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NP-9234

100-MW NUCLEAR POWER PLANT UTILIZING A SODIUM COOLED, GRAPHITE MODERATED REACTOR

NP-9236

AI-2550

ATOMICS INTERNATIONAL

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1. SCOPE

This document describes the conceptual design of a nuclear power plant which has a rated net generating capacity of 100 megawatts electrical output. The power plant utilizes a sodium cooled, graphite moderated nuclear reactor. Engineering drawings for the plant are given at the end of this document.

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2. GENERAL DESCRIPTION & PLANT DATA

2.1 DESCRIPTION

This document describes a complete power plant, from the source of heat in the reactor to the high voltage switchyard.

The perspective and plot plan of the power plant installation are shown in Plates 1 and 2. The assumed site is a level area adjacent to a source of cooling water in a temperate zone with highway and railroad services available. The power plant is housed in one building, with the exception of the high voltage switchyard and the radioactive liquid waste treatment and cooling water structures which are remote from the building.

The main portion of the building contains the reactor area and the turbine area. A low bay area on one side of the building contains the reactor service areas. On the other side of the building a low bay area contains mechanical and electrical equipment, control room, and offices. The reactor, turbine and service areas of the building are shown in Plates 3 to 13 inclusive. The control room serves for both the reactor and the turbine-generator plants, with both plants using the same control board as shown in Plate 20. The reactor and the radioactive portions of the systems are contained in shielded cells below grade, while the non-radioactive systems are above grade. The isometric plant arrangement, Plate 12, shows the general conception of the location of equipment and the shielding of the radioactive portion of the sodium heat transfer system. The building is serviced with a bridge crane, in addition to the gantry crane used for fuel handling. The building is of conventional industrial construction.

Structures remote from the building are shown in Plate 14.

The power plant uses a sodium-cooled graphite-moderated reactor with stainless steel clad, slightly enriched uranium-oxide fuel. The energy released by the fuel heats sodium which is pumped to three separate primary circuits. Each circuit has an intermediate heat exchanger which transfers the energy from the radioactive primary circuit to a non-radioactive secondary sodium heat transfer circuit. Each non-radioactive secondary sodium heat transfer circuit contains a steam generator, where feed water is evaporated and the steam superheated. The non-radioactive steam from the three steam generators is fed into a common

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steam header which serves a single turbine-generator. The reactor and the sodium systems operate at low pressures. Nitrogen at slightly more than atmospheric pressure provides an inert atmosphere over the sodium in the reactor. The sodium heat transfer system is operated at a pressure just sufficient to overcome pressure drops.

The steam cycle used has three stages of regenerative heating. Cooling water for the condenser is supplied from the river. The makeup water is supplied through a demineralization system. The turbine-generator plant has provision for the emergency and normal afterglow cooling required to remove the energy released in the reactor after shutdown.

A sodium service system is used to fill, drain and flush the reactor core tank and sodium heat transfer systems. The sodium service system also contains a purification system to remove oxides from the sodium in order to control corrosion rates and to preclude impairment of mechanical and thermal performance of equipment. Nitrogen systems are used to provide an inert gas within the reactor and sodium system and inert gas atmospheres in the shielded cells. There are also systems to remove, store and dispose radioactive gases and radioactive liquid wastes. An organic cooling system provides auxiliary cooling to the concrete biological shielding of the reactor, certain sodium handling components and the atmosphere in the shielded radioactive cells.

The fuel handling system consists of a fuel handling cask, fuel storage and washing cells and all necessary equipment for receiving new fuel, refueling the reactor and shipping spent fuel. The fuel handling cask is supported on a gantry crane.

A plant control system is provided which allows automatic operation over the range of 20 per cent to 100 per cent load, or manual operation at all loads. In addition, a plant protective system allows rapid detection of any off-normal condition in the reactor plant and automatically takes corrective action. This action includes alarm, one-loop shutdown, setback, fast setback, and scram. All power plant control is from a central control room integrating both reactor and turbine-generator instrumentation.

2.2 PLANT DATA

Steam and Turbine-Generator

Nominal net electrical output	100 Mw	
Nominal gross electrical output	106 Mw	
Steam pressure at turbine	800 psig	
Steam temperature at turbine	825° F	
Feedwater temperature	300° F	
Steam flow at nominal power	905,700 lb/hr	
Generator output voltage	13,800 v, 50 cps	
Power transformer output voltage	66,000 v	

Reactor

Nominal thermal power	308 Mw	
Sodium inlet temperature	500° F	
Sodium outlet temperature	925° F	
Total sodium flow at nominal power	8,080,000 lb/hr	
Core height (not including reflector)	14 ft	17
Core diameter (not including reflector)	15 ft	13
Nominal reflector thickness	2 ft	
Power of central fuel element	2100 kw	4030
~~Radial peak-to-average power-density~~	~~1.57~~	
Average specific power in fuel	423 kw/kg U^{235}	
Average thermal flux in fuel	1.7×10^{13} n/sec-cm^2	
Peak thermal flux in fuel	4.1×10^{13} n/sec-cm^2	
Initial atomic per cent of U^{235} in fuel	3.5%	2.5
Uranium inventory (in core only), for 230 fuel elements	52,000 lb UO_2 20,800 kg U 728 kg U^{235}	
Initial conversion ratio	0.54	.65
Maximum fuel temperature	4,000° F	2500 °F
Average exposure of fuel	9,600 megawatt-days per ton of UO_2 (ton = 2000 lb)	10,000/T.
Pu produced (average)	41.0 kg per year	53 kg.
Number of fuel channels	251	156

(Continued on next page)

Number of fuel elements for 308 MWT	230	150
Number of safety rods	8	8
Number of shim rods	9	7
Number of regulating rods	1	1
Center channel average velocity	10 fps	
Average number of fuel elements changed per refueling shutdown	60	25
Average period between refueling shutdowns (75% plant utilization coefficient)	275 days	180 days.

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3. SITE & SITE DEVELOPMENT

3.1 DESCRIPTION

The assumed site is a level area adjacent to a source of cooling water in a temperate zone with highway and railroad service available.

3.2 SOIL CONDITIONS

The soil bearing capacity at the site is assumed to be 4000 pounds per square foot. The frostline is assumed at 2 feet. Ground water is assumed to be 6 feet below finished grade.

3.3 GRADING AND DRAINAGE

Grading of site includes only that necessary for construction of roads, buildings and work areas.

Surface drainage is used where practicable except for the main plant area where catch basins and reinforced concrete pipe are provided. Roof drainage is discharged into the underground system. Culverts are provided where surface drainage crosses roads and railroad spurs.

3.4 ROADS, WALKS AND SURFACING

Roads and a 35-car parking lot are paved with a sealed asphaltic surfacing on a 6-inch gravel base course and suitable subgrade. Necessary asphalt surfaced work areas are provided as required. The area surrounding the transformers is provided with a suitable rock blotter to absorb transformer oil spills. The switchyard has a similar rock surfacing.

3.5 RAILROAD

A railroad spur serves the main building.

3.6 FENCING

The main plant area, the cooling water intake structure, and switchyard are fenced with chain link fencing provided with extension arms carrying barbed wire.

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3.7 UTILITIES

Domestic water is assumed available at the plant site. A 50,000-gallon flat bottom storage tank is provided for domestic water supply, instrument air compressor aftercooler, and the demineralized water makeup system.

Outside fire protection is provided by 8-inch cement asbestos pipe loops complete with hydrants, isolating valves, and connections for hose reels in the buildings. The loops encircle the main plant area and switchyard. A hydrant is provided near the cooling water intake structure. Hydrants are spaced at approximately 200-foot centers. Two hose carts with accessories are furnished.

A diesel-driven fire pump supplies screened river water from the intake structure. This pump is connected in parallel with the screen wash pump. Pressure is normally maintained by a 3000-gallon head tank on the roof of the main building.

A CO_2 system provides fire protection for the turbine lube oil equipment and the generator.

Sanitary wastes are disposed of by a septic tank and leaching field. The system is designed for an occupancy of 40 people.

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4. REACTOR

The reactor structure is shown on Plate 21.

4.1 ACTIVE CORE

The active core, which includes moderator and fuel elements, and the reflector region are formed by an array of closely packed and canned hexagonal graphite elements. The corners of the hexagonals are fluted to allow for the placement of the process tubes, most of which contain fuel elements. The fuel elements are suspended in the middle portion of the core such that a reflector region is provided to surround the fuel elements, both radially and axially. All of the moderator and reflector elements are supported by the pedestals which form the core supporting structure.

4.2 SODIUM FLOW

The process tubes and the grid plate form the moderator cooling plenum, which allows low velocity sodium to flow vertically along the sides of the moderator elements. High velocity sodium, which comes from the higher pressure plenum under the grid plate, flows vertically in the process tubes. The flow through the process tubes is controlled by orifice sizing. The moderator coolant flow is controlled by valves, which are located in the reflector region and are controlled from the upper surface of the loading face. The sodium streams merge when they flow into the sodium pool, which is located on top of the core.

4.3 MODERATOR AND REFLECTOR ELEMENTS

The moderator and reflector elements are of graphite in the form of fluted hexagonal logs contained in stainless steel cans.

4.4 FUEL ELEMENTS

The fuel elements, in the form of clusters of fuel rods, are suspended from the loading face. The rods forming the cluster contain slightly enriched uranium-oxide fuel slugs, which are contained in thin-walled stainless steel tubing. Helium fills the thin annular space between the fuel slug and the jacket wall.

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4.5 SHIM, REGULATING, AND SAFETY RODS

The shim, regulating, and safety rods, the neutron source, and the moderator coolant off-on valves are located at the hexagonal corners of the moderator and reflector cans.

Shim and regulating rods permit an estimated 10 per cent control of reactivity, which is adequate to handle reactivity changes associated with temperature, poisons, and fuel depletion. Each control element operates in a thin-walled stainless steel thimble which extends from the top of the loading face down through the core, and each element is cooled by sodium. The neutron-absorbing material is suspended on a steel pull tube controlled by a variable speed drive mechanism. Shielding is used in the thimble where it passes through the loading face. Each rod has provisions to indicate "in" and "out" positions. Synchro transmitters indicate control rod locations.

The safety rods have a total reactivity of approximately 9 per cent. The safety rods operate within stainless steel thimbles similar to those used for the shim and regulating rods. Synchro transmitters indicate safety rod positions. Provisions are made to indicate rod-in or rod-out positions. The rods fall into the core by gravity and an impact snubber decelerates each through the last portion of its fall.

4.6 STARTUP NEUTRON SOURCE

A startup neutron source is located in a thimble near the core center. A gamma source capsule, sealed in a stainless steel tube, ensures an adequate neutron flux for reactor startup and may be replaced from the loading face. Activated to the desired level by exposure within another reactor, the neutron source provides adequate flux for measurement by the fission chambers located external to the thermal shield.

4.7 LOADING FACE AND RING SHIELDS

The loading face and ring shield are made of heavy concrete encased in stainless steel forms and are stepped to prevent radiation leakage. The plates at the sides and bottom are seal-welded throughout. Immediately above the bottom, or seal plate, there is a layer of lead and a plate of low carbon steel.

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The part of the casing above the carbon steel plate is filled with dense concrete. The lead and the steel plate serve as a thermal shield for nuclear radiations. This portion of the shield is cooled by an organic coolant circulated through coils embedded in the lead. Thermal radiation insulation in the form of a series of thin horizontal stainless steel plates is suspended from the seal plate. The loading face is penetrated by vertical holes which are filled with plugs that are used to suspend fuel elements, dummy elements, neutron source, and control valve extensions for moderator cooling. Holes for the shim, regulating and safety rods are plugged with shielding which is integral with the units. All holes are aligned with their channels in the reactor core. Gas seals between the loading face and the ring shield and between the ring shield and the cavity liner are made by use of a low melting point alloy, cast into a trough slightly below the floor level.

4.8 CORE SUPPORT

The core supporting structure consists of the grid plate and pedestal supports which support moderator and reflector elements at the scalloped corners.

4.9 CORE TANK

The core tank is a vertical cylindrical vessel with a flat head at the lower end. The core tank is sealed just below the ring shield by convoluted bellows which are welded to the top edge of the core tank and to the cavity liner. The tank is equipped with three nozzles for the sodium inlets to the reactor, located in the lower portion of the shell; three nozzles for sodium outlets located in the upper portion of the shell; two small nozzles located in the upper part of the tank for drain and vent connections.

The core tank is equipped with a liner and a grid plate. The liner is made of steel plate, and extends all around the inside of the tank from a few feet above the bottom of the tank to an elevation near the top edge of the tank. The liner provides an annulus of stagnant sodium against the wall of the core tank, thus minimizing thermal gradients along the tank wall during changes in power.

The core tank and its miscellaneous parts are made of stainless steel. All joints are welded.

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4.10 THERMAL SHIELD

The thermal shield consists of mild steel flat plates which fit into fabricated columns to form a multi-sided polygon.

4.11 OUTER TANK

The outer tank provides a completely enclosed region and provides a secondary barrier to the leakage of sodium from the core tank. All material for this vessel is high quality mild steel.

4.12 CAVITY LINER

The sides of the cavity liner are lined with insulation which extends all around the tank. The cavity liner serves as the outermost container for the reactor and as an attachment point for the various reactor seals and expansion bellows. During construction of the reactor, the cavity liner serves as the inner concrete form for the biological shield.

4.13 BIOLOGICAL SHIELD

The reactor is surrounded by a biological shield of concrete, portions of which are high density concrete as required for radiation shielding. This shield also serves as a structural support for the reactor.

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5. SODIUM SYSTEMS

5.1 GENERAL

The sodium systems consist of the sodium heat transfer system and the sodium service systems. All material in these systems is stainless steel with welded joints. All inaccessible sodium piping has instrumentation to detect sodium leaks. Sodium piping and equipment have electric heating to preheat the system before admitting sodium and also to keep the sodium in a liquid condition when the reactor is not in operation. All sodium piping and equipment is thermally insulated. Nitrogen and vent connections are provided to purge air from all equipment and piping before admitting sodium.

5.2 SODIUM HEAT TRANSFER SYSTEM

The sodium heat transfer system, shown in Plate 22, consists of three independent circuits with separate connections to the core tank. Each circuit handles one-third of the designed full load sodium flow and consists of a radioactive primary and a non-radioactive secondary sodium circuit. The primary sodium circuits transfer thermal energy from the reactor to the intermediate heat exchangers, and the secondary circuits transfer thermal energy from the intermediate heat exchangers to the steam generators. The sodium pumps in any one circuit can be run on emergency power at a reduced flow rate. All primary circuit sodium piping drains back to the reactor by gravity.

The layout of the sodium heat transfer system in the building is shown in Plates 3, 4, 7, 8, 10, and 12.

The arrangement of the cells for the intermediate heat exchangers, shown in Plate 3, provides adequate neutron shielding for the cells and prevents activation of the sodium in the secondary circuits. In order to enter an intermediate heat exchanger cell, the reactor must be shut down and time allowed for primary sodium activity to decay, or the primary sodium must be drained from the system in the cell; it is not necessary to drain the sodium from the primary circuits in adjacent cells. All radioactive sodium piping outside the intermediate heat exchanger cells is contained in the shielded area below grade between the reactor and the heat exchanger cells.

There is a stop valve and a flow control valve in each primary circuit. These valves are operated from the reactor floor. A check valve in each primary circuit prevents sodium backflow in case of a primary pump failure. The only valve in each secondary circuit is a control valve located outside of the shielded cells. The control valves are used only to control the sodium flow during the period of dissipating reactor decay heat.

Access to the shielded areas is provided by hatches in the reactor floor.

The expansion tanks in the secondary circuits have a regulated gas pressure to maintain the pressure of the secondary circuits higher than that of the primary circuits at the intermediate heat exchangers. This prevents radioactive contamination of the secondary circuits in case of a failure in an intermediate heat exchanger.

The pumps are of the centrifugal type. The pump drivers are connected to their pumps through variable speed magnetic couplings. Each pump also has coupled to it an emergency driver supplied from the emergency source. The primary circuit pumps handle radioactive sodium and incorporate biological shielding in the pump casing. The pump rotating parts, pump cover, gland and bearings can be extracted without disturbing the pump casing or piping. The pump case, impeller and parts in contact with sodium are of stainless steel.

The intermediate heat exchangers have primary radioactive sodium flowing through the tubes and non-radioactive sodium in the shell. The units are of welded construction.

The steam generators are of welded construction with natural circulation of water and steam in the shells, separate superheaters, and sodium flowing in the tubes.

5.3 SODIUM SERVICE SYSTEMS

The sodium service systems include the following: sodium fill, drain, flush and purification, as shown on Plate 23.

5.3.1 Sodium Filling

Sodium is received in drums or in a tank car. The sodium is melted, passed through a filter, and then distributed to the primary fill tank or the secondary fill tanks. Wrap-around electric heaters are used to melt the sodium in the drums. A circulating hot oil system melts the sodium in the tank car. Sodium from the drums flows to a transfer tank which is pressurized by nitrogen gas to force the sodium through the filter. The sodium receiving area is shown on Plate 4.

There are five primary fill tanks. Four have sufficient capacity to hold the sodium in the reactor, the three primary heat transfer circuits, and one secondary circuit (in case of a leak in an intermediate heat exchanger). The fifth tank holds the sodium to be used for flushing a primary circuit.

The reactor and primary circuits are filled by gravity to a level above the pump suction. At this time the centrifugal pumps can be started at low speed to fill the primary piping system and to fill the reactor core tank to the desired level. The reactor vents directly to the primary fill tanks and the primary piping also vents to the primary fill tanks through a freeze trap which does not permit passage of sodium. This results in a volumetric exchange of nitrogen and sodium between the primary heat transfer system and the primary fill tanks.

The secondary circuits are filled by pressurizing the secondary fill tanks with nitrogen. The secondary circuits vent to the atmosphere.

5.3.2 Sodium Drain

The reactor and primary circuits are drained collectively or separately by the primary service pump to the primary fill tanks. Heaters on the freeze traps in the primary circuits melt the sodium in the traps and permit nitrogen to enter the system.

The secondary circuits are drained to the secondary fill tanks by nitrogen pressure or by the secondary service pump.

5.3.3 Sodium Flush

Sodium flushing provides a means to reduce the activity of a primary circuit before the heat exchanger cell is entered. The circuit to be flushed is drained to a primary fill tank, and then filled with sodium from the fifth primary fill tank. This operation is repeated several times.

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5.3.4 Sodium Purification

Purification is accomplished by removing oxides from the sodium. Cold traps remove the oxides and plugging meters measure the oxygen content of the sodium.

In the reactor and primary circuits, a circulating-type cold trap is used to remove oxygen from the sodium in the primary fill tanks before the reactor and piping are filled with sodium. The same cold traps also purify the sodium after the reactor and primary circuits are in operation. The two primary cold traps with their associated plugging meters are located in shielded cells below the reactor floor level (refer to Plate 3). One cold trap can be cleaned while the other is in operation.

The secondary circuits have a diffusion-type cold trap at each secondary fill tank. These cold traps purify the sodium before filling the secondary circuits. After the secondary circuits are filled with sodium, two circulating-type cold traps, similar to the primary cold traps, are used. These cold traps and their associated plugging meters are located below grade in an accessible area, shown in Plate 3.

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6. REACTOR AUXILIARY SYSTEMS

The reactor auxiliary systems include the following systems: Organic cooling system; nitrogen system; radioactive vent system; and radioactive liquid waste system.

6.1 ORGANIC COOLING SYSTEM

The organic cooling system, Plate 24, provides cooling for all components in the reactor plant that are to be maintained at controlled temperatures. Because the system provides services in areas where possible leakage might result in interaction with sodium, a coolant such as tetralin, which is relatively inert to sodium, is used. There are three circuits, all served by the same pumps and heat exchangers. One pump and one heat exchanger handles the full load.

Circuit 1 is composed of items which require uninterrupted cooling. In case of a power failure, the battery powered emergency organic pump and two emergency cooling water pumps automatically carry the load for this circuit. As soon as the emergency diesel-generated power is available, a regular organic pump and two regular water cooling pumps carry the load until the plant power is restored.

Circuits 2 and 3 are not critical, and can stand interrupted service until the diesel-generated power is available in case of a plant power failure. These circuits are split into two circuits for piping convenience.

Carbon steel and all-welded joints are used for the piping systems. The valves, pumps and heat exchangers are of conventional construction.

6.2 NITROGEN SYSTEM

The nitrogen system, shown in Plate 25, is used to provide an inert gas atmosphere, at controlled pressures, in all sodium services, and also in shielded cell areas where radioactive sodium might come in contact with the atmosphere because of equipment or piping rupture.

A NaK bubbler is used to remove oxygen from the nitrogen that can normally come in contact with sodium. Nitrogen used for the cell atmospheres bypasses the bubbler. The nitrogen system maintains an atmosphere with less than five per cent of oxygen in the cell atmosphere.

Freeze traps and vapor traps prevent sodium from entering the nitrogen system.

The piping is made of carbon steel with welded joints.

6.3 RADIOACTIVE VENT SYSTEM

The radioactive vent system, shown in Plate 26, collects and stores radioactive gases until they can be released to the atmosphere. The gases consist of a mixture of nitrogen, air, hydrogen and water vapor.

The gases collected fall into two basic groups: gases that would normally be expected to be radioactive; and gases that are normally not but could become radioactive.

Gases that are normally radioactive come from the reactor and primary fill tank atmosphere. These gases flow directly to the suction tank and compressor system which stores the gases at high pressure. After sufficient decay time the gases are diluted in controlled amounts with the air in the ventilation system stack, and released to the atmosphere.

Gases which are normally not radioactive flow past radiation indicators. The gases below a specified radiation level are bypassed directly to the ventilation system stack. If the radiation level is above the specified value, the gases follow the same path as previously described for radioactive gases.

The piping system and suction tank are kept at a slight negative pressure by the compressors. One compressor can handle the normal load.

The compressor suction tank and the compressors are located below grade as shown in Plate 3. The decays tanks are buried alongside the building.

Carbon steel piping is used with welded joints.

6.4 RADIOACTIVE LIQUID WASTE SYSTEM

The radioactive liquid waste system, shown on Plate 27, washes, collects, stores, and disposes of the radioactive waste resulting from the cleaning of fuel rods and miscellaneous equipment such as valves and pumps. The system also stores and disposes of the wastes from the laundry.

The fuel cleaning cells are provided with water, nitrogen, vent, vacuum and drain services. The equipment cleaning cell operation is similarly provided.

Liquid wastes from the cleaning cells drain to a transfer tank. With air pressure, the waste is forced from the transfer tank to a selected hold-up tank. A radioactivity check is made in the hold-up tanks to check for fission products that might result from a fuel rupture. Wastes with normal activity are transferred to a short half-life decay tank. After sufficient decay, the waste is pumped to the steam plant cooling water discharge for dilution. Wastes with fission products go from the hold-up tanks to a fission product decay tank; from there they are diluted and discharged in small controlled amounts to the cooling water discharge.

Laundry wastes are stored in the laundry storage tank before discharging to the cooling water discharge.

Wastes in the laundry storage tanks are agitated by a mechanical mixer before taking a sample. Mixing in the decay tanks is obtained by the use of air.

The cleaning cell waste system piping is stainless steel with welded joints. Carbon steel with welded joints is used for the laundry waste.

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7. FUEL HANDLING SYSTEM

7.1 FUNCTIONS OF FUEL HANDLING SYSTEM

The functions of the fuel handling system are: to receive new fuel; prepare new fuel for use in the reactor; exchange new fuel for spent fuel in the reactor; store spent fuel prior to shipping; and prepare the spent fuel for shipping. These functions require the use of a series of fuel handling cells located in the vicinity of the reactor, equipment to maintain a nitrogen atmosphere in the cells, and a fuel handling cask. The system maintains a nitrogen atmosphere around the fuel elements and provides shielding for radioactive fuel elements.

7.2 NITROGEN ATMOSPHERE

A nitrogen atmosphere is maintained in the fuel preheat cells and the fuel cleaning cells by the nitrogen system. A nitrogen atmosphere is established in all the other cells by means of a portable unit which evacuates the cells with a vacuum pump and injects nitrogen into the cells.

7.3 FUEL HANDLING CASK

The fuel handling cask transports all fuel elements and plugs from one position to another and maintains a nitrogen gas atmosphere while open to the reactor or the various cells. The cask is long enough to accommodate the over-all length of the fuel element, reactor plug, and hanger rod, and has sufficient internal diameter to enclose two fuel assemblies at one time. The cask assembly, which consists of the cask body, shielding, self-contained drive mechanism, gas interlock assembly, operator's platform, and controls, weighs approximately 110 tons. A gantry crane, which moves on rails set in the reactor floor, supports and positions the cask.

7.4 NEW FUEL HANDLING

New fuel is received assembled, one fuel cluster per shipping container, packed in frozen sodium. Provision is made for above-floor storage of 11 racks of 8 shipping containers each. The element is removed from its container in a preheat cell.

7.5 PREHEAT CELLS

Eight preheat cells are utilized. One shipping container at a time is manually loaded into a preheat cell by means of a small hoist. A mechanism within the cell permits opening the shipping container lid and connecting the fuel element to the seal plug at the top of the preheat cell. The fuel element and seal plug may then be removed by the fuel handling cask. The empty shipping container is manually removed from the cell.

7.6 NEW FUEL STORAGE CELLS

Ninety new fuel storage cells are provided to hold new fuel elements. Each new fuel storage cell consists of an insulated steel liner set in a sleeve in concrete. Each fuel element is stored attached to a reactor plug and hanger rod. Electric heaters are provided to maintain the stored fuel near 400° F.

7.7 CONNECT CELLS

The two connect cells permit exchanging the type of plug attached to the fuel element. The operation is accomplished with the aid of the fuel handling cask. A connect-disconnect mechanism is built into the cell to accomplish the remote coupling of the fuel element to the grapple on the plug.

7.8 SPENT FUEL HANDLING

Spent fuel elements are removed from the reactor, washed in the fuel cleaning cell to remove any adhering radioactive sodium, then stored in the spent fuel storage cells to permit decay of activity to a level permitting shipment.

7.9 FUEL CLEANING CELLS

Three cleaning cells wash sodium from the fuel elements (also control rods and source) with demineralized water under an inert atmosphere. Effluent from the cell is removed through the radioactive liquid waste system. Tubes with circulating organic coolant are coiled in the water jacket to remove fuel element decay heat.

7.10 SPENT FUEL STORAGE CELLS

Irradiated fuel elements, when removed from the reactor, are stored in the spent fuel cells. Each cell consists of a steel thimble immersed in a pool of demineralized cooling water. The cooling water is circulated through a heat exchanger to remove the decay heat produced. Sufficient cells are provided to store 90 spent fuel elements during their decay period, plus enough cells to permit unloading the entire reactor. All fuel is stored on reactor plugs and hangers. The storage cells are spaced to provide ever-safe geometry.

7.11 SHIPPING CASK CELLS

Two cells handle the shipping casks, holding them in position to permit the fuel cask to insert a spent fuel element removed from decay storage. The fuel element is separated from its hanger rod after entering the shipping cask. The hanger rod and reactor plug are re-used. Storage is provided near the railway spur for storing 8 shipping casks. Each shipping cask will hold 8 irradiated fuel elements.

7.12 PLUGS

Three types of fuel plugs are used: 1) reactor plugs, complete with hanger rods; 2) shield plugs, similar to reactor plugs but without hangers; and 3) seal plugs, which seal off the openings but do not provide full radiation shielding. Seal plugs are not used to handle irradiated fuel. Sufficient plugs are provided to seal all openings in the reactor, and all fuel handling cells, plus spares.

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8. TURBINE-GENERATOR

8.1 STEAM SYSTEM

8.1.1 Steam Supply

Three steam generation loops are provided. Each loop contains a sodium-to-water preheater, a sodium-to-water steam generator, and a sodium-to-steam superheater. The 815 psig and 825° F superheater steam is carried to a header running to the turbine. The shell and nozzles of the steam generators are ferritic steel. Alloy steel is used for steam piping. A common feedwater header is used for all three generators with separate feedwater regulating equipment for each. For part load operation, a portion of the feed water bypasses the preheater to maintain the desired sodium outlet temperatures.

8.1.2 Emergency Cooling

Emergency and afterglow cooling is provided by a turbine-driven pump taking suction from the condensate storage tank. This pump discharges through a preheater into one of the steam generators while the sodium coolant loop is operating at reduced flow. Most of the steam generated is blown to the atmosphere; the remainder of the steam is used to drive the feed pump and operate the preheater.

An 8-hour emergency feedwater supply for this pump is maintained at all times in the condensate storage tank.

8.1.3 Startup Warm-Up

Pressurized hot water is used to preheat the steam generators before liquid sodium is admitted at startup. This water, heated by the plant heating system boiler in a steam-to-water heat exchanger is supplied from an expansion tank to the warm-up feed pump suction and pumped through the main feedwater system to the steam generators.

8.1.4 Turbine

The turbine is a 106,000-kw, 3000-rpm unit with three feedwater extraction stages. Oil for the hydraulic system and bearings is normally supplied by a turbine shaft driven pump. A full capacity a-c motor driven auxiliary oil pump supplies the oil requirements whenever the unit is below normal speed. A d-c motor driven emergency bearing oil pump and an a-c motor driven turning gear oil pump are also provided.

8.1.5 Turbine and Main Steam Control

Standard turbine control and supervisory instruments are provided. Main steam flow control is accomplished automatically through the hydraulic governing system of the turbine. Direct-contact desuperheaters with automatic controls are provided for controlling steam temperature. A bypass to the main condenser is provided to handle full steam flow in the event of a turbine trip. This bypass also functions as a relief to avoid scramming the reactor during rapid load reductions.

8.1.6 Condenser

A single-pass surface condenser with hotwell is provided. The water boxes are divided to permit maintenance on one half while the plant is operating at half load. Condensate makeup or rejection is controlled automatically from condenser hotwell level.

8.1.7 Air Ejector

A twin-stage, two-element main air ejector equipped with inter and after condensers is provided. A motor-driven mechanical vacuum pump is provided to evacuate the steam spaces during startup.

8.1.8 Condensate Pumps

Two half-capacity condensate pumps are provided. These are of the vertical, multi-stage, centrifugal, submerged suction type.

8.1.9 Gland Seal Condenser

A gland seal condenser designed to maintain sufficient vacuum for removal of the steam-air mixture from the main turbine shaft seals and the valve leak offs is provided. Condensate is used for the cooling medium.

8.1.10 Feedwater System

Two electric motor driven one-half capacity pumps supply feedwater to the steam generators. Separate three-element feedwater regulating equipment is used on each steam generator. The pumps take suction from the storage space of the deaerator with a 200-foot suction head.

8.1.11 Feedwater Heaters

Three stages of feedwater heating are provided. The first stage, a high pressure heater, is a deaerating type with 6-minute storage below normal water level. Water level is maintained by control of feedwater flow. The deaerator is selected as the highest pressure heater to minimize temperature transients in the steam generators.

The second and third stage, low pressure heaters, are horizontal shell-and-tube type with "U" tubes in removable bundles and with integral drain coolers. Heater level control is by means of a controlled cascade of heater drains from the second to the third stage heaters, with the total drain flow going to the main condenser.

Abnormally high heater level is signalled by an alarm. A separate high level trip device closes an extraction non-return valve in the extraction steam line to prevent backflow to the turbine. This trip device also initiates an alarm.

8.2 WATER SYSTEMS

8.2.1 Circulating Water

Cooling water for the condenser is drawn from the source through travelling screens. Two half-capacity, mixed-flow circulating water pumps circulate the water through two 72-inch lines to and from the condenser. Equipment for intermittent chlorination for algae and slime control is provided. Motor operated butterfly valves on the circulating water pump discharge serve the dual function of check valves and isolating valves.

8.2.2 Makeup Water

The makeup water system consists of two fully automatic demineralizer units, together with the required pretreating equipment, storage tanks and pumps. The source of water for the demineralizer is a domestic water storage tank. Untreated water is pumped from the water storage tank through the filters and cation exchangers to the degasifier. From the degasifier, water is pumped through the anion exchangers and the mixed bed exchangers to the demineralized water storage tank. The demineralized water storage tank is fabricated of aluminum to preclude corrosion.

8.2.3 Domestic Water System

A water system supplying domestic and cooling water for the instrument air compressor aftercooler is provided.

8.2.4 Cooling Water System

Treated cooling water is pumped in a closed system by three half-capacity cooling water pumps, with one reduced capacity cooling water pump provided for emergency service. Station cooling water exchangers which remove heat from the cooling water system are supplied with river water by three half-capacity auxiliary pumps, with one reduced-capacity pump provided for emergency service.

The cooling water is provided for the following:

- Service air compressor jacket and aftercooler
- Instrument air compressor jackets and dryer
- Hydrogen seal oil cooler
- Hydrogen cooler
- Turbine lube oil cooler
- Feedwater pump oil cooler
- Condenser vacuum pump
- Miscellaneous sample coolers
- All organic-to-water heat exchangers
- Fuel storage heat exchangers

8.3 AUXILIARY SYSTEMS

8.3.1 Lubrication Oil System

The turbine is supplied with lubrication oil from lube oil storage tanks for clean and dirty oil. Oil transfer is effected by a lube oil transfer pump. The used oil can be filtered while in storage prior to being returned to the turbine oil tank.

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8.3.2 Air Supply

Instrument Air

Two motor-driven, carbon ring, full capacity air compressors are provided together with inter and after coolers, air dryer, intake silencer and filter. The air receivers provide a total reserve storage capacity of 10 minutes during which time pressure drops from 100 psig to 45 psig.

Service Air

One electric-motor-driven compressor with intake silencer and filter, inter and after cooler and air receiver is provided for the machine shop and general plant service. The receiver has storage capacity of 10 minutes during which time the pressure drops from 100 psig to 45 psig.

8.3.3 Auxiliary Steam Supply

During main plant shutdown auxiliary steam for plant heating, tank car oil heating, and startup warm-up of the steam generators is provided from a boiler located adjacent to the administration and control building.

8.4 GENERATOR AND STATION AUXILIARY POWER SYSTEM

8.4.1 Generator and Connections

The main generator is a 3000-rpm conventional hydrogen-cooled machine with a rating of 130,000 kva at 0.85 power factor and 30 psig hydrogen pressure. Energy is generated at 13.8 kv and, by means of a three-phase main power transformer, stepped up to 66 kv; at this voltage, connection is made to the switchyard high voltage bus and from there channeled to the connecting 66-kv system.

Connection from the generator terminals to the main transformer is made by a 6000-ampere, self-cooled isolated phase bus. An isolated phase, metal-clad cubicle containing the generator potential transformers required for metering, relaying and surge protection equipment, is tapped off the bus. The generator neutral connection is immediately external to the machine and is grounded through a resistance-loaded distribution transformer.

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Generator excitation is normally supplied by a shaft-driven exciter. A spare full capacity motor-driven exciter is also provided. Metal-clad excitation switchgear contains generator field breakers, voltage regulating apparatus and auxiliaries.

8.4.3 Generator Cooling

The generator is cooled by means of hydrogen. Two hydrogen coolers integral with the generator housing receive their water supply from the cooling water system. The hydrogen system consists of hydrogen supply tanks, necessary piping and a hydrogen-seal oil unit complete with all pumps, controls and alarms.

8.4.4 Main Power Transformer

The main power transformer is a conventional two-winding, forced oil-to-air cooled, three-phase unit with a rating of 127,000 kva and a full load voltage ratio of 13.8 kv to 66 kv. The transformer is wye connected, grounded neutral on the high side, delta on the low side and provided with two 2-1/2 per cent no-load taps above and below rated voltage. Lightning arresters are provided for the protection of the high voltage winding.

8.4.5 High-Voltage Switchyard

The high-voltage switchyard contains a single 66-kv bus and provides for two transmission line terminals, one main transformer connection and one auxiliary transformer connection. Four outdoor oil circuit breakers and associated disconnect switches are provided. The oil circuit breakers are rated 69 kv, 2000 amperes continuous and 3500 mva interrupting. Potential transformers on the 66-kv bus provide potentials for metering, synchronizing and relaying.

8.4.6 Protective Relaying

Conventional modern relaying for the protection of the generator, main transformer and 66-kv bus are provided. The relaying includes generator, transformer and bus differential schemes, generator over-current backup, loss of field, negative sequence and ground fault relaying. Carrier current relaying coordinated with remote terminal equipment protects the incoming transmission lines.

8.4.7 Station Auxiliary Power System

The station auxiliary power system reliably supplies the normal station auxiliary loads and provides a high degree of availability of power required during shutdown or post-incident periods. Auxiliary power system voltages and utilization system voltage are predicated on United States practice to facilitate rapid design and cost estimation. In detailed plant design, voltages and ratings characteristic of practice in the customer's country would be used.

Two main sources of auxiliary power are provided, one from an auxiliary transformer connected to the generator leads in a unit scheme and the other from an auxiliary transformer tied to the 66-kv system. The latter, in addition to supplying its share of normal auxiliary power, supplies startup power. Each transformer is capable of supplying approximately two-thirds of normal full station operating requirements. During startup, with only one source available, the large sodium heating load must be reduced before operating all the larger auxiliaries at full capacity. Each auxiliary transformer feeds its own 4160-volt bus with a normally open bus tie breaker connecting the two buses. With each source supplying approximately half of the normal requirements, both sources must be available for full load operation. With but one source available, reduced load operation is possible until orderly shutdown can be accomplished. Upon loss of one of the 4160-volt sources an automatic partial bus transfer closes the bus tie breaker after tripping from the dead bus all loads except the 750 kva, 480-volt load center transformer.

The 4160-volt system supplies the motors of the larger auxiliaries and two 480-volt load centers. The 480-volt load centers supply directly the medium size auxiliaries and the smaller auxiliaries through several 480-volt motor control centers located near the centers of load.

Emergency power for auxiliaries essential for safe shutdown of the plant is supplied from an automatically started diesel generator. Certain of the essential auxiliaries are supplied from the station batteries during the short time necessary for the diesel generator to start and come up to speed.

8.4.8 Auxiliary Power Transformers

The two auxiliary power transformers are three-phase, oil immersed outdoor units with a 3750-kva self-cooled rating and a 4687-kva forced-air

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cooled rating. The transformer supplied from the generator bus is connected 13.8-kv delta on the high side and 4160-volt grounded wye on the low side. The transformer supplied from the high voltage bus is connected 66-kv grounded wye on the high side, 4160-volt grounded wye on the low side and has a delta connected tertiary winding. The transformers have four no-load voltage taps. Transformer differential relaying is provided.

8.4.9 4160-Volt Switchgear

The 4160-volt switchgear is located in the switchgear area and is divided into two buses, each connected to one of the two auxiliary transformers. The transformers are not normally paralleled except briefly while making a manual bus transfer as during startup. The switchgear is of the conventional metal-clad type with drawout air circuit breakers and contains all necessary relays and instrument transformers. The breakers are rated 75 mva interrupting ability, 1200 amperes continuous.

8.4.10 480-Volt Load Centers

Two 480-volt load centers, one located in the switchgear area and the other located in the reactor area supply the 480-volt station auxiliary power requirements. One load center is of the double ended type with two 750-kva transformers feeding two sections of low voltage switchgear. A normally open tie breaker connects the two sections. This load center supplies primarily reactor and turbine-generator auxiliaries. The other load center is of the single-ended type rated 1500 kva and supplies power for preheating the sodium tanks and lines. Electric induction and resistance heaters heat the sodium pipes and tanks to 350° F for filling operations and maintain this temperature during shutdown by on-off cycling. Heating controls are contained in control center units.

The load centers are of the indoor unit substation type with transformers close coupled to the switchgear. Metal-clad switchgear containing drawout low-voltage air circuit breakers is used.

8.4.11 480-Volt Motor Control Centers

Several 480-volt motor control centers supplied from the 480-volt load centers distribute power to the smaller station auxiliaries. The motor control centers are located near the centers of load and are of the grouped, metal enclosed type with drawout type motor starter and feeder units. Control centers for the emergency power system also include low-voltage metal-clad switchgear sections with drawout circuit breakers.

8.4.12 Emergency Power System

The emergency system supplies highly reliable power for control, instrumentation, and other essential loads, when necessary. The emergency power system consists of a 250-volt power battery, a 125-volt control battery, a diesel-driven generator and the required switchgear and control apparatus.

The emergency system is divided into four buses as follows:

a) 250-Volt d-c Power Bus - To this bus are connected essential loads which, though normally not running, must be available for immediate start in event of loss of normal power. Loads served are the emergency cooling pumps, emergency primary and secondary sodium pumps and the turbine-generator emergency lube oil and seal oil pumps.

b) 480-Volt Emergency Bus "A" - This bus, normally supplied from the 480-volt system, primarily serves essential loads which are required for normal operation and which must continue to be supplied without interruption on loss of normal supply. Loads served are the control rod drives and lubrication pumps. Also supplied by this bus are emergency lighting and the turning gear motor. Emergency bus "A" is connected to the 250-volt d-c bus through two battery charging motor-generator sets, one of which is a spare. Upon loss of normal power emergency bus "A" is supplied from the 250-volt battery through one of the battery charging motor-generator sets.

c) 480-Volt Emergency Bus "B" - This bus, normally supplied from the 480-volt system, serves essential loads which are required for normal operation but which may be interrupted briefly upon loss of normal supply. Loads served are essential cooling pumps. Upon loss of normal power

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this bus is supplied by an automatically started 350-kw, 480-volt, three-phase diesel driven generator. Because the essential loads connected to bus "B" are relatively large as compared to the rating of the diesel generator, they are left connected to the bus when normal power is lost and are brought up to speed as the diesel generator comes up in speed. An electrically operated circuit breaker connects emergency buses "A" and "B."

d) 125-Volt d-c Control Bus - This bus supplies all essential instruments on the main control board and all essential control circuits. The battery is charged by m-g sets connected to the 480-volt emergency bus "B."

Under normal conditions emergency buses "A" and "B" are connected by means of the tie circuit breaker and are fed from the normal 480-volt system. Upon loss of normal supply the tie circuit breaker and incoming breaker are automatically opened. Bus "A" is supplied without interruption from the 250-volt battery by means of the battery charger running as a motor to drive the 480-volt motor as a generator. The emergency pumps on the 250-volt d-c bus are automatically started as required. The diesel generator is automatically started and as it comes up to speed it brings with it the essential pumps on bus "B." After the diesel is up to speed it is automatically synchronized to bus "A", at which time the tie circuit breaker is closed. The diesel-generator then takes over the battery charging load and the loads on the 250-volt d-c bus. The 125-volt d-c bus remains energized from the control battery throughout the emergency transfer operations.

8.4.13 Grounding

Earth potential for the purpose of system and equipment grounding and for lightning protection is established by means of a system of ground rods interconnected with buried copper cable. Transformer neutrals, switchgear, equipment and building members are all solidly connected to the grounding system.

8.4.14 Motors

In general, motors over 250 hp are rated 4000 volts, 3 phase, 50 cycles, while those 250 hp and below are rated 440 volts, 3 phase, 50 cycles.

Drip-proof motors are used in all normally clean and dry locations. Motor enclosures for other locations are appropriate for their environment. Motor winding insulation is appropriate for the temperatures and radiation levels expected to be encountered.

8.4.15 Communications

A communication system is used to maintain contact between the control room, the plant engineer, and all operating and process areas. The system consists of master stations, paging, speakers, and talk-back stations. Telephone conduits are installed, extending from a telephone junction box to the outlets in the work and process areas.

A centrally controlled electric time system is installed to operate directly from the 120-volt, 50-cycle alternating current building supply. A manual resetting control unit, with a current interrupting indicator and key switches for stopping or resetting the system at ten times the normal rate, is installed in the plant engineer's office.

9. INSTRUMENTATION-CONTROL

9.1 REACTOR INSTRUMENTATION

The reactor instrumentation includes the measurement of neutron flux, process temperatures, sodium level, and shim, regulating and safety rod positions. The nuclear instrumentation block diagram is given in Plate 29.

The flux instrumentation is divided into seven channels: two count rate, two log N, and three power level channels. These instruments provide adequate flux measurements from source level to approximately 150 per cent of full power. The components are conventional nuclear reactor instruments. In addition to providing reactor control signals, the nuclear instrumentation provides signals to the plant protective system. The neutron detectors are positionable in the instrumentation thimbles which are located in close proximity to the reactor core. Cooling is provided for the chambers. All chambers are of the sealed type.

<u>Neutron Count Rate Channels</u> - Two count rate channels are used for reactor startup. This equipment furnishes the operator with information of neutron flux level and period in the range shown on Plate 29.

<u>Log N Channels</u> - Two log N channels are used for reactor operation. The equipment furnishes the operator with information of neutron flux level and period in the range shown on Plate 30.

<u>Power Level Channels</u> - Three power level channels are used for reactor power level operation and safety. The equipment furnishes the operator with power level flux information from the reactor instrument thimbles. The equipment indicates the flux signals from all of the channels and records the flux signal from any one of the channels. Signals from the three channels actuate the plant protective system through coincident circuits. The automatic control system also uses these signals to regulate reactor power level.

<u>Reactor Temperature Measurements</u> - Thermocouples are used to measure fuel channel sodium exit temperatures. These temperature signals are used for normal reactor control as well as for actuating the reactor plant protective system. Representative fuel channel sodium exit temperatures are recorded. However, all thermocouples are continually monitored. Additional thermocouples

are located throughout the reactor vessel and biological shielding. These temperatures are monitored by means of a single pushbutton-type selector and indicator.

Sodium Level - The sodium level in the core tank is measured over the complete operating range. High and low-level alarms are provided.

Rod Position Indicators - A position indicator for each shim, regulating and safety rod is mounted on the control console near the appropriate rod drive switches.

9.2 SODIUM AND REACTOR AUXILIARY SYSTEMS

The sodium systems are provided with instrumentation to measure sodium pressures, temperatures, flow rates, and levels. These measurements are identified on Plates 22 and 23. All instrument parts exposed to sodium are constructed of corrosion-resistant steel and are of all-welded construction.

Pressure sensing units are used in both the primary and secondary sodium systems.

Thermocouple well-type sensing units are used to measure sodium temperatures. The thermocouples are removable without opening the sodium systems. Temperature information required for preheating is obtained primarily from thermocouples welded to the sodium vessels and piping.

All required sodium flow rates are measured by the use of magnetic flowmeters. Alarm coils and continuous type transducers are used for measuring sodium levels in the various tanks. All tanks requiring continuous type sodium level measurements are provided with an additional thimble which is used for calibration purposes and for the alarm coils when required.

Diagrams of the instrumentation for the organic cooling, radioactive liquid waste, nitrogen, and radioactive vent systems are shown in Plates 24, 25, 26, and 27. The accuracy of all measuring systems adheres to the system requirements and to that of commercially available process instruments. Isolation valves are installed with sensing units, such as pressure gauges, to facilitate removal for repair or calibration. Special emphasis is placed on using sealed sensing units when measurements are made in lines or tanks containing radioactive material.

9.3 PLANT CONTROL SYSTEM

The plant control system shown in Plate 28 provides automatic operation over the range of 20 to 100 per cent load, or manual operation at all loads. The plant output is determined by the turbine governor. The turbine-generator may be allowed to participate in system load changes, or the operators may base-load the machine. The control system provides operation approximately as flexible as that of a conventional steam power plant.

The following list indicates the major elements to be held constant, or varied to accomplish the desired load change.

Elements Held Constant

1) Reactor outlet sodium temperature
2) Reactor inlet sodium temperature
3) Steam pressure
4) Main steam temperature

Elements Allowed to Vary

1) Secondary sodium hot leg temperature
2) Secondary sodium cold leg temperature
3) Feedwater temperature
4) Steam temperature at superheater outlet

The following list indicates the regulating elements and the controlled quantities:

Regulating Elements	Controlled Quantity
1. Regulating rod position	Reactor power-sodium outlet temperature
2. Sodium pump speed	Sodium flow-steam pressure
3. Preheater bypass valve	Sodium outlet temperature from steam generator
4. Feedwater valve	Steam generator water level
5. Attemperator valve	Main steam temperature
6. Turbine governor	Plant output

9.4 REACTOR PLANT PROTECTIVE SYSTEM

The reactor plant protective system is shown in Plate 30, and is described in Sect. 11, Safety Characteristics.

9.5 CONTROL ROOM

The plant control room is a separate room adjacent to the reactor-turbine-generator area.

A walk-in type control console is used from which plant control operations are initiated. The console contains: reactor control instrumentation; a graphic panel with controls for the sodium heat transfer systems; the control instrumentation for the steam and condensate systems; the power generation and distribution controls. The control board arrangement is shown on Plate 20.

10. BUILDINGS

10.1 GENERAL

The power plant includes four main components: a reactor unit, a turbine-generator unit, a sodium handling unit, and a control and office unit.

10.2 REACTOR AND TURBINE-GENERATOR UNITS

The reactor and turbine-generator units are housed in the main building which is 307 feet long, 92 feet wide and 80 feet high. A 60-ton capacity bridge crane covers the entire length of the building. The crane handles heavy equipment during construction, and during operation of the plant is used for maintenance handling of the spent fuel shipping casks. A fuel handling cask mounted on a gantry transfers fuel to and from the reactor. To permit delivery of heavy components and direct unloading of sodium from tank cars in the reactor area, a railroad spur track extends into the main building under the crane.

The reactor section of the main building is fully enclosed to preclude undue leakage of any contaminated gases into other sections of the plant. A concrete wall separates the reactor and turbine areas. An opening at the top of the wall for transferring loads between the reactor and turbine areas is closed by hinged metal panels which can be swung upward. The trusses above the wall are covered with permanent sheathing to complete a floor-to-roof barrier. The railroad track within the main building is totally enclosed by a concrete block wall with a removable top structure. This enclosure completes the sealing of the reactor section and also confines spillage in the event of an accident to a tank car delivering sodium.

Gastight compartments in the substructure of the reactor portion of the main building contain the reactor, the intermediate heat exchangers, the primary sodium pumps, various storage and auxiliary equipment cells, and the hot pipe tunnel. An equipment laydown and normal maintenance space extends beyond the turbine-generator in the main building.

10.3 CONSTRUCTION

Construction described herein is based on common United States practice for this class of work. The final design will be based on the actual site and consideration of practices and economics in the customer's country.

The main building is a steel frame structure with insulated steel roof deck and light gauge, fluted, insulated, and protected metal siding. Steel trusses support the building roof and the dearator. Basement tunnels and cells for sodium equipment are of regular concrete of adequate thickness to fulfill the shielding requirements. High density concrete is used only above the reactor and locally in the primary cold trap operating area. Steel lining of the intermediate heat exchanger cell floors and walls to two feet above the floor will contain sodium leakage in the event of a leak. Concrete hatches over the tunnel and basement openings and are sealed to prevent vapor leakage. Hatch joints are stepped to preclude radiation streaming.

10.4 FOUNDATIONS

Foundation design is based on preliminary data and is subject to review on the basis of a detailed foundation investigation which would be required before final design is started. A safe bearing value for building foundations of about 4000 pounds per square foot is assumed.

10.5 FINISH

The metal siding has coloring in the protective material on both sides. Exposed structural steel, miscellaneous steel surfaces and the underside of the steel roof decking are painted.

10.6 BUILDING SERVICES

Forced warm air steam unit heaters are located in the turbine and reactor sections. Forced ventilation is provided for the summer with roof exhaust fans and intake dampers. Radiation sensing controls will shut off the reactor area exhaust fans and close the intake dampers in the event of an accident. The reactor end of the building then becomes a closed volume which will hold up the contamination gases until the radiation level diminishes to a non-hazardous level, before exhausting them to the atmosphere. Lighting is supplied by high bay mercury fixtures. Power for lighting and convenience outlets is provided by 208/120-volt regulated transformers supplied from 480-volt motor control centers. Floodlights mounted on the exterior of the building illuminate the yard. Fire protection hose reels are placed in the turbine-generator section. A carbon dioxide system

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protects the lube oil and the generator areas. Pressurized Met-L-X power extinguishers are placed throughout the reactor area for sodium fires.

10.7 SODIUM HANDLING UNIT

The sodium handling building, 123 feet long, 38 feet wide, and 25 feet high, is adjacent to the reactor area of the main building. The sodium building has basement cells for primary fill tanks, primary and secondary cold traps, primary sodium pumps, nitrogen compressors and coolers. The secondary fill tanks, the nitrogen manifolds and organic cooling equipment and sodium melt station are located on the first floor of this building.

The sodium handling building is a steel frame structure with insulated roof deck and light gauge, fluted, insulated and protected metal siding. The basement cells, hatches and tunnels are of regular concrete.

The metal siding has coloring in the protective material on both sides. Exposed structural steel, miscellaneous steel surfaces and the underside of the steel roof decking are painted.

Fire protection and first aid equipment for sodium accidents are provided. High capacity exhausters are provided to remove fumes in the event of a sodium fire. Incandescent lighting fixtures are provided, together with power and convenience outlets.

10.8 CONTROL AND OFFICE UNIT

The control room located on the second floor of this two-story building is arranged to permit observation of both reactor and turbine units. Under the control room is the cable spreading room which also contains the lighting load center and distribution panel, 208/120-volt reactor motor control center, and telephone equipment.

Central access to all levels of the plant, including the roof of the main building, is provided by a stair system adjoining the control room. On the other side of this central access is located the plant heating boiler, emergency generator, instrument air compressors, the plant battery system and lube oil storage. The office area is located on the second floor with the showers, locker rooms, and the decontamination area on the first floor.

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The exterior walls of the control and office unit are of precast concrete, tilt-up construction. The roof is steel decking covered with insulation and composition roofing. The offices and control room ceilings are of acoustical tile, with plaster walls and partitions and resilient tile floors.

The offices and control room are heated by convectors from the plant heating steam system. Fluorescent lighting is provided throughout the office areas. The control room has a luminous ceiling.

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11. SAFETY

11.1 INTRODUCTION

11.1.1 General

The reactor and its coolant systems operate under low pressure. High pressure is found only in the conventional steam portion of the plant.

The reactor and its associated radioactive components are located in shielded areas below the reactor floor level. The shielding reduces radiation levels in all working areas to well below normal standards of radiation. Secondary non-radioactive sodium coolant circuits transfer heat from the radioactive primary sodium coolant to the steam portion of the plant. Steam plant components, such as the steam generators, are located in the working area above the reactor floor level.

Containment of radioactive fluids is provided by welded steel containers and piping, steel liners on the concrete shielding, and sealed joints. In the steam generator there are double-walled tubes for containing sodium, and an inert monitoring gas passes between the tube walls for detecting any leakage before penetration of both walls. An inert gas atmosphere is used in all areas containing primary system piping and components. This prevents any possible reaction between radioactive sodium and air.

Within the reactor there is no releasable potential energy from pressurization or chemical reaction because the reactor operates under low pressure and because all materials used in the reactor are chemically compatible. There is no necessity for a gastight pressure shell surrounding the reactor. Instead a typical industrial building structure is used.

11.1.2 Reactor Thermal Safety

There are three independent sodium heat transfer circuits for cooling the reactor. During a plant shutdown, one or more of these circuits may be used for forced cooling of the reactor to remove stored and afterglow heat. An emergency power system, using storage batteries and a diesel-driven generator, ensures that shutdown coolant flow is maintained during any electric power failure.

If loss of all forced sodium flow should be postulated, natural convection flow within the reactor and in the three sodium coolant loops would provide continuous cooling of the reactor after shutdown. Even without flow in the coolant loops, a slow rise in over-all reactor temperature after shutdown is ensured by the large heat capacity of the reactor structure. The upper limit of the reactor temperature would be established at a safe level by the heat removal capacity of the organic coolant in the biological shielding.

11.1.3 Reactor Nuclear Safety

An automatic plant control system provides for safe normal operation of the reactor power plant. A plant protective system provides additional automatic control of the reactor systems for safety against failure or improper operation of any component. The protective system is designed for reliability, with reactor scrams reduced to a minimum and in general replaced by means which provide merely a power reduction or a shorter shutdown time.

The regulating and shim rods, which serve to control reactor power level during normal operation, have a limited motion which is to ensure that excessive reactivity cannot be inserted by erroneous action. Safety rods which fall by gravity into the reactor core provide scramming action in the event other protective system action cannot adequately ensure plant safety.

The strong negative prompt fuel temperature coefficient of reactivity provides reactivity control over upsurges in fuel temperature. The negative over-all steady-state reactor power coefficient further ensures that any increase in power is counteracted by a decrease in reactivity.

11.2 STRUCTURAL SAFETY OF REACTOR AREA

11.2.1 Reactor Structure and Containment Features

The principal components of the reactor structure are shown in Plate 21. The steel tanks and piping are of welded construction.

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Primary containment for the sodium and inert gas atmosphere in the core tank is obtained by the combination of the core tank, core tank bellows, linings of the loading face shield and ring shield, and by a cast alloy seal between the loading face shield and the ring shield.

The outer tank serves as secondary containment for any sodium which may leak from the core tank. The outer walls of the double-walled inlet and outlet downcomer sodium piping attached to the outer tank also serve as secondary containment. The outer tank is sized such that in the event of a sodium leak from the core tank or downcomer piping, the sodium level within the core tank would remain above the outlet nozzles. The cavity liner, which covers the concrete biological shielding surrounding the reactor cavity, serves as a final containment for sodium leakage and also as a secondary containment for the core tank atmosphere, in the event a leak should develop in the core tank bellows. The outer tank is open at the top so that the atmospheres in the outer tank and the cavity liner are the same. There is a cast alloy seal between the cavity liner and the ring shield. A diaphragm seal assembly serves as an atmosphere barrier between the cavity liner and the pipe cells.

The concrete biological shielding adjacent to the reactor, including the loading face and ring shields, is continuously cooled by the organic system to prevent excess thermal gradients and high temperatures.

11.2.2 Substructure

The various equipment and pipe cells are shown in Plates 3, 6, 7, 8, 9, 10 and 12. The primary radioactive piping and equipment are located in concrete cells which are below the reactor floor level. The cells form an integral part of the substructure and are lined with steel plate on the bottom and sufficiently high up the sides to serve as secondary containment in the event of any sodium leakage into the cells. The arrangement of the cells forms an effective neutron shield for the secondary non-radioactive sodium.

An inert gas atmosphere is continuously maintained in the cells. The use of inert gas reduces the oxygen content in the cell atmosphere to a negligible amount and eliminates any possible chemical reactions in the event of a sodium liquid or vapor leak into the cells. The inert gas pressure is held slightly above atmospheric. This positive pressure minimizes oxygen in-leakage, while the low pressure differential minimizes inert gas losses.

Concrete walls between cells serve as radiation shielding to allow maintenance in any one area during reactor shutdown, and also to confine any leak of liquid sodium to the one area in which the leak occurred. To prevent thermal gradients and excessive temperature buildup in the cells, the atmosphere in each area is continuously cooled by forced convection coolers using an organic for heat removal.

Access to the cells is through stepped concrete hatches entered from the reactor floor level. These hatches are sealed to minimize vapor or gas leakage into or out of the cells. The external surfaces of the cells exposed to subsurface water are completely covered with a waterproof membrane. The steel cell liners serve as an additional barrier to prevent leakage. The substructure is capable of withstanding earthquake loads and external water pressure consistent with the reactor site.

11.2.3 Piping and Equipment

The piping and equipment arrangement for the primary sodium system is shown in Plates 3, 6, 7, 8, 9, 10, and 12. The piping in contact with liquid sodium and sodium vapor is stainless steel and this piping serves as the primary containment for these components. Pressures in the system are low enough that they are not critical in establishing pipe wall thicknesses. All joints are welded. Leak detectors are located on all inaccessible sodium piping to indicate any sodium leakage.

In order to provide for isolation of any loop in the event of a sodium leak, blocking valves are installed in the suction and return legs of the primary heat transfer circuits. Check valves are provided in each of the return legs between the blocking valves and the intermediate heat exchangers. The check valves prevent back-flow of sodium, which might occur if the primary pump power should be cut off in one circuit while the other primary circuits were operating.

The elevation of the core tank suction nozzle is above the top of the moderator cans, so that the reactor core and reflector cannot be uncovered by pumping down the sodium level. The low pressure drive provides additional assurance that sodium cannot be forced out of the core tank below the level of the top of the moderator cans. The reactor atmosphere relief valve is set such that a minimum pressure drive exists between this atmosphere and the piping and equipment cells.

11.3 REACTOR PLANT PROTECTIVE SYSTEM

11.3.1 Functions of the Reactor Plant Protective System

Instrumentation and control is provided for the purpose of rapidly detecting any off-normal condition in the reactor plant, and when necessary, automatically reducing reactor power level and coolant flow. This instrumentation and control system constitutes the reactor plant protective system. It is in addition to the plant control system, which serves to automatically regulate power generation during normal operation. The plant control system is described in Sect. 9.3.

In the event of an off-normal condition which is of such severity that its continuation could cause damage to any part of the reactor plant, the protective system would take corrective action automatically. The corrective action could be in the form of removing a coolant loop from operation, reducing reactor power, or scramming the reactor.

11.3.2 Design Emphasis

Safety and reliability are the two prime considerations in the design of the protective system. Because excessively complex safety systems can reduce the reliability of the plant, a balance is sought which ensures adequate safety while minimizing power losses from shutdowns or setbacks caused by false (spurious) signals.

This reactor concept has many inherent safety features. These safety features ensure reasonable safety for personnel even without the existence of the plant protective system. The protective system is an additional safety feature to protect the plant investment as well as to arrest any condition which could potentially create even the slightest hazard to personnel.

Some of the important safety features incorporated into the protective system are the following:

a) Fail-safe circuits and equipment wherever possible.

b) Duplication of circuitry, so that failure of any one circuit leaves one or more other circuits intact and operable.

c) Backup circuits using entirely different types of sensing elements.

Reliability of the protective system is maintained in several ways. Highly reliable individual components are used, having coincident circuitry for the source of shutdown signals. Testing and monitoring systems determine proper operation of the protective system circuitry. Plant outages are reduced to a minimum, while adequate safety is maintained to protect personnel and prevent damage to the reactor plant caused by off-normal conditions.

Coincident circuitry is used for the source of all setback, fast setback and scram signals except the manual and period signals. Generally, three sensing instruments are used for receiving signals relative to any given variable which should require corrective action if abnormal. With this type of coincident circuitry, corrective action is not taken unless at least two of the three sensing instruments give simultaneous abnormal signals.

Though each circuit is fail-safe, the signal given by the failure of a single circuit in a coincident circuit arrangement merely causes an alarm. The malfunction detection circuit then actuates the appropriate protective system failure annunciator. This permits remedial action without loss of plant output when a single circuit failure occurs. A failure or abnormal signal on either of the remaining two circuits would then cause automatic corrective action.

Manual signals to initiate any form of power reduction do not require coincidence of more than one signal. This permits the operator to manually reduce power at his discretion. The period circuits are not on coincident

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circuitry because they are only intended for startup conditions rather than for normal power operation. They are inoperative at normal operating power levels. Coincident circuitry is thereby limited to circuits which normally function continuously at all power levels.

The testing and monitoring system is used to make regular checks on the complete functioning of the circuitry in the protective system. Indicators and error-detecting circuits detect any failures or unsafe conditions. These circuits also detect any drifting or aging of components so that repair or replacement can be made before failure occurs.

The types of protective system action taken in the event of off-normal conditions include the following:

a) Alarm.
b) One-loop shutdown.
c) Setback.
d) Fast setback.
e) Scram.

By the combination of these various types of protective action, reliability is ensured while maintaining the maximum practicable level of safety.

11.3.3 Protective System Description

A block diagram of the reactor plant protective system is shown in Plate 30. The system consists of the circuits which cause the various types of corrective actions necessitated by off-normal and emergency conditions, plus circuits for functional testing, monitoring, and malfunction detection.

Alarm annunciators which do not initiate automatic corrective action are provided to warn the operator whenever an important reactor variable reaches an off-normal condition. They include warnings from reactor auxiliary systems as well as from the principal reactor systems.

An alarm makes the operator aware of off-normal conditions in any circuit, whether caused by an operating signal through a functioning circuit or a signal caused by failure of a circuit. Each alarm consists of an audible annunciator and a visual indicator, the latter indicating which particular variable is not within its operating range. The operator must acknowledge each alarm signal by pushing an appropriate button. This silences the audible signal, but leaves a visual indication of the off-normal condition until it has been corrected.

All signals which may cause automatic corrective action have alarms associated with them. These include all signals associated with one-loop shutdown, setback, fast setback, or scram action. In most cases a no-action alarm setpoint is established so that this alarm occurs before the automatic setpoint is reached. The no-action alarm warning generally allows the operator time to make any necessary manual correction, so that automatic action is not required.

Automatic action is provided for those situations in which the operator does not have time to act or fails to act properly in response to the no-action alarms. Automatic action is accompanied by alarms which indicate the type of action and the off-normal variables. The alarm system is further arranged to give the operator a signal as to which off-normal condition first occurred to cause an automatic power reduction, even though several variables may be shown to be out of the normal operating range following the automatic action. When automatic power reduction is initiated, there is an additional audible annunciator which sounds appreciably louder than the other protective system alarm annunciators.

Each of the three sodium coolant loops has an independent shutdown system. This permits the reactor to operate on two sodium loops when there is a severe off-normal condition in one loop. The shutdown systems are identical for each loop. Shutdown consists primarily of a substantial flow reduction,accomplished by changing from use of main to emergency pump power in the loop being taken out of service.

Any off-normal condition arising within the reactor as a result of changes in reactor power level, coolant temperature, or coolant flow must be corrected before reactor temperatures or rates of change of temperatures become excessively high. The setback in reactor power level is the first automatic action to correct such conditions within the reactor, as distinguished from conditions within a single sodium coolant loop. The one-loop shutdown is intended to prevent damage to the reactor in case of an off-normal condition in a single loop. The setback is intended to correct any off-normal conditions in the reactor itself without a complete shutdown and without introducing further rapid temperature transients associated with fast setbacks and scrams.

The distinguishing difference between a setback and a fast setback is that the former causes the regulating rod to be inserted at a controlled rate while the latter causes rapid insertion of all shim rods. Because the setback does not involve shim rod action, it results in a relatively slow power reduction and causes a less severe transient than the fast setback.

The setback is initiated whenever a condition causing high power-flow ratio or high reactor sodium temperature is not corrected after indication by an alarm and increases in severity to the setpoint for a setback. Setback action automatically lowers the regulating rod at a controlled speed, thereby reducing reactor power. Power reduction is continued until all conditions requiring a setback are corrected.

If a setback does not successfully correct the off-normal conditions causing high power-flow ratio or high reactor sodium temperature, a fast setback is initiated when a further setpoint is reached. However, the period circuit has only a fast setback setpoint beyond an alarm setpoint. A fast setback is intended to reduce power level as rapidly as possible without completely shutting down the reactor. This is accomplished by lowering all shim rods at their fast rate. The lowering of shim rods continues until all conditions requiring a fast setback are corrected.

An automatic reactor scram is a rapid shutdown action, resulting in insertion of all control rods into the reactor core. It is only initiated if all other automatic measures of the plant protective system should fail to correct a condition which is potentially dangerous to the plant and personnel. The reactor may be scrammed manually if the operator is not satisfied that a serious condition is being adequately corrected.

The most rapid shutdown action of a scram comes from gravity fall of all safety rods into the core. In addition, rod motor drive mechanisms automatically act to lower all safety and shim rods into the core at their fast speeds. If any safety rod should not separate from its drive mechanism to drop into the core, it would be driven in by the drive motor. Either the safety rods or the shim rods could independently remove all excess reactivity from the reactor, but for extra security both sets of rods are inserted during a scram.

The power, flow, and temperature circuits have scram setpoints beyond the alarm and other protective system setpoints, to permit operator or automatic action before a scram. In the cases of a severe earthquake or loss of electric power to all three of the primary sodium pumps, the reactor is scrammed immediately without a prior alarm or lesser action.

The protective system is designed throughout to permit all possible action which could prevent a scram, when such alternatives are available without endangering the reactor and personnel. A scram causes greater power loss, time delay, and thermal shock than other operator and protective system actions.

11.4 SAFETY FEATURES

Many safety features are incorporated into the reactor. These features decrease the probability of an accident, reduce its severity, and shut the reactor down in case of any severe accident in which conditions are not brought back to normal by the plant control or protective system instrumentation or operator action.

11.4.1 Control Rods

The neutron-absorbing control rods include safety rods which are only used for complete reactor shutdown, shim rods which permit major reactivity adjustments, and a regulating rod which is used for fine reactivity adjustments. These rods are further described in Sect. 4.5.

Separate safety rods are always withdrawn above the reactor core prior to operation of the reactor. In the event of a scram they fall into the core by gravity. These safety rods always have sufficient reactivity control to shut the reactor down, regardless of the position of the shim rods. Electrical interlocks are provided to ensure that the shim rods are not withdrawn until the safety rods are fully withdrawn and ready to scram. The safety rod latches are held in position by means of an electromagnet forcing against a spring. In case of electrical failure, the safety rods fall into the core, regardless of the position or motion of the regulating and shim rods.

A fast speed in the down direction is provided for both the shim and safety rods. This fast down speed results in a rapid reduction in reactor power level. During a reactor scram, both the safety and shim rods are automatically driven down at fast speed. This serves two main purposes:

a) It provides a backup which rapidly shuts the reactor down in case the safety rods fail to drop by gravity.
b) It places the rods in position for a startup; thereby the time necessary to restart the reactor after a scram is reduced, because interlocks prevent withdrawing rods after a scram until all have been fully inserted.

The fast down speed on the shim rods is also used in accomplishing a reactor fast setback, and is actuated either automatically by the reactor protective system or manually. Both the shim and safety rods are mechanically and electrically interlocked so that the fast speed can only be used in the down direction.

Shim and safety rod withdrawal speeds are limited absolutely by the use of induction motors whose speed cannot exceed synchronous speed. This limits the rate at which reactivity can be added by shim and safety rod withdrawal, thereby eliminating the possibility of obtaining a short reactor period during rod withdrawal.

The total length of upward travel during fast motion of the regulating rod is limited both mechanically and electrically to substantially less than the amount which could put the reactor on a dangerously short period. When the automatic control system tends to drive the regulating rod beyond its normal operating range, the shim rods are slowly adjusted so as to permit the regulating rod to move back into its operating range through action of the automatic control system.

11.4.2 Interlocks

Interlocks are provided wherever necessary to prevent improper manual action which could damage the plant.

11.4.3 Plant Control System

The plant control system, described in Sect. 9.3, is designed to match power generation to power demand, and simultaneously to maintain safe conditions during normal operation. For example, a limited rate of change of sodium flow rate is provided in the sodium flow control system. This prevents fast transients which would cause excessive overheating.

11.4.4 Alternate Electric Power Sources

Electric power for normal plant operation is available from both the external power supply and the generator in the reactor plant, as indicated in Plate 19. An alternate power supply is thus provided whenever either an internal or external power outage occurs. In the event that both these normal sources of power should fail simultaneously, electricity would be supplied by the emergency power system for emergency needs only.

The emergency power system consists of storage batteries and a diesel-driven generator. The storage batteries supply power for critical loads during the time necessary to bring the diesel-driven generator to its full power. In this way continuous power is ensured during shutdown.

11.4.5 Heat Removal Characteristics

The use of three independent heat transfer circuits for removing heat generated in the reactor ensures that failure of any circuit will not leave the reactor without external cooling. Though the reactor may sometimes be operated using only two of the three heat transfer circuits, it would never be operated with only one such circuit. However, a single circuit may be used to remove after-glow heat from the reactor after shutdown.

The upper reactor plenum contains a large quantity of liquid sodium which mixes with the sodium flowing out of the fuel channels before discharge into the three heat transfer circuits. In the event of overheating of the sodium in any of the fuel channels, the upper plenum mixing would ensure that the localized or transient high temperatures would be reduced. If any sodium vapor should be formed in a fuel channel, the vapor would be condensed in the upper plenum and there would be no significant pressure rise. During full power operation the upper plenum sodium temperature is approximately 700° F below the sodium boiling point.

Natural convection flow in the sodium coolant loops is sufficient to remove afterglow heat from the reactor after shutdown in the event of the simultaneous loss of power to all coolant pumps. Total loss of all pumps is highly unlikely, however, because of having three sodium coolant loops and an emergency power source.

There is also natural sodium convection flow within the reactor to provide distribution of heat and prevent excessive localized temperatures.

If the sodium coolant loops should fail in their heat removal function after a shutdown, the large heat capacity of the core structure, and particularly of the graphite moderator, would ensure a slow reactor temperature rise. In such an event sodium convection flow would provide distribution of fuel afterglow heat within the reactor, transferring the heat to the graphite and to the outer elements of the reactor structure, from which it would eventually be carried away by the organic biological shield coolant. These heat capacities are sufficient to ensure that no dangerous conditions would develop during establishment of an equilibrium condition. At equilibrium the organic coolant in the biological shielding could remove heat at the rate it would be generated by fission product decay in the fuel. The organic coolant system is described in Sect. 6.1.

11.4.6 Reactivity Coefficients

The prompt fuel temperature coefficient of reactivity results from changes in the resonance absorption cross section of the fuel, particularly the U^{238} isotope, caused by the Doppler effect of broadening resonances. In the sodium graphite reactor, which has a large proportion of U^{238} in the fuel, resonance absorption provides an immediate significant reduction in reactivity whenever fuel temperature is raised.

The exact magnitude of the prompt fuel temperature coefficient is a function of reactor dimensions, but it is strongly negative for any similar sodium graphite reactor whether using uranium oxide or metal fuel.

Because of the amount of heat generated within the fuel element, its response to a change in reactor power is rapid and quickly tends to reduce the power level in any type of increased reactivity transient. Thus, it acts as a strong restoring force to prevent large power excursions.

The over-all steady state reactor power coefficient of reactivity is defined as the change in reactivity caused by a change in power level. The reactor has an over-all steady state reactor power coefficient of reactivity which is negative, so that following any increment of power increase the reactor tends to reduce power because of reduced reactivity.

11.4.7 Ultimate Shutdown Mechanism

The melting of fuel elements and the subsequent dropping of fuel out of the central core region provides an effective shutdown mechanism during a maximum conceivable accident in which the protective system is assumed not to function. In order to ensure shutdown, melting of steel fuel jackets is necessary in only a small proportion of the total number of fuel elements. Even under such an extreme condition no significant pressure rise would occur in the reactor core tank.

11.5 RADIATION HAZARD CONTROL

11.5.1 Operational Exposure to Ionizing Radiation

All areas which could constitute a radiation hazard to operating personnel are shielded to maintain routine exposures at less than 0.75 mrem per hour (1.5 rem per year). The International Committee on Radiation Protection (ICRP) advises that 5.0 rem per year should not be exceeded for long term exposures, when averaged over a 10-year period.

11.5.2 Control of Gaseous and Particulate Radioactive Material

All areas containing radioactive gas or contaminants are provided with gas seals to ensure against leakage to the reactor room or other routinely occupied areas. All systems are operated at low pressures, thereby minimizing both the causes and the effects of leakage to adjacent areas.

Gases which are normally radioactive are piped directly to shielded gas hold-up tanks. Gases which are normally not radioactive are monitored before release to the atmosphere or to the gas hold-up tanks as determined by the radiation level. The radioactive vent system which handles these gases is further described in Sect. 6.3, and shown in Plate 26.

From the gas hold-up tanks representative samples are obtained and analyzed for radioactive constituents. The gas is retained in the tanks for sufficient time to permit the maximum practical decay. It is then released to the atmosphere at a controlled rate, dependent upon final decayed activity. Automatic radiation detection equipment measures and records all releases of radioactive material. Design of the gas hold-up tanks is based on a rate of release of radioactive gas to the atmosphere at the point of release equal to no more than the maximum permissible concentrations designated by ICRP regulations.

In addition to the gas handling systems, the reactor area of the building is equipped with automatic air and gas monitoring devices which actuate an alarm system in the event abnormal radiation levels are detected. The building ventilation system is designed to cope with any eventualities such as a leaky gas line, rupture of a gallery seal, or spillage of small quantities of radioactive sodium. Pressure differentials between areas are designed to minimize the spread of contamination and facilitate the control of any possible leakage of radioactive material to the building atmosphere. Ventilation is further described in Sect. 10.6.

11.5.3 Radioactive Liquid Waste

Radioactive liquid waste is piped to a series of liquid hold-up tanks where representative samples are obtained and analyzed for radioactivity content. The major portion of radioactive liquid waste originates from the fuel cleaning cells and contains primarily Na^{24} which decays with a 15-hour half-life. The liquid waste is stored for a decay period necessary to reduce the activity contributed by short lived isotopes. It is then released, at a controlled rate, to the condenser circulating water discharge, utilizing this available large dilution to maintain final concentrations below those advised by the ICRP. Storage space is provided for the limited quantities of liquid waste which may contain long-lived isotopes in quantities greater than that which may be released to the condenser circulating water discharge. The radioactive liquid waste system is further described in Sect. 6.4, and shown in Plate 27.

LIST OF ENGINEERING DRAWINGS

1. Perspective
2. Plot Plan
3. Reactor Area, Basement Plan
4. Reactor Area, Ground Floor
5. Turbine Area, Plan
6. Reactor Area, A-A
7. Reactor Area, B-B
8. Turbine Area, B-B
9. Reactor Area, C-C
10. Reactor Area, D-D
11. Turbine Area, E-E
12. Plant Arrangement
13. Control Room and Offices, Plans and Elevation
14. Radioactive Liquid Waste, Plan and Elevation
15. Heat Balance, Steam and Condensate
16. Flow Diagram, Steam and Condensate
17. Flow Diagram, Service and Cooling Water
18. Flow Diagram, Miscellaneous Services
19. Single Line Diagram, Generator, 66 kv and 4160 v
20. Control Board Arrangement
21. Reactor Structure
22. Flow Diagram, Sodium Heat Transfer
23. Flow Diagram, Sodium Service Systems
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27. Flow Diagram, Radioactive Liquid Waste System
28. Plant Control Diagram
29. Nuclear Instrumentation Block Diagram
30. Reactor Plant Protective System

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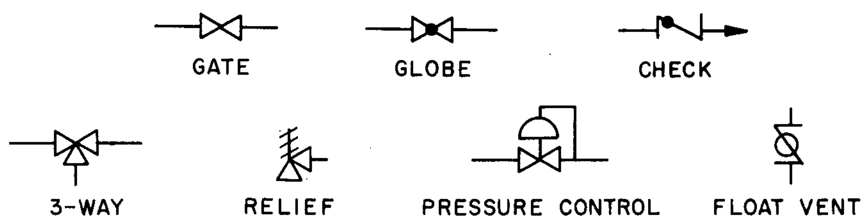
LEGEND



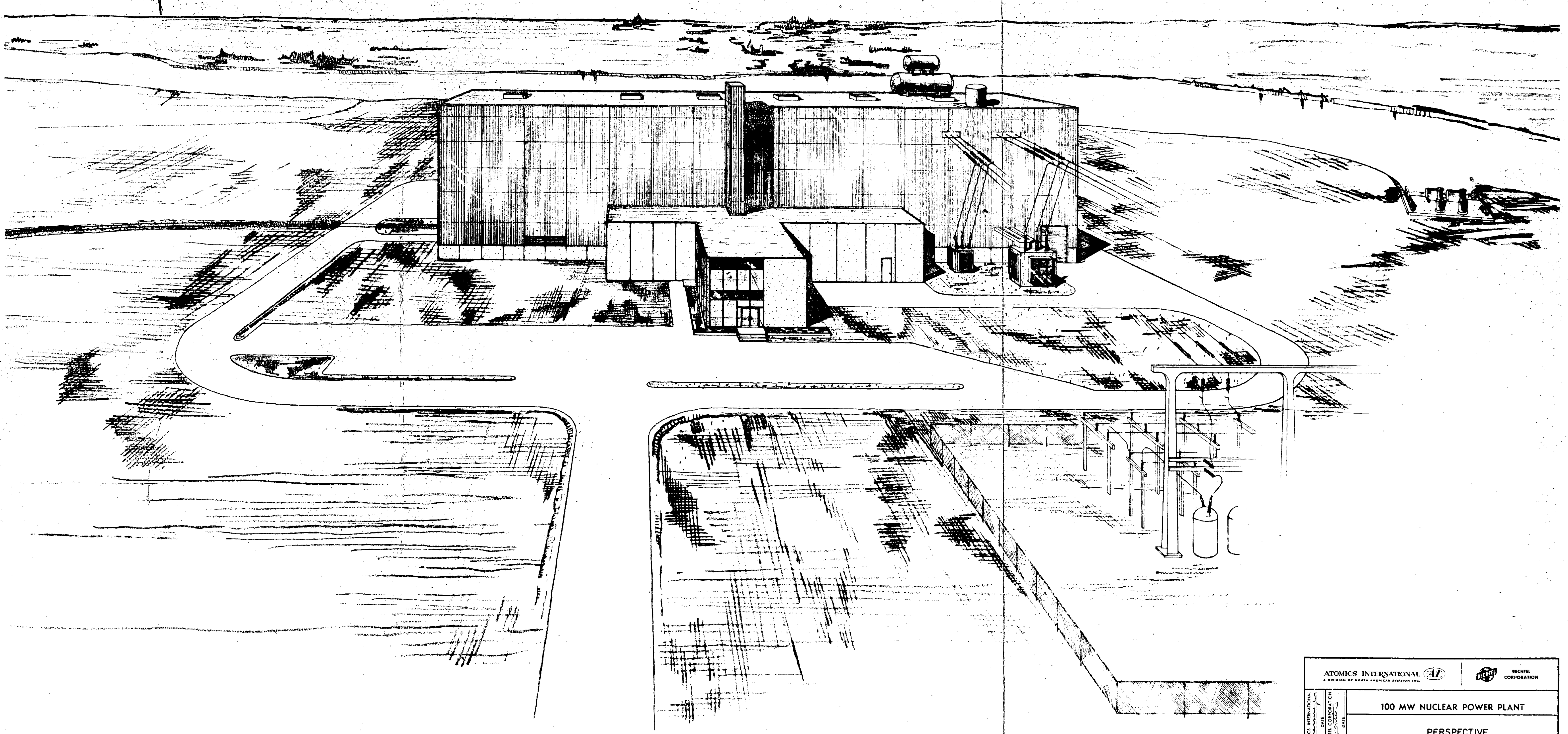
INSTRUMENT LETTER DESIGNATION			
	FIRST	SECOND	THIRD
A		ALARM	
C		CONTROL	CONTROL
F	FLOW		
H			HIGH
I		INDICATING	INDICATING
L	LEVEL		LOW
P	PRESSURE		
R	RADIOACTIVITY	RECORDING	RECORDING
S		SCRAM	
T	TEMPERATURE		
V			VALVE
d		DIFFERENTIAL	
SV	SOLENOID VALVE		
SC	SAMPLE CONNECTION		
RO	RESTRICTING ORIFICE		

—//—//—//— INSTRUMENT AIR LINES

(TI) LOCALLY MOUNTED INSTRUMENTS

(TI) BOARD MOUNTED INSTRUMENTS

056 – 061



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100 MW NUCLEAR POWER PLANT

PERSPECTIVE

PLATE 1 — REV. 0

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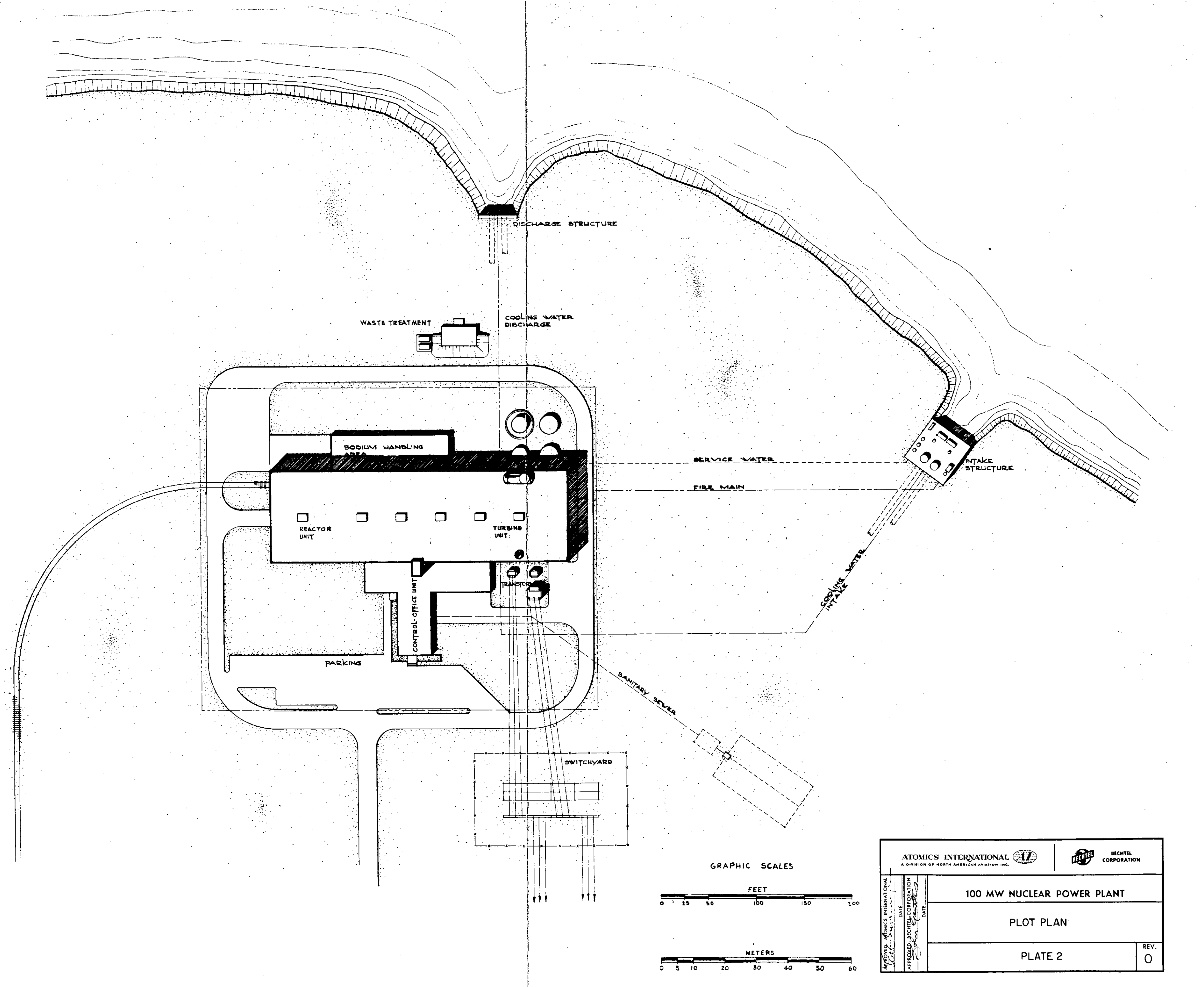

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100 MW NUCLEAR POWER PLANT

PLOT PLAN

PLATE 2

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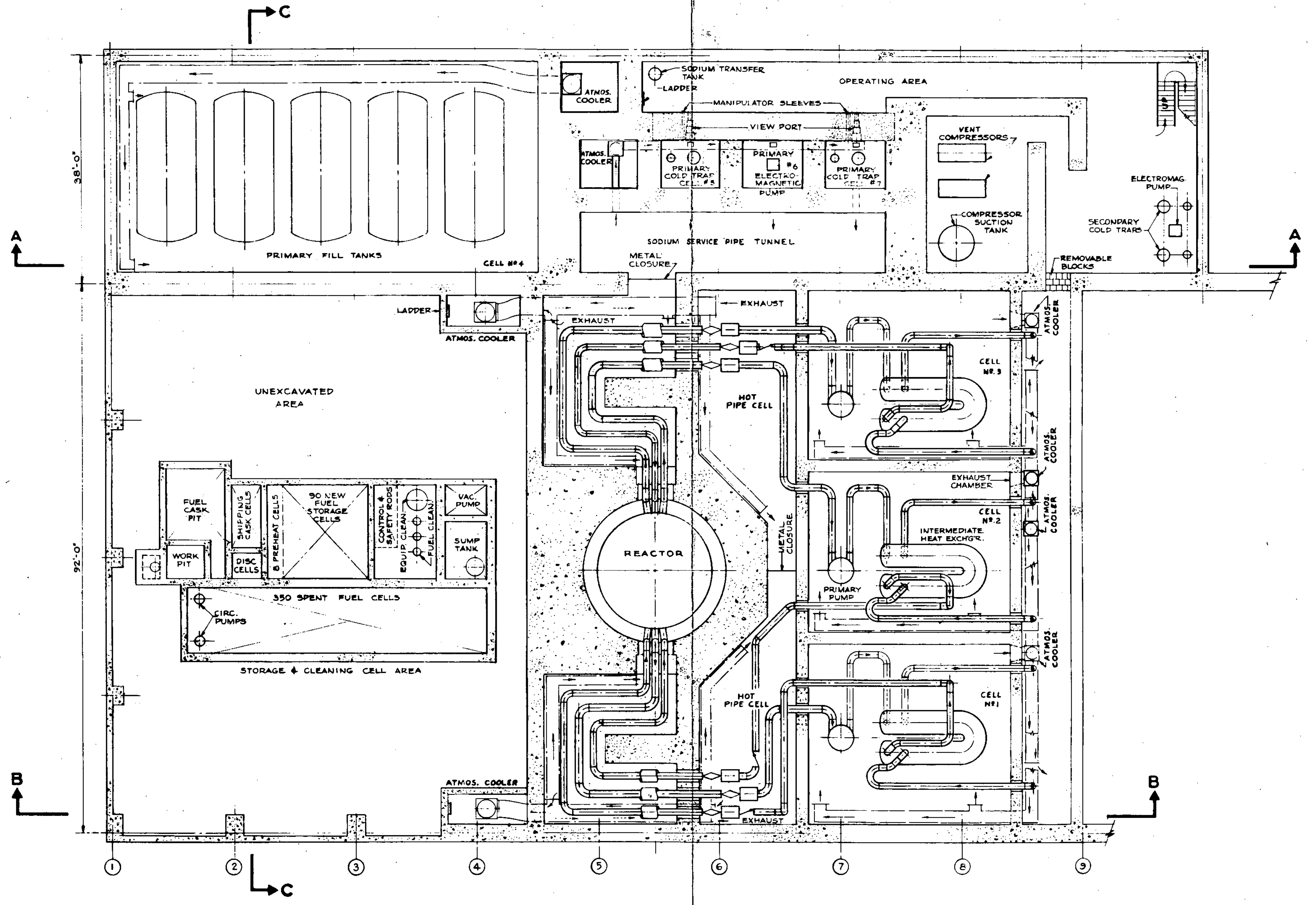

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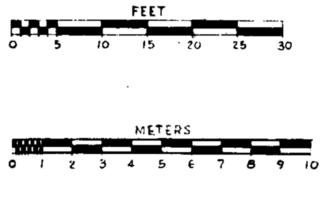

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100 MW NUCLEAR POWER PLANT

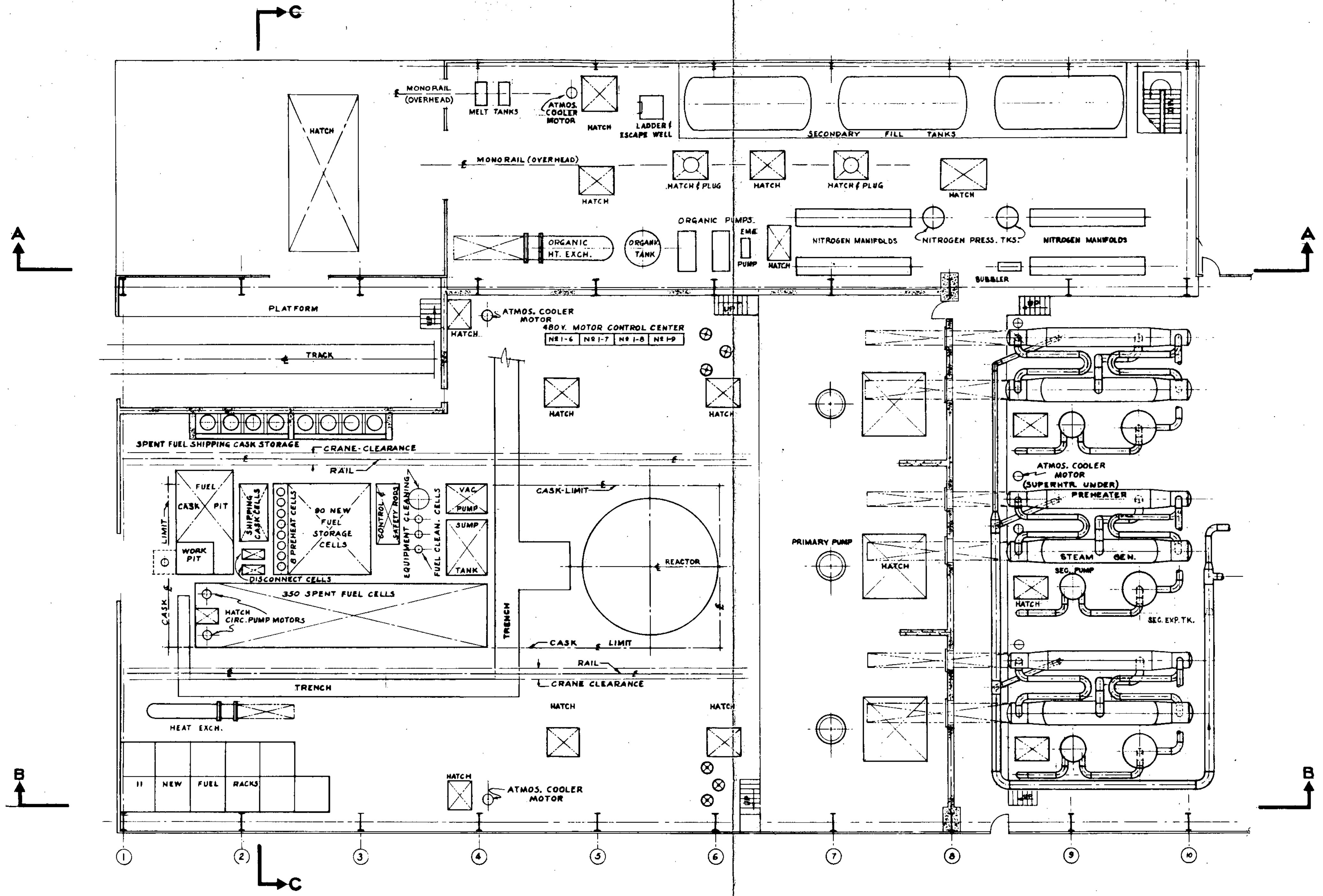
REACTOR AREA

BASEMENT PLAN

PLATE 3

REV. 0

056 - 064



GRAPHIC SCALES

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100 MW NUCLEAR POWER PLANT

REACTOR AREA

GROUND FLOOR PLAN

PLATE 4

REV. 0

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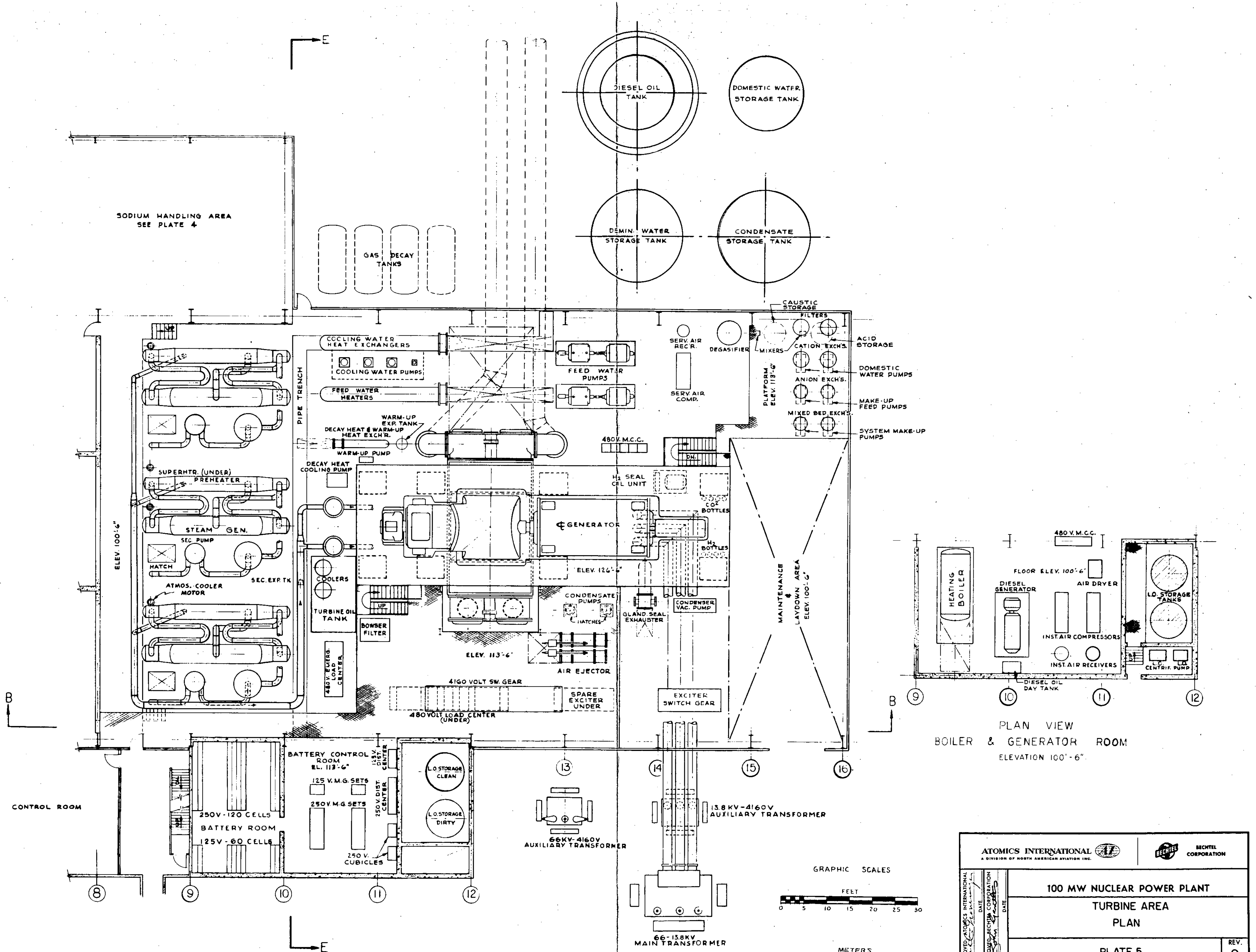

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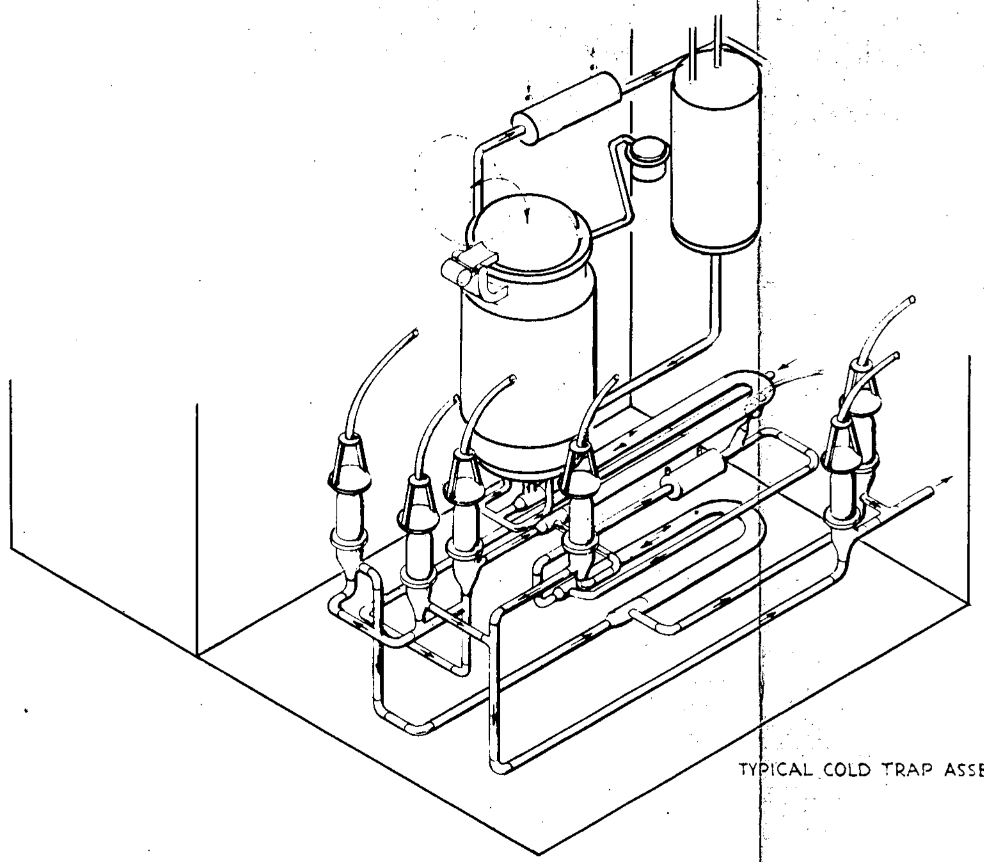
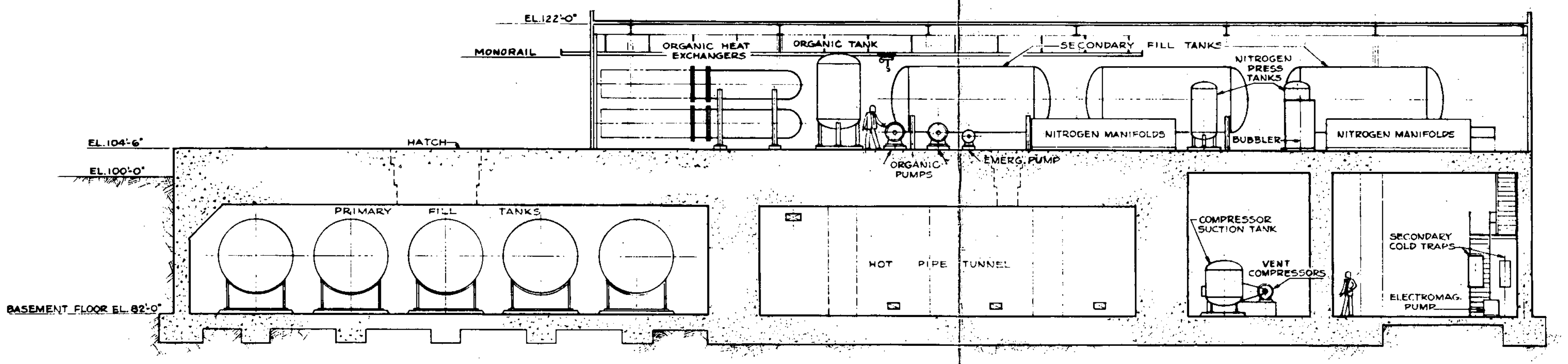
100 MW NUCLEAR POWER PLANT
TURBINE AREA
PLAN

PLATE 5 — REV. 0

066



TYPICAL COLD TRAP ASSEMBLY



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100 MW NUCLEAR POWER PLANT
REACTOR AREA
SECTION A—A

PLATE 6 | REV. 0

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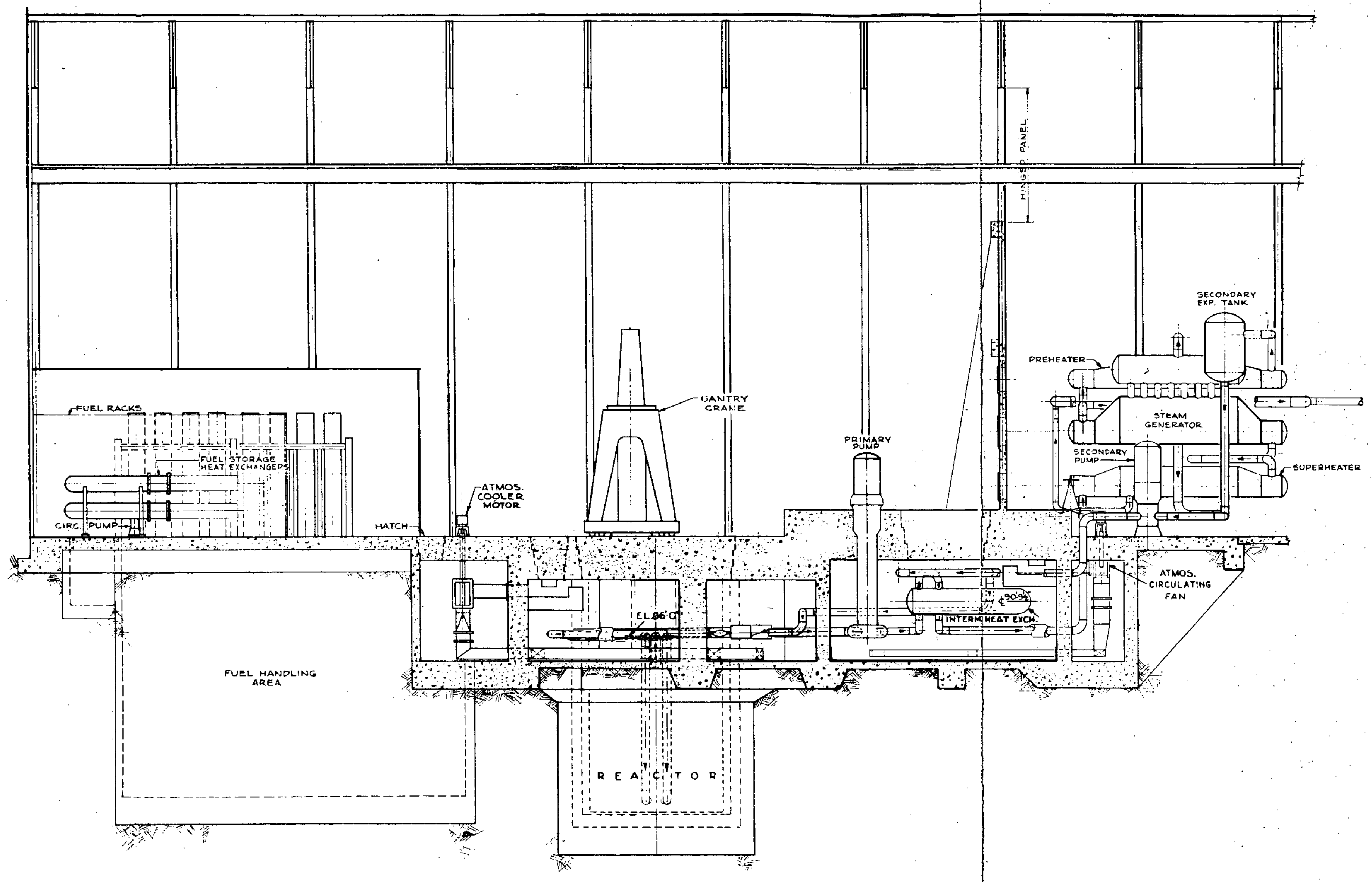

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100 MW NUCLEAR POWER PLANT

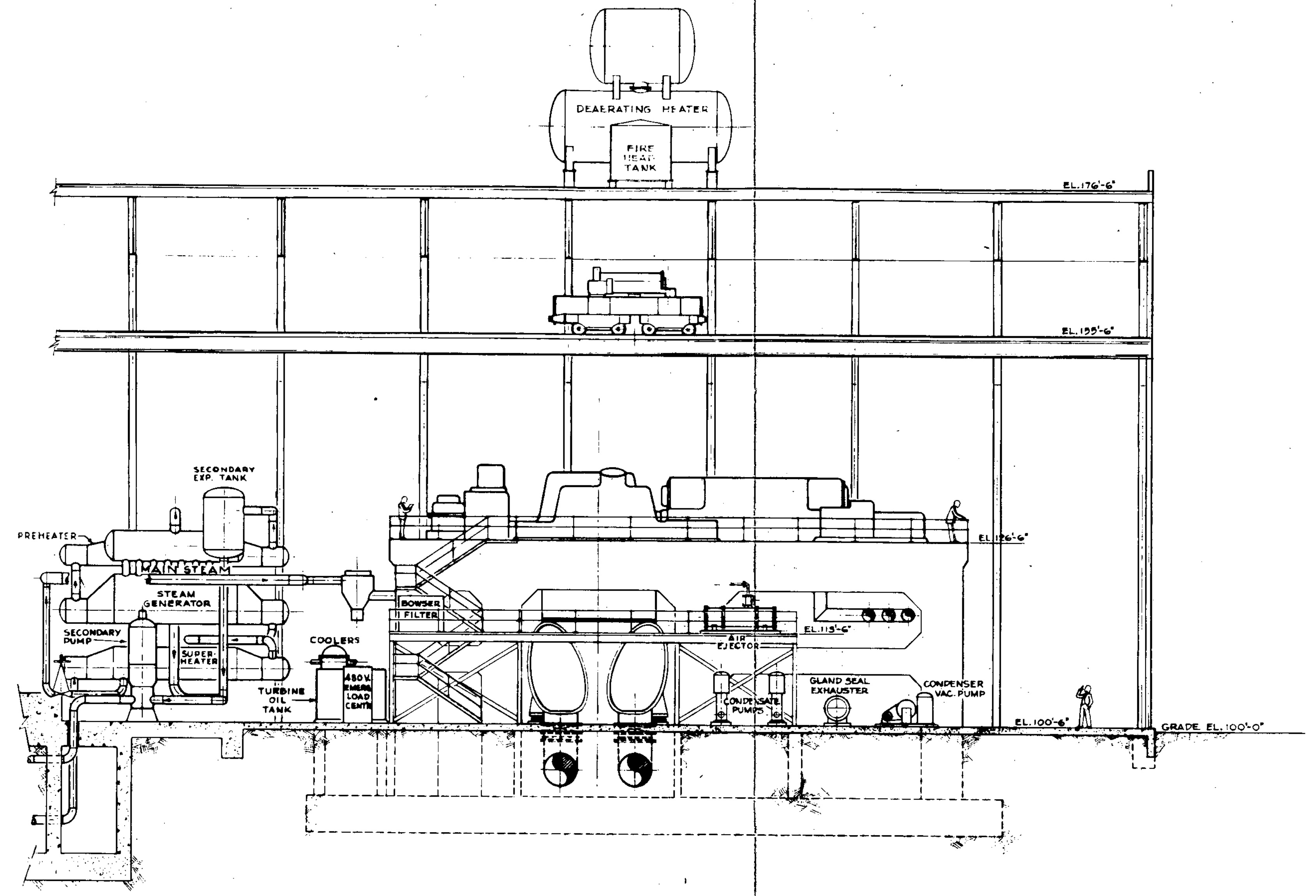
REACTOR AREA

SECTION B—B

PLATE 7

REV. 0

068



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100 MW NUCLEAR POWER PLANT

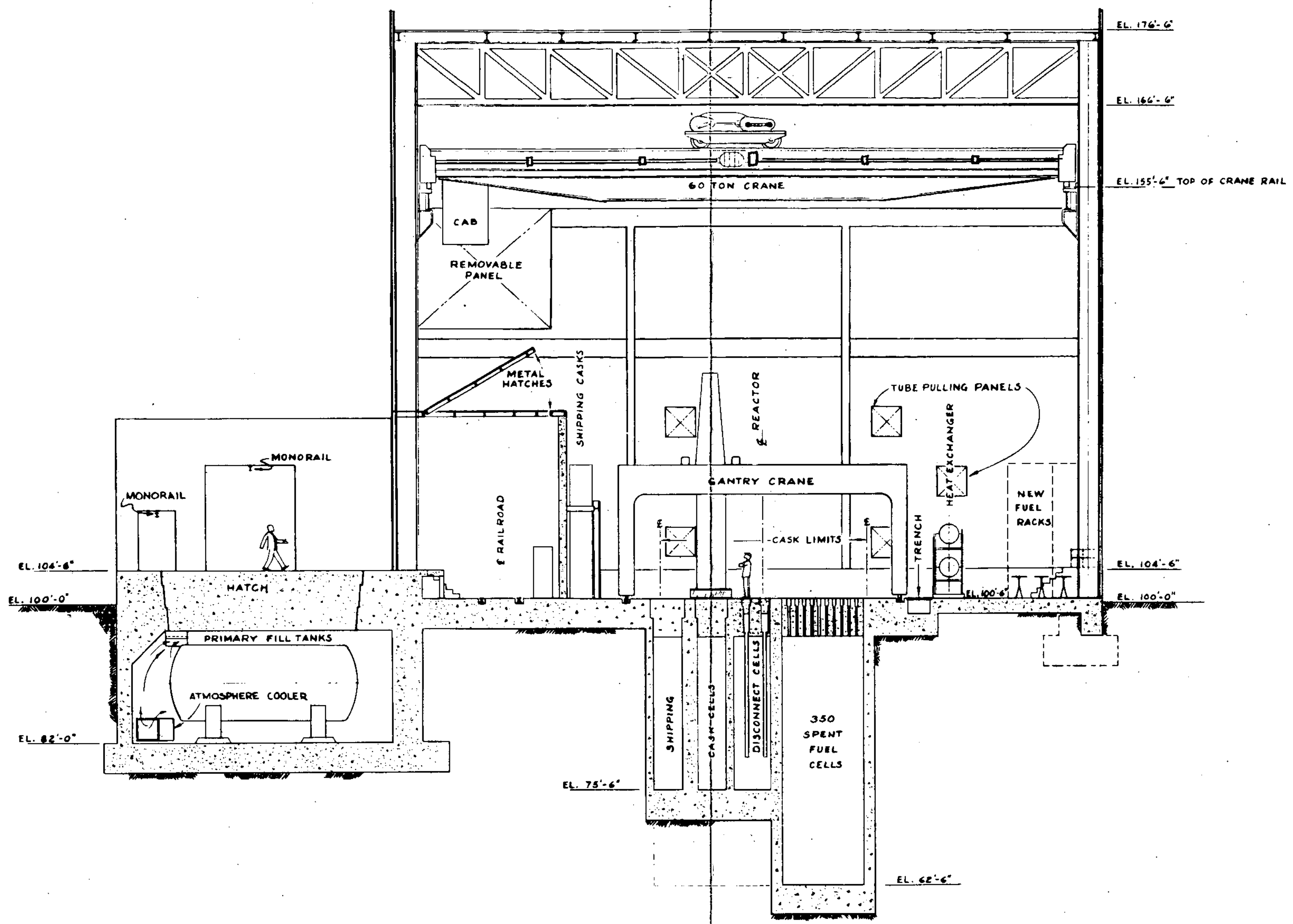
TURBINE AREA

SECTION B–B

PLATE 8

REV. 0

069



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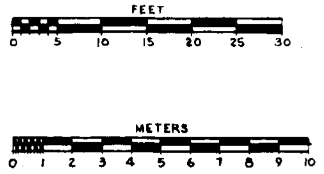

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100 MW NUCLEAR POWER PLANT

REACTOR AREA

SECTION C–C

PLATE 9

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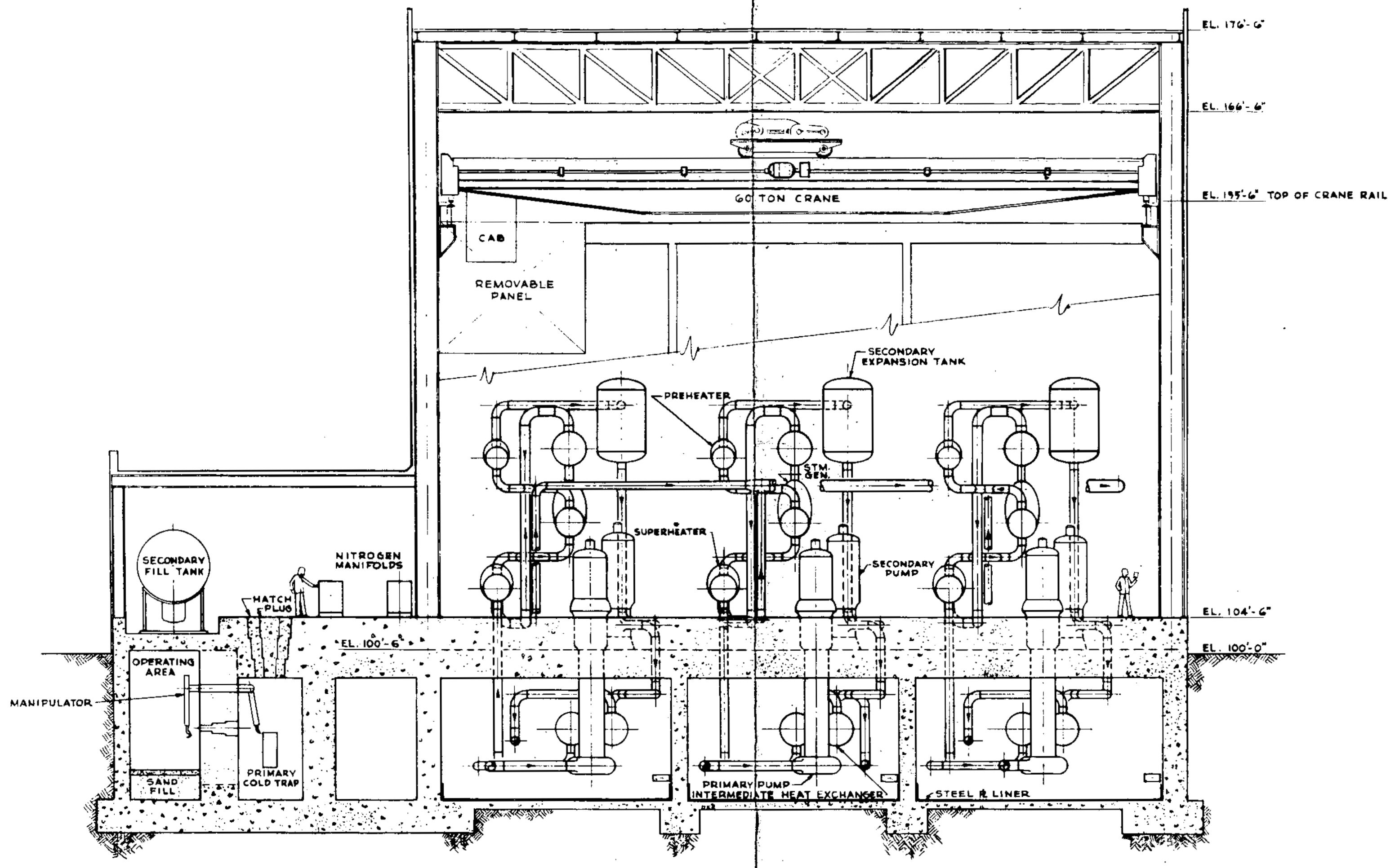

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100 MW NUCLEAR POWER PLANT

REACTOR AREA

SECTION D–D

PLATE 10

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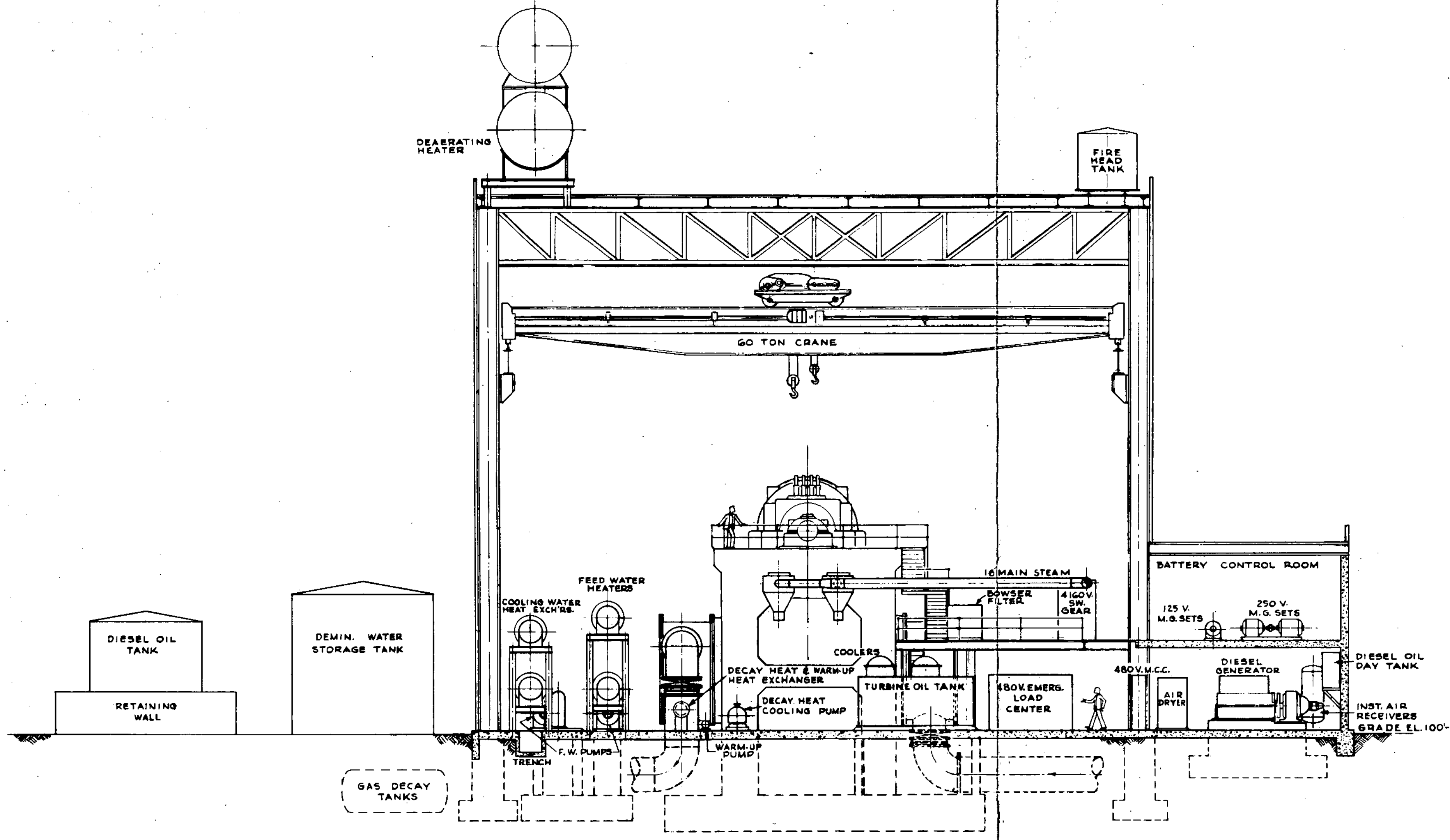

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100 MW NUCLEAR POWER PLANT

TURBINE AREA

SECTION E–E

PLATE 11

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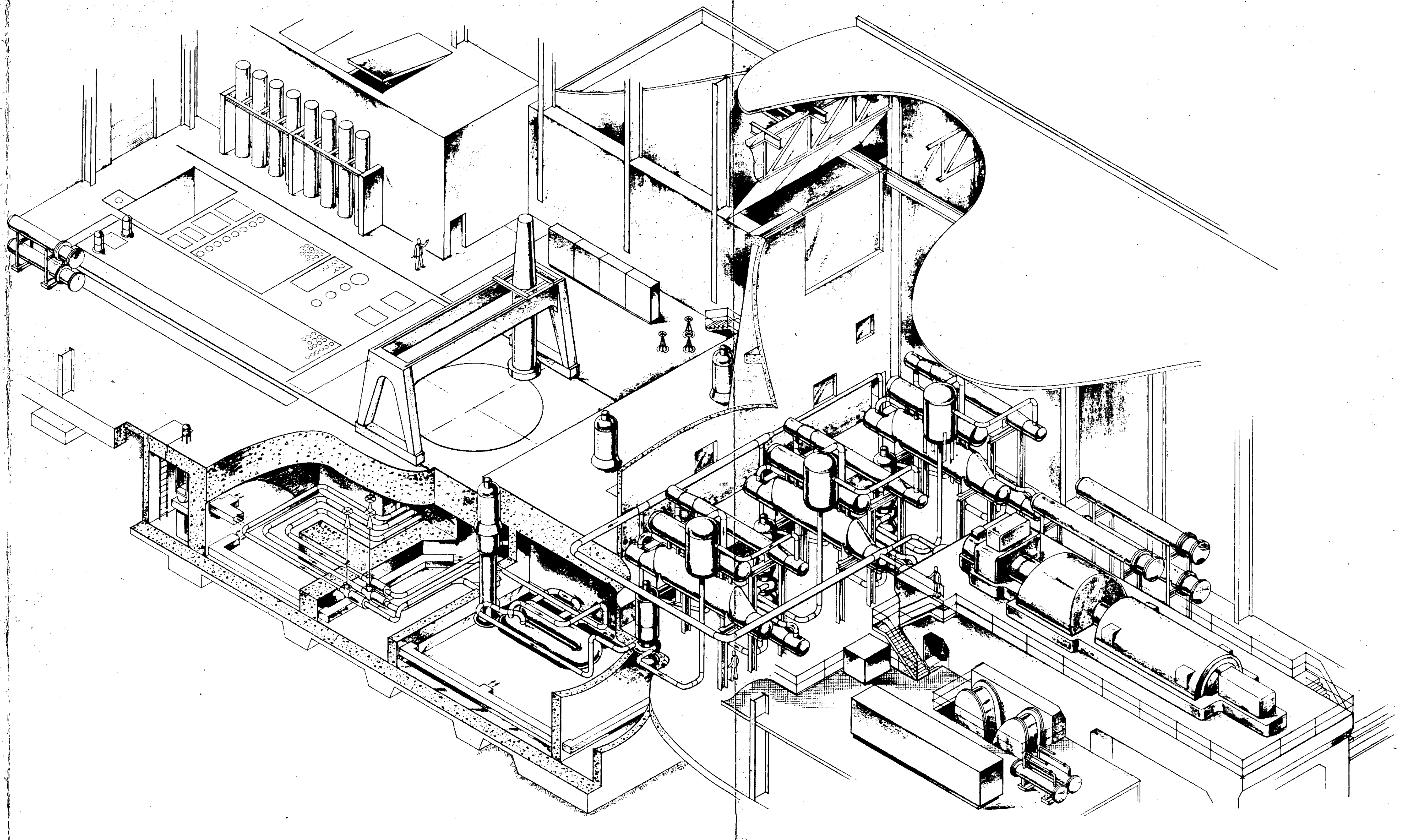

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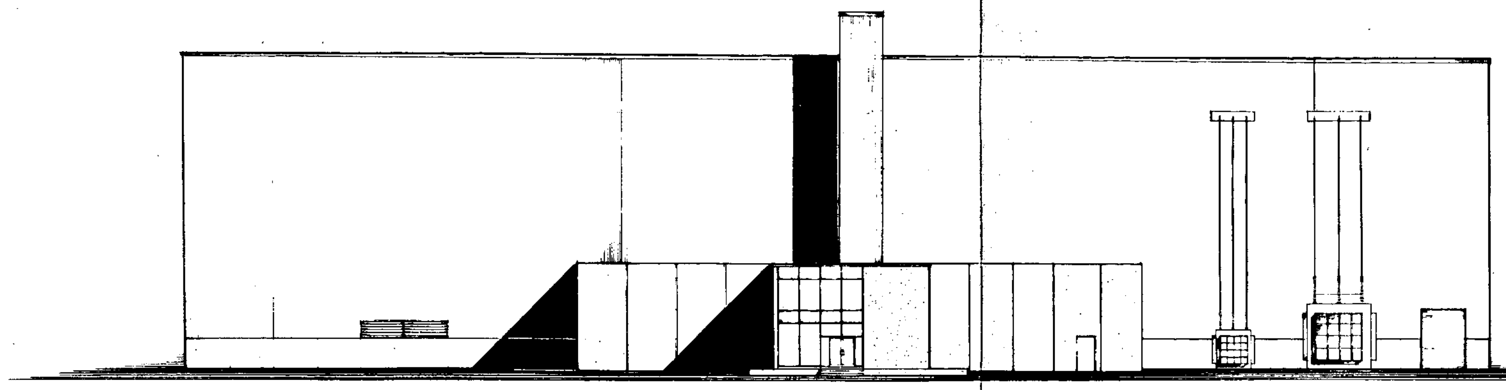
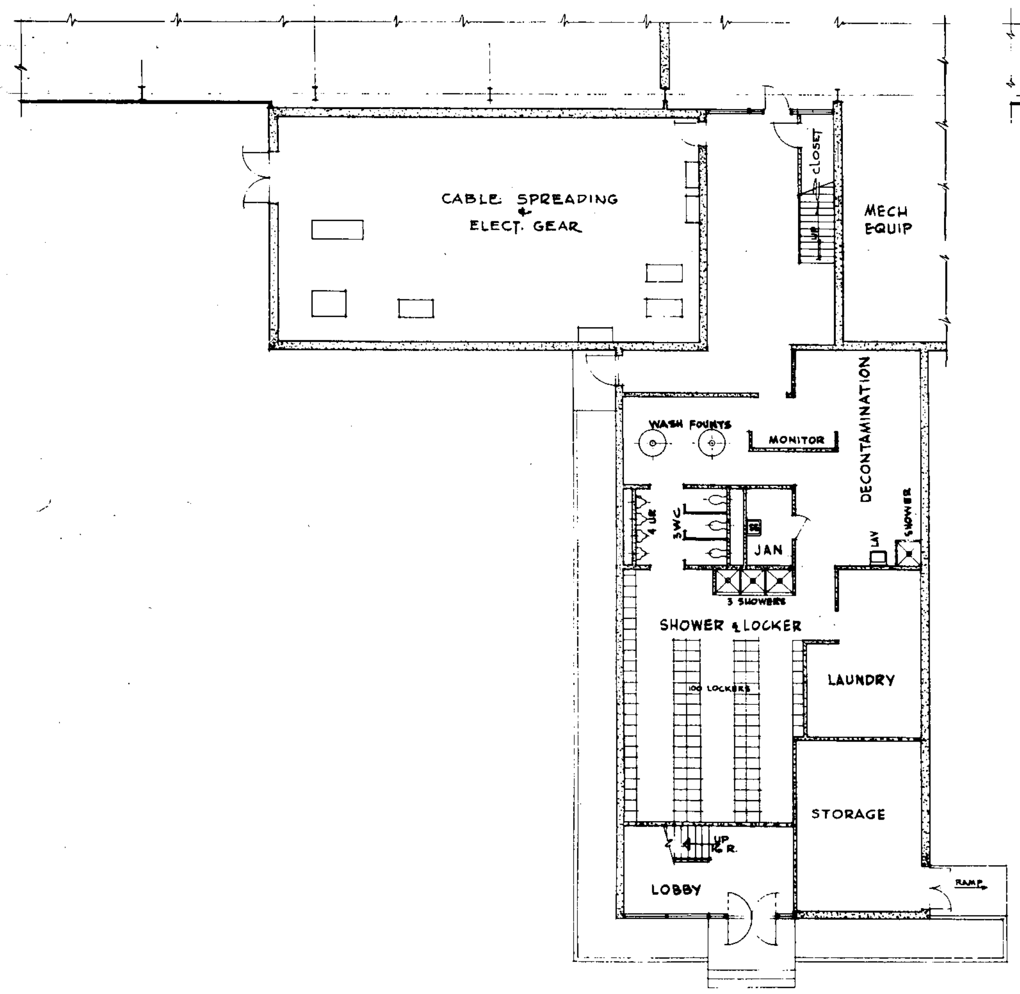
100 MW NUCLEAR POWER PLANT
ISOMETRIC
PLANT ARRANGEMENT

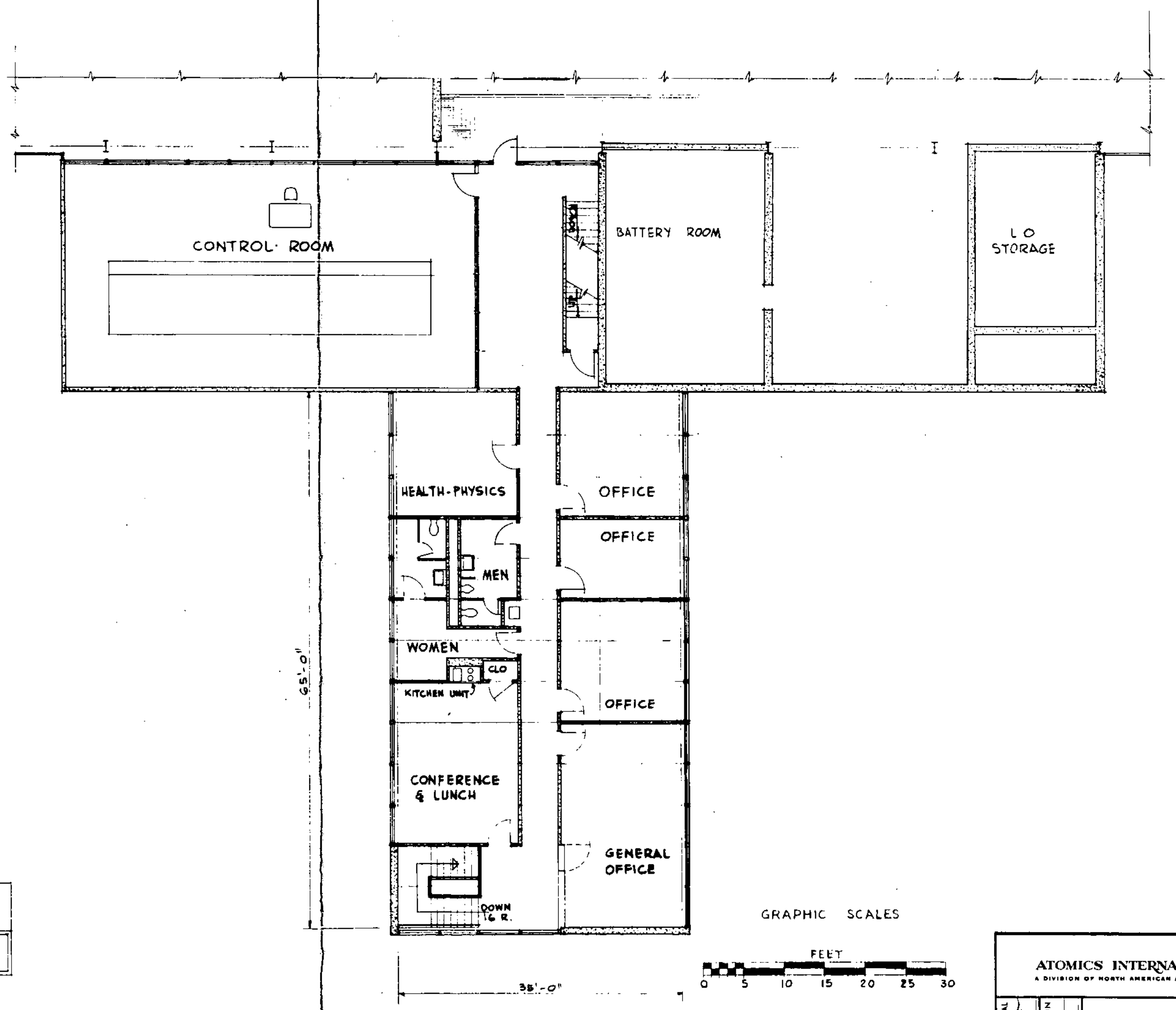
PLATE 12 — REV. 0



FRONT ELEVATION
SCALE 1/16" = 1'-0"

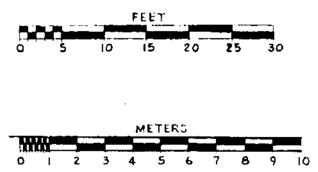


GROUND FLOOR PLAN
SCALE 1/8" = 1'-0"



SECOND FLOOR PLAN
SCALE 1/8" = 1'-0"

GRAPHIC SCALES



ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

BECHTEL CORPORATION

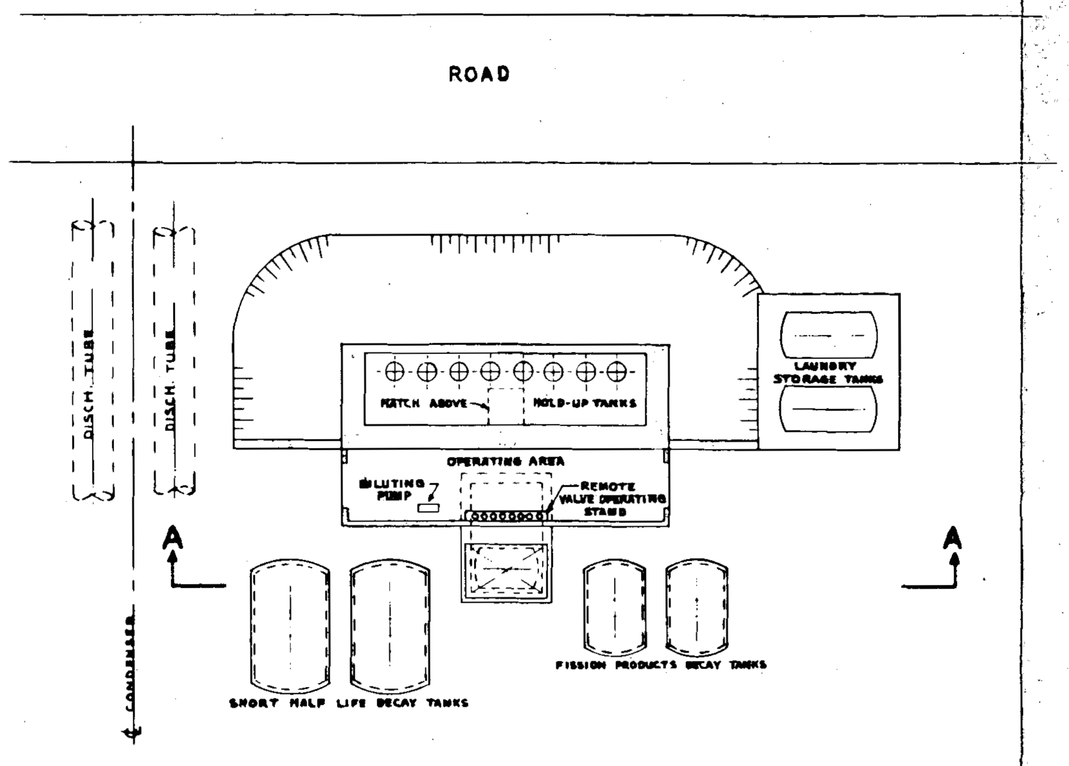
APPROVED ATOMICS INTERNATIONAL / DATE
APPROVED BECHTEL CORPORATION / DATE

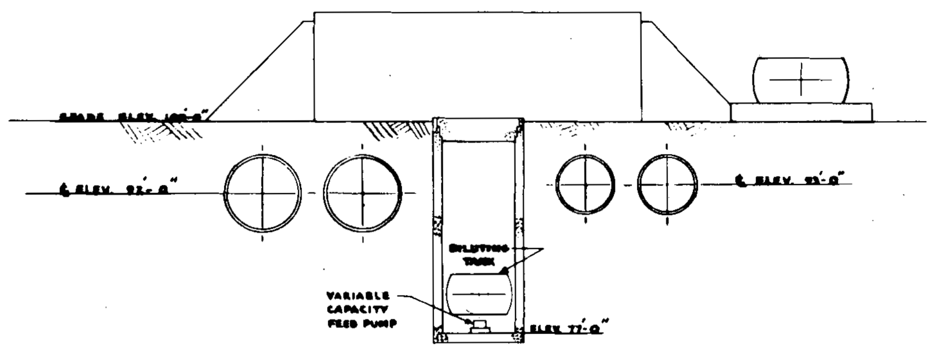
100 MW NUCLEAR POWER PLANT

CONTROL ROOM AND OFFICES
PLANS AND ELEVATIONS

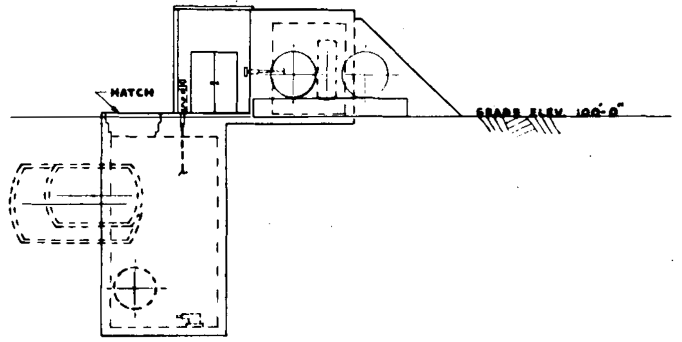
PLATE 13 — REV. 0

074



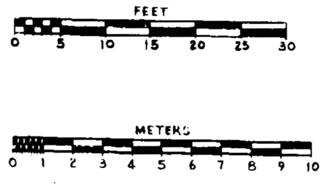


SECTION A-A



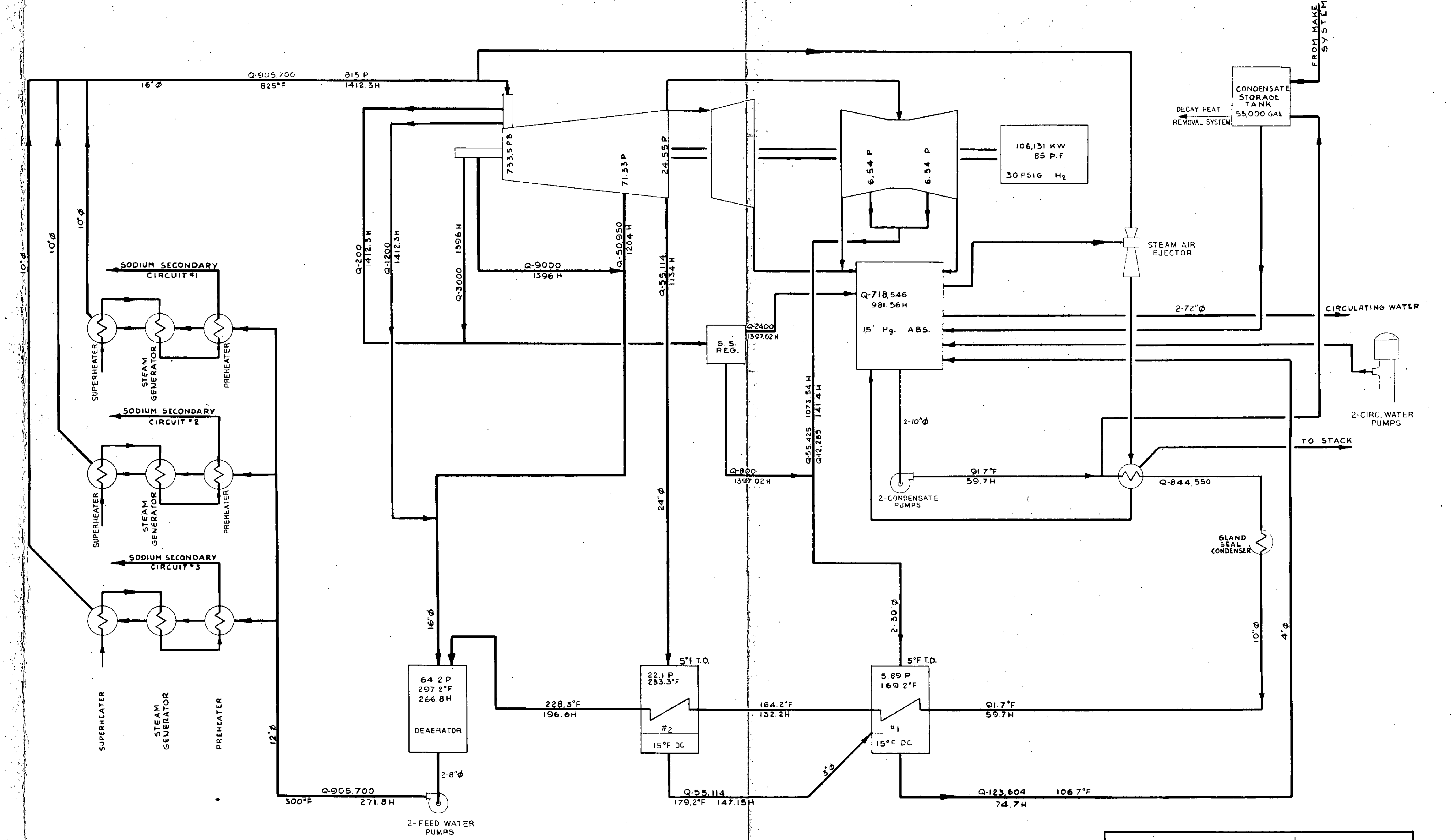
SECTIONAL ELEVATION

GRAPHIC SCALES



ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION INC.	BECHTEL CORPORATION
APPROVED ATOMICS INTERNATIONAL / DATE APPROVED BECHTEL CORPORATION / DATE	100 MW NUCLEAR POWER PLANT
	RADIOACTIVE LIQUID WASTE AREA PLAN AND ELEVATIONS
	PLATE 14 — REV. 0

000 075



LEGEND

P - PRESSURE PSIA
°F - TEMPERATURE FAHRENHEIT
H - ENTALPY BTU/LB
Q - FLOW LBS/HR
φ - NOMINAL DIAMETER

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

BECHTEL CORPORATION

APPROVED ATOMICS INTERNATIONAL DATE

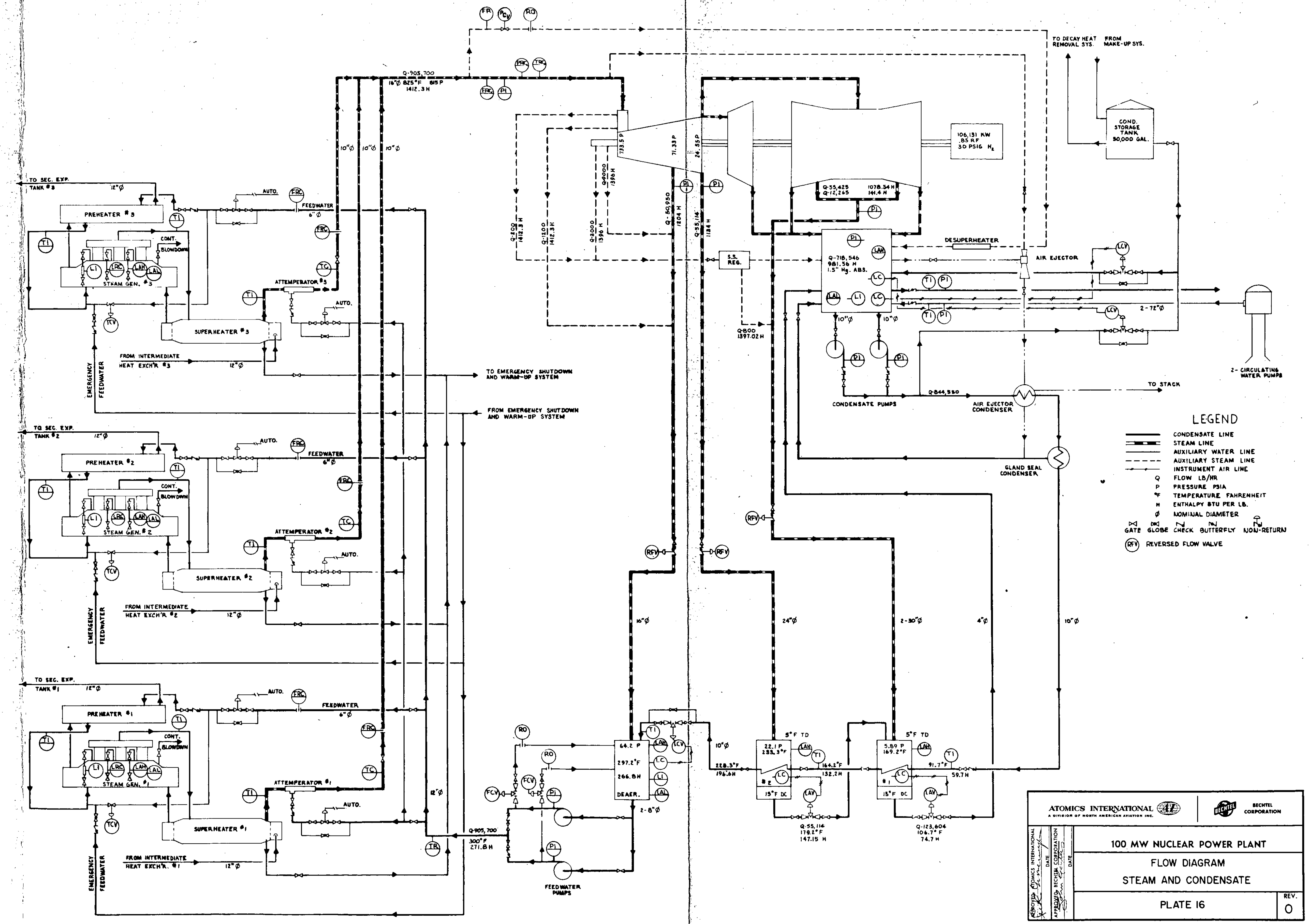
APPROVED BECHTEL CORPORATION DATE

100 MW NUCLEAR POWER PLANT

HEAT BALANCE DIAGRAM
STEAM AND CONDENSATE

PLATE 15

REV. 0



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BECHTEL CORPORATION

100 MW NUCLEAR POWER PLANT

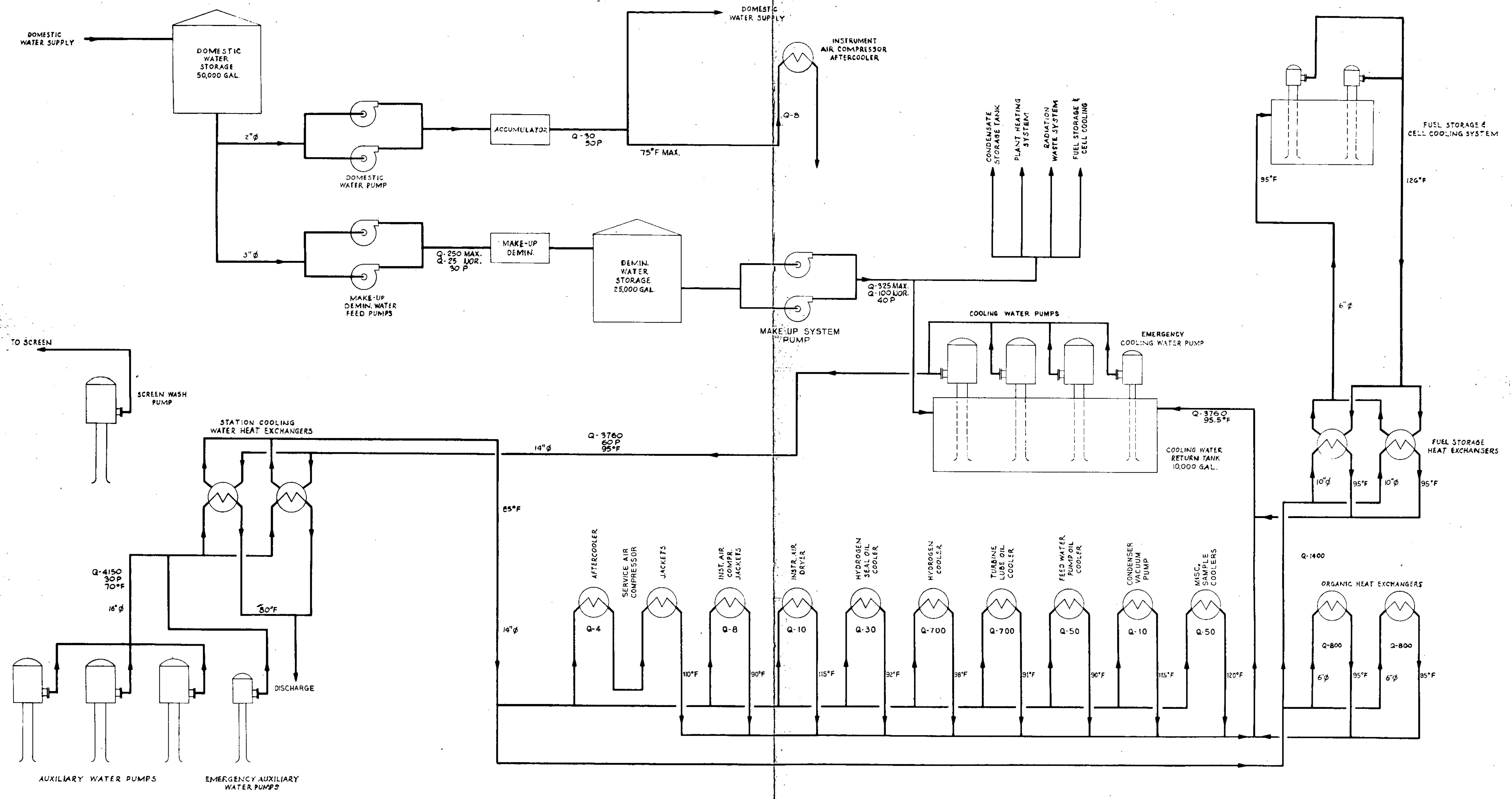
FLOW DIAGRAM

STEAM AND CONDENSATE

PLATE 16

REV. 0

077



LEGEND

Q - FLOW GPM
P - PRESSURE PSIA
°F - TEMPERATURE FAHRENHEIT
φ - NOMINAL DIAMETER

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

BECHTEL CORPORATION

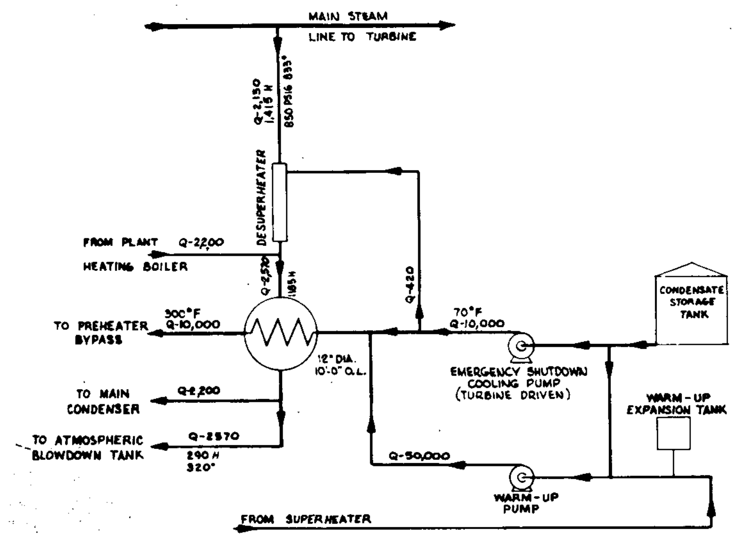
APPROVED: ATOMICS INTERNATIONAL DATE
APPROVED: BECHTEL CORPORATION DATE

100 MW NUCLEAR POWER PLANT

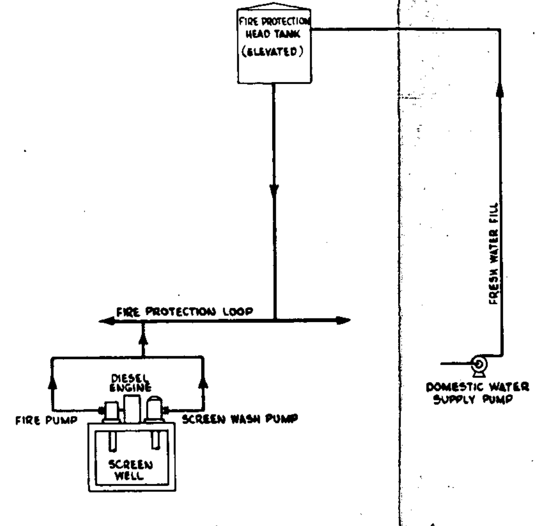
FLOW DIAGRAM
SERVICE AND COOLING WATER

PLATE 17

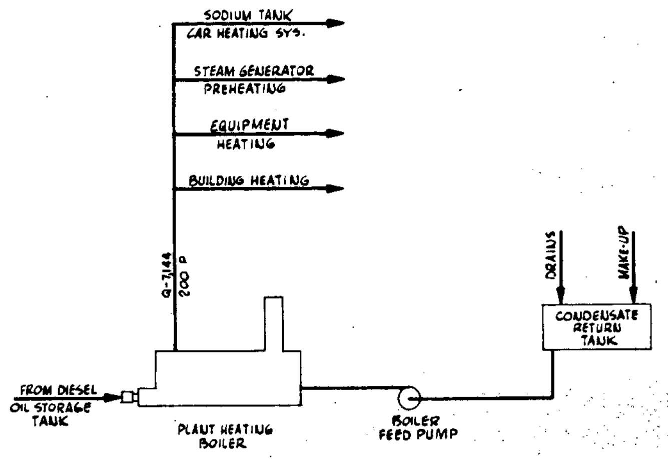
REV. 0



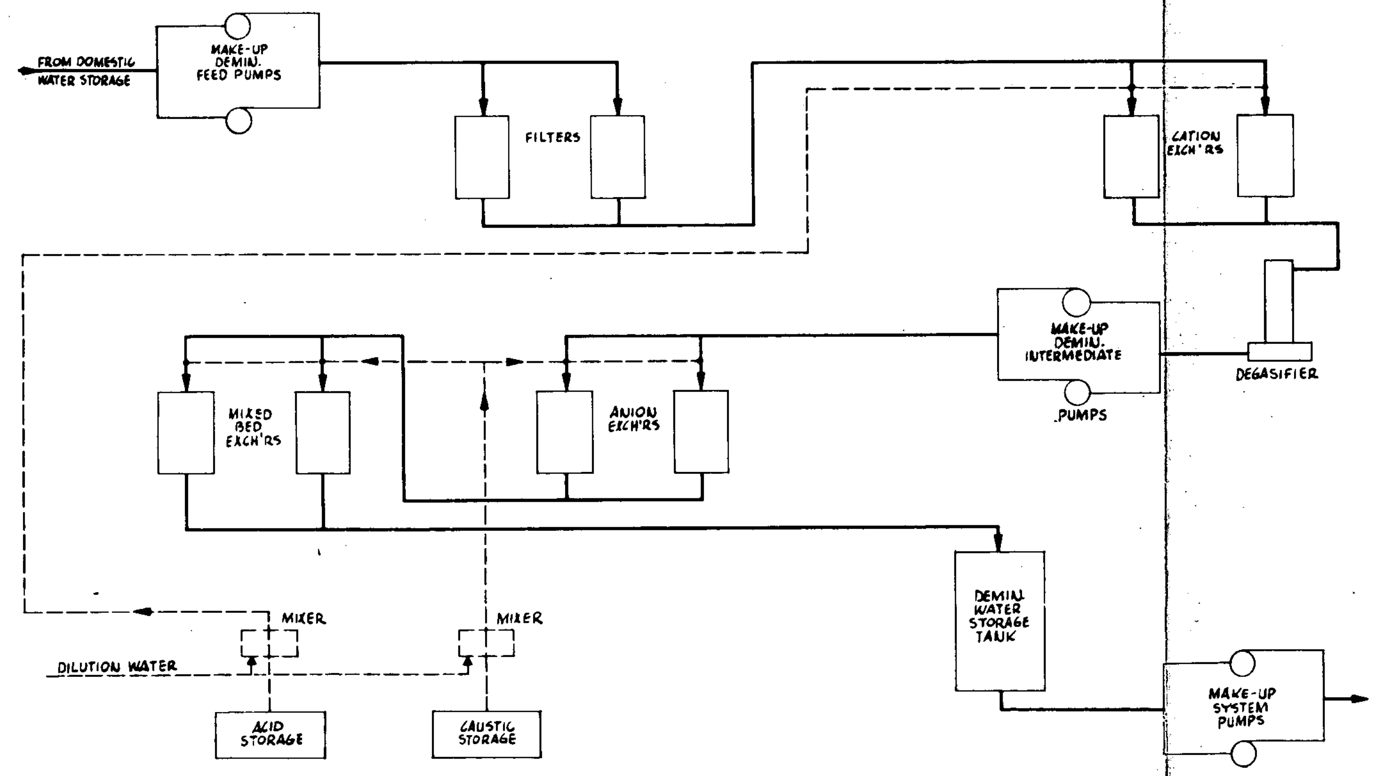
EMERGENCY SHUTDOWN & WARM-UP SYSTEM



FIRE PROTECTION SYSTEM



PLANT HEATING SYSTEM



MAKE-UP DEMINERALIZER SYSTEM

LEGEND

°F - TEMPERATURE FAHRENHEIT
P - PRESSURE PSIA
Q - FLOW LB/HR

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

BECHTEL CORPORATION

APPROVED: ATOMICS INTERNATIONAL DATE

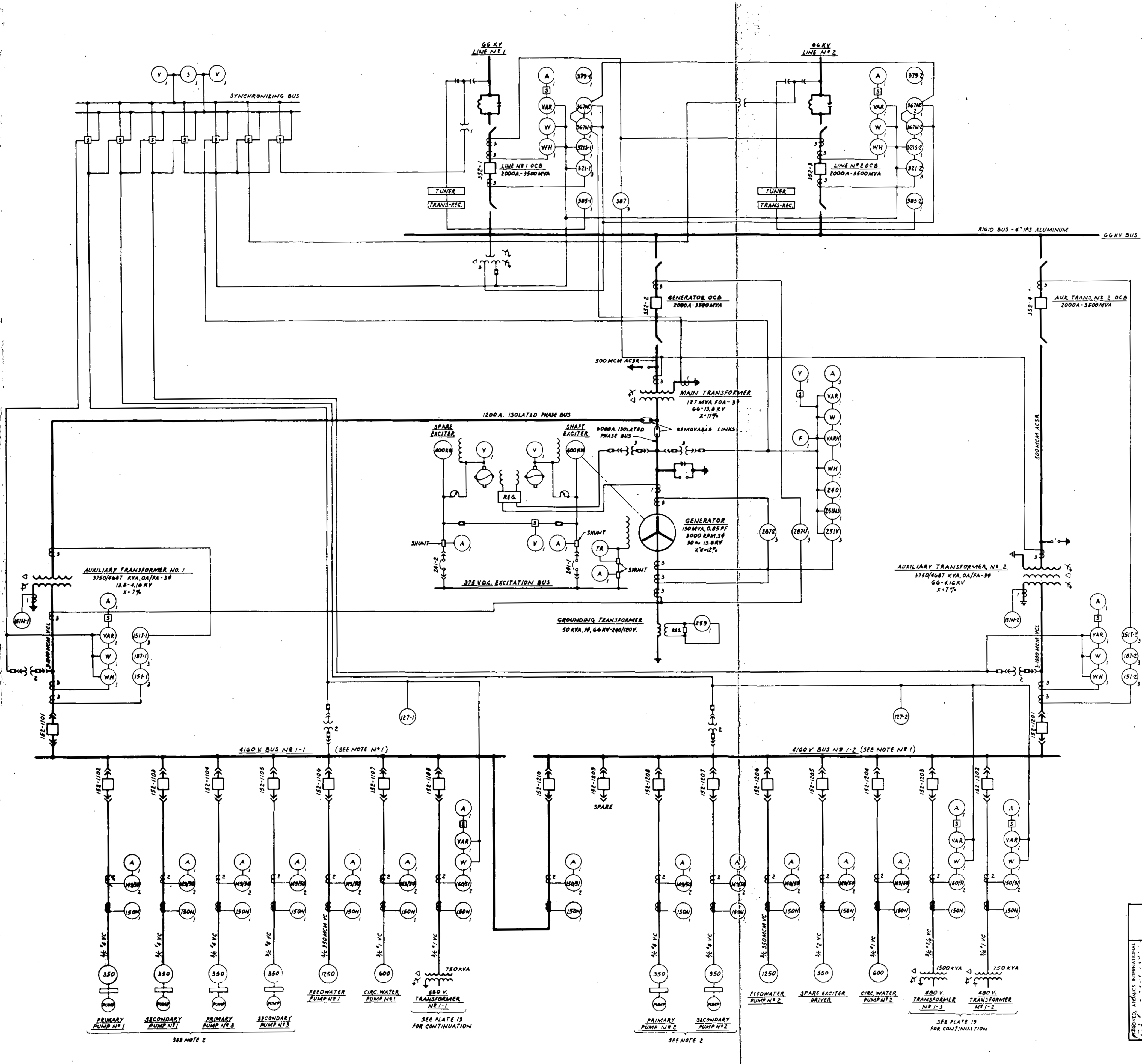
APPROVED: BECHTEL CORPORATION DATE

100 MW NUCLEAR POWER PLANT

FLOW DIAGRAMS
MISCELLANEOUS SERVICES

PLATE 18

REV. 0



DEVICE TABLE (SEE NOTE 4)

DEVICE	DESCRIPTION	FUNCTION (SEE NOTE Nº 3)
241-1, -2	AIR CIRCUIT BREAKER, 1600A. 500 V.D.C.	CONNECTS EXCITERS TO EXCITATION BUS
127-1	BUS Nº 1-1 UNDERVOLTAGE RELAY	TRIPS 152-1101 AND ALL 4KV FEEDERS ON BUS Nº 1-1 EXCEPT 152-1108 AND CLOSES 152-1210 ON BUS UNDERVOLTAGE.
127-2	BUS Nº 1-2 UNDERVOLTAGE RELAY	TRIPS 152-1201 AND ALL 4KV FEEDERS ON BUS Nº 1-2 EXCEPT 152-1202 AND CLOSES 152-1210 ON BUS UNDERVOLTAGE.
149/50	MOTOR THERMAL OVERLOAD RELAY WITH INSTANTANEOUS UNIT.	TRIPS ASSOCIATED BREAKER
150-N	GROUND FAULT INSTANTANEOUS OVER-CURRENT RELAY	TRIPS ASSOCIATED BREAKER
150/51	PHASE FAULT INSTANTANEOUS AND TIME DELAY OVERCURRENT RELAY.	TRIPS ASSOCIATED BREAKER
151-1	AUX. TRANSFORMER SECONDARY TIME DELAY OVERCURRENT RELAY.	TRIPS 152-1101
151-2	AUX. TRANSFORMER SECONDARY TIME DELAY OVERCURRENT RELAY	TRIPS 152-1201
151N-1	AUX. TRANSFORMER GROUND FAULT TIME DELAY OVERCURRENT RELAY.	TRIPS TURB-GEN.
151N-2	AUX. TRANSFORMER GROUND FAULT TIME DELAY OVERCURRENT RELAY.	TRIPS 352-4
151T-1	AUX. TRANSFORMER PRIMARY TIME DELAY OVERCURRENT RELAY.	TRIPS TURB.-GEN.
151T-2	AUX. TRANSFORMER PRIMARY TIME DELAY OVERCURRENT RELAY.	TRIPS 352-4
152	AIR CIRCUIT BREAKER, 1200A., 4160V., 75 MVA.	
187-1	AUX. TRANSFORMER DIFFERENTIAL RELAY.	TRIPS TURB-GEN
187-2	AUX. TRANSFORMER DIFFERENTIAL RELAY	TRIPS 352-4 & 152-1201
240	GENERATOR LOSS OF EXCITATION	TRIPS TURB-GEN.
251NS	GENERATOR NEGATIVE SEQUENCE RELAY	TRIPS TURB.-GEN.
251V	GENERATOR OVERCURRENT RELAY WITH VOLTAGE RESTRAINT (GEN. BACKUP).	TRIPS TURB.-GEN.
259	GENERATOR NEUTRAL OVERVOLTAGE RELAY	TRIPS TURB.-GEN.
287G	GENERATOR DIFFERENTIAL RELAY	TRIPS TURB-GEN.
287U	UNIT DIFFERENTIAL RELAY	TRIPS TURB-GEN.
321-1, -2	DIRECTIONAL DISTANCE RELAY	TRIPS ASSOCIATED LINE BREAKER
321S-1, -2	CARRIER NON-DIRECTIONAL STARTING	STARTS CARRIER ON ASSOC. LINE BRR.
352	OIL CIRCUIT BREAKER, 2000A., 66KV, 3500 MVA	
367N-1, -2	DIRECTIONAL GROUND OVERCURRENT-BACKUP	TRIPS ASSOCIATED LINE BREAKER
367NC-1, -2	DIRECTIONAL GROUND OVERCURRENT-CARRIER	TRIPS ASSOCIATED LINE BREAKER
379-1, -2	SINGLE SHOT RECLOSING RELAY.	RECLOSES ASSOCIATED LINE BREAKER
385-1, -2	CARRIER CURRENT RECEIVER RELAY	CONTROLS CARRIER CURRENT TRIPPING
387	66 KV BUS DIFFERENTIAL RELAY	TRIPS ALL 66KV BREAKERS

NOTES

1. ALL 4160V. ACB'S RATED 1200A., 75 MVA.
2. PRIMARY AND SECONDARY SODIUM PUMP DRIVERS ARE CONNECTED TO THEIR PUMPS THROUGH VARIABLE SPEED MAGNETIC COUPLINGS. EACH PUMP ALSO HAS COUPLED TO IT A 20 HP EMERGENCY DRIVER SUPPLIED FROM THE EMERGENCY SOURCE.
3. TURBINE-GENERATOR TRIP — TRIPS BREAKERS 152-1101, 352-2, 241-1 & 241-2 AND SHUTS DOWN TURBINE.
4. DEVICE NUMBERS DENOTE FUNCTION IN ACCORDANCE WITH ASA STANDARDS. NUMBER PREFIX TO ASA NUMBER DENOTES VOLTAGE LEVEL AS FOLLOWS:

PREFIX	VOLTAGE LEVEL
NONE	480 V OR LESS
1	4160 V
2	13.8 KV OR GEN. EXCITATION
3	66 KV

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BECHTEL CORPORATION

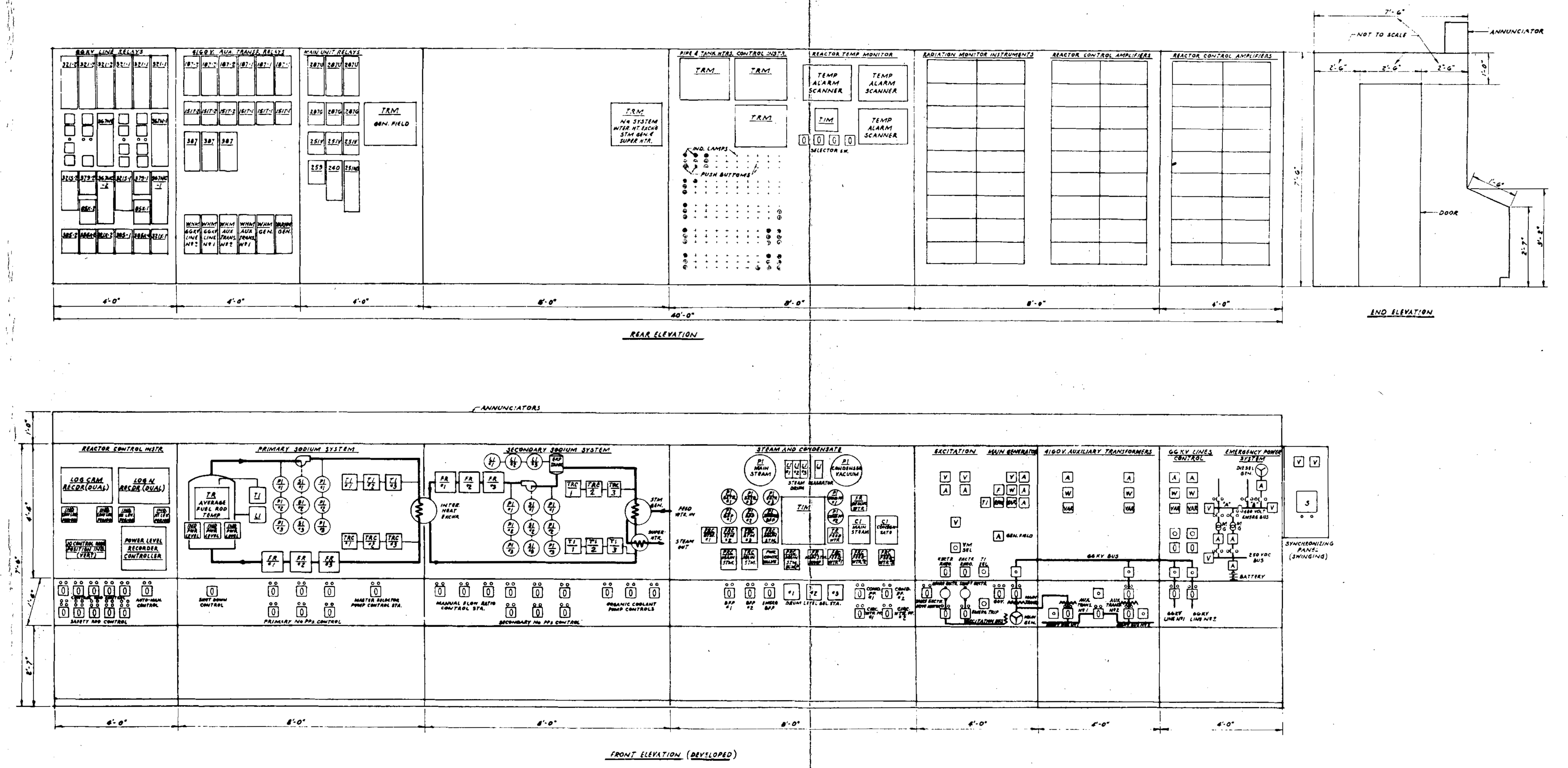
100 MW NUCLEAR POWER PLANT

SINGLE LINE METER & RELAY DIAGRAM
GENERATOR, 66 KV & 4160 V SYSTEMS

PLATE 19

REV 0

080



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A DIVISION OF NORTH AMERICAN AVIATION INC.

BECHTEL CORPORATION

100 MW NUCLEAR POWER PLANT

CONTROL BOARD ARRANGEMENT

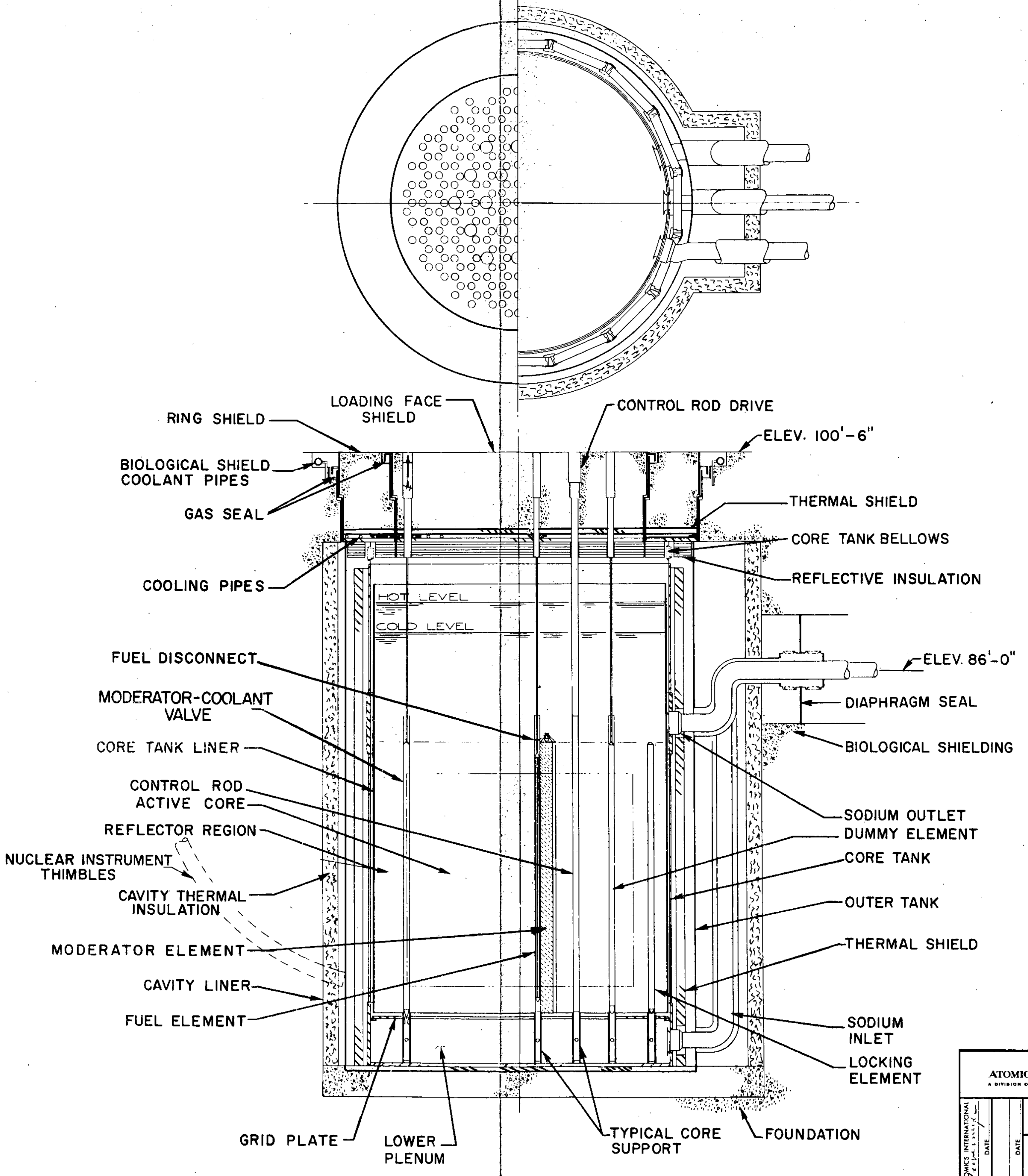
PLATE 2C

REV. 0

APPROVED ATOMICS INTERNATIONAL DATE

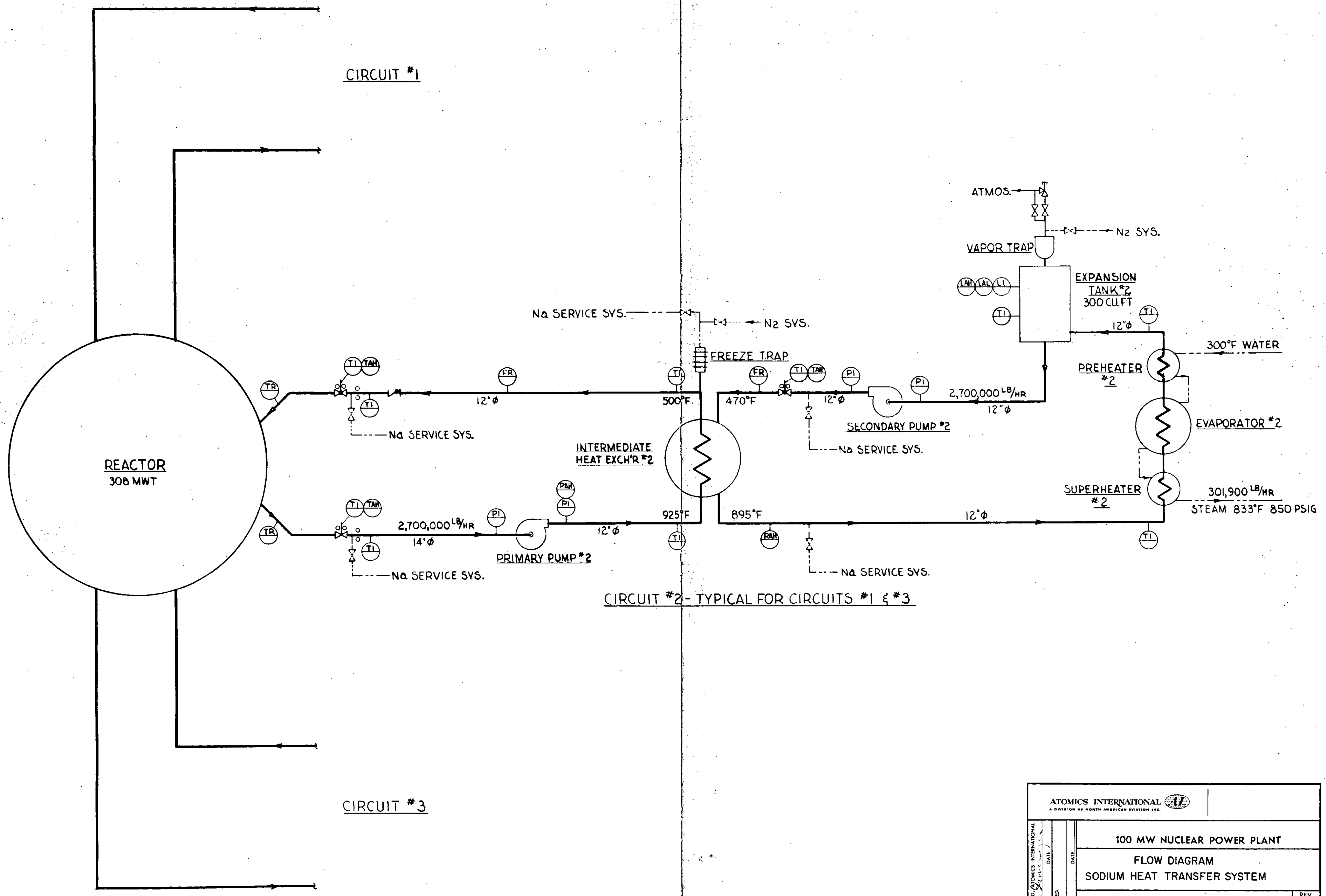
APPROVED BECHTEL CORPORATION DATE

081



ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION INC.
100 MW NUCLEAR POWER PLANT
REACTOR STRUCTURE
PLATE 21 — REV. 0

082



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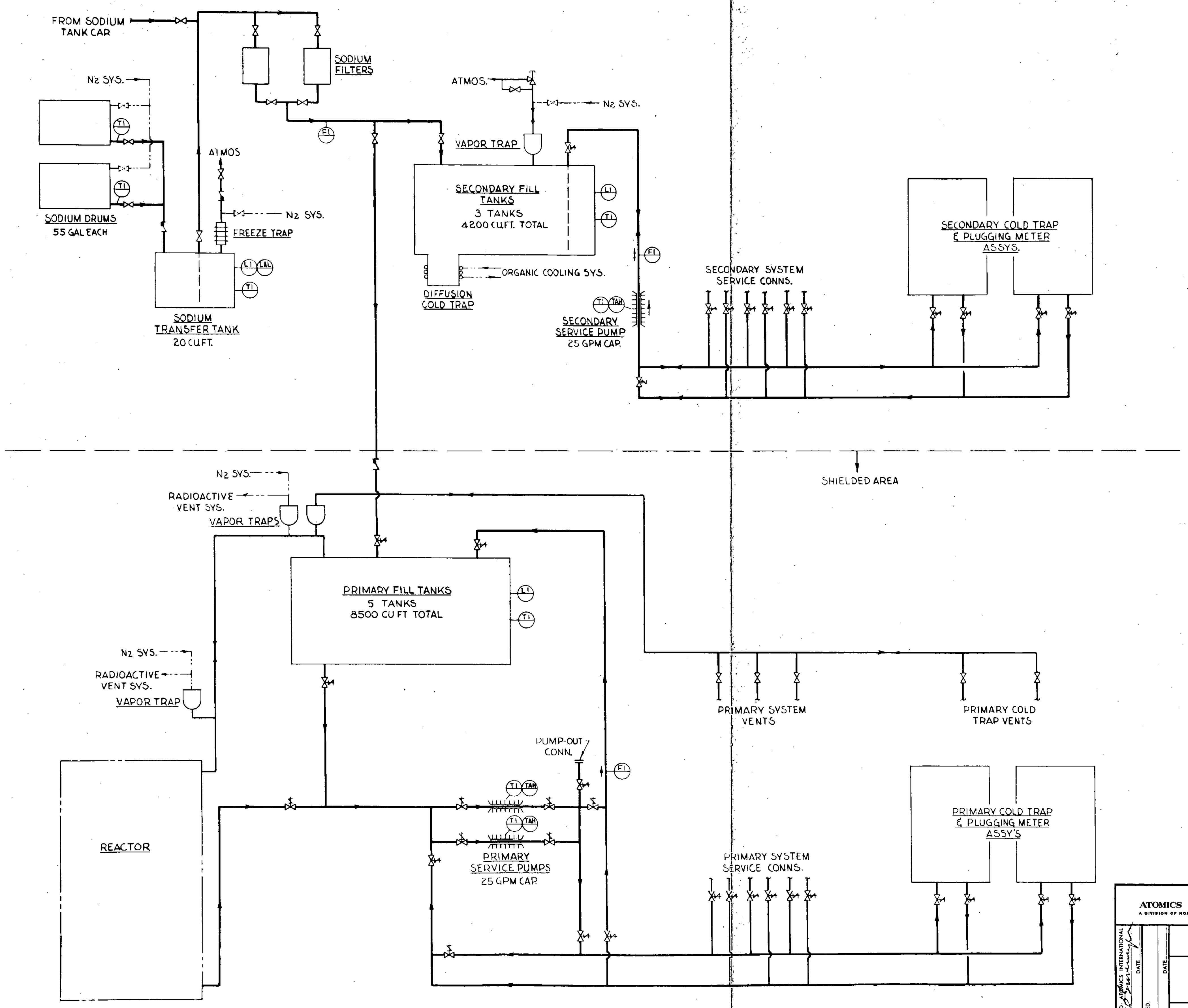
100 MW NUCLEAR POWER PLANT

FLOW DIAGRAM
SODIUM HEAT TRANSFER SYSTEM

PLATE 22

REV. 0

083



ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

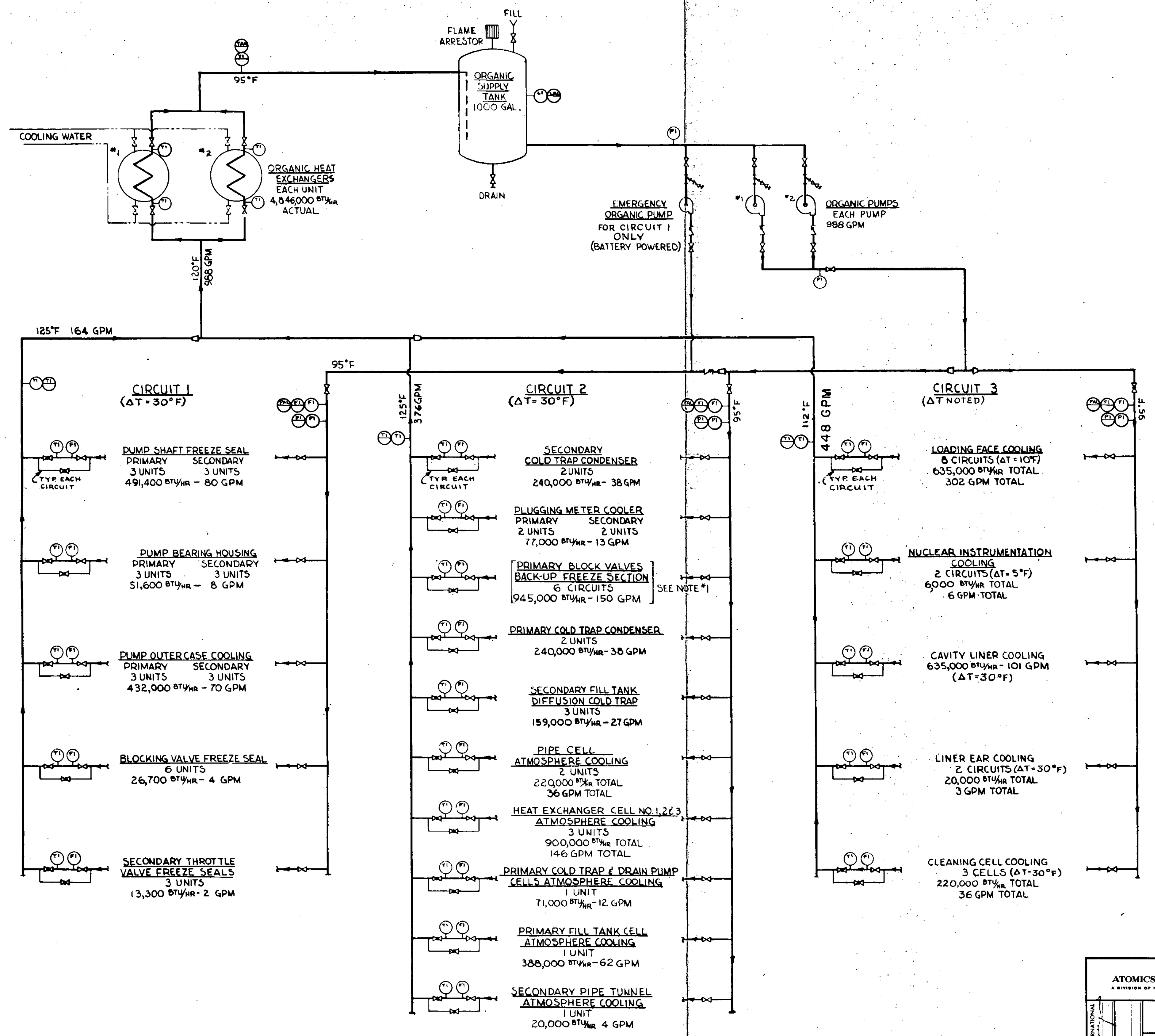
APPROVED | DATE
APPROVED | DATE

100 MW NUCLEAR POWER PLANT

FLOW DIAGRAM

SODIUM SERVICE SYSTEMS

PLATE 23 | REV. 0



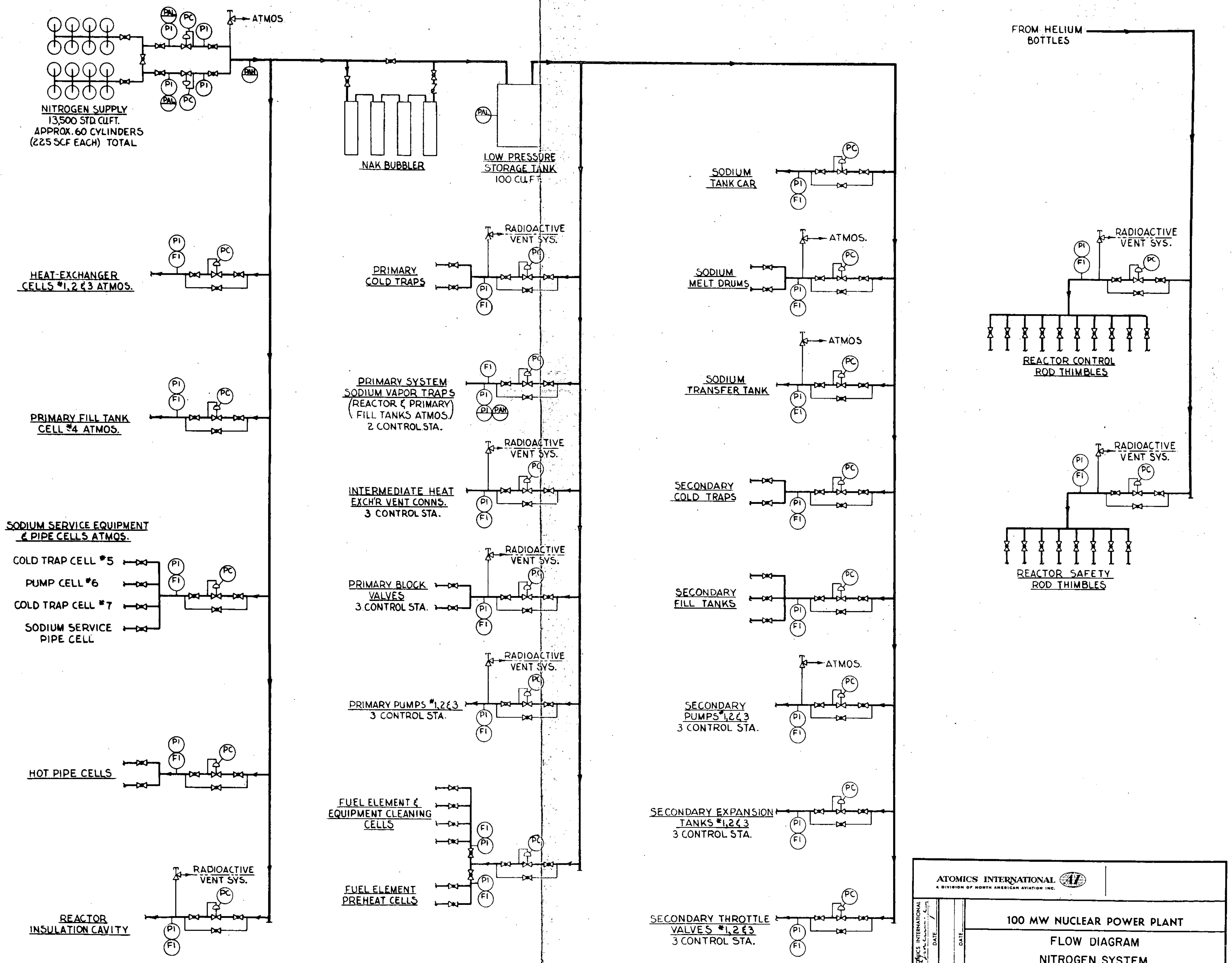
NOTE:
1. WHEN PRIMARY BLOCK VALVES REQUIRE COOLING TO FREEZE A BACK-UP SECTION IN THE PIPE, FLOW CAN BE DIVERTED FROM EQUIPMENT IN SHUT-DOWN CIRCUIT.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION INC.

100 MW NUCLEAR POWER PLANT
FLOW DIAGRAM
ORGANIC COOLING SYSTEM

PLATE 24 | REV. 0

056–085



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100 MW NUCLEAR POWER PLANT

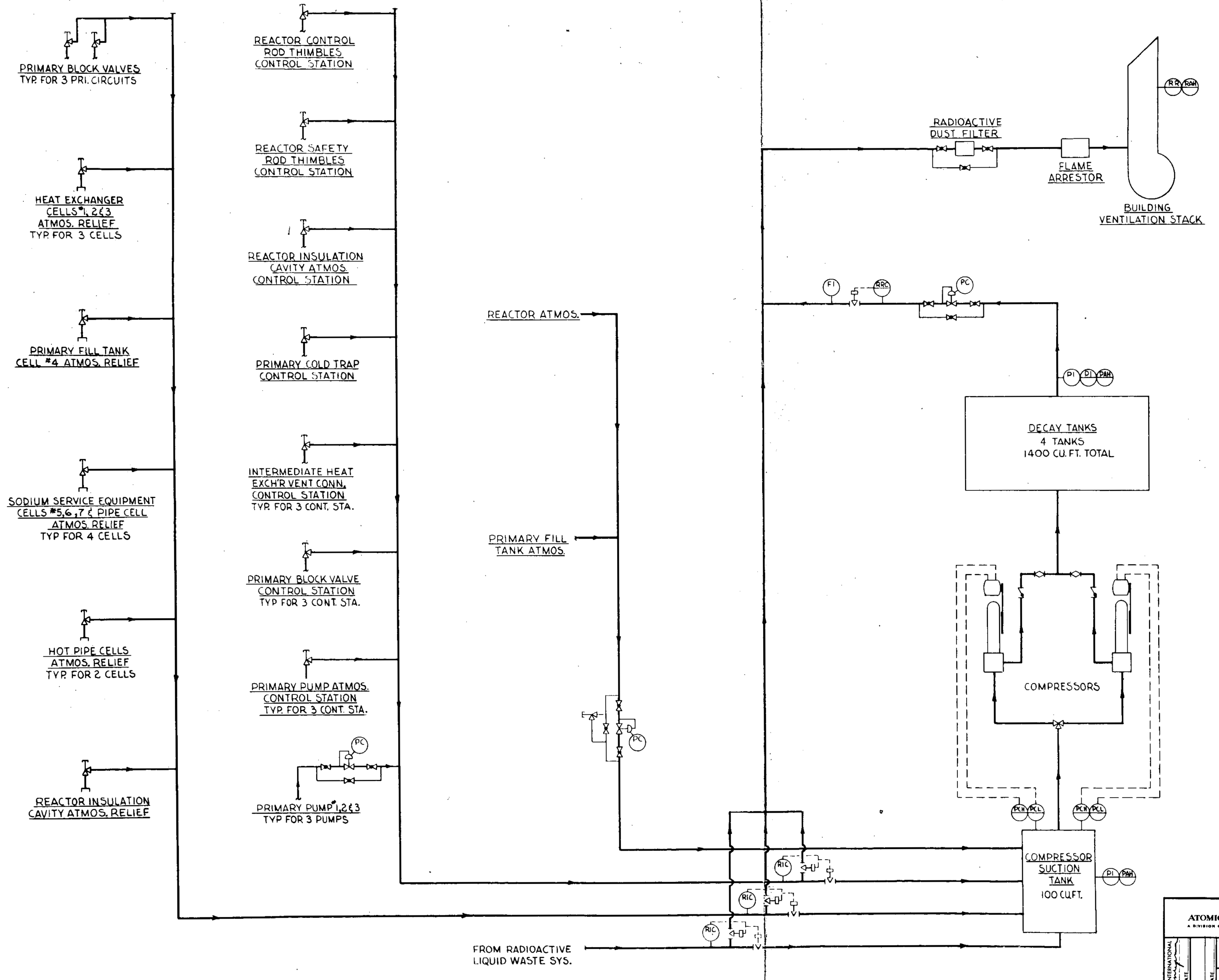
FLOW DIAGRAM

NITROGEN SYSTEM

PLATE 25

REV. 0

056 -086



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100 MW NUCLEAR POWER PLANT

FLOW DIAGRAM

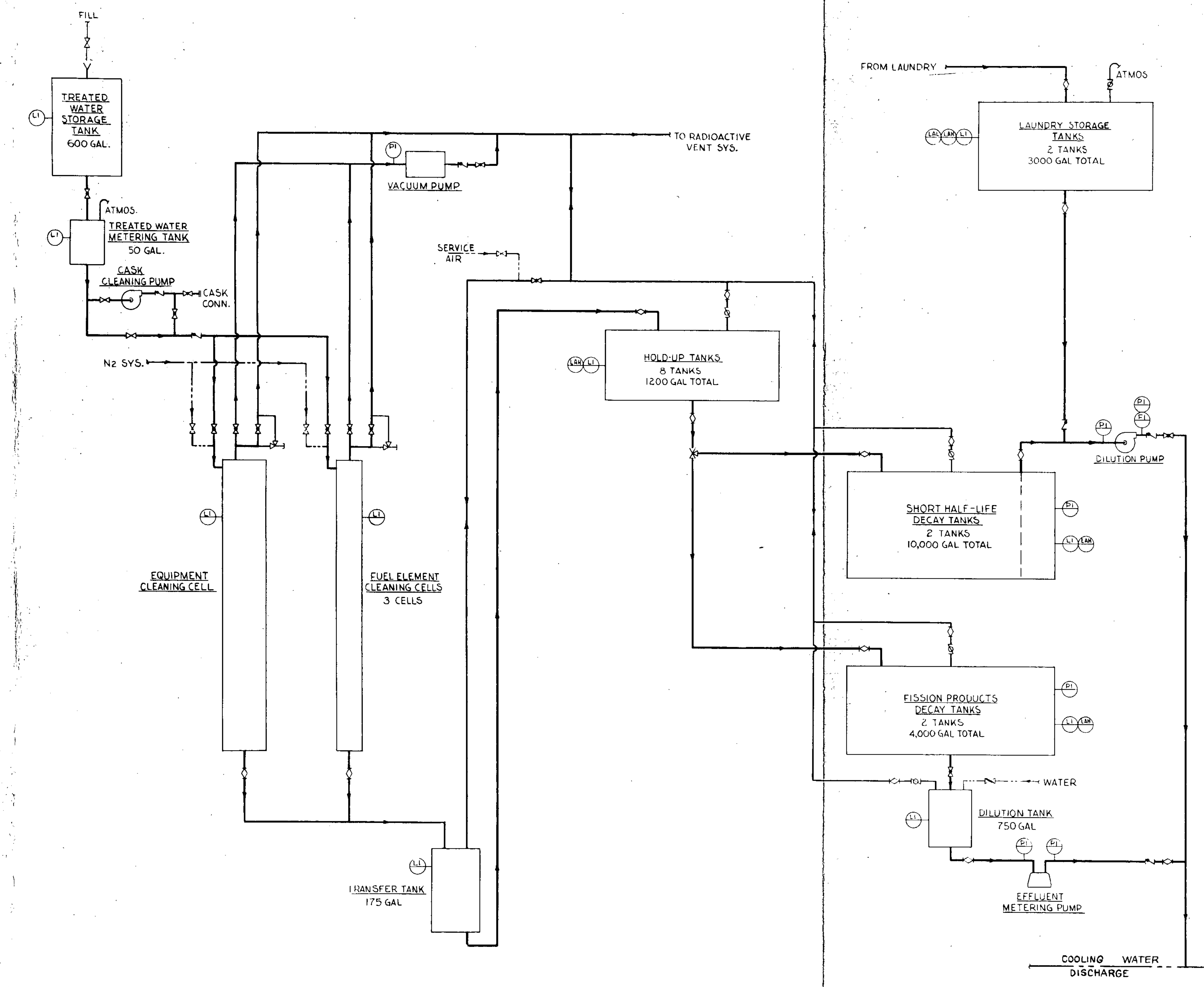
RADIOACTIVE VENT SYSTEM

PLATE 26

REV. 0

APPROVED: DATE:

056 ~ 087



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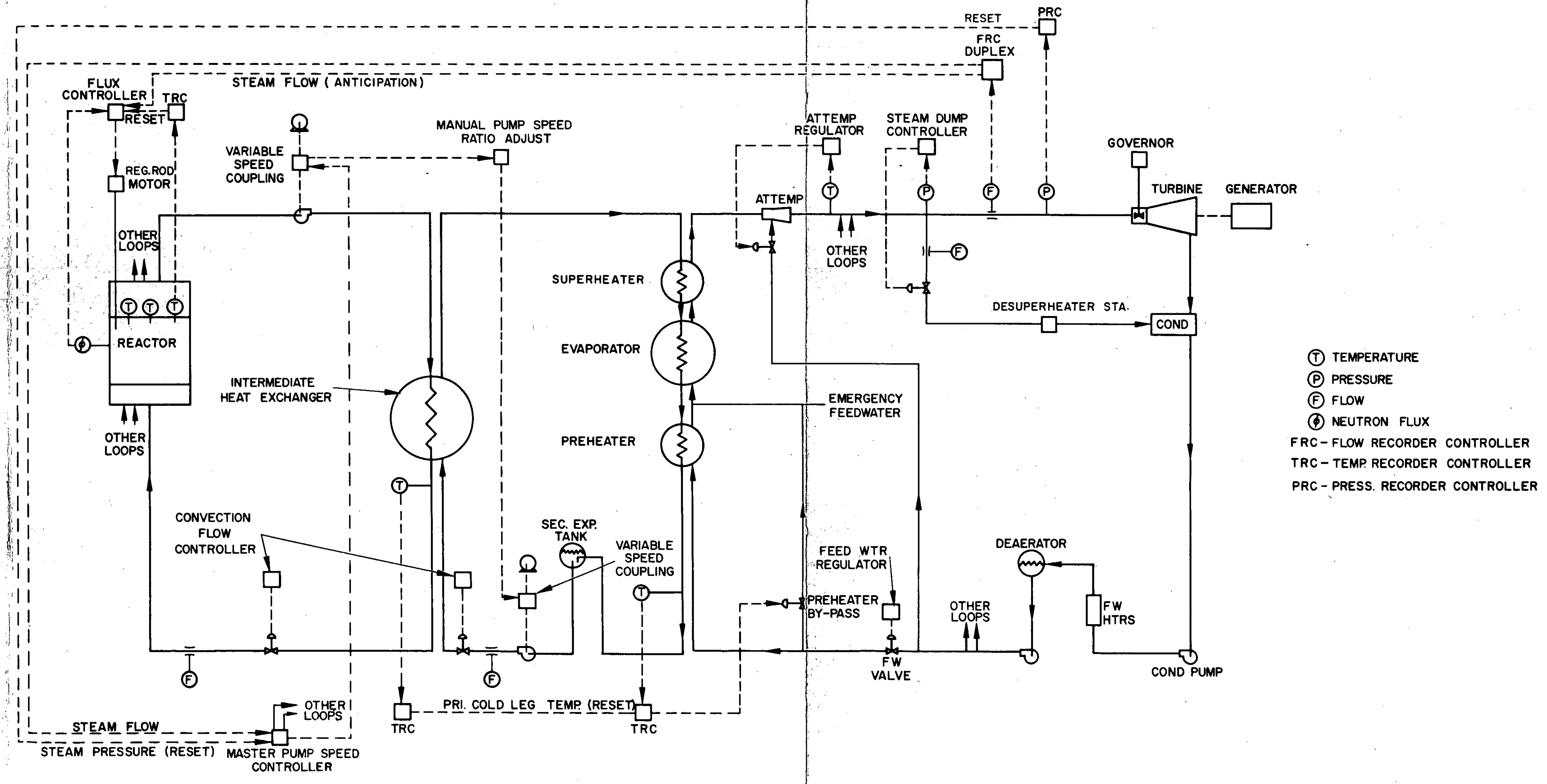
100 MW NUCLEAR POWER PLANT

FLOW DIAGRAM
RADIOACTIVE LIQUID WASTE SYSTEM

PLATE 27

REV. 0

056 - 088



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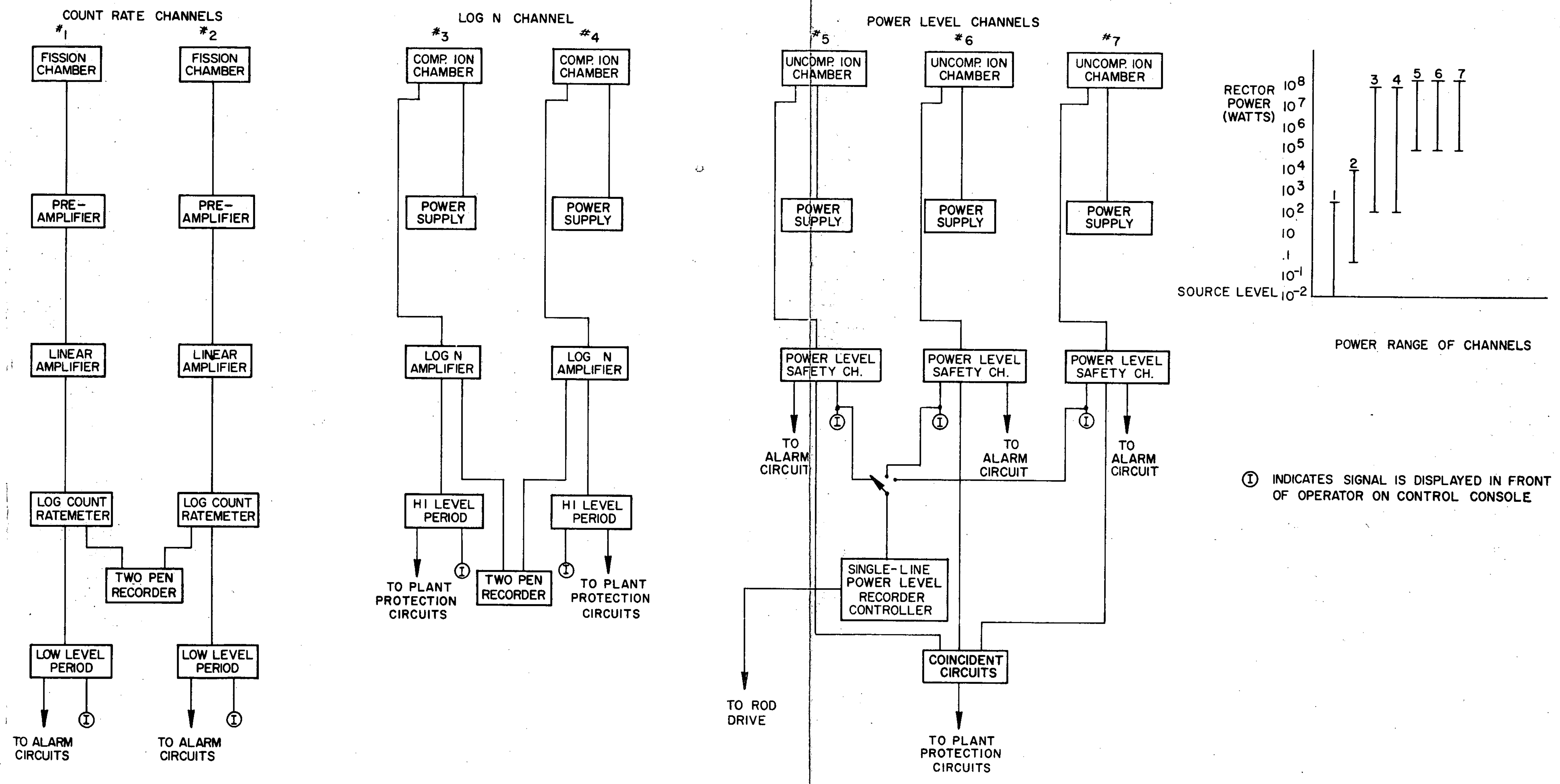
100 MW NUCLEAR POWER PLANT

PLANT CONTROL DIAGRAM

PLATE 28

REV. 0

056 089



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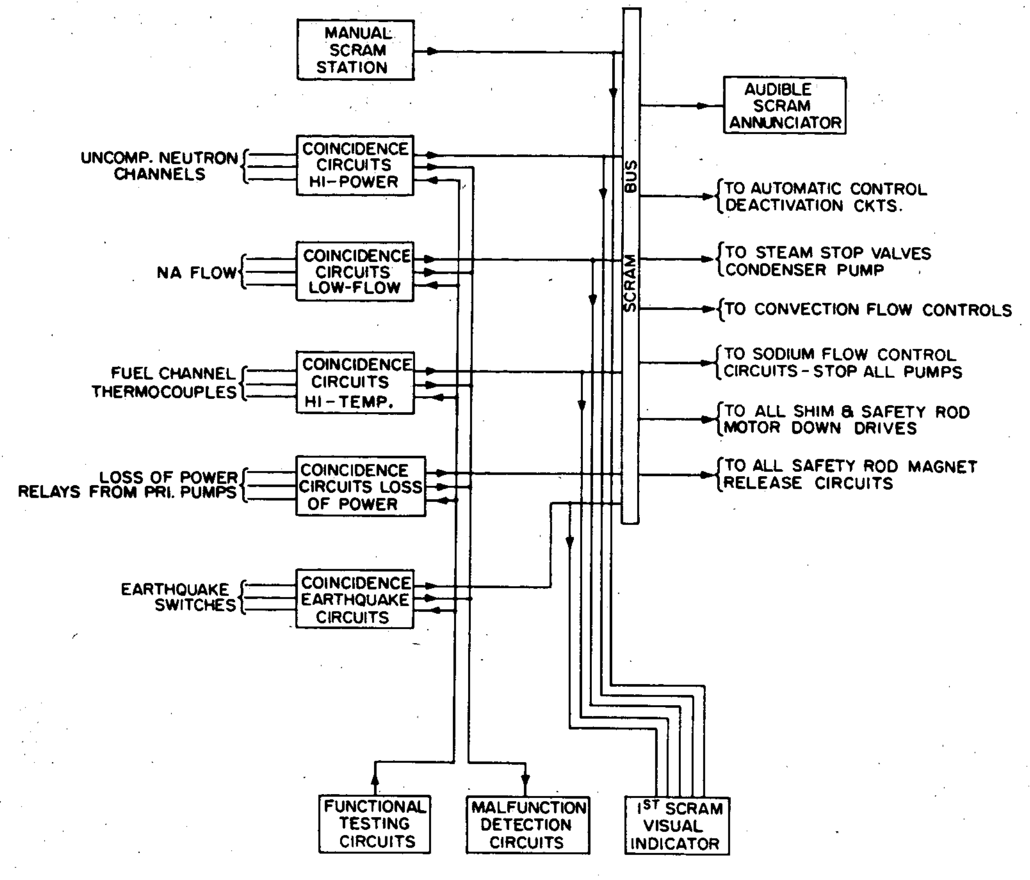
100 MW NUCLEAR POWER PLANT

NUCLEAR INSTRUMENTATION BLOCK DIAGRAM

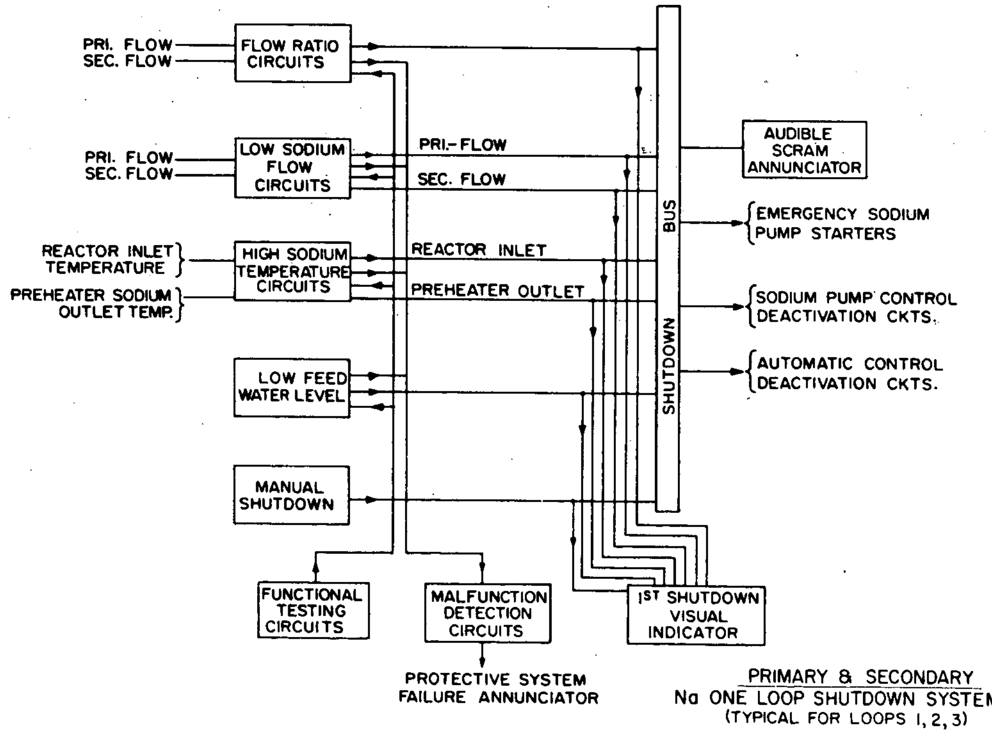
PLATE 29

REV. 0

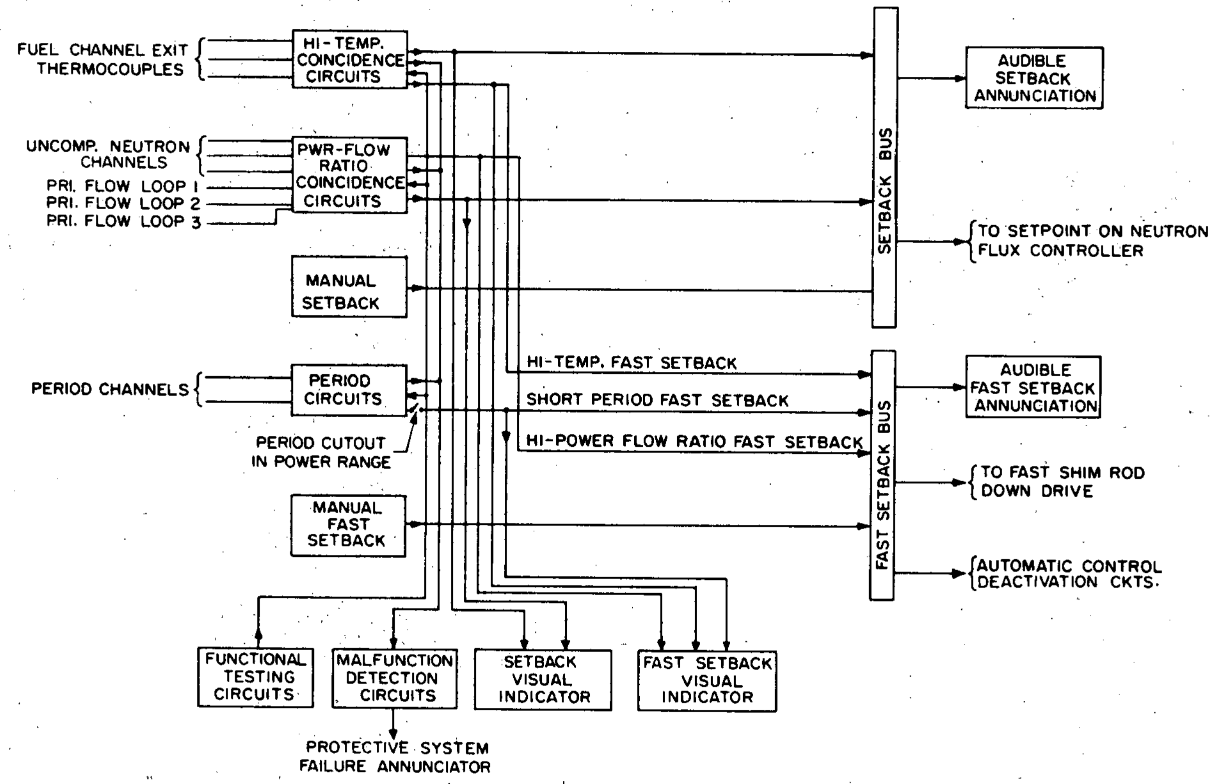
056 - 090



REACTOR SCRAM SYSTEM



PRIMARY & SECONDARY
Na ONE LOOP SHUTDOWN SYSTEM
(TYPICAL FOR LOOPS 1, 2, 3)



REACTOR SETBACK CIRCUITS

1. THE MALFUNCTION DETECTION CIRCUITS WILL INDICATE A DEVIATION FROM NORMALCY OF ANY CHANNEL WHICH SERVES AS AN INPUT TO A COINCIDENCE CIRCUIT.

2. A COINCIDENCE CIRCUIT REQUIRES THAT 2 OUT OF 3 INPUT CHANNELS DEVIATE FROM NORMALCY BEFORE A SETBACK OR SCRAM ACTION IS TAKEN.

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100 MW NUCLEAR POWER PLANT	
PLANT PROTECTIVE SYSTEM	
PLATE 30	REV. 0

056 091

056 - 091