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**STORAGE OF 90% AND 98% BY WEIGHT
HYDROGEN PEROXIDE IN SEALED
CONTAINERS FOR EXTENDED PERIODS**

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I. FORWARD

This contract has been monitored by the Rocket Development Laboratory of Edwards Air Force Base Flight Test Center with Mr. Forrest S. Forbes as Project Engineer. The work upon which this document is based was accomplished by Becco Chemical Division, FMC Corporation, at Buffalo, New York, under Air Force Contract AF-04(611) 6342, and also includes experimental test data generated by Becco at Corporate expense. Technical personnel contributing to the above contract work include:

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This is the final report, submitted per Part III, Item B., of the contract. This report discusses all work accomplished from 15 December 1960 to 15 July 1961.

Work carried out under Air Force Contract AF-33(616)6732 is also listed in this report where advantageous, to make this a complete document.

II. ABSTRACT

This document describes work performed under Contract AF-04(611)6342, pertaining to the storage of Hydrogen Peroxide in sealed storage containers.

Four grades of Becco Hydrogen Peroxide were evaluated: Commercial 90% by weight H_2O_2 , Propulsion 90% by weight H_2O_2 , Commercial 98% by weight H_2O_2 , and Propulsion 98% by weight H_2O_2 , in 1 gallon capacity TFE Teflon bladders contained in mild steel test tanks at 70-72°F for five months, 120°F for seven days, and 165°F for 72 hours. The bladders were not as compatible as desired due to bleaching and crack development experienced with this dispersion-type Teflon.

These tests showed the oxygen loss from the H_2O_2 during the storage period can be decreased by utilizing improved passivation techniques, surface pre-treatment techniques and improved stabilizers for the H_2O_2 .

The use of an oxygen absorbant bag in the H_2O_2 tank proved non rewarding due to breakdown of the absorbant solution. However, the use of a more suitable oxygen absorbant should prove satisfactory.

The most promising test results were obtained with the 98% Propulsion H_2O_2 containing stabilizer P.

Brief screening tests showed other bladder materials such as N.A.A. Vicone 185, 3M Fluorel #2141 and Dupont Viton B cure 805 to give comparable or superior compatibility in contact with the H_2O_2 when compared to the dispersion-type Teflon material.

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Concentrated Hydrogen Peroxide and especially 98% by weight H_2O_2 has proved to be a high-energy oxidant and monopropellant suitable for use in propulsion systems. Examples are the high-energy H_2O_2 -Aluminum enriched Polyethylene hybrid rocket and the 98% H_2O_2 -Pentaborane propellant combinations(1-4). Ninety Percent Hydrogen Peroxide is used in the X-15, Scout missile, Mercury capsule, and the Centaur missile as a monopropellant for attitude controls (5).

Hydrogen Peroxide storage vessels are normally vented to relieve oxygen gas formed by the very slow decomposition of the H_2O_2 . Normal concentration loss is less than 1% per year in 30 gallon capacity storage drums and less than this amount in larger storage tanks. The rate of H_2O_2 decomposition is controlled by the surface of the vessel (heterogeneous decomposition), the surface-to-volume ratio, and the purity of the solution (homogeneous decomposition). The heterogeneous reaction can be decreased by the selection of proper materials, decreasing the surface area contacting the H_2O_2 , and passivation (6). The heterogeneous and homogeneous reaction can be decreased by the use of stabilizers. The original H_2O_2 solution is 99%-plus stable, therefore, little has been done in reducing the homogeneous effect. Table I lists the physical, thermal, and heat transfer properties of Becco 90% and 98% H_2O_2 .

"It has been well established by the work of various investigators that pure hydrogen peroxide of any concentration, in the absence of contaminating catalyst and a thoroughly clean container of non-catalytic material, is a very stable substance. Although the rate of decomposition of the most highly purified hydrogen peroxide is known to be very low, the attainment of such ideal conditions as perfect purity and the absence of all catalytic effects from the walls of the containing vessel or from dissolved or suspended impurities, is of course practically impossible and the best available data on the intrinsic stability of hydrogen peroxide must be considered on one hand only as approximations to that ideally attainable, and on the other hand as a goal for which to strive in practical manufacturing, storage, and handling procedures." (7)

"In practice, decomposition is minimized during storage or use by three measures: (1)-The initial production of hydrogen peroxide in a state of high purity, (2)-The addition of certain substances, termed stabilizers, which counteract the effect of catalytic impurities or container surfaces, (3)-Control of the environment to which hydrogen peroxide is exposed. Hydrogen peroxide is not an inherently unstable material and the development of the electrolytic manufacturing processes, which permitted the production of much purer hydrogen peroxide," (7) than that produced earlier by other production methods showed that high-purity hydrogen peroxide could be produced for propulsion uses.

The Navy has successfully employed a heavy-stabilized grade of 70% H_2O_2 for torpedo power plants. The stabilizer is used as protection against minor contamination.

Becco has developed MS grade 90% H_2O_2 for specific military applications where storage in stainless steel tanks or systems is required.

One specially-stabilized grade of hydrogen peroxide, tailored for sealed-storage was evaluated in this test program.

The H_2O_2 producers can tailor hydrogen peroxide for almost any application, from freezing depressants to high-energy monopropellants.

2.0 PROGRAM OBJECTIVES

The object of this work was to determine the limit of hydrogen peroxide storage time in sealed containers without excessive pressure buildup during periods to six months, and this data extrapolated to one year.

This sealed storage is required in many applications where the propulsion system must be ready for instant use after various storage periods.

"Hydrogen peroxide has the advantage over other well-known oxidizers that properly handled, it is extremely stable at room temperature (while ready for instant use). It poses few of the problems characteristic of cryogenic oxidizers like lox and fluorine, nor is it as corrosive as are the more exotic oxidizers." (8)

The future long-period space flights will require oxygen-bearing chemicals such as hydrogen peroxide to maintain a proper atmosphere for life support, provide attitude controls, and refrigeration.

Hydrogen peroxide also offers much in stand-by ICBM system as a main oxidant, turbo pump drives, and attitude control.

To simulate the various temperatures and ullages that could be expected in actual applications, the test program as shown in the next section was adopted.

3.0 PROGRAM OUTLINE

The origin approach as called out in the final report under contract AF-33(616)6732, and the proposal prior to contract AF-04(611) 6342, listed the test propellants to be commercial grades 90% and 98% by weight hydrogen peroxide and 90% and 98% by weight hydrogen peroxide containing 10 ppm PO_4 . Tests carried out at 212°F for 24 hours prior to the start of this contract showed that Becco stabilizer P was superior to the 10 ppm PO_4 stabilizer in reducing the homogeneous decomposition of 90% and 98% hydrogen peroxide. The results of these tests are shown in Table II. The encouraging test results showed that if this stabilizer were employed in place of the 10 ppm PO_4 , more favorable storage would result due to a decrease in the homogeneous decomposition of the H_2O_2 . The new stabilized grades of H_2O_2 were hereafter referred to as Propulsion Grades (experimental).

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The selection of a bladder material was carried out under the previous contract AF-33(616)6732. Table III shows the results of the laboratory screening tests. TFE (tetrafluoroethylene) proved to give the best and most consistent results with 90% and 98% H₂O₂. Table IV shows the results of small-scale sealed TFE bag tests at various temperatures using 90% H₂O₂. Figure 1 shows the results of a 3-month storage test with 90% H₂O₂ in a Teflon FEP bladder.

In view of these test results, TFE Teflon was selected as the test bladder material. The bladders were to be passivated and conditioned using the techniques proven most rewarding in the laboratory tests and shown by Table III.

Another approach to the storage problem is the use of an oxygen absorbent to pickup the oxygen gas liberated during the slow H₂O₂ decomposition. Table V shows the results of screening tests with two absorbent solutions. The most suitable absorbent solution was made up in molar ratios of 1:3:10 alkaline pyrogalllic acid-potassium hydroxide and water respectively.

The absorbent was found to have no detrimental effect upon a vinyl sponge material. The absorbent solution contained in a vinyl sponge and enclosed in a 1 to 2 mil. TFE Teflon film bag was developed under AF contract AF-33(616)6732, and planned for test evaluation under this contract.

The contract work program outline is as follows:

Absorbent	Comm. 90% H ₂ O ₂			Propulsion 90%			Comm. 98% H ₂ O ₂			Propulsion 98%		
	R.T.	120°	165°	R.T.	120°	165°	R.T.	120°	165°	R.T.	120°	165°
No	2			2			2			2		
Yes	2			2			2			2		
No		2			3			2			3	
Yes		2			2			2			2	
No			2			2			2			2
Yes			2			2			2			2

4.0 TEST EQUIPMENT AND PROCEDURES

The following sections list the various pieces of equipment, passivation procedures, and the test procedures employed.

4.1 Test Equipment Used

The test equipment consisted of a bladder, pressure vessel, pressure gage, hand vent valve, and connecting tubing and fittings, as shown by Figure 2.

The bladder capacity was 1.08 gallon. The shape of the bladder was set to give a minimum surface-to-volume ratio for the volume employed and standard available components, to enclose the bladder. The surface-to-volume ratio was 0.69 sq.in./cu.in. The bladder was fabricated of TFE Teflon, having a wall thickness of .015 inches. A two-section bladder was fabricated to facilitate installation of the absorbent bags and the use of a minimum diameter plastic rupture disc. The bladder was constructed in such a way to insure the H_2O_2 would contact only the TFE Teflon during the test. Figure 3.

When received, the bladders were dark brown, instead of white. A room-temperature check with 90% H_2O_2 showed the bladder material to be compatible: thus, no further checks were made prior to the testing. The bladders were fabricated by Chemgineers, Inc., Los Angeles, California.

4.1.1. Test Vessel

The pressure vessel used to confine the bladder consisted of two 6-inch schedule-40 mild steel welding caps welded to two 6-inch schedule-40 modified mild steel stub ends. The lower tank half was equipped with a rupture disc holder assembly. A 1/4-inch tube fitting was welded to the upper tank section to facilitate connecting a pressure gage to show the pressure buildup in the upper tank half during test and a hand vent valve.

The bladder sections were sealed at the vessel girth and at the rupture disc section by the use of a single-groove clamping arrangement held in place with bolts as shown by Figure 2. The pressure vessel was painted inside and out with metallic aluminum paint prior to test use.

4.1.2. Test Tank Attachments

The test tank also included such attachments as a 0-500 psi Murphy & Morse Style AAO pressure gage and a 1/4-inch size #62 316-stainless steel Alloy Steel Products Company hand vent valve. Polyethylene rupture discs were also employed. Figure 3.

The test tanks were mounted as shown by Figure 4 for the room-temperature tests and as shown by Figure 5 for the elevated-temperature tests. The rupture disc was mounted at the low

point of the tank to facilitate draining of the propellant if it became contaminated. Polyethylene rupture discs were employed due to its readily available supply in various thicknesses. Also, there is little to no difference in compatibility between Teflon and Polyethylene in contact with either 90% or 98% H_2O_2 (9). We do not recommend the use of Polyethylene as a storage material in contact with concentrated H_2O_2 as it will ignite at a fairly low temperature when in contact with H_2O_2 (10). The rupture discs were submerged in water during the high temperature tests. Thus, there was no possibility of ignition.

4.2 Passivating and Conditioning the Test Bladders

The bladders were inspected for cracks, thin spots, noticeable color variations and other non-satisfactory conditions prior to use. They were then mounted in the test tanks and the bolt clearance holes cut. The bladders were cleaned with a solvent (trichlorethylene), flushed with distilled water, washed with a .2% Nacconal (detergent)-water solution, flushed with distilled water and then mounted in the test tanks. After installation of the bladder halves, the girth flange bolts were torqued to 70 inch-pounds. The bladder was filled with distilled water, the rupture disc installed and bolted in place. The tank was pressurized to 200 psi.

The complete assembly was then submerged in a water bath, as shown by Figure 6, for 30 to 45 minutes. If no leaks were observed and the tank pressure did not decrease, the tank was removed and readied for test.

The test bladders were passivated and conditioned with H_2O_2 prior to use as follows:

- (1)-Degreased with trichlorethylene solvent.
- (2)-Flushed with distilled water.
- (3)-Scrubbed using .2% Nacconal-water solution.
- (4)-Flushed with distilled water
- (5)-Filled with 20% HNO_3 and exposed for 1 hour at room temperature.
- (6)-Flushed with distilled water.
- (7)-Filled with Becco commercial 35% H_2O_2 , left for 24 hours, emptied.
- (8)-Filled with Becco commercial 90% H_2O_2 , left for 24 hours, emptied.

If there was no abnormal H_2O_2 decomposition, the tank was considered suitable for use.

A portion of the test tanks were to contain the absorbent bags (vinyl sponges saturated with Pyrogallol solution and contained in 1-ml. TFE Teflon bags). The bag-units were passivated similarly to the bladders to insure compatibility. They were put into the tanks during initial assembly and therefore, received an additional complete

passivation and conditioning cycle when the bladders were passivated and conditioned. The absorbent bag volume was quite small (40 to 60 ml.) therefore it had little effect upon tank ullage, reducing it from 10.4% to 9.1%. Figure 7.

4.3. Filling the Test Tanks

An air-chamber-volume was provided between the Teflon bladder and inner head of the upper tank section. To achieve this free volume, 3730 ml. of 90% H_2O_2 or 98% H_2O_2 was put into the bladder through the rupture disc port. Figure 8. This left a void of 390 ml. The gas pressurizing line was then connected to the outlet fitting on the hand vent valve. The gas regulator was opened and 1 to 2 psi N_2 gas passed through the hand vent valve and into the tank between the bladder and the tank wall. The gas pressure pushed the bladder away from the tank wall. When the H_2O_2 in the bladder rose and filled the bladder neck at the rupture disc port, the hand vent valve was closed and the rupture disc installed and locked in place by a seal ring held firmly by four $\frac{1}{4}$ -inch 20 cap screws torqued to 30 inch-pounds. After the rupture disc was bolted in place, the gas regulator was turned off, the line hand vent valve and the hand vent valve on the tank were opened, venting off any pressure in the air chamber. The hand valve was then closed, the gas pressurizing line removed, the tank set upright, and put on test.

The air chamber served as an accumulator to transmit the decrease in chamber volume and increased pressure due to H_2O_2 decomposition during storage to the pressure gage, thus, giving a working media. Calculations showed a safe room temperature pressure buildup before bladder bottoming was 220 psi and 300-350 psi in the room-temperature and elevated-temperature tests, respectively.

4.4. Testing Procedures

The tests fell under two types: room temperature, 70°F. to 72°F.; and elevated temperature, 120°F. and 165°F.

The room-temperature tests were set up in steel racks. Pressures were recorded weekly, Figure 4.

The elevated-temperature tests were carried out in automatic temperature-controlled water baths. Pressures were recorded daily. Figure 5.

4.5. Special Tests Carried Out

4.5.1. Sealed Storage Tests with Specially-Treated Teflon Bladders (Farrellok-Solution Conditioned) (*)

When it was found the TFE bladders bleached and increased the heterogeneous decomposition rate, other bladder-conditioning techniques were considered. One treating solution, Farrellok

(*) Farrellok -- A product of Farrelloy Corporation, Philadelphia, Pa.
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(a phosphoric-acid based metal treating solution) has proved quite effective in conditioning stainless steel components for high-pressure test systems. This treating solution has proved rewarding in treating cast stainless steel surfaces in flow meters and valves.

Two test tanks were passivated and H_2O_2 -conditioned as described in Section 4.2. of this report. In addition, the bladders were conditioned with Farrellok solution (full-strength) for one hour at room temperature ($20^\circ C$.) following the acid treatment. Thirty-seven hundred milliliters of Becco commercial grade 98% by weight H_2O_2 were put into each tank bladder.

4.5.2. Evaluation of Used TFE Teflon Bladders in Sealed-Storage Tests

These tests were carried out to determine if the bladders were more compatible after the bleaching experienced in the initial exposure. The bladders selected each had experienced a minimum of 300 hours exposure to 90% or 98% H_2O_2 . The bladder surfaces were light tan to a dull white in appearance at the start of the test. Two tanks each of 90% H_2O_2 and 98% H_2O_2 were put on test. Each tank contained 3730 ml. of H_2O_2 .

4.5.3. Special Tests Conducted on Samples of New and Used TFE Bladders

One new bladder and one used bladder (100 hrs. exposure) were cut up for laboratory evaluation. The tests consisted of 7 days exposure to 90% H_2O_2 at $66^\circ C$ ($151^\circ F$.) following standard passivation, including a 1-hour conditioning period in 20% HNO_3 . One set of used samples was not acid treated as a control to see what effect the acid would have on the used bladder samples.

4.5.4. Comparison of TFE Teflon Bladders with Other Bladder Materials and Kanigen-coated Mild Steel

The TFE Teflon bladder is not the most desirable bladder material due to its poor physical properties, thus more suitable bladder materials are required. Laboratory tests were carried out to determine the compatibility of Fluorel (3-M), Viton-B (DuPont), Silicone compound #TH-1131 (Stillman), and Kanigen-plated mild steel (Keystone Chromium Company). The Kanigen plating with a tin coating has proved an effective covering for mild steel poppets in solenoid valves now used in at least one major space program, in contact with 90% H_2O_2 . As high-stress steel alloys are not suitable for use with H_2O_2 , the use of Kanigen plating may prove useful in some applications. The use of the tin-plated Kanigen should further reduce the H_2O_2 decomposition.

4.5.5. Sealed-Storage Tests with one Becco High-Energy Low-Freezing Monopropellant: BMP-DEG-1800 $-20^\circ F$.

BMP = Becco Monopropellant, DEG = Fuel component (diethylene glycol), 1800 = $1800^\circ F$ flame temperature, and $-20^\circ F$ = freezing point.

The use of high-energy propellants for space projects is increasing at a rapid rate. The BMP solution tested shows a relatively high Isp at altitude, 200 secs. and higher, and can be decomposed similarly to 90% H_2O_2 or 98% H_2O_2 , thus, shows promise as a monopropellant. Table VI lists the physical properties of this propellant. Table VII lists the results of performance tests at room and depressed temperature with this type propellant after 6-months storage in aluminum drums at 70-72°F, showing satisfactory performance.

The BMP solution was evaluated in the sealed storage tanks for 7 days at 49°C. and 10 weeks at 20°C. Figs. 19 & 20.

5.0 TEST RESULTS and DISCUSSION OF THE TEST RESULTS

5.1 Room Temperature Tests

5.1.1. Without Absorbent Bags

A total of eight tests were carried out, two with 90% commercial H_2O_2 , two with 98% commercial H_2O_2 , two with 90% propulsion H_2O_2 , and two with 98% propulsion H_2O_2 . Each tank contained 3730 ml. of propellant.

The pressure buildup was most rapid in tanks containing 98% commercial H_2O_2 . This is not surprising as the greater oxygen content of the 98% H_2O_2 will result in an effect upon the plastic liner. One tank was removed after 9 weeks with a pressure buildup of 196 psi, while the other tank was removed after 16 weeks with a pressure buildup of 184 psi. The oxygen weight loss was 0.2% in four months. The bladders were bleached from the dark brown color to a light tan color and considerable porosity was noted by the presence of H_2O_2 between the bladder and the tank wall in a few locations.

Tests with commercial 90% H_2O_2 did not show as rapid a pressure buildup. One tank was removed after 15 weeks with a pressure buildup of 144 psi. The other tank was removed after 20 weeks with a pressure of 31 psi. The oxygen weight loss was 0.25% in 5 months storage. Examination of the first tank bladder showed porosity and severe bleaching. The second tank bladder did not bleach as severely and there was no sign of porosity. This definitely had an effect upon the pressure buildup.

The tests with 90% propulsion H_2O_2 proved encouraging in the early period of testing, as there was no pressure buildup during the first four weeks. The pressure in one tank rose slowly from the 5th through the 8th week and then rose sharply to 184 psi at 13 weeks. The pressure buildup in the second tank was more rapid, as it reached 196 psi at the 9th week. The bladders in both tanks were bleached and porous. The oxygen weight loss was 0.19% over a 13-week storage period.

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The most successful room temperature sealed storage tests were those with 98% propulsion H_2O_2 . Both test tanks completed 20 weeks of tests. One tank showed a final pressure of 144 psi and the other tank showed a final pressure of 49 psi. The oxygen weight loss was 0.11% in 5 months' storage. Calculated pressure buildup based on oxygen loss determined from H_2O_2 concentration change checked fairly closely with the measured pressures; Table VIII shows the test results and Figure 9 shows optimum pressure curves of the various propellants taken from the test data.

5.1.2. With Absorbent Bags

A total of eight tests were carried out; two with 90% Commercial H_2O_2 , two with 98% Commercial H_2O_2 , two with 90% Propulsion H_2O_2 and two with 98% Propulsion H_2O_2 . Each tank contained one absorbent bag and 3730 ml. of propellant.

The pressure buildup was most rapid in tanks containing 90% Propulsion H_2O_2 . One tank showed a normal pressure rise for six weeks and then a sharp pressure rise to 180 psi at 7-1/2 weeks at which time it was removed. The second tank showed a normal pressure rise for 7 weeks and then a sharp rise to 190 psi at the end of 11 weeks when it was removed. The oxygen weight loss was 0.23% in 11 weeks' storage. The bladders showed considerable bleaching and porosity; the absorbent bags were bloated. Tests with Commercial Grade 90% H_2O_2 did not show as rapid a pressure rise. Both tanks maintained nearly uniform pressures along a uniform curve. Both tanks were removed after 17 weeks' storage with pressures of 150 to 160 psi. The oxygen weight loss was 0.13% in 19 weeks' storage. The bladders were bleached, slight porosity was noted and the absorbent bags had bloated.

Tests with 98% Commercial H_2O_2 showed low pressure buildup in the first three weeks of storage. One tank showed no pressure buildup for three weeks, while the other tank showed 2 psi at the end of the second week. One tank completed 5 months' storage and was removed with 102 psi pressure. The oxygen weight loss was 0.28% in 5 months' storage. The other tank showed a low pressure rise to 9 weeks and then a more rapid rise to 158 psi at 16 weeks when it was removed. The bladders in both tanks bleached, the latter tank showed greater bleaching and more porosity than the other tank. Both absorbent bags were bloated.

The most favorable storage was noted with 98% Propulsion H_2O_2 . One tank showed no pressure buildup for 3 weeks, while the other showed 4 psi after 3 weeks. Both tanks showed a uniform pressure buildup for 4 to 5 months. However, one tank was removed after 19 weeks when the pressure rose to 114 psi. Both bladders were bleached, slight porosity was noted and the absorbent bags were bloated. The oxygen weight loss was 0.19% in 5 months' storage.

The bloated bags were checked and found to contain CO_2 gas which had formed when the pyrogalllic acid broke down in the heavy oxygen atmosphere. Table IX lists the test results. Figure 10 shows the most optimum pressure curves from the test data.

5.2. 49°C (120°F) Storage Tests

5.2.1. No Absorbent Bags

A total of ten tests were carried out; two with 90% Commercial H_2O_2 , two with 98% Commercial H_2O_2 , three with 90% Propulsion H_2O_2 and three with 98% Propulsion H_2O_2 . Each tank contained 3730 ml. of propellant.

Due to a tie-up of test facilities (heated water baths), the filled tanks were stored in a 13 to 15°C available non-heated water bath for 4 weeks prior to starting the 120°F tests, as no steel storage racks were available.

There was no pressure buildup in the tanks containing the propulsion (stabilized) H_2O_2 during the 4 week storage period. One tank containing 90% Commercial H_2O_2 also showed no pressure buildup through 4 weeks of storage. The pressure buildup was most rapid in tanks containing 98% Commercial H_2O_2 .

Prior to putting the tanks on test at 120°F, each tank was vented to insure there would be no trapped gas that could expand and give an unwarranted pressure rise.

The tanks were placed in the controlled 120°F water baths and left for 7 days. Only one tank failed to complete the seven day test--this was one containing 98% Commercial H_2O_2 . The 98% Propulsion H_2O_2 showed the least pressure buildup, followed by 90% Propulsion H_2O_2 , 90% Commercial H_2O_2 and 98% Commercial H_2O_2 in that order. The oxygen weight loss was 0.13%, 0.21%, 0.27% and 0.23% respectively in these tests (30 days 20°C and 7 days 120°F).

Examination of the bladders revealed severe bleaching with very slight porosity. Figure 11 shows the before and after a 120°F test condition of the test bladders. Note the severe bleaching. This severe bleaching was believed to be the removal of an organic material from the plastic. Laboratory tests with one of these bladders and a new one are covered in Section 5.6 of this report.

Table X lists the test results. Figure 12 shows the most optimum test curves.

5.2.2. Tests With Absorbent Bags

A total of eight tests were carried out; two with 90% Commercial H_2O_2 , two with 90% Propulsion H_2O_2 , two with 98% Commercial H_2O_2 and two with 98% Propulsion H_2O_2 . All tanks contained 3730 ml. of propellant except one tank that contained only 3675 ml. of 98% Commercial H_2O_2 . Each tank contained one absorbent bag.

The tanks were placed in the controlled 120°F water baths and left for 7 days. One tank containing 98% Commercial H_2O_2 was removed at the end of the 5th day with a pressure of 170 psig. The oxygen weight loss was 0.35% in 5 days' storage at 120°F. The bladder showed severe bleaching and porosity and the absorbent bag was bloated.

The other tanks completed the test period. Examination of the bladders revealed severe bleaching with minor porosity. The absorbent bags were bloated and had lost weight. Figure 13 shows the absorbent bags before and after test. Figure 14 shows one of the bladders that was found to have failed sometime during the test. The bladder failure did not have an adverse effect upon the H_2O_2 it contained. Table XI shows the test data. Figure 15 shows the optimum test curves.

5.3. Results of 74°C (165°F) Tests

5.3.1. Tests Without Absorbent Bags

A total of eight tests were carried out; two with 90% Commercial H_2O_2 , two with 90% Propulsion H_2O_2 , two with 98% Commercial H_2O_2 , two with 98% Propulsion H_2O_2 . Each tank contained 3730 ml. of propellant.

The tanks were placed in controlled 165°F water baths and left for 3 days or when the tank pressure exceeded 200 psi.

One tank containing 90% Commercial H_2O_2 and one containing 98% Commercial H_2O_2 were removed after 24 hours when the pressures reached 239 and 183 psi. The oxygen weight loss in these tests was 0.11% and 0.15% respectively. Two tanks containing 90% Propulsion H_2O_2 and one containing 98% Propulsion H_2O_2 completed 72 hours of test. The oxygen weight loss was 0.29% and .15% in these tests.

The bladders were found to be bleached severely. Porosity was most noticeable in the first two bladders removed. Table XII lists the test results while Figure 16 shows the optimum curves from the data.

5.3.2. Tests With Absorbent Bags

A total of eight tests were carried out; two with 90% Commercial H_2O_2 , two with 90% Propulsion H_2O_2 , two with 98% Commercial H_2O_2 and two with 98% Propulsion H_2O_2 .

Each tank contained one absorbent bladder and 3730 ml. of propellant.

The tanks were placed in the controlled 165°F water baths and left for 72 hours or shorter periods depending upon the rate of pressure buildup.

The tanks containing 90% Commercial H_2O_2 were removed after 24 hours. The tanks containing 90% Propulsion H_2O_2 and 98% Commercial H_2O_2 were removed after 48 hours and the 98% Propulsion H_2O_2 removed after 72 hours. The oxygen weight loss was 0.18%, 0.16%, 0.13% and 0.02% respectively in these tests. Slight leaks were noticed at the girth flange of three of the tanks.

Examination of the bladders revealed severe bleaching and noticeable porosity. The absorbent bags were bloated and had lost weight.

Table XIII lists the test results. Figure 17 shows the optimum test curves.

5.4. Results of Sealed Storage Tests With Specially Treated TFE Teflon Bladders

These tests were carried out to determine if Farrellok treated TFE Teflon bladders would be more passive than standard treated bladders when in contact with 98% Commercial H_2O_2 . Two test tanks each containing 3730 ml. of 98% Commercial H_2O_2 were placed on test at 20°C.

The pressure buildup in these tanks was uniform and although it did not show lower pressure buildup until 3 to 4 months' storage when compared with similar tests without the use of Farrellok, it does show promise. The oxygen weight loss averaged 0.2% in 4 months' storage. The bladders did not appear to bleach as severely as that noted in other 20°C tests. Table XIV lists the test data. Figure 18 shows the pressure versus time curve obtained with these tests.

5.5. Results of Sealed Storage Tests When Employing Used TFE Teflon Bladders

The bladders were reused in the elevated temperature tests with total exposure reaching 200 plus hours. These tests were to determine if bladders having 300 and greater hours H_2O_2 exposure would be adversely affected.

Two tanks contained 3730 ml. of 90% Commercial H_2O_2 and two tanks contained a similar amount of 98% Commercial H_2O_2 . The oxygen weight loss was 0.1% with 90% H_2O_2 and 0.21% with 98% H_2O_2 in 6 weeks' storage at 20°C.

The pressure buildup rate was greater than that experienced with new bladders.

The test results are listed in Table XV.

5.6. Results of Laboratory Tests on Samples of New and Used TFE Teflon Bladders

These tests were carried out to determine if there was a degrading of the passivity of the TFE Teflon bladder with use.

The original bladder samples bleached to a white color from the dark brown. The used samples bleached slightly, but not as severe as the original sample. The used samples that were not acid treated were not as compatible as the new or treated bladders. The acid treated used sample was not as compatible as the original sample. There was no detrimental effect upon the samples or the H_2O_2 .

The test results are listed in Table XVI. The test data shows there to be little difference in compatibility of the new and used bladders if they are acid treated; however, if the used bladder was not acid treated, the active oxygen loss was nearly double that of the original sample in these tests.

5.7. Comparison of TFE Teflon Bladders With Other Bladder Materials and Kanigen Coating Mild Steel

Various laboratory tests to evaluate various bladder materials were carried out. The results of these tests are shown by Table XVII.

The 9711 Silicone rubber tests showed this plastic was attacked by 98% H_2O_2 . The samples also bleached slightly in all tests.

The N.A.A. "Vicone" (Viton and Silicone Rubber) material was evaluated and showed slight bleaching. There was little to no difference between the test sample lot and the bladder section piece tested. The active oxygen loss in tests with 98% H_2O_2 was greater than that with 90% H_2O_2 . All the samples bleached slightly.

Tests with Dielectrix Corporation TFE Teflon bladder samples in the four types of propellants for one week at 120°F showed slight bleaching and low active oxygen loss, especially with the stabilized 90% and 98% H_2O_2 . Tests with the same materials at 165°F for 3 days showed slightly higher active oxygen loss. The active oxygen loss in tests with the stabilized H_2O_2 grades was 75% to 33% of that with the regular propellants.

Another bladder material briefly evaluated was Stillman Rubber Company Compound #TH1131 (no iron oxide). The samples were evaluated in 90% and 98% Commercial H_2O_2 at 66°C (151°F) for one week. The active oxygen loss was fairly uniform with 90% and 98% H_2O_2 . The samples bleached lightly during the test.

Tests with Dupont Viton B (Compound #805) in 90% H_2O_2 at 66°C (151°F) for 1 week showed swelling and blistering; however, when similar samples were placed on test for 3 days under the same test conditions, there was no effect upon the sample. Following 1 week tests in 90% and 98% Commercial H_2O_2 at 120°F, the test samples were found to be very slightly blistered.

One test carried out for 30 days at 30°C (86°F) in 90% H_2O_2 showed a 1% active oxygen loss.

Viton "A" materials have been used for "O" rings, diaphragms and other plastic members in H_2O_2 systems.

Fluorel 2141 from Minnesota Mining and Manufacturing Company blistered in tests with 90% H_2O_2 at 66°C (151°F) for 1 week. In similar tests for 24 hours, the samples were not affected. Following one week in 90% and 98% Commercial H_2O_2 at 120°F, the samples showed signs of possible slight blisters. A five month storage test at 70-72°F was also carried out using 90% and 98% H_2O_2 as the propellants. The active oxygen loss at the end of five months was 1% with 90% H_2O_2 and 0.9% with 98% H_2O_2 . The samples were not affected.

Tests with "Kanigen," electroless nickel, coated 1020 mild steel in 90% H_2O_2 at 66°C (151°F) for 1 week showed the active oxygen loss to be equal to that of many of the stainless steels. The sample stained slightly and there was no breaking of the coating even though the sample edges were knife sharp at some points. To improve the compatibility of the Kanigen coating, a few tin plated Kanigen plated samples were received from Keystone Chromium Corporation, Buffalo 13, New York, and placed on test. The active oxygen loss from the H_2O_2 after a one week test was 11% to 14% which compares favorably with some of the plastic bladder materials. The samples stained slightly during the tests.

5.8 Results of Sealed Storage Tests with a Becco Experimental Low Freezing High Energy Monopropellant

Two series of tests were carried out using the monopropellant BMP-DEG-1800-72.5. The first tests were carried out in duplicate at 120°F for 1 week. The pressure buildup averaged 115 psi which compares very well with 90% Commercial H_2O_2 (Table X). The results of these tests are listed in Table XVIII.

The results of the room temperature tests are listed in Table XIX. The pressure rise during the room temperature storage test was more rapid than was expected based on the results of the 120°F tests. This was possibly due to the use of bladders having excess H_2O_2 exposure. Figure 19 shows the average pressure rise versus storage period in the 120°F tests. Figure 20 shows the pressure buildup in 20°C tests.

6.0. CONCLUSIONS

6.1. Room Temperature Tests

The room temperature sealed storage tests show that Becco 90% and 98% Commercial H_2O_2 can be sealed up in suitable containers for extended periods to one year when employing a 10% ullage. Using a greater ullage will increase the allowable storage period. The use of the Propulsion (stabilized) grades of Becco 90% and 98% H_2O_2 will allow for longer sealed storage periods, and the use of a bladder that does not leach organics into the H_2O_2 would also decrease the H_2O_2 decomposition rate, thus a slower rate of pressure buildup would be experienced. The TFE Teflon bladders used in these tests bleached severely and developed considerable porosity in some tests resulting in increased pressure buildup. The use of a 20% by weight Nitric Acid 1 hour room temperature bladder treatment was effective in reducing H_2O_2 decomposition by stripping metallic impurities from the bladder wall.

Treating bladders with "Farrellok" solution resulted in more uniform bladder compatibility. This solution is easily applied as it is in a liquid form, non-toxic and commercially available. The use of this solution as an additional step in the regular conditioning and treating procedure is rewarding. This can be seen by comparing Figure 9 with Figure 18. Note the decrease in pressure buildup in the sealed storage tests.

Figure 21 shows the results of the 20°C sealed storage tests extrapolated to 1 year. Note the low pressure buildup with Becco 90% and 98% Commercial H_2O_2 and that experienced with 98% Propulsion H_2O_2 . The 98% Propulsion H_2O_2 and one tank of 90% Commercial H_2O_2 did not show a pressure buildup in the first 3 to 4 weeks. The oxygen weight loss with all the H_2O_2 solutions was low in the 20°C tests, thus extrapolating this data to a one year storage period, resulting in a low oxygen weight loss as shown below:

90% Commercial H_2O_2	- 0.6 % by wt./yr.
90% Propulsion H_2O_2	- 0.76% by wt./yr.
98% Commercial H_2O_2	- 0.6 % by wt./yr.
98% Propulsion H_2O_2	- 0.26% by wt./yr.

This data was calculated from H_2O_2 concentration changes.

Three month 20°C storage tests were also carried out with 30 gallon capacity 99.6 aluminum H_2O_2 shipment drums containing 98% Commercial and 98% Propulsion H_2O_2 . The results obtained are as follows:

98% Commercial H_2O_2	- 0.75% by wt./yr.
98% Propulsion H_2O_2	- 0.28% by wt./yr.

The use of Farrellok treated virgin teflon bladders will reduce the oxygen loss from the H_2O_2 in sealed storage still further.

6.2. Tests With Absorbent Bags

The room temperature tests with tanks containing the oxygen absorbent bags failed to show any effect that would indicate the absorbent solution was functioning. The breakdown of the pyrogalllic acid released CO gas that was rapidly converted to CO₂ by the oxygen present. The presence of the teflon bags in the tanks did not show any adverse effects. This shows that the principle of placing an oxygen absorbent in a thin TFE Teflon bag and placing it in an H₂O₂ tank is feasible to remove the oxygen gas formed during storage; however, pyrogalllic acid is not suitable as the oxygen absorbent media unless it is in the alkaline form and then its use is doubtful due to the heavy oxygen atmosphere present. In no case was there an indication of liquid H₂O₂ entering the absorbent bags.

6.3. Elevated Temperature Tests

The elevated temperature storage tests resulted in rapid bleaching of the TFE Teflon bladders and greater pressure rise than would be expected. We believed the material bleached from the bladder was an organic used to stabilize the bladder material during the dispersion spray forming operation.

The heavy amount of leached material resulted in lowering the stability of some of the H₂O₂ solutions. Reusing the same bladders in the other elevated temperature tests showed the pressure buildup was less than that experienced earlier and the H₂O₂ stability was not affected.

The 98% Propulsion (stabilized) H₂O₂ proved very rewarding in the high temperature tests. The pressure buildup was less than that experienced with the other H₂O₂ solutions. Table XIII shows the low rate of pressure buildup with the stabilized 98% H₂O₂ at 165°F over a 3 day test period.

The laboratory tests backed up the results obtained with the test tanks. Tests with TFE bladder samples in contact with 90% and 98% Commercial H₂O₂ and 90% and 98% Propulsion H₂O₂ for 7 days at 120°F and 2 to 3 days at 165°F showed the H₂O₂ gas evolution was at least 50% less when the plastic was in contact with the Propulsion (stabilized) H₂O₂.

The 120°F sealed storage tests with the Propulsion (stabilized) H₂O₂ were not as rewarding as first expected. By referring to Table II it can be seen that this grade of H₂O₂ showed low oxygen loss at 212°F in pyrex glass. The bleaching of the TFE bladder as shown by Figure 11 indicated a considerable amount of impurity from the bladder was released and entered the H₂O₂ solutions. The use of more virgin bladder materials should result in lower pressure buildup during 120°F storage.

6.4 Tests with Kanigen Plated and Tin Coated Kanigen Plated Samples

Kanigen plating proved encouraging in the laboratory tests. This coating makes possible the use of high stress steels for vehicle H_2O_2 tankage. The tests with tin coated-Kanigen platings also proved rewarding. The tin plating decreased the H_2O_2 decomposition rate to a low order. It was interesting to note that even though the Kanigen plating was placed over sheared samples of 1020 mild steel having sharp edges, there was no break down of the plating at these edges during test.

Upon more complete evaluation, it may be feasible to build light-weight H_2O_2 missile propellant tanks. Figure 23 shows a Kanigen plated plus tin plate missile H_2O_2 tank.

6.5 Tests with a Hydrogen Peroxide Based Low Freezing Monopropellant

Storage tests with the experimental low freezing H_2O_2 based BMP-DEG-1800-20°F shows this solution can be stored for limited periods in sealed containers. If this solution were stored at depressed temperature, such as in high altitude vehicle, the pressure buildup would be still lower.

6.6 Summary of Test Results

The results of the sealed storage and laboratory tests show that when employing proper materials of construction, suitable passivation procedures and minimum surface to volume ratios, hydrogen peroxide can be stored in sealed containers for extended periods. This allowable storage period can be increased by acid treating the bladders, Farrellok treatment and by other methods.

In most space vehicles, the H_2O_2 would be partly expended prior to the orbital or space flight; thus the tank ullage would increase and the pressure buildup would proceed at a lower rate.

The use of stabilized or unstabilized 90% or 98% H_2O_2 as the oxidant in a standby ICBM is feasible. The high performance possible with 98% H_2O_2 and many fuel components offers highly desirable propellant combinations.

6.7 98% Propulsion H_2O_2 is an experimental grade of H_2O_2 . Further tests will be carried out before it is available for field use.

7.0 ADDITIONAL OBSERVATIONS

The sealed storage tests carried out under this contract show that it is possible to store 90% or 98% hydrogen peroxide in sealed containers for extended periods. The use of an oxygen

absorbent chemical such as chromus chloride in a heat sealed thin film TFE Teflon bag could possibly decrease the pressure buildup in a sealed propellant tank. Theoretically this solution has an oxygen absorbent capability 4 to 5 times that of pyrogalllic acid. Figure 22 shows an H_2O_2 feed tank incorporating an absorbent bag.

However, a completely sealed storage system is not the usual case. H_2O_2 tanks equipped with a pressure relief valve that can be blocked closed upon tank pressurizing have been used successfully. The use of a vented hydrogen peroxide missile feed tank is feasible and has been employed successfully by the British in their Sprite engine systems. Figure 23 shows a Kanigen plated and tin plated high stress steel H_2O_2 feed tank. Note how this vent would be closed off upon applying pressure to the tank. Ninety or ninety-eight percent hydrogen peroxide can be stored for long periods, 1 to 3 years, in a proper type vented tank. The H_2O_2 oxygen loss would be low, expecially with Propulsion (stabilized) 98% H_2O_2 .

The oxygen loss would be approximately 1/4 percent per year, thus 1% loss in 4 years' storage.

Figure 24 shows an H_2O_2 feed tank incorporating a gas relief valve.

Analysis of ten (10) 30 gallon shipment drums of Becco 90% hydrogen peroxide following shipment back and forth across the country in a three year period showed an oxygen loss less than one (1) percent in five (5) of the ten drums. Two of these drums were stored for at least half this period in San Diego, California.

The surface to volume ratio of the test tanks used was higher than that to be experienced in tanks used in flight vehicles. In general the less surface the H_2O_2 contacts the lower the H_2O_2 decomposition during storage. Figure 25 shows the effect of H_2O_2 decomposition versus the surface to volume ratio of the storage container (11). Note the sharp decrease in H_2O_2 decomposition when the surface area contacting the H_2O_2 is decreased.

Appendix A covers recommended procedures for the passivation of aluminum, glassware, and plastics in contact with Hydrogen Peroxide.

8.0 RECOMMENDATIONS FOR FUTURE WORK

The following work is recommended:

8.1 Laboratory Studies

8.1.1. Evaluate various stabilizers for use in the H_2O_2 to reduce the gas evolution to a low level at 120°F and 140°F. The stabilizer developed for 98% Propulsion H_2O_2 could possibly be improved to give the desired results.

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8.1.2. Determine the compatibility of the various materials of construction with the most promising grade of stabilized H_2O_2 .

8.1.3. Check the fallout property of the stabilizer.

8.1.4. Evaluate the use of a saturated solution of chromus chloride in acetic acid and contained in a thin film TFE Teflon bag. Other oxygen absorbent agents would also be screened.

8.2. Service Type Testing

The purpose of the proposed work is to increase the storability of 90% and 98% hydrogen peroxide for military propulsion applications.

8.2.1. Carry out sealed storage tests under the following conditions:

8.2.1.1. Sealed storage tests employing virgin TFE-FEP Teflon, Fluorel, Viton B or Vitone bladder, most promising stabilized H_2O_2 , passivation procedure to include 20% HNO_3 and Farrellok treatment, 72, 120, 140°F temperature range.

8.2.1.2. Same as 8.2.1.1., but with an absorbent bag installed.

8.2.1.3. Tests with tanks containing relief valves. Tank held at 400-425 psig simulating an attitude control system.

8.2.1.4. Sealed storage tests in 30 gallon and 500 gallon tanks with and without absorbent bags, when employing the most promising stabilized propellant.

8.2.1.5. Carry out decomposition tests to determine if the stabilizer employed has a detrimental effect upon the catalyst.

8.2.1.6. Carry out sealed storage tests with tin plated-Kanigen plated mild steel tanks.

8.2.1.7. Carry out sealed storage tests with anodized aluminum tanks.

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APPENDIX A

Passivation and Conditioning Procedures For Materials of Construction in Contact With 90% and 98% H₂O₂

The passivation and conditioning procedure given in Becco Bulletin #104, "Materials of Construction for Equipment in Use With Hydrogen Peroxide," and AF T.O. 42B-1-17, "Field Handling of Concentration Hydrogen Peroxide (Over 52 Weight Percent Hydrogen Peroxide)" are sufficient for most cases.

However, where exceptional low gas evolution is required, the following additional treatments are suggested.

Aluminum - In specific cases, the aluminum tanks, tubing and other vehicle components are conditioned with Becco Commercial 35% H₂O₂ for 24 hours followed by 90% H₂O₂ for 24 hours. To improve the passivity of the aluminum surface, one hour exposure to Farrellok solution prior to the H₂O₂ exposure proves rewarding.

Stainless Steel - When tube fittings and other components must be stored ready for use, the 3% HF - 10% HNO₃ - water etching solution was shown to be ineffective; however, increasing the HF strength to 10% by weight proved rewarding. Exposure to Farrellok solution prior to the 24 hour exposure to 35% and 90% H₂O₂ improves compatibility.

Plastics - All bladders, "O" rings, diaphragms and other plastic parts should be wetted with 20% by weight HNO₃ for one hour to remove metallic impurities in the plastic surface. A one hour exposure to Farrellok solution prior to the 24 hour exposure to the 35% and 90% H₂O₂ is beneficial.

Glassware - When testing plastic materials having very low gas evolution, the A.O.L. (active oxygen loss) of the glassware dwarfs the test results. To obtain super clean glassware, the use of a 35% H₂SO₄ for a minimum of 3 hours and a 24 to 48 hour conditioning in 90% or 98% H₂O₂ at 151°F (66°C) has proved rewarding.

Bladder Data: Manufactured by Joclin Manufacturing Co.

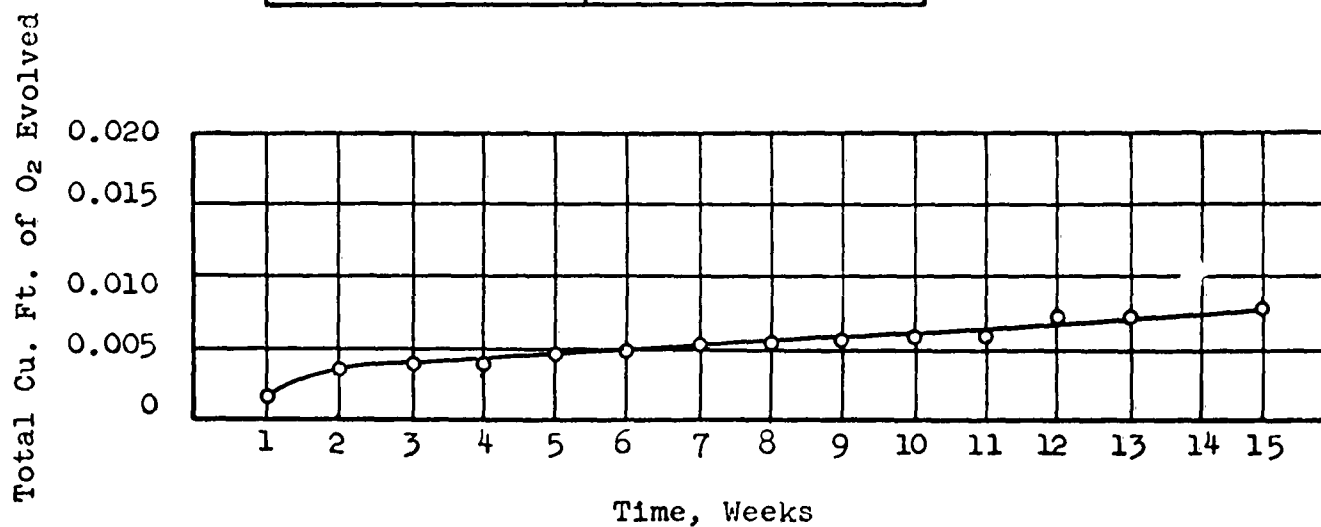
Material: 30 mil FEP Teflon

Surface to Volume ratio: 1.6 Sq. In./Cu. In.

Capacity: 3 gallons

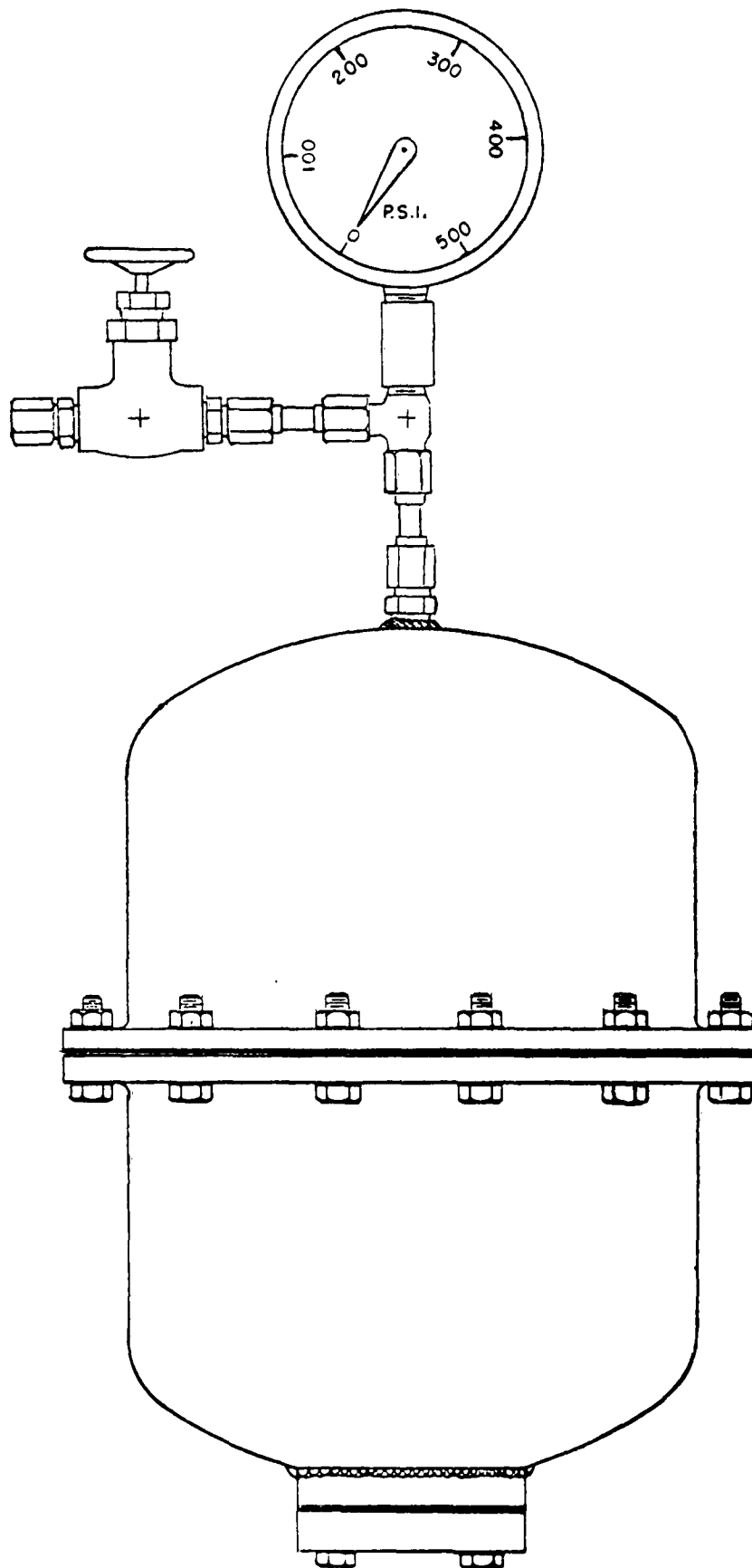
H₂O₂ Data:

H ₂ O ₂	Initial	Final.
Concentration	90.1%	90.3%
Stability	98.9%	98.8%



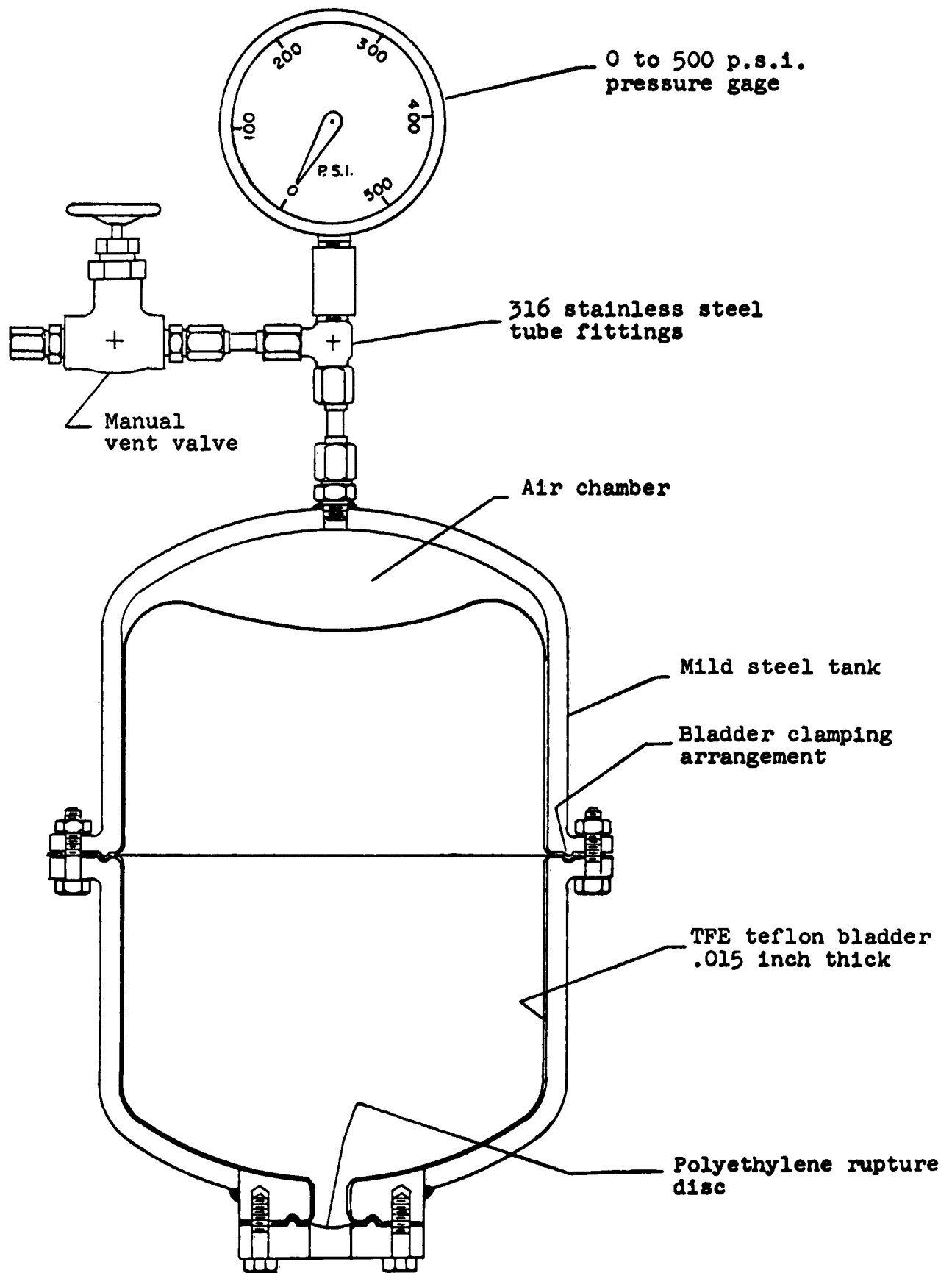
RESULTS OF A 3 MONTH STORAGE TEST OF
90% H₂O₂ IN A FEP TEFLON BLADDER AT 72-75°F.

FIGURE 1



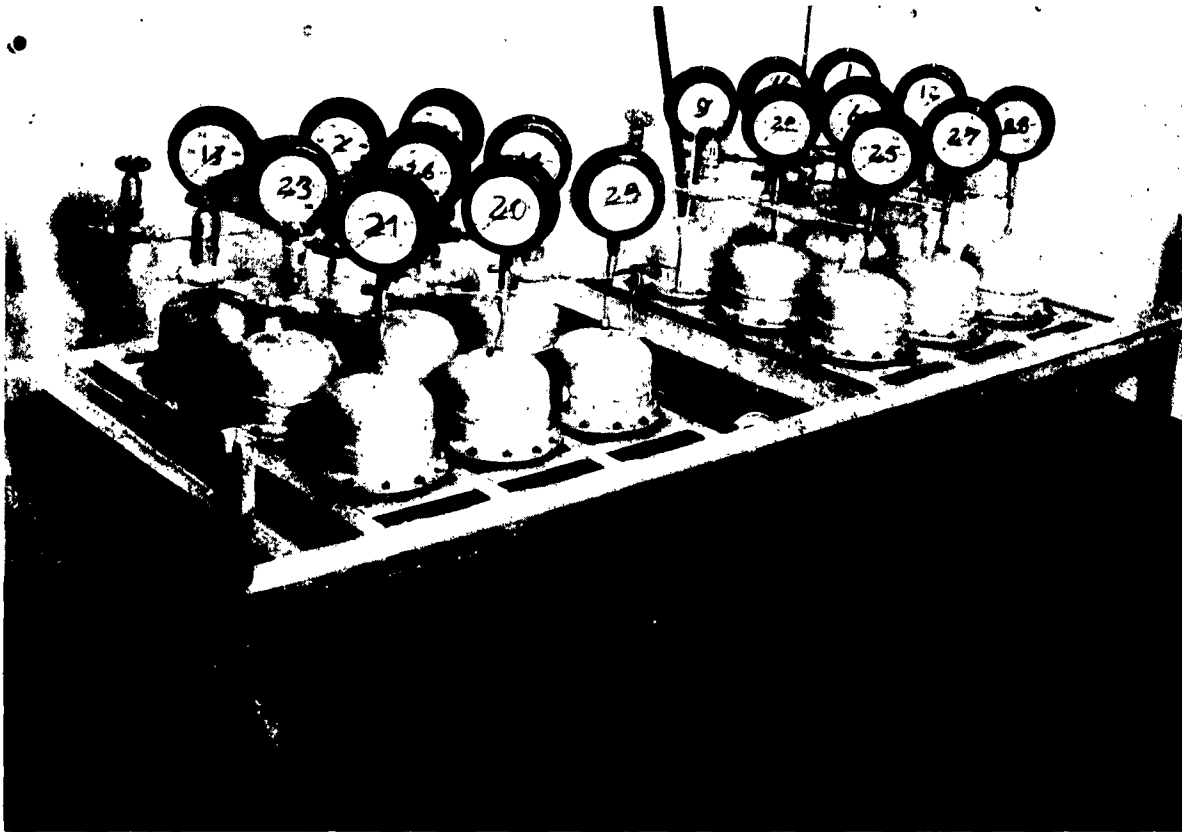
COMPLETE TEST TANK ASSEMBLY

FIGURE 2



CUT-AWAY VIEW OF TEST TANK ASSEMBLY

FIGURE 3



TEST TANKS AS SETUP FOR ROOM TEMPERATURE TESTS

FIGURE 4

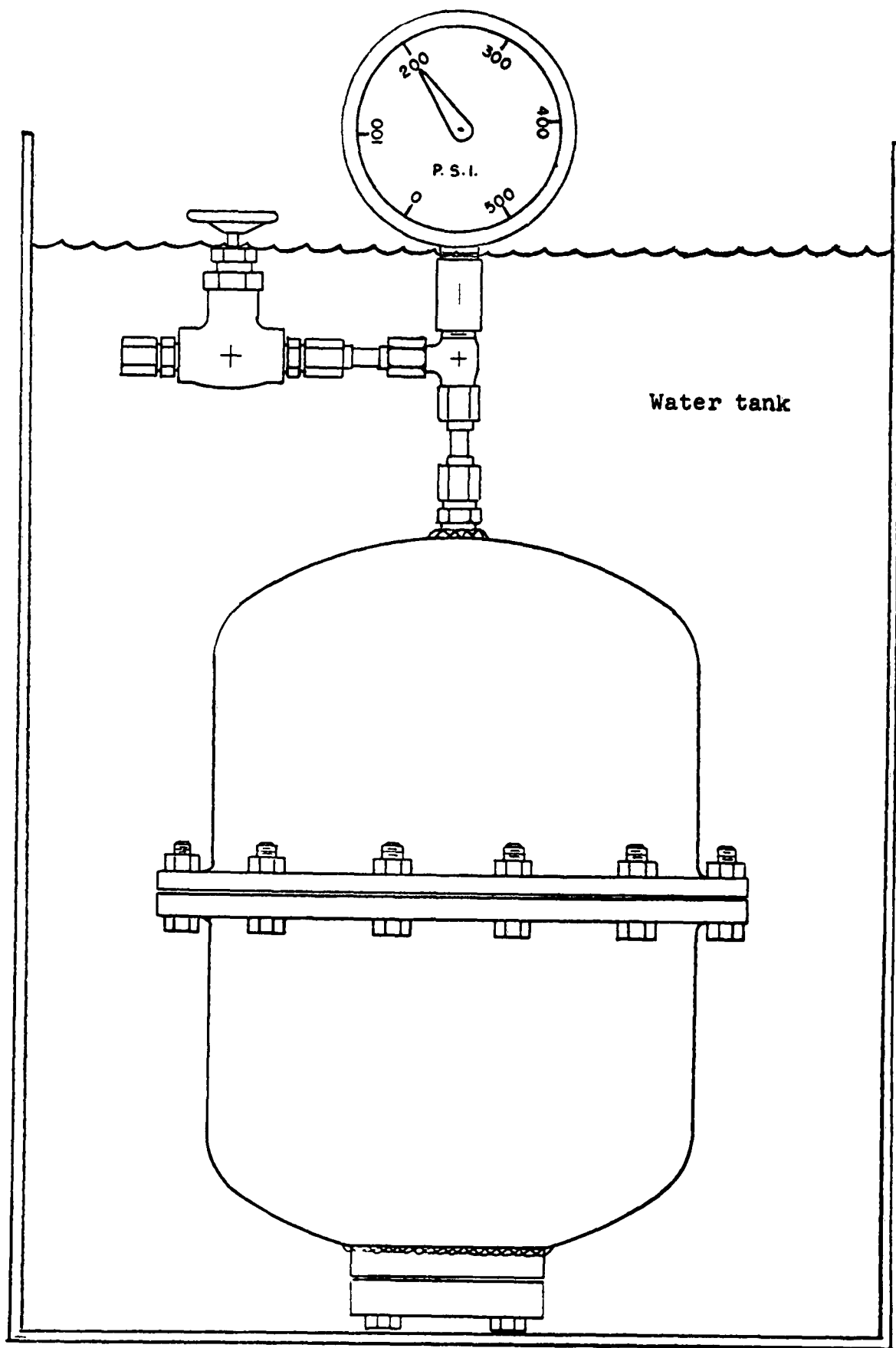
SSD-TR-61-29



TEST TANKS AS SETUP FOR THE
ELEVATED TEMPERATURE TESTS

FIGURE 5

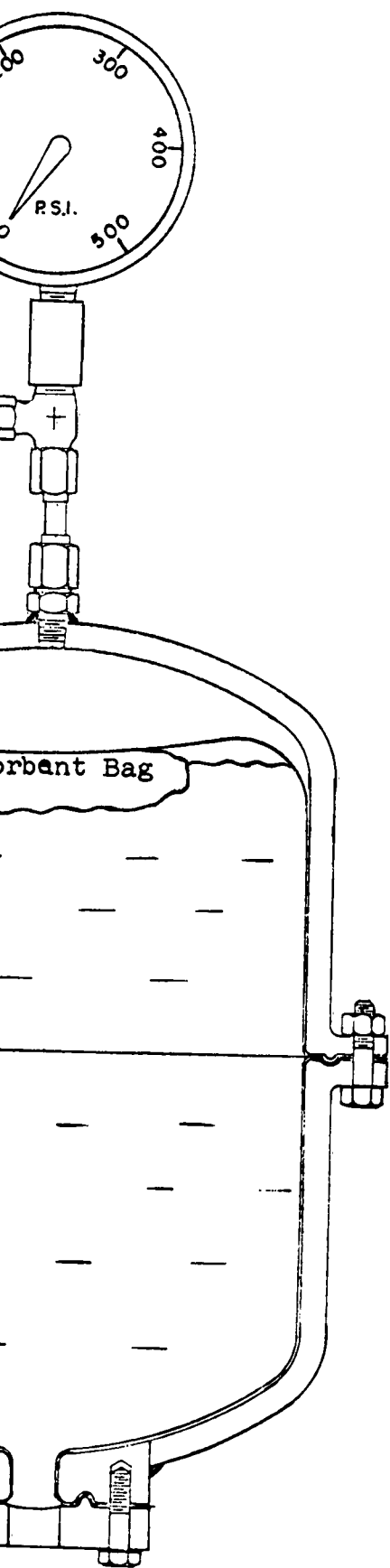
SSD-TR-61-29



TEST TANK AS SUBMERGED IN WATER BATH FOR LEAK CHECKING

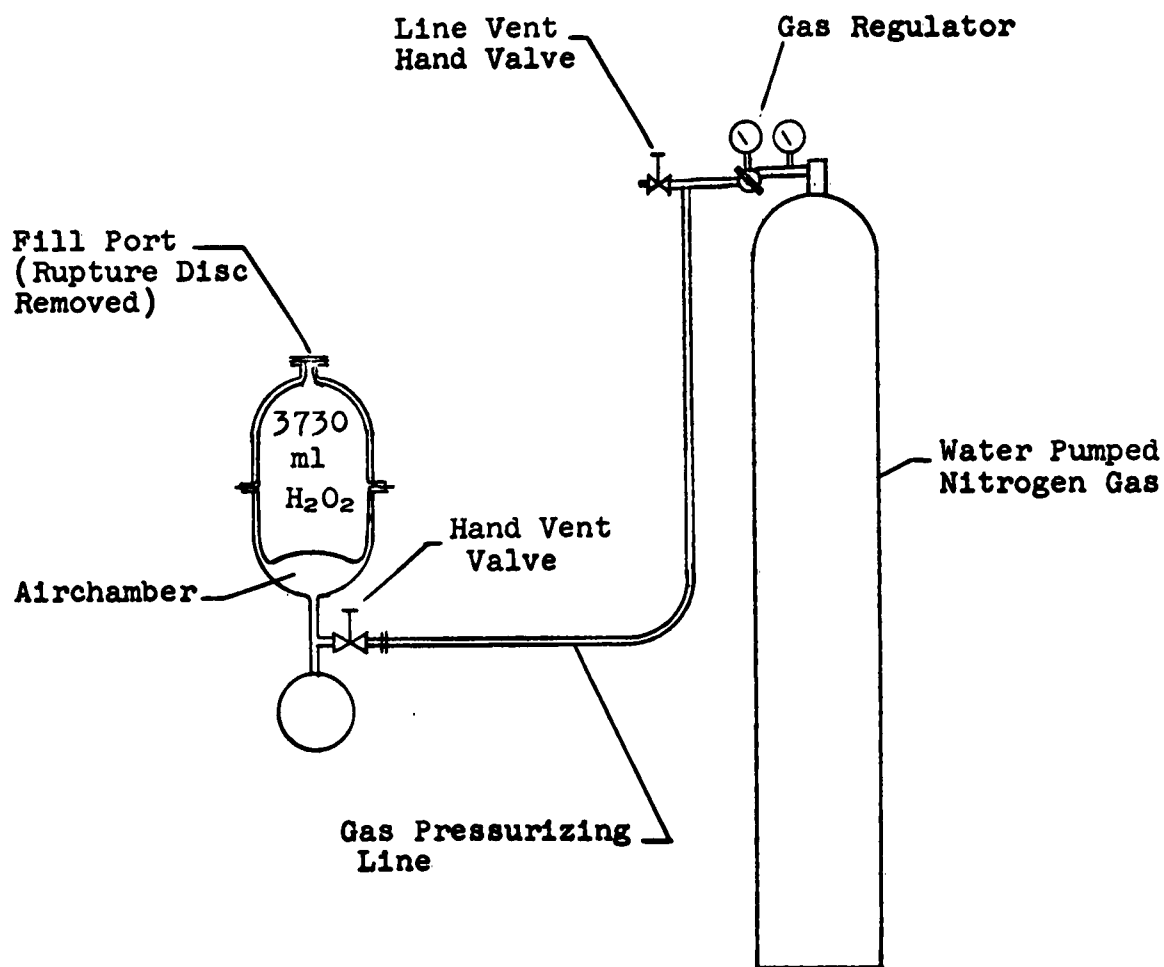
FIGURE 6





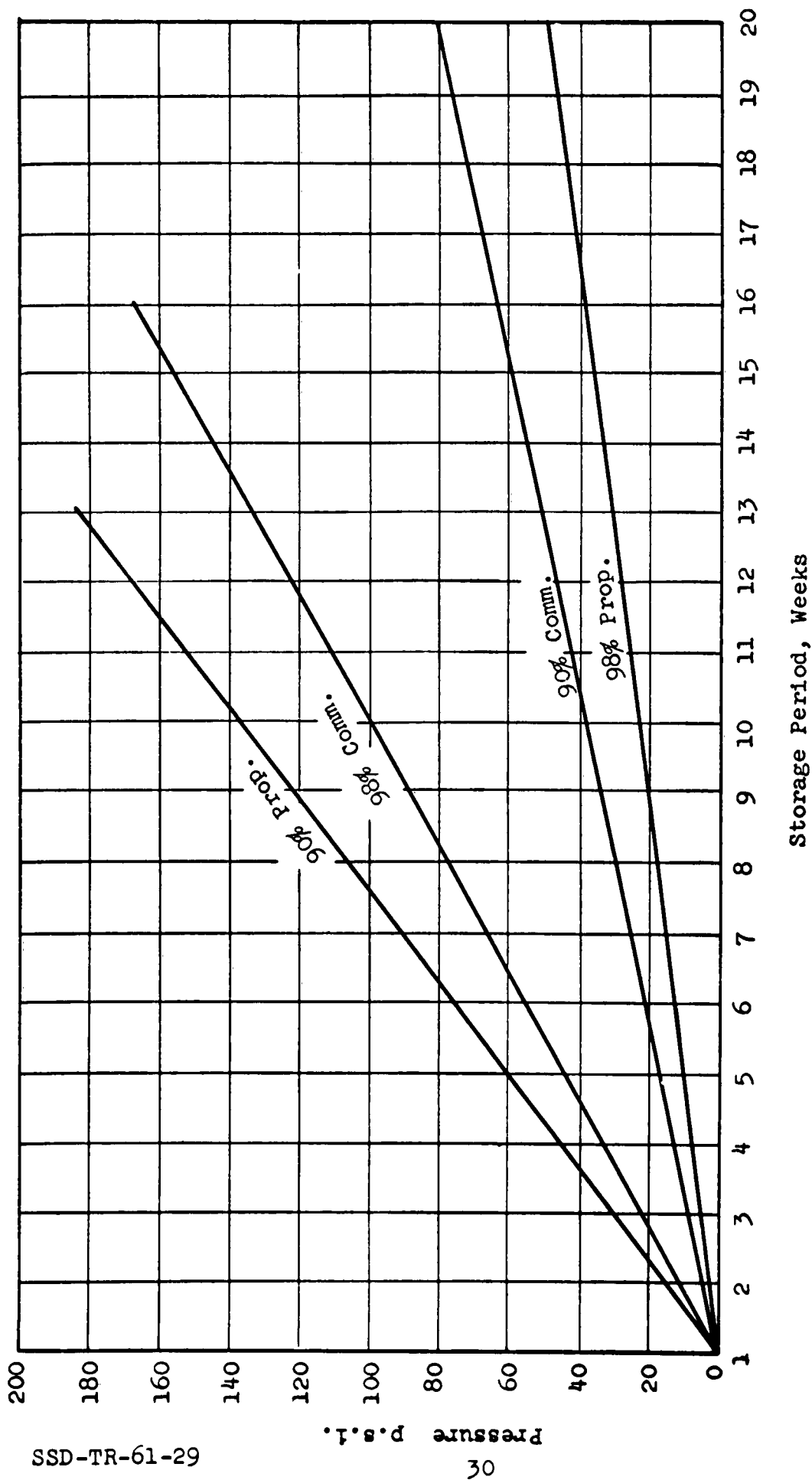
CORBANT BAG INSTALLED FOR TEST

FIGURE 7



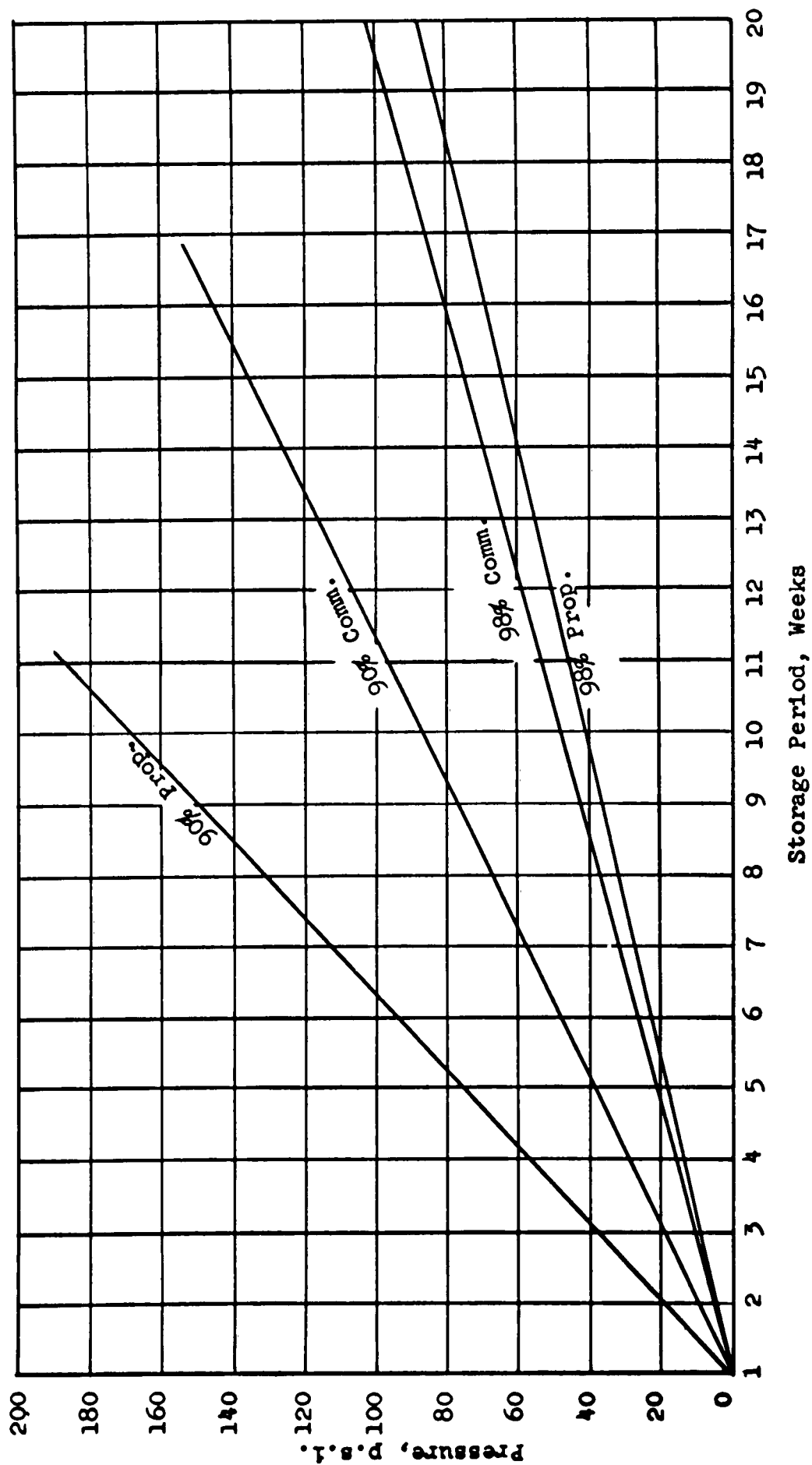
TEST TANK AS CONNECTED TO OBTAIN THE REQUIRED AIRCHAMBER
VOLUME PRIOR TO START OF A TEST

FIGURE 8



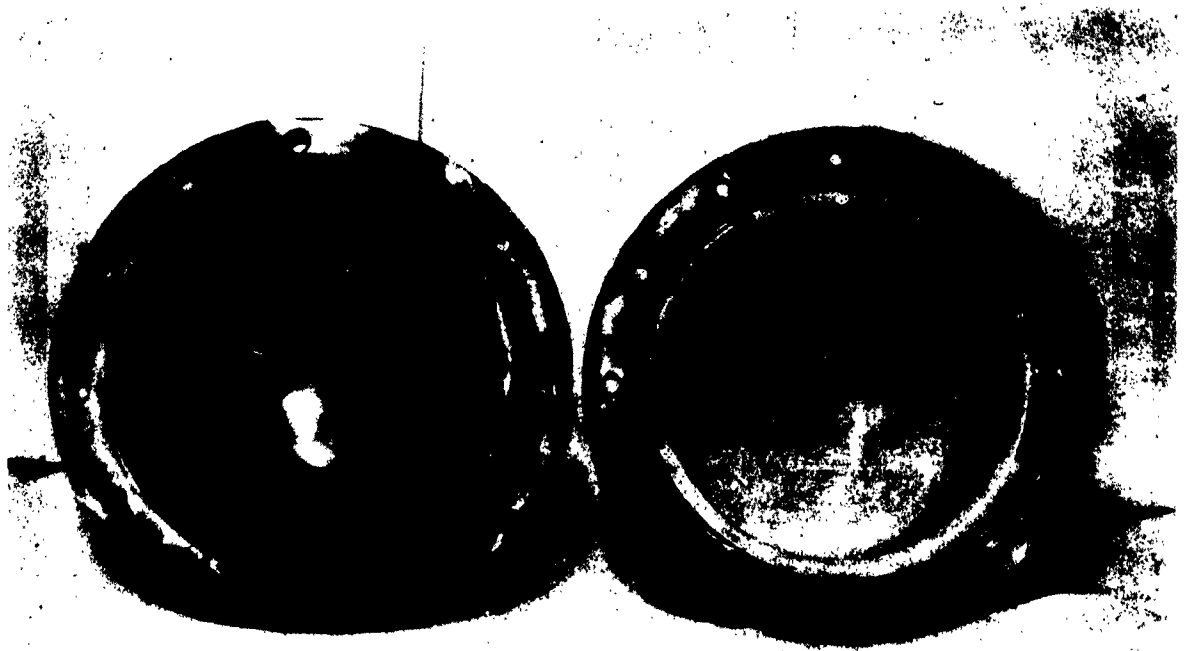
RESULTS OF 20°C. (68°F.) LONG TERM SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE
SOLUTIONS IN TFE TEFLON BLADDERS - S.V. RATIO 0.69/in²/in³, 10.4% ULLAGE

FIGURE 9



RESULTS OF 20°C. (68°F.) LONG TERM SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE SOLUTIONS IN TFE TEFLON BLADDER. EACH BLADDER CONTAINED AN ABSORBENT BAG. S.V. RATIO 0.69 in²/in³, 9.1% ULLAGE

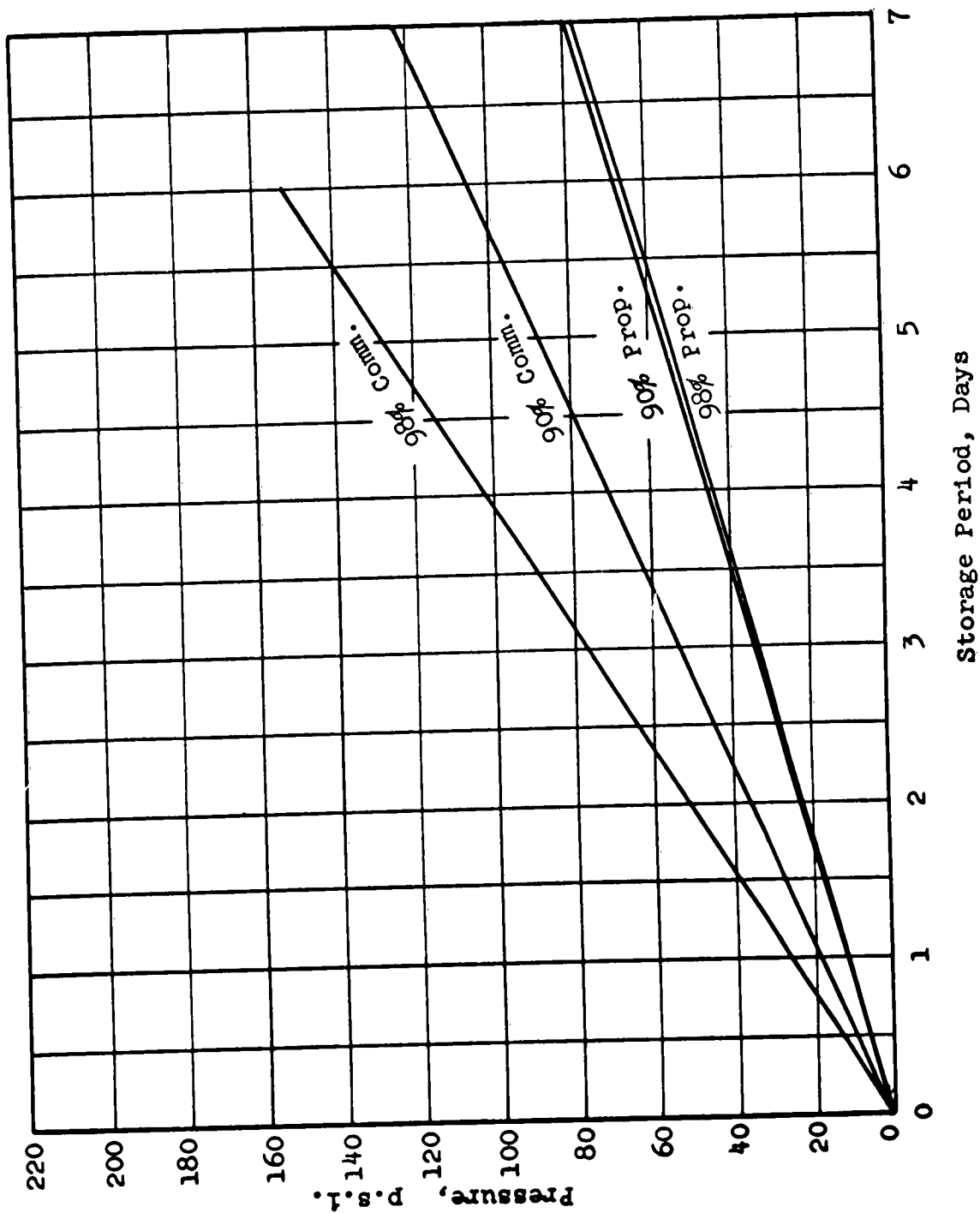
FIGURE 10



TFE TEFLON BLADDER SECTIONS BEFORE AND AFTER H_2O_2 EXPOSURE
NOTE THE BLEACHED CONDITION OF THE USED BLADDER ON THE RIGHT

FIGURE 11

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RESULTS OF 49°C. (120°F.) SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE SOLUTIONS IN TFE TEFLON BLADDERS. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE

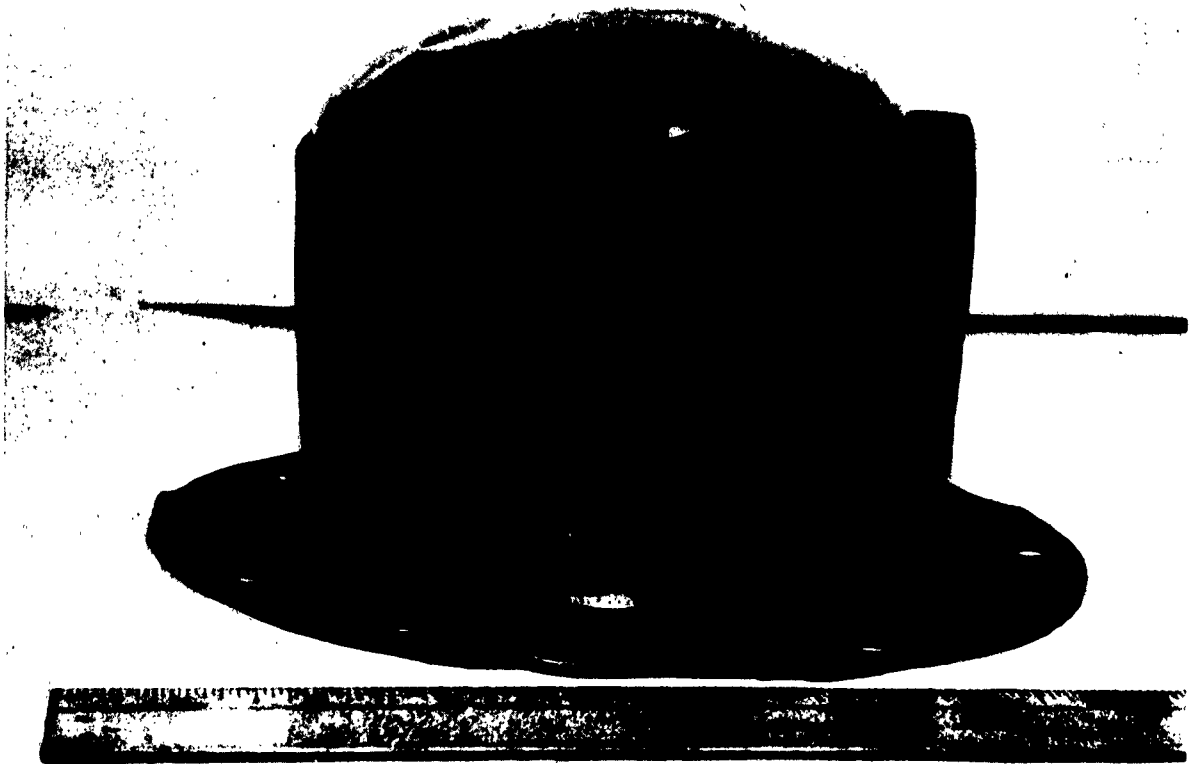
FIGURE 12



TYPICAL ABSORBENT BAGS BEFORE AND AFTER SEALED
STORAGE TESTS IN CONTACT WITH HYDROGEN PEROXIDE
NOTE THE BLOATED CONDITION OF THE EXPOSED BAGS

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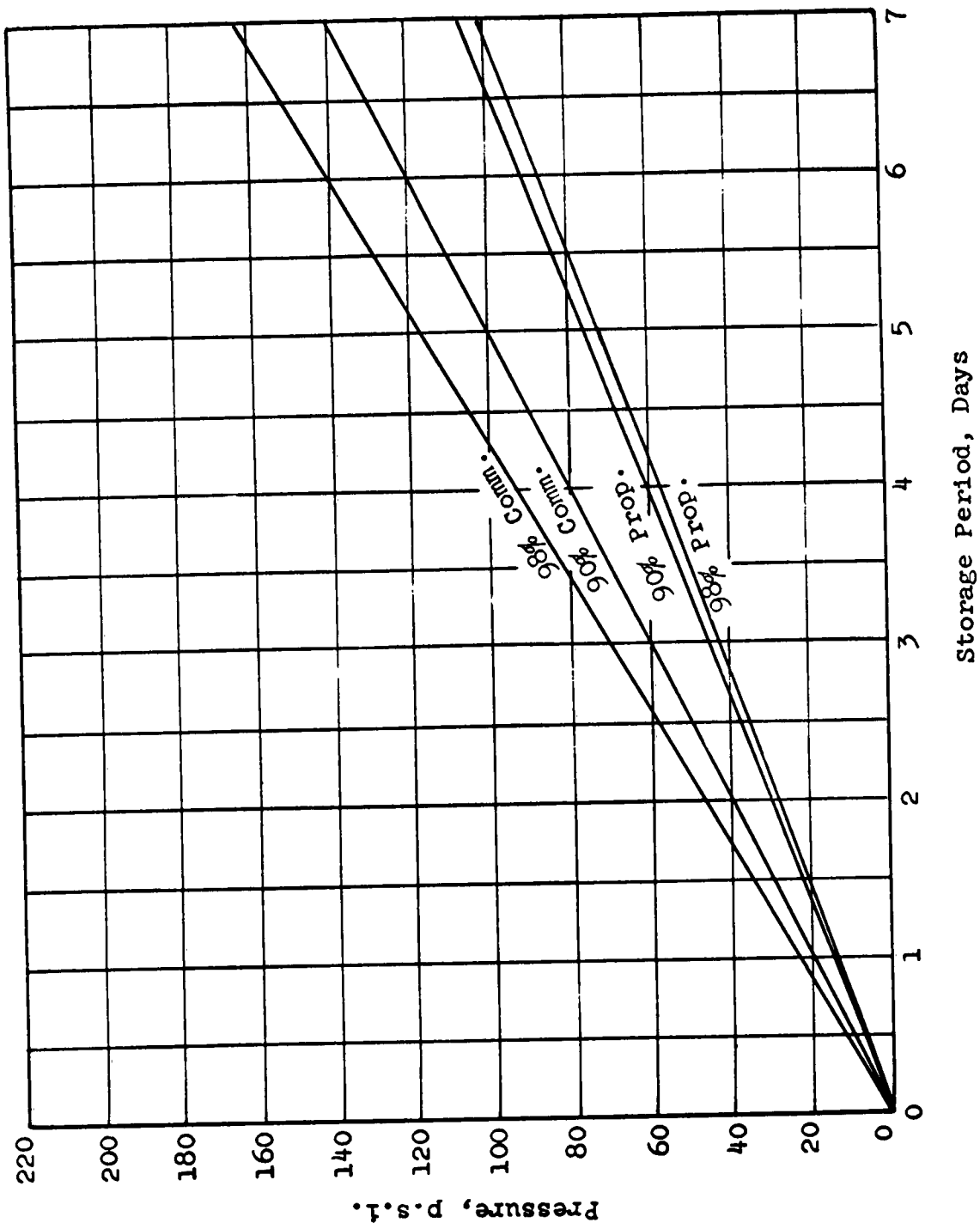
FIGURE 13



TFE TEFLON BLADDER FAILURE DURING THE 120°F. TESTS

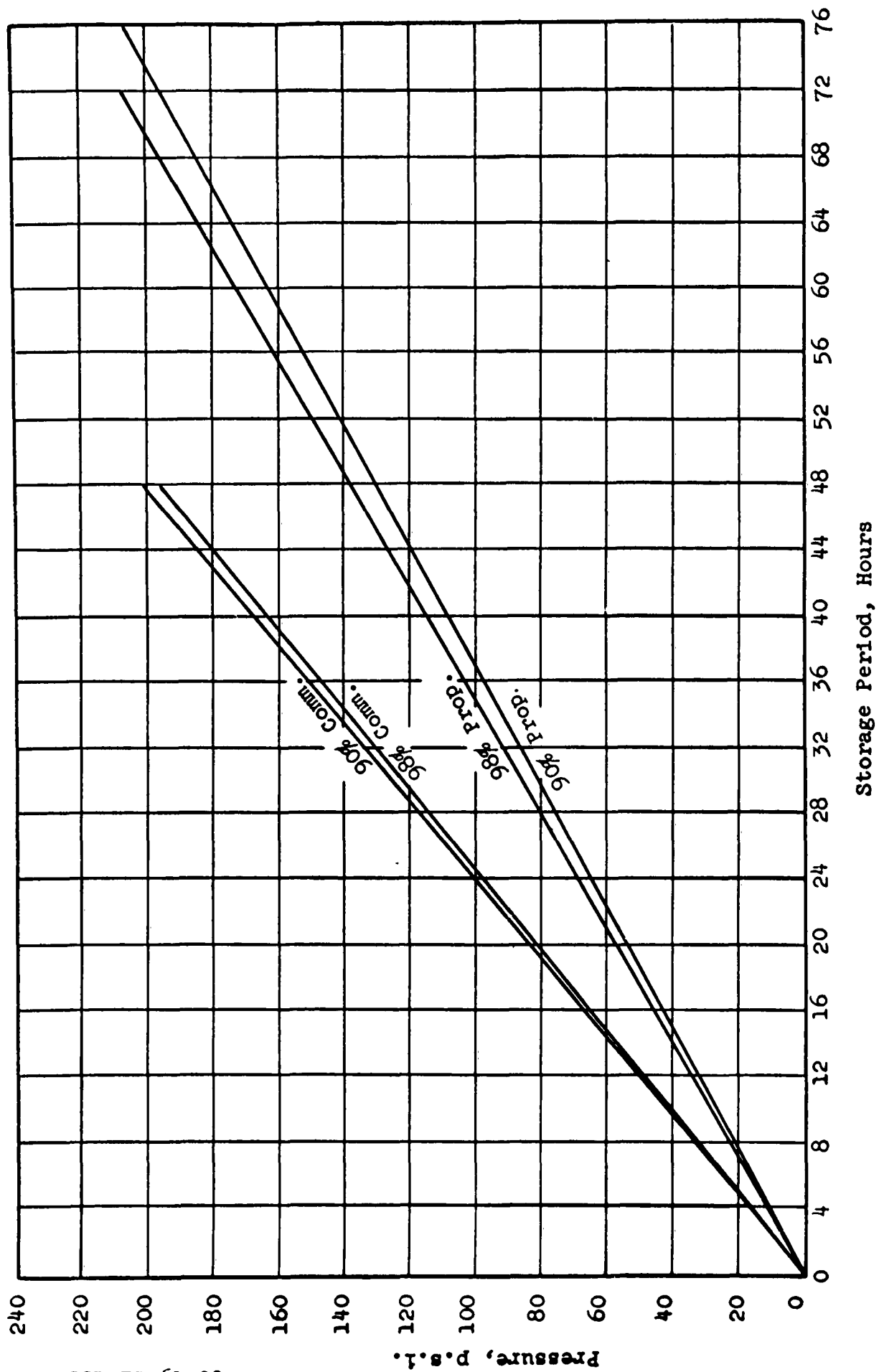
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FIGURE 14



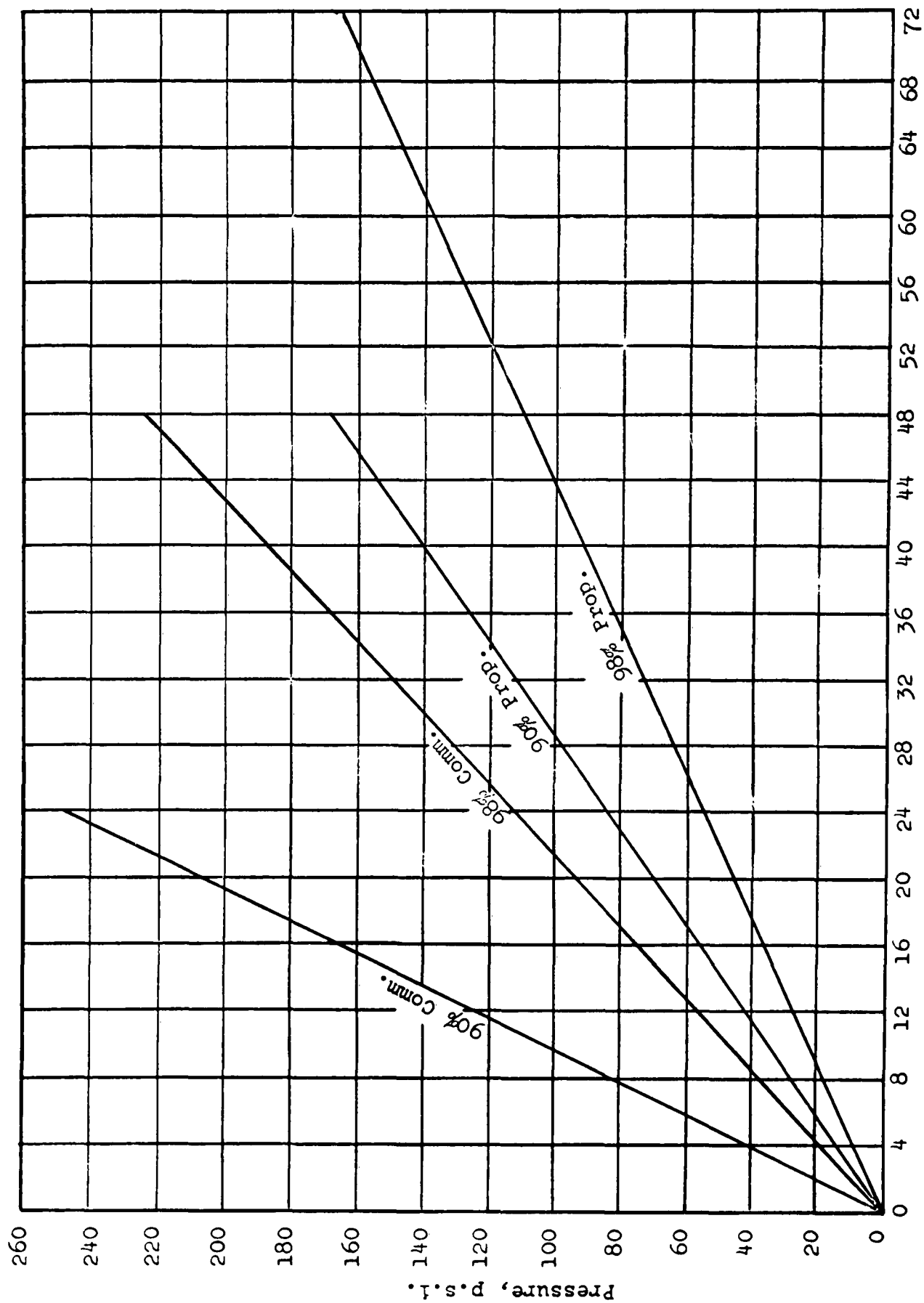
RESULTS OF 49°C. (120°F.) SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE SOLUTIONS IN TFE
 TEFLON BLADDERS. EACH BLADDER CONTAINED AN ABSORBENT BAG. S.V. RATIO 0.69 in²/in³

FIGURE 15



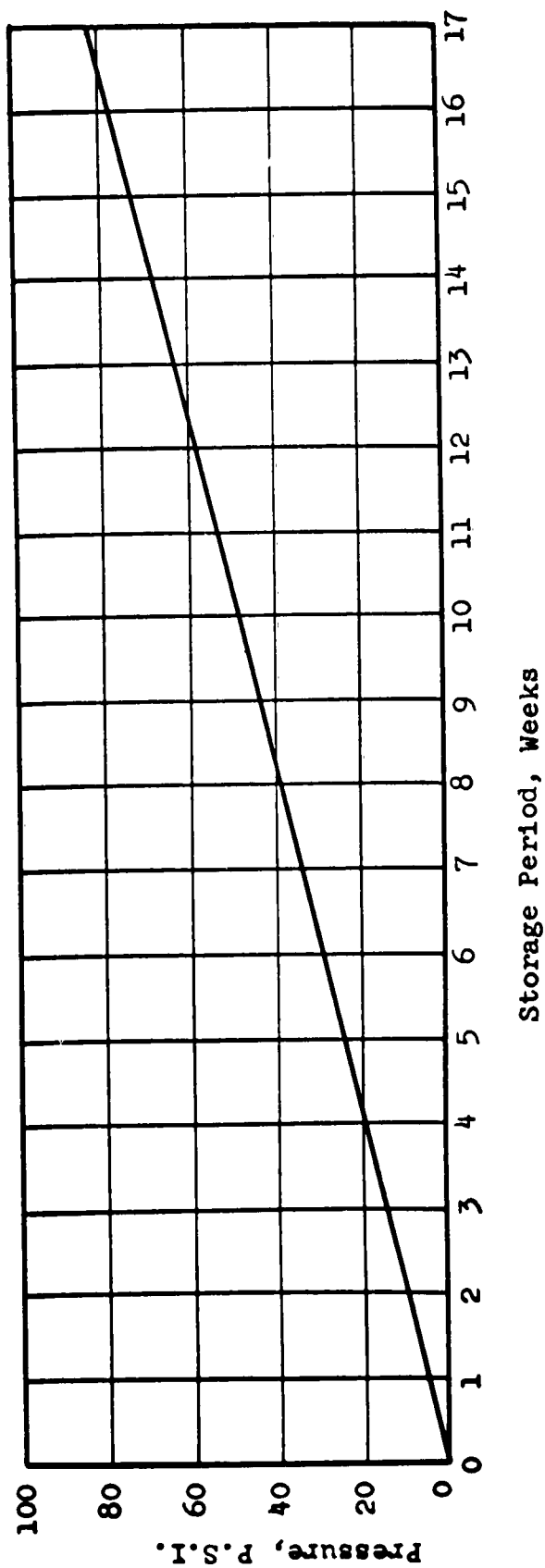
RESULTS OF 74°C. (165°F.) SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE SOLUTIONS IN TFE BLADDERS. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE

FIGURE 16



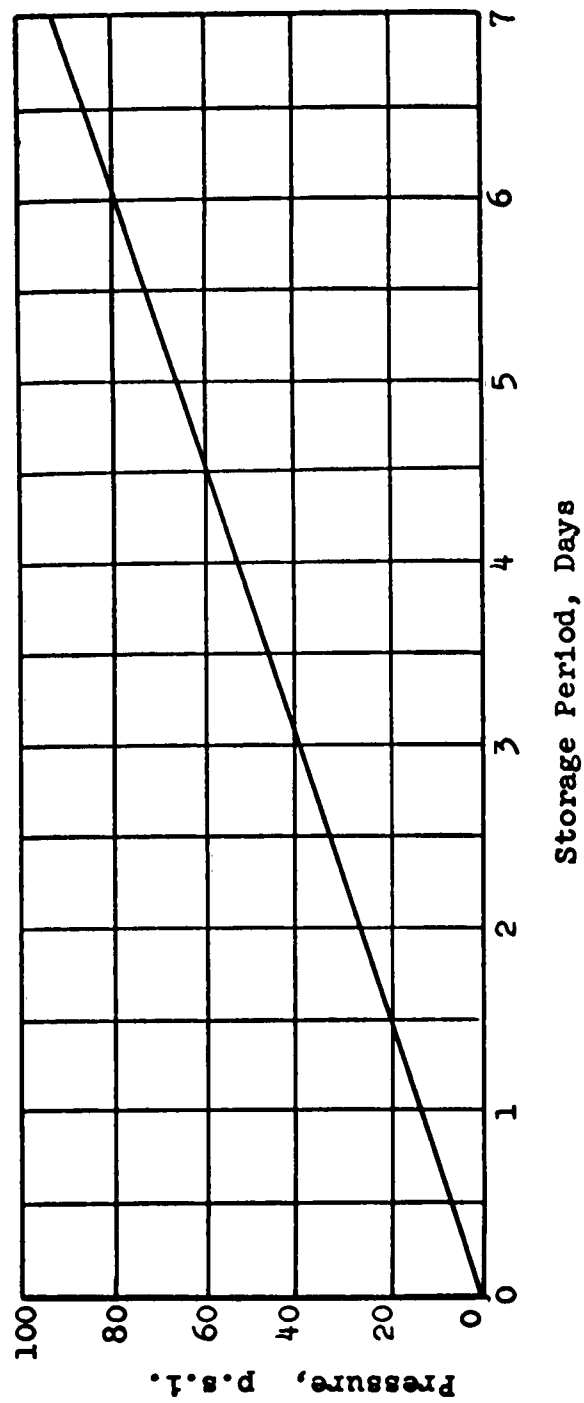
Storage Period, Hours

RESULTS OF 74°C. (165°F.) SEALED STORAGE TESTS WITH HYDROGEN PEROXIDE SOLUTIONS IN TFE TEFLON BLADDERS. EACH BLADDER CONTAINED AN ABSORBENT BAG. S.V. RATIO 0.69 in²/in³, 9.1% ULLAGE

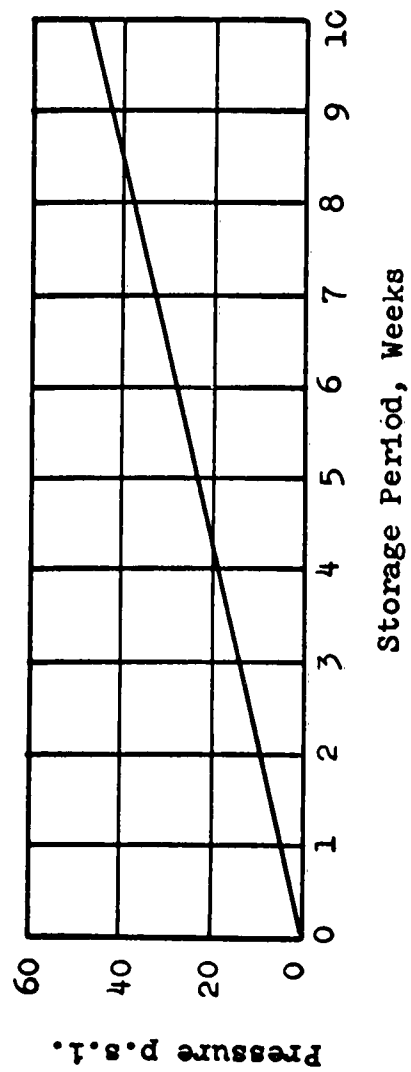


RESULTS OF 20°C.(68°F.) LONG TERM SEALED STORAGE TEST WITH 98%
COMMERCIAL HYDROGEN PEROXIDE SOLUTIONS IN "FARRELLOK" TREATED
TFE TEFLON BLADDERS. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE

FIGURE 18

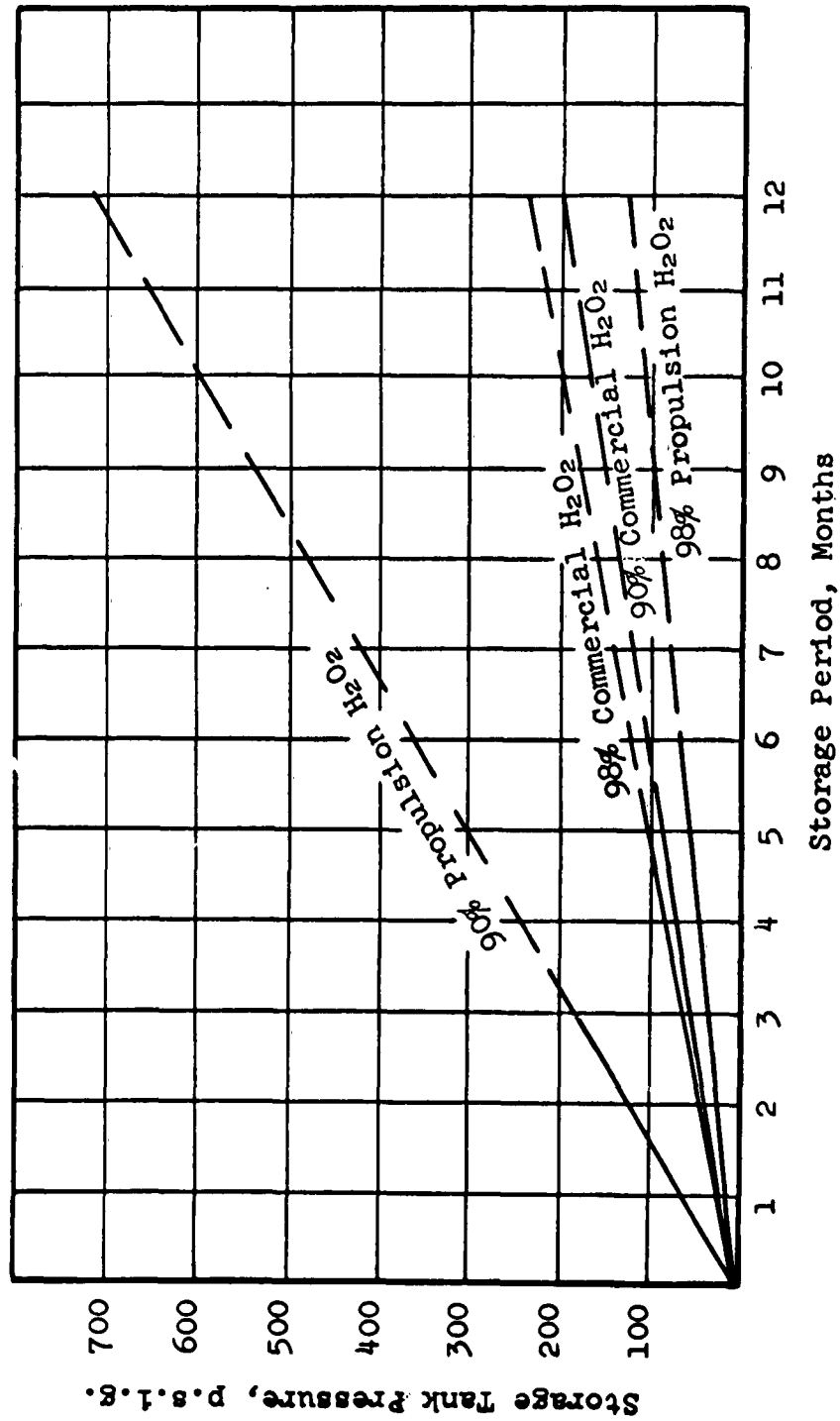


RESULTS OF 49°C.(120°F.) SEALED STORAGE TESTS WITH A BECCO EXPERIMENTAL MONOPROPELLANT BMP-DEG-1800-20°F. IN TFE TEFLON BLADDER. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE

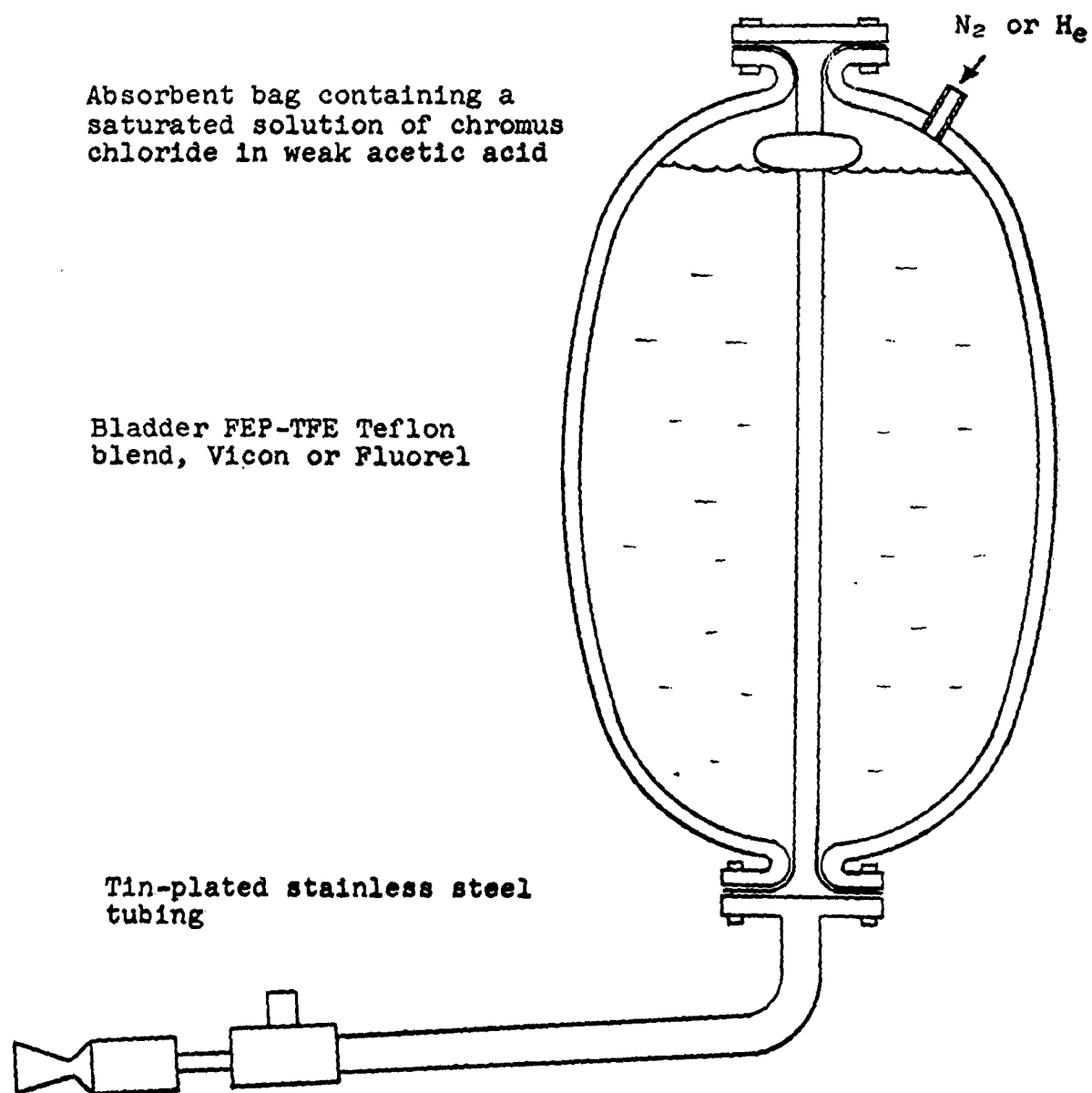


RESULTS OF 20°C.(68°F.) SEALED STORAGE TESTS WITH A BECCO
EXPERIMENTAL MONOPROPELLANT BMP-DEG-1800-20°F. IN TFE
TEFLON BLADDERS. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE

FIGURE 20

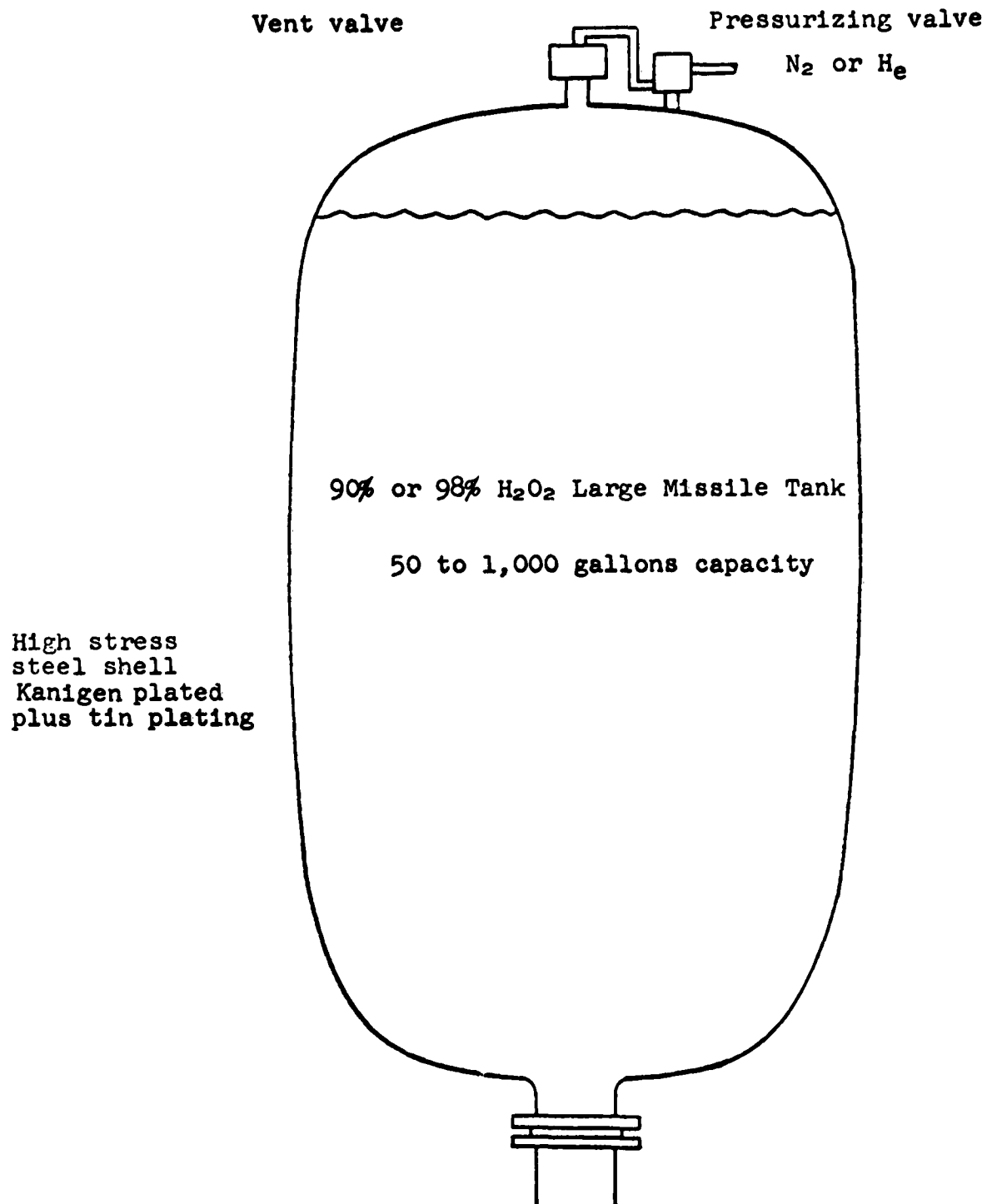


PLOT OF THE 20°C. (68°F.) 3 TO 5 MONTHS STORAGE TESTS WITH HYDROGEN PEROXIDE IN TFE TEFLON BLADDERS EXTENDED TO A ONE YEAR STORAGE PERIOD. S.V. RATIO 0.69 in²/in³, 10.4% ULLAGE



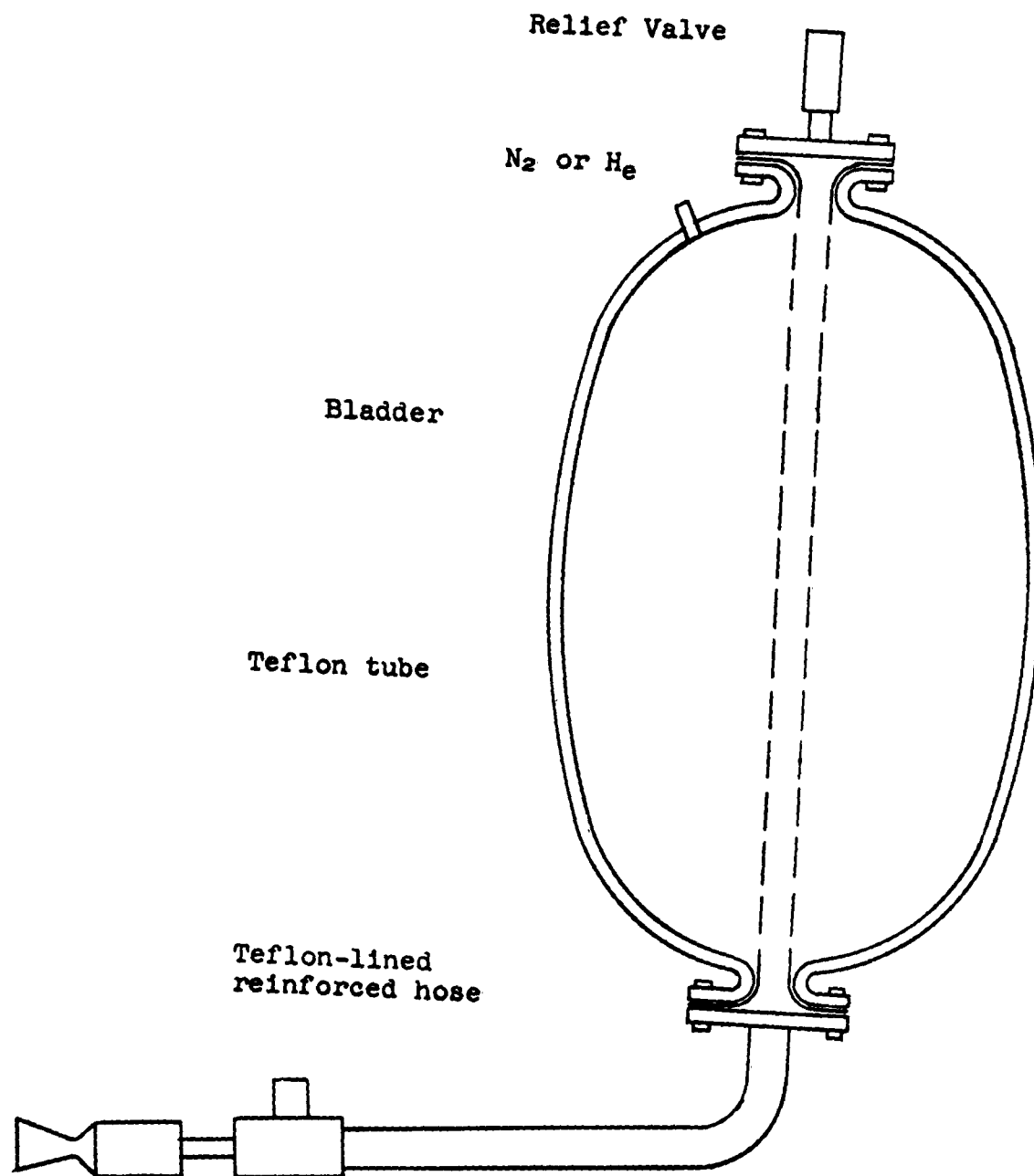
H_2O_2 FEED SYSTEM INCORPORATING AN ABSORBENT
BAG AND TIN PLATED FEED LINES

FIGURE 22



KANIGEN PLATED PLUS TIN PLATED MISSILE
FEED TANK INCORPORATING A VENT VALVE

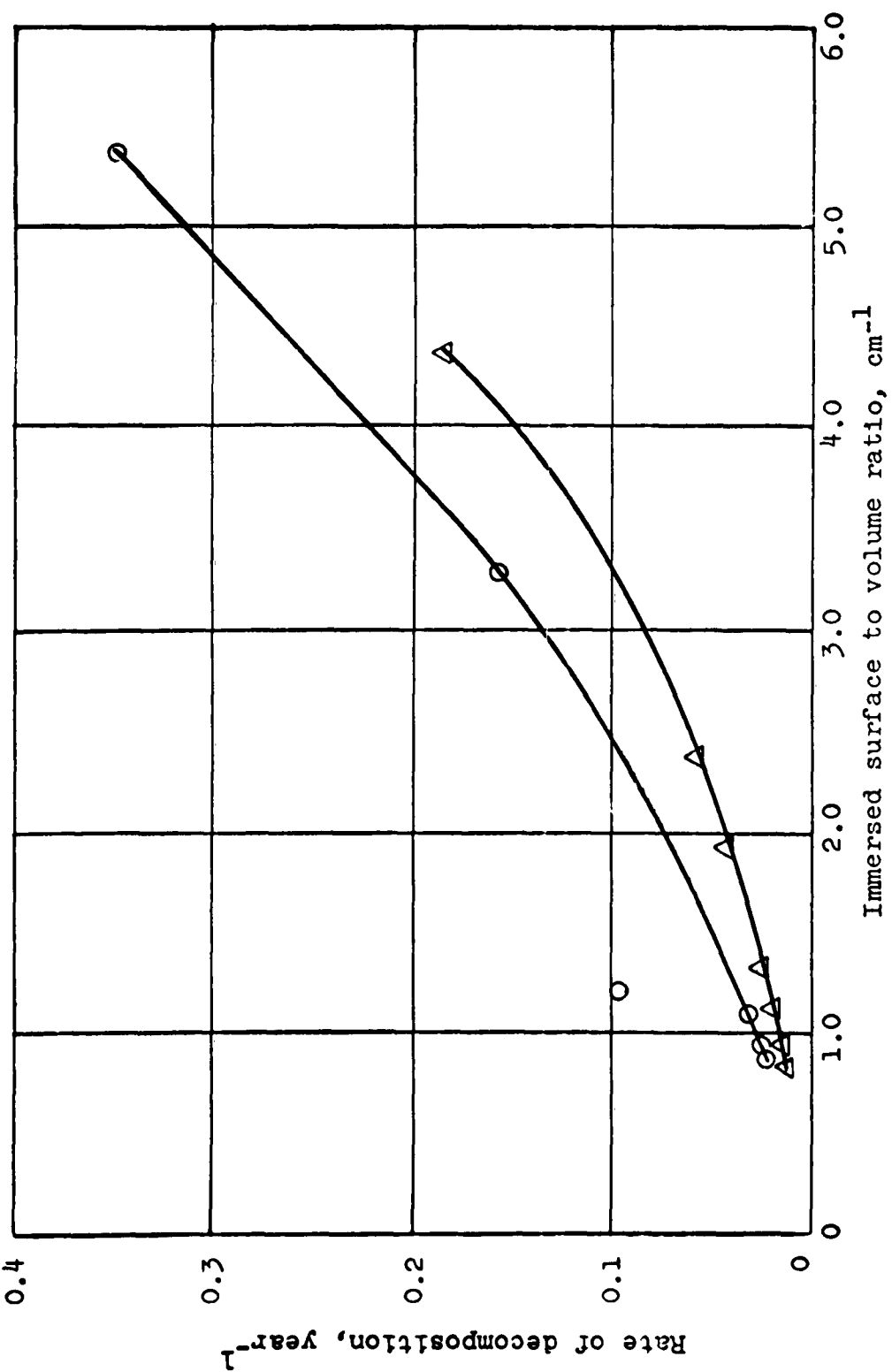
FIGURE 23



H_2O_2 FEED SYSTEM INCORPORATING A RELIEF
VALVE AND TEFLON REINFORCED FEED LINES

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FIGURE 24



EFFECT OF SURFACE TO VOLUME RATIO ON THE STABILITY OF PURE HYDROGEN PEROXIDE

Ref: I&EC Oct.53

FIGURE 25

TABLE I

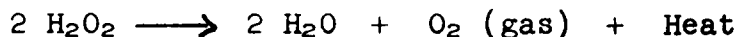
PHYSICAL, THERMAL, and HEAT TRANSFER PROPERTIES
of Becco 90% and 98% Hydrogen Peroxide

Hydrogen peroxide is a clear, colorless, water-like liquid with the chemical formula H_2O_2 . It can be diluted with water to any concentration. It is insensitive to mechanical shock under normal conditions and can be stored for long periods of time in containers made of the proper materials.

Ninety percent hydrogen peroxide contains 90% by weight of hydrogen peroxide and 10% by weight of water. Eighty percent hydrogen peroxide contains 80% by weight of hydrogen peroxide and 20% by weight of water and so on for other concentrations. Ninety-nine percent hydrogen peroxide is the highest strength commercially available.

Concentrated hydrogen peroxide, procured for Military use, will conform to Military Specification Mil-H-16005C, dated 1956, or such military Specification as may supersede this specification and be in effect at the time of purchase.

Hydrogen peroxide is an energy-rich material which can decompose, yielding water, oxygen gas, and heat. The decomposition reaction is represented by the following equation:



A. Physical Properties of Hydrogen Peroxide

Property	Conditions	Units	Concentration, wt. %	
			90	98
Density	77°F	lb./gal.	11.57	11.95
Boiling Point	1.0 atm.	°F.	286.2	299.2
Freezing Point	1.0 atm.	°F.	11.3	27.5
Refractive Index				
Sodium D-line	77°F.	--	1.3980	1.4049
Vapor Pressure	77°F.	mm.Hg	3.8	2.2
Electrical Conductivity	77°F.	10^{-6} ohm ⁻¹ cm. ⁻¹	1.9	0.8
Viscosity	77°F.	centipoise	1.153	1.155
	32°F.	centipoise	1.860	1.810
Surface Tension	68°F.	cynes/cm.	79.3	80.2
Total Heat of				
Vaporization	77°F	Btu/lb. sol.	700.3	662.0
Dielectric Constant	68°F	--	77	77

TABLE I (continued)

B. Chemical and Thermal Properties of Hydrogen Peroxide

Property	Conditions	Units	Concentration, Wt. %	
			90	98
Avg. Molecular Weight	--		31.241	33.422
Active Oxygen	--	wt. %	42.3	46.9
Heat of decomposition	77°F			
	1.0 atm.	Btu/lb.sol.	1108.	1215.
Adiabatic Decomposition temperature	1.0 atm.	°F	1364	1735
Heat of Dilution to Infinite Dilution	77°F	Btu/lb.sol.	-31.2	-41.0
Total Heat of Vaporization	77°F	Btu/lb.sol.	700.3	622.0
Mean Heat Capacity	32-81°F	Btu/lb.sol./°F	0.660	0.635
	500°F		0.813	0.780
Critical Temperature	--	°F	--	--
Critical Pressure	--	atm.	--	--

C. Decomposition Products

Property	Initial Concentration, Wt. % H ₂ O ₂	
	90	98
Mole Fraction H ₂ O	0.7076	0.6748
Mole Fraction O ₂	0.2924	0.3252
Gas composition, wt. % H ₂ O	57.7	53.1
Gas composition, wt. % O ₂	42.3	46.9
Avg. Molecular Weight	22.10	22.57
Temperature, °F	1364	1735
Gas Volume, C.Ft.	60.2	70.8
Cp/Cv of products	1.266	1.251

D. Heat Transfer Properties

Commercial 90% Hydrogen Peroxide has been used in the N.A.A. AR series engines as coolant. The following is a quote taken from a report covering Becco 90% H₂O₂ heat transfer tests carried out by Pratt & Whitney Aircraft Company for Becco.

"The high values of peak heat flux which were obtained at the high velocity conditions show that 98% Hydrogen Peroxide is a potentially excellent coolant at this condition. The results were close to those which can be expected with water, which is one of the best-known coolants. At low velocities, the peak heat flux was considerably reduced. However, only a few rocket propellants have ever been reported to yield values comparable to even these lower peak heat flux values. Such propellants are diethylenetriamine, hydrazine, and unstabilized nitric acid. Data

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TABLE I (continued)

reported for other propellants such as ammonia, chlorine trifluoride, nitrogen tetroxide, monomethylhydrazine, unsymmetrical dimethylhydrazine, and stabilized nitric acid, fall considerably below those measured for 98% hydrogen peroxide."

E. Peak Heat Flux Data for 90% Hydrogen Peroxide

P	V	T _B	(Q/A) _P 90% H ₂ O ₂ Peak Heat Flux BTU sec-in ²	(Q/A) _{GR} Griffith Peak Heat Flux BTU sec-in ²	(Q/A) _P /(Q/A) _{GR}	(Q/A) _{H₂O} Peak Heat Flux for H ₂ O BTU sec-in ²
Fluid Press.	Fluid Veloc.	Bulk Temp. °F				
psia	fps					
300	12.6	250	3.55	11.9	.298	11.0
300	15.9	250	4.39	12.6	.348	15.0
600	12.9	235	3.29	11.7	.281	12.1
600	16.8	225	3.99	12.7	.314	13.4
1000	13.6	235	3.33	9.9	.336	10.6
1000	15.5	209	4.89	10.6	.461	11.7
1000	17.8	230	4.15	10.6	.391	11.7
1000	20.8	183	5.52	11.9	.463	13.3
1000	22.9	129	6.69	13.1	.510	15.0
1000	25.9	105	7.16	14.1	.507	16.1
1000	33.9	195	6.45	13.6	.474	15.5
1000	41.3	195	7.80	14.6	.534	16.7

TABLE I (continued)

F. Tabulation of Local Heat Transfer Data for 98% Hydrogen Peroxide
1½" Upstream from Exit of Heated Section

Run	V Fluid Veloc. fps	P Fluid Press. psia	(Q/A) Heat Flux BTU sec-in ²	T _{o.w.} Ave. Out- side Wall Temp. °F	T _{l.w.} Ave. In- side Wall Temp. °F	T _{sat} Satura- tion Temp. °F	T _b Fluid Bulk Temp. °F	h Heat Transf. Coefficient BTU hr-ft ² -°F
1	62.4	1060	1.03	203	116	685	58	9090
2	62.6	1020	1.93	346	203	679	66	7300
3	61.9	975	3.14	500	293	671	78	7570
4	61.9	985	3.05	470	256	672	77	8860
5	61.9	985	3.07	471	257	672	77	8860
6	61.9	995	3.10	495	291	673	77	7520
7	62.3	995	4.57	640	360	673	92	8840
8	63.1	995	7.58	933	545	673	120	9250
9	63.5	1000	10.00	1200	789	675	139	7990
10	63.8	1000	10.80	1200	731	675	150	9610
11	63.5	1000	12.20	1380	917	675	151	8270
12	64.6	1000	13.80	1510	1010	675	179	8630
13*	64.8	1000	14.70	--	--	675	--	--
1	58.4	565	1.01	218	136	602	68	7730
2	58.6	585	1.88	340	200	606	77	7910
3	59.6	585	3.00	480	282	606	88	8000
4	53.6	585	3.75	588	360	606	99	7300
5	54.1	585	5.46	768	471	606	117	8000
6	61.9	685	7.07	903	547	624	126	8710
7	61.5	685	7.95	982	606	624	134	8740
8	61.7	685	8.72	1040	640	624	142	9080
9	62.6	695	9.89	1110	669	626	153	9940
10	62.3	695	10.8	1180	735	626	162	8780

* Runs in which burnout occurred.

TABLE I (continued)

Run	V Fluid Veloc. fps	P Fluid Press. psia	(Q/A) Heat Flux BTU sec-in ²	T _{O.W.} Ave. side Wall Temp. °F	T _{I.W.} Ave. side Wall Temp. °F	T _{sat} Satura- tion Temp. °F	T _b Fluid Heat Transf. Bulk Coefficient Temp. °F	h hr-ft ² -°F
11	62.2	690	12.8	1340	854	625	179	9820
12	61.8	695	13.8	1410	924	626	189	9760
13*	66.8	700	15.4	--	--	627	--	--
1	14.6	325	1.03	360	290	545	93	2700
2	14.5	325	1.47	458	362	545	112	3040
3	14.4	305	1.95	542	429	538	134	3480
4	15.0	305	2.48	606	462	538	153	4160
5	14.9	305	3.12	692	522	538	181	4740
6	15.4	305	3.82	770	572	538	206	5420
7*	14.9	305	4.58	--	--	538	--	--
1	14.3	645	1.06	354	278	617	98	3060
2	14.5	645	1.97	525	400	617	135	3860
3	14.1	645	2.57	609	453	617	163	4600
4	14.2	645	2.89	676	409	617	174	4500
5	14.4	645	3.52	718	521	617	204	5750
6*	14.5	645	3.91	--	--	617	218	5960
1	14.1	1000	1.23	367	268	675	95	3690
2	14.4	1000	2.23	510	347	675	134	5460
3	14.7	1000	3.60	669	436	675	186	7520
4*	14.3	1000	4.33	--	--	675	--	--

* Runs in which burnout occurred.

TABLE II

OXYGEN LOSS (milligrams) from BECCO Commercial and Stabilized
Commercial Hydrogen Peroxide while at 100°C for 24 Hours in
Pyrex Glass (standard laboratory stability test) - Typical Results

Grade of H ₂ O ₂	H ₂ O ₂ Concentration	
	90% H ₂ O ₂	98% H ₂ O ₂
Commercial	360	140
10 ppm PO ₄	250	--
Stabilizer P (Propulsion)	70	60

All tests were carried out in a steam bath.

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TABLE III

COMPATIBILITY TESTS: Plastic Materials with H₂O₂, 7 days at elevated temperature

Material	TREATMENT										CONDITIONING					
	Detergent Wash	35% HNO ₃	Standard Passivation	Saturated Citric Acid	85% H ₃ PO ₄	NH ₄ PF ₆ 10%	NH ₄ PF ₆ 10%	Farrellok	Perma Spray-W	Perma Spray-ND	90% H ₂ O ₂ R. T.	90% H ₂ O ₂ 66°C	98% H ₂ O ₂ 66°C	No. of Tests	90% H ₂ O ₂ 66°C	98% H ₂ O ₂ 74°C
Teflon TFE	x													4	1.1 ± 0.1	
	x	16 hr.												6	1.0 ± 0.1	
	x	16 hr.									2 hr.			6	0.9 ± 0.0	
			x	½ hr.							24 hr.			8	0.6 ± 0.2	
			x	½ hr.							7 da.			2	2.2 ± 0.3	
			x		½ hr.						7 da.			2	0.7 ± 0.1	
			x								48 hr.			6	0.5 ± 0.1	
			x											8	0.5 ± 0.1	
	x					x								2	3.1 ± 0.3	
	x					x								2	3.0 ± 0.2	
	x						x							2	2.9 ± 0.2	
	x						x							4	2.6 ± 0.2	
	x							x						4	2.2 ± 0.1	
	x								x					6	1.8 ± 0.1	
	x									x				4	0.8 ± 0.2	
	x										x			4	0.8 ± 0.3	
x													2	7.1 ± 0.6		
x													2	2.0 ± 0.3		
			x										6	0.3 ± 0.0		
			x										6	0.3 ± 0.1		
													24 hr.			

Ref. AF Contract - AF-33(616)6732

TABLE IV
RESULTS OF GAS EVOLUTION TESTS: With Becco 90% H₂O₂ in TFE Teflon Film Bags -- S/N 3.5:1

Test Temperatures:	77°F.						100°F.						120°F.					
	H ₂ O ₂ Inside and Outside Bag			H ₂ O ₂ Inside Bag			H ₂ O ₂ Inside and Outside Bag			H ₂ O ₂ Inside Bag			H ₂ O ₂ Inside and Outside Bag			H ₂ O ₂ Inside Bag		
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Initial H ₂ O ₂ Concentration	91.0%	91.0%	91.0%	91.0%	91.0%	91.0%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%	90.3%
Final H ₂ O ₂ Concentration	87.9%	90.7%	90.3%	90.2%	90.5%	90.2%	89.7%	89.7%	89.7%	89.7%	89.8%	89.4%	89.3%	89.4%	89.3%	89.2%	89.5%	89.2%
H ₂ O ₂ Stability After Test	91.5%	98.9%	99.4%	99.1%	98.7%	98.8%	97.1%	97.9%	98.2%	98.2%	97.9%	97.9%	98.3%	97.9%	97.9%	99.0%	96.3%	98.2%
Gas Evolution from 75 ml. H ₂ O ₂ (ft. ³ at ambient pressure	0.0 (65 hrs.)	0.0 (65 hrs.)	0.0 (65 hrs.)	0.0 (65 hrs.)	0.0 (65 hrs.)	0.0 (65 hrs.)	0.0 (24 hrs.)	0.0 (24 hrs.)	0.0 (24 hrs.)	0.0 (24 hrs.)	0.0 (24 hrs.)	0.0 (24 hrs.)	.0045 ft. ³ (65 hrs.)	.0055 ft. ³ (65 hrs.)	.0055 ft. ³ (65 hrs.)	.0050 ft. ³ (24 hrs.)	.0020 ft. ³ (24 hrs.)	.0025 ft. ³ (24 hrs.)
Average Gas Evolution from 75 ml. H ₂ O ₂ (ft. ³ at ambient pressure)	--	--	--	--	--	--	--	--	--	--	--	--	0.0019 ft. ³ (24 hrs.)	--	--	0.0032 ft. ³ (24 hrs.)	--	--
Average Gas Evolution ft. ³ /24 hrs./ft. ² of bladder surface	--	--	--	--	--	--	--	--	--	--	--	--	0.00071 ft. ³	--	--	0.00012 ft. ³	--	--

Reference AF Contract - AF-33(616)6732

TABLE IV (continued)

Test Temperature	140°F.			160°F.			180°F.			200°F.		
	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6	H ₂ O ₂ Inside and Outside Bag 1 2 3	H ₂ O ₂ Inside Bag 4 5 6
Initial H ₂ O ₂ Concentration	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%	90.3% 90.3% 90.3%
Final H ₂ O ₂ Concentration	89.5% 89.4% 89.5%	89.4% 89.5% 89.4%	88.8% 88.8% 88.8%	88.5% 88.5% 89.1%	87.1% 88.4% 87.5%	87.1% 88.7% 87.2%	86.1% 84.8% 86.0%	84.4% 85.7% 86.3%	86.1% 84.8% 86.0%	84.4% 85.7% 86.3%	86.1% 84.8% 86.0%	84.4% 85.7% 86.3%
H ₂ O ₂ Stability After Test	98.7% 98.1% 98.3%	98.7% 99.0% 97.0%	97.9% 97.9% 99.0%	96.9% 98.3% 99.0%	97.3% 95.7% 96.5%	97.8% 98.7% 97.9%	98.5% 98.7% 99.3%	99.3% 99.3% 99.3%	98.5% 98.7% 99.3%	99.3% 99.3% 99.3%	98.5% 98.7% 99.3%	99.3% 99.3% 99.3%
Gas Evolution from 75 ml. H ₂ O ₂ (ft. ³ at ambient press.)	.0035 .0085 .0075 ft. ³ (16 hrs.)	.0055 .0025 .0050 ft. ³ (16 hrs.)	.0190 .0210 .0215 ft. ³ (24 hrs.)	.0190 .0075 .0195 ft. ³ (24 hrs.)	.0460 .0600 .0320 ft. ³ (24 hrs.)	.0540 .0360 .0430 ft. ³ (24 hrs.)	.0880 .1215 .0851 ft. ³ (24 hrs.)	.0830 .0630 .0750 ft. ³ (24 hrs.)	.0880 .1215 .0851 ft. ³ (24 hrs.)	.0830 .0630 .0750 ft. ³ (24 hrs.)	.0880 .1215 .0851 ft. ³ (24 hrs.)	.0830 .0630 .0750 ft. ³ (24 hrs.)
Average Gas Evolution from 75 ml. H ₂ O ₂ (ft. ³ at ambient pressure)	0.0097 ft. ³ (24 hrs.)	0.0065 ft. ³ (24 hrs.)	0.0215 ft. ³ (24 hrs.)	0.0153 ft. ³ (24 hrs.)	0.0460 ft. ³ (24 hrs.)	0.0443 ft. ³ (24 hrs.)	0.0982 ft. ³ (24 hrs.)	0.0737 ft. ³ (24 hrs.)	0.0982 ft. ³ (24 hrs.)	0.0737 ft. ³ (24 hrs.)	0.0982 ft. ³ (24 hrs.)	0.0737 ft. ³ (24 hrs.)
Average Gas Evolution (ft. ³ /24 hrs./ft. ² of bladder surface)	0.0037 ft. ³	0.0081 ft. ³	0.0081 ft. ³	0.0058 ft. ³	0.0175 ft. ³	0.0168 ft. ³	0.037 ft. ³	0.031 ft. ³	0.037 ft. ³	0.031 ft. ³	0.037 ft. ³	0.031 ft. ³

Reference AP Contract - AF-33(616)6732

TABLE V

Results of Screening Tests With Two Oxygen Absorbent Solutions

Oxygen-Getter					Number of Tests	Pounds Oxygen-Getter per 300# 90% H ₂ O ₂ at 1% Decomp/year	
Molar Ratios							
Pyrogalllic Acid	Alkali			H ₂ O			
	KOH	LiOH	NaOH				
Pyrogallol	1	1			0	1	200
	1	1			2	1	34
	1	1			6	1	25
	1	1			30	1	25
	1	2			10	8	16
	1	3			20	7	18
	1	3			30	3	28
	1	3			60	1	34
	1	6			30	2	33
	1	6			60	1	48
	1	10			30	1	32
	1	10			60	1	50
	1			3	20	2	21
	1			3	30	2	22
	1		3		30	1	23
	1		3		35	4	23
P-Benzoquinone							
P-Benzoquinone	1	0.5			20	1	62
	1	1			20	1	26
	1	3			10	7	17
	1	3			20	5	19

Reference Air Force Contract AF33(616)6732

TABLE VI

PHYSICAL AND THERMAL PROPERTIES OF BMP-DEG-1800 SOLUTIONS

<u>PHYSICAL PROPERTIES:</u> <u>MONOPROPELLANT</u>	<u>BMP-DEG-1800-40</u>	<u>BMP-DEG-1800-20</u>
Chemical Composition	67.8% H ₂ O ₂ , 6.8% DEG, 25.4% water	72.5% H ₂ O ₂ , 5.8% DEG, 21.7% water
Molecular Weight, #/mole	28.9	29.5
Density at 77°F g/cc lb/gal.	1.309 10.9	1.330 11.1
Boiling Point (1 atm.) °F	225	approx. 225
Melting Point °F	<-40	<-20
Viscosity Centistokes +77°F -15°F -38°F	0.996 3.14 (-13°F) 5.62	1.05 4.16 --
Refractive Index	1.3880	--
Apparent pH by Glass Electrode	2.1	--
Color	Colorless	Colorless
Effect on Metals	Corrosive except on 300 series stainless steel, tin, aluminum	Corrosive except on 300 series stainless steel, tin, aluminum
Effect on Most Organic Materials (grease, oil, skin, etc.)	Reaction, fire or severe oxidation resulting	Reaction, fire or severe oxidation resulting
Fire Hazard	Solution is dangerous if exposed to intense heat for extended period	Solution is dangerous if exposed to intense heat for extended period

SSD-TR-61-29

TABLE VI (continued)

PHYSICAL AND THERMAL PROPERTIES OF BMP-DEG-1800 SOLUTIONS
PHYSICAL PROPERTIES:

<u>MONOPROPELLANT</u>	<u>BMP-DEG-1800-40</u>	<u>BMP-DEG-1800-20</u>
Toxicity	Vapors are non-toxic, solution is a strong oxidizer than can cause skin blisters. (Blisters are rapid healing.)	Vapors are non-toxic, solution is a strong oxidizer that can cause skin blisters. (Blisters are rapid healing.)

TABLE VI (continued)

BMP-DEG-1800 (-20° and -40°F) SOLUTIONS

THERMAL PROPERTIES:

<u>TERMS</u>	<u>BMP-DEG-1800-67.8</u>	<u>BMP-DEG-1800-72.5</u>
Exhaust Products	CO ₂ - H ₂ O O ₂	CO ₂ - H ₂ O O ₂
Available O ₂ #/# Solution	0.221	0.253 ,
BTU/# Solution	1,472	1,465
Reaction Temp. °F		
Solution Temp.		
+68°F	1800	1800
-20°F	--	1700-1725
-40°F	1575-1600	--
Heat Capacity BTU/#/°F	0.716	0.691
CP/CV Solution at -40°F	1.234	--
-20°F	--	1.227
+68°F	1.237	1.240
Molecular Weight Exhaust Product	21.44	20.67
C* (1800 pc) Solution at		
-40°F	3310	--
-20°F	--	3395
+68°F	3500 .	3560
Isp at 122-1 expansion ratio		
Solution at		
+68°F	176	179
-20°F	--	169
-40°F	165	--

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TABLE VII

RESULTS OF TESTS WITH BMP-DEG-1800 SOLUTIONS STORED IN 99.6 ALUMINUM SHIPMENT DRUMS FOR 6 MONTHS

Run No.	BMP Temp. at Start °F.	Chamber Temp. at Start °F.	Chamber Press. psi	Chamber Temp. °F.	Flow Rate Lbs./Min.	Time To Peak Press. Sec.	Peak Press. psi	Total Time on Bed-Min.	Time of Initial Flow-Sec.	Total Thru-put Lbs.	Catalyst and Reactor	Remarks
822	75	80	1300	1880	8.8	0.80	1175	5.97	0	54	C-XIII-26	Satisfactory Performance
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												
823	75	85	1300	1875	8.8	0.48	1160	7.85	0	72	"	"
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												
824	75	85	1320	1890	8.6	--	--	9.85	0	90	"	"
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												
838	-20	-30	1375	1740	8.3	1.40	1275	11.76	Manual Start	108	"	"
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												
839	-20	-40	1350	1760	8.3	1.32	1325	13.72	1.0	126	"	"
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												
840	-17	-30	1400	1750	8.5	1.32	1375	15.89	1.0	144	"	"
Unstab. BMP-DEG-1800-72.5 stored for 6 months.												

TABLE VIII

RESULTS OF ROOM TEMPERATURE (20°C)
SEALED-STORAGE TESTS WITH BECCO HYDROGEN PEROXIDE IN 1-GALLON CAPACITY TPE TEFLON BLADDERS
S/V ratio .69 in.²/in.³

Test No.	Test Tank No.	Type	Hydrogen Peroxide		Loss %	Pressure Buildup psi											Remarks
			Before Conc.	After Conc.		1-wk	2-wk	3-wk	4-wk	5-wk	6-wk	7-wk	8-wk	9-wk	10-wk	Calc.*	
1	1	90% comm.	89.53	98.9	.70	.3	3	7	11	16	21	27	34	40	36	--	Removed at 15-wk, Press. 144
2	16	90% comm.	89.53	98.9	.59	.25	0	2	4	6	9	11	14	17	12	31	Removed at 5 months
3	9	90% prop.	90.4	98.9	.38	.16	0	0	0	0	4	9	30	85	--	--	Removed at 9-wk, Press. 196
4	17	90% prop.	90.4	98.9	.46	.19	0	0	0	0	3	6	9	12	140	--	Removed at 13-wk, Press. 184
5	6	98% comm.	98.26	99.8	--	--	10	13	17	21	27	35	47	62	170	--	Lost test sample
6	12	98% comm.	98.26	99.8	.47	.2	10	12	16	20	23	27	31	30	84	163	Removed at 16-wk.
7	13	98% prop.	98.26	99.8	.38	.18	0	0	2	4	10	13	16	17	48	139	Removed at 5-mo.
8	2	98% prop.	98.26	99.8	.25	.11	0	0	0	0	3	5	6	8	16	28	Removed at 5-mo.

NOTES: Each bladder contained 3730 ml. of Hydrogen Peroxide
 90% comm. = Becco commercial grade 90% by weight Hydrogen Peroxide
 90% prop. = Becco propulsion grade 90% by weight Hydrogen Peroxide
 98% comm. = Becco commercial grade 98% by weight Hydrogen Peroxide
 98% prop. = Becco propulsion grade 98% by weight Hydrogen Peroxide

All bladders bleached during test use
 All pressures corrected to 20°C (68°F)
 Tank Volume - 10.4%

(*) Calculated pressure buildup based on H₂O₂ concentration change.

TABLE IX
RESULTS OF ROOM TEMPERATURE (20°C.) SEALED-STORAGE TESTS WITH BECCO HYDROGEN PEROXIDE
IN 1-GALLON CAPACITY TPE BLADDERS S/V ratio .69 in.²/in.³
Each bladder contained one absorbent bag*

Test No.	Test Tank No.	Type	Hydrogen Peroxide				Loss %		Pressure Fulling											Remarks	
			Before Conc.	After Conc.	Stab.	Oz	Conc.	1-wk	2-wk	3-wk	4-wk	5-wk	6-wk	7-wk	2-mo	3-mo	4-mo	5-mo	Calc.**		
9	27	90% comm.	90.61	99.0	90.27	97.8	.34	.144	0	2	6	11	15	21	28	36	79	139	--	99	Removed at 17-wk, 154 psi
10	28	90% comm.	90.61	99.0	90.33	95.6	.31	.131	0	3	9	15	22	28	35	42	60	34	--	94	Removed at 19-wk, 102 psi
11	29	90% prop.	90.40	98.9	90.17	84.3	.25	.1	0	4	11	18	26	38	117	--	--	--	--	75	Removed at 7.5-wk, 183 psi
12	25	90% prop.	90.40	98.9	89.86	96.0	.5	.23	0	0	4	11	16	24	34	60	--	--	--	175	Removed 11½-wk, 190 psi
13	22	90% comm.	98.26	99.8	97.77	97.2	.5	.23	0	0	0	3	8	18	19	48	96	175	--	180	Removed 16-wk, 175 psi
14	14	90% comm.	98.26	99.8	97.67	95.8	.60	.28	0	2	6	11	15	20	26	33	60	84	102	--	Removed 20-wk, 102 psi
15	26	90% prop.	98.26	99.8	97.3	41.5	.96	.45	0	0	4	10	13	16	20	22	28	37	--	--	Removed 19-wk, 114 psi
16	23	90% prop.	98.26	99.8	97.85	88.1	.42	.19	0	0	0	3	5	8	10	13	24	46	88	140	Removed 20-wk.

NOTES: Each bladder contained 3730 ml. of H₂O₂.
For H₂O₂ designations, See notes Table VIII.
All tank pressures corrected to (20°C).
Tank Ullage 9.1%.
All bladders bleached during test.

* Each absorbent bag was double thickness (2-1 ml. TPE Teflon Film).
2 - 1" x 3/4" x 3/4" vinyl sponges saturated with 30 ml. of a molar solution
1:3:10 alkaline pyrogalllic acid--potassium hydroxide and water were
placed in the bags and the bags heat sealed.
All bags lost weight.

** Calculated pressure buildup based on H₂O₂ concentration change.

TABLE I
RESULTS OF 49°C. (120°F.) SEALED STORAGE TESTS WITH BECCO HYDROGEN PEROXIDE
IN 1-GALLON CAPACITY TFE TEFLON BLADDERS S/V .69 in.²/in.³

Test No.	Test Tank No.	Type	Hydrogen Peroxide				Absorb. bag wgt. Chng.	Pressure Buildup										Remarks		
			Before		After			Loss %	1-wk	2-wk	3-wk	4-wk	1-da	2-da	3-da	4-da	5-da		6-da	7-da
			Conc.	Stab.	Conc.	Stab.														
17	7	90% comm.	89.53	98.9	88.76	99.1	.71	.3	0	0	0	0	15	61	85	110	133	Rupture disc failed. Lost sample		
18	10	90% comm.	89.53	98.9	88.82	98.6	.64	.27	0	2	4	7	14	62	85	102	123			
19	18	90% prop.	90.40	98.9	--	--	--	--	0	0	0	0	11	32	47	68	221			
20	24	90% prop.	90.40	98.9	89.81	96.8	.54	.23	0	0	0	0	8	13	14	59	143			
21	5	90% prop.	80.40	98.9	89.94	74.6	.51	.21	0	0	0	0	10	19	29	67	80			
22	19	98% comm.	98.26	99.8	98.0	68.0	.26	.11	0	10	15	17	24	123	166	--	--	Removed 5th day		
23	3	98% comm.	98.26	99.8	97.72	93.8	.55	.23	0	9	19	25	0	47	66	128	153	Removed on 7-da. Slight leak noted 5-day. ** Sample contaminated		
24	4	98% prop.	98.26	99.8	97.81	68.4	.45	.19	0	0	0	0	16	55	68	87	100			
25	11	98% prop.	98.26	99.8	97.82	** 50.2	.45	.19	0	0	0	0	16	44	--	--	--			
26	8	98% prop.	98.26	99.8	97.97	** 0.0	.29	.13	0	0	0	0	13	32	53	65	79			

NOTES: Each bladder contained 3730 ml. of H₂O₂
For H₂O₂ designations see TABLE VIII.
Tank Ullage, 10.4%
All bladders bleached during test.

* Test tanks stored for 4-wk. at 13°C to 15°C prior to start of 49°C tests.
These tanks were vented prior to the 49°C tests.

TABLE XI
RESULTS OF 49°C. (120°F.) SEALED-STORAGE TESTS WITH BECCO HYDROGEN PEROXIDE IN 1-GALLON CAPACITY TFE TEFLON BLADDERS
S/V ratio 0.69 in.²/in.³
Each Bladder Contained One Absorbent Bag *

Test No.	Test Tank No.	Type	Hydrogen Peroxide						Absorb. Bag Wgt. Chg.	Pressure Buildup							Remarks
			Before		After		Loss %			1-da	2-da	3-da	4-da	5-da	6-da	7-da	
			Conc.	Stab.	Conc.	Stab.	Conc.	Oz									
27	7	90% comm.	90.61	99.0	90.17	98.2	.48	.23	-2.58	33	56	91	--	--	114	139	Bladder Bleached
28	10	90% comm.	90.61	99.0	90.39	98.2	.24	.093	-3.98	30	48	74	--	--	--	174	Bladder Bleached
29	24	90% prop.	90.61	99.0	90.34	40.6	.27	.11	-0.51	--	--	57	--	--	90	91	Bladder Bleached
30	5	90% prop.	90.61	99.0	90.56	98.5	.05	.02	-3.00	25	--	--	--	83	95	106	Bladder Bleached
31	19	98% comm.	98.26	99.8	97.43	95.5	.84	.35	-2.82	53	80	109	120	170	--	--	Removed after 117-hrs.
32	4	98% comm.	98.26	99.8	97.81	98.8	.46	.19	-4.47	40	60	92	--	--	156	191	Bladder Bleached
33	18	98% prop.	98.08	99.8	97.57	84.0	.7	.29	-3.66	13	21	32	--	--	--	75	Bladder Bleached
34	11	98% prop.	98.08	99.8	97.32	86.8	.95	.4	-4.44	13	31	45	--	--	--	94	Bladder Bleached

NOTES: Each bladder contained 3750 ml. of H₂O₂.
For H₂O₂ designations See Table VIII
Tank Village 9.15
All bladders bleached

* Each absorbent bag was double thickness (2-1 ml. TFE Teflon bags)
2 - 1" x 3/4" x 3/8" vinyl sponges saturated with a 30 ml. of a molar solution 1:3:10
alkaline pyrogallin acid-potassium hydroxide and water were placed in the bags and
the bags heat-sealed.

TABLE XII

RESULTS OF 74°C (165°F) SEALED STORAGE TESTS WITH
BECCO HYDROGEN PEROXIDE IN 1 GALLON CAPACITY TFE TEFLON
BLADDERS S/V RATIO .69 IN²/IN³

TEST NO.	TEST TANK NO.	HYDROGEN PEROXIDE				ABSORBENT			PRESSURE BUILDUP			REMARKS
		TYPE	Before Conc.	Before Stab.	After Conc.	After Stab.	Loss Conc.	BAG WEIGHT O ₂ CHANGE	24 Hrs.	48 Hrs.	72 Hrs.	
35	3	90C	90.40	99.2	90.18	95.9	.244%	.105%	239	-	-	24 hour test
35	24	"	90.40	99.2	90.25	97.3	.166%	.071%	99	208	-	48 hour test
37	7	90P	90.59	98.6	89.97	96.5	.68%	.29%	74	144	205	72 hour test
38	4	"	90.59	98.6	-	-	-	-	67	161	260*	*R.D. blew
39	8	98C	98.68	99.5	98.36	99.2	.32%	.15%	183	-	-	30 hour test
40	5	"	98.68	99.5	98.2	99.7	.486%	.224%	110	197	-	48 hour test
41	10	98P	98.64	99.8	98.16	98.7	.486%	.224%	112	201	-	48 hour test
42	18	"	98.64	99.8	98.32	98.7	.32%	.149%	62	109	207	72 hour test very slight sign of leakage

NOTE: Each bladder contained 3730 ml of H₂O₂. For H₂O₂ designations see Table VIII.
Tank ullage 10.4%

TABLE XIII

RESULTS OF 74°C (165°F) SEALED STORAGE TESTS WITH
BECCO HYDROGEN PEROXIDE IN 1 GALLON CAPACITY TFE TEFLON
BLADDERS S/V 0.69 IN²/IN³

EACH BLADDER CONTAINED ONE ABSORBENT BAG.*

TEST NO.	TEST TANK NO.	HYDROGEN PEROXIDE							ABSORBENT BAG WEIGHT CHANGE	PRESSURE BUILDUP			REMARKS
		TYPE	Before		After		Loss			1 Day	2 Day	3 Day	
			Conc.	Stab.	Conc.	Stab.	Conc.	O ₂					
43	3	90% Comm.	90.15	99.8	89.76	98.3	.43%	.18%	258			24 hour test	
44	29	"	90.15	99.8	89.76	98.3	.43%	.18%	250			24 hour test Rupture disc blew	
45	4	90% Prop.	90.32	97.2	89.97	90.6	.38%	.16%	81	169		48 hour test	
46	19	"	90.32	97.2	89.97	86.4	.38%	.16%	160	115		Leak at Girth Flange - 48 hour test	
47	11	98% Comm.	98.32	99.7	98.01	98.9	.31%	.13%	148	92		Leak at Girth Flange - 48 hour test	
48	24	"	98.32	99.7	98.19	99.5	.13%	.03%	114	135		Leak at Girth Flange - 48 hour test	
49	18	98% Prop.	98.08	98.7	98.04	99.5	.04%	.017%	71	140	207	72 hour test	
50	7	"	98.08	98.7	98.05	99.3	.03%	.012%	72	118	150	72 hour test	

NOTES: Each bladder contained 3730 ml of H₂O₂. For H₂O₂ designations see Table VIII.
*Tank ullage 9.1%. Each absorbent bag was double thickness (2 - 1 mil TFE Teflon bags)
2 - 1" x 3/4" x 3" vinyl sponges saturated with 230 ml of a molar solution 1:3:10 alkaline.
Pyrogalllic acid, potassium hydroxide and water were placed in the bags and the bags were heat sealed.

TABLE XIV

RESULTS OF SEALED STORAGE TESTS AT 20°C IN TPE TEFLON BLADDERS TREATED WITH FARRELLOK SOLUTION
S/V ratio 0.69 in.²/in.³

Test Tank No.	Test Tank No.	Type	Hydrogen Peroxide				Absorb. bag Wgt. Chg.	Pressure Buildup										Remarks		
			Before		After			Loss % conc.	O ₂	1-wk	2-wk	3-wk	4-wk	5-wk	6-wk	7-wk	2-mo		3-mo	4-mo
			Conc.	stab.	Conc.	stab.														
51	20	98% comm.	98.26	99.8	97.87	99.0	.39	.18	8	12	15	19	23	27	28	39	54	70	Removed 16-wks.	
52	21	98% comm.	98.26	99.8	97.74	99.3	.53	.22	9	10	15	19	23	26	28	43	72	96	Removed 16-wks.	

Farrellok-Treated Bladders
Room Temperature

NOTES: Each bladder contained 3730 ml. of H₂O₂
For H₂O₂ designations, see TABLE VIII.
Tank ullage 10.4%
Bladders bleached slightly

TABLE XV

RESULTS OF 20°C. (68°F.) SEALED STORAGE TESTS WITH BECCO HYDROGEN PEROXIDE IN 1-GALLON CAPACITY USED TPE TEFLON BLADDERS
S/V ratio 0.69 in.²/in.³

Test No.	Test Tank No.	Type	Hydrogen Peroxide						Absorb. Bag Wgt. Chg.	Pressure Buildup						Remarks
			Before		After		Loss % Conc.	O ₂		1-wk	2-wk	3-wk	4-wk	5-wk	6-wk	
			Conc.	Stab.	Conc.	Stab.										
57	25	90% comm.	90.44	99.0	90.20	98.3	.25	.10		6	18	28	40	49	61	Bladders bleached
58	9	90% comm.	90.44	99.0	90.4	97.0	.04	--		16	37	54	78	102	--	Bladders bleached
59	5	98% comm.	98.70	99.6	98.25	99.5	.45	.21		4	17	30	45	70	82	Bladders bleached
60	7	98% comm.	98.70	99.6	98.20	98.8	.50	.23		7	18	30	45	53	61	Bladders bleached

Used Bladders
Room Temperature

NOTES: Each bladder contained 3730 ml. of H₂O₂
All bladders had a minimum of 300 hours exposure
Tank ullage 10.4%

TABLE XVI

RESULTS OF LABORATORY TESTS WITH NEW AND USED TFE BLADDERS

Test propellant Becco 90% Commercial H_2O_2

All samples exposed to 90% H_2O_2 at 66°C (151°F) for 1 week

<u>BLADDER SAMPLE</u>	<u>TREATMENT</u>	<u>A.O.L.</u>	<u>H_2O_2 FINAL STABILITY</u>
New TFE	Regular passivation	4.4%	96.2%
Teflon	+20% HNO_3 1 hr.	3.2%	97.4%
		3.2%	99 %
Used TFE	" "	4.0%	98 %
Teflon		5.4%	99.4%
		3.3%	98.1%
Used TFE	Regular passivation	7.2%	94.8%
Teflon	No acid treatment	6.4%	97.6%
		6.7%	96.2%

TABLE XVII

RESULTS OF SCREENING TESTS WITH VARIOUS BLADDER MATERIALS
INCLUDING KANIGEN PLATED AND TINPLATED-KANIGEN PLATED MILD STEEL

TEST MATERIAL		TEST CONDITIONS			HYDROGEN PEROXIDE			Remarks
Source & Type	Treatment	Temp.	Period	A.O.L.	Conc.	Stability		
9711 Silicone	Regular	151°F	7 days	9.7%	90%	98.2%	Samples bleached slightly	
"	"	"	"	8.2%	"	99.8%	"	
"	"	"	"	9.5%	"	94.3%	"	
"	"	"	"	9.1%	98%	92.3%	Samples bleached, swelled and distorted	
"	"	"	"	8.3%	"	94.6%	"	
"	"	"	"	8.7%	"	98.6%	"	
Vicone #185 ASTM Slab (N.A.A. Corp.)	"	"	"	4.1%	90%	96.4%	Samples bleached slightly	
"	"	"	"	6.1%	"	93.2%	"	
"	"	"	"	8.7%	"	88.9%	"	
Vicone #31-2 ASTM Slab (N.A.A. Corp.)	"	"	"	19.5%	98%	81.0%	"	
"	"	"	"	20.6%	"	80.7%	"	
"	"	"	"	19.5%	"	83.4%	"	
Vicone #185 Bladder Sample (N.A.A. Corp.)	"	"	"	4.1%	90%	97.8%	"	
"	"	"	"	3.8%	"	99.2%	"	
"	"	"	"	3.8%	"	98.3%	"	
Vicone #31-2 Bladder Sample (N.A.A. Corp.)	"	"	"	15.9%	98%	88.9%	"	
"	"	"	"	15.8%	"	89.0%	"	
"	"	"	"	13.5%	"	74.0%	"	
Dielectric Co. TFE Teflon 0.015"	"	120°F	"	3.1%	90%	92.8%	Sample bleached very slightly	
"	"	"	"	2.8%	"	96.9%	"	
"	"	"	"	2.2%	98%	93.8%	"	
"	"	"	"	3.4%	"	91.2%	"	

TABLE XVII (Continued)

TEST MATERIAL		TEST CONDITIONS		HYDROGEN PEROXIDE			Remarks
Source & Type	Treatment	Temp.	Period	A.O.L.	Conc.	Stability	
TFE Teflon	Regular	120°F	7 days	1.3%	90% Prop.	91.3%	Sample bleached slightly
"	"	"	"	1.9%	98% Prop.	89.5%	"
"	"	165°F	3 days	4.0%	90% Prop.	95.5%	"
"	"	"	"	7.4%	98%	92.5%	"
"	"	"	"	3.3%	90% Prop.	79.4%	"
"	"	"	"	2.7%	98% Prop.	90.4%	"
Stillman	"	151°F	7 days	14.4%	90%	96.4%	"
Co. Compound	"	"	"	14.4%	90%	97.6%	"
#TH1131	"	"	"	16.1%	90%	91.2%	"
"	"	"	"	16.4%	98%	96.8%	"
"	"	"	"	16.9%	98%	86.6%	"
"	"	"	"	16.0%	98%	90.6%	"
duPont	"	"	"	2.6%	90%	98.4%	Sample blistered
Compound	"	"	1 day	0.6%	90%	99.1%	No effect upon the sample
#805	"	"	2 days	0.6%	90%	99.4%	No effect upon the sample
Viton B	"	"	3 days	0.6%	90%	95.3%	No effect upon the sample
"	"	"	4 days	3.5%	90%	97.2%	Sample became swollen & blistered
"	"	120°F	7 days	3.3%	90%	96.8%	Signs of slight blister formation
"	"	"	"	3.1%	98%	99.5%	"
"	"	86°F	30 days	1%	90%	96.1%	No effect upon the sample
3-M	"	151°F	7 days	1.1%	90%	98.5%	Sample blistered on one surface
Fluorel	"	"	1 day	.3%	90%	99.1%	No effect upon the sample
#2141	"	120°F	7 days	3.3%	90%	98.2%	Very slight indications of blistering
"	"	"	"	2.9%	98%	99.6%	"

TABLE XVII (Continued)

TEST MATERIAL		TEST CONDITIONS		HYDROGEN PEROXIDE			Remarks
Source & Type	Treatment	Temp.	Period	A.O.L.	Conc.	Stability	
Fluorel #2141	Regular	70-72°F	5 Mons.	1.0%	90%	94.4%	No effect upon the sample
Keystone	"	"	"	0.9%	98%	97.9%	" " " "
Chromium	Kanigen	151°F	7 days	82.1%	90%	88.8%	Samples stained slightly
Company	Coated	"	"	51.2%	90%	95.1%	" " " "
Buffalo	1020 Steel	"	"	60.3%	90%	92.5%	" " " "
New York	Tinplated	151°F	"	10.6%	90%	98.2%	Samples very slightly stained
" "	Kanigen	"	"	13.7%	90%	98.0%	" " " "
" "	Coated	70-72°F	7 days	0.55%	90%	96.7%	" " " "
" "	1020	"	"	0.55%	90%	96.3%	" " " "
" "	Mild Steel	"	"	0.98%	90%	94.2%	" " " "

NOTES: Passivation - Procedure used with plastics:

1. Washed with detergent solution (Nacconal-water)
2. Rinsed with distilled water
3. Placed in 20% HNO₃ for 1 hour room temperature
4. Rinsed with distilled water

Kanegin and tinplated samples:

1. Washed with detergent solution (Nacconal-water)
2. Double rinse in distilled water

TABLE XVIII

RESULTS OF 49°C. (120°F.) SEALED-STORAGE TESTS WITH ONE OF BECCO'S EXPERIMENTAL LOW-FREEZING HIGH-ENERGY MONOPROPELLANTS IN 1-GALLON CAPACITY TPE TEFLON BLADDERS -- S/V ratio .69 in.²/in.³

Test No.	Test Tank No.	Type	Hydrogen Peroxide						Absorb. Bag Wgt. Chg.	Pressure Buildup						Remarks	
			Before		After		Loss %			1-da	2-da	3-da	4-da	5-da	6-da		7-da
			Conc.	Stab.	Conc.	Stab.	Conc.	O ₂									
55	5	BMP	74.0	94.8	71.93	0.0	2.7	.6	20	34	52	70	139	7-day Test			
56	7	BMP	74.0	94.8	72.98	95.5	1.3	.33	16	26	41	51	90	7-day Test			

BMP - DEG - 1800
120°F.

NOTES: Each bladder contained 3730 ml. propellant
Tank ullage 10.4%

TABLE XIX

RESULTS OF ROOM TEMPERATURE (20°C.) SEALED-STORAGE TESTS WITH ONE OF BECCO'S EXPERIMENTAL LOW-FREEZING HIGH-ENERGY MONOPROPELLANTS IN 1-GALLON CAPACITY TPE TEFLON BLADDERS -- S/V ratio .69 in.²/in.³

Test No.	Test Tank No.	Type	Hydrogen Peroxide				Absorb. Bag Wgt. Chg.	Pressure Buildup										Remarks	
			Before		After			Loss %	1-wk	2-wk	3-wk	4-wk	5-wk	6-wk	7-wk	8-wk	9-wk		10-wk
			Conc.	Stab.	Conc.	Stab.													
53	8	BMP	73.2	95.3	73.3	80.1	0.0	0.0	5	9	11	15	20	29	39	51	62	--	Bag Porosity Noted Removed after 10-wk.
54	18	BMP	73.2	95.3	72.87	84.4	.45	.15	9	11	12	14	21	27	33	35	42	49	

BMP - DEG - 1800
Room temperature

NOTES: Each bladder contained 3730 ml. of H₂O₂.
Tank ullage 10.4%