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COOLING-WATER SYSTEMS

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The cooling-water systems which serve the accelerator and its RF drive system, the Beam Switchyard (BSY), the research area, and supporting laboratories and shops are described in this chapter. The special problems of radioactive water loops are discussed in detail.

There are three major groups of interrelated cooling-water systems at SLAC. The "general purpose systems" consist of a closed-loop, low-conductivity cooling-water system for laboratories and shops, a distilled water plant, and a cooling tower having a 10 MW rating at 68°F (wet bulb) ambient. The "accelerator systems" consist of a large number of closed-loop, low-conductivity cooling-water systems for accelerator components, a low conductivity water makeup system, and two cooling towers each having an 11 MW rating at 68°F (wet bulb) ambient. The "beam switchyard and end station systems" consist of several closed-loop, low-conductivity cooling-water systems for BSY magnets and power supplies, a large closed-loop, low-conductivity cooling-water system for research equipment, several closed-loop, low-conductivity radioactive cooling-water systems for beam energy-absorbing devices, a low-conductivity water makeup system, and a cooling tower having a 23 MW rating at 65°F (wet bulb) ambient.

All closed-loop, primary cooling-water systems use water which has been filtered and demineralized. This is done to minimize loss of copper from equipment operating at high voltages, to inhibit deposit of scale on important heat transfer surfaces, to prevent plugging small flow passages which may be relatively inaccessible for cleaning, and to reduce corrosion of equipment and piping. Experience to date indicates low-conductivity water at over 1 megohm specific resistance is easy to maintain using about 1% bypass flow through demineralizing cartridges. In a few systems the water has also been deoxygenated to reduce still further deposition of

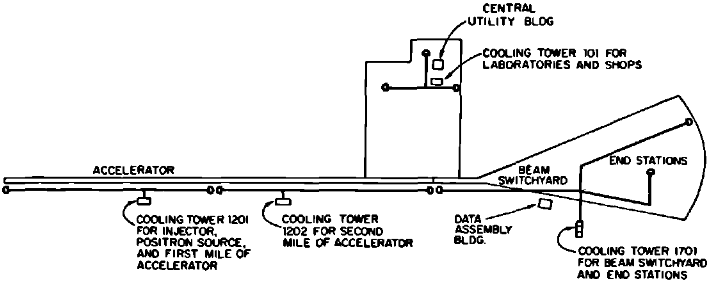

Figure 24-1 Location of cooling tower water systems.

conducting oxides on the inner walls of ceramic connectors to critical magnet coils.

For various reasons no single combination of materials has been used or could conceivably have been used economically throughout SLAC. The following combinations are now in service, and no evidence of serious corrosion has been found up to the present date (July 1967):

1. Low-zinc bronze, stainless steel, and copper
2. All stainless steel
3. Stainless steel and copper
4. Stainless steel and aluminum
5. Low-zinc bronze, stainless steel, aluminum, and copper.

The general purpose systems have been in operation since 1963. The accelerator systems were put into service during 1964 and 1965. The BSY and end station systems were started up in 1966. All systems were designed for continuous service and pumps are shut down only when absolutely necessary. All cooling towers are of the induced draft counterflow type. Cooling tower 101 serves the laboratories and shops. Cooling tower 1201 serves the injector, the positron source, and the first mile of the accelerator. Cooling tower 1202 serves the second mile of the accelerator. Cooling tower 1701 serves the BSY and end stations. The general location of each tower and the system served is shown in Fig. 24-1.

24-1 Laboratory and shop, general purpose systems (GIR)

The laboratory and shop systems comprise a general purpose, closed-loop, low-conductivity cooling-water system, a distilled water plant, and cooling tower 101. The tower, heat exchangers, tanks, pumps, and other equipment are located outdoors, south of the Central Utility Building, as shown in Fig. 24-2.

General purpose system

The general purpose cooling-water system transfers heat from equipment in the Test Laboratory, Central Laboratory, Fabrication Building, and Heavy

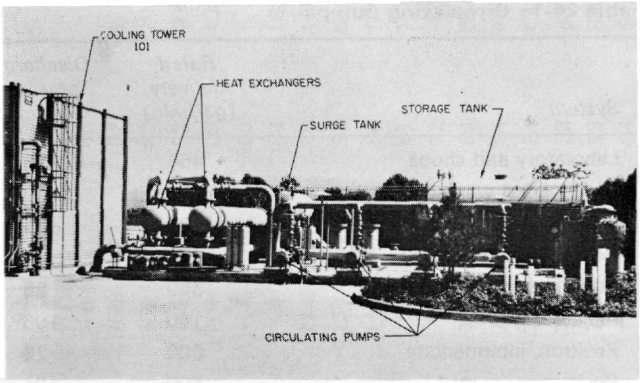

Figure 24-2 Outdoor equipment, general purpose cooling-water system.

Assembly Building to the cooling tower water system. The four circulating pumps are in parallel, with one normally on standby. A flow diagram of the system is shown in Fig. 24-3.

The circulating pumps have a rated delivery of 450 gal/min, a discharge pressure of 110 psig, and a 50-hp drive motor as shown in Table 24-1. The pumps are of the single radial stage centrifugal type. The vertical-split casings and open impellers are low-zinc bronze. The single mechanical shaft seals have carbon rotating faces, ceramic stationary faces, and Teflon secondary seals. Each pump is driven through a flexible coupling.

Figure 24-3 Flow diagram of general purpose cooling-water system.

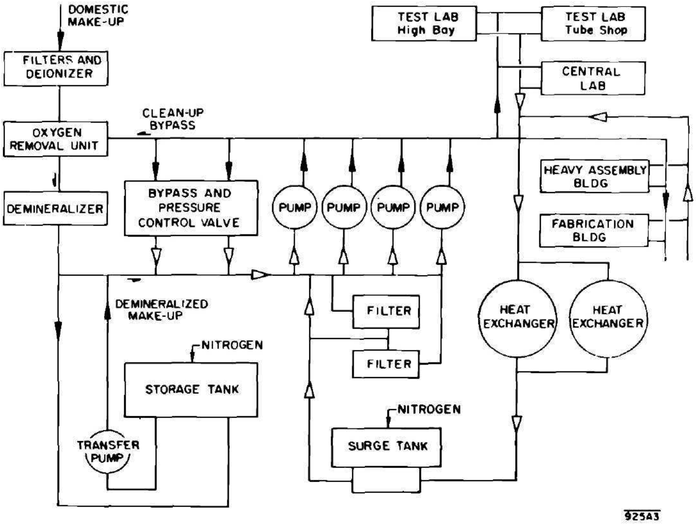

Table 24-1 Circulating pumps

System	*Rated delivery (gal/min)*	*Discharge pressure (psig)*	*Drive motor (hp)*
Laboratory and shops	450	110	50
Disk-loaded waveguide	480	79	30
Injector	100	71	10
Rectangular waveguide–drive line	160	66	10
Main klystron	360	88	25
Injector klystron	160	106	25
Positron, intermediate	600	26	15
Positron, primary 1	500	121	60
Positron, sub-loop	73	246	15
Positron, primary 2	70	87	10
Positron, primary 3	30	87	5
Magnet coil	650	146	75
Magnet power supply	225	117	25
Pulsed magnet power supply	85	79	7.5
Collimators	1020[a]	49	40
A-beam slit	520	49	25
B-beam slit	520	49	25
A-beam dump	520	64	30
Beam dump east	520	64	30
Target area	1500	269	350

[a] Flow is equally divided between a section for horizontal collimation and one for vertical collimation.

The two heat exchangers, each with a surface area of 3510 ft^2, have a rated capacity of 3450 kW. Low-conductivity water enters the tube side of a heat exchanger at 120°F, makes four passes, and leaves at 85°F at a rate of 660 gal/min. The cooling tower water enters the shell side at 78°F at a rate of 1540 gal/min, makes one pass, and leaves at 93°F. (See Table 24-2.) The two exchangers are of the floating head shell and tube type. The 90-10 copper–nickel tubes are $\frac{3}{4}$ in. o.d. The tube sheets, channels, and floating head cover are aluminum bronze. The shell and shell baffles are steel.

Copper is used for piping up to and including 2-in. nominal diameter. Fittings are copper or low-zinc bronze. Aluminum is used for pipe over 2 in. in diameter. Generally, building supply and return headers are aluminum, whereas small branch lines are copper, connected to the headers by dielectric nipples. Makeup water from the domestic supply passes through anthracite and activated carbon filters and cation and anion deionizers. The capacity of the deionizers is 10 gal/min. The 9400-gal storage tank provides a reserve supply of deionized water which can be fed into the system through the

Table 24-2 Heat exchangers

		Low-conductivity water[a]				Cooling tower water[a]				
			Output				Input			
System	Rated capacity (kW)	Passes	(gal/min)	(°F)	Input (°F)	Passes	(gal/min)	(°F)	Output (°F)	Surface area (ft²)
Laboratory and shops	3450	4	660	85	120	1	1540	78	93	3510
Disk-loaded waveguide	173	1	480	110	113	2	92	75	88	75
Injector	147	1	100	102	112	2	24	75	85	75
Rectangular waveguide–drive line	27	1	96	112	114	2	24	75	83	10
Main klystron	3000	1	384	105	158	1	756	75	102	872
Injector klystron	540	1	160	95	119	2	300	75	87	280
Positron, intermediate	1870	2	719	91	109	2	745	75	92	1400
Positron, primary 1	1870	2	500	104	129	2[b]	719	91	109	1400
Positron, sub-loop	38	1	4	152	113	1[b]	4	265	200	2
Positron, primary 2	106	1	360	91	93	2	96	75	83	108
Positron, primary 3	106	1	360	91	93	2	144	75	80	108
Magnet coil	2850	1	570	104	138	1	1150	75	92	1050
Magnet power supply	275	1	174	100	115	1	144	75	88	170
Pulsed magnet power supply	74	1	85	86	92	2	85	75	81	103
B Target	100	1	50	103	120	2	40	75	92	82
Collimators	1000	1	1000	104	111	1	750	75	84	514
A-beam slit	1000	1	500	104	118	1	750	75	84	432
B-beam slit	1000	1	500	104	118	1	750	75	84	432
A-beam dump	2000	1	500	104	131	2	750	75	93	890
Beam dump east	2000	1	500	104	131	2	750	75	93	890
Target area	3190	1	750	95	124	1	1150	75	94	1512

[a] In all heat exchangers, the low-conductivity water passes through the shell side, and the cooling tower water passes through the tube side except for the laboratory and shops system which is just the reverse and except for the target area system where the low-conductivity water passes through tubes mounted in the cooling tower itself.

[b] The tube side in these systems carries low-conductivity water rather than cooling tower water.

transfer pump. The tank is constructed of steel and is lined with Amercoat 23,* a five-coat air-drying vinyl resin system which remains flexible and can be easily repaired. The coating was recently inspected and found to be severely blistered. The tank is equipped with a liquid-level sight glass. Gaskets are Teflon and couplings are stainless steel. The tank is pressurized to 3 psig with nitrogen to prevent oxygen from entering the system.

No temperature control is provided. The water temperature varies with the ambient and load conditions.

The volume above the water level in the surge tank is filled with nitrogen at 10 psig. The surge tank serves three purposes: (1) it accommodates the thermal expansion of the water, (2) it acts as a reservoir to replenish system losses, and (3) it provides a positive pressure to keep air out of the system. The tank has a total capacity of 1020 gal and a design working pressure of 50 psig. The same materials are used in the construction and lining of the surge tank as were used in the storage tank.

System protection is provided by a normally closed 4-in. manual, bypass valve and a parallel automatic 2-in. pressure control valve which minimize pump discharge pressure fluctuations.

To remove oxygen and other impurities, a flow of 10 gal/min is continuously bypassed through an oxygen removal unit and a mixed bed demineralizer. A recording conductivity meter checks the performance of the demineralizer. Two 5-μ filters with a capacity of 540 gal/min each are provided in the return header.

Distilled water plant

Distilled water for use in the Fabrication Building cleaning and plating area is produced in a vacuum-type evaporator with a capacity of 10 gal/min. It is powered by a 75-hp electric motor. Water entering the evaporator is softened by an automatically regenerating water treatment unit consisting of a filter, softener, and brine and salt tanks. A 12,000 gal storage tank holds sufficient distilled water for two-shift operation of the cleaning and plating area. The plant also furnishes the klystron gallery and target area with low-conductivity makeup water produced by passing distilled water through a mixed bed demineralizer. A flow diagram of the plant is shown in Fig. 24-4.

The filter is of the graded sand bed type. Its capacity is 11 gal/min at a flow rate of 3 gal/min/ft^2 of filter bed area. The all-welded steel filter tank is built in accordance with the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. It is lined with a bitumastic coating.

The softener contains approximately 4 ft^3 of high-capacity polystyrene-base resin. The all-welded steel tank is also built to ASME code requirements and lined with a bitumastic coating. The capacity between regenerations is 32,000 gal of water having a hardness of 3 grains/gal as calcium carbonate.

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* Amercoat Corporation, Southgate, California.

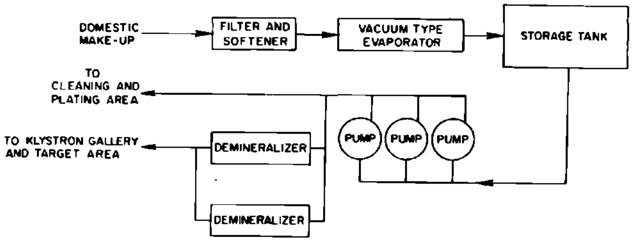

Figure 24-4 Flow diagram of distilled water plant.

Twenty-four pounds of salt are required for regeneration. The brine tank serves as a combination measuring and storage tank. The tank has a storage capacity of about 10 ft^3 and includes a makeup float valve in a separate chamber. It is constructed of steel and lined with a bitumastic coating.

Distilled water is stored in an all-welded stainless steel tank. The present tank replaced an equivalent wound-glass filament-reinforced epoxy resin tank which proved unsuitable because of the contamination of the distilled water by the continuous leaching out of the mold-release agent.

Three stainless steel canned-rotor centrifugal pumps, each rated to deliver 45 gal/min at a discharge pressure of 50 psig, are provided to distribute the water from the storage tank both to the cleaning and plating area and, through a pair of demineralizers, to the line serving the klystron gallery. One pump is normally on standby.

The two demineralizers on the line to the gallery are connected in parallel. The flow rate of each unit is 20 gal/min and the capacity between regenerations to the end point of 1 megohm specific resistance is 12,000 grains as calcium carbonate. The demineralizer resin is furnished as a replaceable cartridge, encased in fiberglass-reinforced polyester. Each cartridge contains $1\frac{1}{2}$ ft^3 of general purpose mixed bed resin. Although the maximum flow rate to the gallery is 40 gal/min, normal flow is less than 20 gal/min. Since the demineralizers handle distilled water, the life between rechargings is more than a year and ample time is available to service the cartridges without the necessity of providing a spare.

The low-conductivity water is piped to the klystron gallery in a 2-in. copper line. A valved connection to a $1\frac{1}{2}$-in. copper header running the length of the gallery is provided near the east end of Sector 29. A 2-in. underground line from the east end of Sector 30 connects the gallery header to the target area cooling-water system.

Cooling tower water system

Cooling tower 101 provides cooling water for the general purpose water system heat exchangers, the main air-conditioning water chiller condensers in the Central Utility Building, and the local air-conditioning chiller condensers at the Fabrication Building and the Test Laboratory. A flow diagram

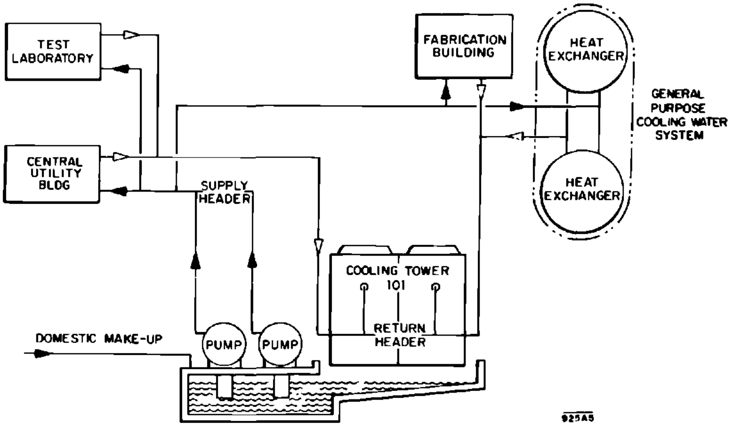

Figure 24-5 Flow diagram of laboratory and shop cooling tower water system.

of the cooling tower water system is shown in Fig. 24-5. The two-cell tower is of the counterflow induced draft type. It is rated at 10 MW, cooling 4600 gal/min from 93 to 78°F at 68°F (wet bulb) ambient. The low profile tower is 60 ft long, 24 ft wide, and 21 ft high. Redwood is used for the structural frame, fill, flumes, drift baffles, fan outlet rings, and top deck. The air-intake louvers and side panels are cement asbestos. The two-speed fan in each cell is driven by a motor which develops alternatively 7.5 and 30 hp to allow for variation in the heat load. The two tower water circulating pumps each deliver a rated 2800 gal/min at 50 psig discharge pressure. A 100-hp motor drives each pump. The pumps are of the two-stage vertical turbine type. A 30-mesh screen protects the suction well of each pump. System makeup water is introduced through an automatic float-controlled valve. Switches are provided that shut the fans down in the event of excessive vibration. An automatic " deluge " system protects the tower against fire.

24-2 Accelerator systems (FFH)

Approximately 80% of the power consumed by the electronic components of the SLAC linear accelerator is rejected as heat energy to one of the following closed-loop low-conductivity, cooling-water systems:

1. Disk-loaded waveguide systems, including the injector constant metal temperature system
2. Rectangular waveguide—drive line system
3. Klystron systems, including the injector klystron system
4. Positron system, including primary and intermediate circuit 1 and primary circuits 2 and 3.

These four accelerator systems and the associated cooling tower water systems are described in subsequent sections.

A branch from a $1\frac{1}{2}$-in. makeup header extending the length of the klystron gallery provides low-conductivity makeup water to each of the thirty sector mechanical alcoves. The branch line is connected to the surge tanks of the accelerator systems in the alcoves through automatic solenoid-operated valves. Water is supplied to the header from the distilled water plant. It can also be supplied from the target area storage tank.

Compressed air is supplied to the east end of the klystron gallery from the central compressed air utility system described in Chapter 27. Air can also be supplied from a separate compressor in the BSY substation. Compressed air passes through automatic duplex drying units before entering the 3-in. steel header extending the length of the gallery. Branch lines carry the air from the header to the mechanical equipment alcove in each sector and to the hatch cover actuating cylinders, beam-line vacuum valves, alignment targets, and wherever it is needed in the gallery and accelerator housing. System pressure is 100 psig. At each mechanical alcove, compressed air from the 3-in. steel header is filtered, reduced to 20 psig, and distributed to the pneumatic controllers used in the water systems.

To insure electrical phase stability, the metal temperature of all 10-ft accelerator sections is held at 113.0° ± 1.4°F. To hold critical high-power accelerator sections, such as the one in the injector and the three at the upbeam end of Sector 1, within these limits under all conditions of steady state RF loading, the temperature of cooling water supplied to the sections is automatically controlled by sensors responsive to the metal temperature of the sections themselves. Each sector throughout the rest of the accelerator is held within the same limits by controlling the supply water temperature in the gallery to within 0.2°F of a value preset to maintain the required metal temperature in the housing. The individual rotameter-type flow indicator and globe valve provided for each accelerator section facilitate temperature control by making it possible to equalize the bulk flow rate and water velocity throughout the accelerator. To insure symmetrical temperature distribution, the cooling-water supply and return connections are both located at the midpoint of each accelerator section. Water flows lengthwise to and from each end of the section through four hairpin loops of copper tube brazed to the periphery. The eight legs of the loops are spaced at equal intervals around the sections. Alternate legs carry supply and return water. To minimize temperature variation along the two-mile accelerator, the controller in each sector is calibrated against a very accurate reference standard.

To eliminate operating temperature as a design variable, rotameter-type flow indicators and globe valves are provided to equalize the rate at which water is supplied to each klystron and to each of a number of other machine components.

High purity low-conductivity water was chosen as the coolant offering the best long-term assurance of unrestricted flow through small apertures and scale-free heat transfer surfaces. Copper pipe was selected for exclusive use throughout the accelerator systems on the basis of economy and compatibility with the accelerator materials and with low-conductivity water.

Going from 245 klystrons in Stage 1 to 965 in Stage 2 will result in a fourfold increase in the load on the heat exchangers of the accelerator systems. The klystrons themselves account for some 75% of the rejected heat. At present the thirty sectors are served by ten klystron cooling-water systems. Each system handles three sectors at eight klystrons per sector or a total of twenty-four klystrons. In Stage 2, each sector of thirty-two klystrons will require a separate cooling-water system. Another 20% of the rejected heat derives from the disk-loaded waveguides and the remaining 5% from the rectangular waveguides and drive lines. New and larger heat exchangers will be needed for the thirty disk-loaded waveguide systems. However, the heat exchangers presently used in the disk-loaded waveguide systems will be more than adequate for the rectangular waveguide–drive line systems in Stage 2. The existing pumps and piping are sized to meet Stage 2 requirements.

A large number of identical components are used in the accelerator water systems. For this reason, time was well spent in reviewing the many possible alternatives in search of the least expensive way of doing a given job. As an example, one proposal was to use a reduced pressure flash tank of special design in which low-conductivity water is evaporated at nominal temperature. The condensate is collected on tube bundles cooled by tower water and is pumped back into the system. Although the surface area is less than that of the equivalent shell and tube exchanger, the more conventional device was finally chosen, primarily because the proposed flash tank had not yet been proved in service. The anticipated economies in fabrication also appeared questionable in comparison with the mass-produced exchangers of the shell and tube type. With some 1400 low flow switches required to protect the accelerator cooling-water systems, the use of the least expensive commercially available type was an important factor in reducing installation costs. However, this choice of switches proved to be a mixed blessing due to the uncertainty of actuation at the marginal flows required in many branch lines and to the tendency for the initial setting to vary with time. Fortunately, it was possible to substitute a hermetically sealed, switching unit of adequate set-point stability while retaining the original body and orifice assembly. The modified switch is still less expensive than any equivalent, commercially available, differential pressure switch.

It was predicted[1] that cooling water passing through the accelerator housing would become slightly radioactive when the beam was on. In an effort to minimize the hazard to personnel in the gallery, the protective features described in subsequent sections have been included in the design of the disk-loaded waveguide and positron cooling-water systems.

Pumps used throughout the accelerator cooling-water systems are close-coupled, single radial stage, centrifugal pumps with vertical-split, low-zinc bronze casings, with open, low-zinc bronze impellers, and with single mechanical shaft seals. The shaft seals have a carbon rotating face, a ceramic stationary face, and Teflon secondary seals, except for the two primary circuit 1 pumps in the positron system, which have double mechanical seals of the same material and Viton* secondary seals. Pressure gauges are pipe-mounted at the discharge from each pump.

The heat exchangers are shell and tube type. Low-conductivity water is on the shell side, and tower water is on the tube side, except as noted for the positron system. Shells, baffles, and tube sheets are silicon bronze. Tubes are 5/8-in. o.d. 90-10 copper–nickel. Channels and channel covers are steel. The design pressure is 150 psig for both shell and tube sides. Dial-type thermometers and pressure gauges are pipe-mounted at each inlet and outlet.

Piping in the several systems is copper, joined with 95-5 tin–antimony solder, using a water-soluble flux. In the positron system, the joints are made up with self-fluxing silver brazing alloy. Valve bodies, flexible metal hose, and other fittings not generally available in copper, are low-zinc bronze. Unless otherwise noted, flow indicators are all of the rotameter type.

Disk-loaded waveguide systems (DBR)

A closed-loop, low-conductivity cooling-water system is provided to remove heat from all thirty-two disk-loaded waveguides (10-ft accelerator sections) in each of the thirty sectors except Sectors 1 and 11. The injector constant metal temperature system serves the first three accelerator sections in Sector 1 in addition to the beam-line components of the injector. Heat is removed from the accelerator sections on girders 11-3B and 11-3C in Sector 11 by primary circuits 2 and 3 of the positron system. Each disk-loaded waveguide system also cools the beam scraper and the beam position monitor in the drift section at the downbeam end of the preceding sector.

The standard sector system in the diagram in Fig. 24-6 is designed to cool the accelerator sections and their output loads. The water leaving the output load of each odd-numbered section also cools the adjacent rectangular waveguide. Flow rates through the various components are itemized in Table 24-3. The pump, heat exchanger, and auxiliary equipment for each system are located in the mechanical alcove of the respective sector.

A flow diagram of the injector constant metal temperature system appears in Fig. 24-7, with flow rates itemized in Table 24-4. The pump, heat exchanger, and auxiliary equipment are located in the mechanical alcove in Sector 1. Figure 24-8 shows the heat exchanger, together with other cooling-water equipment in the Sector 1 alcove.

Design and operating parameters for the standard sector system and for the injector constant metal temperature system are included in Tables 24-3 and 24-4. Inlet and outlet water temperatures over the range of RF power loading may be taken from the curve in Fig. 24-9. Although the accelerator

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* DuPont Company, Wilmington, Delaware.

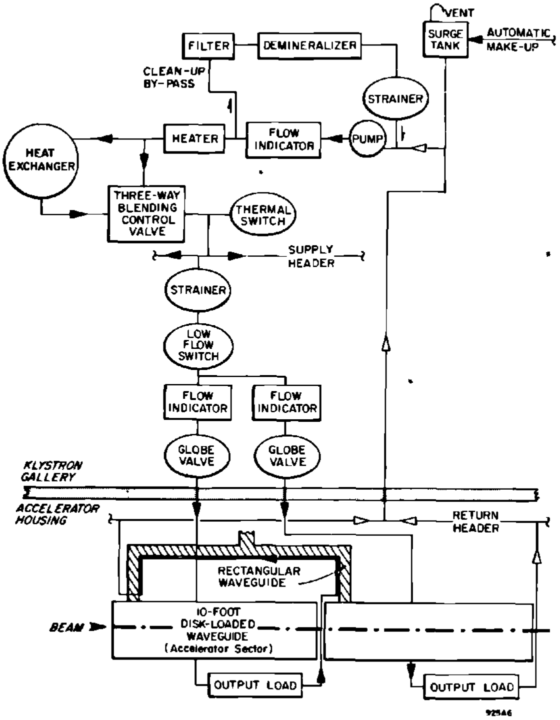


Figure 24-6 Flow diagram of disk-loaded wave-guide cooling-water system.

Figure 24-7 Flow diagram of injector constant metal temperature cooling-water system.

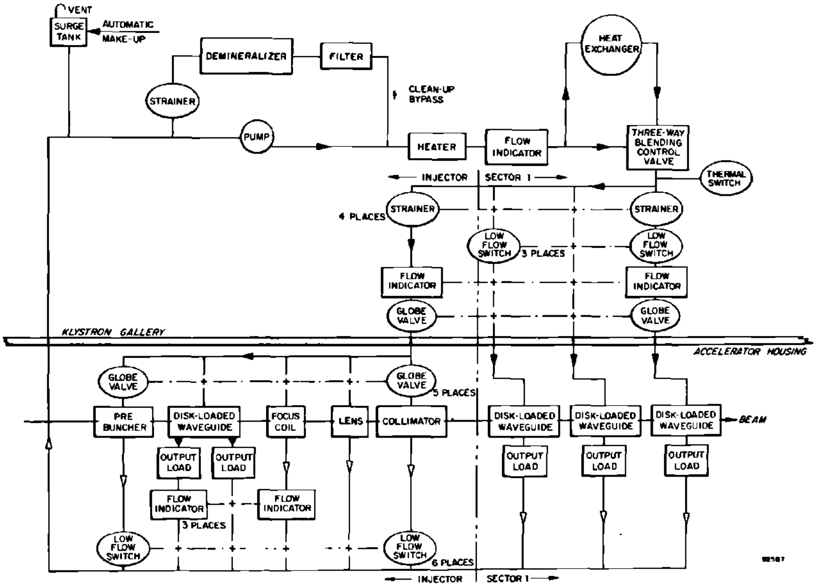


Table 24-3 Design parameters for standard disk-loaded waveguide cooling-water system

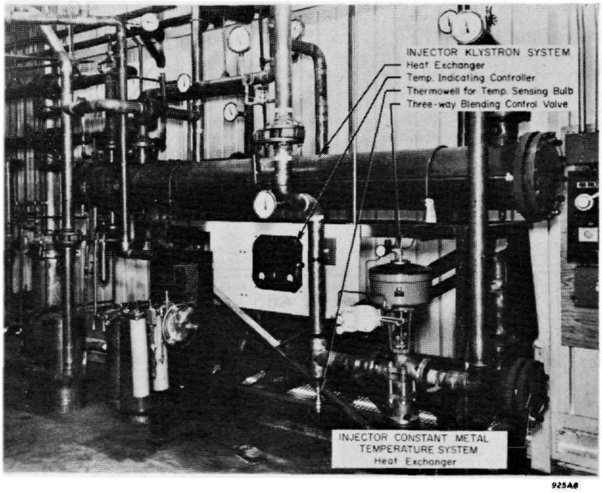
Parameters	*Stage 1*	*Stage 2*
Accelerator section		
Flow (gal/min)	13 ± 1	13 ± 1
Heat load, max (kW)	3.1	12.4
Water temperature in, max heat load (°F)	110.3 ± 0.2	101.8 ± 0.2
Water temperature rise (°F)	1.625	6.5
Metal temperature (°F)	113.0 ± 1.4	113.0 ± 1.4
Pressure drop, max (psi)	8	8
Output load		
Flow (gal/min)	13 ± 1	13 ± 1
Heat load, max (kW)	1.5	6.0
Water temperature in, max heat load (°F)	111.9	108.3
Water temperature rise (°F)	0.8	3.2
Pressure drop, max (psi)	5	5
Rectangular waveguide		
Flow (gal/min)	13 ± 1	13 ± 1
Heat load, max (kW)	0.05	0.2
Water temperature in, max heat load (°F)	112.7	111.5
Water temperature rise (°F)	0.025	0.1
Pressure drop, max (psi)	4	2
Totals—Average 10-ft accelerator section		
Flow (gal/min)	13 ± 1	13 ± 1
Heat load, max (kW)	4.65	18.6
Water temperature rise (°F)	2.45	9.8
Water temperature out, max heat load (°F)	112.7	111.6
Pressure drop, max (psi)	17	15
Beam scraper, flow (gal/min)	40	40
Beam position monitor, flow (gal/min)	1	1
Cleanup bypass, flow (gal/min)	8	8
System totals		
Flow (gal/min)	465	465
Design flow (gal/min)	480	480
Heat load less the contribution of the scraper and position monitor, max (kW)	148.8	602
Design heat load (kW)	173	—
Design pressure drop, max (psi)	75	75

Table 24-4 Design parameters of injector constant metal temperature cooling-water system

Component	*Flow (gal/min)*	*Heat load (kW)*
Prebuncher	2	3
Focus coil	26	40
Injector accelerator section, loads and waveguide	13	19
Lens	2	3
Collimator	2	3
Sector 1 accelerator sections, loads and waveguides—three at 13 gal/min and 19 kW each	39	57
Cleanup bypass	8	—
System totals		
Flow (gal/min)	92	92
Design flow (gal/min)	100	100
Heat load, max (kW)	125	125
Design heat load (kW)	147	147
Design pressure drop, max (psi)	67	67

would operate satisfactorily at a metal temperature anywhere between 80° and 120°F, it was necessary to specify the design temperature in order that the proper allowance could be made for dimensional changes due to the difference in metal temperature during fabrication and during operation. If the metal temperature during operation is set too low, the size and cost of the heat exchangers is unduly increased. On the other hand, if it is set too

Figure 24-8 Injector cooling-water equipment.



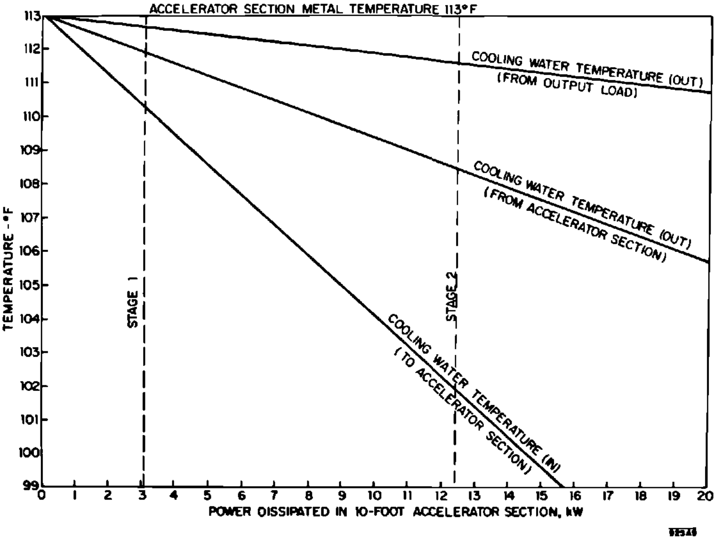


Figure 24-9 Water temperature versus RF power loading.

high, the resistivity of the section increases and the resulting decrease in the Q and shunt impedance reduces the beam energy. An excessive metal temperature could also warm up the surrounding concrete enough to make it uncomfortable to do maintenance work in the accelerator housing during shutdown. As a compromise, a temperature of 113°F was set for the disk-loaded waveguides. During the 8 hours/week that the accelerator housing is open for maintenance, the air temperature runs approximately 80°F with the ventilating fans turned on. When the accelerator is in operation, the air temperature in the closed housing averages 90°F.

Components of all thirty disk-loaded waveguide systems (thirty sectors) are identical. The basic features common to pumps, heat exchangers, and piping of all accelerator cooling-water systems are summarized above. Operating characteristics of the circulating pumps and heat exchangers for the disk-loaded waveguide and for the injector are included in Tables 24-1 and 24-2.

The sector supply headers for the disk-loaded waveguide system are of 4-in. pipe. An in-line strainer and a low flow switch are provided in valved, $1\frac{1}{2}$-in. supply branches located at 20-ft intervals along the header. Each branch feeds a pair of 1-in. risers serving two adjacent accelerator sections through a 27-in. service penetration. A globe valve and flow indicator permit adjustment of the rate at which water is supplied through each riser. The 1-in. risers are connected to the accelerator sections through 4-ft lengths of flexible metal hose with union ends. Water returns through a similar hose to a 4-in. header in the accelerator housing. A 5-in. return riser approximately in the middle of the sector carries the water up through a 20-in. penetration to a trench in the gallery floor leading to the mechanical equipment alcove.

The beam scraper and position monitor are also connected to the return header with flexible metal hose. Block valves are provided in the accelerator housing on the return line from each accelerator section and water-cooled drift section component. Supply headers and risers are insulated.

The injector system serves the first three accelerator sections in Sector 1 through three risers. The arrangement is similar to that of the standard sector except that the risers are fed directly from the 2½-in. supply header instead of being connected in pairs through a 1½-in. branch. Each riser has its own strainer and low flow switch. The system also supplies water through a 2-in. riser equipped with a flow indicator and globe valve to a 2-in. header serving the injector equipment in the accelerator housing. Block valves are included in the branch line to each component, together with a low flow switch on the return side. Flow indicators are provided on the two return lines from the injector accelerator section and on the return line from the focus coil. Water is collected from all components in the housing through a 2½-in. return header. Both supply and return headers in the klystron gallery are insulated.

For temperature control in the disk-loaded waveguide system, each heat exchanger is provided with a bypass and a pneumatically positioned three-way blending control valve. The blending valve is a piston-operated device designed to pass a constant flow irrespective of stem position. A mercury-filled temperature-sensing bulb is mounted in a thermowell downstream of the three-way valve. A capillary tube connects the bulb to a pneumatic transmitter where the temperature signal is converted to a 3–15-psig air signal to the indicating controller on a nearby panel. The controller is preset to the temperature at which the water must leave the gallery to hold the average metal temperature of the disk-loaded waveguides in the sector between 111.6° and 114.4°F. The controller compares the actual water temperature with the preset temperature. An air signal from the controller to the valve positioner readjusts the setting of the three-way valve in proportion to the direction and magnitude of the difference between the two temperatures. As directed by the positioner, the three-way valve combines a stream of cool water from the heat exchanger with a warmer stream bypassing the exchanger to maintain the preset water temperature. During startup and low-power operation when the heat loads are negligible and all the flow is through the bypass, water temperature is maintained by a 50-kW in-line electric heater. The heater is energized through a relay actuated by a set of contacts in the controller.

In Stage 1 operation, as has been described, four accelerator sections in a standard sector share the output of a single klystron. In contrast, the four accelerator sections cooled by the injector system are powered by separate klystrons. To hold these high-power sections within the specified metal temperature limits, the temperature of the cooling water supplied by the injector system is automatically varied to maintain the minimum practicable differential between a preset control point of 113°F and the average metal temperature of the four sections themselves. The control instrumentation consists of mercury-filled temperature-sensing bulbs in thermowells brazed to the periphery of the four accelerator sections, pneumatic transmitters which convert the temperature signal from each bulb to a 3–15-psig air signal, an averaging relay which forwards a single signal equivalent to the average of the four received from the transmitters, and an indicating controller. The controller compares the actual average metal temperature with the preset temperature of 113°F and, by air signal to the valve positioner, readjusts the setting of the three-way valve in the same manner as in a standard sector. A 25-kW in-line heater maintains the water temperature during startup and low-power operation.

A copper surge tank accommodates thermal expansion of the water in each system. The 35-gal tank is mounted 10 ft above the pump suction in each mechanical equipment alcove. It is connected to the return header by a 2-in. riser. The tank is vented to the atmosphere. Each tank is equipped with a liquid-level sight glass. Automatic control of the water level in the tank and protection against excessive leakage is provided by a float and two limit switches.

As the return water may be slightly radioactive, confining it to a header in the housing and to a single return riser simplifies any problem of shielding that may arise in the klystron gallery. The principal activity is from ^{15}O with a half-life of 2 min. The radiation level in the gallery could be reduced by adding a shielded holdup tank in the return line and by stacking lead bricks over the trench through which the 5-in. riser returns to the alcove. However, it has been unnecessary to resort to either of these expedients as background radioactivity remains below the allowable tolerance. Individual low flow switches are interlocked to shut off the modulator serving the klystron of the corresponding accelerator section if the flow drops to 80% of normal. In the injector system, flow switches on the buncher, focus coil, lens, and collimator cooling-water lines are interlocked with the respective power supplies. A Venturi-type flowmeter is installed in the pump discharge line with the pressure taps connected to an indicator and a differential pressure switch on the control panel in the alcove. The switch is interlocked to shut down the in-line heater and variable-voltage substations if the flow drops to 70% of normal. In addition, a thermal switch mounted on the piping downstream of the three-way valve is interlocked with the variable-voltage substations to interrupt power to the modulators should the system temperature exceed 130°F. As the water level in the surge tank goes down, the first limit switch opens a solenoid valve, admitting low-conductivity makeup water. The second switch shuts down the circulating pump when the level drops to within about an inch of the bottom of the tank, a condition which indicates excessive leakage from the system.

Water is held to a specific resistance of more than a megohm by a 5-μ replaceable cellulose filter and a mixed bed demineralizer located on a bypass between pump discharge and pump suction. The bodies of the filter and the demineralizer tanks are Type 304 stainless steel. Isolating valves are provided so that the filter elements and the demineralizer resin can be replaced while the system is operating. A 100-mesh strainer in the bypass downstream of the demineralizer prevents resin carryover into the circulating system.

Rectangular waveguide–drive line systems (DBR)

Thirty closed-loop, low-conductivity cooling-water systems serve the rectangular waveguides and RF drive lines. These systems have three functions. They remove the heat generated by the RF losses in the rectangular waveguides, provide constant temperature water for tracing the drive line and the phase monitoring cables, and cool the sub-booster modulators. A typical system is shown diagrammatically in Fig. 24-10. In Sector 1, the system cools the injector rectangular waveguides and one standby sub-booster modulator in addition to the typical sector loads. Although rated for 160 gal/min at 66 psig discharge, the pump is capable of delivering the 185 gal/min required for Stage 2 operation. The corresponding discharge pressure of 59 psig is ample to overcome system impedances. The pumps, heat exchanger, and other auxiliary equipment are located in the mechanical alcove in each sector.

Figure 24-10 Flow diagram of rectangular waveguide–drive line cooling-water system.

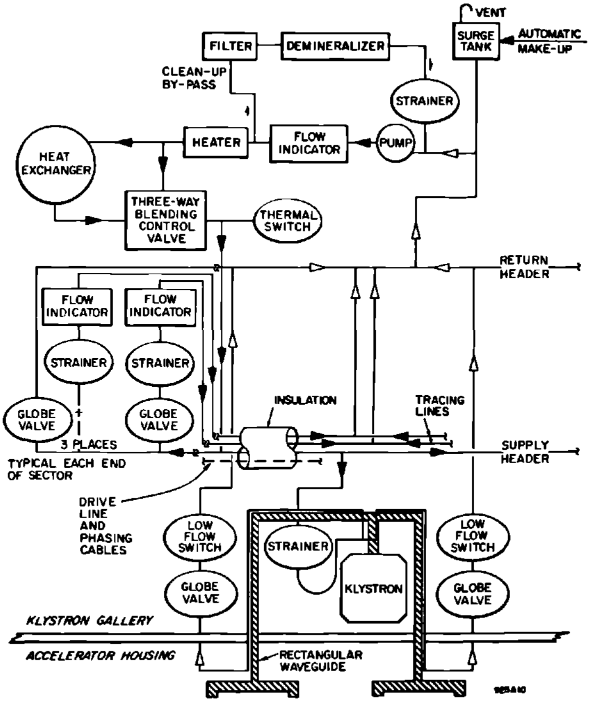


Table 24-5 Design parameters for rectangular waveguide–drive line systems

	Stage 1	Stage 2
Waveguide		
Flow per klystron (gal/min)	10	5
Heat load per klystron (kW)	2.75	2.75
Water temperature in (°F)	112±1	112±1
Water temperature rise (°F)	1.87	3.74
	Flow (gal/min)[a]	*Heat load (kW)*[a]
Drive line and phase monitoring cables	10	nil
Subbooster modulator	2	0.5
Supply-to-return header bypass	5	—
Cleanup bypass	8	—
	Stage 1	*Stage 2*
System totals		
Flow (gal/min)	105	185
Design flow (gal/min)	160	185
Heat load (kW)	22.5	88.5
Design heat load (kW)	26.5	—
Design pressure drop, max (psi)	62	55

[a] Quantities apply to both Stage 1 and Stage 2.

Design and operating parameters for the system are included in Table 24-5. The temperature of the cooling water supplied to the rectangular waveguides and drive lines must be held at 112° ± 1°F to maintain electrical phase stability. Water at the same temperature is used to cool the sub-booster modulators. Whereas the temperature along an individual waveguide may vary by more than ±1°F, depending on power level, the temperature variation at corresponding points on the sixteen waveguides in each sector may not exceed ±1°F.

Identical components are used on all thirty systems. The basic features common to the pumps, heat exchangers, and piping of all accelerator cooling-water systems are summarized above. Operating characteristics of the circulating pumps and heat exchangers for this system are included in Tables 24-1 and 24-2.

Hollow copper waveguides carry RF power from the klystrons to the accelerator. A short length of full power waveguide on the klystron couples equally into two half-power branch waveguides of rectangular cross section with a cooling-water channel brazed to the face of each. The thermally insulated waveguides enter the accelerator housing through separate penetrations, one upbeam and one downbeam from the klystron. Within the housing, each waveguide divides through a 3-dB coupler into two one-quarter power waveguides feeding the individual accelerator sections. Water from

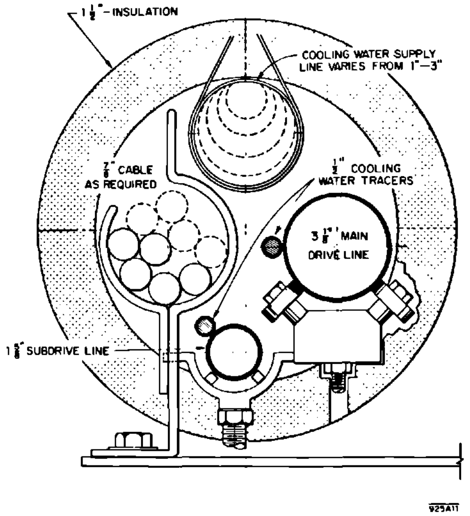


Figure 24-11 Drive line and phase-monitoring cable package.

this system cools the waveguides from the klystron as far as the couplers in the housing. Beyond the couplers, the rectangular waveguides are cooled by the disk-loaded waveguide cooling-water system. The $2\frac{1}{2}$-in. supply header serving each sector is located within the insulated drive line and phase-monitoring cable package shown in cross section in Fig. 24-11. The valved 1-in. supply branch above each klystron includes an in-line strainer. Each branch connects to the cooling channels on the waveguides through a length of flexible metal hose. The cooling channel on each waveguide ends at the lower coupler and a riser carries the water back up through the penetration to the return header in the klystron gallery. A globe valve, low flow switch, and block valve are located near the header end of the riser. Stubs are provided on the supply header for the additional branches required for expansion to Stage 2.

In order to take advantage of the constant temperature environment provided by the supply header of the rectangular waveguide–drive line cooling-water system, the main and subdrive lines and phase-monitoring cables are included in the same insulated package. It was found necessary to fasten "tracers" of $\frac{1}{2}$-in. copper pipe to the two drive lines in order to insure the required degree of temperature stability. Water is supplied to the tracer lines through a globe valve and flow indicator at each end of the sector.

Temperature control for this system is the same as for a standard sector disk-loaded waveguide system. A 20-kW in-line electric heater holds the system at temperature when the beam is off, during startup, and during low-power operation.

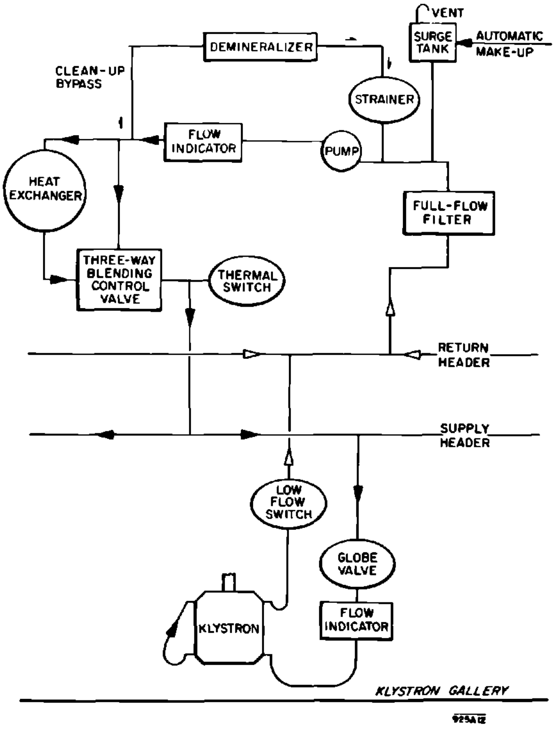
The surge tanks, the filter demineralizers, and protection against low flow, against high system temperature, and against low water level in the surge tank are all the same as for the disk-loaded waveguide systems.

Klystron cooling-water systems (DBR)

Eleven closed-loop, low-conductivity cooling-water systems are provided to remove the heat generated in the klystrons, including ten main klystron systems and one injector klystron system. During Stage 1 operation, twenty-four klystrons in three adjacent sectors are connected to a typical main klystron system, as shown in the flow diagram in Fig. 24-12. The pumps, heat exchangers, and other auxiliary equipment are located in the mechanical alcoves of Sectors 2, 5, 8, 11, 14, 17, 20, 23, 26, and 29. A klystron heat exchanger is seen in Fig. 24-13. In addition to the normal complement of twenty-four klystrons, the main system for Sectors 10, 11, and 12 serves an additional klystron in the positron area in Sector 11.

The injector klystron system depicted in Fig. 24-14 cools the two injector klystrons and their RF switches and output loads, the two main boosters and their output load, and the first three klystrons in Sector 1. The pump,

Figure 24-12 Flow diagram of klystron cooling-water system.



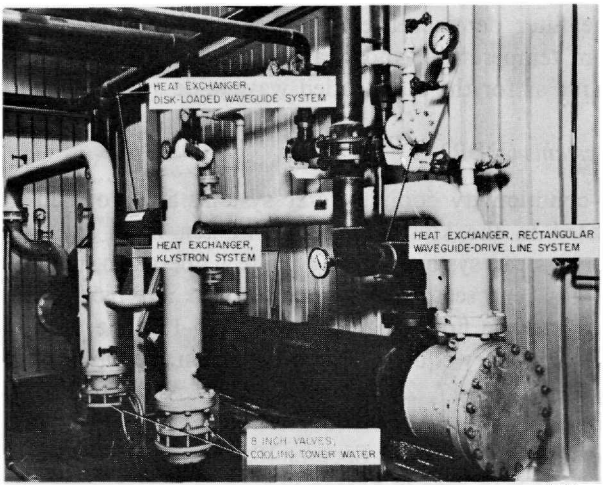


Figure 24-13 Heat exchangers in Sector 11 mechanical alcove.

heat exchanger, and other auxiliary equipment are located in the Sector 1 mechanical alcove. Figure 24-13 includes a view of the heat exchanger and some of the other equipment in the alcove. Adding a standby circulating pump to the system for Sectors 1, 2, and 3 and providing normally closed interconnections between the supply and return headers of this system and the injector klystron system, increases the overall reliability of the klystron water systems at the injector end of the accelerator.

Figure 24-14 Flow diagram of injector klystron cooling-water system.

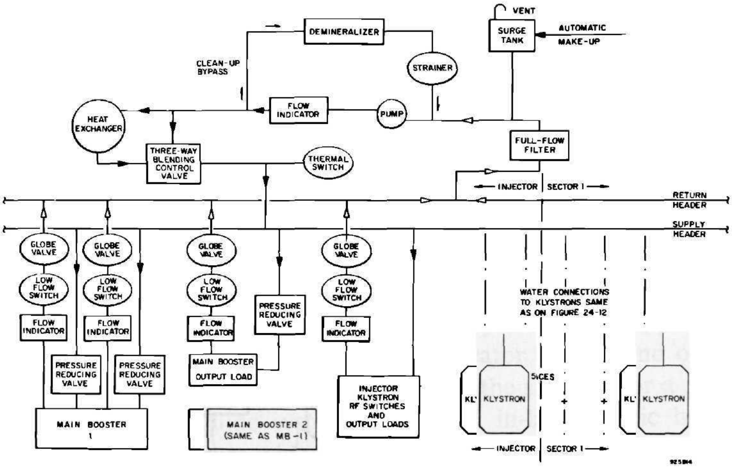


Table 24-6 Design parameters for main klystron cooling-water system

Parameters	*Stage 1*	*Stage 2*
Klystron tube and pulse transformer		
Flow (gal/min)	11	11
Heat load, normal (kW)[a]	57.4	57.4
Heat load, standby (kW)[a]	79.0	79.0
Water temperature, in, normal (°F)	95.0	95.0
Water temperature, out, normal (°F)	129.8	129.8
Water temperature, out, standby (°F)	143.0	147.5
Pressure drop, max (psi)	30	30
Cleanup bypass		
Flow (gal/min)	8	8
System totals		
Sectors per system	3	1
Klystrons per system	24	32
Flow (gal/min)	270	360
Heat load, normal (kW)	1378	1837
Heat load, standby (kW)	1896	2528
Water temperature, in, standby (°F)	95	99.5
Design pressure drop, max (psi)	85	85

[a] Includes 3 kW from pulse transformer.

Stage 2 operation requires thirty main systems, each serving thirty-two klystrons in a typical sector.

Design and operating parameters for the klystron cooling-water systems are summarized in Tables 24-6 and 24-7. Constant-temperature cooling water improves klystron performance, but a few degrees either way is not critical. A flow of 8.1 gal/min is required to hold the bulk temperature rise in the water within allowable limits. The operating flow was set at 11 gal/min to give a margin for resetting the low flow switches and to permit the use of later-model klystrons which can deliver more than the rated 24-MW peak power.

Identical components are used in all ten main klystron systems, and the injector klystron system components are similar to these. The basic features common to the pumps, heat exchangers, and piping of all accelerator cooling-water systems are summarized above. Operating characteristics of the circulating pumps and the heat exchangers for the main klystrons and for the injector klystrons are included in Tables 24-1 and 24-2.

Table 24-7 Design parameters for injector klystron cooling-water system

Components	*Flow (gal/min)*	*Heat load (kW)*
Two main boosters		
Regulator tube at 15 gal/min, 25 kW	30	50
Klystron tube and magnet at 25 gal/min, 50 kW	50	100
Main booster output load	10	25
RF switches and output loads	10	25
Klystrons and pulse transformers, five, at 11 gal/min, 79 kW (standby)	55	395
Cleanup bypass	5	—
Injector klystron system[a]	160	595

[a] Design pressure drop is 62 psi.

The main klystron system headers are 4-in. pipe, with block valves between sectors for easy conversion to Stage 2 operation. Injector klystron system headers are 3-in. pipe. Valved 1-in. branches are provided at each klystron. Capped stubs are included for each Stage 2 klystron. Pressure reducing valves, pressure gauges, and relief valves are incorporated in the $1\frac{1}{2}$-in. branches supplying the injector main boosters to hold the water pressure below the 70-psig rating of ceramic connectors used in the boosters. Each supply branch includes an in-line strainer and a flow indicator. A low flow switch is provided in each return branch. Supply and return connections to the klystrons are through short lengths of reinforced rubber hose fitted with double-valved quick-disconnect couplings.

Temperature control is the same as for the standard sector disk-loaded waveguide systems. However, since a single klystron can deliver 34 kW to the water, in-line heaters are omitted. Surge tanks, system protection, and demineralizers for the klystron systems are the same as for the disk-loaded waveguide systems. The frequent replacement of klystrons during accelerator operation increases the likelihood of contaminating the water system, as compared to the disk-loaded or rectangular waveguide systems. Thus a full-flow 5-μ filter is included at the pump suction to trap any particles entering the return header. The demineralizer is the same as that used in the disk-loaded waveguide systems.

Positron system (KGC)

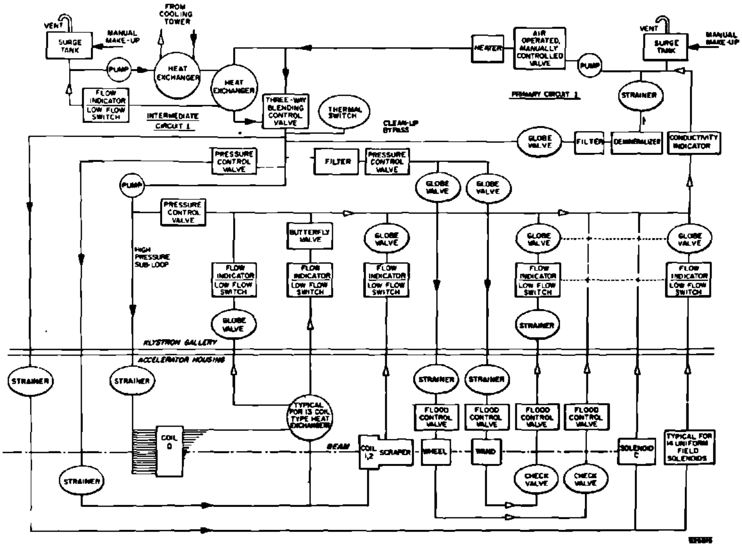
The positron cooling-water system is made up of three primary circuits and one intermediate circuit. Primary circuit 1 and the intermediate circuit cool the solenoids, positron radiators, and the scraper as shown in Fig. 24-15.

Primary circuit 2 cools accelerator sections 11-3B and 11-3C and the associated output loads and rectangular waveguides in the accelerator housing. During positron generation, primary circuit 3 handles the extra heat developed in fast valve 11-3 and in the coupler end plate and disk-loaded waveguide of accelerator section 11-3B. Primary circuits 2 and 3 appear in Figs. 24-16a and b, respectively.

Each primary circuit includes a pump, a heat exchanger, temperature control, a surge tank, provision for system protection, and a filter and demineralizer. The additional pump and the thirteen parallel-connected, double-wall, spiral-wound heat exchangers serving coil 0 are incorporated in a high-pressure sub-loop of primary circuit 1. The pump supplies the extra head needed to force sufficient water through the thirteen hollow conductors comprising coil 0 to remove over 700 kW of heat without exceeding the maximum allowable operating temperature of the interturn insulation. The thirteen exchangers reduce the bulk temperature of the water as it leaves the accelerator housing to a level compatible with the ratings of rotameter-type flow-monitoring instrumentation. Intermediate circuit 1 follows the same pattern as the primary circuits, but without the heater, three-way valve, filter, and demineralizer.

The pumps, demineralizers, filters, and most of the valves are located in a concrete-shielded cubicle in the positron equipment alcove in the klystron gallery. The four shell and tube heat exchangers are also in the cubicle, but the thirteen coil-type exchangers are installed in the accelerator housing. The cubicle walls are 1-ft thick, barite concrete with a density of 225 lb/ft^3.

Figure 24-15 Flow diagram of primary and intermediate circuit 1, positron cooling-water system.



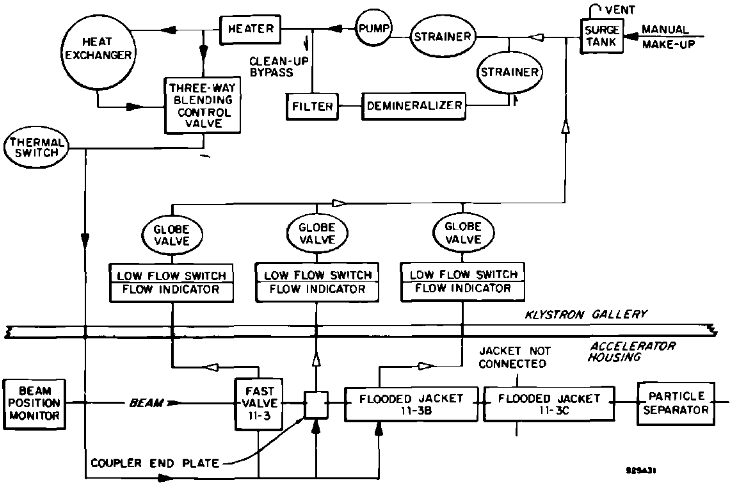
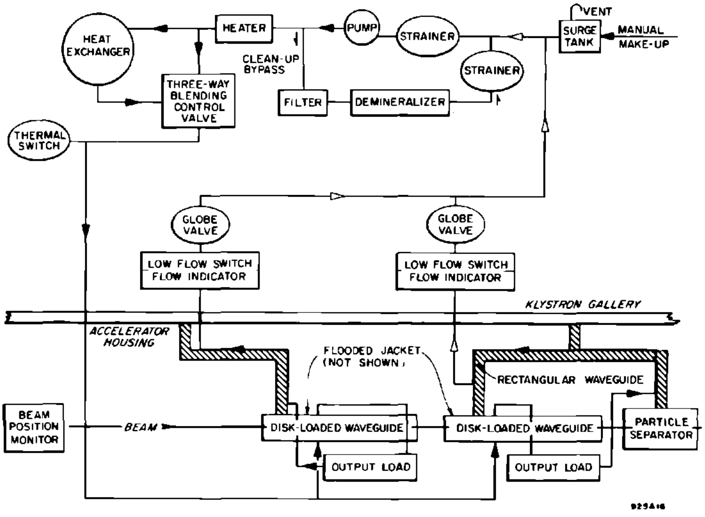


Figure 24-16a Flow diagram of primary circuit 2, positron cooling-water system.

During positron generation, flow control valves are operable from outside through slots in the wall of the cubicle, as shown in Fig. 24-17.

Heat loads and water flow for each circuit are summarized in Table 24-8. The beam positron monitor at the upbeam end of girder 11-3A and the particle separator at the downbeam end of girder 11-3C are cooled by the Sector 11 disk-loaded waveguide cooling-water system.

Figure 24-16b Flow diagram of primary circuit 3, positron cooling-water system.



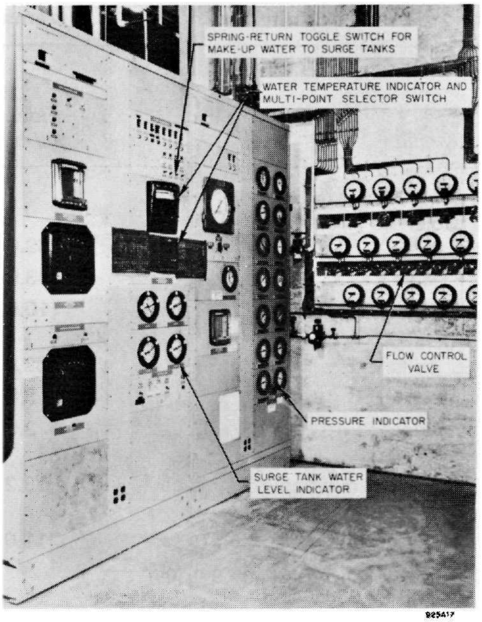


Figure 24-17 Water control center in the positron cooling-water system.

The basic features common to the pumps, heat exchangers, and piping of all accelerator cooling-water systems are summarized above. Characteristics of the positron system circulating pumps are included in Table 24-1. The pump in the sub-loop is of the vertical in-line type, with the pump shaft coupled to the motor shaft. Mechanical, face-type, shaft seals in the pumps in primary circuits 2 and 3 are interchangeable with those used on the pumps in the accelerator cooling-water systems. A pump seal injection circuit with two sub-loops is provided, one sub-loop for the main pump and one for the high-pressure pump. Low-conductivity water at a pressure above the suction pressure of the respective pump is circulated through the annulus between the inside diameter of the packing gland and a pair of face-type mechanical seals mounted back-to-back along the pump shaft. Water level in the supply tank of this auxiliary circuit is monitored by a differential pressure transmitter, a level indicator, and two pressure switches. As the seal injection water absorbs the heat developed by friction between the seal faces, a small branch of the cooling tower system is piped through the supply tank. The seal injection circuit also supplies 175 psig water pressure to stop leakage along the stems of the butterfly valves in primary circuit 1.

Characteristics of the positron system heat exchangers are included in Table 24-2. All heat exchangers except those for the sub-loop are of the shell

Table 24-8 Design and operating parameters for positron system cooling-water systems

Circuit	*Flow (gal/min)*	*Heat load (kW)*	*Water temperature rise (F°)*
Primary circuit 1			
Solenoid A			
Coil 0	39.0	705	123
Coil 1	43.0	81.2	6.5
Coil 2	10.0	17.4	11.9
Scraper—cooled by water from coils 1, 2	53.0	350	44.8
Solenoid C	3.84	17.7	54.0
Solenoid F	3.60	23.3	54.0
Solenoids G, I, N, P, R, T at 2.2 gal/min and 16.5 kW each	13.2	99.0	54.0
Solenoids H, J, O, Q, S at 2.2 gal/min and 16.8 kW each	11.0	84.0	54.0
Solenoids K, M at 2.64 gal/min and 20.0 kW each	5.28	40.0	54.0
Totals	128.9	1417.6	—
Radiators, total for wheel operation[a]	50.0	150.0	—
Primary circuit 1, totals	178.9	1567.6	—
Intermediate circuit, totals	550.0	1567.6	—
Primary circuit 2, totals	26.0	38.0	10.0
Primary circuit 3, totals	83.0	65.0	9.1

[a] Wand requirements at 3.0 GPM and 1.0 kW are considerably less than for the wheel.

and tube type. The inner and outer tubes of the thirteen coil-type, sub-loop exchangers are copper. Water from coil 0 flows through the inner tube. Water from the supply line to coils 1, 2, and the scraper is circulated through the outer annulus. The heat exchanger in primary circuit 1 is shown in Fig. 24-18.

The 6-in. main pump discharge header shown diagrammatically in Fig. 24-15 continues into the housing as one 6-, one 2-, and one 1½-in. supply line to the solenoids and one 2- and one ½-in. supply line to the radiators. In the housing, the 6-in. line branches into a 2½-in. line to coils 1, 2, and the scraper and into a 2-in. header cooling the thirteen coil-type heat exchangers. Thirty-one separate lines return the water to the main pump through a 6-in. suction header in the cubicle. Supply and return lines in primary circuits 2 and 3 are shown in Figs. 24-16a and b. The supply lines in

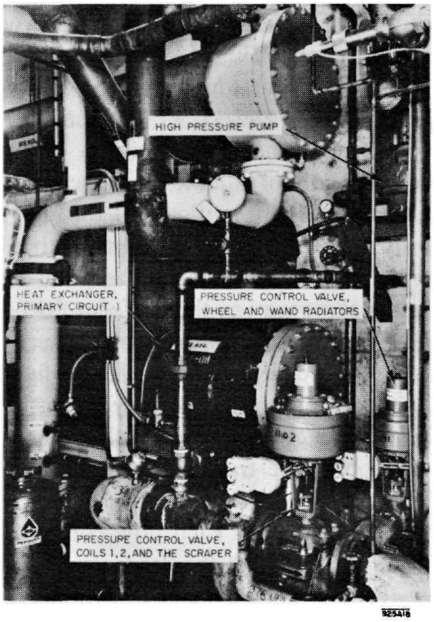


Figure 24-18 Heat exchanger and control valves in the positron cooling-water system.

the three primary circuits are insulated from the three-way valve to a convenient point in the housing. Return lines are not insulated. The drift tube, solenoids A and C, and the beam line and service equipment between fast valves 11-2 and 11-3 are mounted on the horizontal web of an all-welded aluminum I-beam, fabricated of 1-in. plate. The method of locating and supporting the resulting radiator, strongback subassembly on girder 11-3A permits the removal and replacement of the entire subassembly as a single unit.

To keep the girders free for realignment, connections between pipes fixed to the housing and components mounted on the jack-supported girders are made through flexible metal hose. The radiation to which personnel will be exposed in breaking the water lines leading to the strongback is minimized by locating the strongback end of each connection as far upbeam as practicable and by using quick-disconnect-type couplings. The water lines leading to and from coils 1, 2, and the scraper are stainless steel pipe with welded joints.

The two 2000-A power connectors and the associated bus bars on girder 11-3A are cooled by water from the high-pressure sub-loop. The water returns through the two 2000-A feedthroughs to coils 1 and 2 and the scraper or through the 2-in. return header for cooling water from the thirteen heat exchangers. Ceramic insulators prevent an electrical short-circuit to ground along the water lines.

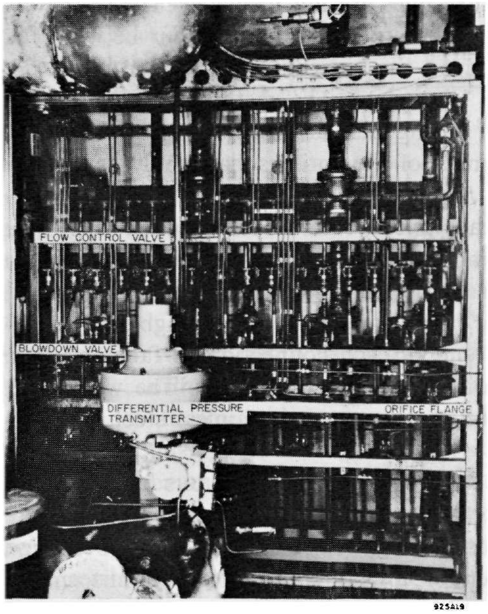
Water to the uniform field solenoids is delivered to two headers fixed to girders 11-3B and 11-3C, respectively. A short length of flexible bronze hose connects the header through a ceramic insulator to the inlet lead of each coil, or pair of double pancakes, in each of the fourteen solenoids. Water returns from the outlet lead through another ceramic insulator and flexible bronze hose to a header common to all coils in the given solenoid. A separate return line is provided for the water from each solenoid. Solenoid C is cooled in the same way as the uniform field solenoids.

With one exception, globe valves are used for flow control in all return lines. The exception is the butterfly valve used in the cooling-water return line from the thirteen coil-type heat exchangers.

Figure 24-19 shows the close-packed array of pipes, orifice flanges, differential pressure transmitters, and valves on the inside of the shielding wall. The outside of this wall is shown in Fig. 24-17. Air can be introduced through the valve beneath each flow control valve in Fig. 24-19 to blow radioactive water out through the drain valve in the accelerator housing.

Temperature control in primary circuit 1 is accomplished in essentially the same manner as in the disk-loaded waveguide system in a standard sector. The indicating controller returns the water to the solenoids and radiators at a

Figure 24-19 Inside west wall of cubicle, positron cooling-water system.



preset temperature of 104°F. An in-line heater keeps the supply water up to temperature during standby in order to prevent condensation on the coils and the uninsulated conductors in the housing and to reduce the severity of the thermal shock to which the circuit components are subjected at the commencement of positron generation.

Each of the four circuits is vented to atmosphere through a 30-gal copper surge tank connected through a 2-in. pipe to the pump suction header. The tanks also provide a reservoir for thermal expansion of the water as it rises to operating temperature. The three tanks in the primary circuits are connected to a common overflow and vent pipe leading up through the roof. Overflow from this line discharges into a concrete trench in the floor of the gallery from where it is drained down into the housing. Overflow and venting from the intermediate circuit is through a hole in the side of its surge tank. The tanks are filled through individual, manually controlled, normally closed, solenoid-operated valves fed off a common low-conductivity, makeup water header. Each tank is equipped with a differential pressure transmitter for water level indication and two pressure switches.

The water in primary circuits 2 and 3 may become slightly radioactive during positron generation. As the pressure in these two circuits is less than that of the cooling tower water, there is no danger of contaminating the tower in the event of leakage through either heat exchanger. Conditions are just the opposite in primary circuit 1. Water in this circuit not only runs at a higher pressure than cooling tower water, but it also becomes highly radioactive during positron generation. To avoid contamination of the tower in the event of leakage through the heat exchanger, primary circuit 1 is cooled by low-pressure intermediate circuit 1, which, in turn, is cooled by tower water. Leakage of radioactive water from the two pumps in primary circuit 1 is prevented by the pump seal injection circuit. One of the two pressure switches provided to monitor the water level in the seal injection supply tank gives a low level alarm, the other shuts off the seal injection pump when the water level drops to within 3 in. of the bottom of the supply tank. Two additional pressure switches in the seal injection sub-loop to each primary pump shut off the seal injection pump if the pressure in the line is either too high or too low. The pumps in primary circuit 1 cannot be started unless the pump in the seal injection circuit is running.

The solenoid-operated flood-control valves in the water lines serving the wheel and wand radiators and the four air-operated drain valves in primary circuit 1 are necessarily located in the accelerator housing. To prolong the life of radiation-resistant elastomeric seals and packing, these valves are grouped within two lead brick enclosures on the floor of the housing. A detailed account of the purpose and operation of the flood-control system is given in Chapter 23. Capped nipples are union-connected to stubs in the return lines of both radiators, providing an emergency vacuum connection between the flood control valves on the wheel and wand supply and return lines in the housing. The vacuum pump can be located in the gallery, pumping through a $1\frac{1}{2}$-in. copper pipe installed in penetration 11-04. A 2-in. flexible bronze hose runs from the end of the copper pipe to the immediate vicinity of the stubs. The hose is terminated with a "T" and fittings mating with both the 2-in. stub on the wheel radiator line and the $\frac{1}{2}$-in. stub on the wand radiator line. All openings in this emergency vacuum line are capped to keep out dirt. Diagnostic lines running up to the gallery facilitate leak-checking the portions of the wheel and wand supply and return lines isolated in the housing by closure of the flood control valves.

Water released by drain valves is piped downbeam into a 600-gal concrete sump tank built into the alcove at the foot of Sector 11 accessway. A low-crested dam on the floor of the housing just downbeam from girder 11-3C retains any water that leaks or is spilled from the system. Water trapped behind the dam is piped into the sump. Leakage from equipment in the concrete-shielded cubicle is collected in a concrete trench in the gallery floor and drains into the gutter on the south side of the housing floor at a point above the dam. A pump with remote control and level indication makes it possible for personnel in the gallery to empty the contents of the sump into a tank for disposal or storage, depending on the radioactivity of the water.

When power to solenoid C and the uniform field solenoids is interrupted, heat generation in the coils immediately ceases and the temperature of water leaving the coils quickly drops from 158° almost to 104°F, the temperature of the supply water. The ceramic insulators that prevent electrical short-circuits to ground along the water return lines from the individual coils would be subjected to a severe thermal shock by this sudden temperature change. To minimize the shock, the pump motors in primary circuit 1 are interlocked with the three solenoid power supplies. When any one of the power supplies is turned off, the pumps stop, thereby cutting off the supply of "cold" water to the coïls. An adjustable time delay, presently set at 5 min, prevents restarting the pumps until the insulators have had a chance to cool down.

The in-line heater in each primary circuit is interlocked with its pump motor to make sure the pump is on before the heater is energized. Heaters are also interlocked so that power is cut off when failure of instrument air results in loss of temperature control.

On solenoid C and the uniform field solenoids, gas-filled, hermetically sealed, bimetallic thermostats are mounted in pairs on the outlet lead from each coil, as close to the body of the coil as possible. A normally closed contact in each thermostat opens at 186°F to break an interlock chain which, in turn, shuts off the power supply. The interlock chain is a series circuit made up of all the thermostats in any given solenoid. The thermostats protect against burnout should the water line serving a particular coil become plugged anywhere between the supply and return header on the solenoid—a condition not readily detectable as a change in the total flow through the five or six coils comprising the solenoid. Thermostats are likewise provided on the return line from coil 1, 2, and the scraper. Protection against malfunctioning of the three-way valve is afforded by a thermal switch mounted on the piping downstream of the valve. It is set to break the interlock chain, shutting off the power supplies when the system temperature exceeds 130°F. Temperatures at thermocouples on the thirteen outlet leads from coil 0 are indicated in the Sector 11 instrumentation and control alcove.

Primary circuit 1 includes an air-operated manually controlled butterfly valve, spring returned to the normally closed position. The valve and the pump motor are interlocked through a pressure switch in the air line to the valve. The switch does not allow the pump to start until the valve is closed, as evidenced by loss of pressure in the air line. The purpose of the interlock is to protect primary circuit 1 piping from the pressure surges that accompany pump startup. Pushing the "start" button turns on the main pump of primary circuit 1. A pressure switch downstream from the air-operated valve delays startup of the sub-loop pump until the main pump is running and the valve is open.

The pressure of water supplied to the radiators is automatically controlled by an air-operated valve. The pressure of water supplied to coils 1, 2, and the scraper is controlled by a similar valve. Both valves are shown in Fig. 24-18, together with the pump in the high-pressure sub-loop. As a precaution against overpressure in the supply line to the wheel radiator, a pressure switch in the gallery is tied to the supply line in the housing through a small-diameter copper tube. Should the switch setting be exceeded, the pump is shut off. Provision is made for flushing this line with low-conductivity makeup water.

On all lines except those from coil 0, an orifice flange and differential pressure transmitter provide an air signal for indication and alarm. Rotameter-type flow indicators and low flow switches of the type used in the accelerator cooling-water systems are provided in the return lines from coil 0. Monitoring flow in the return instead of the supply line eliminates the possibility that a leak may give a false indication of adequate flow.

One of the pressure switches provided to monitor water level in the surge tank gives a low level alarm light; the other shuts off the pump when the water level drops to within 3 in. of the bottom of the tank.

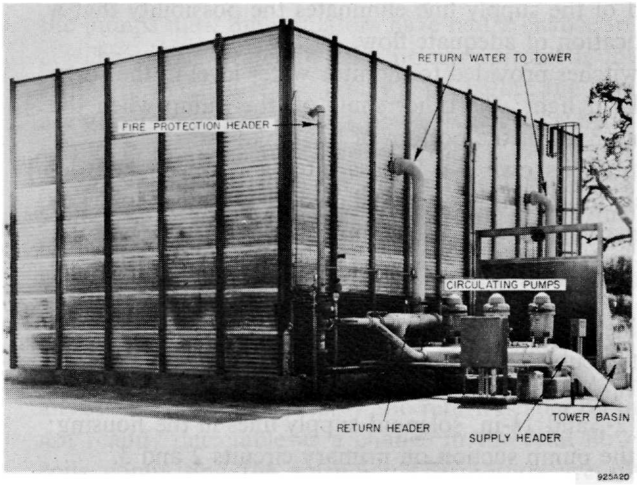
Each primary circuit has its own 5-μ bypass filter and mixed bed demineralizer. A 100-mesh in-line strainer is installed at the outlet of each demineralizer. Each primary circuit is also equipped with a temperature-compensated conductivity sensor. The supply line to the radiators includes a full-flow filter in the cubicle as well as individual Y-type strainers on the wheel and wand supply lines in the housing. An additional Y-type strainer on the wand return line in the cubicle picks up any particles that may spall off the heat transfer surface of the wand during irradiation. The Y-type strainers are also used in the 6-, 2-, and 1½-in. solenoid supply lines in the housing; similar strainers protect the pump suction on primary circuits 2 and 3.

Cooling tower water (DBR)

The cooling tower water for the two-mile accelerator is supplied from two independent systems. Cooling tower 1201 serves the first mile, through Sector 15. Cooling tower 1202 serves the second mile. The towers are located at Sectors 9 and 22, respectively, on the south side of the klystron gallery. Each tower comprises two cells of the counterflow-induced draft type. Each tower is rated at 11 MW and cools 5000 gal/min from 90° to 75°F at 68°F (wet bulb) ambient. The towers are 60 ft long, 30 ft wide, and 26 ft high. The materials are the same as those used in cooling tower 101 described earlier in the chapter.

The two-speed fan in each cell is driven by a motor which develops alternatively 15 hp and 60 hp to allow for variation in heat load. Each tower has three pumps, one of which serves as a spare. The pumps each deliver 2500 gal/min at 41-psig discharge pressure. Each pump is driven by a 75-hp motor. The pumps are of the two-stage vertical turbine type. A 30-mesh screen protects the suction well of each pump. Cooling tower 1201 appears in Fig. 24-20. The water is distributed through underground headers running along the south side of the klystron gallery. The headers include flanges for adding a tower to each system. The 16-in., cement asbestos pipe used for the headers adjacent to the tower steps down to 10 in. at the ends of each system. Valved supply and return takeoffs of 8-in. steel pipe serve branches feeding the heat exchangers in the mechanical equipment alcove of each sector. Similar $1\frac{1}{2}$-in. takeoffs serve the electrical substation alcoves. Butterfly valves are provided to isolate each exchanger for cleaning and repairs. A flow

Figure 24-20 Accelerator cooling tower 1201.



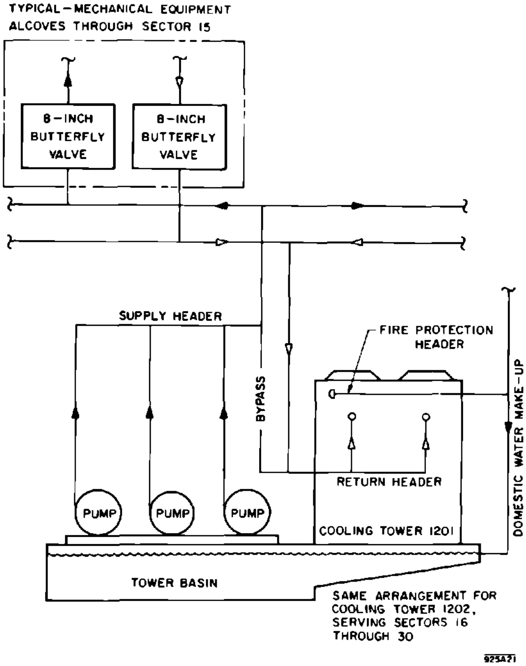


Figure 24-21 Flow diagram of accelerator cooling tower water systems.

diagram typical for the two accelerator cooling tower water systems is shown in Fig. 24-21. A two-step thermostat immersed in the basin of each tower controls the fans. When the fans are turned on, they both run at low speed. A rise in water temperature above 70°F puts one fan on high speed. The second fan goes on high speed when the water exceeds 75°F. Pump discharge pressure is indicated locally and in the Central Control Room (CCR). Makeup water is introduced as it is needed through a float-controlled valve. A low level switch shuts off the pump motors and relays an alarm to the CCR. Switches are provided which shut down the fans in the event of excessive vibration. An automatic "deluge" system protects the tower against fire.

Operating experience—accelerator cooling-water systems (CJH)

Cooling-water systems serving the injector and Sectors 1 and 2 were put into operation in September 1964. All systems through Sector 15 except the positron system were operating by August 1965. Systems in Sectors 16 through 30 were ready by October 1965. The positron system followed early in 1966. The installation subcontract required that the subcontractor flush, clean, rinse, refill, and turn on each system. Upon completion of each system, it was thoroughly flushed with domestic water to wash out bits of solder and to dissolve flux and other water-soluble foreign materials on the inside of the pipes. After flushing, the system was filled with a commercial phosphoric acid-base detergent solution and left to soak for several hours to clean out scale, products of corrosion, and other contaminants remaining after the water flush. The solution was then drained and the system was rinsed with low-conductivity water to remove all traces of the detergent. Filters were replaced, strainers were emptied, and the system was refilled with low-conductivity water. The pump was then turned on and the system was put into operation. The accelerator cooling-water systems have been operating since startup with only minor problems.

Even before all the systems were completed, continued evidence of foreign matter in those accepted as operational led to the decision to reclean and backflush all accelerator cooling-water systems. The debris afterward removed from the filters and strainers included many small droplets of solder, metal chips, fibrous paper-like materials, fragments of Teflon joint tape, pipe sealing compound, and demineralizer resin. This experience and the results from the analysis of many water samples led to the addition of strainers in each supply branch upstream from the low flow switch.

Although equipped with separate temperature controls and three-way valves, the injector constant metal temperature system and the disk-loaded waveguide system for the Sector 1 originally shared a common heat exchanger and heater. The heater was energized only through the Sector 1 controller. With the controller set at 113°F, water temperature excursions ranging between 109° and 115°F were occasionally observed in the injector system during the first months of operation, particularly when the pulse repetition rate was increased to 360 per second. Upon investigation, it was found that the temperatures of the two systems changed at different rates. When one controller called for more heat and the other for less, the temperature of the injector system fluctuated above and below that of the disk-loaded waveguide system. The "hunting" instability was attributed to the existence of separate temperature controls for water from a common recirculating source. Stability could be restored by a manual adjustment of the injector system controller to compensate for the increased range of temperature fluctuation. The problem was ultimately corrected by isolating the two systems and providing each with its own heat exchanger and heater.

Instances of low water temperature observed when the beam was off were caused by early failure of the in-line heaters described earlier. The original heaters incorporated multiple U-shaped copper-clad heating elements, heliarc welded to a stainless steel flange. The heating elements were electrically connected for 480-V delta operation. In eight or ten of the heaters, an open circuit in one leg of the delta was responsible for water temperatures running

5°–7°F below normal when the accelerator was turned off. The problem was solved by substituting stainless-clad heater elements.

A specific resistance of between 2 and 6 megohms is maintained in the various systems by using low-conductivity makeup water and by continuously bypassing 5 to 15 gal/min through a mixed bed demineralizer containing $1\frac{1}{2}$ ft^3 of resin. Regeneration of the resin is necessary about once a year.

Some difficulty was experienced with the low flow switches installed in large numbers along the accelerator to protect components from overheating due to interruption of the cooling-water supply. In practically every instance of switch failure reported, the equipment was turned off when the water flow was normal or was not turned back on when flow was restored after shutdown. Substitution of a hermetically sealed switching unit for the one furnished as original equipment has taken care of this problem.

Cooling tower makeup water is taken from the domestic supply. Although relatively soft (20–40 ppm total hardness), it is corrosive and must be treated to protect pipes and heat exchangers. Tower water is treated with a corrosion inhibitor and a biocide, both of which are commercially available products. The inhibitor contains a blend of active ingredients in a polyphosphate base. The inhibitors cover all metal surfaces with a film protecting them against the formation of anodic and cathodic corrosion cells. The maximum rate of corrosion recorded from test pieces in the several systems was less than 0.004 in./yr. The commercial biocide is toxic to microorganisms and contains a dispersant to retard microbial deposits. It is necessarily nontoxic to animal and fish life, because the overflow from the tower ends up in San Francisquito Creek.

The proper surveillance of tower water requires a number of routine tests. The pH value is measured every day. Total hardness, calcium hardness, and phosphate concentration are checked weekly. The tower baffles and the basin are inspected every month for algae, slime, and deposits of bacterial growth. Every 3 months, samples are submitted to a laboratory for the following tests: tower water microbiological analysis; slime microbiological analysis; makeup water chemical analysis for hardness, pH, and chlorides; tower basin water analysis for hardness, pH, and chlorides; and a chemical analysis of solid deposits taken from the tower piping. The test pieces in the tower system are inspected, measured, and weighed every quarter to determine corrosion rates. The results of the treatment and control of tower water as outlined above have been very satisfactory. There has been little trouble either with heat exchanger fouling or with corrosion in the tower water system.

Experience with the positron system has been much the same as that with the other accelerator systems. On one occasion, the failure of an edge-cooled magnet coil filled the system with copper and copper oxide particles. This rapidly decreased the specific resistance of the water from above 6 megohms to the neighborhood of 0.15 megohm. However, within 72 hours, continued recirculation of the water through the demineralizer cleaned up the system and increased the resistivity to an acceptable level.

24-3 Beam switchyard and end station water systems

Magnet coil cooling-water systems (SRC)

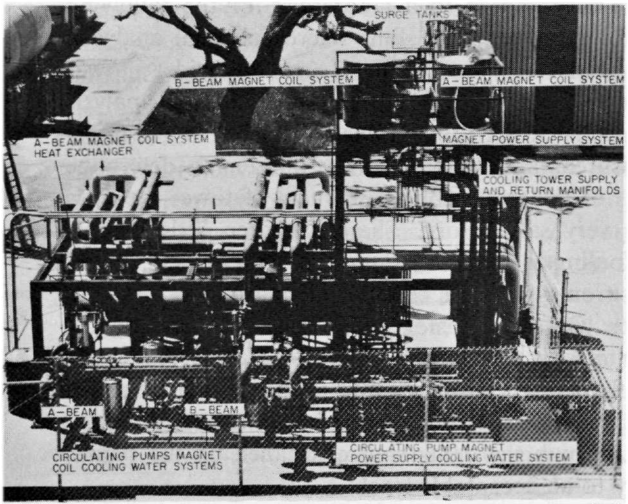
A closed-loop, low-conductivity cooling-water system serves the A-beam magnets, high-*Z* collimator C-10, high-*Z* slit SL-11, and tune-up dump D-2. A similar system serves the B-beam magnets, high-*Z* collimator C-0, high-*Z* slit SL-31, and tune-up dump D-10. The two systems are cross-connected through normally closed valves. The pump and heat exchanger in each system are designed to handle the aggregate flow of both systems. The pumps, heat exchangers, and other auxiliary equipment are located on the magnet heat exchanger pad, as depicted in Fig. 24-22. A flow diagram typical for both magnet coil, cooling-water systems is shown in Fig. 24-23.

Operating characteristics of the circulating pumps for the magnet coil cooling water systems are included in Table 24-1. The pumps are of the close-coupled single radial-stage centrifugal type. The vertical split casings and open impellers are low-zinc bronze. Shaft seals are mechanical, with a carbon rotating face, a carbide stationary face, and Teflon secondary seals.

Operating characteristics of the heat exchangers are included in Table 24-2. The shells, baffles, and tube sheets are silicon bronze. The $\frac{5}{8}$-in. o.d. tubes are 90-10 copper–nickel. Steel is used for the channels and channel covers.

Piping for the systems is copper. The fittings are copper or low-zinc bronze. Individual lengths of flexible metal hose connect the supply headers on the upper level of the BSY housing with each item of equipment in the

Figure 24-22 Magnet heat exchanger pad.



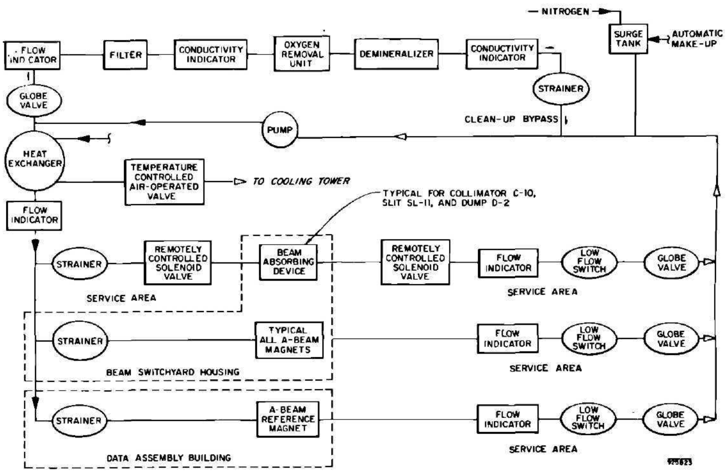
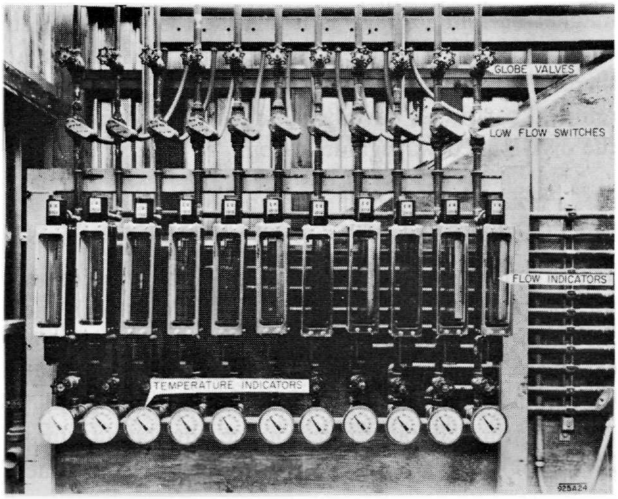


Figure 24-23 Flow diagram of magnet coil cooling-water system.

lower level. The individual return lines are flexible metal hose to the upper level and continue as rigid pipe through the service shafts to a thermometer, rotameter-type flow indicator, and a low flow switch in one of the service areas, as shown in Fig. 24-24. A single header along the cableways returns the water to the heat exchanger pad.

The low-conductivity water temperature is maintained at 95° ± 2°F by an indicating controller through an air-operated butterfly valve which regulates

Figure 24-24 Return lines, magnet coil cooling-water system.



the flow of cooling tower water through the heat exchanger. The temperature-sensing element is a mercury-filled bulb. When the magnets are turned off, the flow of cooling tower water through the heat exchanger is reduced to the point where the energy contributed by the circulating pump is sufficient to hold the water temperature at 95°F to prevent condensation on the magnets and exposed conductors in the BSY housing, which is hermetically sealed during high-power beam operation.

A 115-gal copper surge tank to accommodate the thermal expansion of the cooling water in the system is located above the magnet heat exchanger pad and is connected to the return line at the pump suction. The tank is equipped with an automatic makeup water supply, a liquid level sight glass, and level controller. The makeup water is introduced through a solenoid valve controlled by a pressure switch. A nitrogen atmosphere is maintained above the water in each surge tank.

The differential pressure across an orifice downstream from the circulating pump is converted to a pneumatic signal and transmitted to a flow indicator mounted on the local control panel. When the flow rate drops below a safe level, a pressure switch actuates an alarm in the Data Assembly Building (DAB). Individual supply piping is provided from the service areas to the two collimators, two slits, and two dumps which have water-to-vacuum interfaces. To minimize the amount of water entering the vacuum system in the event of a leak at any point in the water-to-vacuum interface, remotely operated solenoid valves are provided in each supply and return line. The solenoid valves are located in the service areas. When an accident occurs they are closed from switches on the water control panel in the DAB. A pressure switch monitors the water level in the surge tank and turns on a light in the DAB when it reaches the low level alarm point. When it drops a further 6 in., another pressure switch shuts off the circulating pump.

Because of the close tolerances on momentum resolution, the allowable magnet current leakage is less than 1 mA. A buildup of a low-resistance copper oxide film across the ceramic insulators at the magnets would, therefore, be intolerable. In this system, therefore, replaceable oxygen-removal cartridges have been added to the typical cleanup bypass as used in the disk-loaded waveguide system.

Magnet power supply system (SRC)

The magnet power supply, cooling-water system serves the power supplies for the magnets used in the BSY, together with the reference magnets and the incidental test equipment in the DAB. The pump, heat exchanger, and other auxiliary equipment are located at the magnet heat exchanger pad shown in Fig. 24-22. A flow diagram appears in Fig. 24-25.

Operating characteristics of the circulating pump are included in Table 24-1. The basic features of the pump are the same as those given for the

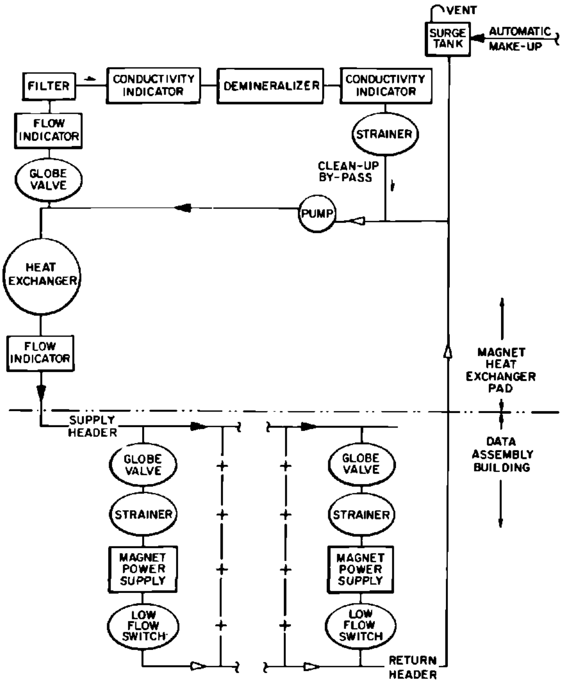


Figure 24-25 Flow diagram of magnet power supply cooling-water system.

pumps used in the magnet coil systems except that the stationary seal face is ceramic.

Operating characteristics of the heat exchangers are included in Table 24-2. The basic features of the heat exchanger are the same as those given for the exchangers used in the magnet coil systems.

The piping is copper. The fittings are copper and low-zinc bronze. The water is distributed through two sets of insulated 2-in. supply and return headers in the DAB, with individual branches to and from each piece of equipment. A block valve is included in each branch.

No temperature control is provided. The temperature varies with the ambient and load conditions.

A 20-gal copper surge tank to accommodate the thermal expansion of the cooling water is located over the magnet heat exchanger pad and is connected to the return line at the pump suction. The tank is equipped with an automatic makeup water supply, a liquid-level sight glass, and a level controller. These are similar to the ones in the magnet coil system. The tank is vented to the atmosphere.

Provision for flow indication and low flow alarm are the same as for the magnet coil system. There are no branch flow indicators. The filter demineralizer is the same as for the disk-loaded waveguide system.

Pulsed magnet power supply system (SRC)

This closed-loop, low-conductivity cooling-water system serves the pulsed magnet power supplies and two regulators. The pump, heat exchanger, and other auxiliary equipment are located in a cabinet adjacent to the power supplies in the DAB.

Operating characteristics of the circulating pump are included in Table 24-1. The basic features of the pump are the same as those given for the pumps used in the magnet coil system.

Operating characteristics of the heat exchanger are included in Table 24-2. The shell is red brass, the baffles yellow brass, the tube sheets forged brass. The $\frac{3}{8}$-in. o.d. tubes are Admiralty Metal. Forged brass is used for the channels and cast iron for the channel covers.

The piping is copper. The fittings are copper and low-zinc bronze. The water is distributed through a $2\frac{1}{2}$-in. insulated supply and return header, with individual branches to and from each power supply and regulator. Block valves are provided in each branch.

Water at a constant temperature of 85°F is required for the operation of the pulsed magnet power supplies. The method of temperature control is the same as that used in the disk-loaded waveguide system for a standard sector. An in-line electric heater of approximately 6 kW capacity brings the system up to 85°F from a cold start and holds it at temperature during periods of low-power operation.

A small copper surge tank to accommodate the thermal expansion of the cooling water in the system is located overhead. The tank is connected to the return line at the pump suction and is equipped with a liquid-level sight glass. The tank is vented to the atmosphere.

When flow drops below 80% of normal in any branch line, a low flow switch de-energizes the power supply or regulator served by that line. The filter demineralizer is the same as for the disk-loaded waveguide system.

B-beam target system (KGC)

The B-beam target, cooling-water system serves a number of small loads in the B-beam target room. Supply and return connections to the system are also provided for end station B. The pump, heat exchanger, and other auxiliary equipment are located in a shielded heat exchanger housing beside the end station, as shown in Fig. 24-26. The circulating pump is the same as used in the rectangular waveguide–drive line systems, with a single-speed motor and a single mechanical seal. Operating characteristics of the heat exchanger are included in Table 24-2. The type, arrangement, and materials are the same as for the exchanger in the pulsed magnet power supply system. The cooling tower water temperatures given in Table 24-2 include no allowance for changes in input temperature due to simultaneous operation of the radioactive systems connected in the same series cooling tower water circuit.

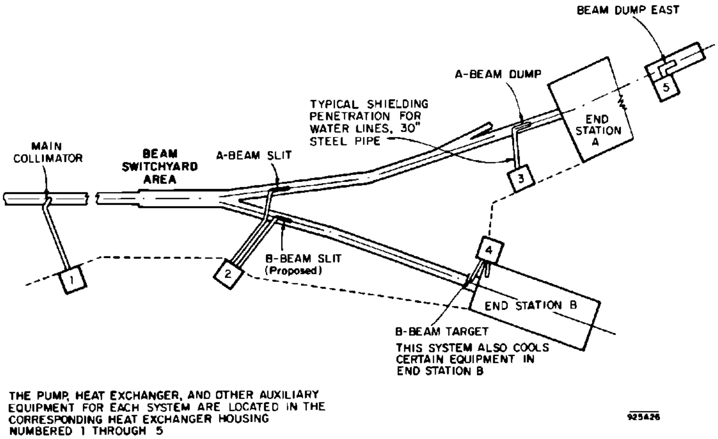


Figure 24-26 Location of B-beam target and radioactive cooling-water systems.

Copper pipe is used throughout. The fittings are copper and low-zinc bronze. A remotely controlled solenoid valve is installed in the supply header to the target room, another in the supply header to the end station. A length of flexible metal hose connects each piece of equipment to a branch from the supply header and to an individual return line. A check valve replaces a second solenoid valve in the return line. The solenoid and check valves are installed within the target room or end station shielding. In the event of a leak of sufficient magnitude to close the solenoid valve, the check valve prevents further loss of water due to reversed flow in the return line.

No temperature control is provided. The water temperature varies with the ambient and load conditions.

A 50-gal surge tank accommodates thermal expansion of the water in the system. The low alarm and pump shutdown levels are 6 and 12 in., respectively, below the operating water level. A 6-in. drop in level is equivalent to a loss of 5 gal from the 120-gal system. Makeup water is introduced through a manually controlled solenoid valve. The sump tank is vented to the atmosphere.

A positive pressure differential is maintained between the tube and shell sides of the heat exchanger. Because of the higher pressure of the cooling tower water on the tube side, any leakage will be into the radioactive shell side, thereby preventing contamination of the cooling tower. Should the pressure differential fall below a preset value, an interlock in the pump motor control circuit shuts down the circulating pump. The pump is also automatically stopped when the water level in the surge tank indicates excessive leakage from the system. Another signal simultaneously closes the two solenoid valves on the supply headers. An alarm light alerts the DAB to low flow in any of the return lines. An air-operated, manually controlled butterfly valve in the pump discharge line protects the system against pressure surges during startup. Operation of a similar valve is described in connection with primary circuit 1 in the positron system. Pressure, level, and flow instrumentation is pneumatic, with indicators and pressure switches mounted in cabinets outside the heat exchanger housing.

The filter demineralizer is the same as for the magnet coil systems except that no provision is made for deoxygenation. Flow through the cleanup bypass is 10 gal/min.

Radioactive systems (FFH, SRC, GIS)

The radioactive systems comprise the five closed-loop, low-conductivity cooling-water systems serving the main collimator, the A-beam slit, the A-beam dump, beam dump east, and a future B-beam slit. Each system must be capable of absorbing the full energy of the beam. The pump, heat exchanger and other auxiliary equipment for each system are located in one of the heat exchanger housings shown in Fig. 24-26. When the beam strikes water, the water is partly decomposed into hydrogen and oxygen. The gases are carried through the system, eventually collecting above the water surface in the surge tank. Since flame propagation in air requires only 4% by volume of hydrogen, the resulting mixture of free hydrogen and oxygen constitutes a serious explosion hazard.

The beam power may reach 600 kW in Stage 1 and 2.2 MW ultimately. The level of radioactivity will be very high in the 1500 gal of water used to absorb the beam energy in each system. The saturation activity for a 1-MW beam has been estimated[2] as shown in Table 24-9. Hydrogen peroxide and small amounts of tritium will also be generated. Because of the radioactivity of the gases accompanying the hydrogen, particularly the carbon dioxide and tritium, venting is not permissible during high-energy runs. The presence of an explosive gas mixture and the radiation level during operation dictate the requirement for separate shielded water systems. The dangers inherent in piping radioactive water over the relatively long distances between the beam-absorbing devices and the difficulty of scheduling emergency maintenance without shutting down the beam also favors the use of individual systems.

Table 24-9 Saturation activity for a 1-MW beam

Radioactive isotope	*Half-life (min)*	*Activity (Ci)*
Oxygen-15	2	35,000
Nitrogen-13	10	1,390
Carbon-11, present in CO_2	20	1,390
Beryllium-7	(53 days)	280
Total activity		38,060

The two most promising ways of removing the hydrogen were by delayed venting and by recombination with oxygen to form water. In comparison with a recombiner for each closed-loop water system, studies showed that economical removal of the CO_2 would require a costly chemical complex, including a holdup tank and the piping linking the tank with the CO_2 removal equipment, the radioactive cooling-water systems, and the atmosphere. It was found that the ^{7}Be is effectively removed in the demineralizers, thus greatly reducing the time after shutdown before the system is accessible for maintenance.[3] The metal surfaces in contact with the radioactive water are Type 316L stainless steel except as noted below. This material is compatible with the aluminum used in the collimators and slits and the copper used in the beam dumps. It is also relatively insensitive to carbide precipitation in the heat-affected zones adjacent to welds and is less susceptible than the other 18-8 stainless steels to stress corrosion cracking and pitting corrosion in the presence of chlorides. Where a cast material was required, as for the valve bodies, pump casings, and impellers, cast Type 316 stainless steel was used.

Operating characteristics of the circulating pumps at 1750 rpm are included in Table 24-1. The pumps are of the single-stage radial centrifugal type. The vertical-split casings and open impellers are Type 316 stainless steel. The pumps are driven through flexible couplings by two-speed (875/1750 rpm) motors, since half the rated flow will suffice during most of Stage 1 operation. Calculations also indicate that the life of the beam-line windows in the two dumps can be greatly increased by reducing the water pressure. The double mechanical seal used in each pump is of the type used in the pumps in primary circuit 1 of the positron system, except that the secondary seals are Buna-N. At the dose rate measured along the pump shaft, it is predicted that the carbon and ceramic sealing faces themselves will wear out at least 2 yr before the secondary seals succumb to radiation damage. A pump seal injection circuit similar to that described for the positron system circulates low-conductivity water at 100 psig through the space between the two shaft seals. The seal injection circuit also supplies water to back up the polyurethane O-rings sealing the stem of the air-operated valve in the pump discharge line. The transfer pumps are of the self-priming centrifugal type, with a single mechanical shaft seal. They are used to move the water between the system and a mobile retention tank. Transfer hoses may be attached to blind flanges provided on each system.

Operating characteristics of the heat exchangers are included in Table 24-2. All joints between the tube and shell sides of the exchangers are seal-welded to avoid any possibility of radioactive water diffusing into the cooling tower water system. A mass spectrometer-type leak detector sensitive to less than 1×10^{-7} cm^3/sec of helium at atmospheric pressure was used to establish the integrity of each exchanger.

Type 316L stainless steel pipe of x-ray quality was used throughout. The welds were made by the heliarc process using AWS/ASTM, Type ER 316L

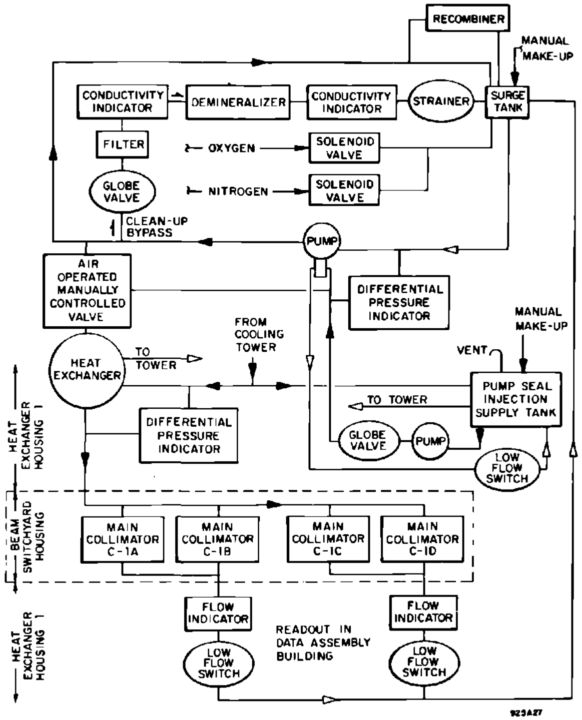


Figure 24-27 Flow diagram of typical radioactive cooling-water system.

filler rod.* Both the welders and the procedures were qualified under the provisions of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. All welds were radiographically examined. The supply and return headers for each system leave the heat exchanger housing through a large-diameter access sleeve and enter the lower level of the BSY housing near the device they serve. Flexible metal hoses with remote disconnect couplings at both ends connect the supply and return headers to the device. Provision is made for draining each system through a line passing through the access sleeve to the transfer pump. A flow diagram for the system serving the collimator is included in Fig. 24-27. It is typical of the radioactive water systems discussed in this section.

No temperature control is provided. The temperature varies with the ambient and load conditions.

The surge tanks are of all-welded stainless steel construction as shown in Fig. 24-28. To help separate the entrained gases, the return water is introduced tangentially above a perforated plate. The water level is maintained

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* American Welding Society/American Society for Testing and Materials.

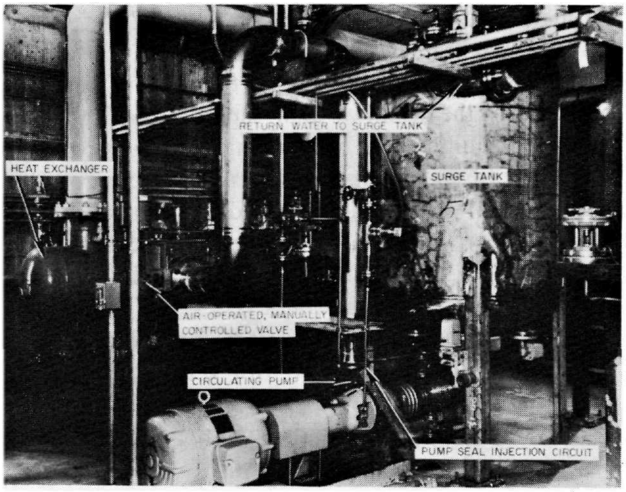


Figure 24-28 Surge tank, radioactive cooling-water system.

below the plate. The water returns to the pump suction through an antivortexing arrangement to prevent pump cavitation. The manually operated, makeup valves for each surge tank and seal injection supply tank are located outside the shielded housing.

The recombiner which eliminates the explosion hazard by disposing of the free hydrogen mounts on the top of the surge tank. The gases in the tank are drawn through a heated catalyst which recombines the hydrogen and oxygen. To make sure that there is always a surplus of oxygen, an oxygen sensor is connected to the recombiner. If it reads too low, a solenoid valve is automatically opened, admitting additional oxygen through the bottom of the surge tank. Provision is made for flooding the surge tank with nitrogen should the hydrogen content of the evolved gases rise above 2%.

Five interlocks stop the pump of the respective radioactive system and interrupt the beam under the following conditions:

1. Low differential pressure between the pump seal injection circuit and the main pump suction
2. Low level in the seal injection supply tank
3. Low flow in the seal injection circuit
4. Low level in the surge tank
5. High level in the surge tank.

To keep makeup water from leaking through the supply valves and overfilling the surge tanks and seal injection supply tanks, normally closed valves are installed in pairs, one at each end of a "T" in the supply line. The valve on the tank side is of the spring-return type. During operation, leakage through the valve on the supply side is drained through a normally open valve on the branch of the "T."

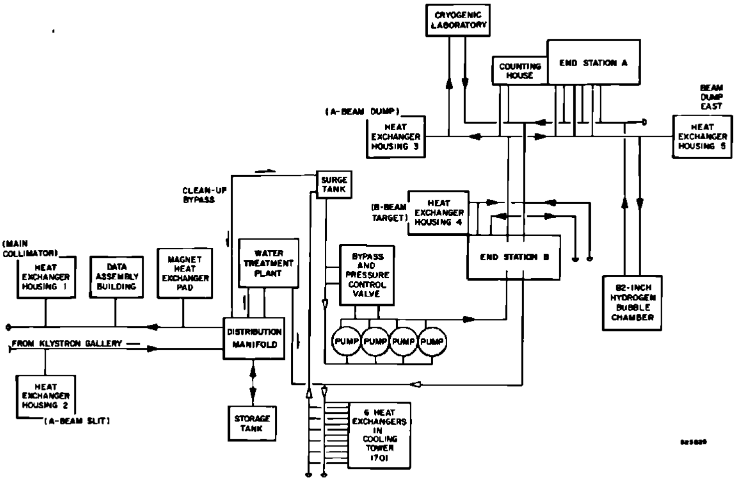
To prevent pressure surges from damaging any part of the system, particularly the windows that separate the water from the vacuum in the two beam dumps, the main pumps are interlocked so that they cannot be started until an air-operated manually controlled butterfly valve in the respective discharge line is closed. The valve is opened after the pump is started. Operation of a similar valve is described more fully in connection with primary circuit 1 in the positron cooling-water system.

The filters and demineralizers are the same as those used in the disk-loaded waveguide systems except that the demineralizer tank is of all-welded construction and is shielded with 1 in. of lead around the periphery. The conductivity of the water is measured before and after the demineralizer in each system. The flow rate through the cleanup bypass is 10 gal/min.

Target area cooling-water system (FFH, SRC)

The 41,500-gal target area system serving end station A, end station B, the research yard, and the cryogenics building is the largest of the low-conductivity, cooling-water systems. The system also supplies low-conductivity makeup water to cooling-water systems in the BSY and the end stations and can be used to supply makeup water to LCW systems in the klystron gallery. A flow diagram is given in Fig. 24-29. At present, the system includes four circulating pumps and six heat exchangers. Provision is made for the addition of a fifth pump. Figure 24-30 shows the pumps and cooling tower 1701, in which the heat exchangers are located.

Figure 24-29 Flow diagram of target area cooling-water system.



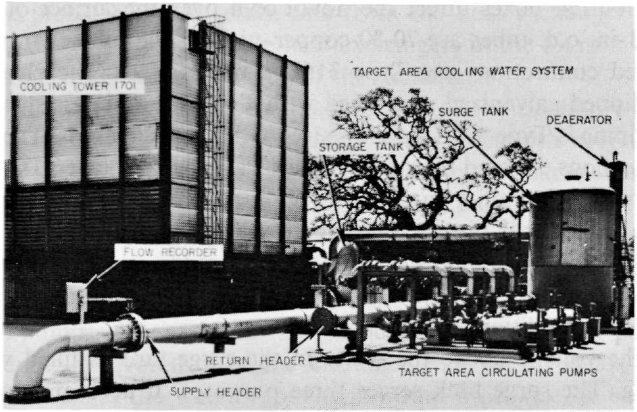
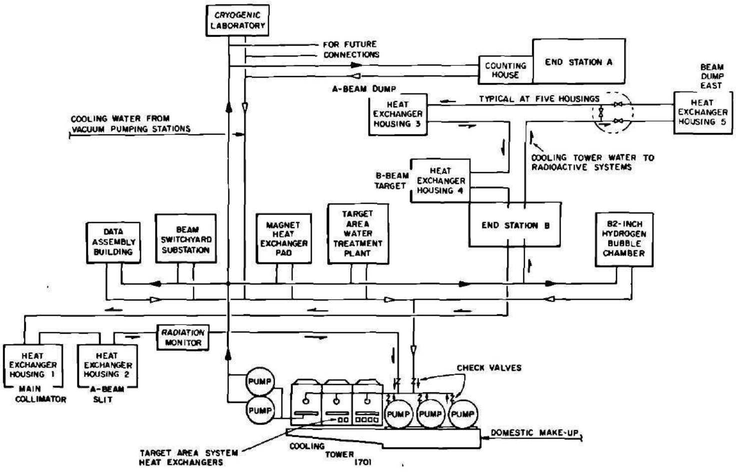


Figure 24-30 Target area cooling-water pumps.

Operating characteristics of the circulating pumps are included in Table 24-1. The pumps are of the single radial stage centrifugal type. The vertical-split casings and open impellers are Type 316 stainless steel. The shaft seals are mechanical, with a carbon rotating face, a ceramic stationary face, and Teflon secondary seals. The pumps are driven through flexible couplings.

Operating characteristics of the heat exchangers are included in Table 24-2. The six exchangers are of the atmospheric coil type. The tubes are formed into rectangular coil sections. Each exchanger is made up of two coil sections. The exchangers are mounted in a common horizontal plane in two of the three cells of cooling tower 1701—four in one cell, two in another—as shown in Fig. 24-31. The cooling tower water is collected in pans above the exchangers.

Figure 24-31 Flow diagram of beam switchyard cooling tower water system.



Distribution boxes direct the flow down over the surface of the bare tubes. The 1-in. o.d. tubes are 70-30 copper–nickel. The tube channels, baffles, and flanged connections are Type 316L stainless steel. The channel covers are hot-dipped galvanized steel lined with Type 304 stainless steel sheet.

Piping is Type 304L stainless steel with two exceptions. The heat exchanger connections exposed to cooling tower water are Type 316L stainless steel and the lines in the utility yard in sizes through 4-in. nominal diameter are copper pipe. The copper pipe is joined with self-fluxing silver brazing alloy. A flow recorder is provided in the main supply header.

No temperature control is provided. The temperature varies with ambient and load conditions.

The volume above the water in the surge tank is filled with nitrogen at 2 psig. The surge tank serves three purposes. It accommodates the thermal expansion of the water in the system; it pressurizes the system to prevent the entry of air when the pumps are not operating; and it provides a 4500-gal reservoir immediately available to make up for losses from the system, or, in the event of a major line break, to give the operators time to shut down the research equipment before the circulating pumps stop. The water level in the tank is float-controlled. When the level is low, a valve is opened and makeup water from the storage tank is admitted through the transfer pump. When the system is full, another valve drains excess water back into the storage tank. The surge tank has a total capacity of 6300 gal and a design pressure of 15 psig. A relief valve set at 12 psig protects the tank against overpressure. A vacuum breaker is also provided. The tank is of all-welded construction, using Type 304L stainless steel, and conforms to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. It is mounted vertically on a carbon steel skirt.

The makeup water for the target area system is provided from a storage tank normally containing between 8000 and 12,000 gal of low-conductivity water. The volume above the water in the tank is filled with nitrogen at from 1 to 15 psig. The water level in the tank is float-controlled. When the level is low, a valve is opened admitting low-conductivity, i.e., distilled and demineralized makeup water received from the distilled water plant through the klystron gallery header. A 2-in. hose connection is provided for loading or unloading tank trucks. Should the need arise, water from the storage tank can be pumped back into the klystron gallery header.

The storage tank has a total capacity of 16,900 gal and is mounted horizontally on two steel saddles supported on concrete piers. It is protected against overpressure by a relief valve set at the design pressure of 15 psig. A vacuum breaker is also provided. The tank is of all-welded construction, using Type 304L stainless steel, and conforms to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

A stable supply pressure is insured by a 4-in. air-operated pressure control valve which bypasses water from the supply header to the return header when the supply pressure exceeds 275 psig. The valve also opens the bypass when the pressure in the return line from the heat exchanger coils exceeds 100 psig, thereby protecting the heat exchangers in the event a valve should be closed on the downstream side of the exchangers.

The water treatment plant is an enlarged version of the cleanup bypass used to maintain high purity low-conductivity water in the other systems. A 3-in. branch off the 16-in. return header upstream from the heat exchangers carries the water being bypassed through a filter and into a deaerator. The deaerator is an upright cylindrical tank, relatively tall in comparison to its diameter. The water inlet and outlet are through the top and bottom heads, respectively. Another line leads from the top of the tank to a heat exchanger and two vacuum pumps. As the water falls through the deaerator, a partial vacuum encourages the evolution of the entrained and dissolved air. The heat exchanger condenses the water vapor that would otherwise be carried over into the vacuum pumps. A control valve responsive to the water level in the deaerator adjusts the rate at which water flows into the tank to equal the rate at which it is pumped out at the bottom. A transfer pump returns the air-free water through one of the two demineralizers to the surge tank. The 33 ft^3 capacity of each demineralizer is further evidence of the relative size of the target area system. In comparison, the demineralizers used throughout the rest of the system hold only $1\frac{1}{2}$ ft^3 of resin. Two filters and two transfer pumps are also provided, with interconnections affording the maximum operating flexibility.

Cooling tower water (SRC)

Cooling tower 1701 serves the heat exchangers in the BSY and end stations, the air compressor in the BSY substation, and equipment in the data assembly and cryogenic laboratory. It is located southeast of the DAB. The tower includes three cells of the counterflow induced draft type. It is rated at 23 MW when cooling 8700 gal/min from 93° to 75°F at 65°F (wet bulb) ambient. The tower is 92 ft long, 32 ft wide, and 33 ft high. The materials are the same as those used in cooling tower 101 described in a previous section, except that the fill is plastic.

The two-speed fan in each cell is driven by a motor which develops, alternatively, 15 and 60 hp to allow for variation in heat load. The two main circulating pumps each deliver 2400 gal/min at 80-psig discharge. Each is driven by a 150-hp motor. These pumps are of the two-stage vertical turbine type. They circulate water from a pan inside the tower through the cooling tower water system piping to the heat exchanger areas and to buildings throughout the target area. The three tower recirculating pumps each deliver 4600 gal/min at 36-psig discharge. Each is driven by a 125-hp motor. These pumps are of the single-stage vertical turbine type. They take water from the tower basin and recirculate it through the spray heads at the top of the tower. Normally one pump in each set is a spare. The pump suction wells are protected by 30-mesh screens.

Six atmospheric-type heat exchangers are provided within the tower to cool the target area, low-conductivity water. As previously mentioned, the heat exchangers for the radioactive systems and the B-beam target system are connected in series, with cooling tower water flowing successively through the exchangers serving beam dump east, A-beam dump, B-beam target, the main collimator, A-beam slit, and, eventually, B-beam slit. Bypasses are provided so that failure of an exchanger will not interfere with the operation of the system as a whole.

A radiation monitor is located in the cooling tower return line at the BSY substation. Should radioactivity ever be detected in the cooling tower water, the monitor will turn on an alarm light in the DAB and shut down the cooling tower water circulating pumps.

Makeup is taken directly from the domestic water supply or indirectly from vacuum pumping stations PS-0 through PS-6. The domestic water which cools the pumps discharges into the cooling tower return header. A float-controlled valve automatically regulates the amount of water taken from the domestic supply. A flow diagram of the system is shown in Fig. 24-31.

The fans are equipped with excess vibration shutdown switches. An automatic "deluge" system protects the tower against fire.

Operating experience—Beam switchyard and end station systems (CJH)

The magnet coil, magnet power supply, and pulsed magnet power supply, cooling-water systems were put into operation during the summer of 1966 in essentially the same manner as outlined in the section covering accelerator system operating experience. No major problems have been encountered in these systems. The low flow switches protecting the magnets against failure of the cooling-water supply have been modified in the manner previously described. Low-conductivity water has been maintained in the radioactive systems by diverting approximately 10 gal/min through a bypass demineralizer. Specific resistance varies from 0.5 to 1.5 megohms depending on the condition of the demineralizer and the degree of contamination generated in the system. The demineralizers in these systems contain $1\frac{1}{2}$ ft^3 of resin which lasts about 6 weeks between regenerations. Special procedures have been worked out for handling the resins because of the radioactivity of the ^{7}Be isotope removed from the water.

Hydrogen evolution in the A-beam dump, cooling-water system caused numerous beam shutoffs. With the development and installation of a hydrogen recombiner, operation has become relatively routine.

The full capacity of the four 1500-gal/min pumps in the target area, low-conductivity cooling-water system has yet to be utilized. Pump discharge pressure is 269 psig. Users in the end stations require that a pressure not less that 230 psi be maintained at the pumps and that pressure surges be held as low as possible. Manual operation of the pump controls, supply valves, and the bypass valve between the main supply and return headers are often necessary to hold the pressure within these limits when user's equipment drawing over 600 gal/min is suddenly thrown on or off the target area system. Load changes up to 600 gal/min are automatically accommodated by an air-operated, pressure control valve on the bypass between the main supply and return headers. A controller adjusts the valve opening to maintain a constant pressure in the supply header.

The water treatment plant serving the target area system includes two demineralizers, each containing 33 ft^3 of mixed bed resin. The demineralizers are used one at a time. When the resin in the first demineralizer is fully depleted, it is removed for regeneration and the second demineralizer is valved into the system. When the system was started up, the first demineralizer lasted 3 months. The second demineralizer was still good after 8 months of operation. Specific resistance of the water normally runs about 4 megohms.

The treatment plant also includes a deaerator. An external heat exchanger is provided to condense the moisture out of the air leaving the deaerator. Due to insufficient cooling, quantities of water vapor were being carried over into the vacuum pumps that remove the air. The original exchanger was replaced with one having a larger cooling capacity.

At one time or another, failure to close the supply valves before the return valves has resulted in damage to a user's equipment and piping, particularly if it was designed to withstand less than the full supply pressure of the target area system. Users who wish to tie into the system are now required to install check and relief valves to protect their equipment against overpressure.

Cooling tower water is chemically controlled, using the same techniques as in the accelerator system cooling towers. It has been much more difficult to hold the water in this system within the desired limits because of the influx of domestic water from several small vacuum pumping stations. When the tower is operating at very light loads, the amount of domestic water discharged into the system as a conservation measure often exceeds the losses due to evaporation and leakage. The constant overflow carries a portion of the treatment chemicals out of the basin into the nearby storm sewer before they become thoroughly mixed into the system.

The graphite-impregnated packing used in the seal injection pumps in the radioactive systems leaked continuously. It was difficult to stop the leak by tightening the packing without causing the shaft to seize. The packing was replaced with mechanical seals.

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