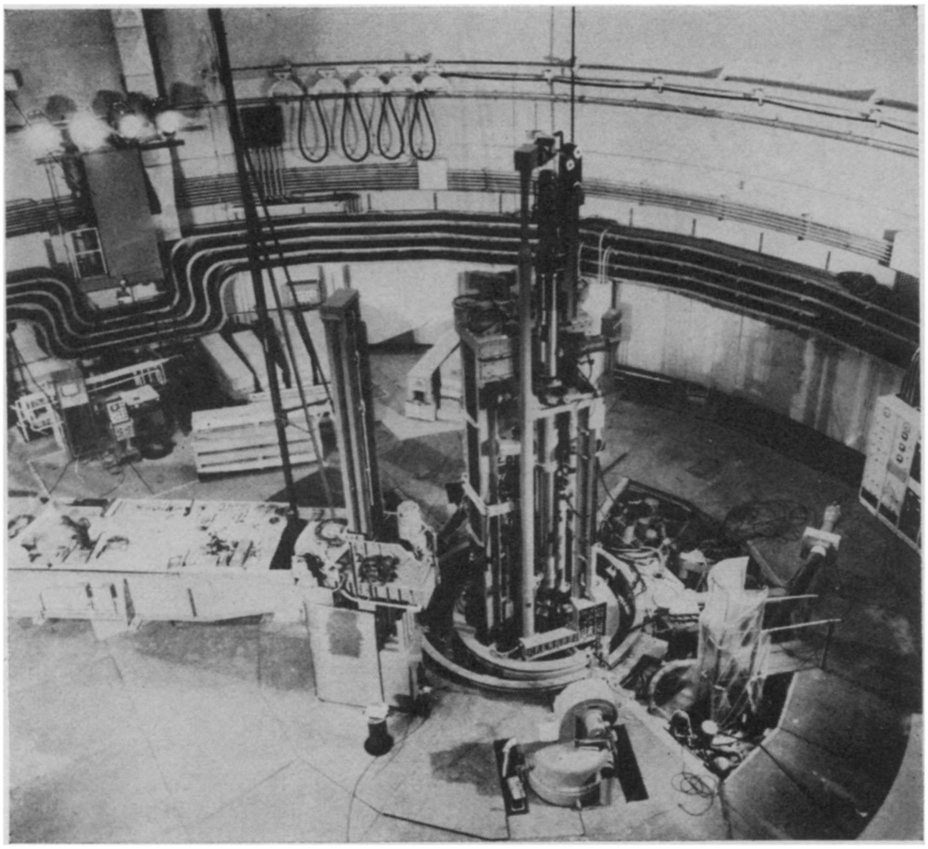
REACTOR ENGINEERING

Thinning the Reactor Jungle

The Atomic Energy Commission is picking and choosing among reactor concepts for one to make the grade.

by Carl Behrens



Argonne National Laboratory

Sodium-cooled reactor at the National Reactor Testing Station, Idaho.

By closing out an advanced concept reactor program last month, the Atomic Energy Commission has increased its bet that the sodium-cooled breeder is going to become the power reactor of the future.

At stake is the $2 billion to $3 billion electric power companies are spending now on nuclear reactors (SN: 12/31/66). The type of reactor available at present uses a form of uranium —U-235—that is in very short supply. Unless reactors can be developed that use more available fuels, thorium or U-238, the power stations now being constructed will soon find their fuel costs climbing sharply.

The reactor type the AEC dropped from its development program—called the organically cooled heavy-water reactor—is one of three intermediate types: not as efficient as a fast breeder reactor, but not as wasteful of fission fuel as the light-water reactors being built today. The remaining two of these fair-mileage concepts will continue to be developed in the hope that one will tide the industry over until the real economy-model breeder reactor is developed.

The crowded list of different reactor concepts, which the AEC must constantly thin out if it isn't to spend more than the Defense Department or end its support for reactor development, comes from the many factors that affect reactor economy and efficiency. They complicate a basically simple process.

Nuclear power is produced by bombarding a fissionable atom with a neutron. Under the right conditions, the fissionable atom splits, releasing heat energy, and also ejects more neutrons, which then split other fissionable atoms to continue the process.

The heat from the splitting atoms is absorbed by a coolant. The coolant in turn transfers the heat to water, which, as steam, drives turbine generators.

The complications begin with the choice of fissionable fuels. There are three—uranium 235, plutonium 239, and uranium 233—and each fissions under different circumstances.

The only fuel that occurs naturally is U-235. The other two have to be produced in the reactor itself from what are called fertile materials: uranium 238 and thorium.

The easiest reactor to build—the type now in use—depends on U-235. The trouble is that U-235 makes up less than one percent of natural uranium; the rest is U-238. Separating the two is a big job because chemically and physically they are very similar. Besides, as a source of the kind of large-scale power generation now foreseen U-235 is much too scarce to depend on. So the artificial fissioning materials have to be developed.

Neutrons cause fission; they also change fertile materials into fissionable ones. Which they do depends on how fast they are moving. Getting neutrons to do the right thing while preventing them from being absorbed and wasted by the walls of the reactor, the waste products or the coolant is largely a matter of controlling the speed of the neutrons emitted and designing the fuel elements so right material is in a spot to absorb the right neutrons.

U-235 fissions best with slow-moving neutrons, so present-day reactors contain a moderator that slows them down. But slow-moving neutrons are also more likely to be absorbed by fission products. When too many neutrons are absorbed, not enough cause fission and the chain reaction is broken. Then the fuel element, though it may contain a good deal of U-235, has to be replaced and reprocessed.

Fissionable plutonium 239, however, can be produced from fertile U-238. This happens when an atom of U-238 absorbs a neutron to become U-239, an unstable isotope which decays in a few days to plutonium.

Plutonium, although formed with slow neutrons, fissions better with fast neutrons. Once you have plutonium, then, fast neutrons are better because they cause more fission and are less likely to be absorbed by waste.

Fast neutrons have another advantage—sometimes they will cause the fertile U-238 to fission. When they do, an extra bonus of fission heat results.

With a fast reactor, then, uranium, mostly U-238, is mixed with plutonium produced elsewhere, and the two are bombarded by fast neutrons. The plutonium fissions, producing heat and more fast neutrons. Some of the U-238 fissions, but most of it absorbs neutrons and is changed to plutonium. If more plutonium is produced than is consumed, the reactor is called a breeder. Eventually, of course, when all the available U-238 is changed or fissioned, the fuel element must be replaced.

Breeders can also be made using slow neutrons. Thorium, the other fertile material, absorbs a neutron and then decays to U-233, which fissions best with slow neutrons. With a fuel combination of U-235 and thorium, a slow neutron either fissions the uranium, producing more neutrons, or is absorbed by the thorium, producing U-233 which also can be fissioned.

For slow breeders, also called "thermal" breeders, some way of slowing the neutrons down must be provided. This is done by any of a number of moderators.

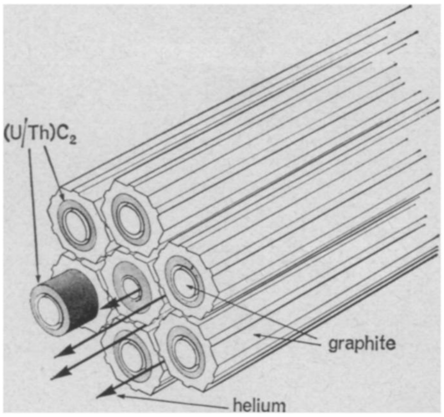
Out of this welter of variables, a number of basic reactor types have been conceived.

• The basic reactor being produced today uses more-or-less concentrated U-235 with thermal neutrons moderated by a solid such as graphite. The heat is removed by either boiling or pressurizing water. This is not a breeder, although some plutonium is produced and can be salvaged from spent fuel elements.

• Some advantages can be gained from using heavy water as a moderator, and a hydrocarbon fluid for a coolant. The organic coolant doesn't have to be operated at such a high pressure, and the fluid moderator makes for more efficient use of the fissionable uranium. But the advantages were not great enough to carry a development program ahead. The AEC, having decided that it had gone far enough to show that the organically cooled heavy-water reactor could be built, has left it at that point.

• Next in line is a high-temperature gas-cooled reactor, which uses thorium and U-235 as a fuel and helium gas as a coolant. Although not a breeder, this type does use thorium, which is more abundant than uranium.

• Most promising of the slow-neutron type of reactor is a thorium breeder that uses ordinary pressurized water as a coolant. Since the present reactors also use water coolants, the engineering problems are largely solved, and

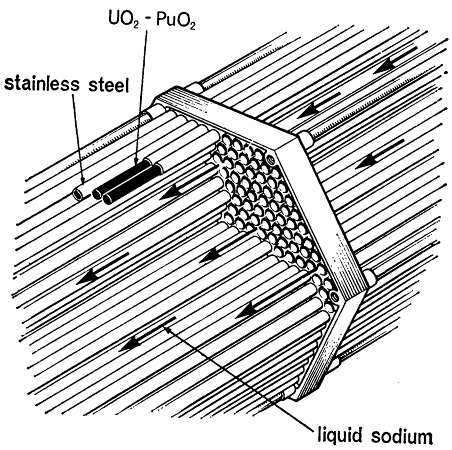


Science Journal

Prototype cores using helium . . .

only the fuel itself has to be developed. The AEC expects to decide in fiscal 1968 whether to put a thorium core into an existing pressurized water reactor as a demonstration project.

• While the thorium breeder produces its own fuel—U-233—from the fertile thorium, it doesn't make much of a surplus. But fast breeders, using the plutonium-U-238 cycle, do. The estimate is that a fast breeder will be able to double the amount of fissionable material it started with in the space of eight to 10 years—which means that the surplus can be taken out and a new plant started with it.



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. . . and liquid sodium.

The fast breeder the U.S. is banking on uses liquid sodium as a coolant. Other coolants could be a gas, such as helium, or pressurized water. Sodium has an advantage; it doesn't have to be pressurized as do gas and water.

But the fast-gas and fast-water breeders have their backers—in Europe. England particularly has developed the gas-cooled systems. West Germany is working on both sodium-cooled and water-cooled breeders.

The chances are that one of these systems will come through in time—in time being before the demand for economical nuclear power pushes the cost of nuclear fuel out of sight.