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CAPITAL COST EVALUATION 1000 MWe MOLTEN SALT CONVERTER REACTOR POWER PLANTS

REPORT PREPARED FOR

OAK RIDGE NATIONAL LABORATORY

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SARGENT & LUNDY
ENGINEERS
CHICAGO

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CAPITAL COST EVALUATION
1000 Mwe MOLTEN SALT COOLED REACTOR POWER PLANT

1. INTRODUCTION

In July, 1959, the Oak Ridge National Laboratory initiated an evaluation of reactor systems to determine their capability for the efficient utilization of thorium and generation of electrical power. A preliminary survey indicated that five reactor types offered sufficient potential for these purposes to merit detailed consideration. The reactor types are the aqueous homogeneous (AHBR), molten salt (MSBR), liquid bismuth (LBBR), gas-cooled graphite moderated (GGBR), and deuterium-moderated gas-cooled (DGBR).

Evaluation of each system is being conducted by Oak Ridge National Laboratory in three phases: (1) economic optimization of fuel cycle costs and doubling times; (2) conceptual design and capital cost estimate of the reactor power plants; (3) analysis and cost estimate of the operating and maintenance requirements of each plant. Studies of the fuel cycles were completed in May, 1961, and are reported in ORNL CF-61-3-9, Thorium Breeder Reactor Evaluation, Part 1, Alexander, L.G., Carter, W.L., et al.

In March, 1961, Sargent & Lundy was engaged to assist Oak Ridge National Laboratory in the preparation of the conceptual design and capital cost estimates of aqueous homogeneous power reactor plants of approximately 1000 Mwe capacity, this size having been established as the basis upon which all of the concepts would be evaluated. The results of this study are being used by Oak Ridge National Laboratory as a basis for evaluating the remaining four systems.

This report presents the results of a conceptual design and capital cost estimate of three variations of the molten salt cooled power reactor cycle, each of sufficient capacity to develop an electrical output of approximately 1000 Mwe. A mixture of fluorides of lithium, beryllium, uranium and thorium serves as the transport media for the reactor fuel in each case, and the three concepts include a binary vapor cycle, using mercury and steam turbines, an indirect power removal cycle, which uses a nonfuel bearing salt mixture as an intermediate coolant, and a direct power removal cycle in which the fuel salt transfers its heat to boiling water and steam in a system of heat exchangers.

Oak Ridge National Laboratory established the design conditions of the three cycles, and prepared conceptual designs of the primary and intermediate heat transfer systems and their components. Using this information as a basis, Sargent & Lundy prepared the design of the major elements of the steam turbine systems, plant auxiliary and electrical systems and the buildings of the three concepts. In addition, Sargent & Lundy prepared capital cost estimates of each of the three systems; the estimates include all primary and intermediate coolant heat exchangers, the major steam cycle

components, turbine plant auxiliaries and the buildings required to house the reactor and turbine plant and the turbine auxiliaries. An estimate was not made of the reactor, the primary system pumps, and the associated reactor plant auxiliaries: the charging and relief systems, instrumentation and control, fuel purification system, coolant receiving, storage and make-up, fuel handling and storage, radioactive waste handling and disposal systems, and cover gas systems.

The power plants and associated auxiliaries are described in the body of the report. A description of the primary and intermediate heat transfer systems, which was prepared by Oak Ridge National Laboratory as the basis for the plant designs and estimates, is presented in Appendix A.

A detailed analysis of the potential hazards arising from component failures and operational errors has not been undertaken in this study.

II. SUMMARY

Three heat removal and power generating cycles, each suitable for use with a molten salt cooled reactor and capable of producing an electrical power of approximately 1000 Mwe are reported herein. All three concepts receive heat from a single 2500 Mwt reactor, cooled with a mixture of molten fluorides of beryllium, lithium, uranium and thorium at a maximum temperature of 1300 F, and moderated by graphite, through which the fuel-coolant mixture flows. All three cycles were conceived by Oak Ridge National Laboratory; Sargent & Lundy prepared the conceptual design of the plant and prepared the cost estimates, which include only the power generating system, buildings, and associated auxiliaries. The reactor, primary coolant pumps, and the reactor auxiliaries are not included in the estimate.

Preliminary performance diagrams of the three concepts as developed by ORNL appear in Figs. 1, 2 and 3. A summary of the characteristics of each plant is presented in Table I.

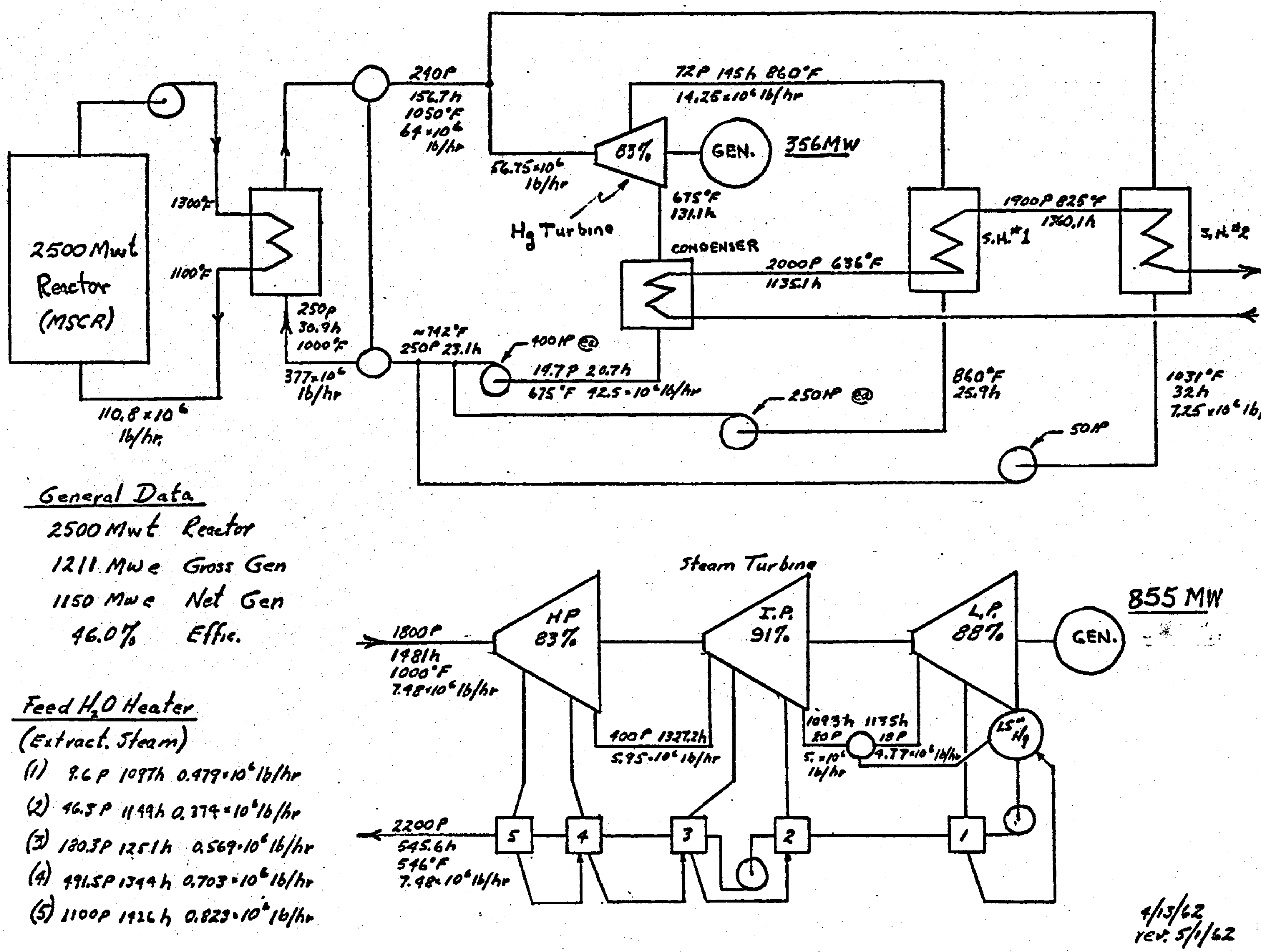
The mercury binary cycle employs boiling mercury to remove heat from the reactor fuel-coolant mixture in eight horizontal shell-and-tube heat exchangers. INOR-8 is used for all surfaces in contact with the fuel salt. The mercury vapor drives two 178 Mwe mercury turbines at 240 psia, 1050 F. The heat of vaporization of the mercury from the turbine exhaust is used to generate saturated steam at 1800 psi, in which process the mercury is condensed and returns to the mercury boilers. Mercury vapor is also used in four superheaters, of shell-and-tube design, to superheat the steam to 1000 F for use in a cross-compound, six-flow turbine-generator of 855 Mwe capacity. Seven stages of feed-water heating are provided to heat the steam generator feed-water to a final temperature of 537 F at a total flow rate of 7.88×10^6 lb/hr.

The net station output under these conditions is 1181 Mwe, with auxiliaries for the station consuming about 60 Mwe.

In the direct power cycle, heat is transferred from the fuel-coolant mixture to the feed water-steam cycle in a system of eight boilers, superheaters and reheaters. Each of the heat exchangers is a vertical shell and tube unit, with thimble-tube combinations providing a layer of stagnant salt between the high temperature fluorides and the feed-water or steam. Feed-water is converted to saturated steam in the boilers at about 2500 psi, and is superheated in the superheaters, which also use fuel salt as a heat source. Inconel and INOR-8 are used in the heat exchangers, with Inconel on the steam side and INOR-8 on the salt side.

Steam at 2400 psia, 1000 F is provided at the turbine throttle, and the exhaust from the high-pressure turbine cylinder is reheated to 1000 F before flowing to the intermediate-pressure cylinder and low-pressure cylinders. With this cycle, involving a reheat turbine, a steam flow of 6.882×10^6 lb/hr., and eight stages of feed-water heating, the turbine output is 1000 Mwe. The plant auxiliaries require 29 Mwe, resulting in a net output of 971 Mwe.

Fig. I MSCR MERCURY BINARY CYCLE



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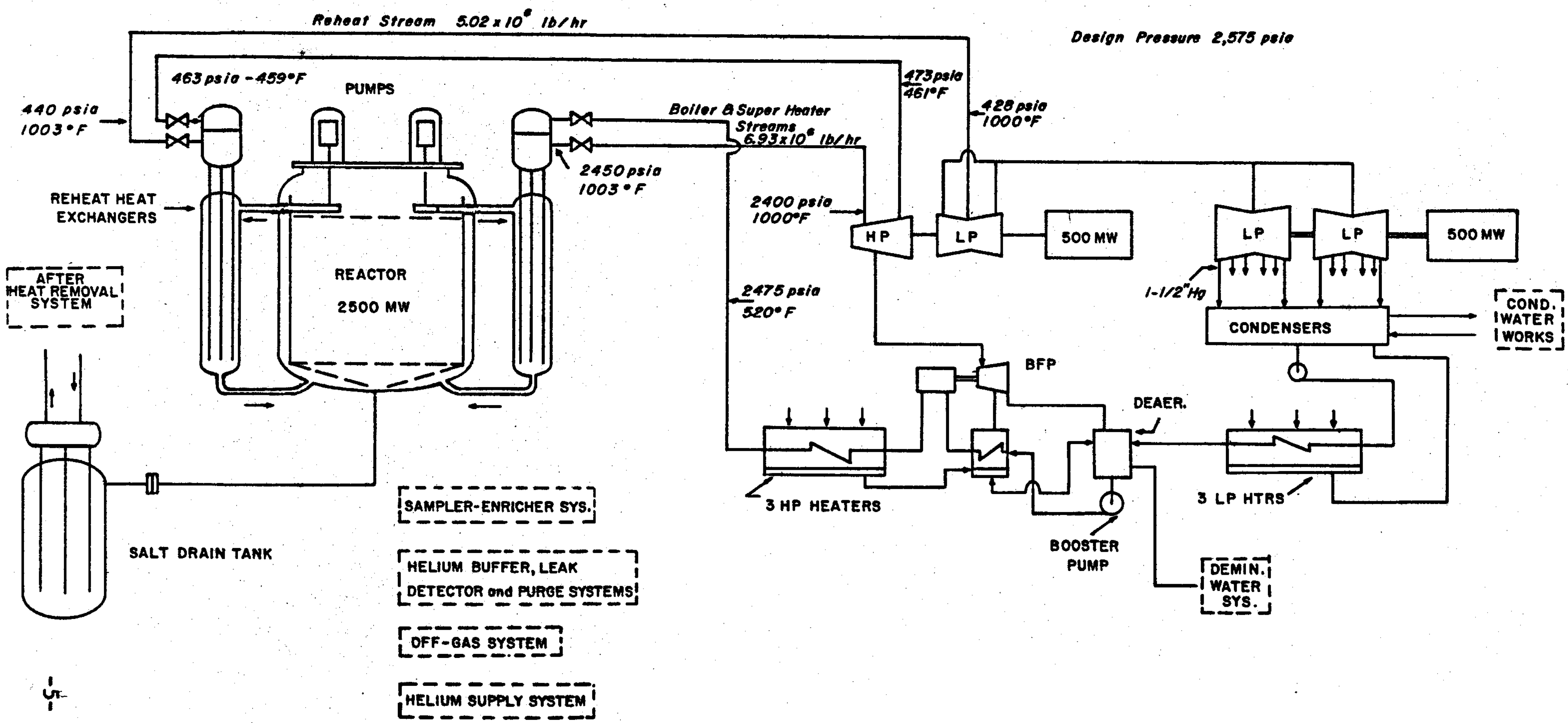

FIG. 2 MOLTEN SALT CONVERTER REACTOR
Direct Power Cycle Flowsheet

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STATION SUMMARY

Reactor 2500 MWT
Gross Generation 1023 MWE
Net Generation 982 MWE
Overall Plant Eff. 39.3 %
Aux. Elec. Req.
Reactor Pl. 3 %
Gener. Pl. 1 %

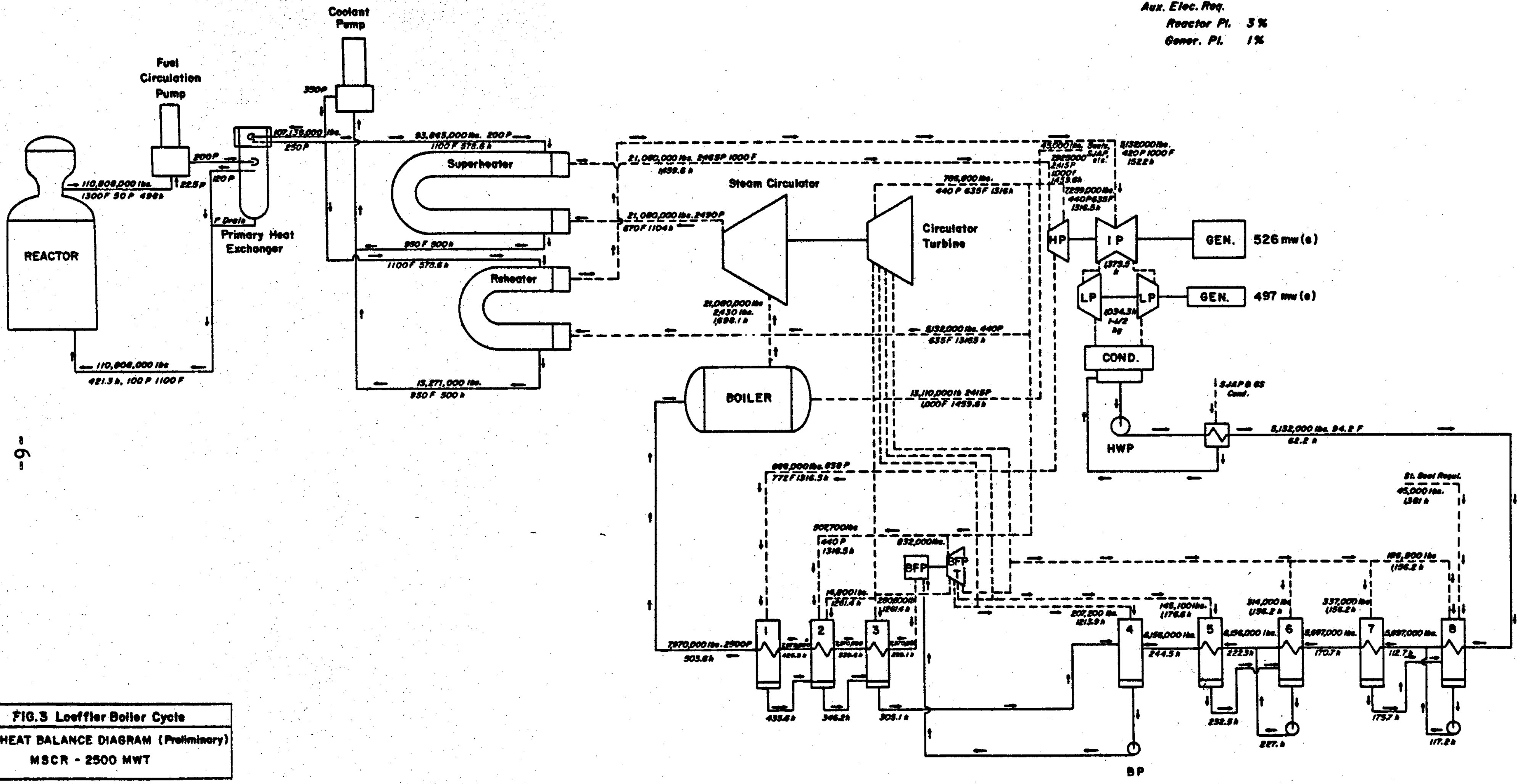

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FIG.3 Loeffler Boiler Cycle
HEAT BALANCE DIAGRAM (Preliminary)
MSCR - 2500 MWT

TABLE I

Summary of Design and Operating Characteristics

Molten Salt Cooled Power Reactor Plants

	Binary Vapor Cycle	Direct Power Cycle	Indirect Power Cycle
Station Gross Electrical Power, Mwe	1211	1135	1062
Station Net Electrical Power, Mwe	1151	1105	1017
Station Thermal Power, Mwt	2500	2500	2500
Station Net Efficiency, %	~46	~44	~41
Number of Turbines - Mercury	2	-	-
Steam	1	1	1
Number of Reactors	1	1	1
Fuel Salt Flow Rate, ft^3/sec.	162	162	162
Fuel Salt Reactor Inlet Temp., F	1100	1100	1100
Fuel Salt Reactor Outlet Temp., F	1300	1300	1300
Total Mercury Flow Rate, 10^6 lb/hr.	64	-	-
Mercury Vapor Conditions, psia/F	240/1050	-	-
Power Output of Mercury Turbines, Mwe	356	-	-
Reactor System Materials	INOR-8	INOR-8	INOR-8
Mercury System Materials	Croloy 5 Si		
Inert Salt Flow Rate, ft^3/sec.	-	-	248
Inert Salt Inlet/Outlet Temp., F	-	-	1100/950
Steam Flow Rate to Turbine, 10^6 lb/hr.	7.48	7.82	7.63
Steam Conditions at Turbine, psia/F	1800/1000	2400/1000/1000	2400/1000/1000
Estimated Capital Requirement for Direct Construction Cost of Energy Conversion Systems, $\$10^6$	77.856	65.481	72.970

The steam-feed water conditions for the indirect cycle are the same as those just described for the direct power cycle. This cycle differs in the manner of generating steam. The reactor heat is transferred to a circulating nonfuel bearing (inert) salt mixture in eight vertical shell-and-tube heat exchangers. The inert salt temperature varies between 950 and 1100 F. Saturated steam is generated at about 2400 psi from the turbine feed water by direct contact with superheated steam in four Loeffler boilers. The saturated steam flows at a rate of 21 x 10^6 lbs/hr. to 16 shell-and-tube superheaters, which receive heat from the inert salt loop and produce superheated steam at 2400 psi, 1000 F. A part of the superheated steam is used to generate more steam in the Loeffler boilers; the remainder, 6.88 x 10^6 lb/hr., drives the steam turbine. Exhaust steam from the high pressure-turbine cylinder is reheated to 1000 F in eight shell-and-tube reheaters before flowing to the intermediate pressure turbine.

The turbine has a gross output under these conditions of 1000 Mwe and the auxiliaries require about 45 Mwe, resulting in a net power output of 955 Mwe.

The plants are assumed to be located on an Atomic Energy Commission reference site in Western Massachusetts. The site is assumed to have an adequate source of circulating water for the turbines. Because of the low vapor pressure of the reactor coolant, high pressure containment is not considered necessary; the reactors and their auxiliaries are contained in a sealed, steel lined concrete structure which forms a part of a sub-divided biological shield with a total thickness of 10 feet.

The turbine-generators and the other components of the steam-condensate system are housed in a conventional steel frame building. The turbine building and the reactor building are arranged so that one traveling bridge crane services both buildings.

Other structures on the site which are included in the cost estimate are the crib house, circulating water intake and discharge flumes and tunnels, waste gas stack, and foundations for fuel and condensate tanks and transformers. Road and rail access are also provided for the plant.

The estimated direct construction cost for the plants, including the reactor and turbine buildings, all turbine plant components and systems, primary heat exchangers, intermediate coolant systems, but excluding the reactor primary system pumps and coolant, and all reactor auxiliary systems, is indicated in Table I.

The cost estimates are based on a "second generation" design, therefore the assumption is made that development costs have been recovered in a previous generation of molten salt cooled reactors. Nevertheless, technological and economic uncertainties in the application of new materials, notably INOR-8, with which limited experience has been accumulated, may be reflected in a conservative design and a somewhat higher cost estimate than may be the case in later plants. All material and labor costs are based on prices in effect in June, 1962.

The cost estimates reported herein are arranged in accordance with the U.S. Atomic Energy Commission system of accounts for reactor power plants.

III. PLANT DESCRIPTIONS

A. General

Three complexes, each based on a nominal 2500 Mwt reactor power output, are considered in this report. All utilize a graphite moderated, molten salt cooled reactor as an energy source. In two of the plants, steam turbine-generators produce all of the electrical power. The third plant utilizes mercury in a binary vapor cycle, resulting in a power output of about 350 megawatts from two mercury turbine-generators, with the remainder being produced by a steam turbine-generator.

A mixture of molten fluorides of lithium, beryllium, thorium and uranium serves as the fuel bearing fluid in the reactor and primary system. A thermal power of about 2500 Mw is developed by circulating the salt between temperature limits of 1300 F and 1100 F through heat exchangers, where the heat is transferred to either an intermediate fluid, such as mercury or an inert salt, or directly to steam.

The reactor and the primary system design conditions, which were developed by Oak Ridge National Laboratory, are described in Appendix A.

Because of the low vapor pressure of the primary fluid, high pressure containment of the reactor system is not considered to be required. A sealed, subdivided biological shield is provided, surrounding the radioactive systems, and it is installed in a conventional building which adjoins the turbine building. The dimensions of the reactor primary shield are based on conceptual designs of the primary system components; the reactor building and the secondary shield structure provide space for unspecified reactor auxiliaries, such as those required for fuel processing, handling and storage, radioactive waste removal and storage, and fuel melting and charging systems.

The plant is considered to be located on 1200 acres of a site which has been specified by the Atomic Energy Commission as a reference site for power reactor plant design studies. All plant utilities are provided, including domestic water supply and sewage systems, fire protection equipment, plant heating, ventilation and air conditioning, communications systems, access by rail and truck, and parking facilities for personnel and visitors.

B. Binary Vapor Cycle

A composite flow diagram of the binary vapor system is shown in Exhibit 1. The heat released in the reactor is transferred to mercury by pumping the liquid fuel salt from the reactor through eight shell-and-tube mercury boilers. Mercury vapor drives two mercury turbine-generators, producing 178 Mwe per turbine. The heat of vaporization of the mercury is used in the mercury condensers to generate saturated steam, which is superheated by mercury vapor side streams in four shell-and-tube superheaters to produce superheated steam for the steam

turbine-generator at 1800 psia. Approximately 855 Mwe is produced by the steam turbine. The condensate passes through seven stages of feed-water heating before entering the mercury turbine condensers, where it is vaporized by condensing the mercury from the turbine exhaust.

Reactor Fuel System

The reactor fuel system consists of the reactor, eight vertical centrifugal salt pumps, which are motor-driven and mounted on the reactor vessel, and eight shell and tube mercury boilers, all of which are located within the primary shield of the reactor building, as indicated in Exhibits 4 and 5. To conserve fuel salt volume, the salt flows on the tube side of the mercury boiler, and the mercury is on the shell side. The boiler is a horizontal U-tube and shell type. All surfaces in contact with the fuel salt are fabricated of INOR-8, a nickel base alloy which is also known as Hastelloy N. The tubes and tube sheets of the mercury boilers are of duplex construction, with INOR-8 clad on a 5% Cr-0.5% Mo-1.5% Si low carbon alloy steel. The latter is used in all components and piping in contact with mercury. A detailed description of the fuel salt system and its components as developed by ORNL is presented in Appendix A.

In order to drain the fuel salt, a shielded tank of noncritical geometry, and provisions for both removing decay heat and providing heat if required for melting the fuel, is necessary. To accommodate the estimated 2025 ft^3 of fuel salt in the system, 90 cylindrical tanks, of about 2 feet inside diameter and 11 feet high are required. By locating these tanks in a trench below the reactor building grade floor and within the primary shield, gravity drain is possible, and the shielding requirements are simplified. The trench is shown in Exhibits 4 and 5.

The fuel salt inventory is estimated to be made up of 1265 ft^3 in the reactor, 584 ft^3 in the eight boilers, and 176 ft^3 in the piping system. This does not include any fuel in the reactor auxiliary systems.

The biological shield consists of a total thickness of 10 feet of ordinary concrete, subdivided into a sealed primary shield 6 feet thick surrounding the reactor and the mercury boilers, and a secondary shield 4 feet thick which forms the wall of the reactor building and encloses the mercury systems. The top of the primary shield is formed of 2 foot thick slabs of concrete, sectionalized to allow access to individual components within the shield, and overlapped to prevent streaming. The top shield has a total thickness of 6 feet and is supported by steel beams and columns. The traveling crane is used to remove the slabs as desired, and can handle all components within the shield. All reactor auxiliaries are intended to be located in the reactor building. The conceptual design of the systems was not included in the scope of the project, but they would include auxiliaries for processing the fuel salt to remove uranium and fission products, adding new fuel into the carrier salt, melting and charging the salt into the system, maintaining, storing and disposing of radioactive components, removal and disposal of liquid and gaseous radioactive wastes, removing decay heat on shutdown, and processing the fuel cover gas.

Because of the high liquidus temperature of the salt (887 F), a heat source is necessary to melt the salt and preheat the salt-bearing components and piping before adding it to the system. The heat source will also be energized upon shutting down in order to maintain the salt in a molten condition. The fuel-bearing salt would remain in a molten condition for some time after shutdown through the release of decay heat, but a prolonged shutdown could conceivably require the application of heat to prevent solidification in the reactor and other components of the primary system.

Several methods of removing decay heat are conceivable, all of which must remove the heat at temperatures of approximately 1000 F. The present study did not include the design of such a system.

The salt melting and heating system is designed on the basis of melting the salt in a small stream, charging it into the preheated primary system, and holding it at a temperature of approximately 1100 F until operation is initiated. Upon shutdown, the preheating system will be used to maintain the salt at a temperature of approximately 1100 F after the post-fission heat has decayed. All fuel drain lines, the storage tanks, and the fuel processing system will also require heat during certain periods of operation.

Electrically powered strip heaters, placed on the surface of all components which contain salt, provide the means of preheating the primary system and maintaining its temperature after shutdown. The heaters for the reactor vessel are designed to preheat the reactor vessel and the graphite core in a reasonable time, while those on all other components are designed to hold a temperature of 1100 F, with 100 F still air and approximately 6 inches of insulation. On this basis, the reactor requires about 500 kw of heat during preheating, and 100 kw to hold a temperature of 1100 F. A 150 kw electric furnace provides heat for melting the salt on initial charge. A maximum coincidental power of 1100 kw is estimated to be required when preheating and charging the salt into the system.

The cost estimate includes the electrical auxiliaries and cable to supply the necessary power, and the strip heaters on the mercury boilers, but does not include the salt melting furnace, or the heaters for the primary system, fuel purification system, salt charge piping and pumps, or the fuel drain tank system.

Mercury Vapor System

The heat of the fuel salt is transferred to mercury in eight mercury boilers. The mercury vapor is distributed from the boilers to a pair of mercury turbines and four shell-and-tube superheaters as shown on the composite flow diagram. The condensate from the turbines and superheaters is pumped back to the mercury boilers. Table II lists the design conditions of the mercury vapor cycle. All materials exposed to the mercury, in either liquid or vapor form, are of a low carbon steel alloy consisting of 5% Cr-1/2% Mo-1-1/2% Si, (ASTM A335, Grade P5b).

Each mercury turbine consists of a high pressure cylinder and two low pressure cylinders connected in tandem to a 224,000 kva 13.8 kv generator. Each low pressure casing exhausts to a condenser where the heat of vaporization of the mercury is used to generate steam from the steam turbine feed water. The steam is superheated in the four superheaters, two of which receive mercury vapor from an extraction point on the mercury turbines, and the remaining two receive high temperature mercury vapor.

The condensate from the mercury turbines and the four superheaters is pumped back to the mercury boilers. Each mercury condenser has one full capacity horizontal centrifugal mercury pump, capable of pumping 10.65×10^6 lb/hr. of mercury at 14.7 psia and 675 F, with a 400 horsepower motor drive. The superheaters each have two half-capacity horizontal mercury pumps.

The pumps for the low temperature superheaters are each designed to pump 3.6×10^6 lb/hr. of mercury at a discharge pressure of 250 psia and a temperature of 860 F. The pump motors are rated at 125 horsepower. Two half-capacity mercury pumps are provided for each of the high temperature superheaters. These pumps are designed for a flow of 18×10^6 lb/hr. at discharge conditions of 230 psia and 1031 F with a motor rated at 25 horsepower.

TABLE II

Performance Characteristics of Mercury Vapor Cycle

Total Hg flow from boilers, 10^6 lb/hr.	64
Hg vapor conditions, psia/F	240/1050
Hg flow to turbines, total, 10^6 lb/hr.	56.76
Power output of Hg turbines, kwe	356,000
Hg flow to high temperature superheaters, total, 10^6 lb/hr.	7.24
Hg flow to low temperature superheaters, total, 10^6 lb/hr.	14.26
Hg vapor to low temperature superheater, psia/F	72/860

The mercury condensers are shell and U-tube heat exchangers, with mercury on the shell side and boiling water on the tube side. The tube headers consist of a pair of 2.5 feet O.D. drums approximately 12 feet in length, with 2040 tubes averaging 66 feet in length penetrating each drum. A total of 30,600 ft^2 of heat exchange surface is provided by this arrangement.

The wetting properties of the mercury are increased by diverting a sidestream from the turbine condensate pumps to a system containing tanks of titanium hydride powder and pieces of small diameter magnesium rod. A flow of about 1% of the total mercury system flow (0.64×10^6 lb/hr.) is estimated to be sufficient to assure proper wetting. Sludge is formed by impurities which the mercury picks up from the system; this is settled out

in a sludge removal drum by decreasing the mercury flow to about 2 fps through the drum. The developed head of the condensate pumps is estimated to be sufficient to circulate the mercury through the additive and sludge removal system.

Croloy (A335, Grade P5b) is used for piping throughout the mercury system with the sizes being selected on the basis of the number of units served and a mercury velocity of 7 fps (liquid) and 200 fps (vapor). The pipe wall thickness is selected to agree with the ASME code for power piping.

The mercury inventory required for the heat transfer system during normal operation is estimated to be 5 x 10^6 lbs. made up as follows:

Mercury boilers	2,480,000 lbs.
Mercury condensers	1,420,000 lbs.
Superheaters #1	476,000 lbs.
Superheaters #2	242,000 lbs.
Piping system	383,000 lbs.

A mercury storage system is provided to allow 25% of the system to be drained upon shutdown. A total of two tanks, each of 12,000 gallon capacity, are provided for this purpose. Drainage is accomplished by pumping, using two 50 gpm pumps and appropriate valving to provide filling and draining functions.

The mercury turbines, superheaters and pumps are located in an area of the building between the reactor system and the steam system, as shown in Exhibit 4. The mercury components are arranged to minimize the length of mercury piping while providing convenient access by the high pressure steam and feed-water piping for the steam turbine. The entire mercury system is located within a concrete shield wall, 4 feet thick, which provides biological protection from the mercury activation products. By locating the mercury turbines, superheaters, etc., below the main floor, the upper shield becomes a part of the main floor. The turbine and condensers are supported on concrete foundations, as shown in Exhibit 5. Removable sections are provided in the main floor to allow access to the mercury system components from above. Horizontal access is provided through the vertical shield wall for the railroad track.

Steam System

The steam turbine-generators, main condensers, feed-water heaters, circulating water system, and associated buildings and structures comprise the steam system. The steam, feed-water and circulating water conditions and piping sizes are shown on Exhibit 1, and the arrangement of the components and buildings is indicated in Exhibits 3, 4 and 5.

Saturated steam is generated in the mercury condensers at 2000 psia, and flows to the superheaters, where it is heated to provide superheated steam

at 1800 psia and 1000 F at the turbine throttle. The steam flow rate is 7.88×10^6 lb/hr. at a turbine output of 885 Mwe. The condensate passes through 7 stages of feed-water heating to provide feed-water to the mercury condensers at 2250 psia, 537 F.

The steam turbine consisting of a cross-compound, six-flow nonreheat unit, with 40 inch exhaust blades, a 3600 rpm high pressure unit and 1800 rpm low pressure unit. At a throttle steam flow of 7.88×10^6 lb/hr., and a condenser pressure of 1.5" Hg, the turbine output is 885 Mwe.

A separate condenser is provided for each low pressure casing. The overall surface area is 665,950 ft^2, with a tube length of 40 feet. Admiralty metal is used for the 1" x 18" BWG tubes. Condensate flows at a rate of 4,628,000 lb/hr. to six 1/6 capacity horizontal condensate pumps, each equipped with a 450 horsepower motor, and is discharged at 297 psia to the feed-water heaters. Flow control is performed by valves. Three parallel strings of heaters are required. The six low pressure units (A and B) are located in the condenser neck. Heater drains are pumped from heaters A and C. The two deaerating heaters are located on the roof of the turbine building.

The feed water is pumped by four horizontal centrifugal motor-driven pumps, each capable of handling 25% of the total flow, and equipped with hydraulic couplings for flow control. Each motor is rated at 8,000 horsepower.

The condensate and feed water piping is fabricated from seamless carbon steel pipe, ASTM A106, Grade B, in accordance with the ASA Code for Pressure Piping B31.1, Section 1, using water velocities ranging from 3 fps to 10 fps. The main steam piping consists of a pair of 24 inch O.D. x 3.05 inch wall hollow forged pipe, designed for 1890 psia and 1000 F at a steam velocity of 15,000 fpm. The pipe material is ASTM A335, Grade P11.

Valves are provided in accordance with normal steam power plant practice.

Feed-water storage is provided by two 100,000 gallon tanks, located to the northwest of the main building.

Cooling water for the condensers is pumped from the crib house by six 1/6 capacity vertical circulating water pumps, each of which has a capacity of 149,000 gpm and a 1750 horsepower motor drive. The water flows to the condensers through six 84 inch steel pipes and, after leaving the condenser, is discharged through a concrete tunnel to a seal well, from where it flows to the river through a discharge flume. The total circulating water flow is 894,000 gpm, requiring eight 10 foot traveling screens and a stop log and bar grille system at the crib house.

The crib house is an outdoor structure built to accommodate the circulating water pumps and screens, the service water pumps, fire pump, screen wash pumps, and chlorination equipment.

Electrical Systems

Electrical power is supplied by the two mercury turbine-generators and the

two generators of the cross-compound steam turbine. Each of the mercury turbines produces 178 Mwe gross, at 13.8 kv. The steam turbine output is 885 Mwe at 24 kv. This power is assumed to be generated on a 60/40 basis by the low pressure and high pressure units respectively. The plant auxiliaries are supplied by a pair of auxiliary power transformers from the low pressure turbine-generator.

Excitation for the generators is provided by motor-driven exciters, a separate exciter being provided for each generator. One motor-driven reserve exciter, equal in capacity to each of the exciters for the mercury turbine-generators, serves as a stand-by for the mercury turbine-generator exciters. A second motor-driven reserve exciter is provided for the steam turbine-generator. This exciter is equal in capacity to the exciter for the low pressure turbine-generator, and as such, is capable of serving the high pressure turbine-generator as well.

Isolated phase bus connects the generators to individual transformers; the bus for the two mercury turbines is rated at 10,000 amperes, 15 kv, while the high and low pressure turbine-generator outputs are carried through 10,000 ampere and 14,000 ampere bus duct rated at 24 kv. The taps to the two auxiliary power transformers are 1200 ampere, 24 kv isolated phase bus.

The mercury turbine-generators each feed a 190 mva three-phase type FOA transformer with winding voltages of 13.8 and 345 kv. The low pressure and high pressure steam turbine-generators are connected to type FOA transformers rated at 485 and 390 mva respectively at a voltage ratio of 23-345 kv.

The plant auxiliaries require a coincidental power input of about 60 Mwe at a power factor of 0.8. Because of the size of the load, and the number of large motors in the plant, a part of the auxiliary power (about 40 Mva) is supplied at 13.8 kv and the rest (30 Mva) at 4160 volts.

The auxiliary power is normally supplied from two 3-winding auxiliary power transformers, each of which is rated at a maximum fan cooled rating of 37.5 Mva, and voltage ratios of 24-13.8 - 4.16 kv. A reserve auxiliary transformer is fed from the station switchyard bus, and serves as a stand-by in the event of loss of either of the two unit auxiliary transformers.

The 13.8 kv switchgear has a fault interrupting capacity of 500 Mva. Two separate buses are provided, each of which is connected to one of the unit auxiliary transformers and the reserve auxiliary transformer. The switch-gear is metal-enclosed, for indoor service, and supplies the feed-water pumps and the exciters for the steam turbine-generators.

Two sections of 4160 volt metal-enclosed indoor switchgear provide power for the remaining plant auxiliaries from the 4160 volt windings of the unit auxiliary transformers. The switchgear uses 2000 ampere main circuit breakers and 1200 ampere feeder circuit breakers, all with an interrupting capacity of 350 Mva. The loads fed at 4160 volts consist of motors rated at more than 125 horsepower and the auxiliary power transformers required

for station lighting, 480 volt auxiliaries, and the fuel melting and preheating system. The 480 volt auxiliaries are supplied from four 750 kva 4160-480 volt dry type transformers, throat-connected to the switchgear through 1600 ampere air circuit breakers. Two sections of switchgear are furnished. Each section is divided into two buses, with normally open tie breaker between bus sections.

Two 750 kva 4160-480 volt transformers are also provided for the fuel preheating and melting systems, which are fed at 480 volts from two bus sections, in one set of 480 volt switchgear.

All auxiliary feeder cables consist of ozone resistant rubber insulated cable.

Smaller auxiliaries, of 30 horsepower or less, and those whose continuous operation is not considered vital to station operation, are fed from motor control centers in the vicinity of the load. Two 15 kva 480-120 volt transformers supply a 115 volt a-c control and instrumentation bus for each unit. An emergency supply to this bus is provided from a 15 kva inverter motor-generator set which is driven by the 250 volt battery.

One 250 volt battery and distribution center are provided. The 250 volt bus supplies the emergency equipment, emergency lighting, and the various d-c control devices.

A 277 volt fluorescent lighting system is used for general lighting in the plant buildings. Mercury vapor lights are used at the turbine room main floor. A 10 kva 480-120 volt transformer in the lighting distribution cubicle supplies convenience outlets, door lights and other 120 volt lighting systems. The emergency lighting system uses 125 volt d-c incandescent lamps to provide minimum illumination levels in strategic areas in the event of failure of the normal lighting system.

<u>Plant Auxiliary Systems</u>

The plant auxiliaries include the following:

a) Service Water System
b) Shield Cooling System
c) Control and Station Air Systems
d) Cranes and Hoists
e) Instrumentation and Control
f) Plant Utilities

A summary of the characteristics of these systems is presented below.

Service Water System

The service water system supplies river water for cooling purposes throughout the plant, including the reactor auxiliaries and the turbine plant

components. Information necessary to determine the requirements of the reactor plant was not developed in this investigation, and the estimate of the service water system was based on that provided for the aqueous homogeneous power reactor plant as reported in SL-1875.

The service water is supplied by three 15,000 gpm, half-capacity, vertical centrifugal pumps. Each pump is driven by a 1250 horsepower motor, and is located in the circulating water intake structure. During normal operation, two pumps supply the system with water at 100 psig, with the third pump employed as a stand-by. The main piping delivering service water to the plant is a 36 inch plate pipe with a 1/2 inch wall.

The service water pumps discharge into two twin basket backwashing type strainers. Conventional materials are used throughout the system on all pumps, piping, and strainers. Prior to use in the plant, the service water is chlorinated.

Shield Cooling System

The design of the shield cooling system is based on removing 1.5% of the reactor thermal power from the primary shield, using water cooled coils embedded in the shield. Demineralized water is pumped through the coils and the tube side of a shell and tube heat exchanger, where the heat picked up in the shield is transferred to service water.

Assuming a temperature rise in the coils of 55 F above a 125 F minimum, a flow of 4650 gpm is required to remove 37.5 Mw of heat. A 3,000 gallon demineralized water storage tank is provided, and three half-capacity pumps, each rated at 2500 gpm at a developed head of 100 feet. The pumps are driven by 75 horsepower motors.

To cool the demineralized water, it is passed through the tubes of a two-pass heat exchanger, where the heat is transfered to service water. The heat exchanger has a heat transfer area of 7760 ft^2, made up of 563 tubes per pass, at a tube length of 35 feet.

Control and Station Air Systems

The compressed air system for the plant consists of separate, interconnected air supplies for the station and for control purposes. The station air system consists of a system of supply to hose valves for operating and maintenance requirements throughout the station. Control air is used primarily for instrument transmitters and air operated valves. The two air systems are cross connected so that compressed air may be supplied to the control air system in event of a compressor failure.

The control air system of the plant supplies air operated control devices at a header pressure of 115 psia and is reduced to 55 psia and 45 psia for supply to various drive units and instrument transmitters.

Control air is supplied by two single stage compressors rated at 250 cfm each at 115 psia which discharge through aftercoolers into two 34 $ft.^3$ air

receivers. Air from the receivers passes through a dryer and a bank of filters insuring a clean, dry, air supply to instrument transmitters and control devices.

The station air system supplies 165 psia air for distribution throughout the plant, terminating at hose connections. Station air is supplied by two single stage compressors rated at 200 cfm each and 165 psia, discharging through an aftercooler into two 34 $ft.^3$ air receivers. The use of two separate compressors and receivers for both the station air and control air systems is intended to allow for a more independent operation and flexibility in a plant of this size.

A detailed analysis of the control air and station air requirements has not been performed for this study. The systems and equipment described herein form an adequate basis for cost estimating purposes.

Cranes and Hoists

A single traveling bridge crane serves the reactor, mercury and steam turbine buildings. Its lifting capacity is based on handling the rotor of the low pressure steam turbine-generator, which requires about 150 tons. The bridge span is 130 feet, and the crane lift is sufficient to reach the lowest portion of the building. All heavy equipment coming into the building by rail may be handled by the crane. Its capacity is sufficient to allow removal of all components within the reactor primary shield except the reactor.

Instrumentation and Control

The requirements for instrumentation and control of the turbine systems are similar to those which would exist for turbine systems of a conventionally fueled power plant. Sensing devices, transmitters, controllers and actuators are necessary to control the levels, flow rates, pressures and temperatures of the steam and feed water systems and to provide safe, continuous operation of these systems at a rate which is required to meet the load demand during normal operation. In addition, controls, instrumentation and alarm systems are required for startup, shutdown and unusual operating conditions.

Instrumentation for the reactor system functions to monitor the reactor neutron flux and primary system pressure, temperature, level and flow rates, and to provide control and alarm signals to actuate the appropriate device or call for operator action when changes occur in the measured quantities, through either changes in load or malfunction of system components.

Control and instrumentation panels are located in the control room, for convenience of reading, recording and operating the most important quantities and components. Other auxiliary control panels or isolated instruments may be located at appropriate places in the plant: area radiation monitors, alarm or warning signals, hydrogen and seal oil controls for the generators, etc.

Information of a detailed nature, sufficient to form an accurate basis on which to estimate the cost of instrumentation and control systems for the plant, has not been developed in the present study. The cost estimate for these systems is derived from estimates of instrumentation and control costs for other plants with similar requirements.

Plant Utilities

The plant utilities include those systems that are provided for monitoring plant equipment, disposing of nonradioactive wastes, safety of personnel, protection of equipment, and for heating, ventilating and air conditioning the plant buildings. These systems do not differ appreciably from those provided for conventional plants, and are therefore not developed in detail.

Buildings and Site

Plans and sections of the plant buildings are shown on the general arrangement drawings, Exhibits 3, 4 and 5, and the property plat, Exhibit 2.

The reactor building and turbine building are adjacent to each other, the secondary shield wall forming a separation between the two from the grade floor to the main floor. The buildings are two-level structures with the grade floor of the turbine and reactor buildings at an elevation of one foot above grade, and the main floor at thirty-six feet above grade. The secondary shield wall extends to the height of the main floor and forms the walls of the lower part of the reactor and auxiliary building.

The steam turbine building and the upper level of the reactor and auxiliary buildings is a steel frame structure, with insulated metal panel siding. The arrangement of the equipment within the buildings is indicated on the general arrangement drawings.

A three level steel frame and insulated metal panel structure adjoining the turbine building houses the administrative offices, control room, switchgear, batteries, plant heating boiler and makeup water demineralization plant. Lockers, showers and toilets for plant personnel are also located in this building.

A 200 foot waste gas stack is provided for dispersal of plant ventilating air and waste gases from the various reactor equipment rooms.

The site conditions assumed for this plant design are those specified in recent Atomic Energy Commission design studies. The 1200 acre grass-covered site has level terrain and is located on the bank of a river. Grade level of the site is 40 feet above the river low water level and 20 feet above the high water level. An adequate source of raw water flow for the ultimate station capacity is assumed to be provided by the river with an average maximum temperature of 75 F and an average minimum temperature of 40 F.

Soil profiles for the site assume alluvial soil and rock fill to a depth of 8 feet, Brassfield limestone to a depth of 30 feet, blue weathered shale and fossiliferous Richmond limestone to a depth of 50 feet, and bedrock over a depth of 50 feet. Allowable soil bearing is assumed to be 6000 psf and rock bearing characteristics are assumed to be 18,000 psf and 15,000 psf for the Brassfield and Richmond strata, respectively.

Access is provided to the site by secondary roads and the river is navigable throughout the year for boats with drafts of up to six feet. A main line railroad is 5 miles distant from the plant and a spur track interconnection with this rail line is incorporated in the design.

C. Direct Power Cycle

Exhibit 6 is a composite flow diagram of the direct power cycle, showing fluid conditions for the design power output of 1000 Mwe gross. The concept is referred to as a direct power cycle because no intermediate circulating heat transfer fluid is used between the fuel salt and the boiling water of the steam cycle. A layer of inert salt is interposed between the feed water or steam on the tube side of the heat exchangers and the fuel salt on the shell side. This layer constitutes a buffer zone across which a significant temperature drop appears, reducing thermal stresses in the tubes. These stresses would result from the temperature difference between the fuel salt and the feed water or steam.

The fuel salt transfers its heat to boiling water and steam in a system of shell-and-tube heat exchangers, producing superheated steam at the turbine throttle at 2400 psia, 1000 F. The turbine-generator gross output is 1000 Mwe. Eight stages of feed water heating are provided in the feed water cycle.

Reactor Fuel System

The general arrangement of the reactor fuel system, consisting of the reactor and eight fuel loops, is indicated in Exhibits 8 and 9. Each fuel loop consists of a boiler, superheater, reheater and a vertical centrifugal pump, which provides the head necessary to circulate the fuel through the heat exchangers and the reactor. Fuel salt volume is conserved by mounting the pump casings on the reactor vessel and by minimizing the spacing between all components. The entire primary heat transfer system is located within a primary biological shield, which consists of a cylinder of ordinary concrete 6 feet thick, capped by a series of removable slabs amounting to a total thickness of 6 feet.

The heat exchangers are of a thimble tube vertical design, developed by ORNL, with steam or feed water flowing downward through the center tube of a bayonet tube complex, flowing upward through the thimble and leaving through nozzles in an intermediate steam chest. Each of the bayonet tube assemblies is centered in a second thimble containing inert salt, and fuel salt flows around the outside of the latter thimble. All materials in contact with salt are fabricated from INOR-8; those surfaces in contact

with steam or feed water are made of Inconel or INOR-8. Approximately 225 ft^3 of salt is held in the piping system. A detailed description of the heat exchangers is presented in Appendix A.

In order to drain the fuel salt, a shielded tank of noncritical geometry, and provisions for both removing decay heat and providing heat if required for melting the fuel, is necessary. To accommodate the fuel salt in the system, 90 cylindrical tanks, of about 2 feet inside diameter and 11 feet high are required. By locating these tanks in a trench below the reactor building grade floor and within the primary shield, gravity drain is possible, and the shielding requirements are simplified. The trench is shown in Exhibits 8 and 9.

The biological shield consists of a total thickness of 10 feet of ordinary concrete, subdivided into a primary shield 6 feet thick surrounding the reactor and the heat exchangers, and a secondary shield 4 feet thick which forms the wall of the reactor building and encloses the reactor auxiliary systems. The top of the primary shield is formed of 2 foot thick slabs of concrete, sectionalized to allow access to individual components within the shield, and overlapped to prevent streaming. The top shield has a total thickness of 6 feet and is supported by steel beams and columns. The reactor cavity is sealed by a welded liner of 1/4 inch steel plates. The traveling crane is used to remove the slabs as desired, and can handle all components within the shield. All reactor auxiliaries are intended to be located in the reactor building. The conceptual design of the systems was not included in the scope of the project, but they would include auxiliaries for processing the fuel salt to remove uranium and fission products, adding new fuel into the carrier salt, melting and charging the salt into the system, maintaining, storing and disposing of radioactive components, removal and disposal of liquid and gaseous radioactive wastes, removing decay heat on shutdown, and purifying the helium cover gas.

Because of the high liquidus temperature of the salt (887 F), a heat source is necessary to melt the salt and preheat the salt-bearing components and piping before adding it to the system. The heat source will also be energized upon shutting down in order to maintain the salt in a molten condition. The fuel-bearing salt would remain in a molten condition for some time after shutdown through the release of decay heat, but a prolonged shutdown could conceivably require the application of heat to prevent solidification in the reactor and other components of the primary system.

Several methods of removing decay heat are conceivable, all of which must remove the heat at temperatures of approximately 1000 F. The present study did not include the design of such a system.

The salt melting and heating system is designed on the basis of melting the salt in a small stream, charging it into the preheated primary system, and holding it at a temperature of approximately 1100 F until operation is initiated. Upon shutdown, the preheating system will be used to maintain the salt at a temperature of approximately 1100 F after the post-fission heat has decayed. All fuel drain lines, the storage tanks, and the fuel processing system will also require heat during certain periods of operation.

Electrically powered strip heaters, placed on the surface of all components which contain salt, provide the means of preheating the primary system and maintaining its temperature after shutdown. The heaters for the reactor vessel are designed to preheat the reactor vessel and the graphite core in a reasonable time, while those on all other components are designed to hold a temperature of 1100 F, with 100 F still air and approximately 6 inches of insulation. On this basis, the reactor requires about 500 kw of heat during preheating, and 100 kw to hold a temperature of 1100 F. A 150 kw electric furnace provides heat for melting the salt on initial charge. A maximum coincidental power of 2000 kw is estimated to be required when preheating and charging the salt into the system.

The cost estimate includes the electrical auxiliaries and cable to supply the necessary power, and the strip heaters on the heat exchangers, but does not include the salt melting furnace, or the heaters for the primary system, fuel purification system, salt charge piping and pumps, or the fuel drain tank system.

Steam System

The steam turbine-generators, main condensers, feed-water heaters, circulating water system, and associated buildings and structures comprise the steam system. The steam, feed water and circulating water conditions and piping sizes are shown on Exhibit 6, and the arrangement of the components and buildings is indicated in Exhibits 8 and 9.

Saturated steam is generated in the eight boilers at 2500 psia, and flows to the superheaters, where it is heated to provide superheated steam at 2400 psia and 1000 F at the turbine throttle. The steam flow rate is 6.882×10^6 lb/hr. at a gross turbine output of 1000 Mwe. The condensate passes through eight stages of feed water heating to provide feed water to the boilers at 2500 psia, 545 F.

The steam turbine consists of a cross-compound, six-flow reheat unit, with 40 inch exhaust blades, a 3600 rpm high pressure unit and 1800 rpm low pressure unit. At a throttle steam flow of 6.882×10^6 lb/hr., and a condenser pressure of 1.5" Hg, the turbine output is 1000 Mwe.

A separate condenser is provided for each low pressure casing. The overall surface area is 670,530 ft^2, with a tube length of 50 feet. Admiralty metal is used for the 1" x 18 BWG tubes. Condensate flows at a rate of 4.253×10^6 lb/hr. to six 1/6 capacity horizontal condensate pumps, each equipped with a 400 horsepower motor, and is discharged at 297 psia to the feed-water heaters. Flow control is performed by valves. Three parallel strings of heaters are required. The six low pressure units (A and B) are located in the condenser neck. Heater drains are pumped from heaters A and C. The two deaerating heaters are located on the roof of the turbine building.

The feed water is pumped by three horizontal centrifugal turbine-driven pumps, each capable of handling 1/3 of the total flow. Each turbine

delivers 10,000 horsepower at rated flow and pressure. A motor-driven pump is provided for startup. This pump is designed to deliver normal flow at 1/3 normal discharge pressure, and is driven by a 3500 horsepower motor. The condensate and feed water piping is fabricated from seamless carbon steel pipe, ASTM A106, Grade B, in accordance with the ASA Code for Pressure Piping B31.1, Section 1 using water velocities ranging from 3 fps to 10 fps. The main steam piping consists of a pair of 21½ inch O.D. x 3.12 inch wall hollow forged pipe, designed for 2520 psia and 1000 F at a steam velocity of 15,000 fpm. The pipe material is ASTM A355, Grade P11.

Valves are provided in accordance with normal steam power plant practice.

Feed water storage is provided by two 100,000 gallon tanks, located to the northwest of the main building.

Cooling water for the condensers is pumped from the crib house by six 1/6 capacity vertical circulating water pumps, each of which has a capacity of 119,300 gpm and a 1250 horsepower motor drive. The water flows to the condensers through six 78 inch steel pipes and, after leaving the condenser, is discharged through a concrete tunnel to a seal well, from where it flows to the river through a discharge flume. The total circulating water flow is 715,800 gpm, requiring seven 10 foot traveling screens and a stop log and bar grille system at the crib house.

The crib house is an outdoor structure built to accommodate the circulating water pumps and screens, the service water pumps, fire pump, screen wash pumps, and chlorination equipment.

<u>Electrical Systems</u>

At design steam flow and a condenser pressure of 1.5 inch HgA, the turbine-generator produces a gross power output of 1000 Mwe. The power output is assumed to be generated on a 55-45 basis by the high pressure and low pressure turbines, respectively, each of which drives a 24 kv generator with a liquid cooled stator and gas cooled rotor. The plant auxiliaries are supplied by a pair of auxiliary power transformers which are connected to the high pressure turbine-generator leads.

Excitation for the generators is provided by a pair of motor-driven exciters, a separate exciter being supplied for each generator. A motor-driven reserve exciter, equal in capacity to the larger of the two normal exciters, serves as a stand-by unit to provide excitation if either of the normal excitation systems fails. Isolated phase bus duct, of a 24 kv design and forced air cooled, connects each of the two generators to individual power transformers, where the generator voltage is stepped up to 345 kv for transmission through the station switchyard. The bus for the high pressure turbine is capable of carrying 15,000 amperes, while that for the low pressure turbine is rated at 13,000 amperes. The taps to the two auxiliary power transformers consist of 1200 ampere, 24 kv isolated phase bus. The two main power transformers are type FOA, with a voltage ratio of 24-345 kv, and power ratings of 476 and 560 Mva.

The plant auxiliaries have a maximum coincidental loading of 25,000 kw; this power combined with the losses in the station transformers results in a net station output of 971 Mwe.

Auxiliary power is normally supplied at 4160 volts by a pair of auxiliary power transformers, each of which is a type OA/FA, 24-4.16 kv unit with a maximum fan-cooled rating of 16 Mva. A reserve auxiliary transformer, equal in capacity to one of the two unit auxiliary transformers, and fed from the switchyard bus, serves as a standby unit in the event of failure of either of the two unit auxiliary transformers.

Each auxiliary transformer feeds one section of 4160 volt metal enclosed indoor type switchgear, with 3,000 ampere main air circuit breakers and 1200 ampere feeder air circuit breakers, all of which have a fault interrupting capability of 250 Mva. The loads fed at 4160 volts include all motors rated at 150 hp or more, and the auxiliary power transformers required for station lighting, 480 volt auxiliaries, and the fuel melting and preheating system.

The 480 volt auxiliaries are fed from two double ended sections of switchgear, with each section split into two buses. A tie circuit breaker automatically closes to pick up selected auxiliaries on either bus should its power supply fail. One set of switchgear feeds the reactor plant auxiliaries, and is supplied from two 500 kva dry type transformers. The second set handles the turbine plant auxiliary load through a pair of 1250 kva transformers. All transformers are throat connected to the switchgear and are located indoors.

Two 1250 kva transformers are also provided for the fuel preheating and melting systems, whose maximum power demand is approximately 2000 kw. These systems are supplied from a sectionalized 480 volt bus, with a tie circuit breaker between sections.

All auxiliary feeder cables consist of ozone resistant rubber insulated cable.

Smaller auxiliaries, of 30 horsepower or less, and those whose continuous operation is not considered vital to station operation, are fed from motor control centers in the vicinity of the load. Two 15 kva 480-120 volt transformers supply a 115 volt a-c control and instrumentation bus for each unit. An emergency supply to this bus is provided from a 15 kva inverter motor-generator set which is driven by the 250 volt battery.

One 250 volt battery and distribution center is provided. The 250 volt bus supplies the emergency equipment, emergency lighting, and the various d-c control devices.

A 277 volt fluorescent lighting system is used for general lighting in the plant buildings. Mercury vapor lights are used at the turbine room main floor. A 10 kva 480-120 volt transformer in the lighting distribution cubicle supplies convenience outlets, door lights and other 120 volt lighting systems. The emergency lighting system uses 125 volt d-c incandescent lamps to provide minimum illumination levels in strategic areas in the event of

failure of the normal lighting system.

Plant Auxiliary Systems

The plant auxiliaries include the following:

a) Service Water System

b) Shield Cooling System

c) Control and Station Air Systems

d) Cranes and Hoists

e) Instrumentation and Control

f) Plant Utilities

A summary of the characteristics of these systems is presented below.

Service Water System

The service water system supplies river water for cooling purposes throughout the plant, including the reactor auxiliaries and the turbine plant components. Information necessary to determine the requirements of the reactor plant was not developed in this investigation, and the estimate of the service water system was based on that provided for the aqueous homogeneous power reactor plant as reported in SL-1875.

The service water is supplied by three 15,000 gpm, half-capacity, vertical centrifugal pumps. Each pump is driven by a 1250 horsepower motor, and is located in the circulating water intake structure. During normal operation, two pumps supply the system with water at 100 psig, with the third pump employed as a stand-by. The main piping delivering service water to the plant is a 36 in. plate pipe with a 1/2 inch wall.

The service water pumps discharge into two twin basket backwashing type strainers. Conventional materials are used throughout the system on all pumps, piping, and strainers. Prior to use in the plant, the service water is chlorinated.

Shield Cooling System

The design of the shield cooling system is based on removing 1.5% of the reactor thermal power from the primary shield, using water cooled coils imbedded in the shield. Demineralized water is pumped through the coils and the tube side of a shell and tube heat exchanger, where the heat picked up in the shield is transferred to service water.

Assuming a temperature rise in the coils of 55 F above a 125 F minimum, a flow of 4650 gpm is required to remove 37.5 Mw of heat. A 3,000 gallon demineralized water storage tank is provided, and three half-capacity pumps, each rated at 2500 gpm at a developed head of 100 feet. The pumps are driven by 75 horsepower motors.

To cool the demineralized water, it is passed through the tubes of a two-pass heat exchanger, where the heat is transferred to service water. The heat exchanger has a heat transfer area of 7760 ft^2, made up of 563 tubes per pass, at a tube length of 35 feet.

Control and Station Air Systems

The compressed air system for the plant consists of separate, interconnected air supplies for the station and for control purposes. The station air system consists of a system of supply to hose valves for operating and maintenance requirements throughout the station. Control air is used primarily for instrument transmitters and air operated valves. The two air systems are cross connected so that compressed air may be supplied to the control air system in event of a compressor failure.

The control air system of the plant supplies air operated control devices at a header pressure of 115 psia and is reduced to 55 psia and 45 psia for supply to various drive units and instrument transmitters.

Control air is supplied by two single stage compressors rated at 250 cfm each at 115 psia which discharge through aftercoolers into two 34 ft^3 air receivers. Air from the receivers passes through a dryer and a bank of filters insuring a clean, dry, air supply to instrument transmitters and control devices.

The station air system supplies 165 psia air for distribution throughout the plant, terminating at hose connections. Station air is supplied by two single stage compressors rated at 200 cfm each and 165 psia, discharging through an aftercooler into two 34 ft^3 air receivers. The use of two separate compressors and receivers for both the station air and control air systems is intended to allow for a more independent operation and flexibility in a plant of this size.

A detailed analysis of the control air and station air requirements has not been performed for this study. The systems and equipment described herein form an adequate basis for cost estimating purposes.

Cranes and Hoists

A single traveling bridge crane serves the reactor, mercury and steam turbine buildings. Its lifting capacity is based on handling the rotor of the low pressure steam turbine generator, which requires about 150 tons. The bridge span is 130 feet, and the crane lift is sufficient to reach the lowest portion of the building. All heavy equipment coming into the building by rail may be handled by the crane. Its capacity is sufficient to allow removal of all components within the reactor primary shield except the reactor.

Instrumentation and Control

The requirements for instrumentation and control of the turbine systems are similar to those which would exist for turbine systems of a conventionally fueled power plant. Sensing devices, transmitters, controllers and

actuators are necessary to control the levels, flow rates, pressures and temperatures of the steam and feed water systems and to provide safe, continuous operation of these systems at a rate which is required to meet the load demand during normal operation. In addition, controls, instrumentation and alarm systems are required for startup, shutdown and unusual operating conditions.

Instrumentation for the reactor system functions to monitor the reactor neutron flux and primary system pressure, temperature, level and flow rates, and to provide control and alarm signals to actuate the appropriate device or call for operator action when changes occur in the measured quantities, through either changes in load or malfunction of system components.

Control and instrumentation panels are located in the control room, for convenience of reading, recording and operating the most important quantities and components. Other auxiliary control panels or isolated instruments may be located at appropriate places in the plant: area radiation monitors, alarm or warning signals, hydrogen and seal oil controls for the generators, etc.

Information of a detailed nature, sufficient to form an accurate basis for estimating the cost of instrumentation and control systems for the plant, has not been developed in the present study. The cost estimate for these systems is derived from estimates of instrumentation and control costs for other plants with similar requirements.

Plant Utilities

The plant utilities include those systems that are provided for monitoring plant equipment, disposing of nonradioactive wastes, safety of personnel, protection of equipment and for heating, ventilating and air conditioning the plant buildings. These systems do not differ appreciably from those provided for conventional plants, and are therefore not developed in detail.

Buildings and Site

Plans and sections of the plant buildings are shown on the general arrangement drawings, Exhibits 8 and 9, and the property plat, Exhibit 7.

The reactor building and turbine building are adjacent to each other, the secondary shield wall forming a separation between the two from the grade floor to the main floor. The buildings are two-level structures with the grade floor of the turbine and reactor buildings at an elevation of one foot above grade, and the main floor at 36 feet above grade. The secondary shield wall extends to the height of the main floor and forms the walls of the lower part of the reactor and auxiliary building.

The steam turbine building and the upper level of the reactor and auxiliary buildings is a steel frame structure, with insulated metal panel siding. The arrangement of the equipment within the buildings is indicated on the general arrangement drawings.

A three-level steel frame and insulated metal panel structure adjoining the turbine building houses the administrative offices, control room, switchgear, batteries, plant heating boiler and makeup water demineralization plant. Lockers, showers and toilets for plant personnel are also located in this building.

A 200 foot waste gas stack is provided for dispersal of plant ventilating air and waste gases from the various reactor and reactor equipment rooms.

The site conditions assumed for this plant design are those specified in recent Atomic Energy Commission design studies. The 1200 acre grass-covered site has level terrain and is located on the bank of a river. Grade level of the site is 40 feet above the river low water level and 20 feet above the high water level. An adequate source of raw water flow for the ultimate station capacity is assumed to be provided by the river with an average maximum temperature of 75 F and an average minimum temperature of 40 F.

Soil profiles for the site assume alluvial soil and rock fill to a depth of 8 feet, Brassfield limestone to a depth of 30 feet, blue weathered shale and fossiliferous Richmond limestone to a depth of 50 feet, and bedrock over a depth of 50 feet. Allowable soil bearing is assumed to be 6000 psf and rock bearing characteristics are assumed to be 18,000 psf and 15,000 psf for the Brassfield and Richmond strata, respectively.

Access is provided to the site by secondary roads and the river is navigable throughout the year for boats with drafts of up to 6 feet. A main line railroad is 5 miles distant from the plant and a spur track interconnection with this rail line is incorporated in the design.

D. Indirect Power Cycle

Heat released in the reactor of the indirect power cycle is transferred from the reactor fuel salt to an intermediate nonfuel bearing (inert) salt in eight shell-and-tube primary heat exchangers, as shown on the flow diagram, Exhibit 10. The inert salt is pumped through the shell side of sixteen steam superheaters and eight reheaters. This cycle was conceived by Oak Ridge National Laboratory.

About 33% of the superheated steam flows to the throttle of the turbine generator; the remainder is used in four Loeffler boilers, where it generates saturated steam by direct contact with the turbine feed water. The saturated steam flows to the superheaters and the cycle is repeated.

The steam turbine generator uses 2400 psia 1000 F steam in a reheat cycle with eight stages of feed water heating to produce a gross power output of approximately 1000 Mwe.

Reactor Fuel System

The flow diagram and general arrangements of the primary system are shown on Exhibits 10, 12, 13 and 14. Each fuel loop consists of a primary heat exchanger, pump and associated piping. The heat exchangers are vertical

shell-and-tube units and the pumps are of a vertical centrifugal type driven by motors. Fuel salt is pumped from the reactor through the shell side of the eight heat exchangers at a total flow rate of 162 ft^3 per second. The fuel salt temperature is reduced from 1300 F to 1100 F in transferring heat to the inert salt on the tube side of the heat exchangers, and the inert salt is pumped to a system of U-tube, U-shell superheaters and reheaters at a total flow rate of 248 ft^3 per second. The operating conditions of the fuel and inert salt systems are summarized in Table III.

TABLE III

Fuel and Inert Salt System Operating Conditions

Fuel Salt	
Flow Rate, total ft^3/sec.	162
Max/Min Temperature, F	1300/1100
Reactor Inlet/Outlet Pressure, psia	100/30
Thermal Power, Mw	2500
System Materials	INOR-8
No. Primary Heat Exchangers	8
Pumping Power, total BHP	11,200
Inert Salt	
Flow Rate, total ft^3 per sec.	248
Max/Min Temperature, F	1100/950
Heat Exchanger Inlet Pressure, psia	350
System Materials	INOR-8
No. Superheaters/Reheaters	16/8
Superheater Outlet Steam Pressure/Temperature, psia/F	2465/1000
Superheater Steam Flow Rate, total lb/hr	21.08 x 106
Superheater Salt Flow Rate, total ft^3 per sec.	217.3
Reheater Outlet Steam Pressure/Temperature, psia/F	430/1000
Reheater Steam Flow Rate, total lb/hr	5.132×10^6
Reheater Salt Flow Rate, total ft^3/sec.	30.72
Maximum Salt Velocity in Piping, ft. per sec.	40

Oak Ridge National Laboratory developed the conceptual design of the primary system components, the superheaters and the reheaters.

The primary heat exchangers are vertical U-tube units, with fuel salt on the shell side and inert salt on the tube side. Salt volume is minimized on both the shell and tube sides by designing the inert salt headers for minimum volume and by providing filler pieces between the tubes on the shell side of the heat exchanger. All materials in the primary system are fabricated of INOR-8. A detailed description of the primary system components is presented in Appendix A.

The primary system, including the reactor, fuel pumps, primary heat exchangers, piping and fuel drain tanks, are located within a sealed primary shield structure which consists of a capped cylinder of ordinary concrete 6 feet thick. The cap consists of segments of concrete, supported on steel beams and columns and designed to be removed by the overhead traveling crane when access to the interior of the shield is desired.

A breakdown of the estimated fuel salt volume of the primary system is as follows:

Reactor		1265 ft^3
Primary Heat Exchangers		496 ft^3
Piping		260 ft^3
	Total	2021 ft^3

In order to drain the fuel salt, a shielded tank of noncritical geometry and provisions for both removing decay heat and providing heat if required for melting the fuel, is necessary. To accommodate the fuel salt in the system, 90 cylindrical tanks of about 2 feet inside diameter and 11 feet high are required. By locating these tanks in a trench below the reactor building grade floor and within the primary shield, gravity drain is possible, and the shielding requirements are simplified. The trench is shown in Exhibits 13 and 14.

The biological shield consists of a total thickness of 10 feet or ordinary concrete, subdivided into a sealed primary shield 6 feet thick surrounding the reactor and the primary heat exchangers, and a secondary shield 4 feet thick which forms the wall of the reactor building and encloses the reactor auxiliary systems and the superheaters and reheaters. All reactor auxiliaries are intended to be located in the reactor building. The conceptual design of the systems was not included in the scope of the project, but they would include auxiliaries for processing the fuel salt to remove uranium and fission products, adding new fuel into the carrier salt, melting and charging the salt into the system, maintaining, storing and disposing of radioactive components, removing and disposing of liquid and gaseous radioactive wastes, removing decay heat on shutdown and purifying the helium cover gas

Because of the high liquidus temperature of the salt (887 F), a heat source is necessary to melt the salt and preheat the salt-bearing components and piping of both the primary and intermediate salt systems before adding it to the systems. The heat source will also be energized upon shutting down in order to maintain the salt in a molten condition. The fuel-bearing salt would remain in a molten condition for some time after shutdown through the release of decay heat, but a prolonged shutdown could conceivably require the application of heat to prevent solidification in the reactor and other components of the primary system.

Several methods of removing decay heat are conceivable, all of which must remove the heat at temperatures of approximately 1000 F. The present study did not include the design of such a system.

The salt melting and heating system is designed on the basis of melting either the fuel or inert salt in a small stream, charging it into the preheated system and holding it at a temperature of approximately 1100 F until operation is initiated. Upon shutdown, the preheating system will be used to maintain the salt at a temperature of approximately 1100 F after the post-fission heat has decayed. All salt drain lines, the storage tanks, and the salt processing systems will also require heat during certain periods of operation.

Electrically powered strip heaters, placed on the surface of all components which contain salt, provide the means of preheating the primary and intermediate systems and maintaining the proper temperature after shutdown. The heaters for the reactor vessel are designed to preheat the reactor vessel and the graphite core in a reasonable time, while those on all other components are designed to hold a temperature of 1100 F, with 100 F still air and approximately 6 inches of insulation. On this basis, the reactor requires about 500 kw of heat during preheating, and 100 kw to hold a temperature of 1100 F. A 150 kw electric furnace provides heat for melting the salt on initial charge. A maximum coincidental power of 2000 kw is estimated to be required when preheating and charging the salt into the system.

The cost estimate includes the electrical auxiliaries and cable to supply the necessary power, and the strip heaters on the heat exchangers, but does not include the salt melting furnace, or the heaters for the primary system, salt purification systems, salt charge piping and pumps, or the salt drain tank systems.

Intermediate Coolant System

The heat of the fuel salt is transferred to the inert salt in the primary heat exchangers, as shown on Exhibit 10. The operating conditions of the inert salt system are indicated in Table III. Sixteen shell-and-tube vertical heat exchangers serve as superheaters for the main steam to the Loeffler boilers, deriving their heat from the inert salt, which flows on the shell side. Eight heat exchangers, of a design similar to the superheaters, also receive inert salt on their shell sides and transfer the heat to the turbine cold reheat steam. The eight vertical centrifugal pumps circulate the inert salt between the primary heat exchangers and the superheaters and reheaters at a total flow rate of 248 ft^3 per second, and between temperature limits of 1100 F and 950 F. All surfaces in contact with the inert salt are fabricated of INOR-8. A detailed description of the components in the inert salt system as developed by Oak Ridge National Laboratory is included in the Appendix.

The activation products of the inert salt are biologically harmful, requiring a shield to attenuate radiation from the salt systems during operation. The superheaters, reheaters, pumps and piping are therefore enclosed in a shielded area with a wall of ordinary concrete 4 feet thick. This wall also forms a secondary shield around the reactor building, as shown on the general arrangement drawings. The inert salt system is located below the main floor of the building in order to allow the use of the main floor as

a top shield. Removable sections of concrete are provided in the main floor to allow access to the reheaters, superheaters and other components when required for maintenance, inspection or repair.

Electrical strip heaters are located beneath the insulation of all salt-bearing components and piping, as described in the previous section.

Drain tanks, with sufficient capacity for two inert salt loops, are located within the secondary shield. The drain system consists of two INOR-8 tanks, with electrical strip heaters to maintain the salt in a molten condition, and a total capacity of 1400 ft^3. The necessary piping and valves are provided for pumping the salt to or from the drain tanks under pressure from helium gas, as described in Appendix A. Since it is not anticipated that emergency drainage will be required, the tanks need not be located for gravity drainage, and need not be kept in a preheated condition.

The design of the salt processing and purification system was not included in the present study.

Steam System

The source of steam in the indirect power cycle is the Loeffler boiler, four of which are provided as shown on the flow diagram, Exhibit 10. These boilers generate steam by direct contact between the steam from the superheaters and the feed water from the turbine cycle. Four steam compressors circulate the saturated steam from the boilers through the superheaters of the inert salt system, providing steam at 2400 psia, 1000 F at the turbine throttle and at the superheated steam inlet of the Loeffler boilers.

For purposes of categorization, the Loeffler boilers, steam circulators, main turbine, main condensers, feed-water heaters, circulating water system and associated piping and pumps are considered to comprise the steam system. The steam feed water and circulating water conditions and piping sizes are shown on Exhibit 10. A summary of the operating characteristics of the steam system appears in Table IV.

The Loeffler boilers consist of four cylindrical drums with an inside diameter of about 72 inches, with distribution pipes for superheated steam and feed water located on the vertical centerline and below the horizontal centerline of each drum. Conventional cyclone steam separators, located somewhat above the horizontal center line and arranged in four parallel rows along the inside of the drum, separate the steam from the boiling water. A system of scrubber type steam driers occupies the upper part of the drum. In operation, superheated steam and feed water are mixed as they leave the two distribution pipes and boiling occurs. The boiling water is guided by internal baffles through the cyclone separators where the water is removed by centrifugal force. Steam and a small amount of moisture flow through the scrubbers, where the steam is dried to approximately 99.7% quality. The drums are fabricated of carbon steel and are designed for a pressure of 2625 psia. A wall thickness of 7 inches is required for an inside diameter of 72 inches and a temperature of 650 F. Each drum is about 100 feet in length and has hemiellipsoidal heads.

The steam circulators are single-stage axial compressors suitable for a steam flow of 5.27 x 10^6 lb/hr at a discharge pressure of 2480 psia. The circulators are driven by steam turbines, using steam from the cold reheat lines of the main turbine-generator. At design conditions, each circulator requires a power input of 4750 BHP. Steam from the turbines is returned to the cycle through the feed-water heaters. One circulator has a motor drive suitable for full flow at design pressure to be used during start-up and shutdown. An oil-fired package boiler, designed for a saturated steam flow of 50,000 lb/hr at 300 psia, is provided for startup purposes.

The system is designed to operate as four 1/4 capacity units; each unit consists of one Loeffler boiler, one steam circulator and four superheaters. Valves are located according to this philospphy. Interconnections between various units are not provided except at the inlet to the boilers and the discharge from the superheaters.

TABLE IV

Characteristics Of Loeffler Boiler Steam System

Gross Power Output, Mwe	1,000
Throttle Steam Pressure/Temperature, psia/F	2,400/1,000
Throttle Steam Flow, 10^6 lb/hr	6.884
Number of Loeffler Boilers	4
Conditions for Loeffler Boilers, total	
Superheated Steam Press./Temp., psia/F	2,400/1,000
Inlet Superheated Steam Flow, 10^6 lb/hr	14.20
Outlet Saturated Steam Press./Temp., psia/F	2,400/636
Saturated Steam Flow Rate, 10^6 lb/hr	21.08
Feed Water Press./Temp., psia/F	2,450/545
Feed Water Flow Rate, 10^6 lb/hr	6.884
No. Steam Circulators	4
Power Required by Circulators, total BHP	19,000

The condensate passes through 8 stages of feed-water heating to provide feed water to the boilers at 2500 psia, 545 F.

The steam turbine consists of a cross compound, six-flow reheat unit, with 40 inch exhaust blades, a 3600 rpm high pressure unit and 1800 rpm low pressure unit. At a throttle steam flow of 6.882 x 10^6 lb/hr, and a condenser pressure of 1.5" Hg., the turbine output is 1000 Mwe.

A separate condenser is provided for each low pressure casing. The overall surface area is 670,530 ft^2, with a tube length of 50 feet. Admiralty metal

is used for the 1" x 18 BWG tubes. Condensate flows at a rate of 4.253×10^6 lb/hr to six 1/6 capacity horizontal condensate pumps, each equipped with a 400 horsepower motor, and is discharged at 297 psia to the feed-water heaters. Flow control is performed by valves. Three parallel strings of heaters are required. The six low pressure units (A and B) are located in the condenser neck. Heater drains are pumped from heaters A and C. The two deaerating heaters are located on the roof of the turbine building.

The feed water is pumped by three horizontal centrifugal turbine driven pumps, each capable of handling 1/3 of the total flow. Each turbine delivers 10,000 horsepower at rated flow and pressure. A motor-driven pump is provided for startup. This pump is designed to deliver normal flow at 1/3 normal discharge pressure, and is driven by a 3500 horsepower motor. The condensate and feed-water piping is fabricated from seamless carbon steel pipe, ASTM A106, Grade B, in accordance with the ASA Code for Pressure Piping B31.1, Section 1, using water velocities ranging from 3 fps to 10 fps. The main steam piping consists of a pair of 21-1/2 inch O.D. x 3.12 inch wall hollow forged pipe, designed for 2520 psia and 1000 F at a steam velocity of 15,000 fpm. The pipe material is ASTM A335, Grade P11.

Valves are provided in accordance with normal steam power plant practice.

Feed-water storage is provided by two 100,000 gallon tanks, located to the northwest of the building.

Cooling water for the condensers is pumped from the crib house by six 1/6 capacity vertical circulating water pumps, each of which has a capacity of 119,300 gpm and a 1250 horsepower motor drive. The water flows to the condensers through six 78 inch steel pipes and, after leaving the condenser, is discharged through a concrete tunnel to a seal well, from where it flows to the river through a discharge flume. The total circulating water flow is 715,800 gpm, requiring seven 10 foot traveling screens and a stop log and bar grille system at the crib house.

The crib house is an outdoor structure built to accommodate the circulating water pumps and screens, the service water pumps, fire pump, screen wash pumps and chlorination equipment.

Electrical Systems

At design steam flow and a condenser pressure of 1.5 inches HgA, the turbine generator produces a gross power output of 1000 Mwe. The power output is assumed to be generated on a 55-45 basis by the high pressure and low pressure turbines, respectively, each of which drives a 24 kv generator with a liquid cooled stator and gas cooled rotor. The plant auxiliaries are supplied by a pair of auxiliary power transformers which are connected to the high pressure turbine-generator leads.

Excitation for the generators is provided by a pair of motor-driven exciters, a separate exciter being supplied for each generator. A motor-driven reserve

exciter, equal in capacity to the larger of the two normal exciters, serves as a standby unit to provide excitation if either of the normal excitation systems fails. Isolated phase bus duct, of a 24 kv design and forced air cooled, connects each of the two generators to individual power transformers, where the generator voltage is stepped up to 345 kv for transmission through the station switchyard. The bus for the high pressure turbine is capable of carrying 15,000 amperes, while that for the low pressure turbine is rated at 13,000 amperes. The taps to the two auxiliary power transformers consist of 1200 ampere, 24 kv isolated phase bus. The two main power transformers are type FOA, with a voltage ratio of 24-345 kv, and power ratings of 476 and 532 Mva.

The plant auxiliaries have a maximum coincidental loading of 41,000 kw; this power combined with the losses in the station transformers results in a net station output of 955 Mwe.

Auxiliary power is normally supplied at 4160 volts by a pair of auxiliary power transformers, each of which is a type OA/FA, 24-4.16 kv unit with a maximum fan-cooled rating of 25 Mva. A reserve auxiliary transformer, equal in capacity to one of the two unit auxiliary transformers, and fed from the switchyard bus, serves as a standby unit in the event of failure of either of the two unit auxiliary transformers.

Each auxiliary transformer feeds two sections of 4160 volt metal enclosed indoor type switchgear, with 2,000 ampere main air circuit breakers and 1200 ampere feeder air circuit breakers, all of which have a fault interrupting capability of 350 Mva. The loads fed at 4160 volts include all motors rated at 150 horsepower or more, and the auxiliary power transformers required for station lighting, 480 volt auxiliaries, and the fuel melting and preheating system.

The 480 volt auxiliaries are fed from two double ended sections of switchgear, with each section split into two buses. A tie circuit breaker automatically closes to pick up selected auxiliaries on either bus should its power supply fail. One set of switchgear feeds the reactor plant auxiliaries, and is supplied from two 500 kva dry type transformers. The second set handles the turbine plant auxiliary load through a pair of 1250 kva transformers. All transformers are throat connected to the switchgear and are located indoors.

Two 1250 kva transformers are also provided for the fuel preheating and melting systems, whose maximum power demand is approximately 2000 kw. These systems are supplied from a sectionalized 480 volt bus, with a tie circuit breaker between sections.

All auxiliary feeder cables consist of ozone resistant rubber insulated cable.

Smaller auxiliaries, of 30 horsepower or less, and those whose continuous operation is not considered vital to station operation, are fed from motor control centers in the vicinity of the load. Two 15 kva 480-120 volt transformers supply a 115 volt a-c control and instrumentation bus for each unit. An emergency supply to this bus is provided from a 15 kva inverter motor-

generator set which is driven by the unit 250 volt battery.

One 250 volt battery and distribution center is provided. The 250 volt bus supplies the emergency equipment, emergency lighting and the various d-c control devices.

A 277 volt fluorescent lighting system is used for general lighting in the plant buildings. Mercury vapor lights are used at the turbine room main floor. A 10 kva 480-120 volt transformer in the lighting distribution cubicle supplies convenience outlets, door lights and other 120 volt lighting systems. The emergency lighting system uses 125 volt d-c incandescent lamps to provide minimum illumination levels in strategic areas in the event of failure of the normal lighting system.

Plant Auxiliary Systems

The plant auxiliaries include the following:

a) Service Water System

b) Shield Cooling System

c) Control and Station Air Systems

d) Cranes and Hoists

e) Instrumentation and Control

f) Plant Utilities

A summary of the characteristics of these systems is presented below.

Service Water System

The service water system supplies river water for cooling purposes throughout the plant, including the reactor auxiliaries and the turbine plant components. Information necessary to determine the requirements of the reactor plant was not developed in this investigation, and the estimate of the service water system was based on that provided for the aqueous homogeneous power reactor plant as reported in SL-1875.

The service water is supplied by three 15,000 gpm, half-capacity, vertical centrifugal pumps. Each pump is driven by a 1250 horsepower motor, and is located in the circulating water intake structure. During normal operation two pumps supply the system with water at 100 psig, with the third pump employed as a standby. The main piping delivering service water to the plant is a 36 inch plate pipe with a 1/2 inch wall.

The service water pumps discharge into two twin basket backwashing type strainers. Conventional materials are used throughout the system on all pumps, piping and strainers. Prior to use in the plant, the service water is chlorinated.

Shield Cooling System

The design of the shield cooling system is based on removing 1.5% of the reactor thermal power from the primary shield, using water cooled coils imbedded in the shield. Demineralized water is pumped through the coils and the tube side of a shell and tube heat exchanger, where the heat picked up in the shield is transferred to service water.

Assuming a temperature rise in the coils of 55 F above a 125 F minimum, a flow of 4650 gpm is required to remove 37.5 Mw of heat. A 3,000 gallon demineralized water storage tank is provided, and three half-capacity pumps, each rated at 2500 gpm at a developed head of 100 feet. The pumps are driven by 75 horsepower motors.

To cool the demineralized water, it is passed through the tubes of a two-pass heat exchanger, where the heat is transferred to service water. The heat exchanger has a heat transfer area of 7760 ft^2, made up of 563 tubes per pass, at a tube length of 35 feet.

Control and Station Air Systems

The compressed air system for the plant consists of separate, interconnected air supplies for the station and for control purposes. The station air system consists of a system of supply to hose valves for operating and maintenance requirements throughout the station. Control air is used primarily for instrument transmitters and air operated valves. The two air systems are cross connected so that compressed air may be supplied to the control air system in event of a compressor failure.

The control air system of the plant supplies air operated control devices at a header pressure of 115 psia and is reduced to 55 psia and 45 psia for supply to various drive units and instrument transmitters.

Control air is supplied by two single stage compressors rated at 250 cfm each at 115 psia which discharge through aftercoolers into two 34 ft^3 air receivers. Air from the receivers passes through a dryer and a bank of filters insuring a clean, dry air supply to instrument transmitters and control devices.

The station air system supplies 165 psia air for distribution throughout the plant, terminating at hose connections. Station air is supplied by two single stage compressors rated at 200 cfm each and 165 psia, discharging through an aftercooler into two 34 ft^3 air receivers. The use of two separate compressors and receivers for both the station air and control air systems is intended to allow for a more independent operation and flexibility in a plant of this size.

A detailed analysis of the control air and station air requirements has not been performed for this study. The systems and equipment described herein form an adequate basis for cost estimating purposes.

Cranes and Hoists

A single traveling bridge crane serves the reactor, mercury and steam turbine buildings. Its lifting capacity is based on handling the rotor of the low pressure steam turbine-generator, which requires about 150 tons. The bridge span is 130 feet, and the crane lift is sufficient to reach the lowest portion of the building. All heavy equipment coming into the building by rail may be handled by the crane. Its capacity is sufficient to allow removal of all components within the reactor primary shield except the reactor.

Instrumentation and Control

The requirements for instrumentation and control of the turbine systems are similar to those which would exist for turbine systems of a conventionally fueled power plant. Sensing devices, transmitters, controllers and actuators are necessary to control the levels, flow rates, pressures and temperatures of the steam and feed water systems and to provide safe, continuous operation of these systems at a rate which is required to meet the load demand during normal operation. In addition, controls, instrumentation and alarm systems are required for startup, shutdown and unusual operating conditions.

Instrumentation for the reactor system functions to monitor the reactor neutron flux and primary system pressure, temperature, level and flow rates, and to provide control and alarm signals to actuate the appropriate device or call for operator action when changes occur in the measured quantities, through either changes in load or malfunction of system components.

Control and instrumentation panels are located in the control room, for convenience of reading, recording and operating the most important quantities and components. Other auxiliary control panels or isolated instruments may be located at appropriate places in the plant; area radiation monitors, alarm or warning signals, hydrogen and seal oil controls for the generators, etc.

Information of a detailed nature, sufficient to estimate the cost of instrumentation and control systems for the plant, has not been developed in the present study. The cost estimate for these systems is derived from estimates of instrumentation and control costs for other plants with similar requirements.

Plant Utilities

The plant utilities include those systems that are provided for monitoring plant equipment, disposing of nonradioactive wastes, safety of personnel, protection of equipment and for heating, ventilating and air conditioning the plant buildings. These systems do not differ appreciably from those provided for conventional plants, and are therefore not developed in detail.

Buildings and Site

Plans and sections of the plant buildings are shown on the general arrangement drawings, Exhibits 12, 13 and 14, and the property plat, Exhibit 11.

The reactor building and turbine building are adjacent to each other, the secondary shield wall forming a separation between the two from the grade floor to the main floor. The buildings are two-level structures with the grade floor of the turbine and reactor buildings at an elevation of one foot above grade, and the main floor at 36 feet above grade. The secondary shield wall extends to the height of the main floor and forms the walls of the lower part of the reactor and auxiliary building.

The steam turbine building and the upper level of the reactor and auxiliary buildings is a steel frame structure, with insulated metal panel siding. The arrangement of the equipment within the buildings is indicated on the general arrangement drawings.

A three-level steel frame and insulated metal panel structure adjoining the turbine building houses the administrative offices, control room, switchgear, batteries, plant heating boiler and makeup water demineralization plant. Lockers, showers and toilets for plant personnel are also located in this building.

A 200 foot waste gas stack is provided for dispersal of plant ventilating air and waste gases from the various reactor and reactor equipment rooms.

The site conditions assumed for this plant design are those specified in recent Atomic Energy Commission design studies. The 1200 acre grass-covered site has level terrain and is located on the bank of a river. Grade level of the site is 40 feet above the river low water level and 20 feet above the high water level. An adequate source of raw water flow for the ultimate station capacity is assumed to be provided by the river with an average maximum temperature of 75 F and an average minimum temperature of 40 F.

Soil profiles for the site assume alluvial soil and rock fill to a depth of 8 feet, Brassfield limestone to a depth of 30 feet, blue weathered shale and fossiliferous Richmond limestone to a depth of 50 feet and bedrock over a depth of 50 feet. Allowable soil bearing is assumed to be 6000 psf and rock bearing characteristics are assumed to be 18,000 psf and 15,000 psf for the Brassfield and Richmond strata, respectively.

Access is provided to the site by secondary roads and the river is navigable throughout the year for boats with drafts of up to six feet. A main line railroad is 5 miles distant from the plant and a spur track interconnection with this rail line is incorporated in the design.

IV. CAPITAL COST ESTIMATE

The capital investment required for the three concepts which are considered in this report has been estimated on the basis of preliminary designs and material quantities prepared by Oak Ridge National Laboratory and Sargent & Lundy. The heat cycles and estimating data for the primary and intermediate system components were prepared by Oak Ridge National Laboratory, and are described in Appendix A. Sargent & Lundy prepared the design of the turbine plant and the cost estimate, using accounting procedures specified by the U. S. Atomic Energy Commission in the Nuclear Power Plant Cost Evaluation Handbook.

The estimate does not include the reactor, primary system pumps nor any of the reactor auxiliaries, but does include all systems necessary to convert the reactor heat into electrical power. The indirect costs, which are derived as a percentage of total direct cost when using the procedures prescribed by the Cost Evaluation Handbook are omitted in this study, since the total direct cost of the plant is not known. Therefore, the estimated investment, which is summarized in Exhibit 15, includes only the direct cost of material and labor to erect the power generating system and the associated buildings and structures.

The details of the cost estimate for each concept are presented in Exhibits 16, 17 and 18.

SARGENT & LUNDY

BY C. A. Hatstat

EXHIBIT I
SL-1954

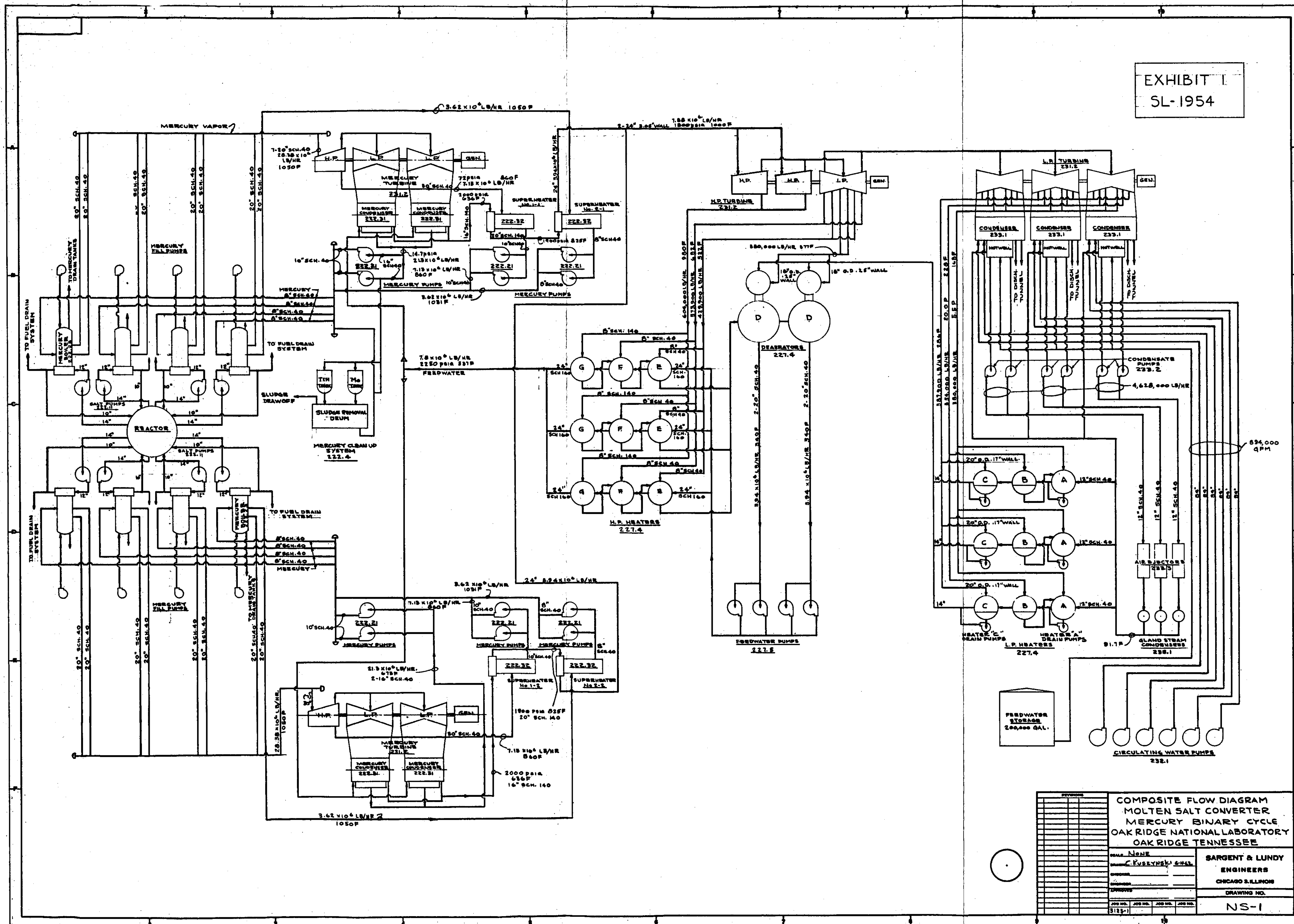
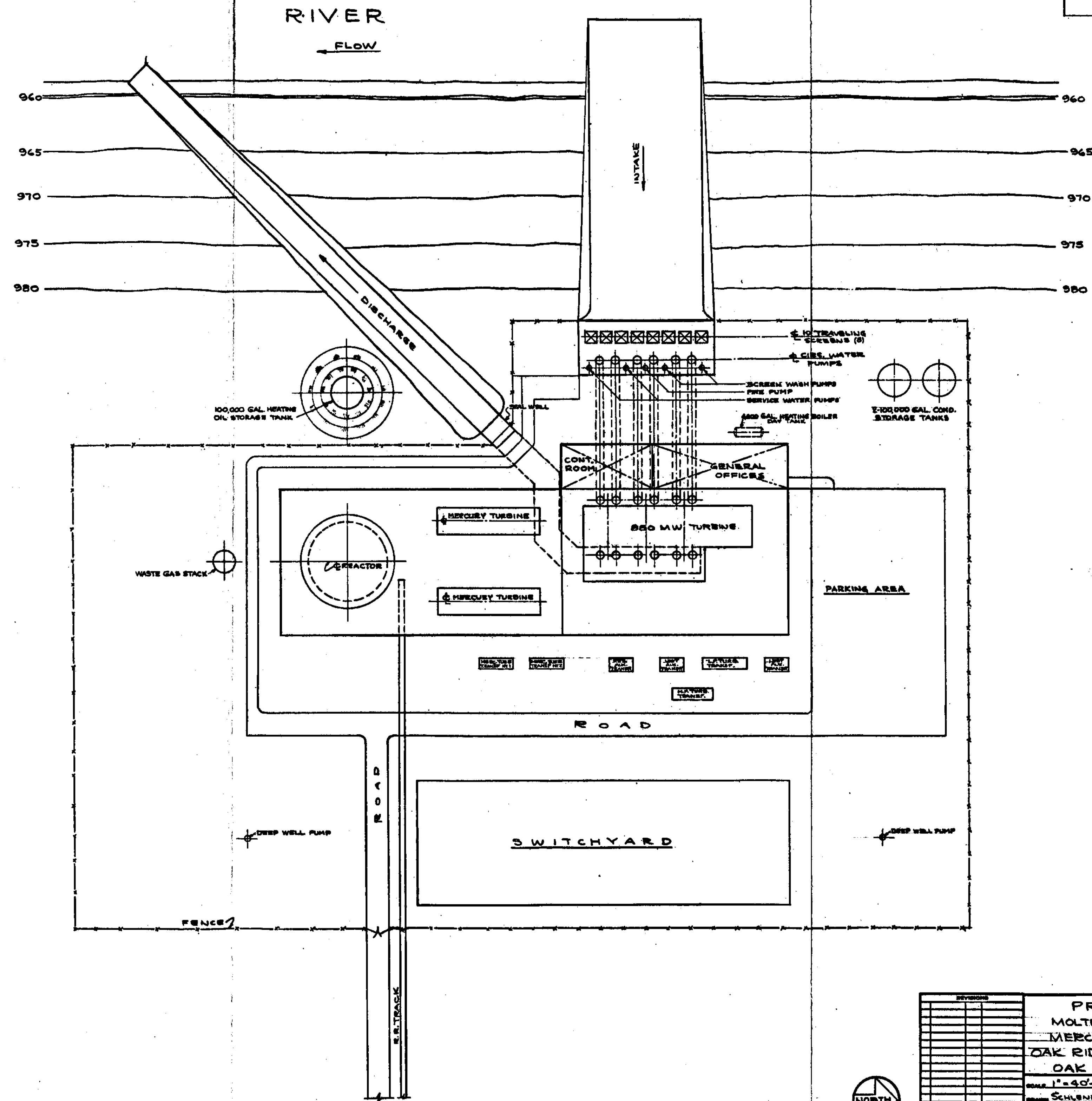


EXHIBIT 2
SL-1954



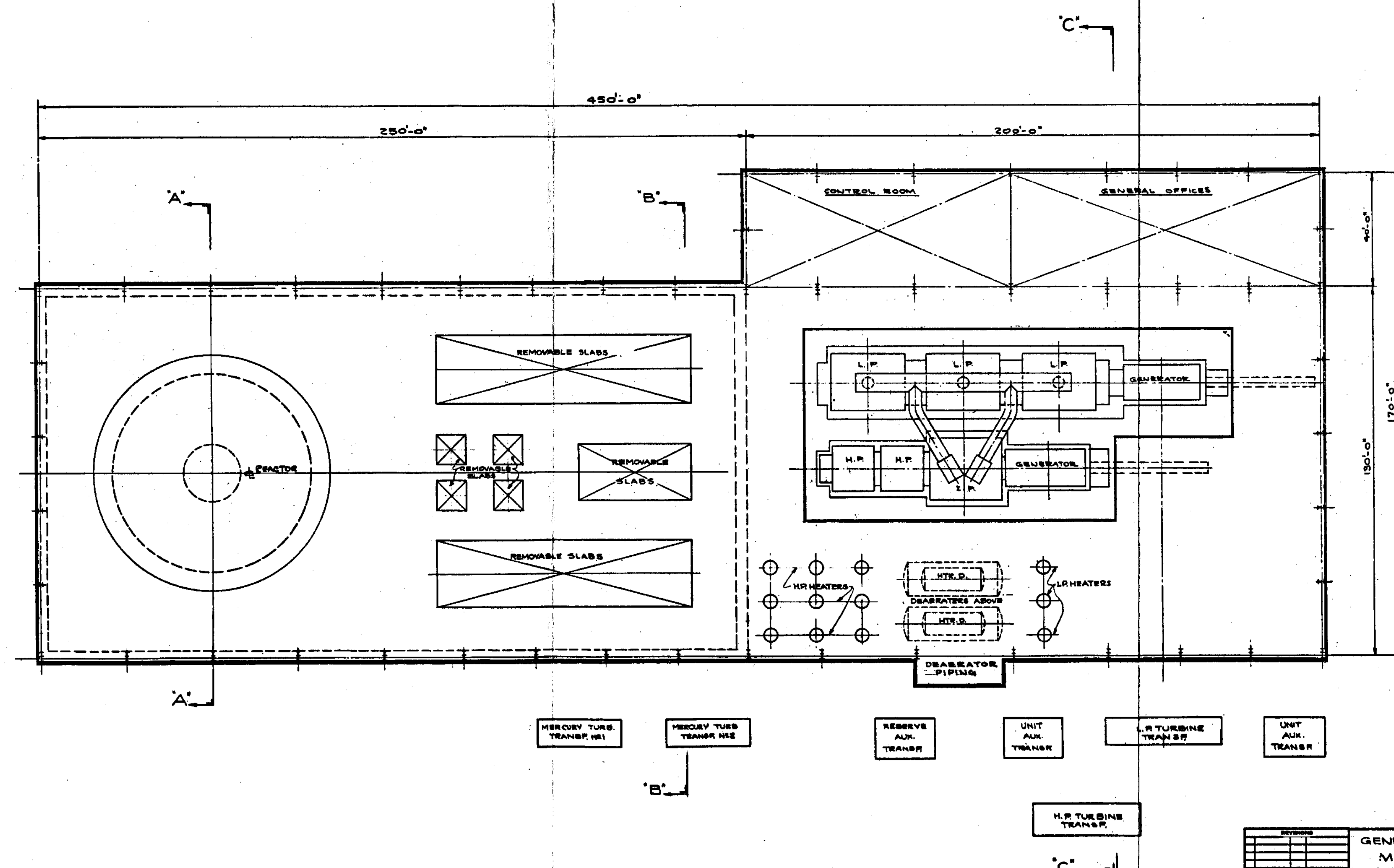
PROPERTY PLAT
MOLTEN SALT CONVERTER
MERCURY BINARY CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

SCALE 1" = 40'-0"
DRAWN Schlenkert 6-11-62
CHECKED
ENGINEER
APPROVED
JOB NO. 3123-1

SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO.
NS-2

EXHIBIT 3
SL-1954



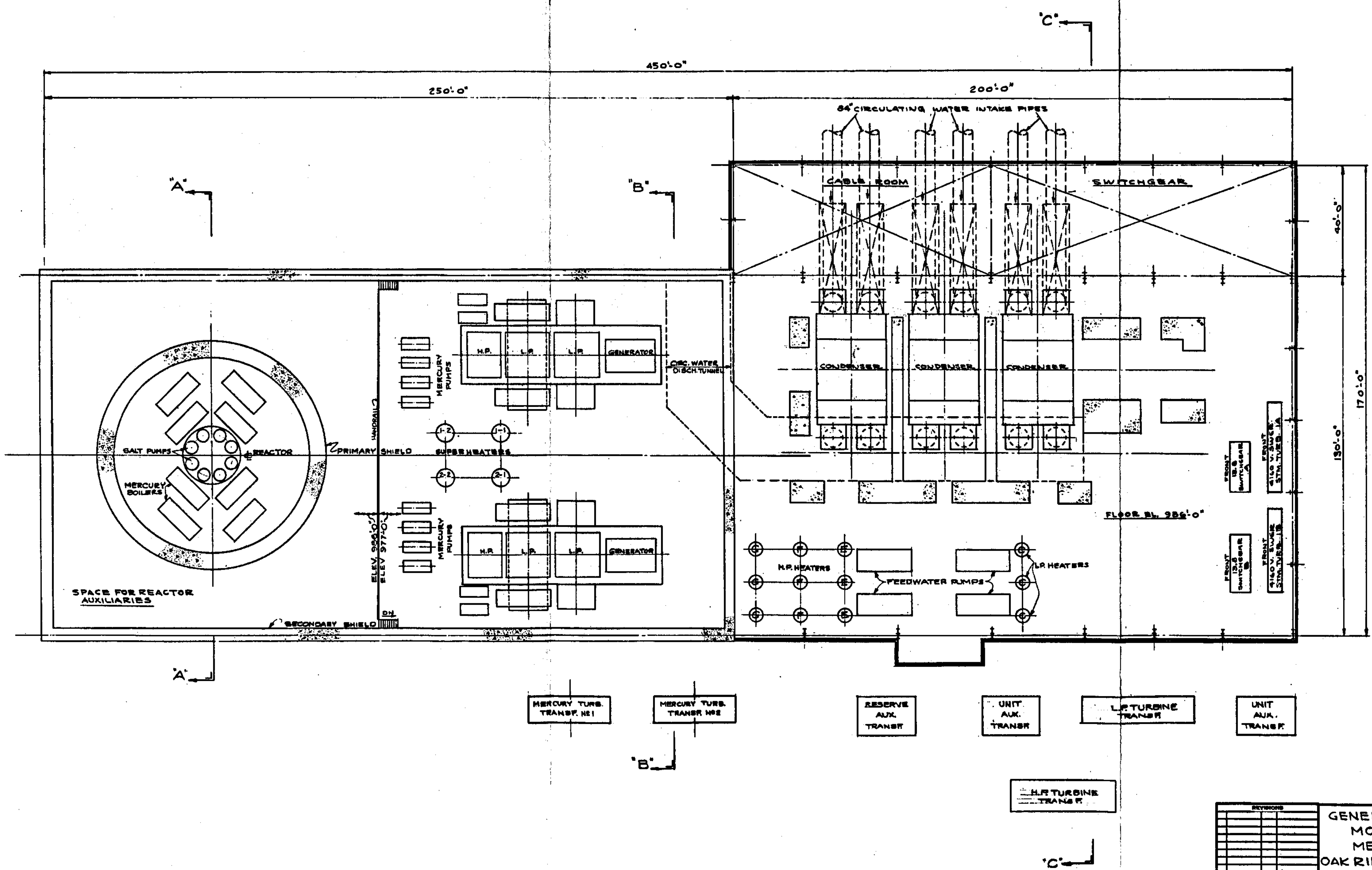
GENERAL ARRANGEMENT PLAN
MOLTEN SALT CONVERTER
MERCURY BINARY CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

SCALE 1/16" = 1'-0"
DRAWN SCHLENKERT 6-11-62
CHECKED
ENGINEER
APPROVED
JOB NO. 3123-1

SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO.
NS-3

EXHIBIT 4
SL-1954



GENERAL ARRANGEMENT PLAN
MOLTEN SALT CONVERTER
MERCURY BINARY CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

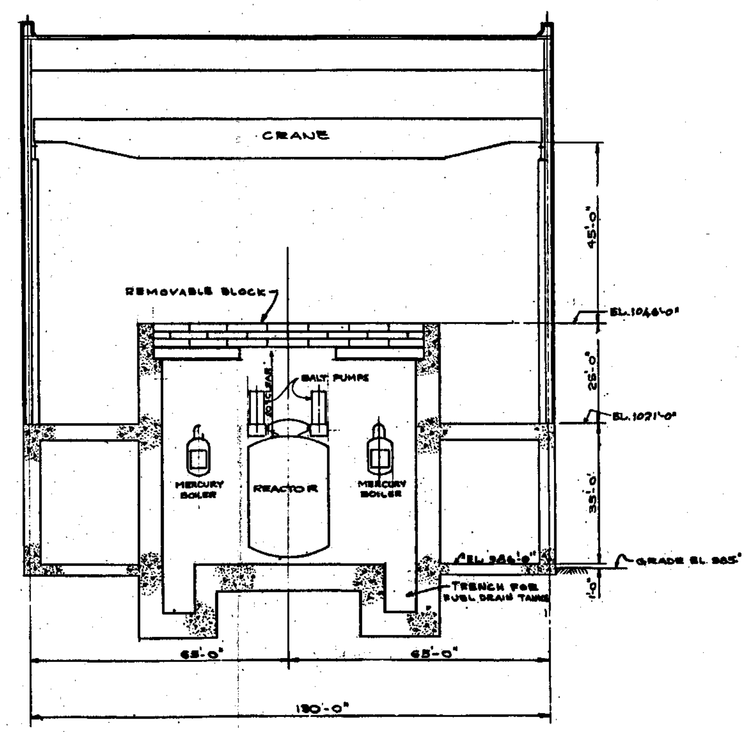
SCALE 1/16" = 1'-0"
DRAWN SCHLENKERT 6-11-62
CHECKED
ENGINEER
APPROVED

JOB NO.	JOB NO.	JOB NO.	JOB NO.
3123-1			

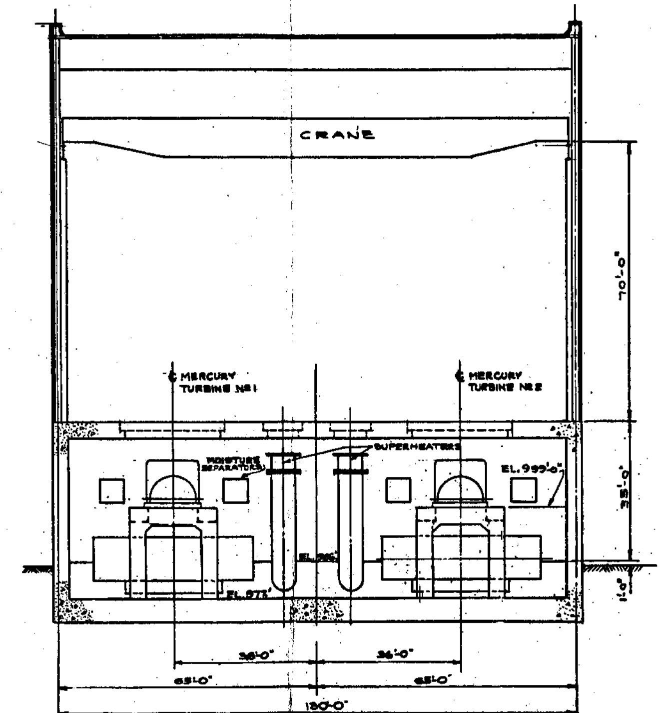
SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO.
NS-4

EXHIBIT 5
SL-1954



SECTION "A-A"



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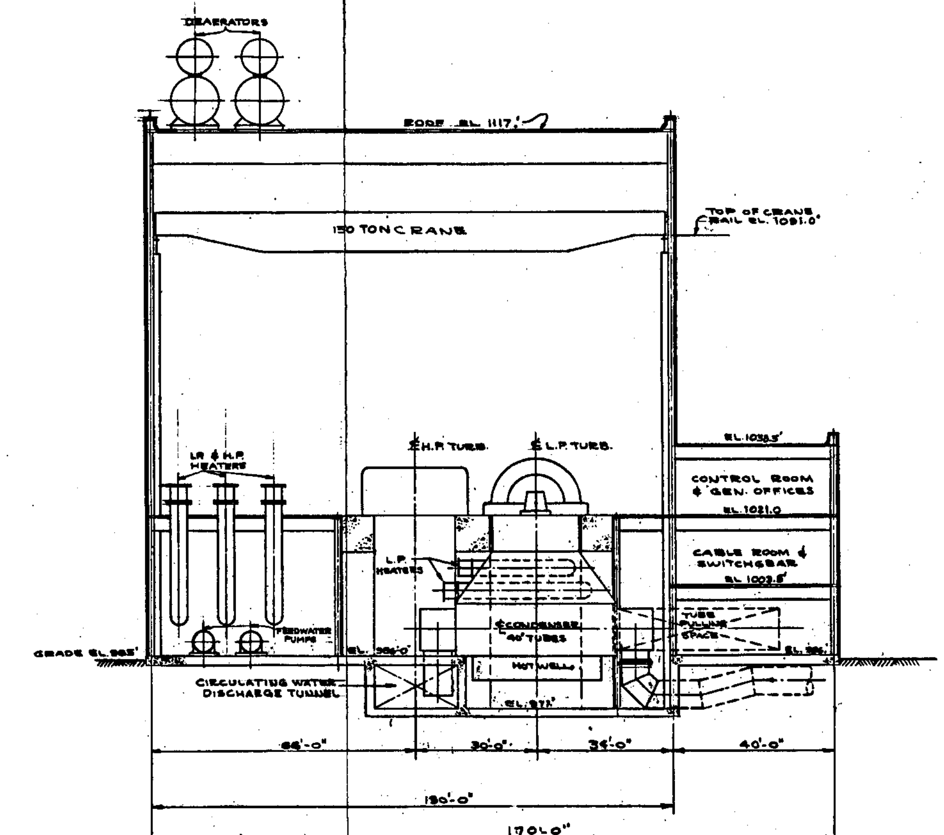


SECTION "C-C"

REVISIONS	
GENERAL CROSS SECTIONS MOLTEN SALT CONVERTER MERCURY BINARY CYCLE OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE	
SCALE 1/16" = 1'-0" DRAWN Schlenker 6-11-62 CHECKED ENGINEER APPROVED	SARGENT & LUNDY ENGINEERS CHICAGO 3, ILLINOIS
JOB NO. 3123-1	DRAWING NO. NS-5

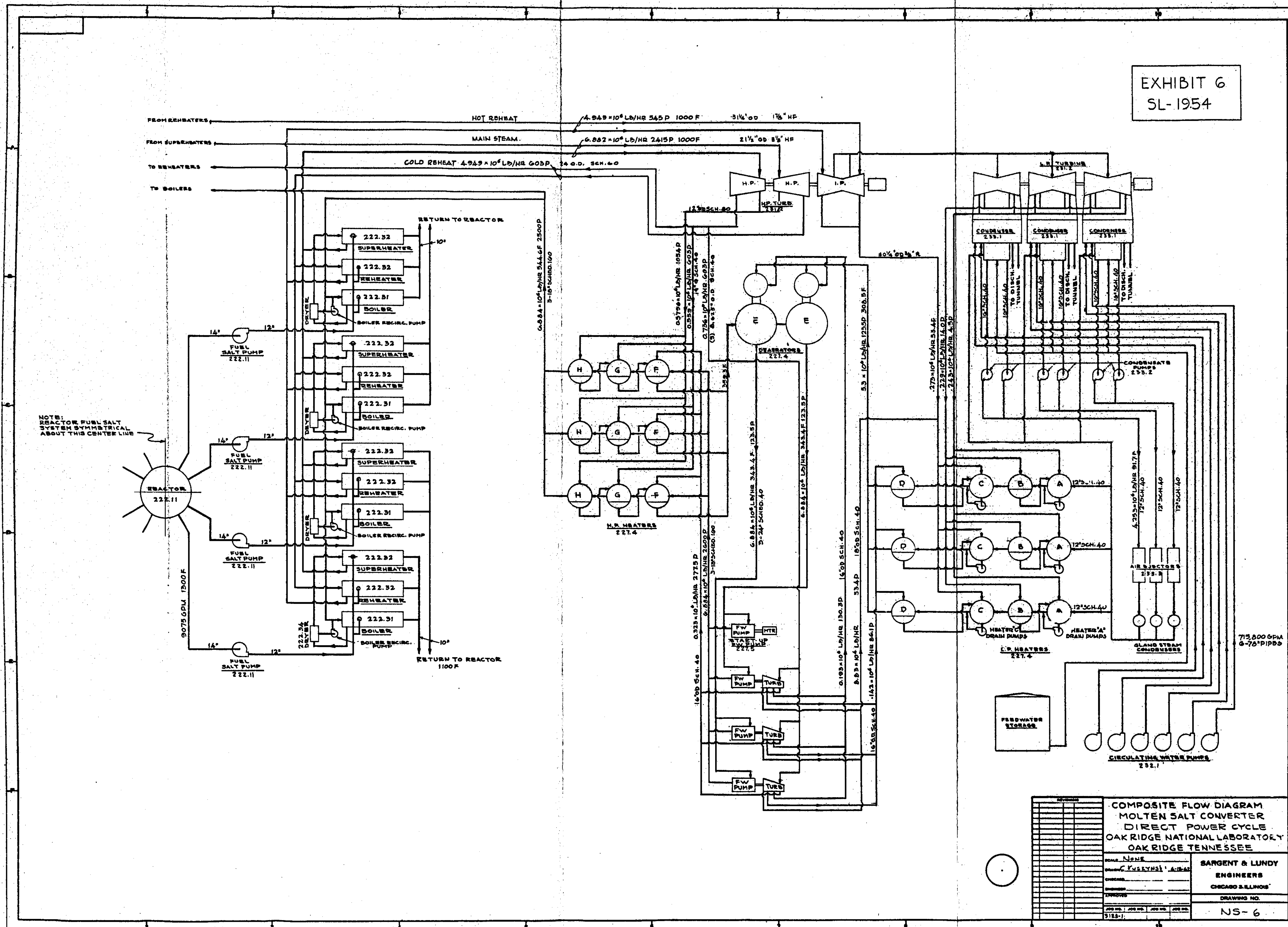
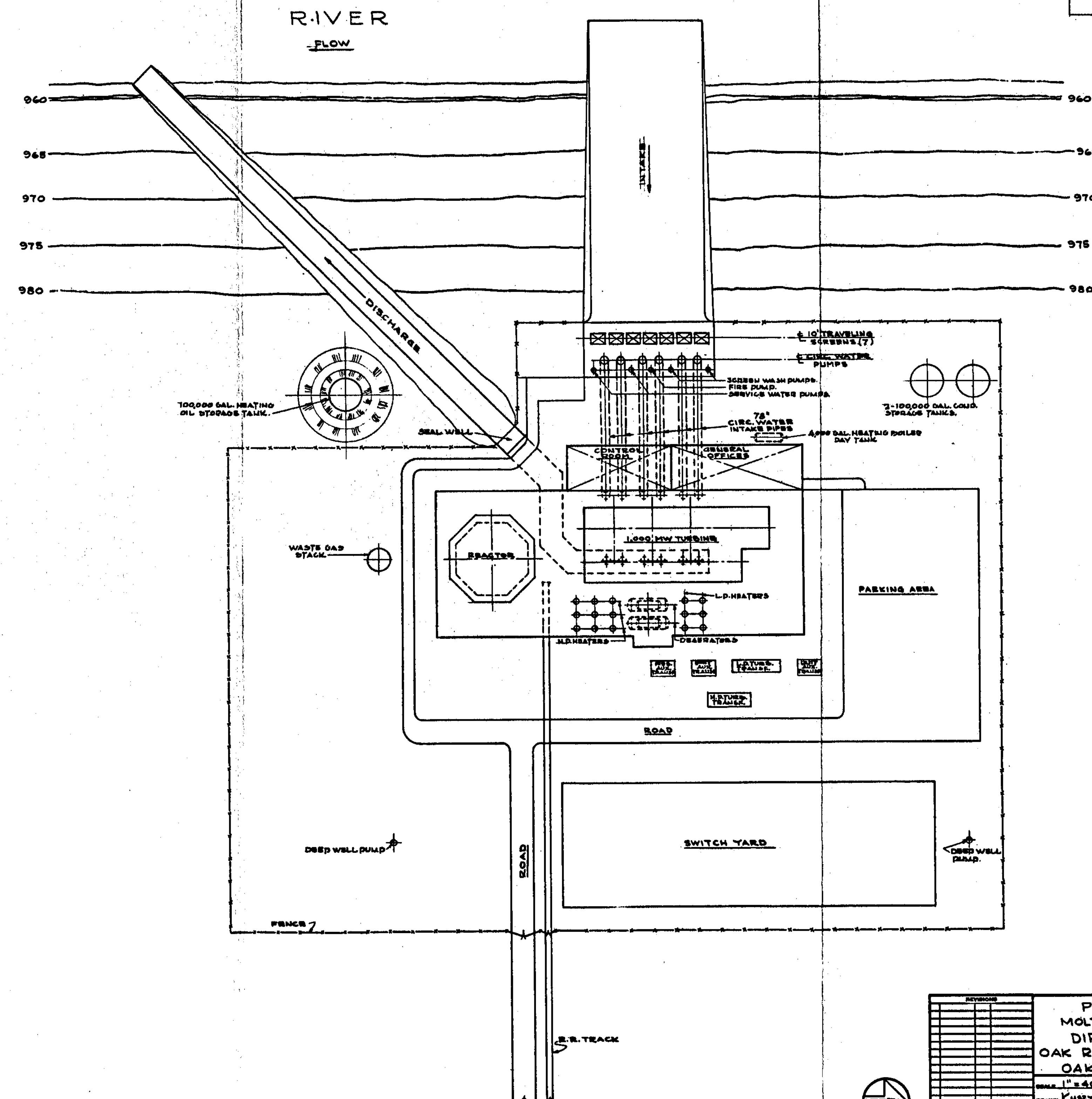


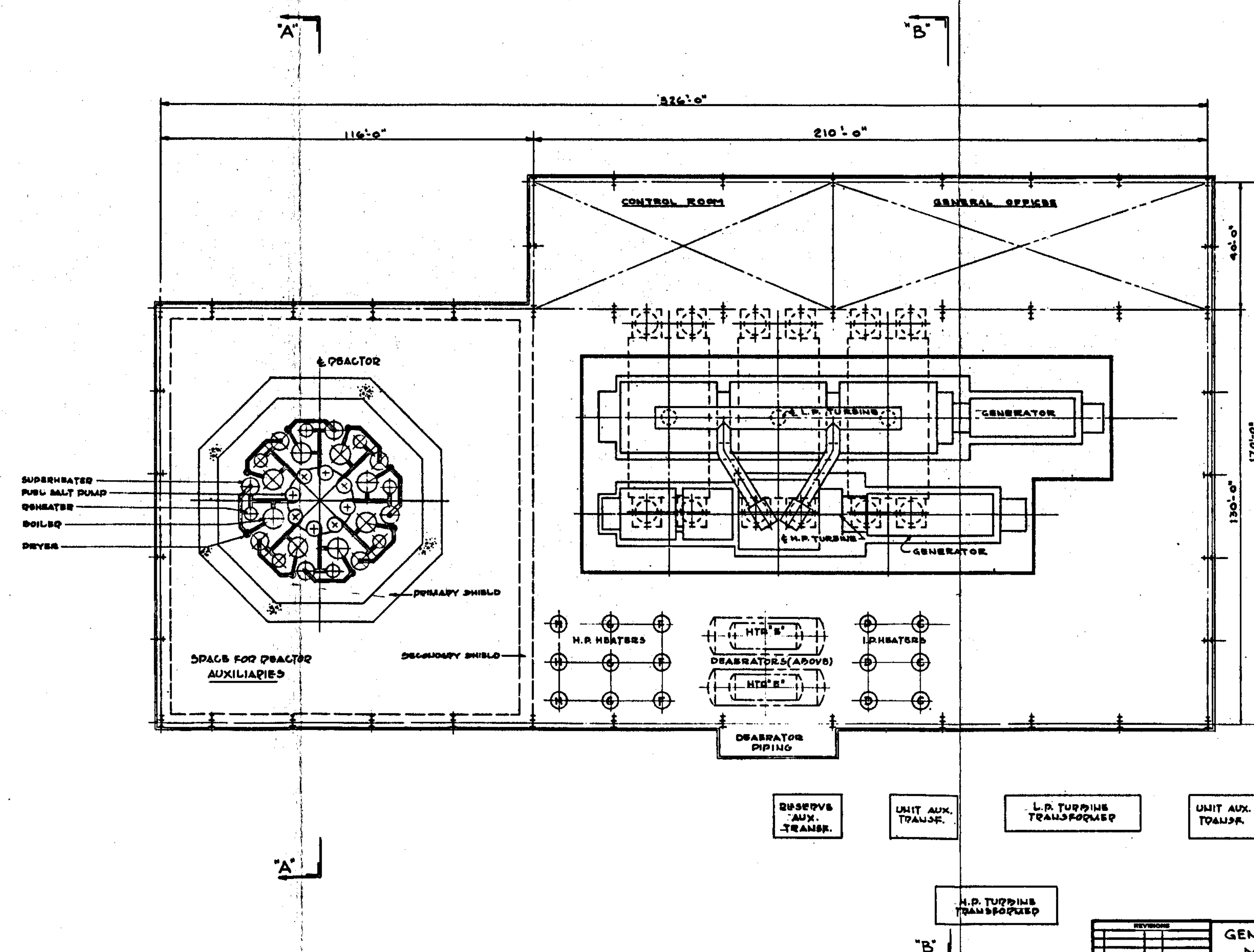
EXHIBIT 6
SL-1954
FROM REHEATERS
FROM SUPERHEATERS
TO REHEATERS
TO BOILERS
HOT REHEAT
MAIN STEAM
COLD REHEAT
RETURN TO REACTOR
SUPERHEATER
REHEATER
BOILER
DRYER
BOILER RECIRC. PUMP
FUEL SALT PUMP
222.11
NOTE: REACTOR FUEL SALT SYSTEM SYMMETRICAL ABOUT THIS CENTER LINE
REACTOR
222.11
9075 GPM 1300F
RETURN TO REACTOR
1100 F
H.P. HEATERS
227.4
DEAERATORS
227.4
H.P.
I.P.
L.P. TURBINE
CONDENSER
CONDENSATE PUMPS
L.P. HEATERS
227.4
AIR EJECTORS
GLAND STEAM CONDENSERS
FEEDWATER STORAGE
CIRCULATING WATER PUMPS
FW PUMP
TURB
START-UP FW PUMP
715,800 GPM
COMPOSITE FLOW DIAGRAM
MOLTEN SALT CONVERTER
DIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE TENNESSEE
SARGENT & LUNDY
ENGINEERS
CHICAGO & ILLINOIS
DRAWING NO.
NS-6

EXHIBIT 7
SL-1954



PROPERTY PLAT MOLTEN SALT CONVERTER DIRECT POWER CYCLE OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE	
SCALE 1" = 40'-0" DRAWN Kuszynski 6-13-62 CHECKED ENGINEER APPROVED	SARGENT & LUNDY ENGINEERS CHICAGO 3, ILLINOIS
JOB NO. 3173-1	DRAWING NO. NS-7

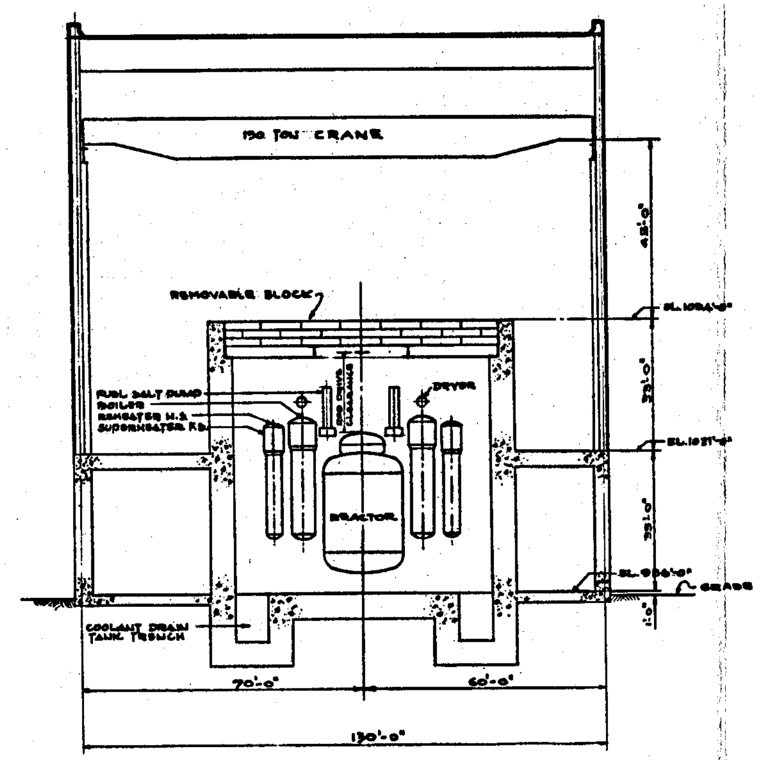
EXHIBIT 8
SL-1954



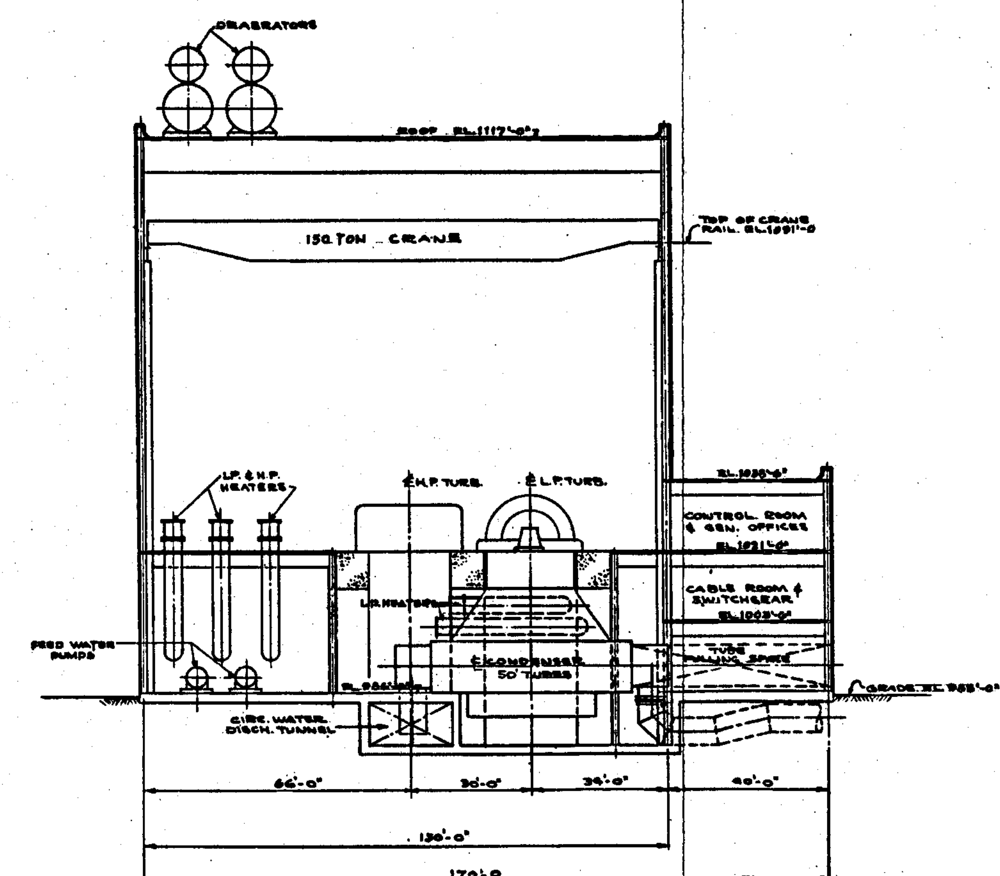
GENERAL ARRANGEMENT PLAN
MOLTEN SALT CONVERTER
DIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE TENNESSEE

SCALE 1/16" = 1'-0"	SARGENT & LUNDY ENGINEERS CHICAGO 3, ILLINOIS
DRAWN Kuszynski 6-11-62	
CHECKED	
ENGINEER	
APPROVED	DRAWING NO.
JOB NO. 3123-1	NS-8

EXHIBIT 9
SL-1954



SECTION "A-A"



SECTION "B-B"

GENERAL CROSS SECTIONS MOLTEN SALT CONVERTER DIRECT POWER CYCLE OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE	
SCALE 1/16" = 1'-0"	SARGENT & LUNDY ENGINEERS CHICAGO 3, ILLINOIS
DRAWN Schlenkert 6-11-62	DRAWING NO.
JOB NO. 3123-1	NS-9

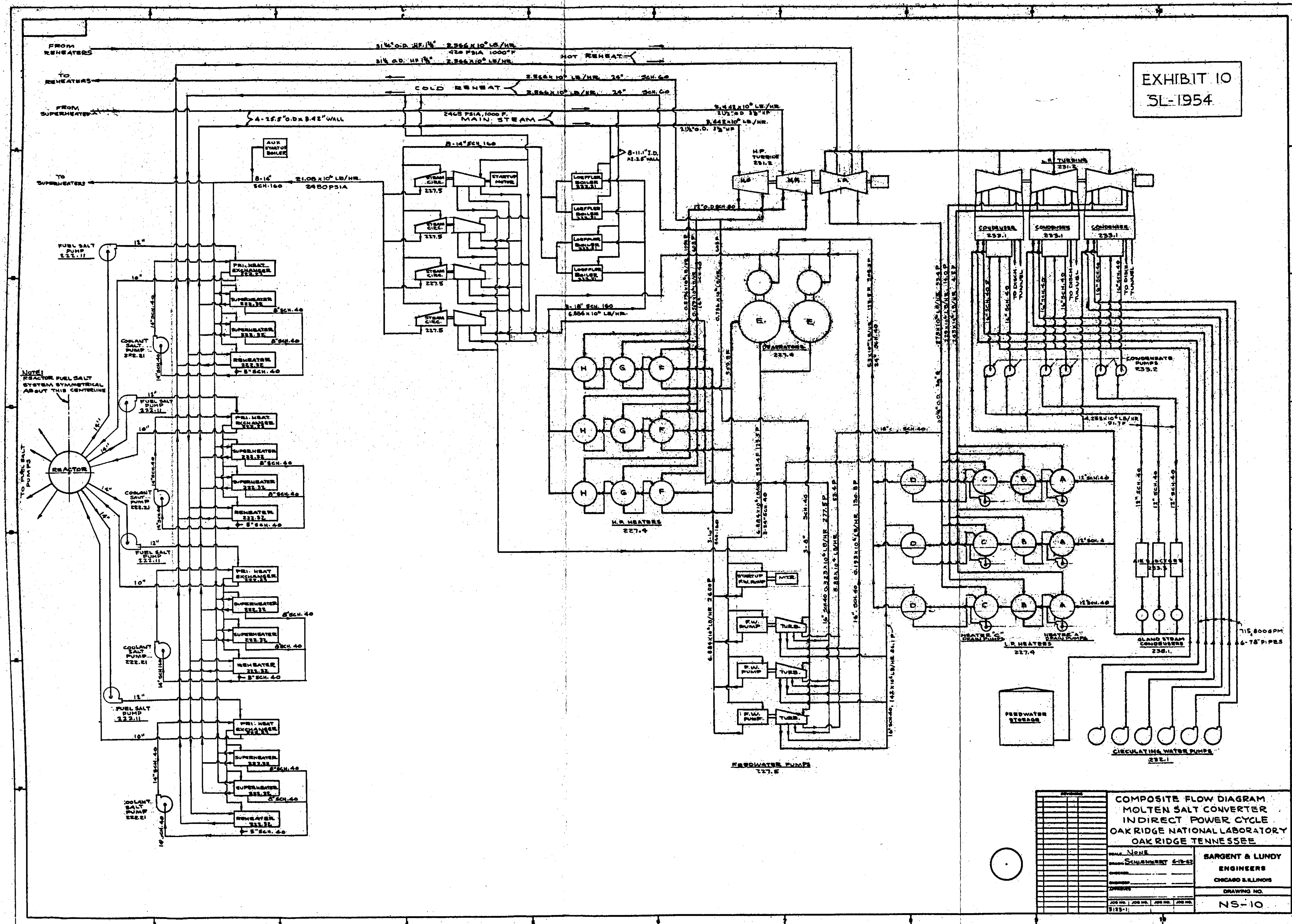


EXHIBIT 10
SL-1954
FROM REHEATERS
TO REHEATERS
FROM SUPERHEATERS
TO SUPERHEATERS
HOT REHEAT
COLD REHEAT
MAIN STEAM
2468 PSIA, 1000 F.
AUX STARTUP BOILER
21.08 x 10^6 LB/HR.
2480 PSIA
H.P. TURBINE
L.P. TURBINE
CONDENSER
CONDENSATE PUMPS
DEAERATOR
H.P. HEATERS
L.P. HEATERS
FEEDWATER PUMPS
FEEDWATER STORAGE
CIRCULATING WATER PUMPS
232.1
GLAND STEAM CONDENSERS
AIR EJECTORS
715,800 GPM
6-78" PIPES
REACTOR
FUEL SALT PUMP
COOLANT SALT PUMP
PRI. HEAT EXCHANGER
SUPERHEATER
REHEATER
NOTE: REACTOR FUEL SALT SYSTEM SYMMETRICAL ABOUT THIS CENTERLINE
TO FUEL SALT PUMPS
COMPOSITE FLOW DIAGRAM
MOLTEN SALT CONVERTER
INDIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE TENNESSEE
SCALE NONE
DRAWN SCHLUENKERT 6-19-62
SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS
DRAWING NO.
NS-10
JOB NO.
5123-1

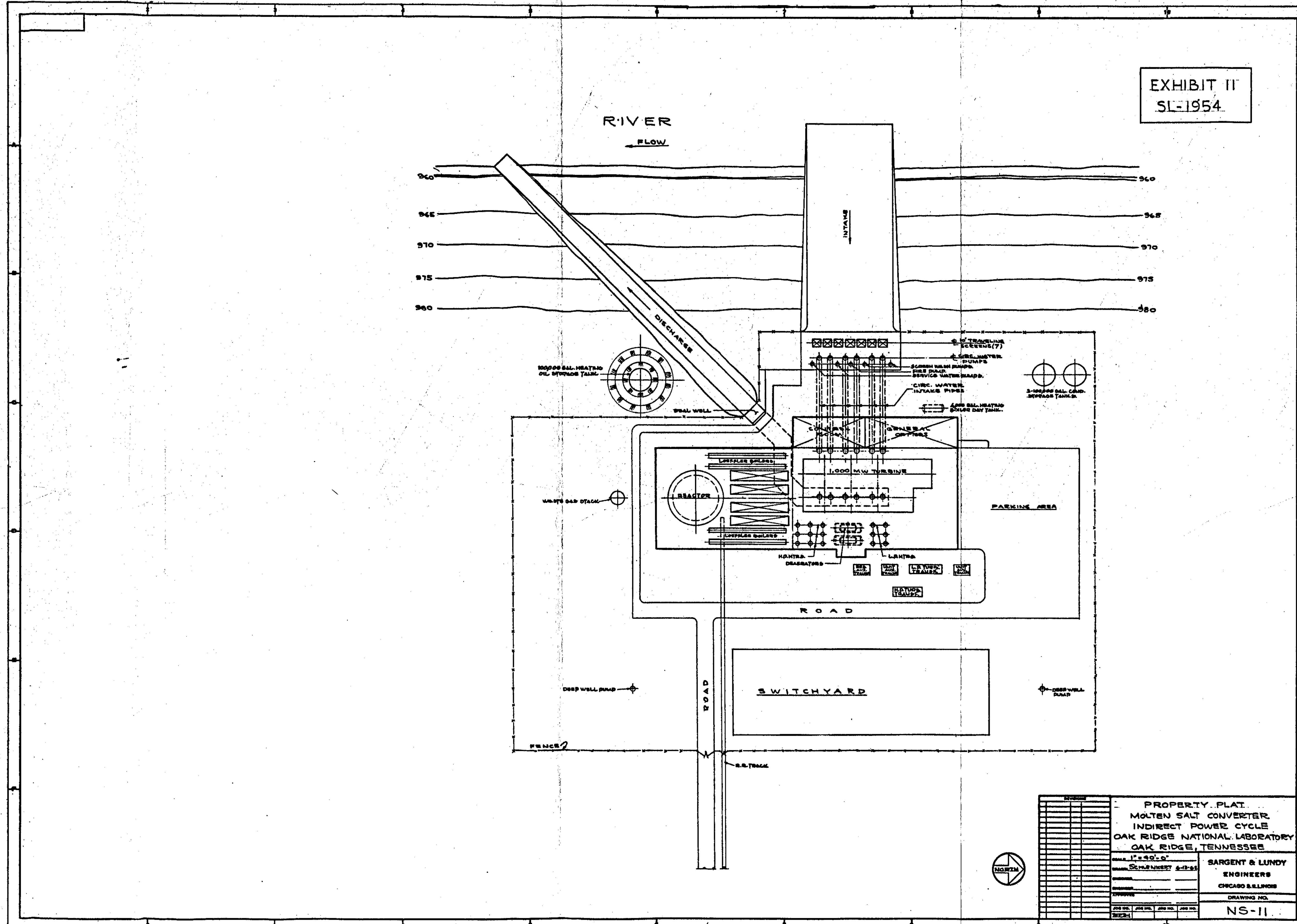
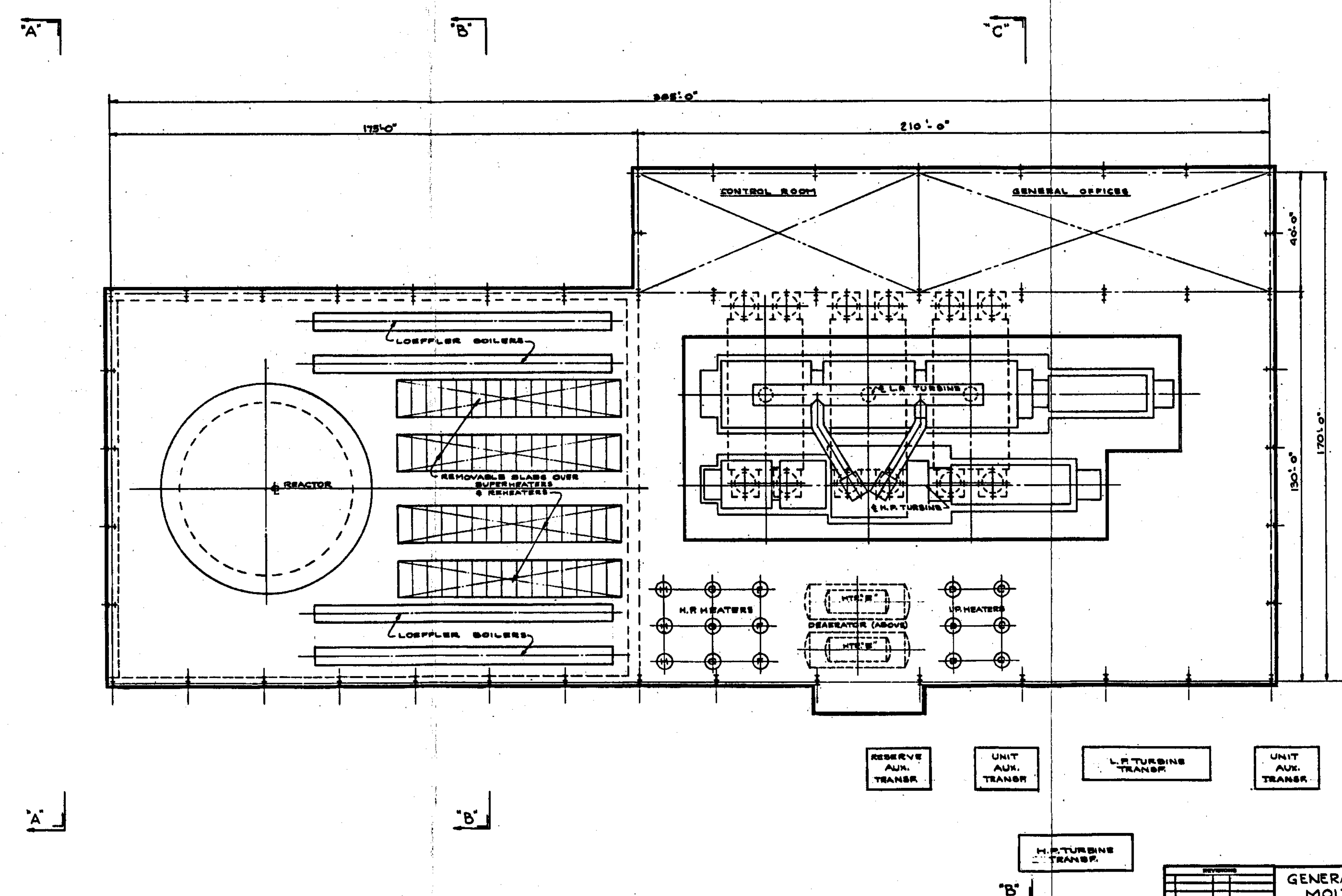


EXHIBIT II
SL-1954
RIVER
FLOW
960
965
970
975
980
INTAKE
DISCHARGE
10' TRAVELING SCREENS (7)
CIRC. WATER PUMPS
SCREEN WASH PUMPS.
FIRE PUMP.
SERVICE WATER PUMPS.
CIRC. WATER INTAKE PIPES
100,000 GAL. HEATING OIL STORAGE TANK
SEAL WELL
2-100,000 GAL. COND. STORAGE TANKS.
4,000 GAL. HEATING BOILER DAY TANK.
CONTROL ROOM
GENERAL OFFICES
LOEFFLER BOILERS
1,000 MW TURBINE
REACTOR
WASTE GAS STACK
PARKING AREA
LOEFFLER BOILERS
H.P. HTRS.
DEAERATORS
L.P. HTRS.
L.P. TURB. TRANSF.
H.P. TURB. TRANSF.
ROAD
ROAD
SWITCHYARD
DEEP WELL PUMP
DEEP WELL PUMP
FENCE
R.R. TRACK
NORTH
PROPERTY PLAT
MOLTEN SALT CONVERTER
INDIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE
1" = 40'-0"
SCHLENKERT 6-13-62
SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS
DRAWING NO.
NS-11

EXHIBIT 12
SL-1954



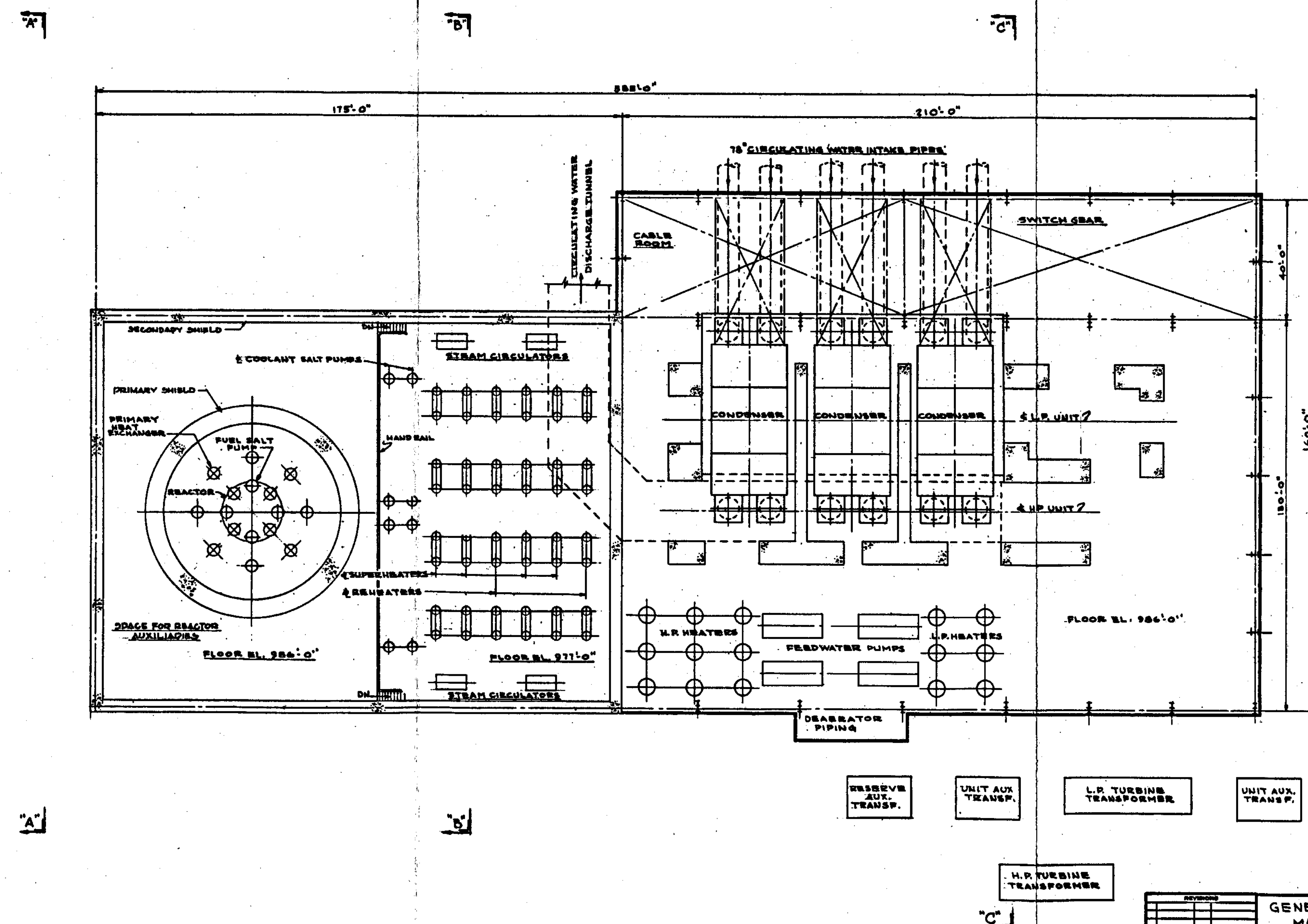
GENERAL ARRANGEMENT PLAN
MOLTEN SALT CONVERTER
INDIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE TENNESSEE

SCALE 1/16" = 1'-0"
DRAWN Kuszynski 6-11-62
CHECKED
ENGINEER
APPROVED
JOB NO. 3123-1

SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO. NS-12

EXHIBIT 13
SL-1954



NORTH

REVISIONS

GENERAL ARRANGEMENT PLAN
MOLTEN SALT CONVERTER
INDIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

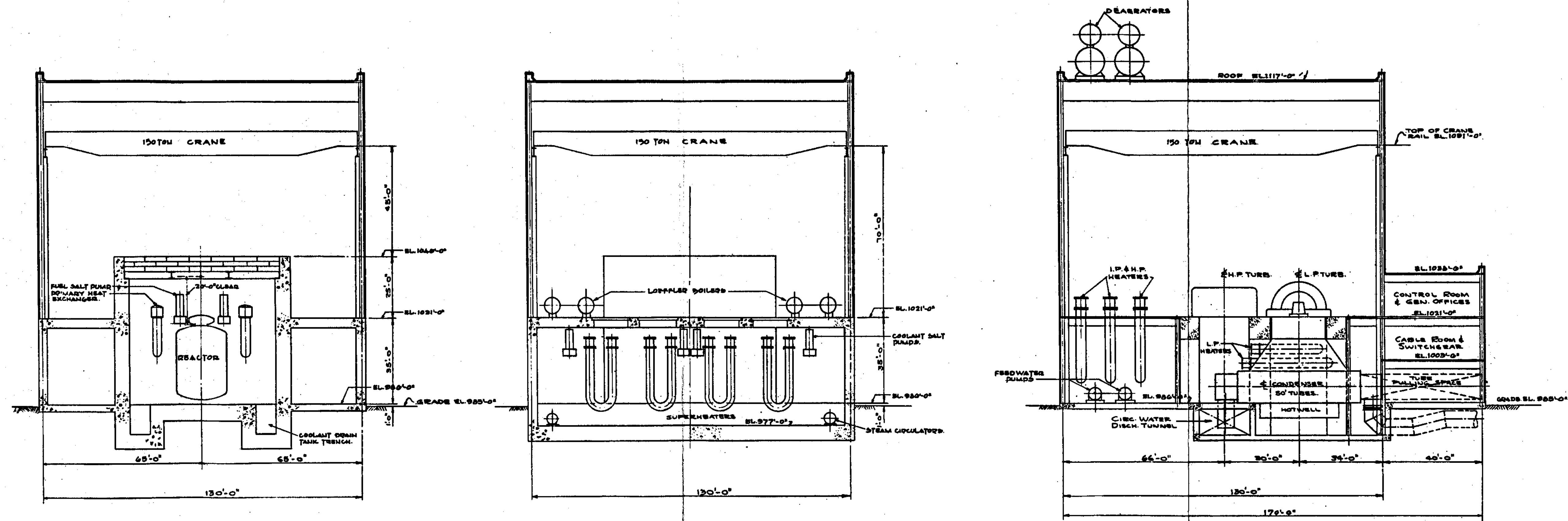
SCALE 1/16" = 1'-0"
DRAWN Kuszynski 6-11-62
CHECKED
ENGINEER
APPROVED

JOB NO.	JOB NO.	JOB NO.	JOB NO.
3123-1			

SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO.
NS-13

EXHIBIT 14
SL-1954



SECTION "A-A"

SECTION "B-B"

SECTION "C-C"

REVISIONS			

GENERAL CROSS SECTIONS
MOLTEN SALT CONVERTER
INDIRECT POWER CYCLE
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

SCALE 1/16" = 1'-0"
DRAWN SCHLENKERT 6-11-62
CHECKED
ENGINEER
APPROVED

JOB NO.	JOB NO.	JOB NO.	JOB NO.
3122-1			

SARGENT & LUNDY
ENGINEERS
CHICAGO 3, ILLINOIS

DRAWING NO.
NS-14

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 15
Report No. SL-1954
Est. Nos. 4682, 4683
& 4684
Job No. 3123-1
Date 7-6-62

1000 MWe MOLTEN SALT CONVERTER REACTOR PLANT
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

SUMMARY OF ESTIMATED DIRECT CONSTRUCTION COST FOR
ENERGY CONVERSION SYSTEMS

Concept A: (From Details of Estimate #4682) Direct Power Cycle
One (1) 2500 MWt Molten Salt Reactor
One (1) 1,000 MWe Reheat Turbine Generator Unit
c.c.6F - 40" L.S.B. - (2400 Psi. - 1000°F - 1000°F)

Concept B: (From Details of Estimate #4683) Indirect Power Cycle
One (1) 2500 MWt Molten Salt Reactor
One (1) 1000 MWe Reheat Turbine Generator Unit
c.c.6F - 40" L.S.B. - (2400 Psi. - 1000°F - 1000°F)

Concept C: (From Details of Est. #4684) Mercury Binary Cycle
One (1) 2500 MWt Molten Salt Reactor
One (1) 880 MWe Non-Reheat Turbine Generator Unit
c.c.6F - 40" L.S.B. (1800 Psi. - 1000°F - 1000°F)
Two (2) 178 MWe Mercury Turbine Generator Units (Each)
t.c.4F - (165 Psi. - 1050°F)

(Prices as of 7-6-62 and Based on a 40 Hour Work Week)

		DIRECT POWER CYCLE	INDIRECT POWER CYCLE	MERCURY BINARY CYCLE
ACCOUNT 21 - STRUCTURES AND IMPROVEMENTS				
211	Ground Improvements	$486,100	$501,500	$506,800
212	Buildings	3,806,900	4,302,700	4,860,800
218	Stacks	71,000	71,000	71,000
219	Reactor Container Structures	Not Included	Not Included	Not Included
	TOTAL ACCOUNT 21	$4,364,000	$4,875,200	$5,438,600
ACCOUNT 22 - REACTOR PLANT EQUIPMENT				
221	Reactor Equipment	$532,300	$476,300	$598,300
222	Heat Transfer Systems	16,736,000	17,005,000	8,434,500
223	Fuel Handling and Storage Equipment	Not Included	Not Included	Not Included
224	Fuel Processing and Fabrication Equipment	Not Included	Not Included	Not Included

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 15
Report No. SL - 1954
Est. Nos. 4682, 4683 & 4684
Job No. 3123-1
Date 7-6-62

1000 MWe MOLTEN SALT CONVERTER REACTOR PLANT
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		DIRECT POWER CYCLE	INDIRECT POWER CYCLE	MERCURY BINARY CYCLE
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
225	Radioactive Waste Treatment and Disposal	Not Included	Not Included	Not Included
226	Instrumentation and Control	-	-	-
227	Feed Water Supply and Treatment	3,227,500	4,939,500	2,503,500
228	Steam, Condensate, Feed Water and all Other Piping	7,330,000	11,850,000	7,980,000
229	Other Reactor Plant Equipment	-	-	-
	TOTAL ACCOUNT 22	$27,825,800	$34,270,800	$19,516,300
ACCOUNT 23 - TURBINE - GENERATOR UNITS				
231	Turbine - Generators	$21,495,000	$21,495,000	$37,995,000
232	Circulating Water Systems	1,644,200	1,644,200	1,989,900
233	Condensers and Auxiliaries	3,104,900	3,104,900	3,145,900
234	Central Lubricating System	36,000	36,000	36,000
235	Turbine Plant Boards, Instruments and Controls	426,600	426,600	792,000
236	Turbine Plant Piping	Included in Acct. 228	Included in Acct. 228	Included in Acct. 228
237	Auxiliary Equipment for Generators	137,000	137,000	172,000
238	Other Turbine Plant Equipment	Included in Acct. 228	Included in Acct. 228	Included in Acct. 228
	TOTAL ACCOUNT 23	$26,843,700	$26,843,700	$44,130,800
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT				
241	Switchgear	$483,000	$637,400	$763,800
242	Switchboards	257,600	286,000	356,800
243	Protective Equipment	112,400	131,600	140,800
244	Electrical Structures	151,900	213,200	211,900
245	Conduit	211,900	210,200	263,100
246	Power and Control Wiring	2,073,200	2,281,900	2,589,300
247	Station Service Equipment	553,300	615,000	612,800
	TOTAL ACCOUNT 24	$3,843,300	$4,375,300	$4,938,500

Exhibit No. 15
Report No. SL - 1954
Est. Nos. 4682, 4683
& 4684
Job No. 3123-1
Date 7-6-62

1000 MWe MOLTEN SALT CONVERTER REACTOR PLANT
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		DIRECT POWER CYCLE	INDIRECT POWER CYCLE	MERCURY BINARY CYCLE
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT				
251	Cranes and Hoisting Equipment	$195,000	$195,000	$195,000
252	Compressed Air and Vacuum Cleaning Systems	64,100	64,100	64,100
253	Other Power Plant Equipment	517,600	540,800	531,000
	TOTAL ACCOUNT 25	$776,700	$799,900	$790,100
	ACCOUNTS 52 - 53 - MAIN POWER TRANSFORMER	$1,827,500	$1,805,000	$3,042,000
	TOTAL DIRECT CONSTRUCTION COST	$65,481,000	$72,969,900	$77,856,300

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

ESTIMATE OF DIRECT CONSTRUCTION COST
ENERGY CONVERSION SYSTEM

ONE (1) 2500 MWt MOLTEN SALT REACTOR
ONE (1) 1000 MWe REHEAT TURBINE GENERATOR
UNIT C.C.6F 40" L.S.B.
(2400 Psi. - 1000°F - 1000°F)

(Prices as of 7-6-62 and Based on a 40 Hour Work Week)

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u>				
211 <u>Ground Improvements</u>				
.1 Access Roads for Permanent Use				
.11 Grading)				
.12 Surfacing)				
.13 Culverts)				
.14 Bridges & Trestles)	15 Miles	-	-	In Place
.15 Guards & Signs)				
.16 Lighting)				
.2 General Yard Improvements				
.21 Grading & Landscaping	Lot	$6,000	$19,200	$25,200
.22 Roads Sidewalks & Parking Areas	47,000 SF	16,500	7,600	24,100
.23 Retaining Walls, Fences & Railings				
.231 Fence, Post, Gates	2,450 LF	8,500	3,200	11,700

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.2 General Yard Improvements (Cont'd.)				
.24 Outside Water Distribution Systems Including Fire Hydrants & Water Tanks for General Use				
.241 Domestic Water System				
.2411 500 G.P.M. Deep Wells, Including Pump & Accessories .2412 Storage Tank, 300 Gal. & Controls .2413 Water Softener, Piping & Controls .2414 Piping	Lot	13,000	17,600	30,600
.242 Fire Protection System				
.2421 Water Storage Tank .2422 2000 GPM Fire Pump & Motor Drive .2423 Other Fire Protection Equipment .2424 Piping, Including Hydrants .2425 Hose & Hose Houses	Lot	27,500	27,500	55,000

SARGENT & LUNDY
ENGINEERS
CHICAGO

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.2 General Yard Improvements (Cont'd.)				
.25 Sewers & Drainage Systems:				
.251 Yard Drainage & Culverts	Lot	4,000	7,000	11,000
.252 Sanitary Sewer System				
.2521 Septic Tank) .2522 Dosing Syphon) .2523 Distribution Box) .2524 Tile Field (Drainage))	Lot	$12,000	18,400	30,400
.253 Storm Sewer System:				
.2531 Excavation & Backfill) .2532 Vitrified Clay Tile (6" & 8")) .2533 Reinforced Concrete Pipe (27" & 30")) .2534 Manholes) .2535 Outfall Structure)	Lot	13,000	11,200	24,200
.26 Roadway & General Lighting				
.261 Security Fence Lighting) .262 Roadway Lighting) .263 Parkway Cable) .264 Trenching for Parkway Cable)	Lot	8,000	11,200	19,200

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
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Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.3 Railroads				
.31 Off Site				
.311 Grading)				
.312 Bridges, Culverts & Trestles)	5 Miles	135,000	132,000	267,000
.313 Ballast & Track)				
.314 Signals & Interlocks)				
.32 On Site				
.321 Ballast & Track	265 LF	1,500	1,600	3,100
TOTAL ACCOUNT 211		$245,000	$256,500	$501,500
212 Buildings				
212A Turbine Generator Building Including Office, Control Room, Cable Room, Switch Gear Room				
.1 Excavation & Backfill				
.11 Earth Excavation	11,500 CY	-	11,500	11,500
.12 Rock Excavation	5,650 CY	-	45,200	45,200
.13 Backfill	6,350 CY	2,000	9,400	11,400
.14 Disposal	10,800 CY	-	4,400	4,400
.15 Dewatering	Lot	-	75,000	75,000
.3 Substructure Concrete				
.31 Forms)				
.32 Reinforcing)				
.33 Concrete)				
.34 Waterproofing)	6,750 CY Conc.	232,000	218,400	450,400
.35 Patch & Finish)				
.36 Miscellaneous Anchor Bolts, Sleeves Etc. Embedded in Concrete)				

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Cable Room, Switch Gear Room (Cont'd.)				
.4 Superstructure				
.41 Superstructure Concrete				
.411 Forms)				
.412 Reinforcing)	34,000 SF of Floor	$57,500	$49,000	$106,500
.413 Concrete)				
.42 Structural Steel & Miscellaneous Metal				
.421 Structural Steel	1,650 T	535,000	128,000	663,000
.422 Stairs, Ladders, Railings, Walkways, Gratings, Etc.	Lot	55,000	24,000	79,000
.43 Exterior Walls				
.431 Masonry	-	-	-	-
.432 Insulated Metal Siding	66,400 SF	134,000	46,400	180,400
.44 Roofing & Flashing				
.441 Pre-Cast Roof Slabs)				
.442 Built-Up Roofing & Flashing)				
.443 Poured Concrete Roof Deck)	35,600 SF	32,000	36,000	68,000
.444 Insulation)				

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTAL
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)					
212	Buildings (Cont'd.)				
212A	Turbine Generator Building Including Office, Control Room, Cable Room, Switch Gear Room				
.4	Superstructure (Cont'd.)				
.45	Interior Masonry & Partitions				
.451	Structural Tile	29,800 SF	$15,100	$20,300	$35,400
.46	Doors & Windows				
.461	Doors	Lot	11,500	4,400	15,900
.462	Windows	12,600 SF	48,000	20,000	68,000
.47	Wall and Ceiling Finish				
.471	Glazed Tile)				
.472	Metal Ceiling)				
.473	Plastering Including Lathing and Furring)	6,200 SF	5,000	4,400	9,400
.474	Acoustical Tile)				
.48	Floor Finish				
.481	Cement)				
.482	Tile)	Lot	30,000	38,100	68,100
.49	Painting Glazing and Insulation				
.491	Painting	Lot	10,500	32,400	42,900
.492	Glass and Glazing	-	-	-	Incl. 462
.5	Stack (Heating Boiler and Auxiliary Boiler)	1	4,000	1,600	5,600

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
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MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room (Cont'd.)				
.6 Building Services				
.61 Plumbing & Drainage Systems)				
.611 Plumbing)				
.612 Drainage)	Lot	$60,000	$32,000	$92,000
.613 Duplex Sump Pump)				
.614 Domestic Cold Water Tank)				
.615 Domestic Hot Water Tank)				
.62 Heating Boiler & Accessories				
.621 Heating Boiler)				
.622 Unit Heaters)				
.623 Discharge Ducts)				
.624 Condensate Pump & Receiver)				
.625 Flash Tank)	Lot	77,000	50,400	127,400
.626 Piping)				
.627 Fuel Oil Transfer Pump)				
.628 Heating Oil Tanks - Day & Storage)				
.6221 Berm for Fuel Oil Storage Tank)				
.6222 Foundation for Heating Oil Day Tank)				
.63 Ventilating System				
.64 Air-Conditioning System)				
.641 Air-Conditioning Control Room)	Lot	55,000	28,000	83,000
.642 Office Air-Conditioning)				
.643 Laboratory Air Conditioning)				

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room (Cont'd.)				
.6 Building Services (Cont'd.)				
.66 Lighting & Service Wiring				
.661 Control Panels & Cabinets) .662 Conduit) .663 Wiring) .664 Fixtures Switches & Receptacles)	Lot	$46,500	$39,200	$85,700
.67 Fire Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	12,000	2,400	14,400
TOTAL ACCOUNT 212A		$1,422,100	$920,500	$2,342,600
212F Miscellaneous Buildings				
.1 Gate House	Lot	$5,500	$5,200	$10,700
.2 Electrical	Lot	3,000	2,800	5,800
TOTAL ACCOUNT 212F		$8,500	$8,000	$16,500
212G Reactor Plant Building				
.1 Excavation & Backfill				
.11 Earth Excavation	5,460 CY	-	$5,500	$5,500
.12 Rock Excavation	1,920 CY	-	38,500	38,500
.13 Backfill	622 CY	-	1,000	1,000
.14 Disposal	6,758 CY	-	2,700	2,700
.15 Dewatering	Lot	-	55,000	55,000

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 16
Report No. SL-1954
Est. No. 4683
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.3 Substructure Concrete				
.31 Forms) .32 Reinforcing) .33 Concrete) .34 Waterproofing) .35 Patch & Finish) .36 Miscellaneous Anchor Bolts, Sleeves Etc. Embedded in Concrete)	4,013 CY	$155,000	$144,000	$299,000
.4 Superstructure				
.41 Superstructure Concrete				
.411 Forms) .412 Reinforcing) .413 Concrete Interior)	5,862 CY	285,000	180,000	465,000
.42 Structural Steel & Miscellaneous Steel				
.421 Structural Steel & Reactor Supports	840 T	265,000	68,000	333,000
.422 Stairs, Ladders, Railings, Walkways, Grating, Etc.	Lot	25,000	12,000	37,000
.43 Exterior Walls				
.431 Masonry	-	-	-	-
.432 Insulated Metal Siding	40,750 SF	85,000	28,000	113,000
.433 Concrete Walls	2,460 CY	117,000	74,400	191,400

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MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.4 Superstructure (Cont'd.)				
.44 Roofing & Flashing				
.441 Pre-Cast Roof Slabs)				
.442 Built-Up Roofing & Flashing)	23,300 SF	$21,000	$21,600	$42,600
.443 Insulation)				
.45 Interior Masonry & Partitions				
.451 Structural Tile	-	-	-	-
.46 Doors & Windows				
.461 Doors	Lot	2,500	1,200	3,700
.462 Windows	7,250 SF	27,000	12,000	39,000
.48 Floor Finish				
.481 Cement	35,000 SF	12,000	14,400	26,400
.49 Painting Glazing & Insulation				
.491 Painting	Lot	6,000	15,200	21,200
.492 Glass and Glazing	-	-	-	Included 462
.493 Insulation of Reactor Chamber	-	-	-	Incl. in Acct. 221.32
.5 Stack (When Supported on Building)		←Included in Account 212A→		
.6 Building Services				
.61 Plumbing & Drainage System				
.611 Plumbing)				
.612 Drainage)	Lot	15,000	8,000	23,000
.613 Sump Pump)				

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Equipment (Cont'd.)				
.6 Buildings (Cont'd.)				
.62 Cooling System)				
.63 Ventilating System)	Lot	$130,000	$70,000	$200,000
.66 Lighting & Service				
.661 Control Panels & Cabinet)				
.662 Conduit)				
.663 Wiring)	Lot	$17,000	19,600	36,600
.664 Fixtures, Switches & Receptacles)				
.67 Fire Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	8,500	1,500	10,000
TOTAL ACCOUNT 212G		$1,171,000	$772,600	$1,943,600
TOTAL ACCOUNT 212		$2,601,600	$1,701,100	$4,302,700
218 Stacks				
218A Concrete Chimney				
.1 Excavation and Backfill)				
.2 Substructure Concrete)	1	$35,000	$36,000	$71,000
.4 Concrete Chimney)				
.6 Obstruction Lighting)				
TOTAL ACCOUNT 218A		$35,000	$36,000	$71,000
TOTAL ACCOUNT 218		$35,000	$36,000	$71,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)					
219	Reactor Container Structure		←Not Included→		
	TOTAL ACCOUNT 21		$2,881,600	$1,993,600	$4,875,200
ACCOUNT 22 - REACTOR PLANT EQUIPMENT					
221	Reactor Equipment				
.1	Reactor Vessel and Supports		←Not Included→		
.2	Reactor Controls		←Not Included→		
.3	Reactor Shield				
.32	Biological Shielding - Insulation, Shield Plugs, Etc.	Lot	$255,000	$124,000	$379,000
.34	Shield Cooling System				
.341	Closed Loop Liquid System				
.3411	Shield Cooling Heat Exchanger (4000 Ft.^{2} Surface - Admiralty)	2	35,000	2,500	37,500
.3412	Shield Cooling Circulating Pumps & Motors (2500 GPM 75 HP Motor)	3	7,500	800	8,300
.3413	Piping & Valves	Lot	← Included in Account 228→		
.3414	Cooling Coils Embedded in Concrete (16000 Ft. 1" Steel)	Lot	17,500	32,500	50,000
.3415	H_2O Storage Tank 3000 Gallons	1	1,200	300	1,500
.4	Reactor Auxiliary Cooling & Heating Sytem		←Not Included→		
.6	Moderator & Reflector		←Not Included→		
.7	Reactor Plant Cranes & Hoists		←Included in Account 251→		
	TOTAL ACCOUNT 221		$316,200	$160,100	$476,300

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OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)					
222	Heat Transfer Systems				
.1	Reactor Coolant Systems		←Not Included→		
.2	Intermediate Coolant System				
.21	Pumps Including Supports				
.211	Coolant Salt Pumps - 13,900 GPM Including 1,750 HP Motors	8	$3,600,000	$30,000	$3,630,000
.212	Auxiliary Pumps and Drives		←Not Included→		
.213	Insulation		←Included in Account 228→		
.22	Intermediate Coolant Piping & Valves				
.221	Piping	Lot	←Included in Account 228→		
.222	Block & Control Valves				
.223	Other Valves				
.224	Piping Supports				
.23	Primary Heat Exchangers & Supports	8	2,320,000	28,000	2,348,000
.3	Steam Generators Superheaters & Reheaters				
.31	Loeffler Boilers	4	4,000,000	160,000	4,160,000
.32	Superheaters	16	5,280,000	40,000	5,320,000
.322	Steam Reheaters	8	1,400,000	10,000	1,410,000
.35	Auxiliary Start-up Boiler (300 Psi. 50,000 lb/hr. oil Fired)	1	60,000	5,000	65,000
.36	Insulation for Above Equipment		←Included in Account 228→		

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
222 Heat Transfer Systems (Cont'd.)				
.4 Reactor Coolant Receiving Supply and Treatment		← Not Included →		
.5 Intermediate Coolant Storage Tanks, Etc.	2	$70,000	$2,000	$72,000
TOTAL ACCOUNT 222		$16,730,000	$275,000	$17,005,000
223 Fuel Handling and Storage Equipment		← Not Included →		
224 Fuel Processing and Fabrication Equipment		← Not Included →		
225 Radioactive Waste Treatment & Disposal		← Not Included →		
226 Instrumentation and Controls				
.1 Reactor		← Not Included →		
.2 Heat Transfer System		← Included in Account 235 →		
.3 Service to Fuel Handling and Storage		← Not Included →		
.4 Service to Radioactive Waste & Disposal		← Not Included →		
.5 Radiation Monitoring		← Not Included →		
.6 Steam Generator		← Included in Account 235 →		
.7 Control & Instrument Piping & Wiring		← Included in Account 235 →		
.8 Electrical Connections	Lot	← Included in Account 235 →		
.9 Other Miscellaneous		← Included in Account 235 →		
TOTAL ACCOUNT 226		-		

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			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)						
227	Feed Water Supply and Treatment					
	.1	Raw Water Supply	1 Lot	← Included in Account 211 →		
	.2	Make-up Water Treatment				
	.21	Evaporators	-	-	-	-
	.22	Ion Exchange Equipment, Filters, Etc.	1 Lot	$45,000	$10,000	$55,000
	.23	Acid & Caustic Transf. Pumps & Drives	2	600	200	800
	.24	Demineralized Water Storage Tanks	2	30,000	Included	30,000
	.25	Caustic Tank	1	2,200	400	2,600
	.26	Acid Tank	1	2,200	400	2,600
	.27	Foundation	1 Lot	3,500	2,500	6,000
	.28	Piping & Valves	1 Lot		← Included in Account 228 →	
	.29	Insulation			← Included in Account 228 →	
	.3	Steam Generator Feed-Water Purification	-	-	-	-
	.4	Feed-Water Heaters				
	.41	Deaerating Heaters - "E" 3,500,000 #/Hr. 150 Psig.	2	240,000	15,000	255,000
	.42	Closed Heaters				
	.421	L.P. Heater "A"	3	75,000	5,000	80,000
	.422	L.P. Heater "B"	3	63,000	5,000	68,000
	.423	L.P. Heater "C"	3	63,000	3,000	66,000
	.424	L.P. Heater "D"	3	81,000	3,000	84,000
	.425	H.P. Heater "F"	3	315,000	3,000	318,000
	.426	H.P. Heater "G"	3	429,000	3,000	432,000
	.427	H.P. Heater "H"	3	441,000	3,000	444,000

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			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)						
227		Feed Water Supply and Treatment				
	.5	Feed-Water Pumps and Drives				
	.51	Feed-Water Pumps & Drives				
	.511	5900 GPM Pumps - 2465 Psig. Hd.	3	$405,000	$12,000	$417,000
	.512	10,000 H.P. - B.F. Pump Turbine Drive 5600 RPM	3	750,000	30,000	780,000
	.52	Motor Driven Start-Up F.W. Pump				
	.521	6000 GPM Pump 850 Psig. Hd.	1	70,000	3,000	73,000
	.522	3500 H.P. Start-Up FW Pump Motor	1	55,000	2,000	57,000
	.53	Heater "A" Drain Pumps and Drives				
	.531	560 GPM Pump 285 Psig. Hd.)				
	.532	125 H.P. Heater "A" Drain Pump Motor)	3	22,500	1,500	24,000
	.54	Heater "C" Drain Pumps and Drives				
	.541	625 GPM Pumps 210 Psig. Hd.)				
	.542	100 H.P. Heater "C" Drain Pump Motor)	3	30,000	2,500	32,500
	.55	Boiler Steam Circulators and Drives				
	.551	5,300,000 #/Hr. Steam Circulator - 2500 #675°F	4	975,000	40,000	1,015,000
	.552	5000 H.P. Turbine Drive for Steam Circulator 500 # Steam; 10,000 RPM	4	560,000	30,000	590,000
	.553	5000 H.P. Motor for Steam Circulator Including Gear and Mag. Coupling	1	100,000	7,000	107,000
		TOTAL ACCOUNT 227		$4,758,000	$181,500	$4,939,500

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
228 Steam, Condensate, Feed Water, and all Other Piping, Valves Etc. - For Turbine Plant, Crib House and Others Covered by This Estimate.				
.1 Pipe, Valves, Fittings, Etc.				
.11 Turbine Plant)				
.12 Other Interior Piping)	1 Lot	$6,200,000	$3,900,000	$10,100,000
.13 Yard Pipe Etc.)				
.2 Insulation				
.21 Piping Insulation	1 Lot	700,000	800,000	1,500,000
.22 Equipment Insulation	1 Lot	110,000	140,000	250,000
TOTAL ACCOUNT 228		$7,010,000	$4,840,000	$11,850,000
229 Other Reactor Plant Equipment	-	-	-	-
TOTAL ACCOUNT 22				$34,270,800
ACCOUNT 23 - TURBINE GENERATOR UNITS				
231 Turbine Generators				
.1 Turbine Foundations				
.11 Concrete - Including Reinforcing Steel, Etc.	1 Lot	$175,000	$175,000	$350,000
.12 Miscellaneous	1 Lot	10,000	10,000	20,000
.2 Turbine Generators				
.21 Turbine Generator Units - As Follows: 1000 MWe Reheat Turbine Generator Unit C.C.6F. 40" L.S.B. Complete with Accessories Steam Conditions 2400 Psi - 1000°F -1000°F Generators: 1,280,000 KVA Total .85 P.F. and .64 SCR	1	19,815,000	960,000	20,775,000

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
231 Turbine Generators (Cont'd.)				
.2 Turbine Generators (Cont'd.)				
.22 Accessories - Other Than Standard		← Included in Account 231.21 →		
.23 Generator		← Included in Account 231.21 →		
.24 Exciter (Motor Driven)		← Included in Account 231.21 →		
.3 Reserve Exciter	1	$340,000	10,000	350,000
TOTAL ACCOUNT 231		$20,340,000	$1,155,000	$21,495,000
232 Circulating Water System				
.1 Pumping and Regulating Systems				
.11 Pumps, Drives & Controls				
.112 120,000 GPM Vertical Mixed Flow Circulating Water Pumps Head 30 ft.	6	360,000	18,000	378,000
.113 1250 H.P. Motor Drive for Circulating Water Pumps	6	270,000	10,000	280,000
.12 Traveling Screens, Etc.				
.121 Traveling Screens Complete with Motors	7	122,500	8,700	131,200
.122 1200 GPM Screen Wash Pumps 230 Ft. Discharge Head	2	5,000	1,000	6,000
.123 100 H.P. Motor for Screen Wash Pump	2	4,500	Included	4,500
.124 Trash Rake Complete with Appurtenances	1	27,500	2,500	30,000
.125 Pipe & Valves	1 Lot	← Included in Account 228 →		

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
232 Circulating Water System (Cont'd.)				
.2 Circulating Water Lines				
.21 Supply Lines - To Condenser				
.211 Circulating Water Piping, Valves, Fittings, Etc.				
.2111 Steel Circulating Water Piping, Valves Expansion Joints, Fittings, Etc.	1 Lot	$155,000	$70,000	$225,000
.22 Discharge Lines - From Condenser				
.221 Circulating Water Piping, Valves, Fittings, Etc.				
.2211 Steel Circulating Water Piping Valves, Expansion Joints, Fittings, Etc.	1 Lot	← Included in Account 232.21 →		
.3 Intake and Discharge Structures				
.31 Intake Structures				
.311 River Dredging & Rock Removal	1 Lot	-	12,000	12,000
.312 Intake Flume				
.3121 Intake Flume Proper	1 Lot	-	45,000	45,000
.3122 Floating Boom	1	7,000	10,400	17,400
.3123 Concrete Retaining Walls	2	28,500	29,200	57,700
.313 Intake Crib House				
.3131 Substructure	1 Lot	140,000	135,000	275,000
.3132 Superstructure	-	-	-	-
.3133 Steel	35 T	11,000	4,000	15,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)					
232	Circulating Water System (Cont'd.)				
.3	Intake and Discharge Structures (Cont'd.)				
.3134	Electrical Work	1 Lot	$11,000	$13,600	$24,600
.32	Discharge				
.321	Seal Well & Discharge Tunnel	Lot	29,500	28,400	57,900
.322	Discharge Flume	Lot	4,500	22,400	26,900
.4	Fouling, Corrosion Control and Water Treatment				
.41	Chlorinating System				
.411	Chlorination Equipment	1 Lot	45,000	8,000	53,000
.412	Chlorine Handling Facilities	1 Lot	3,000	2,000	5,000
	TOTAL ACCOUNT 232		$1,224,000	$420,200	$1,644,200
233	Condensers and Auxiliaries				
.1	Condensers				
.11	Foundations	3	$7,000	$6,400	$13,400
.12	Condenser Shell and Appurtenances				
.121	225,000 Sq. Ft. Single Pass Condensers Complete with Appurtenances Including Shell, Water Boxes, Tube Sheets, Tube Supports, Hot Well, Extended Neck with Expansion Joint, Etc.	3	1,320,000	440,000	1,760,000
.13	50 Ft. Long Admiralty Condenser Tubes	3 Sets	1,053,000	Included	1,053,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
233 Circulating Water System (Cont'd.)				
.1 Condensers (Cont'd.)				
.17 Instruments & Accessories	3 Sets	$15,000	Included	$15,000
.2 Condensate Pumps				
.21 Pumps & Drives				
.211 1675 GPM Condensate Pumps Complete with Appurtenances, Discharge Head - 325 Ft.	6	87,000	6,000	93,000
.212 400 H.P. Motors for Condensate Pumps	6	46,800	4,200	51,000
.22 Suction Piping	Lot	← Included in Account .121 →		
.3 Air Removal Equipment and Piping				
.31 Steam Jet Air Ejector, with Inter & After Condensers	6	100,000	9,000	109,000
.32 Air Suction Piping	Lot	← Included in Account 228 →		
.33 Priming Ejectors	Lot	10,500	Included	10,500
TOTAL ACCOUNT 233		$2,639,300	$465,600	$3,104,900
234 Central Lubricating System				
.1 Treating & Pumping Equipment	1 Lot	17,000	2,000	19,000
.2 Storage Tanks & Appurtenances	1 Lot	14,000	3,000	17,000
.3 Fire Protection	1 Lot	← Included in Account 237 →		
TOTAL ACCOUNT 234		$31,000	$5,000	$36,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
235 Turbine Plant Boards Instruments & Controls				
.1 Control Equipment				
.11 Mechanical Control Boards)				
.12 Isolated Controller, Transmitters Etc.)	1 Lot	$275,000	$25,000	$300,000
.2 Isolated Recording Gauges Meters & Instruments)				
.3 Control & Instrument - Piping & Tubing	1 Lot	20,000	55,000	75,000
.4 Electrical Connections	1 Lot	18,000	33,600	51,600
TOTAL ACCOUNT 235		$313,000	$113,600	$426,600
236 Turbine Plant Piping				
.1 Main Steam Between Stop Valves and Turbine Inlet		← Included in Account 231.2 →		
.2 Drip, Drain and Vent Piping and Valves		← Included in Account 228 →		
TOTAL 236		← Included in Account 228 →		
237 Auxiliary Equipment for Generators				
.1 Excitation Panels, Switches & Rheostats		← Included in Account 231.2 →		
.2 Generator Cooling Water Systems				
.21 Lubricating Oil Cooling System)				
.22 Generator Hydrogen Cooling System)	Lot	60,000	12,000	72,000
.23 Generator Liquid Cooling System)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATORS UNITS (Cont'd.)				
237 Auxiliary Equipment for Generators (Cont'd.)				
.3 Central Hydrogen Cooling System	-	-	-	-
.4 Fire Extinguishing Equipment Including Piping and CO_2 System Exclusively for Generators) .5 Fire Extinguishing Equipment for Oil Room, Etc.)	Lot	$50,000	$15,000	$65,000
TOTAL ACCOUNT 237		$110,000	$27,000	$137,000
238 Other Turbine Plant Equipment				
.1 Gland Seal Water System	1	←Included in Account 228→		
.2 Vacuum Priming System		←Included in Account 228→		
TOTAL ACCOUNT 238		←Included in Account 228→		
TOTAL ACCOUNT 23				$26,843,700
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT				
241 Switchgear				
.1 Generator Main and Neutral Circuits				
.11 Generator Potential Transformer Compartment	2	$38,000	$4,000	$42,000
.12 Surge Protection Equipment	2	14,000	1,600	15,600
.13 Generator Neutral Equipment	1	6,000	800	6,800
.14 Miscellaneous Items	Lot	10,000	19,200	29,200

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Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe INDIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)					
241	Switchgear (Cont'd.)				
.2	Station Service				
.21	13.8 KV Switchgear	Lot	-	-	-
.22	4160 V. Switchgear	Lot	365,000	51,200	416,200
.23	480 V. Switchgear	Lot	110,000	17,600	127,600
	TOTAL ACCOUNT 241		$543,000	$94,400	$637,400
242	Switchboards				
.1	Main Control Board	Lot	$82,000	$31,200	$113,200
.2	Auxiliary Power Battery & Signal Board				
.21	Battery & Battery Charging Panels	1	15,000	5,600	20,600
.22	D.C. Control & Auxiliary Panels	2	18,000	4,800	22,800
.23	A.C. Control & Instrument Panels	1	7,000	1,600	8,600
.24	Motor Control Centers	Lot	80,000	13,600	93,600
.25	Miscellaneous Panels & Boards	Lot	16,000	11,200	27,200
	TOTAL ACCOUNT 242		$218,000	$68,000	$286,000
243	Protective Equipment				
.1	General Station Grounding Equipment	Lot	$60,000	$48,800	$108,800
.2	Fire Protection System	Lot	14,000	8,800	22,800
	TOTAL ACCOUNT 243		$74,000	$57,600	$131,600

SARGENT & LUNDY
ENGINEERS
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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)					
244	Electrical Structures				
.1	Concrete Cable Tunnels, Compartments and Cable Trenches in Earth	Lot	$14,000	$21,600	$35,600
.2	Cable Trays & Supports	192,000 lb.	80,000	72,000	152,000
.3	Pipe and Steel Frames and Supports	Lot	7,000	8,000	15,000
.4	Foundations & Pads for Electrical Equipment	Lot	5,000	5,600	10,600
	TOTAL ACCOUNT 244		$106,000	$107,200	$213,200
245	Conduit				
.1	Conduit				
.11	Power Conduit	Lot	$25,000	$61,200	$86,200
.12	Control and Instrument Conduit	Lot	22,000	54,400	76,400
.2	Concrete Envelopes				
.21	10" Transite Pipe Duct Run	Lot	6,000	6,800	12,800
.22	Iron Conduit Enclosed in Concrete	Lot	9,000	15,200	24,200
.3	Manholes & Covers	5	5,000	5,600	10,600
	TOTAL ACCOUNT 245		$67,000	$143,200	$210,200
246	Power and Control Wiring				
.1	Main Power Cables and Bus Duct				
.11	Isolated Phase Bus Duct (Generator)	Lot	$576,000	$49,600	$625,600
.12	Main Power Cables	1	110,000	16,000	126,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)					
246	Power and Control Wiring (Cont'd.)				
.2	Control Auxiliary Power Excitation Wiring				
.21	Auxiliary Power Cable (Including Excitation Wiring)	Lot	$391,500	$248,800	$640,300
.22	Control and Instrument Wiring	Lot	510,000	380,000	890,000
	TOTAL ACCOUNT 246		$1,587,500	$694,400	$2,281,900
247	Station Service Equipment				
.1	Station Service Transformers & Voltage Regulators				
.11	Unit & Reserve Auxiliary	Lot	273,000	11,200	284,200
.12	4160/480 V. Auxiliary Transformers	Lot	38,000	4,000	42,000
.13	Miscellaneous Small Transformers	Lot	6,000	2,400	8,400
.2	Batteries, Charging Equipment and Motor Generating Sets	Lot	40,000	8,000	48,000
.3	Remote Controls at Motors and Equipment	Lot	42,000	50,400	92,400
.4	Electrical Heating - Salt Melting	Lot	64,000	76,000	140,000
	TOTAL ACCOUNT 247		$463,000	$152,000	$615,000
	TOTAL ACCOUNT 24		$3,058,500	$1,316,800	$4,375,300
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT					
251	Cranes and Hoisting Equipment				
.1	Combined Turbine and Reactor Plant Crane 4 Motor Bridge Type 150 Ton Main and 15 Ton Auxiliary Hoist Capacity Respectively	1	150,000	20,000	170,000

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OAK RIDGE, TENNESSEE

			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT (Cont'd.)						
251	Cranes and Hoisting Equipment (Cont'd.)					
	.2	Miscellaneous Cranes and Hoists	Lot	$23,000	$2,000	$25,000
		TOTAL ACCOUNT 251		$173,000	$22,000	$195,000
252	Compressed Air and Vacuum Cleaning System					
	.1	Compressors and Accessories				
	.11	200 C.F.M. Station Air Compressors Including Motor Drives	2	$13,500	$1,200	$14,700
	.12	250 C.F.M. Control Air Compressors including Motors	2	15,500	1,200	16,700
	.13	Air Drying Equipment for Control Air System	2	9,000	500	9,500
	.14	Receivers				
	.141	Station Air	2	1,300	300	1,600
	.142	Control Air	2	1,300	300	1,600
	.2	Pipe Valves and Fittings	Lot	← Included in Account 228 →		
	.3	Vacuum Cleaning System	Lot	16,000	4,000	20,000
		TOTAL ACCOUNT 252		$56,600	$7,500	$64,100
253	Other Power Plant Equipment					
	.1	Local Communication, Signal and Call System	Lot	$50,000	$44,800	$94,800
	.2	Fire Extinguishing Equipment				
	.21	2000 GPM Fire Pump Including Drive and Accessories			Included in Account 211.24	
	.22	Other Fire Protection Equipment	Lot	$19,000	$1,000	$20,000

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OAK RIDGE, TENNESSE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT (Cont'd.)				
253 Other Power Plant Equipment (Cont'd.)				
.3 Furniture and Fixtures	Lot	$10,000	-	$10,000
.4 Lockers, Shelves, and Cabinets	Lot	7,000	-	7,000
.5 Cleaning Equipment	Lot	4,000	-	4,000
.6 Machine Tools & Other Station Maintenance Equipment	Lot	240,000	10,000	250,000
.7 Laboratory, Test & Weather Instruments				
.71 Radiation Monitoring Equipment	Lot	23,000	2,000	25,000
.72 Miscellaneous Laboratory, Test & Weather Instruments	Lot	20,000	-	20,000
.9 Diesel Generator Unit 1000 KW Including Oil Tank	1	100,000	10,000	110,000
TOTAL ACCOUNT 253		$473,000	$67,800	$540,800
TOTAL ACCOUNT 25				$799,900
TRANSMISSION PLANT				
ACCOUNT 52 - STRUCTURES & IMPROVEMENTS				
521 General Yard Improvements		← Included in Account 21 →		
522 Substation Buildings		← Included in Account 21 →		
523 Outdoor Substation Structures				
.1 Foundations (Main Power Transformer)	Lot	$14,000	$16,800	$30,800
TOTAL ACCOUNT 52		$14,000	$16,800	$30,800

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 53 - STATION EQUIPMENT					
531	Switchgear			← Not Included →	
532	Protective Equipment				
.1	Lightning Arresters	Lot	-	-	Incl. in Acct. 533
.2	Grounding System	Lot	$5,000	$5,600	$10,600
533	Main Conversion Equipment				
.1	Main Transformer	Lot	$1,656,000	$44,000	$1,700,000
536	Station Service Equipment				
.3	Insulating Oil Storage and Treatment System	Lot	$4,000	$5,600	$9,600
.5	Fire Protection Equipment	Lot	20,000	32,000	52,000
	TOTAL ACCOUNT 536		$24,000	$37,600	$61,600
	TOTAL ACCOUNT 53		$1,685,000	$87,200	$1,772,200
	TOTAL ACCOUNTS 52 & 53		$1,699,000	$104,000	$1,803,000
	TOTAL DIRECT CONSTRUCTION COST				$72,969,900

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MOLTEN SALT CONVERTER
1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

ESTIMATE OF DIRECT CONSTRUCTION COST
ENERGY CONVERSION SYSTEM
ONE (1) 2500 MWt MOLTEN SALT REACTOR
ONE (1) 880 MWe NON-REHEAT TURBINE GENERATOR UNIT
C.C.6F 40" L.S.B.
(1800 psi. 1000°F)
Two (2) 178 MWe (EACH) MERCURY TURBINE GENERATOR UNITS
T.C, 4F
(165 Psi. 1050°F)

(Prices as of 7-6-62 and Based on a 40 Hour Work Week)

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS				
211 Ground Improvements				
.1 Access Roads for Permanent Use)				
.11 Grading)				
.12 Surfacing)				
.13 Culverts)	15 Miles	-	-	In Place
.14 Bridges & Trestles)				
.15 Guards & Signs)				
.16 Lighting)				
.2 General Yard Improvements				
.21 Grading & Landscaping	Lot	$6,500	$20,400	$26,900
.22 Roads, Sidewalks & Parking Areas	47,000 S.F.	16,500	7,600	24,100
.23 Retaining Walls, Fences & Railings				
.231 Fence, Post, Gates	2,560 L.F.	9,000	3,200	12,200

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1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.24 Outside Water Systems Including Fire Hydrants & Water Tanks for General Use				
.241 Domestic Water System				
.2411 500 GPM Deep Well, Incl. Pump & Accessories	2			
.2412 Storage Tank, 300 Gal. & Controls	Lot	13,000	17,600	30,600
.2413 Water Softener, Piping & Controls	Lot			
.2414 Piping	Lot			
.242 Fire Protection System:				
.2421 Water Storage Tank	Lot			
.2422 2000 GPM Fire Pump & Motor Drive	1	29,000	28,800	57,800
.2423 Other Fire Protection Equipment	Lot			
.2424 Piping Including Hydrants	Lot			
.2425 Hose & Hose Houses	Lot			
.25 Sewers & Drainage Systems				
.251 Yard Drainage & Culverts	Lot	4,500	6,800	11,300

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u> (Cont'd.)				
211 <u>Ground Improvements</u> (Cont'd.)				
.25 Sewers & Drainage Systems (Cont'd.)				
.252 Sanitary Sewer System:				
.2521 Septic Tank) .2522 Dosing Siphon) .2523 Distribution Box) .2524 Tile Field (Drainage))	Lot	$12,000	$18,400	$30,400
.253 Storm Sewer System:) .2531 Excavation & Backfill) .2532 Vitrified Clay Tile (6" & 8")) .2533 Reinforced Concrete Pipe (27" & 30")) .2534 Manholes) .2535 Outfall Structure)	Lot	13,000	11,200	24,200
.26 Roadway & General Lighting:) .261 Security Fence Lighting) .262 Roadway Lighting) .263 Parkway Cable) .264 Trenching for Parkway Cable)	Lot	8,000	11,200	19,200

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.3 Railroads)				
.31 Off Site)				
.311 Grading)				
.312 Bridges, Culverts & Trestles)	5 Miles	$135,000	$132,000	$267,000
.313 Ballast & Track)				
.314 Signals & Interlocks)				
.32 On Site)				
.321 Ballast & Track)	265 LF	1,500	1,600	3,100
TOTAL ACCOUNT 211		$248,000	$258,800	$506,800
212 Buildings				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room				
.1 Excavation & Backfill				
.11 Earth Excavation	11,000 CY	-	11,200	11,200
.12 Rock Excavation	5,650 CY	-	45,200	45,200
.13 Backfill	6,250 CY	2,000	9,200	11,200
.14 Disposal	10,450 CY	-	4,400	4,400
.15 Dewatering	Lot	-	75,000	75,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room (Cont'd.)				
.3 Substructure Concrete) .31 Forms) .32 Reinforcing) .33 Concrete) .34 Waterproofing) .35 Patch & Finish) .36 Miscellaneous Anchor Bolts, Sleeves Etc. Embedded in Concrete)	6,400 CY (Conc.)	$220,000	$208,000	$428,000
.4 Superstructure) .41 Superstructure Concrete) .411 Forms) .412 Reinforcing) .413 Concrete)	31,000 SF of Floors	52,000	46,400	98,400
.42 Structural Steel & Miscellaneous Metal				
.421 Structural Steel	1,550 T	500,000	120,000	620,000
.422 Stairs, Ladders, Railings, Walkways, Grating, Etc.	Lot	55,000	24,000	79,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room (Cont'd.)				
.43 Exterior Walls				
.431 Masonry	-	-	-	-
.432 Insulated Metal Siding	64,300 SF	$132,000	$44,000	$176,000
.44 Roofing & Flashing)				
.441 Pre-Cast Roof Slabs)				
.442 Built-Up Roofing & Flashing)	34,000 SF	31,000	34,000	65,000
.443 Poured Concrete Roof Deck)				
.444 Insulation)				
.45 Interior Masonry & Partitions)				
.451 Structural Tile)	29,400 SF	15,000	20,000	35,000
.452 Metal Partition)				
.46 Doors & Windows				
.461 Doors	Lot	11,500	4,400	15,900
.462 Windows	11,400 SF	43,000	18,000	61,000
.47 Wall and Ceiling Finish)				
.471 Glazed Tile)				
.472 Metal Ceiling)				
.473 Plastering Incl. Lathing & Furring)	6,200 SF	5,000	4,400	9,400
.474 Acoustical Tile)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room (Cont'd.)				
.48 Floor Finish) .481 Cement) .482 Tile)	Lot	$29,000	$36,800	$65,800
.49 Painting Glazing & Insulation				
.491 Painting	Lot	9,500	28,500	38,000
.492 Glass & Glazing	-	-	-	(Incl. .462)
.5 Stack (Heating Boiler)	1	4,000	1,600	5,600
.6 Building Services) .61 Plumbing & Drainage Systems) .611 Plumbing) .612 Drainage) .613 Duplex Sump Pump) .614 Domestic Cold Water Tank) .615 Domestic Hot Water Tank)	Lot	60,000	32,000	92,000
.62 Heating Boiler & Accessories) .621 Heating Boiler) .622 Unit Heaters)	Lot	77,000	50,400	127,400

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room (Cont'd.)				
.62 Heating Boiler & Accessories (Cont'd.))				
.623 Discharge Ducts)				
.624 Condensate Pump & Receiver)				
.625 Flash Tank)				
.626 Piping)				
.627 Fuel Oil Transfer Pump,)				
.628 Heating Oil Tanks - Day & Storage)				
.6221 Berm For Fuel Oil Storage Tank)				
.6222 Foundation for Heating Oil Day Tank)				
.63 Ventilating System)				
.64 Air-Conditioning System)				
.641 Air-Conditioning Control Room)	Lot	$55,000	$28,000	$83,000
.642 Office Air-Conditioning)				
.643 Laboratory Air-Conditioning)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office, Control Room, Switch Gear Room (Cont'd.)				
.66 Lighting & Service Wiring)				
.661 Control Panels & Cabinets)				
.662 Conduit)				
.663 Wiring)	Lot	$44,500	$37,600	$82,100
.664 Fixtures, Switches, & Receptacles)				
.67 Fire Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	12,000	2,400	14,400
TOTAL ACCOUNT 212A		$1,357,500	$885,500	$2,243,000
212F Miscellaneous Buildings				
.1 Gate House	Lot	$5,500	$5,200	$10,700
.2 Electrical	Lot	3,000	2,800	5,800
TOTAL ACCOUNT 212F		$8,500	$8,000	$16,500
212G Reactor Plant Building				
.1 Excavation & Backfill				
.11 Earth Excavation	9,750 CY	-	$9,800	$9,800
.12 Rock Excavation	2,950 CY	-	58,800	58,800
.13 Backfill	6,950 CY	2,000	9,600	11,600
.14 Disposal	5,750 CY	-	2,400	2,400
.15 Dewatering	Lot	-	75,000	75,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 **Buildings** (Cont'd.)				
212G **Reactor Plant Building** (Cont'd.)				
.3 Substructure Concrete) .31 Forms) .32 Reinforcing) .33 Concrete) .34 Water Proofing) .35 Patch & Finish) .36 Miscellaneous Anchor Bolts, Sleeves Etc. Embedded in Concrete)	5,750 CY (Conc.)	$220,000	$216,000	$436,000
.4 Superstructure) .41 Superstructure Concrete) .411 Forms) .412 Reinforcing) .413 Concrete Interior)	8,550 CY	405,000	260,000	665,000
.42 Structural Steel & Miscellaneous Steel				
.421 Structural Steel & Reactor Support Steel	935 T	305,000	76,000	381,000
.422 Stairs, Ladders, Railings, Walkways, Grating, Etc.	Lot	35,000	16,000	51,000
.43 Exterior Walls				
.431 Masonry	-	-	-	-

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.43 Exterior Walls (Cont'd.)				
.432 Insulated Metal Siding	53,400 SF	$110,000	$36,000	$146,000
.433 Concrete Exterior Walls	3,850 CY	180,000	117,600	297,600
.44 Roofing & Flashing)				
.441 Pre-Cast Roof Slabs)				
.442 Built-Up Roofing & Flashing)	33,600 SF	30,000	32,400	62,400
.443 Insulation)				
.45 Interior Masonry & Partitions)				
.451 Structural Tile)	-	-	-	-
.452 Metal Partitions)				
.46 Doors and Windows				
.461 Doors	Lot	2,500	1,200	3,700
.462 Windows	9,300 SF	35,000	14,500	49,500
.47 Wall & Ceiling Finish)				
.471 Glazed Tile)				
.472 Metal Ceiling)				
.473 Plastering Incl. Lathing)	-	-	-	-
& Furring)				
.474 Acoustical Tile)				

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MOLTEN SALT CONVERTER
1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.48 Floor Finish				
.481 Cement	60,000 SF	20,000	24,000	44,000
.49 Painting, Glazing and Insulation				
.491 Painting	Lot	6,500	18,800	25,300
.492 Glass & Glazing	-	-	-	(Incl. Acct..462)
.493 Insulation of Reactor Chamber	-	-	-	(Incl. Acct. 221.32)
.5 Stack (When Supported On Building)	-	-	-	(Incl. Acct. 212A)
.6 Building Services				
.61 Plumbing & Drainage System				
.611 Plumbing) .612 Drainage) .613 Sump Pump)	Lot	15,000	8,000	23,000
.62 Cooling System) .63 Ventilating System)	Lot	130,000	70,000	200,000
.66 Lighting & Service				
.661 Control Panels & Cabinet) .662 Conduit) .663 Wiring) .664 Fixtures, Switches & Receptacles)	Lot	22,000	25,200	47,200

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.67 Fire-Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	10,000	2,000	12,000
TOTAL ACCOUNT 212G		$1,528,000	$1,073,300	$2,601,300
TOTAL COST ACCOUNT 212		$2,894,000	$1,966,800	$4,860,800
218 Stacks				
218A Concrete Chimney				
.1 Excavation & Backfill) .2 Substructure Concrete) .4 Concrete Chimney) .6 Obstruction Lighting)	1	35,000	36,000	71,000
TOTAL ACCOUNT 218A		$35,000	$36,000	$71,000
TOTAL ACCOUNT 218		$35,000	$36,000	$71,000
219 Reactor Container Structure			Not Included	
TOTAL ACCOUNT 21		$3,177,000	$2,261,600	$5,438,600
ACCOUNT 22 - REACTOR PLANT EQUIPMENT				
221 Reactor Equipment				
.1 Reactor Vessel and Supports		← Not Included →		
.2 Reactor Controls		← Not Included →		
.3 Reactor Shield		← Not Included →		
.32 Biological Shielding Insulation, Shield, Plugs, Etc.	Lot	345,000	156,000	501,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
221 Reactor Equipment (Cont'd.)				
.3 Reactor Shield (Cont'd.)				
.34 Shield Cooling System				
.341 Closed Loop Liquid System				
.3411 Shield Cooling Heat Exchanger (4000 Ft_2 Surface - Admiralty)	2	$35,000	$2,500	$37,500
.3412 Shield Cooling Circulating Pumps & Motors 2500 GPM 75 HP Motor	3	7,500	800	8,300
.3413 Piping & Valves		← Included in Account 228 →		
.3414 Cooling Coils Embedded in Concrete (16,000 ft.)	Lot	17,500	32,500	50,000
.3415 H_2O Storage Tank - 3000 Gallons	1	1,200	300	1,500
.4 Reactor Auxiliary Cooling & Heating System		← Not Included →		
.6 Moderator & Reflector		← Not Included →		
.7 Reactor Plant Cranes & Hoists		← Included in Account 251 →		
TOTAL ACCOUNT 221		$406,200	$192,100	$598,300
222 Heat Transfer Systems		← Not Included →		
.1 Reactor Coolant Systems				
.2 Intermediate Coolant System				
.21 Pumps and Drives				
.211 Mercury Fill Pumps Including Motor Drives	2	15,000	500	15,500

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MOLTEN SALT COVERTER
1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 22 - REACTOR PLANT EQUIPMENT</u> (Cont'd.)				
222 <u>Heat Transfer Systems</u> (Cont'd.)				
.21 Pumps and Drives				
.212 Mercury Pumps Incl. Motor Drives (From Mercury Condenser)	4	$290,000	$4,000	$294,000
.213 Mercury Pumps Incl. Motor Drives (From Superheaters No. 1 - 1 and No. 2 - 1)	4	130,000	3,000	133,000
.214 Mercury Pumps Incl. Motor Drives (From Superheaters No. 1 - 2, and No. 2 - 2)	4	100,000	2,000	102,000
.215 Mercury Make-Up, Supply & Storage Facilities - 15,000 gallon tank and Pumps, Pits	1	20,000	20,000	40,000
.22 Intermediate Coolant Piping and Valves				
.221 Piping)		← Included in Account 228 →		
.222 Valves, Including Control)				
.223 Other Valves)				
.224 Piping Supports)				
.23 Intermediate Heat Exchangers and Supports				
.231 Mercury Boilers	8	5,600,000	100,000	5,700,000

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
222 Heat Transfer Systems (Cont'd.)				
.2 Intermediate Coolant System (Cont'd.)				
.24 Mercury Clean-Up System		← Not Included →		
.3 Steam Generators and Superheaters				
.31 Steam Generators				
.311 Mercury Condensers	4	$1,200,000	$70,000	$1,270,000
.32 Superheaters				
.321 No. 1 Steam Superheater Including Supports	2	400,000	15,000	415,000
.322 No. 2 Steam Superheaters Including Supports	2	450,000	15,000	465,000
.4 Reactor Coolant Receiving, Supply, and Treatment		← Not Included →		
TOTAL ACCOUNT 222		$8,205,000	$229,500	$8,434,500
223 Fuel Handling and Storage Equipment		← Not Included →		
224 Fuel Processing and Fabrication Equipment		← Not Included →		
225 Radioactive Waste Treatment & Disposal		← Not Included →		

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
226 Instrumentation and Controls				
.1 Reactor		← Not Included →		
.2 Heat Transfer System		← Included in Account #235 →		
.3 Service to Fuel Handling & Storage		← Not Included →		
.4 Service to Radioactive Waste & Disposal		← Not Included →		
.5 Radiation Monitoring		← Not Included →		
.6 Steam Generator		← Included in Account #235 →		
.7 Control & Instrument Piping & Wiring		← Included in Account #235 →		
.8 Electrical Connections		← Included in Account #235 →		
.9 Other Miscellaneous		← Included in Account #235 →		
TOTAL ACCOUNT 226		-	-	-
227 Feed Water Supply and Treatment				
.1 Raw Water Supply	Lot	Incl. Acct. 211	Incl. Acct. 211	Incl. Acct. 211
.2 Make-Up Water Treatment				
.21 Evaporators	-	-	-	-
.22 Ion Exchange Equipment, Filters, Etc.	Lot	$45,000	$10,000	$55,000
.23 Acid & Caustic Trans. Pumps & Drives	2	600	200	800
.24 Demineralized Water Storage Tanks	Lot	30,000	Included	30,000
.25 Caustic Tank	1	2,200	400	2,600

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OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)					
227	Feed Water Supply and Treatment (Cont'd.)				
.2	Make-Up Water Treatment (Cont'd.)				
.26	Acid Tank	1	$2,200	$400	$2,600
.27	Foundation	Lot	3,500	2,500	6,000
.28	Piping & Valves	Lot	-	-	Incl. Acct. #228
.29	Insulation	Lot	-	-	Incl. Acct. #228
.3	Steam Generator Feed-Water Purification	-	-	-	-
.4	Feed Water Heaters				
.41	Deaerating Heaters ("D") 3,900,000 #/Hr. 150 psig.	2	250,000	15,000	265,000
.42	Closed Heaters				
.421	L.P. Heater "A"	3	100,000	5,000	105,000
.422	L.P. Heater "B"	3	75,000	5,000	80,000
.423	L.P. Heater "C"	3	78,000	3,000	81,000
.424	H.P. Heater "E"	3	228,000	3,000	231,000
.425	H.P. Heater "F"	3	209,000	3,000	212,000
.426	H.P. Heater "G"	3	247,000	3,000	250,000
.5	Feed Water Pumps and Drives				
.51	Feed Water Pumps and Drives				
.511	4960 GPM Pumps - 2000 psig hd.	4	514,000	16,000	530,000
.512	8000 H.P. 3600 RPM Motor	4	360,000	8,000	368,000
.513	Fluid Drive for F.W. Pump	4	240,000	6,000	246,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)					
227	Feed Water Supply and Treatment (Cont'd.)				
.5	Feed Water Pumps and Drives (Cont'd.)				
.53	Heater "A" Drain Pumps and Drives				
.531	1300 GPM Pump 265 psig hd. 1200 RPM	3	$24,000	$1,500	$25,500
.532	250 HP Heater "A" Drain Pump Motor	3	12,000	1,000	13,000
	TOTAL ACCOUNT 227		$2,420,500	$83,000	$2,503,500
228	Steam Condensate Feed Water, and all Other Piping, Valves, Etc. - for Turbine Plant, Crib House and Others Covered By this Estimate				
.1	Pipe, Valves, Fittings, Etc.				
.11	Turbine Plant)				
.12	Other Interior Piping)	Lot	4,500,000	2,000,000	6,500,000
.13	Yard Pipe, Etc.)				
.2	Insulation				
.21	Piping Insulation	Lot	625,000	675,000	1,300,000
.22	Equipment Insulation	Lot	75,000	105,000	180,000
	TOTAL ACCOUNT 228		$5,200,000	$2,780,000	$7,980,000
229	Other Reactor Plant Equipment	-	-	-	-
	TOTAL ACCOUNT 22		$16,231,700	$3,284,600	$19,516,300

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OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS					
231	Turbine Generators				
.1	Turbine Foundations				
.11	Concrete- Including Reinforcing Steel	Lot	$200,000	$200,000	$400,000
.12	Miscellaneous	Lot	12,000	13,000	25,000
.2	Turbine Generators				
.21	Turbine Generator Units - As Follows: - 880 MWe Turbine Generator Unit C.C.6F 40" L.S.B. Complete with Accessories, Steam Conditions @ Throttle: 1,800 psig - 1000°F Generators: H.P. Unit) L.P. Unit) 1,090,000 KVA .85 PF	1	19,580,000	850,000	20,430,000
.21A	Mercury Turbine Generator Units As Follows: - 178 MWe Turbine Generator Units T.C.4F 15 psia. Exhaust - Complete with Accessories Hg. Conditions @ Throttle: 165 psig. - 1050°F Generator - 224,000 KVA, .85 PF	2	16,000,000	675,000	16,675,000
.22	Accessories - Other Than Standard		← Incl. In Account 231.21 →		
.23	Generator		← Incl. In Account 231.21 →		
.24	Exciter (Motor Driven)				
.241	Steam Unit Motor Driven Exciters		← Incl. In Account 231.21 →		
.242	Mercury Unit Motor Driven Exciters		← Incl. in Account 231.21A →		

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OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd)					
231	Turbine Generators (Cont'd.)				
.3	Reserve Exciter				
.31	Steam Unit - Exciter - 4200 KW	1	$310,000	$10,000	$320,000
.32	Mercury Unit - Exciter - 1500 KW	1	140,000	5,000	145,000
	TOTAL ACCOUNT 231		$36,242,000	$1,753,000	$37,995,000
232	Circulating Water System				
.1	Pumping and Regulating Systems				
.11	Pumps Drives & Controls				
.112	149,000 GPM Vertical Mixed Flow Circulating Water Pumps - Head 30 ft.	6	510,000	21,000	531,000
.113	1750 HP Motor Drive for Circ. Water Pumps	6	360,000	12,000	372,000
.12	Traveling Screens, Etc.				
.121	Traveling Screens Complete with Motors	8	140,000	10,000	150,000
.122	1200 GPM Screen Wash Pumps - 230 Ft. Discharge Head	2	5,000	1,000	6,000
.123	100 HP Motor for Screen Wash Pump	2	4,500	Included	4,500
.124	Trash Rake Complete with Appurtenances	1	27,500	2,500	30,000
.125	Pipe & Valves	Lot	← Included in Account #228 →		

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
232 Circulating Water System (Cont'd.)				
.2 Circulating Water Lines				
.21 Supply Lines - To Condenser				
.211 Circulating Water Piping, Valves, Fitting, Etc.				
.2111 Steel Circulating Water Piping, Valves Expansion Joints, Fittings, Etc.	Lot	$175,000	$75,000	$250,000
.22 Discharge Lines - From Condenser				
.221 Circulating Water, Piping, Valves, Fittings, Etc.				
.2211 Steel Circulating Water Piping, Valves, Expansion Joints, Fittings, Etc.	Lot	← Included in Account 232.21 →		
.3 Intake and Discharge Structures				
.31 Intake Structures				
.311 River Dredging & Rock Removal	Lot	-	12,000	12,000
.312 Intake Flume				
.3121 Intake Flume Proper	Lot	-	45,000	45,000
.3122 Floating Boom	1	7,000	10,400	17,400
.3123 Concrete Retaining Walls	2	28,500	29,200	57,700
.313 Intake Crib House				
.3131 Substructure	Lot	155,000	150,000	305,000
.3132 Superstructure	-	-	-	-

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)					
232	Circulating Water System (Cont'd.)				
.3	Intake and Discharge Structures (Cont'd.)				
.3133	Steel	35 T	$11,000	$4,000	$15,000
.3134	Electrical Work	Lot	11,000	13,600	24,600
.32	Discharge				
.321	Seal Well & Discharge Tunnel	Lot	34,000	32,500	66,500
.322	Discharge Flume	Lot	6,000	27,200	33,200
.4	Fouling, Corrosion Control and Water Treatment				
.41	Chlorinating System				
.411	Chlorination Equipment	Lot	55,000	10,000	65,000
.412	Chlorine Handling Facilities	Lot	3,000	2,000	5,000
	TOTAL ACCOUNT 232		$1,532,500	$457,400	$1,989,900
233	Condensers and Auxiliaries				
.1	Condensers				
.11	Foundations	3	7,000	6,400	13,400
.12	Condenser Shell and Appurtenances				
.121	225,000 Sq. Ft. Single Pass Condensers Complete with Appurtenances Including Shell Water Boxes, Tube Sheets, Tube Supports, Hot Well, Extended Neck with Expansion Joint, Etc.	3	$1,365,000	$445,000	$1,810,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
233 Condensers and Auxiliaries (Cont'd.)				
.1 Condensers (Cont'd.)				
.13 40 Ft. Long Admiralty Condenser Tubes	3 Sets	$1,047,000	-	$1,047,000
.17 Instruments & Accessories	3 Sets	15,000	Included	15,000
.2 Condensate Pumps				
.21 Pumps & Drives				
.211 2350 GPM Condensate Pumps Complete with Appurtenances, Discharge Head - 600 Ft.	6	84,000	6,000	90,000
.212 450 HP Motors for Condensate Pumps	6	46,800	4,200	51,000
.22 Suction Piping	Lot		← Included Account 228 →	
.3 Air Removal Equipment & Piping				
.31 Steam Jet Air Ejectors, with Inter & After Condensers	6	100,000	9,000	109,000
.32 Air Suction Piping	Lot		← Included Account 228 →	
.33 Priming Ejectors	3	10,500	Included	10,500
TOTAL ACCOUNT 233		$2,675,300	$470,600	$3,145,900
234 Central Lubricating System				
.1 Treating & Pumping Equipment	Lot	17,000	2,000	19,000
.2 Storage Tanks & Appurtenances	Lot	14,000	3,000	17,000
.3 Fire Protection	Lot		← Included in Account 237 →	
TOTAL ACCOUNT 234		$31,000	$5,000	$36,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)					
235	Turbine Plant Boards Instruments & Controls				
.1	Control Equipment				
.11	Mechanical Control Boards)				
.12	Isolated Controller, Transmitters Etc.)	Lot	525,000	50,000	575,000
.2	Isolated Recording Gauges Meters & Instruments)				
.3	Control & Instrument - Piping & Tubing	Lot	35,000	100,000	135,000
.4	Electrical Connections	Lot	30,000	52,000	82,000
	TOTAL ACCOUNT 235		$590,000	$202,000	$792,000
236	Turbine Plant Piping				
.1	Main Steam Between Stop Valves and Turbine Inlet	Lot	← Included In Account 231.2 →		
.2	Drip, Drain and Vent Piping and Valves	Lot	← Included In Account 228 →		
	TOTAL 236		← Included In Account 228 →		
237	Auxiliary Equipment for Generators				
.1	Excitation Panels, Switches & Rheostats	Lot	← Included In Account 231.2 →		
.2	Generator Cooling Water Systems				
.21	Lubricating Oil Cooling System)				
.22	Generator Hydrogen Cooling System)	Lot	$60,000	$12,000	$72,000
.23	Generator Liquid Cooling System)				

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)					
237	Auxiliary Equipment for Generators (Cont'd.)				
.3	Central Hydrogen Cooling System	-	-	-	-
.4	Fire Extinguishing Equipment Including Piping and CO_2 System Exclusively for Generators				
.5	Fire Extinguishing Equipment for Oil Room, Etc.	Lot	$77,000	$23,000	$100,000
	TOTAL ACCOUNT 237		$137,000	$35,000	$172,000
238	Other Turbine Plant Equipment				
.1	Gland Seal Water System	Lot	← Included in Account 228 →		
.2	Vacuum Priming System	Lot	← Included in Account 228 →		
	TOTAL ACCOUNT 238		← Included in Account 228 →		
	TOTAL ACCOUNT 23		$41,207,800	$2,923,000	$44,130,800
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT					
241	Switchgear				
.1	Generator Main & Neutral Circuits				
.11	Generator Potential Trans. Comp't.	4	$60,000	$6,400	$66,400
.12	Surge Protection Equipment	4	23,000	3,200	26,200
.13	Generator Neutral Equipment	3	13,000	2,400	15,400
.14	Miscellaneous Items	Lot	12,000	24,000	36,000
.2	Station Service				
.21	13.8KV Switchgear	Lot	82,000	10,400	92,400
.22	4160V Switchgear	Lot	352,000	49,600	401,600
.23	480V Switchgear	Lot	109,000	16,800	125,800
	TOTAL ACCOUNT 241		$651,000	$112,800	$763,800

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MOLTEN SALT CONVERTER
1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)					
242	Switchboards				
.1	Main Control Board	Lot	$120,000	$45,600	$165,000
.2	Auxiliary Power Battery & Signal Board				
.21	Battery & Battery Charging Panels	1	15,000	5,600	20,600
.22	D.C. Control & Auxiliary Panels	2	18,000	4,800	22,800
.23	A.C. Control & Instrument Panels	2	12,000	3,200	15,200
.24	Motor Control Centers	Lot	75,000	12,000	87,000
.25	Miscellaneous Panels & Boards	Lot	28,000	17,600	45,600
	TOTAL ACCOUNT 242		$268,000	$88,800	$356,800
243	Protective Equipment				
.1	General Station Grounding Equipment	Lot	65,000	52,000	117,000
.2	Fire Protection System	Lot	15,000	8,800	23,800
	TOTAL ACCOUNT 243		$80,000	$60,800	$140,800
244	Electrical Strucutres				
.1	Concrete Cable Tunnels, Compartments and Cable Trenches in Earth	Lot	15,500	25,200	40,700
.2	Cable Trays & Supports	181,000 lb.	75,000	68,000	143,000
.3	Pipe, and Steel Frames & Supports	Lot	7,000	8,000	15,000
.4	Foundations & Pads for Electrical Equipment	Lot	6,000	7,200	13,200
	TOTAL ACCOUNT 244		$103,500	$108,400	$211,900

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ENGINEERS
CHICAGO

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1000 MWe MERCURY BINARY CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)					
245	Conduit				
.1	Conduit				
.11	Power Conduit	Lot	$28,000	$72,000	$100,000
.12	Control & Instrument Conduit	Lot	25,000	66,400	91,400
.2	Concrete Envelopes				
.21	6 Cell - 4" Transite Korduct Duct Run	710 Ft.	8,500	10,000	18,500
.22	10" Transite Pipe Duct Run	Lot	6,000	7,200	13,200
.23	Iron Conduit Enclosed in Concrete	Lot	11,000	18,400	29,400
.3	Manholes & Covers	5	5,000	5,600	10,600
	TOTAL ACCOUNT 245		$83,500	$179,600	$263,100
246	Power & Control Wiring				
.1	Main Power Cables & Bus Duct				
.11	Isolated Phase Bus Duct (Generator)	Lot	770,000	68,000	838,000
.12	Main Power Cables	Lot	121,000	19,200	140,200
.2	Control Auxiliary Power Excitation Wiring				
.21	Auxiliary Power Cable (Including Excitation Wiring)	Lot	401,500	256,800	658,300
.22	Control & Instrument Wiring	Lot	544,000	408,800	952,800
	TOTAL ACCOUNT 246		$1,836,500	$752,800	$2,589,300

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OAK RIDGE, TENNESSEE

			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)						
247	Station Service Equipment					
	.1	Station Service Transformers & Voltage Regulators				
	.11	Unit & Reserve Auxiliary	Lot	$329,000	$16,000	$345,000
	.12	4160/480 V. Auxiliary Transformers	Lot	33,000	4,000	37,000
	.13	Miscellaneous Small Transformers	Lot	8,000	3,200	11,200
	.2	Batteries, Charging Equipment and Motor Generating Sets	Lot	40,000	8,000	48,000
	.3	Remote Controls at Motors and Equipment	Lot	40,000	48,000	88,000
	.4	Electric Heating - Salt Melting	Lot	38,000	45,600	83,600
		TOTAL ACCOUNT 247		$488,000	$124,800	$612,800
		TOTAL ACCOUNT 24		$3,510,500	$1,428,000	$4,938,500
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT						
251	Cranes and Hoisting Equipment					
	.1	Combined Turbine & Reactor Plant Crane 4 Motor Bridge Type 150 Ton Main and 15 Ton Auxiliary Hoist Capacity Respectively	1	$150,000	$20,000	$170,000
	.2	Miscellaneous Cranes & Hoists	Lot	23,000	2,000	25,000
		TOTAL ACCOUNT 251		$173,000	$22,000	$195,000

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OAK RIDGE, TENNESSEE

			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT (Cont'd.)						
252	Compressed Air and Vacuum Cleaning System					
	.1	Compressors and Accessories				
	.11	200 C.F.M. Station Air Compressor including Motor Drive	2	13,500	1,200	14,700
	.12	250 C.F.M. Control Air Compressor including Motor	2	15,500	1,200	16,700
	.13	Air Drying Equipment for Control Air System	2	9,000	500	9,500
	.14	Receivers				
	.141	Station Sir	2	1,300	300	1,600
	.142	Control Air	2	1,300	300	1,600
	.2	Pipe Valves and Fittings	Lot	← Included in Account 228 →		
	.3	Vacuum Cleaning System	Lot	16,000	4,000	20,000
		TOTAL ACCOUNT 252		$56,600	$7,500	$64,100
253	Other Power Plant Equipment					
	.1	Local Communication, Signal & Call System	Lot	$45,000	$40,000	$85,000
	.2	Fire Extinguishing Equipment				
	.21	2000 GPM Fire Pump Including Drive and Accessories		← Included in Account 221.24 →		
	.22	Other Fire Protection Equipment	Lot	19,000	1,000	20,000
	.3	Furniture and Fixtures	Lot	10,000	-	10,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT (Cont'd.)				
253 Other Power Plant Equipment (Cont'd.)				
.4 Lockers, Shelves, and Cabinets	Lot	$7,000	-	$7,000
.5 Cleaning Equipment	Lot	4,000	-	4,000
.6 Machine Tools & Other Station Maintenance Equipment	Lot	240,000	10,000	250,000
.7 Laboratory, Test & Weather Instruments				
.71 Radiation Monitoring Equipment	Lot	23,000	2,000	25,000
.72 Miscellaneous Laboratory Test & Weather Instruments	Lot	20,000	-	20,000
.9 Diesel Generator Unit 1,000 KW Including Oil Tank	1	100,000	10,000	110,000
TOTAL ACCOUNT 253		$468,000	$63,000	$531,000
TOTAL ACCOUNT 25		$697,600	$92,500	$790,100
TRANSMISSION PLANT ACCOUNT 50 - LAND AND LAND RIGHTS		← Not Included →		
ACCOUNT 51 - CLEARING LAND & LAND RIGHTS OF WAY		← Not Included →		
ACCOUNT 52 - STRUCTURES & IMPROVEMENTS				
521 General Yard Improvements		← Included in Account 21 →		
522 Substation Buildings		← Not Included →		
523 Outdoor Substation Structures				
.1 Foundations (Main Power Transformer)	Lot	20,000	24,000	44,000
TOTAL ACCOUNT 52		$20,000	$24,000	$44,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 53 - STATION EQUIPMENT				
531 Switchgear		← Not Included →		
532 Protective Equipment				
.1 Lightning Arresters	Lot	-	-	Incl. Acct. 533
.2 Grounding System	Lot	9,000	7,200	16,200
533 Main Conversion Equipment				
.1 Main Transformers	Lot	2,840,000	68,000	2,908,000
536 Station Service Equipment				
.3 Insulating Oil Storage & Treatment System	Lot	5,000	6,400	11,400
.5 Fire Protection Equipment	Lot	24,000	38,400	62,400
TOTAL ACCOUNT 536		$29,000	$44,800	$73,800
TOTAL ACCOUNT 53		$2,878,000	$120,000	$2,998,000
TOTAL ACCOUNTS 52 & 53		$2,898,000	$144,000	$3,042,000
TOTAL DIRECT CONSTRUCTION COST				$77,856,300

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1000 MWe DIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

ESTIMATE OF DIRECT CONSTRUCTION COST
ENERGY CONVERSION SYSTEM
ONE (1) 2,500 MWt MOLTEN SALT REACTOR
ONE (1) 1,000 MWe REHEAT TURBINE GENERATOR
UNIT C.C.6F 40" L.S.B.
(2400 Psig. - 1000°F - 1000°F)

(Prices as of 7-6-62 and Based on a 40 Hour Work Week)

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS				
211 Ground Improvements				
.1 Access Roads for Permanent Use				
.11 Grading)				
.12 Surfacing)				
.13 Culverts)				
.14 Bridges & Trestles)	15 Miles	-	-	In Place
.15 Guards & Signs)				
.16 Lighting)				
.2 General Yard Improvements				
.21 Grading Landscaping	Lot	$5,500	$10,000	$15,500
.22 Roads, Sidewalks & Parking Areas	47,000 SF	16,500	7,600	24,100
.23 Retaining Walls Fences & Railings				
.231 Fence, Post, Gates	2,360 LF	8,000	3,200	11,200
.24 Outside Water Distribution Systems Including Fire Hydrants & Water Tanks for General Use				
.241 Domestic Water System				
.2411 500 GPM Deep Well, Including Pump and Accessories				

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UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
211 Ground Improvements (Cont'd.)				
.2 General Yard Improvements (Cont'd.)				
.241 Domestic Water System (Cont'd.)				
.2412 Storage Tank, 300 Gal. & Controls)				
.2413 Water Softener, Piping & Controls)	Lot	$12,000	$16,800	$28,800
.2414 Piping)				
.242 Fire Protection System:				
.2421 Water Storage Tank)				
.2422 2000 GPM Fire Pump & Motor Drive)				
.2423 Other Fire Protection Equipment)	Lot	27,000	26,400	53,400
.2424 Piping Including Hydrants)				
.2425 Hose & Hose Houses)				
.25 Sewers & Drainage Systems				
.251 Yard Drainage & Culverts	Lot	4,000	7,000	11,000
.252 Sanitary Sewer System)				
.2521 Septic Tank)	Lot	12,000	18,400	30,400
.2522 Dosing Syphon)				
.2523 Distribution Box)				
.2524 Tile Field (Drainage)				
.253 Storm Sewer System				
.2531 Excavation & Backfill)				
.2532 Vitrified Clay Tile (6" & 8"))				
.2533 Reinforced Concrete Pipe (27" & 30")	Lot	12,000	10,400	22,400
.2534 Manholes)				
.2535 Outfall Structures)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u> (Cont'd.)				
211 <u>Ground Improvements</u> (Cont'd.)				
.26 Roadway & General Lighting				
.261 Security Fence Lighting)				
.262 Roadway Lighting)	Lot	$8,000	$11,200	$19,200
.263 Parkway Cable)				
.264 Trenching for Parkway Cable)				
.3 Railroads				
.31 Off Site)				
.311 Grading)				
.312 Bridges, Culverts & Trestles)	5 Miles	135,000	132,000	267,000
.313 Ballast & Track)				
.314 Signals & Interlocks)				
.32 On Site				
.321 Ballast & Tract	265 LF	1,500	1,600	3,100
TOTAL ACCOUNT 211		$241,500	$244,600	$486,100
212 <u>Buildings</u>				
212A <u>Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room</u>				
.1 Excavation & Backfill				
.11 Earth Excavation	11,500 CY	-	11,500	11,500
.12 Rock Excavation	5,650 CY	-	45,200	45,200
.13 Backfill	6,350 CY	2,000	9,400	11,400
.14 Disposal	10,800 CY	-	4,400	4,400

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room, (Cont'd.)				
.1 Excavation & Backfill (Cont'd.)				
.15 Dewatering	Lot	-	75,000	75,000
.3 Substructure Concrete				
.31 Forms)				
.32 Reinforcing)				
.33 Concrete)				
.34 Waterproofing)	6,750 CY (Conc.)	232,000	218,400	450,400
.35 Patch & Finish)				
.36 Miscellaneous Anchor Bolts Sleeves Etc. Embedded in Concrete)				
.4 Superstructure				
.41 Superstructure Concrete				
.411 Forms)				
.412 Reinforcing)	34,000 SF (Floors)	57,500	49,000	106,500
.413 Concrete)				
.42 Structural Steel & Miscellaneous Metal				
.421 Structural Steel	1,650 T	535,000	128,000	663,000
.422 Stairs, Ladders, Railings, Walkways, Gratings, Etc.	Lot	55,000	24,000	79,000

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u> (Cont'd.)				
212 <u>Buildings</u> (Cont'd.)				
212A <u>Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room</u> (Cont'd.)				
.4 Superstructure (Cont'd.)				
.43 Exterior Walls				
.431 Masonry	-	-	-	-
.432 Insulated Metal Siding	66,400 SF	134,000	46,400	180,400
.44 Roofing & Flashing				
.441 Pre-Cast Roof Slabs)				
.442 Built-Up Roofing & Flashing)	35,600 SF	32,000	36,000	68,000
.443 Poured Concrete Roof Deck)				
.444 Insulation)				
.45 Interior Masonry & Partitions				
.451 Structural Tile	29,800 SF	15,100	20,300	35,400
.46 Doors & Windows				
.461 Doors	Lot	11,500	4,400	15,900
.462 Windows	12,600 SF	48,000	20,000	68,000
.47 Wall and Ceiling Finish				
.471 Glazed Tile)				
.472 Metal Ceiling)				
.473 Plastering Incl. Lathing & Furring)	6,200 SF	5,000	4,400	9,400
.474 Accoustical Tile)				

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212A Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room (Cont'd.)				
.4 Superstructure (Cont'd.)				
.48 Floor Finish				
.481 Cement) .482 Tile)	Lot	30,000	38,100	68,100
.49 Painting, Glazing & Insulation				
.491 Painting	Lot	10,500	32,400	42,900
.492 Glass & Glazing	-	-	-	Included 462
.5 Stack (When Supported on Building)	1	4,000	1,600	5,600
.6 Building Services				
.61 Plumbing & Drainage Systems				
.611 Plumbing) .612 Drainage) .613 Duplex Sump Pump) .614 Domestic Cold Water Tank) .615 Domestic Hot Water Tank)	Lot	60,000	32,000	92,000
.62 Heating Boiler & Accessories				
.621 Heating Boiler) .622 Unit Heaters) .623 Discharge Ducts) .624 Condensate Pump & Receiver)	Lot	77,000	50,400	127,400

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u> (Cont'd.)				
212 <u>Buildings</u> (Cont'd.)				
212A <u>Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room</u> (Cont'd.)				
.6 Building Services (Cont'd.)				
.62 Heating Boiler & Accessories) (Cont'd.))				
.625 Flash Tank)				
.626 Piping)				
.627 Fuel Oil Transfer Pump)				
.628 Heating Oil Tanks - Day and Storage)				
.6221 Berm for Fuel Oil Storage Tank)				
.6222 Foundation for Heating Oil Day Tank)				
.63 Ventilating System)				
.64 Air Conditioning System)				
.641 Air Conditioning Control Room)	Lot	$55,000	$28,000	$83,000
.642 Office Air-Conditioning)				
.643 Laboratory Air-Conditioning)				
.66 Lighting & Service Wiring				
.661 Control Panels & Cabinets)				
.662 Conduit)				
.663 Wiring)	Lot	47,000	39,200	86,200
.664 Fixtures, Switches, & Receptacles)				

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)					
212	Buildings (Cont'd.)				
212A	Turbine Generator Building Including Office Control Room, Cable Room, Switch Gear Room (Cont'd.)				
.6	Building Services (Cont'd.)				
.67	Fire Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	$12,000	$2,400	$14,400
	TOTAL ACCOUNT 212A		$1,422,600	$920,500	$2,343,100
212F	Miscellaneous Buildings				
.1	Gate House	Lot	5,500	5,200	10,700
.2	Electrical	Lot	3,000	2,800	5,800
	TOTAL ACCOUNT 212F		$8,500	$8,000	$16,500
212G	Reactor Plant Building				
.1	Excavation & Backfill				
.11	Earth Excavation	2,900 CY	-	3,000	3,000
.12	Rock Excavation	1,250 CY	-	25,000	25,000
.13	Backfill	240 CY	-	400	400
.14	Disposal	3,940 CY	-	1,600	1,600
.15	Dewatering	Lot	-	40,000	40,000
.3	Substructure Concrete				
.31	Forms)				
.32	Reinforcing)				
.33	Concrete)				
.34	Waterproofing)				
.35	Patch & Finish)	3,000 CY (Conc.)	115,000	108,000	223,000
.36	Miscellaneous Anchor Bolts, Sleeves Etc. Embedded in Concrete)				

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)					
212	Buildings (Cont'd.)				
212G	Reactor Plant Building (Cont'd.)				
.4	Superstructure				
.41	Superstructure Concrete				
.411	Forms)				
.412	Reinforcing)	4,980 CY	255,000	163,200	418,200
.413	Concrete Interior)				
.42	Structural Steel & Miscellaneous Steel				
.421	Structural Steel & Reactor Supports	565 T	180,000	48,000	228,000
.422	Stairs, Ladders, Railings Walkways, Grating Etc.	Lot	22,000	10,400	32,400
.43	Exterior Walls				
.431	Masonry	-	-	-	-
.432	Insulated Metal Siding	31,070 SF	65,000	20,000	85,000
.433	Concrete Walls	2,550 CY	120,000	76,800	196,800
.44	Roofing & Flashing				
.441	Pre-Cast Roof Slabs)				
.442	Built-Up Roofing & Flashing)	15,700 SF	14,000	15,200	29,200
.443	Insulation)				
.45	Interior Masonry & Partitions				
.451	Structural Tile)	-	-	-	-
.452	Metal Partition)				

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OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
<u>ACCOUNT 21 - STRUCTURES & IMPROVEMENTS</u> (Cont'd.)				
212 <u>Buildings</u> (Cont'd.)				
212G <u>Reactor Plant Building</u> (Cont'd.)				
.4 Superstructure (Cont'd.)				
.46 Doors & Windows				
.461 Doors	Lot	$2,200	$1,000	$3,200
.462 Windows	5,430 SF	20,000	8,800	28,800
.47 Wall & Ceiling Finish				
.471 Glazed Tile)				
.472 Metal Ceiling)				
.473 Plastering Including Lathing) and Furring)	-	-	-	-
.474 Accoustical Tile)				
.48 Floor Finish				
.481 Cement	24,000 SF	8,000	9,600	17,600
.49 Painting Glazing and Insulation				
.491 Painting	Lot	4,000	10,400	14,400
.492 Glass & Glazing	-	-	-	Included .462
.493 Insulation Of Reactor Chamber				Included in Account 221.32
.5 Stack - (When Supported on Building)	-	-	-	Included in Account 212A
.6 Building Services				
.61 Plumbing & Drainage System				
.611 Plumbing)				
.612 Drainage)	Lot	12,000	6,400	18,400
.613 Sump Pump)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 21 - STRUCTURES & IMPROVEMENTS (Cont'd.)				
212 Buildings (Cont'd.)				
212G Reactor Plant Building (Cont'd.)				
.6 Building Services (Cont'd.)				
.62 Cooling System) .63 Ventilating System)	Lot	$32,500	$17,500	$50,000
.66 Lighting & Service				
.661 Control Panels & Cabinet) .662 Conduit) .663 Wiring) .664 Fixtures, Switches & Receptacles)	Lot	11,500	12,800	24,300
.67 Fire Protection System (Water Lines, Hose, Sprinkler, Etc.)	Lot	7,000	1,000	8,000
TOTAL ACCOUNT 212G		$868,200	$579,100	$1,447,300
TOTAL ACCOUNT 212		$2,299,300	$1,507,600	$3,896,900
218 Stacks				
218A Concrete Chimney				
.1 Excavation & Backfill) .2 Substructure Concrete) .4 Concrete Chimeny) .6 Obstruction Lighting)	1	$35,000	$36,000	$71,000
TOTAL ACCOUNT 218A		$35,000	$36,000	$71,000
TOTAL ACCOUNT 218		$35,000	$36,000	$71,000
219 Reactor Container Structure		Not Included	Not Included	Not Included
TOTAL ACCOUNT 21		$2,575,800	$1,788,200	$4,364,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT					
221	Reactor Equipment				
.1	Reactor Vessel and Supports		← Not Included →		
.2	Reactor Controls		← Not Included →		
.3	Reactor Shield				
.32	Biological Shielding (Above Grade Floor Including Plug)	Lot	$294,000	$141,000	$435,000
.34	Shield Cooling System				
.341	Closed Loop Liquid System				
.3411	Shield Cooling Heat Exchanger (4000 Ft^2 Surface Admiralty)	2	35,000	2,500	37,500
.3412	Shield Cooling Circulating Pumps & Motors (2500 GPM 75 HP Motor)	3	7,500	800	8,300
.3413	Piping & Valves		← (Included in Account 228) →		
.3414	Cooling Coil Embedded in Concrete (16,000 Ft.) 1" Steel	16,000 LF	17,500	32,500	50,000
.3415	H_2O Storage Tank - 3000 Gallons	1	1,200	300	1,500
.4	Reactor Auxiliary Cooling		← Not Included →		
.6	Moderator & Reflector		← Not Included →		
.7	Reactor Plant Cranes & Hoists	-	← (Included in Account 251) →		
	TOTAL ACCOUNT 221		$355,200	$177,100	$532,300

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT-22 - REACTOR PLANT EQUIPMENT (Cont'd.)					
222	Heat Transfer Systems				
.1	Reactor Coolant Systems		← Not Included →		
.2	Intermediate Coolant System		← None →		
.3	Steam Generators Superheaters & Reheaters				
.31	Boilers and Supports	8	$6,400,000	$80,000	$6,480,000
.32	Superheaters	8	6,640,000	64,000	6,704,000
.34	Steam Dryers	8	140,000	8,000	148,000
.35	Steam Reheaters	8	3,280,000	40,000	3,320,000
.36	Steam Dryer Recirculating Pumps 1250 GPM - 25 Psig Hd.	8	80,000	4,000	84,000
.37	Insulation for Above Equipment		← Included in Account 228 →		
.4	Reactor Coolant Receiving Supply & Treatment		← Not Included →		
	TOTAL ACCOUNT 222		$16,540,000	$196,000	$16,736,000
223	Fuel Handling and Storage Equipment		← Not Included →		
224	Fuel Processing and Fabrication Equipment		← Not Included →		

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
225 Radioactive Waste Treatment and Disposal		← Not Included →		
226 Instrumentation and Control				
.1 Reactor		← Not Included →		
.2 Heat Transfer System		← Included in Account #235 →		
.3 Service to Fuel Handling & Storage		← Not Included →		
.4 Service to Radioactive Waste & Disposal		← Not Included →		
.5 Radiation Monitoring		← Not Included →		
.6 Steam Generator		← Included in Account #235 →		
.7 Control & Instrument Piping & Wiring		← Included in Account #235 →		
.8 Electrical Connections		← Included in Account #235 →		
.9 Other Miscellaneous Items		← Included in Account #235 →		
TOTAL ACCOUNT 226		-	-	-
227 Feed Water Supply and Treatment				
.1 Raw Water Supply	Lot	← Included in Account #211 →		
.2 Make-Up Water Treatment				
.21 Evaporators	-	-	-	-
.22 Ion Exchange Equipment Filters, Etc.	Lot	$45,000	$10,000	$55,000
.23 Acid & Caustic Transf. Pumps & Drives	2	600	200	800
.24 Demineralized Water Storage Tanks	2	30,000	Included	30,000

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		QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)					
227	Feed Water Supply and Treatment (Cont'd.)				
.2	Make-Up Water Treatment (Cont'd.)				
.25	Caustic Tank	1	$2,200	$400	$2,600
.26	Acid Tank	1	2,200	400	2,600
.27	Foundation	Lot	3,500	2,500	6,000
.28	Piping & Valves		← Included in Account 228 →		
.29	Insulation		← Included in Account 228 →		
.3	Steam Generator Feed-Water Purification	-	-	-	-
.4	Feed Water Heaters				
.41	Deaerating Heaters (E) 3,500,000 #/Hr; 150 Psig.	2	240,000	15,000	255,000
.42	Closed Heaters				
.421	L.P. Heater "A"	3	75,000	5,000	80,000
.422	L.P. Heater "B"	3	63,000	5,000	68,000
.423	L.P. Heater "C"	3	63,000	3,000	66,000
.424	L.P. Heater "D"	3	81,000	3,000	84,000
.425	H.P. Heater "F"	3	315,000	3,000	318,000
.426	H.P. Heater "G"	3	429,000	3,000	432,000
.427	H.P. Heater "H"	3	441,000	3,000	444,000
.5	Feed-Water Pumps and Drives				
.51	Feed-Water Pumps & Drives				
.511	5900 GPM Pumps - 2465 Psig Hd.	3	405,000	12,000	417,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
227 Feed-Water Supply and Treatment (Cont'd.)				
.5 Feed-Water Pumps and Drives (Cont'd.)				
.51 Feed-Water Pumps & Drives (Cont'd.)				
.512 10,000 H.P. - B.F. Pump Turbine Drive	3	750,000	30,000	780,000
.52 Motor Driven Start-Up F.W. Pump				
.521 6000 GPM Pump: 850 Psig. Hd.	1	70,000	3,000	73,000
.522 3500 HP - Start-Up F.W. Pump Motor	1	55,000	2,000	57,000
.53 Heater "A" Drain Pumps and Drives				
.531 560 GPM Pump: 285 Psig. Hd.) .532 125 H.P. Heater "A" Drain Pump Motor)	3	22,500	1,500	24,000
.54 Heater "C" Drain Pumps and Drives				
.541 625 GPM Pumps 210 Psig Hd.) .542 100 H.P. Heater "C" Drain Pump Motor)	3	30,000	2,500	32,500
TOTAL ACCOUNT 227		$3,123,000	$104,500	$3,227,500

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 22 - REACTOR PLANT EQUIPMENT (Cont'd.)				
228 Steam, Condensate, Feed Water and all Other Piping Valves Etc. for Turbine Plant Crib House and Others Covered by this Estimate				
.1 Pipe, Valves, Fittings, Etc.				
.11 Turbine Plant)				
.12 Other Interior Piping)				
.13 Yard Pipe Etc.)	-	$3,770,000	$2,150,000	$6,100,000
.2 Insulation				
.21 Piping Insulation		575,000	625,000	1,200,000
.22 Equipment Insulation		90,000	120,000	210,000
TOTAL ACCOUNT 228		$4,435,000	$2,895,000	$7,330,000
229 Other Reactor Plant Equipment	-	-	-	-
TOTAL ACCOUNT 22				$27,825,800
ACCOUNT 23 - TURBINE GENERATOR UNITS				
231 Turbine-Generators				
.1 Turbine Foundations				
.11 Concrete - Including Reinforcing Steel, Etc.	Lot	$175,000	$175,000	$350,000
.12 Miscellaneous	Lot	10,000	10,000	20,000
.2 Turbine Generators				
.21 Turbine Generator Units As Follows: 1000 MWe Turbine Generator Unit C.C. 6F 40" L.S.B. Complete with Accessories Steam Conditions 2400 Psig - 1000°F-1000°F Generators: 1,280,000 KVA Total - .85 P.F. and .64 SCR	1	$19,815,000	$960,000	$20,775,000

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			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)						
231	Turbine-Generators (Cont'd.)					
	.2	Turbine Generators (Cont'd.)				
	.22	Accessories - Other Than Standard		← Included in Account 231.21 →		
	.3	Reserve Exciter	1	340,000	10,000	350,000
		TOTAL ACCOUNT 231		$20,340,000	$1,155,000	$21,495,000
232	Circulating Water System					
	.1	Pumping and Regulating Systems				
	.11	Pumps Drives & Controls				
	.112	120,000 GPM Vertical Mixed Flow Circulating Water Pumps - Head 30'	6	360,000	18,000	378,000
	.113	1250 H.P. Motor Drive for Circulating Water Pumps	6	270,000	10,000	280,000
	.12	Traveling Screens, Etc.				
	.121	Traveling Screen Complete with Motors	7	122,500	8,700	131,200
	.122	1200 G.P.M. Screen Wash Pumps - 230 Ft. Discharge Head	2	5,000	1,000	6,000
	.123	100 H.P. Motor for Screen Wash Pump	2	4,500	Included	4,500
	.124	Trash Rake Complete with Appurtenances	1	27,500	2,500	30,000
	.125	Pipe & Valves	Lot	← Included in Account 228 →		

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
232 Circulating Water Systems (Cont'd.)				
.2 Circulating Water Lines				
.21 Supply Lines - To Condenser				
.211 Circulating Water Piping, Valves, Fitting, Etc.				
.2111 Steel Circulating Water Piping, Valves Expansion Joints, Fittings, Etc.	Lot	$155,000	$70,000	$255,000
.22 Discharge Lines - From Condenser				
.221 Circulating Water Piping, Valves, Fittings, Etc.				
.2211 Steel Circulating Water Piping, Valves, Expansion Joints, Fittings, Etc.		← Included in Account 232.21 →		
.3 Intake and Discharge Structures				
.31 Intake Structures				
.311 River Dredging and Rock Removal	Lot	-	12,000	12,000
.312 Intake Flume				
.3121 Intake Flume Proper	Lot	-	45,000	45,000
.3122 Floating Boom	1	7,000	10,400	17,400
.3123 Concrete Retaining Walls	2	28,500	29,200	57,700
.313 Intake Crib House				
.3131 Substructure	Lot	140,000	135,000	275,000
.3132 Superstructure	-	-	-	None
.3133 Steel	35 T	11,000	4,000	15,000
.3134 Electrical Work	Lot	11,000	13,600	24,600
.32 Discharge				
.321 Seal Well and Discharge Tunnel	Lot	29,500	28,400	57,900
.322 Discharge Flume	Lot	4,500	22,400	26,900

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			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)						
232	Circulating Water Systems (Cont'd.)					
	.4	Fouling, Corrosion Control and Water Treatment				
	.41	Chlorinating System				
	.411	Chlorination Equipment	Lot	$45,000	$8,000	$53,000
	.412	Chlorine Handling Facilities	Lot	3,000	2,000	5,000
		TOTAL ACCOUNT 232		$1,224,000	$420,200	$1,644,200
233	Condensers and Auxiliaries					
	.1	Condensers				
	.11	Foundations	3	7,000	6,400	13,400
	.12	Condenser Shell and Appurtenances				
	.121	225,000 Sq. Ft. Single Pass Condenser (50' Tubes Complete with Appurtenances Including Shell, Water Boxes, Tube Sheets, Tube Supports, Hot Well, Extended Neck with Expansion Joint, Etc.)	3	1,320,000	440,000	1,760,000
	.13	50 Ft. Long Admiralty Condenser Tubes	3 Sets	1,053,000	Included	1,053,000
	.17	Instruments & Accessories	Lot	15,000	Included	15,000
	.2	Condensate Pumps				
	.21	Pumps & Drives				
	.211	1675 GPM Condensate Pumps Complete with Appurtenances, Discharge Head - 325 Psi.	6	87,000	6,000	93,000

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
233 Condensers and Auxiliaries (Cont'd.)				
.2 Condensate Pumps (Cont'd.)				
.212 400 H.P. Motors for Condensate Pumps	6	$46,800	$4,200	$51,000
.3 Air Removal Equipment & Piping				
.31 Steam Jet Air Ejectors, with Inter & After Condensers	6	100,000	9,000	109,000
.32 Air Suction Piping	Lot	←Included in Account 228→		
.33 Priming Ejectors	3	10,500	Included	10,500
TOTAL ACCOUNT 233		$2,639,300	$465,600	$3,104,900
234 Central Lubricating System				
.1 Treating & Pumping Equipment	Lot	17,000	2,000	19,000
.2 Storage Tanks & Appurtenances	Lot	14,000	3,000	17,000
.3 Fire Protection	Lot	-	-	Incl. Acct. 237
TOTAL ACCOUNT 234		$31,000	$5,000	$36,000
235 Turbine Plant Boards Instruments & Controls				
.1 Control Equipment				
.11 Mechanical Control Boards)				
.12 Isolated Controller, Transmitters, Etc.)	Lot	275,000	25,000	300,000
.2 Isolated Recording Gauges, Meters & Instruments)				

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)				
235 Turbine Plant Boards Instruments & Controls (Cont'd.)				
.3 Control & Instrument - Piping & Tubing	Lot	$20,000	$55,000	$75,000
.4 Electrical Connections	Lot	18,000	33,600	51,600
TOTAL ACCOUNT 235		$313,000	$113,600	$426,600
236 Turbine Plant Piping				
.1 Main Steam Between Stop Valves and Turbine Inlet		← Included in Account 231.2 →		
.2 Drip, Drain and Vent Piping & Valves		← Included in Account 228 →		
TOTAL 236		← Included in Account 228 →		
237 Auxiliary Equipment for Generators				
.1 Excitation Panels, Switches & Rheostats		← Included in Account 231.2 →		
.2 Generator Cooling Water Systems				
.21 Lubricating Oil Cooling System)				
.22 Generator Hydrogen Cooling)	-	$60,000	$12,000	$72,000
.23 Generator Liquid Cooling System)				
.3 Central Hydrogen Cooling System		-	-	-
.4 Fire Extinguishing Equipment Including Piping and CO_2 System exclusively for Generators)	Lot	50,000	15,000	65,000
.5 Fire Extinguishing Equipment for Oil Room Etc.)				
TOTAL ACCOUNT 237		$110,000	$27,000	$137,000

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			QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTAL
ACCOUNT 23 - TURBINE GENERATOR UNITS (Cont'd.)						
238	Other Turbine Plant Equipment					
	.1	Gland Seal Water System	Lot	← Included in Account 231.2 →		
	.2	Vacuum Priming System	Lot	← Included in Account 228 →		
		TOTAL ACCOUNT 238		← Included in Account 228 →		
		TOTAL ACCOUNT 23				$26,843,700
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT						
241	Switchgear					
	.1	Generator Main & Neutral Circuits				
	.11	Generator Pot. Transformer Compartment	2	38,000	4,000	42,000
	.12	Surge Protection Equipment	2	14,000	1,600	15,600
	.13	Generator Neutral Equipment	1	6,000	800	6,800
	.14	Miscellaneous Items	Lot	8,000	16,000	24,000
	.2	Station Service				
	.21	13.8KV Switchgear	-	-	-	-
	.22	4160V Switchgear	Lot	231,000	36,000	267,000
	.23	480V. Switchgear	Lot	110,000	17,600	127,600
		TOTAL ACCOUNT 241		$407,000	$76,000	$483,000
242	Switchboards					
	.1	Main Control Board	Lot	82,000	31,200	113,200

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)				
242 Switchboards				
.2 Auxiliary Power, Battery & Signal Board				
.21 Battery & Battery Charging Panels	1	$15,000	$5,600	$20,600
.22 D.C. Control & Auxiliary Panels	2	18,000	4,800	22,800
.23 A.C. Control & Instrument Panels	1	7,000	1,600	8,600
.24 Motor Control Centers	Lot	60,000	9,600	69,600
.25 Miscellaneous Panels & Boards	Lot	14,000	8,800	22,800
TOTAL ACCOUNT 242		$196,000	$61,600	$257,600
243 Protective Equipment				
.1 General Station Grounding Equipment	Lot	50,000	42,400	92,400
.2 Fire Protection	Lot	12,000	8,000	20,000
TOTAL ACCOUNT 243		$62,000	$50,400	$112,400
244 Electrical Structures				
.1 Concrete Cable, Tunnels, Compartments and Cable Trenches in Earth	Lot	9,500	17,600	27,100
.2 Cable Trays & Supports	132,000 lb.	55,000	49,600	104,600

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)				
244 **Electrical Structures** (Cont'd.)				
.3 Pipe and Steel Frames & Supports	Lot	$5,000	$6,400	$11,400
.4 Foundations & Pads for Electrical Equipment	Lot	4,000	4,800	8,800
TOTAL ACCOUNT 244		$73,500	$78,400	$151,900
245 **Conduit**				
.1 Conduit				
.11 Power Conduit	Lot	$23,000	$56,400	$79,400
.12 Control & Instrument Conduit	Lot	21,000	52,000	73,000
.2 Concrete Envelopes				
.21 6 Cell - 4" Transite Korduct Duct Run	700 Ft.	8,000	9,600	17,600
.22 10" Transite Pipe Duct Run	Lot	5,500	6,800	12,300
.23 Iron Conduit Enclosed in Concrete	Lot	7,000	12,000	19,000
.3 Manholes & Covers	5	5,000	5,600	10,600
TOTAL ACCOUNT 245		$69,500	$142,400	$211,900

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UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)				
246 Power & Control Wiring				
.1 Main Power Cables & Bus Duct				
.11 Isolated Phase Bus Duct (Generator)	Lot	$576,000	$49,600	$625,600
.12 Main Power Cables	Lot	110,000	16,000	126,000
.2 Control Auxiliary Power Excitation Wiring				
.21 Auxiliary Power Cable (Including Excitation Wiring)	Lot	321,000	205,600	526,600
.22 Control & Instrument Wiring	Lot	455,000	340,000	795,000
TOTAL ACCOUNT 246		$1,462,000	$611,200	$2,073,200
247 Station Service Equipment				
.1 Station Service Transformers & Voltage Regulators				
.11 Unit & Reserve Auxiliary	Lot	221,000	8,800	229,800
.12 4160/480V Auxiliary Transformers	Lot	38,000	4,000	42,000
.13 Miscellaneous Small Transformers	Lot	5,500	2,000	7,500
.2 Batteries, Charging Equipment and Motor Generating Sets	Lot	40,000	8,000	48,000

SARGENT & LUNDY
ENGINEERS
CHICAGO

Exhibit No. 18
Report No. SL-1954
Est. No. 4682
Job No. 3123-1
Date 7-6-62

MOLTEN SALT CONVERTER
1000 MWe DIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 24 - ACCESSORY ELECTRIC EQUIPMENT (Cont'd.)				
247 Station Service Equipment (Cont'd.)				
.3 Remote Controls at Motors and Equipment	Lot	$35,000	$43,200	$78,200
.4 Electric Heating - Salt Melting	Lot	67,000	80,800	147,800
TOTAL ACCOUNT 247		$406,500	$146,800	$553,300
TOTAL ACCOUNT 24		$2,676,500	$1,166,800	$3,843,300
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT				
251 Cranes and Hoisting Equipment				
.1 Combined Turbine & Reactor Plant Crane 4 Motor Bridge Type 150 Ton Main and 15 Ton Auxiliary Hoist Capacity Respectively	1	$150,000	$20,000	$170,000
.2 Miscellaneous Cranes & Hoists	Lot	23,000	2,000	25,000
TOTAL ACCOUNT 251		$173,000	$22,000	$195,000
252 Compressed Air and Vacuum Cleaning System				
.1 Compressors and Accessories				
.11 200 C.F.M. Station Air Compressors including Motor Drive	2	$13,500	$1,200	$14,700

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT (Cont'd.)				
252 Compressed Air and Vacuum Cleaning System (Cont'd.)				
.1 Compressors and Accessories (Cont'd.)				
.12 250 C.F.M. Control Air Compressors including Motor Drive	2	$15,500	$1,200	$16,700
.13 Air Drying Equipment for Control Air System	2	9,000	500	9,500
.14 Receivers				
.141 Station Air	2	1,300	300	1,600
.142 Control Air	2	1,300	300	1,600
.2 Pipe Valves and Fittings	Lot	-	-	Incl. Account 228
.3 Vacuum Cleaning Systems	Lot	16,000	4,000	20,000
TOTAL ACCOUNT 252		$56,600	$7,500	$64,100
253 Other Power Plant Equipment				
.1 Local Communication, Signal & Call System	Lot	38,000	33,600	71,600
.2 Fire Extinguishing Equipment				
.21 2000 GPM Fire Pump Including Drive & Accessories	-	-	-	Incl. Account 211.4
.22 Other Fire Protection Equipment	Lot	19,000	1,000	20,000

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1000 MWe DIRECT POWER CYCLE
UNION CARBIDE NUCLEAR COMPANY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 25 - MISCELLANEOUS POWER PLANT EQUIPMENT (Cont'd.)				
253 Other Power Plant Equipment (Cont'd.)				
.3 Furniture and Fixtures	Lot	$10,000	-	$10,000
.4 Lockers, Shelves, and Cabinets	Lot	7,000	-	7,000
.5 Cleaning Equipment	Lot	4,000	-	4,000
.6 Machine Tools & Other Station Maintenance Equipment	Lot	240,000	10,000	250,000
.7 Laboratory Test & Weather Instruments				
.71 Radiation Monitoring Equipment	Lot	23,000	2,000	25,000
.72 Miscellaneous Laboratory Test Weather Instruments	Lot	20,000	-	20,000
.9 Diesel Generator Unit - 1000 KW - Including Oil Storage Tank	1	100,000	10,000	110,000
TOTAL ACCOUNT 253		$461,000	$56,600	$517,600
TOTAL 25				$776,700
TRANSMISSION PLANT				
ACCOUNT 50 - LAND AND LAND RIGHTS		← Not Included →		
ACCOUNT 51 - CLEARING LAND & LAND RIGHTS OF WAY		← Not Included →		

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OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 52 - STRUCTURES & IMPROVEMENTS				
521 General Yard Improvements		← Included in Account 21 →		
522 Substation Buildings		← Not Included →		
523 Outdoor Substation Structures				
.1 Foundations (Main Power Transformer)	Lot	$14,000	$16,800	$30,800
TOTAL ACCOUNT 52		$14,000	$16,800	$30,800
ACCOUNT 53 - STATION EQUIPMENT				
531 Switchgear		← Not Included →		
532 Protective Equipment				
.1 Lightning Arresters	Lot	-	-	Included in Account 533
.2 Grounding System	Lot	$5,000	$5,600	$10,600
533 Main Conversion Equipment				
.1 Main Transformers	Lot	1,680,500	44,000	1,724,500
536 Station Service Equipment				
.3 Insulating Oil Storage and Treatment System	Lot	4,000	5,600	9,600

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	QUANTITY	MATERIAL OR EQUIPMENT	LABOR	TOTALS
ACCOUNT 53 - STATION EQUIPMENT (Cont'd.)				
536 Station Service Equipment (Cont'd.)				
.5 Fire Protection Equipment	Lot	$20,000	$32,000	$52,000
TOTAL ACCOUNT 536		$24,000	$37,600	$61,600
TOTAL ACCOUNT 53		$1,709,500	$87,200	$1,796,700
TOTAL ACCOUNTS 52 & 53		$1,723,500	$104,000	$1,827,500
TOTAL DIRECT CONSTRUCTION COST				$65,481,000

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APPENDIX A

MOLTEN SALT CONVERTER REACTOR

CYCLE AND PRIMARY SYSTEMS

OAK RIDGE NATIONAL LABORATORY

APPENDIX A

MOLTEN SALT CONVERTER REACTOR CYCLES AND PRIMARY SYSTEMS

L. Alexander, D. Janney, R. Robertson,
J. Westsik, R. Van Winkle,
Oak Ridge National Laboratory

I. Summary

This section contains the information which has been submitted to Sargent & Lundy for a capital cost study of three different thermal conversion systems that might be used to generate 1000 Mwe from a molten salt converter reactor operating in the temperature range of 1100 to 1300 F. The information consists of flowsheets, major equipment specifications, suggested equipment arrangements and piping layouts, and a price list for various forms of INOR-8, a specially developed high strength, corrosion resistant alloy metal. None of the systems has been optimized from the point of view of structural design or operating conditions. The three systems chosen for study were: (1) The Loeffler boiler cycle, which represents a near-term system with probably the fewest development problems; (2) the mercury binary cycle, which represents an advanced technology capable of higher thermal efficiencies than the others; and (3) a direct fuel-salt-to-steam cycle, which represents a system of possibly simpler mechanical design with fewer items of equipment. It is hoped that the cost study will: (1) provide a basis for assessing the incentives of undertaking development work on the more advanced concepts (assuming that the Loeffler boiler cycle represents a starting point); (2) provide a tabulation of costs of typical equipment items that might be used in studies of other possible heat removal cycles, and which might be used in a capital cost study of a reference design of a molten salt reactor nuclear power station; and (3) reveal areas which might be subject to important reductions in cost as a result of optimization studies.

II. Introduction

The energy produced in the fuel salt of a molten-fluoride reactor system may be converted to useful electric power by the transfer of heat from the salt at high temperature to one, or to combinations, of several different thermodynamic working fluids which may be used to drive turbogenerators. Mercury and water are common fluids which have had application in central-station power plants; and of these, only water is being used in large, modern plants.

Although a molten-fluoride reactor may be operated using fuel salt at temperatures high enough to produce steam at conditions which would satisfy the demands of the most modern steam turbine, and a number of different systems have been proposed for removing heat from the salt and transferring it to water, there exists no salt-to-water power cycle which has been tested, even on a small pilot-scale. The design of heat exchangers for transporting heat from molten salt to water is made difficult by the large temperature differences between salt and water, which may cause high temperature gradients with attendant unacceptably high thermal stresses in the tube walls. The high melting points (the order of 850 F and higher) of the various salts of interest make large temperature differences unavoidable; however, metal wall temperature gradients may be kept within acceptable limits by reducing the heat flux by the addition of thermal resistance between the salt and the water or steam. This is accomplished in the direct fuel-salt-to-water heat exchangers by separating the fuel-salt from the boiling water or steam with an annulus of buffer salt, thereby isolating the fuel-salt from the steam and reducing the over-all heat transfer coefficient and heat flux to acceptable values.

In a second type of heat exchanger, the Kinyon boiler, the same effect is accomplished by interposing an annulus of steam (which is also being superheated) between the boiling water in the inner tube and the intermediate coolant salt on the outside of the tube.

In a third scheme, which uses the steam from a Loeffler boiler to cool the salt, the high film resistance of steam limits the heat flux across the tube wall. The mass flow rate of steam through the tubes may be varied to control the value of the steam film heat transfer coefficient.

In all three of these methods of transferring heat from fuel salt to steam, possible mixing of fuel salt with steam as a result of fuel-salt-tube failure is avoided by having a buffer fluid between the fuel salt and the steam. In the direct salt-to-steam heat exchanger the buffer fluid is a stagnant salt (either a binary fluoride of beryllium and lithium or a mixed alkali carbonate), while in the other two systems an intermediate coolant is circulated through a primary heat exchanger, where heat is transferred from the fuel salt, and transported to the steam generators or superheaters. Sodium has been

proposed as an intermediate heat transfer fluid, but it is not likely to be seriously considered for this use because it is incompatible with both fuel salt and with steam.

Mercury is an alternate intermediate fluid which may be used either as a simple heat transport medium as is the intermediate coolant salt, or it may serve a dual purpose in driving a mercury-vapor topping turbine and supplying heat (that which is rejected by the mercury turbine) to generate and superheat steam in mercury-heated, water-cooled heat exchangers (thus the term "mercury binary cycle"). Higher thermal cycle efficiencies (up to 48%) are possible using the mercury binary cycle. An added advantage of the mercury cycle is that leakage of mercury into the fuel salt is not expected to have adverse effects on the fuel salts because the mercury would be volatilized at the high salt temperature and removed as a gas; nor would the mercury react with the fuel salt.

Of the systems discussed above, the Loeffler boiler cycle appears to be the one that is nearest to being a "developed system". The design of the steam-cooled superheaters and reheaters appears to be straightforward, and the salt pumps and primary heat exchangers will be tested in the MSRE. Some development work would be required before the large size steam circulators and boilers could be built, nevertheless no unforeseen or difficult problems either in design or development are anticipated. Disadvantages of the Loeffler boiler cycle are that it has a lower thermal efficiency than the other two cycles because of the extra power consumed by the steam circulators, and that it may also be burdened with a higher capital investment because of the extra equipment that is required (primary heat exchangers, inventory of coolant salt, coolant salt pumps and piping, steam circulators, and larger size steam handling equipment such as boiler drums and piping necessary to handle the greater-than-normal flows of superheated steam peculiar to the Loeffler cycle).

Flowsheets were developed for three different power conversion cycles based on the use of a single-region molten salt converter reactor fueled with a particular fuel-bearing fertile salt mixture (MSCR No.2 fuel salt) operating between the temperature limits of 1100 and 1300 F, and developing enough heat to produce a nominal 1000 Mwe of power. In order to obtain a comparison of probable capital costs associated with these conversion systems, information consisting of major equipment specifications, suggested equipment arrangement, and piping layout was submitted to Sargent & Lundy for cost study. It should be noted that none of the systems was optimized from the point of view of structural design or operating conditions. Sargent & Lundy combined each of these systems with appropriate turbo-generators in conceptual designs from which capital costs were determined. Some of the equipment and systems common to the three different power conversion cycles were excluded from the cost studies.

The three systems chosen were: (1) the Loeffler boiler cycle, which represents a near-term system with the fewest apparent development problems; (2) the mercury binary cycle, which represents an advanced technology capable of higher thermal efficiencies than the others; and (3) a direct fuel-salt-to-steam cycle, which represents a system of possibly simpler mechanical design with fewer items of equipment made possible by the elimination of the intermediate coolant pump and heat exchanger circuits. The Kinyon boiler was not included in this study because its heat exchanger design is quite similar to those of the direct system, and it also has the intermediate coolant salt circuits of the Loeffler boiler cycle.

Results expected of this cost comparison study include: (1) a basis for assessing the incentives, if any, for undertaking the development work on the more advanced concepts (assuming that the Loeffler boiler cycle represents a starting point); (2) a tabulation of costs of typical equipment items that might be used in other possible heat removal cycles which are modifications of the three cycles being studied; (3) cost figures which might be used in a capital cost study of a reference design of a molten salt reactor nuclear power station; and (4) revelation of areas which might as a result of optimization studies be subject to important reductions in cost.

Results which ought not be expected are: (1) an absolute figure, in terms of dollars per installed kilowatt, which can be said to represent the required capital investment in the thermal conversion systems of molten salt power reactors; (2) a system design from which a practical power reactor could be built (there are too many areas of uncertainty where problems such as maintainability, thermal stresses, safety, etc., could not be considered in sufficient detail); (3) a system which has no unnecessary conservatism in its design, such as the specification of materials which may be much better than absolutely required by the expected service conditions; and (4) a system which has no features in its design that would make it unfeasible, or impractical.

III. Description of Reactor Components Common to all Three Thermal Conversion Systems

A. Discussion

Although equipment items such as the reactor vessel and core, and fuel-salt handling systems (drain tanks, preparation areas, etc.) are not included in the cost estimate of the thermal conversion systems, certain features and design assumptions in the reactor and primary fuel circuits will affect the design requirements and cost of the various heat removal circuits. For instance, pressure drop across the core and top and bottom distribution headers enters into the specification of the design pressure of the salt piping and heat exchangers, both primary and secondary, and of course, the higher the required design pressure, the more will be the cost of the heat exchange equipment. It is for this reason that design criteria, assumptions, and problems associated with the reactor itself are included in the following descriptions.

B. General Description of a Molten Salt Converter Reactor

The MSCR is a single-region, unreflected, graphite-moderated fluid fuel reactor utilizing a mixture of molten fluorides of lithium, beryllium, thorium and uranium as a fuel salt which flows through the core in contact with the bare graphite. The generation of heat by the nuclear reaction raises the temperature of the fuel salt. This heat is carried by the fuel salt to heat exchangers where it may be transferred to intermediate coolant fluids, such as a coolant salt or mercury, or directly to boiling water or steam. In the reference design of this study, the reactor core is assumed to be a 20-foot diameter by 20-foot high cylinder of graphite pierced by fuel salt flow channels which comprise about 10% of the total core volume. Salt and graphite are contained in a reactor vessel constructed of INOR-8, a nickel alloy. Fuel salt enters the bottom of the reactor vessel and flows upward through the core. At the top of the core the heated fuel salt is collected by the top plenum and is distributed to multiple external pump and heat exchanger circuits where it gives up its heat and is returned to the bottom of the reactor. In all of the thermal conversion cycles being studied here, the reactor vessel, pump suction lines, pumps, pump discharge nozzles, and salt return headers are assumed to be identical although the developed head and flow rates may differ slightly. The number, size and location of the fuel salt heat exchangers differ among the three cycles as do inside dimensions of the primary shield which surrounds all fuel-containing components of the fuel-salt circuits. A neutron shield 18 inches thick is assumed to surround the core. This makes the effective outside diameter of the reactor equal to 23 feet. Whether this shield is inside or

outside the reactor vessel is immaterial to the cost study of the heat removal system.

C. MSCR Vessel, Fuel, and Moderator

Purpose--- The reactor vessel contains the moderator and holds it in a stable position during all phases of operation, provides for accepting fuel discharged from the heat exchangers, passage of fuel through the moderator, and discharge to the fuel pumps (see Fig. 1).

Criteria--- The reactor must be designed to expose the fuel to neutrons at a specified ratio of graphite volume to fuel volume. The graphite must be supported and restrained under several conditions, including the drained condition. Allowance must be made for differential expansion between graphite and vessel. Provision must be made for distributing the flow of fuel over the core entrance, and for collecting the flow at the exit. A free surface in an expansion chamber must be provided somewhere in the fuel circuit, and circulation through the expansion chamber must be maintained. Provision must be made for preheating the reactor vessel prior to charging molten salt, for cooling the reactor vessel during operation and after shutdown. This cooling must be accomplished without the generation of excessive thermal stresses. The vessel must be designed in conformance with the pressure vessel code developed for nuclear reactors by ASME . Means of purging the fuel in the expansion chamber with an inert gas must be provided to remove xenon and other volatile materials, if any. Excessive thermal stress in the graphite must be avoided, hence it must be composed of pieces sufficiently small that differential shrinkage due to exposure to neutrons will be tolerable in each piece.

Stagnation of the fuel between adjacent blocks of graphite or between graphite and metal structure must be avoided if such stagnation leads to excessive temperatures or stresses in either the fuel, graphite, or metal structure. Temperature at the fuel-graphite interface should be below that at which chemical reaction, if any, takes place at an appreciable rate, and below the temperature at which any important constituent of the salt (other than volatile fission products) has appreciable vapor pressure (e.g., if UF_4 were to vaporize appreciably and diffuse into pores in the graphite, this would be disadvantageous and perhaps hazardous). Temperature gradients in the graphite near stagnation areas should not exceed those corresponding to tolerable thermal stresses.

Fuel salt should permeate the graphite not more than 0.1 per cent by volume. With this penetration, and 10 volume per cent of fuel in the core, about 0.9 per cent of the fuel will be in

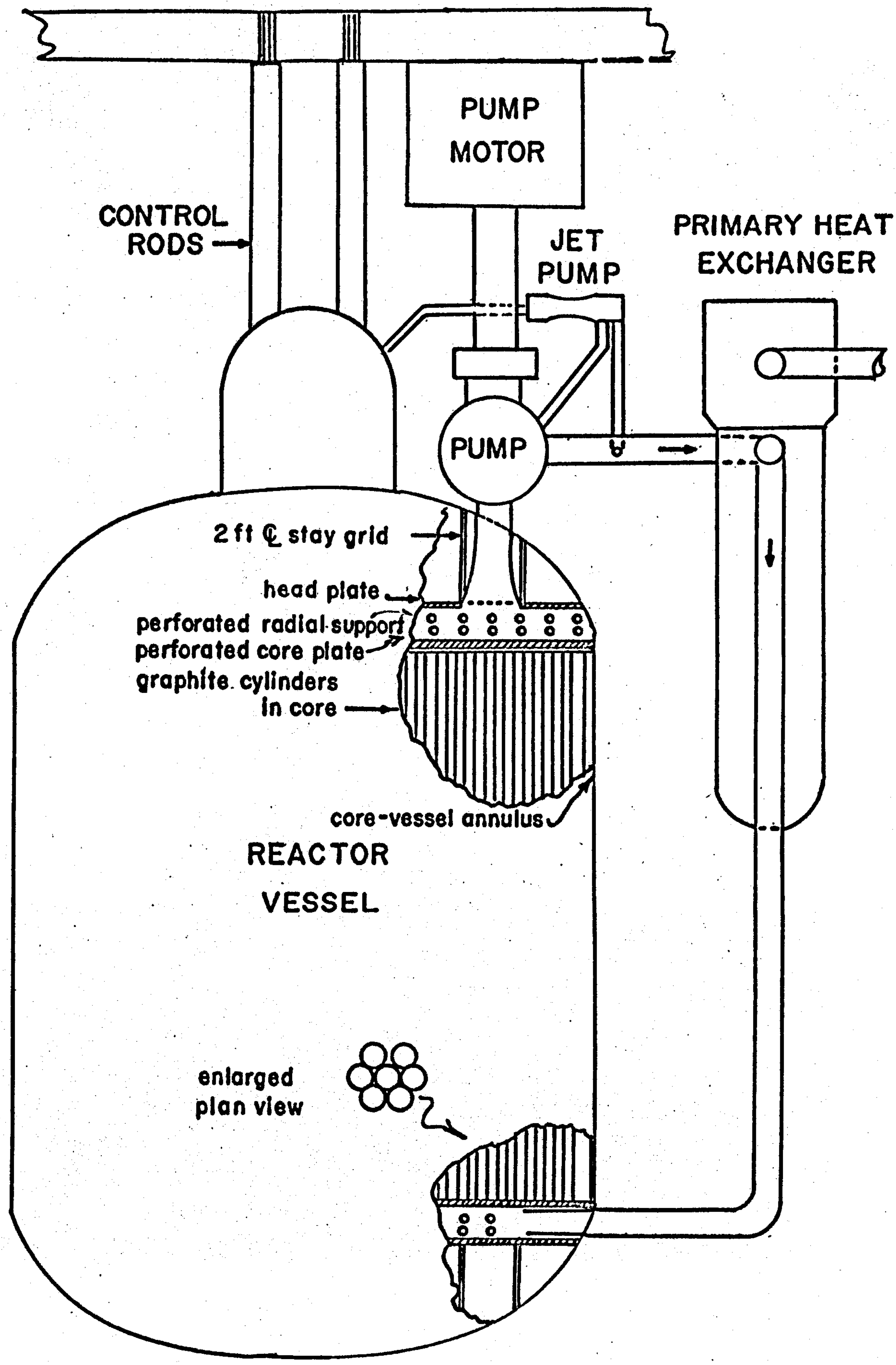

FIG. 1 MSCR REACTOR VESSEL -- Schematic

the pores in the graphite. This is probably tolerable, especially if the accessible pores are those near the surface, as seems to be the case.

Fuel stagnation in cracks between blocks and in pores in the blocks is closely related to the problem of afterheat, since the fuel so involved is probably not readily drainable. Means of flushing out the fuel-salt thus retained must be provided if possible, and if this is not possible, means of removing the heat generated in the core after drainage must be provided.

Temperature rise and thermal stress in the reactor vessel must be limited to tolerable levels. Differential thermal expansion will leave a gap between the graphite structure and the reactor vessel. It will be necessary to provide some flow through this annulus not only to remove the heat generated there, but also to cool the reactor vessel walls, which are subject to internal heat generation.

It may be necessary to orifice the flow channels, or otherwise vary their width systematically in order to distribute the flow through the core compatibly with the power density distribution and so achieve more nearly uniform temperature rise in all fuel channels.

Fuel make-up and withdrawal facilities, possibly as a part of a fill and drain system, must be included for the continual processing of spent fuel.

Materials--- For the moderator, graphite having properties similar to those of MSRE graphites (MSR-61-139) with a few exceptions (notably the porosity), shall be used. The reactor vessel and all component parts in contact with the salt will be constructed of INOR-8. The properties of INOR-8 will be in accordance with "Proposed Case for Ni-Mo-Cr Alloy," ASME Boiler and Pressure Vessel Code, Section VIII, March 1962. Equipment thermal insulation will be applied in two layers, one of high temperature material (silica type diatomaceous earth) and an outer layer of 85% magnesia.

Table 1. MSCR Fuel and Moderator Properties

	Fuel [1]	Moderator [2]
Composition	$LiF-BeF_2-ThF_4$	———
Mole %	68 - 23 - 9	———
Liquidus Temp., F	887	———
Mol. wt.	56.2	———
Sp. gr. @ 1200 F	3.045	1.9
Viscosity #/hr-ft	21	———
Thermal conduct Btu/hr-ft-F(@ 1200 F)	2.91	15
Specific heat, Btu/lb F	0.383	———
Poisson's ratio	———	0.4
Max. allowable strain	———	0.001 in/in
Max. allowable porosity (accessible to salt)	———	0.1%

(1) MSCR No. 5

(2) MSCR No. 2

Conceptual Design--- The design chosen was adapted from that proposed by MacPherson et al., [1] and is shown schematically in Fig. 1. The inlet nozzles discharge the fuel radially at the bottom. The radial flow area is adjusted to keep the radial velocity approximately constant.

The core is too large to be fabricated from a single, monolithic piece of graphite. Stringers, 4-8 inches in diameter, and similar to those used in the MSRE, but 20 feet long might be used. In that length, however, differential shrinkage might cause severe bowing. It seems desirable to construct the moderator from small pieces. Spheres might be used, but with uniform sized spheres, the void fraction is about 40 per cent. With two sizes of spheres, void fraction of 23% can be achieved, provided they are assembled so that one small sphere is located in each of the voids formed by close packing the large spheres in a regular hexagonal array.

The minimum void space in a triangular lattice of cylinders, amounts to 9.4 per cent. Short cylinders provided with mating pin and socket could be assembled into a lattice having about 10 per cent voids. However, the volume of such a loosely interconnected array would not be fixed; it would undoubtedly expand in the radial direction as the reactor vessel expanded (in being heated from room temperature). In a 20-foot vessel, the radial volume increment amounts to about 1/40 of the volume of the core. A void fraction of 10 per cent would thus be increased to 12.5 per cent by the expansion of the vessel, provided the incremental void spaces were uniformly distributed. This added void fraction may impair the performance (by raising the fuel cycle cost). More important, there is no guarantee that it will distribute itself uniformly; rather, small elements of extra void would probably diffuse through the bed in a random fashion under the influence of mechanical and hydraulic vibrations. Their accidental concentration at the center of the core might result in a power excursion.

The assembled moderator (or "pile") rests on a perforated INOR-8 support plate. The blocks are held in proper position relative to the plate by a number of pins protruding from the plate near its center. Differential thermal expansion due to preheating will then increase the annulus between the pile and the shell periphery. The plate is supported from the bottom of the reactor vessel by radial support plates, perforated to some degree.

The arrangement at the top of the vessel is similar. Initially, the graphite moderator rests on the bottom plate. As molten salt is added, the "pile" floats up against the upper plate, where it is positioned radially by vertical pins similar to those at the bottom. The upper face of the top blocks can be serrated to provide fuel flow channels thus minimizing fuel stagnation at that point. The upper plate must be stronger than the lower since it must bear, in addition to the buoyancy force, the force resulting from the upward flow of the fuel through the core, by far the larger force. Further, the temperature of the fuel is a maximum at the upper plate.

If difficulty with short-circuiting of the fuel through the annular gap between moderator and vessel wall is encountered, this could be controlled by eliminating any gap between the outer blocks of graphite so that the blocks fit tightly one against the other. The annulus thus becomes a channel unconnected to the voids in the moderator, and the flow through it could be orificed at the top where the pile floats up against the upper support plate.

A special dome construction will provide for reactor surge volume, for control rod insertion, and for fuel salt purge. The dome space above the operating liquid level will be in a helium atmosphere; a 10% side stream from the fuel-salt pump discharge will be atomized into this space for pumping of entrained volatiles. The salt volume

in the dome will be minimized by insertion of a suitable filler. The operating liquid level will be such that the pumps will be assured of positive suction pressure.

Design Conditions--- The graphite containing region shall be a cylinder 20 feet in diameter and 20 feet high. The fuel passages shall occupy that fraction of the core volume that will provide a 10% fuel volume including the effects of fuel absorption by the graphite. The fuel salt minimum temperature in the fuel salt cycle shall not approach within 100 F of the salt liquidus temperature. It is believed that the afterheat problem in the fuel salt will be tractable if the power density (averaged over the entire volume of salt including that in the external portions of the circuit) is not greater than 50 watts/cc. INOR-8 structural members are to be of a material thickness that will restrict nuclear induced thermal stresses to within tolerable limits; where this is impossible or impractical adequate thermal shielding must be provided. The vessel design is such that there will be no internal maintenance requirements during the life of the unit; there are therefore, no moving parts, no flanged surfaces, and no sealing surfaces other than those inherent in the graphite core arrangement.

Reactor Vessel Design Specifications

General	
Design temperature, F	1100/1300*
Vessel design pressure, psia	100/50
Reactor thermal power, Mw	2500
Fuel flow rate, 10^6 lb/hr	110.8
Average power density, w/cc	14
Physical Sizes	
Core tank diameter, ft (ID @ 1200 F)	20
Core tank length, ft	20
Vessel entrance head vol., cu ft	170
Vessel exit head vol., cu ft	467
Total vessel vol., cu ft	6917
Reactor vessel over-all height, ft	34
Reactor vessel wall thickness, in.	2
Maximum structural material thickness, in.	2-1/4
Entrance nozzles size, pipe size	10-in. Sch. 20
Exit nozzles size, pipe size	14-in. Sch. 20

*Core entrance and exit conditions 20 feet apart

D. Fuel Circulating Pumps

Purpose--- The fuel circulating pumps circulate the fuel salt through the primary heat exchanger and reactor core.

Criteria--- To minimize the cost of pumps, and the volume of high salt contained in the pumps, it appears preferable to use as high a pump speed and as few pumps as is practicable. The number of pumps is dependent upon the number of primary heat exchangers, and the pump head requirements will be dependent upon the heat exchanger design, suction, and discharge piping size and configuration, as well as upon the reactor vessel design. The pumps should be drainable and accessible for maintenance purposes. The organic materials associated with the drive motor; e.g., insulation and lubricants, must be properly shielded from radiation effects.

Materials--- All pump components that may be in contact with the fuel salt shall be constructed of INOR-8. Salt lubricated lower guide bearings may be used. Shaft lubrication areas and motor windings will be protected by neutron and gamma-radiation shields of Be, B, and Pb. Lubricants and winding insulation are to be of radiation resistant quality. Other component materials will be according to industry standard.

Conceptual Design--- Eight pumps will be in close proximity to the reactor vessel, but accessible for remote maintenance, such as motor or pump impeller replacement. This is depicted in Fig. 2. It is a centrifugal pump similar to the MSRE salt lubricated bearing pump located with respect to the liquid operating level of the reactor such that no priming is necessary for starting. Each unit is insulated and equipped with electrical, resistance-type preheating coils to minimize heat loss during normal operation and to preheat to operating temperature prior to introducing fuel salt to the system. Impeller shaft bearing lubrication leak-off is accommodated by a bowl around the impeller housing. The bowl is of minimum dimensions to maintain low fuel hold-up volume. Gas sparging facilities are incorporated with the bowl for volatiles removal; this system may be interconnected with core vessel dome gas space.

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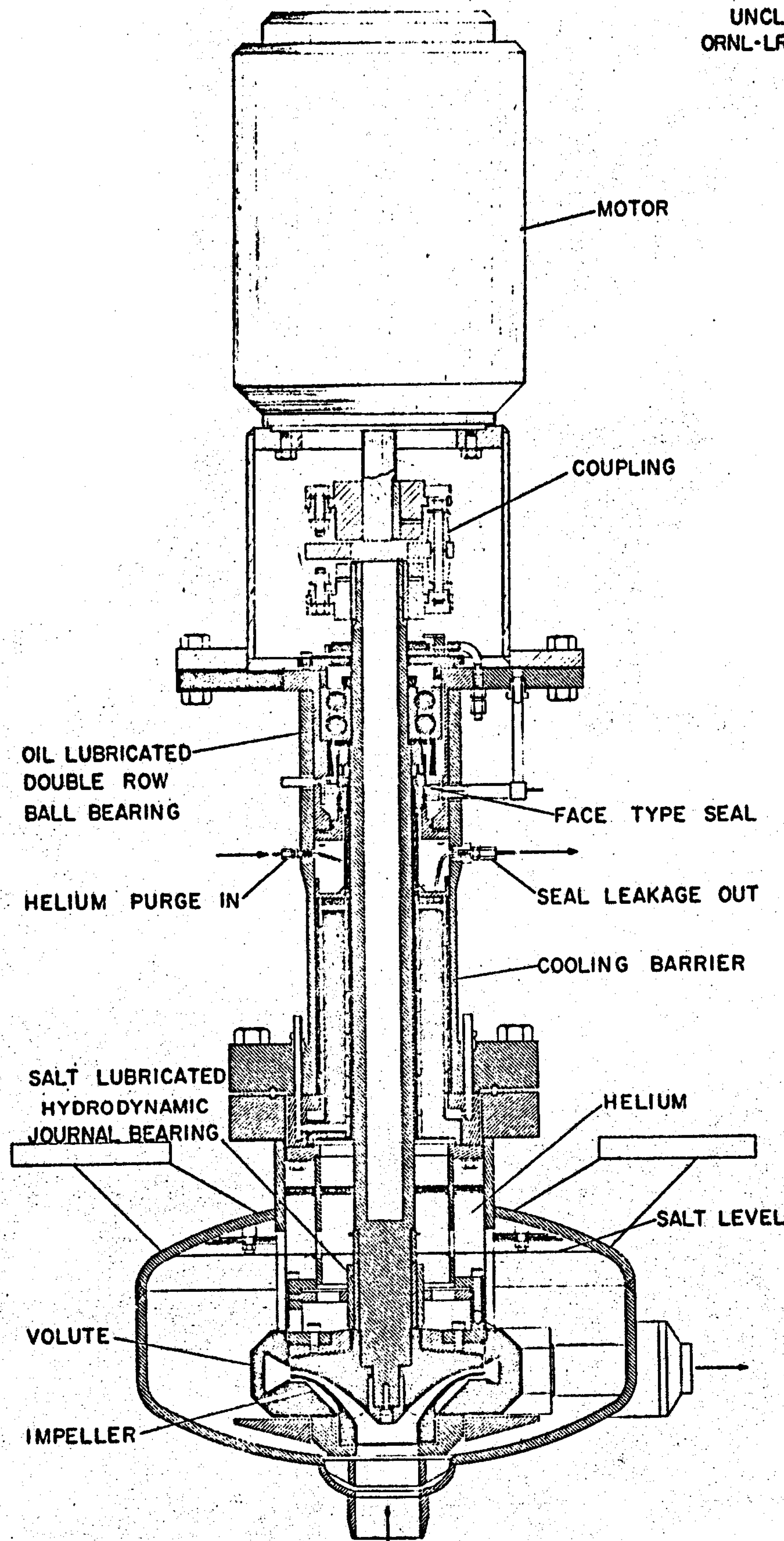

Fig. 2. Molten Salt Pump with Salt Lubricated Bearing

Design Conditions--- Fuel salt circulated by these pumps is at a temperature of 1300 F. The salt is pumped from a pressure of 17 ft. (NPSH) to a pressure of approximately 200 psia at a rate of 9075 gpm. Detailed data are given below.

Design Specifications

No. of pumps per reactor	8
Type	Centrifugal
Fluid pumped	MSCR-2 Fuel Salt
Service temperature	1300 F
Fluid density	190 #/ft^3
Fluid flow	9075 gpm
Suction pressure (17 ft NPSH)	22.5 psia
Discharge pressure (150 ft developed head)	220 psia
Impeller OD	25 inch
Suction ID	14 inch
Discharge ID	12 inch
Over-all pump OD (approx.)	50 inch
Over-all pump height-suction opening to pump housing flange face (approx.)	50 inch
Pump motor rating	2000 hp
Pump motor speed (synchronous)	900 rpm
Pump motor type	totally enclosed (H_2O cooled)

E. Salt Preheating System

Prior to admitting salt into the system, all salt-containing piping and equipment must be preheated to 900 F. This is accomplished by the use of resistance and transformer heating on all piping and components. Wherever practical (in pipe sizes up to about 2 inches),

salt-piping may be heated by passing an alternating current through the piping itself. All pipes heated this way must be electrically insulated. Larger diameter salt-containing pipes will be heated by resistance heaters mounted in the center of a one-inch annulus formed by surrounding the pipe by sheet steel reflector units. Suitable insulation will be on the outside surface of the reflector units. For large pipes (above 10 inches) a three-section assembly should be used. The heater capacity should equal about 2000 watts per foot of pipe. There are about 2200 feet of large diameter piping (including bends) in the system. Piping fittings should be covered by similar prefabricated heater units. Heaters for pumps will be field-fabricated.

The reactor vessel and primary heat exchangers will be heated by tubular resistance heaters attached to the outer surfaces by means of clips on welded studs. The reactor vessel should be provided with about 500 kw heater capacity. Each primary heat exchanger should have 100 kw of heater capacity. Coolant drain tanks require 200 kw of heater capacity.

In inaccessible areas, duplicate spare heater capacity should be provided.

F. Shield and Cell Air Cooling System

Purpose--- The shield and cell air cooling systems serve to remove heat deposited in the inner biological shield by radiation, and heat emanating from the outer surfaces of the reactor vessel, heat exchangers, piping and pumps.

Criteria--- The inner biological shield may absorb about 1.5% of the reactor thermal power. This heat must be removed by water circulating through tubes imbedded in the concrete about 1 foot below surface. A maximum concrete temperature of 200 F is specified to limit dehydration and excessive thermal gradients.

In addition to the heat absorbed in the biological shield, about 0.2% of the reactor thermal power will appear in the cell air within the reactor shield and heat exchanger cells. It is assumed that about 0.1% of the reactor power will be transferred to the cell air by heat leakage from high temperature surfaces through thermal insulation. It is further assumed that it will be necessary to transfer approximately 0.1% of the reactor power from the outer surface of the reactor vessel in order to minimize thermal stress from heat generation by gamma heating in the reactor vessel, and that this heat will appear in the air within the reactor shield. The cell air temperature should not exceed 125 F.

<u>Conceptual Design</u>--- Demineralized water is circulated as coolant through the shield cooling tubes and cell air coolers, and is in turn cooled in shell and tube heat exchangers which use service water as coolant. Separate circuits of demineralized water should be specified---one serving the higher temperature circuit through the shield cooling tubes, and the other serving the lower temperature circuit of the cell air coolers.

<u>Design Conditions</u>

	Shield Cooler	Cell Air Coolers
Heat Load, Mw	37.5	5
<u>Demineralized Water Circuit</u>		
Maximum temperature, F	180	110
Minimum temperature, F	125	95
Flow rate, gpm	4650	2275
<u>Service Water Conditions</u>		
Maximum temperature, F	125	95
Minimum temperature, F	75	75
Flow rate, gpm	5120	1700

G. <u>Fuel Salt Drain Tank Area</u>

<u>Purpose</u>--- The purpose of the fuel salt drain tank area is to provide space for the location of the fuel drain tanks, which are used for the temporary storage of the complete fuel salt inventory.

<u>Criteria</u>--- (1) The drain tanks must have sufficient capacity to store all of the fuel-salt required by the reactor system; (2) they must be able to dissipate, without overheating, the heat-after-shut-down being released by the reactor fuel salt a short time after the reactor has been shut down after having been operated for an infinite time at design power level; (3) the drain tank heat removal system should be operable without attendance and without normal services such as power, and cooling water for some specified period of time after having received the fuel charge; (4) it must be possible to transfer the fuel salt between the drain tanks and the reactor in either direction at controlled rates, and within reasonable periods of time; (5) means must be provided to measure the inventory of salt contained in the tanks, either by liquid level measurement or by weighing the tanks.

Design Specifications

Capacity--- The drain tanks should have, as a first estimate, at least 2700 cubic feet of salt storage capacity.

Heat removal capability--- The heat release rate from a reactor fuel charge will have decreased to about 1% of the steady-state power level approximately 3 hours after shut-down. Selecting 25 Mw and 1300 F as preliminary design values for the heat transfer capability and limiting salt temperature of the drain tank system, the following systems would be required for different assumed methods of transferring the heat from salt to the environment:

(a) Heat Transfer to Air by Natural Convection Only: The limiting heat flux will be about 1500 Btu/hr-ft^2, which would make it necessary to supply about 56,700 ft^2 of heat transfer surface. This could be accomplished by using 20 calandria tanks, each 6-1/4 feet in diameter by 10 feet tall pierced by 320 vertical tubes (3 inch diameter) through which air would flow as through a chimney. Hot air from the tops of the tanks would have to be collected and channeled to the atmosphere through a system of filters and a tall stack.

(b) Heat Transfer by Thermal Radiation from the Tank Outer Surfaces to Water-Cooled Sheet Metal receptors: The limiting heat flux by this method, within the stated temperature limits, is about 15,000 Btu/hr-ft^2. This would require an external drain tank surface area of 5670 ft^2. Using 2 feet diameter by 10 feet long tanks, 90 tanks would be required. Each of these tanks would be surrounded by a sheet-metal shroud which would have six or eight vertical 1-inch water tubes welded or brazed to its outside surface. The metal shrouds would be close to, but not touch, the outer surface of the drain tanks. Water fed to these vertical tubes would boil and the steam produced would be sent to a condenser for refluxing before being returned for another pass through the boiler tubes. A tank farm of 90 of these tanks would require a cell about 44 feet long by 40 feet wide if the tanks were spaced on four foot centers. The heat transmitting and receiving surfaces of the drain tanks and water cooled shrouds would have to be blackened in order to achieve the emissivities and absorptivities necessary to give surface heat fluxes as high as 15,000.

Although the cost of the fuel drain tank system is not to be included in this cost study, the approximate space and service requirements of the fuel salt drain system must be kept in mind when making the conceptual layouts and arrangement drawings of the heat removal and power generating systems.

IV. The Loeffler Boiler Cycle

A. General Description

A Loeffler boiler cycle flowsheet is shown in Fig. 3 . Heat generated by the nuclear reaction raises the temperature of the fuel salt from 1100 to 1300 F. This heat is carried by the fuel salt to a primary heat exchanger where a stream of coolant salt cools the fuel salt, and in turn carries the heat to the steam superheater and reheater units. Most of the heat generated by the reactor is transferred from the coolant salt to steam in the superheater. The balance of the heat carried by the coolant salt is used to reheat steam at 420 psia in a reheater unit. Steam in the superheater is heated from a saturated condition to 1000 F at 2460 psia. Saturated steam that enters the superheater is generated in a Loeffler boiler by the mixing of part of the superheated steam from the superheater with preheated boiler feed water from the main turbine condenser. A steam circulator is required to overcome pressure drop losses in circulating the steam through the superheater, piping and boiler. A possible general arrangement of the reactor and heat exchanger system is shown in plan and elevation views in Figs. 4 and 5. The primary heat exchangers and fuel pumps (in eight circuits) are mounted vertically for maintenance accessibility, and to conserve space and minimize piping lengths in the fuel circuits. An octagonal shield about six feet thick surrounds the reactor and primary heat exchangers. Coolant salt piping, also in eight circuits, penetrates the shield and carries the coolant salt to the superheaters and reheaters. Coolant salt piping galleries around the reactor shield are shielded by 4 feet of concrete, making a total shield thickness of 10 feet around the reactor. All equipment containing coolant salt needs to be shielded by 4 feet of concrete.

The coolant pumps each have a capacity of about 14,000 gpm with a developed head of about 175 psi. Using pipe sizes of 14,12 and 10 inches. Schedule 20 piping in various portions of the coolant circuit, coolant salt velocities up to 40 ft/sec are required. These velocities are permissible from the standpoint of corrosion and erosion, and are also economic from the consideration of head loss and pumping power because of the high cost of the coolant salt and of the piping. A preliminary estimate of the eight coolant circuits shown in Figs. 4 and 5 indicates a need for approximately 1280 feet of 12 inch pipe, 370 feet of 10 inch pipe, whose combined weight of INOR-8 is about 60,000 lbs. The complete coolant salt system shown here contains about 4700 cubic feet of coolant salt.

Table IV-1. General Equipment Specifications
Loeffler Boiler Cycle

Design Summary

Station Gross Electric Power, Mwe	1023
Station Net Electric Power, Mwe	982
Station Thermal Power, Mwt	2500
Station Net Efficiency, %	39.3
Net Plant Heat Rate, Btu/kwh	8688
No. of Turbines	2
No. of Reactors	1
Fuel Volume, ft^3 (1265 reactor, 635 pipe, 500 ht exch)	2400
Fuel Stream Flow Rate, gpm/reactor	72,720
Fuel Stream Reactor Inlet Pressure, psia	90
Fuel Stream Reactor Outlet Pressure, psia	30
Fuel Stream Reactor Inlet Temp., F	1100
Fuel Stream Reactor Outlet Temp., F	1300
Coolant Stream Flow Rate, gpm	91,200
Coolant Stream Heat Exch. Inlet Press, psia	350
Coolant Stream Heat Exch. Inlet Temp., F	950
Coolant Stream Heat Exch. Outlet Temp., F	1100
Superheater Steam Pressure, psia	2465
Superheater Steam Temp., F	1000
Superheater Steam Flow Rate, 10^6 #/hr (per turbine)	10.54
Turbine Steam Flow Rate, 10^6 #/hr (per turbine)	3.99

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STATION SUMMARY

Reactor 2500 MWT
Gross Generation 1023 MWE
Net Generation 962 MWE
Overall Plant Eff. 39.3 %
Aux. Elec. Req.
Reactor Pl. 3 %
Gener. Pl. 1 %

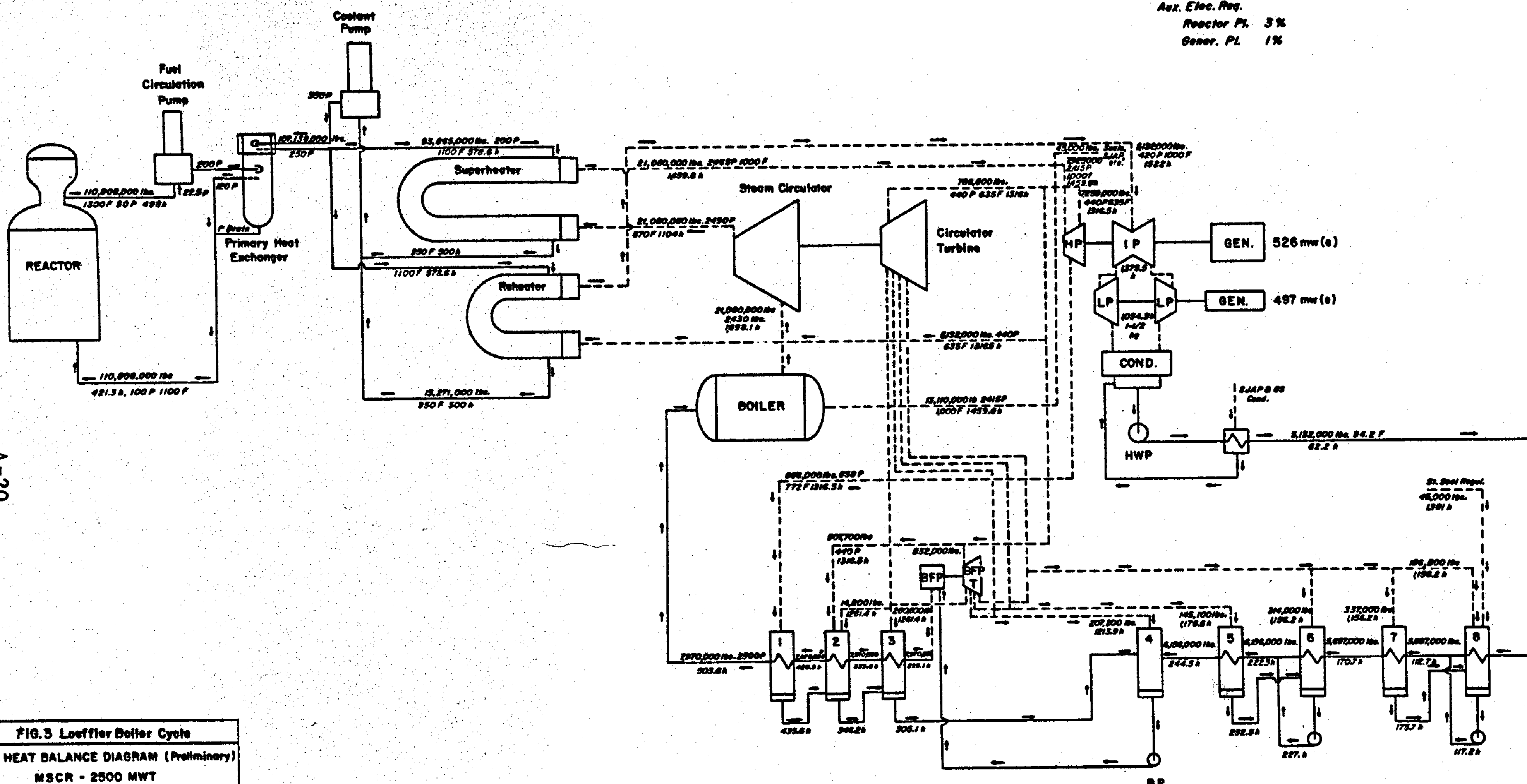
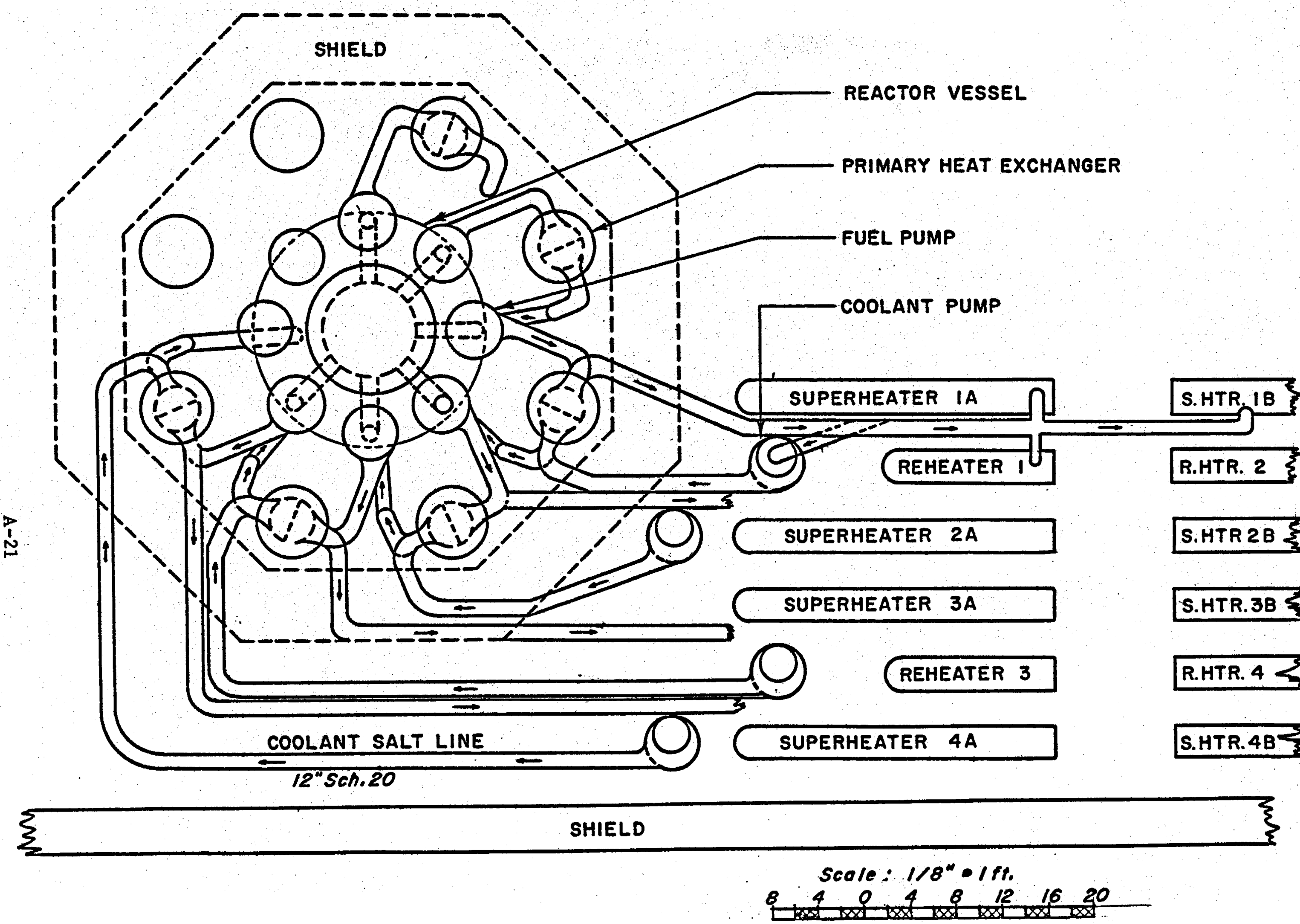


FIG.3 Loeffler Boiler Cycle

HEAT BALANCE DIAGRAM (Preliminary)

MSCR - 2500 MWT

FIG. 4. MSCR Heat Exchanger Arrangement -- Loeffler Boiler Cycle



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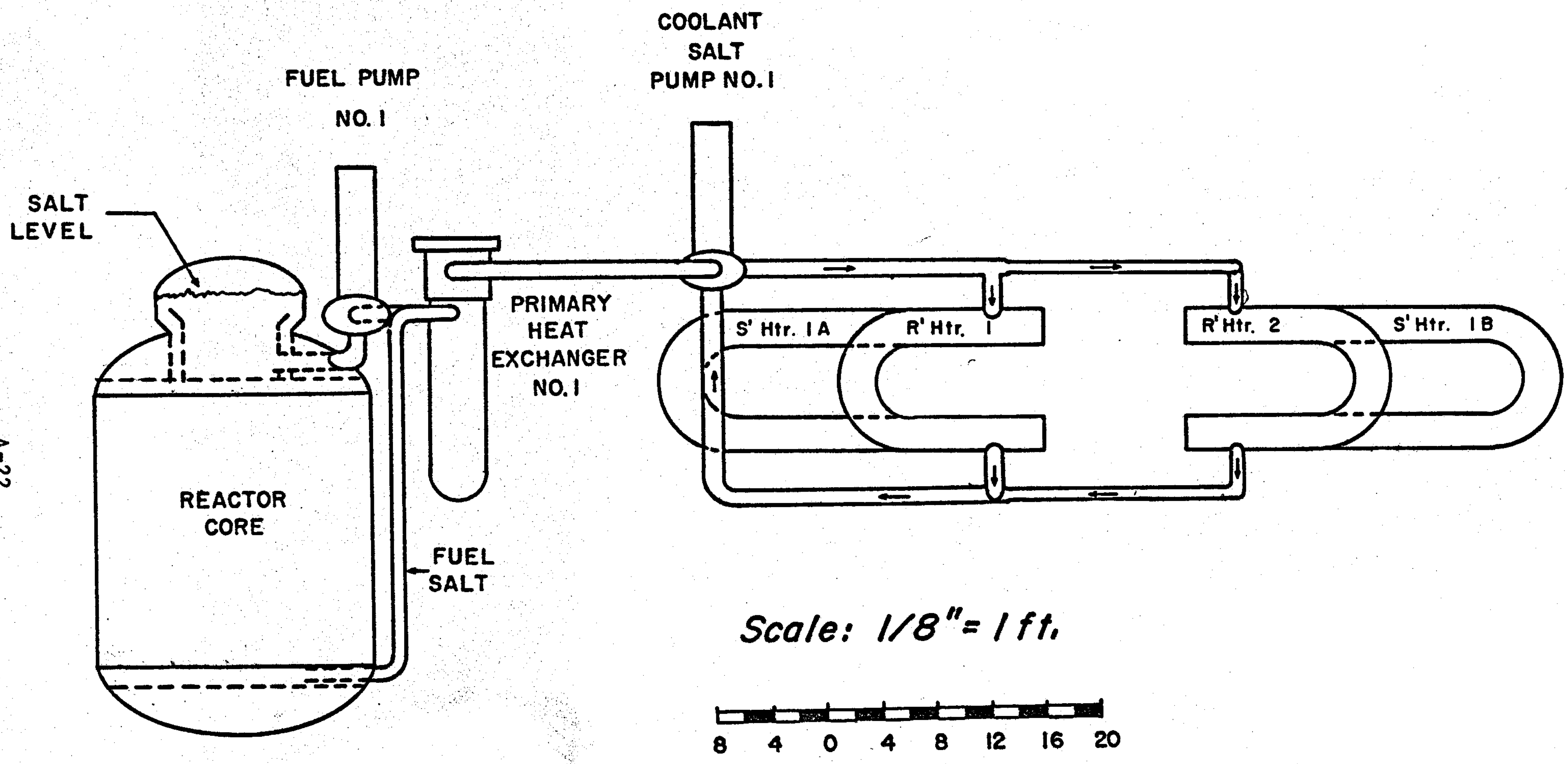

A-22

Fig. 5: Vertical Section MSCR Fuel and Coolant Salt Piping Arrangement for Loeffler Boiler Steam Cycle

B. MSCR Primary Heat Exchanger

Purpose--- The purpose of the primary heat exchanger is to transfer heat from the recirculating fuel salt to an intermediate coolant (such as barren molten lithium and beryllium fluoride), which in turn carries the reactor heat to the steam system and provides decoupling between the extremely radioactive fuel salt and the steam system.

Criteria--- Since the fuel salt is a very expensive heat transport medium (because of the contained fissile material), it is desirable to minimize its volume in the primary heat exchanger and connecting piping in order to minimize inventory costs; however, this volume should not be minimized at the cost of excessive pressure drop and pumping power, or maintainability of the system.

The coolant salt is less costly than fuel salt (by a factor of 10 or 20), but is still quite expensive so that it is also desirable to minimize the volume of coolant salt.

The heat exchanger must be drainable of fuel salt. Because of the possibility of fission product deposition on cool heat transfer surfaces, provision must be made to remove heat from the heat exchanger when it has been drained for maintenance. Provision must be made to preheat the heat exchanger prior to charging fuel salt or coolant salt. Access to the tube sheet should be possible without cutting any connecting salt piping. It is desirable that means be provided for finding and repairing leaking tubes in situ, (by plugging, if necessary) or lacking this, that the tube bundle be readily removable without breaking connecting salt piping.

Temperature drop across tube walls must be such that the permissible thermal stress is not exceeded. The minimum tube wall surface temperature should be at least 50° higher than the liquidus temperature of the fuel salt.

Tube wall thickness should be such that a minimum life expectancy of 10 years is possible for corrosion rates of 0.5 mpy on the fuel salt surface and 0.1 mpy on the coolant salt surface.

The heat exchanger should be located as close to the reactor as feasible, and be so situated in the piping circuit that circulation by natural convection will occur in the event of pump stoppage.

Materials--- The heat exchanger shell, tubing, tube-sheets, baffles and all structural members contacted by fuel salt or coolant salt shall be constructed of INOR-8. The fuel salt is described in Appendix Section III-C. The coolant salt composition shall be 66 mole % LiF and 34% BeF_2, the composition that provides minimum liquidus temperature for this binary mixture. Important properties of the coolant salt are given in the table below.

Table IV-2. MSCR Intermediate Coolant Salt

Composition	66% LiF, 34% BeF_2
Density, lb/ft^3	120 (1.93 sp gr)
Heat capacity, Btu/lb-F	0.526
Viscosity, lb/hr-ft	19.3
Thermal conductivity, Btu/hr-ft-F	3.5
Inlet temperature, F	950
Outlet temperature, F	1100
Liquidus temperature, F	851

Conceptual Design--- A heat exchanger design which fulfills the maintenance requirements listed above is shown in Fig. 6 . The U-Tube bundle is baffled to give true countercurrent flow of the coolant and fuel salt which results in the maximum log mean temperature difference for given terminal temperatures. Normally, minimum volume could be obtained by putting the fuel on the tube-side, but with this configuration the U-Tubes would not be drainable, so the fuel salt must go on the shell-side which can be provided with a bottom drain. Side-entry of nozzles on both the shell-side and tube-side leaves the top clear to permit removal of the top closure for unobstructed access to the tube-sheet from above. The tube-bundle, with associated baffles, which can slide into the shell from above, hangs from the tube-sheet which rests on a shelf machined into the shell. A circumferential seal weld joins the tube sheet to the shell and maintains leak-tightness between the coolant and fuel salt. A hold-down ring keeps the tube sheet in place in case pressure on the shell side should exceed pressure on the tube side. Normal design conditions require that the coolant salt (tube side) be kept at a higher pressure than the fuel salt. Thus, if a leak develops in the primary heat exchanger, coolant salt will leak into the fuel system. Since the rate of replacement of fuel salt in the processing cycle is about 2 ft^3 per day, a total leak rate

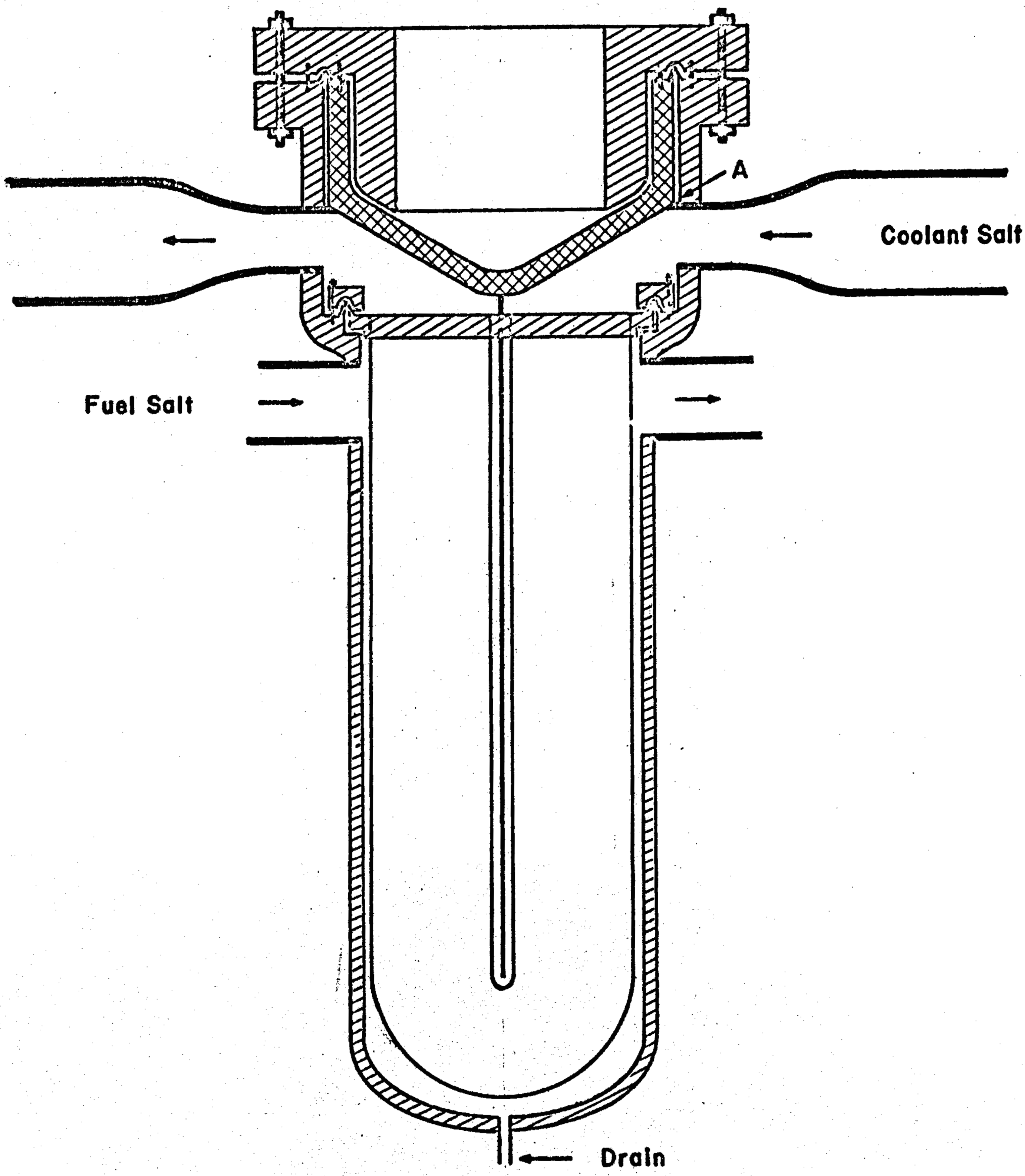

Fig. 6

Primary Heat Exchanger (Schematic)

of coolant salt into fuel salt of about 2 ft^3 per day could be tolerated in normal operation. The LiF-BeF_2 make-up would simply be added to the intermediate coolant system. The LiF and the ThF_4 make-up would be added to the fuel stream to maintain desired composition. Only at some greater leak-rate would it become economical to shut down the reactor and plug the leaking tubes or replace the tube bundle.

The end-closure may be sealed against leakage of coolant salt to the outside by one or more of several ways. A frozen salt seal in the annulus above "A" could be maintained. A seal weld could be made at the top between the flange on the shell side and the inverted head. Or lastly, double gaskets on circles inside and outside of the seal weld lip could confine leakage in case the seal weld, or other seals ahead of the seal weld, should fail. A massive hold-down flange suitably fastened to the top flange provides the necessary strength to hold the inverted head against the several hundred pound pressure of the coolant salt.

A partition attached to the inverted head fits closely into a diametral slot in the tube sheet to separate the inlet coolant salt plenum from the outlet plenum. A small amount of bypass flow may occur through the very small gap between the slot and the partition. The inverted head is shaped so as to minimize the volume of coolant salt in the tube-sheet distribution plenums. The inlet and outlet coolant nozzles are noncircular in cross section (flattened and broadened so as to minimize head-space without sacrificing flow area).

Not shown are cooling and heating provisions for the top head, or heating provisions for the shell. Nor has insulation for the unit been specified.

In order to avoid possible excessive thermal stresses in the tube sheet it may be necessary to provide insulation to reduce the thermal gradient across the tube sheet.

The design of the heat exchanger is such that a considerable heel of coolant salt will remain in the tubes after draining. In order that the salt-containing internals of the heat exchanger be exposed only to inert atmospheres when the top closure is removed, it may be necessary that the upper portion of the heat exchanger (above the coolant nozzles) be provided with a gas-tight caisson that extends from the heat exchanger to the locality of the maintenance equipment.

Design Conditions--- Fuel salt (MSCR No. 2) operating between the temperature limits 1100 to 1300 F transfers heat to coolant salt which is heated from 950 to 1100F in the primary heat exchanger.

For a total heat load of 2500 Mwt, these temperature conditions require total flow rates of 162 ft^3/sec of fuel salt, and 248 ft^3/sec of coolant salt. Loop pressure drop losses require that the coolant pressure at the inlet to the heat exchanger be about 350 psig, and that the fuel salt pressure at the inlet be about 200 psig. Tube side velocity should not exceed 20 ft/sec.

Design Specifications--- The design specifications shown in Table IV-3 are based on 8 heat exchangers per reactor (with a heat load of 1.066 x 10^9 Btu/hr per unit).

Table IV-3. Design Specifications for Primary Heat Exchanger

(Basis: 8 heat exchangers per 2500 Mwt reactor)

Design Data	
Heat rating (full load), Btu/hr x 10^{-9}	1.066
Geometry	U-tubes in a shell
Number of tubes	2025
Active surface area (OD), ft^2	6643
Active tube length (average), ft	25
Tube lengths (longest, shortest), ft	28.8, 23.7
Tube OD, in.	0.5
Tube wall thickness, in.	0.035
Tube pitch (triangular), in.	0.625
Tube and shell material	INOR-8
Shell ID, in.	43.75
Shell thickness, in.	1.5
LMTD, F	173.7
Shell weight, lb	16,000
Tubing weight, lb	10,000
Gross empty weight, lb	36,000
Overall heat transfer coefficient, Btu/hr-ft^2-F	924
Shell-Side Conditions	
Fuel-salt density, lb/ft^3	190
Inlet and outlet temperatures, F	1300/1100
Salt flow rate, ft^3/sec	20.25
Design pressure, psig	200
Pressure drop, psi	80
Fuel salt volume, ft^3	61.6
Tube-Side Conditions	
Coolant salt density, lb/ft^3	120
Inlet and outlet temperatures, F	950/1100
Coolant salt flow rate, ft^3/sec	31
Salt velocity (average), ft/sec	15.2
Design pressure, psig	350
Pressure drop, psi	84
Coolant salt volume, ft^3	61

C. Coolant Salt Circulating Pump

Purpose--- The fuel heat is transferred to the coolant in the primary heat exchanger; the coolant must then be pumped through a second heat exchanger system, steam superheaters and reheaters.

Criteria--- A coolant salt pump, similar in design to the fuel salt pump, must provide the flow and pressure requirements sufficient for the desired heat exchange in the steam superheater, and reheaters, for overcoming coolant cycle head losses, and for assuring outleakage in case a fuel-coolant barrier leak develops. As with the fuel pumps, the coolant pumps should be drainable of salt and accessible for maintenance purposes. Because of fluoride activation, shielding will be necessary to protect organic materials in the motor.

Materials--- All pump components in contact with coolant salt will be constructed of INOR-8. Salt lubricated bearing may be used for lower guide bearing. Gamma radiation shielding for motor insulation and organic lubricants is to be provided.

Coolant Pump

Design Conditions--- The 13,900 gpm of coolant salt circulated by each of these pumps is at a temperature of 950 F and at a primary heat exchanger inlet pressure of 300 psia. The developed head of the pump will be approximately 210 feet.

Design Specifications, Coolant Salt Circulating Pumps

Number of pumps per reactor	8
Type	Centrifugal
Fluid pumped	Coolant Salt
Service temperature, F	1100
Fluid density, lb/ft^3	120
Fluid flow, gpm	11,100
Suction pressure, psia	172.5
Discharge pressure, psia	350
Overall pump OD (approx.), in.	50
Overall pump height-suction opening to flange face (approx.), in.	50
Pump motor rating, hp	1750
Pump motor speed (synchronous), rpm	900
Pump motor type	totally enclosed (H_2O cooled)

Conceptual Design--- Eight pumps will be required to serve the pumping requirements of the sixteen superheater and four reheat exchangers. Each pump (see Fig. 4) will be connected to the discharge of two superheaters and one reheater in parallel with the pump discharge being connected to one primary heat exchanger. The pump design will be similar to the fuel pump in that it will be a centrifugal pump with a bowl around the cylinder to accommodate impeller shaft leak off and the lower guide bearing lubrication requirements. The coolant circulating system will be a closed cycle type with a combination pressurizer and sparging vessel. The system pressurizer requirement results from the need to maintain the coolant pressure above that of the fuel in the primary heat exchanger.

D. MSCR Superheater

Purpose--- The superheater transfers a large fraction of the heat carried by the circulating stream of coolant salt to saturated or slightly superheated steam. Superheated steam from the superheater is divided into several streams. About 1/3 of it is used to drive the turbine-generators for the production of electricity; the

balance is mixed with feed water in the Loeffler boiler to produce the steam required in the cycle.

Criteria--- It is desirable to minimize the steam-side pressure drop in order to reduce the pumping power required by the steam circulators. This may be accomplished at the cost of using large temperature differences between coolant salt and steam, and by using extra heat transfer surface areas and large tubes. But it is also important to minimize the amount of expensive INOR tubing, and coolant salt volume, as well as to limit the temperature gradient across the tube walls so as not to exceed thermal stress limits. Care must be taken to avoid surface temperatures that approach the liquidus temperature (851 F) of the coolant salt. A margin of at least 25 F is required.

Since coolant salt is not compatible with steam, it is important to insure the integrity of the coolant-salt-to-steam heat exchanger.

The heat exchanger design should accommodate the differential expansion between the tubes and the shell, which are at different temperatures.

Since the coolant salt is not expected to be highly radioactive, limited access to these units for maintenance may be possible.

Materials--- INOR-8 will be required for the shell, tubes, and tubesheet since coolant salt will be contained on the shell-side of the heat exchanger. The steam-side plenum chambers, heads, and nozzles may be constructed of high strength alloy steel suitable for 2400 psi, 1000 F steam service.

Conceptual Design--- Sixteen U-tube in U-shell arrangements with fixed tube sheets and countercurrent flow of coolant salt and steam, as shown in Fig. 7, provide the desired total heat transfer surface. Coolant salt is on the shell-side, and steam flows through the tubes. The unit is mounted like a U on its side to minimize building floorspace required for these units. The shell-side must be carefully baffled to develop the required pressure drop and heat transfer coefficients from the near-laminar flow of coolant salt.

The superheater may be brought up to operating temperature as part of the Loeffler boiler system by the use of heating steam from an auxiliary boiler.

Design Conditions--- Coolant salt operating between the temperature limits 950 to 1100 F circulates through the shell-side, transferring heat to steam inside the tubes which enters at 670 F and 2490 psi, and leaves at 1000 F and 2465 psi. For a total heat load of 2190 Mwt, and these temperature conditions, the total coolant salt flow rate through the sixteen superheaters is 219 ft^3/sec, and the steam

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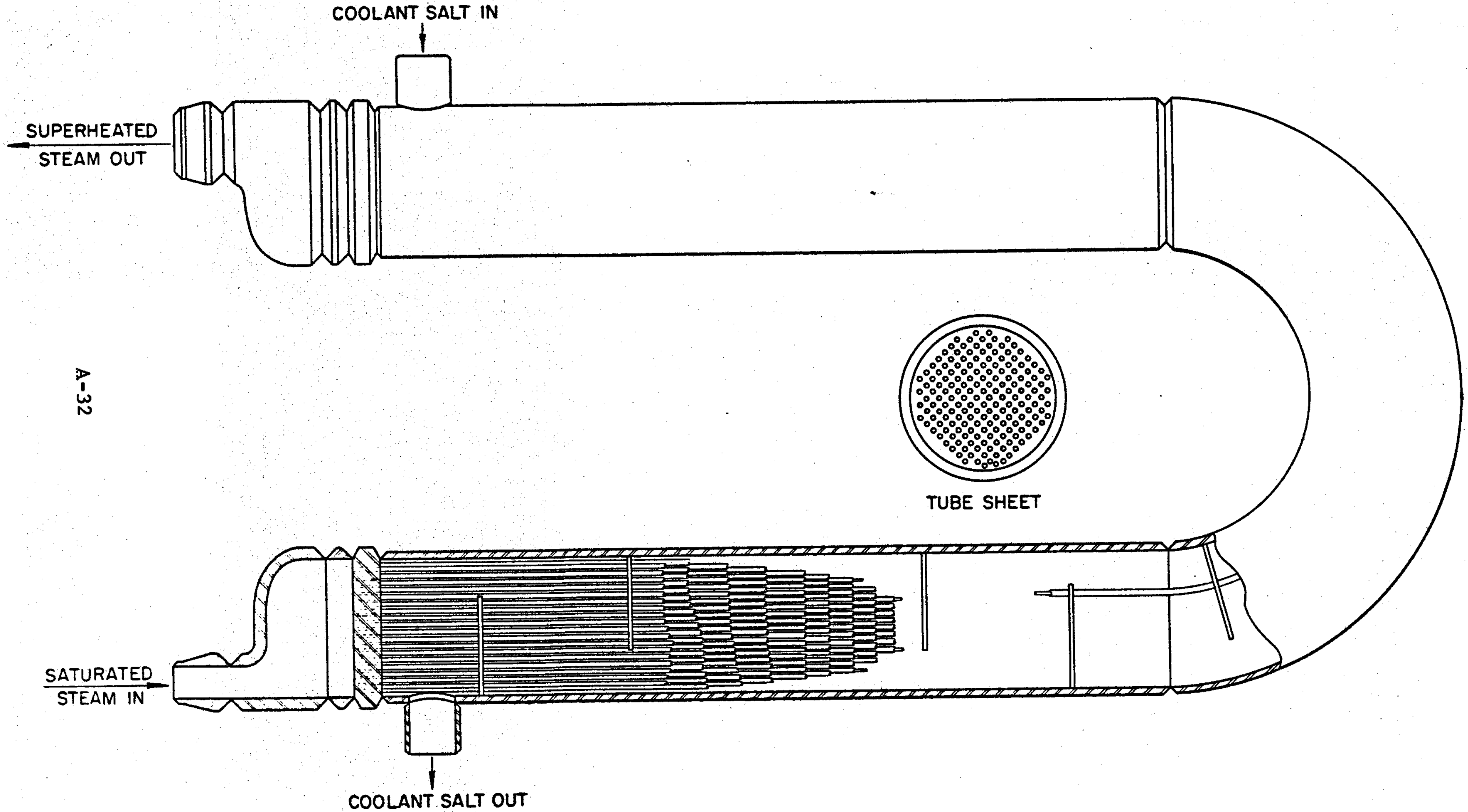

Fig. 7. Coolant-Salt-To-Steam Superheater (Or Reheater) -- Schematic

flow rate is 21.08×10^6 lb/hr. This represents about 87.6% of the total reactor heat, the remaining reactor heat being distributed to the reheat heat exchangers. The design pressure and temperature for the shell is 335 psig, and 1100 F. The tube side velocity of steam does not exceed 80 ft/sec, and the minimum surface temperature in contact with coolant salt is 880 F.

Design Specifications--- The design specifications shown in Table IV-4 are based on 16 superheaters per reactor with a heat load of 0.467×10^9 Btu/hr/unit.

E. MSCR Steam Reheater

Purpose--- The reheaters improve the efficiency of the turbine steam cycle by increasing heat availability. Steam to be used for reheat purposes in the turbine is heated by a portion of the circulating coolant salt.

Criteria--- In order to provide greater energy availability for the turbine work cycle and to provide a lower pressure steam to drive auxiliary turbines, the high pressure turbine exhaust steam is directed to the reheater, the auxiliary turbines, and the second feed water heater. The same general criteria apply to the reheater as to the superheater, although the steam is of lower pressure conditions.

Materials--- As with the superheaters, the reheater structural materials will be INOR-8 and alloy steel.

Conceptual Design--- Eight U-tube in U-shell arrangements will provide the desired heat transfer surface. Again, the coolant salt flows in the shell countercurrently to the steam passing through the tubes. Similar pressure drop and heat transfer coefficient conditions exist in the reheater as in the superheaters.

Design Conditions--- The total coolant salt flow of 30.72 ft^3/sec transfers the 310 Mwt heat load to the 5.14×10^6 lb/hr steam flow in eight reheaters. Coolant salt is in contact with surfaces with temperatures no lower than about 890 F.

Table IV-4. Design Specifications for MSCR Superheater

(Basis: 16 heat exchangers per 2500 Mwt reactor)

Design Data	
Heat rating (full load), Btu/hr x 10^{-6}	467
Geometry	U-tube in U-shell
Number of tubes	785
Active surface area (OD), ft^2	7705
Active tube length (average), ft	50.0
Tube lengths (longest, shortest), ft	54, 46
Tube OD, in.	0.75
Tube wall thickness, in.	0.083
Tube and shell material	INOR-8
Shell ID, in.	31.5
Shell thickness, in.	0.5
LMTD, F	174.8
Shell weight, lb	9900
Tubing weight, lb	21,600
Over all heat transfer coeff., Btu/hr-ft^2-F	347
Shell-Side Conditions	
Coolant salt density, lb/ft^3	120
Inlet and outlet temperatures, F	1100/950
Coolant salt flow rate, ft^3/sec	13.7
Design pressure, psig	300
Pressure drop, psi	(40)
Coolant salt volume, ft^3	128
Tube-Side Conditions	
Inlet steam pressure, psia	2490
Inlet and outlet temperatures, F	670/1000
Steam flow rate, lb/hr x 10^{-6}	1.317
Maximum steam velocity, ft/sec	78
Design pressure, psig	2500
Pressure drop, psi	25

Table IV-5. Design Specifications for MSCR Reheater

(Basis: 8 heat exchangers per 2500 Mwt reactor)

Design Data	
Heat rating (full load), Btu/hr x 10^{-6}	132
Number of tubes	766
Active surface area (OD), ft^2	3543
Active tube length (average), ft	23.6
Tube lengths (longest, shortest), ft	19.6, 27.6
Tube OD, in.	0.75
Tube wall thickness, in.	0.065
Tube pitch (triangular), in.	1.00
Tube and shell material	INOR-8
Shell ID, in.	31
Shell thickness, in.	0.5
LMTD, F	187.5
Shell weight, lb	4500
Tubing weight, lb	9620
Tube sheet thickness and weight, in., lb	2700
Over all heat transfer coefficient, Btu/hr-ft^2-F	199
Shell-Side Conditions	
Coolant salt density, lb/ft^3	120
Inlet and outlet temperatures, F	1100/950
Coolant salt flow rate, ft^3/sec	3.84
Design pressure, psig	300
Pressure drop, psi	40
Coolant salt volume, ft^3	64
Tube-Side Conditions	
Inlet steam pressure, psia	440
Inlet and outlet temperatures, F	635/1000
Steam flow rate, lb/hr x 10^{-6}	0.642
Maximum steam velocity, ft/sec	80
Design pressure, psig	450
Pressure drop, psi	20

F. Coolant Salt Drain Tanks

Purpose--- The coolant drain tanks have several purposes: (1) to provide storage space for the complete volume of coolant contained in two (out of eight) coolant circuits during periods when it might be necessary to drain the coolant from one circuit for maintenance; (2) to provide the reservoir and the motive force for transferring coolant salt into the reactor coolant circuits during initial salt-charging; and (3) to serve as a transfer point from which coolant salt may be removed from the system and transferred to shipping containers for shipping out in case it should become necessary to process and recover, or to discard contaminated coolant salt.

Criteria--- The salt transfer lines must be valved (with freeze-valves) to permit salt to flow to or from any one of the 8 coolant circuits. The transfer lines must be large enough to fill one coolant circuit in a reasonable period of time, say one hour, using gas pressurization to some reasonable pressure the order of 50 psig.

Inadvertent draining of coolant salt from the reactor coolant circuits might permit overheating of fuel salt. In order that the coolant circuits be drainable only by intent, the drain lines should be provided with a siphon break, and with pressure equalization lines between the gas space of the drain tanks and the coolant circuits. These provisions would prevent the accidental draining of coolant salt in case the freeze-valves should fail to hold.

Means must be provided to heat the tanks to specified and controlled temperatures. Knowledge of the inventory of coolant salt contained in the drain tank is required. Salt inventory may be determined either by weighing the tank, or by providing suitable liquid level devices, or both.

In order that the salt transfer line not be subject to plugging by the accumulation of dregs at the bottom, the transfer line should enter the tank from the top as a dip pipe.

A port and access line, with full-opening valve, should be provided to permit sampling the tank using a thief-sampler device.

There are no apparent criticality hazards associated with the coolant drain tanks so that each tank may be as large as it needs to be to contain the salt inventory of one coolant circuit.

Materials--- The tank and all piping contacted by coolant salt shall be constructed of INOR-8.

Conceptual Design--- The coolant drain tanks are cylindrical vessels with ellipsoidal heads containing the penetrations for salt transfer lines, salt sampling ports, gas pressurizing and vent lines, and

thermal elements for temperature measurements. The tanks are heated by electrical resistance heaters suitably mounted on the outside surfaces, and they may be piped up with flexible piping so that they may be suspended from load cells to permit inventory determinations by weighing. The salt transfer lines within the tanks are dip pipes that reach the bottom of the tank from above.

A flowsheet of the coolant drain system is shown in Figure 8.

Table IV-6. Design Specifications for Coolant Salt Drain Tanks

Each Tank	
Number of tanks	2
Design temperature, F	1100
Design pressure, psig	80*
Heater capacity, kilowatts	200
Volume (gross), cubic feet	700
Diameter, ft	8.5
Height, ft	14
Wall thickness, in.	0.5
Material	INOR-8
Gross weight, filled, lb	86,000
Tare weight (approx.), lb	14,000
Salt capacity, cubic feet	600**
Salt capacity, lb	72,000
Size of drain line, in.	2

*This pressure is based on assuming a salt lift of about 35 feet (30 psi) from the bottom of the drain tank to the highest salt level in the coolant circuit plus 50 psig gas over-pressure to impose a reasonable head to induce flow through the drain line when charging salt into the coolant circuit.

**This figure is from a preliminary estimate of the salt volume in one coolant circuit.

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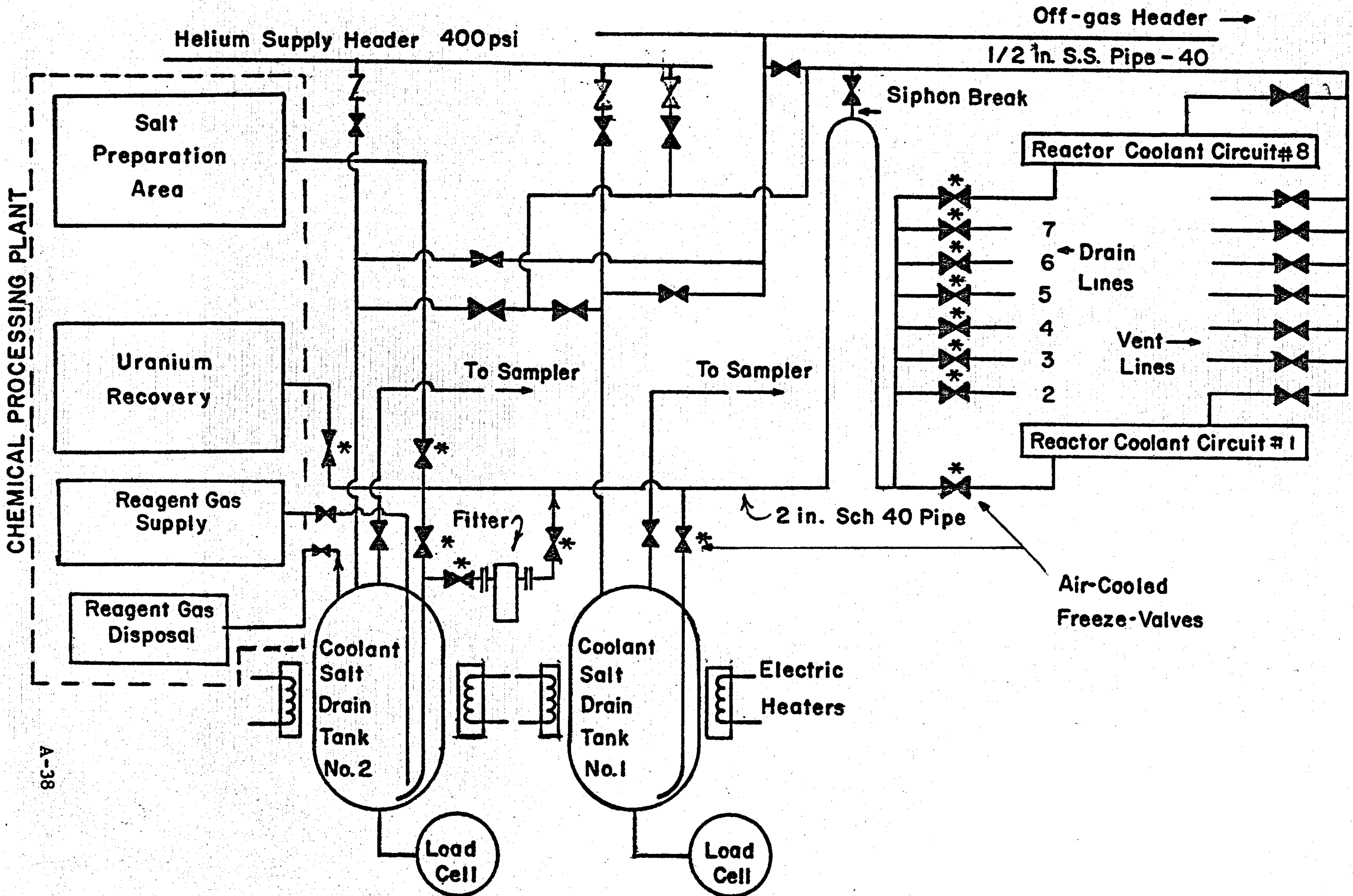

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FIG. 8 COOLANT SALT DRAIN TANK SYSTEM (Revised)

G. Coolant Salt Purification System

Purpose--- The purpose of the coolant salt purification system is to remove impurities such as corrosion products or oxides which could cause fouling of surfaces and plugging of lines and tubes if allowed to accumulate without being removed.

Criteria--- It is unlikely that a single coolant charge could be operated for the lifetime of the reactor without exceeding permissible concentration limits of oxides or corrosion products; however, it probably will not be necessary to employ a continuous treatment of the coolant salt to maintain its purity. Oxide impurities may be introduced into the coolant salt by inadvertent exposure to air or water vapor, and from oxygen present as an impurity in the cover gas used to pressurize coolant salt systems. Although the corrosion rate of INOR-8 or Inconel surfaces by coolant salt is small, the surface area of metal in contact with coolant salt is very large, so corrosion products are certain to accumulate in the many-year time periods of operation required of power plants. It will be assumed that when it becomes necessary to repurify the coolant salt, it would be done batchwise, one coolant circuit per batch, at infrequent intervals during periods of reactor shut down.

If it should happen that the coolant salt became contaminated with fission products and uranium as a result of a leak in the primary heat exchanger (an event not likely to occur because the coolant salt system is kept at a higher pressure than the fuel salt), the contaminated coolant salt would be drained from the affected reactor coolant circuit to a coolant drain tank, and then transferred to the chemical processing plant as rapidly as permitted by processing rate limits of the chemical plant.

Conceptual Design--- There are two coolant salt drain tanks, each with sufficient capacity to contain the contents of one reactor coolant circuit. One of these drain tanks would be designated as a spare-coolant-salt storage tank which would normally only be used to hold in readiness sufficient purified coolant salt to fill one reactor coolant circuit. The second drain tank would normally be empty, ready to receive the coolant salt from any one of the eight reactor coolant circuits either for temporary storage during maintenance on that circuit, or for chemical repurification treatment if required. This latter tank would be called the chemical treatment drain tank.

H. Coolant Salt Freeze Valves

Purpose--- Freeze valves are used only as block valves in lines used for transferring salt from one location to another.

Criteria--- When used as a block valve in the coolant salt system drain lines, the freeze-valve must permit no leakage when the full system pressure is imposed on it. The valve should have a flow area approximately equal to that of the pipe, and flow in either direction should be possible. Not having quick-opening requirements, a reasonable time of a few minutes to thaw the plug is permissible. The air-flow to the valve should be controllable so that when a freeze-plug is being formed, maximum cooling effect may be obtained by a large flow of air, and that air consumption may be reduced to the minimum required to maintain the plug once it is formed.

In the event that the section of pipe containing the freeze-valve should be completely drainable, the freeze valve should be located so as to form a nondrainable pocket in the line.

Materials--- All materials contacted by salt should be made of INOR-8. The heaters may be standard tubular resistance heaters of the Calrod type. Air lines should be of stainless steel.

Conceptual Design--- Freeze-valves are simply formed in any size pipe (up to 2 inches, certainly) by pinching the pipe (as one would a rubber hose) to form essentially a rectangular shaped flow passage of required width and thickness. For a 2-inch pipe, the flattened section should have a flow passage about 0.5 inch thick by whatever width that results from the pinching operation. The length of the flattened section of this 0.5 inch uniform thickness should be about 2 inches. The electric heaters should be bent to form a saddle-shaped series of turns that conforms to the shape of pinched section of pipe. The heater assembly should be saddle-shaped so that it may be easily removed from the pipe. There should be no insulation around the pinched section. Heater capacity should be about 3000 watts per 2-inch valve. Temperature measuring elements should be attached to the heated section.

The freeze-plug is formed by directing jets of cooling air normal to the top and bottom surfaces of the flattened portion of pipe. Normally the valve would be mounted in a horizontal run of pipe with its flattened section parallel to the earth. Air flow to each valve should be controllable between the limits 15 to 50 scfm. The cooling air may be supplied by a positive displacement blower.

There are ten 2-inch and two 1-inch freeze valves in the coolant salt drain system. Additional freeze valves of one inch size are required for other salt transfer systems.

Table IV-7. Design Specifications for Coolant Salt Freeze Valves

Leakage criteria	No leakage when valve closed
Flow area	Approximately same as line
Throttling action	None; full flow when open
Design pressure	400 psig
Design temperature	1100 F
Heater capacity	3000 watts
Air flow for cooling	15-50 scfm

I. Steam Generator

Purpose--- The Loeffler boiler principle is applied to supply steam to the superheater (coolant salt/steam heat exchanger). A portion of the superheated steam produced is diverted to a contact-type evaporator from which the generated steam is pumped directly to the superheater.

Criteria--- To maintain superheater tube material within allowable thermal stresses and to minimize the possibility of coolant salt solidifying on the superheater tubing, steam is to be supplied at the superheater inlet. Boiler feed water and superheated steam are mixed in the evaporator drums. The steam thus formed is pumped by a turbine-driven compressor to the superheater section. There are two such systems, one for each turbine unit.

Design Conditions--- Superheated steam at 1000 F and 2460 psig recirculates to the evaporator at a rate of 6.5×10^6 lb/hr where it evaporates the boiler feed water which enters the drum at 475 F and 2430 psig at a rate of 4.0×10^6 lb/hr. The resulting 10.5×10^6 lb/hr of slightly superheated steam is pumped to the superheater at approximately 670 F and 2490 psig. Facilities are provided for start-up steam from an auxiliary steam generator (oil-fired package boiler). The steam-pump turbine governor is controlled from a superheater outlet temperature device.

Design Data--- The number and size of the drums required to produce saturated steam at the rates and conditions above have not been determined.

J. Salt Preparation Area

Purpose--- To prepare fuel and coolant salt of required purity for charging into the reactor system during initial start-up period, and also during normal reactor operation.

Criteria--- A certain period of time during preoperational testing and reactor start-up must be allotted for fuel loading. In a molten salt reactor the fuel-salt (and the coolant salt as well) must be heated to a temperature above the melting point before it can be charged into the reactor system. Melting and blending vessels must be supplied which can accomplish the salt preparation for the entire inventory of both the fuel and coolant salt within the time scheduled for this operation. Melting and blending vessels used to prepare fuel-salt cannot be used to prepare coolant salt because of possible contamination of the coolant salt with thorium or uranium. Exposure of coolant salt to delayed neutrons in the primary heat exchanger would result in fission product contamination if thorium or uranium were present as impurities in the coolant salt.

It is assumed that a salt preparation area will include two lines of equipment -- one for the preparation of fuel salt and one for the preparation of coolant salt.

The size of the salt preparation area and its equipment will be determined by the time schedule assigned to the initial charging of fuel and coolant salt during start-up. For the purposes of this study it will be assumed that one month is a reasonable period of time to allow for salt-charging into the reactor system.

Conceptual Design of Coolant Salt Preparation System--- It will be assumed that a binary mixture of lithium and beryllium fluorides of the proper composition and purity (except oxide content) will be available on the market in pellet form, and shipped in bags. When received at the reactor site, the only preparation that will be necessary before the salt can be charged into the reactor system is to melt the pellets and remove the oxides that may have been introduced during feeding into the melting vessel. It is assumed that the melting can be accomplished on a continuous basis using a single vessel about 12 feet high by 3-1/2 feet in diameter whose bottom 8 feet of height is surrounded by a furnace with 150 kw of heating capacity. This would have a melting capacity of about 840 lb/hr (7 ft^3/hr) of coolant salt. Oxide removal is accomplished in a batch operation in which a reagent gas mixture of 80% anhydrous hydrogen fluoride and 20% hydrogen is bubbled through the salt at prescribed temperatures in the range 1100 to 1500 F for periods of time ranging from a few hours to a few days, depending on what oxides are being removed, what the temperature is, and what oxide concentration is permitted. A five-hour cycle

will be assumed for filling, oxide removal treatment, and emptying the chemical treatment tank. The salt preparation system will assume to be operated as follows: Pellets will be emptied from bags into a hopper or bin which feeds pellets by gravity at controlled rates into the melting vessel. A pool of molten salt will be maintained continuously in the melting vessel, and the liquid level of this melt will fluctuate between certain upper and lower limits as batches are drained off periodically to the chemical treatment tank.

Table IV-8. Design Specifications for Coolant Salt Preparation System

Pellet melting rate, lb/hr	840
Melting vessel dimensions, dia./ht.,ft.	3.5/12
Melting vessel material	Inconel
Melting vessel wall thickness, in.	3/8
Melting furnace dimensions, I.D./ht.,ft.	3.5/8
Melting furnace heating capacity, kw	150
Nominal operating temperature of melt, F	1200
Chemical treatment tank dimensions, dia./ht.,ft.	3.5/5
Chemical treatment tank material	INOR-8
Chemical treatment tank wall thickness, in.	0.5

V. The Mercury Binary Cycle

A. General Description

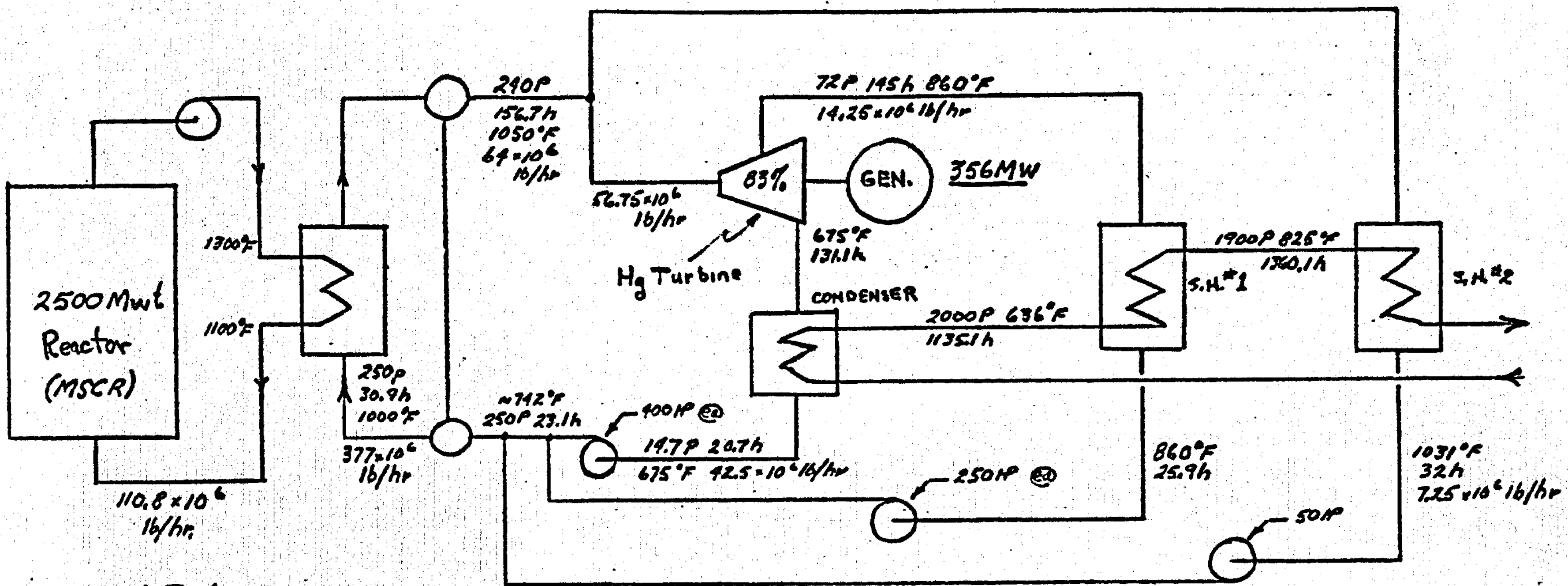
Mercury could serve as an intermediate heat transfer medium. It has the advantage of compatibility with MSCR fuel salt and water, plus the well known attributes of high vapor temperature at low pressure, high critical temperature, chemical stability, and availability in large quantities. In fossil fuel power generating plants the principal use of mercury is for steam cycle "topping" to improve the over-all thermal efficiency. This same approach is taken with the MSCR plant, but, in addition, the mercury is used as the intermediate heat transfer medium between the reactor heat generation cycle and the turbine steam cycle.

In general, this system is an enlargement of a conventional mercury vapor-steam "topping" cycle. The over-all thermal efficiency is relatively high, being on the order of 46% (net) at a 2500 Mwt operating level. Briefly, as shown on the flow sheet, Fig. 9, fuel salt is pumped from the reactor through tubes of eight mercury boilers. The saturated mercury vapor is then distributed to two 180 Mw mercury turbines and the second pair of two sets of steam superheaters. Mercury vapor is extracted from the turbines at 72 psia for use in the first pair of steam superheaters. Mercury vapor exhausted from the turbines is condensed by steam-turbine feed water, which in turn is boiled to saturation. Saturated steam is then superheated to 1000 F at 1800 psia for use in a single 855 Mw six-flow, cross compound, nonreheat, condensing turbo-generator. The condensed mercury from the mercury turbines and two superheaters is pumped back to the mercury boilers.

From this preliminary study it is apparent that current steam turbine cycle technology can provide the required system components. On the other hand, considerable extension of present day mercury "topping" cycle technology is required to provide the large system proposed. Because of the high volumetric expansion of vaporizing mercury large equipment is necessary; for example, at 1050 F, saturated vapor specific volume is 274 times that of saturated liquid. The physical arrangement and size of such items as the mercury boilers, which must be within the reactor shield, and the mercury condensers, which should be adjacent to the mercury turbines present problems not only of technical design but of economical design. Total mercury inventory is estimated to be about 3,000,000 pounds.

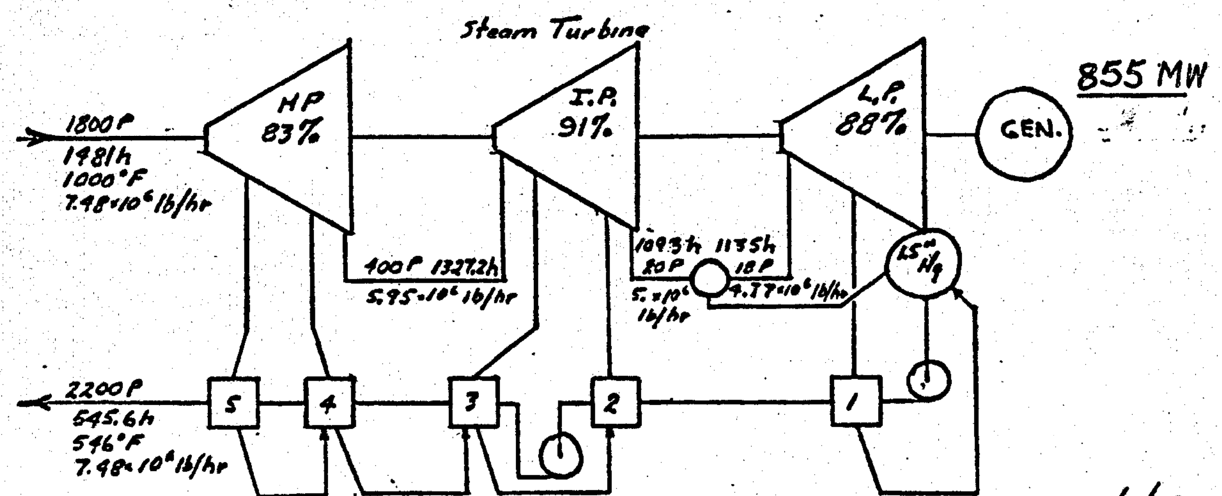
Heat transfer properties of mercury must be given further attention for the configuration proposed in the MSCR system. Considerable experimental work has been performed on the general characteristics of mercury and some on more specific boiling and condensing characteristics.[5]

Fig. 9 MSCR MERCURY BINARY CYCLE



General Data

2500 Mwt	Reactor
1211 Mwe	Gross Gen
1150 Mwe	Net Gen
46.0%	Effic.



Feed H_2O Heater
(Extract. Steam)

(1) 9.6P 1097h 0.479×10^6 lb/hr
(2) 46.3P 1149h 0.374×10^6 lb/hr
(3) 180.3P 1251h 0.569×10^6 lb/hr
(4) 491.5P 1344h 0.703×10^6 lb/hr
(5) 1100P 1926h 0.823×10^6 lb/hr

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The results of the experimental work leaves little doubt that successful operation of the proposed system can be achieved. Development activity will be required, however, to assure reasonable heat exchanger (boilers and condensers) pressure drops, desired saturated vapor qualities, and optimum heat flux conditions.

Although operating procedures for start-up, base load or partial load, and shutdown have not been developed, no serious problems are visualized. Because all fuel salt containing equipment must be preheated to at least 900 F prior to admission of the fuel salt, it is believed preferable to preheat the mercury boilers partially filled with mercury. The mercury fill and drain system size can then be minimized to a single boiler inventory for use after initial start-up. Side-streams for magnesium and titanium wetting agent injection, and for mercury oxide clean-up system are to be provided. These are standard provisions for conventional mercury binary cycles.

Nuclear activation of the mercury due to its proximity to the circulating fuel salt has not been calculated. Biological shielding will be necessary for the entire mercury system in the event of a leak of fuel salt into the mercury; this may be in part made up of lead, pipe-lagging and individual equipment shields as well as general isolation by building construction. Such isolation dictates remote operation and monitoring of all related equipment. It is possible that due to wall thickness of such items as the mercury turbine total shielding will be unnecessary. For cost comparison purposes, however, over-all shielding and containment will be assumed by means of steel-lined concrete walls 4 feet thick.

B. Mercury Boiler for MSCR

Purpose--- The mercury boiler provides a heat transfer medium between the MSCR fuel salt and steam for use in driving a conventional steam turbine.

Turbine--- Mercury is to be boiled from its liquid state to saturated vapor by means of heat transfer from 1300 F fuel salt. The saturated vapor is to be dried in an appropriately designed moisture separator and distributed to a mercury turbine and steam superheaters. Mercury vapor temperature is to be such that 1800 psia, 1000 F steam can be generated. The boiler design should consider minimizing of fuel salt inventory, since it is by far the more expensive of the two liquids to be used in the boiler.

Conceptual Design--- The configuration chosen for the mercury boiler, as suggested by Mr. I. Spiewak of the ORNL Reactor Division, is based on minimum fuel salt inventory. This dictates mercury boiling in the shell of a vessel containing a U-tube bundle, mercury vapor separators, and mercury liquid recirculating channels. This is illustrated by Fig. 10.

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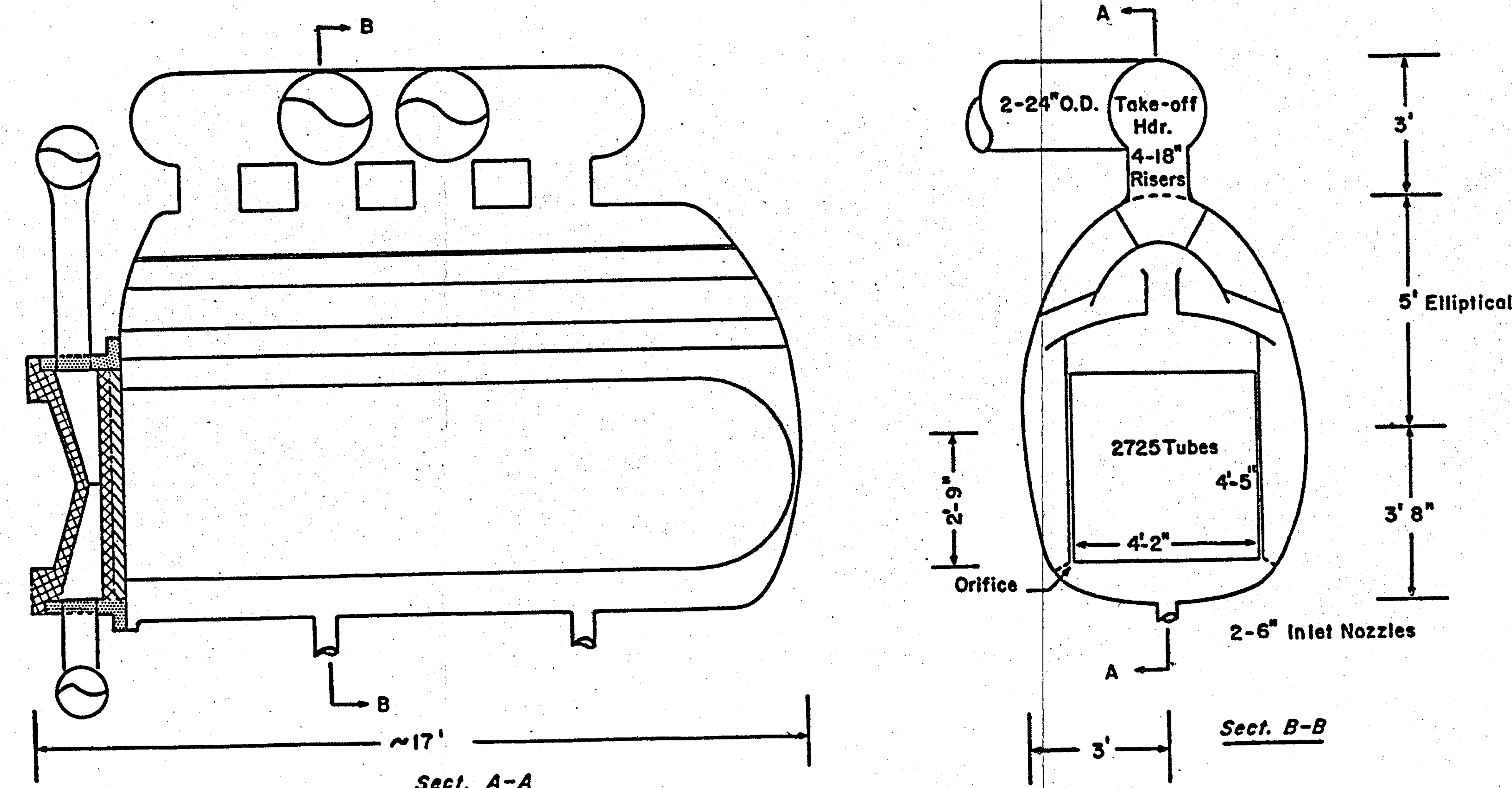
FIG. 10

MSCR MERCURY BOILER



Preliminary conceptual design indicates a horizontal U-tube arrangement of fuel salt tubes to limit the over-all length of the heat exchanger and to provide for a feasible remote maintenance arrangement. Both items are of prime importance since the boilers must be located within the reactor shield. To be consistent with the 2500 Mwt reactor layout determined for the Loeffler cycle, eight mercury boilers were chosen to receive fuel salt from the eight reactor pumps. This allows energy conversion cycle cost comparison independent of reactor configuration. It is possible that other boiler concepts, including vertical, straight tube exchangers, may be more adaptable to the MSCR plant. No optimization of design has been attempted at this stage of the study.

Mercury vapor separation can be accomplished by cyclone separator-screen dryer or baffle separator-screen dryer combinations. The actual sizing of this equipment can probably be patterned after the General Electric Company's baffle separator installation at the Kearny Station, Public Service Electric and Gas Company of New Jersey.[6]

The mercury recirculation channels are arranged on either side and isolated from the tube bundle. Assuming that reasonable thermal isolation can be achieved such that no boiling occurs in the recirculation channel, the saturated liquid mercury can be recirculated through seven orifices of about 3.5 to 4 inch diameter in each of the channels. In order to improve mixing of the "cold" return mercury with the recirculating mercury, it may be necessary to increase the inlet nozzles from two 6-inch size to six 3.5-inch (ID) nozzles; this arrangement would require headering of the liquid mercury return piping at each of the eight boilers.

The tube sheet of INOR-8, if made of flat plate, will be 10 inches thick and will be an integral part of the fuel salt vessel head. It is possible to design a separate tube sheet to allow removal of the tube bundle without the necessity of cutting fuel lines. The probability of this requirement is low, therefore such an arrangement is uneconomical. Ordinarily, access to the tube bundle would be required only for plugging of leaking tubes. The head closure can be made of a convex torospherical type held in place with a shear ring; this design will conserve material, such a head being approximately 4 inches thick.

Design Conditions--- For this cost study the fuel cycle conditions remain constant. Therefore, the conditions of fuel salt temperature and pressure in the mercury boiler are essentially the same as in the base case (Loeffler cycle).

Table V-1. Design Specifications for Mercury Boilers

Each of 8 units

1. Physical Arrangement

No. of tubes	2725
Tube size, OD/t, in.	0.5/.065
Tube length, ft.	28.3
Tube bank configuration	U-tube/triang. pitch
Tube material	5 Cr-1/2 Mo clad INOR-8
Tube weight, lbs	24,800 (clad INOR-8)
Tube sheet and head weight, lbs	17,600 (INOR-8)
Tube side volume, ft^3 (including head)	80
Shell configuration	Fig. 10
Shell thickness, in.	3
Shell volume, net, ft^3	450
Shell material	5 Cr - 1/2 Mo
Vessel weight, lbs tare	95,000
lbs service	420,000
Vessel space requirements, ft (l x w x h)	18 x 6 x 12
Nozzles - Fuel inlet (250 psi 1300 F) 12" sch 20	INOR-8
Fuel outlet (250 psi 1100 F) 12" sch 20	INOR-8
Hg inlet (250 psi 1050 F) 2-6" sch 40	5 Cr-1/2 Mo
Hg outlet (250 psi 1050 F) 2-24" sch 60	5 Cr-1/2 Mo

2. Operating Characteristics, per Boiler

Flow rates, lb/hr - Fuel	13.85×10^6
Hg (vapor)	8×10^6
Hg (recircul.)	39.125×10^6
Heat load, Btu/hr	1.0675×10^9
Heat flux, Btu/hr-ft^2	106,700
Heat transfer coeff. (over-all) Btu/hr-ft^2-F	650
Fuel inlet, psia/F	185/1300
outlet, psia/F	80/1100
Hg inlet, psia/F	250/742
recirculation, F	1050
outlet, psia/F	240/1050
Hg mass, lb	310,000

C. No. 1 Steam Superheater

Purpose--- Mercury vapor transfers its heat of vaporization to saturated steam for initial superheat in the steam cycle.

Criteria--- Saturated mercury vapor is to be condensed in a mercury-steam heat exchanger for return to the mercury boiler. Saturated steam from the mercury turbine condenser (water boiler) is superheated as it passes through the heat exchanger. Adequate biological shielding is to be provided for the heat exchanger and related auxiliaries containing mercury liquid or vapor.

Conceptual Design--- Mercury turbine extraction vapor at saturated vapor pressure of 72 psia provides the desired temperature for superheating the steam generated in the mercury turbine condenser. Mercury vapor is condensed on the shell side of the heat exchanger as steam passes through the tube bundle. To conserve space the design is based on U-tube configuration. Baffling of such an arrangement may be a problem due to the low vapor density and high mass flow rate. Should it be necessary to reduce the baffling, some increase in heat transfer area would be required.

The large diameter shell requires a thick tube sheet and shell head to contain the high temperature-high pressure steam. Head clamping requirements dictate a shear-ring type arrangement.

Liquid mercury is pumped back to a mercury return header which accumulates liquid mercury from the turbine condenser and the No. 2 superheater, as well as from the No. 1 superheater.

Design Specifications--- The tabulation below presents pertinent information for each of two superheaters.

Table V-2. Design Specifications for No. 1 Superheater

A. Physical Arrangement, each unit	
No. of tubes	1300
Tube size, OD/t, in.	0.84/0.11
Tube length, ft	57.3
Tube bank configuration	U-tube, triang. pitch
Tube material	5 Cr - 1/2 Mo steel
Tube-side volume, ft^3 (including head)	208
Shell thickness, in.	0.4
Shell volume, net ft^3	244
Shell material	5 Cr - 1/2 Mo steel
Vessel weight, lbs tare	120,000
lbs service	122,700
Vessel space requirements, ft (l x w x h)	34 x 6-1/2 x 6-1/2
Nozzles - Steam inlet (2200 psi 650 F)	18" sch 120 C-steel
Steam outlet (2200 psi 850 F)	20" sch 120 1-1/4 Cr - 1/2 Mo
Hg inlet (100 psi 900 F)	2 - 30" sch 10 5 Cr - 1/2 Mo.
Hg outlet (100 psi 900 F)	9" OD, t = 0.125 5 Cr - 1/2 Mo
Hg Cond. pump per turbine, motor hp	250

B. <u>Operating Characteristics per unit</u>

Flow rates, lbs/hr - steam	3.74×10^6
Hg	7.125×10^6
Heat transfer, Btu/hr	841×10^6
Heat flux, Btu/hr-ft^2	50,750
Heat transfer coeff. (over-all), Btu/hr-ft^2 - F	500
Steam inlet, psia/F	1990/636
outlet, psia/F	1900/825
Hg inlet, psia/F	72/860
outlet psia/F	/860
Hg volume, lbs	2200

D. <u>No. 2 Steam Superheater</u>

<u>Purpose</u>--- Mercury vapor transfers its heat of vaporization to superheated steam to increase the steam superheat.

<u>Criteria</u>--- Dry saturated mercury vapor is to be condensed in a mercury-steam heat exchanger for return to the mercury boiler, Superheated steam from the No. 1 superheater is given additional superheat as it passes through the heat exchanger. Adequate biological shielding is to be provided for the heat exchanger and related auxiliaries containing mercury liquid or vapor.

<u>Conceptual Design</u>--- Mercury vapor at 1050 F from the mercury boiler passes through the shell side of the superheater and condenser. Due to the pressure drop through the vessel, a pump is required to return the liquid mercury to the return header. The steam is given 175 F additional superheat in the straight tube heat exchanger. Other design requirements are similar to the No. 1 superheater.

<u>Design Specifications</u>--- The tabulation below presents data pertinent to each of two superheaters.

Table V-3. Design Specifications for No. 2 Superheater

A. Physical Arrangement, each unit

No. of tubes	1925
Tube size, OD/t, in.	0.84/0.11
Tube length, ft	33.5
Tube bank configuration	Straight tube, triang. pitch
Tube material	5 Cr - 1/2 Mo steel
Tube side volume, ft^3 (including head)	180
Shell thickness, inches	1.8
Shell volume, net ft^3	203
Shell material	5 Cr - 1/2 Mo steel
Vessel weight, lbs tare	180,000
lbs service	182,600
Vessel space requir., ft (l x w x h)	38-1/4 x 6-1/3 x 6-1/3
Nozzles steam inlet (2200 psi, 850 F)	20" sch 120 1-1/4 Cr-1/2 Mo
steam outlet (2200 psi, 1000 F)	26" t = 3.1" 1-1/4 Cr-1/2 Mo
Hg inlet (250 psi, 1050 F)	2 - 13.5 OD, t = 0.35 5 Cr-1/2 Mo
Hg outlet (250 psi 1050 F)	6.8 OD, t = 0.2, 5 Cr-1/2 Mo
Hg Cond. pump, motor hp	50

B. Operating Characteristics per unit

Flow rates, lb/hr - Steam	3.74×10^6
Hg	3.625×10^6
Heat transfer, Btu/hr	452×10^6
Heat flux, Btu/hr-ft^2	32,050
Heat transfer coeff. (over-all), Btu/hr-ft^2-F	290
Steam inlet, psia/F	1870/825
outlet, psia/F	1820/1000
Hg inlet, psia/F	240/1050
outlet, psia/F	240/1031
Hg volume, lbs	2200

VI. The Direct Fuel-Salt-to-Water Cycle

A. General Description

In a direct cycle, heat is transferred from fuel salt to boiling water or steam without being carried by a circulating stream of intermediate coolant fluid. Double containment of the fuel salt is retained, however, by constructing the salt-to-steam heat exchangers to provide a noncirculating buffer layer of salt between the fuel-salt and steam so that steam and fuel-salt could intermingle only by the simultaneous failure of both the steam-tube and the salt-tube. The pressure in the buffer salt region would probably be maintained at a value less than that in either the steam or in the fuel-salt.

Eight fuel salt circuits are provided. The fuel salt in each circuit is split into three streams with the piping sized, or properly orificed, so that the correct amount of salt will flow through the boiler, superheater and reheater units which are in parallel in each fuel circuit.

Since all the heat exchangers contain fuel salt, they are located within the reactor shield (and within any containment vessel that might be required). These heat exchangers will be referred to as "thimble-tube heat exchangers" since they are composed of multiple re-entrant steam tubes inserted into the same multiplicity of fuel-salt thimble-tubes. Fuel-salt contacts the outside surface of the salt thimble-tubes, and flows downward through annular passages formed by the insertion of cusp-shaped filler-pieces in the spaces between the thimble-tubes.

A flowsheet of the direct cycle salt-to-steam direct thermal conversion cycle is shown in Fig. 11. Suggested equipment and piping layouts of the reactor, fuel-salt pumps, and heat exchangers are shown in plan and elevation views in Figs. 12 and 13. The steam conditions were chosen to correspond to those of the Colbert Plant of TVA. Though not the most modern plant, its conditions are expected to be economically suited for molten salt reactor application. The over-all plant efficiency based on these steam conditions is expected to be 41.7%.

B. Thimble-Tube Heat Exchangers--Boiler, Superheater and Reheater Units

Purpose--- The thimble-tube heat exchangers serve three functions: as boiler, superheater and reheater. The boiler produces wet, saturated steam from preheated boiler feed water. The superheater takes nearly dry, saturated steam (from a moisture separator in the boiler steam discharge line) and heats it to a temperature high enough to give desired cycle efficiency in a modern high-temperature, high pressure turbine. The reheater further increases the steam cycle

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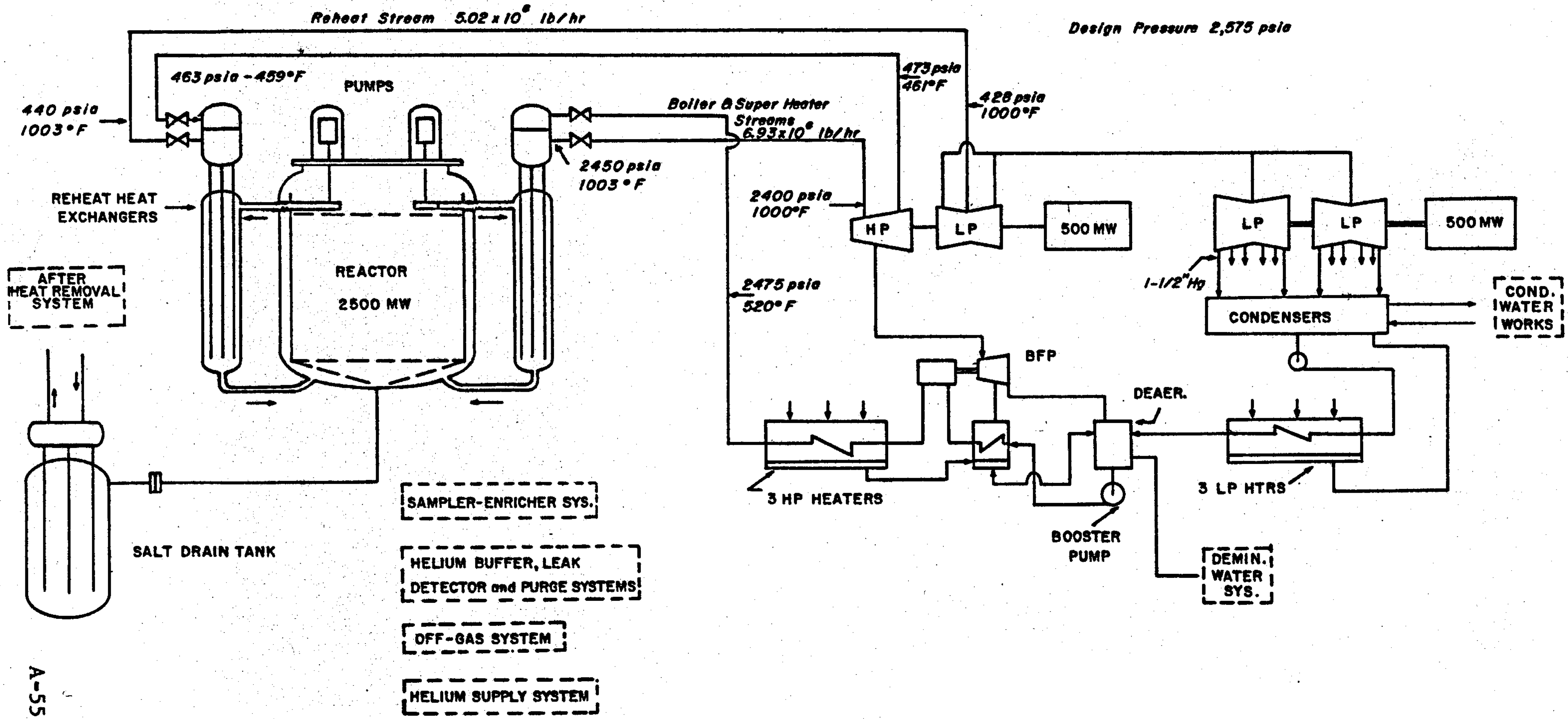

FIG. II MOLTEN SALT CONVERTER REACTOR

Direct Power Cycle Flowsheet

efficiency by taking steam rejected from the high-pressure turbine and reheating it for use in an intermediate pressure turbine.

Criteria--- The same criteria apply to the thimble-tube heat exchangers as were listed for the primary heat exchanger of the Loeffler boiler cycle, but since heat is being removed from the fuel salt by water and steam instead of by an intermediate coolant salt there are added criteria applicable to the thimble-tube units. It is desirable to make the steam tubes and headers removable from and independent of the fuel-salt-containing shell. It is necessary to retain the double-containment philosophy of separating the water and steam systems from the fuel-salt. This latter requirement makes it a misnomer to call this a "direct" fuel-salt-to-water cycle.

Materials--- Surfaces in direct contact with fuel-salt should be made of INOR-8. Steam-containing tubes contacted by buffer salt, and in potential contact with a mixture of buffer salt and fuel salt in the event of a fuel-salt-thimble-tube failure, may be made of Inconel, or of INOR-8. Where possible, Inconel should be used instead of INOR-8 because of its lower cost. The buffer salt will be assumed to be of the same composition as MSCR coolant salt; however, other salts such as mixed alkali carbonates might possibly be used as buffer salt.

Conceptual Design--- Figure 14 shows in schematic form the conceptual design of a salt-to-steam thimble-tube heat exchanger which can serve as a boiler, superheater, or reheater. Pertinent design specifications for each of these three functions in units each capable of producing the necessary steam to generate 125 Mwe of power are listed in Table VI-1.

In principle, heat is transferred from the down-flowing stream of fuel-salt, through successive annular thicknesses of salt thimble-tube, inert salt, and steam riser tube, to steam (as boiling water, saturated steam, or superheated steam) which is flowing upward through the annular space between the steam down-pipe and the steam riser tube. Sufficient flow area is provided in both the steam down-pipe and in the annular flow passage of the steam riser to keep the steam-side pressure drop within reasonable limits. The salt flow-passages on the shell-side are annuli formed by the insertion of filler-pieces in the spaces between the thimble-tubes, which are arranged on a triangular pitch with a 1/4 inch-thick ligament between tubes in the thimble-tube tube-sheet. The filler pieces serve to reduce the inventory of fuel salt, and to increase the salt velocity to approximately 4 ft/sec. In order to provide a fuel-salt inlet plenum to distribute the flow of fuel salt to the various salt annuli, the filler pieces must be hung by small-diameter rods from the tube sheet. The height of this salt inlet plenum must be minimized by having the salt inlet nozzle flattened into an oval shape with its major axis horizontal. The fillers are

20 feet long, making the effective channel length for heat transfer 20 feet. There are two filler-pieces for each thimble-tube. It is felt that the filler pieces could be fabricated simply and cheaply by extruding, or by casting. The filler pieces could be made of Inconel unless by reason of high corrosion rates of the very large surface area of these pieces undue amounts of corrosion products would be introduced into the fuel salt.

As is evident from the previous paragraph, separation of the steam and fuel salt is accomplished by the provision of the stagnant inert salt annulus between the salt and steam flow passages so that in the event of the failure of either a steam tube, or of a salt thimble-tube, the steam would not be exposed directly to the fuel salt. Failure of a salt-thimble-tube is felt to be much less likely than failure of a steam tube, hence the design provides for removing the steam-tube-assembly as a unit by merely lifting it straight up after removing the seal from the seal-well shown in Fig. 14.

The design calculations for these units were based on the assumption that the inert salt contained in the annulus between the fuel salt and the steam was the same binary mixture of lithium and beryllium fluorides that is being used as coolant salt for the MSRE. This requires that a cover-gas plenum be provided to protect the inert salt from atmospheric contamination. This cover gas is presumed to be helium at some nominal pressure not much greater than one atmosphere absolute. It is probable that the cover gas plenum would be made to serve as a leak detector chamber by providing a slow circulation of helium through the plenums and past radiation monitors located external to the reactor shield.

The fuel salt thimble-tube assembly (including the fillers) may also be made removable by providing a lip for seal-welding between the tube-sheet and the heat exchanger vessel, and a hold-down ring assembly (possibly a split-ring type) to hold the tube-sheet down against the 100 psig design pressure of the fuel salt in the shell. This would permit removing all of the tubing from the heat exchanger vessel without having to break the fuel salt piping connections to the heat exchanger.

In Fig. 12 is shown a plan view of the equipment arrangement within the reactor shield with steam line routes and shield penetrations indicated schematically for one of the eight fuel salt circuits. There are two parallel sets of steam headers located on opposite sides of the reactor shield structure, with each set of headers serving four of the fuel salt circuits. Also shown in schematic form is a boiler recirculation pump, and a moisture separator which is intended to remove most of the entrained moisture from the saturated steam leaving the boiler, and thus provide the superheater with nearly dry, saturated steam. With no particular basis for a

specification it was assumed that there would be about 3 pounds of moisture recirculated for every 7 pounds of dry steam produced in the boiler. This requires that each boiler recirculation pump (there are 8 such pumps in the station) have a capacity of about 1250 gpm against a head of about 25 psi. No design specifications have been written for the moisture separator in the boiler steam outlet line.

Steam nozzle sizes have been specified in Table VI-1 for the boiler, superheater and reheater. These same sizes could be used for the steam connecting lines between the heat exchangers and the various steam headers.

Figure 13 shows a partial elevation view of one fuel salt circuit, with the boiler and reheater units shown in relation to the reactor. The superheater steam lines may be located at slightly different elevations than those of the boiler and reheater.

It is recognized that there are a number of unresolved problems connected with the direct-cycle thimble-tube heat exchanger concept shown here. Among these are: (1) There is no easy way of removing the inert salt should it become necessary to do so because of contamination of the salt from a steam-tube failure, or from a salt thimble-tube failure; (2) Differential radial expansion of the three tube sheets (because each tube sheet operates at a different temperature) means that concentricity of the steam tubes in the salt thimbles cannot be maintained. In fact, in the outer rows of tubes in a tube bundle the steam tubes could be contacted and bent by the salt thimble-tube where it passes through the salt tube-sheet. This contact and bending could result in permanent interference which might make it impossible to withdraw the steam tube assembly from the salt tube bundle without damage to the salt tubes. It could also result in early failure of either steam or salt tubes; (3) The close tolerances required to minimize salt hold-up will make it difficult to install a new bundle of steam tubes in a matching array of salt thimble-tubes.

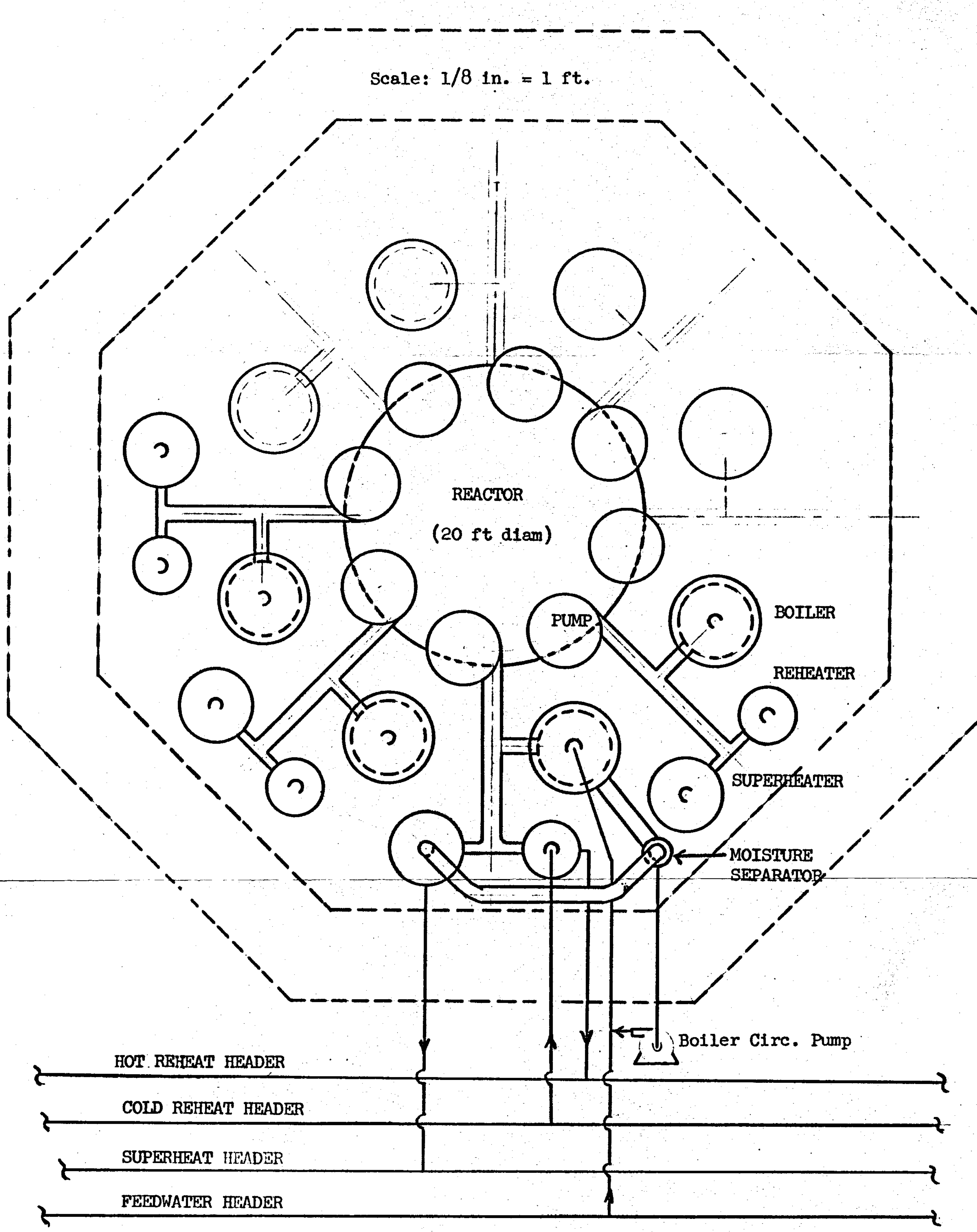

Fig. 12 PLAN VIEW SCHEMATIC -- THIMBLE-TUBE HEAT EXCHANGER ARRANGEMENT FOR DIRECT FUEL-SALT-TO-STEAM CYCLE

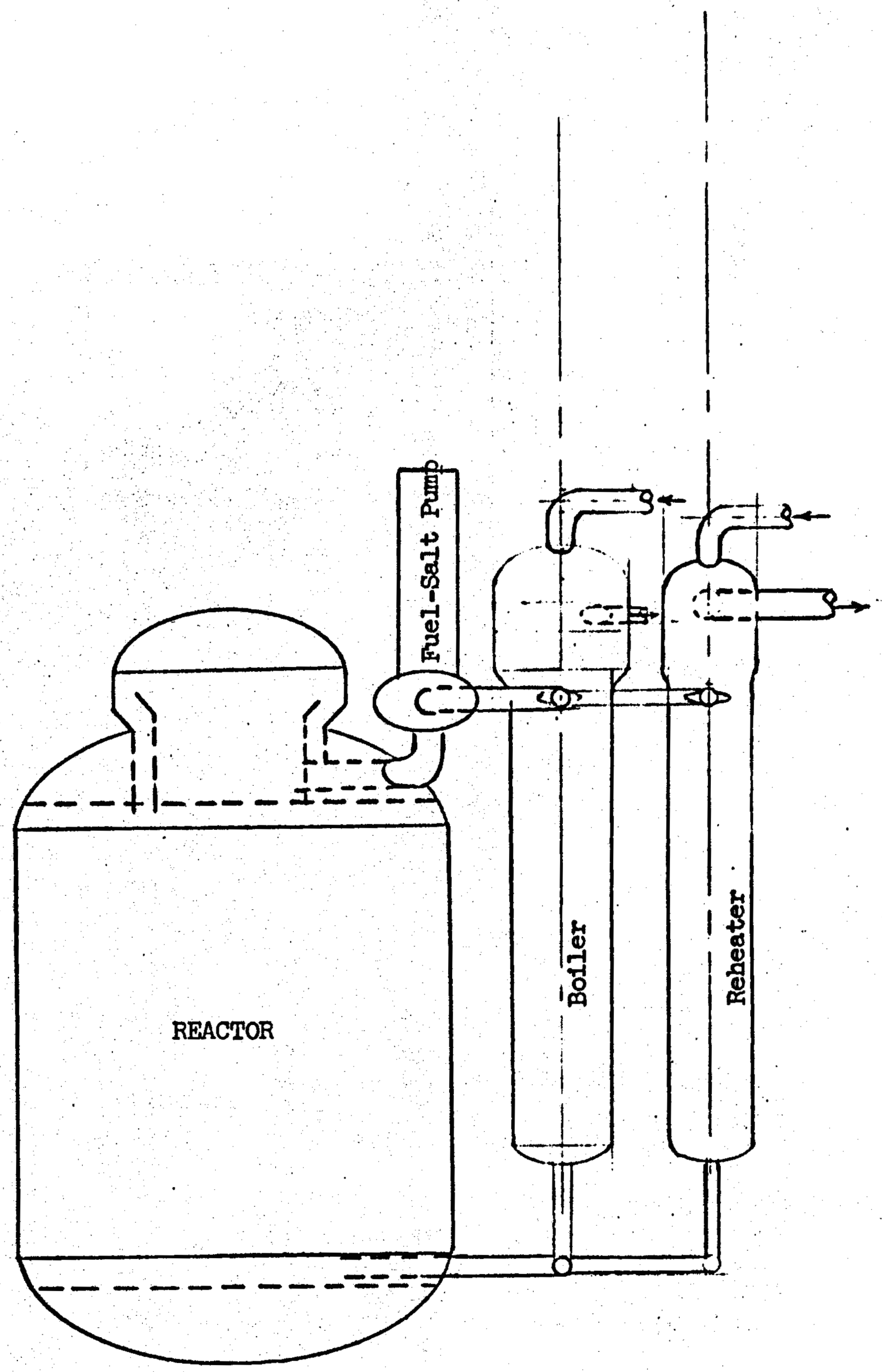

Fig. 13 ELEVATION VIEW OF ONE FUEL SALT CIRCUIT
MSCR WITH THIMBLE-TUBE HEAT EXCHANGERS
DIRECT FUEL-SALT-TO-STEAM CYCLE

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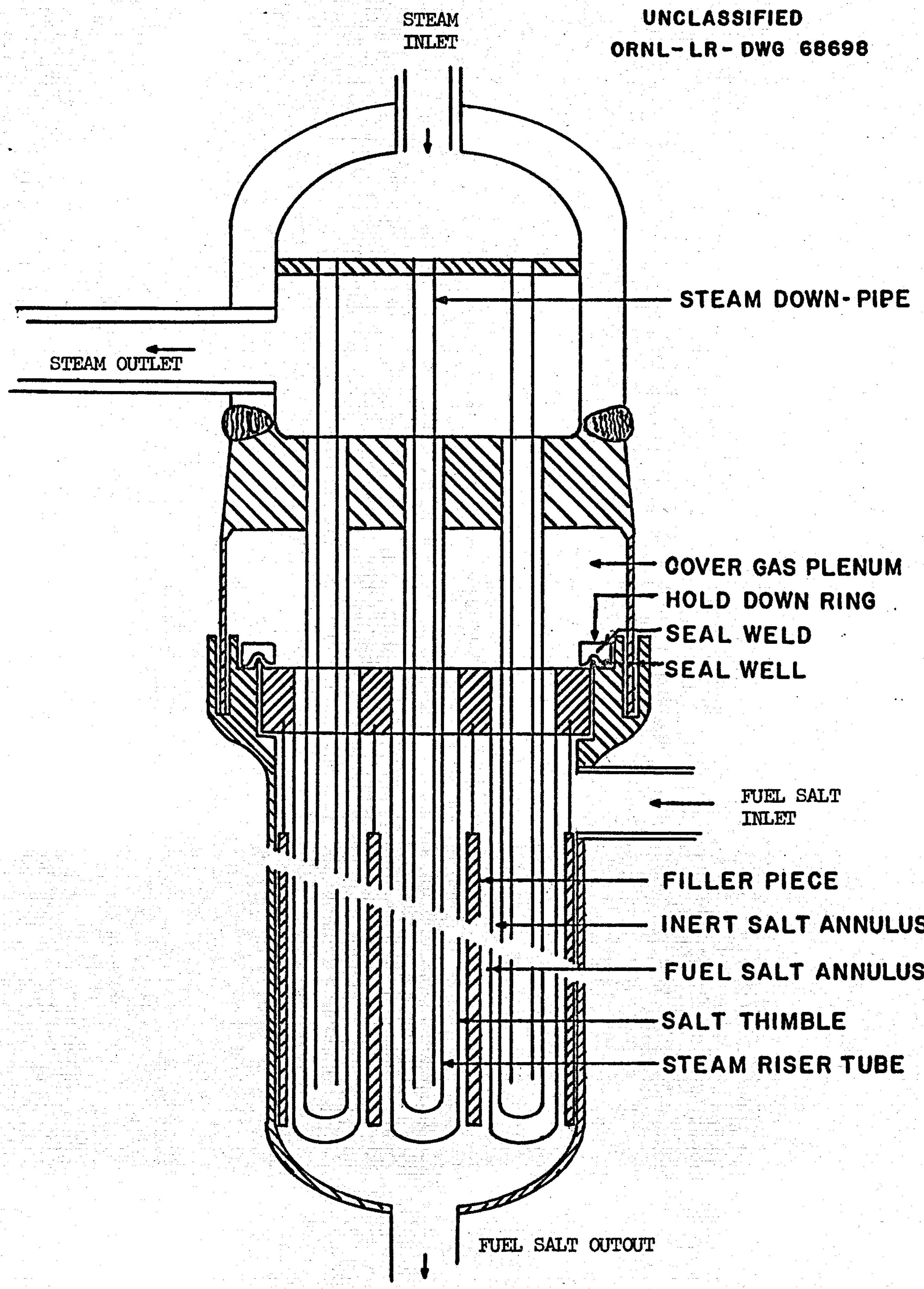

FIG. 14. Salt-To-Steam Thimble-Tube Heat Exchanger

Table VI-1. Thimble-Tube Heat Exchangers - Design Specifications

Each Unit	Boiler	Superheater	Reheater
Number of thimbles	1053	727	313
Pitch, in.	1.75	1.75	2.25
Heat Exchanger Shell			
Inside diameter, in.	60	50	43
Thickness, in.	1	0.875	0.75
Tube Sheet Thickness, in.			
Salt	6.6	5.3	4.7
Bottom steam	13-3/4	12	1.5
Top steam	1	1	1
Fuel Salt			
Annulus thickness, in.	0.065	0.065	0.065
Annulus length, ft	20	20	20
Thimble tube OD, in.	1.50	1.50	2.00
Thimble thickness, in.	0.060	0.060	0.060
Nozzle flow area, $in.^2$	96	60	38
Steam Riser Tube			
Outside diam., in.	1.250	1.250	1.750
Wall thickness, in.	0.083	0.10	0.060
Material	Inconel	INOR-8	INOR-8
Steam Down-Pipe			
Outside diameter,in.	0.765	0.928	1.340
Wall thickness, in.	0.040	0.040	0.040
Material	Inconel	Inconel	Inconel
Steam Nozzles			
Inlet, pipe size, in.	10	8	12
Sch. No.	120	120	40
Outlet, pipe size, in.	8	10	18
Sch. No.	120	120	60
Steam Inlet Plenum			
Inside diam., in.	60	50	43
Wall thickness, in.	4.7	3.9	0.625
Design pressure, psi	2500	2500	500
Material	Inconel	Inconel	Inconel
Steam Outlet Plenum			
Inside diam., in.	60	50	43
Wall thickness, in.	4.7	4.0	0.65
Design pressure, psi	2500	2500	500
Material	Inconel	INOR-8	INOR-8
Cover Gas Plenum			
Inside diameter, in.	68	56	48
Wall thickness, in.	0.5	0.5	0.5
Material	Inconel	Inconel	Inconel

Table VI-2

Weights of Various Forms of INOR and Inconel in Each Thimble-Tube Heat Exchanger Direct Salt-to-Steam Heat Transfer System

	Boiler	Superheater	Reheater
Inconel Requirements, lb			
Tubing	37,170	7,500	4,616
Cyl. Vessel	4,360	700	561
Formed heads	8,940	4,550	477
Total Inconel	50,470	12,750	5,654
INOR Requirements, lb			
Tubing	22,900	39,790	17,852
Tube Sheets (blank)	24,987	16,238	4,532
Cylindrical Vessel	15,000	13,900	8,355
Formed Heads	1,600	685	478
Filler Pieces	37,820	25,470	15,590
Total INOR	102,307	96,083	46,807
Service Weight	168,600	120,500	64,000
Inert Salt, lb	4,712	3,250	1,930

Table VI-3

Tubing Requirements - Thimble-Tube Heat Exchangers
for Direct Salt-to-Steam Heat Transfer

Inconel Tubing	OD in.	Wall Thickness in.	Length ft.	Weight lb.
Boiler	0.765	0.040	26,325	8,840
Boiler	1.25	0.083	25,272	28,330
Superheater	0.928	0.040	18,320	7,500
Reheater	1.340	0.040	7,670	4,620
Total Inconel Tubing per unit*			77,587	49,290
INOR Tubing				
Boiler	1.50	0.060	22,165	22,900
Superheater	1.50	0.060	15,267	15,790
Reheater	2.00	0.060	6,542	9,110
Superheater	1.25	0.100	17,448	24,000
Reheater	1.75	0.060	7,200	8,740
Total INOR Tubing per unit*			68,622	80,540

	Per Unit*		For 8 Units	
Totals	Length	Wt.	Length	Wt.
Inconel Tubing	77,587	49,290	620,696	394,320
INOR Tubing	68,622	80,540	548,976	644,320
INOR Filler-Pieces	41,860	78,880	334,880	631,040

*NOTE: One unit is comprised of the boiler, superheater and reheater for one fuel salt circuit.

VII. Miscellaneous

A. INOR-8 CHEMICAL, PHYSICAL and MECHANICAL PROPERTIES

1. Chemical Composition Requirements

Nickel	Balance (2-66-71)
Molybdenum	15.0 to 18.0
Chromium	6.0 to 8.0
Iron, max.	5.0
Titanium plus Aluminum, max.	0.50
Sulfur, max.	0.02
Manganese, max.	1.0
Silicon, max.	1.0
Copper, max.	0.35
Boron, max.	0.010
Tungsten, max.	0.50
Phosphorus, max.	0.015
Cobalt, max.	0.20
Vanadium, max.	0.5
Carbon	0.04 to 0.08

2. Physical Properties

Density, g/cm^3	8.79
$lb/in.^3$	0.317
Melting point, F	2470 - 2555
C	1353 - 1400

Thermal conductivity, Btu/ft^2-hr-F/ft

Temperature, F	Conductivity, K
212	6.600
400	7.409
600	8.293
800	9.160
1000	10.37
1050	10.81
1100	11.10
1150	11.41
1200	11.71
1250	12.02
1300	12.68
1350	13.26
1400	13.55

INOR-8, Cont.

Physical Properties, Cont.

Temperature, F	Modulus of elasticity, psi x 10^6
57	31.7
430	29.3
770	27.8
930	27.1
1070	26.3
1170	26.2
1290	24.8
1470	23.7
1570	22.7
1660	21.9
1750	20.7
1830	19.1
1920	17.7

Temperature, F	Specific heat, Btu/lb-F
140	0.0977
212	0.1005
392	0.1052
572	0.1091
752	0.1120
896	0.1139
1004	0.1155
1058	0.1248
1094	0.1347
1148	0.1397
1220	0.1387
1256	0.1384
1292	0.1380

Temperature, F	Mean Coefficient of Thermal Expansion in/in/ F x 10^{-6}	T(F)	L/L (in/in)
70-400	6.45	330	2.13 x 10^{-3}
70-600	6.76	530	3.58 x 10^{-3}
70-800	7.09	730	5.18 x 10-3
70-1000	7.43	930	6.81 x 10^{-3}
70-1200	7.81	1130	8.83 x 10-3
70-1400	8.16	1330	10.85 x 10-3
70-1600	8.51	1530	13.02 x 10^{-3}
70-1800	8.85	1730	15.31 x 10^{-3}

3. Mechanical Property Requirements

Thickness, inches	Tensile Strength, psi, min.	Yield Strength, 0.2% Offset, psi, min.	Elongation, 2-inch gauge per cent, min.
To 2-1/2	100,000	40,000	35

4. Maximum Allowable Stress

Metal Temperature Not Exceeding F	Maximum Allowable Stress Values, psi	
	Sheet and Plate	Bolting
100	25,000	10,000
200	24,000	9,300
300	23,000	8,600
400	21,000	8,000
500	20,000	7,700
600	20,000	7,500
700	19,000	7,200
800	18,000	7,000
900	18,000	6,800
1,000	17,000	6,600
1,100	13,000	2,600
1,200	6,000	1,000
1,300	3,500	700

5. Welding Requirements

a. All butt-welded joints shall be examined radiographically for their full length.

b. All butt-welded joints and all nozzle-connection welds shall be examined for the detection of cracks by the fluid-penetrant method.

c. Rejectable defects disclosed by the examinations specified in paragraphs a and b above (such as cracks, pinholes, incomplete fusion, and slag inclusions) shall be removed by mechanical means, after which the joint shall be rewelded, and then re-examined.

d. Welding shall be done only by the inert-gas-shielded tungsten-arc welding process, using filler metal that produces welds which comply with the chemical and mechanical property requirements of paragraphs b and c above.

6. INOR-8 Use in Pressure Vessels

a. Nickel-molybdenum-chromium wrought material, as described, may be used for the construction of vessels under external pressure under the Code rules applying to non-ferrous materials.

b. Heat-treatment, including stress-relief of welded vessels, is neither required nor prohibited. When maximum corrosion resistance is required, it may be advisable to heat treat in such a manner as to place all carbides in solution. For such service it is recommended that the vessel be heated to 2150 F ± 25 F, and held for not less than one hour per inch of thickness; subsequently, all parts of the vessel should be quenched uniformly and as rapidly as possible in water or air. Heat treatment should be done only following all welding and welding repairs.

A Suggested Price List for INOR-8 in Various Forms

1. Plate--$3 per lb
2. Round-rod--$4.25 per lb
3. Welding rod--$8 per lb
4. Pipe (seamless)--$10 per lb
5. Pipe (welded)--$5 per lb
6. Tubing (seamless)--$12 per lb
7. Tubing (welded)--$6 per lb
8. Simple forgings (such as tube-sheets)--$4.50 per lb
9. Items fabricated from plate (such as cylindrical shells for pressure vessels)--$10 per lb
10. Dished heads--$5.50 per lb
11. Forged pipe fittings--$50 per lb
12. Castings--$2 per lb

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