551, General Electric SE-361, and Dow Corning Silastic 675) were investigated in the form of standard ASTM compression-set buttons of cylindrical shape, 0.5 inch thick and about 1.129 inches in diameter.

SE-551 is a methyl-phenyl polysiloxane compounded with both a manufactured silica and a diatomaceous earth type of silica and colored with Titanox. Approximately 40% of SE-551 consists of filler materials.

SE-361 is a methyl-vinyl polysiloxane, also compounded with both a manufactured silica and a diatomaceous earth type of silica and colored with red iron oxide. About 45% of the total composition consists of filler.

Dow Corning Silastic DC 675 is a methyl-phenyl polysiloxane of 7.5 mole % phenyl methyl siloxane units and 92.5 mole % dimethyl siloxane units. Its average molecular weight is about  $4 \times 10^5$  -  $6 \times 10^5$ .

Complete recipes and curing histories of the aforementioned polysiloxane vulcanizates could not be ascertained because of proprietary reservations.

Of each type of elastomer, a set of 35 compression-set samples was prepared in conformance with ASTM procedure D-395-55. In each such set, 10 samples were selected as control specimens, while 5 samples were used for each of the five irradiation conditions.

The thickness, the specific gravity, and the Shore A hardness of the samples were measured prior to compression and irradiation. The thickness was determined by averaging five individual measurements on each sample (i.e., one measurement at each of the four quadrants of the sample's periphery and one in its center). The Shore A hardness values constitute the average of three individual measurements on each sample. The specific gravity of the elastomers used was determined on the basis of weight-in-air and weight-in-water measurements.

All samples were then compressed in devices as prescribed by procedure ASTM D395-55, Method B (Ref. 3). In the present investigation, the standard ASTM procedure was modified in the following respects: (1) Compression plates of 60-61T aluminum alloy were used instead of chrome-plated steel plates to minimize handling problems due to activation of the metal jigs in a neutron field. (2) The spacer thickness was not selected according to the hardness of the rubber, as outlined in step b of Reference 3, because spacers of the required thicknesses were not available; instead, spacers of 0.376-, 0.377-, and 0.378-inch thickness were used randomly for all three types of elastomers and the percentage deflection was calculated for each specimen. (3) The heat treatment (step c of Reference 3) in the procedure was omitted, and the radiation treatment was substituted.

The SE-551 samples were compressed 18 hours before irradiation and the SE-361 and the DC-675 samples were compressed 12 hours before irradiation. All samples were released approximately 216 hours after irradiation. The total time that the

specimens were in compression was approximately 240 hours for the SE-551 samples and 234 hours for the SE-361 and DC-675 samples. The control samples were compressed for the same periods of time and stored in the laboratory at 75°F.

The samples to be irradiated were mounted on five perforated aluminum panels in a circular configuration at an average distance of eight inches from the center point, which corresponded to the reactor centerline when the panels were inserted. Five compression-set bottoms of each elastomer were mounted on each panel.

## 2.2 Dosimetry

Four dosimetry packets were mounted in the circular configurations on each panel, eight inches from the center and at equidistant locations in each of the four quadrants of the circle. The dosimeters contained in each of the four packets on the five panels are given in Table I. The location of Panels 1 and 2 was inadvertently interchanged. The original plan was that Panel 2 should receive the lowest dose, while Panel 1 was to be exposed to the next highest dose. For this reason, Panel 1 was equipped with two types of gamma-ray dosimeters to record a dose that was expected to be close to the upper limit of usefulness of the tetrachloroethylene system and to the lower limit of the nitrous-oxide system.

Table I  
Dosimetry Description

| Dosimeter                                           |                           | Contents of Dosimetry<br>Packets on Panel |   |   |   |   |
|-----------------------------------------------------|---------------------------|-------------------------------------------|---|---|---|---|
| Type                                                | Radiation Detected        | 1                                         | 2 | 3 | 4 | 5 |
| Aluminum foil                                       | Neutrons ( $E > 8$ Mev)   | X                                         | X | X | X | X |
| Sulfur pellet                                       | Neutrons ( $E > 2.9$ Mev) | X                                         | X | X |   |   |
| Sulfur-epoxy disk                                   | Neutrons ( $E > 2.9$ Mev) |                                           |   |   | X | X |
| Pair of bare and<br>cadmium-covered<br>copper foils | Thermal neutrons          | X                                         | X | X | X | X |
| Nitrous-oxide<br>ampoule                            | Gamma rays                | X                                         |   | X | X | X |
| Tetrachloro-<br>ethylene<br>ampoule                 | Gamma rays                | X                                         | X |   |   |   |

### 2.3 Sample Irradiation

The sample irradiation was carried out in the Radiation Effects Testing System at GD/FW's Nuclear Aerospace Research Facility (NARF). In this system, the Ground Test Reactor (GTR) is used as the radiation source. It is located in one side (the west side) of a pool divided by a dam wall into a wet and dry side. The dry side of the pool is the irradiation cell. The GTR is positioned in a closet-like structure that is built into the center of the dam and protrudes into the irradiation cell. Thus, three faces of the closet (the GTR) are available for irradiation testing.

The materials, components, or systems that are to be tested are placed in environmental chambers that are transported on pallets down into the irradiation cell by a remotely controlled three-track shuttle system. Temperatures inside the chambers are controlled ( $-65^{\circ}\text{F}$  to  $450^{\circ}\text{F}$ ) from an air duct system that terminates beneath the pallets at the three testing positions.

Two environmental chambers were used during the tests described here. Panels 1 and 2 were irradiated in one chamber for 2.5 hours at 0.6 Mw reactor power, while Panels 3, 4, and 5 were exposed in a second chamber for 5 hours at 3 Mw. The locations were selected in such a manner that the five panels would receive gamma-ray doses in the range of from  $10^8$  to  $10^{10}$  ergs/gm(C). The irradiation was carried out in an air environment, and the temperature was monitored by a thermocouple embedded within a compression-set button of silicone rubber mounted on each panel. An attempt was made to maintain the temperature within these monitored samples as close to  $75^{\circ}\text{F}$  as possible by circulating a refrigerated-air current in the environmental chambers. This was achieved for the samples mounted on Panels 1, 2, and 3. However, the temperature as monitored in the samples on Panels 4 and 5, which received the two higher dose rates (see Table III), could not be held constant despite the fact that the ambient air had been cooled to  $40^{\circ}\text{F}$ . Radiation-induced heating produced an appreciable temperature rise in the monitored samples of these two panels. Within a period of about 75 minutes after the reactor had been brought to peak power, the temperatures recorded for

Panels 4 and 5 had risen to 120°F and 200°F, respectively, and remained at these levels with short fluctuations of  $\pm 10^\circ\text{F}$  until reactor shutdown.

#### 2.4 Sample Testing

About 216 hours after termination of the irradiation, all samples were released from the compression devices. The thickness of the samples was determined 30 minutes after release. The thickness values of each sample constitute the average of five individual measurements as described in Section 2.1. The Shore A hardness values are the average of three individual measurements per sample.

The percent deflection was calculated as follows:

$$\%D = \frac{t_o - t_\alpha}{t_o} \times 100$$

where  $t_o$  = original thickness and  $t_\alpha$  = thickness of the spacer.

The percent compression set was calculated as follows:

$$\%S = \frac{(t_o - t_s)}{(t_o - t_\alpha)} \times 100$$

where  $t_o$  = original thickness of the sample,

$t_s$  = thickness of the sample 30 minutes after release from the compression device, and

$t_\alpha$  = thickness to which the sample was compressed (spacer thickness).

### III. EXPERIMENTAL RESULTS

Panels 1 and 2 were irradiated for 2.5 hours at 0.6 Mw reactor power and Panels 3, 4, and 5 were irradiated for 5 hours at 3 Mw reactor power. The dosimeters mounted on the panels yielded the dose values listed in Table II. The average rates of irradiation are given in Table III.

The preirradiation values of the specific gravity of the three elastomers were as follows:

| <u>Elastomer</u> | <u>Specific Gravity</u> |
|------------------|-------------------------|
| SE-361           | 1.27                    |
| SE-551           | 1.23                    |
| DC-675           | 1.26                    |

The hardness of each sample was measured both before and after irradiation and the resultant data are presented in Table IV.

The thickness of the compression-set buttons measured before compression and 30 minutes after release from the compression device, the percent deflection during compression, and the percent compression set calculated from these measurements are given in Tables V, VI, and VII, for elastomers SE-361, SE-551, and DC-675, respectively. The average values and the standard deviation of the measurements are also given.

Table II  
Dosimetric Data of Silicone Elastomer Irradiation

| Integrated Neutron Flux (n/cm <sup>2</sup> x 10 <sup>12</sup> ) |                         |                                                | Absorbed Gamma-Ray Dose<br>[ergs/gm(C) x 10 <sup>-9</sup> ] |                             |
|-----------------------------------------------------------------|-------------------------|------------------------------------------------|-------------------------------------------------------------|-----------------------------|
| Aluminum Foil<br>(E > 8 Mev)                                    | Sulfur<br>(E > 2.9 Mev) | Copper foils<br>bare-Cd-cov.<br>(thermal neut) | Nitrous oxide                                               | Tetrachloro-<br>ethylene    |
| Panel 1                                                         |                         |                                                |                                                             |                             |
| 1.38                                                            | 33.3                    | 11.4                                           | 0.168                                                       | 0.219                       |
| 1.38                                                            | 31.8                    | 9.07                                           | 0.244                                                       | 0.219                       |
| 1.35                                                            | 32.6                    | 11.9                                           | 0.261                                                       | 0.210                       |
| 1.34                                                            | 32.1                    | 11.1                                           | 0.244                                                       | 0.219                       |
| Average<br>1.36 ± 0.02                                          | Average<br>32.5 ± 0.66  | Average<br>10.9 ± 1.22                         | Combined Average<br>0.222 ± 0.030                           |                             |
| Panel 2                                                         |                         |                                                |                                                             |                             |
| 3.03                                                            | 71.8                    | 9.88                                           | -----                                                       | 0.455                       |
| 3.20                                                            | 76.9                    | 18.3                                           | -----                                                       | 0.465                       |
| 3.59                                                            | 88.1                    | 11.2                                           | -----                                                       | 0.517                       |
| 3.21                                                            | 73.4                    | 8.75                                           | -----                                                       | 0.455                       |
| Average<br>3.26 ± 0.237                                         | Average<br>77.6 ± 7.35  | Average<br>12.0 ± 4.30                         |                                                             | Average<br>0.473 ±<br>0.033 |
| Panel 3                                                         |                         |                                                |                                                             |                             |
| 9.40                                                            | 251                     | 90.2                                           | 1.51                                                        | -----                       |
| 9.29                                                            | 262                     | 97.7                                           | 1.89                                                        | -----                       |
| 9.40                                                            | 257                     | -----                                          | 1.58                                                        | -----                       |
| 10.8                                                            | 252                     | -----                                          | 1.60                                                        | -----                       |
| Average<br>9.72 ± 0.72                                          | Average<br>256 ± 5.5    | Average<br>94.0 ± 5.3                          | Average<br>1.65 ± 0.17                                      |                             |
| Panel 4                                                         |                         |                                                |                                                             |                             |
| 41.0                                                            | 1230                    | 81.2                                           | 5.08                                                        | -----                       |
| 41.5                                                            | 1230                    | 61.6                                           | 4.91                                                        | -----                       |
| 42.6                                                            | 1380                    | 62.6                                           | 5.08                                                        | -----                       |
| 38.6                                                            | 1410                    | 109                                            | 4.91                                                        | -----                       |
| Average<br>40.9 ± 1.7                                           | Average<br>1310 ± 95    | Average<br>78.8 ± 22.2                         | Average<br>5.00 ± 0.095                                     |                             |
| Panel 5                                                         |                         |                                                |                                                             |                             |
| 106                                                             | 3320                    | -----                                          | 13.8                                                        | -----                       |
| 105                                                             | 3470                    | -----                                          | 14.0                                                        | -----                       |
| 106                                                             | 3270                    | -----                                          | 12.0                                                        | -----                       |
| -----                                                           | 3120                    | -----                                          | -----                                                       | -----                       |
| Average<br>106                                                  | Average<br>3300 ± 145   |                                                | Average<br>13.2 ± 1.14                                      |                             |

Table III

## Rate of Irradiation of Silicone Elastomers

| Panel | Neutron Flux                                            | Gamma-Ray Dose Rate                   |
|-------|---------------------------------------------------------|---------------------------------------|
|       | $n/cm^2\text{-sec} \times 10^{-9}$                      | $\text{ergs/gm(C)-hr} \times 10^{-9}$ |
| 1     | 0.151 (E > 8 Mev)<br>3.61 (E > 2.9 Mev)<br>1.21 thermal | 0.088                                 |
| 2     | 0.362 (E > 8 Mev)<br>8.61 (E > 2.9 Mev)<br>1.33 thermal | 0.189                                 |
| 3     | 0.540 (E > 8 Mev)<br>14.2 (E > 2.9 Mev)<br>5.22 thermal | 0.33                                  |
| 4     | 2.27 (E > 8 Mev)<br>73.0 (E > 2.9 Mev)<br>4.37 thermal  | 1.00                                  |
| 5     | 5.87 (E > 8 Mev)<br>183. (E > 2.9 Mev)                  | 2.64                                  |

Table IV  
Pre- and Postirradiation Shore A Durometer Hardness  
of Silicone Elastomers

| Elastomer | Gamma-Ray Dose [ergs/gm(C) x 10 <sup>-9</sup> ] |       |      |       |      |      |      |      |      |      |
|-----------|-------------------------------------------------|-------|------|-------|------|------|------|------|------|------|
|           | 0                                               | 0.222 | 0    | 0.473 | 0    | 1.65 | 0    | 5.0  | 0    | 13.3 |
| SE-361    | 42                                              | 54    | 47   | 62    | 48   | 72   | 48   | 86   | 50   | 95   |
|           | 50                                              | 58    | 47   | 62    | 49   | 73   | 49   | 86   | 50   | 94   |
|           | 50                                              | 57    | 49   | 63    | 44   | 70   | 50   | 86   | 50   | 94   |
|           | 51                                              | 57    | 49   | 63    | 49   | 72   | 48   | 86   | 50   | 94   |
|           | 50                                              | 57    | 48   | 62    | 48   | 74   | 47   | 86   | 50   | 93   |
|           | 48.6                                            | 56.6  | 48.0 | 62.4  | 47.6 | 72.2 | 48.4 | 86.0 | 50   | 94   |
|           | ±3.7                                            | ±1.5  | ±1.0 | ±0.5  | ±2.1 | ±1.5 | ±1.1 | 0    | 0    | ±0.7 |
| SE-551    | 43                                              | 43    | 41   | 46    | 41   | 57   | 43   | 72   | 43   | 88   |
|           | 42                                              | 42    | 42   | 48    | 42   | 57   | 44   | 72   | 43   | 87   |
|           | 43                                              | 44    | 42   | 46    | 42   | 57   | 43   | 73   | 43   | 87   |
|           | 42                                              | 42    | 42   | 46    | 44   | 56   | 43   | 72   | 44   | 85   |
|           | 44                                              | 43    | 43   | 47    | 44   | 56   | 41   | 71   | 44   | 87   |
|           | 42.8                                            | 42.8  | 42.0 | 46.6  | 42.6 | 56.6 | 42.8 | 72.0 | 43.4 | 86.8 |
|           | ±0.8                                            | ±0.8  | ±0.7 | ±0.9  | ±1.3 | ±0.5 | ±1.1 | ±0.7 | ±0.5 | ±1.1 |
| DC-675    | 68                                              | 68    | 66   | 73    | 68   | 85   | 68   | 94   | 68   | 98   |
|           | 67                                              | 64    | 67   | 72    | 69   | 84   | 68   | 94   | 67   | 98   |
|           | 66                                              | 67    | 68   | 70    | 68   | 83   | 69   | 95   | 67   | 98   |
|           | 66                                              | 65    | 68   | 72    | 68   | 84   | 67   | 94   | 65   | 99   |
|           | 68                                              | 67    | 66   | 70    | 67   | 83   | 68   | 94   | 68   | 97   |
|           | 67.0                                            | 66.2  | 67.0 | 71.4  | 68.0 | 83.8 | 68.0 | 94.2 | 67.0 | 98.0 |
|           | ±1.3                                            | ±1.6  | ±1.3 | ±1.3  | ±0.7 | ±2.6 | ±0.7 | ±0.6 | ±1.2 | ±0.7 |

Table V  
Compression Set of Silicone Elastomer SE-361

| Gamma Ray Dose<br>[ergs/gm(C) x 10 <sup>-9</sup> ] | Sample Thickness<br>(inch) |       | Spacer<br>Thickness<br>(inch) | Deflection<br>(%) | Compression<br>Set (%) |
|----------------------------------------------------|----------------------------|-------|-------------------------------|-------------------|------------------------|
|                                                    | Before                     | After |                               |                   |                        |
| Control                                            | 0.496                      | 0.486 | 0.377                         | 24.0              | 8.40                   |
|                                                    | 0.488                      | 0.487 | 0.377                         | 22.7              | 0.90                   |
|                                                    | 0.488                      | 0.482 | 0.377                         | 22.7              | 5.41                   |
|                                                    | 0.493                      | 0.486 | 0.377                         | 23.5              | 6.03                   |
|                                                    | 0.489                      | 0.484 | 0.377                         | 22.9              | 4.46                   |
|                                                    | 0.484                      | 0.480 | 0.377                         | 22.1              | 3.74                   |
|                                                    | 0.487                      | 0.482 | 0.377                         | 22.6              | 4.55                   |
|                                                    | 0.496                      | 0.492 | 0.377                         | 24.0              | 3.36                   |
|                                                    | 0.481                      | 0.476 | 0.377                         | 21.6              | 4.81                   |
|                                                    | 0.491                      | 0.485 | 0.377                         | 23.2              | 2.26                   |
|                                                    |                            |       |                               |                   | <u>4.69±2.76</u>       |
| 0.222                                              | 0.487                      | 0.437 | 0.376                         | 22.8              | 45.05                  |
|                                                    | 0.484                      | 0.437 | 0.376                         | 22.3              | 43.52                  |
|                                                    | 0.498                      | 0.443 | 0.376                         | 24.5              | 45.08                  |
|                                                    | 0.486                      | 0.438 | 0.376                         | 22.6              | 43.64                  |
|                                                    | 0.483                      | 0.437 | 0.376                         | 22.2              | 42.99                  |
|                                                    |                            |       |                               |                   | <u>44.06±0.95</u>      |
| 0.473                                              | 0.486                      | 0.419 | 0.378                         | 22.2              | 62.04                  |
|                                                    | 0.494                      | 0.419 | 0.378                         | 23.5              | 64.66                  |
|                                                    | 0.485                      | 0.413 | 0.378                         | 22.1              | 67.29                  |
|                                                    | 0.488                      | 0.417 | 0.378                         | 22.5              | 64.55                  |
|                                                    | 0.494                      | 0.421 | 0.378                         | 23.5              | 62.93                  |
|                                                    |                            |       |                               |                   | <u>64.29±0.01</u>      |
| 1.65                                               | 0.497                      | 0.396 | 0.378                         | 24.0              | 84.87                  |
|                                                    | 0.487                      | 0.394 | 0.378                         | 22.4              | 85.32                  |
|                                                    | 0.485                      | 0.392 | 0.378                         | 22.1              | 86.92                  |
|                                                    | 0.483                      | 0.394 | 0.378                         | 21.7              | 84.76                  |
|                                                    | 0.488                      | 0.391 | 0.378                         | 22.5              | 88.18                  |
|                                                    |                            |       |                               |                   | <u>86.01±1.49</u>      |
| 5.0                                                | 0.491                      | 0.378 | 0.376                         | 23.4              | 98.26                  |
|                                                    | 0.486                      | 0.387 | 0.376                         | 22.6              | 90.00                  |
|                                                    | 0.484                      | 0.376 | 0.376                         | 22.3              | 100.00                 |
|                                                    | 0.489                      | 0.380 | 0.376                         | 23.1              | 96.46                  |
|                                                    | 0.490                      | 0.376 | 0.376                         | 23.3              | 100.00                 |
|                                                    |                            |       |                               |                   | <u>96.94±4.15</u>      |
| 13.3                                               | 0.486                      | 0.373 | 0.378                         | 22.2              | 104.63                 |
|                                                    | 0.480                      | 0.368 | 0.378                         | 21.3              | 109.80                 |
|                                                    | 0.487                      | 0.370 | 0.378                         | 22.4              | 107.34                 |
|                                                    | 0.496                      | 0.367 | 0.378                         | 23.8              | 109.32                 |
|                                                    | 0.499                      | 0.366 | 0.378                         | 24.2              | 109.92                 |
|                                                    |                            |       |                               |                   | <u>108.20±2.12</u>     |

Table VI  
Compression Set of Silicone Elastomer SE-551

| Gamma Ray Dose<br>[ergs/gm(C) x 10 <sup>-9</sup> ] | Sample Thickness<br>(inch) |       | Spacer<br>Thickness<br>(inch) | Deflection<br>(%) | Compression<br>Set (%) |
|----------------------------------------------------|----------------------------|-------|-------------------------------|-------------------|------------------------|
|                                                    | Before                     | After |                               |                   |                        |
| Control                                            | 0.480                      | 0.476 | 0.378                         | 21.2              | 3.92                   |
|                                                    | 0.481                      | 0.478 | 0.378                         | 21.4              | 2.91                   |
|                                                    | 0.484                      | 0.480 | 0.378                         | 21.9              | 3.77                   |
|                                                    | 0.493                      | 0.487 | 0.378                         | 23.3              | 5.22                   |
|                                                    | 0.479                      | 0.477 | 0.378                         | 21.1              | 1.98                   |
|                                                    | 0.489                      | 0.486 | 0.378                         | 22.7              | 2.70                   |
|                                                    | 0.484                      | 0.481 | 0.378                         | 21.9              | 2.83                   |
|                                                    | 0.490                      | 0.485 | 0.378                         | 22.9              | 4.46                   |
|                                                    | 0.495                      | 0.489 | 0.378                         | 23.6              | 5.13                   |
|                                                    | 0.491                      | 0.486 | 0.378                         | 23.0              | 4.42                   |
|                                                    |                            |       |                               |                   | <u>3.73±1.22</u>       |
| 0.222                                              | 0.491                      | 0.467 | 0.378                         | 23.0              | 21.24                  |
|                                                    | 0.489                      | 0.461 | 0.378                         | 22.7              | 25.22                  |
|                                                    | 0.495                      | 0.465 | 0.378                         | 23.6              | 25.64                  |
|                                                    | 0.487                      | 0.462 | 0.378                         | 22.4              | 22.94                  |
|                                                    | 0.483                      | 0.458 | 0.378                         | 22.6              | 23.80                  |
|                                                    |                            |       |                               |                   | <u>23.77±1.78</u>      |
| 0.473                                              | 0.492                      | 0.442 | 0.378                         | 23.2              | 43.86                  |
|                                                    | 0.496                      | 0.445 | 0.378                         | 23.8              | 43.22                  |
|                                                    | 0.488                      | 0.442 | 0.378                         | 22.5              | 41.82                  |
|                                                    | 0.495                      | 0.441 | 0.378                         | 23.6              | 46.15                  |
|                                                    | 0.494                      | 0.445 | 0.378                         | 23.5              | 42.24                  |
|                                                    |                            |       |                               |                   | <u>43.46±1.71</u>      |
| 1.65                                               | 0.495                      | 0.408 | 0.378                         | 23.6              | 74.36                  |
|                                                    | 0.488                      | 0.409 | 0.378                         | 22.5              | 71.82                  |
|                                                    | 0.500                      | 0.408 | 0.378                         | 24.4              | 75.41                  |
|                                                    | 0.488                      | 0.408 | 0.378                         | 22.5              | 72.73                  |
|                                                    | 0.478                      | 0.410 | 0.378                         | 20.9              | 68.00                  |
|                                                    |                            |       |                               |                   | <u>72.46±2.86</u>      |
| 5.0                                                | 0.484                      | 0.382 | 0.378                         | 21.9              | 96.23                  |
|                                                    | 0.490                      | 0.385 | 0.378                         | 22.9              | 93.75                  |
|                                                    | 0.494                      | 0.383 | 0.378                         | 23.5              | 95.69                  |
|                                                    | 0.502                      | 0.382 | 0.378                         | 24.7              | 96.77                  |
|                                                    | 0.497                      | 0.382 | 0.378                         | 23.9              | 96.64                  |
|                                                    |                            |       |                               |                   | <u>95.82±1.23</u>      |
| 13.3                                               | 0.491                      | 0.369 | 0.378                         | 23.0              | 107.96                 |
|                                                    | 0.482                      | 0.372 | 0.378                         | 21.6              | 105.77                 |
|                                                    | 0.492                      | 0.369 | 0.378                         | 23.2              | 107.89                 |
|                                                    | 0.486                      | 0.367 | 0.378                         | 22.2              | 110.19                 |
|                                                    | 0.487                      | 0.374 | 0.378                         | 22.4              | 103.67                 |
|                                                    |                            |       |                               |                   | <u>107.10±2.47</u>     |

Table VII  
Compression Set of Silicone Elastomer DC-675

| Gamma-Ray Dose<br>[ergs/gm(C) x 10 <sup>-9</sup> ] | Sample Thickness<br>(inch) |       | Spacer<br>Thickness<br>(inch) | Deflection<br>(%) | Compression<br>Set (%) |
|----------------------------------------------------|----------------------------|-------|-------------------------------|-------------------|------------------------|
|                                                    | Before                     | After |                               |                   |                        |
| Control                                            | 0.498                      | 0.495 | 0.377                         | 24.3              | 2.48                   |
|                                                    | 0.497                      | 0.495 | 0.377                         | 24.1              | 1.66                   |
|                                                    | 0.504                      | 0.500 | 0.377                         | 25.2              | 3.15                   |
|                                                    | 0.508                      | 0.506 | 0.377                         | 25.8              | 1.53                   |
|                                                    | 0.500                      | 0.500 | 0.377                         | 24.6              | 0.00                   |
|                                                    | 0.491                      | 0.489 | 0.377                         | 23.2              | 1.75                   |
|                                                    | 0.495                      | 0.492 | 0.377                         | 23.8              | 2.54                   |
|                                                    | 0.494                      | 0.491 | 0.377                         | 23.7              | 2.56                   |
|                                                    | 0.495                      | 0.495 | 0.377                         | 23.8              | 0.00                   |
|                                                    | 0.484                      | 0.481 | 0.377                         | 22.1              | 2.80                   |
|                                                    |                            |       |                               |                   | <u>1.85±0.30</u>       |
| 0.222                                              | 0.497                      | 0.453 | 0.378                         | 23.9              | 36.97                  |
|                                                    | 0.488                      | 0.451 | 0.378                         | 22.5              | 33.64                  |
|                                                    | 0.498                      | 0.451 | 0.378                         | 24.1              | 39.17                  |
|                                                    | 0.491                      | 0.451 | 0.378                         | 23.0              | 35.40                  |
|                                                    | 0.487                      | 0.442 | 0.378                         | 22.8              | 40.54                  |
|                                                    |                            |       |                               |                   | <u>37.14±2.79</u>      |
| 0.473                                              | 0.488                      | 0.412 | 0.378                         | 22.5              | 69.09                  |
|                                                    | 0.506                      | 0.422 | 0.378                         | 25.3              | 65.63                  |
|                                                    | 0.497                      | 0.427 | 0.378                         | 23.9              | 58.82                  |
|                                                    | 0.495                      | 0.422 | 0.378                         | 23.6              | 62.39                  |
|                                                    | 0.501                      | 0.428 | 0.378                         | 24.6              | 59.35                  |
|                                                    |                            |       |                               |                   | <u>63.06±4.33</u>      |
| 1.65                                               | 0.495                      | 0.392 | 0.378                         | 23.6              | 88.03                  |
|                                                    | 0.497                      | 0.394 | 0.378                         | 23.9              | 86.55                  |
|                                                    | 0.495                      | 0.392 | 0.378                         | 23.6              | 88.03                  |
|                                                    | 0.493                      | 0.391 | 0.378                         | 23.3              | 88.70                  |
|                                                    | 0.480                      | 0.393 | 0.378                         | 21.3              | 85.29                  |
|                                                    |                            |       |                               |                   | <u>87.32±1.38</u>      |
| 5.0                                                | 0.499                      | 0.380 | 0.376                         | 24.6              | 96.75                  |
|                                                    | 0.488                      | 0.378 | 0.376                         | 23.0              | 98.21                  |
|                                                    | 0.499                      | 0.384 | 0.376                         | 24.6              | 93.50                  |
|                                                    | 0.504                      | 0.382 | 0.376                         | 25.4              | 95.31                  |
|                                                    | 0.497                      | 0.381 | 0.376                         | 24.3              | 95.87                  |
|                                                    |                            |       |                               |                   | <u>95.93±1.74</u>      |
| 13.3                                               | 0.492                      | 0.371 | 0.378                         | 23.2              | 106.14                 |
|                                                    | 0.499                      | 0.375 | 0.378                         | 24.2              | 102.48                 |
|                                                    | 0.496                      | 0.376 | 0.378                         | 23.8              | 101.69                 |
|                                                    | 0.506                      | 0.374 | 0.378                         | 25.3              | 103.13                 |
|                                                    | 0.474                      | 0.382 | 0.378                         | 20.3              | 95.83                  |
|                                                    |                            |       |                               |                   | <u>101.85±3.77</u>     |

## IV. DISCUSSION OF RESULTS

### 4.1 Compression-Set Analysis

#### 4.1.1 Empirical Relationships

Analysis of the experimental data of this investigation showed that the radiation-induced compression-set behavior of the three polysiloxane elastomers could be described by the equation

$$S_D = S_m \exp[-\alpha D^{-n}] \quad (1)$$

where

$S_D$  = percent compression set at dose  $D$  [ergs/gm(C)],

$S_m$  = percent compression set at  $D \rightarrow \infty$ , and

$\alpha, n$  = material parameters.

On the basis of a least-squares fit of the experimental data, the numerical values of the material parameters were determined as follows:

for SE-361,  $\alpha = 0.322$ ,  $n = 0.671$

for SE-551,  $\alpha = 0.478$ ,  $n = 0.822$

for DC-675,  $\alpha = 0.250$ ,  $n = 0.905$

Figure 1 shows a plot of Equation 1 for each elastomer investigated together with the experimental data points.

In order to determine whether this empirically derived equation could be satisfactorily applied to other compression-set data, B. F. Goodrich Research Center data (Ref. 1) for ten different elastomers irradiated in the MTR Gamma Facility were

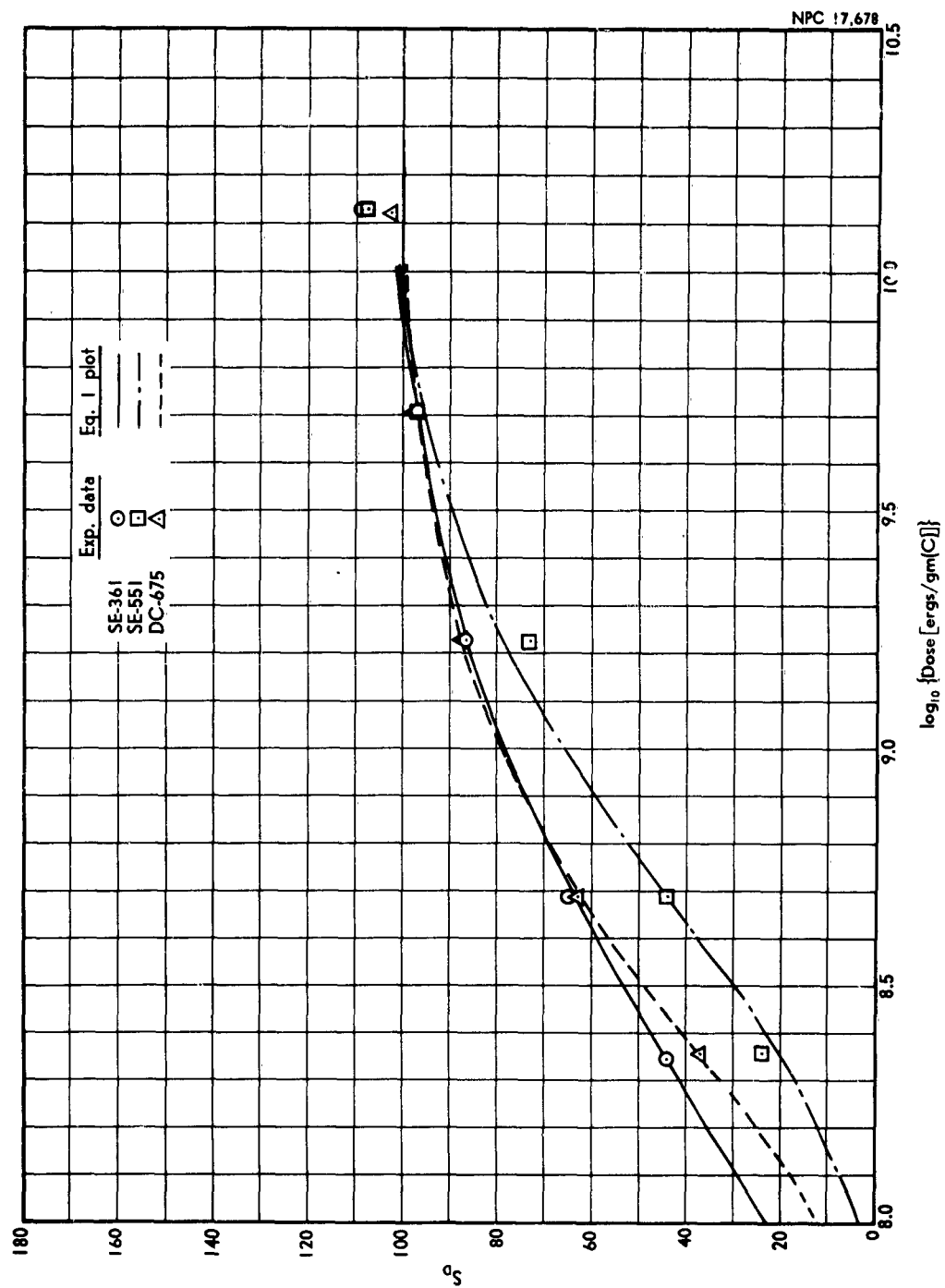


Figure 1. Compression Set of Three Silicone Elastomers as a Function of Absorbed Gamma-Ray Dose

used. The material parameters of  $n$  and  $a$  were determined by the least-squares method. The results of this analysis are presented in Table VIII together with the experimental data. The base recipes of the ten selected elastomers are given in Table IX. In most instances, Equation 1 provides a reasonably good description of the observed compression-set behavior.

#### 4.1.2 Molecular Interpretation

The phenomenon of compression set can be caused by a variety of molecular relaxation processes. When a three-dimensional polymer is placed under constant deformation, the initial decay of stress is due principally to relaxation of secondary bonds. This process is reversible, i.e., upon removal of the deforming stress, the sample returns to its original shape. In addition, physical or chemical agencies may cause primary bonds within the chain molecules to rupture, thus allowing the whole system to relax irreversibly under external stress. In the case of constant deformation, the macroscopic effect of such chain scission is evidenced in a slow irreversible decay of stress, which ultimately approaches zero in an asymptotic fashion. If crosslinking occurs simultaneously while the sample is held at constant strain, the equilibrium shape gradually shifts from the original shape of the unstrained sample to the shape of the strained sample. Since high-energy radiation induces both chain scission and crosslinking reactions in high polymers, compression-set behavior in a radiation field is a sensitive function of dose.

Table VIII  
Radiation-Induced Compression-Set Behavior of Ten Selected Elastomers

| B. F. Goodrich Compound*                          | Gamma-Ray Dose<br>[ergs/gm(C) x 10 <sup>-9</sup> ] | % Compression Set |            | Parameter |       |
|---------------------------------------------------|----------------------------------------------------|-------------------|------------|-----------|-------|
|                                                   |                                                    | Measured          | Calculated | n         | a     |
| Hycar 1001                                        | .089                                               | 30.7              | 26         | 0.466     | 0.432 |
| Base recipe 1                                     | .871                                               | 58.2              | 63         |           |       |
| Curative:                                         | 2.18                                               | 70.6              | 74         |           |       |
| Altax - 3.0 pts. by wt.                           | 4.37                                               | 81.5              | 80         |           |       |
| Sulfur - 2.0 pts. by wt.<br>Cure: 15 min at 293°F | 10.5                                               | 88.1              | 87         |           |       |
| Hycar 1001                                        | .089                                               | 12.9              | 10         | 0.495     | 0.707 |
| Same as above except                              | .871                                               | 41.6              | 46         |           |       |
| Cure: 45 min at 293°F                             | 2.18                                               | 57.5              | 61         |           |       |
|                                                   | 4.37                                               | 69.7              | 71         |           |       |
|                                                   | 10.5                                               | 83.6              | 80         |           |       |
| Hycar 1001                                        | .089                                               | 8.5               | 5          | 0.565     | 0.749 |
| Base recipe 1                                     | .871                                               | 36.9              | 44         |           |       |
| Curative:                                         | 2.18                                               | 56.1              | 61         |           |       |
| Hydrated lime - 4.0 pts.<br>by wt.                | 4.37                                               | 70.9              | 71         |           |       |
| DCP - 1.5 pts. by wt.                             | 10.5                                               | 85.9              | 82         |           |       |
| Hycar 1001                                        | .089                                               | 9.9               | 6          | 0.668     | 0.565 |
| Base recipe 1                                     | .871                                               | 44.5              | 53         |           |       |
| Curative:                                         | 2.18                                               | 66.1              | 71         |           |       |
| Amberol ST 12 pts. by wt.                         | 4.37                                               | 81.0              | 81         |           |       |
| Stannous chloride - 1.5 pts.<br>by wt.            | 10.5                                               | 91.4              | 89         |           |       |
| Hycar 1001                                        | .089                                               | 35.4              | 31         | 0.585     | 0.282 |
| Base recipe 1                                     | .871                                               | 68.5              | 73         |           |       |
| Curative:                                         | 2.18                                               | 82.5              | 83         |           |       |
| Polyac - 2.0 pts. by wt.                          | 4.37                                               | 90.0              | 89         |           |       |
|                                                   | 10.5                                               | 93.4              | 93         |           |       |
| Natural Rubber                                    | .087                                               | 13.7              | 5          | 0.601     | 0.668 |
| Base recipe 2                                     | .438                                               | 22.9              | 33         |           |       |
|                                                   | .868                                               | 36.2              | 54         |           |       |
|                                                   | 4.36                                               | 75.3              | 75         |           |       |
|                                                   | 10.5                                               | 88.5              | 85         |           |       |
| Neoprene GN                                       | .088                                               | 4.6               | 3          | 0.692     | 0.696 |
| Base recipe 3                                     | .871                                               | 38.9              | 46         |           |       |
|                                                   | 2.18                                               | 59.9              | 67         |           |       |
|                                                   | 4.36                                               | 76.5              | 77         |           |       |
|                                                   | 10.4                                               | 90.4              | 87         |           |       |
| Hycar 1001                                        | .087                                               | 8.6               | 3          | 0.432     | 1.13  |
| Base recipe 4                                     | .438                                               | 13.4              | 19         |           |       |
| Antirad:                                          | .868                                               | 21.9              | 34         |           |       |
| Hydroquinone/Antiox 4010<br>(50/50) - 5 phr       | 4.36                                               | 51.3              | 54         |           |       |
|                                                   | 10.5                                               | 73.2              | 66         |           |       |
| SBR 1500/1501                                     | .087                                               | 4.0               | 2          | 0.546     | 1.13  |
| Base recipe 5                                     | .438                                               | 13.3              | 17         |           |       |
| Antirad:                                          | .868                                               | 23.2              | 35         |           |       |
| Antiox 4010 - 5 phr                               | 4.36                                               | 55.3              | 59         |           |       |
|                                                   | 10.5                                               | 76.9              | 73         |           |       |
| Hypalon 20                                        | .088                                               | 18.1              | 13         | 0.467     | 0.649 |
| Base recipe 6                                     | .871                                               | 45.4              | 50         |           |       |
| Antirad:                                          | 2.18                                               | 55.7              | 63         |           |       |
| Hydroquinone/Antiox 4010<br>(50/50) - 5 phr       | 4.36                                               | 70.5              | 71         |           |       |
|                                                   | 10.4                                               | 85.0              | 81         |           |       |

\* Base recipes given in Table IX.

Table IX

## Base Recipes for B. F. Goodrich Compounds

|   |                 |              |
|---|-----------------|--------------|
| 1 | Hycar 1001      | 100          |
|   | SRF Black       | 50           |
|   | Zinc oxide      | 5            |
|   | Stearic acid    | 0.5          |
|   |                 | <u>155.5</u> |
| 2 | Natural rubber  | 100          |
|   | Age-Rite Powder | 1.0          |
|   | EPC Black       | 50           |
|   | Zinc oxide      | 5.0          |
|   | Stearic acid    | 3.0          |
|   | Altax           | 1.0          |
|   | Sulfur          | 3.0          |
|   |                 | <u>163.0</u> |
| 3 | Neoprene GN     | 100          |
|   | EPC Black       | 35           |
|   | Zinc oxide      | 5            |
|   | Stearic acid    | 1            |
|   | Magnesium oxide | 4            |
|   |                 | <u>145.0</u> |
| 4 | Hycar 1001      | 100          |
|   | SRF Black       | 50           |
|   | Zinc oxide      | 5            |
|   | Altax           | 3            |
|   | Sulfur          | 2            |
|   |                 | <u>160.0</u> |
| 5 | SBR-1500/1501   | 100          |
|   | EPC Black       | 40           |
|   | Zinc oxide      | 5            |
|   | Stearic acid    | 1.5          |
|   | Altax           | 3.0          |
|   | Sulfur          | 2.0          |
|   |                 | <u>153.5</u> |
| 6 | Hypalon 20      | 100          |
|   | HAF Black       | 20           |
|   | Rosin           | 2.5          |
|   | Tetrone A       | 1.0          |
|   | Magnesium oxide | 30           |
|   |                 | <u>153.5</u> |

For the largest radiation dose employed in this study  $1.33 \times 10^{10}$  ergs/gm(C) , the samples actually showed a volume contraction when released from the compressive devices. This contraction is most likely attributable to the extremely high crosslinking density attained at that dose.

The behavior of a three-dimensional polymer network relaxing under compression may be viewed, according to the concept of Andrews, Tobolsky, and Hansen (Ref. 4), as a competition principally between two types of chains: (1) chains that are at equilibrium when the sample is in its original undeformed state (i.e., at  $t - t_0$ ), and (2) chains formed by the agency of radiation that are at equilibrium in the strained state (i.e., at  $t = t_\alpha$ ). If  $N_0$  is the number of network species of Type 1 per  $\text{cm}^3$  of elastomer and  $N_\alpha$  is the number of network species of Type 2 per  $\text{cm}^3$  of elastomer, then, applying the kinetic theory of rubberlike elasticity of this model, the stresses developed by these two species of network chains are respectively

$$\sigma_0 = N_0 k T \left[ \left( \frac{t_s}{t_0} \right)^2 - \frac{t_0}{t_s} \right] \quad (2)$$

$$\sigma_\alpha = N_\alpha k T \left[ \left( \frac{t_s}{t_\alpha} \right)^2 - \frac{t_\alpha}{t_s} \right] \quad (3)$$

where  $\sigma_0$  = stress exerted by the network chains,  $N_0$ , tending to restore the sample to its original thickness  $t_0$ ,

$\sigma_\alpha$  = stress exerted by the network chains,  $N_\alpha$ , tending to retract the sample to the equilibrium position for the chains  $N_\alpha$  at  $t_\alpha$ ,

T = temperature ( $^{\circ}\text{K}$ ), and

k = Boltzmann's constant.

As a consequence of the balance between the two oppositely directed stresses associated with these two network species, the sample assumes a shape intermediate between their two equilibrium positions. That is

$$\sigma_o = -\sigma_a$$

The network chain ratio  $\zeta = N_o/N_a$  is given by

$$\zeta = \frac{(t_a/t_s) - (t_s/t_a)^2}{(t_s/t_o)^2 - (t_o/t_s)} \quad (4)$$

where  $t_o$  = original thickness of the sample,

$t_a$  = thickness to which the sample is compressed, and

$t_s$  = thickness of the sample after release from compression.

Calculations of the  $N_o/N_a$  ratio for the three silicone elastomers studied at the various doses is presented in Table X. The change in the ratio as a function of absorbed dose is shown in Figure 2. The quantity  $\zeta$  rapidly decays with dose, and at very high doses tends asymptotically toward a small negative value, which indicates that chain species other than those postulated in the simple model become operative.

#### 4.2 Hardness Analysis

Finally, the Shore A hardness of these elastomers was observed to increase with dose. Within the dose region investigated, the hardness  $H_p$  attained after dose D [ergs/gm(C)]

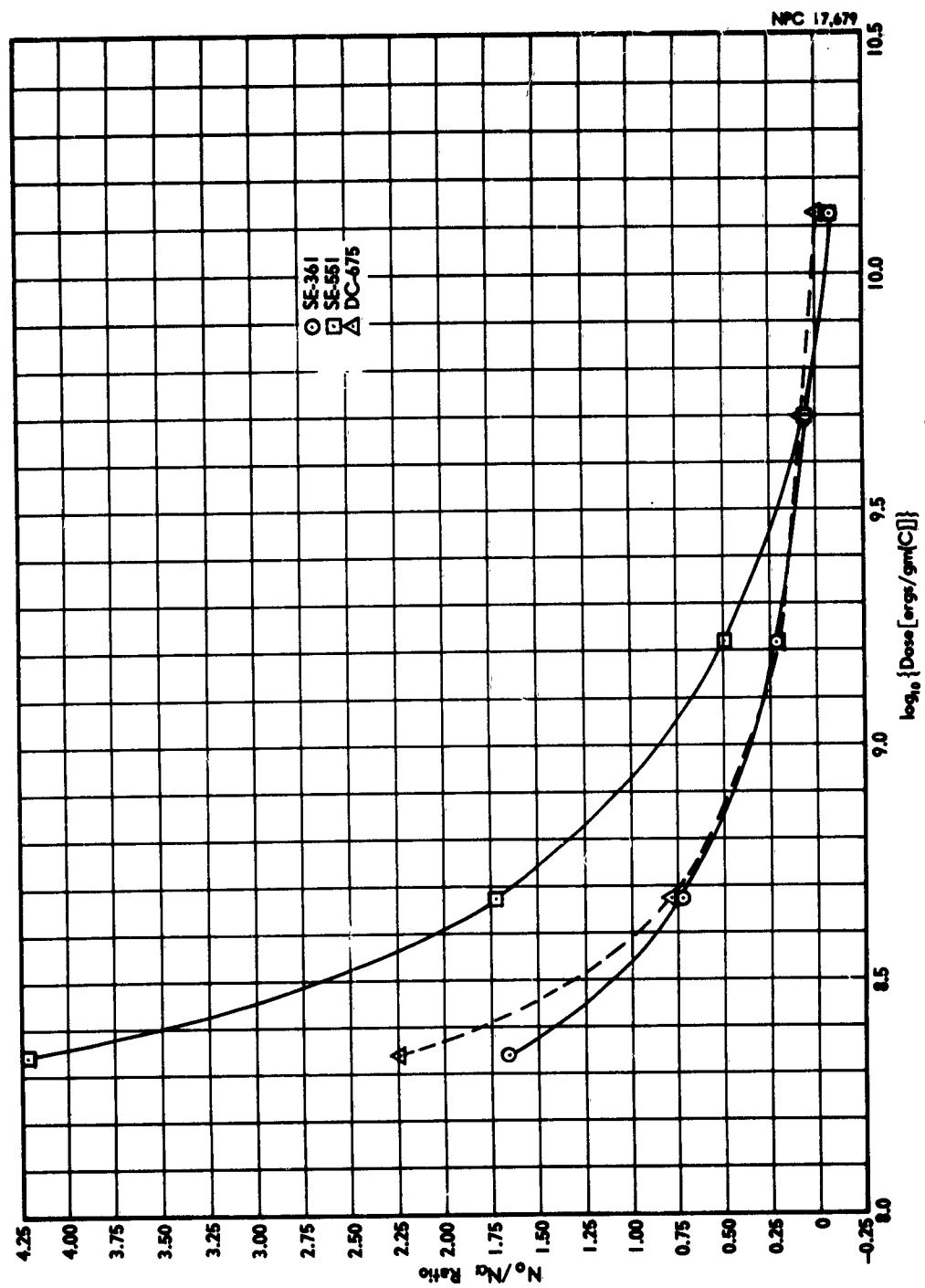


Figure 2. The  $N_0/M_0$  Ratio of Three Silicone Elastomers as a Function of Gamma-Ray Dose

Table X

 $N_0/N_\alpha$  Ratio for Three Silicone Elastomers\*

| Elastomer | Gamma-Ray Dose [ergs/gm(C) $\times 10^{-9}$ ] |             |             |             |             |             |
|-----------|-----------------------------------------------|-------------|-------------|-------------|-------------|-------------|
|           | Control                                       | 0.222       | 0.473       | 1.65        | 5.0         | 13.3        |
| SE-361    | 38.614                                        | 1.653       | 0.719       | 0.211       | 0.042       | -0.078      |
|           | $\pm 38.99$                                   | $\pm 0.051$ | $\pm 0.202$ | $\pm 0.030$ | $\pm 0.059$ | $\pm 0.089$ |
| SE-551    | 35.921                                        | 4.230       | 1.711       | 0.489       | 0.055       | -0.082      |
|           | $\pm 11.92$                                   | $\pm 0.430$ | $\pm 0.111$ | $\pm 0.064$ | $\pm 0.036$ | $\pm 0.027$ |
| DC-675    | 63.318                                        | 2.236       | 0.776       | 0.187       | 0.054       | -0.023      |
|           | $\pm 15.58$                                   | $\pm 0.309$ | $\pm 0.144$ | $\pm 0.021$ | $\pm 0.077$ | $\pm 0.015$ |

\*  $N_0/N_\alpha$  = Average value, polymer network chain ratio

could be expressed by the relation

$$H_D = H_0(D/D_0)^c \text{ for } D \geq D_0 \quad (5)$$

where  $H_0$  = Shore A hardness of the unirradiated sample after being compressed, $D_0$  = virtual dose, i.e., the extrapolated inflection point at which the sample's hardness begins to change, and $c$  = material parameter.

Figure 3 presents the experimental values and the curves calculated according to Equation 5. The following values were determined for Equation 5 for the three silicone elastomers:

| Elastomer | $H_0$ | $\log_{10} D_0$ | $c$    |
|-----------|-------|-----------------|--------|
| SE-361    | 45.7  | 7.5625          | 0.1234 |
| SE-551    | 39.6  | 8.2625          | 0.166  |
| DC-675    | 61.3  | 7.9026          | 0.0935 |

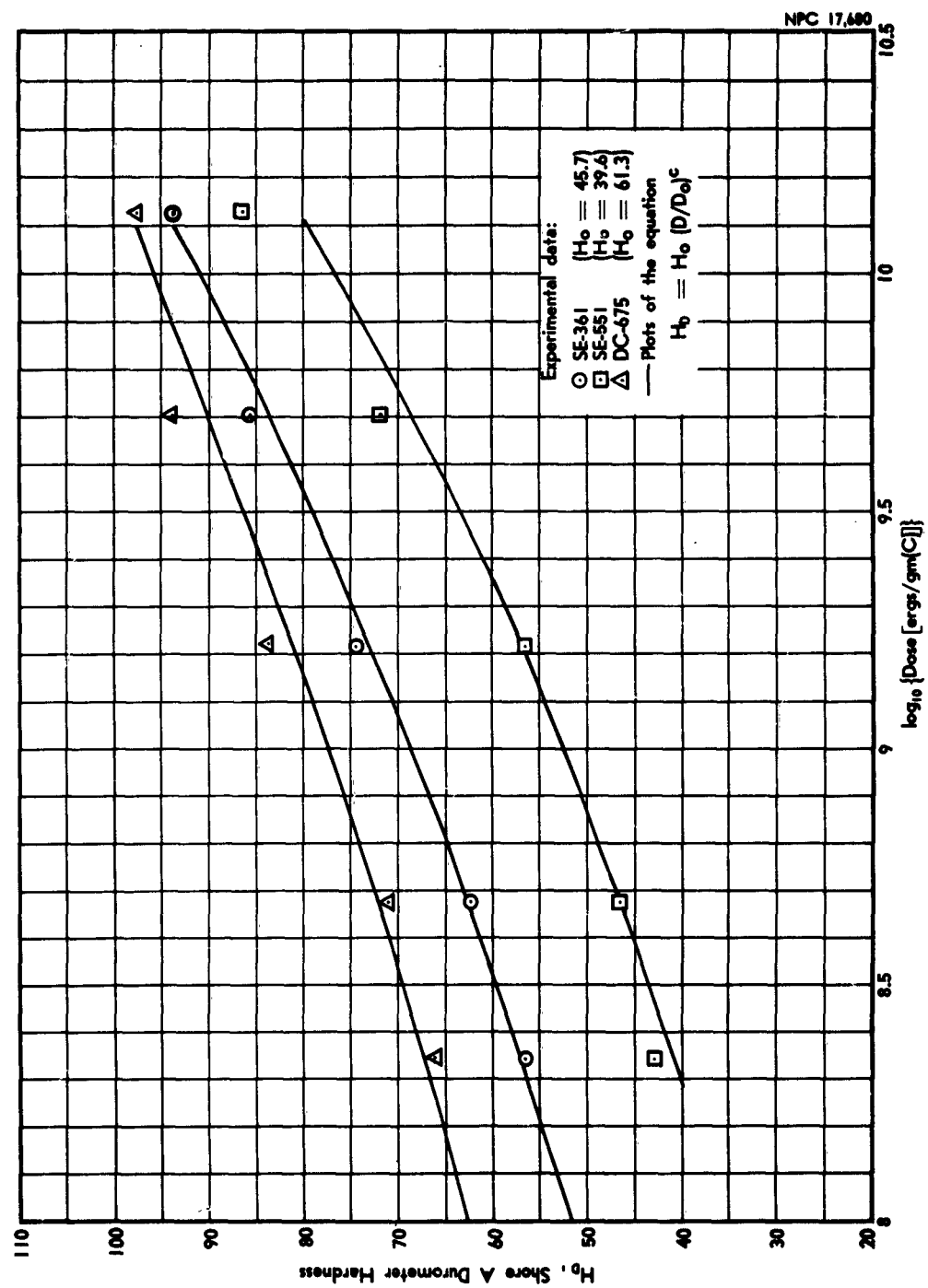


Figure 3. Shore A Durometer Hardness of Three Silicone Elastomers as a Function of Gamma-Ray Dose

#### 4.3 Neutron Contribution

In the foregoing calculations, only the gamma-ray doses recorded were used, and any contribution from the neutrons was neglected. Calculations of the possible neutron contribution to the chemically effective dose in polyethylene were made for this same irradiation and are reported in Reference 5. These calculations indicate that the neutron contribution from this irradiation can be considered negligible for carbon-based polymer chains. Since more energy is required to break Si-Si bonds than C-C bonds, the contribution of the neutrons in producing radiation effects in silicone elastomers should even be less than in polyethylene.

## V. CONCLUSIONS

- (1) It was shown that three commercial silicone elastomers irradiated in a nuclear reactor field under constant compressive strain in an air environment showed a compression-set behavior that is described by the equation

$$S_D = S_m \exp - \left\{ \alpha D^{-n} \right\}$$

where  $S_D$  = percent compression set at dose  $D$  [ergs/gm(C)],

$S_m$  = percent compression set at  $D \rightarrow \infty$ , and

$\alpha, n$  = material parameters.

- (2) The ratio,  $\zeta$ , of the number of network chains at equilibrium with the unstrained thickness to the number of network chains at equilibrium with the applied strain rapidly decays with dose and, at very high doses, tends asymptotically towards a small negative value, which indicates that chain species other than those postulated in the simple model become operative.
- (3) The Shore-A hardness of these elastomers was observed to increase with dose. Within the dose region investigated, the hardness,  $H_D$ , attained after dose [ergs/gm(C)] could be expressed by the relation

$$H_D = H_0 (D/D_0)^c \text{ for } D \geq D_0$$

where  $H_0$  = Shore A hardness of unirradiated sample after compression,

$D_0$  = virtual dose, i.e., the extrapolated inflection point at which the sample's hardness begins to change, and

$c$  = material parameter.

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| <p>Nuclear Aerospace Research Facility, General Dynamics/Fort Worth, Fort Worth, Texas.<br/>COMPRESSION-SET BEHAVIOR OF IRRADIATED SILICONE ELASTOMERS, by P. M. Johnson and E. G. Fritz. 15 May 1963. 35 p. incl. illus., tables, 5 refs. (NARP-63-27; MR-N-301) Unclassified report Contract AF33(657)-7201</p> <p>The effect of nuclear radiation (five different dose levels in the range of from <math>10^8</math> to <math>10^{10}</math> ergs/gm(C) on the compression-set behavior of three types of silicone elastomers (SE-551, SE-361, and DC-675) was examined. During the irradiation, the samples were compressed at constant strain in an air environment. The observed post-irradiation percent compression set after an accumulated dose is described by an empirically derived equation.</p> <p>The ratio of the number of network chains at equilibrium with the unstrained thickness to the number of network chains at equilibrium with the applied strain rapidly decreases with dose.</p> | <p>UNCLASSIFIED</p> <p>1. Elastomers, Silanes<br/>2. *Radiation damage<br/>3. *Compressive properties, Creep, Hardness<br/>4. Light-water reactor, Nuclear physics laboratory, Ground Test Reactor, Experimental data</p> <p>I. Johnson, P. M.<br/>II. Fritz, E. G.<br/>III. Aeronautical Systems Division, Air Force Systems Command<br/>IV. Contract AF33(657)-7201</p> <p>UNCLASSIFIED</p> | <p>Nuclear Aerospace Research Facility, General Dynamics/Fort Worth, Fort Worth, Texas.<br/>COMPRESSION-SET BEHAVIOR OF IRRADIATED SILICONE ELASTOMERS, by P. M. Johnson and E. G. Fritz. 15 May 1963. 35 p. incl. illus., tables, 5 refs. (NARP-63-27; MR-N-301) Unclassified report Contract AF33(657)-7201</p> <p>The effect of nuclear radiation (five different dose levels in the range of from <math>10^8</math> to <math>10^{10}</math> ergs/gm(C) on the compression-set behavior of three types of silicone elastomers (SE-551, SE-361, and DC-675) was examined. During the irradiation, the samples were compressed at constant strain in an air environment. The observed post-irradiation percent compression set after an accumulated dose is described by an empirically derived equation.</p> <p>The ratio of the number of network chains at equilibrium with the unstrained thickness to the number of network chains at equilibrium with the applied strain rapidly decreases with dose.</p> | <p>UNCLASSIFIED</p> <p>1. Elastomers, Silanes<br/>2. *Radiation damage<br/>3. *Compressive properties, Creep, Hardness<br/>4. Light-water reactor, Nuclear physics laboratory, Ground Test Reactor, Experimental data</p> <p>I. Johnson, P. M.<br/>II. Fritz, E. G.<br/>III. Aeronautical Systems Division, Air Force Systems Command<br/>IV. Contract AF33(657)-7201</p> <p>UNCLASSIFIED</p> |
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