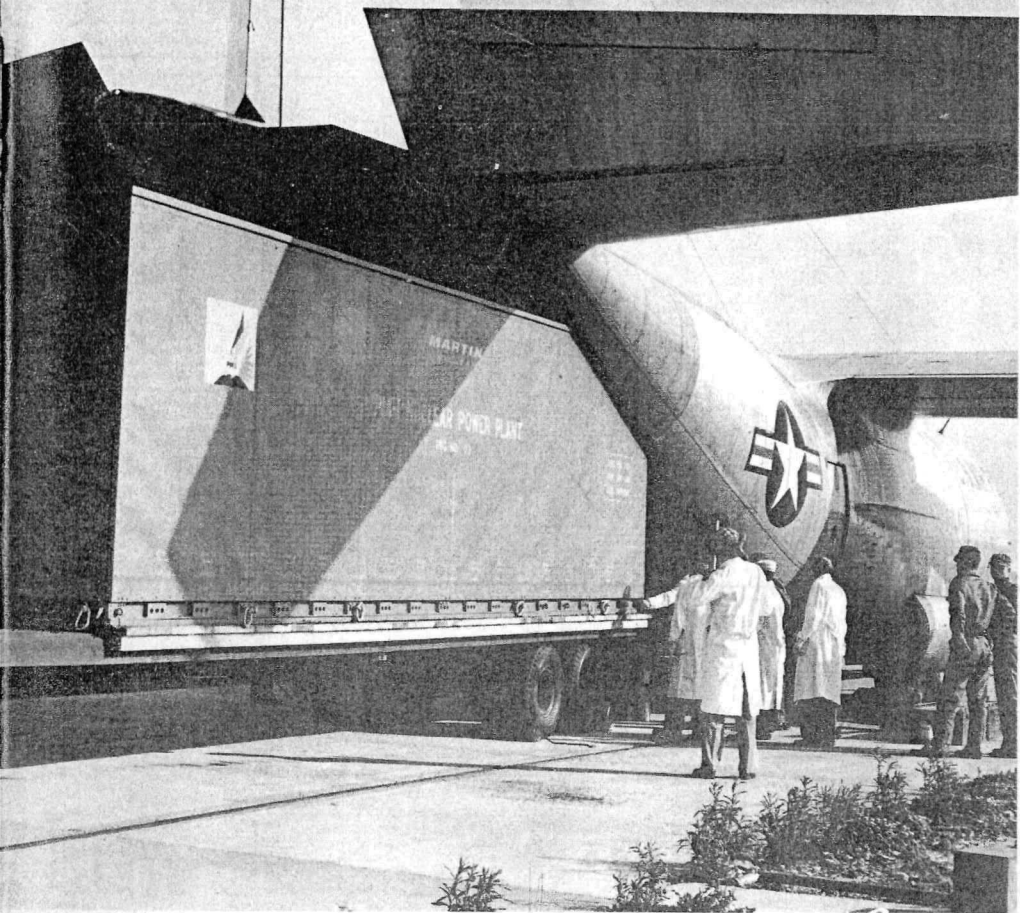# POWER REACTORS IN SMALL PACKAGES

U. S. ATOMIC ENERGY COMMISSION / Division of Technical Information

ONE
OF A SERIES ON
**UNDERSTANDING
THE ATOM**

Nuclear energy
is playing a vital role
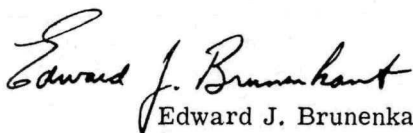in the life of
every man, woman, and child
in the United States today.
In the years ahead
it will affect increasingly
all the peoples of the earth.
It is essential
that all Americans
gain an understanding
of this vital force if
they are to discharge thoughtfully
their responsibilities as citizens
and if they are to realize fully
the myriad benefits
that nuclear energy
offers them.

The United States
Atomic Energy Commission
provides this booklet
to help you achieve
such understanding.

Edward J. Brunenkant
Edward J. Brunenkant
Director
Division of Technical Information

POWER REACTORS
IN SMALL PACKAGES / *contents*

Coast Guard icebreaker East Wind *(left) and Navy icebreaker* Atka *(right) escort the USS* Arneb *through the Antarctic ice of McMurdo Sound to deliver the PM-3A atomic power plant in 1961.*

POWER REACTORS IN SMALL PACKAGES

By William R. Corliss

1 POUND OF URANIUM = 6000 BARRELS OF OIL

Nuclear Power for the Ice Caps

The frigid and desolate reaches of the Arctic and Antarctic are typical remote areas where small, packaged nuclear power plants are potentially superior to those burning oil and coal. Scientific and military bases in these inhospitable regions are hundreds of miles from sources of conventional fuel. Ships and planes cannot carry in supplies during much of the year. Still the men and equipment at McMurdo Sound in Antarctica must have some source of energy to ward off the sixty-below temperatures of the polar night. Heat from the fissioned uranium nucleus has provided this energy in place of flown-in diesel fuel.

When a self-sustaining nuclear fission reaction was first achieved in a converted squash court at the University of Chicago in 1942, would-be prophets predicted that coal and oil would soon be obsolete and that the wheels of the world would turn on nuclear power. More than 25 years have passed, and the road to nuclear power has been a rocky one. Not only have nuclear power plant costs been higher than anticipated, but coal and oil plants have been made more efficient. The economic battle is still going on. Only now are large nuclear power stations becoming economically competitive.

This booklet, however, is an account of the introduction of nuclear power to remote places on earth where the re-

sources of civilization are almost as scarce as they are in a space vehicle in orbit. It is also the story of nuclear power plants designed for use when warfare or natural catastrophes, such as hurricanes and earthquakes, have wiped out the usual sources of energy, and in places beyond the reach of oil pipelines and coal trains. Finally, it tells how nuclear power may one day be used to manufacture chemical fuels for the world's vehicles when fossil fuels begin to run out.

The U. S. Atomic Energy Commission and the Army jointly began studying nuclear power for such applications in 1952. It was quickly found that cost was only one of several important requirements. A power plant in a remote polar location, for example, also had to be *reliable, portable* and *safe*. A power station for use in a storm-ravaged region had to be mobile and capable of quick installation. Small nuclear power plants have proved to be the best engineering solution for these requirements.

In fact, the ideal power plants for these applications have many attributes of nuclear space power plants, although, as we shall see, they are much too large to be launched. Instead of the few kilowatts of power needed in space for instruments, control, and communication, small terrestrial power plants must produce several megawatts.* They are still small, however, in contrast to large, stationary nuclear power plants that generate hundreds of megawatts of electrical power.

With these guidelines the joint AEC – Army Nuclear Power Program moved from studies into hardware development and then into power plant construction. Today there are four small nuclear power plants operating, three of which are indicated in Figure 1. The MH-1A, the fourth plant, is a barge-mounted nuclear power plant that became operational in 1968. Its intended use is to provide electric power to areas whose normal power supplies are inadequate and to demonstrate nuclear power to underdeveloped countries (see page 20). More information on these plants and other designs that were developed is given in the table on page 10.

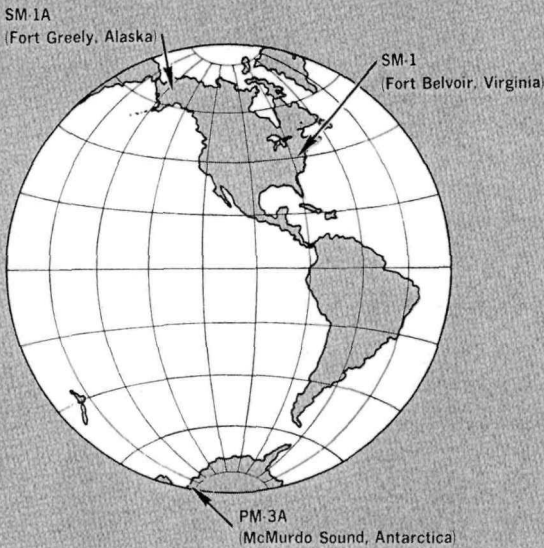*One kilowatt = 1000 watts; 1 megawatt = 1,000,000 watts.

Figure 1

*Locations
of three small
nuclear power
plants built under
the AEC—Army Nu-
clear Power Program.*

Most American reactors have code letters designating type. The small nuclear power plants described in this booklet are no exception. They have a special code:

FIRST LETTER	SECOND LETTER
S = stationary	L = low power (up to 1 megawatt)
P = portable	M = medium power (1 to 10 megawatts)
M = mobile	H = high power (over 10 megawatts)

Different power plants within each two-letter code group are given numbers, such as the PM-3A portable, medium-power plant.

Comparative Fuel Costs

No matter how carefully engineers design small nuclear power plants, it will cost more to make them and install them (say in Antarctica) than it would for a comparable diesel plant. This fact seems to contradict the notion that nuclear plants are cheaper than oil plants in remote locations. But it is the passage of time that makes nuclear power cheaper. Time accentuates a fundamental fact about nuclear energy: *Nuclear fuel provides millions of times more energy per pound than conventional chemical fuels like coal and oil.*

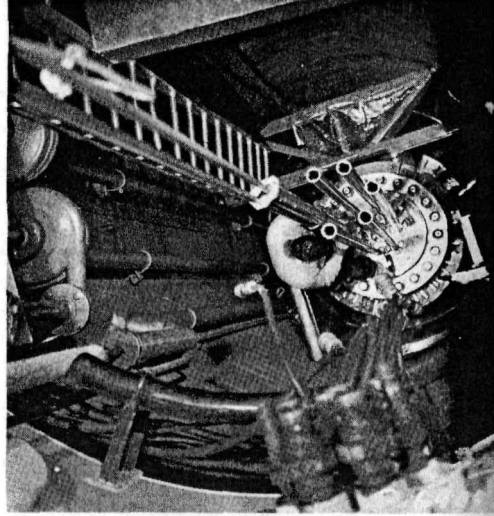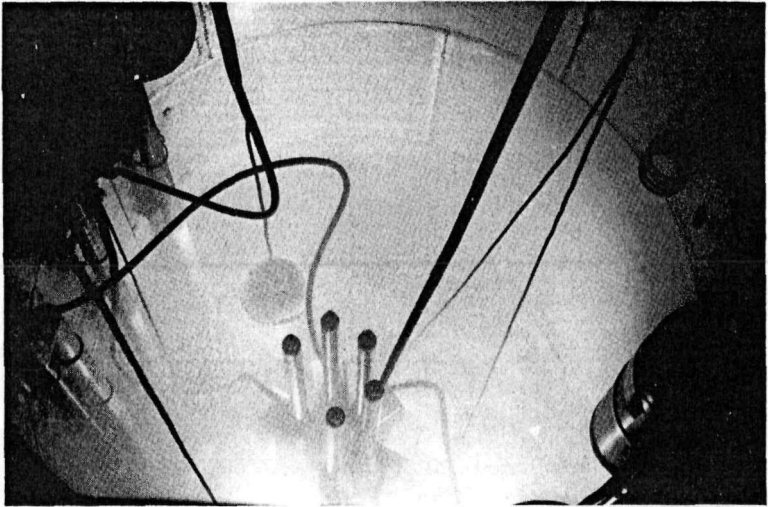**Figure 2** *PM-type reactor core during assembly.*

Figure 3 *Core is immersed in water, which serves as cooling agent, moderator, and reflector.*

The heart of most small, packaged nuclear power plants is a barrel-sized assembly of uranium-filled tubes or rods. When the uranium fissions, heat is produced. This heat is transferred to a fluid agent that drives the turbines and electrical generators. The all-important economic fact is that uranium fuel is extremely expensive per pound but amazingly cheap per unit of heat carried to the turbine. A pound of enriched uranium, consisting mostly of the fissionable isotope uranium-235, costs about $5,000 compared to 3 cents a pound for diesel fuel in the United States. That's

166,667 times more expensive. However, 1 pound of completely fissioned uranium generates 2,000,000 times as much energy as a pound of oil. The advantage of nuclear power becomes even greater when the cost of shipping diesel fuel to remote areas such as Antarctica is considered.*

The high "first costs" of the more complex nuclear machinery make the nuclear power plant initial cost higher. But nuclear plants have to be refueled only once every year or two, and even then the new fuel can be easily transported to the site in a small package. Used fuel elements are removed and shipped back. There is no need for a steady stream of planes and ships carrying diesel fuel. There are no huge stockpiles to maintain. When shipping costs are added to the cost of the fuel for diesel plants, it is possible for the nuclear power plant to be competitive in very remote areas. The higher the shipping cost of diesel fuel, the more favorable nuclear power will be.

These economic facts are important, but they tend to conceal another vital point: *Sometimes nuclear power can do a job better than conventional fuels, no matter how cheap they are.* Take, for example a military command post buried thousands of feet under solid rock to protect it from H-bomb explosions. There is no air to spare for burning oil or coal in such a *superhard* site. The outside surface air would be too contaminated to use after a nuclear attack. Air stored inside must be reserved for human consumption. Unlike oil and coal plants, some nuclear systems need no air and can thus perform their job deep underground, under the ocean, or in the vacuum of outer space. This feature explains why nuclear submarines have such high performance potentials and why we are interested in developing nuclear rockets.

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*In supplying nuclear power at these remote areas, however, the small power usage requires that nuclear power plants operate in the low-power range where unfavorable economics have always resulted. For example, 1- to 2-megawatt nuclear power plants, which have been built for such remote sites, have had operating costs greater than 40 mills per kilowatt-hour. Operating costs have been as high as 184 mills per kw-hr. By comparison, large 500-Mw commercial nuclear power plants are presently capable of obtaining operating costs as low as 5 to 6 mills per kw-hr and can compete with fossil-fired power plants.

Big Things in Small Packages

A nuclear power station large enough to supply electrical power and heat to a polar base may occupy several buildings, each the size of an ordinary house. In most parts of the United States, there would be no transportation problem, since large pieces of equipment could be trucked or barged to the site, much as the immense Saturn rocket sections are sent from Mississippi to Cape Kennedy via barges on the Inland Waterway. However, there is no barge service to McMurdo Sound. Equipment must go by ocean vessel, cargo plane, or tractor snow train. The power plant packages must be small enough for these carriers. They must also be "connectable" with a minimum of tools at the remote bases. Elaborate welding and joining techniques are prohibitive.

The portable medium-power plant (PM-1), which was used for powering a radar station on a lonely Wyoming mountaintop, was transported in 27 packages, each weighing about 30,000 pounds. Each package had to be squeezed into a cargo transport plane. Package dimensions were limited to 8 feet 8 inches by 8 feet 8 inches by 30 feet.

How is a nuclear power plant made small enough to fit into airplanes, truck trailers, or cargo holds? Contrast the radio sets of the 1940s and their large heavy cabinets with the pocket transistor radios of today. This miniaturization came about through technical advances such as the invention of the transistor. Some shrinkage of nuclear power plants comes from engineering advances, but a nuclear reactor can be made only so small before the laws of physics are violated. The major size reduction is obtained by cramming boilers, pipes, and valves into small packages. Conventional nuclear power plants are not particularly cramped for room. Therefore the design tends to expand to fill whole buildings. In contrast, the portable and mobile power plant designer packs machinery together with the spirit of a sardine canner.

To carry the radio analogy further, if you remove the cover from a transistor radio, you will find that its small size is not entirely the result of the replacement of radio tubes by transistors. Electronic circuits are now printed in silver ink to replace wires. Parts are squeezed together

until a small watch movement seems crude in contrast. The same spirit prevails in building small nuclear power plants. "Thinking small" works, as the first generation of polar power plants testifies.

Figure 4 *After testing at the factory near Baltimore, the PM-1 is flown to Ellsworth Air Force Base in South Dakota.*
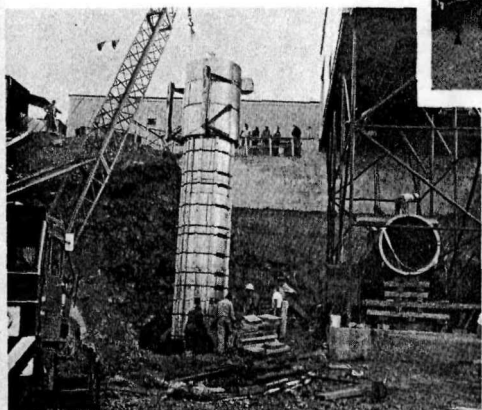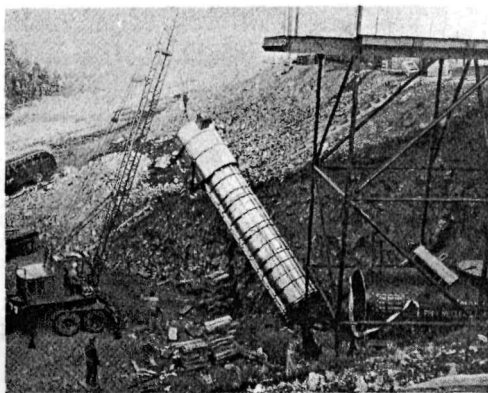

Figure 5 *Brought by truck from the base, components are unpacked and readied for installation at the radar site. One of the power plant containers is jockeyed into final position by a crane. Containers were later buried.*

PROGRESS REPORT

Portable power plant evolution, which includes early prototypes, operating plants, and plants in the design or conceptual stage, is shown in the table on pages 10 and 11. Lessons learned during the development and experimental operation of the two prototypes already constructed guided the production of the first operational units. These units, in turn, were improved upon in the new designs.

Some technical data about each plant have been included in the summary table. The technical background section of this booklet defines and discusses the significance of characteristics listed in the table.

The core life mentioned in the table is a measure of the expected operating lifetime of the shortest-lived plant component, the fuel core. The fuel, of course, is easily replaced when no longer usable.

The primary pressure is of particular importance because it determines the weight of the piping and pressure vessels. The pressure should be as high as possible from the point of view of efficient performance, but as low as possible in consideration of system weight. Obviously the engineer must make a compromise.

The core-outlet temperature is the highest system temperature except that within the fuel element itself. The attainability of high core-outlet temperature depends upon time and money invested in research and development.

TECHNICAL BACKGROUND

How Nuclear Power Plants Work

The heart of any power plant is the energy source. In the conventional coal- and oil-fired plants that provide electricity to many of our cities, a furnace boils water to make steam. In a nuclear power plant, the furnace is replaced by a group of uranium-filled rods, such as those shown in the PM-1 reactor core below. The heat produced by the fissioning of a few pounds of uranium takes the place of that produced by burning vast piles of coal.

All power plants other than hydroelectric stations require an energy converter to change heat into electricity. Usually a turbine transforms the energy of hot steam into the rotary motion of a shaft. An electrical generator attached to the shaft supplies electricity to homes and industry. Another component needed in the power plant is a heat exchanger. The Second Law of Thermodynamics tells us that it is impossible to convert all the heat into useful work in any heat engine. Therefore arrangements must be made to get rid of the unusable remainder, which is called waste heat. The heat exchanger transfers waste heat to a colder fluid, usually a river or lake, but sometimes to the air itself.

CONTROL ROD

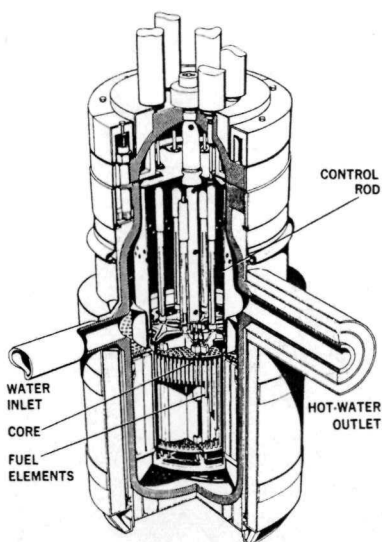WATER INLET
CORE
FUEL ELEMENTS

HOT-WATER OUTLET

Figure 6 *In the PM-1 nuclear reactor, heat was produced by the large cluster of fuel elements at the bottom. Control rods protruded above the core and regulated the power level.*

PORTABLE AND MOBILE NUCLEAF

Designation[a]	Location[a]	Application	Operator	Designer[a]	Date critical[b]	Date operational	Electrical output (megawatts)
							PROTOTYPES
SL-1[e]	NRTS, Idaho	Testing, training	Army	ANL	8-58	10-58	0.2
SM-1	Ft. Belvoir, Va.	Testing, training	Army	A.L.Co.	4-57	4-57	1.85
ML-1[g]	NRTS	Portable mobile power	Army	Aerojet-General	3-61	9-62	0.50
							OPERATIONAL PLANTS
SM-1A	Ft. Greely, Alaska	Base power and heat	Army	A.L.Co.	3-62	6-62	1.64
PM-1[h]	Sundance, Wyo.	Base power and heat	Air Force	Martin Co.	2-62	6-62	1.0
PM-2A[i]	Camp Century, Greenland	Base power and heat	Army	A.L.Co.	10-60	2-61	1.5
PM-3A	McMurdo Sound, Antarctica	Base power and heat	Navy	Martin Co.	3-62	6-62	1.5
MH-1A	Barge mounted (*Sturgis*)	Portable mobile power	Army	Martin Co.	1-67	1-68	10.0

[a]Abbreviations (designations)

First Letter

Second Letter

S = stationary L = low power (up to 1 megawatt)
P = portable   M = medium power (1 to 10 megawatts)
M = mobile   H = high power (over 10 megawatts)

Location:
NRTS = National Reactor Testing Station, Idaho

Designer:
ANL = Argonne National Laboratory
A.L.Co. = American Locomotive Co.

POWER PLANT PROGRAM

Core life (megawatt-year)[c]	Reactor type[a]	Primary coolant	Primary pressure (psia)[d]	Core outlet temp. (°F)	Power cycle	Total weight (tons)	Number of packages
6.3	BWR	Water	300	422	Rankine	—	—
32.0	PWR	Water	1200	450	Rankine	—	—
3.76	GCR	Nitrogen	315	1200	Brayton	$38\frac{1}{2}$	6
32.0	PWR	Water	1200	443	Rankine	—	—
24.0	PWR	Water	1300	479	Rankine	405	27
10	PWR	Water	1750	518	Rankine	310	27
24.0	PWR	Water	1300	479	Rankine	450	33
67.5	PWR	Water	1400	510	Rankine	—	—

Reactor type:
  BWR = Boiling water
  PWR = Pressurized water
  GCR = Gas cooled

[b]Point of attainment of self-sustaining nuclear reaction.
[c]Thermal megawatt-years, not electrical.
[d]Pounds per square inch, absolute.
[e]Reactor dismantled in 1962.
[f]Reactor dismantled in 1963. The pressure vessel was used for radiation-induced embrittlement tests.
[g]Reactor dismantled in 1965.
[h]Reactor shutdown and dismantling initiated in 1968.

Figure 7 shows how a nuclear power plant works if water is boiled directly in the reactor core. This simple arrangement is called a single-loop system. Most nuclear power
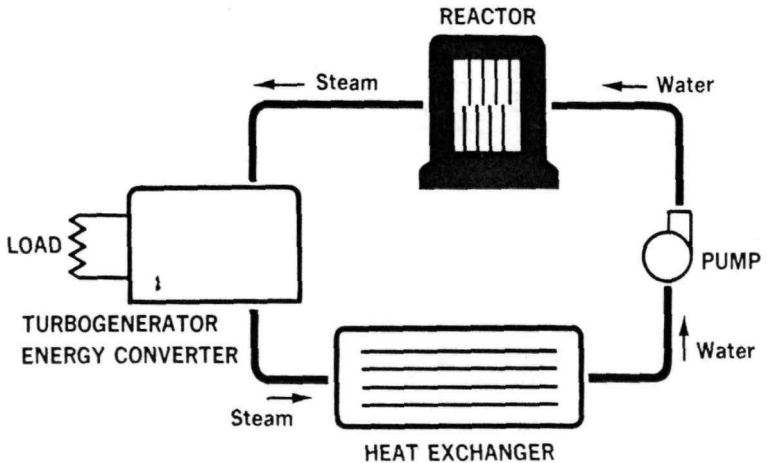

Figure 7 *Power plant showing the energy source (reactor), the energy converter (turbogenerator), and the heat exchanger (condenser). A boiling-water reactor power plant would use a cycle like this.*

plants described in this booklet, however, use the pressurized-water reactor shown in Figure 8. Water is not boiled in a pressurized-water reactor core. Instead it is heated to high temperature under high pressure (usually over 1000 pounds per square inch, too high for boiling) and then pumped to a steam generator. Here heat is transferred to a second stream of water operating at a low enough pressure to permit boiling. The steam from the second loop drives the turbine. This power plant is a two-loop system.

A liquid metal like sodium or a gas like nitrogen may also be used to remove heat from the hot fuel elements. Such fluids are generally reserved for power plants requiring very high temperatures, such as the gas-cooled ML-1.

The Atomic Energy Commission has experimented with water, gas, and liquid metals as coolants for small pack-

aged reactors. The four plants operating today all use pressurized-water reactors as do many of the large, commercial nuclear power plants and all U. S. nuclear submarines.
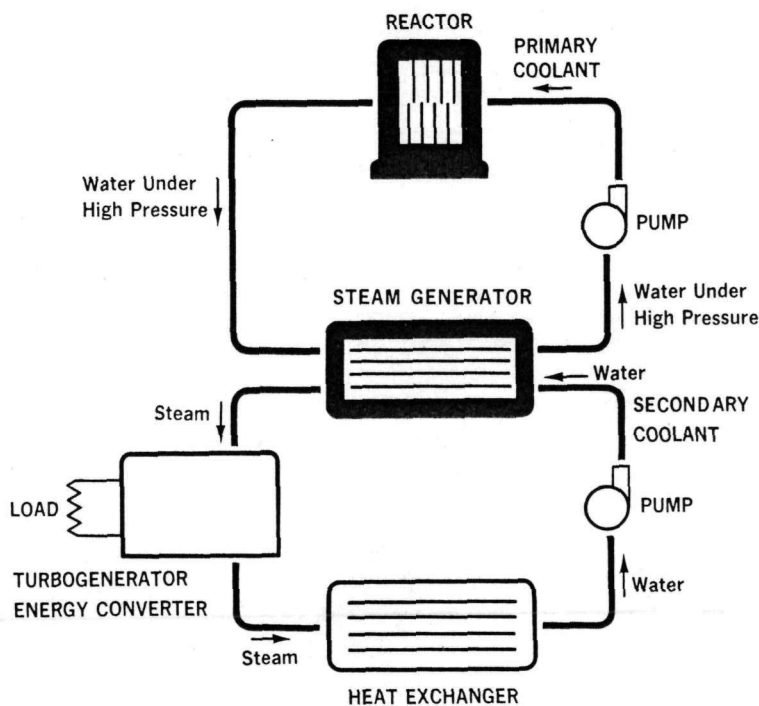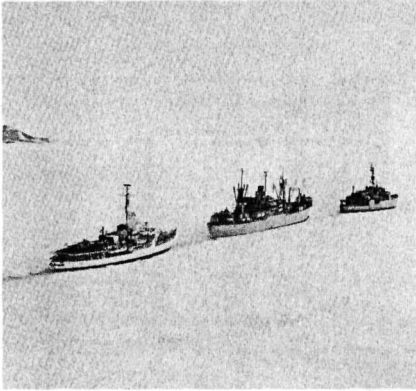
REACTOR

PRIMARY
COOLANT

Water Under
High Pressure

PUMP

STEAM GENERATOR

Water Under
High Pressure

Water

Steam

SECONDARY
COOLANT

LOAD

PUMP

TURBOGENERATOR
ENERGY CONVERTER

Water

Steam

HEAT EXCHANGER

**Figure 8** *Two-loop pressurized-water nuclear power plant.*

Putting Nuclear Power on Wheels

While it is difficult to cram nuclear equipment into packages small enough for transportation, making the power plant mobile is like going from the wheelbarrow to the automobile. In the first part of this booklet, it was suggested that packaging for portability was akin to packing sardines. Clever packing, however, is not enough for mobility. Even well-packaged plants weigh about a million pounds. Mobile plants intended for land use should weigh less than 100,000 pounds, perhaps as much as 10 times lighter. Something drastic must be done to shrink the power plant this much.
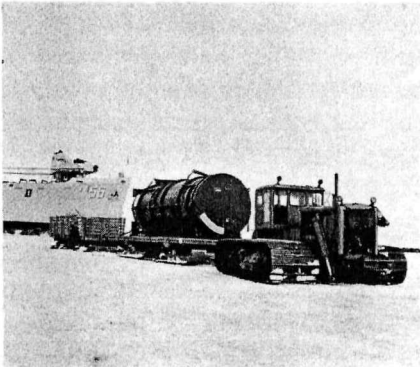
13

NUCLEAR POWER COMES TO ANTARCTICA

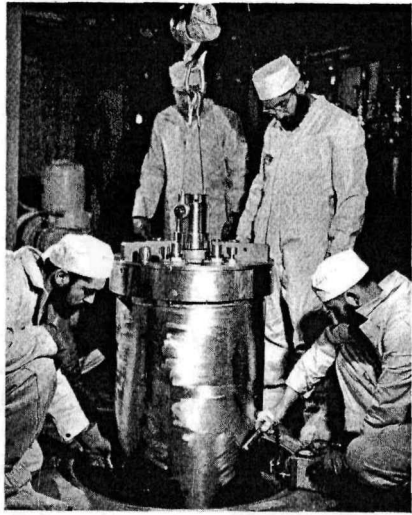(A) Icebreakers escort the ship carrying PM-3A components through the Antarctic waters.
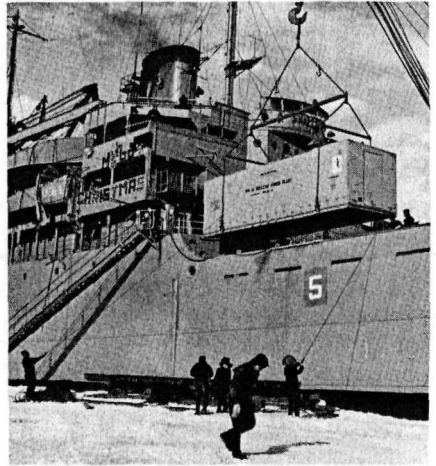
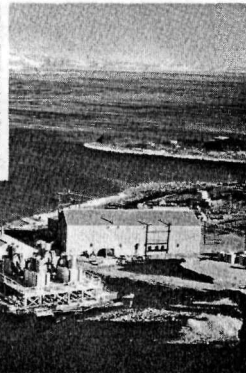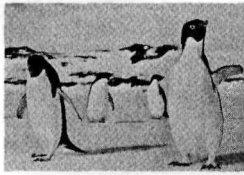(B) Crate containing pre-assembled plant section is unloaded at McMurdo Sound.

(C) Reactor tank is hauled across the ice.

(D) Core is lowered into the reactor. Nuclear engineers are dressed in sterile clothing designed to reduce the chances of getting dirt into the reactor.

(E) Control room during preoperational testing.

(F) The completed installation. In the inset are some local inhabitants.

The major targets of the shrinking campaign are the reactor, the turbogenerator, and the heat exchanger. The pressurized-water reactors are already quite small, as (D) in the figure on page 15 shows. Additional size reduction can be realized by replacing the water cooling agent with a liquid metal, such as potassium, sodium, or lithium. The liquid metal's superior ability to carry away heat permits a smaller core. The reactor may be compressed even more by removing the moderator and making a fast reactor where fissions are caused by the fast, unmoderated neutrons created in the fission process. Instead of the barrel-sized PM-3A core, the fast, liquid-metal-cooled core may be the size of a bushel basket—not a large shrinkage, but worth the effort because shield weights are rapidly reduced as cores get smaller.

Higher Temperatures Mean Lower Weights

Coolants like gas and liquid metals hold the real key to squeezing weight out of power plants. The secret is higher temperature. Two very important things happen when power plant temperatures are raised. First, the power plant becomes more efficient. That is, it turns a larger fraction of available heat into electricity. This means that the heat exchanger can be made smaller because it handles less waste heat. Further reduction in the heat exchanger size is possible because less area is needed to transfer heat at higher temperatures.

Many of these engineering "tradeoffs" are better understood mathematically. A simple equation describing the increase in efficiency was discovered in 1824 by Sadi Carnot, a young French engineer. Carnot found that the efficiency of a heat engine was determined very simply by the hottest and coldest temperatures in the engine. In equation form:

$$e = \frac{T_h - T_c}{T_h} = \frac{\text{heat out}}{\text{heat in}}$$

where e = the Carnot efficiency

T_h = the temperature of the gas or vapor entering the turbine (degrees Rankine or degrees Kelvin)

T_c = the temperature of the gas or condensed liquid in the heat exchanger (°R or °K)

A few simple calculations using Carnot's equation will show that raising T_h from 443°F in the SM-1A to 1000°F in a liquid-metal-cooled reactor has a profound effect on the efficiency.*

An increase in T_h usually means a rise in T_c, although the increase is usually smaller. A larger T_c is welcome because the heat exchanger can more easily transfer the waste heat to the environment. The area of the heat exchanger is given by

$$A = \frac{Q}{h \, \Delta T}$$

where A = the heat exchanger area (square feet or square meters)

    Q = the amount of heat power transferred (Btu or watts)

    h = a constant

    ΔT = the temperature difference between the fluid carrying the waste heat and the environment absorbing the waste heat (river, lake, or atmospheric air)

In summary, increasing T_h increases the efficiency e, making Q smaller for the same work output. Increasing T_h also raises T_c, which increases ΔT. Area A is thus reduced in either case permitting a smaller heat exchanger to be used. Efficiency can also be traded for small size by deliberately raising T_c.

Why is it advisable to use a gas or a liquid-metal coolant to achieve a temperature increase? Water is an excellent reactor coolant from many standpoints, but at higher temperatures its vapor pressure increases and heavy pipes and vessels are needed to contain it. But practical weight reductions can be obtained with water coolant in a certain

---

*For example,

$$e = \frac{903 - 610}{903} = \frac{293}{903} = 0.325 = 32.5\%$$

try it with $T_h = 1000$°F and $T_c = 150$°F. Don't forget to convert °F to °R by adding 460°. Answer: e = 58.2%.

temperature and pressure range* where its efficient heat-transfer properties permit reduction of the overall size of the reactor, including coolant pipes and pressure vessels.
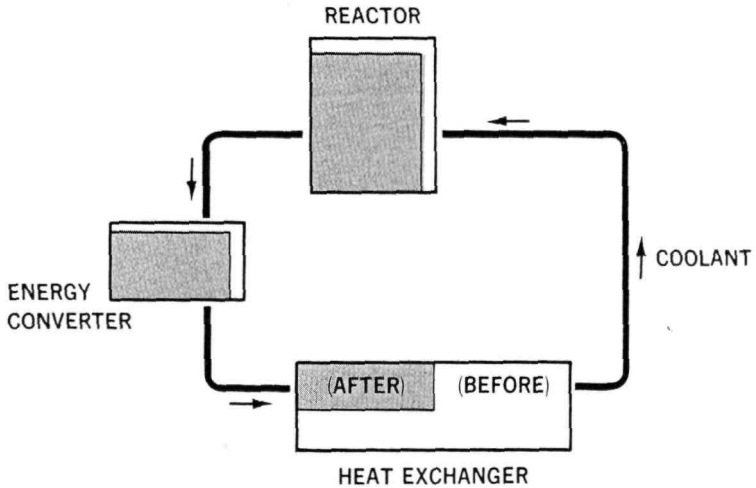

Figure 9 *Size reductions obtained for small nuclear power plants by going to higher temperatures.*

Making Use of the Atmosphere

Next to water, the most obvious prevalent fluid on this planet is the atmosphere. Since air is a gas, it can be heated to high temperatures without incurring the high pressures accompanying use of water. Air is cheap and is readily available.

The simplest way to use air is in a direct-cycle power plant, where air is sucked into the system by a compressor (fan) and then heated in the reactor (Figure 10). The heated gas drives the turbogenerator and is then exhausted to the atmosphere. No heat exchanger is needed since waste heat is carried out with the air. Jet engines work this way; so do the new gas turbines used in cars. The gas power cycle

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*Specifically the "supercritical" state of water above 705°F at 3200 pounds per square inch.

where no change to liquid state occurs is called the Brayton cycle as distinguished from the Rankine cycle in which the gas is condensed to liquid.

Unfortunately air contains oxygen. While it can be used in short-lived jet engines, the oxygen in air would soon eat away (oxidize) the components of a nuclear reactor, which must be designed to operate for years. Materials are being developed permitting the use of the direct air cycle, but until then some less corrosive fluid must be used in the reactor.

Nitrogen, carbon dioxide, helium, and neon all make good, relatively inert, gaseous coolants. Nitrogen has been selected for special study. To this end, an experimental nuclear power plant called the Gas-Cooled Reactor Experi-
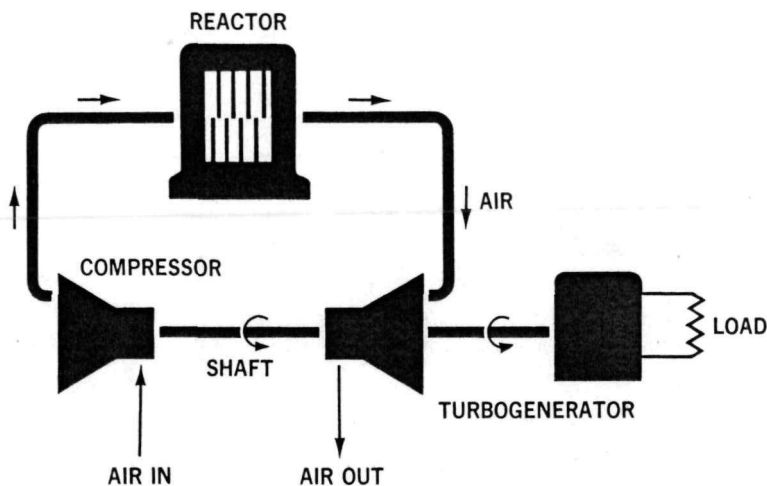

Figure 10 *Direct air cycle nuclear power plant.*

ment was built and operated at the National Reactor Testing Station near Idaho Falls, Idaho. Lessons learned were applied in designing the ML-1, a trailer-mounted nuclear power plant for field use first operated to generate electricity in September 1962.
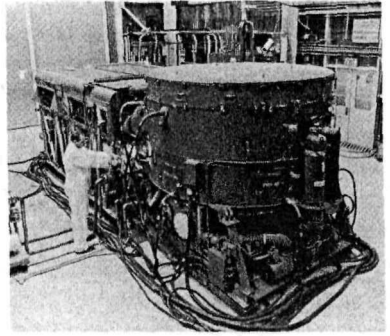
Figure 11 *On the right is the ML-1 mobile nuclear power plant in its test configuration. The ML-1 was designed to travel cross-country on a standard military trailer.*

Instant Power Plants

The portable pressurized-water nuclear power plants now in operation can hardly be called "instant" in the popular sense of the word. It takes 60 to 90 days to assemble a packaged unit like the PM-3A in Antarctica once the pieces have been carried to the site. More time is spent excavating the site. Sometimes large quantities of power are needed more quickly than can be provided with portable plants. Disaster areas where floods, hurricanes, and earthquakes have knocked out normal power supplies are obvious examples.

One approach to fulfilling this need is the *Sturgis*, * the MH-1A nuclear power plant. This pressurized-water reactor is mounted in a converted Liberty ship. It is described as barge-mounted since the propulsion system has been removed and it must be towed from place to place. The plant can operate at full power producing 10,000 kilowatts of electrical power for 1 year without refueling. A diesel power plant capable of producing this much electricity would require 160,000 barrels of fuel per year.

The *Sturgis* can be used in disaster areas where the normal power supply has been cut off. The plant can be anchored offshore and supply power through submarine

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*It is called the *Sturgis* in honor of the late Lt. General Samuel D. Sturgis, Jr., former Chief of Engineers, who was an early advocate of nuclear power plant development for military use.
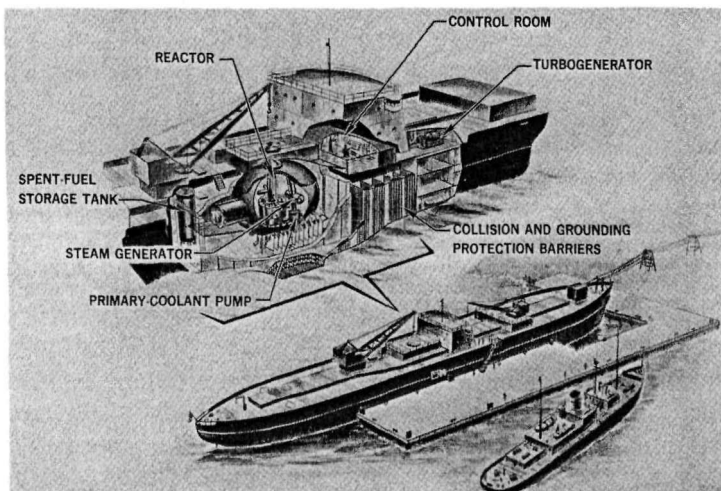
Figure 12 *The* Sturgis *(MH-1A), a floating nuclear power plant, achieved criticality on January 25, 1967. In the diagram the power lines run off the bow into the region needing power. The center photograph shows the* Sturgis *moored at Fort Belvoir, Virginia. On the right one of the 32 fuel elements that compose the core of the* Sturgis *is lowered into place during fueling operations.*
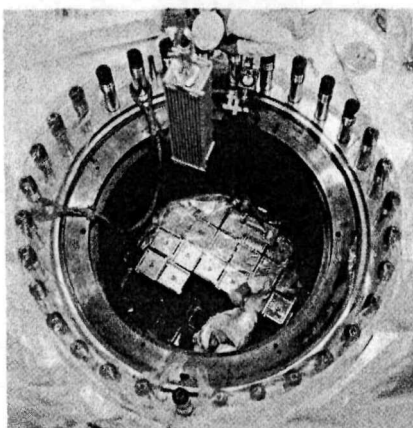
cables or overhead wire. Twelve hundred feet of submarine cable and 300 feet of overhead transmission wire and a shore tower are aboard for this purpose.

It could also supply power to accessible underdeveloped countries as an interim measure. This would help such countries stabilize and develop their economy.

A design for a 500,000-gallon per-day water-desalting plant to be installed aboard the *Sturgis* has been developed by the Corps of Engineers. Full capacity operation of this plant would reduce the electrical output of the *Sturgis* to 7500 kw. This water-desalting capability would be useful in disaster areas and underdeveloped countries where potable water supplies are usually low.

The Ultimate Concept: An Energy Depot

In all the nuclear power applications discussed so far, nuclear energy was seen to be superior to chemical energy (oil and coal) because of the much higher energy release of uranium. Remember the opening line of the booklet? *1 pound of uranium = 6000 barrels of oil.* In terms of money, nuclear power is at its best when a great deal of chemical fuel would otherwise have to be shipped over long lines of supply.

One serious drawback to nuclear power has emerged. In the foreseeable future nuclear reactors cannot be made small enough to drive trucks, cars, and other small vehicles directly. While the portable and mobile devices may be fine for supplying local power, they would not be effective for powering far-ranging vehicles. Will it always be necessary to ship vast quantities of fuel about the world?

A potential solution to this decades-old problem centers around the energy depot concept of chemical fuel regeneration using materials like air and water that are universally available. Some chemical fuels, which readily burn in internal combustion engines and turbines, could be reconstituted by high temperatures or electrolysis. That is, the fuel could be burned; the combustion products could next be decomposed by heat or electricity and stored; then the reconstituted fuel could be burned in an engine again. One possible reversible reaction is

$$2H_2 + O_2 \rightleftharpoons 2H_2O$$
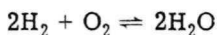
The reaction goes to the right (combustion) inside the engine, turbine, or even the highly efficient fuel cell. It goes to the left (dissociation) inside a hot reactor or an electrolysis cell powered by a reactor. An alternative concept is to take the hydrogen from water and combine it with nitrogen from air to produce ammonia, which is a more easily stored fuel than hydrogen. Ammonia can also be "burned" in internal combustion engines and turbines.

In the energy depot concept sketched in Figure 13, a mobile reactor power plant can be brought into a power-short area along with a fuel manufacture plant. It becomes a combined refinery and gas station. Vehicles in the neighborhood can drive in and tank up with manufactured fuels.

Look ahead one step further. Some day we may run out of cheap chemical fuels like gasoline. This modern world, which depends so much upon vehicles, cannot stop turning because there is an inadequate supply of these fossil fuels. A common fuel easily manufactured by nuclear power will have considerable impact upon our society within the next century.
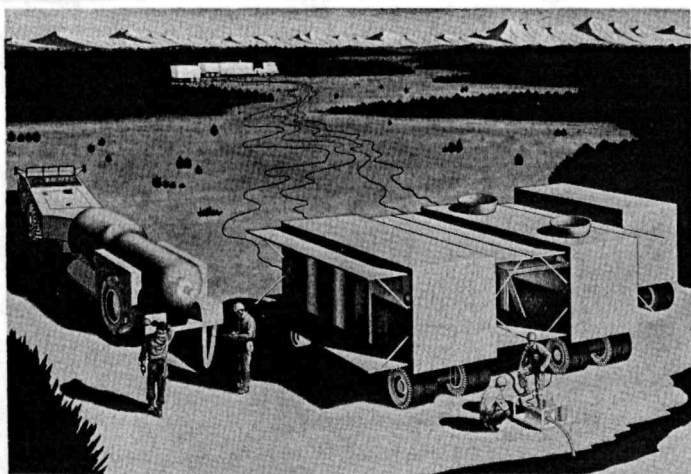

Figure 13 *The energy depot concept. Vehicles could fill up with fuel at the manufacturing plant in the foreground. Ammonia fuel would be produced from water and air using energy from nuclear power plant in background*

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Relocation of PM-2A, 25 minutes, color, 1965. Produced by The Signal Corps. Available from Nuclear Power Field Office, Ft. Belvoir, Virginia 22060, Attn: Training Support Branch. The disassembly and removal of the PM-2A from Greenland is outlined.

Available for loan without charge from the AEC Headquarters Film Library, Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C. 20545, and from other AEC film Libraries.

Army Package Power Reactor, 25½ minutes, color, 1957. Produced by the U. S. Army and the AEC. Describes the inception, design, construction, and operation of the APPR-1, a prototype reactor using components that could be transported by air.

Gas Cooled Reactor Experiment, 39 minutes, color, 1960. Produced for the Army and the AEC by the Lookout Mountain Air Force Station. This film tells the story of the GCRE-1 through interviews with industrial and government personnel. This reactor was one of the first developments in the U. S. mobile nuclear power plant research.

The Story of Camp Century: City Under the Ice, 32 minutes, color, 1961. Produced by the U. S. Army Pictorial Center. Camp Century, a research laboratory, beneath the Greenland ice cap, is shown from planning stage to operating station. A significant portion of the film concerns the PM-2A, the nuclear power plant that supplied electricity and space heating for the laboratory.

PM-1 Nuclear Power Plant, 20 minutes, color, 1962. Produced by the Nuclear Division of the Martin Company. The PM-1 supplies the power for the radar and space heating of a remote Air Defense Command Station in Wyoming. The design and construction of its 16 air-transportable packages are detailed.

PM-3A Nuclear Power Plant—Antarctica, 20 minutes, color, 1963. Produced by the Martin Company for the AEC. This plant supplies electric power and space heating for the McMurdo Sound Station in the Antarctic. The plant's testing in the States and site construction at McMurdo are shown. Use of nuclear power in this remote area is particularly applicable since it reduces the amount of fuel oil that must be transported 11,000 miles from America.

ML-1 Mobile Nuclear Power Plant, 26 minutes, color, 1963. Produced for the U. S. Army and the AEC by Lookout Mountain Air Force Station. The design and testing of the ML-1 is illustrated as is the training of its operating crew.

All photographs courtesy the Martin Company except the following:

Figure 11   Aerojet-General (right); National Reactor Testing Station (left)

Figure 13   Allis-Chalmers Manufacturing Company

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THE COVER

One of the 16 modules of the PM-1 nuclear power plant is loaded aboard an Air Force cargo plane for the flight from the Martin Company's Baltimore plant to Ellsworth Air Force Base in South Dakota. From here it was taken by truck to a radar station in Sundance, Wyoming.

POWER REACTORS IN SMALL PACKAGES

U. S. ATOMIC ENERGY COMMISSION / Division of Technical Information

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This booklet is one of the "Understanding the Atom" Series. Comments are invited on this booklet and others in the series; please send them to the Division of Technical Information, U. S. Atomic Energy Commission, Washington, D. C. 20545.

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