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The buoyancy half-life (flotation reduced 50%) of the syntactic foam tested is expected to be at least 10 yr, and may be as much as 25 yr, depending on the hydrostatic pressure, material density, and test medium. This indication of useful life expectancy is based on data obtained from the exposure of 20 samples having formulation densities in the 37- to 42-lb/ft^3 range.

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PROBLEM STATUS

A final report on one phase of a continuing NRL Problem.

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HYDROSTATIC TESTING OF SYNTACTIC FOAM IN MINERAL OIL

INTRODUCTION

A submerged oceanographic platform was planned for the Atlantic Underwater Test and Evaluation Center (AUTEC) in the early 1960's. The Naval Research Laboratory needed a flotation material to support this deep sea structure at middepth. Syntactic foam appeared to be a promising new material for this application, but there was no information on its long-term hydrostatic properties. A program of testing laboratory-formulated samples was initiated in 1962; fresh tapwater was used as the pressurizing medium.

GENERAL

A 4-yr test on 13 syntactic foam samples was performed by exposing them to water at hydrostatic pressures up to 10,000 psi to simulate the effect of the great ocean depths.* Freshwater was used as a substitute for seawater because of (a) the corrosion of pressure vessels by saltwater and (b) the acceptance of this procedure by the testing community as a convenient approximation. The results of that series of tests indicated a deterioration of the material, with its buoyancy decreasing with time of exposure but at a progressively slower rate. A noticeable decrease in the rate of water absorption after the first year of exposure was observed for several of the test samples. From the data obtained on the 1962 state-of-the-art samples, the half-life expectancy (half of the material's buoyancy being lost) was estimated to be about 5 yrs for a specified density of 42 lb/ft^3 exposed to a hydrostatic pressure of 10,000 psi.

To maneuver deep sea submersibles safely into the ocean depths, it is necessary that these vessels contain a buoyancy component with a compressibility which is approximately equal to that of seawater. Syntactic foam is being employed in this application, since its buoyancy changes very little with the increased pressures of the deep ocean. This material is competitive with other buoyancy materials in cost, when considering syntactic foam's small change in buoyancy per pound caused by exposure to the varying hydrostatic pressures encountered by a submersible during descent into, or ascent from, the ocean depths. Also, this material does not constitute a fire hazard, nor is it corroded by the ocean environment. Submersibles using gasoline for buoyancy require expensive maintenance, since this flammable liquid cannot be installed permanently on board. Because gasoline is more compressible than seawater, it loses buoyancy with depth, requiring the release of considerable ballast from the submersible to reduce its accelerated descent into the deep ocean.

Since syntactic foam is slightly less compressible than seawater (Table 1), it becomes more buoyant at the greater pressures encountered with increasing depth. To maintain a

*J. J. Gennari and H. E. Barnes, "Long-Term Hydrostatic Tests of Syntactic Foam," NRL Report 6577, Oct. 11, 1967.

Table 1
Comparison of Buoyancy Materials with Seawater

Material	Density at 1 atm. (lb/ft^3)	Density at 10,000 psi (lb/ft^3)	Bulk Modulus (psi × 10^{-6})	Relative Compressibility ΔP = 10,000 (%)
Syntactic foam	38-47	39-48	0.35-0.59	1.8-2.7
Seawater	64.0	65.8	0.345	2.8
Mineral oil	55	57	0.24-0.30	3.3-4.3
Gasoline	41-47	43-53	0.12-0.18	5.6-8.2
Silicone oil	51-61	58-64	0.15-0.23	5.0-8.0

buoyancy which is approximately constant with changing hydrostatic pressures, a more compressible material such as mineral oil may be used with the less compressible syntactic foam. Depending on the density of the syntactic foam selected, a ratio of the two materials can be determined so that the combination of the two closely matches the compressibility of seawater. Four years ago NRL began another series of tests on syntactic foam at pressures of 7500 and 10,000 psi to determine the unknown effects of long-term hydrostatic exposure to a mineral oil medium.

TEST OBJECTIVES AND PROCEDURES

To predict the life expectancy of syntactic foam as a buoyancy material in the ocean environment, hydrostatic pressure data were obtained to determine (a) the deteriorating effects of water as compared to those of mineral oil as pressurizing media and (b) the effect of formulation density at pressures other than those for which the syntactic foams were designed.

The data for these objectives were derived from measurements made at atmospheric pressure on 20 samples at intervals which averaged six months. The relative effects of the two pressurizing media were determined by exposure of four samples to water, and the remaining 16 samples to mineral oil. An indication of the consequence of overpressurizing was obtained by subjecting a lower density sample to a pressure which was higher than that for which it was designed. Conversely, underpressurizing was effected by placing a higher density formulation in an environment in which the pressure was lower than the design pressure.

The room temperature test environment was provided by using available pressure vessels having 2-in. inside diameters (Fig. 1). The sample size was limited to a diameter of 1-3/4-in. and a length of 6 in., with each vessel accommodating two test specimens. Typical water-tested samples are shown in Fig. 2. A hydraulic hand pump developed hydrostatic pressures up to 10,000 psi.

At the end of an exposure period, a vessel's hydrostatic pressure was released, the samples were removed, and the test fluid was wiped from the specimen. The sample's weight in air was measured to 0.01 gram on a balance scale. It was then weighed in water by submerging it with a suitably sized sinker. The specimen's volume was determined by water displacement, and this method checked by computing averaged

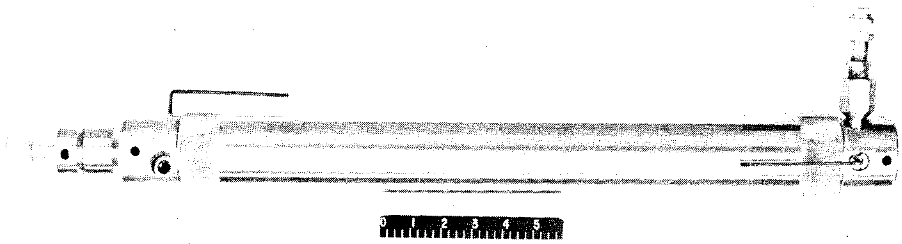

Fig. 1—Hydrostatic test pressure vessel

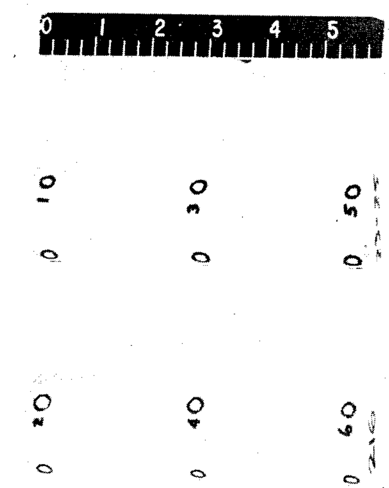

Fig. 2—Uncoated samples of syntactic foam

measurements of six readings of the diameter and five of the length. The progressive effect of hydrostatic pressure as indicated by these measurements provided data for determining the sample's buoyancy in water, its effective payload, and expected useful life.

TEST DATA EXPLANATION

The syntactic foam samples for this second series of tests at NRL were supplied through the cooperation of a commercial source. The four material formulations included specification densities of 37, 38, 40, and 42 lb/ft^3. The measured densities and other physical data for the 20 specimens are listed in Table 2. All samples were uncoated, and were composed of glass beads in epoxy.

The test of first group of four samples began in March 1966. The results of the first year's test on these samples were reported in October 1967.* This set of samples

*See footnote, p. 1.

Table 2
Physical Properties of Test Samples

Sample No.	Dimensions		Volume (in.^{3})	Weight (lb)	Density (Measured) (lb/ft^3)	Density (Specification) (lb/ft^3)
	Diameter (in.)	Length (in.)				
10*	1.764	5.994	14.62	0.323	38.1	38
11	1.760	5.997	14.55	0.317	37.6	38
12†	1.749	5.998	14.35	0.356	42.9	42
13	1.745	5.992	14.27	0.352	42.7	42
14‡	1.756	6.000	14.53	0.296	35.2	37
15	1.755	5.994	14.50	0.309	37.1	37
16	1.756	5.994	14.52	0.302	36.0	37
17	1.755	5.994	14.50	0.312	37.3	37
18	1.759	5.987	14.55	0.311	37.1	37
19	1.762	5.990	14.60	0.304	36.2	37
20	1.756	5.994	14.52	0.314	37.5	37
21	1.756	6.000	14.53	0.311	37.2	37
22§	1.765	5.999	14.68	0.337	39.8	40
23	1.768	5.995	14.72	0.344	40.5	40
24	1.764	5.998	14.65	0.338	40.0	40
25	1.765	5.993	14.67	0.339	40.0	40
26	1.766	5.992	14.67	0.338	39.9	40
27	1.767	5.995	14.70	0.342	40.3	40
28	1.769	5.994	14.73	0.336	39.5	40
29	1.760	5.990	14.56	0.340	40.4	40

*Set 1.
†Set 2.
‡Set 3.
§Set 4.

was exposed to fresh tapwater for over 5 yr and provided a comparison with the remaining samples which were subjected to a mineral oil environment. Samples of set 1 (specification density 38 lb/ft^3) were exposed to a 5000-psi hydrostatic pressure, and Set 2 (specification density 42 lb/ft^3), to 10,000 psi. Table 3 presents data obtained from the first two sets of four samples.

The third set of eight samples was placed under test in mineral oil in September 1967. Seven of these specimens (specification density 37 lb/ft^3) were subjected to the design hydrostatic pressure of 7500 psi, and one to 10,000 psi to determine the effect of overpressure. Table 4 presents the test data generated during the 4-yr period for this set of samples.

A fourth set of eight samples (specification density 40 lb/ft^3) was exposed to mineral oil for the same time period as the second group. Seven of these samples were tested at the rated pressure of 10,000 psi, and the remaining sample at 7500 psi to determine the effect of underpressure. Table 5 summarizes the results of the 4-yr exposure period.

Table 3a
Test Results for Sample 10, Set 1

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Water Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
3/7/66	0.0	–	–	–	–	24	64	–
6/6/66	0.2	1.6	0.0	1.7	6.8	24	61	5
7/19/66	0.4	2.1	0.0	2.1	5.8	24	60	6
12/28/66	0.8	3.1	0.1	3.0	3.8	23	59	8
3/21/67	1.0	3.4	−0.1	3.4	3.2	23	58	10
8/15/67	1.4	4.2	0.0	4.3	3.0	23	57	11
10/16/67	1.6	4.6	0.0	4.6	2.8	22	56	11
12/21/67	1.8	4.8	−0.1	4.8	2.6	22	56	12
5/8/68	2.2	4.9	−0.3	5.4	2.4	22	56	14
11/7/68	2.7	5.7	−0.2	6.0	2.2	22	55	15
3/6/69	3.0	6.2	0.0	6.2	2.1	22	54	15
5/7/69	3.2	6.4	−0.1	6.6	2.1	22	54	16
4/9/70	4.1	7.2	−0.2	7.5	1.8	22	53	18
3/18/71	5.0	8.4	−0.1	8.5	1.7	21	51	19
7/9/71	5.3	8.7	−0.1	8.9	1.7	21	51	19

Table 3b
Test Results for Sample 11, Set 1

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Water Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
3/7/66	0.0	–	–	–	–	25	66	–
6/6/66	0.2	1.8	0.1	1.8	7.2	25	63	5
7/19/66	0.4	2.3	0.1	2.2	5.9	24	62	5
12/28/66	0.8	3.5	0.2	3.2	3.9	24	60	8
3/21/67	1.0	4.0	0.0	3.6	3.4	23	60	9
8/15/67	1.4	4.6	0.0	4.4	3.0	23	59	10
10/16/67	1.6	4.8	0.1	4.7	3.0	23	58	11
12/21/67	1.8	5.2	0.1	4.9	2.8	23	58	12
5/8/68	2.2	5.5	−0.1	5.5	2.6	23	58	13
11/7/68	2.7	6.3	0.0	6.2	2.3	22	56	14
3/6/69	3.0	6.6	0.1	6.5	2.2	22	56	15
5/7/69	3.2	6.8	0.1	6.8	2.1	22	56	16
4/9/70	4.1	7.6	−0.1	7.7	1.9	22	54	18
3/18/71	5.0	8.8	0.0	8.8	1.7	22	53	19
7/9/71	5.3	9.3	0.0	9.2	1.7	21	52	19

Table 3c
Test Results for Sample 12, Set 2

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Water Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
3/11/66	0.0	–	–	–	–	19	46	–
6/16/66	0.3	1.6	0.4	1.2	4.4	19	43	4
8/17/66	0.4	2.2	0.2	2.0	4.6	19	42	5
1/4/67	0.8	3.4	0.0	3.4	4.1	18	40	6
6/9/67	1.2	4.5	0.0	4.5	3.6	18	39	6
9/7/67	1.5	5.0	–0.1	5.1	3.4	17	39	7
10/26/67	1.6	5.5	0.0	5.4	3.3	17	38	7
12/21/67	1.8	5.5	–0.1	5.7	3.2	17	38	7
5/10/68	2.2	6.7	–0.1	6.8	3.1	17	36	7
12/20/68	2.8	7.9	0.0	7.8	2.8	16	35	8
3/11/69	3.0	8.3	–0.1	8.3	2.8	16	34	8
5/13/69	3.2	8.6	–0.1	8.7	2.7	16	34	8
4/28/70	4.1	10.3	0.0	10.3	2.5	15	32	9
3/19/71	5.0	11.8	0.0	11.8	2.4	14	30	10
9/13/71	5.5	12.4	–0.1	12.7	2.3	14	30	10

Table 3d
Test Results for Sample 13, Set 2

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Water Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
3/11/66	0.0	–	–	–	–	20	46	–
6/16/66	0.3	1.5	0.3	1.2	4.6	19	44	4
8/17/66	0.4	2.2	0.2	2.2	5.0	19	43	5
1/4/67	0.8	3.4	0.0	3.5	4.2	18	41	6
6/9/67	1.2	4.5	0.0	4.7	3.7	18	40	6
9/7/67	1.5	5.3	0.1	5.4	3.6	17	39	7
10/26/67	1.6	5.7	0.1	5.6	3.5	17	38	7
12/21/67	1.8	5.7	–0.1	6.0	3.4	17	38	7
5/10/68	2.2	6.7	–0.2	7.0	3.2	17	37	7
12/20/68	2.8	8.2	0.1	8.2	3.0	16	35	8
3/11/69	3.0	8.5	0.0	8.7	2.9	16	35	8
5/13/69	3.2	8.9	0.0	9.1	2.9	16	34	8
4/28/70	4.1	10.4	–0.1	10.6	2.6	15	32	9
3/19/71	5.0	12.4	–0.1	12.6	2.5	14	30	9
9/13/71	5.5	13.3	–0.1	13.6	2.5	14	29	10

Table 4a
Test Results for Sample 14, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/20/67	0.0	–	–	–	–	27	77	–
11/2/67	0.1	2.1	0.1	2.0	16.9	26	73	2
1/16/68	0.3	2.5	0.0	2.4	7.4	26	73	5
5/15/68	0.7	4.6	0.2	4.5	6.8	26	69	5
12/27/68	1.3	5.5	0.1	5.3	4.2	25	68	9
3/13/69	1.5	6.0	0.2	5.7	3.8	25	67	10
12/10/69	2.2	7.4	0.2	7.2	3.2	24	65	12
5/6/70	2.6	8.1	0.3	7.8	3.0	24	64	12
3/22/71	3.5	10.3	0.3	9.8	2.8	24	60	13
9/15/71	4.0	11.9	0.3	11.4	2.9	23	58	13

Table 4b
Test Results for Sample 15, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/22/67	0.0	–	–	–	–	25.3	68	–
11/9/67	0.1	44	3.9	39	290	8.9	17	0.1
12/5/67	0.2	48	3.8	42	210	7.5	14	0.1
3/13/68	0.5	52	3.8	46	97	6.1	11	0.3
5/21/68	0.7	55	3.7	49	74	4.8	8	0.4
1/15/69	1.3	57	3.7	52	39	4.0	7	0.8
3/17/69	1.5	58	3.9	52	35	3.6	6	0.9
1/8/70	2.3	60	3.7	54	24	2.9	5	1.3
8/13/70	2.9	64	3.5	58	20	1.6	3	1.6
3/24/71	3.5	66	3.6	60	17	0.9	2	1.8
10/19/71	4.1	67	3.5	61	15	0.3	1	2.1

Table 4c
Test Results for Sample 16, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/22/67	0.0	–	–	–	–	26	73	–
11/16/67	0.2	1	0.2	1	8	26	71	5
3/27/68	0.5	2	0.3	2	4	26	70	10
5/23/68	0.7	3	0.3	3	5	25	68	8
1/17/69	1.3	38*	6.0	29	22	13	26	1
4/11/69	1.6	38	5.9	30	19	13	25	2
1/15/70	2.3	39	5.8	31	13	12	25	2
12/1/70	3.2	41	5.7	33	10	12	23	3
3/25/71	3.5	42	5.8	34	10	11	22	3
10/7/71	4.0	44	5.7	35	9	11	21	3

*6/18/68, overpressure, 9000 psig, 1 min.

Table 4d
Test Results for Sample 17, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/22/67	0.0	–	–	–	–	25	67	–
11/16/67	0.2	1	0.0	1	9	25	65	4
3/27/68	0.5	2	0.2	1	4	25	65	11
5/23/68	0.7	2	0.2	2	3	24	64	13
1/17/69	1.3	14*	2.0	12	9	20	47	3
4/11/69	1.6	14	2.0	12	8	20	47	4
1/15/70	2.3	15	2.0	12	5	20	46	5
12/1/70	3.2	15	2.0	13	4	19	45	7
3/25/71	3.5	17	2.1	15	4	19	43	7
10/7/71	4.0	19	2.0	17	4	18	40	7

*6/18/68, overpressure, 9000 psig, 1 min.

Table 4e
Test Results for Sample 18, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/28/67	0.0	–	–	–	–	25	68	–
11/24/67	0.2	0.7	0.1	0.6	4.0	25	67	8
4/12/68	0.5	1.0	0.2	0.9	1.6	25	67	18
5/24/68	0.7	1.2	0.1	1.0	1.5	25	66	19
1/23/69	1.3	1.4	0.2	1.2	0.9	25	66	34
4/17/69	1.6	1.4	0.1	1.4	0.9	25	66	39
1/23/70	2.3	1.8	0.1	1.7	0.7	25	65	43
12/22/70	3.2	2.4	0.1	2.2	0.7	24	64	47
3/26/71	3.5	2.4	0.0	2.3	0.7	24	64	51
10/18/71	4.1	3.4	0.1	3.2	0.8	24	63	42

Table 4f
Test Results for Sample 19, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/28/67	0.0	–	–	–	–	26	72	–
11/24/67	0.2	0.9	0.0	0.9	5.6	26	71	7
4/12/68	0.5	1.9	0.1	1.9	3.5	26	69	10
5/24/68	0.7	2.2	0.2	2.0	3.1	25	69	11
1/23/69	1.3	2.4	0.2	2.4	1.8	25	68	20
4/17/69	1.6	2.6	0.1	2.5	1.6	25	68	22
1/23/70	2.3	3.3	0.2	3.1	1.3	25	67	26
12/22/70	3.2	4.0	0.2	3.8	1.2	25	66	30
3/26/71	3.5	4.3	0.1	4.2	1.2	25	65	29
10/18/71	4.1	5.9	0.1	5.7	1.4	24	63	25

Table 4g
Test Results for Sample 20, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight: Increase (%)	Oil Absorption Percentage by Weight: Average Increase (%/yr)	Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
9/28/67	0.0	–	–	–	–	25	66	–
12/1/67	0.2	1.2	0.2	1.0	6.0	24	64	5
4/17/68	0.6	3.7	0.5	3.3	6.0	24	60	5
6/10/68	0.7	4.3	0.6	3.8	5.4	23	59	5
2/7/69	1.4	4.8	0.6	4.3	3.1	23	58	9
4/22/69	1.6	5.0	0.6	4.5	2.9	23	58	10
2/2/70	2.4	5.3	0.5	4.9	2.1	23	58	15
12/31/70	3.3	6.2	0.6	5.7	1.8	22	56	18
3/29/71	3.5	6.6	0.6	6.0	1.7	22	56	17
10/20/71	4.1	7.6	0.6	7.1	1.7	22	54	18

Table 4h
Test Results for Sample 21, Set 3

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight: Increase (%)	Oil Absorption Percentage by Weight: Average Increase (%/yr)	Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
9/28/67	0.0	–	–	–	–	25	68	–
12/1/67	0.2	1.2	0.1	1.1	6.0	25	66	5
4/17/68	0.6	7.2	1.0	6.3	11.4	22	56	3
6/10/68	0.7	7.7	1.0	6.8	9.7	22	56	3
2/7/69	1.4	8.4	1.0	7.4	5.5	22	55	6
4/22/69	1.6	8.7	1.0	7.6	4.9	22	54	6
2/2/70	2.4	9.1	1.0	8.1	3.5	22	54	9
12/31/70	3.3	11.6	1.1	10.6	3.2	21	50	10
3/29/71	3.5	12.1	1.0	11.1	3.2	21	50	10
10/20/71	4.1	14.6	1.1	13.5	3.3	20	46	10

Table 5a
Test Results for Sample 22, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/20/67	0.0	–	–	–	–	23	57	–
11/2/67	0.1	0.3	0.1	0.2	1.7	23	56	11
1/16/68	0.3	0.3	0.1	0.2	0.6	23	56	29
5/15/68	0.7	0.3	0.1	0.2	0.3	23	56	59
12/27/68	1.3	0.3	0.1	0.2	0.2	23	56	120
3/13/69	1.5	0.3	0.2	0.2	0.1	23	56	130
12/10/69	2.2	0.3	0.1	0.2	0.1	23	56	200
5/6/70	2.6	0.3	0.1	0.2	0.1	23	56	240
3/22/71	3.5	0.3	0.1	0.2	0.1	23	56	320
9/15/71	4.0	0.3	0.1	0.2	0.1	23	56	360

Table 5b
Test Results for Sample 23, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/22/67	0.0	–	–	–	–	22	54	–
11/9/67	0.1	0.3	0.3	0.2	1.7	22	54	12
12/5/67	0.2	0.3	0.2	0.2	1.0	22	54	18
3/13/68	0.5	0.3	0.2	0.3	0.5	22	54	42
5/21/68	0.7	0.5	0.3	0.3	0.5	22	53	39
1/15/69	1.3	0.5	0.3	0.4	0.3	22	53	77
3/17/69	1.5	0.5	0.3	0.5	0.3	22	53	87
1/8/70	2.3	0.6	0.2	0.6	0.2	22	53	100
8/13/70	2.9	0.8	0.3	0.7	0.2	22	53	100
3/24/71	3.5	1.1	0.3	1.0	0.3	21	52	88
10/19/71	4.1	1.5	0.3	1.5	0.4	21	52	72

Table 5c
Test Results for Sample 24, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/29/67	0.0	–	–	–	–	22	56	–
12/20/67	0.2	0.3	0.1	0.4	1.5	22	56	20
4/19/68	0.6	0.9	0.2	0.8	1.5	22	55	17
6/14/68	0.7	0.9	0.3	0.8	1.1	22	55	21
2/14/69	1.4	1.1	0.3	1.0	0.7	22	55	36
4/25/69	1.6	1.2	0.3	1.1	0.7	22	55	36
2/5/70	2.4	1.7	0.3	1.4	0.6	22	54	39
3/12/71	3.5	2.2	0.3	1.9	0.5	22	53	45
6/22/71	3.7	3.0	0.3	2.8	0.7	22	52	35

Table 5d
Test Results for Sample 25, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
9/29/67	0.0	–	–	–	–	22	56	–
12/20/67	0.2	0.3	0.1	0.3	1.5	22	55	20
4/19/68	0.6	0.8	0.2	0.8	1.5	22	55	20
6/14/68	0.7	0.9	0.3	0.8	1.1	22	54	21
2/14/69	1.4	1.2	0.3	1.0	0.7	22	54	31
4/25/69	1.6	1.2	0.3	1.0	0.7	22	54	35
2/5/70	2.4	1.4	0.3	1.3	0.6	22	54	47
3/12/71	3.5	2.7	0.4	2.5	0.7	21	52	37
6/22/71	3.7	3.6	0.3	3.4	0.9	21	50	29

Table 5e
Test Results for Sample 26, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
10/4/67	0.0	–	–	–	–	22	56	–
12/20/67	0.2	0.5	0.2	0.3	1.4	22	56	12
4/23/68	0.6	0.6	0.2	0.5	0.9	22	55	25
6/19/68	0.7	0.9	0.2	0.6	0.8	22	55	21
2/20/69	1.4	0.9	0.2	0.8	0.6	22	55	42
4/30/69	1.6	1.1	0.2	0.8	0.5	22	55	40
2/26/70	2.4	1.6	0.2	1.3	0.5	22	54	43
3/15/71	3.5	2.2	0.3	1.8	0.5	22	53	44
6/23/71	3.7	2.5	0.3	2.2	0.6	22	52	42

Table 5f
Test Results for Sample 27, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft³)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
10/4/67	0.0	–	–	–	–	22	55	–
12/20/67	0.2	0.3	0.2	0.2	1.0	22	54	18
4/23/68	0.6	0.3	0.2	0.3	0.5	22	54	49
6/19/68	0.7	0.5	0.2	0.4	0.5	22	54	42
2/20/69	1.4	0.5	0.2	0.4	0.3	22	54	82
4/30/69	1.6	0.5	0.1	0.5	0.3	22	54	93
2/26/70	2.4	0.8	0.2	0.7	0.3	22	54	85
3/15/71	3.5	1.1	0.2	1.0	0.3	22	53	86
6/23/71	3.7	1.4	0.3	1.3	0.3	22	53	73

Table 5g
Test Results for Sample 28, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
10/6/67	0.0	–	–	–	–	23	58	–
12/20/67	0.2	0.6	0.1	0.4	2.1	23	57	10
4/26/68	0.6	1.4	0.2	1.2	2.1	22	56	12
10/30/68	1.1	2.1	0.3	1.7	1.6	22	55	15
2/26/69	1.4	2.4	0.3	1.9	1.4	22	55	17
5/2/69	1.6	2.4	0.3	2.0	1.3	22	55	19
4/3/70	2.5	2.7	0.3	2.3	0.9	22	54	27
3/17/71	3.4	4.0	0.4	3.5	1.0	21	52	25
7/8/71	3.8	4.6	0.4	4.0	1.1	21	51	24

Table 5h
Test Results for Sample 29, Set 4

Date	Exposure Period (yr)	Density Increase (%)	Volume Decrease (%)	Oil Absorption Percentage by Weight		Buoyancy (lb/ft^3)	Payload (lb/100 lb)	Buoyancy Half-Life (yr)
				Increase (%)	Average Increase (%/yr)			
10/6/67	0.0	–	–	–	–	22	55	–
12/20/67	0.2	0.2	0.1	0.2	0.9	22	54	37
4/26/68	0.6	0.2	0.1	0.2	0.3	22	54	99
10/30/68	1.1	0.3	0.1	0.2	0.2	22	54	94
2/26/69	1.4	0.3	0.1	0.3	0.2	22	54	120
5/2/69	1.6	0.3	0.1	0.3	0.2	22	54	140
4/3/70	2.5	0.5	0.1	0.4	0.1	22	54	150
3/17/71	3.4	0.8	0.2	0.7	0.2	22	53	120
7/8/71	3.8	0.9	0.2	0.7	0.2	22	53	110

Figures 3-22 are the graphs of the data presented in Tables 3-5.

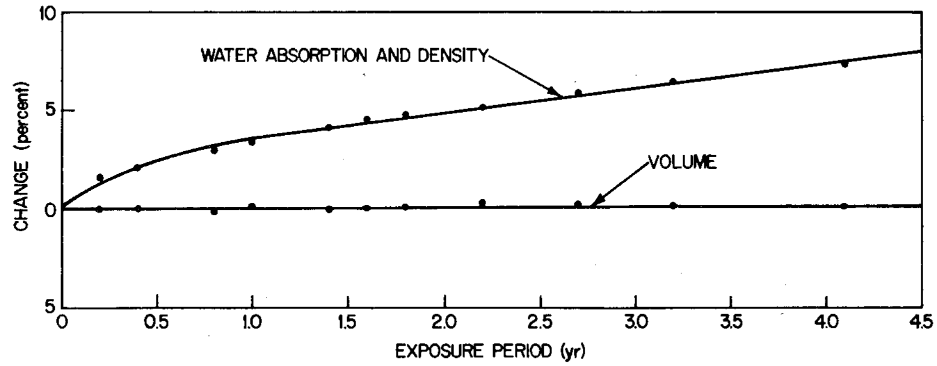

Fig. 3—Effects of hydrostatic pressure at 5000 psig in water on Sample 10; exposure period Mar. 7, 1966 to July 9, 1971

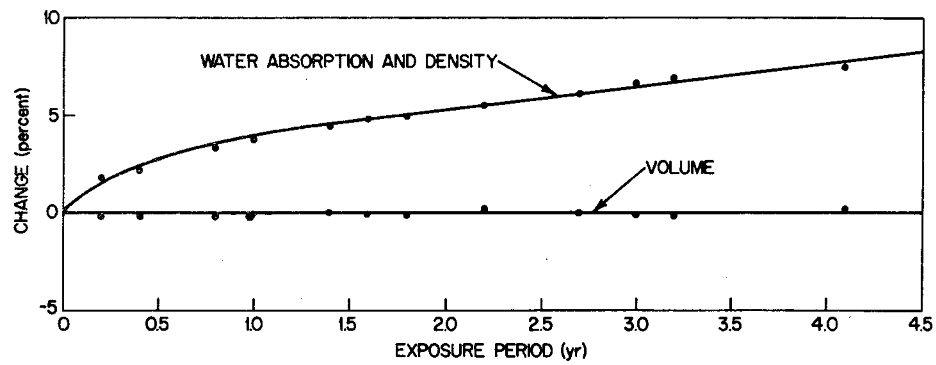

Fig. 4—Effects on Sample 11 of hydrostatic pressure at 5000 psig in water; exposure period Mar. 7, 1966 to July 9, 1971

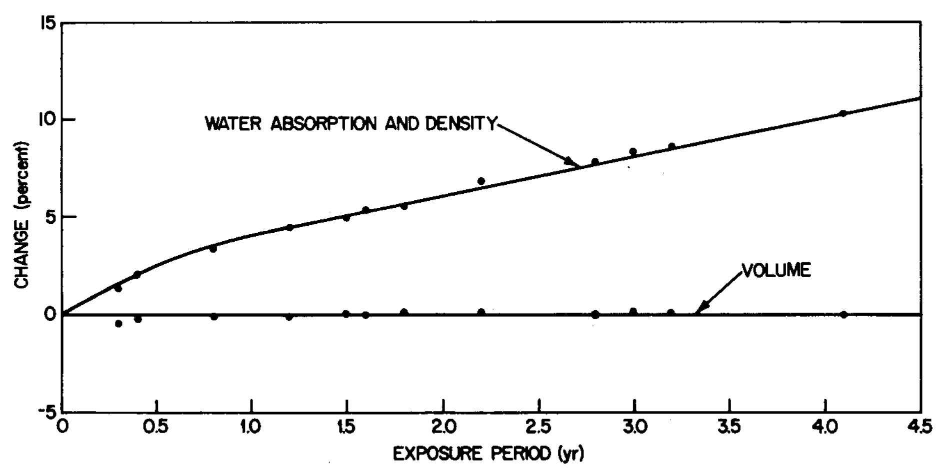

Fig. 5—Effects on Sample 12 of hydrostatic pressure of 10,000 psig in water; exposure period Mar. 11, 1966 to Sept. 13, 1971

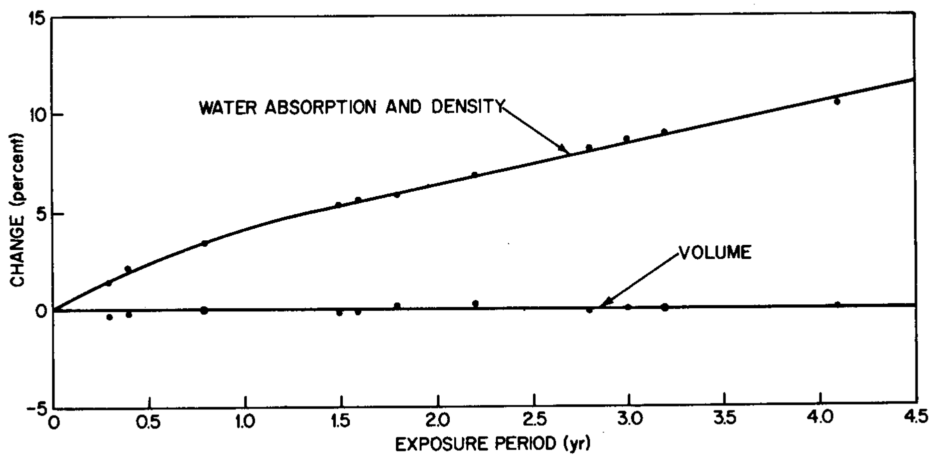

Fig. 6—Effects on Sample 13 of hydrostatic pressure of 10,000 psig in water; exposure period Mar. 11, 1966 to Sept. 13, 1971

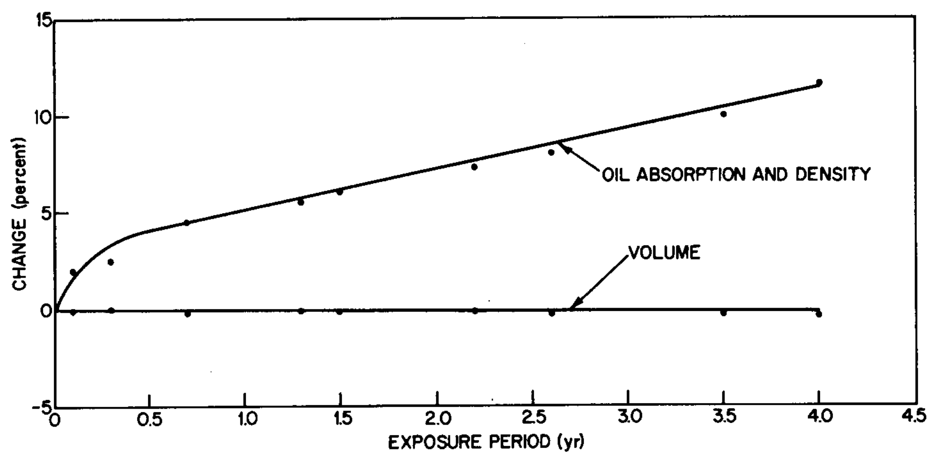

Fig. 7—Effects of 7500 psig hydrostatic pressure in mineral oil on Sample 14; exposure period Sept. 20, 1967 to Sept. 15, 1971

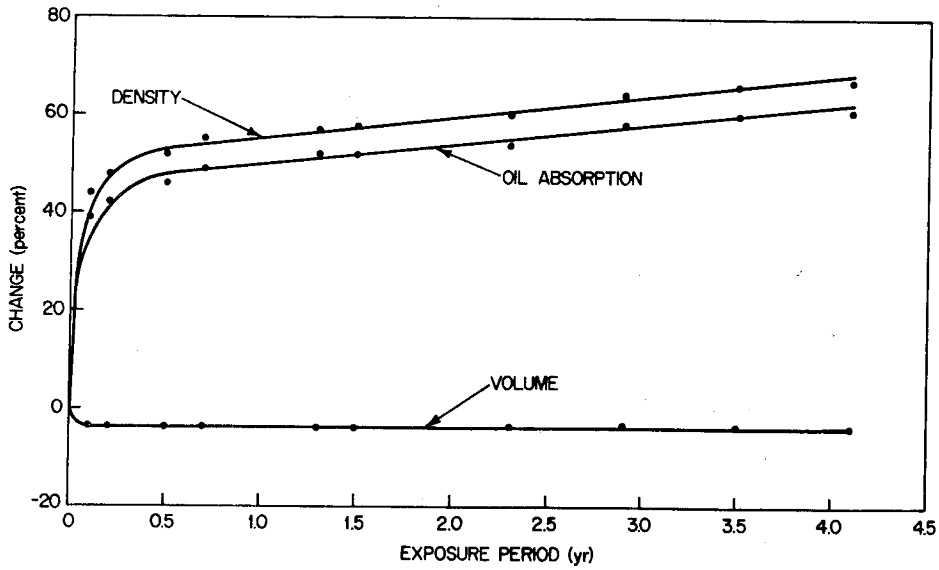

Fig. 8—Effects on Sample 15 of overpressure in mineral oil. The hydrostatic pressure was 10,000 psig (rated 7500 psig), and the exposure period was from Sept. 22, 1967 to Oct. 19, 1971.

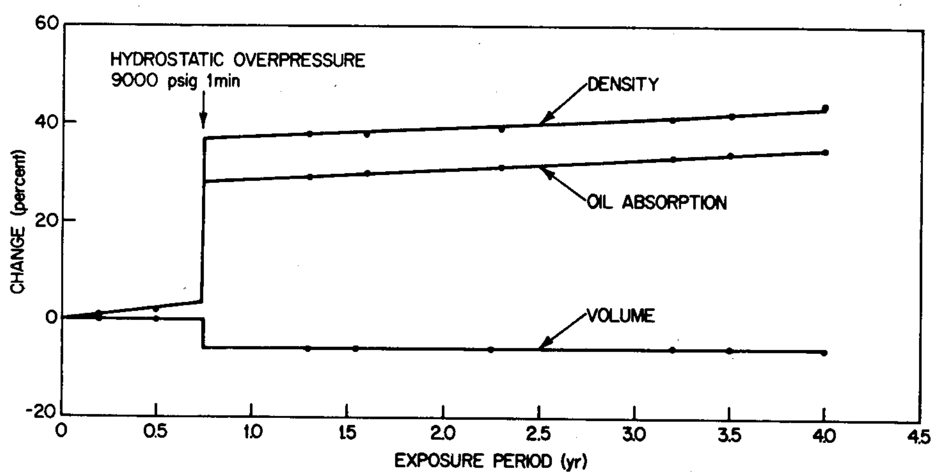

Fig. 9—Effects on Sample 16 of temporary overpressure in mineral oil. The hydrostatic pressure was 7500 psig, overpressure 9000 psig for 1 min, and the exposure period was Sept. 22, 1967 to Oct. 7, 1971.

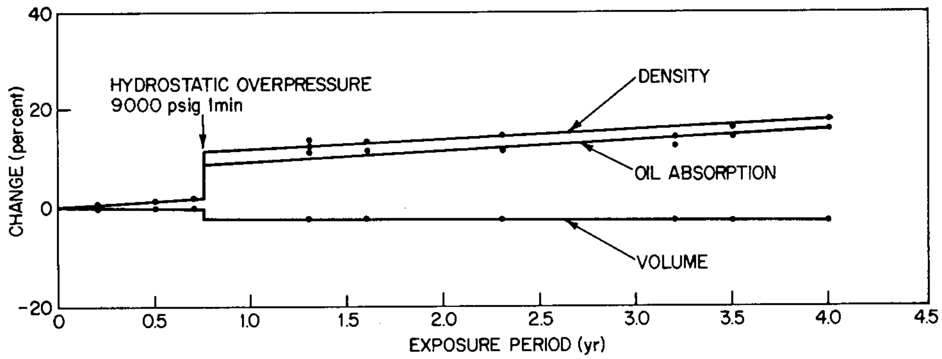

Fig. 10—Effects of temporary overpressure in mineral oil on Sample 17. The hydrostatic pressure was 7500 psig, overpressure 9000 psig for 1 min, and the exposure period from Sept. 22, 1967 to Oct. 7, 1971.

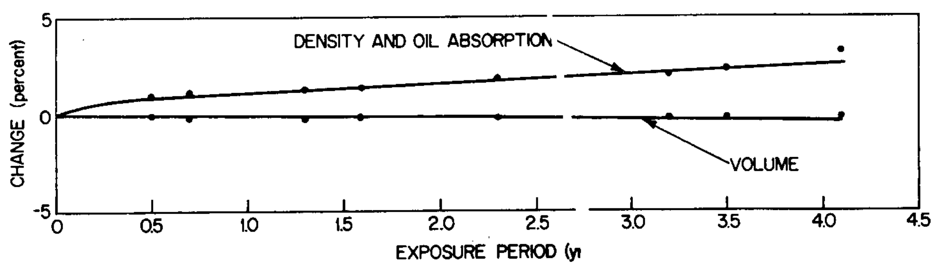

Fig. 11—Effects on Sample 18 of hydrostatic pressure at 7500 psig in mineral oil; exposure period Sept. 28, 1967 to Oct. 18, 1971

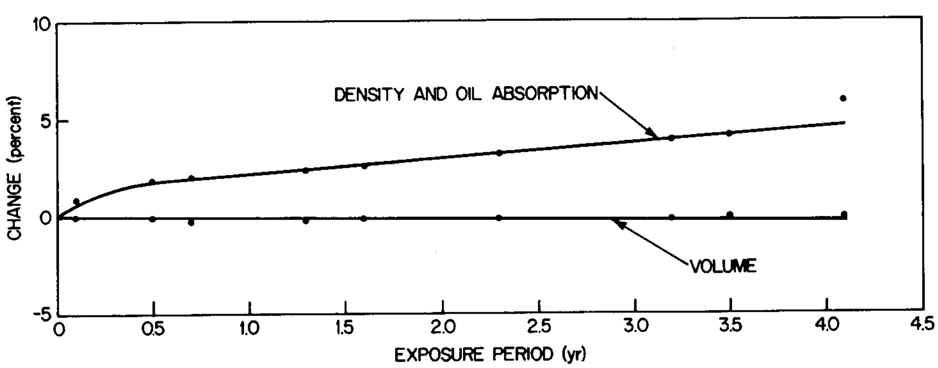

Fig. 12—Effects on Sample 19 of hydrostatic pressure at 7500 psig in mineral oil; exposure period Sept. 28, 1967 to Oct. 18, 1971

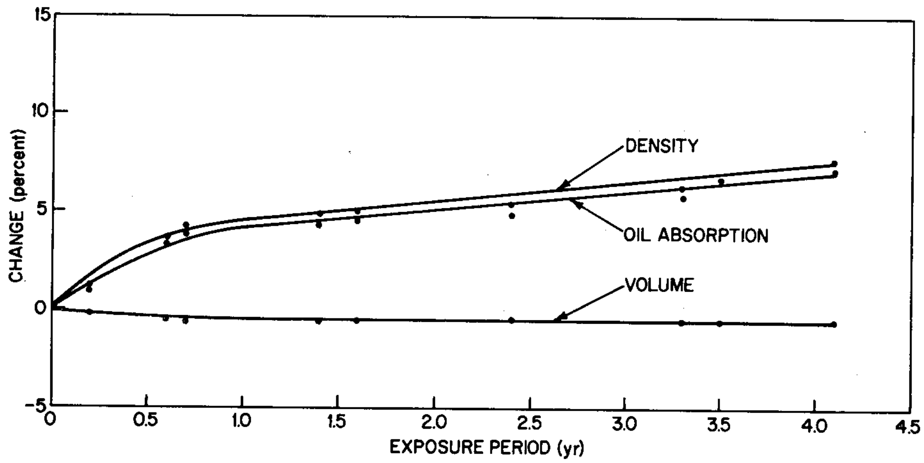

Fig. 13—Effects of hydrostatic pressure at 7500 psig in mineral oil on Sample 20; exposure period Sept. 28, 1967 to Oct. 20, 1971

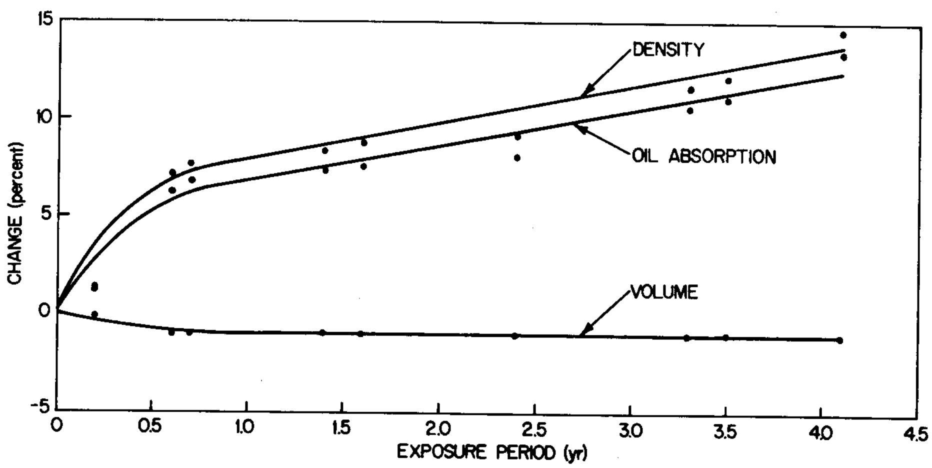

Fig. 14—Effects on Sample 21 of hydrostatic pressure at 7500 psig in mineral oil; exposure period Sept. 28, 1967 to Oct. 20, 1971

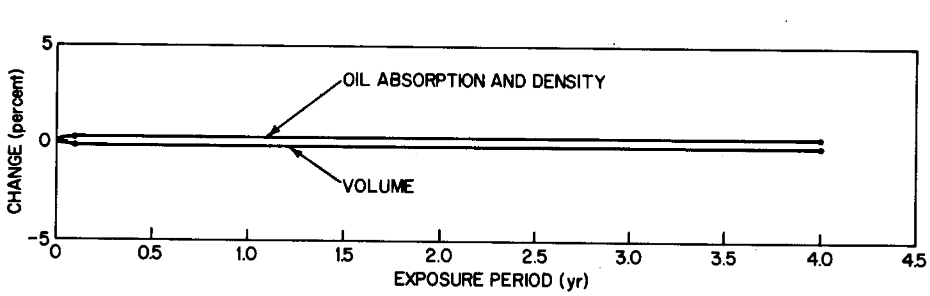

Fig. 15—Effects on Sample 22 of underpressure in mineral oil. The hydrostatic pressure tested was 7500 psig; rated 10,000 psig; exposure period Sept. 20, 1967 to Sept. 15, 1971.

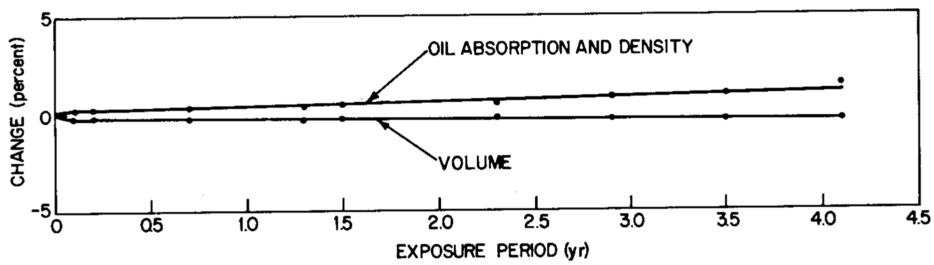

Fig. 16—Effects on Sample 23 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Sept. 22, 1967 to Oct. 19, 1971

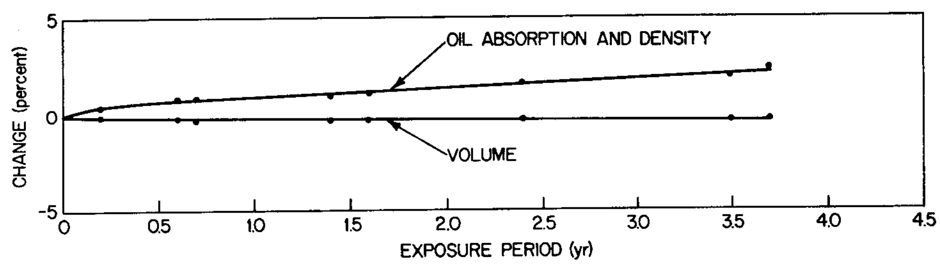

Fig. 17—Effects on Sample 24 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Sept. 29, 1967 to June 22, 1971

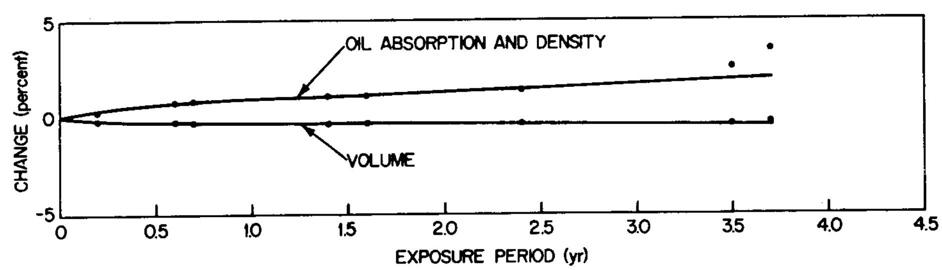

Fig. 18—Effects on Sample 25 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Sept. 29, 1967 to June 22, 1971

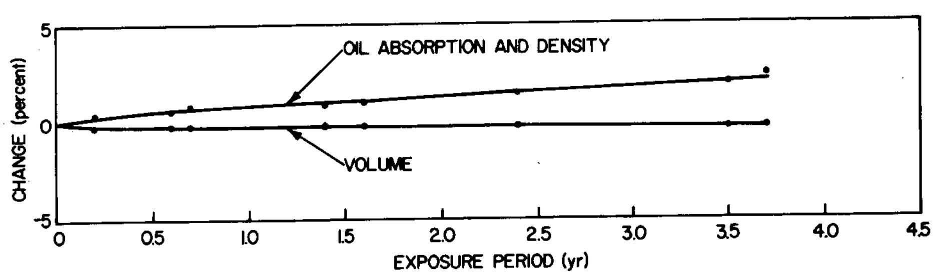

Fig. 19—Effects on Sample 26 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Sept. 29, 1967 to June 23, 1971

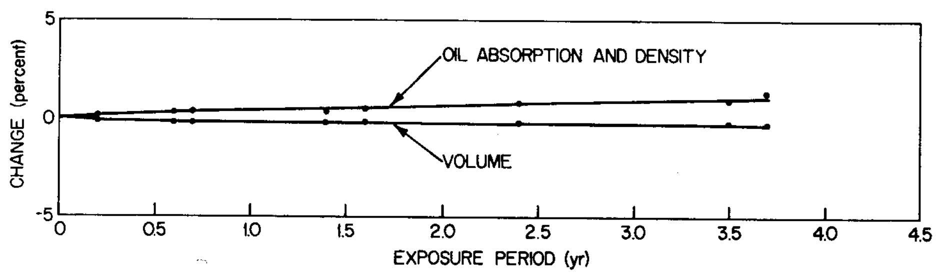

Fig. 20—Effects on Sample 27 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Oct. 4, 1967 to June 23, 1971

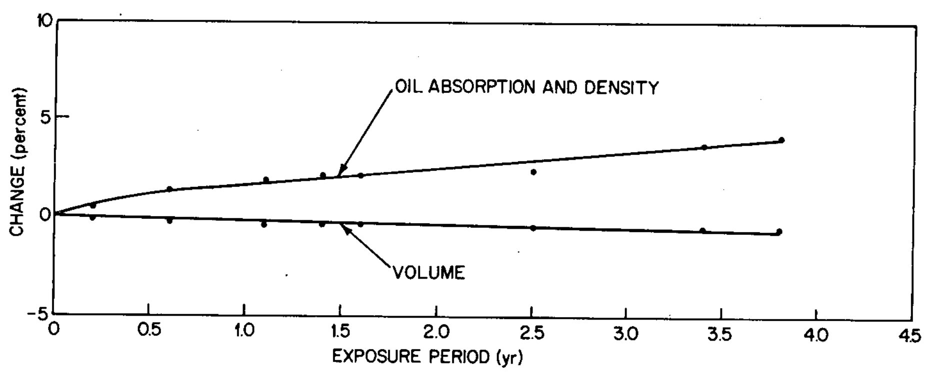

Fig. 21—Effects on Sample 28 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Oct. 6, 1967 to July 8, 1971

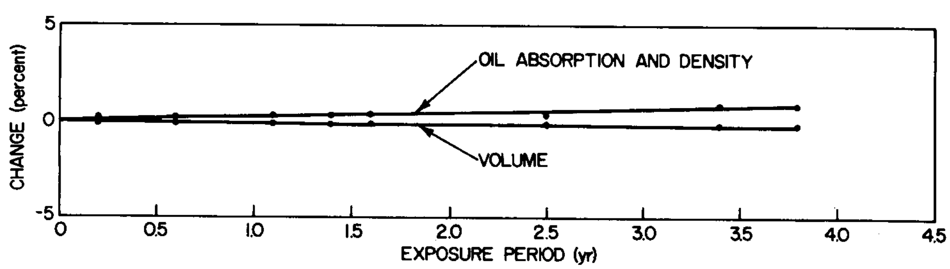

Fig. 22 — Effects on Sample 29 of hydrostatic pressure at 10,000 psig in mineral oil; exposed from Oct. 6, 1967 to July 8, 1971

DISCUSSION

The water-absorption rate of the first two sets of samples appears to have been affected more by hydrostatic pressure than by the original material density (Fig. 23). Samples 10 and 11 (specification density 38 lb/ft^3), tested at 5000 psi, had an 8% increase in weight in 5 yr. Samples 12 and 13 (specification density 42 lb/ft^3), exposed to a 10,000-psi hydrostatic pressure, required only 3 yr to reach the same level of water absorption. Volume changes for these four samples were very small. In fact, this was the case for all samples except those tested at overpressure levels. When drawn to the same scale (Fig. 24) as that used for water absorption and density increase (Fig. 23), no percentage changes in volume are evident.

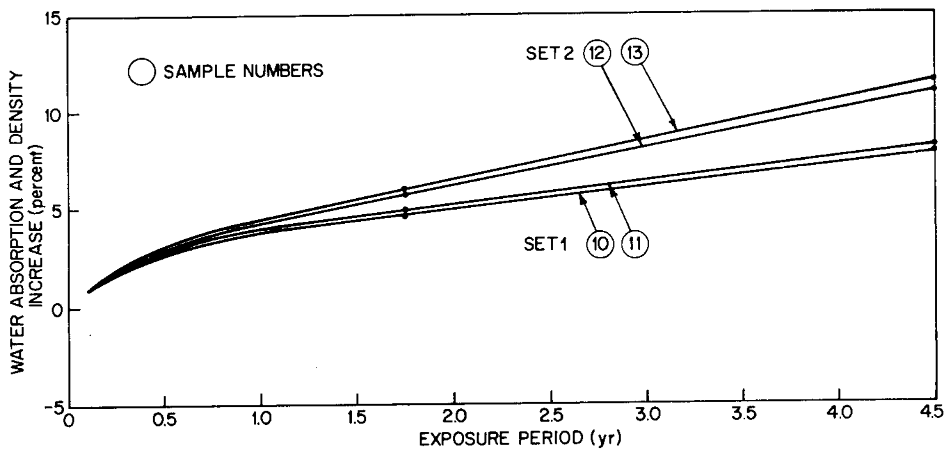

Fig. 23—Water content and density increases of Sets 1 and 2. Set 1 density 38 lb/ft^3, pressure 5000 psig; Set 2 density 42 lb/ft^3, pressure 10,000 psig.

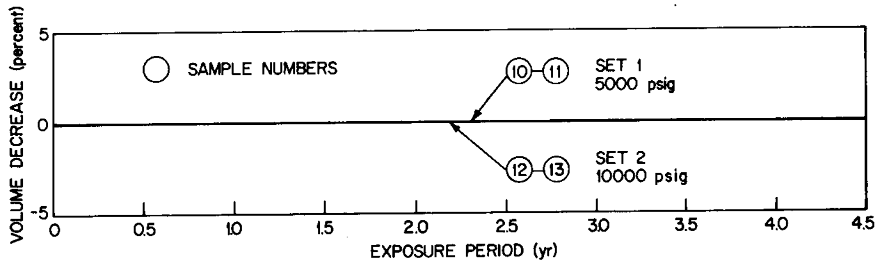

Fig. 24—Volume changes of samples in Set 1 and Set 2

Five of the third set of samples (14, 18, 19, 20, and 21) exposed to mineral oil, had oil absorption and density increases almost linear with time during their 4-yr test (Figs. 25 and 26). Samples 16 and 17 (Figs. 9 and 10) exhibited a sharp increase in density and oil absorption, and a corresponding decrease in volume at about 0.75 yr. This phenomenon was due to an unplanned overpressure of about 1500 psi for approximately 1 min. After the overpressure, these three variables continued at about the same rate as before. The results obtained from these two samples are similar to those shown by sample 15 (Fig. 8). This sample was intentionally subjected to overpressure from the beginning of the test. Its curves show initial rapid changes, but decrease to slopes which

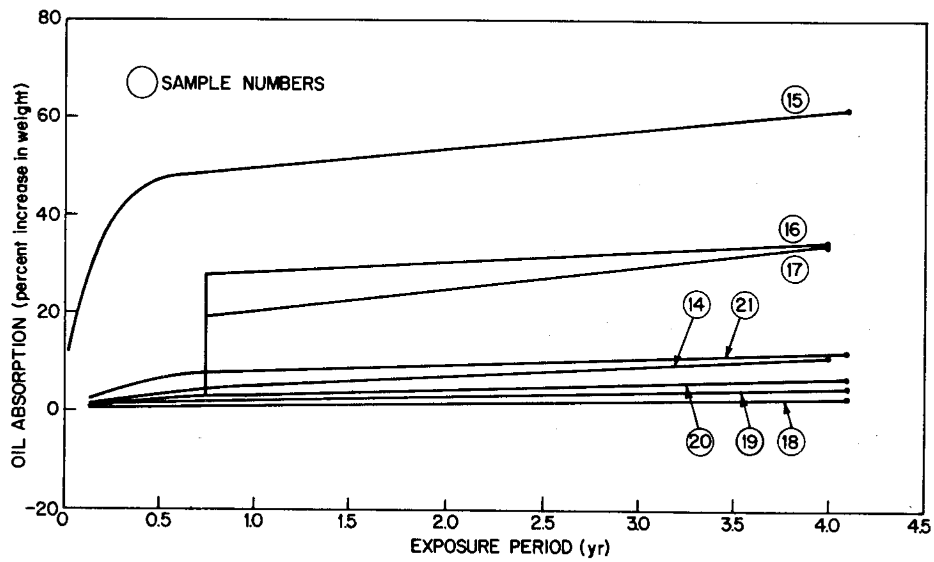

Fig. 25—Oil content increase of samples in Set 3

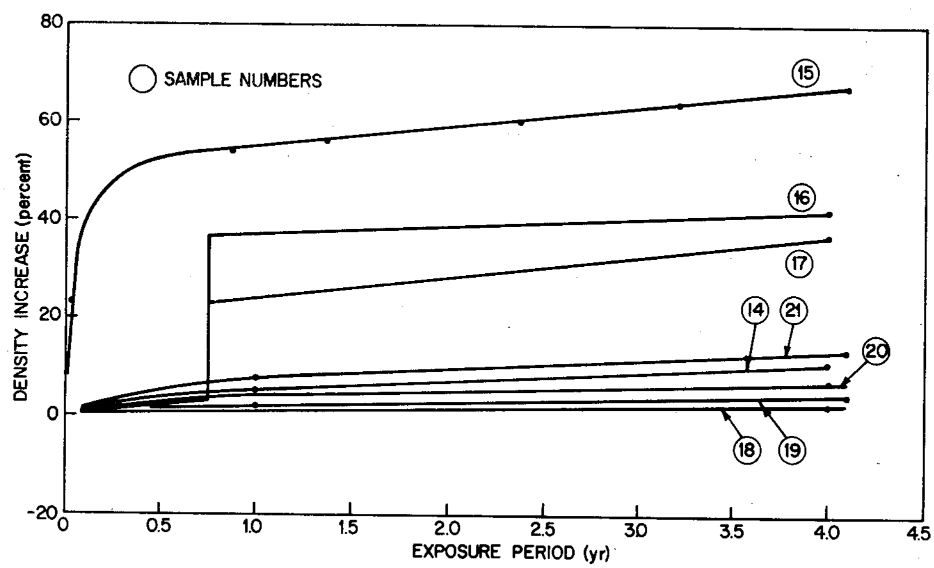

Fig. 26—Density increase of samples in Set 3

are approximately constant after about 0.5 yr. The only volume changes evident in this group (Fig. 27) occurred in those samples (15-17) subjected to an overpressure.

Set 4 samples exhibited a more uniform performance than did the Set 3 specimens. One explanation offered is that none of the Set 4 group was exposed to a pressure greater than its 10,000-psi rated pressure. Also, it is possible either that the 10,000-psi samples (Set 4) were underrated or that the 7500-psi samples (Set 3) were overrated in their capacity to withstand their test pressures. When comparing only those samples tested at their rated pressures, the higher density samples of Set 4 sustained only one-third as great percentage loss in buoyancy as the lesser density samples of Set 3 (Table 6). The volume changes of 0.4% or less are shown in Fig. 30.

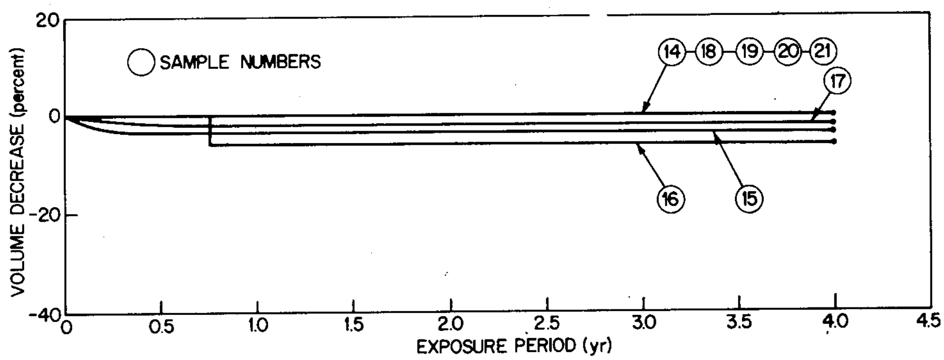

Fig. 27—Volume changes of samples in Set 3

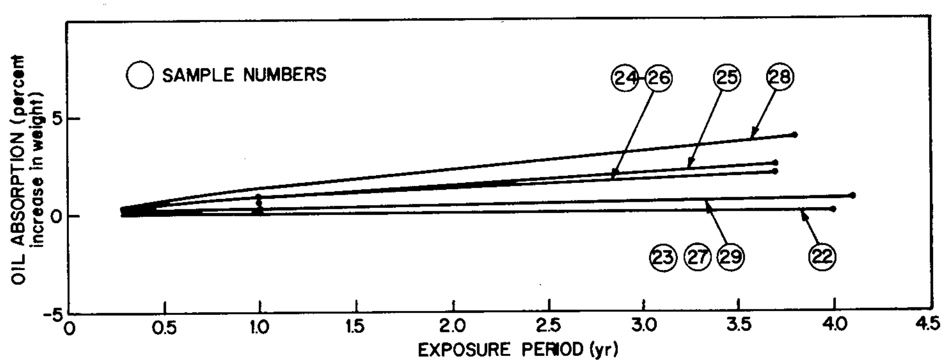

Fig. 28—Oil content increase of samples in Set 4

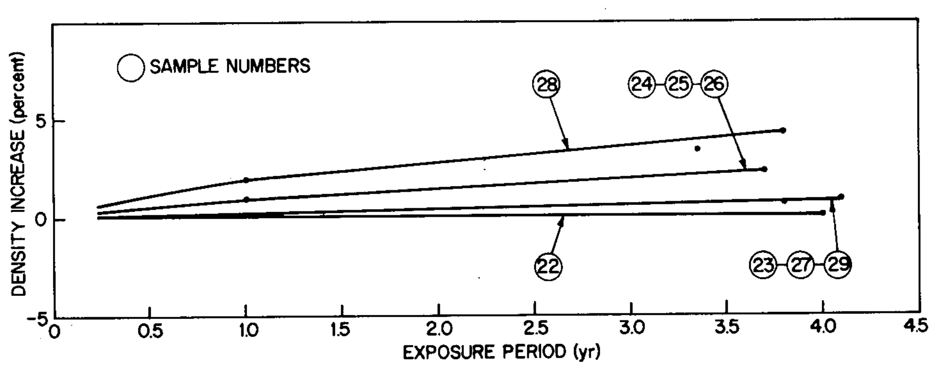

Fig. 29—Density increase of samples in Set 4

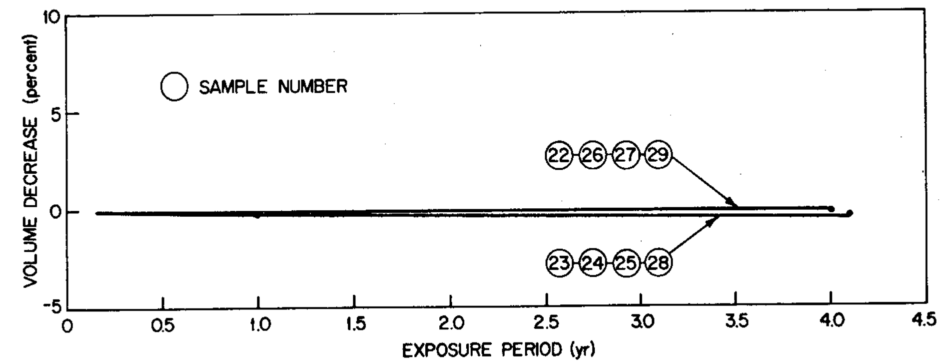

Fig. 30—Volume change of samples in Set 4

Table 6
Syntactic Foam Buoyancy Half-Life

Sample Number	Exposure		Buoyancy				
	Period (yr)	Pressure (psi)	Original (lb/ft^3)	After Exposure (lb/ft^3)	Loss (%)	Payload (lb/100 lb)	Half-Life (yr)
10*	5.3	5,000	24	21	14	51	19
11	5.3	5,000	25	21	14	52	19
12†	5.5	10,000	20	14	27	30	10
13	5.5	10,000	20	14	29	29	10
14‡	4.0	7,500	27	23	15	58	13
15	4.1	10,000	25	0	99	1	2
16	4.0	7,500	26	11	59	21	3
17	4.0	7,500	25	18	29	40	7
18	4.1	7,500	25	24	5	63	42
19	4.1	7,500	26	24	8	63	25
20	4.1	7,500	25	22	12	54	18
21	4.1	7,500	25	20	22	46	10
22§	4.0	7,500	23	23	1	56	360
23	4.1	10,000	22	21	3	52	72
24	3.7	10,000	23	22	5	52	35
25	3.7	10,000	22	21	6	50	29
26	3.7	10,000	22	21	4	52	42
27	3.7	10,000	22	22	3	53	73
28	3.8	10,000	23	21	8	51	24
29	3.8	10,000	22	21	2	53	110

*Set 1.
†Set 2.
‡Set 3.
§Set 4.

To compare the effects of the two exposure media and the two test pressures of 7500 and 10,000 psi, an exposure period of 3.7 yr was chosen, since it was the longest interval common to these four variables. The percentage gain in density was used for the means of comparison. In Table 7 it is shown that, at a pressure of 10,000 psi, the density increased about five times as rapidly in water as in mineral oil. For samples tested in mineral oil, those designed for service at 7500 psi and tested at that pressure gained in density at over three times the rate of those which were designed for and tested at 10,000 psi. For one sample tested at 2500 psi over its rated pressure, the gain in density was over 200 times the amount that it was for a sample tested at 2500 psi under its rated pressure.

Table 7
Density Increase in Syntactic Foam After
3.7 Years of Exposure at Room Temperature

Number of Samples Compared	Media	Hydrostatic Pressure (Rated) (psig)	Hydrostatic Pressure (Tested) (psig)	Average Density (lb/ft^3)	Average Increase in Density (%)
Effect of Media					
2	Water	10,000	10,000	42	9.7
7	Mineral Oil	10,000	10,000	40	2.1
Effect of Pressure					
5	Mineral Oil	7,500	7,500	37	7.3
7	Mineral Oil	10,000	10,000	40	2.1
Effect of Overpressure vs Underpressure					
1	Mineral Oil	7,500	10,000	37	67.0
1	Mineral Oil	10,000	7,500	40	0.3

The effect of density on the exposure time required for a sample to lose half of its original buoyancy is shown in Fig. 31. It can be seen from the grouping of sets of samples that the buoyancy life-expectancy of syntactic foam improves as the density is increased. Sample 22 (Group △), tested at 75% of its rated hydrostatic pressure, would be expected to be useful approximately 150 times as long as Sample 15 (Group □), tested at 133% of its rated pressure. By a similar comparison, the effect of density on the loss of buoyancy of syntactic foam is displayed in Fig. 32. The higher density material withstands a smaller loss in buoyancy than the lower density syntactic foam during a test period of equal length.

CONCLUSIONS

From the data obtained in these tests, the following observations may be made:

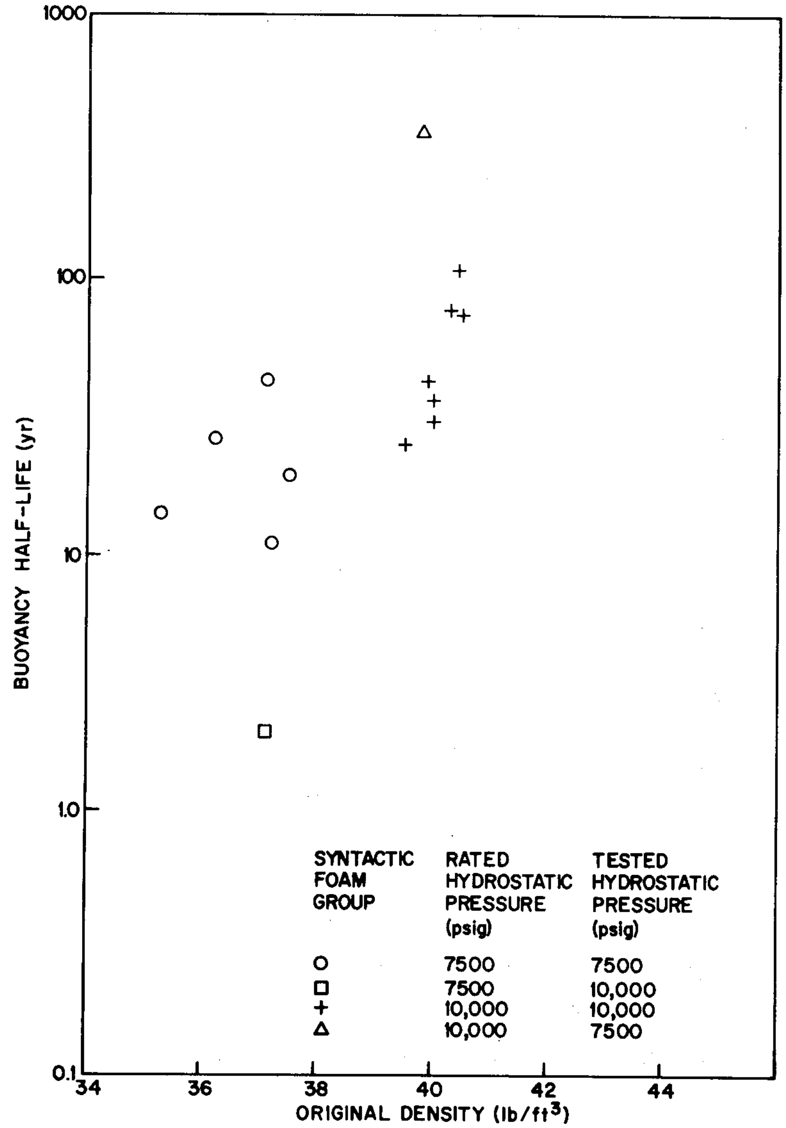

Fig. 31 — Effect of density on buoyancy half-life in a mineral oil medium

1. Syntactic foam absorbs water more readily than it does mineral oil.

2. Absorption in either media is related to hydrostatic pressure and foam density, but more especially the former.

3. Buoyancy decreases rapidly at first, then assumes an almost linear rate of change.

4. Overpressurizing can cause great damage to syntactic foam.

5. The buoyancy half-life for syntactic foam exposed to a 5000-psi water medium is estimated to be about 20 yr for a material of 38 lb/ft^3 specification density; 10 yr for a 42-lb/ft^3 formulation at 10,000 psi. For the samples tested in mineral oil, the half-life is at least 10 yr for material with a nominal density of 37 lb/ft^3 exposed to a hydrostatic

pressure of 7500 psi, and about 25 yr for the 40 lb/ft^3 specimen at 10,000 psi. Table 6 gives an indication of the expected useful life of the samples tested. This reflects the state of the art 6 yr ago when these samples were manufactured.

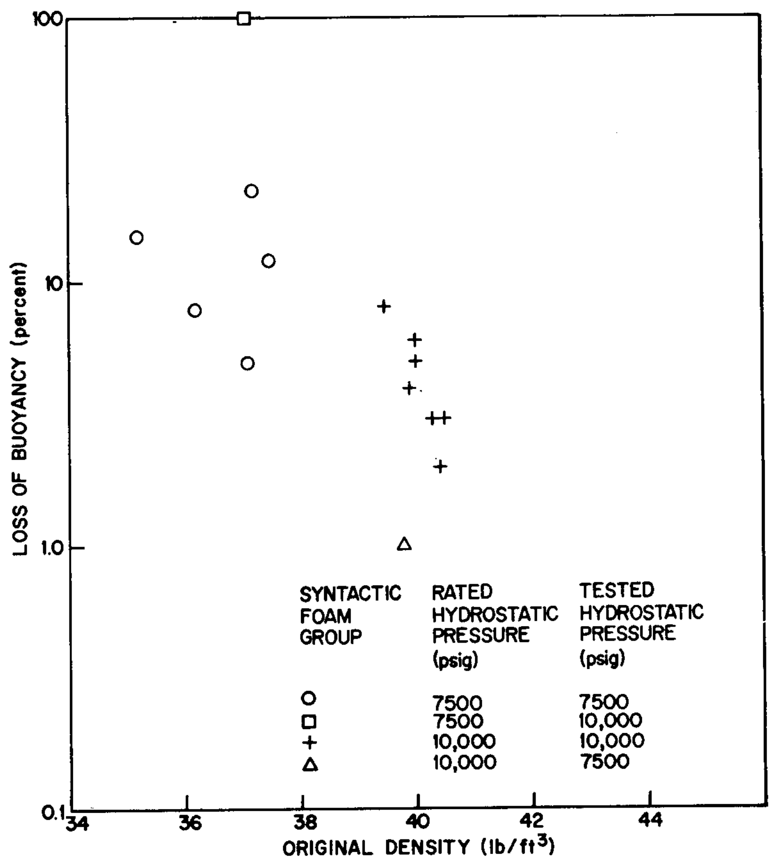

Fig. 32 — Effect of density on loss of buoyancy in a mineral oil medium