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Eighteenth Partial
Report on Oxygen
Source Materials

EXPERIMENTAL CONTROL OF CO₂
AND OXYGEN CONCENTRATIONS
ABOARD THE USS SAILFISH

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ABSTRACT

The atmosphere in the submarine was controlled within rather narrow limits at 3% carbon dioxide and 17% oxygen. The total submerged period lasted for 68 hours of which 14 were required to reach the desired concentrations. For 24 hours the atmosphere was controlled by the chlorate candle-lithium hydroxide system, for the second 24 hours KOX canisters were used and the final 6 hours used up excess materials and allowed a further shift of the concentrations. The purification systems used showed excellent results at the 3% CO₂ concentration, with two canisters of pelleted lithium hydroxide running simultaneously removing the CO₂ exhaled by 90 men. Three canisters of KOX running simultaneously removed the CO₂ and furnished oxygen under similar conditions. One chlorate candle was used each 55 minutes and furnished oxygen at the rate of 1 cu.ft./minute during the time lithium hydroxide was used for CO₂ absorbent.

Both methods of air revivification proved to be equal to the submarine requirement with simple, if any, added apparatus. Analysis for the gases was made on continuous reading meters; the Pauling Meters for oxygen and the Selective Gas Analyzer Mark VI for CO₂. The Dwyer analyzer was also used for intermittent readings on CO₂ and since the values were more dependable they have been used in this report.

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INTRODUCTION

A. Authorization

1. Submarine air purification studies are authorized on Bureau of Ships Project 9R. The submarine tests were authorized on Bureau of Medicine and Surgery letter, Serial #027, BuMed-X-XRP11 All/EN10 (45010) dated January 4, 1945 and BuShips Research Memorandum No. 2-44 NavShips (330) dated 21 March 1945.

B. Statement of Problem

2. This investigation was made for two purposes. First, the controlling of the concentrations of oxygen, carbon dioxide, and hydrogen at satisfactory levels under conditions of continuous underwater operation. Second, to study the efficiency of personnel at 3% carbon dioxide and the corresponding oxygen concentration, since this is the accepted upper limit before CO₂ absorbent is to be spread. The atmosphere control was the part of the program executed by the Laboratory. The evaluation of the efficiencies of the personnel was performed by groups under the auspices of the Medical Research Department at the U. S. Submarine Base at New London; with Captain C. W. Shilling in charge.

3. The groups assigned to the submarine for test purposes other than its crew and officers were as follows:

Copy of List Presented to Lt. Comdr. L. Marcy, (C.O.)
by G. J. Duffner.

OFFICERS

<u>Name</u>	<u>Rank & File No.</u>	<u>Duties</u>
Mark I. H. Young	Lt. Cdr. (MC) USN 107491	Observer M.R.
Gerald J. Duffner	Lt. (MC) USN 180398	Observer M.R.
Wm. S. Verplanck	Lt.(jg) H(S) USNR 143692	Radar Test
N. R. Bartlett	Lt.(jg) H(S) USNR 155248	Radar Test
James F. Curtis	Ens. (S) USNR 391903	Observer M.R.
Ira M. Koger	Ens. D(L) USNR 297268	I.V.C. Test
John D. Harris	Ens. H(S) USNR 409553	Sound Tests
Wm. H. Schechter	Ens. USNR 409866	NRL (Gas)
Robert S. Hartman	Ens. USNR 426696	NRL (Gas)

ENLISTED MEN

<u>Name</u>	<u>Rate & Serial No.</u>	<u>Duties</u>
Hender, Herbert A.	PhMlc USNR 621 55 34	General Testing
Gardin, Henry M.	PhMlc USNR 604 07 25	General Testing
Aronson, Leon	F1c USNR 824 08 86	I.V.C.
Barberio, Fred G.	Slc USNR 713 82 94	Visual Testing
Ziomek, John J.	Slc USNR 813 51 01	Visual Testing
Mason, Robert "D" Jr.	Slc USNR 806 64 48	Visual Testing
McCarthy, Edward V.	Slc USNR 888 70 44	Visual Testing
Kramer, George W.	Slc USNR 246 60 31	Visual Testing
Colley, D. R.	Slc USNR 796 08 92	I.V.C.
Mitchell, Thomas H.	S2c USNR 566 18 10	Visual Testing
Gibbons, Jack V.	S2c USNR 735 84 15	General Testing

CIVILIANS

<u>Name</u>	<u>Location</u>	<u>Duties</u>
John E. Karlin	(Harvard University)	Observer M. R.
R. R. Miller	(NRL)	Gas
J. C. White	(NRL)	Gas
Myron H. Boyer	(NRL)	Gas
James K. Musick	(NRL)	Gas

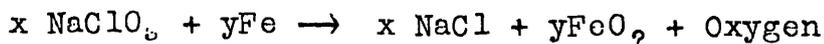
C. Known Facts Bearing on the Problem

4. The air purification study for submarine atmospheres has been active for a number of years and chemicals suitable for absorbents for CO₂ and oxygen liberation have been evaluated. Chamber tests have been conducted and the KOX (one of the materials used on this test) spread in thin layers was evaluated aboard the USS 30 (ref. a). It showed satisfactory CO₂ absorption and oxygen liberation but the method employed was unsatisfactory both from the point of view of operations and hazards. All materials studied on this submarine dive are such that they would be used in the stowage containers. This eliminates any inherent hazards in handling free materials aboard.

5. Other factors which were not satisfactory in previous air purification investigations were the methods of determining the concentration of CO₂ and oxygen. Apparatus has been developed for both which give a continuous indication of the concentration of these gases, and with the Dwyer unit intermittent values on CO₂ can be obtained by simple manipulations of the apparatus. For oxygen, the Pauling Oxygen Meters are available and have been

evaluated for naval use, (ref. b). The continuous reading apparatus for CO₂ is undergoing evaluation tests at present. It is known as the Selective Gas Analyzer MK VI of which the principle is described in ref. (c). The three types of apparatus were used for analysis along with a Haldane gas analysis apparatus for occasional checking of results. Comments on the units with respect to their operation on this cruise will be made later in this report.

6. Two chemical oxygen source materials were used each for a 24 hour period on the submerged submarine. The first was the Sodium Chlorate Candles, (ref. d), which furnish oxygen by the thermal decomposition of the chlorate. This is accomplished by the oxidation of iron powder which is intimately mixed with the chlorate. The reaction may be stated essentially as follows:

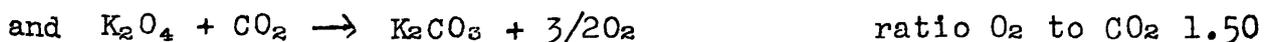
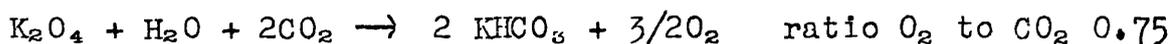


x = mols of Sodium Chlorate

y = mols of Iron

The particular iron oxide formula varies with the conditions under which the decomposition takes place. The available oxygen amounts to from 33% to 36% of the total weight.

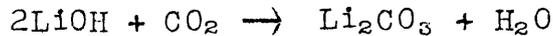
7. The second oxygen source material used was the tetroxide of potassium or referred to as KOX. It reacts with carbon dioxide and water vapor in such a manner that oxygen is displaced roughly in proportion to the CO₂ absorbed. The theoretical ratios are 1.5 or 0.75 volumes of oxygen to one volume of carbon dioxide. Actually the ratio of O₂ evolved to CO₂ absorbed is somewhat less than the 1.5 volume. The KOX reactions with CO₂ can be expressed chemically as:



The relative extent of these reactions account for the ratio of O₂ to CO₂ being more nearly equal to the average ratio for respiration, i.e., O₂ to CO₂ = 1.25.

8. The CO₂ absorption during the use of the chlorate candle was accomplished by blower-canisters of pelleted lithium hydroxide. The pelleting accomplished two purposes. The pellets are sufficiently hard so that little dust results from storage and use. Also the size of the pellets make possible satisfactory air flows for use on a blower or in a ventilation system. The method of production (ref. d and discussed below) makes it

practicable to obtain nearly complete saturation of the material with CO₂. The reaction of CO₂ with anhydrous hydroxide results in as many molecules of water being produced as there are molecules of CO₂ absorbed chemically. The reaction is:



Most of the water is vaporized and escapes from the canister with the effluent air. The water vapor released from this CO₂ absorbent is the only gaseous product other than oxygen evolved by any of the materials used in air purification aboard the submarine.

D. Preparation of Materials

9. The KOX was prepared as described in ref. (e) for breathing canisters. Its preparation consists of pressing powder produced in the manufacturing process with a suitable catalyst (ref. e) into brickettes. These were crushed and screened to size, i.e., through 1/2" mesh and on 1/4" mesh. This material was packed into canisters 6" x 12" x 12" and such that the air passed in and out on opposite 6" x 12" faces of the canister. The internal structure of the canister was of iron mesh wire folded back and forth so that pockets approximately 1" thickness ran the long way of the canister. Above the folded screen was a two or three inch layer of KOX which is closed at the top with a wire screen (ref. f). The canisters held from 14 to 17 lbs. of material with the average weight per canister of 15 lbs. The canisters were arranged on the blowers such that the air was forced upward through the material at approximately 40 cubic feet per minute (CFM). See plates 1 and 2.

10. The candles were prepared by mixing the component parts, fusing all together, and casting the liquid into a suitable mold to solidify. The composition of the candles (ref. d) is given below on weight per cent basis.

Sodium Chlorate	NaClO ₃	85%
Iron (powder)	Fe	5
Glass Fiber	M(SiO ₂)	7
Barium Peroxide	BaO ₂	3

The candles were made up of three components, the main body of oxygen producing material, an ignition cap and a primer. The ignition cap and primer were compounded to furnish high heat

rapidly and for ease of starting respectively. The composition of the starting cap was:

Sodium Chlorate	NaClO_3	55%
Iron Powder	Fe	20
Glass Fiber	$\text{M}(\text{SiO}_2)$	15
Barium Peroxide	BaO_2	10

The primers were composed of:

Iron Powder	Fe	30%
Sodium Metasilicate	Na_2SiO_3	10) Plus 12%
Barium Peroxide	BaO_2	60) added water.

The relative amounts of the three were as follows:

Primer	2 grams
Starting Cap	95 grams
Body of Candle	6400 - 6800

The candle was cast into cylindrical candles $4\text{-}3/4$ " in diameter and 10" long. These were wrapped in a double layer of AA Fiber Blanket (glass) and placed in close fitting tin-plate cans. On the starting end, a unit consisting of a baffle plate, filter, and screen was made up on a short tube which centered the baffle plate, and at the same time held the Bouchon fuse starter in position over the primer. (See Plate 9). These metal parts, since becoming relatively hot while in an atmosphere of pure oxygen, should be of a metal not easily oxidized. Copper or brass for screens, baffle plate, tube, starter, etc. while a good tin plate, copper or brass, should fulfill the canister requirements.

11. The lithium hydroxide was prepared for the blower canister in 4 to 14 mesh particles by hydraulically pressing the commercially available lithium hydroxide monohydrate. The water content of the hydrate ($\text{LiOH}\cdot\text{H}_2\text{O}$) is theoretically 42.86%. At 43.5% it appears wet and heavy, at 41.5% it appears dry and approaches free-flowing material. Material made from water contents of these limits was satisfactory while both higher or lower gave an inferior product with respect to hardness. The process is as follows: The monohydrate was pressed to a pressure of 25,000 pounds per square inch in oversize pellets. These were crushed in a Stokes Granulator to size, screened, and oven-dried at 150°C . Hardness on the dried particles was determined by the method given in Soda Lime Specification 51S26b on 8 to 14 mesh. Hardness numbers above 90 were determined for materials properly prepared. Further investigation showed that satisfactory measure-

ments could be made by the same method using ¼ to 1¼ mesh and only material above a 90 hardness number was used.

THE SUBMARINE ATMOSPHERE CONTROL TEST

12. The general plan of the experiment was drawn up on 4 April 1945 at New London. The groups represented at the conference were Officers from the Submarine Operating Base; Medical Research Unit, New London; National Defense Research Committee, Harvard University; Bureau of Medicine and Surgery, Washington, D. C.; and the Laboratory. The general plan was to submerge the submarine, and allow the oxygen to drop and carbon dioxide to rise until the concentrations were approximately 17% and 3% respectively. With a normal complement it was assumed this would require about 24 hours. The following is copied from the notes taken at the conference, "second phase: 24 hours by means of chlorate candles and lithium hydroxide, the same standard of CO₂ will be maintained. Third phase: 24 hours - the same standard of CO₂ will be maintained by means of KOX". At conferences on May 4 and May 23 with Lt. Comdr. Marcy, C.O. of the USS Sailfish present, the following program of operations of the submarine was agreed upon.

		<u>Total</u>
1. Submerge		
2. Underwater Cruise	2 hrs.	2 hrs. 0600-0800
3. Battle Stations		
Fire Water Slugs	2 hrs.	4 hrs. 0800-1000
4. Evasion Tactics -		
Silent Running	6 hrs.	10 hrs. 1000-1600
5. Normal Cruise	8 hrs.	18 hrs. 1600-2400
6. Reside on Bottom	24 hrs.	42 hrs.
7. Normal Cruise	2 hrs.	44 hrs.
8. Battle Stations	2 hrs.	46 hrs.
9. Silent Running	2 hrs.	48 hrs.
10. Reside on Bottom to		
End of Experiment.	24 hrs.	72 hrs.

13. The tests were scheduled for May 24, 25, 26, and 27. The gear was placed aboard on May 23 and the Sailfish with an accompanying SC, proceeded to the diving area on May 24. The diving started at 0600 on the 25th of May. Submergence was continued for 68 hours with occasional surfacing of the conning tower hatch for exchange of personnel.

Laboratory personnel were aboard as follows:

5/25/45

0600 to 2300 - White, Hartman, Musick, and Miller.

5/25/45 and 5/26/45

2300 to 1200 - White, Schechter, Boyer, and Miller.

5/26/45 and 5/27/45

1200 to 0600 - White, Schechter, Boyer, Hartman, Musick,
and Miller.

5/27/45

0600 to 2100 - White, Schechter, Boyer, and Miller.

5/27/45 and 5/28/45

2100 to 0200 - Schechter, Boyer, Musick, and Hartman.

Transfer of personnel did not take place other than the times indicated.

14. The data collected, by the Laboratory, on the cruise covered carbon dioxide concentration in eight locations through the boat at time intervals, total CO₂ absorbed in canisters, the temperature and relative humidity at 8 locations at time intervals, concentration of hydrogen, concentration of oxygen in the forward torpedo compartment, interval oxygen reading in COC, and oxygen liberated by chemicals. The record of pressure was made in the forward torpedo compartment. The carbon dioxide values for the forward torpedo compartment determined on the Haldane apparatus, Dwyer CO₂ analysis apparatus, and M-6 analyzer are given in Table I along with values for oxygen and the pressure readings in millimeters of Hg. The CO₂ and oxygen values for this compartment are graphed on Plate 11. The curves drawn follow the Dwyer values since it reads on the percentage basis and not the partial pressure as did the M-6 indicator. The Haldane readings are used only as a check. The oxygen curve is drawn through the values of the Pauling meter and have been corrected for pressure which was determined with an aneroid barometer. These values for oxygen are not correct for the period between 1200, 5/26/45 to 0600, 5/27/45, since the pressure was not known accurately. Plate 5 shows the pressure readings recorded, however, on return to the Laboratory the pressure gauge was found to be mechanically stopped at 828 mm or 32.6" of Hg. Corrected pressure values taken from the calibration curve are plotted on Plate 5-A. This leaves the maximum pressure readings in doubt and for this reason the values of oxygen on the Pauling and CO₂ on the M-6 are no doubt in error during this period. Corrected percentage of oxygen are shown on Plate 11. The Pauling readings are shown on Plate 10. Changes in pressure during transfer of personnel account for the breaks shown by the pressure graph. The carbon dioxide values taken throughout the boat are given in Table II and are plotted on Plate 4. The graph shows the maximum and minimum values at a given time

with a curve drawn through the average of the CO₂ values. Since the compartments are not equal in size this is not a quantitative average of the CO₂ present. (Average used hereafter in this manner will be underscored). The average value of 3% was obtained at 2000 on 5/25/45, after 14 hours submergence. There were approximately 90 men aboard and the submarine volume was near 33,000 cu.ft. If the assumption is made that 3% was the quantitative average for CO₂ concentration, then at similar average temperature of 76°F. or 25°C. and pressure of 812 mm of Hg. the CO₂ in the boat at the end of 14 hours was $33000 \cdot 812/760 \cdot 273/298 \cdot 0.03 = 967$ cu.ft. This corrected for .1% in the boat to start (as taken from the graph) gives an increase of 937 cu.ft. of CO₂. For the time required and the number of men present the CO₂ production is 0.740 cu.ft. or .0908 lbs/man/hour. This value corresponds with the value, 0.090 lbs. of CO₂/man/hour, as given in the old C. & R. Manual. It is higher than the .072 lbs/man/hour measured in 1930 or the .0775 measured in July 1931 as given in ref. (g). These values are in line with expected values with the variation in activity aboard. The operations carried out during the first 14 hours of this dive are similar to those of an operating submarine and the .09 lbs. of CO₂/man/hour is near the amount which requires removal to maintain an even CO₂ concentration in the atmosphere.

15. During the 24 hour period following 2000, 5/25/45, (the time 3% was reached) the lithium hydroxide canisters were used to absorb CO₂ and the chlorate candles were used to furnish oxygen. Table III gives the results on the lithium hydroxide canisters. The table gives the canister numbers in the order they were used, the cu.ft. of CO₂ absorbed by each, the duration of the exposure, the average rate of absorption of CO₂ per canister and the % saturation. The flow rates through the canisters were determined at 40 to 50 cu.ft. per minute on canisters run in chamber tests at the Laboratory. It is assumed to be the same for the saturation runs. The following calculation gives the total amount of CO₂ absorbed along with the average amount expired per man per hour.

LiOH

292.3 lbs. of Li₂CO₃ x 0.595 = 174. lbs. of CO₂
 (The factor for CO₂ in carbonate is 0.595)

174 x 8.16 = 1420 cu.ft.

1420/2160 = .66 cu.ft. CO₂/man/hour or

0.0808 lbs. of CO₂/man/hour.

These values are lower than those obtained during the build-up of CO₂, while the percentage CO₂ appears constant in the submarine

during the period, the correction for pressure cannot be made since the true pressure is not known.

16. A chlorate candle was started every 55 minutes during the 24 hour period making a total of 26 candles burned. They average 63 cu.ft. of oxygen per candle which gives a total of 25 x 63 equal to 1575 cu.ft. of oxygen gas released (25 candles were used for calculation since one was flooded with water when a screen burned through. See discussion). The candles were ignited by removing the compression-fit lid (paint can type) and pulling a "ring and pin" from the Bouchon hand grenade starter. The candles start rapidly on the primer and starting cap and the decomposition takes place more slowly through the main part of the candle. The oxygen is released in a narrow horizontal zone at red heat which moves slowly downward. The 10" candles burn for 60 minutes giving a rate of 0.6" of candle decomposed per minute with an evolution of slightly over one cu.ft. of oxygen per minute.

17. During the 24 hours following the LiOH-candle period, KOX canisters were used. Data for these canisters are given in Table IV. The total CO₂ absorbed was 1445.4 cu.ft. which gives 0.670 cu.ft./man/hour which checks with the first 24 hours. The flow rate through the canisters was again near 40 to 50 cu.ft. per minute. KOX canisters were used for 1.5 hours each and rotated in such a way that a new canister was started every 30 minutes. The rate of absorption is higher at first and tapers off with the duration of use. A few periods of longer and shorter duration in the table show this fact. The last columns show the per cent of theoretical on the basis of carbonate, required to give the absorption of CO₂ found. Those over 100% indicate some bicarbonate formation.

18. At the end of the 48 hours of controlled concentrations, another canister was used for CO₂ absorption using the standard CO₂ absorbent. The data on the canister is given in Table III as .25. The canister was the same size as the other lithium canisters used except for a difference in internal structure. (See Plates 1, 2, & 3 (A & B). The method of use was the same as for the loaded canisters except that the material was poured into the canister with the blower running. No irritable dust was apparent, however, the canister was not emptied at the end of the run when more difficulty would be experienced. Loading the cans with the blower running collects the dust of pouring and it is retained on the glass filter cloth.

19. The data taken during the dive on temperature and relative humidity have been recorded on Plates 6 and 7 respectively. The temperature is given as maximum and minimum values with a curve

drawn through the average values for the readings taken at a given time. The data on the moisture content of the atmosphere have been recorded as absolute humidity, with the maximum and minimum shown and the curve drawn through the average values of the readings taken at a given time.

20. During the dive no attempts were made to use the hand blower on either KOX or LiOH since it was desirable to use remaining canisters to extend the dive as much as possible rather than use them for comparison purposes. On return to the Laboratory, two canisters were compared, one on the hand blower and one on a standard blower. The data are shown on Plate 8. The CO₂ at one time was higher than desired and the flow on this sub-blower-canister was higher than normal, however, the two canisters compare satisfactorily. The final oxygen contents on the two samples were 8.2 and 10.5 cu.ft. total in sub-blower and hand blower canisters respectively. The total CO₂ absorbed in the same order was 30.1 and 28.6 cu.ft. This shows the efficiency of the materials will be approximately the same over a rather wide flow range, and the type of blower would make little, if any, difference.

GAS ANALYSIS APPARATUS

A. Carbon Dioxide

21 CO₂ analyses were made by two methods. Partial pressure was read on the Selective Gas Analyzer Mark VI and per cent CO₂ was measured on the Dwyer gas absorption analyzer. The Mark VI unit measures the infra red energy absorbed by the carbon dioxide in the atmosphere. It is accomplished by having twin light beams from a single source which fall on two thermopiles. In one light beam a filter of CO₂ is placed and the thermopiles balanced to zero reading on the current amplifier. Any energy absorbed in the second light beam throws the two piles out of balance electrically and the extent of unbalance determines the CO₂ content. The unit gives a continuous indication of the CO₂ content of the atmosphere.

22. The Mark VI gave satisfactory operation throughout the dive except that values were somewhat low. This was due in part to a failure during the calibration in the submarine, to set properly a known CO₂ percentage at a value suitably corrected for total pressure. Other features of the unit are as yet not completely satisfactory for naval use. One is the variation of reading with temperature, which can be eliminated or reduced to a negligible extent. A full report will be made on this unit after a further investigation of possible alterations, (ref. h).

23. Opportunity was taken during the subject test to try out

the F. W. Dwyer Co. carbon dioxide indicator recently adopted for use by the Navy, (ref. i, j, & k). Three different units were used, all of which had been previously checked for accuracy at this Laboratory. They were used throughout the test for the determination of carbon dioxide concentration in various parts of the submarine; the reported data was obtained with these instruments. Their accuracy was checked occasionally throughout the test with a Haldane Gas analysis outfit. The performance of all three units was found to be satisfactory in all respects:

B. Oxygen Analysis

24. Two units of the submarine model of the Pauling Oxygen Meter (ref. b) manufactured by the Arnold D. Beckman Laboratories, were used for the determination of oxygen partial pressure in the submarine throughout the test. One of the instruments was a model which has been supplied to the British Navy by this company for submarine use. The other was an earlier experimental model, (ref. 1). One was placed in the control room and one in the forward torpedo room where oxygen was being generated. The reported data on oxygen partial pressures throughout the test were obtained with these instruments, occasional checks on their accuracy being obtained by means of the Haldane Gas analysis outfit. The operation of these instruments also appeared to be completely satisfactory.

C. Hydrogen

25. Opportunity was also taken to try out the modification of the Mine Safety hydrogen eliminator described in ref. (m). The hydrogen concentration, however, did not come up to a high enough point that the eliminator would sustain itself without additional electrical heat. The concentration did not get over about 1.2% after 39 hours. The eliminator was run for about 14 hours, even though electrical heat was required to sustain temperature high enough to oxidize the hydrogen. After 14 hours the concentration was reduced to about 0.75% and the eliminator was shut off. The average flow was maintained at from 30 to 35 cfm. The Mine Safety installed hydrogen detector appeared to be functioning satisfactorily and checked the instrument used by the Laboratory.

DISCUSSION

26. The discussion of this report will be restricted to the three chemicals used on the test, i.e., chlorate candles, lithium hydroxide, and KOX.

27. Chlorate candles are highly efficient, easily handled units and of such size that storage on a submarine would not be

difficult. They are without the fire hazards displayed by alkaline peroxides, in that the decomposition can be stopped by wetting with water. In the present dive one candle when about one-third decomposed showed a bright red spot on the iron screen at the top. In the pure oxygen being evolved, the iron burned and ignited the tin-plate iron container which burned downward and around the side. Water was drawn from the drinking water faucet and poured over the candle which stopped the decomposition. Another was immediately started and the group of 26 decomposed without further mishap. The burning of any metal parts would be entirely eliminated by the use of brass or copper on a better protective coating on iron.

28. The cost of oxygen from such a source would be less than from other chemical sources. Thus there are no outstanding difficulties in the use of candles and are considered by the Laboratory to be a highly satisfactory method of carrying and producing oxygen.

29. Lithium hydroxide made in the pellet form has all of the desirable properties of the present service form and at the same time is of such size that the CO₂ laden atmosphere can be ventilated through storage containers. The efficiency of absorption is high as shown by Table III for the three percentage CO₂ concentration. For lower concentrations, efficiencies would be comparable, but greater time would be required to reach saturation. Were a similar arrangement to be used to maintain low concentration (0.5 to 1%) the use of more than two canisters at a time would be required. The data on rate of absorption at lower CO₂ concentrations is not yet known, but will be reported when available.

30. The standard CO₂ absorbent showed good results on efficiency of total saturation partially due to longer exposure. It is to be expected, however, that where air and CO₂ can be forced through a layer of the material, CO₂ absorption would be satisfactory. To permit sufficient air passage, a canister similar in type to that shown in Plate 3-B is necessary. The thickness of the layer of material in the canister is in general never more than 2" by the shortest air route. At the bottom end the path through the material would be somewhat greater. This is considered necessary to avoid having an appreciable amount of air by-passing the material along the outside wall. The only disadvantage to using the present material in blower canisters of this type is the loading and unloading of the canisters at the time of use. While it is possible to make up canisters of

this type which could be loaded and exchanged for those aboard, when ships are in port, and the recovered materials each time reloaded into new type canisters, the amount of time and effort required may outweigh the advantages. The ultimate solution to the CO₂ removal in submarines appears to be a suitable container of absorbent which can be placed in the ventilation system to be used and replaced as required. This type unit would most certainly require pelleted materials with the usual low pressure ventilation system. With higher stack pressure blowers, finer grain size absorbent could be used.

31. The average rate of CO₂ absorption on KOX canisters was 21.79 cu.ft./hour on canisters running for 1-1/2 hours. This showed on the average 87.6% saturation with carbon dioxide towards the formation of potassium carbonate. In a few cases over a 100% efficiency is shown on CO₂ absorption to the formation of potassium carbonate. This indicates that some bicarbonate formed and shows that bicarbonate formation is a possibility in the canisters which were less than 100% saturated towards the formation of carbonate. The KOX analysis at the time of loading the material gave approximately 227 cc of oxygen per gram. This would give approximately 54-1/2 cu.ft. of oxygen per canister or a total of 2400 cu.ft. of oxygen available in the 44 canisters used for the 24 hour period. From the oxygen curve on Plate 4, considering the loss of pressure it is difficult to tell the oxygen content in the submarine. However, from the CO₂ absorbed during this period which was 1445 cu.ft. with Respiratory Quotient of .83, the oxygen required would have been 1740 cu.ft. where the oxygen concentration remained constant in the submarine. Calculated on this basis, approximately 72.8% of the oxygen would have been liberated, however, the loss in pressure from the boat makes the value of such a calculation questionable.

CONCLUSIONS

32. From the data presented in this report it can be concluded that the removal of carbon dioxide can be easily affected in a submarine by rather simple blower apparatus and canisters of either lithium hydroxide pellets or KOX. Where the concentration of CO_2 was 3% the evolution of carbon dioxide by 90 men was absorbed by two canisters of lithium hydroxide or three canisters of KOX, operating simultaneously. From previous work at the Laboratory, it is known that for much lower concentrations (1/2 to 1%) more canisters of either lithium hydroxide or KOX would be required to remove an equal amount of carbon dioxide per unit of time.

33. For the evolution of oxygen, chlorate candles showed an efficient and satisfactory process where approximately 1/3 of the total weight of material carried was available oxygen. The KOX also maintained a satisfactory oxygen level and approximately 25 to 30% of the total weight is available oxygen. However, the total oxygen available may not be obtained in the operation since it would be inefficient to completely react all of the KOX. The best available indications are that from 75 to 90% of the oxygen would be obtained under the varying conditions under which it might be used.

34. Hazards in operation have been eliminated almost completely in the operation for either the chlorate candles and lithium hydroxide or the KOX as used in this dive. Possible hazards are much greater in the case of KOX than the other method. Broken canisters of KOX would be a more serious menace than the broken products of either of the others. Punctured canisters into which oxidizable materials could enter would in the case of KOX cause a hazard, in that serious fire or rapid evolution of oxygen and combustion products could disrupt the canisters and spread the oxidizing material. In the case of the chlorate in the present form, hazards of this type have not been found and it is believed they do not exist. Canisters containing chlorate candles in which organic materials were present would burn with high temperature if at all, and in all probability would evolve an appreciable amount of carbon monoxide. However, it is believed that such canisters would never be used where satisfactory safeguards were present.

RECOMMENDATIONS

35. Considering information obtained on this submarine dive and that available at the Laboratory, either system (KOX or lithium hydroxide and chlorate candles) can be recommended for satisfactory purification of air aboard submarines. The chlorate candle-lithium hydroxide system is more highly recommended at the present because of greater efficiency and less potential fire hazards. It is also recommended that investigations and development be carried out to place the purification units in the ventilation system of the submarine or into a separate system built into the submarine as an integral part.

REFERENCES

- (a) NRL Report P-1691 of February 4, 1941. "Absorption of Carbon Dioxide and Liberation of Oxygen From Alkali Oxides on the Submarine USS S-30".
- (b) NRL Report P-1986 of January 15, 1943. "A Study of the Pauling Oxygen Meter Toward Its Possible Adaptation to Naval Use".
- (c) OSRD Report #5004 of May 31. "Selective Gas Analyzers".
- (d) NRL Letter Report to BuShips, C-SS/S38 (452-WS) Serial 452-56/45 dated May 11, 1945. "Submarine (Air) Purification Using Lithium Hydroxide Canisters and Chlorate Oxygen Candles".
- (e) NRL Letter to BuAer, JC10 (452) of August 17, 1943. "Oxygen Producing KOX Chemical - Specifications for and Availability".
- (f) NRL Report P-1904 of July 11, 1942. "Use of the Alkali Oxide in Canisters For Submarine Air Purification".
- (g) Problem P-14 of January 31, 1933. "Submarine Air Purification".
- (h) A report is also being prepared by Johns Hopkins on OEM S-178 contract covering the research work on the development of the MK VI Analyzer.
- (i) NRL Report P-1877 of July 6, 1942. "A Study of the Dwyer Friez 0-to-5% CO₂ Indicators to Determine Their Suitability for Naval Use".
- (j) NRL Letter JC6/S87 (454-MHB) to S.W. Dwyer Co., Chicago, Ill. of January 27, 1945. "CO₂ Indicator Absorption Type, Inspection of Production Model".
- (k) NRL Letter JC6/S87 (454-MHB) of May 2, 1945, to BuShips. "Dwyer CO₂ Indicator #800, Inspection of Final Production Model".
- (l) NRL Letter C-JC10/S87-1 (454-MHB) of March 17, 1944 to BuShips. "Performance Tests of Pauling Oxygen Meter".
- (m) NRL Report P-2178 of March 24, 1944. "Further Studies on the MSA Hydrogen Eliminator V".

TABLE I

Date and Time	Pressure (mm)	% CO ₂ Determined on			% O ₂ Determined on	
		Haldane	Dwyer	M-6	Haldane	Pauling %
5/25/45						
0605	772		.22			20.4
0620						
0700	774		.3			20.3
0705	774		.3			20.1
0755	777		.4			19.9
0755		.5	.5		20.	
0800	778		.5			19.9
0900			.6			19.6
0915				.765		
1000	783		.9			19.25
1000	783		.9			19.4
1055				1.14		
1100	788		1.2			18.85
1200				1.58		
1200	790		1.5			18.7
1200	791		1.5			18.6
1220		1.6			19.2	
1300			1.8	1.76		
1300	794	1.8				18.3
1400	796		2.0			18.0
1400			2.0	2.26		18.0
1420		2.03	2.03	2.27	(17.3 (17.5 (16.7	17.7
1500	850		2.3			17.6
1530	863	2.4	(2.6	2.50	17.3	17.4
1600			2.4	2.66		
1630		2.4	2.3			
1645	806		2.3			17.3
1700			2.3			17.3
1730				2.16		
1800	806		2.6			17.3
1810		2.56	2.6	2.26	18.0	17.2
1815	806		2.6			17.2
1900	810		(2.7 (2.7			17.1
2000	811	2.94	2.9	2.47	16.8	16.8
2010	811	2.9	2.9		16.8	16.7
2100	813		2.8			16.9
2130	816		2.9	2.46		16.95

TABLE I (Cont'd)

Date and Time	Pressure (mm)	% CO ₂ Determined on			% O ₂ Determined on	
		Haldane	Dwyer	M-6	Haldane	Pauling %
2200	816		2.9			16.95
2230	816		2.8	2.46		16.95
2300	816		2.7	2.35		17.1
2304	814					
2308	809					16.9
2315	808					
2320	813					
2330	816		2.9	2.45		16.95
2345	813		2.8			17.0
2400	813		2.6			17.2
5/26/45						
0010			2.6	2.45		
0100			2.6			
0115			2.9			
0155	817		2.5			17.1
0215			2.7			
0220			2.8			
0350	820		2.8			17.2
0400	822		2.7			17.1
0420	821		2.9			17.1
0500	822		2.7			17.1
0630	824		2.8			17.3
0735	824		2.4			17.3
0800	825		2.8			17.4
0900	825		2.8	2.36		17.6
0915			2.7	2.27		17.6
0925			2.5	2.27		
1000	826		2.7			17.5
1100	827		2.7			17.6
1155	827		2.6			17.6
1230	828		2.7			17.4
1330	828		2.4			17.4
1430	828		2.7	2.05		17.5
1530	828		2.5	2.05		17.5
1600	828		2.5			17.5
1630	828		2.5	2.00		17.5
1730	828		2.7	2.11		17.7
1830	828		2.7	2.05		17.6
1930	828		2.6	2.11		17.6
2035	828		(2.9)	2.41		17.2
			(3.0)			
2130	828		2.9			17.2

TABLE I (Cont'd)

Date and Time	Pressure (mm)	% CO ₂ Determined on			% O ₂ Determined on	
		Haldane	Dwyer	M-6	Haldane	Pauling %
2230	828		3.0	2.67		17.1
2300	828		3.2	2.90		17.1
5/27/45						
0015	828	2.76	3.0		17.35	17.0
0030	828		2.85	2.91		16.9
0130	828		2.8	2.54		17.0
0230	828		2.7	2.17		17.5
0330	828		2.7	2.17		17.7
0400			2.9	2.41		
0430	828		2.3	1.83		17.9
0455	828		2.1	1.69		18.4
0523	828		1.9	1.57		18.5
0525				1.69		
0545				2.00		
0600	828		2.4	1.97		(16.6
						(17.5
0630	790		2.5			16.7
0730			2.8	1.77		
0900	795		2.7	1.89		17.0
1000	800		2.5			16.7
1120		2.67				
1140	815		2.4			16.9
1830	824		2.6			17.2
2125	783		2.9	2.00		16.0
2200	785		3.0			16.2
2230	787		3.0	2.00		16.9
2330	789		2.7	2.31		16.5
2400	790		3.1			16.5
5/28/45						
0030	792		3.1			15.8
0100	792		3.3			15.6
0145	792		3.3			14.7

TABLE II
CO₂ SAILFISH
May 24, 25, 26, & 27

Date and Time	Forward		COC	Pump Room	After Batt.	Forward Engine	After		Average Values
	Torp.	Batt.					Eng.	Torp.	
5/25/45									
0700	0.3								
0800	0.5	0.5	0.5	0.8	0.5	0.6	0.55	0.7	.57
1000	0.9	1.0	1.3	1.3	1.2	1.1	1.00	1.2	1.13
1200	1.5	1.6	1.6	1.6	1.8	1.3	1.25	1.3	1.5
1400	2.0	1.9	2.3	2.1	2.3	2.0	1.7	1.9	2.04
1530	2.4	2.5	2.5	2.6	2.5	2.0	1.9	2.0	2.3
1700	2.3	2.4	2.3	2.4	2.6	2.5	2.5	2.4	2.4
1815	2.6								
1900	2.7		2.8						2.75
2010	2.9	3.1	3.1	3.2	3.1	3.1	3.0	3.1	3.07
2230	2.8	3.1	3.3	3.3	3.2	3.1	3.1	3.1	3.12
5/26/45									
0100	2.6	2.6	2.9	2.9	3.0	3.0	3.0	2.9	2.86
0400	2.7	3.0	3.0	2.9	3.1	3.1	2.8	3.0	2.95
0800	2.8	3.1	3.1		3.1				3.00
1230	2.7	2.9	2.9	3.0	3.1	3.0	3.0	3.1	2.96
1600	2.5	2.9	3.0	2.9	3.4	3.1	3.2	3.3	3.00
1930	2.6	2.9	3.3	3.2	3.3	3.2	3.2	3.4	3.10
2300	3.2	3.5	3.4	3.4	3.5	3.5	3.4	3.5	3.40
5/27/45									
0015	3.0								
0030	2.85								
0130	2.8	3.3	3.4	3.4	3.4	3.3	3.4	3.3	
0525	1.9								
0600	2.4	2.5	2.8		3.1	3.0	3.1	3.3	2.88
0630	2.5								
1000	2.5	2.7	2.9	2.8	2.8	2.8	2.9	3.0	2.80
1440	2.9	2.8	2.7		2.9	3.0	3.0	3.0	2.80
1830	2.6	2.6	2.7		2.7	2.9	2.9	2.9	2.75
2200	3.0	3.0	3.3		3.1	3.3	3.1	3.6	3.20
2400	3.1	3.1	3.1		3.1	3.1	3.2	3.3	3.10

Starting with 0800 to 1530 on 5/25/45 the following were the CO₂ Values in the Radio Shack for the times given above:
0.5, 1.2, 1.6, 2.2, and 2.6.

TABLE III

CO₂ ABSORBED BY LITHIUM HYDROXIDE CANISTERS

Canister No.	Total CO ₂ Absorbed (cu.ft)	Duration of use (Hrs.)	Average CO ₂ Abs./Hrs. (cu.ft)	% of Theoretical
1	58.56	2	29.28	81.
2	58.32	2	29.16	91.
3	56.86	2	28.43	79.
4	63.42	2	31.71	88.
5	70.96	3	23.60	98.5
6	71.93	3	24.00	100.
7	65.61	2.33	28.10	91.
8	71.68	2.33	30.8	99.5
9	71.44	1.5	28.5	99.2
10	63.91	2.25	28.4	88.8
11	61.24	2.5	24.5	85.
12	68.53	2.25	30.4	95.
13	65.37	2	32.68	91.
14	58.32	2.25	25.9	82.
15	62.21	2	31.10	86.5
16	67.55	2	33.77	94.
17	63.67	2	31.83	98.5
18	66.82	2	33.41	93.
19	67.31	2	33.65	93.5
20	69.25	2	34.62	96.
21	65.61	2.08	31.4	
22	52.00	1.08	43.0	

Canisters 23, 24, and 25 were used on May 27.

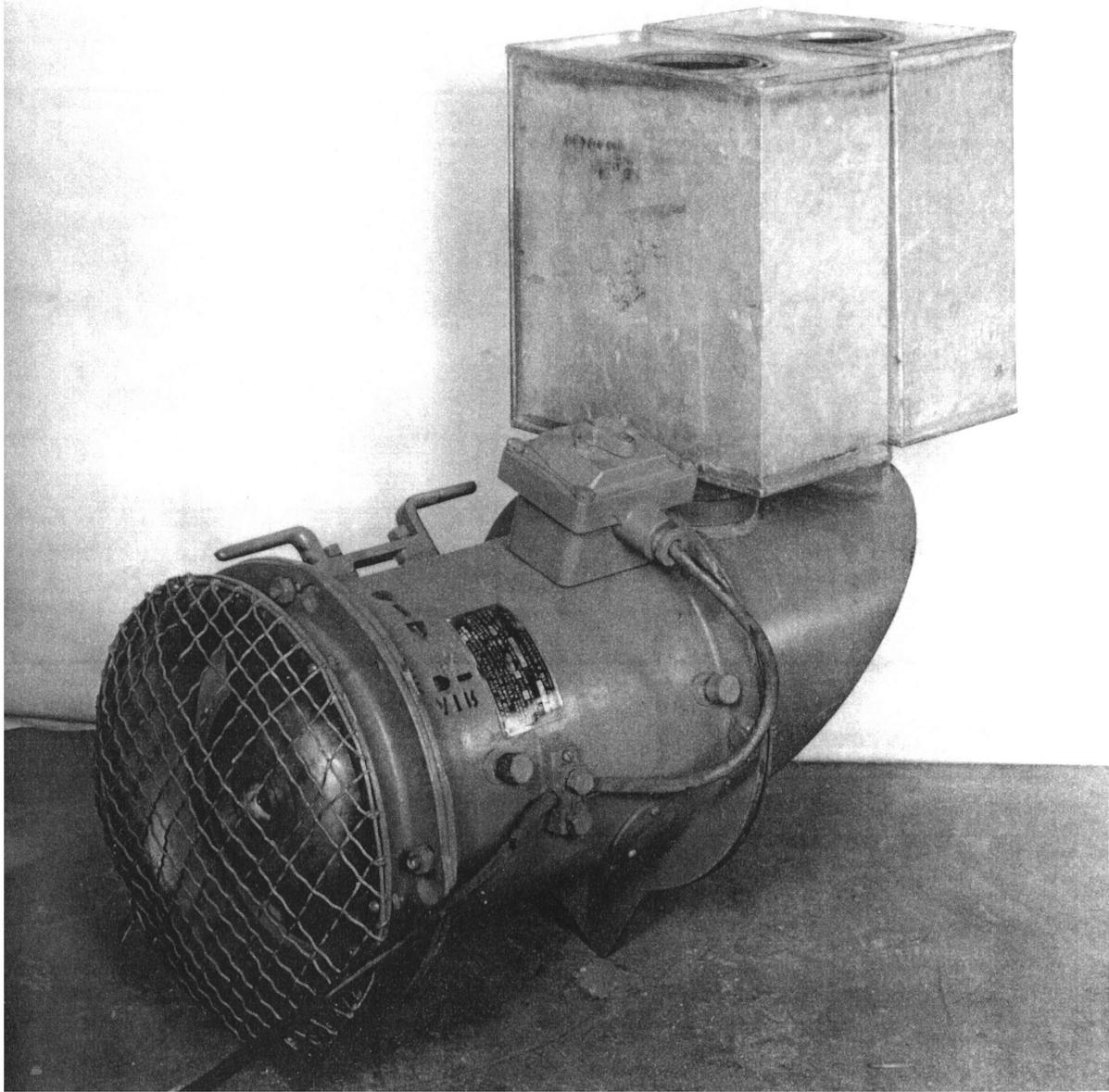
23	61.23	2	30.61	90.0
24	59.53	2	28.76	87.4
25*	61.72	4	15.43	99.7

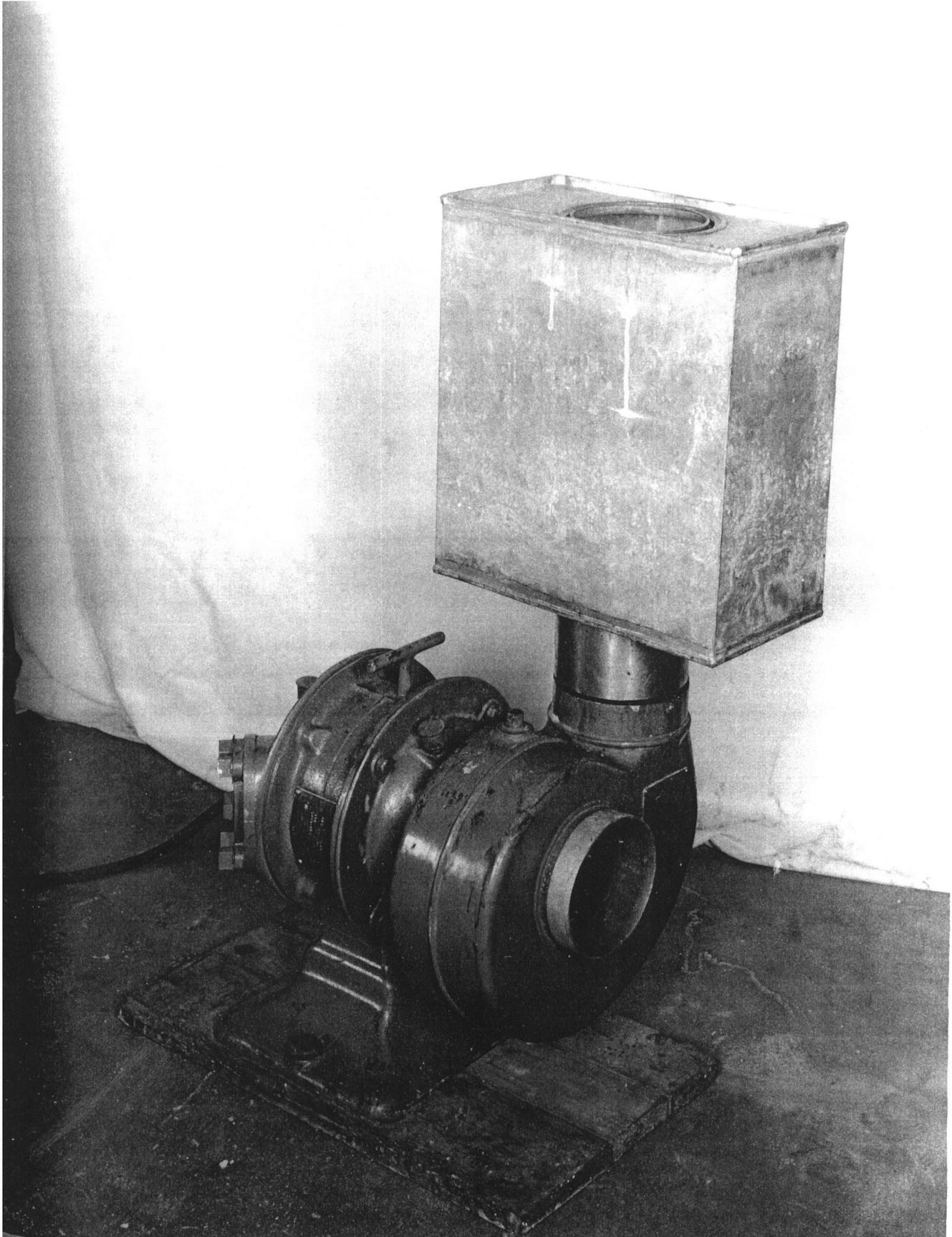
* No. 25 Contained Standard CO₂ Absorbent.

TABLE IV

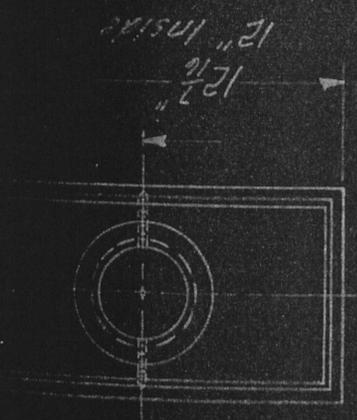
CO₂ ABSORBED BY KOX CANISTERS

<u>Canister No.</u>	<u>Total CO₂ Absorbed (cu.ft)</u>	<u>Duration of use (Hrs.)</u>	<u>Average CO₂ Abs./Hrs. (cu.ft.)</u>	<u>% of Theoretical to Carbonate</u>
1	32	1.17	27.5	85.
2	31	1.25	24.8	81.
3	38	1.17	32.8	98.3
4	38	1.5	25.3	99.5
5	33	1.5	22.0	87.
6	36	1.5	24.0	88.2
7	35	1.5	23.4	96.0
8	34	1.5	22.7	95.4
9	36	1.5	24.0	102.5
10	35	1.5	23.4	97.8
11	33	1.5	22.0	93.2
12	37	1.5	24.7	96.6
13	35	1.5	23.4	85.
14	30	1.5	20.0	84.
15	28	1.5	18.0	77.8
16	33	1.5	22.0	82.4
17	30	1.5	20.0	83.5
18	37	1.5	24.7	103.5
19	33	1.5	22.	81.8
20	29	1.5	19.3	76.6
21	34	1.5	22.7	83.4
22	30	1.5	20.0	83.6
23	33	1.5	22.0	86.0
24	30	1.5	20.0	84.0
25	30	1.5	20.0	83.6
26	33	1.5	22.0	86.8
27	31	1.5	20.7	81.6
28	29	1.5	19.3	82.8
29	29	1.5	19.3	76.3
30	32	1.5	21.3	90.3
31	36	1.5	24.0	86.3
32	31	1.5	20.7	84.4
33	33	1.5	22.0	84.1
34	33	1.5	22.0	89.9
35	35	1.5	23.4	95.3
36	37	1.5	24.7	97.3
37	32	1.5	21.3	91.1
38	31	1.5	20.7	87.5
39	26	1.5	17.3	70.8
40	33	1.5	22.0	93.2
41	32	1.5	21.7	87.1
42	36	2.83	12.7	101.6
43	36	2.5	14.4	94.7
44	36	2.	18.0	98.0

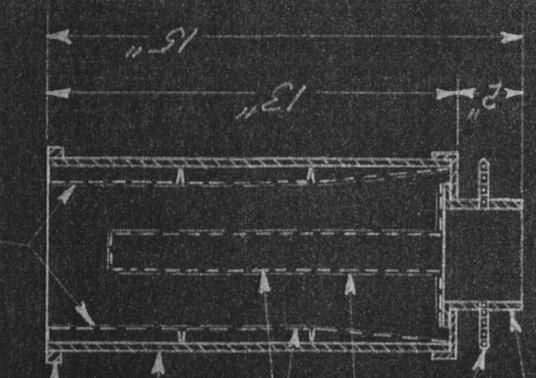




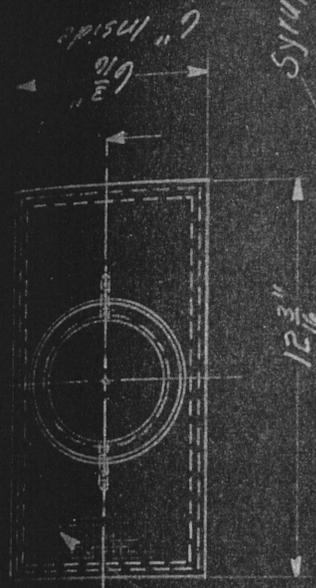
Spot Welded And Soldered Connections



32 Mesh Screen

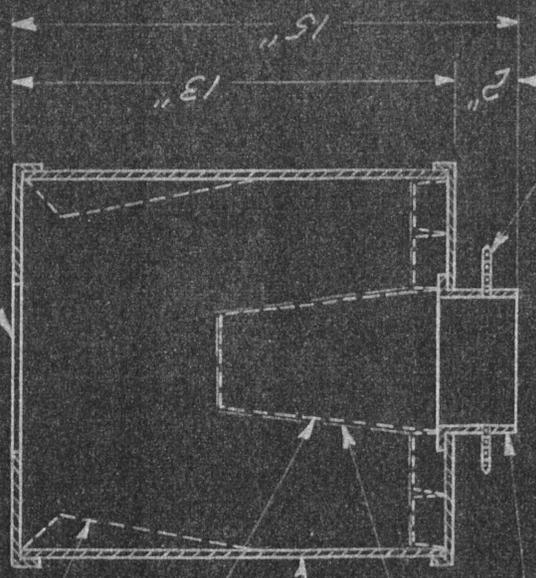


Canister B
Powdered Material



Syrup Can Lid
Spot Welded Here

14 Mesh Screen

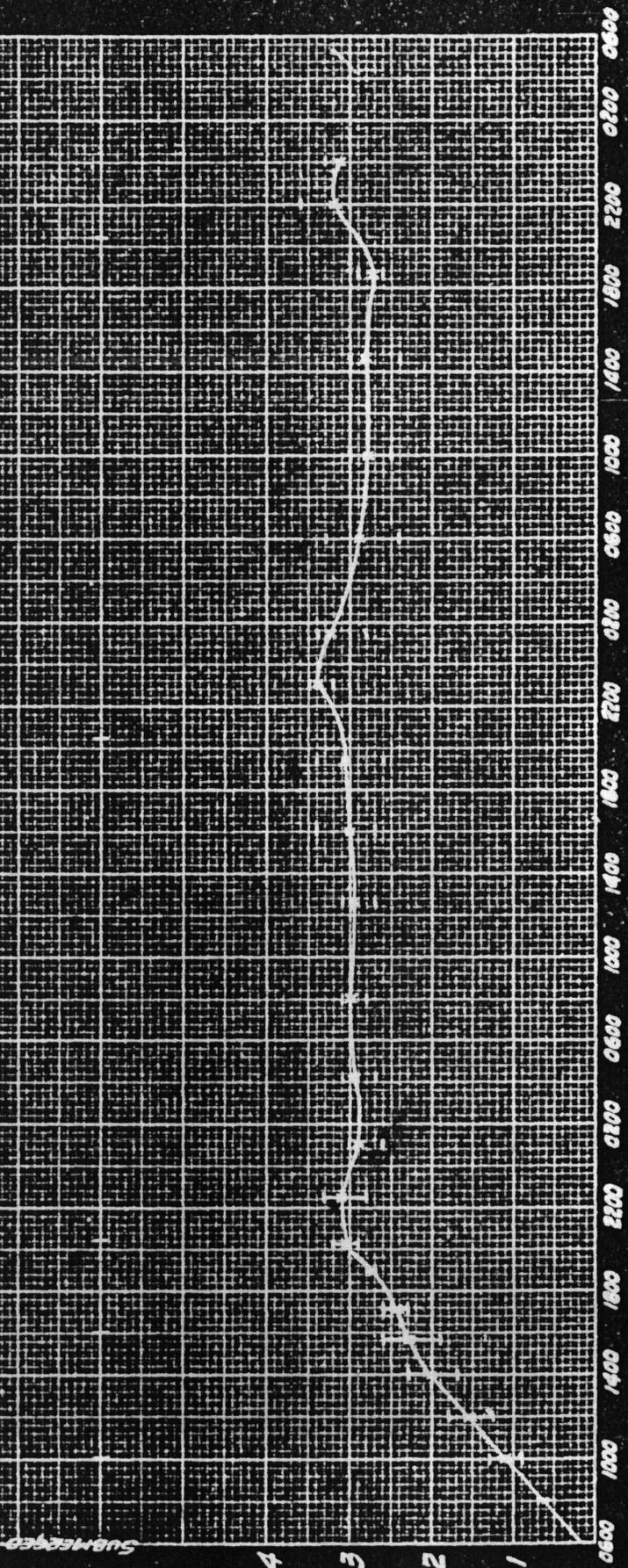


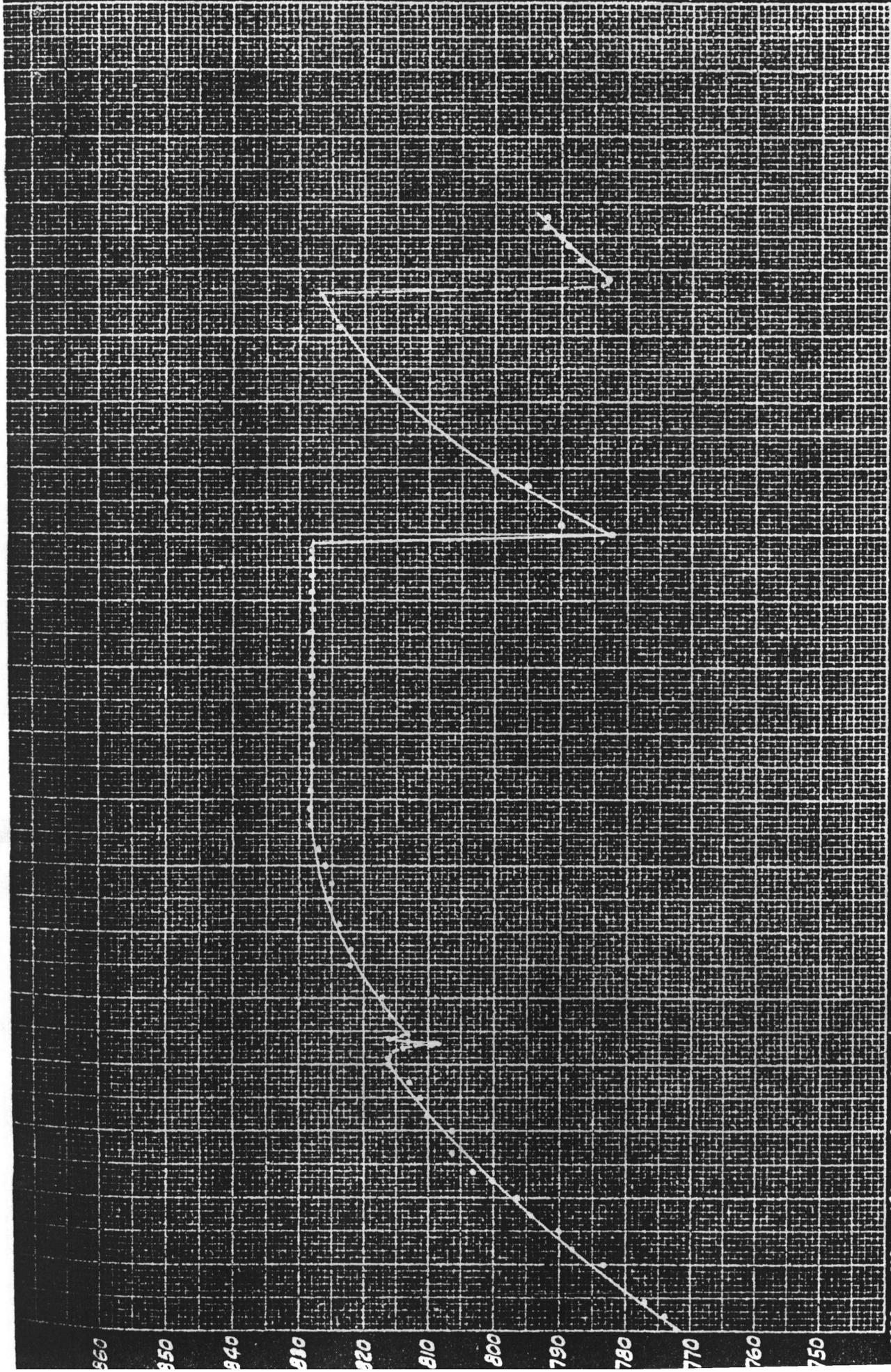
Canister A
Palletted Material

U. S. NAVAL RESEARCH LABORATORY		SCALE 1" = 6"
WASHINGTON 20, D. C.		DR'WN.
B'LD'G.	PHONE	CH'K'D.
ROOM	DATE	APPR'VD.

UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

CO₂ IN U.S.S. SAILFISH 25, 26 AND 27 MAY 1945
 MAXIMUM AND MINIMUM VALUES ARE SHOWN AND A CURVE DRAWN THROUGH
 THE AVERAGE OF THE CO₂ VALUES FOR ALL COMPARTMENTS
 (THE AVERAGE VALUES ARE NOT QUANTITATIVE AVERAGES, BUT THE AVERAGE VALUES TO WHICH
 PERSONNEL WAS EXPOSED IN MOVING FROM END TO END IN THE BOAT)





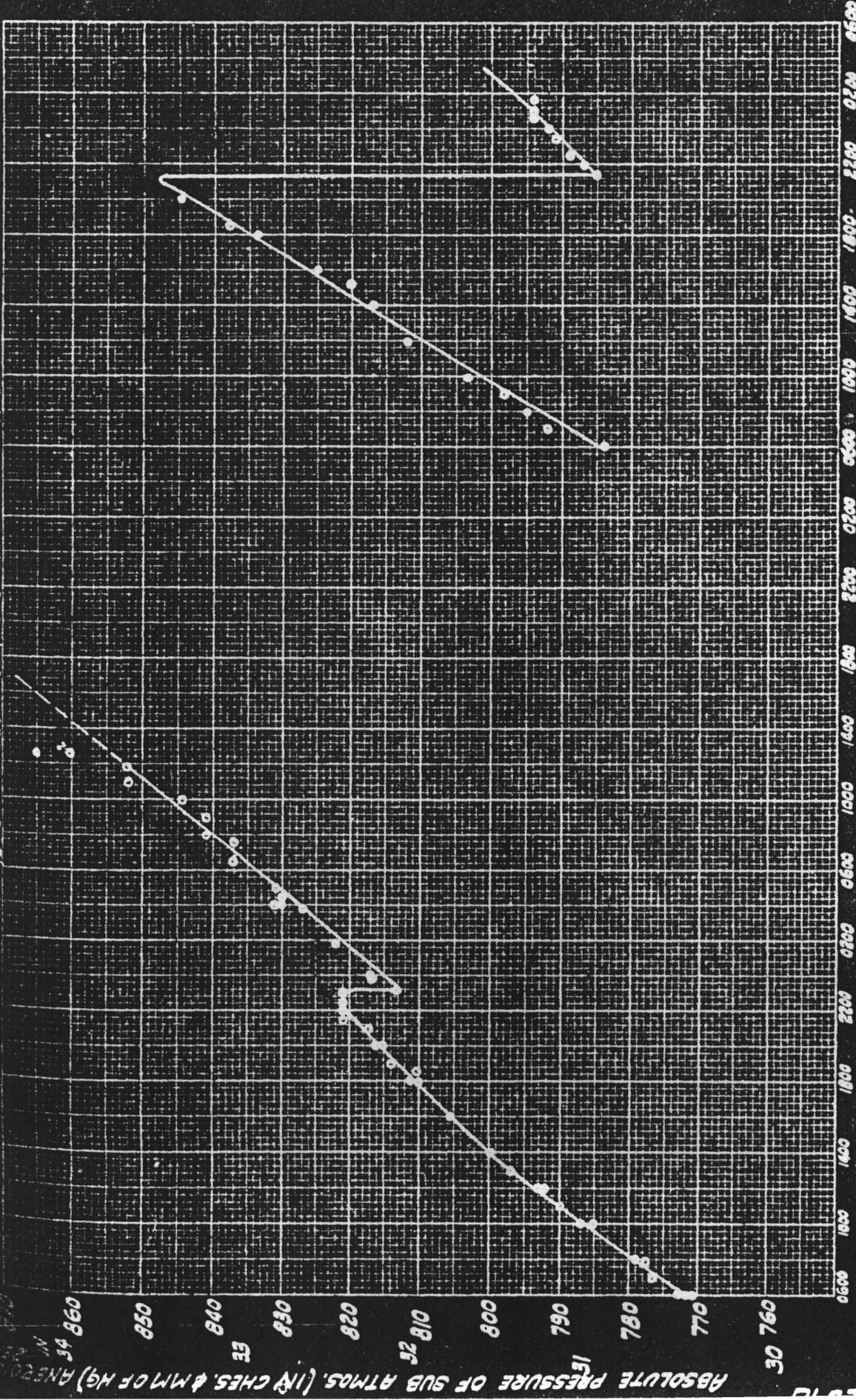
0600 0800 1000 1200 1400 1600 1800
5-28-45

0600 0800 1000 1200 1400 1600 1800
5-27-45

0600 0800 1000 1200 1400 1600 1800
5-26-45

0600 0800 1000 1200 1400 1600 1800
5-25-45

BAROMETER READINGS CORRECTED FROM A CALIBRATION CURVE

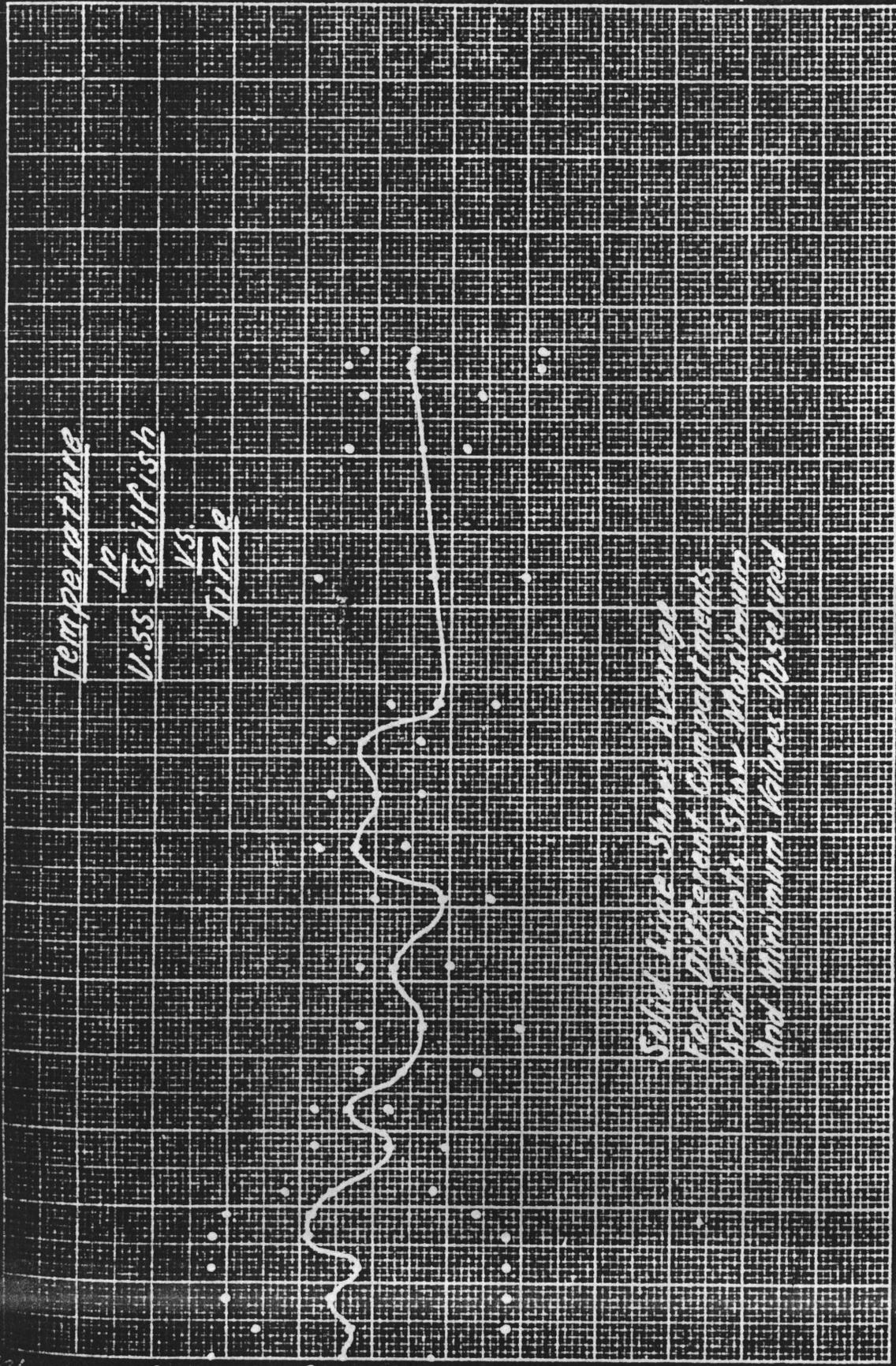


5/25/45

5/26/45

5/27/45

5/28/45



Temperature
in
U.S.S. Sailfish
vs
Time

Solid Line Shows Average
For Different Compartments
and Points Show Minimum
and Maximum Values Observed

Time (Hours)

100

90

80

Temp. (°F)

60

50

40

PLATE 6

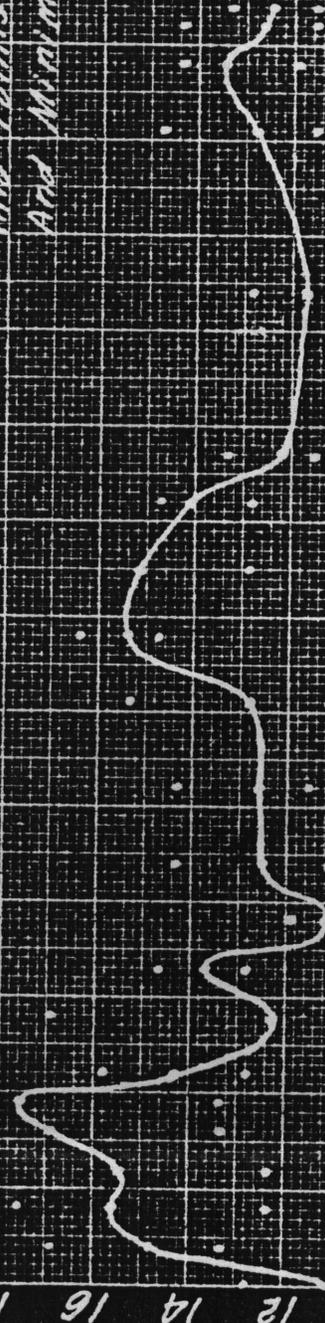
Absolute Humidity
in
USS Sailfish
vs
Time

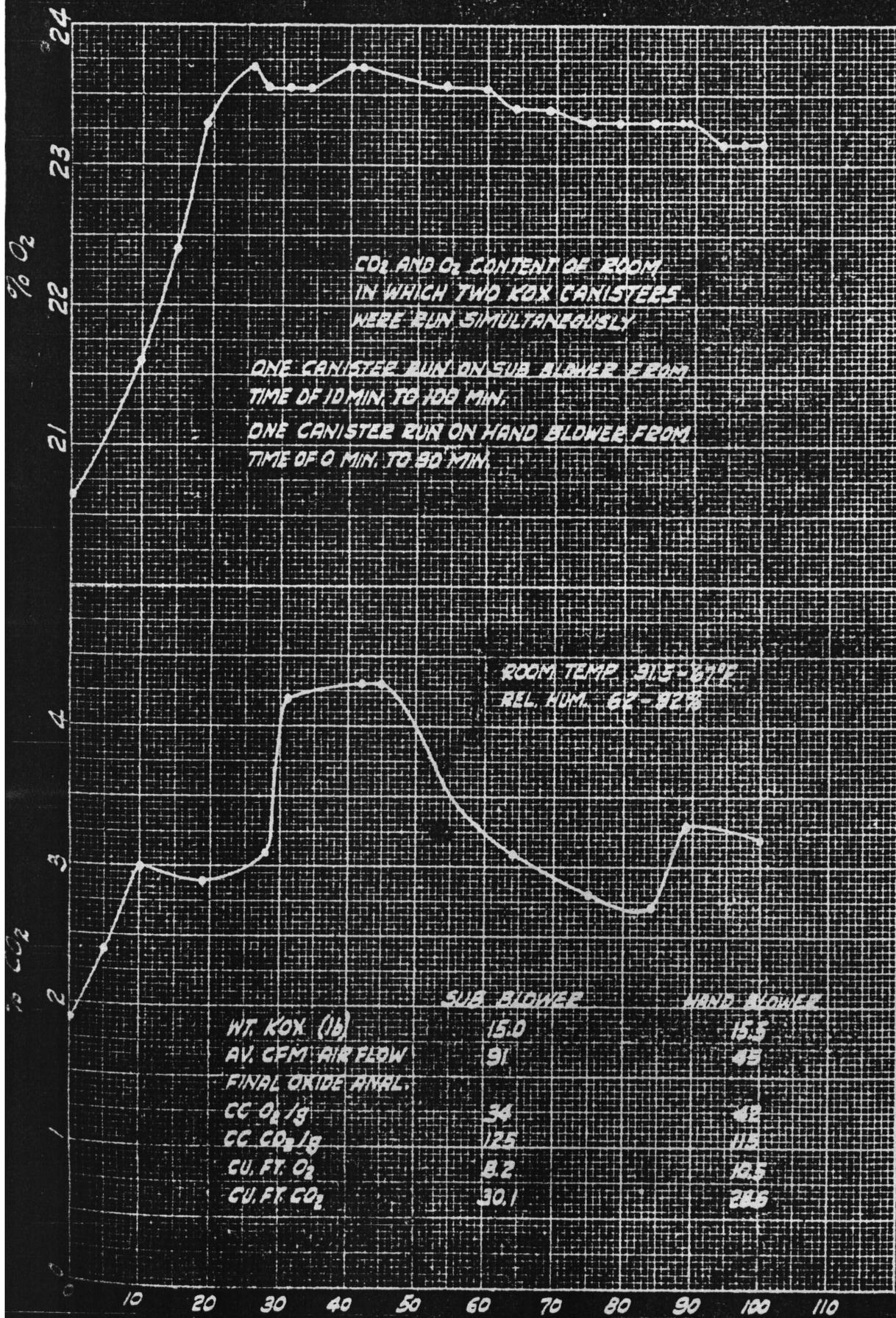
Solid Line Shows Average
For Different Compartments
And Points Show Maximum
And Minimum Values Observed

Abs. Humidity (mm Hg)
4 6 8 10 12 14 16 18 20 22 24 26

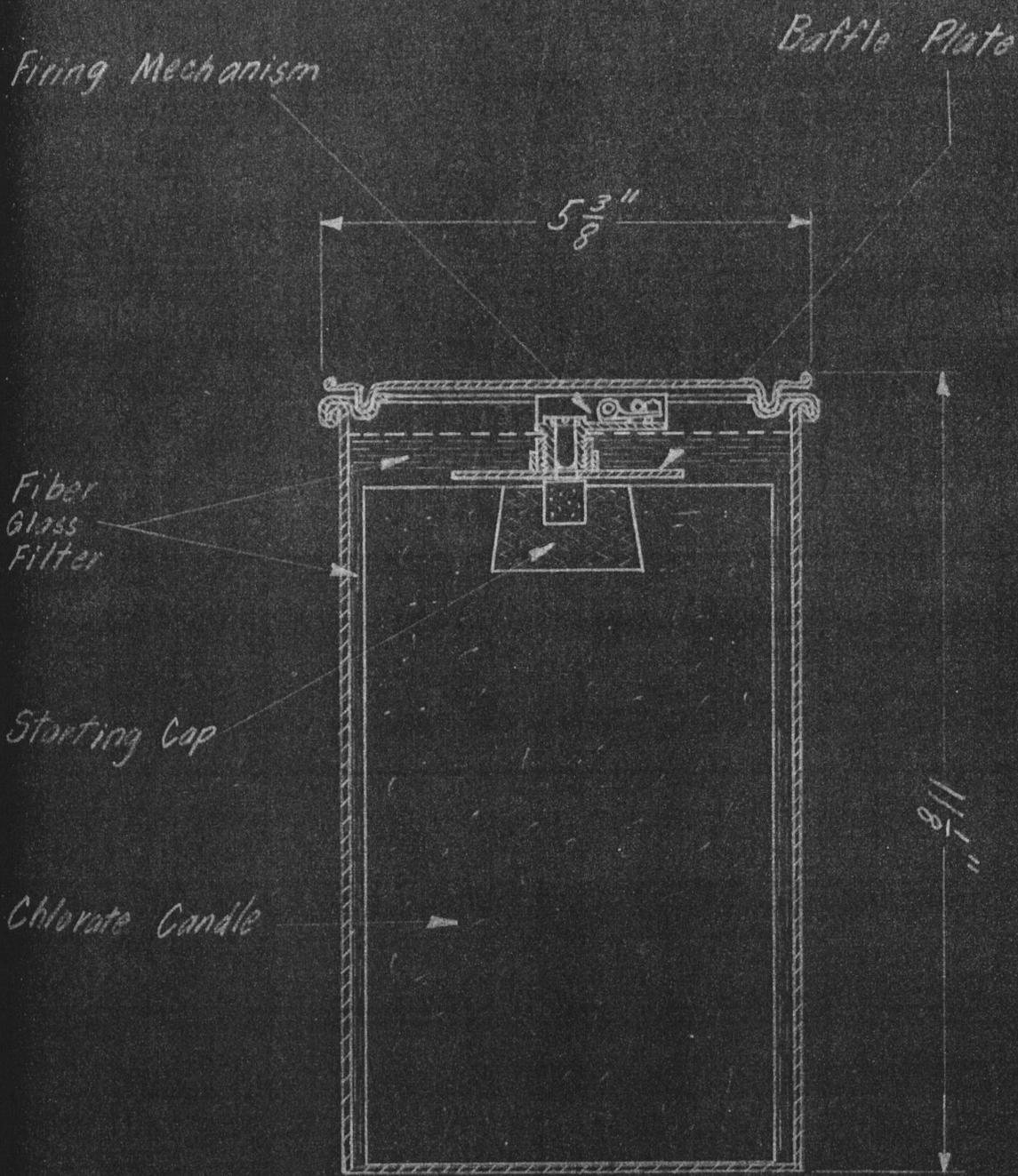
Time (Hours)

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80





TIME (MIN.)



SUBMARINE CHLORATE CANDLE ASSEMBLY

PAULING READINGS
O₂ IN MM OF HG

PLATE 10

CONTROL STARTED

LIGHT CANDLES OFF

KOX OFF

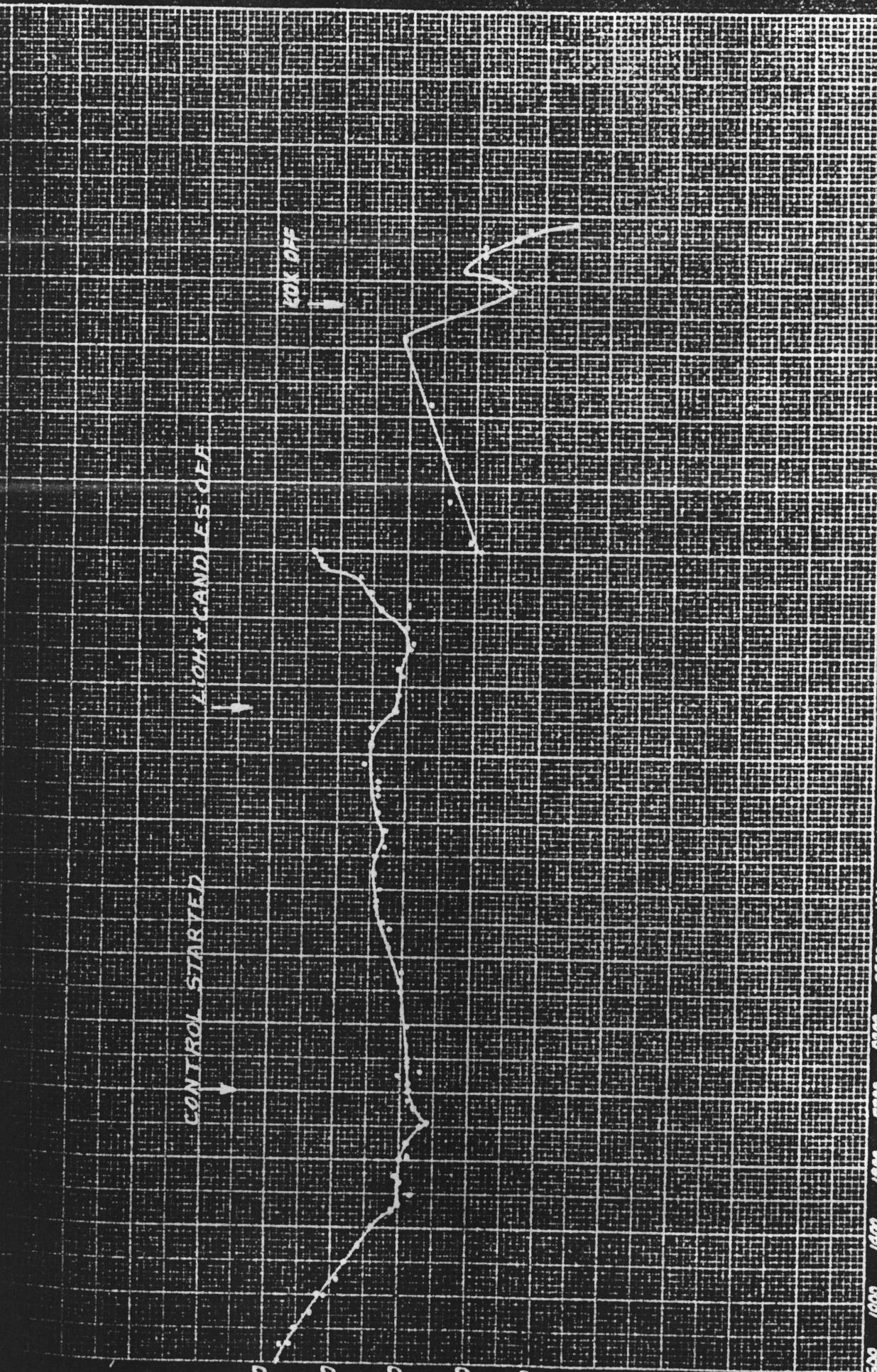
0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000

5-25

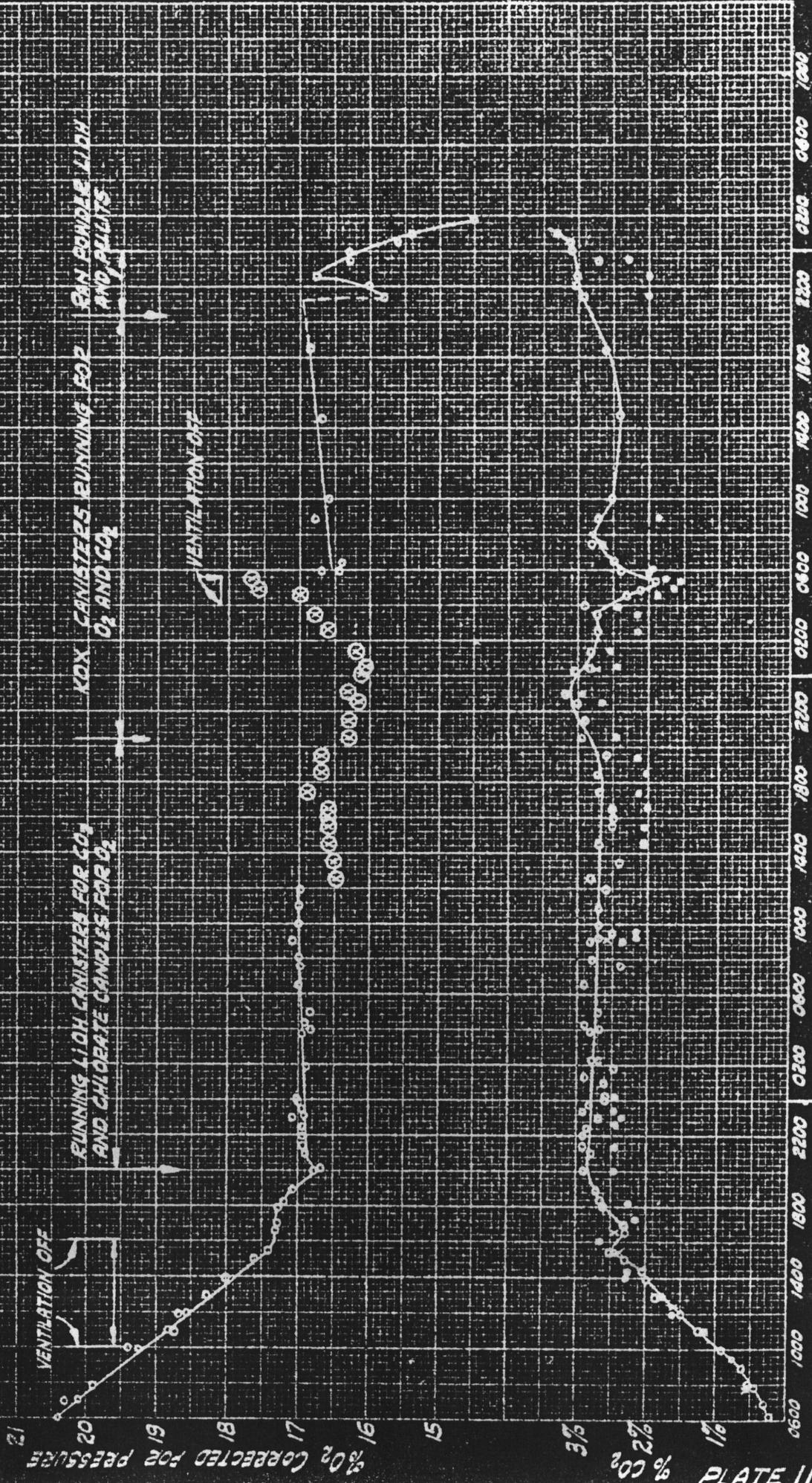
5-26

5-27

5-28



OXYGEN AND CARBON DIOXIDE DETERMINED IN THE FORWARD TORPEDO COMPARTMENT
 CORRECTED FOR PRESSURE EXCEPT FOR VALVES MARKED ③



5-28

5-27

5-26

5-25

DISTRIBUTION

BuShips	(5)
BuAero	(3)
Med. Res. Dept. New London, Conn.	(2)
BuMed, Wash. D.C.	(2)
OR&I	(2)