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AN EVALUATION OF A FOAMED NONRIGID PLASTIC AS A SEAL

J. W. Anderson

Submitted as a thesis to the Graduate Council of the University of Tennessee in partial fulfillment of the requirements for the degree Master of Science.

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JULY 1967

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AN EVALUATION OF A FOAMED NONRIGID PLASTIC AS A SEAL

J. W. Anderson

Abstract

The work reported here was done to evaluate the use of a foamed nonrigid plastic as a material to seal sleeve-type penetrations into cells maintained under negative pressures wherein radioactive processing or research is being conducted. Criteria were developed to define the desired material properties as related to the geometric design of the sleeve and plug, the fabrication and installation methods, and the operational environment. Flexible urethane foams and sponge or expanded cellular rubber products were selected for testing. The test equipment, procedures, and results are described. Closed-cell expanded neoprene seals may be satisfactory for installation in sleeve-type penetrations into radioactive hot cells at pressures up to 40 inches of water if the radiation exposure is substantially less than 10^8 roentgens. Further investigations are needed to determine the change in effectiveness of neoprene foam with age and radiation exposure.

CHAPTER I

INTRODUCTION

The sealing of service penetrations into cells that are maintained at negative pressures where radioactive processing or research is being conducted has for many years presented a major problem to the design and operation of hot cells. In the past, designers have attempted to solve the problem by using two principal approaches: [1] the installation of permanently fixed service lines (conduit, pipe, etc.) into the cell with either coupling or disconnect connections and [2] the installation of permanently fixed sleeves through which shielded service plugs may be inserted or removed as necessary. With the advancement of atomic research and production requiring thicker shielding walls and completely remote maintenance and operation, the second approach has become more widely accepted in the field.

For the most part, the sleeve-type service penetrations are made up of an outer sleeve cast into the walls, floors, and ceilings of the cells into which a two-part plug is installed to carry services or equipment into the cell. These service penetrations have a great variety of sizes and shapes; however, the majority are of cylindrical form similar to that shown in Figure 1.

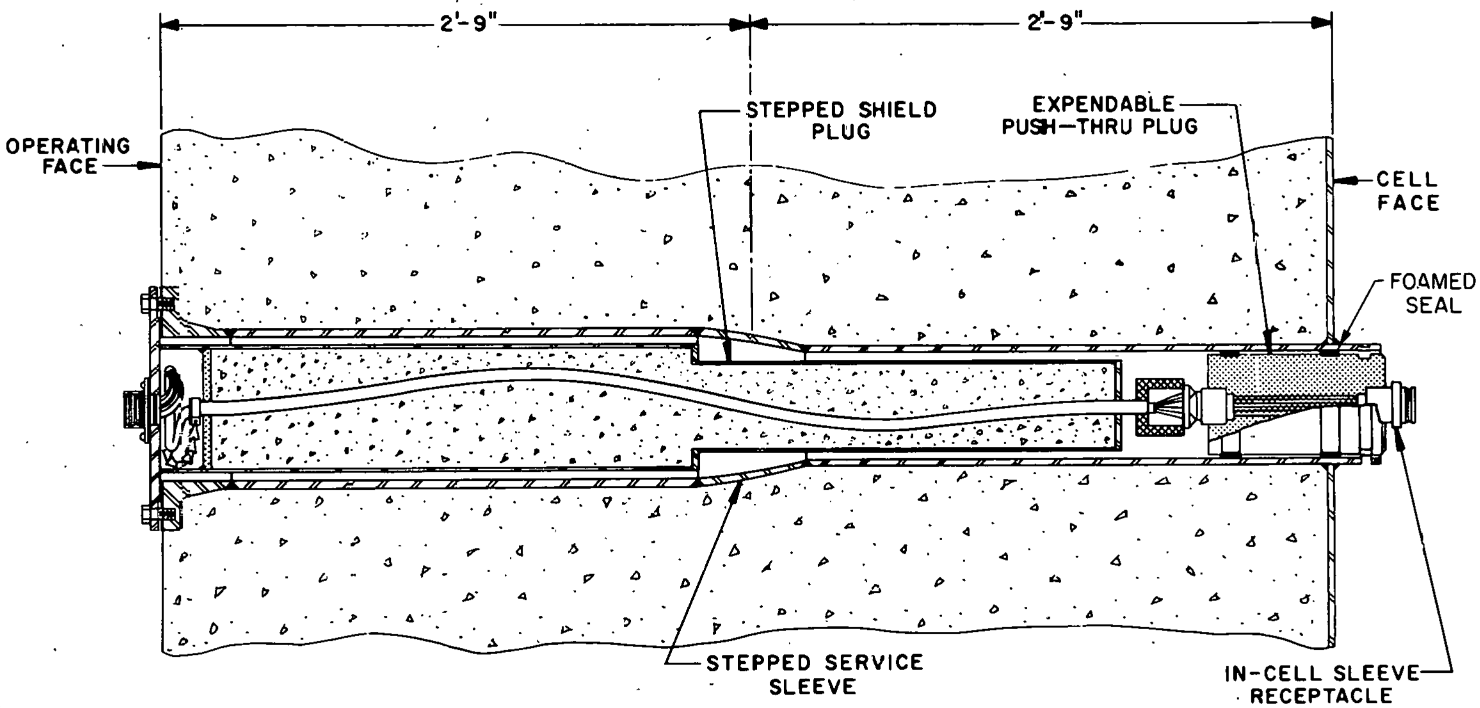

Figure 1. Typical stepped electrical service sleeve and plug installation.

Construction of the High Radiation Level Examination Laboratory (HRLEL) (1)* at Oak Ridge National Laboratory was completed in 1962. The cells in this facility are equipped with many sleeve-type service penetrations, and the designers chose to seal these penetrations by using a standard design for an O-ring static seal. This design requires the inside diameter of the embedded sleeve to be accurately machined and the plug upon which the O-ring is mounted to be accurately fitted to the sleeve. The seal resulting from this design was found to be satisfactory but very expensive to construct and install because of the dimensional tolerances required. Installation and removal of the plugs presented handling problems because of the large forces required to move an individual plug in or out of the sleeve with the O-ring in place.

The Thorium-Uranium Fuel Cycle Development Facility (TUFCDF) (2), presently under construction at Oak Ridge National Laboratory, has approximately 450 sleeve-type penetrations into the cell bank through which electrical, hydraulic, and pneumatic services are fed into the cells. Remote handling and viewing equipment are also installed through certain of these penetrations for operating the in-cell process equipment.

The hot cells of TUFCDF, shown in Figure 2, were designed to be operated initially with an air atmosphere under negative pressure, but

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*Numbers in parentheses refer to items in the List of References in this thesis.

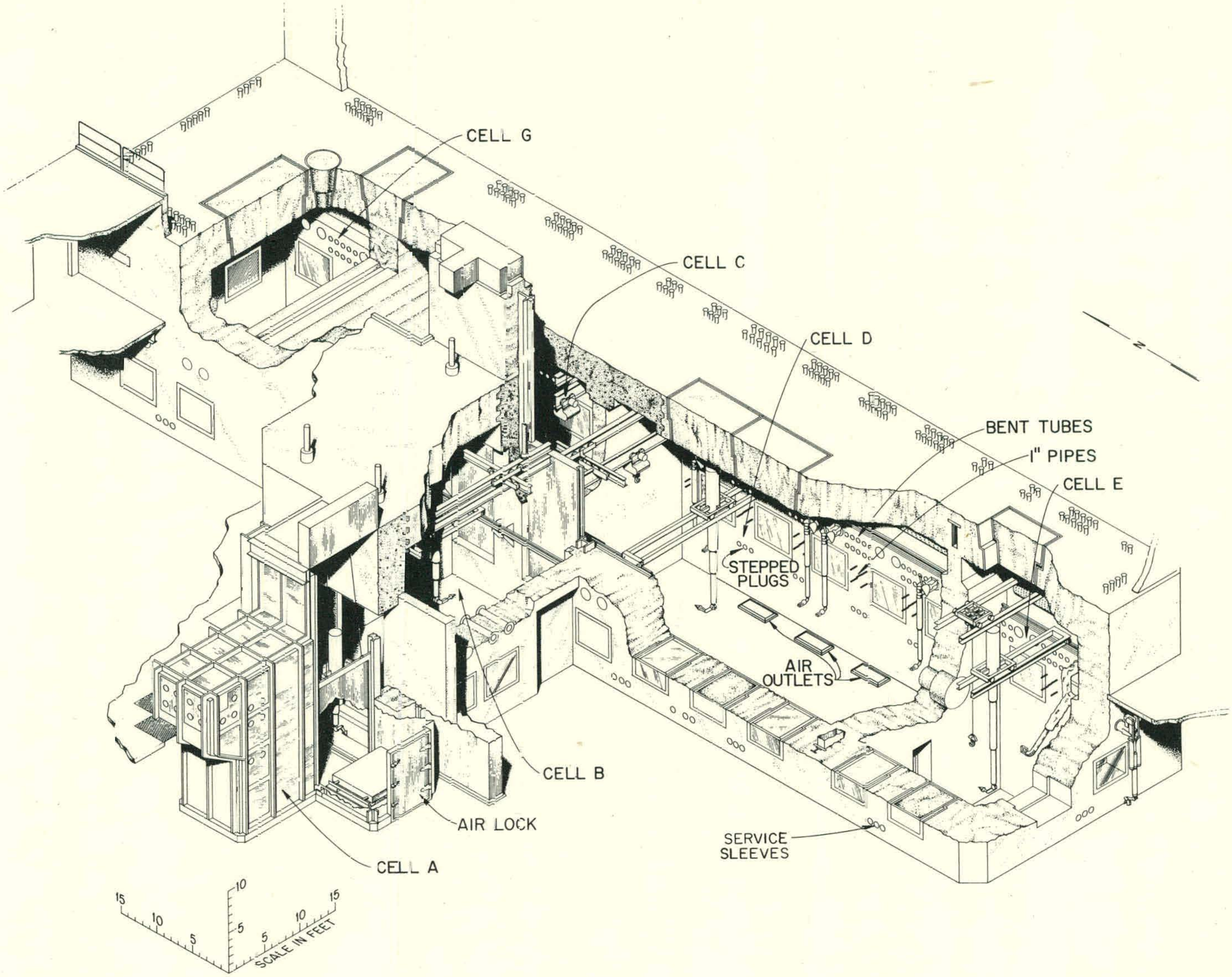


Figure 2. TUFCDF cell bank.

they were also designed to be operated with an inert gas atmosphere under negative pressure. Because of the latter requirement, it is imperative that the service penetrations be effectively sealed to eliminate inleakage of air to the cells. This requirement for near zero leakage and the difficulties and expense encountered with previous sealing methods led the designers of this facility to design the service penetrations with foam gasket seals near the in-cell ends and back-up bolted closures at the out-of-cell ends. However, this back-up out-of-cell flat-gasket seal proved to be expensive and difficult to construct and install.

These problems experienced with designs for previous seals provided the incentive to evaluate the true effectiveness of a foamed nonrigid plastic used as a seal between the service plug and its sleeve. This evaluation is the thesis work carried out and reported here.

CHAPTER II

SEAL CRITERIA AND MATERIAL SELECTION

I. CRITERIA

The criteria defining the desired seal material were developed from an investigation of the variables of the service sleeve and plug related to the

1. geometric design of the sleeve and plug,
2. fabrication and installation, and
3. environment of operation.

As indicated in Chapter I, the majority of service penetrations are of cylindrical form. This investigation was therefore confined to applications having only cylindrical concentric plugs and sleeves.

The experience gained from the HRLEL program indicated that the plug should be designed to provide a clearance gap between the outside diameter of the plug and the inside diameter of the sleeve. This clearance gap should be designed with due consideration being given to the loss of radiation shielding resulting from the gap and to the economics of fabrication and installation of the sleeve. From the viewpoint of economics, the gap should be sufficiently large to permit fabrication of the sleeve from mill-run pipe, either seamless or welded with inside weld bead removed, produced in accordance with standards accepted by the manufacturing industry (3). No machining on the inside diameter of the pipe should be necessary to product the required inside-diameter tolerance. No additional surface finishing operations on the inside diameter of the pipe should be required beyond the approximate 125 micro-inches, root mean square, normally furnished by industry.

The service penetrations of interest in this investigation were all between four and ten inches in diameter. A review of the ASTM (3) and ASA (4) standards revealed that the clearance gap should be approximately one-quarter inch. However, extensive discussions with National Tube Company, Swepco Tube Corporation, and Grinnell Corporation led the author to conclude that no premium in cost resulted from reducing this clearance gap to one-eighth inch. A shielding analysis performed aside from this investigation showed that acceptable radiation levels were not exceeded when a clearance gap of one-eighth inch was used. The annular clearance of one-eighth inch was therefore established as the gap between the plug and its sleeve across which the seal must be effective.

In the third and last area of consideration, study revealed that the nature of hot cell operation requires the service plugs to remain in place for extended periods of time. During much or all of this time, the plug and any component or attachment are subjected to nuclear radiation. Gamma radiation is of primary concern in TUFCDF and is therefore used in this investigation as a basis for criteria in material selection. The philosophy of plug replacement requires that the plug and seal that have been in place for a long period of time will be thrust into the cell by an incoming new plug and seal.

During this change-over operation, the seal must remain effective while being pushed through its sleeve. This requirement makes it imperative that the seal material not retain its total permanent set after deformation under compressive loads for a period of time of up to one year, during which radiation exposure of 10^8 roentgens may be received.

The temperature range within which the seal must function was dictated by the cell atmosphere as being from 60 degrees F. to 180 degrees F. The pressure differential across the seal may vary from a positive 1 inch of water, gage, to a negative 20 inches of water, gage.

II. MATERIAL SELECTION

With criteria established, a search was begun to find a nonrigid foam elastomer or plastic material from which the desired seal might be produced. Virtually no published data were available about the properties of foam materials under compression in a radiation environment. However, a considerable amount of published data were found that defined the characteristics of solid elastomers and plastics.

In view of this situation, those elastomers and plastics available in both the foam and the solid states were first determined. Then the published data of Bopp and Sisman (5), Harrington (6), and others related to the properties of solid elastomers in radiation fields were reviewed. The solid elastomers with the best properties that are also commercially available as foams were chosen for further investigation. All possible choices of material, including natural rubber, were eliminated for undesirable properties of ultraviolet sensitivity, abrasion resistance, resilience, etc., until only the flexible urethane foams produced in accordance with ASTM D-1564 (7) and the closed-cell expanded neoprene produced in accordance with ASTM D-1056 (8) were selected.

Polyurethane Foam

In 1962, data were published by J. K. Backus and E. C. Haag (9) listing properties of the flexible urethane foams, as given in Table I. Some of these polyurethane foams began to be used in a radiation environment in 1959, and the results of this use published in 1960 indicated satisfactory resistance to radiation exposure of 1 x 10^8 roentgens.

In order to evaluate urethane foam as a seal, some sample seals were bought from the Sterling Aldifer Company of Akron, Ohio, for test purposes. The test seals were ordered in accordance with Figure 3, which shows the design of the plug seal. The procurement of these seals proved that foam can be satisfactorily cast or molded. However, this molding process requires expensive tooling and a great deal of time, and for this reason, the unit cost of molded urethane seals was found to be relatively high, as shown in Table II. It was further learned from the manufacturers of urethane that closed-cell foam could only be produced in rigid form; therefore, no further consideration was given the closed-cell fabricated seals.

A test sample of the open-cell urethane foam molded to a density of from 8 to 10 pounds per cubic foot is shown in Figure 4. Sections cut from this test seal were placed in compression fixtures, as shown in Figure 5. One of the samples was placed in a radiation field and

TABLE I

TYPICAL PROPERTIES OF FLEXIBLE URETHANE FOAMS[a]

Property	Polyether Types	Polyester Types
Density ($lb./ft.^3$)	1.1 to 2	1.6 to 6
Tensile strength (p.s.i.)	9 to 20	17.7 to 30
Ultimate elongation (per cent)	220 to 310	235 to 600
Tear limit (lb./linear inch)	4	2.2 to 4
Load for indent of 50 $in.^2$ × 2 in. thick		
25/25[b]	11/9 to 32/28	62/55[c]
50/50	14/12 to 41/37	119/101
65/65	18.5/16.5 to 61/54	229/168
75/75	30/25 to 97/84	428/726
Compression deflection (p.s.i.)		
25/25[b]	0.18/0.15 to 0.54/0.46	0.40/0.30 to 0.86/0.76
50/50	0.21 to 0.63	0.40/0.50 to 1.31
65/65		4.51/4.51
75/75	2.40 to 1.44	0.80/1.05 to 1.68
Compression set, 158 F (per cent)		
50% compression, 22 hours	3 to 4	3.5 to 4.1
90% compression, 6 hours	4 to 4.5	2.3 to 15
90% compression, 22 hours	6 to 8	

[a]This material was taken from John K. Backus and Earl C. Haag, "Urethanes," Machine Design, 34:155, September, 1962.

[b]At percent compression/at percent compression after one minute rest.

[c]For 6 $lb./ft.^3$ density.

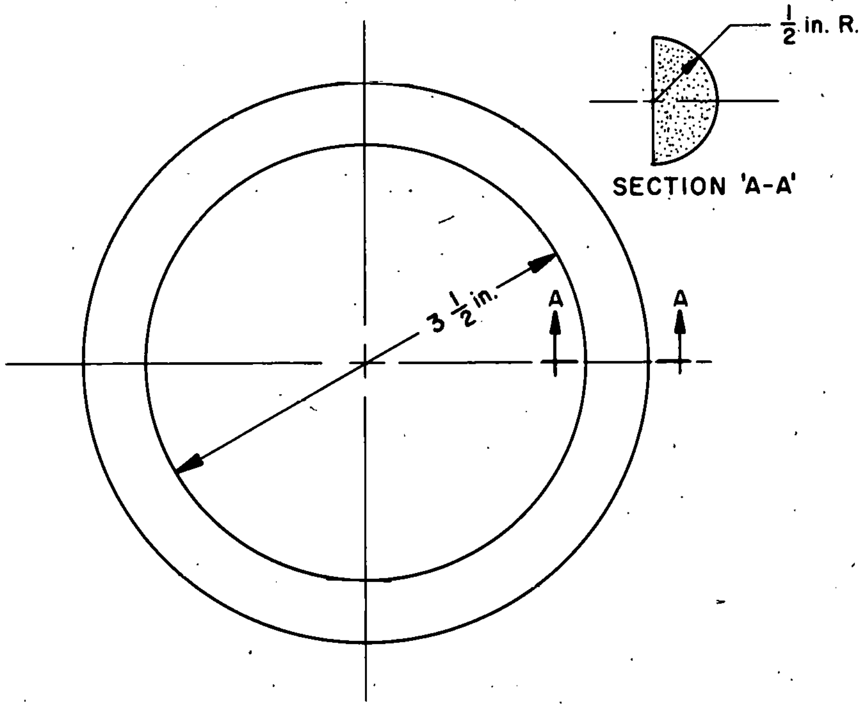


Figure 3. Typical plug seal.

TABLE II

COST OF MOLDED URETHANE FOAM SEALS

Quantity	Unit Price
10	$8.54
25	8.11
50	7.76
100	7.37
500	6.64
1000	6.30

Figure 4. Urethane foam seal.

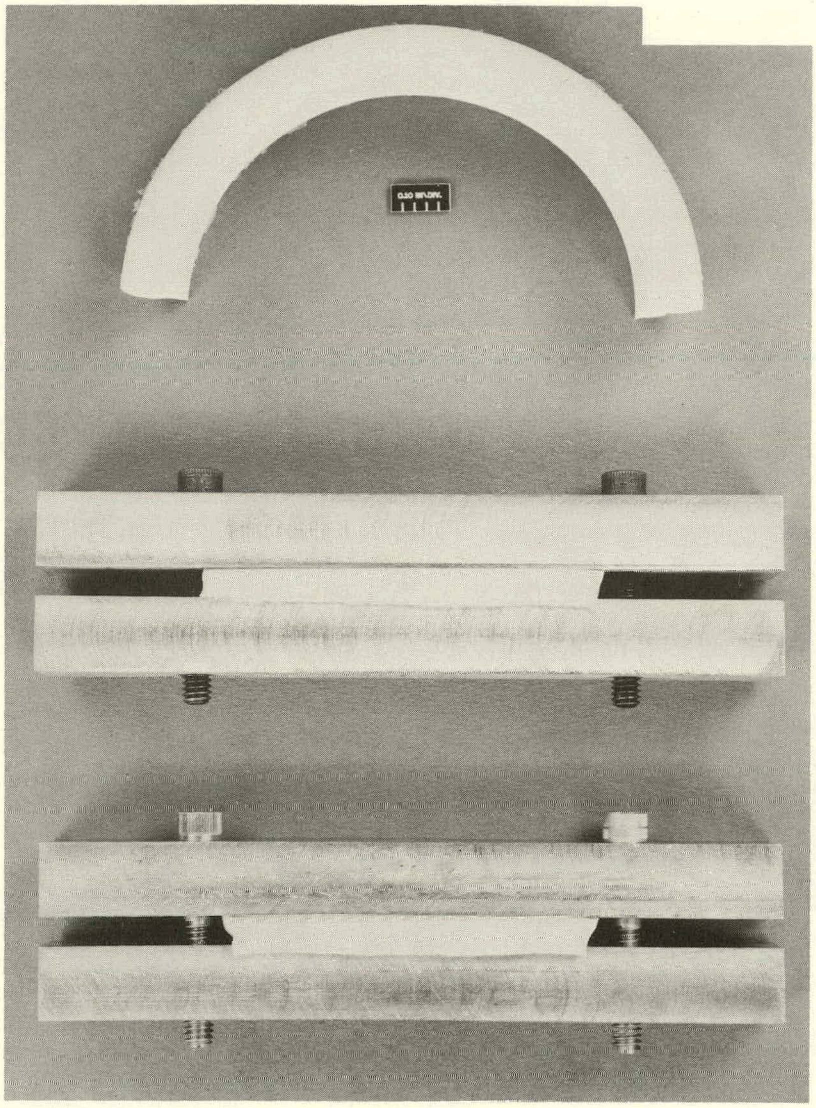


Figure 5. Urethane foam seal shown in as-received condition and in compression test fixture.

received an exposure of 7.5×10^7 roentgens. The other sample was allowed to remain at room conditions for the same period of time. The sample deformed and held at room conditions recovered to approximately 98 per cent of its original shape when released from the fixture. The sample exposed to radiation was observed to be unaffected as to color, flexibility, surface adhesion to metal, or hardness. However, when removed from the compression fixture, this sample retained 100 per cent of its compressed form.

The results of these tests combined with the high production cost and the leakage inherent through an open-cell foam make the urethane foam relatively unattractive as a seal material.

Sponge or Expanded Cellular Rubber Products

Properties of closed-cell expanded neoprene published by the Rubatex Corporation of Bedford, Virginia (11), are given in Table III. Their products are being used for applications in the nuclear field, but discussions with them revealed that they are unaware of any test data relative to the effect of radiation upon their neoprene foams. From the Radiation Effects Information Center at Battelle Memorial Institute it was learned that because of the expansion of the base polymer into a cellular form primarily by mechanical means, the effects of radiation on foam are not expected to be appreciably different from those on the solid neoprene elastomers that are given in Tables X and XI of Appendix A.

To make a better evaluation of the closed-cell expanded neoprene, efforts were initiated to procure some sample seals from the Rubatex

TABLE III

PHYSICAL AND THERMAL PROPERTIES OF CLOSED-CELL RUBBER EXTRUSIONS[a]

Property	Neoprene
Color	Black
ASTM Specifications D-1056 (meets specifications shown on one-fourth inch to one-half inch sheet thickness)	SCE-41
SAE Specification 18-R	SCE-41
Compression Deflection (p.s.i.) Weight required to compress a 1.129 inch diameter disc by 25 per cent. Varies according to thickness.	2.0 to 5.0
Water Absorption by Weight (maximum) ASTM method	5 per cent
Density (p.c.f.)	25 to 40
Temperature Resistance	
Low	−45°F.
High Continuous	150°F.
High Intermittent	200°F.
Migration Stain	Good
Weather Resistance	Good
Chemical Resistance (Room temperature)	
Water	Good
Oil	Good
Gasoline	Fair

[a]This material was taken from "Rubatex Closed Cell Rubber Extrusions," Catalog E-61, issued by Rubatex Division of Great American Industries, Inc., Bedford, Virginia.

Corporation for testing. As in the case of urethane foams, molded seals were found to be too expensive. For this reason, samples of extruded stock were procured from Rubatex for use in an attempt to fabricate a seal from extruded stock. Several seals were made with bonded joints by using neoprene cement. These fabricated seals appeared to be satisfactory; therefore, several sample seals with bonded joints were procured from Rubatex for testing. A photograph of one of these sample seals is shown in Figure 6.

Two sets of test samples were taken from these seals. Each set was placed in a compression fixture as shown in Figure 7. One set of samples was placed in a radiation field and received an exposure of 10^8 roentgens. The other set of samples was allowed to remain at room conditions. The purpose of these tests was to evaluate not only the compression set characteristics of the extruded stock but also the bonded joints. Table IV indicates the type of joint in each test sample and the results of the test. Even though all samples irradiated retained 100 per cent of their compressed form, the samples were still flexible and were unaffected as to color and surface adhesion to metal. The joints bonded with cement were observed to be relatively unaffected by the radiation exposure.

The results of these tests indicate the neoprene foam is affected by radiation much like the polyurethane foam; however, the relatively low production cost, as tabulated in Table V, and the inherently greater sealing capacity of the closed-cell material make the closed-cell expanded neoprene the most attractive seal material known to be available.

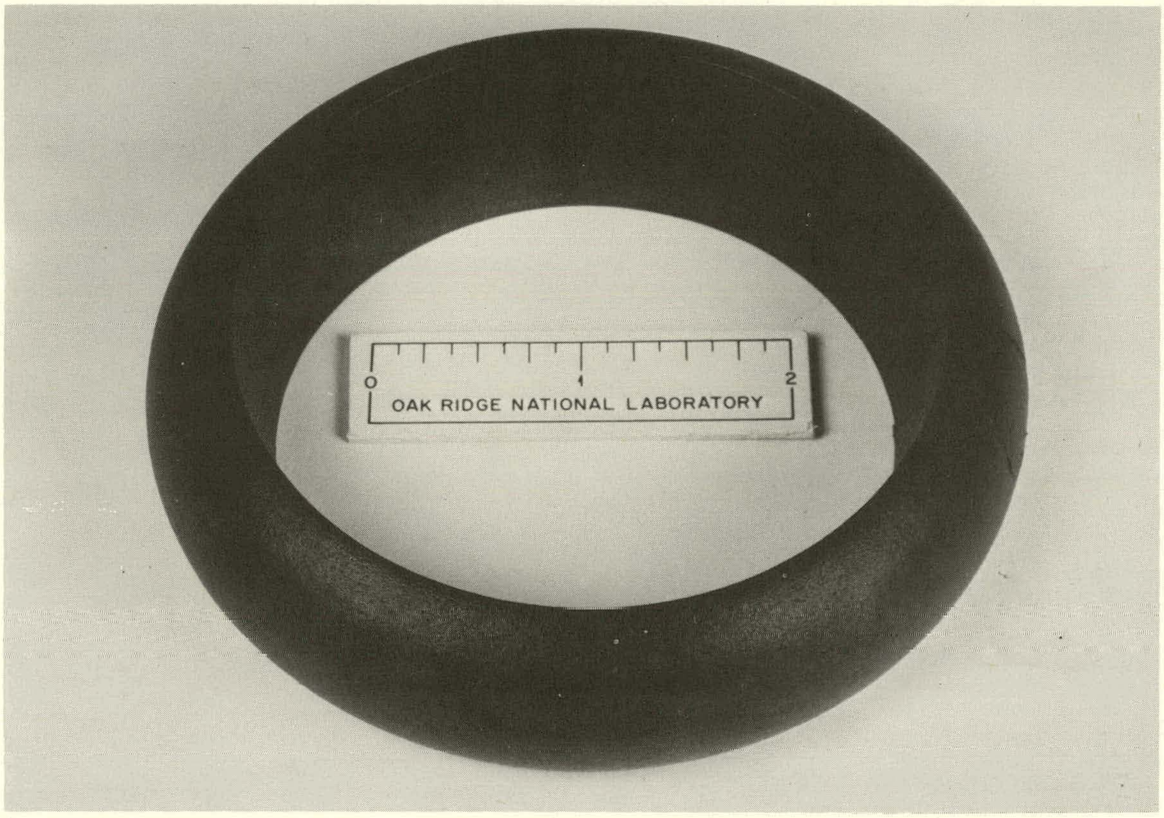


Figure 6. Closed-cell expanded neoprene seal.

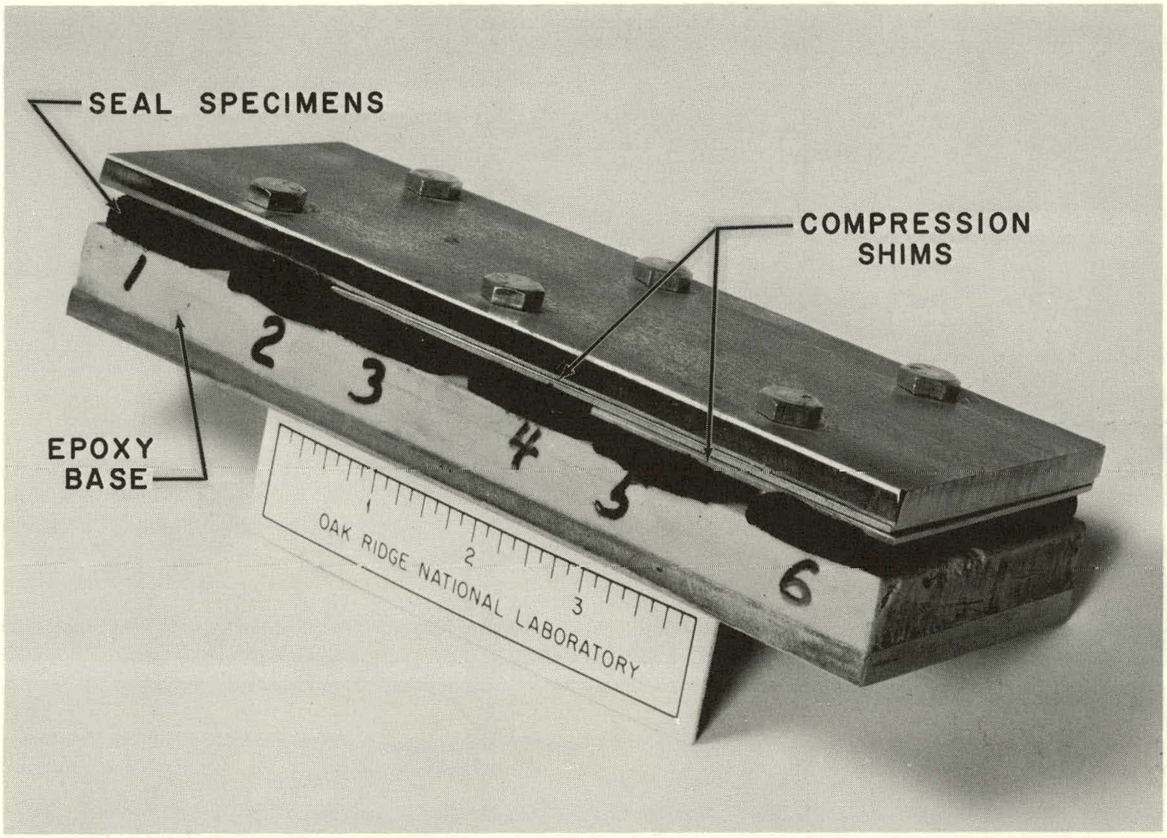


Figure 7. Compression test fixture with samples of closed-cell expanded neoprene seals.

TABLE IV

RESULTS OF COMPRESSION TEST ON SAMPLES OF CLOSED-CELL EXPANDED NEOPRENE

Sample No.[a]	Joint (Butt)	Initial Compression (Inches)	Per Cent Recovery Unirradiated Samples[b]	Per Cent Recovery Irradiated Samples[c]
1	45°	3/16	66.6	0
2	90°	3/16	66.6	0
3	None	1/4	50.0	0
4	90°	1/4	50.0	0
5	45°	5/16	40.0	0
6	90°	5/16	40.0	0

[a]All samples cemented to epoxy surface with neoprene cement.

[b]All samples held compressed at room conditions for 178 days. Upon release of compression, recovery took place continuously for four days with no perceptible recovery in an additional three days.

[c]All samples exposed in air to 10^8 roentgens. All samples hardened with the least damage experienced by the lesser compressed samples.

TABLE V

COST OF FABRICATED CLOSED-CELL EXPANDED NEOPRENE SEALS

Quantity	Unit Cost
10	$0.35
100	0.30
1000	0.28

CHAPTER III

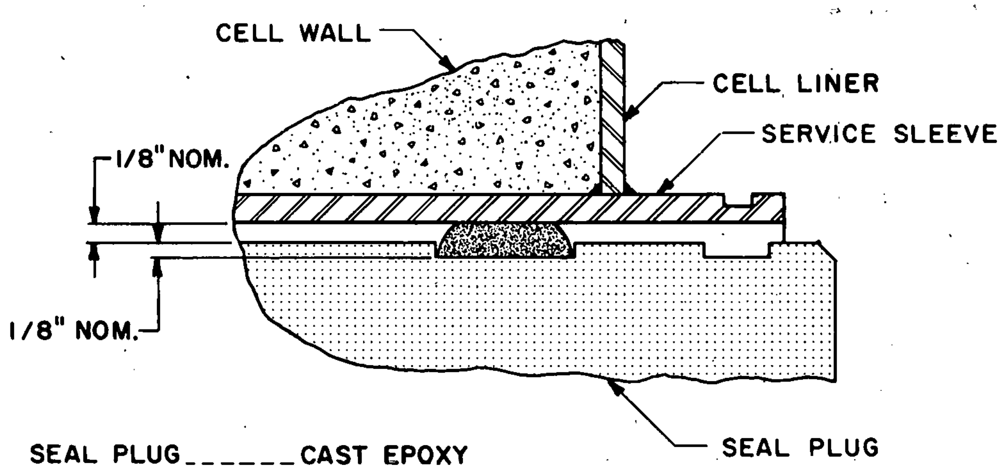
DESIGN OF SEAL EVALUATION TESTING

I. SEAL AND MOUNTING GROOVE

Having chosen the seal material, as reported in Chapter II, attention was turned to the task of evaluating the effectiveness of the seal. In Chapter I, it was mentioned that the approximately 450 service penetrations in TUFCDF (2) were constructed by using a foam seal between the in-cell portion of the plug, referred to as the expendable push-through plug, and its sleeve. The design chosen for TUFCDF for mounting the seal is shown in Figure 8. The configuration for the seal to be evaluated and the plug-to-sleeve clearance gap were designed as defined in Chapter II and were the same as used in TUFCDF.

The design for the seal mounting groove in the seal plug was developed, taking into consideration the amount of seal compression required to effect a seal. The axial forces required to thrust the plug with seal compressed into position in the sleeve were also considered.

ASTM D-1056 (8) indicates that the upper limit of compression of neoprene foam is approximately 50 per cent. Compression appreciably above this point will rupture cells, causing permanent internal damage to the seal. A compression of 30 per cent was selected as the design objective. This was judged to provide the maximum sealing capacity and



SEAL PLUG	CAST EPOXY
SERVICE SLEEVE	ASTM A-312 PIPE STAINLESS STEEL TYPE 304L
CELL WALL	CONCRETE 3'-6" TO 5'-6" THICK DEPENDING UPON LOCATION
CELL LINER	3/16" THICK STAINLESS STEEL TYPE 304L

Figure 8. Typical seal installation.

also to permit a small margin of safety for fabrication and installation tolerances on both the sleeve and the plug.

A 4-inch schedule-40 pipe sleeve was selected to be used in the test. This size pipe, manufactured in accordance with ASTM A312 (3), has an inside diameter of 4.026 inches. A seal was chosen with an inside diameter of 3 1/2 inches. The total volume of the seal in its free state,

$$\text{Volume} = A_s \pi \bar{D} \ ,$$

where

A_s = cross sectional area of the seal = 0.394 inch,

$\bar{D}$ = centrodial diameter of the seal = $3.5 + \frac{0.848}{2}$,

= 3.924 inches.

$$\text{Volume} = (0.394)(3.924)\pi \ ,$$

$$= 4.866 \text{ cubic inches} \ .$$

Using the 3 1/2-inch-diameter seal compressed between the 3 1/2-inch diameter of the plug and the 4.026-inch diameter of the sleeve,

$$\%\ \text{Compression} = \frac{V_{orig} - V_{comp}}{V_{orig}} (100) \ ,$$

where

V_{orig} = 4.866 cubic inches,

V_{comp} = volume of the seal in its compressed state,

$\approx (9/32)(\pi)(3.763)$,

= 3.325 cubic inches.

$$\% \text{ Compression} = \frac{4.866 - 3.325}{4.866} (100) ,$$

$$= 31.6\% .$$

From this approximate calculation, it was concluded that a seal mounting groove 1 1/4 inches wide and 1/8 inch deep was sufficient for this investigation.

From a test conducted by F. E. Adley (12), it is found that a compressive force of approximately 4 3/4 pounds per square inch is required to compress neoprene foam by 31 to 32 per cent. A coefficient of sliding friction of 0.40 between the compressed seal and the stainless steel sleeve was used to determine the axial force required to install or remove the plug. This axial force,

$$F = NF_n C_f ,$$

where

N = number of seals normally installed on a push-through plug
= 2,

F_n = normal compressive force exerted between the seal and the sleeve
= $(4.75)(\pi)(3.763)$ = 56.2 pounds,

C_f = coefficient of friction
= 0.40.

$$F = (2)(56.2)(0.40)$$

$$= 45 \text{ pounds} .$$

This axial force was not considered to be excessive since it is within the capacity of an average man to exert this amount of force to push the plug into place within its sleeve.

II. FIXTURE FOR TESTING

A test fixture was designed, as shown in Figure 9, to furnish the requirements outlined in the previous paragraphs. The test sleeve was fabricated from ASTM A-312 (3), 4-inch schedule-40 seamless pipe. All joints were welded and received a full visual and liquid penetrant examination (13). The test plug was fabricated from aluminum to simulate an epoxy expendable push-through plug. A thrust plate for positioning and holding the plug in place was held in the sleeve by a modified breech locking joint.

III. TEST SETUP

A testing setup was designed by using the test fixture with a temperature-compensating leak detector (14) shown schematically in Figure 10. The leak detection instrument basically provides two volumes: one is a reference volume, and the other a test volume with a differential pressure gage in between. Both volumes are pressurized with gas from a common supply across the sensitive differential pressure gage. When the desired test pressure is reached, the two volumes are isolated. Any ensuing relative change in pressure will be reflected by the differential pressure gage. The instrument is temperature compensating by virtue of the fact that the reference volume is immersed

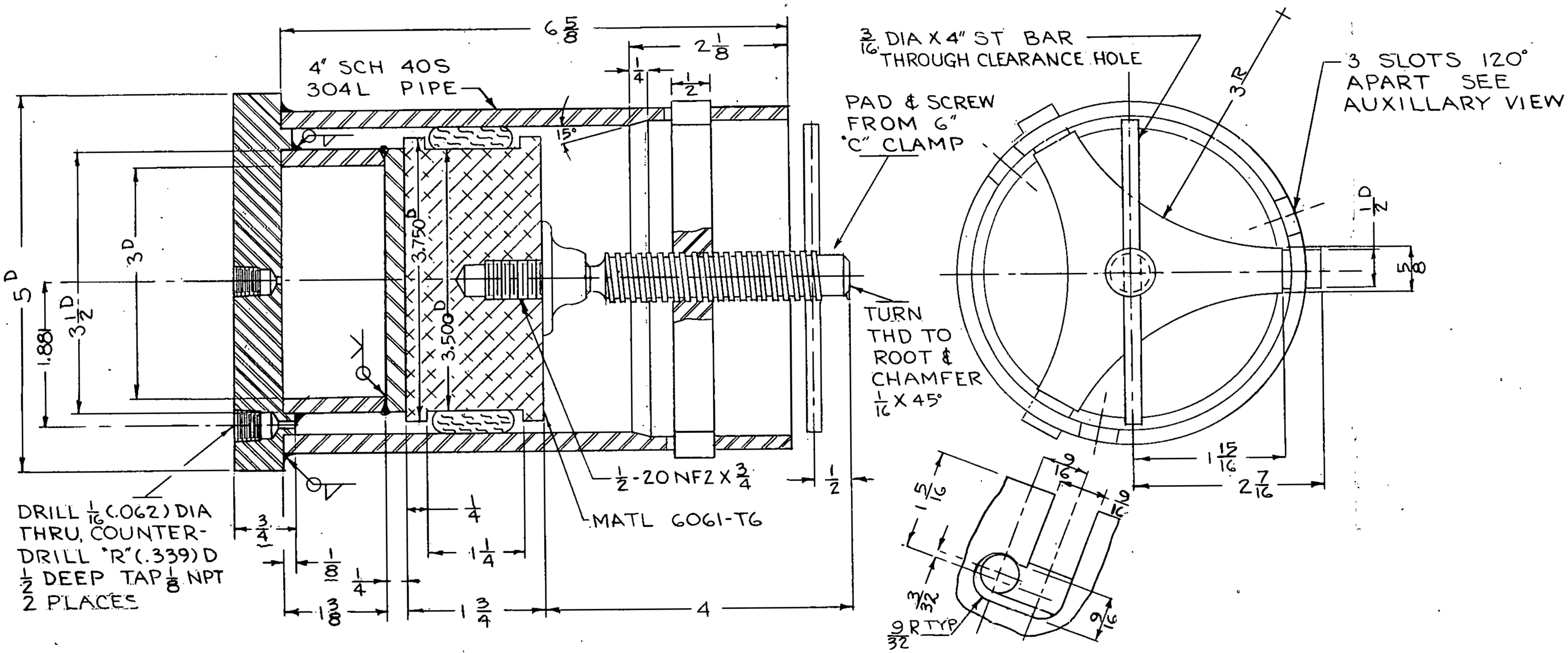


Figure 9. Fixture for leak testing seal.

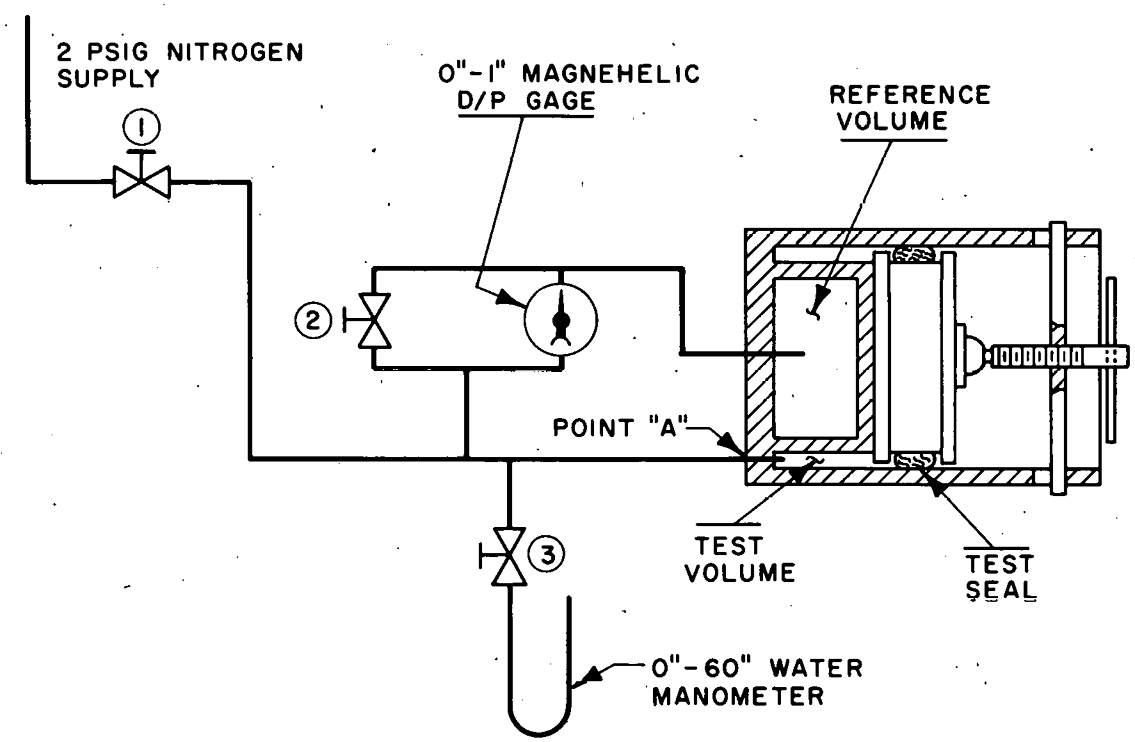


Figure 10. Schematic diagram of equipment setup for leak testing.

in the test volume. The instrument is not affected by changes in atmospheric pressure because both volumes have a common medium within rigid containers.

The differential pressure gage used in this test was a direct-reading 0-to-1-inch-water-scale Magnehelic gage manufactured by the F. W. Dwyer Company. The gage scale was graduated in increments of 0.02 inch of water. A reading of 0.01 inch of water could be estimated from the gage scale.

The leak detection sensitivity of this instrument can be estimated by knowing the volume of the test chamber and the interconnecting tubing. This volume,

$$V_t = \frac{h\pi(d_o^2 - d_i^2)}{4} + \ell A_t \ ,$$

where

h = height of annular test chamber = 1.750 inches,

d_o = inside diameter of the pipe sleeve = 4.026 inches,

d_i = outside diameter of the reference volume = 3.500 inches,

ℓ = length of 1/4-inch interconnecting tubing = 41 inches,

A_t = cross-sectional area of 1/4 inch tubing with 0.040 wall = 0.0227 square inches.

$$V_t = (1.750)(\pi/4)([4.026]^2 - [3.500]^2) + (41)(0.0227) \ ,$$

$$V_t = 6.40 \text{ cubic inches} \ .$$

By assuming that the movement in the diaphragm of the Magnehelic gage is negligible and that nitrogen behaves as a perfect gas with the leakage expansion taking place isothermally, the minimum volume leakage detectable can be estimated as,

$$\Delta V = V_t \left(\frac{P_i}{P_f} - 1 \right) F_s ,$$

where

V_t = the volume of the test chamber = 6.40 cubic inches,

P_i = the absolute pressure in the test volume at the beginning of the test,

P_f = the absolute pressure in the test volume at the completion of the test,

F_s = the correction of test conditions to standard conditions of temperature and pressure.

With the test pressure set at 20 inches of water, gage and the ambient temperature at 70 degrees F.,

$$\Delta V = (6.40)\left(\frac{427.90}{427.89} - 1\right) \left[\frac{427.90}{407.90} \left(\frac{519}{530} \right) \right],$$

$$= 1.56 \times 10^{-4} \text{ cubic inches at standard conditions.}$$

This leakage occurs over the period of time during which the differential pressure gage is observed to change by one-half a graduation. When used in a hold test of one hour duration, the instrument could detect any loss in pressure greater than 9.04×10^{-8} cubic feet per hour at standard conditions.

CHAPTER IV

TEST RESULTS AND CONCLUSIONS

I. TESTS

The fixture for leak testing the seal was fabricated and assembled in the test setup described in Chapter III and shown in Figure 11. The seal for test evaluation was mounted in the middle of the groove in the test plug, as shown in Figure 12, and bonded to the bottom of the groove with Magic Bond foam neoprene cement manufactured by Sportsways, Inc., of Paramount, California. The surface of the seal was lubricated with a very light film of silicone valve lubricant manufactured by Dow Corning Corporation of Midland, Michigan.

To permit installation of the plug and test seal, the tubing joint at Point A shown in Figure 10, page 28, was disconnected. The seal was then installed and locked in place. Prior to remaking the connection at Point A, the system was back-pressurized to 10 pounds per square inch and all joints and the total surface of all the tubing were leak checked with soap solution. All leaks were eliminated, after which the joint at Point A was reconnected. The system was then ready for leak testing.

Test runs were made at pressures of 10, 15, 20, 30, and 40 inches of water, gage. Each test run was carried out in accordance with the procedure outlined in Appendix B. Test runs 1, 2, and 3, at

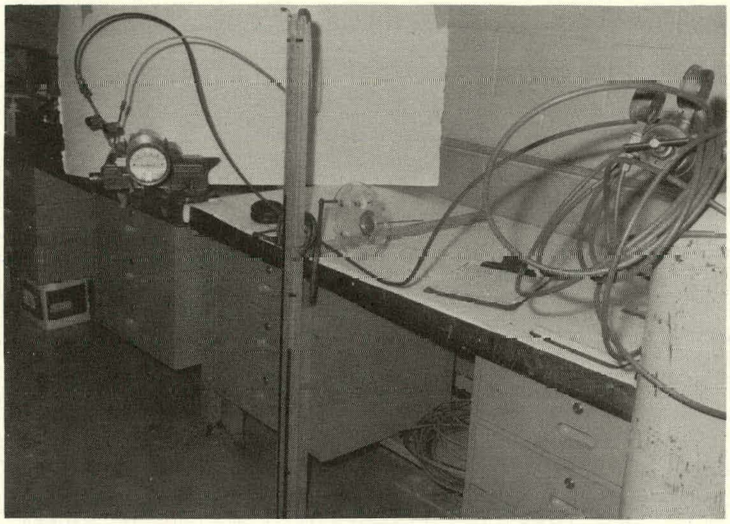


Figure 11. Test equipment setup for leak testing.

Figure 12. Leak testing fixture with seal mounted on plug.

pressures of 10, 15, and 20 inches of water, gage, respectively, were held for one-hour periods of time. Test runs 4 and 5, at pressures of 30 and 40 inches of water, gage, respectively, were held for half-hour periods of time. From these tests, the relationship of leakage at the seal as a function of test pressure was determined and plotted, as shown in Figure 13.

The data from test runs 1 and 2 indicate an increase in pressure within the test volume. It is believed that these test runs were made before the gas from the nitrogen supply bottle was allowed to stabilize at ambient temperature. The gas was bled into the test equipment from a high-pressure cylinder, and it therefore cooled considerably when expansion into the test equipment took place. For this reason, these points were neglected when the leakage curve shown in Figure 13 was plotted.

The loss of pressure during test runs 1 through 5 was observed to vary approximately linearly with time. The rate of leakage was therefore calculated by using the total change in pressure during each test run.

After completion of test runs 1 through 5, the apparatus was allowed to sit with the test seal compressed in position. Approximately four days after the first series of tests, a second series was run. Test runs were again made at pressures of 10, 15, 20, 30, and 40 inches of water, gage. In this series of tests, each run was held for a one-hour period of time. The relationship of leakage at the seal

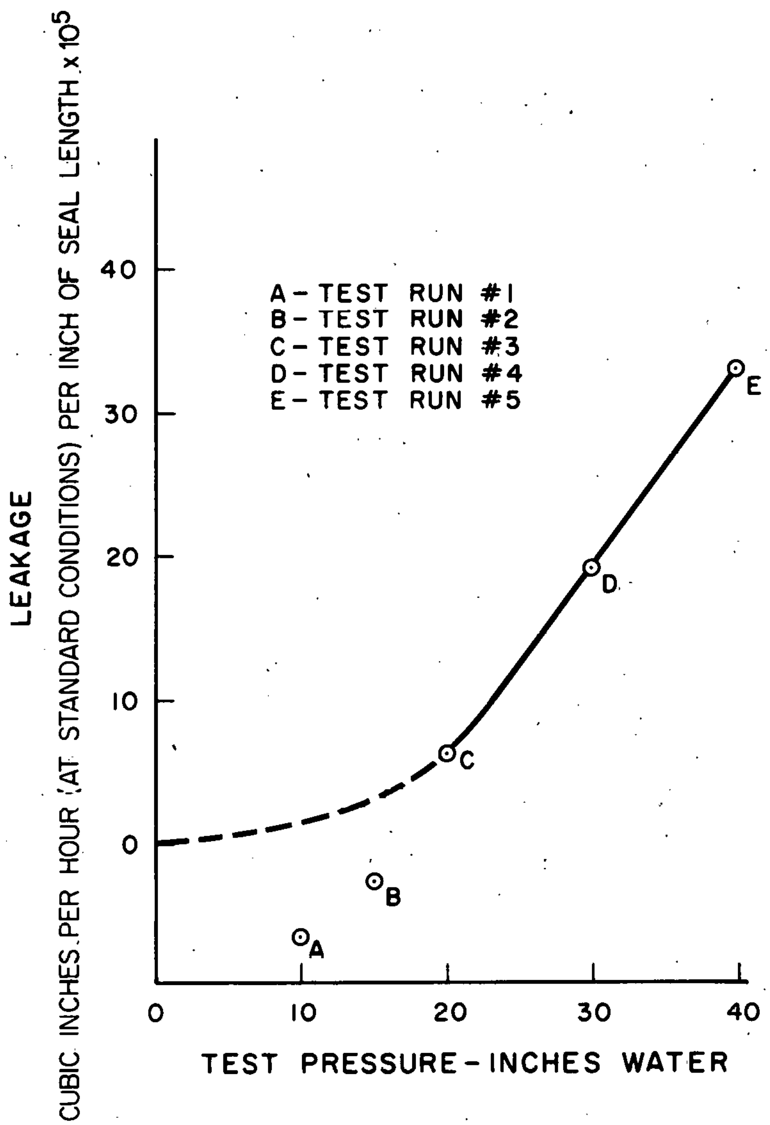


Figure 13. Leakage at initial installation of test seal.

as a function of test pressure was determined and plotted, as shown in Figure 14.

In the second series of tests, runs 1A through 4A, the near constant rate of pressure change in the test volume found in the first series of tests did not reappear. The rate of change in test pressure was found to decrease with time. The rate of leakage was therefore calculated by using the maximum rate of pressure loss. This maximum rate of change was found to occur at the beginning of each test run.

II. CONCLUSIONS

The investigations carried out and reported in Chapters II and III, as well as those previously described in this chapter, lead to the following conclusions.

1. The most promising flexible foam material for use as a seal is closed-cell expanded neoprene.

2. Both polyurethane foam and expanded neoprene will experience a compression set of approximately 100 per cent when exposed to a gamma radiation dose of 7.5×10^7 to 1×10^8 roentgens.

3. Molded seals are twenty to thirty times more expensive than seals fabricated with a cement-bond joint.

4. The results of this investigation have shown that foam neoprene seals may be satisfactory for installation in service sleeves in radioactive hot cells at pressures up to 40 inches of water provided the radiation exposure is substantially less than 10^8 roentgens.

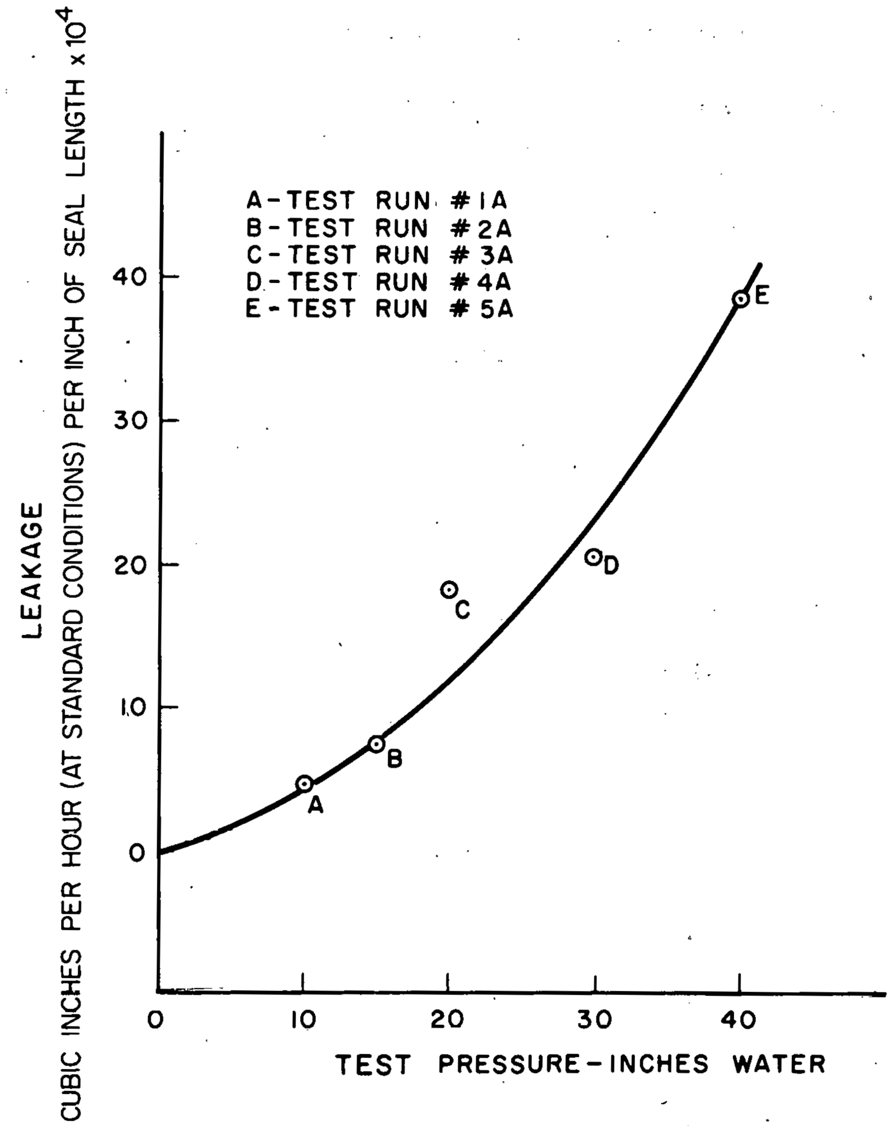


Figure 14. Leakage four days after initial installation of test seal.

6. This investigation has pointed up the change in sealing effectiveness of neoprene foam with age and radiation exposure. More extensive evaluation of these effects should be carried out over a longer period of time under conditions of actual operation.

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APPENDICES

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APPENDIX A

MATERIAL PROPERTIES

The following data are included to give the reader a better understanding of the various properties and characteristics of elastomers considered in this investigation.

TABLE VI

RADIATION STABILITY OF ELASTOMERS[a]

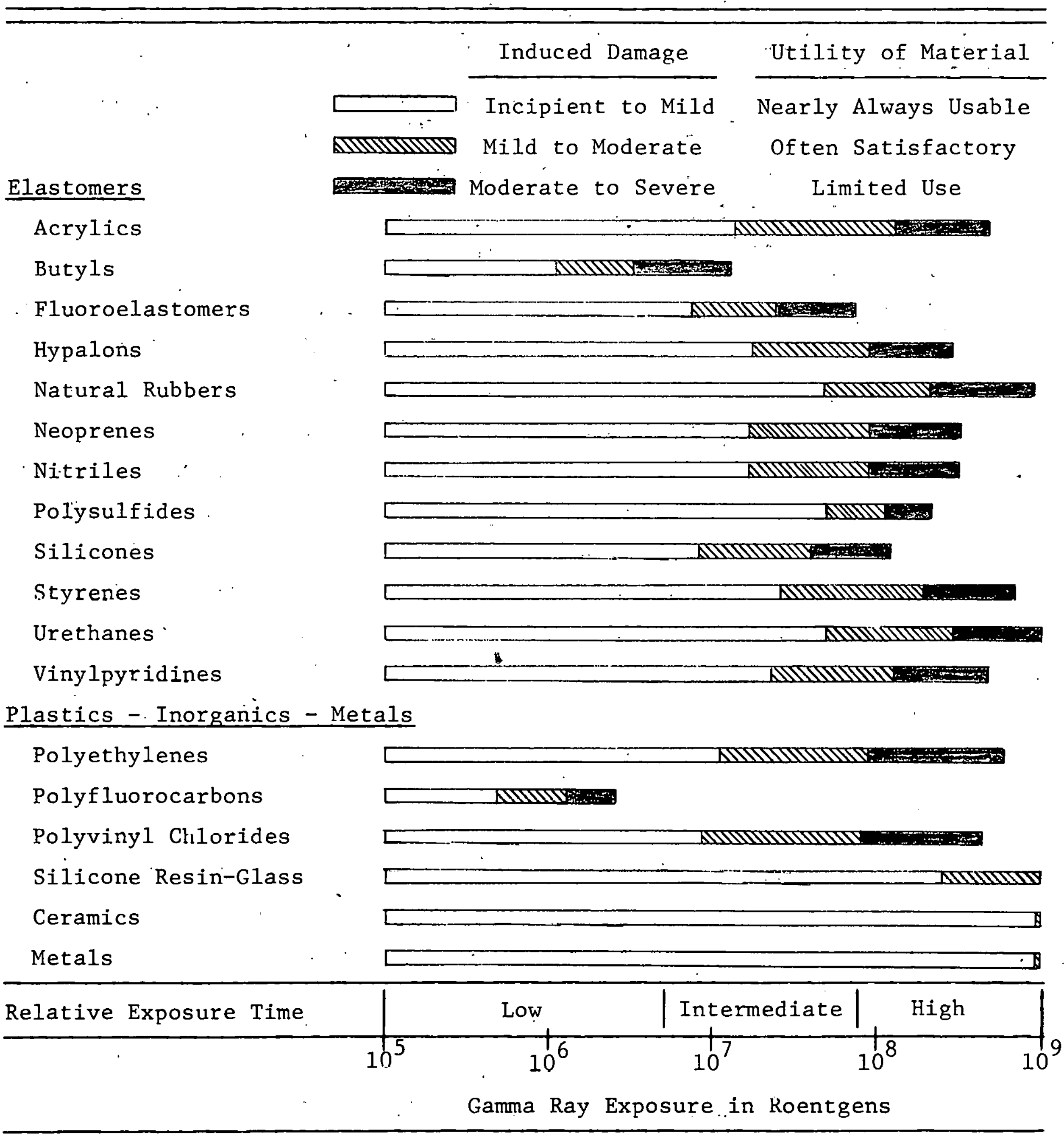
Formulation	absorption (rad./10^9 n.v.t.)	Breaking elongation: Initial value (%)	Breaking elongation: Exposure for 50% decrease (10^9 rad.)	Initial value of dynamic Young's modulus (10^8 dynes/cm.^{2})
Group I. Irradiated in air-filled containers				
Natural rubber	0.6	420	0.5	2.3
Neoprene	2.5	450	0.06	-
Hycar OR	0.6	250	0.10	-
Butyl rubber	0.6	525	0.10	b
GR-S	0.6	270	0.10	1.8
Hycar PA	0.6	230	0.10	-
Thiokol ST	0.4	162	0.10	-
Silastic 7-170	0.7	520	0.06	-
Group II. Irradiated in helium-filled containers				
Polybutadiene	0.8	360	0.1	0.9
Hycar OR-15	0.8	320	0.1	1.2
Hycar OS-10	0.8	380	0.1	1.2
Neoprene GN	2.5	475	0.1	1.2
Thiokol	0.4	180	0.1	-
Silastic 250	0.7	320	0.1	4.0
Natural rubber	0.8	460	0.1	0.3
Hycar PA	0.8	660	0.05	0.6
Hypalon S2	2.5	250	0.1	3.0
Group III. Natural rubber with plasticizer				
L.P. oil	0.8	560	0.1	0.33
Dioctyl phthalate	0.8	440	0.1	0.25
Dioctyl sebacate	0.8	520	0.1	0.30
Tributoxy ethyl phosphate	0.8	440	0.1	0.47
TB90B	0.8	360	0.1	-
"SC"	0.8	390	0.1	-

[a]This material was taken from C. D. Bopp and O. Sisman, "Radiation Stability of Plastics and Elastomers," ORNL-1373, 1954.

[b]Durometer hardness decreases.

TABLE VII

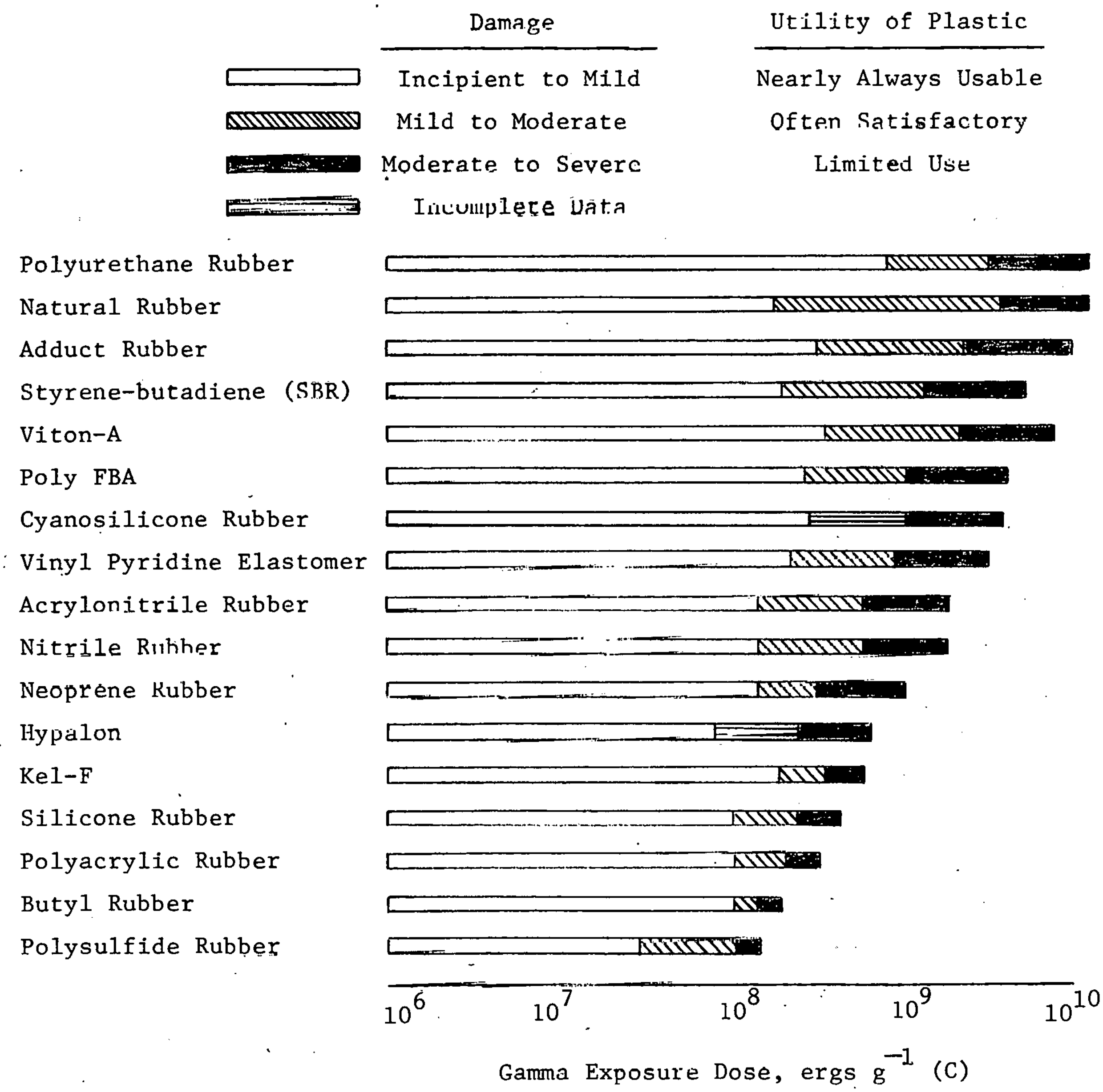
RELATIVE RADIATION RESISTANCE OF ELASTOMERS AND OTHER MATERIALS[a]



[a]This material was taken from R. Harrington, "Effects of Gamma Radiation on Miscellaneous Elastomers and Rubberlike Plastics Material," Rubber Age, 81, September, 1957.

TABLE VIII

RELATIVE RADIATION STABILITY OF ELASTOMERS[a]



[a]This material was taken from N. J. Broadway and S. Palinchak, "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials," REIC Report No. 21 (Addendum), Radiation Effects Information Center, Battelle Memorial Institute, August 31, 1964.

TABLE IX

RADIATION RESISTANCE OF ELASTOMERS[a]

Material	Threshold dose for 25% change[b] (10^6 rads.)
Polyethylene[c]	90
Polyisoprene (natural rubber)[c]	25
Styrene-butadiene rubber[c]	10
Nitrile rubber[c]	7
Neoprene rubber[d]	6
Silicone rubber[c]	6
Butyl rubber[d]	4
Fluoroelastomers[d]	4
Acrylate rubber[c]	3
Polysulfide[d]	2

[a]This material was taken from J. G. Carroll and R. O. Bolt, "Radiation Effects on Organic Materials," Nucleonics, 18(7), September, 1960.

[b]Based on the most sensitive elastomer property, usually tensile strength.

[c]Crosslinks predominantly.

[d]Scissions predominantly.

TABLE X

PERCENT RECOVERY OF IRRADIATED RUBBERS COMPRESSED 25 PER CENT[a]

	Percent Recovery Compressed 25 Per Cent		
Polymer	Doses (r)	Unirradiated Recovery (%)	Irradiated Recovery (%)
Polyisobutylene	5×10^7	91	23
P.C.T.F.E.	-	-	-
Polysulphide	3.3×10^7	90	2
Silicone	5×10^7	97	27
Neoprene	7.5×10^7	62	20
Nitrile	5×10^7	92	62
Chlor Sulphonated Polyethylene	-	-	-
Natural	5×10^7	93	52
Butadiene Styrene	5×10^7	90	53

[a]This material was taken from R. Sheldon, "A Guide to the Irradiation Stability of Plastics and Rubbers," NIRL/R/58, National Institute for Research in Nuclear Science, September, 1963.

TABLE XI

TYPICAL LOAD AND DEFLECTION PROPERTIES OF FLEXIBLE URETHANE FOAMS[a]

		Polyester foam			Polyether foam		
		Density, lb./ft.^{3}			Density, lb./ft.^{3}		
		1.8-2.2	2.25-2.75	4.5-5.5	1.4-1.6	1.6-1.8	1.8-2.1
Compression set, %[b]	(50%)	10 max.	10 max.	10 max.	10 max.	10 max.	10 max.
Indentation-load[c] deflection, lb.	(25%)	30-40	35-45	50-60	13-16	18-22	29-35
	(50%)	40-50	-	-	18-22	24-30	38-42
	(75%)	110-140	-	-	40-50	55-65	90-100
Compression-load deflection, (p.s.i.)	(25%)	0.50-0.60	0.55-0.65	0.75-0.85	0.18-0.22	0.28-0.32	0.45-0.55
	(50%)	0.55-0.75	0.65-0.75	0.10-1.30	0.27-0.33	0.32-0.38	0.60-0.70
	(75%)	1.50-1.80	1.80-2.20	3.25-3.75	0.72-0.88	0.80-1.00	1.60-2.00
Compression resilience, %[d]		38-42	38-42	55-65	55-65	55-65	55-65
Ball-drop resilience, %		25-30	25-30	40-45	45-55	45-55	45-55

[a] Table prepared by Nopco Chemical Company using methods according to ASTM D-1564-60T.

[b] Constant deflection compression set; set based on original thickness.

[c] Specimen size = 15 inches x 15 inches x 2 inches.

[d] Ball, 5/8 inch diameter, 18 inch drop.

TABLE XII

TYPICAL PROPERTIES OF URETHANE ELASTOMERS[a]

Hardness, durometer range	50 Shore A to 70 Shore D
Specific gravity	1.1 to 1.3
Tensile strength (p.s.i.)	4000 to 8000
Ultimate elongation (per cent)	400 to 700
Resilience (per cent)	50 to 80
Compression set, 158 degrees F., (per cent)	0 to 50
Tear strength, split sample method, (pounds per inch)	50 to 400
Abrasion resistance	Excellent
Flexural modulus (p.s.i.)	8000 to 90,000
Compression-deflection at 5 per cent (p.s.i.)	100 to 800
Low-temperature brittle point (degree F.)	−60 to −90
Clash-berg glass transition (degree F.)	−20 to −70
Flame resistance	Fair to Good
Heat resistance (degree F.)	180 to 250
Heating aging, 212 degrees F.	Good
Oxidation resistance	Excellent

[a]This material was taken from J. K. Backus and E. C. Haag, "Urethanes," Machine Design, 34, September, 1962.

APPENDIX B

OPERATING PROCEDURE FOR OPERATING TEMPERATURE COMPENSATING LEAK DETECTOR

(Refer to Figure 10, page 28)

1. Close all valves on the test assembly.
2. Connect regulated supply (2 psig) to valve 1.
3. Connect 0–60 inch manometer to valve 3.
4. Open valves 2 and 3.
5. Open valve 1 and pressurize system to 40 inches, as indicated on the manometer.
6. Close valve 1 and soap test all exposed joints of the test system.
7. After the test system is proven to be leak tight and the manometer remains steady at 40 inches water, close valve 1 and break hose connection to manometer to bleed system down to beginning test run pressure.
8. Close valves 2 and 3. Record time, ambient temperature, and reading of manometer. Set Magnehelic gage on 0.500 inches.
9. Hold test for one hour. At the end of each ten-minute interval, record the ambient temperature and the reading of Magnehelic gage.
10. At the end of one hour, open valve 3 and record reading of manometer.
11. Open valve 2. Break hose connection to manometer to vent system.

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