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List of Tables

8. POWER CONVERSION SYSTEMS

The power conversion systems are the main high pressure steam system supplying the main propulsion unit (see Drawing MS 301-5-536) and the following auxiliary systems:

1. The auxiliary high pressure steam system, which supplies high pressure steam to the turbine generators, main feed pump turbine, and the other auxiliaries shown in the heat balance diagrams.
2. The main and auxiliary feedwater systems, which supply feedwater from the deaerating feedwater heater to the main boilers and the main blowdown evaporator.
3. The main and auxiliary condensate systems, which deliver the condensate to the deaerating feedwater heater from the hotwells of the main and auxiliary condensers and from the air ejectors.
4. The makeup water purification system, which purifies and adds fresh makeup water to the plant from the evaporators as needed.
5. The salt water circulating system, which cools the main and auxiliary condensers.
6. The intermediate steam pressure system.
7. The electric power generating and distribution system.
8. The instrument air and ship service air systems.

All of these systems and their components are conventional. Their arrangement is in accordance with the best practice in conventional engine rooms with a view to accessibility and ease of maintenance (see Drawings RC 04-J-752, RC 04-J-753, RC 04-J-754, and RC 04-J-755). The only unique feature of the engine room resulting from the nuclear power plant is the consolidated control room with its central console. This room is separately air-conditioned and insulated. From its five front windows, the power plant operator has a wide view of the engine room at all times.

The design characteristics of the power plant are summarized in Table 8-1.

Table 8-1. Summary of Power Plant Design Characteristics

Performance parameter	Port load	20,000 shp operation	22,000 shp operation
Propulsion system			
Shaft power, shp	--	20,000	22,000
Propeller speed, rpm	--	107	110
Turbine inlet pressure, psia	706	460	445
Condenser vacuum, in. Hg	28.45	28.45	28.45
Feedwater temperature, F	265	348	340
Total electrical load, kw	1,318	2,169	2,408
Steam consumption, lb/hr			
Main turbine	--	187,400	204,500
Feed pump turbine	--	21,200	21,500
Turbine generators	18,490	32,320	34,540
Low pressure steam generator	700	700	700
Ejectors, evaporators and losses	3,200	4,300	4,610
Total steam generation	22,390	245,920	265,850
Reactor system heat transport, MWt			
Steam generators	6.4	64.1	69.4
Purification system	1.2	1.2	1.2
Primary pumps	-0.1	-0.8	-0.8
Heat losses	0.2	0.2	0.2
Total reactor power	7.7	64.7	70.0
Primary system			
Pressure, psia	1,750	1,750	1,750
Flow, lb/hr	2,600,000	9,400,000	9,400,000
Coolant mean temperature, F	508	508	508
Coolant temperature rise, F	9.0	21.6	23.4
Pressure drop, psi	10.5	61.4	61.4
Primary pumps operating	2	4	4
Steam drum pressure, psia	710	485	472
Boiler blowdown, lb/hr	220	2,400	2,600

8.1. Steam Generators

8.1.1. General Description

The steam generators are used in conjunction with the reactor to generate steam for the propulsion system. The two steam generators, one in the port loop and one in the starboard loop, are located within the containment vessel. Primary coolant water that has been heated in the reactor is circulated through these two heat exchangers by the primary pumps. Each loop circulates about 10,000 gpm through each heat exchanger. The average temperature of the primary coolant water in the steam generators is 508 F.

The steam generators are of the natural circulation, two-fluid type and consist of a horizontal U-shaped heat exchanger and a separate steam drum (see Drawings SK13-G-870, 40784E-12, 40698E-14, and 66588E-3). The heat exchanger is of the shell-and-tube type with the primary coolant flowing through the tubes and steam being generated from the secondary water flowing through the shell side. The steam-water mixture passes upward from the heat exchanger to the steam drum through riser tubes. In the steam drum the steam drum is separated from the water by cyclone separators and scrubbers. The steam passes through a dry pipe assembly and exists through an outlet nozzle at the top of the steam drum. The water returns to the shell side of the heat exchanger through downcomers.

Feedwater is added to the steam drum through a feedwater distribution header located in the center of the steam drum. The feedwater is directed downward into the drum, joins the water from the steam separators, and flows to the downcomers.

Individual surface blowdown and chemical feed connections are provided in the steam drum sections.

8.1.2. Design Conditions

The design conditions of the steam generators are summarized in Table 8-2. The steam generators were designed, built, inspected, and stamped in accordance with regulations of the USCG[5] and ABS.[15] Where particular regulations did not exist, the ASME code[6] was applied, and the matter was forwarded to the AEC and USCG for approval.

8.1.3. Normal Transient Conditions

The steam generators are capable of meeting the following changes in steam demand:

1. From 20% to 85% in 10 seconds.
2. From 100% to 20% in 3 seconds.

The steam generators are capable of enduring the transients at these rates for an unlimited number of cycles with a normal steam quality not exceeding 0.25% moisture carryover during such transients. Normal steam quality not exceeding 0.25% moisture carryover is maintained during full power output of the steam generators.

Table 8-2. Steam Generator Data

Design heat load, Btu/hr	126.3×10^6
Tube side conditions	
Fluid	Primary coolant water
Flow, lb/hr	4.6×10^6
Inlet temperature, F	521.3
Outlet temperature, F	494.7
Volume, cu ft	87
Pressure drop, psig	17.5
Design pressure, psig	2000
Design temperature, F	650
Hydrostatic test pressure, psig	3000
Shell side conditions	
Feedwater temperature, F	345
Steam pressure, psig	455
Steam temperature	Saturated
Water volume to fill shell, cu ft	355
Water volume, operating, cu ft	227
Design pressure, psig	800
Design temperature, F	650
Hydrostatic test pressure, psig	1200

8.1.4. Construction Features

8.1.4.1. Heat Exchangers

The horizontal section of the heat exchanger is a U-tube, U-shell arrangement. The tubes are expanded and welded at both ends to the fixed tube sheets to prevent primary-to-secondary system leakage.

The heat exchanger pressure shell, steam drum, support members, and other components not directly in contact with the primary coolant are fabricated of carbon steel. The U-tubes are seamless drawn type-304 stainless steel, 3/4-inch OD, and 0.072-inch minimum wall thickness. Each heat exchanger has 812 tubes positioned in a 1-1/16-inch triangular pitch (see Drawing 40784E-12).

Eight 6-inch downcomer nozzles are welded to the heat exchanger shell near the bottom. Twelve 8-inch and one 6-inch riser nozzles are welded to the heat exchanger shell along its upper surface. The riser and downcomer tubes connect the steam side of the heat exchanger with the steam drum. The downcomer tubes are shaped to provide the necessary flexibility between these pressure vessels.

8.1.4.2. Steam Drum and Internals

The steam drum is horizontal with elliptical heads. A 12-inch by 16-inch manhole at one end provides the necessary access to the internal parts (see Drawing 66588E-3).

Steam separation is provided by 20 cyclone separators located within the steam drum. The scrubber elements are mounted adjacent to the cyclone section and direct the vapor toward the dry-pipe section (see Drawing 40698E-14). The dry pipe is connected directly to a 7.750-inch-ID outlet nozzle located in the upper drum section, where the steam flow is directed to the containment penetration.

Two spring-loaded relief valves are provided on each steam drum to protect against overpressure. They are set to relieve at 800 psig and have a total relieving capacity of 108,000 lb/hr at the lift pressure. The valve effluent discharges directly to the containment vessel.

Remote indication of water level is provided by three independent systems in each steam drum. These consist of two differential level sensing devices and one electrical conductivity unit provided on an external standpipe. The three assemblies are read out at the main control console. An additional ultrasonic detector assembly has been installed experimentally on one steam drum and is currently under evaluation.

8.2. Main and Auxiliary Steam Systems

The main and auxiliary steam systems (see Drawings MS 301-J-536 and SS 11-J-751) are comparable in arrangement to those found aboard conventional ships of the same size and horsepower. The principal difference is in the utilization of saturated steam for both main propulsion and the auxiliary services. As a result of this arrangement, it has been necessary to employ steam separators at several points to maintain acceptable main steam quality conditions. The steam quality limit has been established at 0.25% and verified through an extensive series of tests performed prior to ship delivery in 1962.

8.2.1. Main Steam System

The main steam system pressure varies inversely as the reactor power demand, and control is based on constant reactor average temperature. This pressure varies as a function of power demand and primary system average temperature.

The main steam lines lead from the individual steam drum exit nozzles through a flexible containment penetration to the two main steam stop valves located in the upper reactor space. The stop valves are motor operated; the pushbutton control and position indicator lights are mounted on the main control console. A 3/4-inch manual bypass valve (with remote position indication) is provided for warmup purposes.

Downstream of each main steam stop valve is a 2-1/2-inch auxiliary steam dump line to the auxiliary condensers. The auxiliary steam dump is controlled by manually operated control valves. This system has not been utilized since its installation and acceptance testing.

The individual main steam lines pass by way of expansion joints through bulkhead 126 and into the main machinery space, where they join in a common header downstream of the manually operated bulkhead stop valves. Pressure and flow instruments are located in the secondary shield area.

The main steam passes through the steam separator, a cyclone separator mounted adjacent to bulkhead 126, and then to the main engine throttles, the turbine generators, the main feed pumps, and the main steam dump system. In addition, the main steam is also reduced in pressure for utilization in intermediate- and low-pressure steam systems. Suitable manual and automatic steam traps and drains are provided throughout the system to ensure proper steam quality.

The main steam dump consists of a 6-inch bypass line from upstream of the main engine throttle to the main condenser. A manual shutoff valve and manually operated pressure reducing valve control the main steam dump. Special perforated diffusion nozzles are provided at the main condenser inlet sections to eliminate direct impingement on the condenser tubes. The system is capable of dumping 190,000 lb/hr into the main condenser. To date, the main steam dump has been used only during the initial testing of the reactor systems.

8.2.2. Auxiliary Steam System

8.2.2.1. Low Pressure Steam Generator

The low pressure steam generator system supplies steam for numerous hotel and heating services throughout the vessel. These include galley services, quarters heating, tank heating, laundry services, and the steam whistle supply. The steam generator is a submerged coil shell-and-tube heat exchanger with a rated output of 7500 lb/hr at 110 psig (see Drawing 3-27213). Coil steam is taken directly from the main steam line and passed through a pressure regulating valve and control orifice before entry to the submerged coil. The coil drains pass through a trap and are then directed to the deaerating heater for recovery.

Feedwater is supplied from one of two electrically driven centrifugal pumps taking suction from a drain tank. Boiler level is maintained by conventional level controls. The heating return drains can be observed through a sight glass prior to filling the drain tank as a check on system integrity. Periodic makeup water as well as chemical additions for inhibiting internal corrosion can be added to the drain collecting tank as required.

This system ensures against the release of potentially radioactive fluid to living and working spaces should there be a primary-to-secondary system failure. In addition, it eliminates the possibility of foreign matter coming in contact with the main steam generator heating surfaces should there be an loss of integrity in the tank heating coils, galley equipment, etc.

8.2.2.2. Auxiliary Boiler

During periods when reactor steam is not available for the low pressure steam generator system, an auxiliary oil-fired boiler is provided for use in supplying the required steam for the hotel loads. This is a fire-tube type, automatically regulated steam generator. It is arranged in parallel with the low pressure steam generator and utilizes the same drain tank and feed pump services.

The auxiliary boiler has a capacity of 7500 lb/hr at 150 psig and has a completely automatic firing sequence and safety system to monitor water level, steam pressure, fuel pressure, air supply, and flame continuity. The 150 psig pressure range permits the steam provided to be utilized for the main air ejector system should it be necessary to reduce windage losses by maintaining vacuum on the main engine while operating on the take home motor. The fuel system operates in conjunction with the fuel arrangement provided for the auxiliary diesel generators.

8.2.3. Intermediate Pressure Steam System

Steam at reduced pressure (see Drawing SS 11-J-751) is supplied to numerous auxiliary components in the main machinery space on either a continuous or intermittent basis. The various pressure systems and components involved are as follows:

150 psig system

Main air ejectors (2 sets).
Auxiliary air ejectors (4 sets).
Salt water evaporator air ejector (2 sets).
Main engine gland seal system.

85 psig system

Blowdown evaporator coils.
Third-stage heater shell side.

26 psig system

Auxiliary exhaust system.

5 psig system

Salt water evaporator heater (2 units).

The various systems involved are fabricated of carbon steel and are sized consistent with the capacity required. The reducing valves provided are either pilot operated or integrally operated to maintain the desired pressure.

Suitable manually operated maintenance stop valves and bypass valves as well as drain traps and local and remote instrumentation are provided. Spring-loaded relief valves are provided on each pressure system to ensure against inadvertent overpressure. The relief valve effluents are directed to an atmospheric pressure collection point.

The steam exhaust system operates at 26 psig. Bleeder steam removes air from feedwater in the deaerating heater. An automatic dump system to the operating condenser releases exhaust steam in excess of the demand required for deaeration and system preheating. A permit system is provided to ensure that adequate conditions exist prior to automatic system dumping.

8.3. Main Propulsion System

The main propulsion unit is a cross-compound turbine with high pressure and low pressure wheels directly coupled to a double reduction gear of conventional design. Steam flow to the propulsion unit is controlled by the main throttle assembly. The vacuum on the propulsion unit is maintained by the main condenser. The main propulsion system also contains auxiliary equipment for system lubrication, overspeed protection, and air extraction.

The main propulsion unit, located in the main machinery spaces between frames 126 and 148, develops 22,000 shp at 112 rpm of the main shaft and propeller. The integral astern unit is capable of developing 5400 shp at 75 rpm. The performance characteristics are shown in Figure 8-1.

8.3.1. Main Throttle Assembly

The main throttle assembly (see Drawing SK13-G-873) consists of two throttling valves: one to control the flow of steam to the ahead turbine and one to control the steam to the astern turbine. Each valve is operated independently from a separate source. The two valves are contained in a single body and arranged so that the ahead valve is controlled by an overspeed governing assembly (see Drawing SK13-G-872). Main steam enters the valve body through the steam inlet between the two valves. A cylindrical steel steam strainer basket is provided in the entrance cavity.

The ahead throttle valve is an external pilot operated, balanced piston valve with a single Stellited seat and disc. The valve may be operated manually or through a Limitorque drive motor. The actuating linkage is arranged with a hydraulic cylinder and piston to provide rapid valve closure in the event of an overspeed condition developing in the ahead elements of the high or low pressure turbines. The ahead throttle will also close on a loss of lubricating oil bearing pressure or lubricating oil pump discharge pressure or on main condenser excess pressure. A mechanical override feature is provided to permit emergency operation of the ahead throttle while in a tripped condition.

The astern throttle valve is an internal pilot operated, balanced valve with a single Stellited seat and disc. The actuating assembly linkage is a direct mechanical arrangement that can be operated manually or through a Limitorque drive motor.

Limit switches are provided to indicate fully open or closed positions of the ahead and astern throttles. A relative position indication is obtained when the throttles are operated by the Limitorque motors.

Electric throttle control is the normal method of plant operation, when the valves are operated from the main control console. Dual shaft speed and bridge-order telegraph indicators in the control room and at the local control station facilitate local pushbutton or hand-wheel control.

A manual-electric astern guardian valve is provided between the astern throttle assembly and the astern turbine element. This valve is opened only when the engine is being maneuvered and is provided to prevent astern valve leakage from reducing the efficiency of ahead rotation during normal sustained ahead operations.

The ahead valve characteristics provide opening or closing that is approximately proportional to the first power of the time the gate is in motion (see Figure 8-2). The opening or closing time for the ahead valve is 25 seconds, and for the astern valve at least 14 seconds.

8.3.2. High- and Low-Pressure Turbines

8.3.2.1. High-Pressure Turbine

The high-pressure turbine unit (see Drawing SK13-G-867) consists of a multistage pressure-compounded impulse turbine. The bucket wheels are forged integral with the rotor shaft. The shaft is supported radially by two split-sleeve bearings and axially by a six-shoe Kingsbury thrust bearing. An external position indicator permits an operational check of rotor axial position. The turbine casing is horizontally split and fixed on the after end to the reduction gear casing. The forward end is supported by a flexible I-beam arrangement to permit expansion.

The upper half of the high-pressure casing has 37 nozzles for power control. These are arranged in four groups as follows:

1. Fourteen nozzles fixed open.
2. Five nozzles controlled by hand valve 1.
3. Ten nozzles controlled by hand valve 2.
4. Eight nozzles controlled by hand valve 3.

The hand valves are controlled as power requirements demand (see Figure 8-1). Stages 2 through 5 of the unit are encased within an inner cylinder of the turbine casing; the diaphragms for stages 6 through 9 are supported within the casing proper. The latter four stages are provided with lipped projections on the outer periphery of the diaphragms to separate and collect any moisture droplets that are formed and thrown off from the steam flow.

Metallic shaft seals are provided at the casing glands and between the individual pressure stages. Suitable drains are directed to the exhaust trunk from the high-pressure gland seal as well as from the second- and sixth-stage steam belts. An external automatic pressure-regulated steam supply is used to seal the rotor glands and hand nozzle valves during periods of light steam loads, when these joints are subjected to subatmospheric pressure conditions (see Drawing SK13-G-869).

The high-pressure turbine exhausts into a cavity, which in turn is connected through a flanged opening to the crossover line and the low-pressure unit. An automatically controlled valve is provided in this section to control the amount of steam admitted to the back-pressure system from the designated high-pressure bleeder opening. This bleeder is used only during sustained sea operation when the crossover pressure is equal to or exceeds the normal exhaust pressure (26 psig).

8.3.2.2. Low-Pressure and Astern Turbine

The low-pressure turbine unit (see Drawing SK13-G-868) consists of an ahead section and astern section fixed to a common forged rotor. These sections are separated by a series of deflector plates mounted in a control exhaust cavity, which directs exhaust steam to the main condenser and prevents steam impingement during periods when the unit is operated alternately ahead and astern.

The ahead unit is a seven-stage pressure-compounded impulse turbine. The first five ahead turbine wheels are keyed and shrunk to the forged rotor assembly, but the remaining sixth- and seventh-stage wheels are forged integral with the rotor assembly.

The second- through seventh-stage diaphragms are provided with lipped projections on the outer periphery to separate and collect any moisture droplets that may be formed during steam passage. In addition, the back faces of the sixth- and seventh-stage moving blades are covered with Stellite to reduce erosion resulting from low-steam quality in the final pressure stages.

The astern element is a two-stage pressure, velocity-compounded turbine. This consists of a single Curtis stage and a single pressure stage. During astern operation, steam is admitted to this section while the ahead steam throttle is closed; thus the ahead elements rotate in a vacuum.

As with the high-pressure assembly, metallic seals have been provided at the casing glands as well as between the individual pressure stages. The same external steam seal supply is used for the high-pressure and low-pressure units. The low-pressure rotor assembly is positioned radially by two split-sleeve bearings and axially by a six-shoe Kingsbury thrust bearing. Axial position can be readily checked by an axial position indicator located on the forward bearing assembly. The low pressure casing is supported at the after end by the reduction gear housing, and the forward end is supported by a vertical structure that incorporates axial flexibility of movement. The main condenser is directly supported from the exhaust casing flange.

8.3.2.3. Safety Protection

Both the high-pressure and low-pressure turbine rotors are fitted with direct driven, gear type oil pumps on the forward ends. These pumps take suction from the associated lubrication system and develop a discharge pressure that is commensurate with the speed of ahead rotation. This hydraulic pressure is applied to a high-pressure and low-pressure spring-loaded cylinder and piston assembly that is directly connected to the ahead throttle valve trip. Should the rotors exceed 115% of the full speed setting, the throttle valve automatically trips and remains shut until the assembly is manually reset.

8.3.3. Reduction Gears

The main engine reduction gears (see Drawing SK13-G-878) are in an articulated, double-helical, double-reduction arrangement. The high-, intermediate-, and low-speed pinions and gears are mounted in a fore-to-aft sequence and have an overall ratio of 42.3 to 1.0. The high-speed pinions are driven by the high- and low-pressure turbines through flexible couplings. These couplings permit limited axial displacement of the rotors and pinions without interfering with helix alignment. The high-speed gear and low-speed pinion connection is made through a quill shaft and coupling. The coupling is fitted with mating internal and external teeth and is located on the after end of the respective pinion. Individual oil supply feeder connections are provided for each flexible coupling.

The high-speed gears attached to the turbine rotors are positioned axially with double six-shoe Kingsbury thrust bearings. The low-speed gear (bull gear) is supported axially by a 45-inch double eight-shoe, self-aligning Kingsbury thrust bearing mounted aft of the gear on a special constructed and reinforced base plate assembly. This thrust assembly absorbs the propeller shaft thrust in the ahead and astern directions. The position of the low-speed gear can be checked by a position indicator mounted on the after end of the main thrust bearing.

Radial positioning of pinions and gears is provided by babbitted, split-sleeve journal bearings. The journal bearing split is not necessarily in the horizontal plane of the gear casing, but may be offset to ensure full bearing surface seating due to reactive load positioning of the journal at power operating conditions.

A motor-driven, shaft-turning gear is mounted on the after end of the low-pressure, high-speed pinion assembly. A worm gear and clutch assembly is provided for gear train rotation (ahead and astern), which allows the turbine rotors and reduction gears to be evenly heated or cooled during startup or shutdown.

The auxiliary 750 hp electric motor is mounted adjacent to the high-pressure, high-speed pinion assembly. A manually operated sliding claw coupling can be used to directly connect the motor rotor to the pinion when auxiliary propulsion is desired. The turning gear and the electric motor arrangements are provided with individual lubrication feed fittings, microswitches, and condition-indicating lights.

The main line-shafting extends from the propeller thrust bearing aft through the shaft alley to the stern tube bearing housing. It consists of six sections of 22-1/2-inch-diameter carbon steel shafting, varying in length (about 20 feet), and is supported in babbitted split bearings. Lubrication is provided by individual bearing sumps working in conjunction with rotating journal rings. Specially constructed sections are provided for use with the main thrust assembly as well as the stern tube bearing.

8.3.4. Main Engine Lubrication System

Main engine lubrication (see Drawings SK13-G-871 and LO 12-J-417) is provided by a combination pressure-and-gravity feed system. In addition to supplying the lubrication requirements, the system is employed as a control oil system for use with the main throttle assembly and the main engine gland seal regulator assembly.

Oil is pumped from the main engine sump to the main engine bearings by way of an in-line duplex strainer and a pressure control orifice. A pressure of approximately 55 psig is maintained by this orifice for governing and control functions. The oil flows from the orifice through a shell-and-tube heat exchanger, where it is cooled before splitting into two parallel paths. One path is by way of a duplex magnetic strainer and a second manual pressure control orifice, which is regulated to exert 12 to 15 psig on the second flow path. A fixed orifice in the second flow path controls the total quantity of oil flow to the engine as a function of the pressure exerted by the variable orifice position.

Excess oil passes through the control orifice and is discharged to a gravity tank and overflow line back to the main pump. In the event of total lubrication oil pump failure, governor oil pressure is lost, which results in closing of the ahead throttle. Then the oil in the gravity tank flows down to the discharge manifold by way of the orifice valve and a parallel check valve assembly. This ensures oil pressure at the bearings until the engine can be stopped. Since the astern throttle assembly is not dependent on oil for operation, astern steam can be applied as a braking force.

Testing of the low lubricating oil pressure, overspeed, and high exhaust pressure trips is performed periodically. Individual bearing flow indicators and thermometers are provided to ensure proper flow and temperature conditions throughout the turbine and reduction gear assemblies.

A lubrication oil purification system is provided in addition to the magnetic in-line strainers (see Drawing LO 12-F-418). This system permits clarification of the oil by preheating and centrifuging. Adequate storage and settling tanks are provided for reserve oil and for batch dehydration of the system oil when the main engines are secured.

8.3.5. Operational Arrangements and Data

8.3.5.1. Port Operations

The main propulsion unit is generally secured when the vessel has completed maneuvering to the dock and has been made fast. When the main throttles have been secured, the turning gear assembly is engaged, and the rotors and gear train are slowly rotated during the period of cooldown. Generally, after several hours the entire unit including lubrication oil and cooling water is secured. Every two days the oil system is activated, and the engine is again rolled over on the turning gear to allow for overall lubrication of moving parts and for repositioning of the rotating parts in their bearings.

On occasion, it may be necessary to anchor the vessel away from dockside. In this situation the engine may be retained in a standby status by maintaining a steam seal and vacuum on the engines while rotating the engines and gear train with the turning gear. With these arrangements it is possible to get steam on the engine in a relatively short time.

8.3.5.2. Sea Operations

When the vessel has departed from port or is expected to be operated on a sustained speed basis, the main engine is aligned as follows. A high-pressure turbine nozzle selection that will produce the required speed and horsepower is made. The lubricating oil temperature is stabilized at approximately 115 F, and hourly checks of the individual bearing temperatures and flows are made. Duplex strainers are changed and cleaned periodically to ensure adequate bearing pressures. Rotor position indicators are checked for the operational alignment of the turbine rotors. High-pressure and low-pressure turbine bleeder valves are opened to provide the required condensate and feed heating while system vents and drains are positioned to ensure maximum efficiency. The crossover steam separator (see Figure 8-3) located between the high-pressure turbine exhaust and low-pressure engine inlet is valved to ensure proper drainage for a sustained sea operation.

Main engine speed changes are initiated from the main control room on receipt of bridge orders on the electrical telegraph. A bell alarm associated with telegraph movement alerts the operator to a demand signal change. The alarm is silenced on acknowledgment. Should there be an inadvertent wrong direction throttle opening, an additional local alarm will light, and an audible signal will sound.

8.3.6. Main Condenser

The main condenser (see Drawing E 4-71RMB-500X1) is a horizontal, single-pass unit with nondivided water boxes. Sea water flow is provided from a main circulating pump discharge (20,000 gpm) through a 30-inch opening or from a 42-inch discharge from a scoop connection (32,600 gpm) in the ship's bottom. An emergency cross connection is provided to the auxiliary circulating pump discharge line. A 38-inch opening is provided for overboard discharge. Swing check valves in each inlet line prevent backflow. The condenser has 22,360 square feet of effective condensing surface made up of 5,696 No. 18 BWG, 3/4-inch-OD tubes approximately 20 feet long. The tube ends are expanded and welded to the vertical tube sheets and are belled on the inlet ends. The tubes are installed with a 1/2-inch upward bow at the center to facilitate drainage and differential thermal tube expansion.

Seven main vertical support members are located at intervals in the condenser shell. These serve as structural strength members as well as tube alignment and support plates. The support plate nearest each tube sheet forms an isolation cavity adjacent to the tube ends. Suitable drainage of this space is provided by manual stop valves serving an external drain loop at each end leading to the condenser hot well. A separate pump is provided to drain the cavity in the event of tube end failure. Thus far use of this system has not been necessary.

An expansion joint is provided in the shell arrangement to relieve unequal stresses between the shell and the tube bundle. Zinc waste plates are mounted in the water boxes to reduce corrosion of the dissimilar metals in the presence of sea water. In addition, sheet copper bonding clamps are provided along with high conductivity bronze tie bolts at the tube sheet connections to ground stray currents.

A baffled air cooler section is provided in the center of the tube nest arrangement. Steam, air, and noncondensibles enter the top of the tube nest and flow downward past the baffles and then are redirected upward toward the air cooler section. The air-moisture mixture then flows over a series of baffles toward the sea water inlet end of the condenser, where it is drawn outward into the air ejector suction lines.

Condensate collecting at the bottom of the condenser is exposed to bypass steam in the hot well section. This heats the liquid droplets to saturation temperature and causes the subsequent release of any entrained noncondensible vapors. These vapors are vented to the air cooler section while the deaerated condensate drops to the hot well section for removal by the condensate pumps.

Two main dump steam nozzles are provided on the shell of the condenser at the sea water inlet side. These consist of 6-inch flanges and diffuser plates to prevent direct steam impingement on the tubes. The total dump capacity is 190,000 lb/hr. A similar auxiliary steam dump connection on the opposite end has a capacity of 35,000 lb/hr at 35 psig.

A waste discharge connection is provided to the salt water inlet side of the water box together with a sampling connection from the discharge side of the condenser. Diluted liquid waste from the WD system may be discharged by way of the main condenser.

In addition to annual inspections required by the USCG, a series of periodic Probolog inspections have been performed on the main condenser tubes as a check of tube wall deterioration. As a result of these inspections, some tubes have been plugged using 25% wastage as a criterion for plugging a tube. The total plugged represents a negligible loss of condensing surface area; there has been no detectable effect on the main engine or overall plant performance.

8.3.7. Main Condensate and Feedwater System

The main condensate and feedwater system consists of a regenerative heat system employing three stages of feedwater heating and two stages of condensate deaeration. Condensate is drawn from the condenser hot wells by two main condensate pumps and is pumped through the main air ejector, the low-pressure heater, and the deaerating feedwater heater (see Drawing DR-114063). The three feed pumps draw water from the deaerating feedwater heater and supply it through the high-pressure heater to the steam generators.

8.3.7.1. Feedwater Controls

Water levels in the boilers are maintained by one of three main feed pumps. Two of these pumps are steam turbine driven and are classified as main feed pumps. The third pump is motor driven and is designated as the port feed pump. The main feed pumps are rated at 735 gpm and are capable of maintaining the required feed flow rate at maximum power. The port feed pump is rated at 125 gpm and is capable of providing the required feed flow during port operation as well as reduced sea operation (about half speed).

The main feed pump governor assembly maintains a constant differential pressure of 125 psig between pump discharge and steam generator pressures. Flow is controlled by a three-element feedwater regulating system to maintain a programmed water level in the operating heat exchangers. Manual and automatic controls of the feed regulating system are provided.

Heat exchanger level control has been closely maintained through all operating and test transients. Recent modifications to the boiler level sensing elements have provided greater dependability of overall operation.

8.3.7.2. Main Air Ejectors

The main air ejectors (see Drawing E 4-M1A55-503X1) are twin-stage, twin-element units with surface type inter- and after-condensers. The function of these ejectors is to remove air and noncondensible vapors from the main condenser during startup and normal operation. Each unit consists of two first-stage and two second-stage ejectors mounted on a single housing, which contains the inter- and after-condensers in separate compartments. Suitable valving is provided to permit the use of either or both elements.

Air and noncondensible vapors are drawn from the air cooler section of the main condenser by the first-stage nozzle assembly and discharged to the inter-condenser. Any moisture present is condensed by the cool condensate that is flowing through the tube side of the heat exchanger. The collected liquid is then drained by way of the loop seal to the main condenser. The air and noncondensible vapors are then drawn from the inter-condenser section by the second-stage steam nozzle and discharged to the after-condenser section. The after-condenser drains are directed to the atmospheric drain tank while the air and noncondensible vapors are drawn into the gland seal exhaust system.

8.3.7.3. Gland Seal Exhaust System

The main engine turbine rotors are sealed against in-leakage of air by a series of steam-sealed labyrinths located at the casing penetrations. The sealing steam is normally supplied at 0.5 to 2.0 psig from an auxiliary steam system. The excess steam from the seals is removed by piping the leakoff connections to the after-condenser section of the main air ejector. The condensed steam then combines with the second-stage nozzle discharge and drains back to the atmospheric drain tank.

A gland seal exhaust fan, rated at 200 cfm with 100 F air at a static head of 10 inches of water, takes suction from the after-condenser section of the main air ejector and discharges to an air cooled, shell-and-tube gland exhaust condenser. Any remaining entrained moisture is condensed and drained to the low-pressure drain system. The combined air and noncondensible vapors are discharged to an engine room exhaust system.

The gland seal exhaust system effluent is continuously sampled by the radiation monitoring system for radioactive particulate daughter products of fission gases. This detector arrangement, operating in conjunction with secondary system water sampling, serves as an early warning for the presence of a primary-to-secondary system leak.

8.4. Emergency Propulsion System

The emergency propulsion system permits the ship to maintain way and maneuverability if the nuclear power system is not available. Emergency propulsion is furnished by a 750 hp motor - the take-home motor.

8.4.1. Description and Operation

Emergency propulsion is furnished by the 750 hp motor, clutch connected to the high-pressure, high-speed pinion of the main reduction gear. Motor data is listed in Table 8-3. The propulsion motor is driven from either of the auxiliary diesel generators through the main switchboard control panel and the locally mounted phase controller. This controller permits operation of the motor in an ahead or astern direction as conditions require.

The main switchboard contains the necessary voltage, amperage, kilowatt, and cycle indicators as well as the speed control and volts-per-cycle controllers. The phase control panel contains the make-and-break switches required for direction control; these are manipulated in conjunction with the main switchboard controllers.

Table 8-3. Emergency Propulsion System Motor Data

Type	Type M, wound-rotor induction motor
System	3-phase
Speed, rpm	1775
Amperes	888
Volts	440
Secondary voltage	625
Secondary amperage	557

The spline coupling assembly is engaged manually, and a microswitch contactor is used as a status indicator for a lamp display in the main control room. A mechanical friction brake is provided on a propeller shaft section in the shaft alley for locking the shaft against movement if required during the engagement. This action is not normally required.

The speed of the auxiliary propulsion motor is governed by the speed of the auxiliary diesel generator selected as the prime mover. Standard operating procedures require that the unit be started at a reduced voltage (300 volts) and reduced cycles (40). After the unit has accelerated through the starting resistor sequence, the speed is increased by increasing the speed of the diesel engine. The volts-per-cycle regulator provided on the main switchboard section maintains a constant relationship during normal operation.

8.4.2. System Modifications

A number of improvements were made on the system after the original acceptance trials in order to obtain greater flexibility and dependability in the emergency propulsion system. These changes include the installation of the phase-reversing controller as well as a modification to the starting resistor sequence arrangement.

The original emergency propulsion motor installation met the required specifications; however, it was considered marginal in the sense that cold engine conditions could result in a delayed starting time. Tests were conducted to determine the actual cold torque required to roll the main engine considering reduced oil temperature (90 F), bearing clearances, friction values, and stern tube friction. Concurrently, it was determined that the starting torque of the motor, as determined by locked rotor tests, was below the required value. The vendor was consulted, and it was determined that the motor was designed for and could produce the required cold starting torque with a modification of starting resistors and timing sequence. This change was completed, and a subsequent test proved the motor satisfactory in rolling the main shaft under cold conditions.

Regulatory authorities expressed concern over the directional restriction of the original installation (ahead motion only). Thus, the phase reversal cabinet and controller assembly was installed.

Subsequent tests showed both ahead and astern directional capability in a cold condition.

8.4.3. Operational Tests and Sea Trials

A series of operational tests and sea trials was conducted to check the performance of the emergency propulsion system and modifications. These tests demonstrated the adequacy of the system by successfully completing undocking, zee, and stopping maneuvers.

8.4.3.1. Undocking

The ship's lines were cast off, and the ship was undocked in 16 minutes using only the auxiliary propulsion motor. Three astern bells and two ahead bells were answered during this period. Wind was from 215° at 4 knots, and an incoming tide prevailed. There was an indication that the tide assisted somewhat in turning the ship. The same maneuver required 33 minutes when there was no appreciable current in the channel.

When the third astern bell was received, a plugging test of the take-home motor was made. After opening the take-home motor breaker at 24 rpm ahead, the reversing controller was thrown to astern. Closing the take-home motor breaker plugged the take-home motor to bring the shaft from 24 rpm to stop in approximately 5 seconds. The breaker was then opened for about 45 seconds and was then reclosed, allowing the shaft to accelerate to 20 rpm astern. The total elapsed time from 24 rpm ahead to 20 rpm astern was 90 seconds. Although this type of service is detrimental to long motor life, it satisfactorily demonstrated that reversing maneuvers can be accomplished in about 45 seconds.

8.4.3.2. Zee Maneuver

After passing into open sea, a zee maneuver was performed to demonstrate response to helm under take-home motor propulsion. This maneuver was performed by applying and holding 30° rudder in alternate directions until the ship's heading changed 30° to each side and back to the base course. The steady state swinging rates and the time to cross the base course were:

Steady swinging rate to right	17°/min
Steady swinging rate to left	22°/min
Time to cross base	8 min, 43 sec

8.4.3.3. Stopping Tests

With the ship's speed at approximately 6.8 knots and the shaft turning at 31 rpm (maximum speed without exceeding rated current), an astern bell was answered. The shaft was allowed to coast down to about 15 rpm; then the shaft brake was applied. The shaft brake was released at a shaft speed of about 4 rpm to allow the shaft to coast to a stop. The total time required for the shaft to stop from the time the astern bell was answered was 3 minutes and 40 seconds. It was recognized that better planning and a more concerted effort to coordinate the application of the shaft brake would have minimized the shaft coastdown time; however, the crew response in applying the brake was about the same that could be expected if no advance warning were given of an emergency stop.

When the shaft was stopped, the take-home motor was started in the astern direction to arrest the ship's forward motion. The astern rotation during the stopping was limited to 26 rpm to hold the motor current within design limits. During a true emergency stop the crew would permit the current to go higher to give maximum rotation and minimum stopping time. The stopping time in this instance was 7 minutes and 45 seconds from the time of the astern bell. The ahead reach was 2625 feet (4.4 ship lengths).

The ship's speed was allowed to build up astern until a maximum speed of an estimated 4 knots at 27 rpm was reached. An emergency stop test then performed gave a shaft coastdown time (with brake assist as before) of 2 minutes and 20 seconds. The time to stop the ship was 5 minutes, and the astern reach was estimated to be 1000 feet. An ahead shaft speed of 26 rpm was used to arrest the ship's astern movement.

The results of the emergency stopping tests are summarized in Table 8-4.

Table 8-4. Emergency Stopping Tests

Speed, knots	Shaft, rpm	Shaft coastdown min	Shaft coastdown sec	Ship stop min	Ship stop sec	Reach, ft
Emergency stop from ahead						
6.8	31	3	40[a]	7	45	2625
4.2	18.5	1	55	4	50	≈860
3	12	1	30	4	0	≈540
Emergency stop from astern						
4	27	2	20[a]	5	0	≈1000
2.5	12	1	0	3	10	≈500

[a]Shaft brake utilized to slow shaft.

8.5. Electrical Power Systems

The electrical power plant (see Drawing ED 52-J-432) provides for the generation, distribution, and control of all electrical power on board. The main generating equipment includes two 1500 kw turbine generator sets, two 750 kw auxiliary diesel-generator sets, and one 300 kw emergency diesel-generator set. The two turbine generators are located on the upper level of the machinery space, and the two auxiliary diesel generators are located on the lower level of the machinery space. The emergency diesel generator is located on the navigation bridge deck.

All of the ship's normal electrical power requirements are supplied by the two turbine generators with the two auxiliary diesel generators on standby. Loss of one or both of the turbine generators results in the automatic starting of the two diesel generators. In the event of the loss of power from the two turbine generators and the two diesel generators, which means loss of all power to the main switchboard, the emergency diesel generator automatically starts. The emergency diesel generator provides power to the emergency switchboard for emergency lighting, communications, emergency cooling, and other vital systems.

In addition to the main sources of power described above, there are two 40 kw, ac-to-dc motor generator sets and two 25 kw, dc-to-ac motor generator sets that provide a reliable (battery-protected) source of power for the control console, nuclear instrumentation, radiation monitoring, and for starting the auxiliary diesel generator sets.

8.5.1. Turbine Generators

8.5.1.1. Turbine Assembly

The turbine assembly (see Drawing SK13-G-874) is a pressure- and velocity-compounded impulse turbine consisting of a Curtis wheel followed by seven pressure stages. The turbine wheels are keyed and shrunk on a solid forged rotor shaft. A horizontal-split casing supports the rotor bearings, diaphragms, nozzle assembly, governor, and shaft-sealing assemblies. The radially mounted diaphragms support the metallic inter-stage packing and fixed blading. The rotor is positioned radially by a split, babbitted sleeve bearing mounted on each end of the turbine casing. Axial position is maintained by a six-shoe double Kingsbury thrust bearing. An external rotor position indicator is mounted on the forward bearing assembly as an axial position check.

Moisture collecting rings are provided on the outer periphery of the last five diaphragms to collect and drain any moisture droplets present in these pressure stages. In addition, the eighth-stage rotor blading is Stellite-backed to reduce erosion due to low-quality steam conditions.

The normal rotor speed of 5600 rpm is controlled by a constant speed governor (see Drawings SK13-G-875 and SK13-G-876) capable of operating over a range of 95% to 107%. Directly driven from the rotor shaft, the fly weight displacement operates a hydraulic power pilot-operated piston assembly to position a nozzle rack for control of steam admission through the nozzle groups. A locally mounted electric motor can be energized from the main switchboard to alter the speed governor setting for generator frequency control. A local manual control knob is also provided for changes in speed settings.

A manually operated, oil-pressure-dependent throttle trip assembly is provided for control of main steam admission. The throttle trips closed on low oil pressure (2.5 to 3.5 psig), high exhaust pressure (0 to 5 psig), and turbine rotor overspeed (115%). The throttle trip assembly operates in conjunction with hydraulic control pressure supplied as part of the lubrication system. Additional electrical protection is provided on the trip assembly by a microswitch contact that throws open the main generator circuit breaker if the throttle trip closes during normal operation.

Turbine rotor gland seal steam pressure is provided by an individual automatic steam seal regulator mounted on each unit. This regulator automatically controls steam admission and excess dump to limit the sealing pressure from 0.5 to 2.5 psig under normal operation. Gland seal leakoff and drainage are provided through a separate gland seal exhauster system operating in conjunction with the aftercondenser assembly of the auxiliary air ejector.

8.5.1.2. Reduction Gear Assembly

The turbine shaft speed of 5600 rpm is reduced to the generator rotor speed, 1200 rpm, in a single reduction by the use of a double-helical planetary gear (see Drawing SK13-G-877). This unit consists of a double-helical sun pinion driving three sets of planet gears, which turn inside of two fixed orbital gears. The entire rotating assembly is radially supported in two babbitted sleeve bearings housed in the reduction gear casing. One of the radial bearings has bearing faces on the vertical edges to provide axial alignment. A separate, but integral, lubrication system is provided for the unit.

8.5.1.3. Generator and Controls

The enclosed electrical power generator and amplidyne is mounted aft of the turbine and reduction gear assembly. The generator unit is a 1875 kva, 1200 rpm, 450-volt, three-phase, 60-cycle alternator operating at a normal power factor of 0.8. The unit can operate at 125% of maximum rating for 2 hours. The generator amplidyne is mounted aft of the main generator and is driven from the main rotor shaft. A constant voltage is maintained by the amplidyne output by varying the direct-current excitation in the generator field windings. The amplidyne output can be regulated by positioning the taps on an adjustable saturable reactor within the amplidyne control circuit. The generator output voltage can be manually or automatically controlled from the main switchboard.

A double-tube air cooler section is mounted above the generator unit. The cooling water service is provided from the auxiliary circulating system associated with the respective condensing units.

8.5.1.4. Lubrication and Safety System

The integral oil system (see Drawing SK13-G-875) on the turbine generator units provides control hydraulic pressure and lubricating oil pressure at three pressure stages for:

1. Control and safety system.
2. Reduction gear assembly.
3. Turbine and generator bearings.

Oil is drawn from the 220-gallon base plate sump by an integrally driven 58 gpm gear pump when the turbine is rotating. A separate motor-driven auxiliary pump and a hand-driven lubrication oil pump are mounted in parallel with the main pump for startup and shut-down periods.

The 115 psig pump discharge pressure is utilized to activate the following:

1. Low-oil-pressure trip valve.
2. High-exhaust-pressure trip.
3. Steam seal regulator.
4. Overspeed trip relay.
5. Speed-limiting governor.
6. Throttle trip valve.

The discharge oil pressure is reduced by an orifice to 25 psig for application to the planetary reduction gear assembly. It is further reduced to 10 to 15 psig for lubrication of the sleeve and thrust bearing assemblies.

Oil temperature is maintained by a salt water cooled, shell-and-tube heat exchanger, while the purity is controlled by in-line duplex strainers and filters. Additionally, the oil may be clarified by the main lubrication oil purifier system.

8.5.1.5. Auxiliary Condensers

The auxiliary condensers (see Drawing EH-8RS-500X1) are two-pass horizontal units mounted directly below the turbine generator level. A flexible bellows is the transition connection from the turbine casing exhaust flange to the condenser shell inlet. Each unit has 2000 square feet of condensing surface consisting of 728 No. 18 BWG, 3/4-inch-OD tubes. The tube ends are secured in the tube sheets by expanding and seal welding. The sea water inlet ends are flared into the tube sheet. Condenser tubes are installed with an upward bow of 1/2 inch to provide for unequal expansion. They are supported by five vertical plates, which are welded to the condenser shell and serve as integral strength members.

The support plate nearest each tube sheet forms an isolation cavity adjacent to the tube sheet. This cavity is drained through an external drain loop at each end leading by way of manual stop valves to the condenser hot well. A separate pump is provided as a contaminated drain pump in the event of tube end failure. To date use of this system has not been necessary.

A welded steel bellows assembly is provided in the return of each condenser shell to relieve unequal expansion strains between the shell and the tube bundle. Water boxes have inspection hand holes on each end. Zinc waste plates are mounted on the water box covers to reduce corrosion of dissimilar metals in the presence of sea water. Sheet copper bonding clamps and high-conductivity tie bolts are provided at the connections between water boxes and tube sheets and in the sea water piping.

Steam flow, as indicated in Drawing EH-8RS-500X1, is directed over the condenser tubes and ultimately to an air cooler section located adjacent to the sea water inlet end. From the cooler section the air and noncondensible vapors are drawn into the air ejector system. The condensate formed is drained to the hot well section for removal by the auxiliary condensate pumps. Auxiliary and main steam dump connections are provided with suitable baffling and diffusers to prevent direct steam impingement. The emergency main steam dump capacity for dry, saturated steam is 10,000 lb/hr at 725 psia.

Periodic Testing

In addition to the routine USCG inspections required, a periodic Probolog test has been perfomed on the condenser tubes to check for tube wall deterioration.

8.5.1.6. Auxiliary Air Ejectors

The auxiliary air ejectors (see Drawing EH-MIA22-531X1) are twin-element, two-stage units with surface type inter- and after-condensers. They are used to remove air and non-condensible vapors from the auxiliary condensers during the startup period and during normal operation. Each unit consists of two first- and two second-stage ejectors mounted on a single shell containing the inter- and after-condenser sections in separate compartments.

The condensate is circulated in series through the tubes of the inter- and after-condensers and makes six passes through the combined unit. The tubes of the inter- and after-condensers are set back and expanded in both tube sheets. The 85 tubes are 3/4-inch OD, No. 18 BWG, and 4 feet 10-1/2 inches long (measured between the inside faces of the tube sheets).

The suction flanges of the first-stage ejectors are attached to the air-vapor connection leading from the air cooler section of the auxiliary condenser. These ejectors discharge the air and noncondensible vapors from the condenser into the inter-condenser section of the air ejector unit. The vapors make three passes through this section and are removed by the second-stage ejectors and are then discharged into the after-condenser section, which operates at atmospheric pressure. The vapors also make three passes in this section. Condensate formed in the inter-condenser section is drained by way of a loop seal to the shell side of the auxiliary condenser. Drains from the after-condenser section are connected to the atmospheric drain tank.

The after-condenser section is connected to a gland seal exhaust fan and to the leakoff from the turbine shaft steam seals. The combined vapor in the after-condenser is discharged to the shell side of the air-cooled gland seal exhaust condenser by the motor-driven 200 cfm auxiliary gland seal exhaust fan, which has a static head of 10 inches of water.

8.5.2. Auxiliary Diesel Generators

There are two auxiliary diesel generators located in the main machinery space to provide power for reactor startup. These generators can be used for spare and emergency electrical power and to drive the auxiliary electric propulsion unit. Each diesel generator can deliver its rated load continuously and 125% of rated load for a period of 2 hours. Design and operating data are summarized in Table 8-5.

Table 8-5. Auxiliary Diesel Generator Data

Diesel rating, bhp	
Continuous	1062
2-hr overload	1340
Generator output, kw	
Continuous	750
2-hr overload	937.5
Diesel rated speed, rpm	720
BMEP, psi	
Continuous	86
2-hr overload	108
Diesel engine	
Type	2-cycle, V-12
Bore, in.	8-1/2
Stroke, in.	10
Firing order (clockwise rotation)	1-12-7-4-3-10 9-5-2-11-8-6
Starting system	Air

8.5.2.1. Diesel Engine

The diesel engine is a 12-cylinder, V-type, two-cycle, direct-injection unit mounted on a common base plate with the electrical generator assembly. The diesel engine is started by an air-driven Bendix motor attached to the flywheel coupling assembly. Three ship's service air tanks each with a capacity of 37.6 cubic feet at 250 psig are provided for air storage. One of the three tanks is kept closed at all times as an emergency air starting supply. The remaining two tanks are utilized as ship service air storage tanks working in conjunction with a 35-cubic-foot, 125 psig storage tank. Acceptance testing of the air system required sufficient compressed air in a fully charged condition for twelve starts without use of the compressors. An automatic timing sequence circuit prevents more than three automatic air-starting cycles in order to conserve the stored air supply.

The diesel engine has an integral lubrication system with indirect cooling and in-line strainer and filter provisions. A low lubricating oil pressure alarm (15 psig) and cutout (5 psig) alerts the operators to abnormal conditions. Engine cylinder and lubricating oil cooling is provided by a fresh water system which in turn is cooled by sea water. Integrally mounted pumps provide circulation in the fresh and sea water systems. Temperature and flow controls maintain the system within specifications. A high fresh water temperature alarm (190 F) is provided to alert the operator to abnormal conditions.

The diesel engine fuel system is connected to the ship's service diesel oil transfer and purification system. Fuel oil is admitted to the injector system and the excess flow serves as an injector coolant as its recirculates to the day tank. A separate oil centrifuge maintains the fuel in a clean condition during normal operations. A low fuel oil pressure trip circuit prevents the diesel from starting on a low oil condition (5 psig).

A mechanically driven trip assembly provides overspeed protection should the constant speed governor assembly fail to function correctly. Manual reset of this system is required before a restart can be attempted. Each engine is provided with a locally mounted gauge panel, which indicates engine and cylinder conditions. Visible and audible alarms are provided in the machinery space and control room.

8.5.2.2. Engine Starting and Control

The auxiliary diesel generators can be started either manually or automatically. Additionally, there are provisions for manual or automatic paralleling of the generators on the main switchboard. The following is a summary of the starting arrangements provided.

Local-Manual

1. Air motor control valve located on the engine.

Remote-Manual

1. Control panel switch adjacent to engine.
2. Main switchboard, manual switches, one or two engines, manual or automatic synchronizing (two locations).
3. Main control console, both engines, automatic synchronizing. (Manual synchronizing requires additional system manipulations.)

Automatic-Remote

1. Reactor scram.
2. Over current at turbine generator.
3. Open breaker at turbine generator.
4. Reverse current trip at turbine generator.
5. Low lubricating oil trip at turbine generator.
6. Overspeed trip at turbine generator.
7. Bus undervoltage (370 volts).
8. Bus tie overcurrent trip.
9. Loss of starting control power.

Poststartup speed of the diesel engines can be controlled through a remote control governor switch on the main switchboard or by local control of the governor assembly. Shutdown of the units can only be accomplished locally. The auxiliary diesel generators are normally left in a standby condition while not in actual use. This consists of a proper speed (cycle) and automatic voltage setting on the governor and main switchboard.

8.5.2.3. Generator

The generators are 750 kw, 440-volt, three-phase, 60-cycle alternators operating at a normal power factor of 0.8. These units are provided with separately mounted amplidyne exciters. Automatic voltage control is provided by the amplidynes in addition to manual voltage control. An additional automatic volts-per-cycle control system is provided for use when a generator is electrically connected to the auxiliary electric motor. This system maintains a constant volts-per-cycle relationship when the diesel engine speed is adjusted for power output and propeller speed.

The generator assembly is air-cooled by an impeller section mounted on the flywheel assembly of each engine coupling. The generator voltage, amperage, power output, power factor, and frequency can be monitored on the main switchboard. A readout of the power output is also placed on the main control console.

The generators are protected by electrically or manually operated air circuit breakers located on the main switchboard. These breakers are equipped with dual, selective, overcurrent series trip devices as well as low voltage and reverse power relays.

8.5.3. Motor Generator Sets

Two 25 kw, dc-to-ac motor generators, driven by the battery-backed, 125-volt, d-c bus, provide power to a vital bus. The motor-generator output is single-phase, 60-cycle ac. Two 40 kw, ac-to-dc motor generators provide power to the 125-volt, d-c bus and maintain the potential of the backup batteries.

Controls and indicators for motor generator sets are locally mounted for unit control. All meters, line breakers, and switches are consolidated on a single section of the main switchboard for convenience. Manual and automatic control of speed and voltage as well as overcurrent, low voltage, and reverse current protection are provided for both motor generator sets.

Both of the motor generator sets are located in the main machinery space adjacent to the control room. Present operating procedures call for one of each type of motor generator set to be in operation at any time. The alternate equipment is aligned for standby use and can be activated with a minimum effort. Periodic transfer of operating equipment as well as performance testing of system capability ensures operational readiness of the systems.

8.5.4. Battery Backup Systems

Nickel-cadmium battery banks have been provided for d-c backup of the two motor generator sets. The 125-volt, d-c bus associated with the main switchboard floats on a battery bank group that is rated at 672 ampere hours at 135 volts dc. A 400-ampere, fused disconnect switch located at the entrance to the machinery space opening on C-deck aft isolates the bank. Instrumentation includes ammeters and voltmeters. A control room alarm is provided to alert the operator to the battery discharging should this situation develop as a result of ac-to-dc motor generator failure or low generator output voltage.

A second battery backup, the emergency battery bank, is located in the emergency generator room on the navigation deck. This battery bank is rated at 512 ampere hours at 120 volts dc. The batteries are directly connected to the 120-volt battery bus through a 600-ampere, fused disconnect switch. This bus serves as an alternate power supply for the 120-volt, d-c, temporary-final bus as well as the 120-volt, ac-to-dc temporary bus. The battery bus is also an alternate power supply for the fire door closing circuit through the arrangement of a high-speed automatic bus transfer switch. The emergency battery bank is charged through a transformer-rectifier circuit connected to a circuit breaker from the 450-volt, three-phase, 60-cycle, a-c power bus at the emergency switchboard.

8.5.5. Emergency Diesel Generator

8.5.5.1. Diesel Engine

The emergency diesel generator is located in the emergency generator room on the navigation deck. It consists of a vertical, seven-cylinder, opposed-piston, two-cycle engine operating at 1200 rpm. The engine has an integral lubricating oil system as well as an air-cooled, fresh-water circulating system. A separate fuel oil day tank is locally mounted and supplied from the fuel oil service system associated with the auxiliary diesel generators. Integrally mounted pumps provide circulation and pressure requirements for the lubrication, fresh water, and fuel systems. Filters are provided in the lubrication and fuel systems.

A mechanically driven constant speed governor is mounted on the engine and can be controlled locally or from the emergency switchboard. A mechanically actuated overspeed trip mechanism functions if the constant speed governor assembly fails. The engine is started by a hydraulically actuated Bendix motor mounted adjacent to the engine flywheel. The hydraulic starting system consists of four accumulators mounted in a local control cabinet and four accumulators mounted on an adjacent bulkhead. Hydraulic oil pressure is maintained at 2500 psig in piston-operated, nitrogen-backed accumulators operating in conjunction with a pressure-switch-controlled motor driving a hydraulic pump. A manually operated standby pump is provided for charging the accumulators. Relief valves are provided in the hydraulic system to prevent overpressure.

The Bendix motor is automatically actuated by the admission of high-pressure oil through two parallel sets of electrically operated solenoid valves. The solenoid valves may also be operated manually.

8.5.5.2. Generator

The generator assembly and amplidyne are mounted adjacent to the diesel engine on a common baseplate. The generator is a 60-cycle, 440-volt, three-phase, a-c unit having a continuous duty rating of 300 kw. Permissible overload is 125% for 2 hours. The generator is directly connected to the diesel engine and turns at 1200 rpm.

Air-cooling is provided by an integral impeller unit mounted on the rotor assembly. Louvered ductwork in the emergency generator room affords an adequate flow of cool air into the space for engine intake, generator cooling, and radiant cooling of the fresh water engine system. A large four-bladed, belt-driven fan exhausts the warm air directly to the atmosphere through a second louvered assembly.

8.5.5.3. Operation and Control

The emergency diesel generator is maintained in a standby condition under normal operating conditions except during tests. The unit has an automatic constant speed setting of the governor assembly and automatic control of the generator output voltage through the use of the amplidyne. The generator output circuit breaker is rated at an overload of 165% (continuous) or 600 amperes in 12 seconds and operates in conjunction with the emergency switchboard automatic circuit breaker control unit to close in on the 440-volt bus when required.

The status of the diesel engine and generator assembly is monitored for immediate availability by position-indicating microswitches and relays wired in series to a condition-ready light. The prerequisites for ready status are:

1. Adequate hydraulic starting pressure (2200 psig).
2. Proper starting valve alignment.
3. Governor overspeed trip in reset.
4. Voltage regulator in auto.
5. Automatic breaker control assembly in auto.

Failure to start is indicated by an audible alarm in the control room main switchboard.

The emergency generator can be started manually or automatically depending on the selected arrangement. Manual starting can be accomplished by manipulation of the hydraulic starting oil valve. Local manual-electric starting can be performed by actuation of the test switch on the switchboard panel. Manual starting is also initiated when the emergency cooling system is activated on the main console. None of these manual starting methods cause the generator breaker to close in on the switchboard.

Automatic starting of the emergency diesel generator occurs upon:

1. Loss of voltage from or at the main switchboard.
2. Actuating of the emergency cooling system (manually or automatically).

The emergency diesel generator is tested weekly for operability and is subject to periodic load testing.

8.5.6. Shore Power Connection

A shore power connection is arranged to supply the electrical load from shore facilities when the NS Savannah is docked and the power plant is secured. Available shore power must be 3-phase, 60-cycle ac rated at 440 to 480 volts. The shore power provides about 450 volts at the main switchboard. There are two 800-ampere shore power connection boxes, one located in the C-deck passageway and another located on the boat deck. Both connections are amidships to facilitate connection from the port or starboard side. A manually operated circuit breaker located on the main switchboard is used to connect shore power to the main buses. This breaker is set to trip at a continuous overload of 120% (960 amperes) for 120 seconds. The main buses and the shore power are electrically interlocked to prevent paralleling. Therefore, the main buses must be de-energized prior to closing the shore power circuit breaker. A console-mounted ammeter and switchboard-mounted voltmeter and ammeter indicate input power at those locations. Phase rotation can be checked by instrumentation on the main switchboard.

8.5.7. Power Distribution

8.5.7.1. Main Switchboard Description

The main switchboard (see Drawing ED 52-J-432) for the control of all normal power sources is located in the central control room. This switchboard is divided into two 450-volt sections; each section is fed by one turbine generator and one diesel generator. Additionally, the main switchboard lineup includes a 120-volt, three-phase, a-c bus; a 125-volt, d-c bus; and a 120-volt, a-c bus. All normal power requirements are served by these buses through group-control centers and power panels located throughout the ship.

Main switchboard bus section 1 is fed by turbine generator 1, diesel generator 1, or the shore connection. Bus section 2 is fed by turbine generator 2, diesel generator 2, or the shore connection (by way of a circuit breaker). Bus sections 1 and 2 are connected together through a normally closed bus tie circuit breaker located in section 2.

The auxiliary propulsion motor is fed by way of a circuit breaker located in bus section 1 or by way of a circuit breaker in bus section 2, depending upon the diesel generator feeding the motor.

Bus section 1 includes a 125-volt, d-c bus fed from the following sources:

1. Bus section 1 by 40 kw motor generator 1.
2. Bus section 2 by 40 kw motor generator 2.
3. The 125-volt, d-c vital instrument bus floating battery.

A 120-volt, single-phase, 60-cycle, a-c vital bus is also included in the bus section 1 lineup. This bus is fed by the two 25 kw motor generators, which are connected to the 125-volt, d-c bus.

Bus section 2 includes a 120-volt, three-phase, 60-cycle bus fed from bus section 1 or 2 by way of an automatic transfer switch and a bank of three 50 kva transformers. Bus sections 1 and 2 are also connected to the emergency switchboard by way of an automatic transfer system located on the emergency switchboard.

All outgoing feeders from the 450-volt buses of the main switchboard are protected by Westinghouse Tri-Pac, molded-case circuit breakers with the exception of the drawout air circuit breakers for the auxiliary propulsion motor. All outgoing feeders from the buses for 125-volt dc, 120-volt, single-phase ac, and 120-volt, three-phase ac are protected by molded-case circuit breakers.

The vital instrumentation bus feeds power panels D-143-1 and D-143-3, which supply vital loads such as:

1. Nuclear instrumentation.
2. Radiation monitoring system.
3. Auxiliary diesel generator governor control.
4. Auxiliary diesel generator automatic starting.
5. Reactor critical instrumentation.
6. Ford instrument boiler level indicator.
7. Data acquisition system.

Power panel D-143-3 has an alternate power supply from the emergency switchboard, 120-volt, a-c final bus through a high-speed automatic bus transfer switch located in the main control room. This alternate source of power ensures starting of the auxiliary diesel generators in the event of loss of the vital bus.

8.5.7.2. Main Switchboard Operation

The main switchboard operating controls for the turbine and diesel generators are essentially the same in that they both have manual speed controls, manual and automatic voltage regulators, voltmeters, ammeters, power meters, and power factor meters. The only difference in individual controls is found on the control panel for the diesel generators. A voltage-per-cycle controller and rheostat is provided to maintain a fixed voltage-per-cycle relationship when the unit is operated in conjunction with the auxiliary propulsion system motor. Additionally, the individual circuit breakers associated with the auxiliary propulsion system are interlocked so that only one generator can be used for propulsion purposes.

An automatic speed-matching and synchronizing unit controls the auxiliary generator breaker-closing sequence and load changing during an automatic start in order to balance the load distribution. There are numerous ways provided to start and synchronize the diesel generators from the main control console and main switchboard. A plant condition selector switch is manually positioned on the main switchboard to indicate the turbine generator demand condition, namely, TG1, TG2, or TG1 and TG2 in operation. The diesels will be automatically started if conditions deviate from the selected condition.

Sections 1 and 2 of the main switchboard are connected through an electrically operated bus tie breaker. Should the tie breaker open as a result of an overload condition on one section, the nonvital loads would be released from the board through their respective circuit breakers, and the auxiliary diesels would start. Should it be desirable to manually split the bus operation without losing the nonvital loads, the circuit breaker could be locked in the open position. If the system is operated as a split board, a condition of undervoltage will cause each diesel generator to start and come on to its respective bus. After tripping the tie breaker, if it is desired to close any nonvital feeders, the pushbutton on the breaker trip can reset the auxiliary contacts. In the event of a bus fault, the bus tie breaker will open before the turbine generator breaker to protect the diesel generator that is on the unfaulted bus.

The automatic starting and synchronizing sequence can be checked by a manual test switch provided on the main switchboard. This switch simulates a complete starting cycle with the exception that the nonvital loads are not released during a test.

8.5.7.3. Group Control Centers

Seven group control centers are provided, each of which consists of circuit-breaker-type combination motor starters mounted in a free-standing, drip-proof cabinet. External connections to the individual motor starters are wired to the terminal boards in a terminal compartment at the bottom of each stack of controllers. The arrangement permits connecting all external cables from the front.

Group control centers A1 and A2 have controllers serving nonvital loads in the reactor auxiliary systems. Group B consists of four separate, free-standing controllers for the windings of the primary pumps. Groups C1 and C2 have controllers serving propulsion auxiliaries. Groups D1 and D2 have controllers serving vital loads in the reactor auxiliary systems, including those required for safe emergency shutdown and cooling.

Each controller in group B has an individual feeder from the main switchboard. The remaining group control centers are supplied from two sources and have automatic bus transfer switches to transfer to the alternate source in the event of failure of the normal source. Group control centers are located as shown in Table 8-6.

Table 8-6. Group Control Centers

Designation	Location
A1	Machinery space, upper level, starboard
A2	Machinery space, lower level, center
B	Machinery space, upper level, port, forward
C1	Machinery space, upper level, starboard
C2	Machinery space, lower level, center
D1	Navigation bridge deck, emergency generator room
D2	Navigation bridge deck, emergency generator room

The control centers are protected by Tri-Pac, molded-case circuit breakers mounted on the main and emergency switchboards. Individual motor controllers are operated by control switches, pushbuttons, pressure switches, etc. These are mounted near the controlled devices, on the main control console, or on the emergency cooling panel. Six of the seven group control centers have normal and alternate power supplies provided by separately mounted automatic transfer switches. Group control center B does not have an alternate power supply since each of the four controllers has a separate source of supply. The automatic transfer switches are enclosed in sheet metal, drip-proof cabinets and are equipped with a manual-automatic selector switch, a test pushbutton, and a manual operator.

8.5.7.4. Motor-Operated Valve Controls

Motor-operated valves for the various systems are controlled by individual, separately mounted contactors. The contactors for the five motor-operated valves in the emergency cooling system are supplied from power panel N-156-1 located in the emergency generator room on the starboard side of the navigation bridge deck. These contactors control the operation of emergency cooling valves DK-4V, DK-19V, DK-20V, DK-21V, and DK-32V. Two primary system gate valve contactors and two main feedwater stop valve contactors are fed from power panel H-122-2, which is located in the machinery space lower level on the port side at frame 122. The motor controllers for primary gate valves PS-3V and PS-4V, starboard feed stop valve SS-13V, and port feed stop valve SS-16V are located in the pump room on the port side.

Two primary system gate valve contactors and the pressurizer three-way transfer valve contactor are supplied from power panel H-126-1 located in the machinery space, lower level, starboard side, near frame 126. The motor controllers for primary gate valves PS-5V and PS-6V and pressurizer three-way transfer valve PR-25V are located in the pump room on the starboard side.

8.5.7.5. 450-Volt Power Panels

Located throughout the ship are 37 power panels that furnish 450-volt, a-c power for loads such as deck machinery, ventilation, and lighting. Generally, the power panels are surface-mounted circuit breaker cabinets fed from main switchboard bus sections 1 or 2.

The 450-volt power panels are listed in Table 8-7, which indicates service, power source, and transfer method. These power panels are protected either by Tri-Pac, molded-case circuit breakers mounted on the main and emergency switchboards or by molded-case circuit breakers in other 450-volt power panels. Various loads taken from these panels are controlled manually by molded-case breakers or by motor controllers.

Table 8-7. 450-Volt Power Panels

Power panel	Service	Power source	Transfer
C-126-1	Stores elevator	Bus 2	--
BO-134-2	Deck machinery	Bus 1	--
B-123-1	Hotel stbd.	Bus 1	--
C-144-2	Mach. space vent.	Bus 2, bus 1	Man.
P-165-1	Quarters vent. aft	B-148-1	--
A-106-2	Quarters vent. fwd.	B-148-1	--
A-188-1	Cargo vent. aft	Bus 1	--
B-148-1	Quarters ventilation	Bus 1, bus 2	Man.
A-80-2	Cargo vent. fwd.	Bus 1	--
C-102-2	Laundry	B-136-2	--
A-36-1	Deck mach. 1B	A-35-1	--
A-35-1	Deck mach. 1A	Bus 1	--
B-136-2	Hotel port	Bus 2	--
H-126-3	Mach. aux. 1	Bus 1	--
D-131-2	Mach. aux. 3	H-126-3	--
B-213-1	Steering gear	Bus 1, bus 2	Man.
C-162-1	Cargo elevator	Bus 1	--
A-81-1	Deck mach. 2B	A-79-1	--
A-79-1	Deck mach. 2A	Bus 2	--
B-108-2	Reactor fuel hdlg.	Bus 1	--
H-148-2	Mach. aux. 2	Bus 2	--
D-130-2	Mach. aux. 4	B-148-2	--
H-109-2	Stabilizer	Bus 1	--
A-193-1	Deck mach. 4B	A-193-3	--
A-193-3	Deck mach. 4A	Bus 2	--
D-140-1	Mach. aux. 5	Bus 1	--
D-141-2	Workshop	D-140-1	--
B-109-2	Reactor space vent.	Bus 2, bus 1	Man.
H-122-2	M. O. valves	H-126-1	--
H-126-1	M. O. valves	Bus 1, bus 2	Man.
B-102-1	Ltg. load center fwd.	Bus 1, bus 2	Auto.
A-176-4	Ltg. load center aft	Bus 2, bus 1	Auto.
D-191-1	Supp. boiler	Bus 1, bus 2	Man.
D-191-2	Supp. boiler vent.	Bus 1, bus 2	Man.
D-191-3	Supp. boiler	D-191-1	--
N-156-1	M. O. valves	Emerg. swbd.	--
C-210-1	Shop equip.	Bus 2	--

8.5.7.6. 120-Volt Power Panels

Thirteen power panels are located throughout the ship to furnish 120-volt, a-c power for various ship loads. Generally, these panels are surface-mounted circuit breaker cabinets. The 120-volt power panels are listed in Table 8-8. Molded-case breakers at source buses protect these panels. Manually operated molded-case breakers control the loads.

Table 8-8. 120-Volt Power Panels

Power panel	Service	Power source
B-99-1	Ltg. load center fwd.	B-102-1[a]
B-115-2	Crew's pantry	B-99-1
A-176-2	Ltg. load center aft	A-176-4[b]
B-125-1	Galley	B-99-1
P-141-2	Service pantries	Main swbd.[b]
D-143-1	Critical instrumentation	Main swbd.[a]
B-135-2	Officers' pantry and galley	Main swbd.[b]
D-118-1	Refrigeration	H-120-2
H-120-2	Refrigeration	Main swbd.[b]
B-108-4	Reactor fuel handling	Main swbd.[b]
N-130-2	Electronics in chart room	Emerg. swbd.
N-131-1	Electronics in radio room	Emerg. swbd.
--	Engine room 1C	Emerg. swbd.

[a] By way of 150 kva transformer bank.
[b] By way of 112-1/2 kva transformer bank.

8.5.7.7. Emergency Switchboard Arrangement

The emergency switchboard is a section of free-standing, metal-clad switchgear located on the navigation bridge deck. This emergency switchboard includes a 450-volt, a-c bus, a 120-volt, ac-to-dc temporary bus, and a 120-volt, d-c temporary final bus. The normal source of power for the 450-volt emergency bus is bus section 1 of the main switchboard. This power source is connected through circuit breaker 52A. Another source of power is provided from bus section 2 through circuit breaker 52B. In an emergency, power is supplied by the emergency diesel generator through circuit breaker 52C. Circuit breakers 52A, 52B, and 52C are electrically and mechanically interlocked to prevent the closing of more than one breaker at a given time. The 120-volt, a-c final bus is fed from the emergency 450-volt bus through one of the two 112-1/2 kva transformer banks. An automatic bus transfer switch provides changeover capability. The 120-volt, d-c battery bus is fed from a 120-volt battery. The 120-volt, ac-to-dc temporary bus is fed normally from the 120-volt, a-c final bus or, in case of emergency, from the battery bus by an automatic transfer switch. The 120-volt, d-c temporary final bus is fed normally from the 450-volt emergency bus through one of two 7-1/2 kw rectifiers or from the battery bus through an automatic transfer switch. Protection and control of the emergency switchboard are provided by the generator breaker and the various feeder breakers.

8.5.7.8. Emergency Switchboard Operation

Emergency switchboard operation consists of setting the board up for normal and emergency power arrangements. The 450-volt section, the 120-volt, a-c section, and the 120-volt, d-c section provide continuous distribution of power to a number of normally operating auxiliary systems. The power under normal operating conditions comes from either section 1 or 2 of the main switchboard through individual manual circuit breakers on the main switchboard sections. This power input to the 450-volt section of the emergency switchboard is by way of manual-automatic circuit breakers in series with the main switchboard breakers. A selector switch on the emergency board permits selecting either of the inputs as the preferred source of power. An automatic circuit breaker control system provides capability to transfer the input breakers from either section 1 or 2 of the main switchboard or, if conditions warrant, from the emergency generator output to the 450-volt section. The transfer function can be initiated on demand or on failure of the selected input breaker to supply the required voltage. If one main board input fails, the load shifts to the alternate automatically. If conditions are still not satisfactory, the emergency generator starts and immediately closes in on the 450-volt, three-phase section.

Emergency power supply status lights are located at the main and emergency switchboards to indicate the operational readiness of the emergency generator and the automatic circuit breaker control system. Additionally, a failure-to-start alarm on the main switchboard alerts the operators to the presence of this condition at the normally unmanned emergency switchboard.

Although the emergency generator cannot be operated in parallel with either of the turbine generators, auxiliary diesel generators, or shore power, the emergency generator can feed back to the main switchboard.

The emergency batteries are charged through a battery charger mounted on the emergency switchboard. A trickle charge is normal for the unit, and a high charge commences if the output voltage drops as a result of a load demand.

8.6. Auxiliary Plant Systems

8.6.1. Instrument Air System

The instrument air system (see Drawing NNI 85-F-390) provides clean, dehumidified air at various pressures for the following uses:

1. Main steam stop valve control (80 to 100 psig).
2. Ship's air conditioning control (80 to 90 psig).
3. Diesel oil tank level indicators (40 psig).
4. Control valves and tank level indicators (40 psig).
5. Control console, signal transmitters, and auxiliary panels A & B (30 psig).
6. Quantichem analyzer (20 psig).
7. Containment vessel personnel air supply (via CO analyzer).

The instrument air system consists of dual air intake filters (NI-F1 and NI-F2), instrument air compressors (NI-P1 and NI-P2), and instrument aftercoolers (NI-C1 and NI-C2) which discharge into the instrument control air tank (NI-T1). From the instrument control air tank, the air is distributed to the two air filters (NI-F6 and NI-F7) and to the pressure-reducing network which supplies the various shipboard air services.

The two air compressors are vertical, reciprocating, water-cooled units that are belt driven by 20 hp, 440-volt electric motors. Each compressor has a rated output of 80 cfm at 100 psig when operating at 537 rpm. Cooling water (with chromates to inhibit rust) is supplied to the compressor and aftercooler by the CW system. A pressure-control valve is installed in the cooling water inlet line to prevent overpressure of the compressors in the event that the CW system pressure is raised for emergency cooling.

A manually operated crossover connection is provided for the ship service air system in the event of total instrument compressor failure. Normal operation calls for one of the compressors to be in operation with the second unit on standby. Local and remote instrumentation is provided to alert the operators to abnormal conditions.

8.6.2. Waste Dilution and Disposal System

The WD system, located in a main machinery space control area, consists of a pump, regulator, valves, and piping (see Drawing WD 32-F-380). The function of the WD system is to transfer radioactive waste water from the PD system and to accurately measure and discharge waste water to the hydrosphere through the main condenser circulating system. Because of the low activity of wastes generated to date, it has not been necessary to use the WD system.

A positive-displacement reciprocating pump that has a discharge capacity of 0 to 30 gph is arranged to take suction from the PD system; it discharges through a pressure control valve (WD-5V) to the salt water circulating system inlet plenum of the main condenser. Operation of the system calls for the waste transfer pump (PD-P1) to discharge to the suction side of the dilution pump. The dilution pump discharge rate is varied as required so that the overboard discharge activity is below acceptable limits for the zone in which the vessel is sailing (see Figures 8-4, 8-5, and 8-6).

The pressure regulator (WD-5V) on the dilution pump discharge is set at 100 psig; this precludes inadvertent direct discharge by the transfer pump because the setting is above the shutoff head of the transfer pump. Sampling connections are provided to check the effluent activity at the dilution pump discharge and at the overboard discharge connection of the main condenser. The 20,000-gpm main condenser salt water flow mixing with a maximum dilution pump discharge of 0.5 gpm provides the required dilution factor. Relief valves are provided on the dilution pump discharge line and on the water side of the main condenser to prevent an inadvertent overpressure of the system.

8.6.3. Engine Room Ventilation System

The main machinery space ventilation arrangement consists of a supply and an exhaust system, each operating independently. There are three supply fans and associated distribution ductwork and three exhaust fans with similar sheet metal ductwork. The total supply system capacity is 96,000 cfm, equally divided between the three axial supply fans. The exhaust system consists of one 40,000- and two 30,500-cfm axial exhaust fans. Both supply and exhaust fan units have two-speed motors that operate from either a local or a remote control station. The units are located on the navigation and bridge deckhouse tops, and the controllers and switches are located at the machinery landing corridor entrance to the main machinery space. Emergency cutoff circuitry is provided at the CO_2 fire extinguishing system.

The control room and instrument shop are provided with an air conditioning network that contains an integral circulating fan assembly. These locally mounted units are locally controlled.

8.6.4. Blowdown Evaporator System

The blowdown evaporator is located in the lower main machinery space (Figure 8-7). The evaporator consists of a single-shell, submerged-tube heat exchanger that has an automatic level controller. Coil steam is supplied from the 85-psig auxiliary steam-reducing station or from the 115-psig main feed pump exhaust header. Coil drains are directed to the deaereating feed heater or to the shell side of the first stage feed heater, as applicable.

Evaporator feed is taken from the surface blowdown connection on each boiler drum and directed through a main-console-controlled, diaphragm-operated valve. Locally mounted, manually operated feed control valves work in conjunction with the level-control feed valve to admit feedwater to the shell at a rate consistent with boiler water conditions. The steam vapor generated in the evaporator shell is valved into the 26-psig auxiliary exhaust line when the heat is reclaimed through action of the deaereating feed heater.

Rated blowdown of each heat exchanger is 1% of total capacity, or a total of 2650 lb/hr at 800 psig and 464 F. The evaporator output is controlled by a fixed orifice. This limits the evaporation rate to the maximum blowdown required, providing coil condition and downstream pressure are properly maintained for constant output conditions. The present operating requirements indicate that less than full blowdown is satisfactory to maintain the boiler water in the desired condition. As a result, the system is operated with manual steam control on an intermittent basis. Evaporator brine or residue is periodically sampled for density and radioactivity and is discharged overboard through a sea-valve connection.

8.6.5. Fresh Water System

8.6.5.1. Fresh Water Production

With the exception of that procured from dockside during port operation, all fresh water consumed on board the vessel is evaporated from the sea. Two flash-type evaporators, each rated at 16,000 gpd, convert sea water to fresh water that has a chloride content of about 5 ppm. This is utilized directly as potable water and is further processed by means of a mixed-bed demineralizer (10 cubic feet) to less than 1 ppm chloride for use as secondary system makeup. Primary system makeup is further demineralized through the PP system demineralizers before it is added to the primary system. In addition to the secondary system demineralizer, two mixed-bed plant makeup demineralizers (2.5 cubic feet each) that can be used for secondary makeup processing are located in the main machinery space.

8.6.5.2. Fresh Water Consumption

The daily consumption of potable or domestic water will vary with the number of crew members on board and with the environment. The normal consumption is 30 to 40 tons of fresh water per day. Although this represents the greatest single use of water, suitable evaporator capacity ensures an adequate supply on board. The salinity of potable water is of less concern than that of the water used for secondary system makeup, since 0.5 to 1.0 gm/gal (10 to 15 ppm) for potable water has proven satisfactory.

The daily loss and control of primary and secondary water is very important. Primary system leakage is controlled by a leakoff system that channels the known or anticipated leakage into suitable tanks or receptacles in the PD system. The daily consumption or loss of primary grade water averages about 50 gallons per day; the leakage has been found to originate mostly from the pressurizer relief valves and from the buffer seal charge pump glands. This leakage is contained and offers no significant hazard to operating personnel or the public. Daily losses from the secondary system are estimated to average 3000 gpd during sea operation and somewhat less during port operation. The major sources of secondary leakage are pump and valve glands, sampling system discharges, whistle steam, and laundry steam.

8.6.5.3. Fresh Water Storage

Potable water is stored on board in two domestic water tanks located in the main machinery space. These have capacities of 40.8 and 62.81 tons, respectively, and are filled directly from the evaporator discharge. The secondary system storage arrangement consists of boiler-feed and distilled-water tanks having capacities of 60.88 and 21.22 tons, respectively.

The evaporator discharge is normally directed to the boiler feed tank; from this tank the water is processed by the secondary demineralizer or plant makeup demineralizer for discharge to the distilled-water storage tank, from whence it is added to the secondary system. In-line instrumentation and periodic analytical checks ensure proper water quality before it is used in the respective systems.

8.7. Water Chemistry and Control

8.7.1. Primary System

The primary system water quality is maintained by the PP system. Table 8-9 summarizes the water quality limits set by the technical specifications and the normal operating values.

Table 8-9. Primary System Water Quality

	Normal operation	Technical specification limits
Solids, ppm:		
Total		3.0 max
Dissolved		1.0 max
Chloride, ppm	0.1 or less	1.0 max
Dissolved hydrogen, cc(STP)/kgH_2O	20 to 25	20 to 40 max
pH	6.0 to 7.0	6.0 to 9.5
Conductivity, μmho/cm^2	2	none

Primary system water quaility is maintained by a continuous letdown of 20 gpm through the mixed-bed demineralizers and effluent filters of the PP system for the removal of corrosion products. When the reactor is critical the pH of the system is maintained between 6.0 and 7.0 by the ratio of cation to anion resins in the mixed-bed demineralizers. During subcritical periods of operation, the pH is raised to between 8.0 and 9.5 by the addition of 2 to 4 ppm of hydrazine. Conductivity is maintained at about 2.0 μmhos/cm^2 as a result of dissolved ionized solids when the reactor is critical. The addition of hydrazine during shutdown periods increases the overall conductivity; therefore, cation conductivity is checked to observe the hydrazine effects.

The alloys used in the NS Savannah primary system were corrosion-tested at operating conditions and at more severe conditions of temperature and water quality. All of the primary system materials have shown excellent corrosion resistance—less than 15 mg/dm^2-month; this corresponds to a penetration of about 9×10^{-5} ipy in austenitic stainless steel). This rate is considered negligible for the design life of the reactor system.

Chloride concentration in the primary system is maintained at 0.1 ppm or less; a concentration of more than 1.0 ppm requires immediate system shutdown. Chloride conditions are precluded by maintaining conductivity at 0.5 μmhos/cm^2 or less during normal critical operations and at 2.0 μmhos/cm^2 or less during subcritical conditions. Suspended solids are checked by a comparator method used in conjunction with 0.45-micron millipore filter paper samples.

The dissolved oxygen concentration is kept at 0.01 ppm or less by maintaining a hydrogen concentration of 20 to 40 cc/liter of primary coolant. During reactor operation, the hydrogen concentration is maintained by a hydrogen overpressure in the buffer seal surge tank. During periods of reactor shutdown, hydrazine is used to maintain the water hydrogen concentration.

Makeup water for the primary system is maintained with less than 1.0 ppm chloride and 5.0 ppm total dissolved solids. This water passes through the secondary system ion exchangers and the PP system before it enters the buffer seal surge tank; hence the primary grade quality is assured.

8.7.2. Secondary System

8.7.2.1. Steam Generators

The control of secondary system boiler water has four objectives:

1. To inhibit general corrosion of the carbon steel in the boiler by maintaining a high pH in the boiler water, without the caustic embrittlement caused by concentration of NaOH at cracks, crevices, and points of leakage.

2. To prevent pitting corrosion of carbon steel by eliminating dissolved oxygen.

3. To inhibit corrosion of the condenser and condensate return lines by maintaining an elevated pH in the condensate.

4. To inhibit chloride stress corrosion of the stainless steel tubes in the boiler's heat exchanger section by eliminating oxygen from the boiler water and maintaining chloride concentration at very low levels. Table 8-10 summarizes the water quality required for the steam generators.

Table 8-10. Steam Generator Water Quality

Steam Drum	
Total dissolved solids, ppm	650
Chlorides, ppm	1(a)
Oxygen, ppm	0(b)
pH (by coordinated phosphate)	10.5 to 11
Sulfite, ppm	20 to 30
Feedwater	
Total dissolved solids, ppm	0.5
Chlorides, ppm	0.01
Oxygen, ppm	0.007

(a) If chlorides exceed 1.0 ppm, increase secondary sulfite concentration and steam generator blowdown immediately; if this corrective action is not successful in bringing the chloride level below 1.0 ppm within a 48-hour period, steam generator shutdown is mandatory. Shutdown is also mandatory if the chloride level exceeds 100 ppm or if the level exceeds 5.0 ppm and the source of chloride introduction has not been isolated from the steam generator within two hours.

(b) The presence of sodium sulfite at temperatures above 212 F precludes the presence of Oxygen.

A high pH (10.5 to 11) is maintained in the boiler water by adding a concentrated solution of trisodium phosphate. This solution is pumped into the steam drum from a storage tank by a variable-capacity, positive-displacement pump. Disodium phosphate is added similarly from a separate tank and pump. This solution is controlled to maintain the pH and phosphate concentration in a ratio that will keep trisodium phosphate in the boiler water without permitting the formation of sodium hydroxide is prevented from forming; this process is called the coordinated phosphate treatment.

The small amount of residual oxygen left in the boiler feedwater after it passes through the deaerating feedwater heater is removed by the reaction of the oxygen with sodium sulfite, which is maintained in the boiler to assure that the oxygen is eliminated. Oxygen elimination is necessary because the oxygen promotes pitting corrosion of carbon steel in high-pH water, and it contributes to chloride stress corrosion of stainless steel.

An elevated pH is maintained in the boiler feedwater by injecting morpholine into the feedwater at the feedwater pump discharge. A variable-capacity, positive-displacement pump moves the morpholine from its storage tank to the injection point. Morpholine is a volatile derivative of ammonia which ionizes in water to increase the pH. It vaporizes with the steam in the steam drum, condenses, and redissolves in the condensate in the condenser. Thus morpholine maintains the condensate and feedwater at an elevated pH throughout the feedwater system, inhibiting the general corrosion of the system.

When the steam generators are idle for prolonged periods they are filled solid in a wet layup condition. The water is circulated daily by a circulating system within the containment vessel. The total-dissolved-solids concentration in the steam generators is limited to 650 ppm during operation and to 1300 ppm in a wet layup condition. These values are checked every third day. Chlorides are maintained at less than 1.0 ppm with normal values less than 0.1 ppm. The units may be operated at greater than 1.0 ppm for a period not exceeding 48 hours, or 5.0 ppm maximum. Phosphate ratios are maintained in accordance with the coordinated phosphate program for pH control (see Figure 8-8). A normal ratio of 2 to 1 tri-to-di sodium phosphate is maintained in the boiler drums. Total phosphates are maintained at 100 to 300 ppm when the heat exchanger is in operation and at 400 to 600 ppm during wet layup periods.

Sodium sulfite is used as an oxygen scavenger in boiler water and is maintained at 20 to 30 ppm under normal conditions. If a chloride condition develops, or if high oxygen content is noted in the makeup feedwater, these values will be increased by a factor of 2 to 3.

8.7.2.2. Boiler Condensate and Feedwater

Boiler feedwater is maintained at a pH of 9.0 to 9.5 by the presence of 4 to 18 ppm morpholine in the boiler steam drums. Dissolved solids are determined from conductivity measurements of the feed and condensate systems. Since the morpholine influences conductivity, a cation column is inserted to strip the morpholine in the test sample. The lowest sensitivity value that can be obtained with the in-line sampling instrument is 2.0 μmhos/cm^2, which is equivalent to 0.33 ppm solids. This is the established alarm point set for the instrument. The presence of greater than 1.0 ppm dissolved solids requires recirculation of the system condensate through the mixed-bed polishing demineralizer.

Chlorides must be maintained below 0.1 ppm in the feed and condensate systems. Chloride content is measured by the Quantichem automatic chloride analyzer, which is provided for sampling the content in several secondary systems.

Dissolved oxygen is removed from the feedwater by the deaerating hot well sections of the main and auxiliary condensers operating in conjunction with the deaerating feedwater heater. A limit of 0.007 ppm is established for the deaerating feedwater heater outlet. Periodic analyses are performed under operating conditions to determine the dissolved oxygen content.

8.7.2.3. Intermediate Cooling Water System

The CW system is employed as the cooling medium for numerous primary system components. Very close water quality is maintained on this system because type-304 stainless steel is used in components that are in direct contact with the CW system water. A pH value of 10.0 to 11.0 is maintained using a coordinated phosphate treatment. Dissolved solids are determined from a neutralized conductivity reading and are limited to 2000 ppm. Phosphates are maintained at between 100 and 300 ppm. Chromates are added to inhibit corrosion of the system and are maintained at between 500 and 1000 ppm. Chlorides are limited to 1.0 ppm maximum under operating conditions; a 5 ppm content requires a reactor shutdown. The 1.0 ppm value may not be exceeded for longer than 48 hours without shutting down the reactor.

8.7.2.4. Cyclotherm and Low Pressure Steam Generator

During normal operation, the low-pressure steam generator is utilized to produce steam for various heating and hotel services. The oil-fired Cyclotherm boiler is installed as a parallel heat supply and is used during reactor shutdown periods. Water quality requirements for these units are summarized in Table 8-11.

Table 8-11. Cyclotherm and Low Pressure Steam Generator Water Quality

Solids, ppm	1000 max (determined by neutralized conductivity)
Chlorides, ppm	4.0 max
Phosphate, ppm	100 to 300
Sulfite, ppm	20 to 50
pH	10.5 to 11.0

8.7.3. Laboratory Arrangements

Provisions have been made for sampling radioactive and nonradioactive water systems throughout the vessel. These provisions include a forward sampling area located adjacent to the secondary shield and within the confines of a controlled area. This area includes a sink and an enclosed, ventilated hood arrangement (see Drawing SA 24-J-383). The ventilation exhaust is led to the inlet section of the reactor space filter housing. Sink drains are piped directly to the PD system.

Samples of primary water and waste liquids can be taken at the sampling sink. The amount of dissolved hydrogen in the primary system can be determined using the hydrogen analyzer. A hot- and cold-water chemistry laboratory is installed adjacent to the main control room. This space is partitioned to provide a closed working area for handling radioactive water samples. It includes a separate sample hood, fan, demister, and absolute filter. A drain-collecting tank is provided for hot sink drains. Radioactive samples can be handled through an access port from the machinery space to avoid direct passage through the main control room.

The secondary system samples are checked in the adjacent semi-enclosed space, which also has a sink, ventilation fan, and filter assembly. Samples from the intermediate cooling water, port and starboard boilers, main and auxiliary condensate, and main feed system are delivered to the laboratory through a pipe and valve arrangement.

8.7.4. Instrumentation

The instrumentation used in analytical determinations of water quality is mounted in the chemistry laboratory. This includes equipment used to determine chloride content, conductivity, dissolved oxygen, pH, and dissolved chemical content. In-line instrumentation is provided for conductivity indications of the purification system influents as well as the secondary system condensate and boiler feedwater.

Alarm points on each indicating system alert the operator to any unusual conditions that require an immediate analytical check of system specifications. The automatic secondary system Quantichem unit records chloride concentrations in addition to alarming abnormal conditions.

8.7.5. Operating Experience

The water quality standards established at the time of ship construction have required no significant changes. During construction and initial sea trial testing, there were no significant water problems. The hot flush period did result in several crud bursts which plugged the flushing filters; however, the situation was corrected. During an early sea trial a high chloride condition developed in a heat exchanger as a result of a tube leak in the gland seal exhaust condenser. The reactor and secondary plant were secured, and the situation was corrected.

During the prolonged 1963 outage, an auxiliary condenser tube was found to be defective and leaking into the shell side of the condenser, which was being used as a makeup storage tank for the CW system. This resulted in a chloride level that exceeded the prescribed limits. The reactor was secured and no major problems were encountered after the CW system was dumped and flushed. Subsequent to this failure, a scheduled Probolog check of main and auxiliary condensers and salt-water cooled heat exchangers was undertaken as a check of system deterioration.

At no time in the operating history of the vessel has any water chemistry problem arisen in the primary system that required shutdown. Minor water chemistry problems have occurred, but their causes have been traced promptly, and corrective actions have precluded any aggravated conditions.

The laboratory consolidation effort and the gradual transfer of routine responsibility from specialists to the specially trained licensed engineers on board the vessel have proved successful.

8.8. Power Plant Performance

8.8.1. Summary of Power Plant Performance

Table 8-1 summarizes the performance of the power plant. Figures 8-9 and 8-10 show the plant heat balance for operation at 20,000 and 22,000 shp, respectively.

8.8.2. Summary of Testing

The ship, reactor, and main engines have been subjected to numerous tests and sea trials since the beginning of construction. Prior to the ship's delivery to the general operating agent in May, 1962, a series of five testing phases were completed, including the final builder's acceptance trial. These test phases are described briefly:

Phase I. Testing adequacy of construction and installation of components.

Phase II. Testing integrity and functional adeqequacy of components prior to reactor operation.

Phase III. Low-power physics test of fuel reactor.

Phase IV. Continuation of Phase III testing from zero power to low power levels (10% full power).

Phase V. Continuation of Phase IV low-power testing to intermediate-power and finally full-power operation (includes builder's acceptance sea trials).

Following delivery of the vessel, periodic operational testing of components continued as required. These tests are reviewed periodically by the ship's staff and technical assistance groups for modifications and upgrading.

Following a period of maintenance, modification, and upgrading, the vessel was required to demonstrate, by means of sea trials, the ability to perform to the satisfaction of the regulatory bodies. These sea trials include scheduled and approved tests designed to demonstrate the functional adequacy of the vessel and any system under review or modification. The vessel is also subjected to an annual USCG inspection.

8.8.3. Official Sea Trials

Following completion of reactor testing up to 10% full power in Camden, New Jersey, the reactor was shut down and the primary system was cooled and depressurized in preparation for moving the ship to Yorktown, Virginia, for further tests and sea trials through 100% full power. The ship left Camden under auxiliary power on January 31, 1962, and arrived at Yorktown on February 2, 1962. The transit to Yorktown (first sea trial) provided an opportunity for preliminary testing of the ship, emergency propulsion equipment, navigational and electronics equipment, and to conduct extensive deep-water vibration surveys of the ship's hull and equipment under forced excitation by a temporary vibration generator.

After arrival at Yorktown, dockside tests at higher reactor powers were conducted to prepare for sea trials off the Virginia coast. The second (preliminary) sea trial was conducted for the primary purpose of operating the reactor through the 80% power range. The third sea trial (builder's trial) was conducted for the purpose of extending reactor power through 100% power range, to demonstrate overall operation of the ship, and to ensure satisfactory operation of the ship during the final acceptance trial. Some acceptance trial events were completed on this trial. The fourth sea trial (final acceptance trial) was confined to ship tests, including standardization and maneuvering, since all pure reactor tests had been completed previously. The history of NS Savannah testing, operation, and maintenance subsequent to arrival at Yorktown is presented in Table 8-12.

A number of acceptance tests were performed during the sea trial and dockside periods. This list is a summary of those tests conducted in relation to the power conversion system on board the vessel:

1. Endurance run—normal power.
2. Endurance run—maximum power.
3. Emergency power test—auxiliary propulsion.
4. Standardization trials.
5. Quick reversal astern.
6. Quick reversal ahead.
7. Astern endurance test.

8. Main condenser scoop test.
9. Shaft brake test.
10. Distilling plant—maximum capacity test.
11. Distilling plant—bleed steam capacity test.
12. Automatic starting and synchronizing of the auxiliary diesel generators.
13. Automatic starting and supplying the emergency switchboard by emergency diesel generators.
14. Parallel operation of diesel and turbine generators.
15. Scram from full power operation.

Table 8-12. Chronology of Testing and Sea Trials — March and April, 1962

Date	Title	Major events
3/11/62 to 3/22/62	Dockside testing	Zero-power physics test; first use of hydrogen in primary system; power operation to 40% full power on two primary pumps; first use of steam dump.
3/23/62 to 3/25/62	Second (preliminary) sea trial	Operation to 60% reactor power on two primary pumps; operation to 80% reactor power on three primary pumps.
4/3/62 to 4/6/62	Third (builder's) sea trial	Operation to 22,300 shp; intentional scram recovery demonstration; some acceptance events completed.
4/6/62 to 4/12/62	Dockside testing	Single-loop operation; zero-power physics.
4/13/62 to 4/23/62	Maintenance	General plant maintenance in preparation for acceptance trial; returned to power operation for transient tests at dockside.
4/24/62 to 4/26/62	Fourth (final acceptance) sea trial	All pure reactor tests completed previously; this trial confined primarily to ship tests, standardization trial, stabilizer tests, maneuvering tests; first automatic steam dump.
4/26/62 to 4/30/62	Dockside operation	Single-loop operation; emergency cooling system operational test; steady operation at base steam and electrical load; preparation for ship delivery.

8.8.3.1. Endurance Run — Normal Power

The normal-power run was conducted, under conditions noted in the 20,000-shp heat balance, to determine the heat rate and obtain data for the post-trial heat balance. The duration of the run was reduced to 2-1/2 hours with concurrence of the trial board and the shipbuilder, since a specified 6-hour endurance run had been successfully completed during the builder's trial, and because plant conditions were stable and normal. The first hour of the normal-power run was accomplished concurrently with the standardization run at 20,000 shp. During one course of the standardization run, stabilizers were extended for a shaft-rpm comparison with housed stabilizers. Very little change in shaft-rpm was noted. The main propulsion plant, with necessary auxiliaries, was operated as closely as possible to the conditions of Figure 8-9. Appendix B shows the average values for readings of horsepower, pressures, temperatures, and the calculated values taken at intervals during the run.

8.8.3.2. Endurance Run — Maximum Power

The maximum-power endurance run was conducted under conditions noted in the 22,000-shp heat balance to determine the heat rate and to obtain data for post-trial heat balance calculations.

The ability of the ship, propulsion plant, and auxiliaries to operate satisfactorily for sustained periods at maximum power were demonstrated during a 12-hour endurance run and an 8-hour full-power run for reactor plant operating coefficients; therefore, readings for the specified 4-hour run were suspended after 1 hour, with concurrence of the trial board and the shipbuilder, to review the recorded data. After review of the data, the run was continued for an additional 1-1/2 hours to confirm the data recorded during the first hour. The endurance run began at 1800 and ended at 2235; recording of data was suspended from 1900 to 2105 while the data and heat balance were checked. The main propulsion plant with necessary auxiliaries was operated as closely as possible to Figure 8-10 conditions (heat balance and flow diagram for 22,000 shp). Appendix B includes the average values for readings of horsepower, pressures, temperatures, and the calculated values taken at intervals during the 3-1/2-hour run.

8.8.3.3. Emergency Power Test — Auxiliary Propulsion Unit

This test was conducted to demonstrate the ability of the auxiliary propulsion unit to assume the propulsion load in event of reactor plant shutdown, to determine available shp and rpm, to determine the time to mechanically engage the motor and bring the shaft up to speed, and to observe adequacy of the startup procedure. Testing was conducted during the voyage from Camden, New Jersey, to Yorktown, Virginia, in the following manner:

The ship was proceeding ahead at 30 rpm, with the formerly installed supplementary startup boiler supplying steam to the main engines (reactor plant secured) and one auxiliary diesel generator on the line for lighting and ship's service power. On signal, the steam to the main engines was secured and the ship was allowed to drift until the shaft speed reached 20 rpm. At this time the shaft brake was applied to stop rotation so that the auxiliary propulsion unit could be connected to the main reduction gears. This action required approximately 1-1/2 minutes.

With one auxiliary diesel generator carrying the ship's electrical load and one available to supply auxiliary propulsion unit power, appropriate circuit breakers were closed, and the auxiliary propulsion unit was started. One half of rated speed was reached in 50 seconds using the recommended starting procedure. The speed of the motor was increased from one-half to full speed by increasing the diesel generator to rated rpm and voltage. During the last 5 minutes of the test, the ship was operated with stabilizer fins extended with no noticeable effect on horsepower or shaft speed. The results of this test are summarized in Table 8-13.

Table 8-13. Auxiliary Propulsion System — Emergency Power Test

Ship's speed, knots[a]	8.2
Shaft revolution, rpm	38.0
Shaft horsepower, shp	
Based on ship's torsion meter (McNab)	821.6
Based on motor input data	825.3
Based on standardization curve	830.0
Motor	
Voltage	456
Current, amps	1005
Power, kw	716
Frequency, cps	58
Power factor	0.83

[a] Based on standardization curve.

8.8.3.4. Standardization Trials

The standardization trials to establish the relationship between speed, shaft horsepower, and shaft revolutions were conducted in deep water (100 fathoms or more) approximately 100 miles east of the entrance to Chesapeake Bay. Hastings-Raydist, Inc., equipment was used to measure the ship's speed. The equipment consisted of a Raydist electronic measuring system utilizing two shore stations (one located at Oyster, Virginia, and a second at Killdevil Hills, North Carolina). The equipment on board the NS Savannah consisted of a transistorized distance-measuring navigator operated in conjunction with a strip chart recorder and precision timing unit.

Shaft horsepower was determined from torsion meter readings and shaft rpm. Two electric torsion meters were used to indicate torque: one was the permanently installed ship's McNab (Ford type B) meter, and the second was a temporary meter furnished by the David Taylor Model Basin (DTMB). Shaft revolutions were obtained from a DTMB dual-register revolution counter. The ship was standardized at rpm's corresponding to approximately 22,000; 20,000; 10,000; 5,000; and 350 shp. Each speed check consisted of three consecutive runs, alternating in direction over the range for a preselected period of time starting after Raydist determination of speed. Time for the 10,000-; 5,000-; and 350-shp runs was 10 minutes; the time for remaining was 5 minutes. A speed-versus-horsepower run with the stabilizer fins extended was made at approximately 20,000 shp to evaluate the effect of the stabilization system on the speed-horsepower curve.

Table 8-14 is a summary of the standardization runs. The curves in Figure 8-11 show the relationship between speed, horsepower, and rpm; Figures 8-12 and 8-13 show similar curves for the vessel with 1800 tons ballast.

Table 8-14. Standardization Runs

Run No.	Shaft speed, rpm	Ship speed, knots	Shaft horse-power[a]	Shaft horse-power[b]	Avg shaft horsepower
1	29.0	6.21	367.8	315.8	341.7
2	71.0	15.59	4,850.2	4,713.2	4,787.7
3	89.4	19.26	9,839.0	9,723.2	9,781.1
4	95.2	20.23	12,832.0	12,209.8	12,295.9
5	109.5	21.97	20,429.0	20,275.0	20,352.0
6	112.05	22.32	21,998.0	21,911.0	21,954.0
7[c]	108.95	21.66	20,326.0	20,199.2	20,257.25

[a]From ship's torsion meter.
[b]From DTMB torsion meter.
[c]Run 7 with stabilizer fins extended.

8.8.3.5. Quick Reversal Astern

The quick-reversal-astern test was conducted, with the ship proceeding ahead at full power, to determine the time required to stop the shaft, bring the ship dead-in-water, and then reach full power astern (75 rpm). Ahead reach was also measured. During this maneuver, the control room maneuvering-valve procedure was used instead of the emergency procedure. The shaft was stopped 1 minute, 35 seconds after the signal for full astern was given; full power astern was attained in 5 minutes, 47 seconds. The ship was dead-in-water in 4 minutes, 2 seconds, with an ahead reach of 4380 feet.

During this particular test no attempt was made to perform the quick reversal at the maximum rate. During the builder's trial a quick reversal was executed in which the shaft was stopped in 30 seconds and full power astern (75 rpm) was reached in 1 minute, 20 seconds. The plot of the quick reversals, ahead and astern, are shown in Figure 8-14.

8.8.3.6. Quick Reversal Ahead

The quick-reversal-ahead test was conducted, with the ship proceeding astern at maximum allowable rpm (75), to determine the time required to bring the shaft to a stop, bring the ship dead-in-water, and then reach full power ahead (112 rpm). Astern reach was also measured. During this maneuver normal control room maneuvering-valve procedure was used instead of the emergency procedure. The shaft was stopped 12 seconds after the signal for full ahead was given; full-ahead shaft speed was attained in 5 minutes. The ship was dead-in-water in 1 minute, 17 seconds, with an astern reach of 840 feet.

As in the quick-reversal-astern test, no attempt was made to perform the quick reversal ahead at the maximum rate. Figure 8-14 shows the plot of the quick reversals ahead and astern.

8.8.3.7. Astern Endurance Test

The astern endurance test was conducted to establish the ability of the turbines to operate continuously at the full-astern power of 8000 horsepower or 75 rpm (whichever occurred first) without overheating or undue vibration, and to demonstrate that astern operation produced no undue structural vibrations. This test began immediately after the quick-reversal-astern trial. The propulsion turbine was successfully operated at maximum allowable astern rpm (75) throughout the test period with no overheating or undue vibration.

Table 8-15 shows the average values for readings of horsepower and shaft speed taken at 10-minute intervals and readings of pressures and temperatures taken at 30-minute intervals.

Table 8-15. Average Values of Horsepower and Shaft Speed — Astern Endurance Test

Shaft revolutions, rpm	74.6
Shaft horsepower, shp	
McNab torsion meter	5226.0
DTMB torsion meter	5621.0
Average	5423.5
Main steam pressure to turbine, psi	570.0
Astern steam chest pressure, psi	217.0
Steam temperature to maneuvering valve, F	480.0
Low-pressure turbine casing	
Thermo-vacuum temperature, F	66.0
Thermo-vacuum pressure, in. Hg	29.3
Main condenser vacuum, in. Hg	29.3
Main condensate temperature, F	73.3
Saltwater temperature, F	
To condenser	50.0
From condenser	64.7
Lube oil pressure to bearings, psi	16.0

8.8.3.8. Main Condenser Scoop Test

No test was conducted to determine the minimum ship speed at which the main condenser scoop would maintain vacuum under 100% reactor power while dumping steam in excess of the ship's requirements. The test was modified (as directed by the trial board) and conducted in the following manner:

With the ship underway at approximately 19 knots (88 rpm), reactor power at a corresponding level and steam dump on standby, the ship's speed and reactor power were reduced slowly until a shaft speed of 20 rpm was reached. During the speed reduction and while running at 20 rpm, the main condenser vacuum did not drop below 29.5 in. Hg.

During slowdown and while running at 20 rpm, the main condenser scoop check valve did not close. The main engine throttle was then closed, and the main circulating pump was started as the shaft was drifting to a stop. The scoop check valve closed after the circulating pump was started. At no time did the main condenser vacuum drop below 29.5 in. Hg.

8.8.3.9. Shaft Brake Test

The ability of the shaft brake to stop the shaft when the ship is drifting either ahead or astern was demonstrated:

With the ship proceeding ahead at 30 rpm, steam to the main turbine was secured. When the shaft speed reached 20 rpm, the shaft brake was applied in 32.5 seconds; it stopped the shaft in 20 seconds (total elapsed time, 52.5 seconds). With the ship drifting astern at approximately 10 rpm without power, the shaft brake was applied in 30 seconds; it stopped the shaft in 10 seconds (total elapsed time, 40 seconds).

8.8.3.10. Distilling Plant Maximum-Capacity Test

The distilling plant maximum-capacity test was conducted simultaneously on units 1 and 2 during the builder's sea trial; the test was repeated during the acceptance trials (for 5 hours). Results of these tests are summarized in Table 8-16 and detailed in Appendix B.

Table 8-16. Distilling Plant Capacity Tests

	Avg capacity, gpd
Builder's sea trial	
Evaporator 1	16,065
Evaporator 2	16,140
Acceptance trial	
Evaporator 1	16,488
Evaporator 2	17,021

8.8.3.11. Distilling Plant Bleed-Steam-Capacity Test

A 7.5-hour bleed-steam-capacity test of the distilling plant was conducted on unit 1 during the normal-power trial. The test was repeated during the acceptance trial and was conducted under full-power conditions. The plant successfully produced fresh water with a salinity content of less than 0.25 grains/gal at a rate in excess of the 10,400-gpd bleed-steam capacity of the unit.

8.8.3.12. Automatic Starting and Supplying the Emergency Switchboard by the Emergency Diesel Generators

These demonstrations were combined with an intentional-scram-and recovery demonstration during the acceptance trials. All electrical controls and switches were set for automatic operation when the scram pushbutton was operated. The emergency diesel generator started and assumed its lead in approximately 5 seconds. Auxiliary diesel generators 1 and 2 started and were paralleled (first 1 and then 2) with the turbine generators within 12 seconds. The diesel generators and the automatic load-transfer equipment performed satisfactorily.

8.8.3.13. Parallel Operation of Diesel and Turbine Generators

The two auxiliary diesel generators operated satisfactorily in various combinations during the dock trials at Yorktown. During the acceptance trials, parallel operation of the auxiliary diesel generators and turbine generators was also demonstrated:

Auxiliary diesel generator 1 with turbine generators 1 and 2.

Auxiliary diesel generator 2 with turbine generators 1 and 2.

The division of the load and parallel performance was satisfactory.

8.8.3.14. Scram and Recovery Demonstration

During the builder's trial the reactor was scrammed intentionally from high power so that the effects on plant equipment, important operational variables, and the recovery procedure could be further examined. The condition of the plant immediately before the scram is shown below:

1. Reactor power at approximately 70 MW.
2. Four primary pumps at full speed.
3. Auxiliary diesel generators on AUTO-START reading.
4. Emergency diesel generators on AUTO-START reading.
5. Pressurizer and buffer seal surge tanks at 40 in. (This adjustment was made to assure an adequate supply of primary water throughout the exercise.)
6. Package boiler (Cyclotherm) supplied with 120 psig steam blanket from the low-pressure steam generator.

Following the scram, the recovery procedure was executed, and these major events occurred:

Time after scram	Events
7 seconds	Switched to two primary pumps at half-speed.
15 seconds	Secured letdown flow.
20 seconds	Tripped quick-closing steam-stop valves after auxiliary diesel generators were paralleled with turbine generators.
3 minutes, 25 seconds	Rod carriages bottomed.
3 minutes, 30 seconds	Pressurizer pressure up to 1900 psi; one primary pump switched to full speed to obtain pressurizer spray flow; high pressure in primary system apparently due to increased level in pressurizer.
4 minutes	Started letdown flow to reduce pressurizer level.
5 minutes	Package boiler up to operating pressure of 150 psig; this boiler employed to supply steam for non-vital hotel loads during scram recovery.
7 minutes	Switched to two primary pumps at full speed to help maintain primary system temperature.
11 minutes, 30 seconds	BF_3 nuclear instrumentation channels (1 and 2) returned to service.

Time after scram	Events
17 minutes, 30 seconds	Jacking gear engaged on main propulsion unit.
19 minutes	Spray flow adjusted to permit use of all pressurizer heaters to help maintain primary system temperature.
36 minutes, 30 seconds	Withdrawal of control rods started.
1 hour, 33 minutes	Reactor critical.
3 hours, 50 minutes	Secondary plant being supplied by reactor steam, main engine ready to answer bells.

The diesel generators and the automatic load-transfer equipment functioned well during the exercise, and we observed no adverse effects on plant equipment. During the exercise, the temperature of the primary system decreased to approximately 484 F—a total drop of about 24° from normal. This demonstration showed that the primary water makeup system is adequate to handle a transient of this magnitude, and with the exception of a small number of minor revisions, the procedure followed in the exercise was considered adequate.

8.8.4. Scheduled-Outage Testing

8.8.4.1. Outage February — May 1963

The first post-delivery scheduled-outage period was conducted in Galveston, Texas, at the Todd Shipyard Corporation facility. Several modifications to the power conversion system were performed, in addition to the annual USCG inspection requirements. For the most part, the work items were of a routine maintenance nature; however, several modifications to secondary systems were performed. A modified ahead-throttle disc was provided to afford closer steam control in the low-speed ranges. Results proved satisfactory, and the valve characteristics have been noted in Figure 8-2. A permanent secondary-system polishing demineralizer was installed for cleanup of the secondary water system. The temporary units that had been provided were removed from the ship. The system has been in operation since installation and has proved to be satisfactory and capable of improving the secondary system water quality.

Additional minor modifications were performed on the in-line automatic chloride-detector system (Quantichem), the chemical-addition system, and salt-water evaporator systems. These were considered operational improvements not directly influencing the safety aspects of the vessel and have since proved to be satisfactory.

The auxiliary propulsion unit was subjected to major modifications. Upon completion of the outage period, the vessel was taken to sea for a 2-day trial, and the operating conditions indicated that all repairs and modifications were satisfactory.

8.8.4.2. Inactive Period May — October 1963

During this period the vessel was inactive alongside Pier E at Todd Shipyard Corporation, Galveston, Texas. Light and power were supplied from a shore feeder connection and no maintenance was performed except that required for ship or equipment safety. A periodic schedule of alternating and operating various electrical components was initiated to ensure their continued operability; this included all shipboard equipment that could be operated under limited conditions.

8.8.4.3. Dockside Testing October 1963 — April 1964

A dockside testing program was initiated during this period. It was intended primarily as a check of the reactor and reactor support system. When reactor power was available for steam generation, the main and auxiliary steam systems and steam-driven components were prepared for operation. Primary-grade demineralized water was brought in by tank truck as required to supplement normal inventories. The steam systems were subjected to an extensive drain-and-flush program to eliminate (where possible) any system contamination from dissolved or suspended oxides. Water chemistry and boiler-blowdown rates were closely checked to ensure meeting the best possible standards during initial startup.

The secondary steam systems were activated in conjunction with the turbine generators and auxiliary condensers after a prolonged warmup period. Equipment safety systems were artificially and operationally checked for release set points prior to unit operation (where possible).

When satisfactory conditions had been met with regard to the auxiliary power operating systems, the turbine generators were brought up to speed, checked for overspeed characteristics, and subsequently placed on the main switchboard. Additional components that were activated for checkout while the vessel was at dockside included evaporators, feed pumps, air ejectors, and gland seal exhausters. The main engines and reduction gears were checked for operability and were finally activated under full operating conditions for reduced-speed-ahead and -astern dock trials.

8.8.4.4. Sea Trial Operations

Six sea trials were conducted between February 20 and April 29, 1964, for the purposes of overall plant checkout and personnel training. The objective of these trials was to determine the plant performance during transient and steady-state conditions at low- and high-power conditions. Nuclear instrumentation and heat balance checks, as well as power checks of the emergency systems' capabilities, were performed. For operator exercise, the emergency propulsion system was operated in conjunction with several training scrams initiated at various power levels.

The ship's speed, power, and shaft rpm characteristics were carefully measured during sea trials 2 and 5 to provide curves of speed and power as a function of shaft rpm for various conditions of ship trim, cargo load, and marine growth. The data taken during sea trials 2 and 5 were for identical conditions, except for the extent of marine growth. Speed runs in sea trial 2 were made under conditions of 16-month marine growth, and the speed runs in sea trial 5 were made immediately after drydock cleaning and painting of the ship's hull. Hence, the effect of marine growth was determined, and interpolation between the two curves allows prediction of the ship's performance at all times under similar load conditions. Future data will be taken under fully loaded conditions (8000 and 9000 tons of cargo) to complete the measurements, which will then cover more practical ship conditions.

The results of the speed runs are plotted in Figures 8-12 and 8-13. Figure 8-12 compares reactor power as a function of shaft rpm for the two conditions of marine growth. Figure 8-13 compares ship's speed and slip as a function of shaft rpm for the same two conditions. Predicted and measured main engine performance were compared as a further check on propulsion system performance during the sea trial period. These values indicate no significant change in engine performance (Table 8-1).

Figure 8- 2. Maneuvering Valve Characteristic

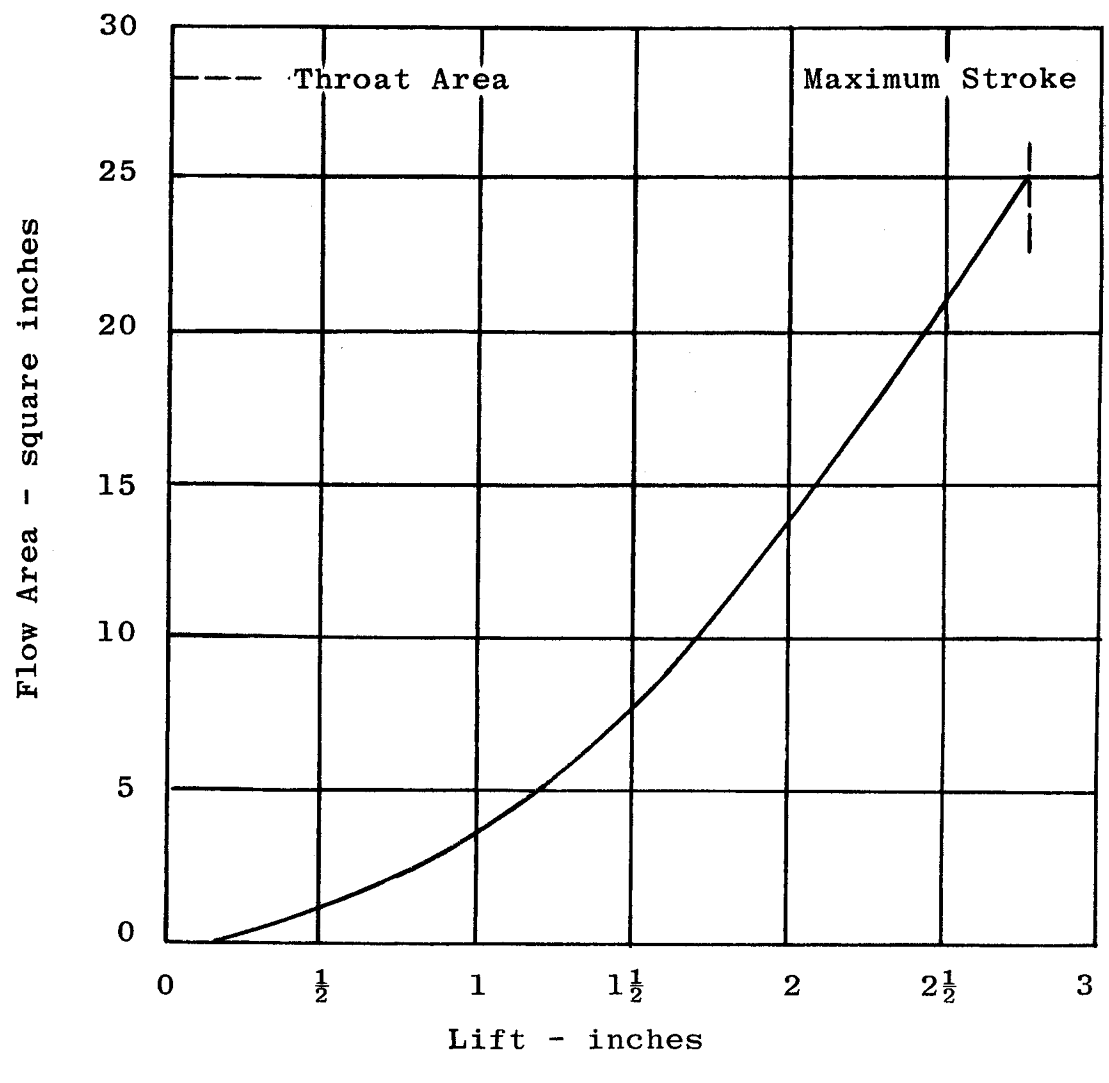

Figure 8-3. Crossover Moisture Separator

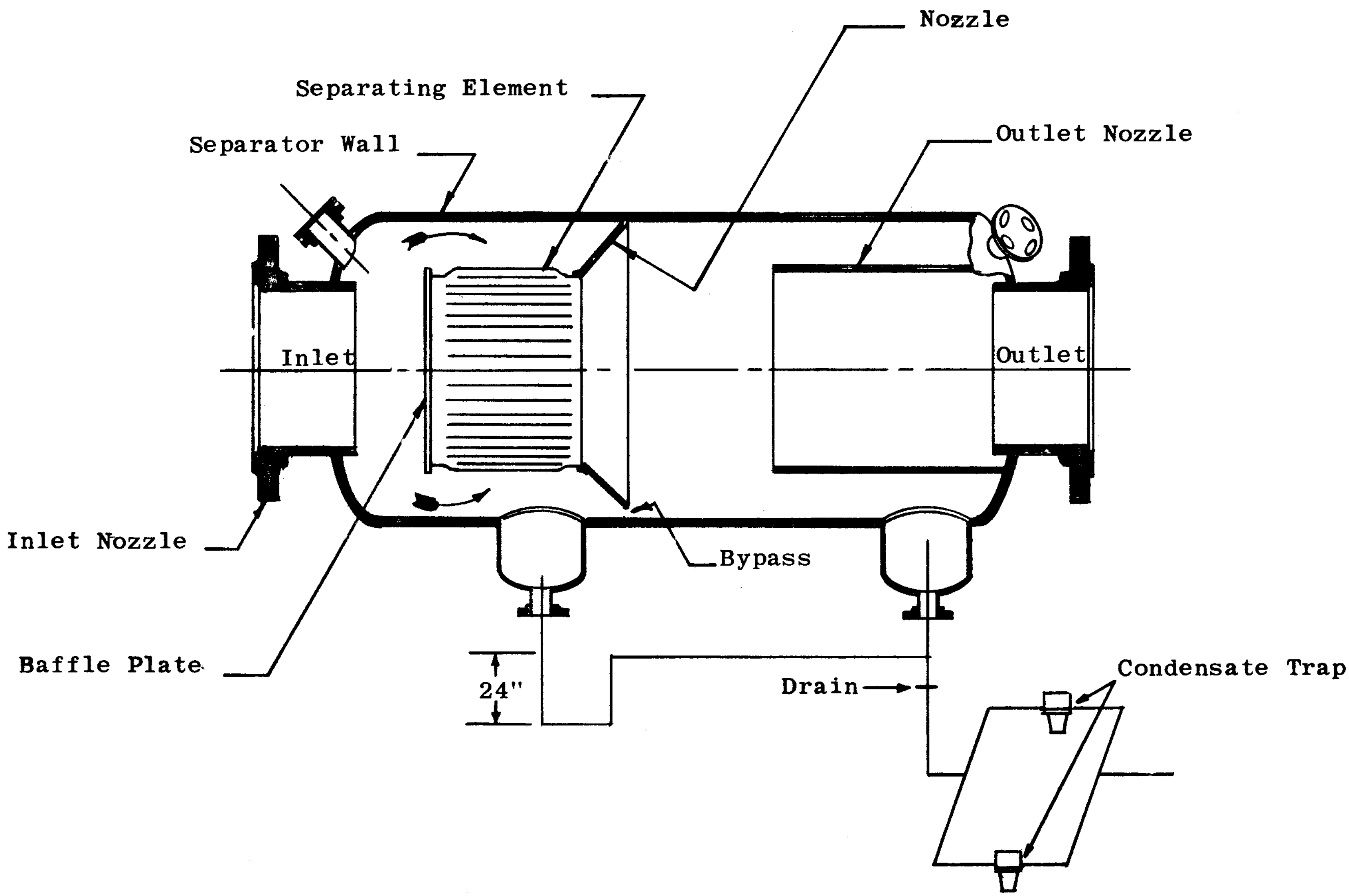

Figure 8- 4. Maximum Allowable Disposal Rate of Radioactive Waste Liquid to Main Condenser Cooling Water

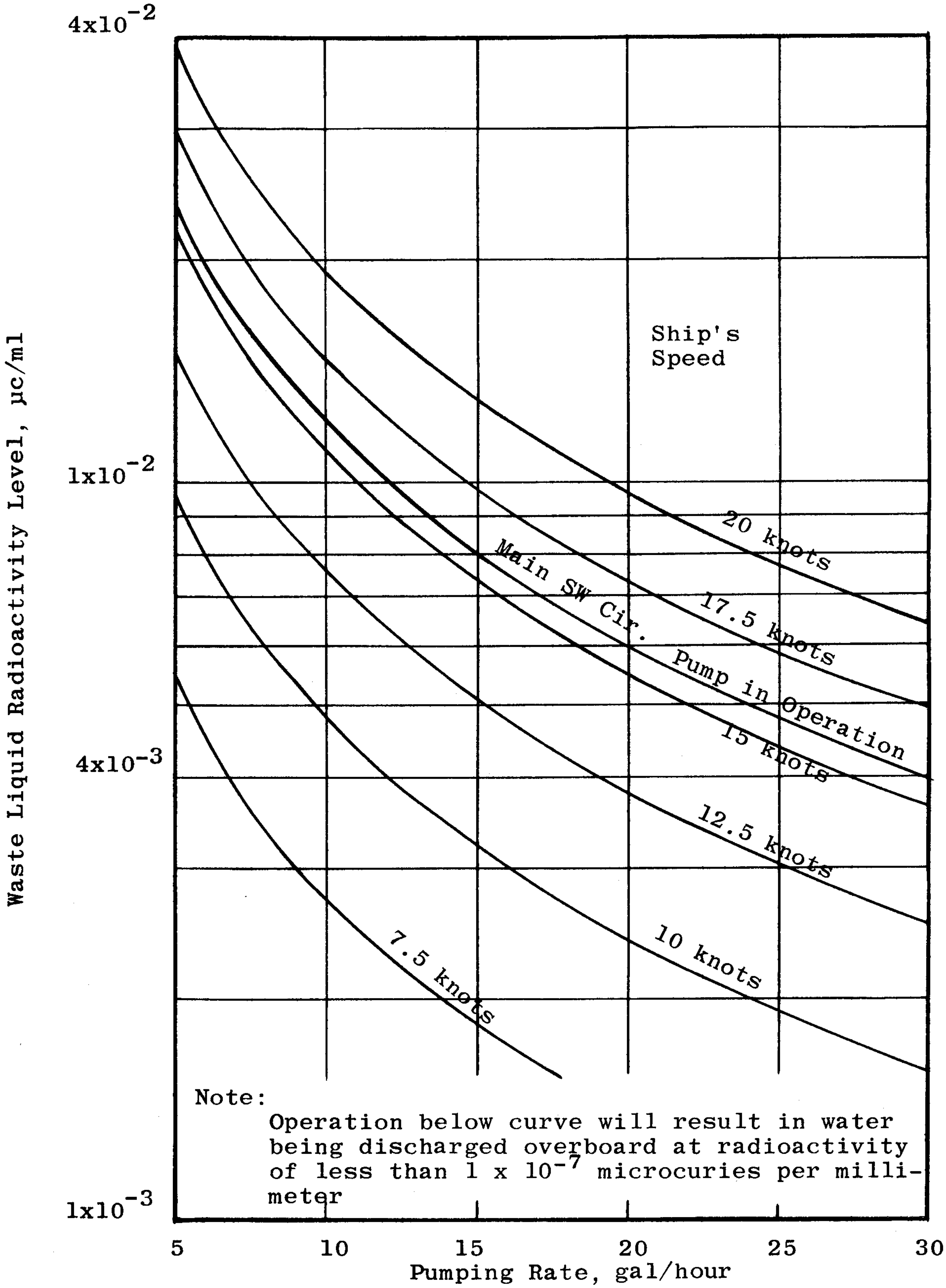

Figure 8- 5. Daily Maximum Allowable Disposal Rate of Radioactive Waste Liquid to Main Condenser Cooling Water

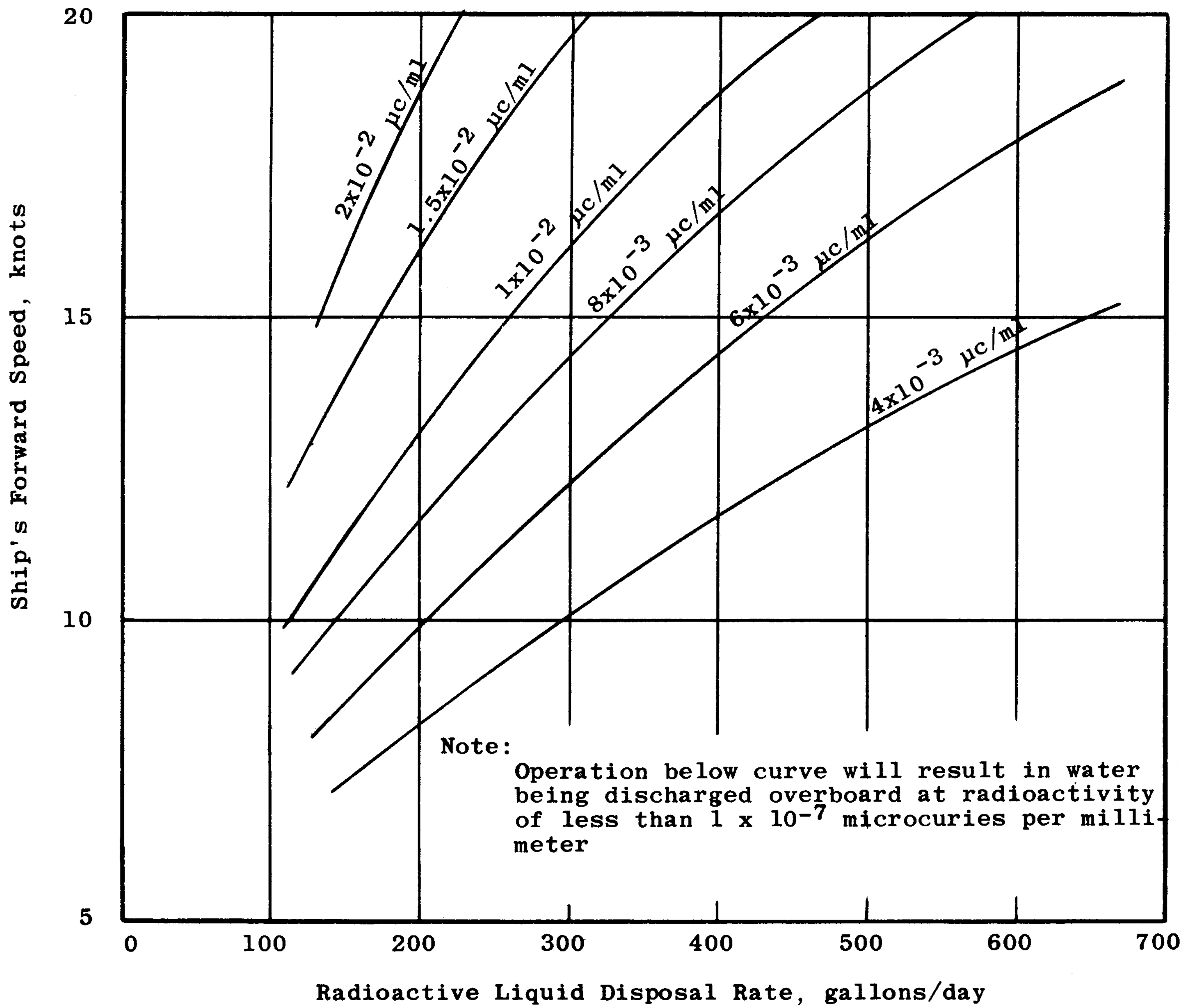

Figure 8-6. Pump Setting Vs Pump Capacity Curve

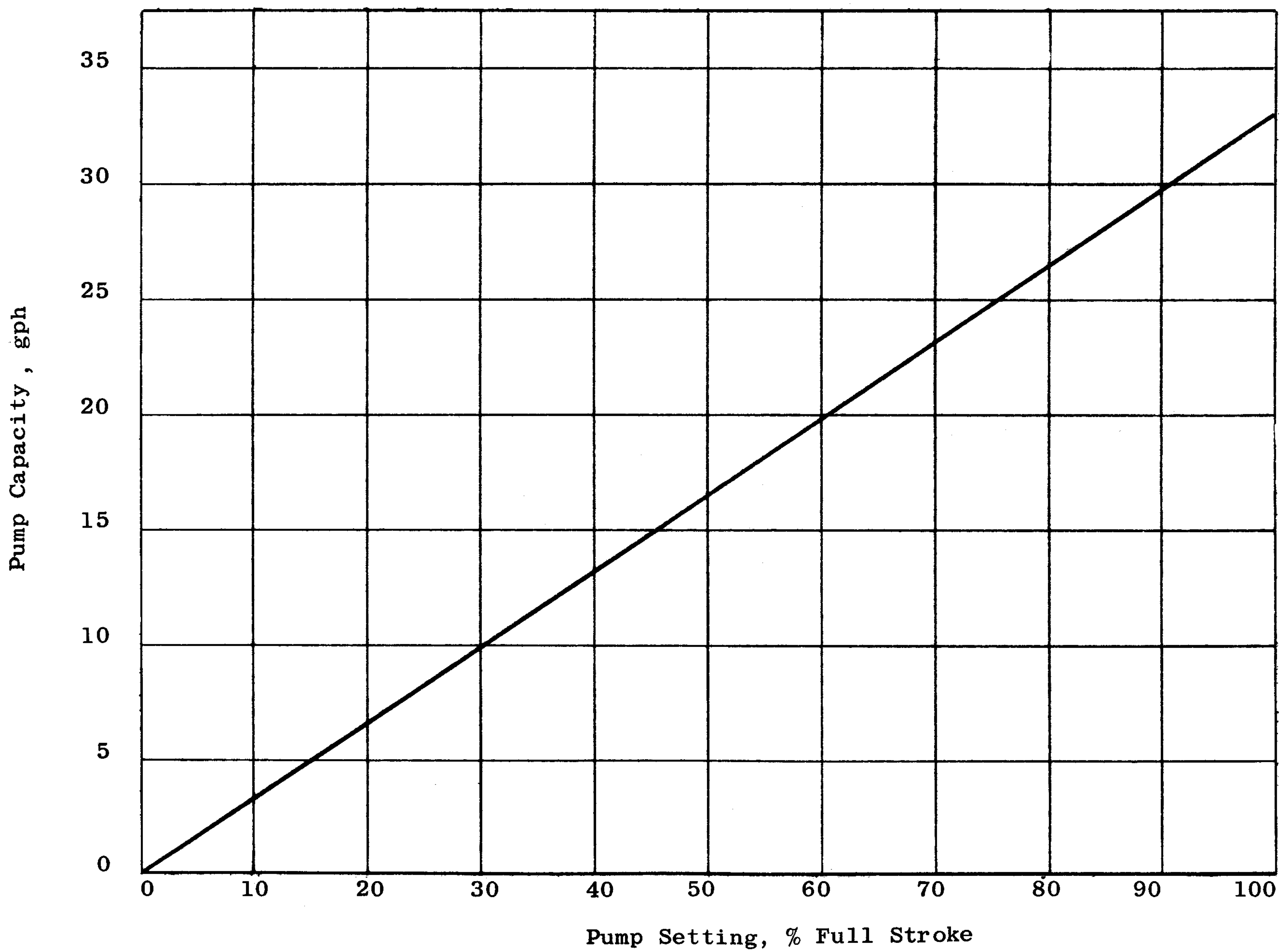

Figure 8-7. Blowdown Evaporator

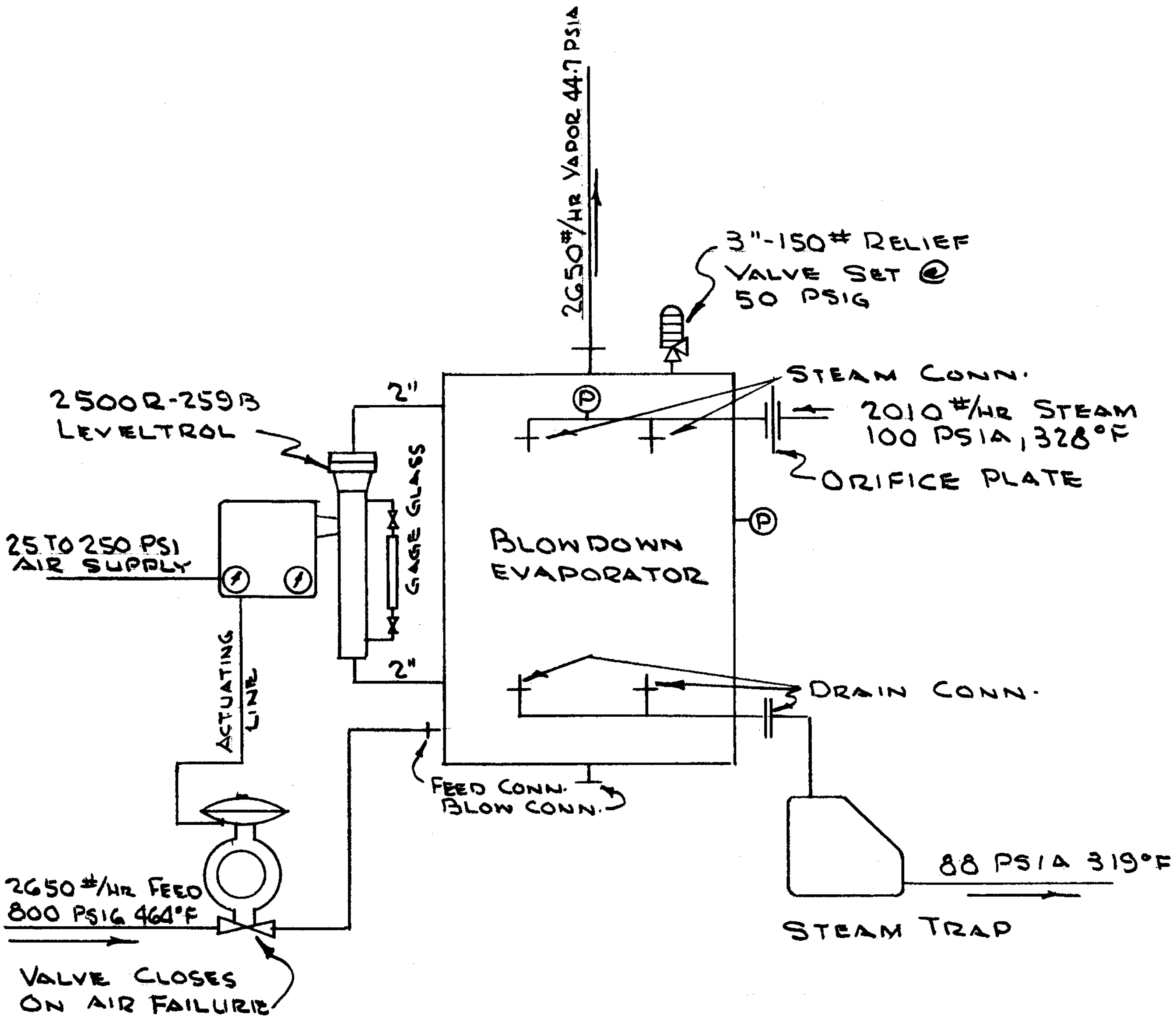

Figure 8-8. pH vs PO_4^{-3} Concentration for Secondary Plant Water Chemistry