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WASHINGTON, D.C.

REPORT

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AD No.

TESTING AND DEVELOPMENT DIVISION

PROJECT CGTD A25-1

HYDROGEN ACCUMULATION IN THE BATTERY POCKETS  
OF BUOYS WITH LEAD-ACID BATTERIES

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JUL 20 1961

TESTING AND DEVELOPMENT DIVISION

PROJECT CGTD A25-1

HYDROGEN ACCUMULATION IN THE BATTERY POCKETS  
OF BUOYS WITH LEAD-ACID BATTERIES

Date: JUL 20 1961

Submitted: \_\_\_\_\_  
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Date: JUL 20 1961

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#### ABSTRACT

This report is a comprehensive study of the causes and prevention of hydrogen gas accumulation in electric lighted buoys powered by lead-acid storage batteries. The chemistry of possible causes of hydrogen evolution is discussed. Measurements of hydrogen concentration in various lighted buoys are presented. Results showed a high percentage of buoys with explosive mixtures in battery pockets. Increasing the size of ventilation tubing and converting to an "open" type vent valve reduced the hydrogen gas concentration below the lower explosive limit.

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## 1. INTRODUCTION

1.1 On 16 November 1951, 26 September 1959, and 10 May 1960 explosions occurred in electric buoys that were powered with low discharge storage batteries. With an increased number of electric buoys being used each year, the hazards of an explosion must be eliminated. Indoctrination in the proper handling, charging and use of lead-acid batteries is not sufficient. Positive preventive measures are considered necessary. It is the purpose of this project to determine probable causes of explosions and eliminate them through corrective action.

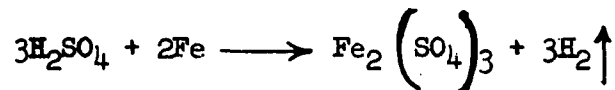
## 2. CHEMISTRY OF THE EXPLOSION.

The prerequisites for an explosion are hydrogen, oxygen and a spark. The presence of oxygen and the accidental spark can never be eliminated from the buoy recharging (not to be confused with battery recharging) operation. There then remains the task of eliminating the presence of hydrogen.

2.1 The following sources of hydrogen appear possible:

- a. Hydrogen produced by the reaction of sulfuric acid with steel,
- b. Hydrogen and oxygen entrapped in the battery as a result of charging, and
- c. Hydrogen released as a result of local cell action (chemical self discharge).

2.1.1. The chemistry of the reaction of sulfuric acid on steel may be approximated by:



For an 8 x 26 buoy having a free volume of 7.2 cubic feet in a pocket, an acid spillage of about 30 cubic centimeters can create a combustible mixture under standard conditions of temperature and pressure. Appendix I shows these calculations.

2.1.2. The gassing of a battery does not cease when the charging current is stopped. Gases continue to be released for several days. In low discharge type batteries this post-charging delayed release of gases continues longer than the high discharge

batteries due to the thickness and porosity of the plates. It appears possible that during the post-discharge release of gases, oxygen will cease coming off prior to hydrogen. No exact data on the post-discharge release of battery gas has been located to date. It is also probable that some gas entrained or trapped in or between the plates may be released by rolling or agitating the battery a considerable time after the stationary battery has ceased to gas.

2.1.3. Hydrogen given off by local cell action (chemical self discharge) was previously thought to be very minor in the case of low discharge type batteries. Assuming the chemical self-discharge of the battery produces the same amount of hydrogen as a trickle charge, an explosive mixture can be readily attained. Appendix II gives details of assumptions and calculations for obtaining the time required to attain a combustible mixture for various types of electric buoys.

### 3. REDUCING THE EXPLOSION HAZARD.

To reduce or eliminate the hazard of an explosion, two methods were considered:

- (1) the use of a catalyst to neutralize the hydrogen as it is emitted, and
- (2) increase the ventilation in the battery pocket.

3.1 The U.S. Navy has used a palladium catalyst to reduce the presence of hydrogen in torpedo batteries. The catalyst allows the hydrogen to combine with oxygen to form water. Discussions with the Naval Research Laboratory indicated that palladium catalysts are easily poisoned by the impurities present in the battery. Trace amounts of arsenic and antimony (which are still present even in the low discharge lead-acid battery plates) give rise to the generation of arsine and stibine which destroy the effectiveness of palladium as a catalyst. The palladium catalyst also requires the motion of the hydrogen gas over the catalyst to accomplish the desired chemical reaction.

Since the catalytic method of reducing hydrogen indicated only a slight chance of success and would require considerable time and research, the catalyst approach was not pursued. In addition, safety considerations dictated a prompt solution.

3.2 Increasing the ventilation of the battery pocket was next considered. Evaluation tests of air cell batteries in buoys were in progress when the explosion hazard problem again arose. Standard

Coast Guard buoys had been modified to provide additional air by increasing the vent lines from 1/4-inch tubing to 3/4-inch tubing and changing the vent valves from a pressure release type to a continuously open type.<sup>(1)</sup> Details of the vent system and tests will be described in the next section.

4. TESTS CONDUCTED. Tests were performed in two phases:

(1) the determination of the extent of hydrogen accumulation in various type buoys and,

(2) the evaluation of the vent system modification.

4.1 Subsequent to an explosion aboard the USCGC WILLOW (WAGL-332), the vessel commenced taking readings of hydrogen gas concentrations in the pockets of various buoys. Appendix III, a letter from the WILLOW to Commandant (RFD) (less enclosures), describes these tests and their results.

4.2 The Field Testing and Development Unit measured hydrogen gas concentrations in the pockets of standard 7 x 17E and 9 x 32E buoys with conventional vent valves and vent tubing. Appendix IV, Field Testing and Development Unit Report No. 230, describes these tests and their results.

4.3 The vent system of one 6 x 20E (RR) buoy at USCG BASE, Gloucester City was modified in accordance with Coast Guard drawing no. BU-58-02. This modification equips each battery pocket with two 3/4-inch vent tubes, one to the top of the pocket and one to the bottom. C-R Development Corporation vent valves type SV-10CL were used. The buoy was outfitted with type 23 racks of DHB-5-1 lead acid batteries and with a 12-volt, 3.05 ampere lamp on a quick flashing characteristic providing the load. One vent tube on one battery pocket was plugged. Daily combustible gas indicator readings of the hydrogen-air mixture were taken on both pockets.

4.3.1. Results of the Gloucester tests are given in Appendix V.

5. RESULTS.

5.1 As shown in Appendices II, III, and IV, every standard electric buoy with the conventional 1/4-inch single vent system and powered by lead acid batteries is potentially dangerous due to hydrogen accumulation.

(1) Valve closes when buoy is inclined at large angles or submerged.

5.2 Appendix V shows that for the conditions of paragraph 4.3:

5.2.1. The hydrogen concentration may reach an explosive mixture within two or three days after recharging the buoy, but the concentration drops to 5 to 10 per cent of the lower explosive limit within a day or two.

5.2.2. The hydrogen concentration in one pocket never exceeded 15 per cent of the lower explosive limit. The variation in concentration between pockets may be caused by a multitude of factors (see Appendix VI) but the primary factor is probably the time the batteries sat between completion of charging and installation in the buoy.

5.2.3. A pocket with one vent is as good as a pocket with two vents with respect to hydrogen venting. This may be due to an equilibrium condition existing between rate of hydrogen evolution, rate of diffusion, and the rate of escape of the gas mixture.

5.3 Appendix IV shows that removal of the pressure release vent valve from a standard 1/4-inch vent system has little or no effect on the hydrogen concentration in the pocket of a 9 x 32E (RR) buoy.

5.4 Appendix V indicates that for choppy seas (higher winds) the hydrogen concentration decreases for the buoy with the 3/4-inch vent system. This indicates that some chimney effect is being attained in the new vent system.

5.5 Appendix VI is a collection of miscellaneous facts which are pertinent to the hydrogen explosion problem.

## 6. DISCUSSION AND CONCLUSION.

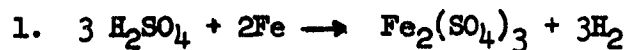
6.1 The present 1/4-inch vent tubing and pressure release vent valve are unsatisfactory since dangerous concentrations of hydrogen gas can exist. Even the removal of the vent valve had no effect on decreasing the hydrogen concentration.

6.2 A single 3/4-inch vent line to each pocket with a continuously open (except under adverse conditions) vent valve will provide adequate ventilation for the lead acid batteries. So as to be on the safe side, and looking toward higher capacity lead acid batteries, two vent lines to each pocket are recommended.

**APPENDIX I**

APPENDIX I

HYDROGEN GENERATED BY ACID SPILLAGE



$$\begin{array}{rcc} 3 \times 98.07 & 2 \times 55.85 & 3 \times 2.016 \\ 294.21\text{g} & 111.70\text{g} & 6.048\text{g} \end{array}$$

2. The free volume in the pocket of an 8 x 26 buoy is 7.2 cubic feet. A 4% mixture of hydrogen then requires  $7.2 \times 0.04$  or 0.288 cubic feet of hydrogen.

3. .288 cu. ft. equals 8.16 liters.

4. 22.4 liters of hydrogen weighs 2.016 grams.

5. Let  $x$  = weight of  $\text{H}_2$  in 8.16 liters

$$\frac{x}{8.16} = \frac{2.016}{22.4}$$

$$x = 0.734 \text{ grams of } \text{H}_2 \text{ in } 8.16 \text{ liters.}$$

6. Let  $y$  = quantity of  $\text{H}_2\text{SO}_4$  to produce 0.734 grams of hydrogen

$$\frac{y}{294.21} = \frac{0.734}{6.048}$$

$$y = 35.7 \text{ grams of } \text{H}_2\text{SO}_4 \text{ (At standard conditions).}$$

7. Volume of  $\text{H}_2\text{SO}_4 = \frac{35.7}{1.2} = 30 \text{ cc.}$

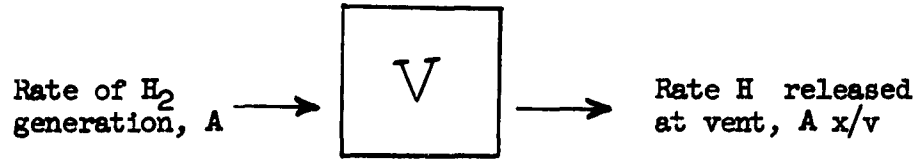
Thus 30 cc. of sulfuric acid reacting on steel is capable of producing sufficient hydrogen for an explosive mixture in a 7.2 cubic foot volume.

APPENDIX II

APPENDIX II

HYDROGEN ACCUMULATION

1. Consider the following illustration:



Where:  $x$  = amount of  $H_2$  in volume  $V$ , cu.-ft.  
 $A$  = rate of hydrogen generation, cu.ft./day/cell.  
 $V$  = free volume of buoy pocket, cu.ft.  
 $\frac{dx}{dt}$  = time rate of change in amount of  $H_2$  in volume  $V$ ,  
 cu.ft./day/cell.

Then  $\frac{dx}{dt}$  = rate of  $H_2$  in - rate of  $H_2$  out

Assume perfect diffusion and that the gases will be released at zero pressure.

$$\text{Then } \frac{dx}{dt} = A - A\frac{x}{V} = A \left( \frac{V-x}{V} \right)$$

$$A dt = \left( \frac{V}{V-x} \right) dx$$

Integrating  $A \int dt = V \int \frac{dx}{V-x}$

$$A \int dt = V \int \frac{1}{V} \left( 1 + \frac{x}{V} + \frac{x^2}{V^2} + \frac{x^3}{V^3} + \dots \right) dx$$

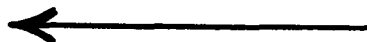
For a 4% hydrogen mixture  $\left( \frac{x}{V} = .04 \right)$  we need only consider the first two terms of the series expansion. Integrating between time 0 and T and hydrogen quantities 0 and .04V:

$$A \int_0^T dt = V \int_0^{.04V} \left( \frac{1}{V} + \frac{x}{V^2} \right) dx$$

$$\left[ At \right]_0^T = \left[ x + \frac{x^2}{2V} \right]_0^{.04V}$$

$$AT = .04V + .0008V = .0408V$$

$$T = .0408 \frac{V}{A}$$



2. Assume the hydrogen produced on trickle charge is 0.0159 cu.-ft./amp.-hr. at 70°F. Also assume that the 500 ampere-hour cell will be discharged over a period of one year. This is typical of an aids to navigation load. Further assume that 10% of the capacity will be lost in self discharge. A 500 ampere-hour cell will then have a total capacity of about 555 ampere-hours  $\left(\frac{500}{.09}\right)$  and thus about 55 ampere-hours consumed as a result of self-discharge. Since 0.0159 cu.ft. of hydrogen are produced per amp.-hr., and the service period is one year,

$$\frac{55}{365} \times 0.0159 = .0024 \text{ cu.ft.}$$

of hydrogen are produced per day per cell.

$$3. T = .0408 \frac{V}{A}$$

If  $V = 1$  cu.ft. and  $A = .0024$  cu.ft./day/cell, then  $T = 17$  days, the time required per cell to obtain a combustible mixture in a volume of one cubic foot.

Several common type buoys attain combustible mixtures in the following times:

Buoy	Free Volume (cu.-ft.)	Number of cells	Days to reach a 4% mixture
5 x 11	3.14	6	9
Solid Pocket 6 x 20	7.2	6	21
Open Pocket 6 x 20	130	12	184
9 x 32	6.9	12	10
8 x 26	7.2	12	10.5

APPENDIX III

Commanding Officer  
USCGC WILLOW (WAGL-332)  
CG Base, Yerba Buena Island  
San Francisco, California

J24-2/A25  
30 August 1960

From: Commanding Officer, USCGC WILLOW (WAGL-332)  
To: Commandant (ETD)  
Via: Commander, Twelfth Coast Guard District (e)

Subj: Explosive gas mixtures within buoy pockets, testing of; report on

1. On 26 September 1959, an explosion occurred in an open battery pocket of a 32 volt system buoy that was being recharged on the deck of this vessel. Prior to this happening, the normal procedure when recharging buoys had been to remove the buoy pocket covers and allow natural ventilation to rid the buoy pockets of any accumulated gas, before allowing unit personnel to disconnect the internal wiring.
2. Since this prementioned explosion, a gas explosimeter has been used to determine the gaseous content contained within buoy pockets prior to there complete uncovering.
3. The procedure presently in use at this unit is to remove all swing bolts from the pocket cover except four (4), spaced 90 degrees apart. The remaining four (4) are then loosened sufficiently to allow the pocket cover to be raised for the insertion of a rubber suction tube which is attached to the explosimeter. A reading of the battery pocket atmosphere is then taken. If the buoy body has separate battery pockets, readings are taken simultaneously from all pockets. No internal work is performed until all readings are safe.
4. Actual attempts to take gas samples through the battery pockets vents proved to be unsatisfactory.
5. Fifty seven (57) buoys have been tested by this unit since 28 September 1959 and the following listed tabulations shows percentages of explosive mixture found within the battery pockets of these tested buoys.

<u>NO. OF BUOYS</u>	<u>% OF EXPLOSIVE MIXTURE WITHIN BUOY</u>
15	100%
01	90%
05	80%
05	70%
05	60%
05	50%
06	40%
00	30%
05	20%
00	10%
10	00%

CO, WILLOW ltr to COMDT  
Via: CCGDL2(e) cont.

6. Attached as enclosures are excerpts from the instruction manual pertaining to the operation of the M-S-A Explosimeter, Model 3, manufactured by the Mine Safety Appliances Company, Pittsburgh, Pennsylvania. Also attached is a copy of the Schematic Flow System and Wiring Diagram from the same manual.

E. S. BATES

Encl: (1) Instructions for operating the Model 3 Explosimeter  
(2) Schematic Flow System and Wiring Diagram

-----  
16 September 1960

FIRST ENDORSEMENT ON CO USCGC WILLOW ltr J24-2/A25 dtd 30 Aug 1960

From: Commander, Twelfth Coast Guard District  
To: Commandant (EFD)

Subj: Explosive gas mixtures within buoy pockets, testing of; report on

1. The use of the Explosimeter should be made mandatory and each unit responsible for recharging buoys should have such a device on their allowance list.

JOHN B. OREN  
By direction

APPENDIX IV

FIELD TESTING AND DEVELOPMENT: UNIT REPORT NO. 230

FIELD TESTING AND DEVELOPMENT UNIT

PROJECT CGTD A25-1

HYDROGEN ACCUMULATION IN THE BATTERY POCKETS  
OF BUOYS WITH LEAD-ACID BATTERIES

by

FIELD TESTING AND DEVELOPMENT UNIT  
U. S. COAST GUARD YARD  
Curtis Bay, Baltimore 26, Maryland

Date: 9 May 1961

Submitted: \_\_\_\_\_

C. F. SCHARFENSTEIN, JR. CDR, USCG  
Commanding Officer, FT&DU

Date: \_\_\_\_\_

Approved: \_\_\_\_\_

Chief, Testing and Development Division  
Office of Engineering  
U.S. Coast Guard Headquarters  
Washington 25, D.C.

Authority: This project was performed under the authority of  
Commandant (ETD) letter dated 30 August 1960, CGTD  
A25-1.

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mission from the Office of Engineering, U.S. Coast Guard Head-  
quarters, Washington 25, D.C.

#### ABSTRACT

The concentration of hydrogen gas in the battery pockets of two standard Coast Guard light buoys with lead-acid batteries was measured under service conditions. Tests indicated a dangerously high accumulation of hydrogen in the buoy pockets. Removal of the pressure release valve from a standard vent system showed no effect on the hydrogen content in the battery pocket.

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## 1. MATERIAL TESTED.

1.1 The tests described herein had as their purpose the measurement of the hydrogen accumulation in the battery pockets of buoys, using lead-acid batteries.

1.2 Measurements were made on two buoys. One was a type 9 x 32 E (RR) and the other a 7 x 17 E (RR). These were the 1958 standard types of Coast Guard buoys, with normal battery pocket vents, shown on U.S. Coast Guard Civil Engineering Division Drawing BU-58-11.

1.3 A Type 23 battery rack (6 Willard DHB-5-1 lead-acid cells) was used in each battery pocket of the 7 x 17E (RR) buoy, giving a capacity of 1000 ampere-hours. The 9 x 32E (RR) buoy was equipped with two Type 34 battery racks (12 DHB-5-1 cells each), providing a total capacity of 2000 ampere-hours.

## 2. TESTS CONDUCTED.

2.1 A Coast Guard 200-millimeter lantern, with a standard motor flasher and lampchanger, was placed on each buoy. Twelve-volt, 3.05-ampere lamps were used, flashing on a characteristic of 0.5 second on, 2.0 seconds off.

2.2 The buoys were placed in service at dockside at the Coast Guard Yard. The lamps were allowed to flash continuously through the normal service period of each buoy battery. Periodic measurements were made of the hydrogen content of each battery pocket, using a Mine Safety Appliances explosive gas meter calibrated for an atmosphere of hydrogen in air.

2.3 Midway through the test of the 9 x 32E (RR) buoy, the pressure release valve was removed from one battery pocket vent line to see whether this valve had any effect upon hydrogen accumulation in the pocket.

2.4 An air test was performed on each battery pocket to insure that no vent line obstructions were present to affect the measurements of hydrogen accumulation.

## 3. RESULTS OF TESTS.

3.1 The results of the tests are shown in Figure 1 and 2. The hydrogen content of the battery pocket atmosphere is shown as a percentage of the lower explosive limit which is a hydrogen-air mixture containing about 4% hydrogen.

## 4. DISCUSSION AND CONCLUSIONS.

4.1 The test batteries were charged two to four weeks before installation in the buoys, and tests were conducted in relatively cold weather (November, 1960 to April, 1961). For these reasons the hydrogen accumulation may have been less than would be experienced under other conditions.

4.2 The tests showed a dangerously high accumulation of hydrogen in the buoy battery pockets.

4.3 Removal of the pressure release valve from a buoy with the current standard vent system has no appreciable effect on the hydrogen content of the battery pocket.

FIGURE 1  
 HYDROGEN ACCUMULATION IN BUOY BATTERY POCKETS  
 TYPE 23 BATTERY ARMS IN TX17E (RR) BUOY

HYDROGEN ACCUMULATION  
 (PER CENT OF LOWER EXPLOSIVE LIMIT)

100

80

60

40

20

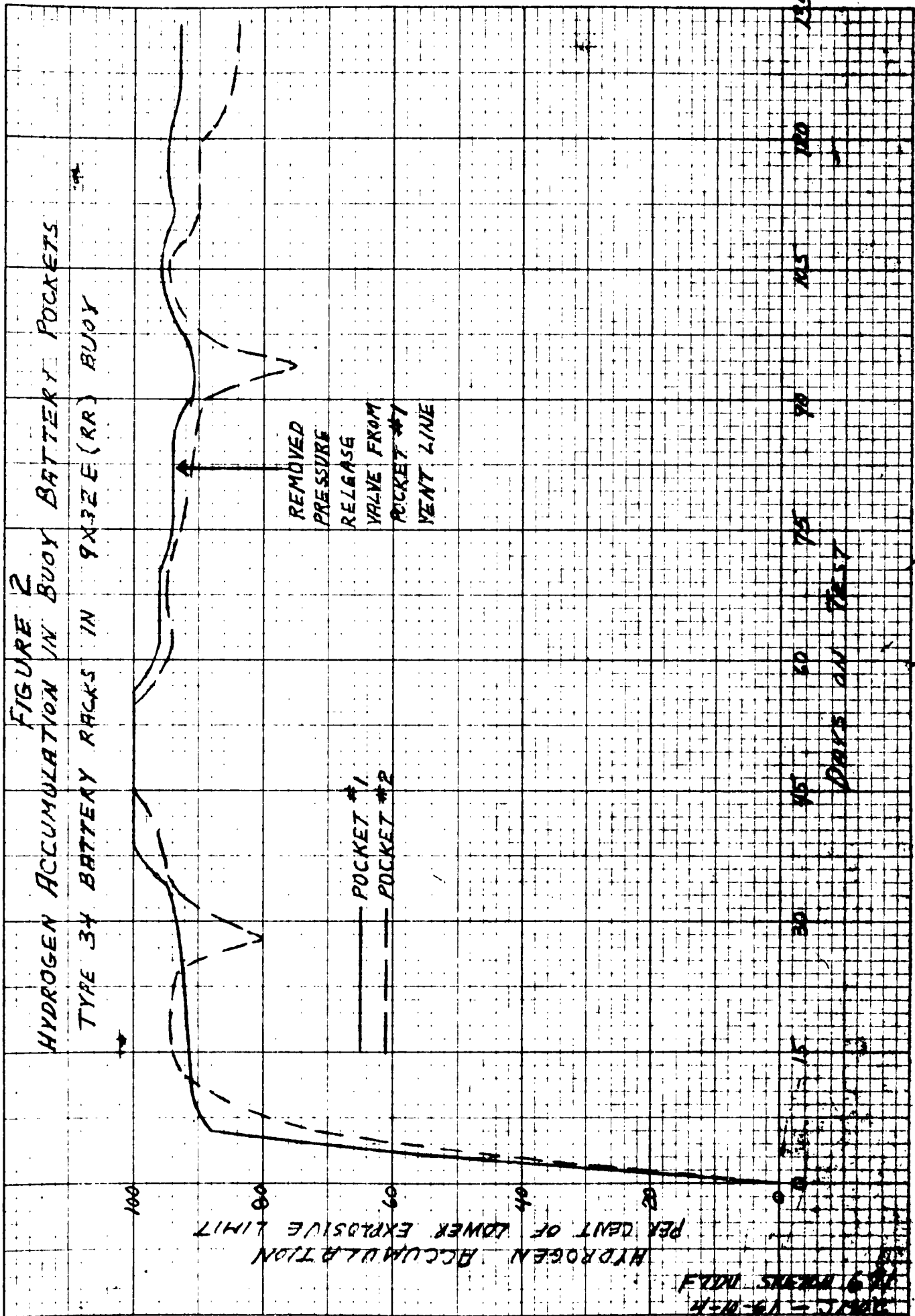
0

POCKET #2

POCKET #1

POCKETS ON TEST

DATE - 10-10-64  
 BY - [illegible]



APPENDIX V

HYDROGEN CONCENTRATION READINGS TAKEN AT BASE, GLOUCESTER

Buoy - 6 x 20 E (RR) Modified per dwg. BU 58-02

Readings taken from 21 October 1960 to 21 March 1961

HYDROGEN READINGS AT BASE, GLOUCESTER

	<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
1.	10-21-60	1300	5%	80%	Sea calm
2.	10-22-60	0850	15%	100%	Sea choppy
3.	10-23-60	0830	15%	100%	Sea calm
4.	10-24-60	0800	5%	5%	Sea choppy
5.	10-24-60	1400	5%	7%	Sea choppy
6.	10-25-60	0845	4%	2%	Sea choppy
7.	10-26-60	0845	4%	2%	Sea calm
8.	10-27-60	1015	10%	18%	Sea calm
9.	10-28-60	1045	7%	20%	Sea choppy
10.	10-29-60	1000	7%	18%	Sea choppy
11.	10-30-60	0800	7%	18%	Sea choppy
12.	10-31-60	1030	7%	18%	Sea calm
13.	11-1-60	0830	5%	15%	Sea calm
14.	11-2-60	0830	5%	10%	Sea calm
15.	11-3-60	0830	5%	10%	Sea calm
16.	11-4-60	0830	5%	10%	Sea choppy
17.	11-5-60	0830	5%	9%	Sea choppy
18.	11-6-60	0830	5%	8%	Sea choppy
19.	11-7-60	0900	5%	7%	Sea choppy
20.	11-8-60	0830	5%	8%	Sea calm
21.	11-9-60	1000	5%	7%	Sea choppy
22.	11-10-60	1000	5%	7%	Sea calm
23.	11-11-60	1000	5%	5%	Sea calm

HYDROGEN READINGS AT BASE, GLOUCESTER

<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
24. 11-12-60	1000	5%	5%	Sea calm
25. 11-13-60	0800	5%	5%	Sea calm
26. 11-14-60	0930	5%	5%	Sea calm
27. 11-15-60	0930	5%	5%	Sea calm
28. 11-16-60	0930	5%	5%	Sea calm
29. 11-17-60	1000	5%	5%	Sea calm
30. 11-18-60	0930	4%	5%	Sea calm
31. 11-19-60	1000	5%	5%	Sea calm
32. 11-20-60	1000	5%	5%	Sea calm
33. 11-21-60	0930	5%	5%	Sea calm
34. 11-22-60	0800	5%	5%	Sea calm
35. 11-23-60	0930	5%	7%	Sea calm
36. 11-24-60	0920	5%	5%	Sea calm
37. 11-25-60	0930	5%	5%	Sea calm
38. 11-26-60	0900	5%	5%	Sea calm
39. 11-27-60	0930	5%	5%	Sea calm
40. 11-28-60	0930	5%	5%	Sea calm
41. 11-29-60	0900	5%	4%	Sea calm
42. 11-30-60	0930	5%	5%	Sea calm
43. 12-1-60	0900	5%	5%	Sea calm
44. 12-2-60	0930	5%	5%	Sea calm
45. 12-3-60	BATTERIES EXHAUSTED			
46. 12-4-60	BATTERIES EXHAUSTED			

HYDROGEN READINGS AT BASE, GLOUCESTER

<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
47. 12-5-60		BATTERIES EXHAUSTED		
48. 12-6-60		BATTERIES EXHAUSTED		
49. 12-7-60		RECHARGED BATTERIES		
50. 12-8-60	0930	10%	10%	Sea calm
51. 12-9-60	0930	10%	10%	Sea calm
52. 12-10-60	1000	11%	10%	Sea calm
53. 12-11-60	1000	10%	10%	Sea calm
54. 12-12-60	0930	10%	10%	Sea calm
55. 12-13-60	0930	8%	9%	Sea calm
56. 12-14-60	0930	8%	9%	Sea calm
57. 12-15-60	1030	8%	9%	Sea calm
58. 12-16-60	1030	8%	9%	Sea calm
59. 12-17-60	1030	8%	9%	Sea calm
60. 12-18-60	1030	8%	9%	Sea calm
61. 12-19-60	0930	6%	8%	Sea calm
62. 12-20-60	1030	6%	8%	Sea calm
63. 12-21-60	1000	6%	8%	Sea calm
64. 12-22-60	1000	5%	7%	Sea calm
65. 12-23-60	0930	5%	7%	Sea calm
66. 12-24-60	0900	5%	7%	Sea calm
67. 12-25-60	1000	5%	7%	Sea calm
68. 12-26-60	1000	5%	7%	Sea calm
69. 12-27-60	0920	5%	7%	Sea calm

HYDROGEN READINGS AT BASE, GLOUCESTER

<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
70. 12-28-60	0910	5%	7%	Sea calm
71. 12-29-60	1430	5%	6%	Sea calm
72. 12-30-60	0900	5%	6%	Sea calm
73. 12-31-60	0900	5%	6%	Sea calm
74. 1-1-61	0900	5%	6%	Sea calm
75. 1-2-61	0900	5%	6%	Sea calm
76. 1-3-61	1000	5%	6%	Sea calm
77. 1-4-61	0900	5%	6%	Sea calm
78. 1-5-61	0930	5%	6%	Sea calm
79. 1-6-61	1000	5%	6%	Sea calm
80. 1-7-61	0930	5%	6%	Sea calm
81. 1-8-61	0930	5%	6%	Sea calm
82. 1-9-61	1000	4%	5%	Sea calm
83. 1-10-61	0930	3%	3%	Light out
84. 1-11-61	1000	3%	4%	Light recharged
85. 1-12-61	0800	5%	6%	Sea calm
86. 1-13-61	0930	5%	6%	Sea calm
87. 1-14-61	0930	5%	4%	Sea calm
88. 1-15-61	0930	5%	6%	Sea calm
89. 1-16-61	0930	5%	6%	Sea calm
90. 1-17-61	0930	5%	6%	Sea calm
91. 1-18-61	0930	5%	6%	Sea calm
92. 1-19-61	0940	5%	5%	Sea calm

HYDROGEN READINGS AT BASE, GLOUCESTER

<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
93. 1-20-61	0900	5%	5%	Sea calm
94. 1-21-61	0900	5%	5%	Sea calm
95. 1-22-61	0900	5%	5%	Sea calm
96. 1-23-61	0945	5%	5%	Ice
97. 1-24-61	0900	5%	5%	Ice
98. 1-25-61	0930	5%	5%	Ice
99. 1-26-61	0900	5%	5%	Ice
100. 1-27-61	Test discontinued due to heavy ice conditions			
101. 1-28-61		do.		Ice
102. 1-29-61		do.		Ice
103. 1-30-61		do.		Ice
104. 1-31-61		do.		Ice
105. 2-1-61	0930	6%	7%	
106. 2-2-61	0930	6%	7%	
107. 2-3-61	0900	6%	7%	
108. 2-4-61	0900	6%	7%	
109. 2-5-61	0930	7%	8%	
110. 2-6-61	0930	7%	8%	
111. 2-7-61	0930	8%	8%	
112. 2-8-61	0900	8%	8%	
113. 2-9-61	0900	8%	8%	
114. 2-10-61	0930	8%	8%	
115. 2-11-61	0930	8%	8%	

HYDROGEN READINGS AT BASE, GLOUCESTER

<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
116. 2-12-61	0900	8%	8%	
117. 2-13-61	0900	8%	8%	Extinguished
118. 2-14-61	0900	12%	13%	Recharged
119. 2-15-61	0900	12%	13%	
120. 2-16-61	0900	12%	12%	
121. 2-17-61	0900	10%	11%	
122. 2-18-61	0930	10%	11%	
123. 2-19-61	0930	10%	11%	
124. 2-20-61	0930	9%	10%	
125. 2-21-61	0930	9%	10%	
126. 2-22-61	0900	9%	10%	
127. 2-23-61	0930	9%	9%	
128. 2-24-61	0900	8%	9%	
129. 2-25-61	0900	8%	9%	
130. 2-26-61	0900	8%	8%	
131. 2-27-61	0900	8%	8%	
132. 2-28-61	0930	8%	8%	
133. 3-1-61	0930	7%	8%	
134. 3-2-61	0930	7%	7%	
135. 3-3-61	0900	7%	6%	
136. 3-4-61	0900	7%	6%	
137. 3-5-61	0900	7%	6%	
138. 3-6-61	0900	7%	6%	

HYDROGEN READINGS AT BASE, GLOUCESTER

	<u>Date</u>	<u>Time</u>	<u>Single Vent</u>	<u>Double Vents</u>	<u>Remarks</u>
139.	3-7-61	0900	6%	6%	
140.	3-8-61	0900	6%	6%	
141.	3-9-61	0930	6%	6%	
142.	3-10-61	0930	6%	5%	
143.	3-11-61	0900	6%	5%	
144.	3-12-61	0900	6%	5%	
145.	3-13-61	0900	6%	5%	
146.	3-14-61	0900	6%	5%	
147.	3-15-61	0900	6%	5%	
148.	3-16-61	0900	6%	5%	
149.	3-17-61	0900	6%	5%	
150.	3-18-61	0900	6%	5%	
151.	3-19-61	0900	6%	5%	
152.	3-20-61	0900	6%	5%	
153.	3-21-61	0900	6%	5%	

APPENDIX VI  
Miscellaneous Facts

### Miscellaneous Facts

1. Hydrogen gas forms an explosive mixture in air whenever its percentage by volume at atmospheric pressure is more than 4.1% and less than 74.2%.
2. The explosion of a mixture of hydrogen and oxygen is more violent than a mixture of hydrogen and air although both may be very destructive.
3. During the battery charging process both hydrogen and oxygen are given off. The mixture of hydrogen and oxygen varies from about 52% H<sub>2</sub>, 47% O<sub>2</sub> by volume at low charging rates to 67% H<sub>2</sub>, 33% O<sub>2</sub>, at high charging rates.
4. The particular construction of buoy cells (DEB-5-1) leaves an appreciable gas volume in the cell above the electrolyte.
5. During self-discharge of a lead-acid cell the amount of hydrogen generated depends upon:
  - a. the ambient temperature
  - b. the number of cycles on the cell
  - c. the specific gravity of the electrolyte
  - d. the cell voltage
  - e. the purity of the plates and electrolyte
  - f. the age of the cell.
6. When trickle charging:
  - a. Each increase of 0.06 volt per cell doubles the trickle charge rate.
  - b. Each temperature increase of 15°F doubles the charge rate.
  - c. Each temperature decrease of 15°F halves the charge rate.
7. As a battery ages the trickle charge rate will gradually increase, approaching 1% by the end of life. The rate of increase and life obtained varies with the quality of maintenance.
8. In going from 70°F to 80°F, there will be 2% more hydrogen produced per ampere hour.

9. Bureau of Ships Technical Manual, paragraph 62-832. **CHEMICAL SELF-DISCHARGE.** Chemical self-discharge is caused by reactions between the electrolyte and the active materials at the plates resulting in decrease in electrolyte specific gravity, consumption of active materials, and loss of plate capacity. The reaction at the positive plate is less than at the negative, so that the predominant cause of normal self-discharge is the reaction between electrolyte and the negative active material lead. For a cell in good condition, the decrease in specific gravity caused by chemical self-discharge is not more than one point a day at 80°F.

10. Bureau of Ships Technical Manual, paragraph 62-834. **HYDROGEN EVOLUTION BY CHEMICAL SELF-DISCHARGE.** The normal reaction responsible for self-discharge at the negative plates results in the formation of lead sulphate and the evolution of hydrogen. Since the amount of hydrogen produced is proportional to the amount of acid and lead consumed in the reaction, it follows that rate of fall of specific gravity, rate of hydrogen evolution, and rate of chemical self-discharge, all increase or decrease in direct proportion to each other so long as the predominant cause of self-discharge is the reaction at the negative plate.

11. Bureau of Ships Technical Manual, paragraph 62-835. **FACTORS AFFECTING CHEMICAL SELF-DISCHARGE.** The rate of chemical self-discharge depends upon a number of factors which include:

(1) Time since charge. The rate of chemical self-discharge is most rapid immediately after a charge and then decreases somewhat to a more or less constant value. For a battery which has been worked enough to develop maximum performance, the capacity lost by standing on open circuit increases with the length of stand.

(2) Specific gravity. The rate of chemical self-discharge increases with the specific gravity of the electrolyte.

(3) Temperature of electrolyte. The rate of chemical self-discharge increases with the electrolyte temperature. The rate of hydrogen evolution on stand increases in proportion to the rate of self-discharge and can be used to show the increase in self-discharge with temperature. Laboratory tests on cells in good condition indicate that the following ratios are fairly representative:

Temperature (° F.):	Hydrogen evolved in percent of evolution at 100° F. (percent)
80 .....	40
90 .....	60
110 .....	150
130 .....	390

Although the actual amount of hydrogen evolved by different batteries is extremely variable, the rapidity with which hydrogen evolution and chemical self-discharge increases with temperature is well shown by the above figures.

(4) Purity of electrolyte. Chemical self-discharge is materially increased by the presence of even extremely small amounts of impurities; notably iron, nickel, chlorine, organic acids, and copper. Antimony is a constituent of the grids, but is an impurity in the electrolyte and greatly increases self-discharge. Because of the pronounced effects of small amounts of impurities, extreme purity of the electrolyte is necessary for the best battery performance.

(5) Antimony migration. Chemical self-discharge at the negative plate is promoted by the migration of antimony from the positive grids to the negative plate. This has two effects:

(a) It increases the rate of reaction between the electrolyte and the negative active material, lead; hence increases the rate of self-discharge.

(b) It lowers the charge voltage. Lower charge voltage decreases the effectiveness of the natural process in which antimony is driven off the negative plate as stibine gas during the gassing phase of charge, and, therefore, tends to make the increase in the rate of self-discharge permanent.

(6) Age and design. Self-discharge and hydrogen evolution increase as a cell ages. Thick plate cells show a relatively slow rate of increase. Thin plate cells show a much higher rate of increase and have required installation of hydrogen eliminators in order to obtain full life without excessive hydrogen.

(7) Previous treatment. A battery which is free from impurities and which has been consistently charged to about 2.7 volts at the end of charge will usually show little chemical self-discharge. This figure refers to the voltage at the end of charge corrected to 80° F. High voltage at the end of charge tends to eliminate antimony from the negative plates and to remove one of the principal causes of self-discharge. Partial charging and the persistent use of finishing and equalizing rates lower than those specified for a battery result in low voltage at the end of charge and increase self-discharge.