UNCLASSIFIED

AD NUMBER: ADB966248
LIMITATION CHANGES
TO:
Approved for public release; distribution is unlimited.
FROM:
Distribution authorized to U.S. Government agencies and their contractors; Administrative or operational use; 28 Mar 1946. Other requests shall be referred to Naval Reseach Laboratory, Washington, DC 20375.
AUTHORITY
ST-A PER NRL (Code 2627) ltr, 5 Dec 1990.

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER

B966 248

CLASSIFICATION CHANGES

TO

FROM

AUTHORITY

NRL (code 2627) ltr,
5 Dec 90

THIS PAGE IS UNCLASSIFIED

Copy No. #1-A

(1)

[redacted]

March 28, 1946

RECLASSIFIED BY AUTHORITY OF
Code 207 ltr Ser. 207-23
dated 3/20/59
By BuShips Code 238. C. Lutz ....
Date: 3-23-59 (Signature)

MEMORANDUM TO DIRECTOR

ATOMIC ENERGY SUBMARINE

by

Dr. Phillip H. Abelson, Head, Special
Research Section

Robert E. Ruskin

Chad J. Raseman, Lt. (jg) USNR

Approved by:

Dr. Ross Gunn
Superintendent
Mechanics & Electricity Division

H. A. Schade, Commodore, US
Director
Naval Research Laboratory

Page a of 27 pages, plus a-c
Copy 1 of 6 copies

[redacted]

TABLE OF CONTENTS

[redacted]

ATOMIC ENERGY SUBMARINE

PART I

GENERAL CONSIDERATIONS

1. Summary

A technical survey conducted at the Naval Research Laboratory indicates that, with a proper program, only about two years would be required to put into operation an atomic-powered submarine mechanically capable of operating at 26 to 30 knots submerged for many years without surfacing or refueling. In five to ten years a submarine with probably twice that submerged speed could be developed.

Design and calculations are based on known performance and power requirements of the "Walter" submarines. The principal research and development work needed immediately for this program is to perfect an atomic pile designed for this power application.

2. History of Project

The Naval Research Laboratory has had for a number of years a project on "Submarine Submerged Propulsion" and also a series of projects on uranium preparation and isotope separation. As early as 1939 it was realized by Dr. Ross Gunn of this Laboratory that energy from Uranium 235 should eventually be applicable for submerged propulsion. Accordingly, work toward this ultimate objective was begun in 1940. The Bureau of Ships since that time has continually maintained a project at the Naval Research Laboratory working toward ultimate development of such a propulsion system. For the past several years the work on submerged propulsion systems themselves has been deferred for the necessary preliminary work on Uranium isotope separation.

During the war the decision was made to divert temporarily the Navy Uranium project from its original objective of submarine propulsion to the more immediately urgent work of completing an atomic bomb. This decision has since proved to be fruitful inasmuch as the completion of the atomic bomb was aided. Simultaneously the Manhattan District contractors, in developing the Plutonium piles, have learned enough about piles so that an energy pile for Naval use would require much less design work for application in submarine propulsion than would otherwise have been the case.

3. Present Project at Naval Research Laboratory

In order to evaluate the present state of development of the atomic energy field and to formulate a program for expeditious completion of a working submarine, Rear Admiral T.A. Solberg of the Bureau of Ships, Dr. Ross Gunn and Dr. P.H. Abelson of the Naval Research Laboratory, have visited parts of the Manhattan District projects at Oak Ridge, Chicago, and Hanford. Dr. Abelson has spent the past several months working at the Clinton Laboratories, Oak Ridge, as the Navy's only representative in power work. Based on our earlier studies and influenced by the visits thus made, three projects have been going forward at the Naval Research Laboratory as follows:

(a) Separation of isotopes of various metals for construction of more efficient atomic piles for Naval use.

(b) Research on new methods of isotope separation for possible less expensive methods of concentrating U235 for atomic energy use by the Navy.

(c) Survey of problems and engineering analysis involved in the design of an atomic-powered submarine.

Due to the uncertainties of atomic energy legislation pending in Congress, the principal expenditure of funds for material so far has been in setting up equipment for (a) and (b) above for a flexible program such that the research to be performed using this equipment can continue to produce useful results regardless of what legislation may be passed; viz., the same setup can be used for (1) tracer studies in metallurgy and medicine; (2) atomic pile structural materials with presently unavailable nuclear characteristics; or (3) separation of Uranium isotopes, depending on what restrictions are imposed as a result of Congressional legislation.

4. Conclusions from Naval Research Laboratory Survey

In connection with the submarine survey of (c) above and in order better to analyze the problems involved in developing an atomic-powered submarine for high speed long range submerged use, a suggested design has been worked out and is presented later in this report. As a result of this survey the conclusion has been reached that a submarine with an indefinite range, submerged at a speed of 26 knots or higher, can be developed, built, and ready for operational tests within about two years provided: (1) sufficient priority is given this work by the Navy, the President, and the Manhattan District; and provided: (2) that the present cooperation between the Manhattan District and the Navy is expanded somewhat to permit greater emphasis on and Naval participation in design and construction of a Uranium pile of proper characteristics for this application.

It is estimated that the atomic submarine herein proposed could be improved in five to ten years such that it could operate for sustained periods at submerged speeds of forty to sixty knots or higher, using a jet system for propulsion. This development would require radical modification of hull design and many mechanical features that are at present untried, hence would require extensive research.

5. Proposed Design

In the design sketched in the present report, principal emphasis has been placed on conservative design, using presently available, well-tested equipment as far as practical. On this basis the only hulls available at present for submerged speeds as high as 26 to 30 knots are those of the German "Walter" submarines. These hull designs can undoubtedly be greatly improved, but to wait until this is accomplished would lose considerable time during preliminary design, test, and construction. A submarine patterned after the Type 26 Walter submarine, for example, would require only minor hull alterations and could retain intact much of its machinery as designed including the Diesel electric gear for standby power. The hydrogen peroxide storage tanks beneath the pressure hull could be converted to mount the Uranium pile, heat exchanger system, condensers, and pumps.

6. Proposed Program

Assuming that a submarine of this design can be obtained, the principal research and development program needed is in perfecting a suitable pile, and investigating the heat-exchange and handling characteristics of certain suitable fluids, including liquid alloys of potassium-sodium. It is proposed that these two programs be initiated immediately. At the proper stage in their advancement, the two could be combined in a shore test installation for endurance and control runs. Simultaneously the rest of the submarine could be entirely fitted and mountings arranged for all of this power plant equipment. Little time would then be consumed in installing the pre-tested power plant and starting operational tests.

7. <u>Recommendations</u>

(a) It is recommended that the Navy obtain authority and support for establishment of a high priority project with a special "task force" sufficiently informed on all phases of the problem to supervise and coordinate the over-all project of research, development, construction, and test of an atomic-powered submarine.

(b) Request the Manhattan District to give high priority to an energy program adapted to the submarine needs with participation of a team including half a dozen highly competent Naval scientists and engineers. Failing this:

(c) Request a Presidential directive to permit full mutual cooperation between the scientists of the Manhattan District and the Navy as needed to develop and operate an atomic power plant for Naval use.

(d) Authorize the design and construction of a new submarine hull and machinery suitable for the exploitation of atomic power in accordance with the requirements of the research group responsible for this project.

(e) Provide facilities and competent men to permit:

(1) Development of an atomic pile heat exchanger system with all controls for Naval use.

(2) Construct a suitable submarine as above.

(3) Carry out research projects as necessary, including work on heat-exchange media, salt water evaporators, steam jets, etc. for high submerged speeds.

PART II

DESIGN OF SUBMARINE

1. INTRODUCTION

In this report, a system is proposed for the utilization of atomic energy to propel naval vessels, viz. submarines. The submarine was chosen because it is believed that it will be by far the best vessel to operate in seas threatened with atomic warfare.

The atomic powered submarine in this report is designed to operate at 26 knots submerged for many years. As a comparison, the radius of operation of the Walter Type 26 under similar conditions is 144 miles. The power unit requires no added fuel or oxygen, and personnel oxygen could be replenished by electrolysis or chemical methods.

It should be remembered that the 26 knots proposed is merely a beginning. With better power conversion, machinery and hull design, there is no reason why the speed should not go up to approximately 40 knots using screw propellors. Beyond this speed, combining atomic power with jet propulsion may provide speeds well over 60 knots.

To function offensively, this fast submarine will serve as an ideal carrier and launcher of rocketed atomic bombs.

The characteristics of the atomic power pack appear to be so much better than any other method of propulsion for submarines that it is believed a research and developmental program should be set up soon.

2. DESCRIPTION OF CYCLE

A schematic diagram (Plate I, titled, "Flowsheet for Atomic Power Pack") of the cycle shows the whole system to be very simple for design and operation.

The atomic pile is the heart of the whole power unit where the energy is generated. Potassium sodium alloy is recirculated through the pile to pick up thermal energy and this alloy is then pumped through heat exchangers to pass its heat energy to water which is pumped through the other side of the heat exchangers.

The water is converted to high pressure, superheated steam and then passed into tw high speed turbines of 3750 H.P. each which are geared to the propeller shaft. From the turbines the steam is led to a condenser where it is returned to the liquid state and is ready to be recycled through the heat exchangers.

3. DESCRIPTION OF EQUIPMENT

(a) THE HULL

Since this submarine was to have a speed of 26-30 knots it was decided to base this design on a hull the Germans had drawn up for the Walter Type 26-U-boat. Much valuable information has been obtained from studying the U.S. Naval Technical Mission in Europe reports concerning these high speed U-boats.

(b) THE ATOMIC PILE

The Type 26 Walter boat was designed to obtain a speed of 26 knots with one 7500 horsepower turbine. With the horsepower requirement determined, the approximate size of the atomic pile was fixed by making the following assumption: One cubic foot of pile core can generate approximately 950 B.T.U.'s per second. The pile core must be surrounded by about three feet of shielding to absorb harmful radiation.

This shielding will probably be of a laminated nature consisting of alternate 3-inch layers of iron or lead and water. When the pile is at full power output, which also is the time of greatest readiation generation, this shielding will protect the crew from any dangerous radiation.

(c) THE POTASSIUM-SODIUM ALLOY (KN_a)

This alloy has been considered but never used as a heat transfer medium in a large installation.* It has many properties that make it seem at the present the most useful agent for power pile operation.

The alloy is a eutectic mixture of potassium and sodium. It is a liquid at room temperature and boils at approximately 1400°F. It is somewhat lighter than water and has a high specific heat. An organization has been contacted, the Mine Safety Appliance Co., that has produced

*DuPont Report on Sodium

thousands of tons of the KN_a alloy. The alloy can be moved with ordinary pumps with standard packing and, in fact, is poured from bucket to bucket in the open air.

The reaction that one would expect when KN_a and water are mixed, which would occur in the heat exchangers if a leak developed, is not hazardous if oxygen is absent. There is only the rapid evolution of hydrogen and heat.* A pacifying agent for this reaction may be found, and if not, the system can be designed to minimize danger from all possible mishaps. Under operating conditions the pressure of the KN_a will just be enough to overcome the pumping heads. The KN_a system should be designed to be safe at pressures higher than the steam system.

The alloy cannot be decomposed and also satisfies certain neuclear qualifications for proper pile operation.

(d) <u>THE HEAT EXCHANGERS</u>

The heat exchangers should be constructed of nickel and be designed to take care of pressures and temperatures developed if a leak should occur between the KN_a alloy and the water. This will probably require pop-off valves for the alloy set at a pressure higher than those of the steam system and connected to blowdown tanks. The exchangers and all equipment handling the KN_a should be of welded construction. Should a large leak occur in the KN_a heat exchangers, the high pressure steam will leak into the KN_a system until the reaction with the alloy produces a pressure higher than that in the steam system. At that time the KN_a will start leaking to the steam side, producing a pressure increase due to hydrogen formation. The steam pop-off valve will then blow off the excess pressure until the reaction is stopped by shutting down this section of the heat exchanger. Operation can still continue at 20 knots on the other section until repairs are made.

The heat transfer coefficients for these exchangers should be determined experimentally, but the alloy's thermal properties are so good as compared to water that most of the resistance to heat transfer is in the water film.

(e) <u>THE TURBINES</u>

The main features of the turbines used in this system should be their ability to be operated remotely and with

*Conference Report with Dr. Jackson, of the Mine Safety Appliance little or no maintenance. The turbines used in the Walter U-boats should be studied as they had to function in a sealed turbine room because of the danger of leaking carbon dioxide and carbon monoxide.

A geared turbine drive is used to save weight and space by eliminating large electric generators and motors.

(f) CONDENSER

The condenser for this design was assumed to operate at 15 p.s.i.a. instead of a vacuum for two reasons: One, to keep the last stages of the turbine and the size of the condenser small; two, to prevent the leaking of air into the water system through hotwell pump glands, etc. This air would have to be removed to prevent corrosion and would tend to "sweat" the atmosphere of the submarine. However, it is realized that the condenser should be operated at a vacuum and the above objections overcome.

Since the submarine will probably be operated at 1000 feet the condenser must be designed for this pressure. The sea water is forced through the condenser by scoop action in the same manner as the Walter Type 26.

(g) AUXILIARY DRIVES

In addition to the two 3750 horsepower turbines this submarine will have all the variable drives the Walter Type 26 has except that the main 600 horespower Diesel has been removed.

(1) Main Motor-Generator

There is a main motor-generator (1) that is always in operation when the turbine is running as it furnishes power for the auxiliaries, i.e. pumps, in the power cycle. The main motor (1) has a continuous rating of 421 horsepower at 220 V, 1530 A and 670 revolutions per minute. It has a 1 1/2 hour rating of 535 horsepower at 220 V, 1950 A and 725 revolutions per minute. The main motor (1) will produce a submerged speed of 10 knots with coupling (2) connected and the remaining coupling disconnected.

When connected to the turbine the main generator has a continuous rating of 299 horsepower at 320 V, 390 A and 1770 revolutions per minute.

(2) Creeping Motor

The creeping motor (3) has a rating of 70 horsepower at 320 V and 334 revolutions per minute. It can produce a maximum submerged speed of 4 knots with coupling (4) connected and (2) disconnected. The motor is connected to the shaft by means of the V-belt drive (5). With such an arrangement it is reported that exceptionally silent underwater propulsion is achieved.

(3) Auxiliary Diesel-Generator

A 350 horsepower auxiliary Diesel-Generator unit (6), (7) is provided for propulsion and battery charging in the event the pile is incapacitated.

(4) Battery Room

One battery room is left in the submarine to handle emergency propulsion and electrical needs. This battery has 62 cells and will drive the submarine 100 miles at 4 knots submerged.

4. INSTALLATION OF EQUIPMENT

(a) THE PILE INSTALLATION

The pile and its shielding can be quite nicely fitted outside of the pressure hull along the keel of the submarine. In this position the pile can be readily changed in drydock without disturbing the pressure hull. It is not necessary that the pile core be a cube and this allows the streamline form of the outer hull to be retained. Although shielding surrounds the entire pile, special attention would be applied to provide proper shielding between the pile and personnel.

(b) THE KN_a-WATER HEAT EXCHANGERS INSTALLATION

The KN_a-Water heat exchangers should also be situated between the pressure hull and the outer hull. In this position the radiation shielding required would be a minimum, and any major reaction between KN_a and water due to battle damage leaks, could be more readily dissipated.

(c) THE TURBINE AND PUMP INSTALLATIONS

The turbines and other rotating pieces of equipment such as the KN_a pumps and the feedwater pumps should be installed so that they can be serviced by remote control. This remote servicing has had a great amount of development and is commonly performed on plutonium plant equipment such as centrifuges, pumps, etc.

In the design calculations for this report all pumps and turbines are supplied in duplicate so that in case of a failure, the vessel could continue operation on half power. The speed at half power would be approximately 20 knots. Servicing can be done when the pile is not operating. All equipment that is subject to radiation can be approached closer a short time after the pile is secured, in that the amount of radiation drops almost immediately to less than one per cent of the amount of radiation given off while operating.

5. OPERATION OF THE PILE

The operation of the pile can best be explained by quoting the Smyth report: "..the most striking feature of the pile is the simplicity of operation. Most of the time the operators have no hing to do except record the readings of various instruments ..... the pile performance of June 1944 considerably exceeded expectations. In ease of control, steadiness of operation, and absence of dangerous radiation, the pile has been most satisfactory."

PART III

CALCULATIONS

1. **Comparison between Walter Cycle and Atomic Powered Submarines.**

(a) **Power Comparison**

	Auxiliary	Water Cycle #26 Sub.	Atomic Sub
1.	CO_2 compressor	525 HP	---
2.	Triple pump	157	---
3.	Condensate pump	160	11 HP
4.	KNa pump	---	200
5.	CO_2 gland pump	55	---
6.	Feedwater pump	---	470
7.	Oil cooling pumps, etc.	30	30
8.	Gearing losses	313	313
9.	Summation of power for auxiliaries and gearing losses.	1,240	1,024
10.	Shaft horsepower (7500 HP minus auxiliaries and gearing losses)	6,260	6,476

(b) <u>Detailed List of Walter Cycle Machinery to be Removed from Walter Type #26 Hull</u>

No.		kg.
6	Catalyst chamber	580
7	Combustion chamber	550
8	(Leave separator in)	
14	Three way pump (Ingolene fuel H_2O) (Must replace with boiler feed pump)	150
18	Proportioning devices	170
19	Main condenser	1,800
20	Condensate pump (must replace)	780
21	Condensate cooler (scoop type)	7,200
23	CO_2 compressor	900
28	Gas separator (for Ingolene)	20
29	Device for recording Ingolene consumption	50
30	Ingolene bag	85
10	Turbine exhauster (water ring type)	320
1	Motor for turbine gland exhaust (item 10)	520
2	Motor for three-way pump (item 14)	745
3	Motor for condensate pump (item 20)	710
		14,580 kg, or
		32,100 lb

(c) **Summation of all Equipment to be Removed from Walter #26 Hull**

The normal fuel, water, Ingolene ratio is 1 : 10 : 10

125 short tons of Ingolene	250,000 lb
12.5 short tons of fuel oil for Walter Cycle	25,000
"Walter cycle" machinery	32,100
600 H-P main diesel	50,000
Main diesel fuel oil	44,000
Total	401,100 lb

(d) **Weight Comparison between Walter Cycle and Atomic Powered Submarines**

Weight to be Added for Pile Operation

Pile weight	230,370 lb.
Another turbine for twin operation	5,500
Condenser	11,000
KNa-Water Heat Exchanger, Liq-Liq.	3,000
KNa-Water Heat Exchanger, superheater	2,350
KNa pumps	5,000
Feedwater pumps	8,000
Condensate hotwell pumps	5,500
Total	270,720 lb

Weight removed from Walter system....	401,000 lb
*Weight added for pile system.........	270,720
Added positive buoyancy...........	130,280 lb

* The circulating fluids in the two systems are assumed to be of approximately the same weight.
The weights of unlisted items, i.e., piping, are assumed to be the same for both systems.

2. Calculation of Pile Weight and Size

7500 h.p. turbine. 7500/.65* = 11,530 h.p. = 8,600 kw pile. Therefore, there should be approximately 8.6 cubic feet of pile core. Make core: 1' x 1' x 9' = 9 cubic feet. With 3 foot thick shielding:

$$\text{Shielding Wt.} = [(15'\text{x}8'\text{x}7') - (9'\text{x}2'\text{x}1')]\ \text{ft}^3\ \frac{276.2\ \text{lb}}{\text{ft}^3} = 227{,}000\ \text{lb}$$

Shielding to be laminated iron and water. Each in three inch layers. For weight calculations the shielding taken to be a heterogeneous mixture of iron and water and weighs 276.2 lb/ft^3, which is a specific gravity of approximately 4.42.

Assume core to require 6" on two sides for header work, etc.
Core weight = (9x2x1)ft^3 62.4 lb (3)/ft^3 = 3370 lb. Taking core sp.gr. to be 3. This includes piping, controls, etc.
Total pile weight = 230,370 lb.
Overall dimensions (with shielding): 15'x8'x7'.

3. Machinery Weight and Size Calculations

(a) Turbine

Plan on using a Walter Type 26 hull.

h.p. = $KD^{2/3}\ v^3$ (where K = coef., D = displacement in tons, v = velocity in knots).

$$K = \frac{\text{h.p.}}{D^{2/3}\ v^3} = \frac{7500}{(1050)^{2/3}\ (24)^3} = \frac{7500}{(103)(14000)} = .0052$$

2 - 3750 h.p. turbines using 1500 psi, 900°F steam exhausting to 14.7 psia, 212°F.

Water rate (h.p.), $WR_{h.p.} = \frac{2546}{(H - H_x)\ N}$ where

H = initial enthalpy, H_x = final enthalpy, and
N = efficiency.

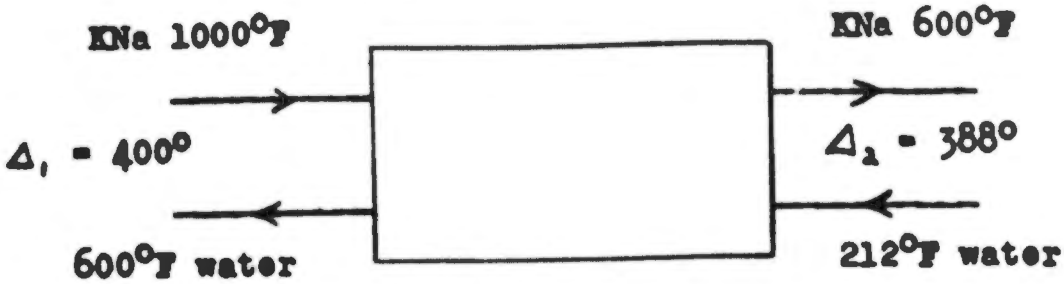
$$WR_{h.p.} = \frac{2546}{(1440 - 1020)\ (.65)} = 9.34\ \frac{\text{lb steam}}{\text{h.p. - hr}}$$

$$\text{Steam required} = 7{,}500\ \text{h.p.}\ (9.34\ \frac{\text{lb}}{\text{h.p.hr}}) = 70{,}000\ \text{lb/hr}$$

* Turbines generally assumed to have eff.of approx. 65%.

(b) **Area of Heat Exchangers**

Liquid-Liquid (Sensible Heat)



Logarithmic mean temperature difference:

$$t = \frac{\Delta_1 - \Delta_2}{\ln \frac{\Delta_1}{\Delta_2}} = \frac{12}{\ln \frac{400}{388}} = \frac{12}{\ln 1.03} = \frac{12}{.0296} = 405^\circ$$

Sensible heat: $Q = U_o A \; t$ where Q = heat transferred.
U = overall heat transfer coef
A = area of heating surface.

$$A = \frac{Q}{U_o \Delta t} = \frac{(70{,}000 \text{ lb}) \; 432 \text{ Btu} \; ft^2 \; hr \; ^\circ F}{hr \; 1030 \; \text{Btu lb} \; 405^\circ F}$$

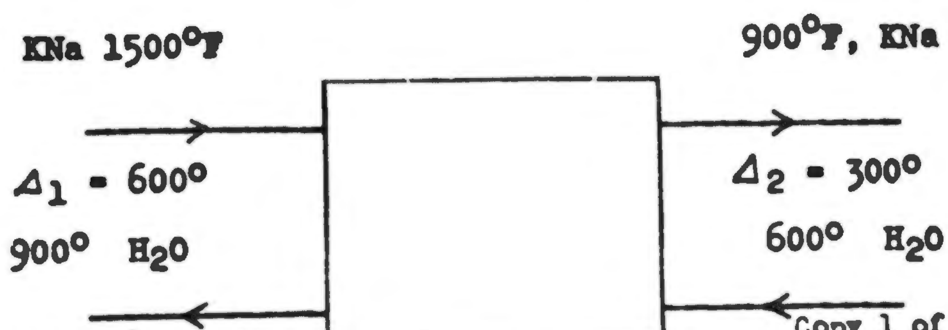
$A = 72.5 \; ft^2$

Flashing of water:

$$A = \frac{Q}{U_o \Delta t} = \frac{70{,}000 \text{ lb} \; 556 \text{ Btu} \; ft^2 \; hr \; ^\circ F}{hr \; 617^\circ F \; lb \; 695 \text{ Btu}}$$

$A = 92.4 \; ft^2$

Superheating Area



$$t = \frac{600 - 300}{hr \frac{600}{300}} = \frac{300}{hr\ 2} \quad \frac{300}{.694} = 433^{\circ}F$$

$$A = \frac{Q}{U \Delta t} = \frac{70{,}000\ lb \quad 262\ Btu \quad ft^2 \quad hr \quad ^{\circ}F}{570\ Btu \quad hr \quad lb \quad 433^{\circ}F}$$

$$A = 74.2\ ft^2$$

Condenser Area and Size

$$A = \frac{Q}{U \Delta t} = \frac{70{,}000\ lb \quad 990\ Btu \quad ft^2 \quad hr \quad ^{\circ}F}{hr \qquad lb \quad 500\ Btu \quad 132^{\circ}F}$$

$$A = 1050\ ft^2$$

20" nom. dia., (995 + 62) = 1057 ft^2

Length = 19' 6"

Shell dia = 23-3/4", dia. with nozzles = 37-1/2"

Wet wt = (7505 + 291) 1.40 = 11,000 lb.

SIZE OF HEAT EXCHANGERS

KNa-Water Heat Exchangers

Sensible + flashing = 72.5 ft^2 + 92.4 ft^2 = 164.9 ft^2

10" nom. dia.
236 ft^2 - 3 ft (14.7 ft^3) = 192 ft^2

$$\frac{(192 - 165)\,100}{165} = \frac{27}{165}\,100 = 16\% \text{ overage}$$

Length = 14' - 8"

Shell dia. = 14", dia. with nozzles = 26 1/2"
Wet wt. = 2405 - 3(94) 1.4 = 3000 lb.

Superheater

8" nom. dia.
136 ft^2 - 6 x 8.5 ft^2 = 85 ft^2

$$\frac{85 - 74}{74} = \frac{11\ ft}{74} = 15\% \text{ overage}$$

Length = 11 ft - 8 in

Shell dia. = 12" dia. with nozzles = 24½"

Wet wt. = 1680 - 6(67) 1.4 = 2350 lb.

(c) Pumps

KNa pumps for liq-liq exchangers $Q = (1168 - 180)\,\frac{Btu}{lb}\;70{,}000\,\frac{lb}{hr} =$

$$69.2 \times 10^6\ \frac{Btu}{hr}$$

$$\frac{69.2 \times 10^6\,Btu\ lb^oF}{hr(1500-600)^oF\ .208\,Btu} = 830\ \frac{gal\ KNa}{min} \text{ liq-liq exchangers}$$

KNa Pumps for superheaters:

$$Q = (1430 - 1168)\,\frac{Btu}{lb}\;70{,}000\,\frac{lb}{hr} = 18.4 \times 10^6\ \frac{Btu}{hr}$$

$$\frac{18.4 \times 10^6\ Btu\quad lb^oF}{hr\ (1500 - 900)^oF\ .208\ btu} = .147 \times 10^6\ \frac{lb}{hr} \text{ of KNa thru superheater exchangers}$$

$$\frac{.147 \times 10^6 lb\ gal\quad hr}{hr\ 8.33\ lb\ (.89)\ 60\ min} = 330\ \frac{gal\ KNa}{min} \text{ thru superheater exchangers}$$

KNa Pumps for Taking Care of Both Liq-Liq & Superheater Heat Exchangers

Volume of KNa equals 830 + 330 or 1160 gal/min. Approx. size and wt:

84" x 32", wt. = 2500 lb., h.p. = 100

Total wt. for two pumps = 5000 lb. (Drive included)
Total H.P. for two pumps = 200

Note: Plan that condenser will be supplied with sea water forced through by scoop action. Type #26 hull utilized this feature.

Feedwater pumps

$$\frac{35{,}000\ \text{lb}\quad \text{gal}\quad \text{hr}}{\text{hr}\quad 8.33\ \text{lb}\quad 60\ \text{min}} = 70\ \frac{\text{gal}}{\text{min}}$$ thru each pump

Approx. size and wt: 106" x 25" x 34", approx. 4,000 lb wt.

Total wt for 2 pumps ... 8,000 lbs (drive included)

Condensate hot well pumps $70\frac{\text{gal}}{\text{min}}$ thru each pump

Approx. size and wt: 80" x 21" x 32", approx 2750 lb.

Total wt for 2 pumps, ... 5500 lb (drive included)

H.P. Required for Feed water and Hotwell Pumps

Feedwater Pumps

Power $= \frac{Q\,d\,H}{550}$ Where $Q = \frac{ft^3}{sec}$, H = head in feet, $d = \frac{lb}{ft^3}$

$$\text{Power} = \frac{70\ \text{gal}\ ft^3\ \text{min}\ 62.4\ \text{lb}\ 3450\ \text{ft sec h.p.}}{\text{min}\ 7.48\ \text{gal}\ 60\ \text{sec}\ ft^3\ 550\ \text{lb ft}}$$

Power = 61 h.p. at 100%

Pump will have approximately 6 stages, each stage 80% eff.

$$\therefore \quad \text{Power} = \frac{61}{.8^6} = \frac{61}{.26} = 235 \text{ h.p. for feedwater pump}$$

Hot well Pump:

$$\text{Power} = \frac{QdH}{550} = \frac{70\ \text{gal}\ ft^3\ 62.4\ \text{lb min}\ 200\ \text{ft h.p. sec}}{\text{min}\ 7.48\ \text{gal}\ ft^3\ 60\ \text{sec}\ 550\ \text{ft lb}\ (.8)\ (.8)}$$

Power = 5.6 h.p for hotwell pump

(a) REMOVAL OF MAIN DIESEL ENGINE AND SURPLUS FUEL OIL FROM TYPE #26 HULL

600 h.p., 6 cylinder, 4 stroke: (approx) 50,000 lb. MVM diesel engine capable of producing a surcace speed of 12 knots. The surface endurance reported to be 8,000 miles. (Weight obtained from American "Worthington Marine" Diesel catalog)

$$\frac{.42 \text{ lb fuel oil}}{\text{h.p.}} = \text{Diesel consumption (Perry's Handbook)}$$

Type #26 range said to be 7,300 miles at 10 kts.

$$\frac{7,300 \text{ mi knot hr } 535 \text{ h.p. } .42 \text{ (lb fuel oil) gal}}{10 \text{ knots } 1.15 \text{ mi h.p. hr } 8.33 \text{ lb } (.8)} =$$

Fuel oil for Walter cycle $= \frac{25,000}{(8.33)(.8)} = 3,750$ gal

(Assume 5,000 miles of fuel would get boat back from almost anywhere.)

h.p. $= KD^{2/3} V^3 = (.0052)(1050)(10) = 535$ (K = coeff. for type #26 sub)

Fuel oil for main diesel $= 21,400 - 3,750 = 17,650$ gal

(BuShips Sub Section list gave 17,053 gal for fuel oil)
In that the main diesel is being removed, the amount of fuel oil needed is reduced. The amount of fuel oil required for the 350 h.p. auxiliary diesel for 5,000 miles at 8.7 knots would be:

$$\frac{5,000 \text{ mi knot hr } 350 \text{h.p. } (.42) \text{ lb fuel oil gal}}{8.7 \text{ knots } 1.15 \text{ mi h.p. hr } (8.33) \text{ lb } (.8)} = 11,050 \text{ gal}$$

Therefore surplus oil removed from hull $= 17,650 - 11,050 = 6,600$ gal or 44,000 lb.

4. CALCULATION OF HEAT TRANSFER COEFFICIENTS

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{1}{h_{si} A_i} + \frac{1}{k A_{av}} + \frac{1}{h_{so} A_o} + \frac{1}{h_o A_o}$$

Assume: 5/8" O.D. Nickel Tubes; $\frac{P}{S} = \frac{1-R}{R} = \frac{1,500}{15,000} = 0.1$, $R = .9$

where P = allowable stress, P = working pressure

$R = \frac{I.D.}{O.D.}$, I.D. $= (.9)(.625) = .562$, wall $= \frac{.625 - .562}{2} = .032$

5/8 I.D. with a 1/32" (.03125) wall would be satisfactory for 1500 p.s.i. pressure but for corrosion reasons, etc., assume approximately a 1/16 (.0625) wall.

Standard tubing is:

O.D.	.625"	.052 ft
I.D.	.495"	.0413 ft

NOTE: The following calculations for heat transfer coefficients were done with a requirement of 30,000 h.p. in mind. However, the final coefficient as calculated can be used for any horsepower requirement if the same conditions, i.e. flow velocities, are used.

(a) Heat transfer coefficient for sensible heating of [redacted].
(From Perry's Handbook, p.977, eq.28)

$$h = \frac{160\,(1+0.012t_f)\,(V_s)^{.8}}{(D')^{0.2}}$$

$$h = \frac{160\,[1+(.012)(600)]\,(5)^{.8}}{.495^{.2}}$$

$$h = 5470 \frac{BTU}{hr\ ft^2\ {}^{\circ}F}$$

Tube at 800 °F Water at 400 °F

$$T_f = 800 - \frac{(800-400)}{2}$$

$$T_f = 600^{\circ}$$

(b) KNa (850°F) Outside of tube, direction of flow normal to tubes.

Perry's eq. (37) p.982, because $\frac{DG}{\mu} > 2{,}000$

$$\frac{(h_m)}{(c_p\,G_m)}\,\frac{(c_p\,\mu_f)^{2/3}}{(k)} = .33\left(\frac{D_o\,G_m}{\mu_f}\right)^{-0.4}$$

Area for G calculation $= \frac{(1.88)\,10^6\,lb\ KNa\,(.80)\ ft^3\ sec\ hr}{hr\,(45.5\,lb\ KNa)\,(5ft)(3600sec)} = 1.835\ ft^2$

80% of heat transmitted in liq-liq exchanger

$$\frac{(D_o\,G_m)}{\mu_f} = (.052ft)\left[\frac{(5)\,(.376)\,10^6\,(.8)\,lb}{hr\ 1.835\ ft^2}\right]\left[\frac{hr\ \ ft}{(2.42)(.178)\,lb}\right]$$

$t_1 = 1200^{\circ}$

$G = 82\cdot 10^4$

$t_{av} = 900\ {}^{\circ}F$

$t_2 = 900\ {}^{\circ}F$

assume μ_f at 850°F equals $.43\ \frac{lb}{ft\ hr}$

$$\frac{(D_o\,G_m)}{(\mu_f)} = 99{,}000$$

$$\left[\frac{h_m}{(.208)(82.10^4)}\right]\left[\frac{(.208)(.43)}{31.4}\right]^{2/3} = .33(99{,}000)^{-0.4}$$

h_m (for KNa 800°F) = 29,200

Perry's Handbook: For flow in well-baffled exchangers, to allow for leakage around the baffles, assume no leakage and deduct 40% from the values given by Eqs. 37 and 38.

$\therefore h_{KNa\ 800°} = (29{,}200)(.60) = 17{,}500$

TUBE WALL RESISTANCE

$$\frac{1}{k} = \frac{.065 \text{ in ft}}{12 \text{ in}} \; \frac{ft^2 \; hr \; °F}{31 \text{ Btu ft}} = 1.75 \times 10^{-4} \frac{hr\ ft^2\ °F}{Btu}$$

(c) Liquid-Liquid Coefficient

water film, water scale, metal wall, KNa film

$$\frac{1}{U_o} = \frac{D_o}{h_i D_i} + \frac{1}{h_{si}} + \frac{1}{k} + \frac{1}{h_o}$$

$$\frac{1}{U_o} = \frac{(.052)}{(5470)(.0413)} + \frac{1}{2000} + 1.75 \times 10^{-4} + \frac{[illegible]}{17{,}500}$$

$$\frac{1}{U_o} = \frac{1}{4{,}350} + \frac{1}{2000} + \frac{1}{5{,}700} + \frac{1}{17{,}500}$$

$$U_o = \frac{1}{9.62 \times 10^{-4}} = .103 \times 10^4 = 1030 \frac{Btu}{hr\ ft^2\ °F}$$

(d) Flashing Water Coefficient

$$h_{KNa(1250°F)} = (.33)\left[\frac{\mu_f}{D_o G_m}\right]^{0.4} \frac{C_p G_m}{1} \left[\frac{k}{C_p \mu_f}\right]^{2/3}$$

$$= (.33)\left[\frac{(.112)(2.42)}{(.052)(82 \cdot 10^4)}\right]^{.4} (.208)(82 \times 10^4) \left[\frac{41.5}{(.208)(.112)(2.42)}\right.$$

$$= 3.84 \times 10^4 = 38{,}400$$

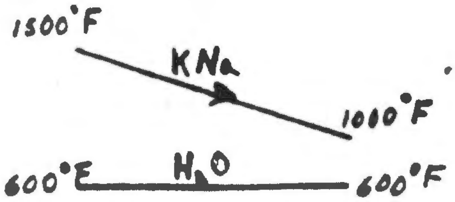
After introducing 60% design factor:

$$h_{KNa(1250F)} = (.60)\, 38{,}400 = 23{,}000 \frac{BTU}{Hr\ ft^2\ °F}$$

(p.1041, Perry's Handbook)

$$U = \frac{435 u^{0.45}}{\mu^{0.25} \Delta t^{0.1}}$$

$$U = \frac{(435)(5)^{.45}}{[(.088)(2.42)]^{.25} (617)^{0.1}}$$



$$\Delta t = \frac{\Delta_1 - \Delta_2}{\ln \frac{\Delta_1}{\Delta_2}} = \frac{900-400}{\ln \frac{900}{400}} = 617°F$$

$$U = 695 \frac{Btu}{ft^2\ hr\ ^\circ F}$$

(e) **SUPERHEATING COEFFICIENT**

(p. 973, Perry's Handbook)

$$h = \frac{16.6\ c_p\ (G')^{0.8}}{(D_i)^{0.2}}$$

$$h = \frac{(16.6)\ (.75)}{(.495)^{0.2}} \left[\frac{(5)\ (.563 \times 10^5)\ lb\ hr}{.391\ ft^2\ hr\ 3600\ sec} \right]^{0.8} \quad (200)^{.8}$$

NOTE: C = .75 (Keenan & Keyes, p.8)

$$h = \frac{(16.6)\ (.75)\ (69)}{(.869)} = 990 \frac{Btu}{ft^2\ hr\ ^\circ F}$$

U_o for superheating

$$\frac{1}{U_o} = \frac{D_o}{h_i D_i} + \frac{1}{h_{si}} + \frac{L}{k} + \frac{1}{h_o}$$

$$\frac{1}{U_o} = \frac{.052}{(990)(.0413)} + \frac{1}{4000\ (\text{assumed})} + \frac{L}{k} + \frac{1}{23{,}000}$$

(f) Overall heat transfer coefficients summary

∴ Liq-Liq*: $U_o = 1030 \frac{Btu}{hr\ ft^2\ ^\circ F}$

Flashing: $U_o = 695$ "

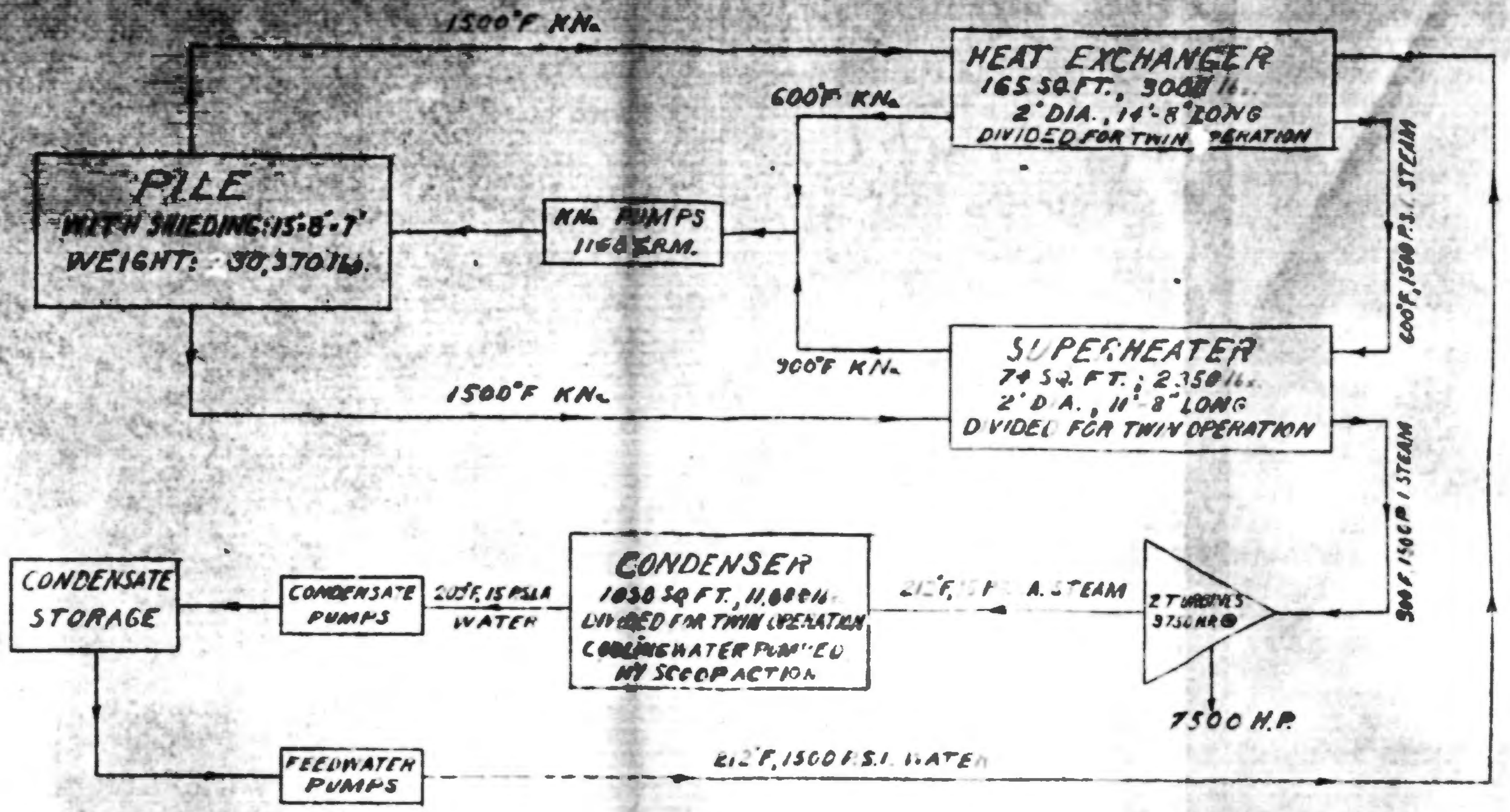
Superheating: $U_o = 570$ "

*NOTE: The Liq-Liq coefficient was calculated with a scale factor on the water side.

ACKNOWLEDGMENT

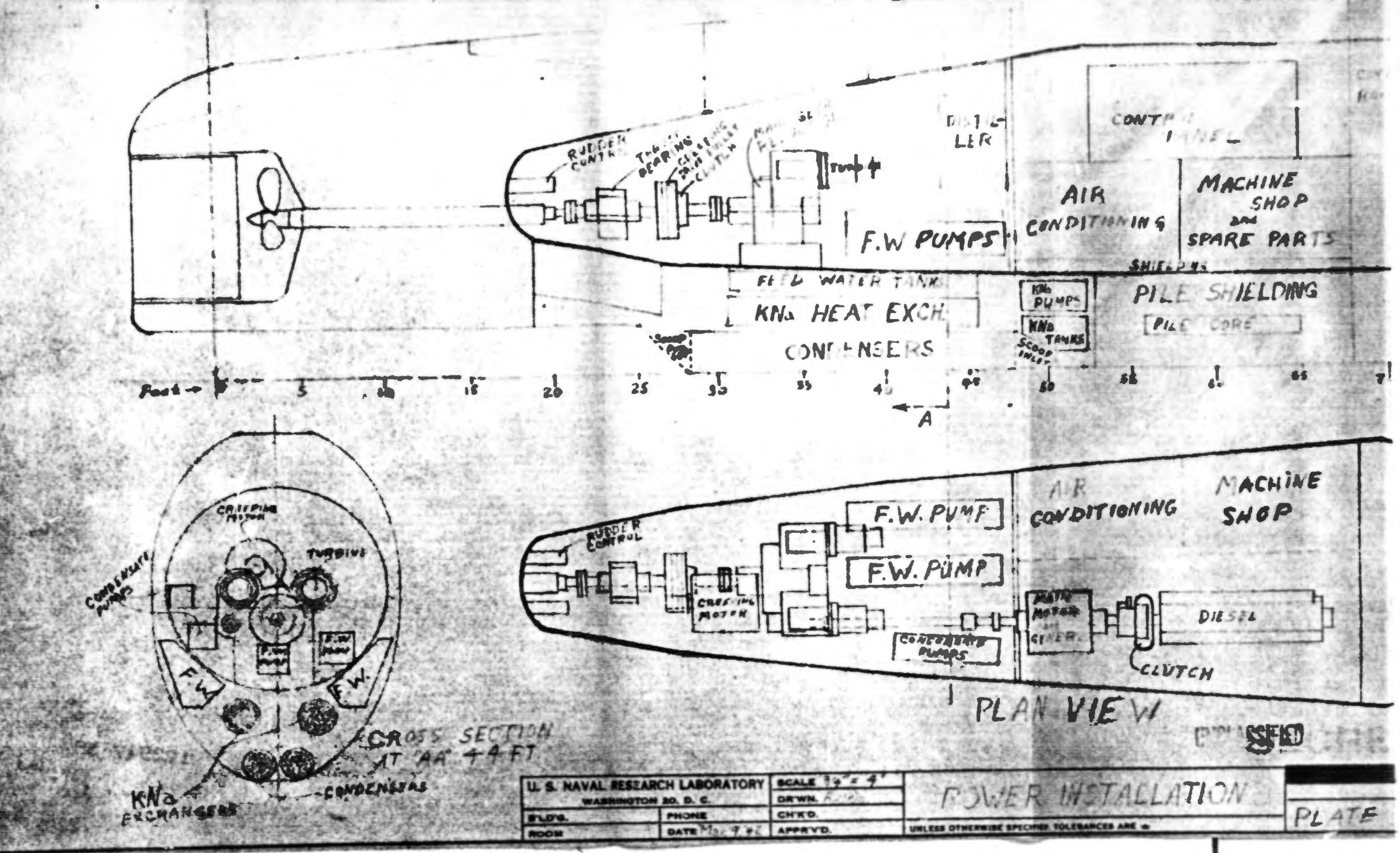
The authors of this memorandum wish to acknowledge the assistance of Commander R. I. Olsen, USN, Submarine Project Officer at the Naval Research Laboratory. His aid was invaluable in furnishing the necessary submarine information and liasion with the following, whose assistance is also greatly appreciated:

Capt. G. C. Weaver, USN Bu Ships
Comdr. G. W. Underwood, USN Bu Ships
Lt. (jg) G. C. Lindquist, USNR NRL
Naval Shipyard, Portsmouth, N. H.



U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.		SCALE None	FLOWSHEET FOR ATOMIC POWER PACK
BLDG	PHONE	DRWN.	
ROOM	DATE 17 Dec 1945	CHKD.	
		APPR'VD.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

PLATE


RUDDER CONTROL
THRUST BEARING
CRUISING DRIVE CLUTCH
DISTILLER
CONTROL PANEL
AIR CONDITIONING
MACHINE SHOP and SPARE PARTS
F.W PUMPS
SHIELDING
FEED WATER TANK
KNa HEAT EXCH.
CONDENSERS
KNa PUMPS
KNa TANKS
SCOOP INLET
PILE SHIELDING
PILE CORE
Feet
5
10
15
20
25
30
35
40
45
50
55
60
65
70
A
CRUISING MOTOR
TURBINE
CONDENSATE PUMPS
F.W. PUMP
F.W
F.W.
CROSS SECTION AT "AA" 44 FT
KNa EXCHANGERS
CONDENSERS
RUDDER CONTROL
F.W. PUMP
F.W. PUMP
CRUISING MOTOR
CONDENSATE PUMPS
AIR CONDITIONING
MACHINE SHOP
DIESEL
CLUTCH
PLAN VIEW
U. S. NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.
BLD'G.
ROOM
PHONE
DATE
SCALE
DR'WN.
CH'K'D.
APPR'V'D.
POWER INSTALLATION
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE ±
PLATE

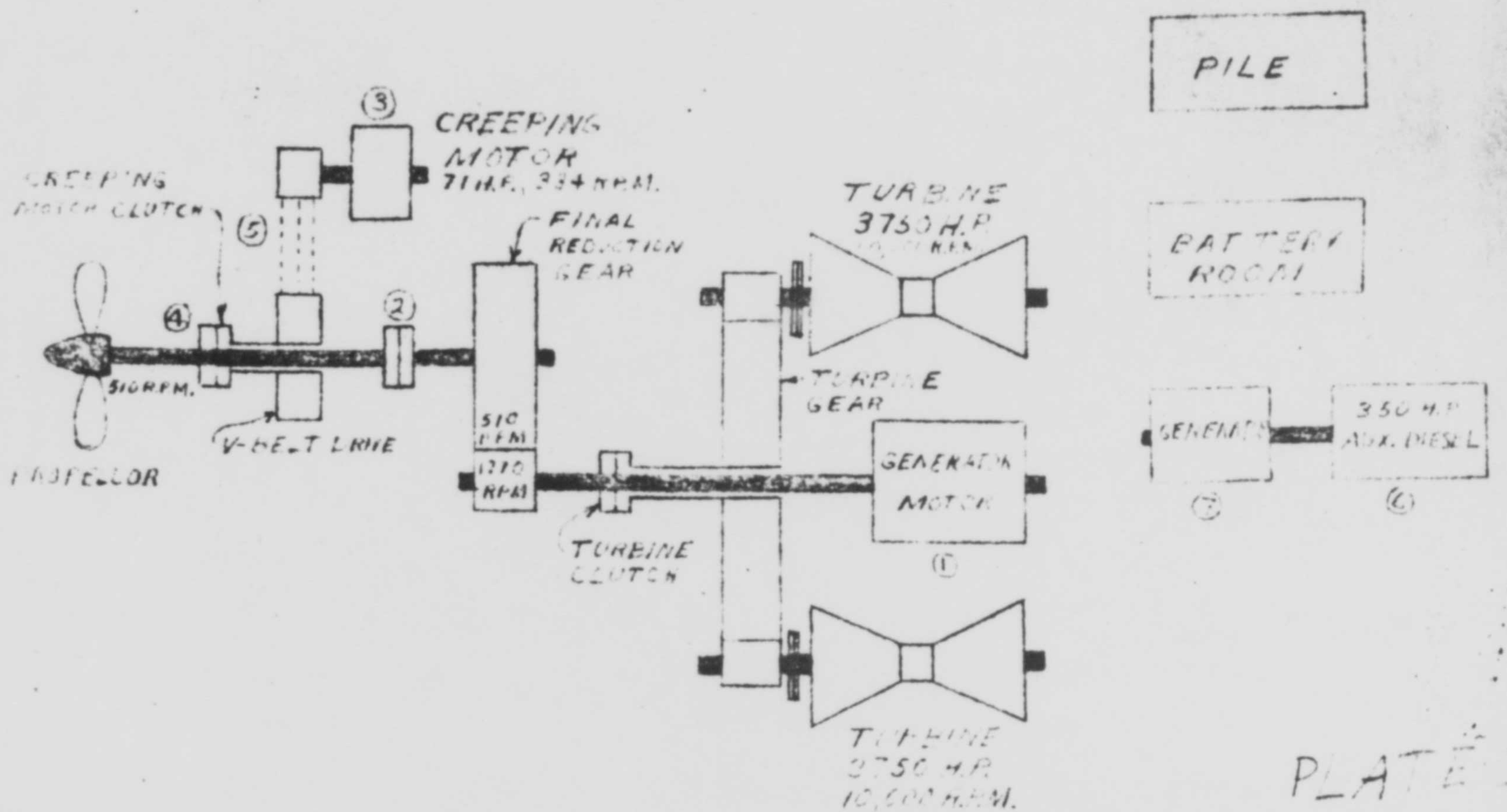
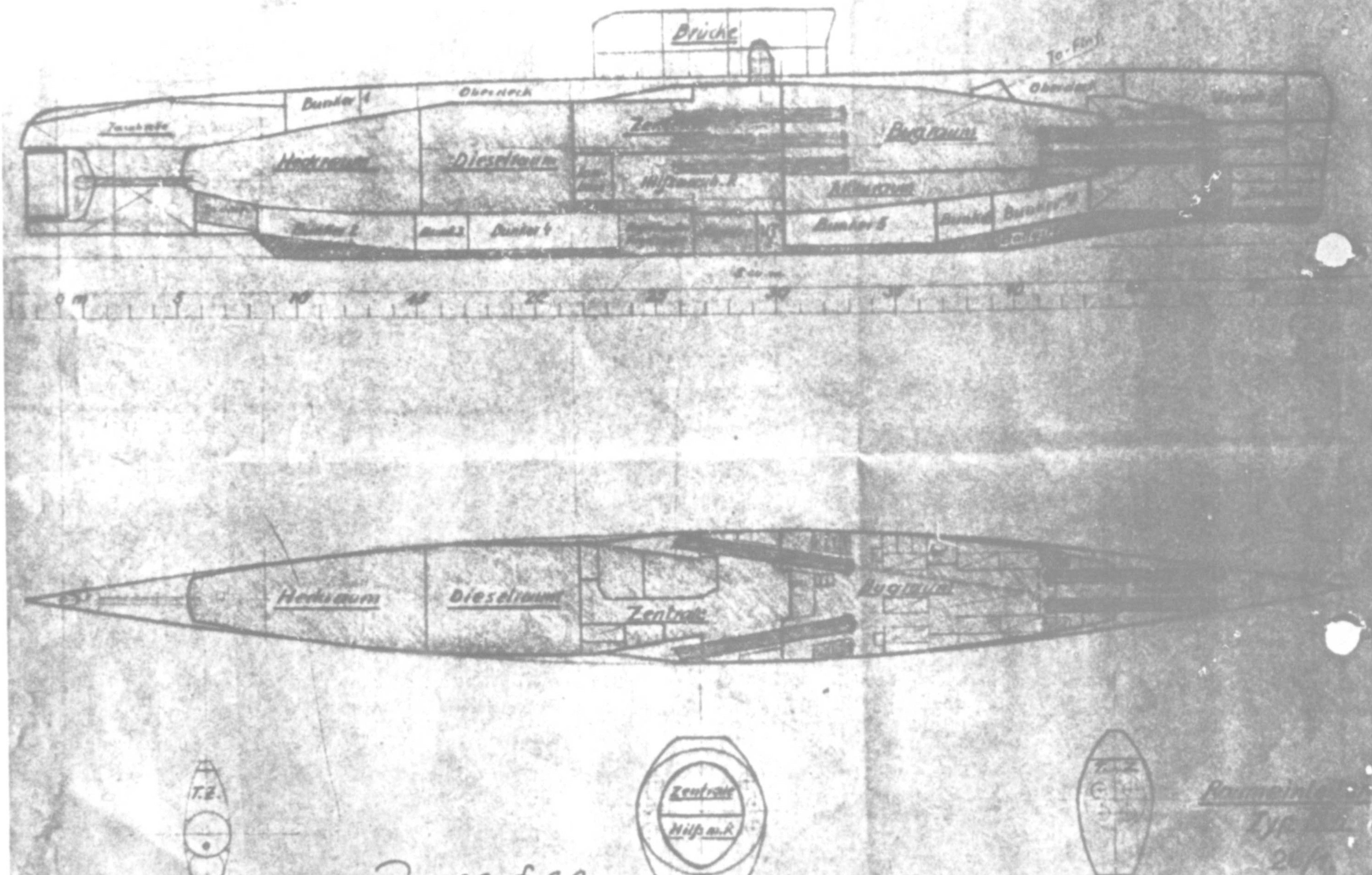

PILE
BATTERY ROOM
GENERATOR
350 H.P. AUX. DIESEL
TURBINE 3750 H.P.
TURBINE GEAR
GENERATOR MOTOR
TURBINE 3750 H.P. 10,000 R.P.M.
TURBINE CLUTCH
FINAL REDUCTION GEAR
510 RPM
1270 RPM
CREEPING MOTOR 71 H.P., 334 R.P.M.
CREEPING MOTOR CLUTCH
V-BELT DRIVE
510 RPM.
PROPELLOR
1
2
3
4
5
6

PLATE III



Page 27 of 27 pages
Copy 1 of 6 copies