43.A+7:22/K-981

K-981
Chemistry

EVOLUTION OF HALIDES FROM HALOGENATED PLASTICS EXPOSED TO GAMMA RADIATION

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JAN 22 1953
NEW MEXICO

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Engineering Practice School

Prepared From Work Performed Under Subcontract 70

With The

CARBIDE AND CARBON CHEMICALS COMPANY
A Division of Union Carbide and Carbon Corporation
Oak Ridge, Tennessee

metadc957881

Approved for Issue: J. Byrne

Report Number: K-981

Date of Issue: November 15, 1952

File Number: EPS-X-172

Subject Category: CHEMISTRY

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This report is distributed according to the category "Chemistry," as given in the "Distribution Lists for United States Atomic Energy Non-Classified Research and Development Reports, "TID-4500, July 15, 1952.

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Prepared from work performed at the X-10 Plant of the

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I. ABSTRACT

The purpose of the investigation was to study the effects of gamma radiation from a cobalt-60 source on the physical properties and halogen evolution from the plastics polyvinyl chloride and poly-monochlorotrifluoroethylene. Samples exposed for 2 to 28 days to a source of approximately 25,000 Roentgens per minute showed an appreciable evolution of both fluorine and chlorine. Tests on poly-monochlorotrifluoroethylene for tensile, impact, and shear strength showed rapidly decreasing values as the radiation exposure was increased. Similar physical tests on exposed polyvinyl chloride showed increased impact and shear strengths and a lower tensile strength.

ACKNOWLEDGEMENT

The authors wish to express appreciation for the guidance and aid given by Mr. C. D. Watson of the Oak Ridge National Laboratory. Thanks are also given to Carbide and Carbon Chemicals Company for making available the facilities and materials for this study.

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II. SUMMARY

A study was made of the effect of cobalt-60 gamma radiation on the physical properties and halogen evolution from plasticized and non-plasticized polymonochlorotrifluoroethylene and non-plasticized polyvinyl chloride.

The cobalt-60 source, available at the Oak Ridge National Laboratory, radiated gamma energy at approximately 25,000 Roentgens per minute.

The study of halogen evolution from the plastics was conducted with one-eighth inch cubes and shavings of the materials. The samples were covered with a solution of sodium hydroxide and irradiated for periods of time from 2 to 28 days. The solution was analyzed for chloride ion and fluoride ion.

It was found that the samples consisting of shavings evolved more halogen than the cubes, indicating there had been a non-steady state condition in the cubes. The maximum rate of evolution was found to be nearly equal for the three plastic materials and was approximately 7 millimoles of halide (total) per gram of sample exposed to a total radiation of one billion Roentgens.

Tensile, impact, and shear tests were conducted on specimens irradiated in the same source as chemical test specimens. All strengths of the polymonochlorotrifluoroethylene declined rapidly with radiation exposure. Polyvinyl chloride showed increased impact and shear strengths and a somewhat lower tensile strength after exposure.

It is recommended that these results be considered when using these plastics for materials of construction in gamma-active processes.

III. INTRODUCTION

Recently, interest has arisen in the changes of physical properties and halogen evolution of halogenated plastics subjected to gamma radiation. In equipment designed to handle radioactive materials, parts like gaskets and bushings are frequently made from plastic materials, particularly chlorinated and fluorinated polymers which are usually chemically inert. In the presence of gamma radiation, a breakdown occurs with release and evolution of chlorine and fluorine, and a normally inert material becomes a source of corrosive agents.

Previous to this study, C. D. Watson (7) of the Oak Ridge National Laboratory conducted an investigation of the effects of gamma radiation on Teflon (polytetrafluoroethylene) which is similar to Fluorothene (polymonochlorotrifluoroethylene) used in this study. An appreciable evolution of fluorine occurred.

Bopp and Sisman (2), and Burton (1), have made studies of the reactor radiation on some physical properties of a number of plastics. In such tests the specimens received a mixed irradiation of neutrons, beta and gamma rays. The results of Bopp and Sisman on vinylidene chloride (Saran) and polymonochlorotrifluoroethylene (Fluorothene) indicated a substantial diminution, or a complete loss, of strength after an accumulated exposure of 10^{17} to 10^{18} NVT units. The NVT unit is the product of neutron flux, neutrons/(sq.cm.)(sec.), and total time of exposure. Bopp and Sisman (2) estimated that during 10^{18} NVT units the gamma-radiation exposure was 330 million Roentgens.

The planning of experiments and interpretation of the results required consideration of an unsteady-state mass transfer. In order to achieve a distinction necessary to discuss unsteady-state condition, release of halogen is used to refer to the destruction of a chemical bond between the halogen and the polymer molecule; evolution of halogen is used to refer to the escape of halogen from the surface of the plastic object. It was assumed that the halogen was released from the chemical bond uniformly throughout the solid whereas the halogen evolved at the surface was at a small rate initially, increasing to constant value as steady-state was attained. Since the "diffusion" of halogen through the plastic was considered to be very slow, the unsteady-state time was expected to be long. As developed in detail later, the results showed that unsteady-state existed throughout some of the tests.

The data gathered were: (1) the evolution of halogen and (2) the changes in physical properties of plastics which had been exposed to gamma radiation.

The materials chosen for investigation were plasticized and non-plasticized polymonochlorotrifluoroethylene and a non-plasticized polyvinyl chloride. The polymonochlorotrifluoroethylene was manufactured by Carbide and Carbon Chemicals Company and is herein called by its trade name "Fluorothene" for convenience. The polyvinyl chloride was obtained from the Van Dorn Iron Works of Cleveland, Ohio, under the trade name "Lucoflex." The plasticizer used for Fluorothene was a similar material of lower molecular weight. In addition, a few samples of carbon tetrachloride were irradiated.

No attempt was made to determine the chemical state of the halogen evolved. Halide is used in reporting the results since the halogens were determined as halides in the analytical procedure.

IV. PROCEDURE

The plastic materials were either cut into cubes, approximately one-eighth inch on a side, or were made into shavings, using a band saw. Samples of 1.0 to 2.5 gm. of cubes, and 0.5 gm. of shavings were weighed, placed into 10 ml. polystyrene vials, and covered with 10 ml. of sodium hydroxide solution. These samples were exposed for 2 to 28 days to gamma radiation from cobalt-60 at a nominal intensity of 25,000 R./min. At intervals of about 48 hours, two vials of the cubes and one of the shavings were removed from the source. The caustic solution was withdrawn and analyzed for chlorine and fluorine in the case of Fluorothene, and chlorine only for the polyvinyl chloride samples. The analyses were made for either halide after converting any hypohalite to the halide form.

For comparative purposes, a few samples of carbon tetrachloride were irradiated to determine the evolution of halogen in a liquid system.

The changes in physical properties were observed by irradiation of additional samples prepared for shear, impact, and tensile tests. Bundles of these samples were exposed to gamma radiation and specimens were removed at two-day intervals. The tests and sample shapes were similar to those of Bopp and Sisman (6).

V. RESULTS

A. Experimental Data

The experimental results of halide evolution are presented in Figures 1-3 which show evolution as a function of the radiation exposure. The choice of radiation exposure, rather than time, as the independent variable was made on the assumption that the release of halogen from the chemical bond is independent of intensity. The actual intensities in these experiments varied from 20,500 to 35,700 R./min., but the variation was not sufficiently extensive to determine any effect of intensity. The data were originally plotted both against time and against accumulated exposure, and it appeared that radiation exposure gave a slightly smoother appearance to curves drawn through the data. In view of the scatter of the points, no definite conclusion may be made.

The chloride evolved from polyvinyl chloride is shown in Figure 1 for radiation exposures up to 1500 million R. for both cubes and shavings. The data for shavings are represented by a straight line, indicating a steady-state condition; the data on cubes indicate both in amount and curvature that unsteady-state existed. The slope of the curve at 1100 million R. is approximately equal to that of the straight line through the data on shavings.

The chloride and halide evolved from non-plasticized Fluorothene are shown in Figure 2, the ordinate representing either chloride or fluoride. The ordinates for Figures 2 and 3 are on a scale ten-fold that of Figure 1. In view of the considerable scatter of the data, only one curve was drawn for cubes and one for shavings, in effect taking the rate of evolution chloride and fluoride to be equal. It is evident that unsteady-state existed throughout the experiments on cubes. The data on shavings show considerable scatter, but it seems likely that steady state was being approached at the higher exposures.

The chloride and fluoride evolution from plasticized Fluorothene are shown in Figure 3, the scale being the same as Figure 2. The data for shavings coincide with those for non-plasticized Fluorothene. The cubes, however, showed a higher rate of evolution than for non-plasticized material although steady-state was not reached.

The changes in impact, shear, and tensile strengths are shown in Figure 4 as a function of radiation exposure. The polyvinyl chloride withstood the radiation better than the Fluorothene. The latter showed almost complete loss of strength at 200 million R. while polyvinyl chloride was useable after 800 million R.

▣ cubes
○ shavings

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CHLORIDE EVOLVED
FROM
POLYVINYL CHLORIDE

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FIG.
I

HALIDE EVOLVED
millimoles halide / gram

□ Cl⁻ cubes
△ F⁻ shavings
○ Cl⁻
▽ F⁻

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HALIDES EVOLVED
FROM
FLUOROTHENE

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FIG. 2

HALIDE EVOLVED
millimoles halide / gram

PLASTICIZED

1.0

0.5

0

RADIATION EXPOSURE
millions of Roentgens

▣ Cl^- cubes
▴ F^- shavings
○ Cl^- shavings
▾ F^- cubes

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FIG. 3

PERCENT OF ORIGINAL STRENGTH

○ polyvinyl chloride

□ non-plasticized Fluorothene

△ plasticized Fluorothene

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CHANGES IN PHYSICAL
PROPERTIES DURING
IRRADIATION

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X 172

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The maximum rates of halide evolution, shown in Table I, were obtained from the slopes of the curves drawn in Figures 1-3. The evolution of chloride from carbon tetrachloride is shown for comparison.

B. Visual Observations

After two or four days of irradiation, the polyvinyl chloride turned from a translucent light-brown to an opaque black. No further change in color occurred. Samples exposed longer than 20 days had blisters at the surface, some of which had evidently burst.

The Fluorothene became brittle after four days and remained so for 22 additional days. After still longer but unrecorded exposure, the non-plasticized Fluorothene became pliable and soft, somewhat like limp rubber.

TABLE I

MAXIMUM RATE OF HALOGEN EVOLUTION

<u>Geometry</u>	<u>Halogen Evolved</u>	<u>MAXIMUM RATE OF HALOGEN EVOLUTION</u> <u>millimoles halide/(gm.)(billion R.)</u>			
		<u>Carbon tetra-chloride</u>	<u>Plasticized Fluorothene</u>	<u>Non-plasticized Fluorothene</u>	<u>Polyvinyl Chloride</u>
CUBES	Fluoride		1	0.4	
	Chloride		1	0.4	7
	Total halide		2	0.8	7
SHAVINGS	Fluoride		2.5	3	
	Chloride		2.5	3	7
	Total halide		5	6	7
LIQUID		9			
MAXIMUM RATE IRRESPECTIVE OF GEOMETRY	Total Halide	9	5	6	7

VI. DISCUSSION OF RESULTS

A. Engineering Use of the Data

The amount of halide evolved during the physical lifetime of the materials can be tolerated in some systems and not in others. There are two important reasons for concern about halides evolved: (1) excessive corrosion resulting in physical weakness or leaks and (2) contamination of process materials by corrosion products. The data reported here can be used to estimate the order of magnitude of both the amount of corrosion and the amount of contamination.

For example, consider corrosion of an iron surface in contact with a gasket 2 mm. thick. Assume that: (1) the evolution occurs at the maximum rate reported in Table I, namely, 7 millimoles/(gm.)(billion R.); (2) each mole of halide removes one-half mole of iron; (3) the attack is uniform and occurs at point where the halogen is evolved; (4) only gamma radiation is present at an intensity of 1000 R./min.; and (5) evolution is equal on each face of the gasket. The calculation is shown below using a basis of one square centimeter imagined to be in the center of a large area of gasket material.

$\frac{1}{2}^*$	0.2	1.4	0.007	56	$\frac{1}{2}$	...
*	cm.	$\frac{\text{gm. plastic}}{\text{cu. cm.}}$	$\frac{\text{moles halide}}{(\text{gm.})(\text{billion R.})}$	$\frac{\text{gm. Fe}}{\text{mole Fe}}$	$\frac{\text{mole Fe}}{\text{mole halide}}$	

$\frac{1}{7.8}$	1000	525,600	$\frac{1}{2.54}$	0.0007
$\frac{\text{cu. cm.}}{\text{gm. Fe}}$	$\frac{\text{R.}}{\text{min.}}$	$\frac{\text{min.}}{\text{yr.}}$	$\frac{\text{in.}}{\text{cm.}}$	$\frac{\text{in.}}{\text{yr.}}$

*Dimensionless correction for two surfaces, assuming that half of the halogen released leaves one surface.

Thus the calculated corrosion rate is 0.0007 inches per year (0.7 mils) and the contamination is approximately 1 millimole halide and 0.5 millimole iron per year. In this example the use of polyvinyl chloride seems reasonable since the contamination would in most cases be trivial, and the physical life of the material would be more than two years. On the other hand, Fluorothene would withstand the radiation only a few months. The rate of corrosion is within limits normally considered acceptable.

An inherent assumption made in the above calculation is that the evolution is independent of intensity of radiation. In view of the assumption (already made) that release for a given exposure is independent of intensity, it is evident that during unsteady-state the evolution for a given exposure will be a function of intensity. In the case of a high rate of irradiation, for example, the release would occur rapidly, but the diffusion would proceed in the same mode as for other intensities. From separate samples which had received equal total exposure at different intensities, the following comparisons are made: (1) at the end of irradiation, the amount of halogen evolved would be greater from the sample irradiated at lower intensity; and (2) at any given time, the amount of halogen evolved would be greater from the sample irradiated at the higher intensity. For construction purposes, the unsteady-state condition is advantageous, for as long as the released halogen is "stored" within the plastic, corrosion and contamination cannot occur. There are not, however, sufficient data available to permit estimation of the extent of storage in systems of geometry different from the experimental samples.

For engineering purposes, a conservative assumption for the amount of evolution may be based on the maximum rates shown in Table I. It is recommended that the data presented in this report be considered when using polyvinyl chloride and Fluorothene, or similar materials, in the construction of systems to handle gamma-active materials.

B. Significance of the Results from a Fundamental Viewpoint

While the objective of the work was to obtain engineering data on evolution, the release of the halogens from the chemical bond is of fundamental interest. There are, however, two principal difficulties in interpreting these data: (1) the unsteady-state condition and (2) the determination of the gamma-energy absorbed.

1. Unsteady-state Considerations

The data obtained give clear indication that unsteady state existed throughout most of the experiments with cubes and in some experiments with shavings. Indications of steady state were considered to be: constant slope of the curve of halide evolution as a function of radiation exposure and slope of the curve for cubes equal to that of shavings with both slopes being constant.

If certain simplifying assumptions are made, it is possible to write a differential equation relating evolution, release, and time. The assumptions used were: (1) space-uniform release of the halogen from the chemical bond; (2) diffusion of the halogen (in unspecified form) in a manner proportional to the concentration, with a constant diffusion coefficient which is neither a function of time nor radiation exposure; (3) constant radiation intensity; and (4) no resistance to escape of

the halogen at the surface of the solid. It would be possible to solve the equation by numerical methods, but the solution is too tedious for hand calculation. Machine calculation was deemed unwarranted since the assumption of a constant diffusion coefficient is not realistic. Bubbles appeared at the surface of the plastic, some of which had evidently burst, and some surface cracks were visible. Bubbles and cracks in the plastic would change the diffusion coefficient and surface area making the equation inappropriate. The scatter of the data may reasonably be attributed to such deformations. It is evident that fundamental studies of reaction mechanism must be based on experiments different in method and precision.

No attempt has been made to estimate the amount of gamma energy actually absorbed in the plastic, and no estimate of the energy involved in breaking the chemical bond can be made from these data. Since the gamma absorptivity of the plastic is small, the amount of absorption would necessarily require an indirect technique.

The assumption of space-uniform release, postulated above, is based on the small absorption of gamma in the plastic material; namely, the gamma intensity is assumed uniform throughout the material, and the release is assumed proportional to intensity.

C. Relative Release of Chlorine and Fluorine

The data for shavings in Figures 2 and 3, and Table I, show a nearly equal maximum rate of evolution of chlorine and fluorine on a molar basis, although the Fluorothene contains a ratio of three moles fluorine to one mole of chlorine. If this result is significant, two explanations seem plausible: (1) fluorine is less readily released or (2) the fluorine, once released, displaces the chlorine. The choice of explanations is complicated by the result that the maximum rate of chloride release from polyvinyl chloride and carbon tetrachloride is approximately equal to the maximum rate of total halide release from Fluorothene. It is evident further experiments will be necessary to resolve questions of relative rates of release.

D. Changes in Physical Properties

The polyvinyl chloride survived exposure better than Fluorothene and actually showed substantial improvement in shear and impact strength during part of the experimentation. The improvement possibly resulted from plasticization by smaller molecules produced by splitting of the polymer chain. Similar improvement in impact strength was noted by Bopp and Sisman(3) for polytetrafluoroethylene (Teflon).

The changes in the physical properties of non-plasticized Fluorothene are similar to those found by Bopp and Sisman for reactor radiation (2).

Complete loss of strength occurred in the reactor after exposure estimated to be 50 million R. of gamma, plus beta and neutron irradiation. In these experiments with gamma alone, complete failure occurred at 100-200 million R., indicating that beta and neutron irradiation as well as gamma are harmful.

It is worth noting that Bopp and Sisman (5) found some materials, e.g. polystyrene, which were unchanged in strength after prolonged radiation. Consequently the data reported here on physical properties must be considered specific for the materials studied.

VII. CONCLUSIONS AND RECOMMENDATIONS

It was concluded that:

1. When polymonochlorotrifluoroethylene (Fluorothene) and polyvinyl chloride are exposed to gamma radiation, the quantities of halogen evolved may be significant from corrosion and contamination viewpoints.
2. For engineering purposes, the rate of evolution can be taken as 7 millimoles of halide per gram of material per billion Roentgens of exposure.
3. Polyvinyl chloride retained physical strength better than polymonochlorotrifluoroethylene during exposure to gamma radiation.

It is recommended that the data presented in this report be used when considering polyvinyl chloride or Fluorothene as construction materials in gamma-active systems.

VIII. APPENDIX

A. SUMMARY OF DATA

Tables II and III are presentations of the experimental data and calculated values.

B. LOCATION OF ORIGINAL DATA

The original data are recorded in Notebook No. 1879 which is on file at the M.I.T. Engineering Practice School, K-25, Oak Ridge, Tennessee.

C. LITERATURE CITATIONS

1. Burton, M., J. Phys. and Colloid Chem. 51, 786, (1947).
2. Sisman, O., and Bopp, C. D., Physical Properties of Irradiated Plastics, Report No. ORNL-928, p. 9, Oak Ridge National Laboratory Carbide and Carbon Chemicals Company, 1951.
3. Ibid., p. 85.
4. Ibid., p. 90.
5. Ibid., p. 166.
6. Ibid., p. 202.
7. Watson, C. D., unpublished data, personal communication, April 1952.

TABLE II
HALOGEN EVOLUTION

Sample No.	Radiation Intensity	Time of Irradiation	Total Radiation Exposure	Chloride Evolved	Fluoride Evolved
	(Thousands of Roentgens) min.	Hours	Millions of Roentgens	Millimole Cl ⁻ gm.	Millimole F ⁻ gm.
Polyvinyl Chloride					
	Samples 1-20 Cubes		Samples 21-30 Shavings		
1	29.0	43	75	0.234	
2	35.7	138	286	1.078	
3	29.0	67	116	0.367	
4	29.0	161	280	0.888	
5	35.7	281	602	2.18	
6	35.7	329	704	2.76	
7	29.0	425	739	2.55	
8	29.0	474	823	3.0	
9	29.0	578	100	3.76	
10	35.7	521	1114	4.72	
11	29.0	43	75	0.147	
12	29.0	138	241	0.739	
13	29.0	161	280	0.795	
14	35.7	281	602	2.58	
15	29.0	67	116	4.11	
16	29.0	424	739	2.35	
17	35.7	329	704	2.76	
18	35.7	576	1232	1.025	
19	29.0	462	802	2.48	
20	35.7	521	1114	4.52	
21	35.7	43	92	1.095	
22	35.7	138	286	2.74	
23	35.7	329	704	4.52	
24	35.7	281	1602	5.0	
25	35.7	588	1260	9.31	
26	35.7	474	1013	6.15	
27	29.0	161	280	1.405	
28	35.7	690	1475	8.58	
29	35.7	521	1114	7.74	
30	35.7	642	1372	7.92	

Non-plasticized Fluorothene					
	Samples P1-P20 Cubes		Samples P21-P30 Shavings		
P1	20.5	54	66	0.0282	0.0034
P2	29.0	102	177	0.013	0.0058
P3	35.7	221	475	0.051	0.011
P4	35.7	169	382	0.045	0.035
P5	29.0	121	211	0.027	0.0079
P6	29.0	216	377	0.027	0.014
P7	35.7	361	773	0.197	0.12
P8	35.7	409	877	0.347	0.26
P9	29.0	529	920	0.186	0.12
P10	29.0	494	858	0.226	0.19
P11	20.5	54	66	0.016	0.025
P12	29.0	102	177	0.012	0.052
P13	35.7	221	474	0.031	0.016
P14	35.7	169	361	0.022	0.026
P15	29.0	121	210	0.012	-----
P16	29.0	216	376	0.012	0.012
P17	35.7	361	773	0.19	0.016
P18	35.7	409	877	0.395	0.32
P19	29.0	529	920	0.18	0.14
P20	29.0	494	858	0.21	0.16
P21	20.5	54	66	-----	-----
P22	29.0	102	177	0.062	0.095
P23	35.7	221	453	0.690	0.785
P24	35.7	169	361	0.781	0.815
P25	29.0	121	211	0.114	0.118
P26	29.0	216	377	0.24	0.26
P27	35.7	361	773	1.03	0.25
P28	35.7	409	877	1.32	1.54
P29	29.0	---	858	1.14	1.28
P30	29.0	494	---	-----	-----

Plasticized Fluorothene					
	Samples F1-F20 Cubes		Samples F21-F30 Shavings		
F1	20.5	67	82.1	0.0965	-----
F2	20.5	120	148	0.0781	0.0172
F3	20.5	168	207	0.114	0.0518
F4	20.5	240	296	0.135	0.0385
F5	20.5	288	354	0.167	0.0658
F6	20.5	336	413	0.266	0.1005
F7	20.5	408	502	0.303	0.187
F8	20.5	456	562	0.275	0.196
F9	20.5	475	596	0.460	0.208
F10	20.5	475	596	0.326	0.195
F11	20.5	67	82	0.0236	-----
F12	20.5	120	148	0.0455	0.0137
F13	20.5	168	207	0.0541	0.0177
F14	20.5	240	296	0.186	0.0742
F15	20.5	288	354	0.153	-----
F16	20.5	336	413	0.228	0.0926
F17	20.5	408	502	0.499	0.363
F18	20.5	456	562	0.185	0.128
F19	20.5	475	596	0.398	0.262
F20	20.5	475	596	0.356	0.165
F21	20.5	67	82	0.0505	0.0579
F22	20.5	120	148	0.0521	0.0431
F23	20.5	168	207	0.055	0.120
F24	20.5	240	296	0.336	0.267
F25	20.5	288	354	0.451	0.318
F26	20.5	336	413	0.474	0.379
F27	20.5	408	502	0.685	0.600
F28	20.5	456	562	0.558	0.448
F29	20.5	475	596	0.920	0.779
F30	20.5	475	596	0.513	0.374

TABLE III
PHYSICAL PROPERTIES

Sample No.	Radiation Intensity	Time of Irradiation	Total Radiation Exposure	Indicator Reading	Breaking Load	Percent of Original Strength
	(Thousands of Roentgens) (min.)	Hours	Millions of Roentgens	Dimensionless	(lb.)	
IMPACT TEST						
Polyvinyl Chloride						
Blank	0	0	0	0.092		100
A1-A4	20.6	52	65	0.054		59
A5-A8	20.6	172	213	0.085		92
A9-A12	20.6	220	273	0.156		170
A13-A16	20.6	316	391	0.192		208
A17-A20	20.6	365	452	0.210		228
A21-A24	20.6	411	507	0.143		155
A25-A28	20.6	480	594	0.229		248
A29-A32	20.6	534	660	0.156		169
A33-A36	20.6	582	720	0.101		110
A37-A40	20.6	654	810	0.225		244
Non-plasticized Fluorothene						
Blank	0	0	0	0.221		100
B1-B4	20.6	52	65	0.045		20
B5-B8	20.6	172	212	0.046		21
B9-B12	20.6	220	271	0.043		20
B13	20.6	316	388	0.046		21
B21-B24	20.6	411	514	0.045		20
Plasticized Fluorothene						
C1-C4	0	0	0	0.267		100
C5-C8	20.6	72	89	0.034		13
C9-C12	20.6	119	147	0.034		13
C13-C16	20.6	168	207	0.033		12
C17-C20	20.6	240	295	0.034		13
C21-C24	20.6	288	354	0.035		13
TENSILE TEST						
Polyvinyl Chloride						
G1-G4	0	0	0		684	100
G5-G9	35.6	49	105		553	81
G9-G12	35.6	97	207		522	76
G17-G20	35.6	164	350		533	78
G17-G20	35.6	218	464		541	79
G25-G28	35.6	266	566		546	80
G25-G28	35.6	338	720		543	80
G29-G32	35.6	385	824		548	80
G33-G36	35.6	434	926		544	80
G33-G36	35.6				555	80
G37-G40	35.6	505	1080		503	74
Non-plasticized Fluorothene						
Blank	0	0	0		326	100
H1-H4	35.6	49	60		53	16
H5-H and up	35.6	97	118		0	0
Plasticized Fluorothene						
J1-J4	0	0	0		134	100
J5-J8	35.6	72	153		22	16
J9-J and up	35.6	120	254		0	0
SHEAR TEST						
Polyvinyl Chloride						
Blank	0	0	0		2004	100
M1-M4	20.6	52	65		2747	137
M5-M8	20.6	172	213		2616	130
M9-M12	20.6	220	273		2699	135
M13-M16	20.6	316	391		2676	134
M17-M20	20.6	365	452		2600	130
M21-M24	20.6	411	507		2521	126
M25-M28	20.6	480	594		2391	119
M29-M32	20.6	534	660		2243	112
M33-M36	20.6	582	720		2099	105
M37-M40	20.6	654	810		1926	96
Non-plasticized Fluorothene						
Blank	0	0	0		1458	100
N1-N4	20.6	53	65		1565	107
N5-N8	20.6	172	212		478	33
N9-N12	20.6	220	271		439	30
N13-N16	20.6	316	388		367	25
N17-N20	20.6	365	449		---	---
N24	20.6	411	514		115	8
Plasticized Fluorothene						
Q1-Q4	0	0	0		915	
Q5-Q8	20.6	72	89		1065	116
Q9-Q12	20.6	120	147		1143	125
Q13-Q16	20.6	168	207		950	104
Q17-Q20	20.6	240	295		515	56
Q21-Q24	20.6	288	354		314	34
Q25-Q28	20.6	306	376		229	25
ORININAL STRENGTH						
				Tensile	Shear	
				lb.force/sq.in.		
Polyvinyl Chloride				8100	6000	
Fluorothene				4600	5200	
Plasticized Fluorothene				2700	4600	