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REGIONAL WATER SUPPLY BY NUCLEAR DESALINATION*

by

R. Philip Hammond

ABSTRACT

Comparison of nuclear desalting plants with conventional water supply projects now proposed for the southwestern United States shows that the nuclear stations are at least competitive in some areas, and this competitive position will improve as water needs increase and nuclear costs come down. An independent study made for the Office of Science and Technology confirms the Oak Ridge National Laboratory's estimates of low energy costs from very large reactors.

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REGIONAL WATER SUPPLY BY NUCLEAR DESALINATION

by

R. Philip Hammond*

The Atomic Industrial Forum is this week devoting separate sessions to each of four applications of nuclear energy--central-station power, space power, maritime propulsion, and desalting the sea. Each of these uses seems unquestionably destined to provide a major new industry. This indication of the coming industrial maturity of nuclear energy is fittingly keynoted by Gale Young's address this week: "The Coming of Age of Atomic Power."

Construction of desalination plants will not be the least of these new nuclear industries. In this paper I will show that nuclear water stations are already competitive with other water sources in some areas, that this competitive position must improve, and that there is reason to expect a construction rate for these plants of a quarter of a billion dollars a year within the next 30 or 40 years.

Power Cost Conclusions are a Milestone in Nuclear Energy

The above conclusions can be demonstrated using published data and the technical information developed by the Office of Science and Technology Panel assigned to study large reactors for nuclear desalination. The Panel's study itself is incomplete, but the reactor portion of the work has been published.[1] This document in itself constitutes a milestone in nuclear energy because of its findings about the future of electric power cost.

These findings should be noted before going on to the desalination plants, for the power-only results of the OST study may be even more important to the nuclear industry than the prospects for desalination. The information can be summarized into two statements:

1. Nuclear power at 3 mills/kwhr or less appears feasible in large stations which could be operating by 1980.

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2. The reactors which can achieve these low costs are efficient converters and breeders; in the large sizes, these types exhibit lower costs than the enriched reactors which are favored for small stations.

Construction Cost vs. Size

The curves in Figure 1 show the cost of constructing nuclear electric stations as predicted by the OST study for two types of reactors, together with results for another type studied by Oak Ridge National Laboratory (ORNL). The three lower curves, representing the cost of the nuclear portion of the plant, show that similar construction costs can be expected for all types. The upper curves represent the cost of adding on the turbine, condenser, and electric parts of the station. The actual numbers for this increment are due to Westinghouse, Bechtel Corporation, and Sargent and Lundy, who seem to have three different ideas as to what these conventional components cost.

The OST study did not develop designs and cost estimates for graphite-moderated reactors or fast breeders, but merely assigned these types the same capital cost as the heavy water type.

Converters and Breeders Have Lowest Fuel Cost

The fuel cost information presented in the OST study is, in my opinion, a major contribution to the future of the nuclear industry. The work shows clearly the great economies which are available to us by using mass production methods for fuel elements and fuel processing. These results are shown in Figure 2, which shows direct fuel costs of three types as a function of the size of the industry. (The unit costs were related to electric capacity by assigning average burnups of 25,000, 7,000, and 30,000 Mw days per ton to the enriched, natural uranium, and fast breeder respectively.

It is worth noting that once large capacity exists for a given type of fuel, the lowest fuel cost is available to any size of reactor which uses that type. How far off is such growth in capacity? One projection published by the Federal Power Commission[2] stated that by 1983 there would be about 25 million kilowatts of nuclear power installed in the Pacific Southwest area alone. This growth may be accelerated if the power costs predicted by the OST study are achieved. If a policy of

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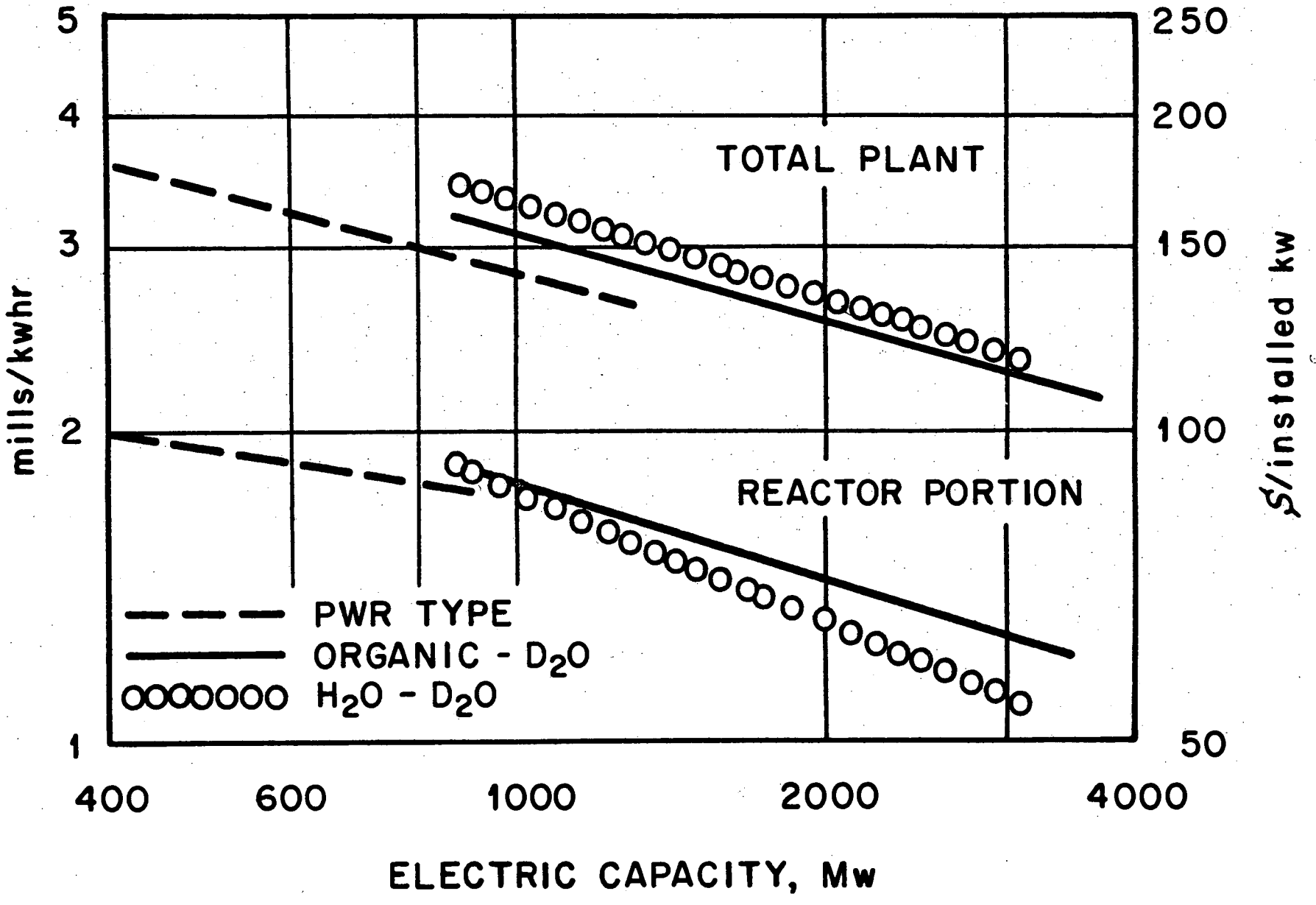
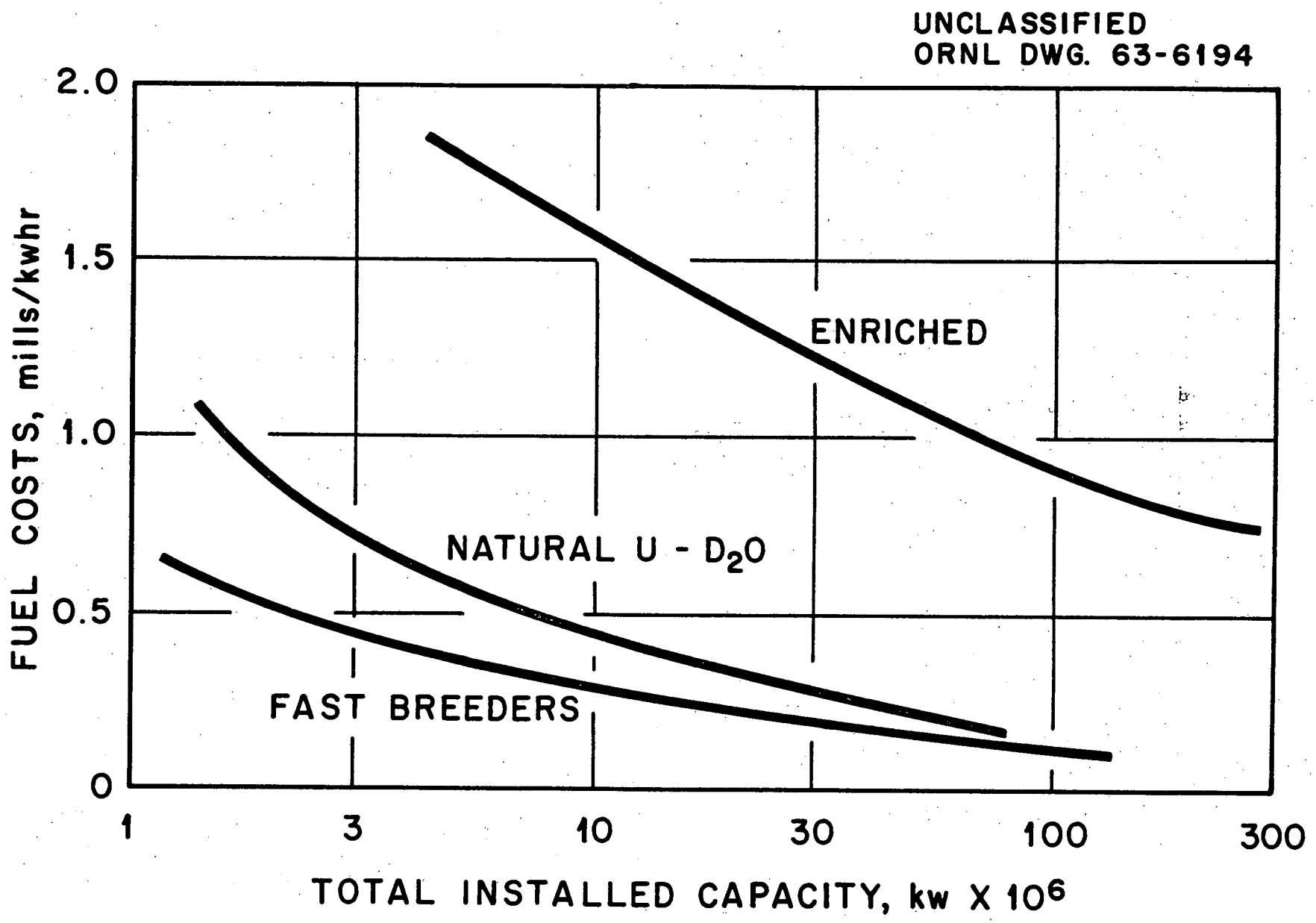


Fig. 1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FUEL COSTS, mills/kwhr
2.0
1.5
1.0
0.5
0
ENRICHED
NATURAL U - D_2O
FAST BREEDERS
1
3
10
30
100
300
TOTAL INSTALLED CAPACITY, kw X 10^6

Fig. 2

"toll processing" were adopted, the AEC's existing fuel plants could be used to achieve low natural uranium fuel costs at once.

Converters and Breeders not Dependent on High Ore Price

Total power costs, including operating and inventory charges, are shown by the study to range down to about 3 mills for the converter reactors and 2.8 mills for the breeder. The enriched reactors show costs about half a mill higher because of their more expensive fuel. This emergence of the converters and breeders over enriched reactors has been predicted before by Pittman and Staebler[3] and anticipated in the AEC "Report to the President."[4] The OST study shows that these types of reactors can be exploited much sooner than had been expected since they exhibit economic advantages which are not dependent on higher priced ore. This finding is an important one for the nuclear industry.

Evaluation of Nuclear Desalination by the Method of Equivalent Alternates

Coming now to the application of these reactors to water desalination, we must first select an effective evaluation technique. This requires some means of comparison with conventional methods of water supply. As everyone in the water business knows, there is no such thing as a "standard" cost for water. The cost depends upon the location, upon riparian rights, and other circumstances--it may be a dollar a gallon in one place, and people may be getting paid to take it away in another. Therefore a computation of the "cost" of water and its comparison with the "average" price of water is meaningless, just as information about the "average" rainfall is meaningless to a thirsty man in Death Valley.

The most acceptable technique for evaluating a proposed new source of water is to choose some specific need and investigate how it can be met in two ways: With the new method, and with the best conventional method, applying the same assumptions and ground rules to both. Comparing the basic cost elements of the two equivalent systems instead of the product cost minimizes the number of such rules. The necessary information for this procedure is readily available, and I propose to make use of it here.

Conventional Water Plans and Their Costs

In the Pacific Southwest region of the U. S. two large water supply projects are now proposed, amounting to about $6 billion over the next 35 years, in addition to many smaller works. These schemes are designed

to provide the best available means for supplying new water to Southern California and Arizona. The main features of these two projects are shown in Figure 3. The California Water Plan,[5] now partly under construction, is shown in grey. This Plan, costing about $1.75 billion, has as its main purpose the delivery of about 1.8 million acre-feet of water per year (1.64 billion gallons per day) to Southern California from the region north of the Sacramento River. The Plan does not provide for distribution of the water, but turns it over to "canalside" purchasers, such as the Metropolitan Water District. An important item in the cost of the water is the lift to nearly 3500 feet in crossing the Tehachapi Mountains. Not shown on this map are the portions of the project which divert and store the additional water along the Feather River and the Sacramento River. This Plan is already committed for construction.

The Pacific Southwest Water Plan is shown in black on the map. This Plan,[6] recently proposed by Secretary of the Interior Udall, calls for enlargement of the California aqueduct (the main ditch of the California Plan) to carry an additional 2 million acre-feet of water per year. The new water would be provided by new diversion and storage works along the Trinity River, near the California-Oregon border. The water, once in the Tehachapi Mountains, would be divided into two streams, one half continuing to Perris Reservoir in Riverside County, and the other being carried across the desert to Lake Havasu on the Colorado River.

The Plan also includes the Central Arizona project, two power dams on the Colorado, and a number of smaller local projects. These do not contribute to the supply of new water, but are necessary in distributing and using it. Since they would probably be necessary whether long-range conveyance or water desalting were to provide the new water, they are omitted from comparison with a nuclear alternate. The portions which are essential to the new water supply are stated in the Plan to cost about $2.1 billion. These portions are listed in Figure 4, together with the initial cost and the annual upkeep and operating expense listed in Secretary Udall's report.

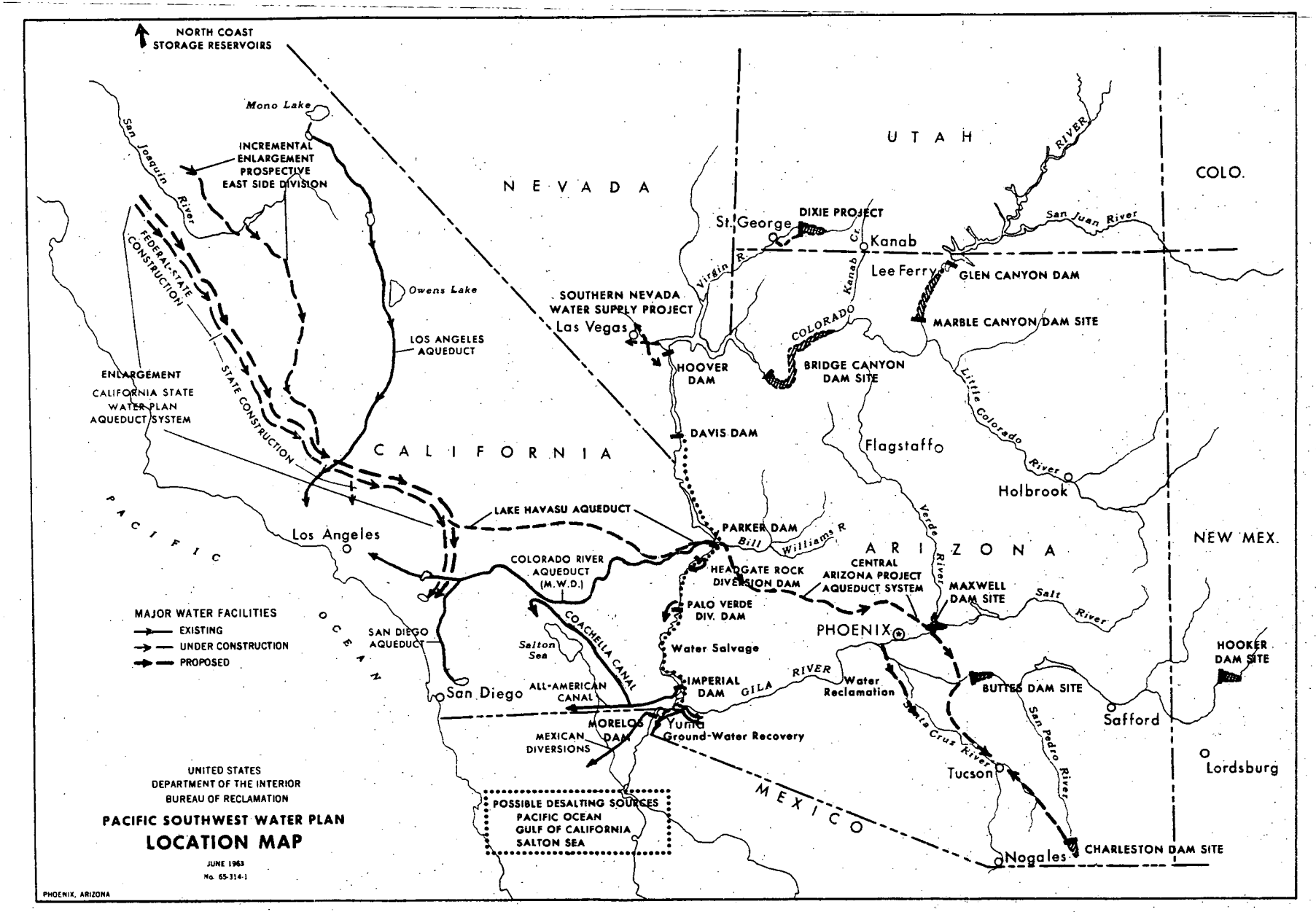
NORTH COAST STORAGE RESERVOIRS
Mono Lake
INCREMENTAL ENLARGEMENT PROSPECTIVE EAST SIDE DIVISION
San Joaquin River
FEDERAL-STATE CONSTRUCTION
STATE CONSTRUCTION
ENLARGEMENT CALIFORNIA STATE WATER PLAN AQUEDUCT SYSTEM
Owens Lake
LOS ANGELES AQUEDUCT
NEVADA
UTAH
COLO.
NEW MEX.
ARIZONA
CALIFORNIA
PACIFIC OCEAN
MEXICO
St. George
DIXIE PROJECT
Kanab
Lee Ferry
GLEN CANYON DAM
MARBLE CANYON DAM SITE
San Juan River
Virgin R.
Kanab Cr.
COLORADO RIVER
SOUTHERN NEVADA WATER SUPPLY PROJECT
Las Vegas
HOOVER DAM
BRIDGE CANYON DAM SITE
DAVIS DAM
Little Colorado River
Flagstaff
Holbrook
LAKE HAVASU AQUEDUCT
Los Angeles
PARKER DAM
Bill Williams R
COLORADO RIVER AQUEDUCT (M.W.D.)
HEADGATE ROCK DIVERSION DAM
CENTRAL ARIZONA PROJECT AQUEDUCT SYSTEM
Verde River
MAXWELL DAM SITE
Salt River
PALO VERDE DIV. DAM
PHOENIX
Water Salvage
COACHELLA CANAL
Salton Sea
SAN DIEGO AQUEDUCT
San Diego
ALL-AMERICAN CANAL
IMPERIAL DAM
GILA RIVER
Water Reclamation
BUTTES DAM SITE
HOOKER DAM SITE
Safford
Lordsburg
MORELOS DAM
Yuma
Ground-Water Recovery
MEXICAN DIVERSIONS
Santa Cruz River
San Pedro River
Tucson
Nogales
CHARLESTON DAM SITE
POSSIBLE DESALTING SOURCES
PACIFIC OCEAN
GULF OF CALIFORNIA
SALTON SEA
MAJOR WATER FACILITIES
EXISTING
UNDER CONSTRUCTION
PROPOSED
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PACIFIC SOUTHWEST WATER PLAN
LOCATION MAP
JUNE 1963
No. 65-314-1
PHOENIX, ARIZONA

FIGURE 3

Fig. 4

COMPARISON OF PART OF SOUTHWEST WATER PLAN WITH NUCLEAR POWER

PACIFIC SOUTHWEST WATER PLAN

	INITIAL COST $ million	*ANNUAL COST O, M AND REPLACEMENT $ million*
SOURCE AND CONVEYANCE FACILITIES		
California Aqueduct Increment	527	*
Lake Havasu Aqueduct	984	*
South Fork Trinity Project	419	*
Trinity River Project	165	*
TOTAL	2095	34.4

OUTPUT: 2.14 billion gpd at 100% load factor.

NUCLEAR DESALINATION PLAN

CASE 7-3 REACTOR AND POWER PLANT	782	19.188
HEAVY WATER AND FUEL	132	9.834
EVAPORATOR PLANT R = 11.8	730	17.38
CONVEYANCE, SEA LEVEL TO PERRIS RES.	275	1.8
EXCHANGE OF WATER, PERRIS AND L. HAVASU	0	Credit, not evaluated
TOTAL	1919	48.2

OUTPUT: 2.20 billion gpd at 80% load factor.
3400 Mwe at 80% load factor.

A Nuclear Alternate to the Pacific Southwest Water Plan

Let us now see how the same job can be done with desalting plants. To produce the same daily output of water by nuclear means, a dual-purpose reactor station was taken from case 7-3 of the OST study. This station has three heavy-water-moderated natural uranium reactors, each with 8300-Mw heat rating, and could be constructed by the time that the first water is expected from the conventional system. The flash evaporator chosen was designed by the Union Carbide Nuclear Company,[7] using the compact multi-level plant layout which they have found offers greatly improved economy as compared with one-level plants. This design has been thoroughly reviewed by internationally known experts on sea water evaporation. The basic process parameters are the same as those used in the Point Loma Plant of the Office of Saline Water.

It was assumed that this plant was located near San Clemente, about 40 miles from Perris Reservoir mentioned above. In order to get the water to the reservoir, a local conveyance system was included, and the necessary pumping energy diverted from the electric output of the station.

A difference in the two schemes so far is that the desalting plant delivers all its water to Perris Reservoir, while the Plan takes half to Lake Havasu, which is the diversion point for the Metropolitan Aqueduct. Through this aqueduct the Metropolitan Water District is presently engaged in conveying about the same amount of water from Lake Havasu back to the same area served by Perris Reservoir (see map). It seems plausible that the District would accept high-quality distilled water already in Riverside County in exchange for Colorado River water which is already in Lake Havasu, and this exchange would reduce the District's pumping costs.

Assuming this exchange, we can make the comparison shown in Figure 4. The two systems deliver approximately the same amount of water to the same places and cost approximately the same to construct. The nuclear system produces about 3400 Mw of electric power in excess of its own needs, or about 1130 Mw for each reactor, which is an independent unit. The marketing of this power should be no different than for any other 1100-Mw units.

In order to evaluate these two systems, all that is necessary is to compute the break-even price for the power--that is, the power price

which will reduce the operating expense of the nuclear system to the same $34.4 million level of the Water Plan. We would then have two systems with the same water output, the same construction cost, and the same net annual expense. If the break-even price for power is in the range of its market value, the systems can be said to be competitive; if it is lower than the probable market value, the nuclear system is more than competitive.

OST Nuclear Plants and Advanced Reactors Competitive or Superior to Conventional Plan

The computation gives 0.6 mill/kwhr as the break-even price of power. One must conclude, therefore, that the nuclear system is at least competitive with the Pacific Southwest Water Plan. If the power actually were worth 2.7 mills, for example, the distilled water would cost about 8¢ per 1000 gallons less than conveyed water.

In Figure 5 is shown the comparison which we have just made, the Pacific Southwest Water Plan in column 1 and the nuclear station using the OST reactor estimated by Bechtel in column 2. In the third column is shown cost of the same station using the type of reactor proposed by Oak Ridge for nuclear desalination, but not so far included in the OST study. The detailed design and cost estimate for this reactor was made by Sargent and Lundy[8] and is available in published form. The ORNL type has lower capital costs and lower operating costs, hence makes cheaper steam than the organic-cooled reactor. This low-cost, low-pressure steam makes it particularly adapted to desalination. Both types make about the same cost power in a power-only plant since the organic system yields more power. The surplus electric output of the Plan-3 station is only 930 Mw per reactor. This system has a substantially lower capital cost than Plan 1, and needs no power revenue to break even, so the cost difference plus the full value of the power becomes the measure of the advantage gained over the other system.

Why Use Dual-Purpose Plants?

At this point it is appropriate to compare the dual-purpose plants with single-purpose water-only plants for nuclear desalination. Dual-purpose plants are preferred because they have inherently higher

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Fig. 5

COMPARISON OF THREE WATER PLANS

	PLAN 1 PACIFIC SW PLAN	PLAN 2 CASE 7-3 ORNL EVAP.	PLAN 3 ORNL
INITIAL COST ($ x 10^6)	2095	1919	1686
ANNUAL DIRECT COSTS	34	48	35
BREAK-EVEN POWER PRICE (mills/kwh)		0.6	0.0

thermodynamic efficiency. The economic superiority conferred by this higher efficiency will be illustrated using smaller plants than the giant installations discussed above. Figure 6 shows graphically the procedure followed. The example is based on the one-reactor station described in case 6-1 of the OST study which, when fitted with an appropriate evaporator, produces 815 million gallons per day of water and 1480 Mw of electric power in addition to that needed within the plant. A water-only plant having the same water output was estimated by interpolating the cost of appropriate components between cases 4 and 6. The station included enough electric output to serve just its internal needs. Similarly, a power-only station of 1480-Mw capacity was interpolated from the power-only cases 4 and 6.

As shown in Table I the capital cost of the dual-purpose station is $115 million less than the sum of the costs of the two single-purpose plants making the same output. The annual operating expense is $12 million less than for the two separate cases. The incremental cost of adding the electric output to the water-only case is only $60 per kilowatt of capacity and 0.2 mill/kwhr in operating expense, a compelling reason for dual-output plants whenever there is a market for the power.

Table I. Comparison of Single and Dual-Purpose Plants

	Water Only	Water + Power	Power Only
Initial Cost ($\$10^6$)	530	619	204
Annual Direct Operating Expense	21.2	23.4	14.2
Water Output, mgd	815	815	
Power Output, Mw		1480	1480

Private Ownership of the Power Facilities is Feasible

This same example allows another important fact to be illustrated: Joint ownership of a dual-output plant is economically feasible. Table II shows two ways of dividing up the ownership. In the first case a portion of the plant cost just equal to the cost of a water-only station

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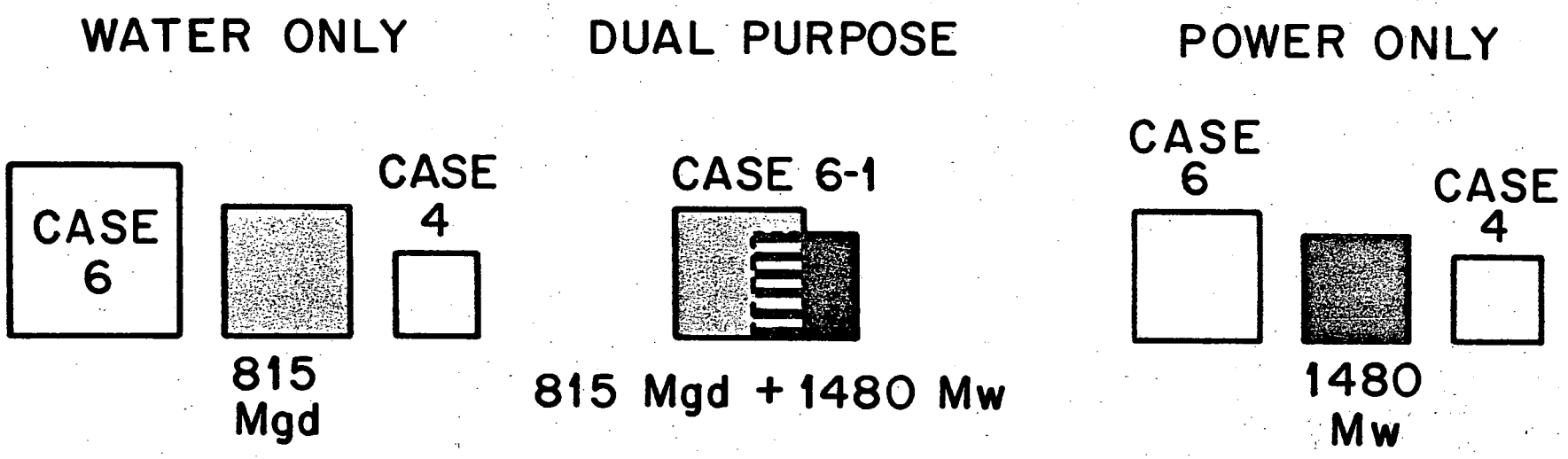

Fig. 6

Table II. Cost of Water in a Dual-Ownership Plant

	Method 1	Method 2
Initial cost allocated to water at 3.5% ($\$10^6$)	530	415
Initial cost allocated to power at 14%	89	204
Price of power, mills/kwhr	4.1	4.1
Cost of water, ¢/1000 g	4.9	9.9

carries capital charges at the 3.5% rate used by Secretary Udall's water plan, and the balance is considered to be privately owned and carries 14% capital burden. At the other extreme, only the incremental cost of water is carried at public interest rate, and the balance is assumed by private ownership. The costs of plantside water in the two cases are 4.9 and 9.9¢ per 1000 gallons. Some intermediate allocation might be used in an actual case.

Unit Cost Comparison of Conventional and Nuclear Systems

Figure 7 presents another convenient but less specific means of comparing water systems and power systems in terms of unit costs and unit expense. This method is frequently used in the electric power industry. The gas-fired desalination plant listed is one described in the Appendix[9] to the Pacific Southwest Water Plan Report. The single- and dual-purpose plants based on the Bechtel reactor estimates are the small ones just described in Table I. Compared with them are single- and dual-purpose plants using the ORNL reactor type. None of the systems or plants listed include water distribution.

Conclusions: A Turning Point in Water Planning

The OST study of large reactors for sea water distillation, compared and supplemented as I have indicated, provides the basis for a turning point in our methods of planning water supply in this country, and in the whole world. I believe that the study is conservative, and properly so, but the field which it covers is technically "soft," and is yielding rapidly to our first exploratory efforts. In the past year we have had constantly to revise downward our estimates of the

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COMPARISON OF CONVENTIONAL AND NUCLEAR WATER SUPPLY SYSTEMS

TYPE OF SYSTEM	*CONSTRUCTION COST*		*OPERATING COST*	
CALIFORNIA WATER PLAN (southern portion)	86¢	gpd	8.1¢	1000 g
(with nuclear pumping)			(5.1)	
PACIFIC-SOUTHWEST WATER PLAN (essential features)	98¢	gpd	4.4¢	1000 g
(hydro power features)	$383	kw	1.25	m/kwh
GAS-FIRED DESALINATION PLANT (OSW, water only)	57¢	gpd	22.4¢	1000 g
NUCLEAR PLANT, WATER ONLY (Bechtel reactor)	65¢	gpd	8.9¢	1000 g
(ORNL r.)	57¢		4.7¢	
NUCLEAR PLANT, POWER ONLY (Bechtel r.)	$138	kw	1.4	m/kwh
(ORNL r.)	140		0.4	
DUAL PURPOSE NUCLEAR PLANT (Bechtel r.)	$138	kw	1.4	m/kwh
	51¢	gpd	3.9¢	1000 g

Fig. 7

cost of evaporators, for example, because of rapid improvement in the art. Figure 8 shows a set which is already nearly obsolete. A year ago this line would have been a third higher on the page, and two years ago nearly off the top. The same is true of the reactors.

The cost of conventional water supply, like electric power, presents a "moving target" to the nuclear alternative, but unlike the power case, the cost of water supply is going up. Each new increment of water must be brought from a longer distance or pumped from a deeper well. The advance of nuclear technology will bring nuclear costs down, so that the market for "nuclear" water must increase rapidly with time. The cost of supplying municipal and industrial water in this country is about $100 to $200 per capita. The total water supply including food production and other uses requires an investment of perhaps $300 to $500 per capita for new additions, depending on the region. By the year 2000 AD the population increase may be 3.75 million persons per year,[4] of which at least one-third will by then be in water-deficient regions. A nuclear water-equipment industry of $250 to $500 million per year would not be at all unlikely. Some of this capacity would be in the form of waste-water renovation. Other estimators have placed the potential market for nuclear desalination as high as one billion dollars a year, on the assumption that great increases in the food demand will necessitate much more irrigation water.

The Pacific Southwest Water Plan has provided a very useful basis against which to compare nuclear desalination plants with conventional supply means. In fairness to the Secretary of the Interior, however, I should point out that the desalination alternative is mentioned in many places throughout the report. The Plan itself provides for immediate construction of a 50-million-gallon-a-day desalting plant, and the longer range portions of the Plan, called Phase II, are scheduled for reexamination as the technology of water desalting becomes established. I do not think that there will be any lack of readiness from Interior to make use of nuclear desalination. The main difficulty at present comes from the fact that we in the nuclear field are not yet ready to build reactors of sufficient size to achieve the low costs which we foresee are possible. There will be about ten more years before a real crisis in water supply exists, but some means of meeting the crisis

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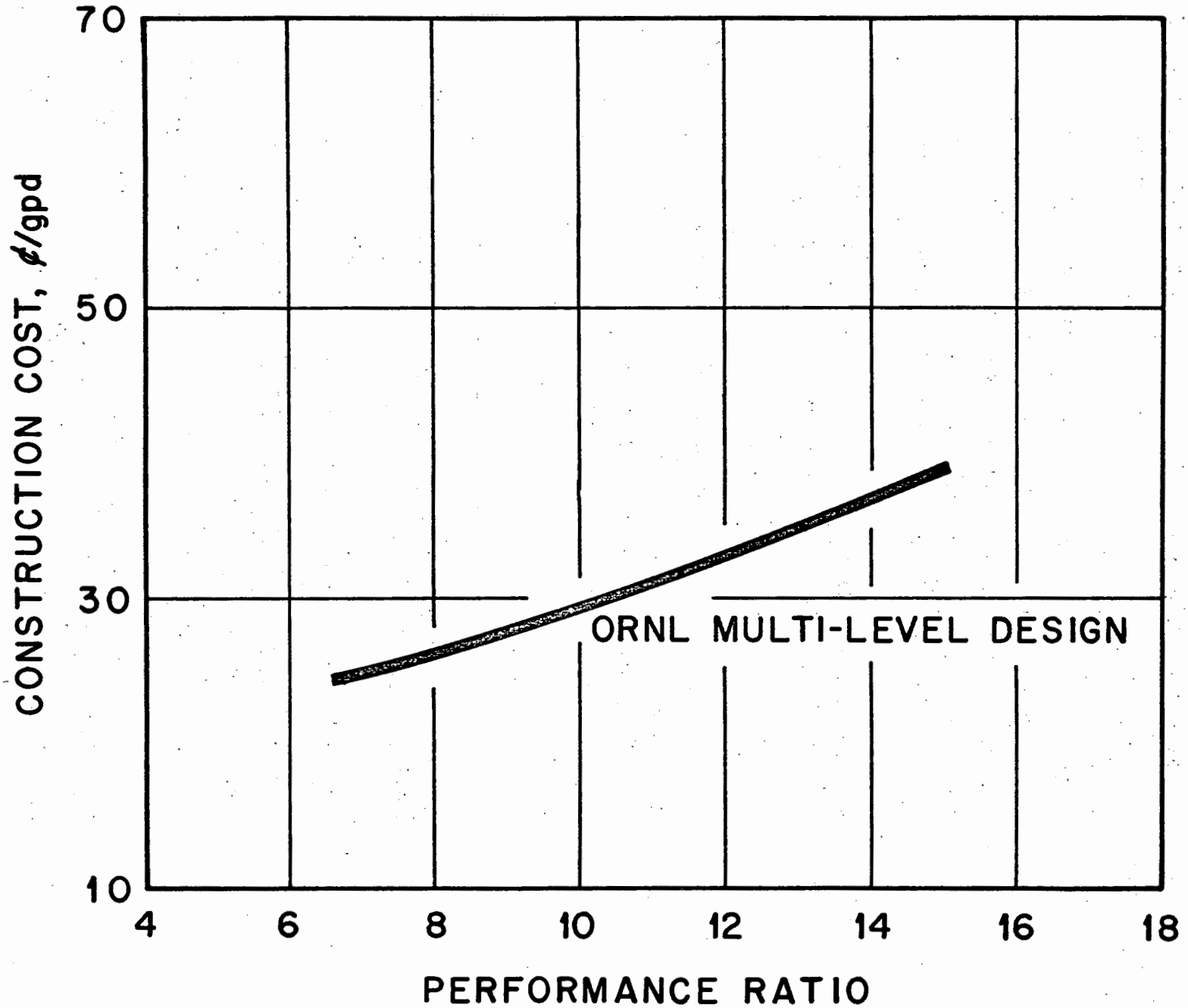

Fig. 8

must be committed for construction some years before that. Since we must construct intermediate-size plants first, there is barely sufficient time with even a vigorous program to be ready for the presently foreseeable need.

Nuclear desalination plants will never, of course, completely take the place of conventional water conveyance. Some combination of the two will provide the best solution in most cases, with low-cost pumping energy from the reactors helping to lower costs of the conveyance system. There is urgent need of planning on how best to combine these two methods.

Finally, one must give thought to the enormous potential market for nuclear desalination plants overseas. The arid lands of the earth greatly exceed the presently cultivated areas; many countries are desperately short of water. I suspect that the foreign market for desalination plants will eventually exceed the domestic one.

A new era is dawning on the earth, I believe, in which no nation need be a "have not." A few tons of natural uranium can be the means of providing a plentiful supply of food, water, and electric power anywhere in the world.

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