POTENTIALS FOR WATER DEVELOPMENT

WITH ATOMIC POWER

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Nuclear reactors and nuclear explosives both have potential applications to water resource development. I'd like to begin with reactors and proceed to peaceful uses of nuclear explosives.

Nuclear reactor construction is increasing. In 1965 less than 1 percent of the electricity in the United States was generated by nuclear plants. By January 1969, 91 central station nuclear power reactors, with a net capacity of 65,482 MWe, approximately 20% of the nation's generating capacity in 1969, were either under contract, under construction, or in operation (1). In 1968 alone, electric utilities contracted for 17 nuclear power stations in the United States. By 1980 it is estimated that the nuclear share of our American electricity generating capacity will have risen above 25%, and by the year 2000 about half our generating plants will be nuclear.

Figure 1 shows a forecast of electric utility generating capacity, prepared by the Joint Committee on Atomic Energy, Congress of the United States (2). The steep slope of the curve marked "nuclear" is not surprising in view of the fact that nuclear power plant "starts" already exceed fossil fuel "starts" in this country, and will increase their lead from now on. The economic reason for this is indicated by the following table (based on Reference 2) of comparative costs for a 600 MWe[2] power station:

	Capital Costs $/kWe	Operation Maintenance & Insurance Mills/kWh	Fuel Mills/kWh	Total Energy Cost Mills/kWh
Nuclear Plant	135	.3	1.5	4.5
Fossil Plant	120	.2	2.55	5.15

Current estimates project capital costs at $150 per MWe and bus bar electricity costs at 4.5 mills per KWH from a 1000 MWe nuclear reactor.

The term thermal reactor refers to the energy of the neutrons causing fission. It is sometimes used to refer to the type of reactor which merely consumes uranium and produces thermal energy since all commercial power producing thermal reactors are of this type.

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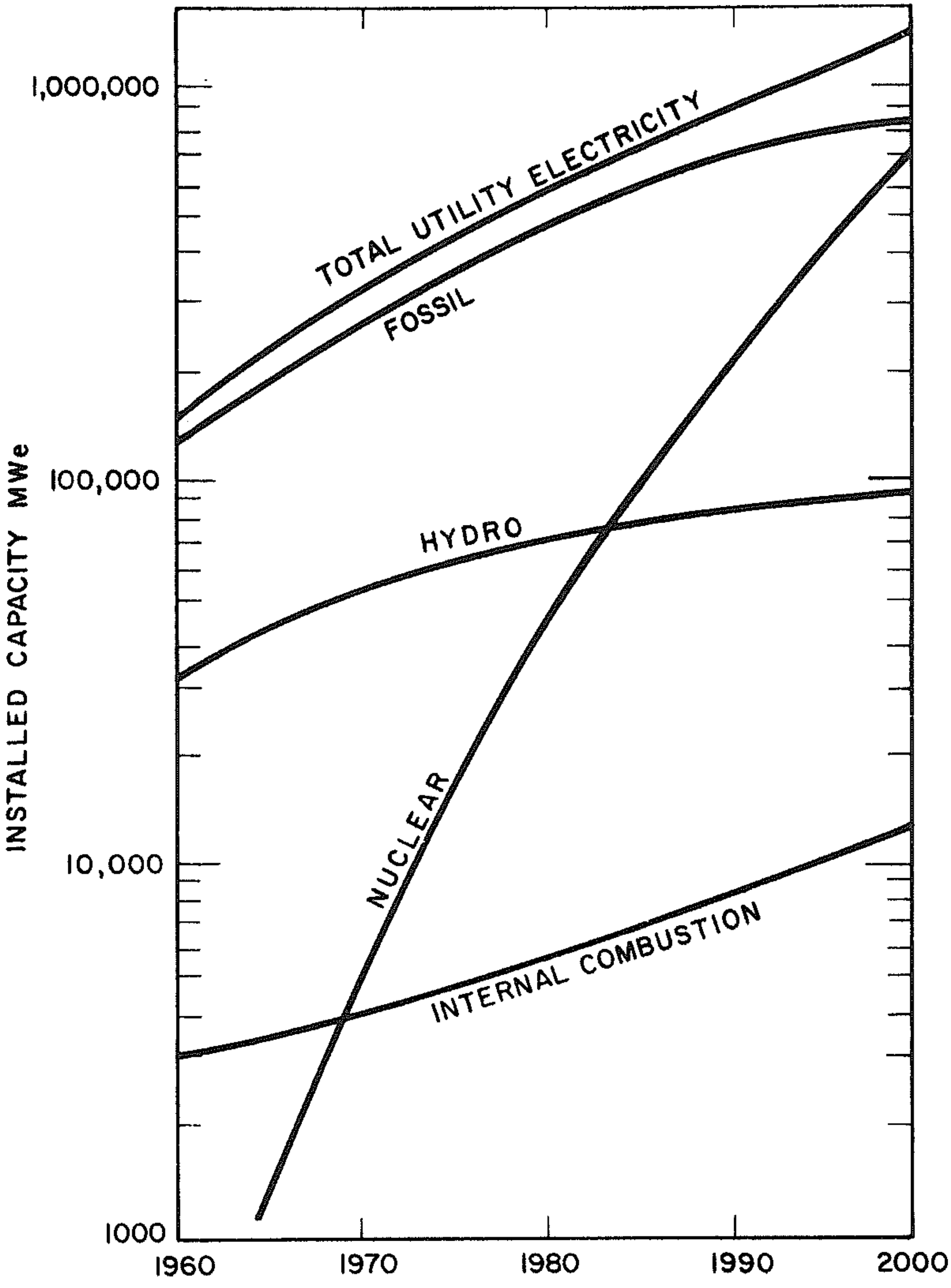
[2] According to W. Kenneth Davis of Bechtel Corporation, quoted in Nucleonics Week, March 13, 1969, there will be much wider use of nuclear power world-wide as countries reach the point where their utility systems can utilize economically large nuclear units of 500 MWe or more.



ELECTRIC UTILITY GENERATING CAPACITY

Figure 1

A breeder reactor refers to the type of reactor which, in addition to producing thermal energy, also produces additional fuel by, for example, the capture of neutrons in uranium 238 thereby creating plutonium 239. Since the supply of ^{238}U is very large (natural uranium is 99.3% ^{238}U, .7% ^{235}U), and it is actually possible to produce more fuel than is consumed, this concept promises a system with very low fuel costs. Since most concepts for breeder reactors utilize fast or high energy neutrons they are usually referred to as Fast Breeder reactors.

The AEC budget for Fast Breeder reactors has ranged from $48.3 million in fiscal 1967 to $88.3 million in 1969. In the private enterprise sector, more than $100 million had been invested, by January 1969, in Fast Breeder research, development and construction. Westinghouse plans a $50 million corporate investment in liquid-metal Fast Breeder reactor work during the next three years, and General Electric and Babcock and Wilcox are also expanding their interest in Fast Breeders (1).

The problem with Fast Breeder reactors is one of solving the many engineering difficulties facing the construction of an economic power producing reactor.

With a limited budget, the United States program has moved rather slowly at first in order to avoid wasted effort on uneconomical systems. The approach now being emphasized is the liquid metal cooled Fast Breeder. Much effort has gone into the selection and testing of possible fuel systems, and into the development of testing facilities such as the Fast Flux Test Facility (FFTF) at Hanford, which will cost almost $100 million. We are nearing the time when, in conjunction with the testing facilities now under construction, a demonstration project would provide much of the remaining information necessary for the commercial exploitation of the Fast Breeder concept.

Breeder reactors are very likely to be the answer to the earth's shortage of energy sources after fossil fuels (mainly petroleum products and coal) become less plentiful. Even with Breeders, however, the shortage of fertile material from which fissionable material can be bred may some day force us to develop machinery for extracting nuclear energy from more abundant material, such as water. In theory, the way to do so is by exploiting the nuclear fusion reaction, the principle of the hydrogen bomb.

Research and development has been underway for several years to find ways in which nuclear fusion can be controlled and harnessed for useful work, such as water desalination and pumping. The AEC budget for controlled fusion research has ranged from $21.7 million dollars in fiscal 1966 to a projected $28.3 million in 1969. It is worthwhile to note that the Russians are spending twice this amount on fusion research.

As an example of interest from the private sector, private support for similar research at the University of Texas is running at $400,000 per year (3) --evidence that the utilities consider controlled fusion a good potential energy source.

The problem with fusion research, as with so many areas of science, is not with the science itself but with its application. The reactions are known; the problems involve maintaining the required high temperatures and pressures necessary to sustain the reactions. The approach which seems most promising is to heat and compress the deuterium-tritium plasma with a strong magnetic field. So far this has been successful only on a laboratory scale, for short periods of time. Research directed toward extending the reaction times so that power can be extracted ultimately on a commercial scale is being carried out at several laboratories in the United States, including Los Alamos. Factors involved in this effort are as follows:

> The basic physics problem is to demonstrate a process for extracting energy from a plasma of deuterium gas. A plasma is an ionized gas where all of the electrons have been stripped away from the nucleus.
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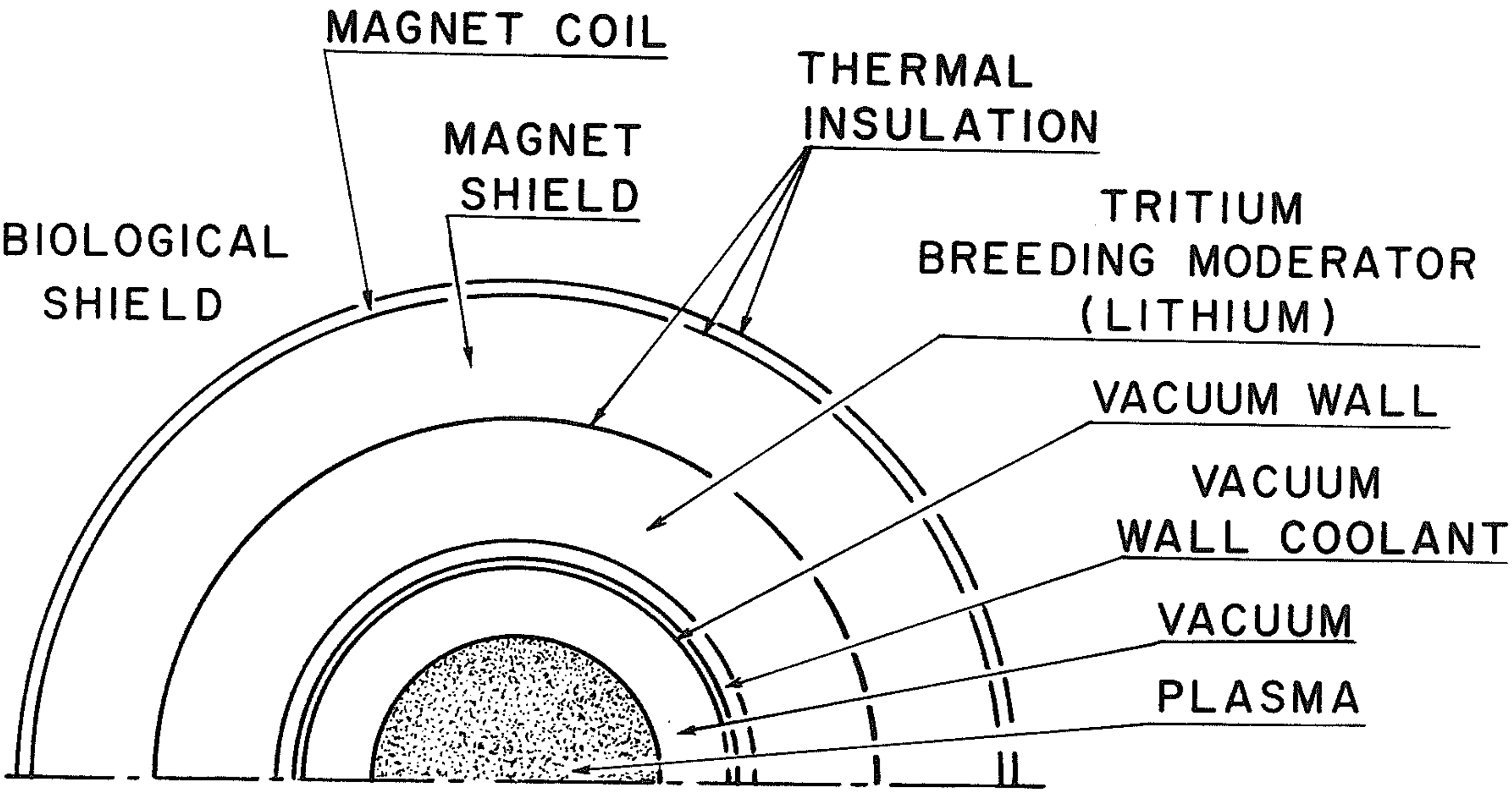
> Deuterium is "heavy oxygen", or an isotope of hydrogen, having one extra neutron in the nucleus. To extract the energy, the deuterium must be heated to approximately 400 million degrees Kelvin. (The interior temperature of the sun is estimated to be 15 million degrees Kelvin). At this temperature, the only known way of containing the plasma is in a magnetic field and this has been done for brief periods.
>
> Deuterium exists in nature: for every 6500 atoms of regular hydrogen in water, there is 1 atom of deuterium.
>
> Each gallon of water (fresh or salt) will yield about 1/8 gram of deuterium. This amount of deuterium can be extracted for a cost of about 5 cents.
>
> The energy present in the 1/8 gram of deuterium is equal to the energy content of 300 gallons of gasoline.
>
> At the world's current rate of consumption of power, there is enough energy in the deuterium in the world's oceans to supply our energy needs for over 1 billion years.

Dr. Fred Ribe, a leader in fusion research at the Los Alamos Scientific Laboratory, predicts it will take 10 to 15 years to solve the physics problems involved in controlled fusion. Engineering problems, says Dr. Ribe, may perhaps be solved by the turn of the century. However, the expenditures for such engineering development will far exceed those involved in the physics research now under way.

One interesting fusion reactor concept (Figure 2) includes a lithium moderator in which tritium reactor fuel will be "bred" in a way roughly parallel to the breeding of fissionable fuel in fission



CONFIGURATION OF A CONCEPTUAL STEADY — STATE D-T FUSION SYSTEM

Figure 2

Fast Breeders. Neutrons from the fusion reaction will bombard the lithium, producing both useful heat and new tritium.

There is little room for doubt about the economic feasibility of desalting sea water in evaporators heated with nuclear energy, whether from fission or fusion reactions. Dr. R. P. Hammond, Director of the Nuclear Desalination Program, Oak Ridge National Laboratory, predicts that sea water can be desalinated for as little as 22 cents per thousand gallons (4). But there is great need for further study devoted to optimizing such factors as plant location and the proper proportion between desalting and electric power production. These are largely economic, rather than technological problems, but they are large. They deserve the close attention they are being given at the Oak Ridge National Laboratory and elsewhere. Figure 3 shows an artist's concept of a dual-purpose plant for desalting sea water and for power. The large building near the sea water intake houses a 250 million gallon per day evaporator. The sphere contains the nuclear reactor steam supply, and the other buildings house the power station and the sulfuric acid plant used for pretreatment of the sea water feed stream.

The economics of such plants has been studied intensively, and the conclusion most usually drawn has been that dual-purpose nuclear desalting and power plants will pay their way, especially if they are large.

In October 1965, an agreement was signed between Mexico, the United States, and the International Atomic Energy Agency, IAEA, which established the framework for the first study in which two emerging technologies, nuclear energy and desalting, were to be analyzed for the benefit of an arid region common to the two countries. Several cases were considered in the three-year study effort, including a case in which design and cost features were as follows: Water capacity, one billion gallons per day; electrical power capacity, 2,000 MWe; reactor size, 10,000 MWth; all costs to be based on a 1966-67 cost index; escalation beyond this cost base not included; nine to ten years required to plan, design, construct and place in operation after authorization to proceed.

Estimated capital operating and product costs are as follows, based on fixed charge rates of four and ten percent, thirty-year life: Capital cost range - approximately $850 million to $1 billion with present technology; advanced technology system 1990 (breeder reactor) - 20 percent less. Annual costs vary from $80 to $180 million. Water costs in 1980, 16 cents to 33 cents per thousand gallons; in 1990 6 cents to 10 cents per thousand gallons due to technology improvements. Electricity costs excluding transmission vary from 1.8 to 3.1 mills per KW hour. Breeder reactors projected for advanced plants in the 1990 period are expected to reduce electricity cost by .5 mills per KW hour (5).

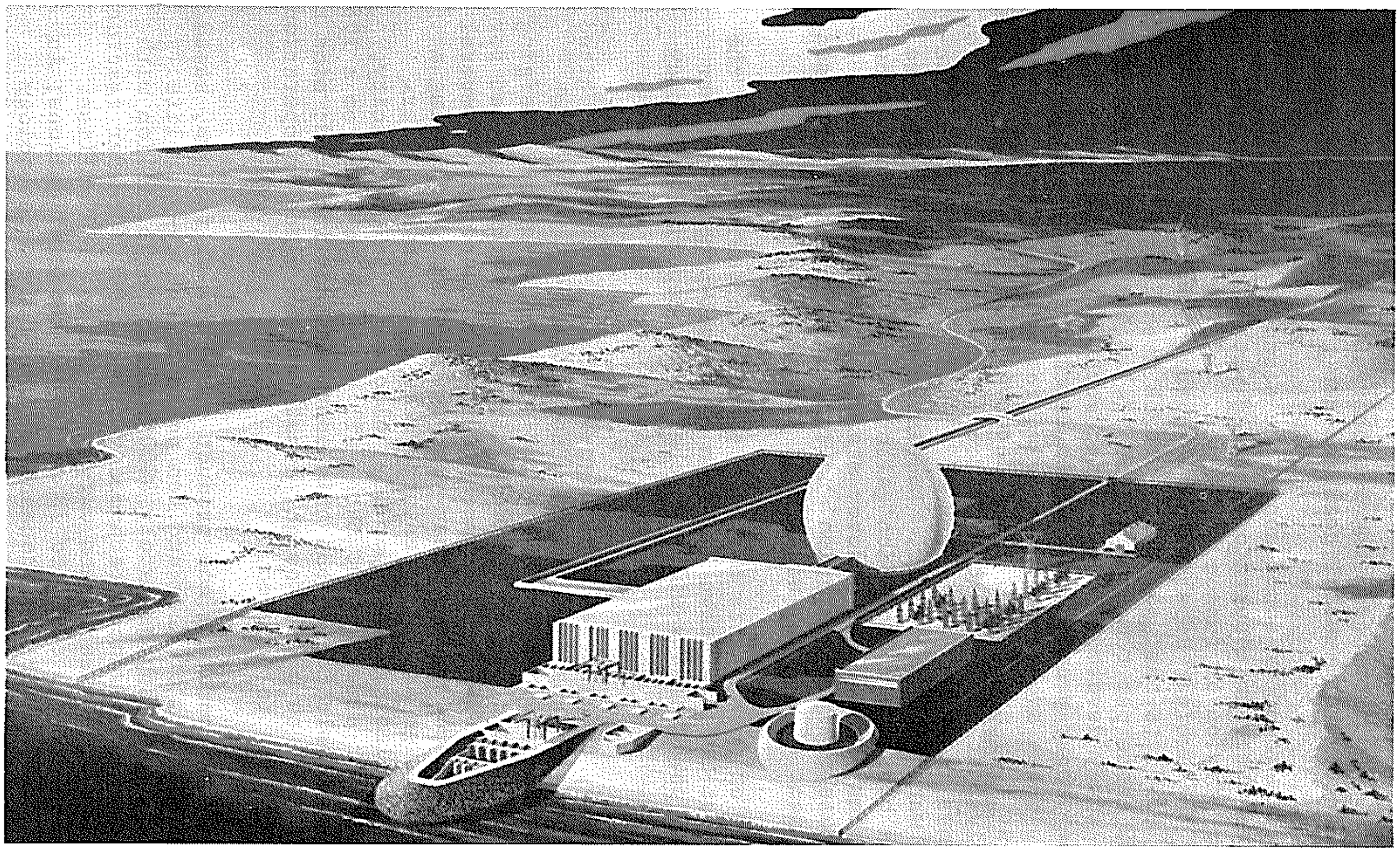


Figure 3

According to U. S. Atomic Energy Commissioner Wilfred E. Johnson, "Nuclear fuel when used in a light-water reactor produces heat in the boiler at a cost of about 14 cents to 20 cents per million Btu. . . Coal prices have tended to run higher than this and fall into the range of 25 cents to 35 cents per million Btu's." It is hoped that Fast Breeder technology will provide fuel costs in the order of 5 cents to 7 cents per million Btu's. Mr. Johnson continues, "The availability of low-cost nuclear energy will permit us to conserve our fossil fuels and reserve them for more vitally needed functions, such as transportation and the production of chemicals and plastics. Low-cost nuclear energy can also provide us with the process heat required for desalination and for the purification and recycling of water" (6).

So much for the usefulness of nuclear reactors, with their rather slow release of atomic energy. Is there any hope that their more violent cousins, the atomic and hydrogen bombs, can be made useful in equally peaceful ways? There certainly is.

The technology of peaceful nuclear explosives (PNE) is advancing rapidly. Project Gasbuggy in the recent past and Project Rulison in the near future were both designed to stimulate natural gas flow underground. Gasbuggy was a 26 kiloton explosion at a depth of 4240 feet. If it lives up to expectations (7), Gasbuggy will multiply the well's total yield by a factor of seven. Rulison will be 40 kt at 8500 feet. Project Sloop is scheduled to fracture underground copper ore beds in southeastern Arizona, and will pioneer PNE application for the mining industry. Once an underground chimney is formed and partially filled with copper ore rubble, dilute sulfuric acid will be added to the rubble to leach the copper from the rock. The pregnant liquor will then be pumped to the surface for extraction of the copper.

Certain PNE applications are exceedingly attractive from the economic point of view. A ton of TNT costs something like $1000, as against the AEC projected charge of 35 cents for the equivalent potential in thermonuclear explosives --if one buys the explosives in megaton amounts. Figure 4 shows the AEC projected prices, which include the services of an arming and firing team. The price of 35 cents per ton of explosive yield is based on the $500,000 price for two megatons. At that end of the scale, nuclear explosive is about 3600 times cheaper than TNT. As the figure shows, however, the nuclear advantage decreases for smaller shots. For half a megaton, nuclear explosive is only a thousand times cheaper, and for 20 kilotons, only fifty times cheaper. Even in such small sizes, however, the nuclear advantage over conventional explosives is large enough to make it seem very likely that PNE will find many applications in water supply development.

One interesting study of such applications is sponsored by the Arizona Atomic Energy Commission in cooperation with the University of Arizona. Its preliminary report (8) describes a potential site investigation for the following projects:

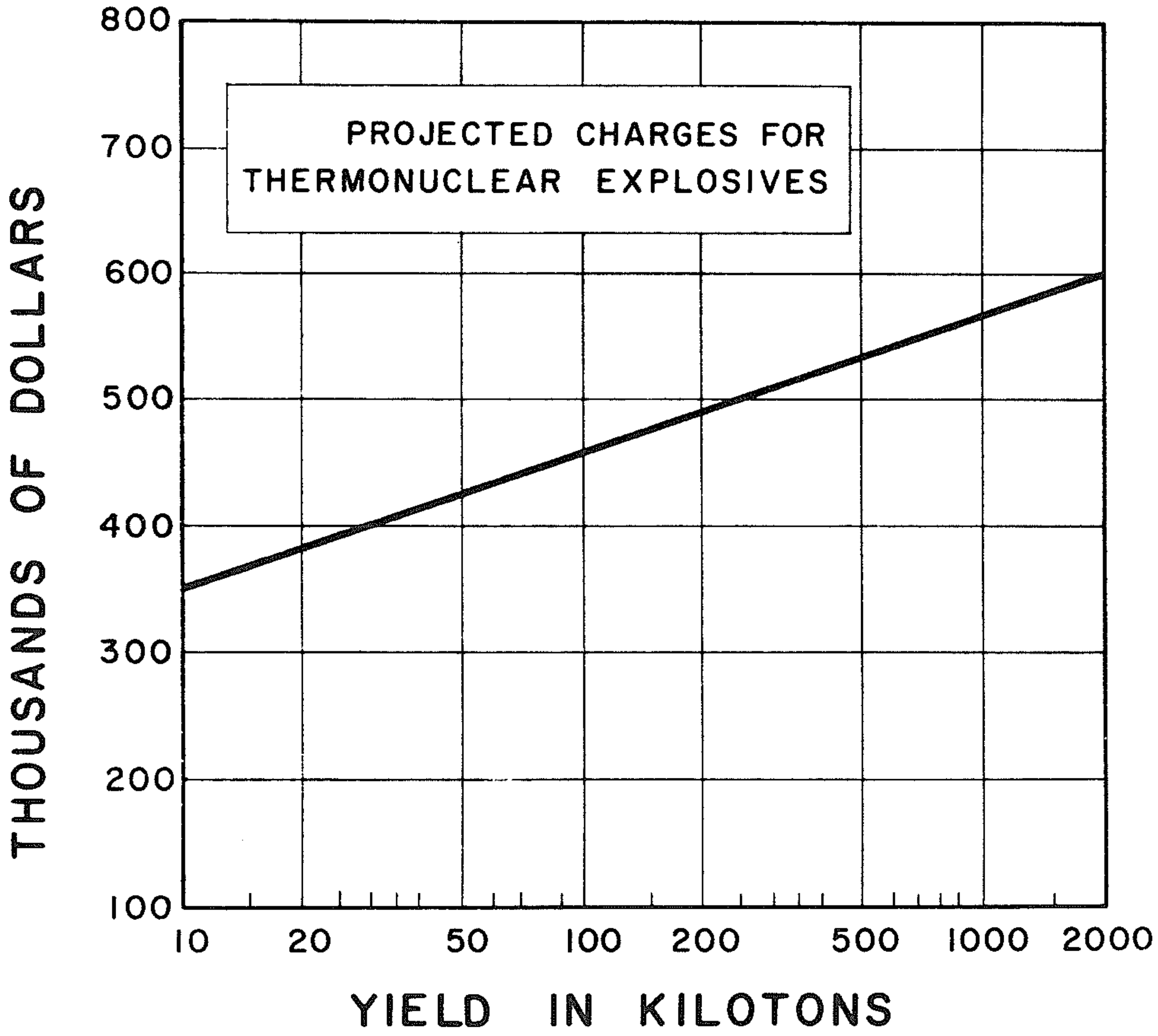

PROJECTED CHARGES FOR THERMONUCLEAR EXPLOSIVES
THOUSANDS OF DOLLARS
800
700
600
500
400
300
200
100
10
20
50
100
200
500
1000
2000
YIELD IN KILOTONS

Figure 4

1. Development of ground water reservoirs and conservation of streamflow.

2. Development of ground water from low yield aquifers.

3. Combination system --recharge of streamflow and low yield aquifers.

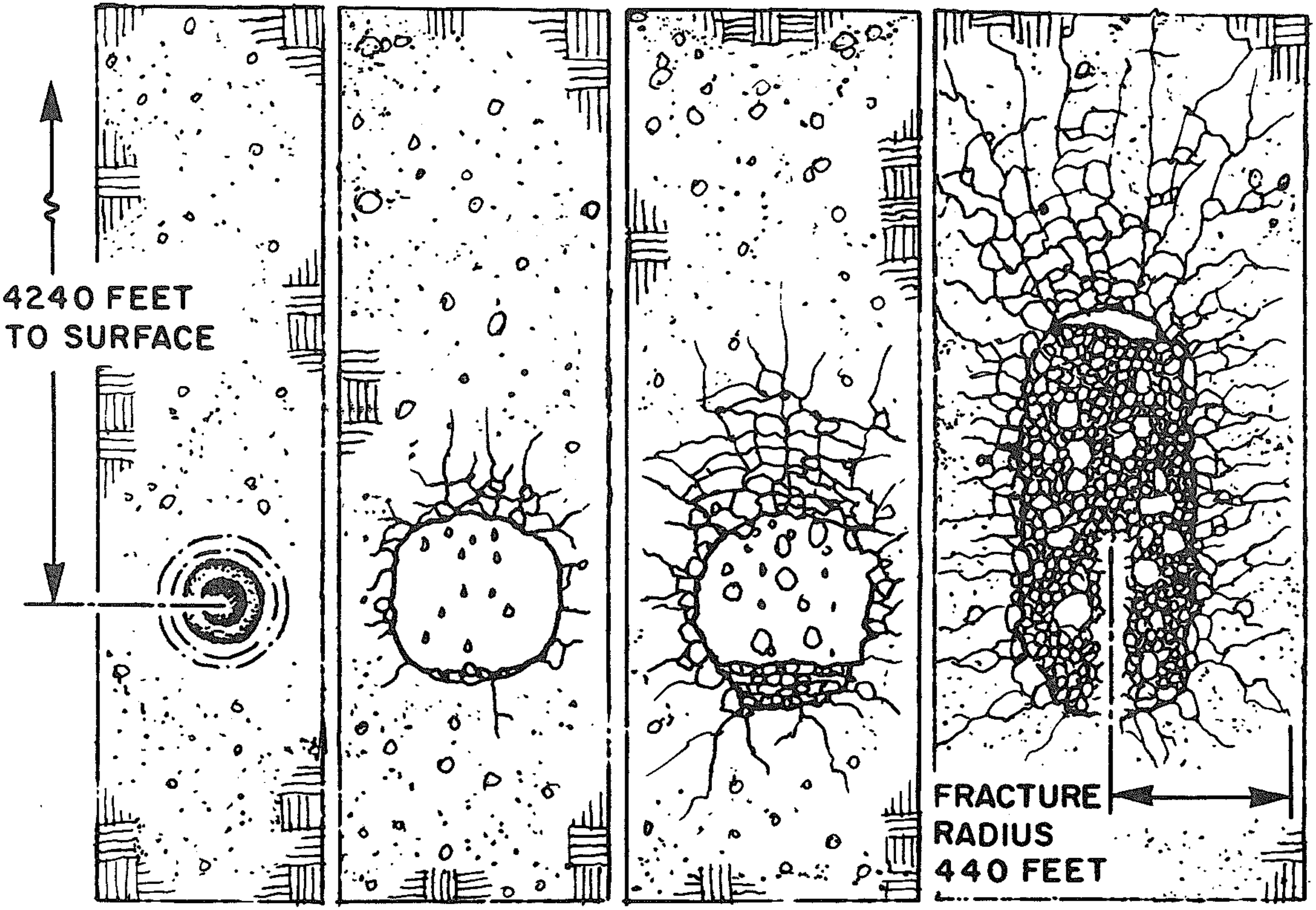
4. Development of surface reservoirs for water storage.

Figure 5 demonstrates a possible application for PNE. This shows what happens at four successive stages after the underground detonation of a nuclear charge -- specifically a charge of the same yield and depth used in Project Gasbuggy. The first stage, shown three microseconds after firing, is the one in which an expanding sphere of high-temperature gas --mainly vaporized rock-- creates a spherical cavity underground. The second stage, 500 microseconds later, shows condensed material (molten rock) falling to the bottom of the cavity. (Note the fracture lines in the surrounding rock; these fractures can be useful.) The third stage, a few seconds to a few hours after the blast, is a time of collapse, when the weakened rock forming the ceiling of the cavity breaks loose and falls. This falling process goes on (depending on the nature of the rock, the size of the charge, and other factors) until the final configuration, or chimney, shown at right in the figure, has been reached. It is easy to imagine situations in which underground fracturing like this, especially with the creation of a large chimney of highly permeable rock fragments, might serve purposes related to improved water supplies.

On the earth's surface as well, when the several political, social, and ecological problems are solved, PNE will become quite useful. Figure 6 shows how a row of craters, created by nuclear detonations, can form a vast canal, useful for navigation or water transport or both.

A year ago this month, at the Nevada Test Site, five nuclear charges of 1 kiloton each were used to dig a ditch 65 feet deep, 255 feet wide, and 855 feet long. Several single cratering experiments were also made, including Project Schooner, last December 8, in which a 35 kiloton charge created a crater 270 feet deep and 800 feet across. Such experiments have amply demonstrated that nuclear explosives can be handled safely.

Nuclear energy, both from reactors and from explosives, can become an important tool in the achievement of water abundance. By means of the proper use of this tool, many arid regions of the world can eventually acquire the water they need.



FOUR STAGES OF CHIMNEY FORMATION

Figure 5

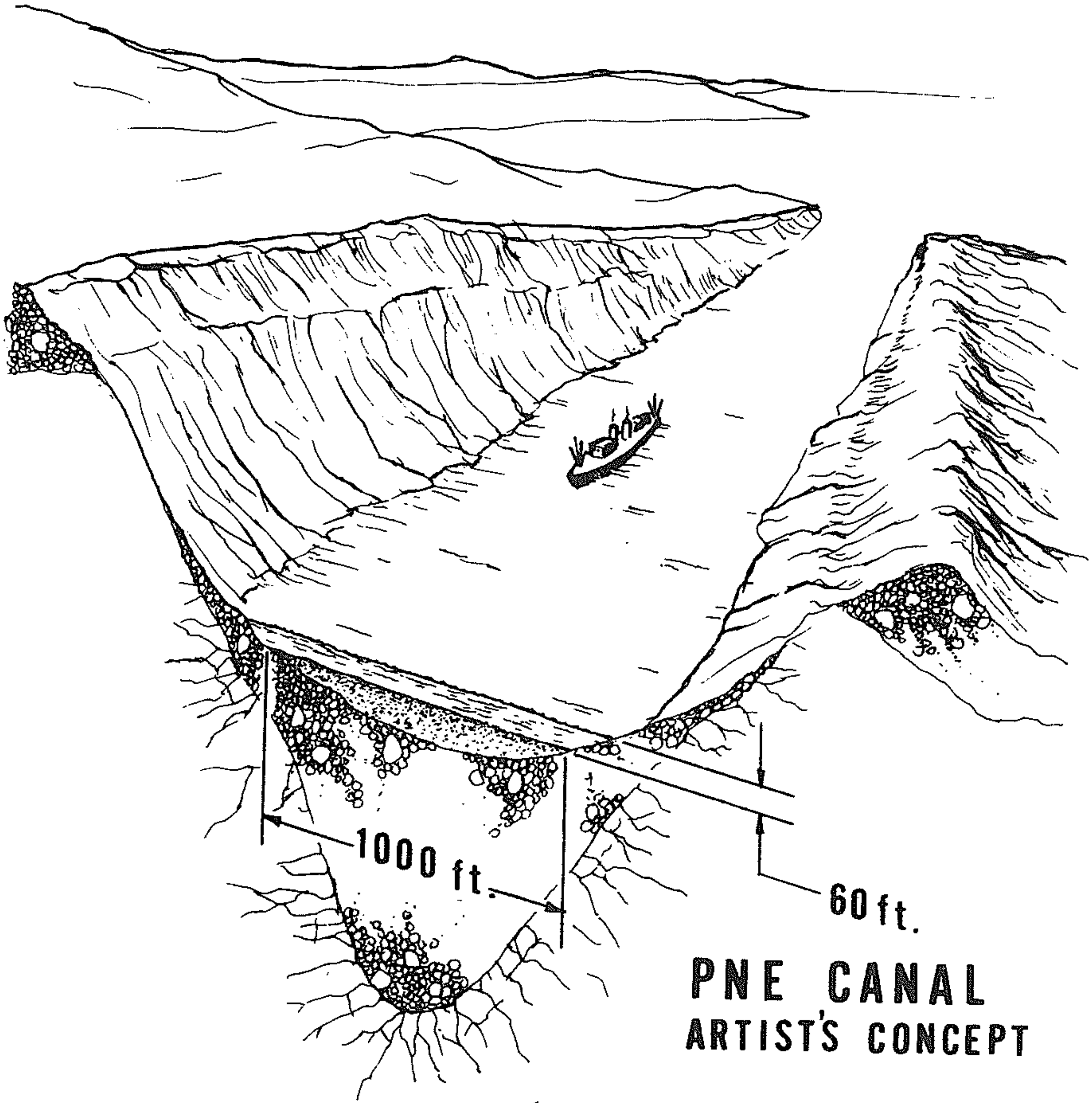


Figure 6

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