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**PUBLIC SERVICE COMPANY OF COLORADO PLANT
CONCEPTUAL DESIGN REPORT**

Prepared under
Contract AT(04-3)-633
for the
San Francisco Operations Office
U.S. Atomic Energy Commission

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I. INTRODUCTION

The plant will be a self-contained, load following, central station power plant, designed for construction at a generating site of the Public Service Company of Colorado (PSC), in the general vicinity of Denver.

The high-temperature, helium-gas-cooled, graphite-moderated reactor, utilizing a uranium-thorium fuel cycle, will be designed to supply 829 Mw of thermal power for steam generation at 2400 psig and 1000° F with reheat to 1000° F. The steam thus provided will drive an indoor turbine generator capable of delivering 330 Mw of electrical power to the transmission system. Net thermal efficiency of the plant is estimated at about 40%. Electrical power output from the generator will feed a single main power transformer which will step up to the transmission system potential.

In order to take maximum advantage of the potentially high thermal efficiency of the steam cycle of modern steam turbine-generators, high operating steam temperatures have been established as a primary requirement for the HTGR.

Helium gas offers the best combination of physical, chemical, and nuclear properties for high-temperature operation. Since it undergoes no phase changes, transition from ambient to operating conditions presents no discontinuity in physical properties. Pressures and temperatures may be selected independently for economic optimization of the system.

The fuel element design, which utilizes graphite as the material for both moderator and cladding, eliminates the need for neutron-absorbing metal cladding within the core. At the same time, temperature limitations imposed by metal cladding are removed, because the strength of graphite increases with temperature up to about 4500° F.

The extremely high fuel burnup (about 85,000 Mwd/tonne) and long reactivity lifetime anticipated for this reactor make the U^{235} -Th²³²- U^{233} fuel cycle very attractive. The semihomogeneous core, which contains essentially only fuel and moderator, has very little neutron-absorbing material other than fissionable uranium and fertile thorium. Therefore, a high conversion ratio (for this reactor size) is obtained. The conversion of thorium to fissile U^{233} and the ability to fission significant amounts of this material in the reactor is an outstanding characteristic of the HTGR.

I. INTRODUCTION - Continued

In essence, this characteristic permits a substantial portion of the total reactor power to be drawn from the inexpensive thorium.

This report describes the conceptual design of the plant and the information contained herein will be modified and revised as further research and development, and design and engineering work on the plant proceeds.

II. PLANT DESCRIPTION

2.1. DESIGN PARAMETERS

The major design parameters and estimated full load operating conditions of the Public Service plant are summarized below:

General

Reactor type	High-temperature gas-cooled reactor employing uranium-thorium fuel cycle, helium cooling, and graphite moderation.
Number of coolant loops	2
Design output:	
Net electrical output (To main power transformer).	330,000 kw
Reactor thermal power	829,000 kw
Design capacity factor of plant.	80%
Design life of plant	30 years

Reactor Physics

Thermal neutron lifetime for initial core	1.6×10^{-4} sec
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Core parameters:

	Initial Cold, Clean	Initial Hot Operating (without Xe and Sm)
k_{∞}	1.17	1.10
Nonleakage probability	0.95	0.95
k_{eff}	1.11	1.05
Resonance escape probability	0.64	0.60

2.1. DESIGN PARAMETERS - ContinuedReactor Physics - Continued

Neutron flux (initial core), average:

Thermal (< 2.38 ev)	5.0×10^{13} n/cm ² -sec
Fast (> 0.18 Mev)	3.0×10^{13} /cm ² -sec
Total	1.7×10^{14} n/cm ² -sec

Reactivity defect:

Temperature and power	7% Δk
Xe and Sm (at operating temperature)	2.8% Δk
Fuel burnup with burnable poison (at operating temperature)	2.5% Δk
Maximum excess reactivity (at room temperature)	12.3% Δk
Minimum shutdown margin (at room temperature)	3%

Reactor

Number of fuel blocks in core	2964
Number of shim control rods	60
Number of safety control rods	14
Number of control rod drives	37
Effective core diameter	19.5 ft
Fuel block stack height (cold, new)	15.61 ft
Nominal average side reflector thickness	36 in.
Top reflector thickness	47 in.
Bottom reflector thickness	31 in.
Reactor vessel inside diameter (inside liner)	30 ft
Reactor vessel inside height (inside liner)	53 ft

2.1. DESIGN PARAMETERS - ContinuedFuel

Type	Hexagonal blocks containing packed beds of fuel particles
Cold core array pitch	14.212 in. (minor block size differences required for thermal expansion, etc.)
Block length (cold)	15.61 in.
Active fuel block column height	12 blocks

Fuel Cycle

Refueling period	1 yr
Fuel lifetime, 85% capacity factor (fuel design basis only)	6 yr
Annual uranium feed, equilibrium (93.4% enrichment)	237 kg/yr
Annual thorium feed	2660 kg/yr
Conversion ratio	0.61
Average burnup per tonne of U and Th	85,000 Mwd/tonne
Fissions per initial fissile atom	1.2

Primary Coolant System (design conditions)

Total helium flow rate	3.385×10^6 lb/hr
Helium pressure, maximum operating (circulator discharge)	575 psia
Total system pressure drop	10.3 psi
Helium temperature at core inlet	754°F
Helium temperature at core outlet	1427°F
Coolant flow direction through core	Downward
Number of primary loops	2
Helium circulators	Single-stage axial compressor
Helium circulator drives	Steam turbine

2.1. DESIGN PARAMETERS - ContinuedPrimary Coolant System - Continued

Steam generators	Once through
Auxiliary circulators	Single-stage axial compressor
Auxiliary circulator drives	Motor or water turbine

Turbine Plant

Main turbine	Tandem-compound double- flow reheat turbine
Throttle steam pressure	2400 psig
Throttle steam temperature	1000°F
Reheat steam temperature	1000°F
Throttle steam flow rate	2.276×10^6 lb/hr
Nominal design back pressure	2.5 in Hg abs

Over-all Plant Output

Gross generator output	342 Mw
Auxiliary electrical power	12 Mw
Net station output (to main power transformer)	330 Mw
Net station efficiency	39.8%

2.2. PLANT SITE

The plant is to be located on a site of the Public Service Company of Colorado near Denver. A perspective drawing of the plant is shown on Fig. 1.* The site has not been selected at this time.

Cooling towers will be used to cool condenser circulating water. Surface water will be obtained from one or more streams to supply make-up water for the cooling towers. Shallow wells will be used as a backup supply for cooling tower makeup and plant auxiliary water. Potable water will be obtained from deep wells.

Two outside sources of electrical power will be available to the plant. The transmission voltages will be 230 kv and/or 115 kv.

* Figures 1 through 15 appear at the end of this report

2.3. GENERAL ARRANGEMENT

The plant arrangement described herein incorporates features which permit the addition of possible future HTGR units so as to make common use of certain facilities that must be installed as a part of the initial unit.

The installation consists basically of: -

- (1) A reactor building containing:
 - a. Prestressed concrete reactor vessel enclosing the reactor, primary coolant system, and part of the secondary coolant system.
 - b. General operating area.
 - c. Fuel handling and storage facilities.
 - d. Radioactive waste disposal equipment.
- (2) A turbine building containing:
 - a. A tandem compound turbine generator with condensing, feedwater, and other auxiliary systems.
 - b. An area housing the reactor plant ventilation equipment and the controlled personnel access to radioactive areas.
 - c. An area housing the control room and miscellaneous electrical services.
 - d. A general service area which provides space for the machine shop, auxiliary steam systems, and administration.
- (3) A cooling tower

Plans and sections showing equipment areas within the above noted reactor plant structures are shown in the following figures:

<u>Title</u>	<u>Figure No.</u>
<u>Reactor Plant</u>	
Plan at Operating Floor	3
Plan Below Operating Floor	4
Elevation	5

2.3. GENERAL ARRANGEMENT - Continued

Areas not requiring radiological control of access are entered through the general service structure adjacent to the main turbine building. Areas requiring radiological control of access are entered through the monitoring station located in the access-control area. Personnel decontamination rooms and clean clothing storage are also provided in this latter area. Other facilities located in the access-control area adjacent to the reactor building include a health physics and first-aid station, and locker room facilities.

The prestressed concrete reactor vessel is located at one end of the reactor building. Service facilities and auxiliary systems that are associated with the reactor plant are located in the reactor building. Positioned under the operating floor level in the reactor building are the fuel storage area, storage facilities for various pieces of equipment, the loading port for the fuel shipping cask, a hot service facility for servicing equipment that could become contaminated, and a decontamination facility.

The radioactive gas waste and radioactive liquid waste systems are located in the reactor building. These systems are designed to accept all effluents from the plant that could be contaminated. The gas waste system includes surge tanks to collect radioactive gaseous effluents for analysis and identification of radio-isotopes prior to controlled release through filters to the plant stack. The liquid waste system provides for processing radioactive aqueous wastes by evaporation and/or demineralization as required to enable disposal of the effluent water to the surrounding area.

The location of a number of the reactor auxiliary systems facilitates their use in common with a second reactor unit. These common facilities will be sized for a first unit only, but they will also be capable of servicing a second reactor unit. In a two-unit plant, the two prestressed concrete reactor vessels would be located under opposite ends of a single extended reactor building so as to allow a single set of fuel handling equipment to service both reactors. The following reactor plant equipment and facilities would also be shared by the two units: overhead crane, auxiliary equipment, the hot service facility, the decontamination system, the fuel shipping area, the radiochemistry laboratory, miscellaneous personnel facilities, and some components of the radioactive waste systems.

2.4. STRUCTURES

2.4.1. REACTOR BUILDING

General

The reactor building will be designed as a controlled leakage structure with a slightly negative internal pressure maintained by operation of the reactor plant ventilation system. Building design features will include: (1) restricted leakage construction with conventional building materials through the use of appropriate construction joints and seals, and (2) the elimination of essentially all windows and louvers.

Leakage collected by the reactor building from all systems in the reactor building will be released via the stack after being processed by the reactor plant ventilation system and associated activity monitors.

Architectural

1. Enclosure Walls

The exterior superstructure of the reactor building will be enclosed with insulated metal panels composed of a colored, fluted exterior sheet, fiberglass insulation, and a colored interior sheet.

2. Roof

The roof system of the reactor building will consist of galvanized steel decking, on top of which will be insulation and built-up gravel surfaced roofing.

Overhead Crane

Capacity

~200 tons

2.4.2. TURBINE BUILDING

General

The turbine building will have reinforced concrete foundations and structural steel framing. Usual construction methods will be used. Necessary administrative and service areas will be provided. A room will be provided to enclose the turbine oil reservoir and purification system.

Architectural

1. Enclosure Walls

The exterior superstructure of the turbine building will be enclosed with insulated metal panels composed of a colored, fluted exterior sheet, fiberglass insulation, and a colored interior sheet.

2. Interior Partitions

Interior partitions will consist of concrete block, surfaced concrete block, steel panels, or combinations of the above.

3. Room Finish

An appropriate room finish will be provided for the administrative and service areas. Quarry tile will be used on the turbine room operating floor. In all other areas of the turbine building, exposed floor, wall, and ceiling construction will be provided.

4. Roof

The roof system of the turbine building will consist of galvanized steel decking, on top of which will be insulation and built-up gravel surfaced roofing.

5. Doors and Windows

- a. Doors will be provided in the turbine building as necessary for noise, dust, and security control.
- b. Doors will be flush metal industrial type with heavy-duty industrial-type hardware.
- c. Windows including hardware will be of the industrial type.

2.4.2. TURBINE BUILDING - Continued

Overhead Crane

Capacity

~ 65 tons

Elevator

An elevator which will be arranged to serve both the turbine building and the reactor building will be provided.

Heating and Ventilation

1. Turbine Building Service Area

Perimeter rooms will be supplied with steam-heated, finned-tube, cabinet-type convectors with automatic individual room control. An overhead duct system will supply year-round conditioned air to the administration areas, locker room, and shower room from a central air conditioner. The unit will incorporate both heating and cooling coils and will provide outside air for proper ventilation.

Heating and ventilation will be provided for other areas in the turbine building.

2. Control Room

An overhead duct system will supply year-round conditioned air from a central air conditioner. The unit will incorporate both heating and cooling coils and will provide outside air for proper ventilation.

3. Other Turbine Building Areas

Heating will be supplied by steam-type unit heaters. The heaters will be capable of maintaining 70°F with minus 20°F outdoors. Roof exhaust fans will supply ventilation air by pulling air in through windows and doors. Sufficient cooling capacity will be provided to maintain an average temperature of 105°F with ambient outdoor conditions of 95°F.

2.5 SYSTEM DESCRIPTIONS

2.5.1. REACTOR VESSEL AND INTERNAL COMPONENTS

System Description

The prestressed concrete reactor vessel (PCR V) will contain the entire primary coolant (helium) loop of the nuclear steam supply system and part of the secondary coolant (steam) loop (see Fig. 6). The major components of the primary coolant loop are (1) the reactor core, (2) the steam generators, (3) the main helium circulators, and (4) the auxiliary circulators.

The PCR V consists of a concrete structure with embedded reinforcing steel and a system of prestressed steel tendons plus the liner and liner cooling system, the liner thermal barrier, and the PCR V penetrations, penetration cooling system, and closures. The reactor is supported within the PCR V. The main helium circulators and the auxiliary circulators, the control rod drives, and the helium purification system components are supported within their respective penetrations.

Cool helium from the circulator discharge flows upward in the generally annular space between the core barrel and the inside surface of the PCR V liner thermal barrier, is heated in downflow through the core, and is distributed to the steam generators where heat is transferred to the secondary coolant; the cool helium then flows to the circulator inlets.

Prestressed Concrete Reactor Vessel

The internal shape of the PCR V is that of a right circular cylinder with a flat top and bottom joined to the cylinder with transition geometry as required for structural strength.

The PCR V (see Fig. 7) will be designed in accordance with the following data and performance requirements:

1. Internal dimensions (inside liner). . 30 ft ID x 53 ft high
2. External dimensions 47 ft across hexagonal flats x 85 ft high
3. Maximum normal working pressure 575 psia

2.5.1. REACTOR VESSEL AND INTERNAL COMPONENTS - ContinuedPrestressed Concrete Reactor Vessel - Continued

4. Maximum concrete temperature 150°F
5. Nominal design temperature difference
across PCRV wall and heads 50°F
6. Nominal effective fast-neutron
(>1 Mev) exposure 2×10^{18} nvt
7. Minimum hypothetical failure pressure 2.5 x maximum
normal working pressure.

Type of prestressing system

Circumferential	Post-tensioned tendons
Vertical and heads	Post-tensioned tendons

Location of steam generators

Under the core

Location of dust collection system

Lower section of PCRV

Location of helium purification units

PCRV top head

PCRV Liner and Liner Cooling System

The PCRV will have a steel liner that acts as a membrane to prevent the escape of coolant gas and fission products from the vessel. The liner functions to prevent leakage under all conditions short of ultimate failure of the PCRV.

The liner will be of welded construction and will be composed mainly of 3/4-in. plate. It will be attached to the PCRV by shear and tension anchors in the concrete. The anchors will be designed to prevent liner buckling. The liner will be securely attached and sealed to all PCRV penetration linings so as to present an uninterrupted barrier against gas leakage from the vessel.

A thermal barrier will be applied to the inside of the liner, and cooling water pipes will be attached to the outside, embedded in the concrete of the PCRV. The cooling pipes function to maintain the temperature of the liner and the concrete at a safe level at about 150°F.

2.5.1. REACTOR VESSEL AND INTERNAL COMPONENTS - Continued

PCRVR Liner and Liner Cooling System - Continued

Liner cooling water pressure.	100 psig nominal
Cooling water design inlet temperature	95°F
Cooling water design outlet temperature	105°F
Nominal heat flux into liner.	900 Btu/hr-ft ²
Nominal effective fast-neutron (>1 Mev) exposure to liner	2×10^{18} nvt

PCRVR Penetrations

The PCRVR penetrations will be tubular steel components anchored in the concrete structure and welded to the PCRVR liner at the inner end. The designs of all penetrations of significant size will incorporate means for limiting to a safe value the rate of escape of primary coolant which might result from credible failure of a penetration or its closure.

All penetration closures will be designed to be essentially leak-tight at the designed PCRVR ultimate failure pressure. To achieve this leaktight condition, the stress levels in the penetration closures at the ultimate failure pressure will be generally below the short-term yield stress of the penetration materials of construction.

The PCRVR penetrations consist of 37 19-in. ID Control Rod Drive/Refueling Nozzles on a 37.6-in. triangular pitch, plus openings for the steam generators, helium circulators, auxiliary circulators, dust separator, and helium purification system. There will be a number of instrument nozzles.

Thermal Barrier

The PCRVR liner will be protected from helium at reactor inlet temperature by a metallic thermal barrier mounted on the interior surface of the liner. The thermal barrier, acting in conjunction with the cooling coils on the outside of the liner, will maintain the concrete temperature at or below 150°F.

2.5.1. REACTOR VESSEL AND INTERNAL COMPONENTS - Continued

Thermal Barrier - Continued

The thermal barrier will be of sandwich-type construction, consisting of alternate layers of steel sheet and stagnant helium with suitable spacers. It will be attached to the PCRV liner by welding studs.

Nominal average heat flux 900 Btu/hr-ft²

Hot face gas temperature 754°F

Average liner temperature 130°F

PCRV Internal Structure

The reactor core and reflector assembly will be supported and laterally restrained inside the PCRV by a composite structure, in which all the main parts, at core inlet temperature, will be of carbon or low-alloy steel. These parts of the structure will be largely nonremovable.

Directly underneath the core and reflector will be a supporting structure constructed from graphite blocks. The coolant leaving the core will flow through this structure to the steam generators directly underneath. This graphite structure will be removable, using special tools.

The metal structural components directly below the graphite core support structure will also be generally removable from the PCRV using special equipment.

Radiation shielding, and ceramic and metallic insulation will be incorporated where required to protect the metal structural components.

The PCRV internal structure will be designed to withstand seismic forces, and particularly to ensure that the reactor can be shut down, if required, under seismic conditions.

The whole system will accommodate the dimensional changes produced by radiation and heat.

2.5.2. CONTROL RODS AND DRIVES

General

The reactor will be controlled by the selective movement of a number of control-rods, each pair of control rods being operated by a control-rod drive. Two types of drives will be provided--shim rod drives and safety rod drives. Any one of the shim rod drives may be selected for automatic control of reactor power. The control-rods move vertically within guide holes that extend through the reactor core, and in guide tubes that extend through the inlet plenum above the core into the nozzles atop the reactor vessel. A control-rod drive, two control rods, two guide tubes, and an integral shield plug constitute an assembly which is removable from the reactor as a unit (see Fig. 8).

Control-rod drive

The control-rod drives are winch-type devices, each of which raises and lowers two control rods simultaneously by winding or unwinding cables from two counterrotating drums (see Fig. 9).

The shim-rod and safety-rod drives are similar, except that the former do not contain scram retarder devices. The upper drive mechanism assembly contains all components most likely to require servicing, and may be unbolted and removed from the drive housing for that purpose. Shielding and seals permit this operation to be performed safely when the reactor is depressurized.

The drive motor is a three-phase induction motor fitted with an electromagnetically applied, spring-released brake. The brake is released whenever the motor is energized, and also upon reactor scram.

The safety rod drive motor is coupled to the cable drum drive shaft through an electromagnetic, gravity-released (spring assisted) scram clutch. A scram velocity retarder device is coupled to the drive shaft through an overrunning clutch. In the case of the regulating rod drives, the scram clutch and the retarder are replaced by a direct coupling, scram velocity being controlled by capacitive self-excitation of the drive motor.

The cable drums are of the "pancake" type, in which the cable is spirally wound on the drums in a narrow groove. Below each drum is a guide pulley and rocker arm assembly designed so that its position indicates, by means of limit switches, when the control rod is fully inserted or fully withdrawn, or whether the cable has become slack. The cable drum and rocker arm assembly is bolted to the underside of the cylindrical shield separating the upper and lower mechanisms.

Electrical and purge gas connections are made to the control-rod drive through sealed connectors near the top of the drive nozzle.

2.5.2. CONTROL RODS AND DRIVES - Continued

Guide Tubes

The guide tubes are spring loaded downward against the top reflector blocks in the reactor core. The springs maintain engagement of the guide tubes and reflector blocks under relative vertical movement caused by thermal expansion.

Drive Operation

During normal operation, the control rods are moved out of or into the core by rotation of the drums driven by the motor.

When the control rods are at the fully inserted position, the rocker arms are rotated to a position in which the "rod in" limit switches are actuated. If a cable goes slack, the rocker arm is rotated to a position in which the "slack cable" switch is actuated. If cable slack occurs as a result of a control rod sticking during insertion, reversal of the drive by the operator will cause the switch to open again, thus differentiating between a stuck rod and any other slack cable condition.

Rod position indication is obtained from an electrical position transmitter coupled to the main drive shaft. The transmitter is connected to a position readout in the control room.

When the reactor is scrammed by a signal from the plant protective system or the operator, the magnetic scram clutches in the safety rod drives are deenergized, disconnecting the drum and scram retarder systems from the drive motors. The safety control rods drop into the core by the action of gravity, rotating the drums and retarders. The scram retarder limits the rod drop velocity so that the rods are stopped at the bottom position with a reasonable decelerating force.

Control Rods

The control rod is a cylinder approximately 3 in. in diameter and approximately 20 ft long, and consists of a number of cylindrical neutron absorber segments. The absorbers are made from boron carbide-filled graphite containing about 30 wt-% boron.

2.5.2. CONTROL RODS AND DRIVES - Continued

Drive Cooling

The control-rod drives are remotely located from the reactor core in the cool top nozzle regions of the reactor vessel, so that no auxiliary cooling is required. The nozzles are within the biological shielding and are cooled by the prestressed concrete reactor vessel liner cooling system. This results in the drive temperature being held at a safe level. Intervening thermal and radiation shields within the nozzle, between the drive mechanism and the reactor chamber, prevent flow of excessive heat to the drive.

Emergency Shutdown System

An emergency shutdown system that will release absorber material into the core and shut down the reactor will be provided. This system will be controlled by the reactor operator.

2.5.3. FUEL HANDLING

Fuel Handling Process

The refueling process is started after a period for reactor cooling-off, coolant cleanup, and depressurizing. Core inlet helium pressure is slightly below atmospheric and the temperature about 250°F during refueling. Each of the 37 nozzles on the pressure vessel is utilized for refueling operations. Based on a six-year refueling cycle, six nozzles are opened for refueling in an average year. Refueling is by core region. The standard region contains 84 fuel blocks, 35 reflector blocks, and 1 pair of control rods. Handling, removal, and insertion operations for an individual region are all performed through one nozzle.

The spent fuel blocks are removed to the fuel storage facility for a nominal decay period of three months before spent fuel shipping commences.

Before actual refueling operations begin, the blind flange on a selected nozzle is removed. The control-rod drive thus exposed with its two rods is then removed from its nozzle, utilizing a reactor isolation valve and an auxiliary transfer cask. The drive is transferred to a storage well in the reactor building, or the drive may be transferred to the hot service facility for service.

After a reactor isolation valve has been mounted on a nozzle and the control-rod drive removed with the auxiliary transfer cask, the fuel transfer machine is installed over the nozzle with the lower end sealing against the isolation valve.

The actual refueling operations consist of removing the top reflector blocks and all the fuel blocks in the region serviced by the opened refueling nozzle, and stacking these in the magazine of the fuel transfer machine, which has been placed on the isolation valve by the reactor building crane.

To inspect fuel blocks in position, as well as for possible salvage operations, a reactor viewing device is provided. This device is inserted in one of the refueling nozzles using the auxiliary cask and reactor isolation valve. The viewing device is also designed for use in conducting various inspections inside the reactor vessel.

2.5.3. FUEL HANDLING - Continued

Fuel Handling Process - Continued

The isolation valve and transfer machine valves are opened and the transfer machine pickup head is lowered into the reactor where the pickup probe engages the center reflector block of a region by means of its central stepped hole. The block is then raised into the magazine of the machine and deposited in the magazine. Reflector blocks and fuel blocks are removed progressively in layers of seven (for a full region) until the machine is full. The valves are closed, and the transfer machine is moved by the reactor building crane to a similar valve at the fuel storage facility. The spent fuel in the transfer machine magazine is emptied into the storage facility using the same motions as were used for loading, and new fuel blocks are then picked up from the same place.

Electrical interlocks are provided to assure safe and proper sequencing of operations, and to prevent damage to components. Protective relaying prevents operation under abnormal electric power conditions.

Fuel Handling Equipment

The fuel transfer machine (see Fig. 10) will be designed to handle and store fuel and reflector blocks and provide adequate shielding to protect the operating personnel. The shielding will consist of iron or lead surrounding the fuel blocks and will be designed to reduce radiation to levels compatible with all applicable federal regulations.

Basically, the transfer machine consists of a shielded storage magazine, a telescoping boom, and a pickup head assembly mounted on the end of an extendable arm.

At the lower end, the fuel transfer machine is equipped with a slide type shield door to cover the bottom opening, to protect operating personnel, and to prevent escape of activated or contaminated matter.

When the fuel transfer machine is located over a nozzle for refueling operations, it establishes a seal with the isolation valve. A shielding skirt on the fuel transfer machine rests against a mating machined surface on the valve.

The fuel transfer machine will incorporate a cooling system designed to remove heat from the helium surrounding the fuel blocks. Two cooling units, each capable of handling the maximum design heat load of the fuel blocks, will be provided.

2.5.3. FUEL HANDLING - Continued

Fuel Handling Equipment - Continued

Interlocks will be provided throughout to prevent improper operation of the machine.

A reactor isolation valve provides a gas-tight closure on the reactor nozzle during refueling operations. The valve is a gate-type valve with a shielded body and a motor-driven shielded gate. Two identical reactor isolation valves are provided.

Attached to the bottom of the reactor isolation valve is a spring-loaded bellows, which effects a gas-tight connection to the top flange of the refueling nozzle.

Fuel Handling Purge System

A fuel handling purge system will be provided to prevent the release of activity to the reactor building atmosphere during refueling, when it is necessary to perform frequent purging operations on transfer casks used to transport fuel blocks and control-rod drive assemblies. The system will be designed to enable transfer of these items between the reactor vessel, the fuel storage facility, and the fuel shipping area without introducing excessive quantities of foreign gases into the reactor vessel or storage facility and without the release of radioactivity to the atmosphere.

The system consists of a vacuum pump, piping, control valves, instrumentation, and control panels. Pressure and radiation indicating instruments as well as control valve operating switches located on the control panel provide the operator with direct and continuous indication of the purge parameters and allow remote control of valve operation, thus minimizing the time required to perform the numerous purging operations.

A vacuum pump is connected by suitable piping to the reactor refueling area, the fuel storage area, and the shipping cask area vacuum headers. The pump is capable of continuous or intermittent operation.

Flexible hoses with quick-disconnect couplings are provided at the vacuum headers in each of the three purging areas. Mating couplings are provided on the equipment to be purged. Automatic shutoff valves in both parts of the coupling seal the equipment purge connection and flexible hose connection upon separation of the coupling.

2.5.3. FUEL HANDLING - ContinuedFuel Handling Purge System - Continued

Flexible hoses with quick-disconnect couplings are similarly installed on a purge helium supply header for attachment to gas-fill connections on all items to be purged. Helium supply pressure in the purge header is nominally controlled at 3 psig.

2.5.4. FUEL STORAGE

For Fuel Storage, the following equipment will be provided:

Fuel storage wells

Fuel storage isolation valve

Storage for new and spent fuel will be provided in tubular wells designed for a total nominal 1/3-core capacity plus some spares.

Storage of spent fuel will be in a dry uncanned condition at essentially atmospheric pressure. The wells will be charged with inert gas. Safety considerations involve adequate shielding and sealing of all joints, penetrations, and openings.

Spent fuel blocks will be stored for a minimum decay period of 90 days before shipment to a reprocessing plant. During this period the activity decays to levels low enough to permit shipping without resorting to complicated cooling apparatus or other provisions on the shipping casks.

Outward leakage from the wells will be guarded against by two means: first, through sealing of the access plugs to each well, and second, through a control system limiting the pressure to atmospheric or slightly below. An exhaust line will be tied in to discharge excess gas from each well into the radioactive gas waste system and thence to the stack.

Access to each well will be through an opening normally sealed and shielded by a removable plug. For access, a removable isolation valve will be provided for use in conjunction with the auxiliary transfer cask for removing the shield plug. The valve will be designed for safe sealing to the well access opening and to the fuel transfer machine. The valve will provide adequate shielding over a full storage well when closed.

2.5.5. FUEL SHIPPING

Equipment for shipment of irradiated fuel will be designed to meet all applicable federal, state, and local codes.

Fuel blocks will be shipped in a dry uncanned condition. Shipment will be by rail. Cooling will be by natural convection and radiation.

The capacity of the cask has as yet not been determined.

2.5.6. AUXILIARY EQUIPMENT

Reactor Viewing Device

An articulated reactor viewing device with a lighting system will be provided for use during shutdown for direct observation of the reactor interior. The device will fit into any one of the refueling nozzles after the control-rod drive has been removed. When installed, it will make a gas-tight closure and provide radiation shielding. Provisions may also be made to insert special grappling and manipulating tools, as may be required, alongside the viewing device.

Auxiliary Transfer Cask

An auxiliary transfer cask (see Fig. 11) will be provided to remove and insert control-rod drives from and into the reactor, with consideration given to safety, sealing, shielding, and cooling of the cask contents. The cask will be designed to contain and transport control-rod drives, the reactor viewing device, as well as other items that later may be determined serviceable by this cask. When in position over either isolation valve it will form a gas-tight containment; it will also provide sufficient radiation shielding from control-rod drives or other items to limit the exposure rate to operating personnel to safe levels.

For mobility, the cask will be moved by the building crane.

A two-speed electric hoist is mounted within the top section of the cask. The hoist is equipped with a solenoid-actuated grapple that matches a lifting adapter on each piece of equipment to be handled by the cask. The grapple is equipped with limit switches serving as interlocks to prevent engaging the pickup latches unless the grapple is properly seated in the lifting adapter and will prevent disengaging the pickup latches unless the grapple has deposited its load. Other limit switches built into the hoist provide interlocks to limit the up travel of the grapple and to limit the high-speed up and down travel of the hoist to positions beyond approximately one foot of the equipment being in the seated position. A load cell acts as an interlock to prevent raising if a load considerably in excess of the equipment weight is sensed. A cable slack sensing device serves as another interlock to stop lowering if the hoist cables become slack as a result of equipment being hung up during lowering. Readouts give continuous indication, on the control panel, of the grapple position.

The cask is equipped with a shield gate that covers the bottom opening to protect personnel from excessive radiation from used control-rod drives that are being transferred to storage. The gate is motor actuated and is equipped with travel stop limit switches, which also function

2.5.6. AUXILIARY EQUIPMENT - Continued

Auxiliary Transfer Cask - Continued

as interlocks to prevent lowering of the hoist unless the gate is open or to prevent raising the skirt unless the gate is closed.

Storage Facilities

Storage tubes and stands will be provided for storing control rods and drive assemblies as necessary during refueling and for storage of isolation valves when not in use.

Hot Service Facility

A hot service facility (see Fig. 12) will be provided in the reactor building. This facility will be designed to enable service, repair, and decontamination work to be performed on control-rod drives, helium circulators, and the fuel transfer machine when they are too active to handle without the protection of shielding. The facility will be provided with adequate shielding, seals, decontamination facilities, a ventilation and filter system, and various remotely operated tools and manipulators.

The hot service facility contains two work areas, one for relatively short items such as helium circulators, the other for longer items such as the control-rod drives and the fuel transfer machine. The first area is serviced by a remotely operated manipulator for disassembly and handling of components. The second area is serviced by an elevator which straddles the longer components. Remotely controlled decontamination sprays can be directed on any part of the components by spray nozzles attached to the elevator. A small pool is provided in the short area for decontamination of smaller parts if needed.

A two-ton overhead crane is provided in the facility for internal handling of components. The facility is designed with integral shielding limiting any exposure rate to operating personnel to a safe level.

Manipulators and Tools

Manipulators and tools will be provided for nonroutine handling operations within the reactor. The tools will be basically long-reach tools, designed to retrieve, for example, pieces of broken fuel blocks. They will be capable of retrieving smaller objects that may have fallen onto the bottom reflector. In these salvage operations, the visual aid provided by the reactor viewing device will be utilized.

2.5.7. REFLECTOR AND CORE ARRANGEMENT

The reactor core will be surrounded on all sides by a graphite reflector of sufficient thickness to limit neutron leakage, to provide adequate power shaping, and to limit neutron exposure of the internal structures and PCRV liner. The exact composition of the reflectors will be based on the results of nuclear and irradiation studies.

The reflector consists of the top, bottom, and side reflectors. The reflectors will be constructed of nuclear grade graphite blocks, of size and shape similar to the fuel blocks. The inner row of side reflector blocks and all top and bottom reflector blocks will be removable, using the fuel transfer machine.

The top and bottom reflector blocks will incorporate a pattern of holes for the flow of coolant that passes through them. The basic hexagonal prism form of the core and reflector blocks will be modified by the inclusion of locating devices such as keys and dowels to ensure that the core structure is properly positioned and restrained. The locating arrangements will take full account of the dimensional changes that occur due to heat and radiation.

2.5.8. PRIMARY COOLANT SYSTEM

The function of the primary coolant system is to transfer heat from the reactor core to the secondary coolant while maintaining acceptable core and metal temperatures. The system will consist of two parallel coolant loops each comprising a steam generator, a helium circulator, an auxiliary circulator, and interconnecting ducting, all contained within the prestressed concrete reactor vessel. The total coolant flow is approximately 3,385,000 lb/hr, each loop being designed for one-half of this flow. The primary coolant system operates at a pressure of 575 psia at the circulator discharge at full load. Helium enters the reactor core at 754°F and leaves at a mixed mean temperature of 1427°F.

The primary coolant fluid is essentially pure, dry helium gas. Control of fission products and chemical impurity concentrations in the circulating helium is accomplished by withdrawing a side stream of approximately 750 lb/hr of helium for processing by the helium purification system. Purified helium from the purification system is returned to the primary coolant system principally as a buffer gas for purging the control-rod drives and the helium circulator seals.

Helium Circulators

Circulation of the coolant through each of the loops will be accomplished by a single-stage axial flow compressor driven by a steam turbine, integrally mounted in a PCRV circulator penetration (see Fig. 13). The steam turbine drives will be in series with the main steam turbine, cold reheat steam being the driving fluid for the turbines.

The circulator will be oriented vertically, with the compressor and turbine sections overhung from a central bearing and seal section. Water, water vapor, and helium will be separated and contained by a system incorporating buffer gas leaking through gas labyrinth seals and controlled leakage lubricant seals. The design of the circulator will be such that the first critical speed occurs above the normal operating speed range.

Necessary auxiliary equipment associated with the circulator seals and bearings, such as tanks and valves, will be provided and will be located in the reactor building as close as is practical to the circulator PCRV penetrations. Bearings will be water lubricated.

2.5.8. PRIMARY COOLANT SYSTEM - Continued

Helium Circulators - Continued

A shutdown seal will be provided for each circulator. The seal will be actuated by a decrease of lubricant pressure when the circulator is stopped. Once the seal is actuated, the water lubricant flow and the buffer helium flow are no longer required for sealing; however, buffer helium will be required for purging.

Each circulator will be provided with speed control over the normal operating range and with overspeed protection. A helium stop valve, which may be an integral part of the circulator assembly, will also be provided.

Auxiliary Circulators

Auxiliary circulators will be provided to ensure adequate cooling of the reactor in the event that both of the main circulators are inoperative. The auxiliary circulators will provide sufficient flow to limit the peak reactor coolant temperature to an acceptable value and perform subsequent plant cooldown. Each auxiliary circulator will be provided with a helium stop valve.

Helium Circulator Removal Cask

A special cask will be provided for removal of main or auxiliary circulators. Circulator removal will be carried out only during plant shutdown and after depressurization of the primary coolant system. The cask will contain shielding designed to enable safe removal of a circulator.

Dust Separator

A mechanical dust separator, located in the PCRV, will be provided. The unit will operate on a bypass flow of the primary coolant. Essentially all collected dust will be stored in a container at atmospheric pressure. Design conditions will be:

Flow, percent of primary coolant flow	0.5
Separation efficiency (Particles greater than 5μ)	99.5%
Dust storage capacity, ft ³	Not yet determined

2.5.8. PRIMARY COOLANT SYSTEM - Continued

Moisture Monitoring System

The moisture monitoring system will provide measurement and indication of the concentration of moisture, carbon monoxide, carbon dioxide, and nitrogen in the primary coolant system helium. When the total concentration of water, carbon monoxide, and carbon dioxide exceeds a preset level, the reactor will be shut down manually.

When the moisture content reaches a higher preset level, a signal to the plant protective system will scram the reactor automatically. At a level higher than the reactor scram level, signals to the plant protective system will result, in addition to reactor scram, in the identification, isolation, and dumping of the water and steam from the failed steam generator loop.

Alarms will also be provided to warn the operators of impending safety actions.

2.5.9. SECONDARY COOLANT SYSTEM

The secondary coolant system will accept feedwater from the feed-water heaters in the turbine plant, distribute it to the steam generators and convey superheated steam to the main steam header. The system will also carry partly expanded steam from the cold reheat header to the main helium circulator drive turbines, then to the reheater sections of the steam generators, and finally to the hot reheat header.

1. Steam Generators (see Fig. 14):

a. Type	Once through
b. Number	2 (1 per loop)
c. Configuration	Eight modular units per steam generator. (It has not been established as to whether the modular units will be identical or whether some of the units will have a reheater and some of the units will have a superheater)
d. Location	Below the core
e. Design conditions:	
Superheater outlet pressure	2514 psia
Superheater outlet temperature	1005°F
Throttle steam flow rate	2.276×10^6 lb/hr
Reheater outlet pressure	600 psia
Reheater inlet enthalpy	1331 Btu/lb
Reheater outlet temperature	1002°F
Reheat steam flow rate	2.222×10^6 lb/hr
Economizer inlet enthalpy	390 Btu/lb
f. Header type	Not yet determined
g. Removability	Through main helium circulator penetrations.

2.5.9. SECONDARY COOLANT SYSTEM - Continued

2. Steam/Water Dump System

A steam/water dump system will be provided for each steam generator. If excessive moisture is detected in one of the primary coolant loops, the plant protective system will scram the reactor, shut down the defective steam generator, and empty the steam/water contents of the economizer-evaporator-superheater sections into a dump tank, thereby lowering the steam pressure and limiting the quantity of moisture that can leak into the primary coolant system. The system will consist of multiple dump valves of conventional type at the economizer inlets. All of the steam generator modular units in the affected loop will be dumped upon signal indicating tube failure. Maximum time to empty steam generators after sensing tube failure has not yet been determined.

3. Steam Generator Tube Plugging

If a steam generator tube should develop a leak, the tube will be taken out of service by plugging both ends. If directly accessible headers are not provided, one or two tube plugging machines will be provided for this purpose. The machine(s) will provide means for locating a defective tube, plugging the ends, and testing the leak tightness of the repair. Servicing will be performed with the plant shut down and depressurized.

2.5.10. HELIUM PURIFICATION SYSTEM

The helium purification system provides for the removal of gaseous activity and chemical impurities from the primary coolant system by purifying a side stream. Fission-produced gaseous isotopes, both radioactive and nonradioactive, are released from the fuel blocks. Trace amounts of tritium activity are produced by the fission process and by neutron bombardment of helium. Chemical impurities arise from the fission process, from water or steam inleakage to the primary coolant system, from outgassing of reactor and primary coolant system components and from contaminants initially present in the reactor plant. Additional chemical impurities may be introduced as a result of refueling and maintenance operations.

Fission-produced gaseous isotopes, other than the noble gases (krypton and xenon) and tritium, will be removed in a high-temperature filter/adsorber. A dryer will remove water and carbon dioxide. Krypton and xenon isotopes and chemical impurities such as carbon monoxide, hydrogen and nitrogen will be removed by a low-temperature (cryogenic) adsorber. Normally, all chemical impurities except hydrogen will be completely removed from the side stream. The hydrogen content will be reduced only to a fraction of its inlet concentration because of a practical limitation on the size of the low-temperature adsorber. The system will be designed to limit the carbon monoxide concentration in the primary coolant system to less than 10 ppm during normal operation. Except for trace amounts of tritium, the helium purification system normally will not return any activity to the primary coolant system.

The purification system will normally process a side stream helium flow of approximately 750 lb/hr. The purified helium will normally be returned to the primary coolant system as purge gas for such components as circulator seals, control rod drive nozzles, penetrations to the PCR.V, etc. The major components that purify and cool radioactive helium will be located within the top head of the PCR.V. Compressor sections handling clean gas, instrumentation, and a sub-system for equipment regeneration will be external to the PCR.V.

There will be a minimum of two parallel purification trains, only one normally on stream at a time. Major items in each train are: a high-temperature filter/adsorber (charcoal), a dryer (molecular sieve), a low-temperature adsorber (charcoal), and several heat exchangers. The helium side stream enters the high-temperature filter/adsorber, which removes dust as well as the gaseous impurities noted above. It is then cooled to about 100°F and flows through the dryer. The stream is then cooled in a regenerative heat exchanger to about -295°F and then passes through the low-temperature adsorber. At this point, the helium

2.5.10. HELIUM PURIFICATION SYSTEM - Continued

side stream is purified. It is cooled by liquid nitrogen before being re-warmed in the regenerative heat exchanger. Finally, the purified helium is brought out of the PCRV, compressed and returned to the primary coolant system. Two compressors are provided.(one standby). Either compressor can handle the gas from the train on stream.

Each low-temperature adsorber will be sized for a delay time in excess of one-year for krypton-85 in the absence of carbon monoxide. Regeneration will normally be required after the adsorber has been on stream six months to a year. Each dryer will be sized for removal of the water and carbon dioxide formed as a result of one steam generator offset tube failure, without regeneration. The helium purification system will also be designed to purify all the primary coolant helium transferred to the helium storage system.

Equipment will be provided for regeneration of the dryers and low-temperature adsorbers. Such equipment will be designed to circulate hot gas through these items to heat them up to a temperature high enough to desorb the impurities. The waste gases will be vented to the radioactive gas waste system for disposal.

2.5.11. HELIUM STORAGE SYSTEM

The helium storage system serves two purposes: first, it provides storage capacity for the plant helium inventory; and second, it provides a supply of high-pressure helium for various purging operations and for operation of the primary coolant system helium stop valves.

When it is desired to store the plant inventory in the helium storage tanks, the following procedure is followed: The primary coolant system is first equalized in pressure with the storage tanks at a controlled rate. Flow of helium is directed through the purification system for removal of radioactive contaminants. When pressures are equalized, the plant pressure will be approximately 350 psia. The helium transfer compressor is then started, taking suction from the purified helium line and discharging to the storage tanks. When plant pressure has been reduced to 12.3 psia, helium pressure in the storage tanks will be approximately 1000 psig.

The primary coolant system is repressurized by essentially reversing the depressurization operation. Helium is bled from the storage tanks to the primary system until pressures are equalized. The transfer compressor is then started, taking suction from the storage tanks and discharging to the primary system.

A supply of high-pressure helium is maintained for operation of the primary coolant system helium stop valves and for purging operations at all times. Replacement of helium used during these operations is accomplished by bleeding helium from the purification system effluent to the helium storage tanks and then transferring it via the helium transfer compressor to the helium supply tanks.

The major nominal design criteria are as follows:

Plant equalization and pumpdown time to subatmospheric pressure	10 hr
Plant equalization and pumpup time to operating pressure	6 hr
Helium storage pressure	1000 to 1250 psig
High-pressure helium supply pressure	1000 to 1250 psig

2.5.12. NITROGEN SYSTEM

The nitrogen system will be designed to furnish liquid nitrogen to the helium purification system and to recondense gaseous nitrogen from this system. This system will be located outside the PCR.V.

Two standard nitrogen liquefier units will be provided to recondense gaseous nitrogen returned from the helium purification system. An atmospheric-pressure liquid-nitrogen storage tank will be provided to supply approximately a one-day supply of liquid nitrogen for emergency use.

2.5.13. TURBINE GENERATOR AND AUXILIARIES

The turbine will be a 3,600-rpm tandem-compound, two-cylinder condensing unit directly connected to and driving a synchronous generator rated at approximately 403 MVA at 0.85 power factor. Nominal throttle conditions will be 2,400 psig and 1,000°F with single reheat to 1,000°F. Nominal design back pressure will be 2-1/2 in. Hg abs. The turbine will be provided with connections to permit extraction of steam for feedwater heating.

The turbine will be a standard reheat design with the exception that steam from the high-pressure turbine exhaust (cold reheat) will be returned to the nuclear steam supply system where it will expand through turbine drives for the main helium circulators before passing through the reheaters and returning to the intermediate pressure element of the turbine. The circulator turbine drives replace two stages in the exhaust end of the high-pressure turbine.

The generator will be hydrogen and/or liquid cooled. Auxiliary equipment will include:

- Generator surge protection
- Grounding transformer
- Exciter
- Excitation switchgear
- Rheostats
- Voltage regulating equipment
- Hydrogen seal oil system

Rating and temperature rise will be in accordance with NEMA and IEEE standards.

2.5.14. TURBINE LUBE OIL PURIFICATION SYSTEM

A turbine lube oil purification system will be provided for the turbine-generator unit consisting of a turbine lube oil storage tank with clean and dirty oil compartments, a transfer pump, and a purifier (centrifuge). Additionally, a filter pump will take suction from the turbine lube oil reservoir and continuously bypass oil through a cartridge type filter back to the reservoir. Both the purifier and filter will be arranged to process lube oil from the turbine lube oil reservoir or the storage tank.

2.5.15. FEEDWATER AND CONDENSATE

The regenerative feedwater heating cycle will consist of six stages. Final feedwater temperature will be 410⁰ F.

Closed Feedwater Heaters

Five closed feedwater heaters will be provided, three low pressure and two high pressure. All will be horizontally mounted. The first low-pressure heater will be located in the neck of the condenser with its tube bundle arranged for withdrawal from the shell. The remaining four heaters will be arranged for withdrawal of shells from the tube bundles. Tubes will be of carbon steel material.

All heaters except the lowest pressure heater will be steam blanketed during periods of shutdown. The lowest pressure heater will be flooded with condensate during shutdown for corrosion protection because it cannot be isolated.

Deaerator

The deaerator will be a tray-type unit with trays of Type 304 stainless steel or material of similar corrosion resistance, with a 40,000-gallon storage tank (approximately 8 minutes storage at full load).

Boiler Feed Pumps

Two or more boiler feed pumps will be provided. They will be driven by auxiliary steam turbines, or electric motors. None of the boiler feed pumps will be shaft-driven from the main turbine generator.

Condensate Pumps

Three 50% capacity motor-driven, vertical, multistage, pit-type condensate pumps will be provided. They will be arranged for suction from the condenser hotwell and for discharging through the air ejector inter- and after-condenser, gland steam seal condenser, polishing demineralizers, and the three low-pressure feedwater heaters to the deaerating heater.

Condensate Storage Tanks

Two condensate storage tanks will be provided. Provision will be made to limit air contamination of the condensate. Pressure relief will be provided for emergency venting.

2.5.16. FEEDWATER HEATER VENTS AND DRAINS

The high-pressure heaters will be equipped with piping and valves to provide means for venting and cascading drains to the deaerator, or to the condenser at low loads.

The low-pressure heaters will be equipped with piping and valves to provide means for venting and cascading drains to the condenser.

2.5.17. WATER TREATMENT

Condensate demineralization, makeup treatment, and chemical injection will be provided.

The condensate demineralization system will include full-flow mixed-bed equipment designed for external regeneration.

Accessory equipment will include:

- Demineralizer outlet strainers
- Suitable backwash resin trap
- External regeneration facilities
- Air-operated valves and controls for remote manual operation
- Control cubicle

The makeup water treatment system will include:

- Two cation units
- Two anion units
- One degasifier
- Rubber or plastic lined tanks

Evaporators may be provided for makeup water treatment in place of the ion exchange units.

Chemical injection system for oxygen scavenging and pH control in the secondary water treatment system includes:

- Chemical pumps
- Solution tanks

2.5.18. CIRCULATING WATER SYSTEM

The circulating water system will be designed based on a net electrical plant output of 330,000 kw and 60°F ambient wet-bulb temperature in conjunction with a cooling tower for heat rejection.

Condenser

The condenser will be designed to maintain a nominal back pressure of 2-1/2 in. Hg abs under the above conditions and will be furnished with phosphorized Admiralty-metal tubes, or other materials suitable for the water conditions. A deaerating hotwell of about 10,000 gallon capacity will be provided.

Ejectors

A twin-element two-stage steam jet air ejector with inter- and after-condenser will provide air removal. A steam jet hogging ejector suitable for use on low-pressure steam will be supplied for startup. Vacuum pumps may be provided instead of steam jets for part or all of this service.

Circulating Water Pumps

Circulating water will be supplied to the condenser water boxes by two half-capacity centrifugal water pumps.

Cooling Tower

The cooling tower will be of the induced draft design. The fan of at least one cell of the cooling tower will be supplied from the essential power bus to provide cooling during plant shutdown.

Circulating Water Makeup

Circulating water makeup will be obtained from surface water or shallow wells.

2.5.19. SERVICE WATER SYSTEM

The service water system will be supplied by water pumped from the cooling tower basin by three 50% capacity motor-driven service water pumps. These pumps will discharge into a loop equipped with connections for the following services:

Turbine lube oil coolers

Hydrogen coolers

Turbine building cooling water system

Office and control room air conditioning units

Hose connections for service water

Reactor plant cooling water system

2.5.20. TURBINE BUILDING COOLING WATER SYSTEM

The turbine building cooling water system will be a closed loop system. Two centrifugal circulating pumps (one standby) will take suction from an elevated atmospheric surge tank and pump the cooling water through two heat exchangers (one standby) to the miscellaneous turbine building equipment to be cooled such as the air compressors, boiler feed pump lube oil coolers, sample coolers, hydrogen seal oil coolers and generator stator coolers.

2.5.21. DOMESTIC WATER SYSTEM

Water will be supplied by deepwell pumps for the domestic water system makeup. Water will be delivered to the condensate storage tanks through the condensate makeup demineralizer or through a domestic hypochlorinator to a domestic-water storage tank which serves as the source of supply within the turbine plant.

2.5.22. FIRE PROTECTION SYSTEM

A fire warning system will be provided and will consist of spot detectors and an annunciator system in the central control room to initiate an alarm in case of fire in critical areas. Fire protection will be provided by fixed fire protection systems supplemented by portable extinguishers.

The fixed protection system will provide a water spray system (manually controlled from the control room and the deluge area) in the following areas adjacent to the turbine-generator:

1. Oil storage reservoir and purification system.
2. Hydrogen seal oil unit.
3. Sump area.
4. Diked areas.

An automatic deluge water spray system will be used to protect:

1. Main power transformer.
2. Unit auxiliary power transformer.
3. Reserve auxiliary power transformer.

Water for fire fighting will be provided by the motor-driven service water pumps with backup provided by an emergency diesel driven fire pump all arranged to deliver water from the cooling tower basin. A fire service head tank of 20,000-gallon capacity will provide an instantaneous supply of water to the protected areas when required.

2.5.23. REACTOR PLANT COOLING WATER SYSTEM

Cooling water supplied to some of the reactor plant heat exchangers (primarily the PCRV liner cooling coils) will be exposed to high radiation fields, leading to substantial radiolytic dissociation of the water. In order to control this water dissociation and the resulting corrosion problem, a closed circulating water loop is provided to serve these exchangers. This closed loop permits maintenance of a hydrogen overpressure to suppress water dissociation and also enables close control of water chemistry to minimize corrosion problems. Since the water chemistry in the closed loop is suitably controlled, this water is also used to cool equipment where water-side scaling could create a maintenance problem. Remaining equipment is cooled directly with service water obtained from, and returned to, the cooling tower .

The reactor plant cooling water system consists of a cooling water return tank, three 50% capacity cooling water pumps, two half-size heat exchangers, and a bypass filter and demineralizer, together with associated piping and controls. The cooling water return tank will be sized to provide approximately 5 minutes surge capacity, with 20% freeboard. The tank will be maintained at about 100 psig by means of an inert gas blanket. Thus, the expected hydrogen concentration in the gas space resulting from radiolysis of the water will, at equilibrium, be well below the lower explosive limit.

The demineralizer will accomplish two purposes: (1) removal of impurities in the water, and (2) maintenance of the water pH at approximately 10.5 to minimize corrosion problems, by release of lithium hydroxide from the demineralizer resin. Additional chemicals may be injected into the circulating closed water loop to provide further control of water chemistry, should this prove necessary.

Water in the return tank is circulated through the loop by two of the three cooling water pumps. The standby pump will start automatically on reduction of loop flow. Loop water leaving the process coolers is cooled, in turn, in the two heat exchangers, rejecting heat to the service water obtained from, and returned to, the cooling tower . After being cooled, the closed loop water is collected in the cooling water return tank.

The initial charge of water for the closed loop, as well as any required makeup, will be obtained from the main condensate pump discharge. This ensures that only high-purity, demineralized water is supplied to the closed loop.

2.5.24. DECONTAMINATION SYSTEM

The decontamination system provides facilities for removal of radioactive contamination from the surfaces of various reactor plant equipment items so that they can be safely maintained. Decontamination operations will be carried out in the hot service facility.

The specific procedures to be followed will depend on the item to be decontaminated and the nature and amount of radioactivity involved. Therefore, facilities are provided which permit the utmost flexibility in the selection and sequence of the processing steps.

In general, the following approach will be used:

1. Vacuum clean the equipment to remove loose dust.
2. Employ high-pressure air jets to dislodge tightly adherent dust.
3. Spray with saturated steam, possibly containing detergents, to aid in washing off surface contaminants.
4. Spray with a commercially available decontamination reagent to remove tightly adherent contaminants.
5. Decontaminate localized "hot spots", using a method such as the electrolytic sponge method. This involves swabbing the equipment item with a sponge moistened with an electrolyte while maintaining an electrical potential between the sponge and the item.

If the foregoing procedures prove inadequate, specialized procedures will be developed for each individual case.

The decontamination system consists of a solution storage tank, a pump to circulate the decontamination solution to the hot service facility, a solution filter, together with air, steam, and hot water supply headers and drain headers. Detergents will be supplied by aspirating concentrated solutions from portable containers using steam as the aspirating medium.

The hot service facility will be equipped with suitable vacuum cleaning, spraying, etc. equipment for the decontamination operations.

The system will be designed for collecting and reusing the decontamination solution. When finally spent, the solution will be pumped to the radioactive liquid waste system for disposal. Detergent and rinse streams collected in the hot service facility will be transferred to the liquid waste system for disposal.

2.5.25. RADIOACTIVE LIQUID WASTE SYSTEM

The radioactive liquid waste system will be designed to handle and process all radioactive aqueous liquid wastes from the plant. These wastes are expected to have maximum activities less than of the order of $1 \mu\text{C}/\text{cm}^3$.

The objective of this system is to concentrate dilute radioactive solutions so that the resultant concentrated radioactive waste can be conveniently disposed of by shipping off site, while the bulk of the fluid can be disposed of on site. Wastes, whose activity exceeds the above value, will be directly packaged for off site disposal.

Concentration of the bulk fluid is achieved in a steam-heated evaporator. The distillate will be demineralized if necessary to permit discharge to unrestricted areas, via the cooling tower blowdown line.

Liquid wastes are collected in the reactor building sump from where they are pumped to the waste receiver tanks. A standby sump pump is provided. As long as the activity level remains low, the flow is directed to one of the receiver tanks used for low-activity liquids. When the receiver tank is full, incoming liquid is diverted to an alternative tank and a liquid sample is obtained from the first tank for laboratory analysis. If the analysis establishes that the tank contents are below maximum permissible concentration, they will be discharged to the cooling tower blowdown line. If the analysis shows the tank contents to be too radioactive for direct disposal, they will be retained for processing. If the activity of the incoming fluid exceeds the setpoint of an in-line process monitor, the flow is automatically diverted to a receiver tank used for high-activity liquid wastes.

The solution in the liquid waste treating unit feed tank is pumped into the evaporator for concentration. Alternatively, if the liquid waste is of low activity and is low in dissolved solids, it can be pumped through the demineralizer, thus bypassing the evaporator.

Distillate is collected in one of two tanks and analyzed. If the distilled water meets purity requirements, it can be discharged. If the activity is too high for disposal, the flow is routed through the demineralizer to a demineralized water tank. Here again, the water is analyzed prior to disposal. If the demineralized water is too active for disposal, it can be recycled through the evaporator or demineralizer.

2.5.25. RADIOACTIVE LIQUID WASTE SYSTEM - Continued

The evaporator concentrate is pumped back to the feed tank for recycle to the evaporator. The process continues until the fluid density in the feed tank reaches the required level. The concentrated sludge is then pumped into shipping drums, mixed with cement, and shipped off site for disposal.

2.5.26. RADIOACTIVE GAS WASTE SYSTEM

The radioactive gas waste system will be designed to handle all radioactive or potentially radioactive gases which must be vented from the reactor plant, except for the effluent from the plant ventilation system. Gas streams to be processed by this system will include equipment vents, gases produced by regeneration of adsorption beds in the helium purification system, and vent gases resulting from purging various items of process equipment.

The radioactive gas waste system will consist essentially of an inlet gas waste vacuum tank, two gas waste surge tanks, two gas waste compressors (one standby), two vent gas filters (one standby), two gas waste blowers (one standby), and associated piping and controls. The compressors employed in the system will be multi-stage reciprocating compressors, similar to those used commercially in acetylene-compression service. Since the compressors will be required to handle radioactive gases, they will be enclosed in containment tanks to prevent leakage of gas to the atmosphere. The vent gas filters will each consist of a pre-filter, an absolute filter, and a charcoal filter for adsorption of iodine, in series, mounted in a suitable tank. The gas waste blowers will be small centrifugal blowers which maintain the system inlet header under a slight vacuum and transfer the system effluent gas to the plant ventilation system exhaust filters.

In operation, all potentially radioactive gases entering the gas waste system are collected in an inlet header and directed through one of the vent gas filters. Filter effluent is continuously monitored for activity. If the activity of the effluent gas is less than a preset value, the gas is transferred via one of the gas waste blowers to the ventilation system exhaust filters for ultimate disposal to the plant stack. Should the gas activity exceed this preset value, the gas is automatically diverted to the inlet gas waste vacuum tank. Inlet gases to the system which are known to be radioactive, such as the helium purification system regeneration gas, are routed directly to the vacuum tank.

When the pressure in the gas waste vacuum tank rises to about 11 psia as a result of gas input to the tank, one of the gas waste compressors is automatically started. The compressor transfers gas from the vacuum tank to one of the gas waste surge tanks. When the vacuum tank pressure falls to about 8 psia, the compressor is automatically stopped. Should pressure in the vacuum tank rise to about 12 psia, the standby compressor will be automatically started.

2.5.26. RADIOACTIVE GAS WASTE SYSTEM - Continued

Radioactive gases collected in the gas waste surge tanks are ultimately disposed of by venting in a controlled manner to the ventilation system exhaust filters and thence to the plant stack after analysis of the tank contents. This is accomplished by opening a vent line from each tank to the inlet of the gas waste blowers. A flow controller limits the rate of release of the tank inventory to the value established by the analysis.

Tentative system design parameters are:

Gas waste compressor capacity, each	50 acfm
Gas waste blower capacity, each	80 acfm
Vacuum tank volume	500 ft ³
Surge tank volume	1000 ft ³

2.5.27. REACTOR PLANT VENTILATION SYSTEM

The reactor plant ventilation system will provide filtered and heated outside air to all plant locations with the exception of the control room, administration offices, and turbine room, which will be separately ventilated.

The ventilation system will be composed of four separate ducting arrangements supplying the following areas:

1. Access control area.
2. Instrument room.
3. Reactor building operating floor.
4. Reactor systems (below operating floor).

The ventilation system will be sized to provide a sufficient number of air changes for personnel comfort based on void air space and expected occupancy of each area. The access control area and the instrument room will be supplied with a minimum of six air changes per hour. The operating floor and reactor systems areas will be provided with a minimum of two air changes per hour. Air will be supplied to the four areas by unit air handlers, each consisting of a filter, a fan, and a heating coil.

Pressures will normally be maintained slightly negative with respect to the outside atmosphere.

A main exhaust header will collect the discharge from the four exhaust headers serving the access control area, instrument room, operating floor, and reactor systems. In addition, exhausts from the reactor refueling area, hogging and steam jet air ejectors, PCRV leak collection system (if required), and gas waste system will be discharged to the main exhaust header. From the main exhaust header, the air will be drawn through two 30,000-cfm filters by two 30,000-cfm exhaust fans. The plant exhaust filter will incorporate a prefilter followed by an absolute filter and charcoal filter to remove a minimum of 99.9% of all particulates 0.3 micron or greater in size and 99% of all radioactive iodine from the exhaust air.

At least one of the two filters will always be in service.

From the plant exhaust fans, all ventilation exhaust air will be drawn into and discharged up the stack by two 35,000-cfm stack fans which provide a stack exit velocity of 125 ft/sec when both fans are in operation.

2.5.27. REACTOR PLANT VENTILATION SYSTEM - Continued

The plant exhaust air will be monitored for radioactive particulates in the main exhaust ducts leading to the plant exhaust filters and for radioactive particulates, iodine, and gases in the stack prior to discharge to the atmosphere.

It is expected that the plant exhaust filters will remove virtually all but the noble gas contaminants from the air prior to being discharged up the stack. If, for any reason, other radioactive gases or particulates should pass through the filters, radiation alarms from the stack monitors would be energized in the central control room and the air handlers would be throttled by the operator. The air supply ducts to the four areas are equipped with check valves to ensure that any pressure buildup in the building will be exhausted to the stack.

2.5.28. INSTRUMENT AND SERVICE AIR SYSTEM

Instrument Air

Instrument air will be supplied by two full-capacity (one standby) nonlubricated, motor-driven air compressors at approximately 100 psig.

Each compressor will have the following accessories:

- Control
- Inlet filter
- Silencer
- Aftercooler

Both compressors will be served by one receiver and one dryer.

Service Air

Service air will be supplied by one oil-lubricated, motor-driven air compressor at 100 psig. The compressor will provide backup for the instrument air compressor. The unit will have the following accessories:

- Control
- Inlet filter
- Silencer
- Aftercooler
- Receiver

2.5.29. COMMUNICATION SYSTEM

The communications provisions will include a combination public address and intercommunication system serving both the turbine plant and the reactor plant, and consist of telephone type handset stations and transistorized amplifier loudspeaker assemblies. This system will have two channels, one for paging and one for partyline service, and the two channels may be used simultaneously without interference.

Tone oscillator equipment will be provided to sound emergency alarms over the paging system. These alarm signals will be controlled from the central control room.

A conduit system will be provided to facilitate telephone system installation and connection by the local telephone company.

Sound-powered telephone jacks will be provided at control panels and strategic locations in the plant, together with an interconnecting wire system.

An enclosed space for installation of telephone equipment will be provided.

2.5.30. AUXILIARY BOILER AND HEATING BOILER

An oil- and/or gas-fired water-tube-type boiler and related equipment will be provided for plant startup or shutdown. During the heating season, this boiler may provide heating steam.

If the boiler is oil fired, a fuel oil storage tank and two light oil pumps, each capable of supplying the requirements, will be provided.

2.6. SERVICES

2.6.1. PIPING

The design, fabrication, and erection of piping and accessories will be in accordance with practices specified in the Code for Pressure Piping ASA B31.1955 and proposed ASA B31.7 "Nuclear Power Piping," if required. Piping containing radioactive fluids under pressure will be helium leak-tested.

Piping will be sized in accordance with good engineering practice. Piping materials will be consistent with the pressure, temperature, and nature of the process fluid. In general, carbon steel will be used for most systems, but stainless steel, chromium-molybdenum, and other alloy steels will be specified for high-temperature, corrosive, or cryogenic service as appropriate.

2.6.2. ELECTRICAL

The selection of equipment and material will conform to PSC central station practice. Sectionalizing of buses, dual power feeds, and automatic transfers will be provided consistent with the over-all reliability philosophy of the nuclear plant.

Bus sections with multiple supplies will be provided to serve those loads that require a high order of power continuity in order to ensure either uninterrupted plant operation, or safe and orderly shut-down and protection of equipment and personnel.

Operation

The electrical system will be monitored and controlled with the electrical control boards in the central control room. The plant will be started using the reserve auxiliary transformer supplied from the outdoor substation to feed the station service power requirements. After the main generator has been brought up to speed and synchronized with the transmission system, the unit auxiliary transformer will be placed in service. When the 4160-volt unit buses have been energized from this source, the reserve auxiliary transformer may be placed on standby.

Motors will be controlled either from the central control room or from centralized control panels at appropriate locations in the plant.

Generator Protective Relays

Generator protective relays will include high-speed differential loss of field, field ground, negative phase sequence, reverse power, backup, and generator ground.

Turbine-Generator Leads

Isolated phase bus will be provided from the generator terminals to the low voltage terminals of the main transformer. Current transformers will be furnished on the generator terminals. Potential transformers and generator surge protection equipment will be connected to isolated phase generator bus taps.

An isolated phase bus tap will be provided from the main transformer bus for the unit auxiliary transformer. A removable link will be provided so that the unit auxiliary transformer can be isolated from the main generator bus.

2.6.2. ELECTRICAL - Continued

Unit Auxiliary Transformer

A unit auxiliary transformer with the primary winding properly rated for the generated voltage and the secondary winding rated at 4.16 kv, 3-phase, 60-cycle, will be closely coupled to the generator bus duct. The secondary of this transformer will be sized to carry the total station auxiliary requirements for full-load operation.

The transformer will be protected by differential current, and phase and ground overcurrent relaying.

Reserve Auxiliary Transformer

A reserve auxiliary transformer of approximately 80% capacity will be rated at either 230 kv or 115 kv on the primary to 4.16 kv, 3-phase, 60-cycle, and the transformer secondary will be connected to the 4160 volt startup switchgear bus. This transformer will be used primarily to start up the plant, may also function as a backup unit for the unit auxiliary transformer, and will normally supply the plant shutdown auxiliary power requirements.

The transformer will be protected by differential current, and phase and ground overcurrent relaying.

Standby Generator(s)

One or more standby generators will be provided to supply essential electrical power in the event of an outage of the normal and reserve power supplies. The generator(s) will have adequate capacity to supply essential shutdown power requirements.

4160-Volt Switchgear

The 4160-volt switchgear will be of dead-front, metal-clad construction. The 4160-volt air circuit breakers will be rated at 250 MVA interrupting capacity at the operating voltage. Loads connected to the 4160-volt switchgear buses will include the feeders to the 4160-to-480-volt load center transformers and the 4160-volt motors. This switchgear will be located outdoors adjacent to the unit auxiliary and reserve auxiliary transformers and will be housed in weatherproof and dustproof enclosures.

2.6.2. ELECTRICAL - Continued

4160-Volt Switchgear - Continued

All 4160-volt breakers will be electrically operated. Three-element phase overcurrent and ground overcurrent protection will be provided for all 4160-volt motors.

There will be three separate 4160-volt switchgear buses. Two of these buses (designated as unit buses) will have their normal feed from the unit auxiliary transformer; the third bus (startup bus) will be fed from the reserve auxiliary transformer. Bus tie breakers will provide a means of energizing the startup bus from either of the two unit buses under normal operation, and will also provide the means of supplying startup power to the unit buses.

4160-480 Volt Transformers

Load center transformers, rated at 4160-to-480-volt, 3-phase, 60-cycle will be utilized to supply 480-volt loads. These transformers will be installed integral with the 480-volt switchgear in typical load center construction, and will be located either indoors or outdoors as appropriate for the load served. The load center transformer and switchgear for the cooling tower fans will be located outdoors and will be of weatherproof and dustproof construction.

480-Volt Switchgear

The 480-volt switchgear will be of dead-front, metal-clad construction. Breakers will be drawout type with thermal magnetic trip elements, electrically operated.

Separate 480-volt switchgear buses will be designated as normal, essential, station service, or cooling tower buses, and the auxiliary electrical loads will be assigned to these buses as appropriate. Vital 480-volt loads will be divided between the essential buses. The standby generator(s) will be connected to an essential bus.

The 480-volt station service bus will be supplied from a separate 4160-to-480-volt transformer. This bus also provides an alternative supply to either of the normal buses, thereby providing enhanced reliability to those station loads. All 480-volt switchgear buses will have an alternative supply so that the normal supply ACB's, transformers, or feeders may be taken out of service for maintenance.

2.6.2. ELECTRICAL - Continued

Motor Control Centers

The motor control center will be of dead-front, metal-clad construction, and will contain combination line starters and molded case air circuit breakers for 480-volt, 3-phase motor control. However, the control rod motor control center will be of special design, and will be rated for 120-volt, 3-phase power. As a general rule, motors rated at 50 hp or below will be connected to the motor control centers. In a few cases, starters may be located at or near the motor.

Instrument Power

There will be three instrument power buses. Two of these will be 120-volt a-c, 1-phase, 60-cycle buses providing non-interruptable power for plant instrumentation. These two buses will each be supplied from separate d-c to a-c inverters. The third instrument bus will be supplied by a 3-phase, 480-to-120/208-volt transformer. This transformer will be supplied from the 480-volt emergency switchgear.

If an inverter set supplying either critical instrument bus is taken out of service, provisions will be made for manual transfer so that continuity of power to the instrument bus will be maintained.

D-C System

Two separate 125-volt d-c buses will be provided, each connected to its own nominal 125-volt d-c battery. One of the 125-volt d-c buses will be designated as the reactor plant bus and one as the turbine plant bus. A static rectifier will be used to maintain a proper charge on each battery and to supply the normal d-c load, which includes one of the inverter sets supplying 60-cycle non-interruptable instrument power. A normally open bus tie circuit will be provided between the reactor plant d-c system and the turbine plant d-c system, to be used in the event one of the rectifiers must be removed from service. The battery room will be fully enclosed and of block wall construction.

Motors

Motors rated 250 hp and above will be supplied from the 4160-volt switchgear. Motors below 250 hp will be supplied from the 480-volt system, except that motors smaller than 1/2 hp will be supplied from the 120-volt, single-phase power system.

2.6.2. ELECTRICAL - Continued

Motors - Continued

Motors located outdoors will have weather-protected NEMA Type II or totally enclosed fan-cooled enclosures. Weather-protected motors will be equipped with space heaters.

Drip-proof motor enclosures will be standard for normally clean and dry locations. Splash-proof or totally enclosed motors will be provided where necessary.

Motors will conform to the applicable NEMA and IEEE Standards.

Lighting System

The plant lighting system will be designed to conform to the latest practice for central station properties. The plant lighting system distribution voltage may be 120 volts or 277 volts. Incandescent, fluorescent, and mercury vapor lamps will be used in suitable fixtures to achieve the intensities and light distribution required for a general lighting system throughout the plant areas. All lighting levels will be maintained-in-service values.

An emergency lighting system will be designed to provide adequate illumination in the event of loss of normal lighting power. About 10% of the installed lighting will be connected to the essential or the d-c power supplies and will consist of incandescent lamps.

Raceways and Wiring

Cables for 4160-volt and 480-volt power service will be 3-conductor, butyl rubber or polyethylene insulated, and run on ladder-type cable trays, clipped to supports, or in conduit.

120-volt a-c control circuits, 125-volt d-c control circuits, and low-voltage (below 125-volts) d-c instrumentation circuits will be multi-conductor polyethylene insulated with PVC jacket, and will be run on metal trays or in conduit.

Low-voltage (below 120 volts) a-c transmitter circuits will be twisted and shielded cables run on the same metal tray as low voltage d-c instrumentation circuits or in conduit.

2.6.2. ELECTRICAL - Continued

Raceways and Wiring - Continued

Thermocouple circuits will be either shielded twisted pair or multiconductor thermocouple cable run on the same metal trays as other low-voltage instrumentation circuits or in conduit.

Nuclear instrumentation and radiation monitoring signal circuits will be coaxial, triaxial, or multiconductor cable. The cables will be run in conduit, except for multiconductor cable, which may be run in the instrument trays.

Power, control, and instrumentation cable runs penetrating the PCRV will be designed to meet the specific requirements of each individual case. These cable runs will utilize mineral-insulated, silicone rubber or other special insulation systems, as appropriate. Shielding and isolation for control and instrumentation wiring will be provided similar to that in the rest of the plant.

A cable-spreading room will be provided immediately below the control room and will be fully enclosed.

Grounding

A low resistance copper grounding system will be installed throughout the plant, both indoors and outdoors, in accordance with the National Electrical Safety Code.

2.6.3. CONTROLS AND INSTRUMENTATION

The plant instrumentation system will be based on the use of electronic control and transmission instruments utilizing miniature recorders and controllers. Controls will be operated from a central control room, except that controls operated infrequently will be located at readily accessible local control stations. Local controls will be monitored from the central control room in accordance with good engineering practice. In the control room an L-shaped duplex control board with integral front control benches and straight back boards will accommodate the instruments and controls. The back boards will be used for those systems not requiring continuous operator surveillance, such as the plant protective system, the radiation monitoring system, and helium circulator seal system controls. Major power plant controls will be located on the front boards; for example, the reactor rod controls and steam generator and circulator controls. Standard back-lighted annunciators will be provided at the top of the appropriate control boards. All thermocouples in the turbine plant will be Chromel-Alumel where possible. The central control room will serve both the reactor plant and the turbine plant.

Pneumatic actuators will be used for most throttling control valves in electronic control systems. Hydraulic actuation will be used where special force or speed is required. Electronic transducers will convert the control signal to pneumatic actuation pressure. Dried instrument air will be used for pneumatic actuators.

Instruments normally containing radioactively contaminated helium under pressure will be of helium leaktight construction and will be connected to the pressure source by welded or brazed tubing or piping, utilizing bellows-sealed helium leaktight manual valves. Excess-flow check valves will be used to minimize the loss of helium in the unlikely event of an instrument line rupture.

Thermocouples will be used for most temperature measurements. Special resistance temperature detectors may be used for reactor outlet helium and high-temperature steam control and safety measurements. Thermocouple temperature monitors will generally consist of multipoint potentiometer recorders and indicators.

Reactor instrumentation will consist of (1) the nuclear instrumentation required to monitor the neutron flux level in the reactor from shutdown to full-power operation; (2) rod control and monitoring instrumentation; and (3) in-reactor instrumentation designed to provide temperature indication of selected reactor components.

2.6.3. CONTROLS AND INSTRUMENTATION - Continued

The nuclear steam supply system protective system will be designed to override the normal plant controls and automatically initiate safety actions. Safety actions will include (1) rod withdrawal prohibit, (2) reactor scram, and (3) automatic coolant loop shutdown. The plant protective system will accept inputs from process and nuclear instrumentation. These inputs will be combined in the logic circuitry to produce outputs that will cause these protective actions.

Radiation monitoring instrumentation will consist of (1) area monitors installed in working areas most subject to accidental irradiation from equipment or pipe lines or from activity released into the building air, and (2) equipment and process monitors to measure the activity contained in equipment or piping. The instrumentation will include monitors for equipment and piping that may contain activity because of equipment malfunction, such as (1) reheat steam activity monitors, (2) ventilation system monitors, and (3) plant effluent monitors.

Space will be provided in the control room for separate control boards for transmission and switchyard lines and for telemetering to and from a remote dispatch office. Space will be provided for possible installation of a data logger.

2.6.4. INSULATION

Piping and equipment will be insulated for the particular system temperature service in accordance with good power station design practice. Insulation for personnel protection will be provided where required.

2.6.5. PAINING

In general, the entire plant will receive two coats of finish paint in the field, where required, after a primer has been applied. Paint will be applied to wet film thicknesses recommended by the manufacturer.

III. PLANT CONTROL AND OPERATION

3.1. CONTROL

The plant control system is basically a boiler-follow-turbine system which will be designed to permit automatic load-following operation with constant steam pressure and temperature at the turbine throttle valves. Feedwater flow to each steam generator is set by a pressure controller at the turbine throttle. A steam temperature controller sets the required helium circulator speed, which is adjusted by bypassing cold reheat steam around the circulator turbine. Hot helium temperature to the steam generators is controlled by the reactor flux controller, which automatically moves a single control rod pair; all other rods requiring only occasional manual control. The hot helium temperature setpoint is varied with plant load to stabilize the boiler transition zone or to control hot reheat steam temperature. In addition to the feedback controllers, anticipatory signals are provided which relate feedwater flow, helium flow, and helium temperature to turbine steam flow and thus minimize steam pressure and temperature deviations during load changes.

3.2. OPERATION

Plant startup is initiated by placing the boiler feed pumps in operation to circulate feedwater through the steam generators. The water leaving the steam generators flows through a bypass line and throttling valve to a flash tank. Water is drained from the flash tank to the condenser hotwell. During the initial phase of startup, steam supplied by the auxiliary boiler is used to provide power for the helium circulator drive turbines. Auxiliary boiler steam is also supplied to the deaerator, the main turbine seals, and the feedwater pumps if they are turbine driven.

With feedwater flow and helium flow established, the reactor is started by manual withdrawal of control rods. Control rods are withdrawn in symmetrical groups of three pairs to achieve balanced flux distribution during the approach to power. As reactor power is increased, heat is added to the high-pressure water circulating through the steam generator, and saturated steam is produced in the flash tank. Flash tank steam is combined with auxiliary boiler steam to provide additional steam flow to the helium circulator drive turbines. Steam leaving the circulator turbines

III. PLANT CONTROL AND OPERATION - Continued

3.2. OPERATION - Continued

flows through the reheaters and hot reheat line, and then is dumped to the main condenser through a turbine bypass line.

Further increases in reactor power and helium temperature lead to steam production in the steam generator. When dry steam having adequate superheat is available, the main turbine is placed in operation using standard turbine startup procedures. Steam pressure and temperature are brought to their rated values by further increases in helium temperature, and turbine load is increased to 25% of rated. At this point, full automatic control is established, permitting a normal load increase to full load.

During operation an increase in load is accomplished by opening the turbine-generator throttle valves. The increase in steam flow and the resulting small steam pressure error raise the setpoint of the feedwater controller. A feedwater flow signal tie to the circulator speed control anticipates the outlet steam temperature error and increases helium flow. The steam temperature controller operates in integral fashion to hold rated steam temperature at the superheater outlet. The increased helium flow tends to reduce the outlet helium temperature slightly. The latter is corrected by the temperature-to-flux loop which withdraws the automatic control rod pair. The helium temperature control setpoint will be changed with load, and thus will anticipate the required direction of rod motion. For load reductions, these operations are reversed: reduced throttle opening raises steam pressure, which reduces feedwater flow and causes a circulator speed decrease. The resultant higher helium temperature then inserts rods, and a new stable load point is reached. Automatic load following can be thus accomplished between 25% and 100% load.

A normal plant shutdown is initiated from the minimum load point, following procedures that are generally the reverse of plant startup. After the reactor and main turbine are shut down, the auxiliary boiler supplies steam to the circulator turbines in order to provide helium flow for decay heat removal. A feed pump provides water flow through the steam generators to the flash tank. During shutdown, either primary coolant loop may be completely shut down and helium pressure may be reduced to atmospheric if necessary for maintenance.

IV. FUEL

Type	Hexagonal blocks containing packed beds of fuel particles (see Fig. 15)
Cold core array pitch	14.212 in. (minor block size differences required for thermal expansion, etc.)
Block length (cold)	15.61 in.
Number of blocks in core	2,964
Block material	Conventional nuclear grade graphite
Graphite density	1.72 g/cm ³
Fuel material	Uranium-thorium carbide and thorium carbide
Particle form	BISO pyrocarbon coated particles
Particle dimensions	200 micron (Th-U)C ₂ with 100 micron coating, 350 micron ThC ₂ with 100 micron coating
Total loading of U ²³⁵ (initial core)	1,330 kg
Total loading of thorium (initial core)	19,200 kg
Effective core diameter	19.5 feet
Active core height	Fueled block column height (12 blocks) cold 187.3 in.
Fuel regions	37, each with 2 control rods (31 with 7 columns, 6 with 5 columns)

PUBLIC SERVICE COMPANY OF COLORADO	
PERSPECTIVE OF PLANT	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 1

PUBLIC SERVICE COMPANY OF COLORADO	
REACTOR PLANT PLAN AT OPERATING FLOOR	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
FIGURE 3

PUBLIC SERVICE COMPANY OF COLORADO	
REACTOR PLANT PLAN BELOW OPERATING FLOOR	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 4

PUBLIC SERVICE COMPANY OF COLORADO	
REACTOR PLANT ELEVATION	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 5

PRESTRESSED CONCRETE
REACTOR VESSEL (PCRIV)

CONTROL ROD DRIVE

CONTROL ROD
DRIVE NOZZLES

CORE

REFLECTOR

CORE SUPPORT
STRUCTURE

STEAM
GENERATOR

MAIN HELIUM
CIRCULATOR

STEAM HEADERS

PUBLIC SERVICE COMPANY OF COLORADO	
PRESTRESSED CONCRETE REACTOR VESSEL	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
FIGURE 7

PUBLIC SERVICE COMPANY OF COLORADO	
CONTROL RODS AND DRIVE ASSEMBLY	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 8

PUBLIC SERVICE COMPANY OF COLORADO		
CONTROL ROD DRIVE (SAFETY)	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS	
	FIGURE 9

PUBLIC SERVICE COMPANY OF COLORADO	
FUEL TRANSFER MACHINE	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 10

PUBLIC SERVICE COMPANY OF COLORADO	
AUXILIARY TRANSFER CASK	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 11

SECTION **A-A**

PUBLIC SERVICE COMPANY OF COLORADO	
HOT SERVICE FACILITY	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 12

PUBLIC SERVICE COMPANY OF COLORADO	
HELIUM CIRCULATOR	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
FIGURE 13

PUBLIC SERVICE COMPANY OF COLORADO	
STEAM GENERATOR	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
FIGURE 14

SECTION A-A

FUEL BLOCK PLAN VIEW

TYPICAL FUEL REGION ARRANGEMENT

PUBLIC SERVICE COMPANY OF COLORADO	
FUEL BLOCK	GENERAL ATOMIC DIVISION OF GENERAL DYNAMICS
	FIGURE 15