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After many hundreds of pages of testimony[2] and several economic studies,[3] there still appears to be considerable uncertainty as to the economic merits of the controversial proposed Marble Canyon Project on the Colorado River just above Grand Canyon National Park in Arizona. This controversy is of importance not only to the conservationists, who are the principal opponents of the Project, but also to the nuclear power industry since nuclear power provides one of the principal alternatives. Demonstration that such an alternative is preferable to the Project would raise many questions as to the economic justification of other proposed hydroelectric projects, a major competing source of power. The purpose of this paper is to review the earlier studies of the question and to present some new and more refined cost-benefit calculations on the Project.

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[2] Most recently in U.S. Congress, House, Committee on Interior and Insular Affairs, Lower Colorado River Basin Project, Hearing before Subcommittee, 89th Congress, 1st Session, August 23 to September 1, 1965.

[3] The most important ones available to us are U.S. Department of the Interior, Bureau of Reclamation, Pacific Southwest Water Plan, Supplemental Information Report on Marble Canyon Project, Arizona, January 1964; U.S. Atomic Energy Commission, Division of Reactor Development and Technology, Office of Civilian Power, "A Specific Comparison of the Economics of Nuclear Electric Power and Hydro Electric Power -- Bridge and Marble Canyon Projects," February 1, 1965; and Alan P. Carlin, "An Economic Reevaluation of the Proposed Marble Canyon Project," Hearing, op. cit., pp. 957-961. Mr. Floyd E. Dominy, Commissioner of the Bureau of Reclamation, has testified (in Hearing, p. 146) that another study, prepared for the Bureau by the Ground Systems Group of the Hughes Aircraft Company, found "that Marble and Bridge Canyon Dams are economically and financially feasible power developments." In fact, however, the report, entitled "Comparative Assessment of Benefits--A Benefits Analysis of Bridge Canyon Dam and Marble Canyon Dam," was not

THE ISSUES

The present status of the argument is that both sides agree that Marble Canyon is not competitive if used for supplying baseloaded power. The Bureau of Reclamation contends that the Project is justified if the power generated is used for peaking purposes, and it is this contention that is to be examined here. This question should be carefully distinguished from whether the Bureau could sell the power generated at a profit if the Project were built. Because Bureau projects carry much lower capital charges than privately financed power projects, it is possible that the Bureau could sell the power at a profit even if the project were not economically justified.

The accepted practice for computing the benefits of a power project is to use the cost of producing the same power by the lowest cost alternative means.[1] Although nuclear power has never been used for peaking purposes, there is no known technical reason why it cannot, and considerable reason to think that it will provide the lowest cost alternative to the Marble Canyon Project. As the Bureau recognizes in its Report,[2] there is little point building the alternative power generation facilities in the Grand Canyon, and considerable economic justification for building them at the load centers. This would avoid the unnecessary expense of transporting the power from the Grand Canyon to the load centers, when it can be generated just as well at the load centers. In order to minimize the costs of the alternative, it is best to build one plant. This could be located in either the Phoenix-Tucson or Los Angeles areas, or wherever else there is sufficient demand for peaking power in the immediate vicinity.

In order to compute the cost of the alternative nuclear plant, the only economically justifiable procedure is to use the same rate

intended to be a cost-benefit analysis of the projects. Although the report does deal with a number of peripheral issues, it will not be treated further in this paper.

[1]Perhaps the best reference is Otto Eckstein, Water-Resource Development, Cambridge, Harvard University Press, 1958, pp. 239-245. A more recent reference is A. R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," The Economic Journal, Vol. 75, No. 300, December 1965, pp. 709-710.

[2]Marble Canyon Project Report, op.cit., p. 22.

of interest as used for the Project.[1] Although there can be and has been considerable debate as to what interest rate should be used in computing the cost of such projects,[2] there can be no doubt that the use of different rates for the Project and the alternative can result in a serious distortion of the results. Although economic theory cannot tell us exactly what the rate is, it does specify that there exists a single equilibrium rate of interest at which the demand and supply for loanable funds of equal risk are in equilibrium. Capital theory does recognize the existence of a risk premium, but if anything the Marble Canyon project, with its much longer assumed pay-out period, contains a greater element of risk than the nuclear alternative.

PREVIOUS STUDIES

With these fundamentals of cost-benefit analysis in mind, it is possible to assess some of the existing economic studies made on the Marble Canyon Project. The Bureau's study, although not very clear on the point, appears to use a higher interest rate for the alternative than for the Project.[3] The alternative examined is "gas-fired steamplants in the Phoenix and Los Angeles areas." At higher interest rates such plants may well be the least expensive alternative, but at the Bureau's three per cent rate nuclear plants appear more attractive.

The AEC study,[4] on the other hand, compares the Project with a nuclear alternative at equal interest rates, but somewhat curiously insists on comparing the Project with a nuclear alternative at the same site. As the Bureau has pointed out, in apparent reference to the AEC study,

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[1] Eckstein, op. cit., p. 242.

[2] For a summary of and references to much of this debate see B. Sobin, "Some Interest Rate Aspects of Weapon Systems Investment Policy," Research Paper P-171, Institute for Defense Analyses, Weapon Systems Evaluation Division, February 1965.

[3] Marble Canyon Project Report, op. cit., p. 22. The Bureau does not specify what rate it used, but assumes "publicly-owned non-Federal" facilities. It is difficult to account for the Bureau's cost estimates in any other way.

[4] AEC, op. cit.

> ...the cost of power per kilowatt-hour from a nuclear substitute for the Bridge Canyon facilities would be 70 per cent higher than power from Bridge Canyon, and for Marble Canyon the nuclear substitute would produce power at a cost 58 per cent higher than from Marble Canyon. These studies were on a comparative basis at-site, neglecting the costs of transmission and water. They were adjusted to account for the difference in plant economic life so that the results are comparable.[1]

What the Bureau neglects to point out is that the study also states that

> ...the cost data apply to generation at the dam site or nuclear plant site and no costs are included for transmission. Once again, this is a simplifying assumption which could place the nuclear plant at a relative disadvantage. If transmission and cooling water costs had been included in the comparison, a nuclear alternative could be more economic (in M/KWH) if its transmission and cooling water costs for the particular site location were equal to or less than 33% and 16% of the Marble and Bridge transmission costs, respectively.[2]

Since the construction of the alternative nuclear plant at or near a load center would certainly result in transmission and cooling water costs less than 33 per cent of Marble transmission costs, this is a very relevant consideration. It is even more damaging to the Bureau's case when it is considered that their statement implies that they have no disagreement with the AEC's estimates of nuclear costs.

The third study, by one of the authors, concludes that the benefit-cost ratio for the Marble Canyon Project is slightly less than one-to-one at the Bureau's 3 per cent rate of interst and progressively less at higher rates. Unlike the other two studies, it assumes a common interest rate and the location of a nuclear alternative at the load center. It uses somewhat more tentative, older (and higher) nuclear costs than those used in this study.

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[1] Letter from N. B. Bennett, Jr., Acting Commissioner, to the Hon. Wayne N. Aspinall, Hearing, op. cit., p. 774.

[2] AEC, op. cit., p. 3.

The earlier study has been criticized by the Bureau of Reclamation on two principal grounds:[1]

(1) That the "usual practice" in "Project Benefit Analysis" is to "measure the benefit in terms of the cost of achieving the same result by the most likely alternative means that would exist in the absence of the project"

(2) That "Mr. Carlin has overlooked the cost of transmitting power to the central Arizona pumping plants which is a project function of the Marble Canyon hydro facility."

It is worth reviewing these arguments in some detail since the Bureau would presumably make the same objections to the analysis to be presented in the next section.

(1) If the alternative cost principle is to be used for measuring the benefits from power projects, the alternative chosen should be the most economical alternative source rather than "the most likely alternative that would exist in the absence of the project." The problem with the latter phrasing is that it leaves the door wide open to an interpretation such as the Bureau appears to have made in this case that robs the principle of any meaning as an economic criterion for selecting projects and turns it into a question of semantics. The choice of the "most likely alternative" becomes a matter of personal preference. The Bureau appears to favor what it alleges to be the preference of "the responsible electrical utilities in the area."[2] But it must be remembered that these utilities face very different costs of capital, insurance, and taxes than the Bureau; to accept their judgment (assuming no bias on their part) is to accept a different

[1]"Analysis of Mr. Alan P. Carlin's Statement 'An Economic Reevaluation of the Proposed Marble Canyon Project'" (unpublished), pp. 1 and 3. One noteworthy feature of the "Analysis" is that it raises no objections to the costs of the nuclear alternative presented in the earlier study other than item (2).

[2]The Bureau argues (p. 2) that because of continuing investment by utilities in the area in conventional thermal generating plants, "the most likely alternative [to Marble Canyon] would be conventional steam electric generating plants financed, constructed, and operated by non-Federal interest." Such an argument ignores the fact that the Southern California Edison Co. and the San Diego Gas and Electric Co. are now building a 450 mw plant at San Onofre and that the Los Angeles Department of Water and Power is currently awaiting an Atomic Energy Commission permit to build 490 mw nuclear plant in Malibu.

set of resource prices in selecting, and, in this case, even in costing the alternative.[1] Because capital charges are higher for nuclear power plants than for conventional thermal plants, while the opposite is true of fuel costs, one would expect to observe a preference for conventional plants at high interest rates (i.e., current private financing) than at low rates (the Bureau's 3 per cent).

(2) The Bureau's position that it is necessary to transmit power from the alternative nuclear plant to the Central Arizone Project pumping plants appears to be in contradiction to the published statements of Commisioner Floyd E. Dominy and Secretary of the Interior Stewart Udall before the House Committee on Interior and Insular Affairs in August 1965 that the Bureau intends to sell Marble Canyon power commercially as peaking power rather than to use it to supply the baseload requirements of the Central Arizona Project.[2] If the Bureau wishes to transform Marble into a baseload facility suitable

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[1] One of the worst features of the Bureau's interpretation of the alternative cost principle is that they apparently feel that it justifies the economically unjustified practice of costing the alternative at a different rate of interest than the Project.

[2] The relevant passage from Hearing, op. cit., pp. 162-163, is as follows:

> MR. REINECKE. I believe I understood the other day that the predominant use of Marble would be for the pumping power required for the central Arizona project.
>
> MR. DOMINY. A good part of the energy out of Marble will be devoted to pumping energy.
>
> MR. REINECKE. And also that the pumping cycle would be based on, I believe someone said 11 months a year, 1 month for downtime and repairs, and so forth.
>
> MR. DOMINY. Yes, sir.
>
> MR. REINECKE So rather than a peaking load, it is pretty much a steady baseload, is it not?
>
> MR. DOMINY. Except that we believe that the proper way to get the maximum revenue from Marble for the basin fund will be to buy baseload steampower or offpeak thermal power and sell Marble as a peaking commodity to the extent that we can work this in and exchange arrangements with the utilities. So we will be looking for the maximum possible use of Marble at peak power values and do our pumping to the extent possible from offpeak thermal power.
>
> MR. REINECKE. I was operating on the basis that the Marble would operate just for this pumping and as such, according to the literature supplied again, the pumping

for supplying the Central Arizona Project, the nuclear alternative will look even better in comparison with Marble Canyon. In brief, the Bureau is trying here to both have its cake and eat it -- to claim the benefits from selling Marble power as peaking power while insisting that the alternative plant do what Marble would no longer do (provide baseloaded power to the Central Arizona Project).

The Bureau recognizes that the "Economic Reevaluation" study is far from dogmatic about locating the nuclear alternative in the Los Angeles area. But, the Bureau says, "if located in central Arizona nearer project water pumping loads, [cooling] water costs could be substantial and electric power transmission costs less."[1] We question that cooling water costs would be larger than the value of the water evaporated by Marble Canyon. Since the latter is not given any numerical value in the tables presented in the "Economic Reevaluation" study, we believe that the effect of omitting both costs in the previous study is if anything to bias the conclusions in favor of Marble Canyon.[2]

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requirement is 1,785,835,000 kilowatt-hours, or on an 11-month basis, 225,000 kilowatts. Twenty-four hours a day, based on a 600,000-kilowatt generating plant provides you an operating characteristic of about 37.5 per cent. Does that sound reasonable? Is that in the area that you are anticipating the operation?

MR. DOMINY. You have come pretty close. We are now planning Marble for an average load factor of about 35 per cent.

MR. REINECKE. Then on that same basis I have calculated the requirement, the water requirement, again looking at a steady baseload and assuming an overall efficiency of 80 per cent, and I find that in order to produce that much power out of Marble, it is going to take 8.1-plus million acre-feet per year. How much does this leave for peaking?

MR. DOMINY. Well, as I say, instead of operating at Marble so as to be producing power only as needed at the pumps, we expect to correlate with the power industry to use offpeak power at the pumps to the maximum extent possible and release Marble production for peaking purposes which will be sold at a higher rate.

MR. REINECKE. I am not familiar with the power generating industry, now. But it seems that we are building a 600,000-kilowatt generating plant and we are only generating an average of 225,000 kilowatts. Granted that there is the peaking characteristics involved, but isn't it

[1] "Analysis...," op. cit., p. 3.

[2] The basis for this judgment is given in unfavorable assumption 3 and favorable assumption 4 below.

NEW CALCULATIONS

In order to overcome the limitations of the "Economic Reevaluation" study, we have made some more detailed calculations based on the current General Electric price list.[1] These costs represent in general the maximum estimated price at which GE will now contract to build nuclear power stations on a turn-key basis and to supply nuclear fuel when the plant is finished. They have usually, in fact, offered to build plants for somewhat less when requested to submit bids on specific projects.[2] The interest rate chosen for the analysis is 3 1/8 per cent, since the bureau has stated that this is the rate at which benefit-cost analyses should not be performed.[3] Although we, along with most other economists who have examined the problem, regard

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more reasonable to pull the size of this plant down and save the coordinating costs?

SECRETARY UDALL. Congressman, may I try to put this in a focus for you that I think will tell you what we really envision.

The negotiations that we are presently carrying on with the West group, include--and I hope before we get through will include--all the public and private utilities in the entire region. If negotiations work out, it may very well turn out in the end that Glen Canyon might have to be redesigned for peaking and Marble used for peaking because we can produce more revenues that way. If we have a highly integrated system of the type we envision, and this is what the engineers are beginning to study, the cheapest and most efficient way to get pumping power would be out of the entire system in terms of using thermal power for pumping, and in terms of using our hydro facilities as a peaking vehicle for the entire region. This is really the road we think we are headed down, but we won't know all the answers until the studies are completed.

[1] General Electric Co., Atomic Power Equipment Handbook, Sections 8801 to 8805.

[2] A case in point is the recently-announced Dresden III reactor of 800 mw, for which the contract price was $79 million (Wall Street Journal, January 21, 1966, p. 10); the GE price list gives an estimate of $90.6 million.

[3] See Hearing, op. cit., p. 127.

this rate as much too low,[1] its use gives the greatest possible benefit of doubt to the Project. At higher rates of interest, the Marble Canyon Project would look progressively worse since capital costs are a much larger percentage of Marble Canyon costs.

The results of these calculations are shown in Table 4, column (4). Because the GE fuel costs are higher than those generally expected to prevail in the late 1970s and early 1980s, we have also made some calculations using our own computations of fuel costs. These are presented in column (3) of Table 4. For purposes of comparison, columns (1) and (2) show the comparable figures according to the Bureau of Reclamation and as adapted from the Atomic Energy Commission report mentioned earlier. It should be stressed that only the figure for power benefits (line 1a) comes directly (with only a minor adaption) from the AEC report. The remaining figures in column (2) are Bureau figures with minor adaptations. They are given for comparative purposes rather than to imply any agreement by the AEC with the figures in parentheses or the use made of their numbers.

The major uncertainty with regard to the figures in columns (3) and (4) concerns the underlying figure in line 2b of Table 3. Because nuclear plants have not been and are unlikely to be built as peaking plants in the near future, little information is available on the minimum levels at which they might be operated if they were designed with this in mind. Technical opinion does favor keeping the nuclear reactor and steam system hot between peaks; keeping them hot enough to maintain the generators in a conditions of spinning reserve also somewhat improves the comparability of the nuclear alternative examined here with the proposed Marble Canyon Project. Table 3 assumes that this can be accomplished with 10 per cent of the fuel needed for full load operation.

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[1] By way of comparison, one careful study recommends that public water projects such as Marble Canyon should use a discount rate of not less than 10 per cent. See Jack Hirshleifer, James C. DeHaven, and Jerome W. Milliman, Water Supply: Economics, Technology and Policy, Chicago, 1960, p. 354.

This whole problem of trying to force a nuclear power plant into a peaking mode where it is relatively less efficient while still using it to determine the power "benefits" from Marble Canyon can be solved, however, by expanding the rather arbitrary boundaries of the Marble Canyon Project to include all power to be generated or used by the Lower Colorado River Basin Project except that generated directly as a part of the Central Arizona Project. Nothing illustrates the lack of a meaningful relation between the Central Arizona Project and the Marble Canyon Project quite so much as the fact that the Bureau plans to operate Marble Canyon as a peaking facility (so as to maximize revenue) while the Central Arizona Project needs baseloaded power (where nuclear power is better suited). What the Bureau intends to do is to sell Marble Canyon power as peaking power and buy baseloaded power from commercial sources. This will mean that someone else will have to build baseload facilities of approximately 225 mw to supply the Central Arizona Project. It is entirely feasible, however, to build a larger nuclear plant that would provide both 225 mw of baseload and 600 mw of peaking power. Columns (5) and (6) of Table 4 compare this alternative with the Bureau's proposal of building Marble and buying 225 mw of baseload. The comparison is even less favorable for the Bureau's proposed solution and, we believe, more meaningful than columns (3) and (4) are for Marble Canyon by itself. It is worth adding that the Dresden plant near Chicago is already being regularly operated without difficulty over a 55 per cent load change in a semi-peaking mode similar to that assumed to columns (5) and (6).

In summary, the figures developed here suggest that the Marble Canyon Project is not economically justified since a nuclear alternative could generate the same electrical power at a lower cost, especially if the same plant were used to generate the power needs of the Central Arizona Project in addition. In reaching these conclusions it has been necessary to make a number of simplifying assumptions. These assumptions tend to bias the conclusion in both directions, although not seriously, we believe. It is nevertheless worthwhile enumerating the more important of these assumptions.

ASSUMPTIONS UNFAVORABLE TO MARBLE CANYON

1. Equal Value of Nuclear and Hydro Power

The calculations made here implicitly assume that one unit of nuclear power is equal in value to one unit of hydroelectric power at the same time of day. This ignores the fact that a hydro plant may be able to respond much more quickly to an emergency need for more power.[1] This quicker response time is not of much value during normal operations, especially in an area such as Southern California and Arizona that already has a larger than average percentage of hydro sources to absorb most of the minor fluctuations. Nuclear response times decrease at higher initial levels so that the 825 mw alternative is better in this respect than the 600 mw.

2. No Allowance for Additional Reserve Capacity for Nuclear Alternatives

The nuclear alternatives examined here include no allowance for the additional reserve capacity that would be required to provide firm power in a system including either of them rather than Marble Canyon. This problem arises because Marble Canyon would consist of four units of 150 mw each rather than a single unit.

3. Exclusion of Possible Cooling Water Costs for Nuclear Alternatives

If a nuclear alternative is located away from the ocean, as would be the case for the 825 mw plant, it would probably be necessary to use substantial quantities of fresh water consumptively for cooling purposes.[2] We estimate that the 600 and 825 mw plants would require

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[1] If the plant is not already being used to capacity.

[2] This assumes that it would not be advisable to use either the Colorado River or Central Arizona and Salt River Projects as sources for "flow through" condenser water. Calculations suggest that it would be possible to do so, but that it might lead to an unacceptable rise in water temperatures (especially in the case of the Colorado River) or minute but nevertheless unacceptable radiation hazards (particularly in the case of Central Arizona and Salt River water).

about 9,300 and 17,100 acre-feet per year, respectively.[1] These figures are to be compared with the estimated 30,000 acre-feet that would be evaporated annually by Marble Canyon Dam[2] plus 7,800 acre-feet annual evaporation by the additional capacity that produces the power the Bureau plans to purchase for the Central Arizona Project.[3] If the 600 mw nuclear alternatives were located on the Ocean, there would be no significant extra cost for cooling water. If the alternatives were located on the Colorado River, the cooling water losses would be substantially smaller than the Marble Canyon losses. If the alternatives are located in Arizona away from the River, something should be added to the cooling tower losses to account for the cost of transporting the water from the Colorado River. We believe that the higher Marble Canyon losses more than account for these extra transit costs.

ASSUMPTIONS FAVORABLE TO MARBLE CANYON

1. Use of General Electric Price List

Use of the GE price list favors Marble Canyon because the list prices are above current market prices and because nuclear costs are expected to fall during the next 100 years. Experience suggests that the GE price list overstates current market prices obtained through competitive bidding by at least 5 to 10 per cent. The GE fuel prices used here refer to plants coming into production between 1969 and 1971. Marble Canyon (and therefore its nuclear alternatives) would not be

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[1] These estimates assume that one pound of cooling water is evaporated for each pound of steam, as suggested by conventional thermal experience. Steam flow is estimated to be about 7.1 and 9.8 million pounds per hour for the 600 and 825 mw plants, respectively.

[2] See favorable assumption 4 below.

[3] The difference between 17,100 acre-feet for the plant that includes such power and the 9,300 acre feet for the plant that does not.

finished before 1973 at the earliest. Nuclear fuel costs can be expected to fall with time. The computer fuel costs take into account the price changes expected through the middle of the 1980s, but assume constant costs thereafter. Nuclear plant costs can also be expected to fall over time. The calculations made here, however, implicitly assume that the costs of hypothetical replacement plants necessary to fill out the assumed 100 year life of the Project are the same as for the initial nuclear plant. In particular, no allowance is made for future replacement by a breeder reactor, for which estimated costs are about half of near term nuclear costs.

2. Constant Prices

No price escalation has been assumed in either the Bureau's Marble Canyon costs or in the costing of the nuclear alternative. Since the Bureau's calculations are about two years older than the current GE price list, inflation may have increased Marble Canyon costs more.

3. Use of General Electric Data Optimized for Baseloaded Plant

Under this heading, we must consider three separate items: cost of money, plant capacity factor, and mode of operation.

A. Cost of money

> If the cost of money is high, it is desirable to design a core with higher specific power (Kw/Kg of fuel) to minimize the fuel inventory. This results in a higher fabrication cost per unit of fuel since the heat transfer surface area must be the same in the smaller core, or other compensating adjustments such as increasing coolant flow rate must be made.
>
> Since increasing specific power increases fuel costs, an optimum design exists between the increasing fabrication cost and the decreasing inventory costs.[1]

Since the GE costs have been optimized on the basis of 5 per cent and 9 per cent rates of interest for fabrication and inventory costs, respectively, merely converting them to the 3 1/8 per cent rate of interest understates the reduction in cost to the extent that

[1] W. J. Doolard and L. E. Strawbridge, "Fuel Management in Large Pressurized Water Reactors," Nuclear Performance of Power Reactor Cores, U.S. Atomic Energy Commission, Division of Technical Information, TID-7672 (1963), p. 329.

the lower interest rate favors a lower fabrication cost (lower specific power) and increased inventory costs.

B. Plant capacity factor

> The plant capacity factor will become an increasingly important consideration. The early nuclear plants are the lowest incremental cost plants on the utility grid. For this reason they are ordinarily base loaded. In the future however, as more nuclear plants are added to the utility system grids, the designs will need to take into account the fact that a lower overall plant capacity factor will naturally occur. At lower capacity factors the cost attributed to fuel inventory increases and becomes a larger fraction of total fuel cost. At the very low capacity factors of peaking plants the fuel inventory can become over one half of the total fuel cost. In cases such as these the fuel inventory would be held to a minimum by decreasing core size as much as possible. Though unit fabrication costs and reprocessing costs might suffer somewhat, the change in design might be warranted. The effect of plant capacity factor should also be considered in the purchase of present plants.
>
> The core initially optimized for a high capacity factor would not be expected to be optimum over the life of the plant when in later years it operates with lower capacity factors. For this reason a plant which can incorporate smaller future cores, which would be more nearly optimum at lower capacity factors, would be given extra consideration in the evaluation of a plant proposal. In addition to decreasing core size, fissionable material inventory can be reduced in thermal reactors by increasing the moderator to fuel ratio in under moderated cores. This reduces the conversion ratio but is economically justified in plants of lower capacity factors.[1]

Again, since the GE plant is optimized for near-baseloaded operation (80 per cent) while our plants are based on 40 and 54 per cent, respectively, merely increasing carrying charges to reflect the longer cycle overstates the cost of operation at a low capacity factor to the extent the adjustments suggested in the statement above optimize plant operations for low capacity figures.

C. Mode of operation

> It has been common practice to rate the core burnup on the basis of full power capacity with equilibrium fission

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[1] Ibid., p. 329-330.

product poisons. Experience at the Yankee Atomic Electric Co. plant, however, has demonstrated that there are situations where it is economically feasible to extend the core burnup beyond the point at which full rated power can be maintained under equilibrium conditions. Each individual utility must decide whether this action is desirable based upon the incremental decrease in fuel costs for extended burnups at reduced power levels versus the incremental increase in other system operating costs which must supply the replacement power. These factors will vary not only from utility to utility but also as a function of time of year, since replacement power costs vary seasonably.

A corollary of this approach is the consideration of operating the nuclear plant as a peaking plant after it can no longer operate at full load continuously. Due to the xenon decay period, a nuclear plant operating on a 24 hour cycle can operate at full load during peak daily load periods and by tapering off to a lower load each night can maintain the daily capacity to meet full power requirements long after it could no longer do so on a steady state basis. This feature will be very useful in the future when nuclear plants must also be used in a peaking type of operation.[1]

Here we find three separate overstatements of costs. First, the General Electric fuel cycle cost data are based on the warranted burnup levels; actual burnup will surely be in excess of warranted burnup, by perhaps 25 per cent. Second, the GE figures are based on operation to the point at which rated power can just be maintained with equilibrium xenon and other fission poisons; both Dresden and Yankee operate beyond these levels, derating plant output (at Dresden, derating level is 100 thermal megawatts or over 14 per cent; at Yankee, the figure is nearer 35 per cent). The extent to which such derating can be carried out depends on the cost of replacement power for the difference between rated and actual power.

Third, since the GE figures are based on a nearly-baseloaded plant while the nuclear alternatives discussed here are peaking and fractional-base plus peaking respectively the "corollary" discussed in the quote above is particularly applicable. To the extent that such a mode of operation can meet "full power requirements long after it could no longer do so on a steady basis," the fuel costs for the nuclear alternatives are overstated.

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[1] Ibid., p. 331.

4. Exclusion of Marble Canyon Evaporation and Seepage Losses

There is no dispute as to whether Marble Canyon Dam will increase the evaporation of water from the Colorado River. No allowance for the value of this water appears to have been made in the Bureau's project report or in this analysis. Evaporation from the proposed reservoir may be as much as 30,000 acre-feet per year.[1]

Although there is considerably more dispute about the matter, there may also be some seepage.[2] A plausible assumption is that the additional seepage resulting from the reservoir exceeds present evaporation from the River. Even more difficult is the question of how to evaluate the economic value of the evaporation losses. If and when Lake Powell is filled,[3] the value of the water will be negligible[4] until such time as the available water is not sufficient to meet all present and authorized uses. This might occur if water flows fall sufficiently short of expectations, the Central Arizona Project is built, or the Upper Basin states use their entire allotment. In that case, the 30,000 acre-feet will come out of the water that would otherwise be used by California, and in particular, the Los Angeles Metropolitan Water District.

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[1]The Marble Canyon project report indicates that the area of the reservoir surface would be about 4,000 acres at the normal water elevation (see Drawing 788-D-21). Evaporation data collected over a 32 year period at Lee's Ferry, Arizona, suggests that the mean annual evaporation from the reservoir might be about 7.5 feet. See U.S. Department of Commerce, Weather Bureau, Hydrologic Branch, Mean Monthly and Annual Evaporation from Free Water Surface for the United States, Alaska, Hawaii, and West Indies, Technical Paper No. 13, Washington, July 1950, p. 2. Lee's Ferry is located on the Colorado River about 40 miles north of the damsite and adjacent to the proposed reservoir.

[2]This possibility has been raised by P. T. Reilly in "Some Recent Observations on Glen Canyon," Sierra Club Bulletin, Vol. 50, No. 3, March 1965, pp. 3-4 and by William C. Bradley, as quoted in Hearing, op. cit., p. 784.

[3]If the use of the River's water by the Metropolitan Water District is restricted in order to fill Glen Canyon, the value of the evaporated water is its value to the MWD, as outlined below.

[4]Limited to its value in diluting the salts carried by the River.

The value of the water to the MWD is equal to the additional costs of obtaining it elsewhere. Although there is a large element of sunk costs involved, it is significant that the incremental cost of Feather River water to the MWD has been estimated at upwards of $63 per acre-foot at a 3.5 per cent rate of discount and more at higher rates.[1] Marginal pumping costs for the Colorado River Aqueduct are about $11 per acre-foot. Therefore, in some future years, it is likely that the additional evaporation losses resulting from the proposed Project may be as much as $1.56 million.[2]

5. Exclusion of Marble Canyon's Effect on the Canyon's Natural Beauty

No value has been attributed by either the Bureau or us to the impairment of the natural scenic beauty of what is commonly acknowledged to be an unusually scenic Canyon.[3] Although it is difficult to attach an exact monetary value to this cost, it is not negligible, especially considering that the site can never be restored to its present natural state and is one of the few stretches of a major scenic river canyon still in a natural state. The Bureau says that it did not allow for such costs in its study "as there are also arguments to the effect that the beauty of the Canyon will not be affected, or may even be enhanced."[4] This appears to be a minority opinion, however, and that of an interested party.

6. Exclusion of Cost of an Afterbay Structure and Continued Use of River by Boating Expeditions.

Neither the Bureau nor we have taken into account the cost of preventing the large current surges and variations of flow below the proposed dam. Mr. Floyd E. Dominy has testified that a so-called afterbay

[1]Hirshleifer, op. cit., p. 354.

[2]The product of 30,000 acre-feet and $52 per acre-foot.

[3]See Francois Leydet, Time and the River Flowing: Grand Canyon, Sierra Club, San Francisco, 1964.

[4]"Analysis...," op. cit., p. 4

[5]Hearing, op.cit., p. 146.

structure may be necessary to prevent such variations if the dam is operated as a peaking plant.[1] Failure to do so would further impair the natural scenic beauty of the Canyon and make boating through the Grand Canyon even more difficult.

Even assuming that such a structure is built, there is some dispute as to whether boating expeditions would still be possible. If they are not, the cost in terms of the producers' and consumers' surplus foregone might be about $120,000 per year.[2]

Any judgment as to the net effect of the assumptions just listed must be a matter of opinion. It is the opinion of the authors that on balance they are favorable to Marble Canyon.

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[1]Hearing, op. cit., p. 146.

[2]The Sierra Club has testified (Hearing, op. cit., p. 814) that about 600 people made the trip in 1964. The average price paid was perhaps $350. If the producers' and consumers' surplus is taken as $200 per person, the net cost would be $120,000 per year. This calculation ignores the fact that the boat trips are rapidly increasing in popularity.

Table 1

CAPITAL COSTS OF ALTERNATIVE NUCLEAR POWER PLANTS
LOCATED AT LOAD CENTER
(millions of dollars)

	600 MW	825 MW
1. Nuclear boiler	26.2	33.4
2. Remainder of plant	44.4	56.9
3. Total costs covered under contract with prime contractor	70.6	90.3
4. Additional costs met directly by power producer	10.6	13.5
5. Total	81.2	103.8

Notes on line:

1. (Interpolated) cost of single-cycle, non-reheat, boiling-water, enriched-uranium nuclear boilers designed for 525 mw and 750 mw plants. Based on General Electric Co., Atomic Power Equipment Handbook, Section 8802, p. 10 (Sept. 13, 1965). Experience suggests that a 525 mw boiler can provide an adequate steam flow for a 600 mw plant, and that a 750 mw rated boiler can supply steam for an 825 mw plant. The base prices given in the Handbook were increased by $10/kw to cover containment costs; these figures represent the estimated cost of the nuclear portion of the plant. Typical stretch ratings experienced or projected are: Dresden, 17 per cent; Yankee, 38 per cent; Oyster Creek, 20 per cent; and Dresden II, 11 per cent.

2. These figures represent the General Electric Handbook prices (Section 8804, p. 7, Sept. 13, 1965) for complete plants of 600 mw (and 825 mw) less the prices for nuclear boilers of 600 mw (and 825 mw) as given in Section 8802 and the $10/kw containment cost. This provides the estimated cost of the non-nuclear portion of a plant sufficiently large to handle the "stretch" capacity of the nuclear boilers of 525 mw (and 750 mw).

4. This item covers costs excluded in paragraphs 1 and 5 of the Handbook, Section 8804, p. 5. Principal components are site and right-of-way, operating spares, interest during construction, property and excise taxes, and escalation. Nucleonics, Nov. 1964, p. 20, estimates these at 15 per cent of the listed price. Dresden station contract cost was $45 million and Commonwealth Edison Co. incurred $6,545,000 of "...site, overhead, and minor plant addition costs...," or about 14.5 per cent of contract cost (as given in an Oct. 20, 1965 release by the Publicity Dept., Commonwealth Edison Co.).

Table 2

NUCLEAR FUEL COSTS OF ALTERNATIVE NUCLEAR POWER PLANTS LOCATED AT LOAD CENTER
(mills/kwh)

Plant Size	600 MW					825 MW				
Core	I	II		III ff.		I	II		III ff.	
Source	GE	GE	Computer	GE	Computer	GE	GE	Computer	GE	Computer
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Uranium depletion	.78	.66	.74	.59	.66	.77	.65	.74	.58	.66
2. Plutonium credit	(.32)	(.22)	(.21)	(.21)	(.21)	(.32)	(.21)	(.21)	(.21)	(.21)
3. Reprocessing	.33	.25	.18	.21	.15	.33	.25	.18	.21	.15
4. Febrictation	.78	.55	.28	.49	.23	.76	.53	.28	.47	.23
5. Financing cost	.22	.21	.16	.20	.15	.18	.17	.12	.16	.11
6. Total	1.79	1.45	1.15	1.28	.98	1.72	1.39	1.11	1.21	.94
7. Years in use (approx.)	4	8	6.8	18	19.2	3	6	4.4	21	22.6
8. 30 year average		1.39	1.13				1.30	1.04		

Notes on columns:

(1), (2), (4), (6), and (9): Lines 1 to 4: Interpolated costs for 525 and 750 mw single cycle, non-reheat plants, based on General Electric Co., Atomic Power Equipment Handbook, Section 8805, pp. 12-13 (May 24, 1965). Columns (4) and (9) show the costs for the third and subsequent cores. Line 5: Represents fuel cycle financing cost at 3.13 per cent interest. Derived by taking 62.5 per cent for columns (1), (2), and (4) and 50.0 per cent for columns (6), (7), and (9) of GE figures, ibid., on the assumption that the GE figures represent 5.0 per cent interest charges for one year prior to irradiation, 9.0 per cent for four years (in the reactor) and one year in cooling and recovery. The 62.5 per cent assumes one year in pre-irradiation, eight years in the reactor, and one year in reprocessing, all at 3.13 per cent. The 50.0 per cent assumes one year in pre-irradiation, six years in the reactor and one year in reprocessing, all at 3.13 per cent. The eight and six years are obtained by comparison of the operating factors of 40 per cent and 54 per cent, respectively, with the GE assumption of 80 per cent load factor and (average) four year operating life per core. Line 7: the third and subsequent cores are assumed to remain in the reactor for eight years each in the case of the 600 mw plant and six years in the 825 mw case.

Table 2 (continued)

(3), (5), (8), and (10): Results of computer calculations using a fuel cost code developed by Dr. N. B. McLeod of NUS Corporation and a code published by the Atomic Energy Commission in its Guide to Nuclear Power Cost Evaluation, Vol. 4, Fuel Cycle Costs, TID-7025, as modified to meet the needs of the present study. The following table illustrates some of the cost assumptions (typical of the values used by GE and others) that were used as inputs in the analysis:

Core	II(1975-79)	III(1980-84)
Fabrication ($/Kg.U)	55.00	44.00
UF_6 prior to enrichment ($/Kg.U)	173.85	156.46
UF_6 at discharge enrichment ($/Kg.U)	26.75	25.68
Conversion charge ($/Kg.U)	5.60	5.60
Pu Credit ($/g)	7.25	7.25
Separation plant charge ($/day)	22,043	17,949
Average fuel exposure (MWD/MTU)	27,000	27,000
Interest on working capital (per cent)	3.13	3.13

Due to cost limitations we were able to obtain cost figures for only the two periods, 1975-79 and 1980-84. Accordingly, we have assumed the costs of the 1980-84 period to hold for future periods, although the downward trend indicated will probably continue.

Table 3

AVERAGE ANNUAL COSTS OF ALTERNATIVE NUCLEAR POWER PLANTS LOCATED AT LOAD CENTER
(millions of dollars)

Plant Size Source of Fuel Costs	600 MW Computer (1)	 GE (2)	825 MW Computer (3)	 GE (4)
1. Capital costs	4.54	4.54	5.80	5.80
2. Fuel costs				
a. Power production	2.40	2.95	4.07	5.08
b. Spinning reserve	.32	.39	--	--
3. Operating and maintenance costs				
a. Fixed	.84	.84	1.16	1.16
b. Variable	.21	.21	.39	.39
4. Special nuclear insurance	.31	.31	.33	.33
5. Total	8.62	9.24	11.75	12.76

Notes on line:

1. Capital cost shown in Table 1, line 5 at 5.59 per cent per year. The 5.59 per cent corresponds to a net return of 3.13 per cent, depreciation (sinking fund) of 2.06 per cent (corresponding to 30 years) and an allowance for interim replacement of 0.40 per cent.

2a. Columns (1) and (2): Assumes average annual generation of 2.123 billion kw at the average fuel costs shown in line 8 of Table 2. The 2.123 billion kwh is the energy that would be generated by Marble Canyon, minus transmission losses to the load centers. Columns (3) and (4): Assumes 3.909 billion kwh. The 3.909 is the sum of 2.123 and 1.786. The latter represents projected annual energy purchased by the Central Arizona Project as given in U.S. Dept. of the Interior, Bureau of Reclamation, Pacific Southwest Water Plan, Supplemental Information Report on Central Arizona Project, Arizona, January, 1964, p. 31.

2b. Assumes that the 600 mw plant would consume 10 per cent of full load fuel requirements for 4718 hours per year. The 4718 represents one year minus three weeks when the plant would be out of service for refueling and maintenance and 3538 hours per year that it would be at full load.

3a. Assumes average fixed operating costs (excluding the interim replacement included in line 1) of $1.40 per kw-year for a 600 mw plant.

Table 3 (continued)

This figure is taken from an unpublished study, U.S. Atomic Energy Commission, Division of Reactor Development and Technology, Office of Civilian Power, "A Specific Comparison of Nuclear Electric Power and Hydro Electric Power -- Bridge and Marble Canyon Projects," February 1965, p. 7.

3b. Assumes average variable operating costs of 0.1 mill per kwh, ibid.

4. Since the Bureau has omitted all mention of insurance costs for Marble Canyon (which is apparently a hidden subsidy by the Federal Government), only the cost of special nuclear insurance is included here. This insurance covers an unusual risk not present in the case of hydroelectric projects. Our treatment of insurance is conservative in that it ignores the special risks also present in the case of a hydroelectric project, especially in the event that the dam should break. The estimates are based on the premium paid by Commonwealth Edison Company for their Dresden plant, as shown in U.S. Congress, Joint Committee on Atomic Energy, Subcommittee on Legislation, Selected Materials on Atomic Energy Indemnity Legislation, 89th Congress, 1st Session, June 1965, pp. 17 and 66. Private nuclear liability insurance rates for Dresden are used for the first $60 million of coverage. The remaining $14 million of private insurance is taken at the rate of 2.5 per cent of the base rate per $1 million coverage. Price - Anderson Act insurance (to $486 million) is computed at the rate of $30/mwt. These estimates are very conservative in that up to 75 per cent of the private premiums are maintained in a special fund which is earmarked for refund on the basis of the first ten years of experience.

Table 4

BENEFITS AND COSTS OF PROPOSED AND EXPANDED MARBLE CANYON PROJECT
(millions of dollars)

	Marble Canyon Project				Revised Lower Colorado River Basin Project Power	
	Bureau of Reclamation	Atomic Energy Commission (as adapted)	Carlin-Hoehn Computer Fuel	Carlin-Hoehn GE Fuel	Computer Fuel	GE Fuel
	(1)	(2)	(3)	(4)	(5)	(6)
1. Benefits						
a. Power	17.17	8.61	8.43	9.05	11.56	12.57
b. Fish and wildlife	.36	(.36)	.36	.36	.36	.36
c. Recreation	.32	(.32)	.32	.32	.32	.32
d. Area redevelopment	.15	(.15)	.15	.15	.15	.15
e. Total	18.00	(9.44)	9.26	9.88	12.39	13.40
2. Costs						
a. Capital charges	8.16	(8.16)	8.45	8.45	8.45	8.45
b. Operating costs	1.94	(1.94)	1.94	1.94	1.94	1.94
c. Power purchases	.39				5.58	5.58
d. Total	10.49	(10.10)	10.39	10.39	15.97	15.97
3. Benefit-cost ratio	1.7 to 1	(0.93 to 1)	0.89 to 1	0.95 to 1	0.78 to 1	0.84 to 1

Notes on column:

(1): Assumes an interest rate of 3 per cent. U.S. Department of the Interior, Bureau of Reclamation, Pacific Southwest Water Plan, Supplemental Information Report on Marble Canyon Project, Arizona, January 1964, pp. 20, 24 and 25.

Table 4 (continued)

(2): Assumes an interest rate of 3 per cent. Line 1a: AEC figure of \$8.80 million minus \$0.19 million representing the annual loss of revenue resulting from the reduction in energy generation from Glen Canyon Powerplant (ibid., p. 22) if the Marble Canyon Project is built. The \$8.80 million figure is that given in U.S. Atomic Energy Commission, Division of Reactor Development and Technology, Office of Civilian Power, "A Specific Comparison of the Economics of Nuclear Electric Power and Hydro Electric Power -- Bridge and Marble Canyon Projects," February 1965, p. 7. Lines 1b to 1d: Assumed to be the same as column (1) since the AEC study does not state. Line 2a: From column (1). The \$0.39 million omitted in line 2c represents the annual cost of purchasing power to firm the on-peak generation of Marble Canyon power. It has also been excluded from the benefits (line 1a).

(3) and (4): Assumes 3.13 per cent interest and the 600 mw plant developed in Tables 1 to 3. Line 1a: Table 3, line 5 minus \$0.19 million. Line 2a: Assumes an initial capital investment of \$257.75 million (see Marble Canyon Project Report, op.cit., p. 25) at a gross return of 3.23 per cent, including 0.16 per cent depreciation (100 year life).

(5) and (6): Assumes 3.13 per cent interest. Line 1a: Table 3, line 5, minus \$0.19 million. Line 2a: Amount the Bureau proposes to spend to purchase additional power for the Central Arizona Project, as given in U.S. Department of the Interior, Bureau of Reclamation, Pacific Southwest Water Plan, Supplemental Information Report on Central Arizona Project, Arizona, January 1964, p. 31.