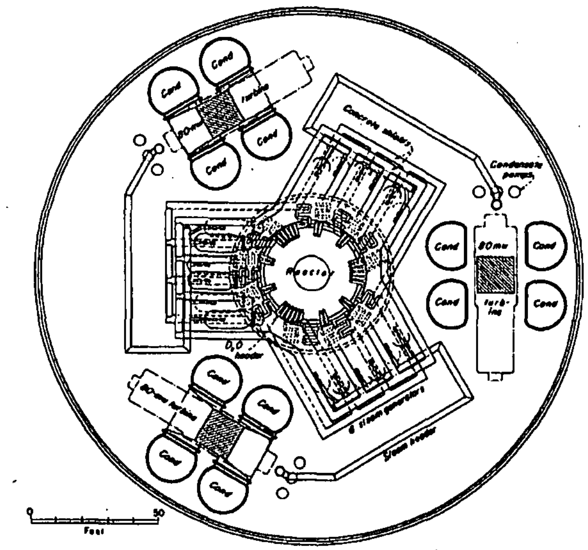
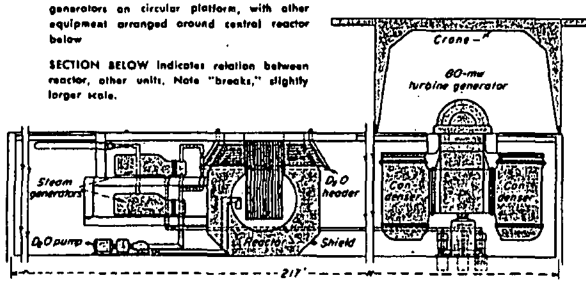
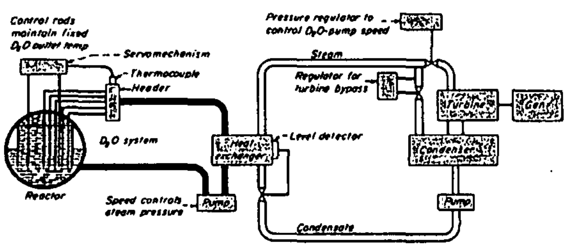


PLAN ABOVE shows layout of three turbine-generators on circular platform, with other equipment arranged around central reactor below

SECTION BELOW indicates relation between reactor, other units. Note "breaks," slightly larger scale.



HEAVY-WATER-COOLED REACTOR feeds 18 steam generators, which supply three 80-mw turbines with 180-psia saturated steam. Design minimizes heavy-water needs



FLOW CIRCUITS OF LIQUID-COOLED REACTOR need controls for safe operation. Bypass around turbine leads steam to condenser on a sudden load drop and on low loads

two right-circular graphite cylinders with adjoining end faces parallel to each other on the same center line. These cylinders contain natural-uranium slugs arranged in a lattice. The slug channels parallel the cylinder axes. The cooling gas (helium) enters the small gap between the two cylinders and divides its flow outward through the two reactor sections. A pressurized steel shell encases this assembly.

The two core sections, each 35 ft dia and 10 ft thick, contain about 985 tons of high-purity high-density graphite. About 500 tons of lower grade carbon surrounds the core sections and acts as a reflector.

Uranium-metal fuel slugs have a center hole and fins resting on the slug-channel surfaces. It was assumed heat generates uniformly within the metal, and flows uniformly from all parts of the surfaces. Maximum metal temperature is limited to 1000 F to prevent phase transformation at 1200 F. More reactor power could be realized by developing an alloy and casing that could withstand internal temperature of about 1300 F.

Coolant. Helium was selected because it has no chemical-combination properties with uranium and has a zero neutron-absorption cross section. Pressurizing the helium to 10 atmospheres reduces the power needed to transfer a fixed quantity of heat.

Reactor Shell. Openings in the 44-ft-dia sphere allow feeding uranium slugs into the graphite core. Tubes connect the end of each fuel channel in the graphite to fittings in the sphere wall. Special closures prevent helium loss at 10 atmospheres and 750 F.

Other openings allow circulating helium through the shell, inserting control rods and instruments, removing irradiated uranium slugs.

Shielding and Ventilation. A concrete radiation shield (having the shape of a modified Quonset hut) completely encloses the reactor sphere. Ten feet from the sphere charging face a vertical 8-ft-thick concrete wall, supported on rollers, moves with expansion of the charging tubes piercing it and the sphere. Six feet from the other side of the sphere stands the opposite 8-ft-thick concrete wall.

Hot air inside the shield rises through a direct-connected stack. This maintains a negative pressure inside the shield, causing all air to leak into the shield. This air becomes radioactive and must be diluted before being discharged to atmosphere.

Charging and Discharging. Two channels at a time may be charged by a 6-cylinder charging machine in a sequence operation. The cylinders move

their charge into the sphere channels by helium pressure. The irradiated slugs drop out of the core on the far side and accumulate at the bottom of the sphere. They are removed through pressure locks into the storage canal located below the sphere.

Reactor Control. The more important reactor instruments measure power level, reactor period, temperature and pressure of helium. Manual and semiautomatic movement of control rods regulates the reactor. Automatic positioning maintains constant helium temperature at the boiler inlet. Remote indicators on the control board show their position. The rods are moved with enough energy storage to operate them several times, over their full travel after an auxiliary power failure.

Eight vertically mounted boron-steel safety rods drop into holes in the reactor graphite when released by normally energized clutches. They quickly stop reactor operation when (1) neutron density exceeds safe value (2) reactor gas-outlet temperature exceeds safe level (3) reactor gas pressure drops suddenly (4) auxiliary power fails (5) reactor period becomes shorter than minimum value (6) helium-coolant flow stops (7) automatic trip button is pressed.

Helium Cycle. Helium leaves the reactor sphere at 650 F to enter the boilers. Leaving boilers at 384 F it enters gas blowers to be returned to the reactor. Multiple take-offs and the need for reasonable duct sizes require 12 separate circuits for the helium.

Boilers are straight-through types in which economizer, evaporating and superheating sections are combined into one continuous pass. A 3½-in. feedwater line enters the shell through a thermal sleeve and connects to a 6-in. inlet header. From this header 48 one-in.-OD tubes spaced on 2-in. horizontal centers form a bundle of 48 hairpin loops spaced on 2-in. vertical centers. These tubes terminate in an 8-in. steam header. There are 95 loops in each of the circuits. The shell is about 13 ft dia and 23 ft, 6 in. long, with 6-ft-dia flanged openings at both ends to which the helium ducts connect.

There are 12 boilers, although 10 can develop full reactor power. Each boiler can produce 90,600 lb per hr of 250-psig 525-F steam from 109-F feedwater. This assumes 2.5-in.-Hg backpressure on main turbine.

Blowers. The axial-flow-type helium blowers must run at constant flow. Flow variations must equal capacity of one blower. Load variations with a fixed number of blowers running are made by varying helium temperature out of the boilers. Twelve blowers, 75,000 cfm each, supply total helium flow. Half the blowers are steam-turbine driven, others are electrically driven. Over-all dimensions of blower and drive are about 20 ft long, 9 ft wide, 9 ft high.

While helium does not become radioactive, it might carry particles of active materials. Removable concrete blocks, 2 ft thick, used for shielding permit maintaining boilers and blowers. No radioactivity transfers from helium to steam in the boilers.

Underground storage tanks, occupying 45 acres, store the helium. Miscellaneous buildings with total area of 15,000 sq ft house the valves, controls and purifying equipment.

Turbine-Generator. The 650-F helium temperature led to selecting 525 F for steam leaving the boilers. The 265-psia pressure kept exhaust moisture below 14.7%. At 2.5-in.-Hg backpressure the turbine generates 61,700 kw gross at 14,500-Btu-per-kwhr heat rate. Electric auxiliaries use 15,000 kw, leaving a net of 46,700 kw. Steam auxiliaries use an equivalent 12,000 kw.

Plant Control. Automatic control-rod adjustments hold reactor helium-outlet temperature to 750 F. Adjusting feedwater flow varies the boiler rating, and the boiler-outlet helium temperatures. Boiler output determines kw generation. Steam temperature varies from 525 F at full load to a theoretical 650 F at zero load. A steam-pressure controller regulates the turbine governing valves.

To achieve high plutonium production the reactor should be held at full power rating even while electric generation is reduced. A steam bypass line around the turbine to the condenser dissipates the heat in excess of that needed by the turbine. The bypass automatically protects the reactor in event of a turbine tripout.

Costs in Table I are based on conditions in the Middle West. They do not include costs of fuel fabrication and processing. Assuming a net output of 45,000 kw, the installed cost averages $889 per kw.

Liquid-Cooled Reactor. This cylindrical unit, enclosed in a spherical steel shell at 800-psia pressure, uses heavy water as coolant, moderator and reflector. Fuel assembly is made up of separate elements, each consisting of a group of uranium slugs in a thin metal casing. These are placed in vertical, cylindrical channels. Heat from the uranium passes through the thin metal cladding to heavy water, passing in a vertical direction upward. Heavy water flows between and through the fuel channels. The flow between channels acts as the moderator; traveling relatively slowly, it discharges through the control-rod assemblies. The fuel elements hanging vertically in the channels are charged and discharged through the cylinder top. Fuel-element maximum surface temperature is 465 F when reactor-outlet heavy-water temperature is 440 F.

An economic analysis showed 440-F heavy water out of reactor and 180-psia steam pressure to be best. This develops 1064 mw of heat in the reactor. The heavy-water system must run at 800 psia. A 25-psi pressure drop in the reactor develops 25-ft-per-sec water velocity.

A helium-blanketing system protects heavy-water surfaces in the re-

I—Estimated Costs, Gas-Cooled Reactor

Reactor structure	$ 1,940,000
Fuel loading, tubes	2,000,000
Instrumentation and controls	1,200,000
Raw graphite, 2400 tons	1,000,000
Finished graphite, 2100 tons, machined and installed	1,260,000
Elevators, charging equipment	300,000
Total reactor assembly	$ 7,700,000
Boilers, 12, accessories	4,025,000
Turbine-generator, 60 mw, accessories	4,305,000
Stack, 500-ft high	500,000
Water system, decontamination area, waste storage	100,000
Buildings	4,200,000
Helium system	1,650,000
Electric facilities	1,725,000
Miscellaneous, site, land, etc	4,325,000
Contingencies	4,420,000
Engineering, 5%	1,700,000
Overhead, 15%	5,350,000
Grand total	$40,000,000

II—Estimated Costs, Heavy-Water Reactor

Reactor	$ 3,846,000
Heavy-water system	3,172,000
Heavy water ($82 per lb)	41,000,000
Helium system	230,000
Total reactor assembly	$48,248,000
Steam-generator plant	4,178,000
Turbine-generator plant (240 mw)	14,285,000
Structural plant	10,024,000
Miscellaneous power equipment	342,000
Electric facilities	5,313,000
Site, other land costs	1,625,000
Miscellaneous, yard improvements, temporary construction	2,740,000
Research and development	2,500,000
Contingencies	8,700,000
Engineering	4,500,000
Overhead, 15%	15,345,000
Grand total	$118,000,000