actor sphere outside the cylinder, and in the dump and makeup tanks.

Shielding. Reinforced limestone-aggregate concrete, 8 ft thick, shields the reactor, see sketch p 102. Steel plates line the inner and outer surfaces of the shield. The vertical fuel-element-charging and control-rod tubes and the horizontal water-discharge pipes leading from these tubes to the headers form a large part of the top shield.

Shielding around steam generators, piping, pumps and miscellaneous storage tanks consists of 3-ft-thick concrete floors, walls and ceilings. Steam generators and pumps stand in individual cells reached through plug-type trap doors. Turbines, turbine piping and auxiliaries stand in open, unshielded areas accessible for normal maintenance.

To make repairs on a unit of equipment, motor-operated shutoff valves first isolate it from the heavy-water system. The activated heavy water in the unit then drains to a shielded storage tank. Light water flushes out the unit until radioactivity falls to a level safe for men to enter the cell and perform the necessary repair work.

Reactor Control. Amount of heavy water flowing from the reactor and its temperature at each fuel-tube outlet and control-rod opening are monitored. Manually operated valves on each tube adjust flow distribution over the reactor lattice area. Adjustments are made on the basis of two thermocouple readings at each tube outlet. A rapid-scanning device for pressures and temperatures helps localize defects as they develop. The scanning equipment automatically shuts down the reactor when certain limits are exceeded. Failure of both thermocouples on any tube shuts down the reactor. Defective flow detectors are considered a serious hazard.

Several thermocouples in the hottest area of the reactor measure and record the uranium-metal temperature.

Safety rods dropping into place automatically shut down the reactor on: (1) loss of sphere pressure (2) excessive reactor power (3) short reactor period (4) fuel-element failure (5) serious heavy-water leak (6) steam-generator failure (7) excessive radioactivity in reactor building.

Control rods of 1.5%-boron steel are clad with stainless steel to resist corrosion. Guide tubes prevent the rods jamming in the tube sheets or shifting their position by flow of the coolant. Coolant flow dissipates heat generated in the rods.

Piping. To minimize the amount of coolant holdup in the piping, a flow velocity of 25 ft per sec was chosen, and the length of piping was held to a minimum by arranging the steam generators in a tight circle around the reactor as shown at top of p 102.

Angle headers, taking the heavy water from the 211 individual fuel elements and control-rod headers, connect to a ring header 21 ft in radius circumscribing the reactor. This header feeds the 18 individual 12-in. headers connected to the top of the steam-generator coolant boxes. The 12-in. outlet connections, from a pair of steam generators, join an 18-in. suction line to one of the nine coolant-circulating pumps. The pumps' discharge headers, 18 in. dia, connect to the reactor at equally spaced intervals around the reactor shell.

Steam Generators. Each of the 18 units produce 180,000 lb per hr of 180-psig saturated steam. These are arranged in pairs to reduce the number of coolant pumps and valves. Each unit has an 88-in.-dia shell, 24 ft long. The 656 U-tubes have a total heat-transfer surface of 3975 sq ft. The coolant enters and leaves at the same end from a single box with a horizontal division wall to separate inlet and outlet compartments.

By using a double tube sheet, one serves as an end plate for the steam and water shell and the other as the plate of the coolant box. This avoids leakage of the coolant into the light-water system and simplifies detection of tube-roll leakage. A subcooling section uses incoming feedwater to subcool the leaving coolant.

Coolant-circulating pumps presented one of the major design problems of the plant. This arose from the combination of the large flows to be handled, the high suction pressure to be sealed, the essentially low gland leakage, the high liquid temperature and the coolant radioactivity. The pumps are single-stage overhanging-impeller design with the one gland exposed to suction pressure. To avoid flashing in the gland, coolant at 100 F enters an intermediate point of the gland. The seal coolant flows along the shaft through labyrinthine packing into the pump in one direction and into an annulus in the opposite direction. About 5 to 10 gpm of seal coolant is needed. The small external leakage drains back to the makeup tank. Gland-seal coolant comes from each pump discharge, passing through a small heat exchanger before entering the gland.

One of the three pumps for each main unit is steam-turbine-driven, the other two are driven by 2000-hp electric motors through hydraulic couplings. The couplings assist in controlling plant output on load variation.

Turbine-Generators. Three 80,000-kw units supplied by the reactor can generate a total of 254,000 kw with 1-in.-Hg abs backpressure, at a heat rate of 14,111 Btu per kwhr. Net steam available for main turbines will generate 246,100 kw. Electrical auxiliaries will use 14,000 kw, leaving a net output of 232,100 kw. At 2.5-in.-Hg backpressure the net drops to 211,500 kw.

The tandem-compound double-flow turbines have 35-in. last-stage buckets. Since the turbines use saturated steam they have two moisture-extraction locations. One uses notches in the leading edge of the buckets to throw the moisture to an annulus in the casing, where it is carried out of the turbine by 1% extraction of steam. This reduces moisture from 7.4 to 6%.

The other consists of a series of corrugated plates in the large crossover. The plates separate the moisture and carry it to a drain, reducing steam moisture content from 10.6 to 6.6%.

Because of the low steam pressure and the nonextraction cycle used, the surface condensers become very large. To attain 1-in.-Hg backpressure there must be 130,000 sq ft of surface. Four 35,000-sq-ft units per turbine seem to be the best arrangement. Makeup water for the plant comes from a demineralizer since bled or exhaust steam is not available for evaporators.

Costs. Table II shows the estimated investment for the 240,000-kw installed-capacity plant. The total of $118,000,000 represents $492 per kw. If the reactor was designed for light-water cooling and moderation, which would require enriched fuel, the initial investment could be reduced by about $47,000,000. Cost per kw would drop from $492 to $297. These cost figures assume that fabricated fuel elements are furnished by others. Cost of the initial fuel charge has not been included.

Conclusions. Considering present status of reactor technology, it is felt that the heavy-water-reactor concept has the best economic possibilities. Uncertainties are availability and cost of heavy water, practicality and cost of chemical plants to process the fuel elements.

The gas-cooled reactor could provide a substantial beginning in atomic power with minimum interference with production reactors now under construction or contemplated. Fuel elements should be less costly than some of those used in production reactors, they can be processed in existing plants. Both reactor designs are feasible from engineering and operating standpoints.

Power's DATA SHEET

No. 253

Typical Cable Applications in Generating Stations

Service	Max 3-ph voltage	Insulation	Installation	Covering	Finish
GENERATOR LEADS, BUS TIES, ETC[1]	2,000	Heat-resistant rubber (RH)	Conduit[2]	Cotton braid	Note 3
			Insulators	Cotton braid	Note 3
			Ducts[4]	Neoprene jacket	None
			Conduit, ducts	Lead sheath	Note 5
	15,000	Ozone-resistant rubber[6]	Conduit[2]	Cotton braid	Note 3
			Ducts[4]	Neoprene jacket	None
			Conduit, ducts	Lead sheath	Note 5
	17,000	Varnished-cambric	Conduit[2]	Cotton braid[7]	Note 8
			Insulators	Cotton braid	Note 8
			Ducts[4]	Lead sheath[7]	Note 5
	17,000	Impregnated paper	Any	Lead sheath	Note 5
AUXILIARY MOTORS	2,000	Heat-resistant rubber (RH)	Conduit[2]	Cotton braid	Note 3
			Conduit, ducts	Neoprene jacket	None
			Ducts[4]	Lead sheath[10]	Note 5
	15,000	Ozone-resistant rubber[6]	Conduit, ducts	Neoprene jacket	None
			Conduit[2]	Cotton braid	Note 3
			Ducts[4]	Lead sheath[7], [10]	Note 5
	17,000	Varnished-cambric	Conduit[2]	Cotton braid	Note 8
			Ducts[4]	Lead sheath	Note 5
	600	Vinyl resin	Conduit	None	None
	5,000	Asbestos-varnished-cambric	Conduit[2]	Cotton braid	Note 8
			Conduit[2]	Asbestos braid	HF[11], [12]
			Ducts[4]	Lead sheath[10]	Note 5
CONTROL CABLES	600	Heat-resistant rubber	Conduit[2]	Cotton braid	Note 3
			Conduit, ducts[4]	Lead sheath[13]	Note 5
			Ducts[4]	Neoprene jacket	None
	600	Ozone-resistant rubber	Conduit[2]	Cotton braid	Note 3
			Conduit, ducts[4]	Lead sheath[10]	Note 5
			Ducts[4]	Neoprene jacket	None
	600	Vinyl resin, polyethylene	Conduit, ducts	Vinyl resin	None
EXCITER AND FIELD LEADS[1]	15,000	Ozone-resistant rubber	Conduit, ducts	Lead sheath[10]	Note 5
			Conduit, ducts	Neoprene jacket	None
			Conduit, ducts	Cotton braid	Note 3
	17,000	Varnished-cambric	Conduit, ducts	Lead sheath[10]	Note 5
RHEOSTATS	300	All asbestos	Faceplate to resistors	Asbestos braid	HF[11]
BOILER ROOMS, ASHPITS	5,000	Asbestos-varnished-cambric	Conduit[2]	Cotton braid	Note 8
			Conduit	Asbestos braid	HF[11]
			Ducts[4]	Lead sheath	Note 5
	5,000	Varnished-cambric	Conduit[2]	Cotton braid	Note 8
			Ducts[4]	Lead sheath	Note 5
	2,000	Heat-resistant rubber (RH)	Conduit[2]	Cotton braid	Note 8
			Ducts[4]	Lead sheath	Note 5
			Conduit, ducts	Neoprene jacket	None
POWER TRANSFORMERS Primary and secondary services	2,000	Heat-resistant rubber (RH)	Conduit	Asbestos braid	Paint-filled
			Ducts[4]	Lead sheath	Note 5
			Conduit, ducts	Neoprene jacket	None
	8,000	Ozone-resistant rubber[6]	Conduit	Asbestos braid	Paint-filled
			Ducts[4]	Lead sheath	Note 5
			Conduit, ducts	Neoprene jacket	None
	17,000	Varnished cambric	Conduit	Cotton braid	Note 8
			Ducts[4]	Lead sheath	Note 5
	132,000	Impregnated paper	Conduit, ducts	Lead sheath	Note 5

Notes: 1—usually overinsulated. 2—essentially dry; if moist consider ducts. 3—smooth black. 4—moist locations. 5—Neoprene hose-type jacket overall for protection against corrosion and electrolysis. 6—preferably shielded above 2 kv. 7—look up shielding recommendations. 8—smooth black or slow-burning paint-filled and finished for indoor work. 9—interlocked steel armor overall for metallic pan construction; alternate of bronze for single conductor or for corrosive conditions. 10—alternate of lead sheath, fibrous covering and interlocked armor for pan construction. 11—heat-, flame- and moisture-resistant. 12—in hotter locations. 13—for more reliability.

Courtesy F Aime, Electrical Engineer, Anaconda Wire & Cable Co