Small Nuclear Power Plants

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SMALL NUCLEAR POWER PLANTS

VOLUME THREE

A General and Economic Assessment

Prepared By
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March 1967

REACTOR ENGINEERING DIVISION
CHICAGO OPERATIONS OFFICE
U. S. ATOMIC ENERGY COMMISSION

PREFACE

Plans and commitments of electric utilities for nuclear generating stations which have been announced in 1965 and early 1966 leave little doubt of the acceptance of this energy source for commercial electric generation. There has been a definite trend, however, toward larger plants in order to minimize the importance of capital costs and other fixed charges relative to fuel costs. With this trend, there has emerged no such clear picture of the potential for economic utilization and acceptance of small nuclear power plants.

In early 1965, the Atomic Energy Commission undertook a study of the technical and economic status and potential of small nuclear power plants. Part One of this study consists of a compilation of design, construction, and operating experience of ten small power reactor projects; Part Two provides an assessment of the current economic status and potential of small reactors, together with an evaluation of courses of action which may be indicated to achieve competitive status and acceptance. The results of the study are presented in a three volume report:

COO-284, "Small Nuclear Power Plants"

- Volume One - Design, Construction and Operating Experience
- Volume Two - The Industrial Expression of Supply and Demand Considerations
- Volume Three - A General Economic Assessment

Volume One was compiled from AEC records with reference to the experience of the reactor supplier, architect-engineer, and operating utility. Volume Two is information as provided by the nuclear industry and utility organizations. Volume Three is data derived by Kaiser Engineers. Kaiser Engineers used both data in Volume Two and information independently solicited from industry. They supplemented the data to assure that the power plants assessed were complete units. The economic assessment was independently derived from basic parameters using conservative assumptions with regard to plant and fuel performance capability.

This study, and the experience and information upon which it is based, reflects in a large measure the accomplishments of the AEC's Power Demonstration Reactor Program, and its support of the long-standing policy to promote the development of competitive nuclear power. Reactor designers, fuel suppliers, electric power utilities, utility organizations, professional nuclear service consultants and control system suppliers have generously contributed information for this study and freely cooperated in its review. They are to be commended for their support.

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1.0 INTRODUCTION

In many areas of the United States large size nuclear power plants now have an economic advantage over fossil-fueled plants for the commercial generation of electric energy. Consequently, the nuclear race is picking up speed, and plans and commitments of the electric utilities show a clear trend towards nuclear power generation. If one were to look at a map of all proposed new power plants one would see many large plants, but also some small power plants. However, a map of nuclear stations only would show that all but one of the nuclear plants under construction or proposed are large in size, ranging from 330 MWe (Colorado Public Service) to a two-unit, 2,100 MWe plant (Tennessee Valley Authority). The reason is clear: the larger the plant, the lower the capital cost (and certain other costs) per kilowatt of capacity, and the cost of energy from a nuclear plant with its higher fuel inventory and capital cost is more sensitive to plant size than the cost of energy from a fossil-fueled plant. Thus, there seems to be general agreement that today only large size nuclear plants can generate electric power at a lower cost than fossil-fueled plants. A study made for the 515 MWe Oyster Creek Nuclear Plant showed a unit cost of 4.25 mills/kwh against 4.34 mills/kwh for a fossil-fueled plant.

There are electric systems in the United States that do not have the advantage of large system size, and may not be able to participate in a large power pool. These systems may continue to add generating capacity in relatively small increments, say in the range of 25 to 100 megawatts. The cost of generation from such fossil-fueled power plants may range from about 11 mills/kwh for the 25 MWe plant down to about 7 mills/kwh for the 100 MWe plant. The manager of such a small system may well ask himself these questions: "Could a small nuclear power plant generate power at a lower cost than a fossil-fueled plant? If not, why not? And if not now, what can be done to lower the costs?"

To answer these questions, the Atomic Energy Commission commenced early in 1965 to study the technical and economic status and potential of nuclear power plants with capacities of 100 megawatts (electrical) and less. The results of this study will be published in a three volume report entitled, "Small Nuclear Power Plants." Volume One will consist of a compilation of design, construction, and operating and cost experience of ten small power reactor projects. Volume Two will consist of information from reactor vendors and other nuclear suppliers. Volume Three consists of this report. It is analytical and exploratory; it attempts to assess the general and economic status of "currently available small nuclear power plants" and examines areas of potential cost reductions, together with an evaluation of courses of action necessary to achieve competitive status and acceptance. "Currently available" means nuclear power plants - or nuclear reactors - currently being offered and guaranteeed by U. S. reactor vendors. "Small nuclear plant" means a net plant rating not exceeding 100 MW electrical.

In November 1965, Kaiser Engineers was engaged by the Atomic Energy Commission to prepare Volume Three of the study. Volume Three has been written for the manager of a small electric utility system interested primarily in the economic aspects of nuclear power. In order to meet the requirements of a high level of service continuity, utility management must continuously study the means of system reinforcement and expansion and develop long-range plans involving future energy needs and the means to satisfy these needs. This objective is met by comparing the available alternative means of electric energy supply in the light of two questions:

1. Is it the lowest cost alternative in the long run?

2. Can the required repayment obligation be met?

The study of small nuclear power plants is directed towards the first question, and it estimates the cost of nuclear power under a particular set of conditions. In order to apply the results to a specific situation, the nuclear cost calculated in this study must first be modified to fit the specific situation, and then compared with the power costs for the alternative power supply sources determined on a similar basis.

Specifically, Volume Three of the study endeavors to provide answers to these questions:

1. Which of the various reactor types are presently available and of proven technology (or nearly so), and which types require further research and development? (Those requiring research and development were not further considered.) The answer to this will be found in Section 4.0.

2. What are the capital costs and power generation costs under present conditions for three plant sizes: 25 MWe, 50 MWe and 100 MWe? The answer to this will be found in Section 5.0, "Present Energy Costs."

3. What are the potential cost reductions and the achievable reduced capital and power generation costs? This is discussed in Section 6.0 and probes such features as technological improvements, regulatory simplifications, multiple plant orders, joint services and so forth.

4. What is the potential market of small utilities based upon forecasted capacity additions by the smaller utilities weighted against probable fuel costs? The answer to this question permits a qualitative judgment as to whether or not a utility might be a potential customer for a nuclear power plant.

In addition, Appendix A of Volume Three contains a set of "Ground Rules" to ensure a uniform evaluation of the various types of nuclear power plants.

2.0 SUMMARY

2.1 Selection of Reactor Types

General

This study estimates capital and power generation costs for small nuclear power plants under (1) existing conditions (Present Costs) and (2) under a set of future achievable conditions which would result in substantial cost reductions (Reduced Costs). In this study, a small nuclear power plant is defined as one having a net electric capacity of 100 MWe or less. Plant ratings of 25, 50 and 100 MWe (net) were selected to bracket the range of interest.

During the summer of 1965, the AEC canvássed reactor vendors in this country to determine what reactors were being offered or might be offered in the near future with economic potential for small nuclear power plants. A number of reactor manufacturers responded with information. Kaiser Engineers made a general assessment of the reactors on which information was received, plus the gas-cooled reactor and the Westinghouse type pressurized water reactor, to select the reactor concepts deemed to be "presently-offered plants of proven technology."

Only the Boiling Water Reactor (BWR) and the Pressurized Water Reactor (PWR) can be classified as "presently-offered plants of proven technology." The Organic Cooled and Moderated Reactor (OCMR) and the Compact Pressurized Water Reactor cannot be so classified until a prototype provides successful demonstration of their operation and reliability. These assessments are sensitive to details of specific designs and one should not assume that broad or final application of these classifications is intended.

The Direct Cycle Thermal Spectrum Reactor and the Closed-Cycle Fast Reactor are in the conceptual state and therefore are not further considered in this study. This part of the study is an evaluation of the comparative merits of plants sufficiently developed to ascertain the likelihood of economic application.

The Swimming Pool Reactor proposed by American Machine and Foundry has a net power output of 2.5 MWe and is designed for multipurpose operation (power, water and isotopes) in an effort to reduce the operating costs of the small nuclear plants. This complexity makes it difficult to meaningfully include the plant in a comparative analysis. Its size is considerably below that of other plants being offered and should be judged upon its merits as well as subject to successful demonstration of its operation. It has not been included in this part of the study.

No reactor vendor proposed a gas-cooled reactor for application to small nuclear power plants. Furthermore, until the prototype High-Temperature Gas-Cooled Reactor (HTGR) has been successfully operated, it cannot be classified as being a presently available reactor type of proven technology.

The above category determinations involve judgment as to the status of the technical development of the concept. In addition, whether a manufacturer would offer the reactor in a given commercial bidding situation depends on the manufacturer's assessment of his chances of being the successful bidder, his current workload, the cost of preparing a bid, the chances of the project proceeding and a risk-versus-potential-profit analysis. In some cases, manufacturers who now are reticent to state whether their reactor concept is offered might bid on an actual project. Thus, the opinion stated here as to the availability of given reactor concepts can only be verified by the manufacturer's willingness to submit an actual "hard-money" proposal on a specific project.

The Boiling Water and Pressurized Water Reactors

Both the Boiling Water Reactor (BWR) offered by the General Electric Company and the Pressurized Water Reactor (PWR) offered by the Westinghouse Electric Corporation are considered fully developed reactor types of proven technology. For large nuclear power plants, the pressurized water reactors and boiling water reactors are in active competition, and neither has an apparent clear-cut advantage over the other. Since the economics of the natural circulation boiling water reactor are representative of both proven BWR and PWR reactors, and since cost data were available in the 50 MWe and 100 MWe sizes, this type was chosen for economic evaluation in this study.

The Organic Cooled and Moderated Reactor (OCMR)

A significant body of operating experience has been accumulated on the organic cooled and moderated reactor proposed by Atomics International. There have been problems including the degradation of the organic fluid in the Piqua Nuclear Power Facility, but it is assumed that these could be corrected by proper redesign. Also, the proposed 50 and 100 MWe sizes represent a scale-up from the presently operating Piqua Nuclear Power Facility which is rated at 11.4 MW. Only upon successful operation of the proposed fuel elements at design conditions can the OCMR be considered "proven technology."

The Compact Pressurized Water Reactor

It was stated earlier that three plant sizes had been selected for this study, viz: 25 MWe, 50 MWe and 100 MWe. On the basis of past experience with small capacity reactors, it was expected that the 25 MWe nuclear power plant would show very high costs and therefore would have little chance to be competitive with fossil-fueled plants in that size; this turned out to be the case. Nevertheless, it was considered important to analyze the situation using a reactor type that might have economic potential in the 25 MWe size. This led to the choice of the compact, pressurized water reactor, a modular unit initially designed for ship propulsion but adaptable to land applications. This reactor type is based upon the well established water reactor technology; however, it incorporates design features which have yet to be demonstrated in order for the reactor type to be deemed "proven technology."

Three reactor vendors have been active in the compact shipboard reactor field, viz: United Nuclear Corporation, Combustion Engineering Company and Babcock & Wilcox Company. For this study, the cost data provided by Babcock & Wilcox for their Pressurized Consolidated Nuclear Steam Generator (PWR-CNSG) was considered typical for a land-based version of the plant.

2.2 Cost Estimates

Conceptual arrangement drawings were prepared using the selected reactor concepts. These drawings serve the two functions of pictorially presenting the nuclear power plants and providing a basis for estimating the cost of structures and improvements.

Estimates of capital costs, nuclear fuel cycle costs, insurance, operation and maintenance costs were prepared, in order to arrive at an estimate of present unit energy costs.

Next, an examination was made of various potential methods of reducing power costs, and this was followed by a determination of the "reduced power costs." Among the economies considered were technological simplifications, regulatory simplifications, possible fuel cost savings and the formation of a utility committee as a vehicle for multi-plant procurement and as a common source of services.

The cost estimates for the nuclear island are based upon cost figures furnished by the reactor vendors. No vendor-supplied cost estimates were available for either the gas-cooled reactor or the Westinghouse type pressurized water reactor. To the extent possible, the reactor vendor cost figures were analyzed and augmented to ensure that they covered a complete scope of supply. The reactor vendor cost figures, however, are not detailed and hence may not be as accurate as may be desirable (see Section 5.0, "Accuracy of Cost Estimates"). The costs for the rest of the plant were estimated in the conventional manner. The resultant cost estimate is the best that can be provided with the limited information available; however, the capital and power generation costs derived appear reasonable and are sufficiently accurate for the purpose of this study.

2.3 Present Costs and Potential Cost Reductions

Cost Summary

1. Present Costs

   The present total capital cost (including non-depreciable capital for fuel) and present unit power generation costs for the nuclear power plants evaluated in this study are shown in Table 1. For the assumed plant capacity factor of 60%, the present unit power generation cost varies from about 17 mills/kwh for a 25 MWe (net) plant capacity to about 9 mills/kwh for a 100 MWe (net) plant capacity. These costs are based on single unit procurement, and on fixed charge rates of 7.75% on depreciable capital and 5.54% on non-depreciable capital. It will be noted from Table 1 that the estimated unit power generation costs for the organic cooled and moderated reactor (OCMR) are slightly lower than for the boiling water reactor (BWR). However, because of the uncertainty in the cost estimates for the respective plants, this apparent difference does not warrant a conclusion that either reactor produces lower cost power. What can be said is that the power production costs from the OCMR and BWR are apparently competitive for a given plant capacity.

   A 60% plant capacity factor is representative of what might be realized by a nuclear power plant operating in a typical small utility system. In economic analyses for large nuclear power plants, however, it is not uncommon to use an 80% plant capacity factor. Table 1 also shows that increasing the plant capacity factor from 60% to 80% results in a 15% to 20% reduction in unit power generation costs from small nuclear power plants. This illustrates the important influence of the plant capacity factor on the cost of power from small nuclear power plants.

2. Reduced Costs

Table 2 lists the capital cost, capital requirements and unit power generation costs which might be realized by implementing the various steps discussed in Section 6.0, "Reduced Energy Costs." The tabulated reduced energy costs take into account savings due to procurement of five "identical" nuclear islands, reduction in plant operating staff, lower fuel costs, and the formation of a utility committee for joint licensing and services and regulatory simplifications. Reduced power generation costs are tabulated for both 60% and 80% plant capacity factors. At a 60% plant capacity factor, the reduced power generation costs vary from 14.0 mills/kwh at 25 MWe (net) to 9.8 mills/kwh at 50 MWe (net) to 7.2 mills/kwh at 100 MWe (net). Figure 1 is a graphical presentation of present and reduced power generation costs at 60% and 80% plant capacity factors. The values plotted for 50 MWe and 100 MWe (net) capacities are the average of those estimated for the OCMR and BWR nuclear power plants. Although the power generation costs are shown as single curves, they really should be considered narrow bands representing the probable distribution of power costs about the plotted curve. Figure 2 shows in bar-graph form both the present and reduced power generation costs from a 100 MWe OCMR power plant at 60% and 80% plant capacity factors. The bar-graph separates the total energy costs into those attributable to the fuel cycle, and those arising from all other sources.

3. Stretch

The reduced energy costs given in Table 2 and shown in Figure 1 do not include any credit for the "stretch" capability of the nuclear boiler. It is estimated that potential stretch of the nuclear boiler is a maximum of 15% of the rated kw capability. If the rest of the plant were initially sized to accommodate the potential stretch of the nuclear boiler, then the capability of the power plant would be 15% greater than its rating. Enlarging the plant in this manner requires an additional investment; on the other hand, the extra capability has a value to the utility. This value depends upon the specific situation. For example, one utility may have a market for both the extra capability and the energy the extra capability could generate; another utility may use the extra capability to delay the addition of a further unit for a certain period. To a third utility, the extra capability may mean a credit from a power pool. Each situation is different and requires a specific analysis. For this study, a conservative method has been used: it has been assumed that the extra capability could be sold for $10 per kw per year, but that no energy is generated with the capability. The sale of the extra capability produces an annual gross income which, when reduced by the annual cost of the extra investment (required for the stretch), yields an annual net income to the utility. This extra net income can be applied to reduce the cost of energy produced by the plant. In this study it has been calculated that income from stretch reduces energy costs by nearly 0.2 mill/kwh at a plant capacity factor of 60% and by three-quarters of this amount at an 80% plant capacity factor.

Areas of Potential Cost Reductions

The "reduced costs" listed in Table 2 can be achieved by undertaking the cost reduction program described in Section 6.0. That program is based upon a conclusion (from an examination of the cost elements in Sections 5.0 and 6.0) that there are five areas in which costs can be reduced. Of these, the first four offer the greatest potential. The five areas are:

1. Price of the Nuclear Island

(See Section 5.0, paragraph 5.3, General, for definition of "Nuclear Island.")

Causes: There are two factors which increase the price of the nuclear island:

a. The high percentage of size-independent items whose impact upon power generation costs is in inverse ratio to plant size. A large plant is not as sensitive to these costs as a small plant.

b. The absence of a market for small nuclear power plants which results in a lack of interest on the part of reactor vendors to develop this market with a consequent lowering of costs arising from such market development.

Means of Cost Reduction: A standardized nuclear island should be developed. Multiple purchases of such standard nuclear islands (probably not less than five) from one reactor vendor is likely to reduce the price for each nuclear island.

2. Application, Licensing and Compliance Costs

Causes: AEC regulations require extensive and time consuming procedures to obtain first a construction permit and then an operating license. After the plant has commenced operation, these regulations require continuing reports to assure compliance. The result of these procedures is uncertain regarding on-time startup and operation; higher capital costs due to the costs associated with the construction and operating permits; and the higher operating cost due to larger plant staffs which are necessary for compliance requirements.

Means of Cost Reduction: Under the concept of five identical nuclear islands only one thorough safety review may be required for the basic plant design followed by reviews of each site. In addition, if the plant would include self-monitoring, fail-safe, and engineering safeguards, a significant reduction in plant staff may be possible. This would reduce the operating cost for each plant.

3. Plant Labor Costs

Causes: Present nuclear power plants have a large plant staff, even when the report functions are reduced as stated above. This is at least partially due to AEC's present requirements for obtaining an operating license, through which the AEC requires a substantial plant staff. Another factor is that each plant provides most of its own service functions.

Means of Cost Reduction: With improved plant design, the plant manning table can be reduced by eliminating dual and overlapping functions (provided that the AEC accepts such eliminations) and by pooling of certain service functions among the five (or more) nuclear plant operators.

4. Improved Plant Capacity Factor

Causes: When a small electric system installs a new power plant, it generally is large enough to meet all (or nearly all) of the system's energy requirements. This, in turn, means that the new power plant operates near the system load factor, generally 60% or less. (In a large system, the new plant capacity is enough below peak demand so that the plant can be base-loaded at the highest plant capacity factor that the new plant can economically develop.) Power generation costs are very sensitive to plant capacity factor; the more energy generated by a given plant, the lower the capital cost component for a unit of energy. Because of their higher capital costs, energy costs from nuclear plants are more sensitive to plant capacity factor than are those for fossil-fueled plants.

Means of Cost Reduction: Interconnection and pooling among the smaller electric systems (and/or power exchange with neighboring systems and industrial users) results in a system large enough to permit the nuclear power plant to operate closer to a base-load condition.

5. Miscellaneous Factors

Both the capital cost of the nuclear island and the operating cost may be further reduced by technological improvements, "stretch" and reduced fuel cycle costs. These reductions will probably not be as significant as the others outlined above.

An Approach to Achieving Cost Reductions

Evaluating potential cost reductions is a difficult task and subject to considerable variations in interpretation, depending as it does upon the judgment of the evaluator. Therefore, the potential cost reductions presented in this report should be viewed not as definitely attainable, but as targets that could be achieved by implementing the steps outlined below. These steps are set forth tentatively not in the sense of proposing a specific program, but rather to indicate a direction and to provide a basis for discussion among those interested in implementing such a program.

Of the five areas of cost reduction outlined above, the first four will have the greatest impact upon power costs, and it is the implementation of these that will require a joint effort by the small utilities. It appears that a committee, group or organization could initiate a joint undertaking and give it direction and focus. Assuming that this is a reasonable starting point, the following course of action is visualized:

1. Organization

    a. A committee (composed of utilities and other interested groups), responsible for formulating, initiating and implementing a nuclear cost reduction program, would be formed.

    b. The committee would undertake a detailed survey to find utilities with a potential requirement for a nuclear power plant and establish their interest in participating in this program. A maximum effort should be made to settle on the largest standard plant rating (preferably as close to 100 MWe as possible) which could be utilized by a number of utility combinations.

    c. The committee would (perhaps by engaging the services of a competent architect-engineer) perform for each candidate the following tasks:

        (1) Prepare a detailed, specific power cost study for each candidate. For economic comparison purposes, the study would consider load

growth, present power costs, power costs from a new fossil-fueled plant and the possibilities of pooling as they apply to each utility candidate. (Note: For this AEC study, fixed charge rates, plant capacity factors, and other economic ground rules typical of those experienced by a smaller utility have been used. See Section 5.0 and Appendix A.)

(2) Perform preliminary, but definitive, design of and produce cost estimate for a standard nuclear island in cooperation with one (or more) established reactor vendor(s).

(3) Determine for each candidate whether or not the nuclear power plant will show a cost advantage over a fossil-fueled plant; determine the amount of this advantage.

2. Joint Utility Action

If such a detailed study shows an economic advantage in favor of nuclear power plants for, say five utilities, these might then consider joining together to undertake a cost reduction program. Such a program might consist of the following steps:

a. Efforts to streamline and simplify the licensing and compliance requirements for nuclear power plants would be continued in close cooperation with the AEC. This is particularly crucial for smaller capacity nuclear stations where the cost of licensing and safeguards, presently experienced for single plant licensing, may be a prohibitive deterrent to economically competitive nuclear power. The concept of pre-licensing the nuclear island for proven reactor types appears to offer considerable incentive, particularly for construction of multiple identical nuclear islands. Thus, only those portions of each plant peculiar to a particular site would have to be given detailed review.

b. An effort would be made to maintain a competitive bidding situation both in the procurement of multiple identical nuclear islands and in subsequent fuel assembly procurement. Several reactor vendors willing to bid competitively on the same type of reactor, or bid competitively on different reactor concepts might have to be found. From the present alignment of reactor vendors and reactor concepts, it appears that each vendor shows preference for a specific reactor type, and it appears likely that they will compete on such a basis. However, the absence of a competitive commercial situation will not necessarily be fatal to plans for competitive nuclear power. The competition between alternative energy sources and nuclear power will still exist. Thus, once the utilities are able to show a potential market for small nuclear power plants, it should be possible to find at least one reactor vendor interested in supplying this market and in passing along some of the savings which will accrue from multiple orders for identical plants.

c. If the above efforts to reduce costs are successful, a final evaluation would be made for each of the candidates to verify that the selection of a nuclear power plant is the correct choice. Once this has been done, one architect-engineer might be selected for final design of the five (or more) power plants, and procurement and installation of the identical nuclear islands could be started. If proper sequencing can be arranged, the same nuclear island construction supervisors can be used at each site.

d. The utility group would undertake to secure the construction and operating license for each plant. Relations with the AEC would be undertaken through the group.

e. The group would be the coordinating agency for operator training and for startup and checkout of each power plant.

f. When operation has started, the group would provide certain services common to all of the nuclear stations.

The above steps are only a brief outline of one course of joint action by the small utilities. Obviously, there are legal, financial and other problems that would require solution. It is hoped that the AEC study will point the way and provide an impetus to those interested in pursuing the matter further.

2.4 Potential Market

Consideration of a nuclear alternative in a system expansion study involves many factors. Basically alternative plant sizes and types are evaluated to determine, by means of economic differences, which plant will show the lowest energy costs. This study could not categorically state which small electric utility could "go nuclear" for its next expansion, but it has found potential candidates by a simple process.

Step 1

Fossil-fueled plant energy costs, as reported by small utilities (as found in the Federal Power Commission's Sixteenth Annual "Steam-Electric Plant Construction Cost and Annual Production Expenses" as well as the American Public Power Association's Sixth Survey on Power Costs and a similar compilation published by REA), range from about 7 mills/kwh for a 100 MWe station to about 11 mills/kwh (and higher) for a 25 MWe station. The best energy cost (accounting for all potential cost reductions including stretch) achievable from a 25 MWe nuclear plant is nearly 14 mills/kwh at 60% plant capacity factor (see Table 1, Section 6.0). It is evident (except in special cases, e.g., location Alaska) that the 25 MWe nuclear plant is not competitive. Therefore, the search for potential candidates will exclude the 25 MWe plant size. The best energy cost for the 50 MWe nuclear plant is 9.3 mills/kwh (see Table 1, Section 6.0); this also seems too high to compete with fossil-fueled plants. Nevertheless, for purposes of finding potential candidates, plant sizes from 44 MWe will be included. Moreover, if one assumes that the new nuclear plant will start operation in 1970, all utilities whose load growth is such as to warrant the addition of a 44 to 100 MWe unit for operation in 1970 are potential candidates. Because load forecasts are uncertain, it seems reasonable to consider them over a five-year period, and to say that all those utilities will be considered potential candidates whose load forecasts show the need for installing a 44 to 125 MWe unit in the years from 1968 to 1972.

Step 2

The second step consists of examining the fuel costs currently paid by the potential candidates and deleting those whose fossil-fuel costs are too low to warrant consideration of a nuclear plant. This step is based on the consideration of a certain fossil-fuel cost as a "break-even" fuel cost. This "break-even" cost can be established by estimating the energy cost (excluding fuel costs) in mills/kwh from a new fossil-fueled power plant, and by then adding a fuel cost (in mills/kwh) of a magnitude sufficient to make the total unit energy cost from the fossil-fueled unit equal to the total unit energy cost from a nuclear unit of the same size. If fossil-fuel costs for a utility are higher than the "break-even" fuel cost, the utility can be considered a candidate for nuclear power.

This type of evaluation should be used with great caution. Load forecasts are subject to considerable changes with the passage of time. Moreover, there are many factors (such as the formation of pools, interchange of energy, etc.) that make any prediction concerning future capacity conditions quite speculative. Nevertheless, it appears from the market survey made in this study that it may be possible to locate five small utilities in an area where a nuclear power plant could be competitive. The validity of this conclusion depends, of course, on other factors besides high fossil-fuel cost, but most of all on the willingness of the utilities to cooperate for joint action, and on the support and encouragement of industry associations and responsible government agencies.

2.5 Conclusions

The Introduction stated that this study endeavors to provide answers to the four questions listed there. Subject to the qualifications and conditions stated in this study, to which the reader's attention is specifically directed, this study presents the following answers:

1. Which of the various reactor types are presently available and of proven technology?

   Answer: Only the Boiling Water Reactor (BWR) and the Pressurized Water Reactors (PWR) can be classified as "presently offered plants of proven technology."

2. What are the capital and power generation costs under present conditions for the 25 MWe, 50 MWe and 100 MWe power plants?

   Answer: See Table 1.

3. What are the achievable reduced capital and power generation costs?

   Answer: See Table 2.

4. Is there a potential market for Small Nuclear Power Plants?

   Answer: Except in special situations, not for the 25 MWe nuclear plant and probably not for the 50 MWe nuclear plant. There is a fair possibility of finding five utilities for whom 100 MWe nuclear plants, and possibly 75 MWe nuclear plants at the reduced cost, could be an attractive alternative to fossil-fueled plants.

TABLE 1

PRESENT CAPITAL AND ENERGY COSTS

(Capital Costs in Thousands of Dollars)

	PWR-CNSG	OCMR		BWR	
CAPITAL COSTS	25 MWe	50 MWe	100 MWe	50 MWe	100 MWe
Total Capital Cost, w/o Fuel	$ 15,000	$ 19,000	$ 25,000	$ 19,500	$ 28,000
Non-Dep. Capital for Fuel	1,350	2,320	4,450	3,360	6,290
Total Capital Required	$ 16,350	$ 21,320	$ 29,450	$ 22,860	$ 34,290
UNIT ENERGY COSTS, MILLS/KWH*					
Total Unit Cost @ 60% P.F.	17.4	12.1	8.6	12.4	9.0
Total Unit Cost @ 80% P.F.	13.8	9.8	7.1	10.2	7.6

*Average for first 10 years of plant operation.

TABLE 2

REDUCED CAPITAL AND ENERGY COSTS

(Capital Costs in Thousands of Dollars)

	PWR-CNSG	OCMR		BWR	
CAPITAL COSTS	25 MWe	50 MWe	100 MWe	50 MWe	100 MWe
Total Capital Cost, w/o Fuel	$ 12,600	$ 15,950	$ 21,800	$ 16,930	$ 25,150
Non-Dep. Capital for Fuel	1,230	1,840	3,490	2,350	5,000
Total Capital Required	$ 13,830	$ 17,790	$ 25,290	$ 19,280	$ 30,150
UNIT ENERGY COSTS, MILLS/KWH*					
Total Unit Cost @ 60% P.F.	14.0	9.5	6.9	10.0	7.6
Total Unit Cost @ 80% P.F.	11.1	7.7	5.7	8.2	6.4

*Average for first 10 years of plant operation.

FIGURE 1

ENERGY COSTS FROM SMALL NUCLEAR POWER PLANTS

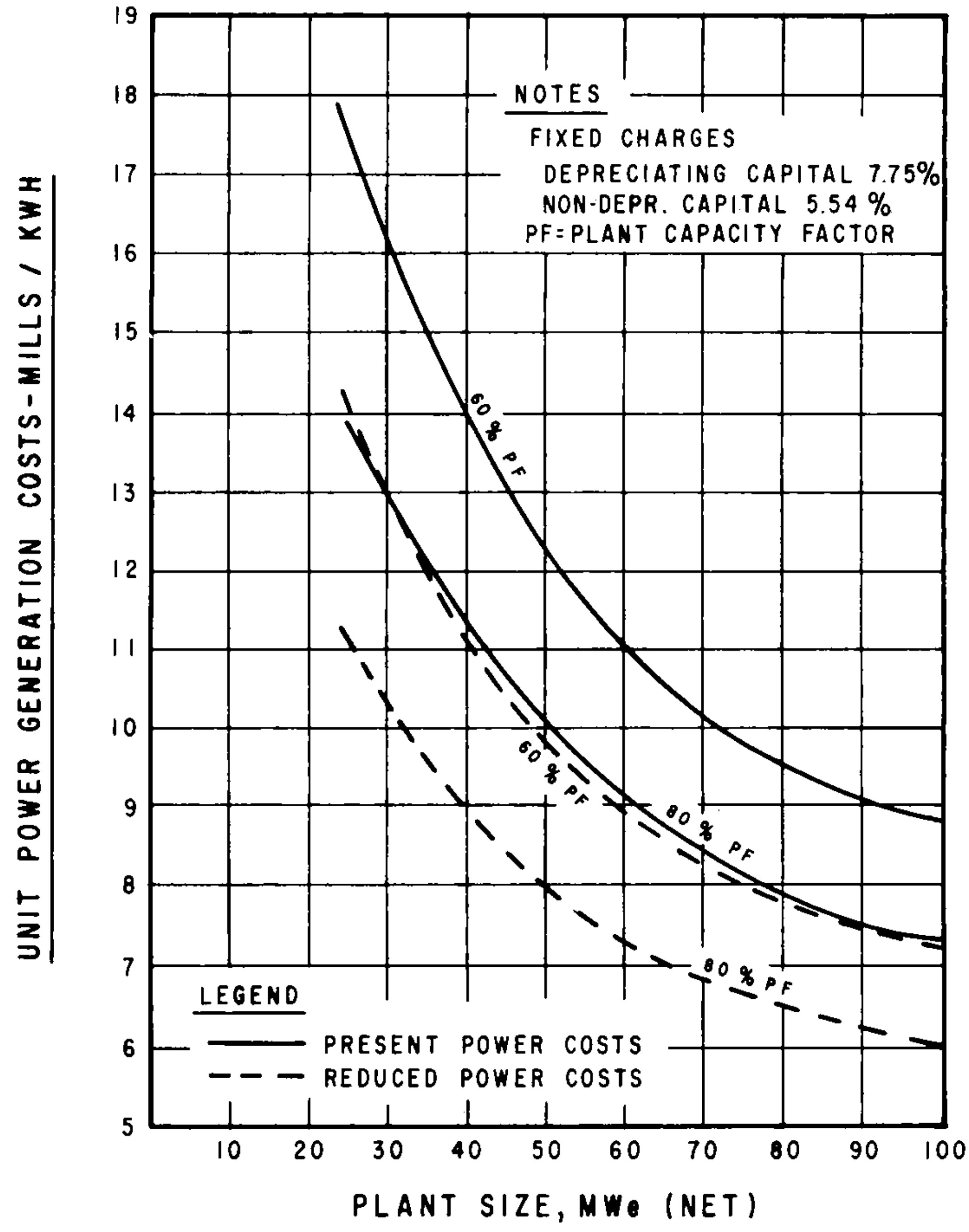
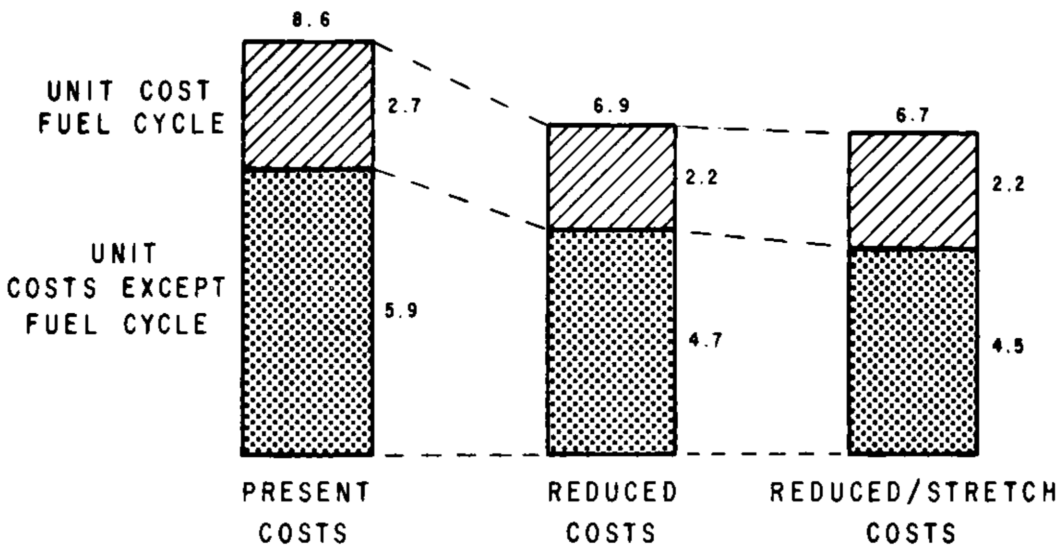


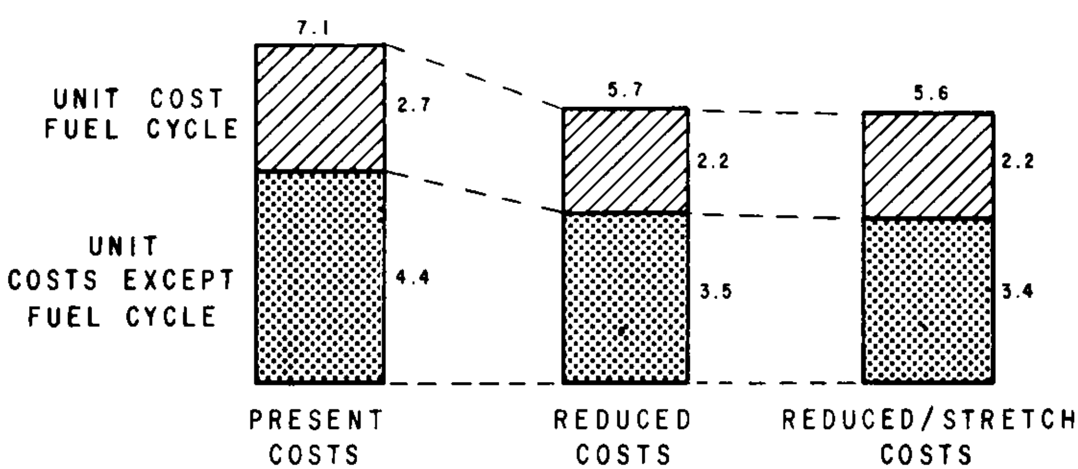
FIGURE 2

ENERGY COSTS FROM A 100 MWe OCMR NUCLEAR POWER PLANT

COSTS IN MILLS/KWH



60 % PLANT CAPACITY FACTOR



80% PLANT CAPACITY FACTOR

3.0 DIFFERENCES BETWEEN FOSSIL AND NUCLEAR-FUELED POWER PLANTS

3.1 General

In recognition of the fact that the manager of the small electric utility system - to whom this report is addressed - may want a concise description of the basic differences between fossil-fueled and nuclear-fueled power plants, the following brief comparison is included.

While there is no such thing as a "typical nuclear-fueled power plant" or a "typical fossil-fueled power plant," the two types have certain common characteristics. The small nuclear plant will have higher fixed costs but lower fuel costs than a fossil-fueled plant. The site for a nuclear plant must have certain special characteristics, but, unlike a fossil-fueled plant, it does not require ready access to a bulk fuel supply. Thus, the fuel costs for a nuclear power plant are essentially independent of site location. Because of the long-level radioactive material generated within the fuel, there is a much greater emphasis placed on safety in the design and operation of a nuclear plant and, by Federal Statute, special licensing procedures are required. Moreover, because certain segments of the public object to nuclear plants, education programs to foster public acceptance must be initiated whenever a nuclear reactor power plant is planned by a utility.

3.2 Siting

The following special considerations must be taken into account in siting a nuclear fuel plant:

1. If possible, a sparsely populated area should be selected so that an adequate exclusion area may be established around the plant site.

2. In order to provide the information required in the application for a construction permit - including a preliminary safeguards report - the history of wind, weather, and other site characteristics must be obtained. The natural radiological background should be determined before the plant is put into operation. This may be done by establishing radioactivity monitoring stations on and near the site before or during construction.

3. In selecting a site, consideration must be given to the possible means for disposing of liquid wastes that may contain slight amounts of radioactivity.

The prospective site for a fossil-fueled plant, in contrast to a nuclear-fueled plant site, should be as close as possible to the source of fuel, so that transportation costs for the bulky fossil fuel can be kept as low as possible. Since nuclear fuel transportation costs are relatively insignificant, the fuel cost for a nuclear plant is independent of site location.

3.3 Safety

With regard to safety, the principal characteristic of a nuclear power plant that distinguishes it from the fossil-fueled power plant is the large quantity of highly radioactive fission products generated during its operation. The heat energy resulting from the fission process is used in a conventional way to generate steam to drive a turbine-generator and this part of the process does not introduce any unusual hazard. However, the associated radioactivity could represent a serious hazard to the public health and safety if it were not adequately controlled and contained. There are usually three separate barriers, in series, that serve to contain this radioactivity: the fuel cladding, the reactor vessel and the containment building.

The nuclear reactor is, in most cases, completely enclosed in a containment building. This containment building is designed and built to prevent the possible escape of any radioactivity in the event of a major reactor accident. The reactor vessel itself, which contains the nuclear fuel together with the reactor auxiliaries, is enclosed within this building. Reactor coolant fluid that flows through the core is circulated through a heat exchanger, within the building, to form non-radioactive steam. This non-radioactive steam is then taken through the wall of the containment building to the part of the plant containing the conventional turbine-generator. In the direct-cycle boiling water reactor, steam is generated in the core and directly utilized to drive the plant turbine. In this case, the steam contains some radioactivity and certain precautions are required in the turbine part of the plant. Concrete shielding is required around the reactor vessel to attenuate radioactivity from the core. Shielding around other items of reactor plant equipment may also be required to permit access for operation and maintenance. Additional safety factors are built into the plant such as an adequate back-up of emergency electrical power and increased reliability of other utilities.

The detailed reactor plant analysis and review, conducted by both the reactor designers and the regulatory agency, ensure that the plant is designed and operated in a safe manner. Thus far, the nuclear power industry has a perfect record as far as public safety is concerned. No accident exposing anyone in the public to significant amounts of nuclear radiation has occurred in a nuclear power plant.

3.4 Fuel Cycle

In a fossil-fueled power plant, fuel must be continuously supplied to the boiler whether the fuel be coal, oil or natural gas. On the other hand, a nuclear reactor requires only periodic refueling. The fuel for a reactor is contained within solid fuel elements which are placed in the reactor core during periods of shutdown. The fissionable material in the fuel elements generates heat during the lifetime of the fuel elements without a significant physical change of the fuel elements. When the fissionable material concentration in the fuel elements has been reduced substantially, the spent fuel elements are replaced by a charge of new fuel elements. The interval between successive fuel element replacements depends on the type of the reactor; however, it is desirable to have as high a fuel burn-up as possible. The refueling cycle should be scheduled so that reactor refueling can be accomplished during the shutdown annually made for other purposes.

3.5 Personnel

A nuclear-fueled power plant requires personnel who have had experience similar to that required for fossil-fueled plants but who have received specialized training in the operation of nuclear reactor plants. The ideal situation is to utilize men experienced in the operation and maintenance of fossil-fueled plants and give them an intensive training period in the operation and maintenance of nuclear power plants. Nuclear plant operators require a special AEC-issued operating license and they must pass a series of tests to obtain this license. Another reason for this intensive training and orientation program is to remove any apprehension about working with this "new" energy source.

A nuclear plant will require more personnel than a fossil-fueled plant of the same size. A nuclear plant may require about one and one-half times the number of personnel needed for a comparable conventional plant. This difference is demonstrated by the manning schedules presented in Sections 5.0 and 6.0. Some of the tasks not found in fossil-fueled power plants are as follows:

1. A health physics group, to monitor the plant for radioactivity and thus ensure safe working conditions, must be maintained. A health physics man usually must accompany a maintenance group if any work is to be done on the radioactive portion of the plant.

2. Records of radiation exposure, obtained by using film badges and other devices, must be maintained as permanent plant records.

3. Detailed records must be kept on the amount and location of fissionable material in the plant, whether this fissionable material is contained in new or spent fuel elements or in other locations.

4. Reports on the activities of a nuclear-fueled plant must be much greater in number than those on the activities of a fossil-fueled plant. These reports, many of which are required by the AEC, cover the details of operating and maintenance experience. In particular, any changes in plant design or operating procedures must be carefully controlled, monitored and recorded.

3.6 Maintenance

Except for a direct cycle boiling water reactor, maintenance work on the conventional parts of fossil-fueled and nuclear-fueled plants are similar. In the BWR, as mentioned above, radioactive steam from the core is piped directly to the turbine, thus making the turbine and its auxiliaries radioactive whenever the plant is in operation.

The following items make maintenance work on the radioactive portion of the reactor plant more difficult:

1. Strict procedures must be adopted during this maintenance work, whether such work is being done during plant operation or during a shutdown period.

2. The presence of radioactivity may require appreciable decontamination before maintenance work can be started.

3. Unlike a conventional boiler, a nuclear reactor produces after-heat for a long period after shutdown. This is due to fission product decay heat which must be removed, and therefore the maintenance procedures must provide assurance that this shutdown heat removal capability is not interrupted.

4. As noted above, many parts of the reactor plant are enclosed in biological shielding. This shielding may have to be removed for maintenance or may actually prevent access to certain parts of the plant.

3.7 Operation

Operating differences between power plants depend not only on whether the plant is fossil-fueled or nuclear-fueled, but also depend to a major extent on their individual design characteristics. Differences between the latter are particularly apparent, however, during start-up and shutdown operations. At start-up, a nuclear plant has its fuel already in the "boiler" while a fossil-fueled plant does not. Before reactor start-up, the auxiliary systems must be put into stable operation, and in some cases, auxiliary heat must be used to achieve intermediate temperature and pressure conditions. The temperature level of a reactor has an important effect upon its reactivity. Using the control rods, the reactor is brought slowly and carefully to criticality and then through the low and intermediate power ranges to the desired power level.

After shutdown, the nuclear fuel continues to provide some heat as the result of fission product decay; therefore, continued cooling of the reactor core is necessary after shutdown. After a long period of operation, this shutdown heat decays from a level of approximately 5% of full power at 10 seconds after shutdown to approximately 1% at 12 hours after shutdown and to 0.5% at 2 days after shutdown. The reactor power plant design provides equipment for reliable removal of this shutdown heat.

3.8 Plant Licensing

The Atomic Energy Commission has adopted a two-step procedure for licensing a reactor. The first step is the issuance of a construction permit. This is normally referred to as "site approval." Before the detailed design of the reactor is completed, a preliminary safeguards report must be submitted, giving site and preliminary plant design data. The AEC must agree that the proposed site is suitable for the type and size of reactor contemplated. Public hearings accompany this step in the licensing procedure.

The second step is the issuance of an operating license when construction has been completed. The applicant must furnish detailed information on the final design and construction of the facility in the form of a final safeguards report. There will customarily be numerous meetings between the applicant and the AEC regulatory staff personnel to discuss questions that arise. A set of technical specifications will be developed to define the operating limits within which the plant will be permitted to operate. The plant must be operated within these limits unless a change is requested from and approved by the AEC. When the AEC regulatory staff and the Advisory Committee on Reactor Safeguards (ACRS) are satisfied, an operating license is issued.

During the operating lifetime of the plant, periodic surveillance by AEC inspectors is made, to ensure that the plant is being operated in compliance with the license and that no safety problems occur.

3.9 Public Education

One major difference between the two types of plants, which is not related to the design or the physical characteristics, is the area of public education and public acceptance. Fossil-fueled plants have been in common use for a long time, and the general public usually is not concerned about them.

On the other hand, when a utility contemplates installation of a nuclear plant, an educational program directed to the general public may be desirable. If the public is shown how, through design, operational and maintenance procedures, operator selection and training, administrative control and under a federal regulatory and inspection procedure unique in industrial history, the hazards are reduced to a very low level, public acceptance may be more readily obtained. This program might also indicate the long-range benefits which nuclear reactors will bring in assuring the reliability of electric supply, the conservation of other fuel resources, and the control of air pollution.

4.0 GENERAL ASSESSMENT OF REACTOR PLANTS

4.1 Summary

General

The objective of this section is to review and assess small reactor power plants to separate those that are "presently-offered plants of proven technology" from those requiring further research and development. The following reactor plants have been assessed:

The BWR (Natural Circulation Boiling Water Reactor)
General Electric Company

The PWR (Pressurized Water Reactor)
Westinghouse Electric Corporation

The Compact Pressurized Water Reactor

PWR-CNSG
Babcock & Wilcox Company

PWR-UNIMOD
Combustion Engineering Company

PWR-U2U
United Nuclear Corporation

The OCMR (Organic Cooled and Moderated Reactor)
Atomics International

The Direct Cycle Thermal Spectrum Reactor
Westinghouse Electric Corporation

The Closed-Cycle Fast Reactor
Westinghouse Electric Corporation

The Swimming Pool Reactor
American Machine & Foundry Company

The HTGR (High Temperature Gas-Cooled Reactor)
General Atomic Division of General Dynamics

Conclusions

Of the reactors assessed in this section, the General Electric Natural Circulation Boiling Water Reactor, the Babcock & Wilcox Consolidated Nuclear Steam Generator, and the Atomics International Organic Cooled and Moderated Reactor were selected for detailed economic evaluation.

The Boiling Water Reactor (BWR) and the Pressurized Water Reactor (PWR) come closest to the criteria of "presently-offered plants of proven technology."

Since the economics of the BWR are representative of proven water cooled reactors, and since reactor vendor costs were available in the 50 MWe and 100 MWe sizes, it was selected for detailed economic evaluation.

The Organic Cooled and Moderated Reactor (OCMR) was also selected for detailed economic evaluation even though this reactor type cannot be classified as "proven technology" until successful operation, in the Piqua Nuclear Power Facility, of the Core II fuel elements at design conditions. The Babcock & Wilcox Pressurized Water-Consolidated Nuclear Steam Generator has been selected as a typical land-based version of a compact shipboard reactor. This reactor type cannot be classified as "proven technology" either, until its successful operation has been demonstrated. It has been included for detailed evaluation because of the requirement to determine power costs for a 25 MWe nuclear power plant.

4.2 Criteria

For this study, a nuclear power plant or nuclear boiler is considered "presently offered" if it can be purchased from a reactor manufacturer on a firm price basis with warranties of performance and delivery.

It is difficult to decide whether or not a particular nuclear reactor concept represents "proven technology" since there are various levels of proof. Clearly if a nuclear power plant of essentially identical design and of approximately the same power rating as that proposed has already been built and operated satisfactorily, it would be of proven technology. Thus, a 50 to 75 MWe natural circulation boiling water plant similar to the Humboldt Bay Unit No. 3 of Pacific Gas and Electric Company would certainly be of proven technology. If a reactor of the same general type has been successfully operated at either a lower or higher power level, it also could be considered to be of proven technology, provided that the difference in power rating from that of an existing plant is not too large. If a proposed nuclear plant concept includes a number of undemonstrated features or components it cannot be considered to be of proven technology. The following sections include an evaluation of each reactor concept. In some cases it has been necessary to make somewhat arbitrary decisions as to whether or not a plant is of proven technology.

4.3 The BWR - General Electric Company

Description

Boiling water reactor power plants such as those offered by the General Electric Company generate steam within the reactor pressure vessel and supply it directly to the turbine-generator. Boiling water reactors in the range from 50 MWe to 100 MWe operate with natural-circulation heat removal from the core.

The nuclear fuel consists of slightly enriched uranium oxide pellets contained in tubular cladding of zirconium alloy. The fuel rods (approximately 0.5 in. O.D.) are arranged in a square array comprising a fuel assembly. In the reactor core, ordinary water is used as the coolant and as a neutron moderator. As steam is generated in the reactor it passes through separators inside the reactor pressure vessel and is supplied to the turbine-generator as dry, saturated steam at about 1,000 psi. The reactor is controlled by control rods which are hydraulically actuated from below the reactor core. The neutron absorbing material is boron carbide contained in stainless steel tubes, which are structurally contained within the cruciform-shaped control rods. The reactor is controlled from a central control room by manual operator action.

The reactor and its auxiliary systems are located within a reactor building which contains refueling and fuel storage facilities as well as the pressure suppression containment system. The pressure suppression containment system consists of a steel pressure vessel, or dry-well, surrounding the reactor pressure vessel and an interconnected pressure suppression chamber containing a pool of water. In the unlikely event of a reactor system rupture occurring, a system of headers and distribution piping vents any released steam into the pressure suppression pool. The reactor building is a gas-tight structure which acts as the containment barrier during refueling operations.

The turbine-generator, condenser, feedwater and condensate pumps, power plant auxiliaries and offices are located within the turbine building. Condensate returned from the condenser hot-well passes through a full-flow condensate demineralizer prior to its return to the reactor. Noncondensable gases removed by the air-ejector are released from a high stack following holdup to permit decay of short lived radioisotopes, and monitoring. The radioactive waste treatment building contains facilities for storage of radioactively contaminated liquid wastes, for filtering and demineralizing these wastes prior to returning them to condensate, and equipment for concentrating liquid wastes prior to their ultimate disposal.

Evaluation

The General Electric Company offers boiling water reactors on a commercial, fixed-price basis with warranties of performance and delivery. These reactors, available at ratings from 50 MWe to 1,000 MWe, are listed in GE's Apparatus Price Book, dated September 12, 1965. The 50 MWe (net) and 100 MWe (net) plant ratings are respectively the minimum and maximum power plant ratings offered by the General Electric Company in the natural circulation boiling water design. Thus, in the range from 50 MWe (net) to 100 MWe (net) the boiling water reactor qualified as "presently offered."

These commercially offered natural circulation boiling water power plants are quite similar to the 70 MWe Humboldt Bay Unit No. 3 of the Pacific Gas and Electric Company at Eureka, California, which has been in commercial operation since August 1, 1963. Therefore, these plants meet the criteria for "proven technology."

4.4 The OCMR - Atomics International

Description

The Organic Cooled and Moderated Reactor (OCMR) proposed by Atomics International utilizes an organic material which serves as both the heat removal medium and as the neutron moderator in the reactor core. This organic fluid is circulated in a closed-loop system and transfers heat through a steam generator and superheater to produce steam, which is supplied to the turbine-generator at 850 psig, 675°F. The organic material is a mixture of terphenyl isomers; it is a radiation-resistant hydrocarbon with a high boiling point.

The nuclear fuel consists of slightly enriched uranium carbide rods, clad with spiral-finned Sintered Aluminum Product (SAP). The fuel rods are arranged in two annular rings between stainless steel shroud tubes. Each fuel element is equipped with a full-flow filter unit and a coolant orifice. A pressure of 150 psig is maintained above the core by pressurized pumps. The reactor is controlled by neutron absorbing rods of the unitized type. The neutron absorber elements and their associated drives are both immersed in the coolant within the reactor core tank. The circular neutron-absorber section of the control rod consists of a double ring of stainless steel tubes filled with boron carbide powder. An automatic control system programs the motion of the rods to maintain constant steam pressure at the turbine throttle.

The reactor core tank, primary coolant piping, primary coolant pumps, surge tank, superheater and steam generator are located within a welded-steel reactor containment structure. In addition, the reactor containment structure contains the fuel storage pool, fuel handling machine, and other reactor auxiliaries.

The turbine-generator, condenser, feed-water and condensate pumps and the power plant auxiliaries are located within the turbine building.

The radioactive waste treatment building contains a system for degasifying the reactor coolant. This system removes hydrogen, methane, water vapors, and the light hydrocarbons formed by radiolytic decomposition of the reactor coolant. These gases pass through an organic trap to the air ejector. From the air ejector the gases pass to the stack through absorbers containing activated charcoal. The radioactive waste treatment building also contains a system which removes high-molecular-weight hydrocarbons from the coolant and returns the purified coolant to the reactor coolant system. These high-molecular-weight compounds, known as "high boilers," are accumulated in storage tanks and then burned in a hydrocarbon burner. A hydrocracker system is under development for use at the Piqua Plant to convert these high boilers to lower-molecular-weight compounds for re-use in the plant.

Evaluation

Two organic moderated and cooled reactors have been operated; the Organic Moderated and Cooled Reactor Experiment (OMRE) at the National Reactor Testing Station (NRTS), Idaho, and the Piqua Nuclear Power Facility (PNPF) at Piqua, Ohio. Another experimental reactor, the Experimental Organic Cooled Reactor (EOCR) at NRTS was mothballed prior to operation; construction was terminated in December 1962.

The Piqua Plant has been in commercial operation since August 1964. The Piqua operating experience provides the main basis for evaluation. The staff of the operating utility reports favorably regarding the freedom of primary systems activation and the ease of maintenance. However, serious problems, notably the recent extended outage caused by accumulation of carbonaceous material in the moderator region, have beset continuity of operation. Atomics International proposes to correct this problem by increasing the flow rate through the moderator region.

The proposed plants of 50 and 100 MWe represent a reasonable scale-up from the Piqua Nuclear Power Facility, which is rated at 11.4 MWe. The fuel elements for the proposed plants differ significantly from those used in the first Piqua core, but are similar to the proposed Piqua Core-II fuel elements being developed in support of the Heavy Water Organic Cooled Reactor Program. Another difference between the proposed plant design and the Piqua design is the use of a somewhat higher coolant outlet temperature (700°F vs 575°F). Only after the Piqua Core-II elements have been installed and successfully operated at design conditions in the Piqua facility, can the Organic Cooled and Moderated Reactor proposed by Atomics International be considered "proven technology."

At the present time Atomics International has not decided whether or not they will enter the utility market with 50 and 100 MWe OCMR power plants.

4.5 The PWR - Westinghouse

Description

The Westinghouse type pressurized water reactors (PWR) utilize pressurized water as the neutron moderator and as the heat removing medium in the reactor core. The pressurized water is circulated in a closed primary coolant piping loop which removes heat from the reactor core and transfers it through a steam generator to the secondary system. The steam produced in the steam generator is supplied to a turbine-generator. After the exhaust steam from the turbine-generator is condensed, it is pumped back to the steam generator through feed-water heaters.

The primary coolant system is maintained at an operating pressure of 2,000 to 2,500 psia to prevent flashing of the primary coolant water. The system pressure is maintained by using electric heating elements to control the water temperature in a separate pressurizer vessel. The pressurizer also accommodates volume changes in the primary coolant system, which may be caused by temperature changes in the bulk of the primary coolant or leakage. The number of primary coolant loops (a loop consists of a steam generator, a pump, and the interconnecting piping) is set by the reactor power rating. Plants of up to 100 MWe rating use a single loop.

The reactor fuel consists of slightly enriched uranium dioxide clad in cylindrical tubes of either stainless steel or a zirconium alloy.

The pressurized water reactor (PWR) is easily controlled due to its large negative temperature coefficient which results from the change in water density with temperature changes. The reactor is further controlled by neutron absorbing control rods which utilize an alloy of cadmium, indium and silver as the neutron absorber. Compensation is made for long term changes in reactivity by varying the concentration of a soluble neutron poison dissolved in the primary coolant.

The entire primary coolant system, consisting of the reactor pressure vessel, pressurizer, primary coolant loops and pumps, and steam generators, is contained within a pressure-type welded steel containment structure.

Evaluation

Westinghouse Electric Corporation, the principal PWR manufacturer, has indicated an interest in bidding only on those nuclear power plant projects which present a reasonable likelihood of proceeding, where terms and conditions are reasonable, and where proposed efforts may lead to the sale of power plant equipment regardless of whether a nuclear or a fossil-fueled power plant is selected.

A large amount of technological and operating experience has been accumulated in the naval propulsion reactor program, in the Shippingport PWR, in the Yankee Atomic Electric power plant and in others. Presently, a number of large commercial PWR power plant projects are committed and in various stages of design and construction. In view of the history of successful operation of PWR power plants, the PWR can be classified as being "proven technology."

4.6 Compact Pressurized Water Reactor (Shipboard Type)

Description

Three manufacturers (Babcock & Wilcox, Combustion Engineering, and United Nuclear) are developing compact pressurized water reactors that have potential for civilian power application. The plants are made compact by designing the steam generator to fit within the reactor pressure vessel, by close-coupling the recirculation pumps in close proximity to the reactor vessel, and by enclosing all these components within a pressure suppression containment vessel.

Heat is removed from the reactor core by a primary system consisting of three forced-circulation loops. The primary system is self-pressurized by nuclear heat to a pressure of 2,000 to 2,500 psig.

The pressurizer vessel normally found in the pressurized water reactor has been eliminated. Turbine steam is generated within the tubes of a once-through type steam generator. Tube bundles are located concentrically with the pressure vessel wall, in the space between a core support cylinder and the vessel wall. The steam outlets and feed-water inlets are spaced around the reactor vessel for uniform flow distribution.

The nuclear fuel is slightly enriched uranium dioxide in pellet form, clad with zirconium alloy tubing. The reactor features inherent load-following performance. Top entry control rods are used to provide further control; they are also used for prolonged shutdown to the cool condition. During normal operation these control rods are completely removed from the core.

The containment vessel enclosing the entire system of reactor vessel, recirculation pumps, steam generators and control rods, contains borated water to a level higher than the top head of the reactor pressure vessel. The borated water, in addition to providing shielding from radiation, serves as the energy absorption medium for the pressure suppression containment system.

The Babcock & Wilcox Company has indicated a willingness to furnish their 25 MWe "Consolidated Nuclear Steam Generator" (CNSG) on a fixed price basis with warranties as to both performance and deliveries.

Combustion Engineering, Inc., has indicated a willingness to furnish their unified modular nuclear boiler (UNIMOD) in sizes from 16.4 MWe to 78.3 MWe on a firm price basis after certain developmental features have been satisfactorily checked out in a first-generation prototype plant. Performance, workmanship and materials will be warranted for second generation plants. Those plant features which Combustion Engineering considers to warrant development and proof-testing in a prototype plant are:

1. Integral Steam Generator

2. Pressure Suppression Containment

3. Self-Pressurization

4. Load Following and Control

5. Low Suction Head Circulating Pumps

United Nuclear is prepared to offer the U1U (16.5 MWe) and U2U (51.6 MWe) on a firm price basis with performance warranties, following successful development and testing of components.

Evaluation

This reactor design has not been operated and therefore cannot be considered as being of proven technology at this time.

The successful development of the reactor type is of potential interest to the electric utilities.

4.7 The Direct Cycle Thermal Spectrum Reactor - Westinghouse

Description

Westinghouse Electric Corporation has proposed a direct-cycle reactor, cooled with a supercritical fluid and operating with a thermal neutron spectrum, for use in small nuclear power plants. The supercritical fluid removes heat from the core in making three passes through the fueled process tubes comprising the reactor core. The reactor supplies supercritical fluid directly to the turbine-generator at 3,400 psia, $960^{o}F$. The 265 MWt rating of the reactor core is based on an electrical output of 100 MWe (net).

The fuel bundles for this reactor consist of bundles of 19 individual rods clad with either Incaloy 800, Inconel 625, or 16 Cr-20 Ni stainless steel. The fuel bundles are contained in Zircaloy-4 process tubes arranged in a triangular pitch within the reactor core.

Evaluation

The supercritical-fluid-cooled direct-cycle thermal reactor offers significant promise for achieving appreciable reductions in the capital and operating costs of future small power reactors. However, this reactor concept cannot be classed as "presently offered" or of "proven technology."

Many of the components and systems already developed for conventional pressurized water reactors will be applicable to supercritical fluid reactors. Major development will be required in the areas of collapsed clad fuel and in coolant chemistry. Some development work already has been accomplished in supercritical fluid heat transfer, corrosion studies and fuel development. A supercritical pressure test loop presently is being installed in the experimental pressurized water reactor at Saxton, Pennsylvania. If this program continues, experimental results with supercritical-fluid-cooled fuel operating in a reactor may be available within the next year or two.

4.8 The Closed-Cycle Fast Reactor - Westinghouse

Description

Another reactor concept proposed by Westinghouse for future application in small nuclear power plants is a fast reactor. The median fission energy is 25 kev. This reactor would utilize a supercritical fluid circulated in a closed-loop primary system as the reactor heat removal medium. The supercritical fluid would be D_2O or a mixture of D_2O and H_2O.

A breeding ratio of 1.0 to 1.2 is considered obtainable using uranium dioxide as the nuclear fuel material. This means the reactor would be capable of producing at least as much new fissionable fuel as it burned up. The primary coolant system would operate at a pressure of 3,400 psia. Steam would be supplied to the turbine-generator at 1,200 psia and $640^{o}F$. The thermal rating of the reactor is 230 MWt corresponding to a 75 MWe (net) electrical output.

Evaluation

The closed-cycle fast reactor using a supercritical fluid as the coolant cannot be regarded as being a "presently available" reactor of "proven technology."

The development work required to achieve the status of "proven technology" is even greater than that described above for the direct-cycle thermal spectrum reactor proposed by Westinghouse.

4.9 The Swimming Pool Reactor - American Machine & Foundry

Description

The American Machine & Foundry Company proposed a nuclear power reactor designated as DIPPER. This reactor is similar to that being designed by AMF for the New York State SURFSIDE (Small Unified Reactor Facility With Systems for Isotopes, Desalting and Electricity) project at Riverhead, New York. The reactor is cooled by pressurized water circulated in a closed loop system. The primary coolant loop is maintained at 300 psig. The reactor concept is one which has evolved from the swimming pool research reactors. It is part of a multi-purpose plant which AMF states is capable of water production at 80¢/gal and isotope production at $222,600/year to provide a power cost of 15 mills/kwh. These are AMF figures and no attempt has been made to assess them other than to recognize the ingenuity of attacking the economic problem by producing more marketable products than just electric power.

The AMF reactor is of the pressurized tube type using a two-pass forced circulation core. The nuclear fuel is slightly enriched uranium oxide fuel clad in Zircaloy-2. Each fuel assembly consists of 37 fuel pins arranged in three concentric rings. A barrier tube separates the outer ring from the two inner rings providing the two-pass flow cooling for the reactor core. The thermal power rating of the reactor core is 36 MWt which corresponds to a net electrical power production of 2.5 MWe and one million gallons of desalted water daily. The reactor core is located in a 30 foot deep pool and consists of a matrix of 84 zircaloy pressure tubes arranged on a triangular pitch.

Evaluation

When the construction and successful operation of the prototype SURFSIDE plant at Riverhead, New York is effected, American Machine & Foundry may be prepared to offer to other utilities the major equipment and auxiliaries of the reactor and turbine plant on a firm price basis with warranted performance and delivery. AMF is currently negotiating with the New York State Atomic and Space Development Authority on a fixed price basis for the major equipment and auxiliaries of the reactor and turbine plant.

The DIPPER reactor concept has evolved from swimming pool research reactors which have been built and operated in numerous countries throughout the world. Although no light water cooled and moderated pressure tube reactors have been operated as power producers in the United States, the technology of the proposed DIPPER reactor systems represents a combination of technological features from presently operating reactors. The DIPPER reactor could be regarded as "proven technology" following construction and operation of the SURFSIDE plant as a prototype.

The achievable power production, however, is only 2.5 MWe and in view of this low power output, this reactor has not been considered further in this study.

4.10 The HTGR - General Atomic

Description

The High-Temperature Gas-Cooled Reactor (HTGR) being developed by General Atomic uses pressurized helium to remove heat generated in the reactor core. The nuclear fuel consists of uranium and thorium carbide particles dispersed in a graphite matrix. The cladding is low-permeability graphite.

The helium coolant is circulated in a closed system. Each coolant loop consists of the reactor, steam generator, helium circulator and auxiliaries.

A prototype HTGR has been constructed at Peach Bottom, Pennsylvania on the Philadelphia Electric Company system. Low-power operating tests have recently been completed on this reactor, which is rated at 40 MWe. Startup is expected in 1967.

In the Peach Bottom HTGR, the helium coolant enters the core at 650^{o}F and leaves at $1,380^{o}$F. Steam is produced at 1,450 psig and $1,000^{o}$F, which makes possible higher plant thermal efficiencies.

A 330 MWe (net) HTGR is presently under design for construction on the system of the Public Service Company of Colorado. Startup is scheduled for 1970. The plant will utilize the first pre-stressed concrete reactor pressure vessel in this country.

Evaluation

Until the Peach Bottom HTGR has been successfully operated at design conditions, this reactor type cannot be regarded as being of proven technology.

5.0 PRESENT ENERGY COSTS

5.1 Summary

General

This section presents the power costs that can be expected from small nuclear power plants. These costs have been estimated for the following five cases, which cover three reactor types and three plant sizes;

Type:	PWR-CNSG	OCMR	BWR
Net Electrical Output	25 MWe	50 & 100 MWe	50 & 100 MWe

Neither the OCMR nor the BWR are offered in sizes below 50 MWe; and the PWR-CNSG is not offered above 25 MWe.

Basis for Cost Estimate

The basis for estimating capital and power generation costs for the cases enumerated above is as follows:

1. Data submitted to the AEC by reactor vendors.
2. Further data obtained from the vendors by Kaiser Engineers (KE).
3. Evaluation of this data by KE.
4. Conceptual design layouts and cost estimates by KE.
5. Fuel cycle analysis by KE.
6. Site development costs by KE.
7. Operation and maintenance costs by KE.

The nuclear vendor data has been reviewed, analyzed and augmented, to develop consistent and comparable capital and power generation costs, so that nuclear plants can be compared with each other and with similarly sized conventionally fueled plants.

Summary of Capital and Generating Costs

Table 1 summarizes the capital and power generating costs for the five nuclear plants considered in this study. These are single plants built and operated under existing conditions. The costs are estimated on the basis of the data supplied by the reactor vendors as outlined above and on the basis of the situation depicted in the Ground Rules (see Appendix A). For a better appreciation of the validity of these cost estimates, refer to the next section, entitled, "Accuracy of Cost Estimates."

Table 1 shows four sets of cost figures. Those in the first set, Items 1 through 6, are the capital costs; i.e., the total investment required for the plant. Included are nondepreciating working capital for the fuel, akin to the investment in a coal pile for a coal-fired plant. Excluded are the costs for the main transformer and switchyard (Account 353). The second set of costs, Items 7 through 12, are annual costs consisting of the annualized capital costs, annual fuel cycle costs, annual operation and maintenance and the annual cost of nuclear insurance. It is common practice to group all costs associated with the fuel in one item called fuel cycle costs. Therefore, the annualized capital costs (Items 7 and 8) do not include the nondepreciating capital for the fuel (Item 5) because that cost has been included in "Fuel Cycle Costs" (Item 9). The third set of cost figures in Table 1, Items 13 through 18, is the unit generation cost in mills/kwh for an annual plant capacity factor of 60%. The unit energy cost is shown for each cost element so that the contribution of each cost element to the total unit energy cost can be readily seen. (The terms "unit energy costs" and "unit power generation costs" have the same meaning, viz. the cost per unit of energy generated; i.e., mills/kwh. Both terms are used in this report.)

The fourth set of cost figures shown in Table 1, Items 19, 20 and 21, is the unit power generation cost at 80% plant capacity factors. All unit costs, except the fuel cycle unit cost, are reduced by the ratio of 60/80. The marked decrease in total unit energy costs demonstrates the importance of the plant capacity factor upon power generation costs. The effect of increased plant capacity factor upon fuel inventory has been excluded.

Conclusions

How do the energy costs from small nuclear plants under present conditions--as shown in Table 1--compare with the energy costs from the same size fossil-fueled stations? An accurate comparison requires calculation of energy costs from fossil-fueled plants under ground rules similar to those established for nuclear stations. But this really is not necessary, because of the wealth of published data on the costs and performance of fossil-fueled plants. For the purpose of this study, it is only necessary to have a general indication of whether or not the energy costs estimated for small nuclear plants under present conditions are "good enough" to be able to compete with those from fossil-fueled plants. The conclusion is that the present energy costs from small nuclear plants are not "good enough" to compete; this will be seen below.

It was stated in Section 2.0 that energy costs from small fossil-fueled plants range from approximately 7 to approximately 11 mills/kwh at a plant capacity factor of 60%. A modern, 100 MW gas-fired or oil-fired plant might achieve the 7 mills/kwh energy costs--or even better than that--while a 25 MW coal-fired plant might experience a cost of 11 mills/kwh. The 7 to 11 mills/kwh range appears to be a reasonable yardstick as determined by an examination of cost data reported by the smaller utilities to the Federal Power Commission (Steam-Electric Plant Construction Cost and Annual Production Expenses), by the American Public Power Association (Sixth Survey on Power Costs) and by the Rural Electrification Administration (in a similar annual publication). There will always be special situations--such as a remote location--where the cost of energy from a small fossil-fired plant will be higher than 11 mills/kwh; nevertheless, for this study the 7 to 11 mills/kwh seems to be a fair yardstick against which to measure the estimated energy costs from a nuclear power plant.

Inspection of the unit energy costs from small nuclear plants in Table 1 shows that both the 25 MWe and 50 MWe nuclear plants have energy costs too high to compete with fossil-fueled plants. Even the 100 MWe nuclear plant shows unit energy costs that are not attractive. The difference in power generation costs between the same sized OCMR and BWR are not significant; the cost estimate is not--and cannot be--sufficiently accurate at this time to say definitively that the OCMR exhibits lower costs than the BWR.

Figure 1 in Section 2.0 shows graphically the relation between unit generation costs and plant size. The costs fall into a narrow band rapidly increasing in cost with decreasing plant size and, conversely, decreasing in cost as the plant size increases. This result is not surprising and corresponds with the results of many other studies and actual cost experience with nuclear power stations.

Cost estimates for small nuclear power plants are a somewhat controversial matter, and there may be some disagreement regarding the cost figures shown in Table 1. However, only if and when reactor vendors are given an incentive to make hard money proposals for small nuclear power reactors, together with a firm performance guarantee, and only if and when they are convinced that there really is a market, will refinement of the present estimate be justified In the absence of such hard money proposals, the costs for a significant part of the small nuclear power plants--i.e., the costs of the reactor plant equipment which range from 45% to 50% of the total construction costs--are subject to a large uncertainty.

Despite the foregoing, the power generating costs shown in Table 1 are considered to be realistic under present day conditions. They are not based upon a set of highly favorable assumptions, but upon a realistic assessment of the probabilities of costs. The power generation cost range of the 100 MWe OCMR and BWR is such that an effort to reduce these costs to a range competitive with fossil fuel plants might be successful. This will be analyzed in Section 6.0.

5.2 Accuracy of Cost Estimates

The question inevitably arises: "How accurate are the cost estimates?"

To make a cost estimate for a conventional power plant presents no particular problem to those experienced in power plant engineering and construction. Vendors' equipment prices for a conventional power plant are readily obtainable, and while "bid" prices will always differ from "estimating" prices, the differences are relatively minor and well within the overall accuracy of the total plant cost estimate. It is usually not necessary--though it is always desirable--to have available a fairly detailed plant layout defining the design in specific terms. The cost estimate is derived in the usual manner by obtaining equipment prices and by estimating the cost of buildings and structures and the cost of installing the equipment therein.

The procedure to estimate the capital cost for a nuclear power plant is the same. Again it is necessary to obtain prices from vendors for the equipment to be installed in the nuclear power plant. One obtains costs for a nuclear steam generator and associated equipment, instead of a fuel fired steam generator.

For large nuclear power plants one finds a highly competitive situation among the reactor vendors, and therefore their interest to participate in evaluation studies is high. They will readily furnish good equipment cost data for their scope of supply. This permits the preparation of a good overall cost estimate for large nuclear power plants.

The situation for small nuclear power plants is drastically different. In connection with this study, all reactor manufacturers were contacted and, although they were willing to cooperate in furnishing some data, there was little evidence that they are currently promoting and offering nuclear power plants in the size range considered in this study. It is not surprising that this is so. There is a market for large nuclear power stations, but there seems to be no market for small nuclear power stations. Obviously manufacturers concentrate their efforts in the area of available business and will pay little attention to a market that does not, in fact, exist. The question arises: "Why don't the reactor vendors promote and develop the small nuclear power market?" The reason for this absence of market development becomes apparent when one considers that the profit potential for a small nuclear power plant is considerably less than that for a large nuclear power plant. It requires nearly as many manhours of engineering, nearly as many drawings, nearly as many hours of purchasing, accounting, etc., for a manufacturer to design and supply a 50 MWe reactor as it does a 500 MWe reactor. Since there is a market for 500 MWe reactors but no present market for the 50 MWe reactors, it is understandable that the reactor vendors concentrate their manpower and effort in the large size reactors and do not wish to spend money or manhours in making detailed designs and in careful cost estimates of small nuclear reactors.

It would not be too difficult for others--e.g., an engineer-constructor--to determine what the costs are for a nuclear reactor. Costs, however, are irrelevant, because the estimator is interested not in cost but in the vendor's price. If a competitive situation existed in the small reactor market one would find that reactor vendors would be willing to do the work necessary to make good estimates, that they would be willing to furnish such estimates and, finally that prices would be significantly lower than presently quoted. The effect of such a price reduction upon the total cost of a small nuclear power plant will be evaluated in Section 6.0, "Potential Cost Reductions." This effect could be substantial, considering that Account 322, "Reactor Plant Equipment," comprises about 45% of the total direct construction costs for nuclear plants in the 50 to 100 MWe (net) range.

The cost figures supplied by the vendors have been analyzed as carefully as possible to ensure that they cover a complete scope of supply. Whenever such scope of supply was not complete the prices for the missing elements were estimated and added to Account 322, "Reactor Plant Equipment."

The rest of the plant was estimated in the conventional manner, and the resultant cost estimate is the best that can be provided based on the limited information available. Nevertheless, it is felt that the cost figures in Table 1 are reasonable and reflect fairly accurately the costs that may be expected under present conditions for a smaller nuclear power plant.

5.3 Plant Design

General

With one important difference, the plant designs used as bases for the capital cost estimates are generally those presented by the respective nuclear vendors. The difference consists of segregating the entire station into two parts, viz:

Nuclear Island

Other Plant

In brief, the "nuclear island" consists of the reactor plant, radioactive waste disposal building and contaminated storage vault; the "other plant" consists of the turbine building, and all other plant facilities. Within the nuclear island are those facilities and equipment items that are essential to a particular reactor; those that are common to any reactor (i.e., change rooms, counting rooms, hot laboratory, etc.) have been removed from the nuclear island and incorporated in the turbine plant. This procedure isolates all costs that arise from using a particular reactor and groups them in the nuclear island. Thus, changes in cost due to changes in location or in design or in choice of the reactor plant, etc., are correctly charged against the proper time, and the effect of such changes can readily be seen in the capital cost estimate. It should be noted that there is a difference between nuclear island and Account 322, "Reactor Plant Equipment." A review of the Uniform System of Accounts (see Appendix B) will make the difference clear.

One advantage of the separation into nuclear island and other plant is that it pinpoints the major differences between various types of nuclear stations. These differences are, of course, in the reactor part of the plant. This separation also has the advantage that during the procurement of a nuclear reactor power plant the utility and its architect-engineer-constructor can contract separately for the nuclear island, thus obtaining economies in equipment procurement. This is similar to the present practice in obtaining equipment for a fossil-fueled power plant in which the "boiler" is obtained from one manufacturer, the turbine-generator is obtained from another, and other equipment items are obtained from further manufacturers. Economies result from this separation because of increased competition for each portion of the reactor power plant equipment.

The Nuclear Island

1. General

The nuclear island is that portion of a nuclear reactor power plant located within the containment building and the containment building itself; it includes the nuclear reactor control panel located in the main control room and the radioactive waste treatment and disposal facilities unique to a particular nuclear reactor. The nuclear island delivers steam to the turbine plant and receives back from it the cooled and conditioned feedwater.

2. Containment Structure

The reactor plant equipment is located within a containment building. The purpose of this containment building is to enclose and contain any radioactive material releases that might take place as the result of an accident. During normal operation, ventilation air and other exhaust streams are constantly monitored for radioactivity so that such flows may be stopped and contained if the radioactivity level exceeds permissible limits. The containment building for the OCMR is a cylindrical steel shell with a hemispherical head. Its design pressure is usually established by the pressure that could conceivably result from the maximum credible accident as determined during the safeguards analysis. The PWR-CNSG and the BWR reactor plants have pressure suppression equipment within the containment building in order to reduce the maximum possible pressure resulting from an accident; therefore, a small, lower pressure, noncirculating containment building is sufficient.

3. Reactor Plant Equipment

The equipment and facilities located within the containment building of a typical nuclear reactor plant are listed below. There are differences in plant equipment between an indirect cycle reactor plant, such as a PWR or OCMR, and a direct cycle plant, such as BWR, and these will be pointed out when applicable.

a. Reactor Pressure Vessel and Internals

The reactor pressure vessel contains the reactor core structure and fuel elements. It is usually located near the center of the containment building and is surrounded by the necessary shielding. The vessel is typically a steel cylinder with hemispherical top and bottom heads. The top head of the reactor vessel is usually bolted on; thus, it is removable to permit the installation of internals during construction and the insertion and removal of fuel elements during the lifetime of the reactor. The reactor vessel has large nozzles providing paths for the entry and discharge of the reactor coolant fluid. Other smaller nozzles are utilized for the penetration of control rod drives and certain reactor instrumentation devices.

b. Steam Generator

In the indirect cycle OCMR reactor plant the steam generator and superheater are located within the containment building. In the PWR-CNSG reactor design the steam generator is combined with the reactor vessel thus eliminating the external primary coolant piping. Steam generators are usually shell and tube heat exchangers of a conventional design but are specially designed to minimize leakage between the shell and tube sides. In the direct cycle BWR reactor the steam generator is not necessary, because the steam produced in the reactor core passes directly from the reactor pressure vessel through the containment building wall to the turbine generator.

c. Reactor Coolant Circulators

Pumps or blowers circulate the reactor coolant fluid through the reactor vessel and steam generators. These circulators are usually located on the reactor inlet lines to accommodate the cooled fluid returned from the steam generators.

d. Control Rods and Drives

Control rods containing a nuclear poison are located in the reactor core for both control and safety shutdown functions. These rods, which may take the form of long cylinders, crosses, or other shapes, are driven by control rod drive devices mounted on the reactor vessel. Control rod drives are usually removable from the reactor vessel as units, to facilitate their periodic inspection and maintenance. For reasons of safety, control rod drives are designed to use either the force of gravity or a stored energy source to insert the control rods during an emergency shutdown.

e. Auxiliary Reactor System

Auxiliary reactor systems depend to a certain extent upon the particular reactor type. Reactors will usually have, however, a coolant fluid purification system in order to maintain the integrity and purity of the fluid in contact with the fuel elements. Because the reactor coolant fluid will contain a certain amount of radioactivity, this equipment is normally located within the containment building. The direct cycle

BWR is again an exception, since part of the coolant purification equipment, a full flow demineralizer, is located outside the containment building; there is also a demineralizer in the containment building that processes a side stream from the reactor vessel. Unless the reactor cooling circuit possesses some inherent capability of removing heat after shutdown, special equipment for this purpose is usually provided within the containment building. Auxiliary shutdown and reactivity control devices supplement the control rods. For the PWR-CNSG they can take the form of a system which increases or decreases the concentration of a boric acid nuclear "poison" in the reactor coolant water.

f. Fuel Handling and Storage Facilities

Facilities are required within the containment building to place the fuel elements in the reactor, to remove the spent fuel elements from the core during shutdown periods, and to store the radioactive spent fuel elements in a shielded environment until they can be packaged and removed from the plant area. While these facilities will vary from reactor to reactor, they typically consist of crane and handling devices to handle the fuel elements through the open top head of the reactor vessel during the shutdown period, and a fuel storage rack located in a water-filled canal to provide the necessary shielding.

4. Reactor Control Equipment

The remote instrumentation and control devices for the nuclear island are normally located in the plant main control room. Because this main control room is not located within the containment building, it is wholly accessible after an accident. The typical instrumentation and control systems are as follows:

a. Reactor Plant Control

This control system determines the location of the control rods in the core, in relation to the required plant power level and plant process conditions.

b. Safety System

The safety system typically is separate and distinct from the plant control system, to ensure the reliability of signals that might indicate the plant was approaching an unsafe condition. The safety system initiates the emergency shutdown of the reactor, which will occur on signals indicating high power levels, high temperature levels, insufficient flow, and other indications of possible trouble.

c. Radiation Monitoring System

Throughout the containment building and in certain locations throughout the plant, radiation monitors transmit information to the main control room concerning radiation levels in those areas. Sometimes, signals from radiation monitors located in the plant stack are used to close the containment building.

5. Radioactive Waste Disposal

Radioactive waste disposal facilities of a nuclear power plant consist of equipment to handle solid, liquid and gaseous wastes. The means of disposal depends, to a certain extent, on the specific reactor site. The gaseous wastes normally would be discharged up the plant stack after they have been monitored for radioactivity. The liquid radioactive wastes would be monitored in hold-up tanks, treated or segregated as necessary and disposed of in a manner appropriate to their radioactive content. The sources of radioactive waste effluents are primarily from the containment building; however, in a direct cycle plant such as the BWR, there will be radioactive wastes from the air ejector and the water purification plant located in the turbine plant.

Other Plant

1. General

This portion of a nuclear power plant consists of all the parts of the complete power plant installation not included in the nuclear island. To a major extent, the equipment and layout in this portion of the plant can be similar to that utilized for a fossil-fueled power plant of the same size and location. Therefore equipment designs and layouts can be used that are familiar to the user and which have performed satisfactorily for him in previous plants.

Brief discussions of the components of the turbine plant are given below, together with comments on specific items not normally included or whose design may differ somewhat from that in a conventional plant.

2. Turbine-Generator, Condenser and Auxiliaries

This equipment is similar to that in a conventional plant with the same process conditions, except that control of the turbine generator may have to be a function of reactor steam pressure rather than system frequency. Also, the turbines for the BWR and the PWR-CNSG operate with steam that is either not superheated or is only slightly superheated. Therefore, this equipment is somewhat different--and more expensive--than those used in modern fossil-fueled plants. Moisture separation devices between the high and low pressure stages of the turbine prevent excessive moisture.

For a direct cycle BWR, radioactive steam from the core is supplied directly to the turbine, and thus the turbine and condenser have to be shielded. Provisions also have to be made to dispose of radioactive effluent from the air ejector.

3. Circulating Water Pumps

The circulating water pumps providing cooling water to the condenser can be similar to those in a fossil-fueled plant of the same size and location. However, since the nuclear reactor plant will have a lower thermal efficiency than a modern fossil-fueled plant with the same net electrical output, the reactor plant will discharge more heat to the heat sink. Therefore, the plant cooling system (condenser, circulating water pumps and lines, and the cooling towers) will have to be somewhat larger than for a fossil-fueled station.

4. Electric Systems

The plant electrical systems can be similar to those of a fossil-fueled plant except that an additional degree of reliability is usually required for reactor plants. Two incoming power lines, and emergency on-site power generation by diesel generators are commonly used. Specific power reliability requirements depend to a certain extent on the reactor type. The electrical power for the instrumentation systems (reactor control and safety systems) can be obtained from a "failure-free" power system utilizing batteries and motor-generator sets.

5. Turbine Building and Main Control Room

There are no particular differences in the requirements for these buildings, between a fossil-fueled plant and a reactor power plant.

6. Water Treatment

Except for the direct cycle BWR, the water treatment requirements for the feedwater can be similar to those utilized in a fossil-fueled plant. A full-flow demineralizer is one of the methods utilized to maintain the purity of this water.

7. Miscellaneous Power Plant Equipment

The equipment supplying a power plant with such services as compressed air, communications system, and fire alarm system can be similar to those in a fossil-fueled plant except that in certain instances additional reliability will be required of the services. For instance, additional reliability may have to be built into the compressed air system in order to ensure a supply of compressed air after plant shutdown or failure of the electrical power source.

8. Fuel Storage

One of the major differences between nuclear and fossil power plants is that of the fuel storage requirements. The only fossil fuel burned in a nuclear power plant would be the fuel for the emergency diesel-generator. A storage tank for diesel fuel or a connection to a supply of natural gas is required for this purpose. New nuclear fuel elements are stored in a secured room either outside or inside the containment building, prior to installation in the reactor.

9. Miscellaneous "Nuclear" Facilities

Certain auxiliary facilities which are common to any nuclear power plant, such as a counting room, change rooms and a small "hot" laboratory are included in this portion of the power plant.

Concept Drawings

1. General

It is usually desirable for purposes of estimating the cost of a power plant, to prepare general arrangement and layout drawings. The greater the detail of these drawings, the greater the accuracy of the cost estimate. It has been pointed out under "Accuracy of Cost Estimates" that nearly 50% of the total plant construction cost is in Account 322, "Reactor Plant Equipment," and that the cost data supplied by the reactor vendors are not in themselves based upon a detailed design. This leads to the conclusion that it is unnecessary to prepare extensive and detailed plant arrangement drawings for this study. While such drawings would permit a fairly accurate cost estimate for the "Other Plant," such accuracy is not warranted due to the lack of accuracy for the cost of the "Nuclear Island." It follows, therefore, that for the purposes of this study, concept drawings should be prepared portraying adequately the general plant configuration, but avoiding unnecessary detail. Moreover, the "Ground Rules" (see Appendix A) define clearly the specific conditions.

For these reasons it was deemed adequate to prepare one plot plan drawing and one turbine plant drawing, typical for any one of the five plants investigated in this study. Differences in sizes between the five plants can be--and have been--accounted for in the construction cost estimate. Similarly, for the nuclear island one drawing each was prepared for the three reactor types; the PWR, the OCMR, and the BWR. Cost differences arising from differences in plant capacity were allowed for in the construction cost estimates.

The following drawings present the conceptual design of the small nuclear power plants for this study:

Drawing No.	Title
201A	Plot Plan
202A	Turbine Plant
203A	25 MWe PWR-CNSG Nuclear Island
204A	50 MWe BWR Nuclear Island
205A	100 MWe OCMR Nuclear Island

2. Plot Plan

The Plot Plan was laid out for a 50 MWe nuclear station, but the arrangement is sufficiently general to be used for the 25 MWe and the 100 MWe stations as well.

3. Turbine Plant

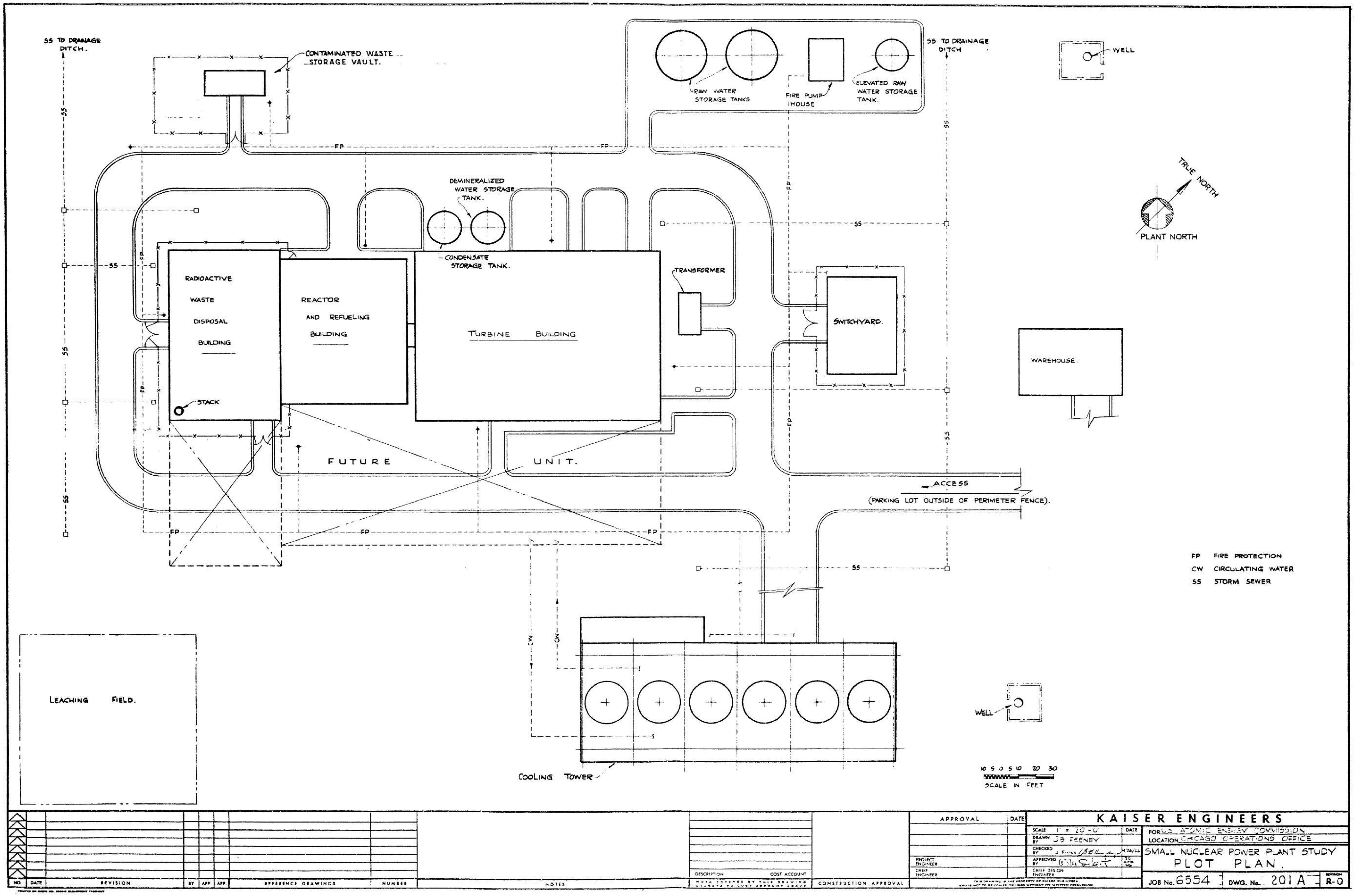
The Turbine Plant also was arranged for a 50 MWe station, but it has been generously sized so that it could also serve for a 100 MWe turbine plant. As shown, it serves a BWR reactor plant; i.e., the turbine is a saturated steam machine, and the extraction cycle has two heaters. The same plant could be used for the 100 MWe OCMR, which uses a standard turbine-generator with a 4-heater extraction cycle. For the PWR-CNSG and the OCMR, shielding would not be required in the turbine plant.

4. The 25 MWe PWR-CNSG

The nuclear island for the 25 MWe PWR Consolidated Nuclear Steam Generator is based upon a design prepared by the Babcock & Wilcox Company and submitted to Kaiser Engineers on March 13, 1964, in connection with studies of nuclear power applications made by KE for the U. S. Navy Bureau of Yards and Docks. The CNSG is a result of the N. S. Savannah experience and was originally developed as a marine nuclear power plant. It is also adaptable to small land-based nuclear power plants. Verbal permission has been received from B&W to use the data and to base the design of the nuclear island upon B&W Drawing 10129F.

5. The OCMR

The nuclear island for the 100 MWe OCMR is based upon Figures 2 and 3 in Atomics International "Letter No. 65AT6831" submitted to the AEC Chicago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CONTAMINATED WASTE STORAGE VAULT.
RAW WATER STORAGE TANKS
FIRE PUMP HOUSE
ELEVATED RAW WATER STORAGE TANK.
SS TO DRAINAGE DITCH
WELL
TRUE NORTH
PLANT NORTH
DEMINERALIZED WATER STORAGE TANK.
CONDENSATE STORAGE TANK.
RADIOACTIVE WASTE DISPOSAL BUILDING
REACTOR AND REFUELING BUILDING
TURBINE BUILDING
TRANSFORMER
SWITCHYARD.
WAREHOUSE.
STACK
FUTURE UNIT.
ACCESS
(PARKING LOT OUTSIDE OF PERIMETER FENCE).
FP FIRE PROTECTION
CW CIRCULATING WATER
SS STORM SEWER
LEACHING FIELD.
WELL
COOLING TOWER
10 5 0 5 10 20 30
SCALE IN FEET
APPROVAL
DATE
PROJECT ENGINEER
CHIEF ENGINEER
KAISER ENGINEERS
SCALE 1" = 20'-0"
DRAWN BY JB FEENEY
CHECKED BY
APPROVED BY
CHIEF DESIGN ENGINEER
FOR US ATOMIC ENERGY COMMISSION
LOCATION CHICAGO OPERATIONS OFFICE
SMALL NUCLEAR POWER PLANT STUDY
PLOT PLAN.
JOB No. 6554
DWG. No. 201 A
REVISION R-0
NO. DATE REVISION BY APP. APP.
REFERENCE DRAWINGS NUMBER
NOTES
DESCRIPTION COST ACCOUNT
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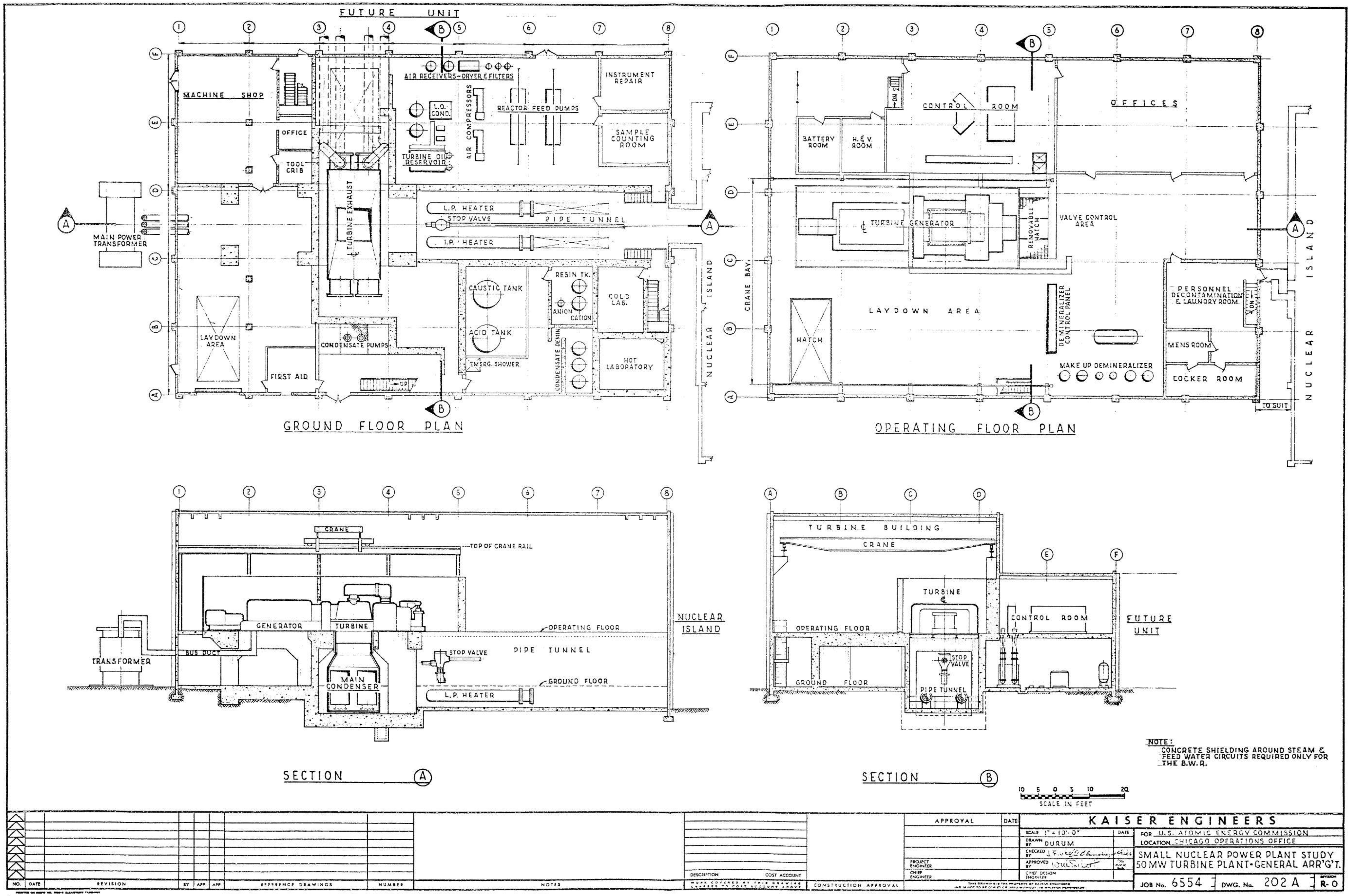
THIS DRAWING IS THE PROPERTY OF KAISER ENGINEERS AND IS NOT TO BE COPIED OR USED WITHOUT ITS WRITTEN PERMISSION


FUTURE UNIT
MACHINE SHOP
OFFICE
TOOL CRIB
AIR RECEIVERS - DRYER & FILTERS
L.O. COND.
AIR COMPRESSORS
REACTOR FEED PUMPS
TURBINE OIL RESERVOIR
INSTRUMENT REPAIR
SAMPLE COUNTING ROOM
MAIN POWER TRANSFORMER
TURBINE EXHAUST
L.P. HEATER
STOP VALVE
PIPE TUNNEL
I.P. HEATER
CAUSTIC TANK
ACID TANK
RESIN TK.
ANION
CATION
COLD LAB.
HOT LABORATORY
CONDENSATE DEMIN.
EMERG. SHOWER
LAYDOWN AREA
CONDENSATE PUMPS
FIRST AID
NUCLEAR ISLAND
GROUND FLOOR PLAN
CONTROL ROOM
OFFICES
BATTERY ROOM
H. & V. ROOM
TURBINE GENERATOR
REMOVABLE HATCH
VALVE CONTROL AREA
CRANE BAY
HATCH
LAYDOWN AREA
DEMINERALIZER CONTROL PANEL
PERSONNEL DECONTAMINATION & LAUNDRY ROOM
MENS ROOM
MAKE UP DEMINERALIZER
LOCKER ROOM
TO SUIT
OPERATING FLOOR PLAN
CRANE
TOP OF CRANE RAIL
GENERATOR
TURBINE
OPERATING FLOOR
NUCLEAR ISLAND
TRANSFORMER
BUS DUCT
STOP VALVE
PIPE TUNNEL
MAIN CONDENSER
GROUND FLOOR
L.P. HEATER
SECTION A
TURBINE BUILDING
CRANE
TURBINE
OPERATING FLOOR
CONTROL ROOM
FUTURE UNIT
STOP VALVE
GROUND FLOOR
PIPE TUNNEL
SECTION B
NOTE: CONCRETE SHIELDING AROUND STEAM & FEED WATER CIRCUITS REQUIRED ONLY FOR THE B.W.R.
10 5 0 5 10 20
SCALE IN FEET
KAISER ENGINEERS
FOR U.S. ATOMIC ENERGY COMMISSION
LOCATION CHICAGO OPERATIONS OFFICE
SCALE 1" = 10'-0"
DRAWN BY DURUM
SMALL NUCLEAR POWER PLANT STUDY
50 MW TURBINE PLANT - GENERAL ARR'G'T.
JOB No. 6554
DWG. No. 202 A
R-0
APPROVAL
DATE
PROJECT ENGINEER
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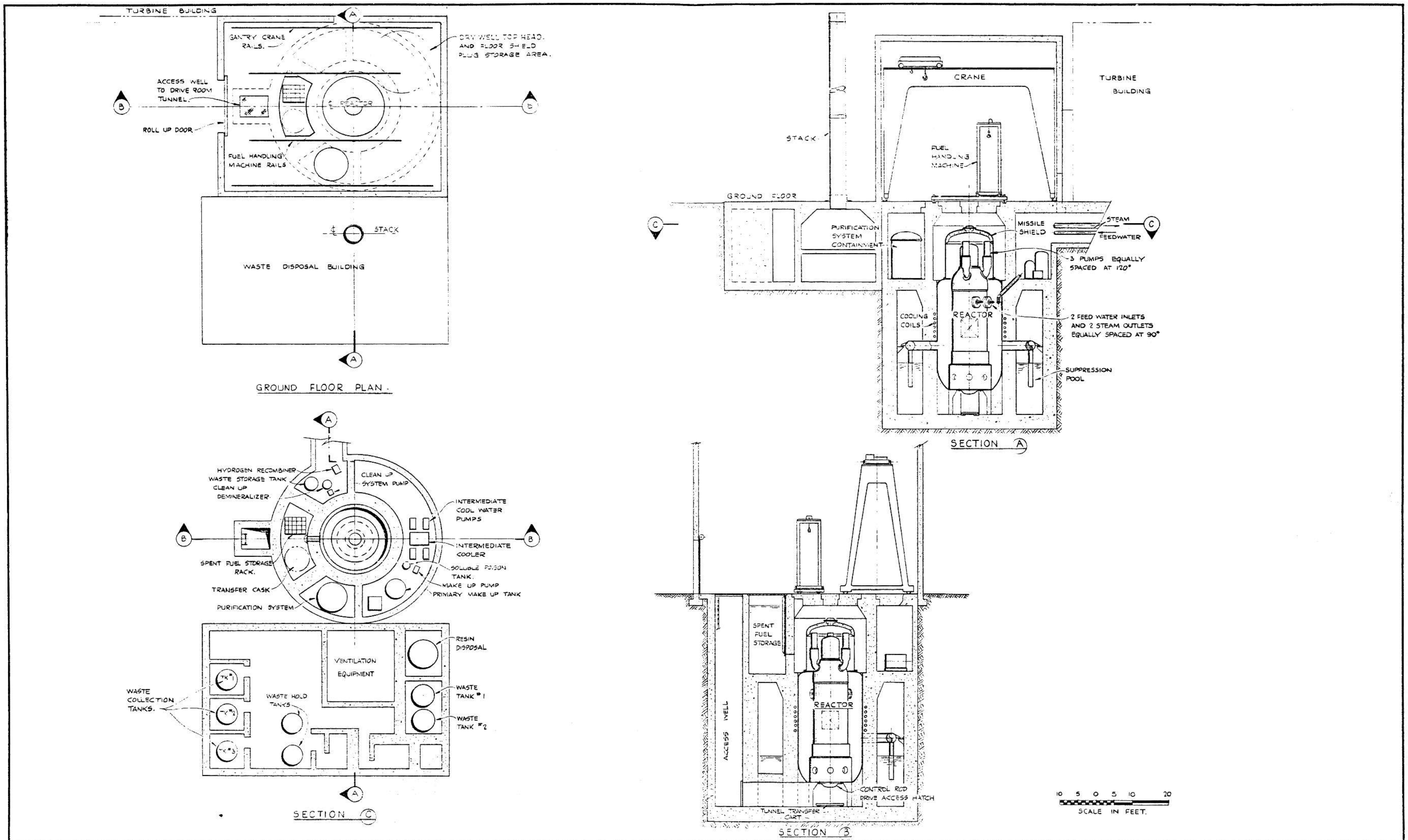

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CHIEF ENGINEER	

KAISER ENGINEERS

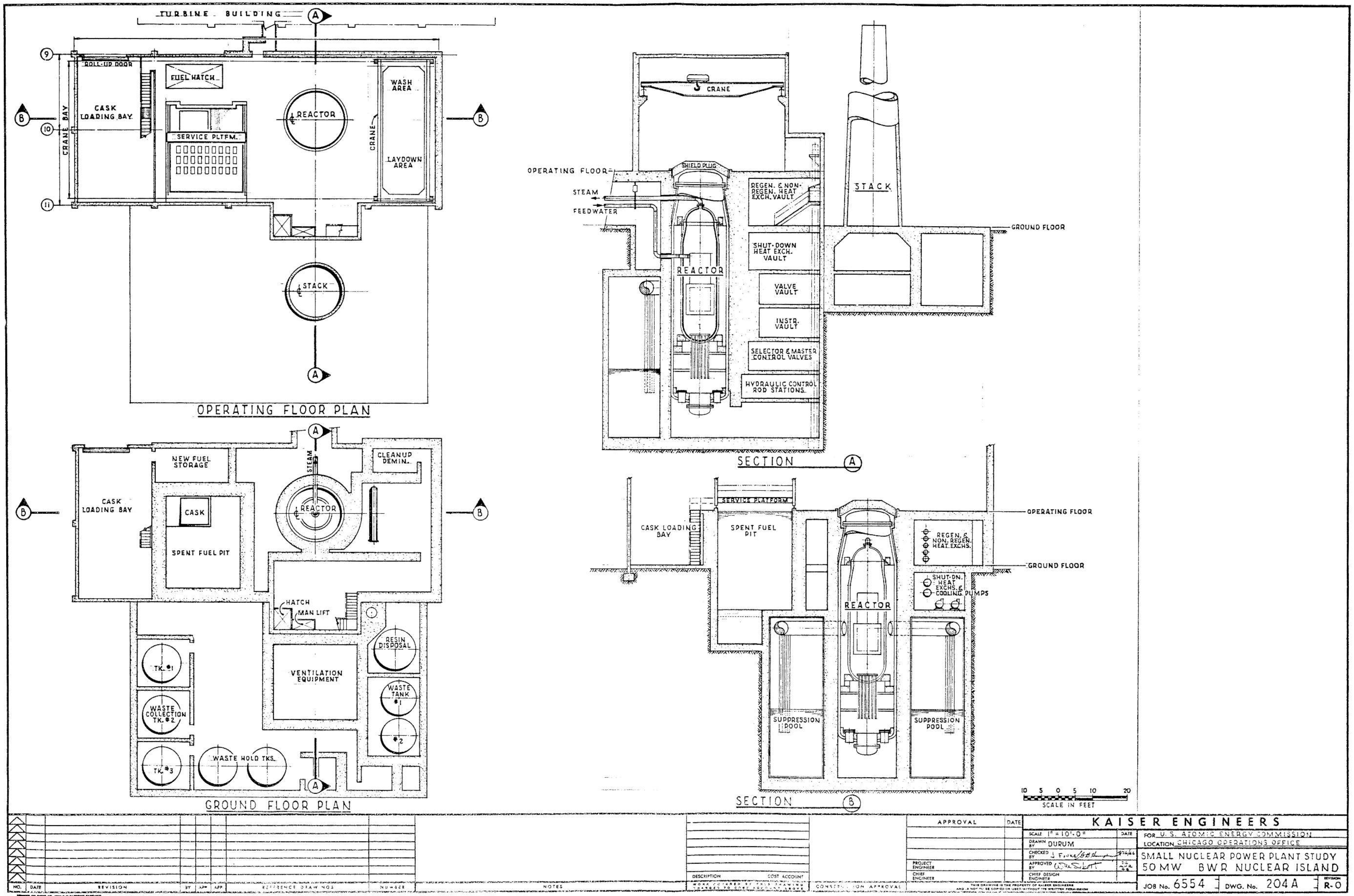
SCALE	1" = 10'.0"	DATE
DRAWN BY	J.B. FEENEY.	
CHECKED BY	J. F...e/S.H. ...	
APPROVED BY	...	
CHIEF DESIGN ENGINEER		

FOR U.S. ATOMIC ENERGY COMMISSION
LOCATION CHICAGO OPERATIONS OFFICE

SMALL NUCLEAR POWER PLANT STUDY
25MW PWR NUCLEAR ISLAND

JOB No. 6554 | DWG. No. 203 A | REVISION R-0

NO. | DATE | REVISION | BY | APP. | APP. | REFERENCE DRAWINGS | NUMBER | NOTES | DESCRIPTION | COST ACCOUNT | CONSTRUCTION APPROVAL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ROLL-UP DOOR
FUEL HATCH
CASK LOADING BAY
CRANE BAY
SERVICE PLTFM.
REACTOR
CRANE
WASH AREA
LAYDOWN AREA
STACK
OPERATING FLOOR PLAN
NEW FUEL STORAGE
STEAM
CLEANUP DEMIN.
CASK
SPENT FUEL PIT
HATCH
MAN LIFT
RESIN DISPOSAL
VENTILATION EQUIPMENT
TK. #1
WASTE COLLECTION TK. #2
TK. #3
WASTE HOLD TKS.
WASTE TANK #1
#2
GROUND FLOOR PLAN
OPERATING FLOOR
FEEDWATER
SHIELD PLUG
REGEN. & NON-REGEN. HEAT EXCH. VAULT
SHUT-DOWN HEAT EXCH. VAULT
VALVE VAULT
INSTR. VAULT
SELECTOR & MASTER CONTROL VALVES
HYDRAULIC CONTROL ROD STATIONS
GROUND FLOOR
SECTION A
SERVICE PLATFORM
REGEN. & NON. REGEN. HEAT EXCHS.
SHUT-DN. HEAT EXCHS. & COOLING PUMPS
SUPPRESSION POOL
SECTION B
10 5 0 5 10 20
SCALE IN FEET
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FOR U. S. ATOMIC ENERGY COMMISSION
LOCATION CHICAGO OPERATIONS OFFICE
SMALL NUCLEAR POWER PLANT STUDY
50 MW BWR NUCLEAR ISLAND
JOB No. 6554
DWG. No. 204 A
REVISION R-0
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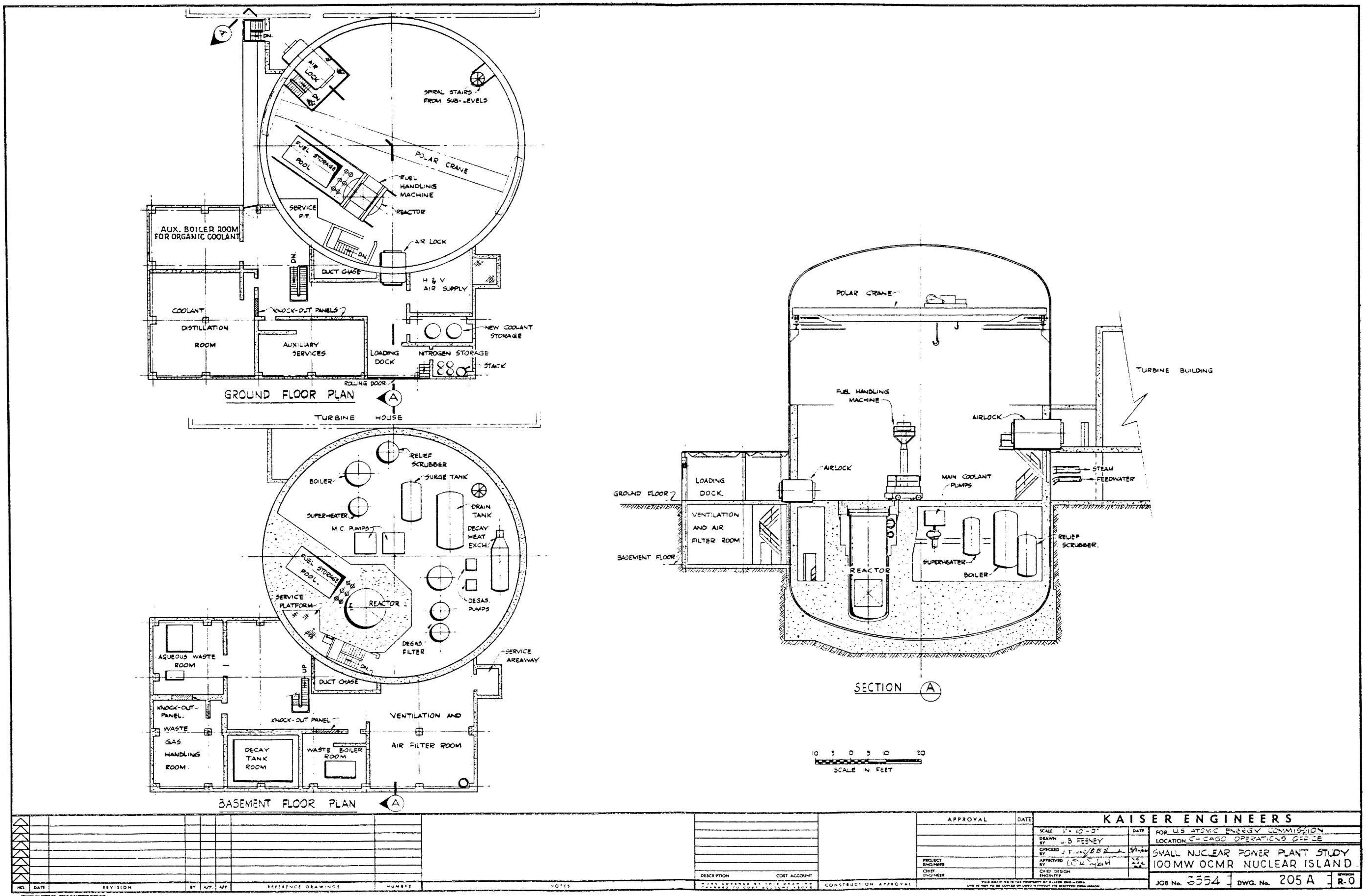
AIR LOCK
SPIRAL STAIRS FROM SUB-LEVELS
POLAR CRANE
FUEL STORAGE POOL
FUEL HANDLING MACHINE
REACTOR
SERVICE PIT
AUX. BOILER ROOM FOR ORGANIC COOLANT
DUCT CHASE
H & V AIR SUPPLY
COOLANT DISTILLATION ROOM
KNOCK-OUT PANELS
AUXILIARY SERVICES
NEW COOLANT STORAGE
LOADING DOCK
NITROGEN STORAGE
STACK
ROLLING DOOR
GROUND FLOOR PLAN
TURBINE HOUSE
RELIEF SCRUBBER
SURGE TANK
BOILER
SUPER-HEATER
M.C. PUMPS
DRAIN TANK
DECAY HEAT EXCH.
SERVICE PLATFORM
DEGAS PUMPS
DEGAS FILTER
SERVICE AREAWAY
AQUEOUS WASTE ROOM
KNOCK-OUT PANEL
WASTE GAS HANDLING ROOM
DECAY TANK ROOM
WASTE BOILER ROOM
VENTILATION AND AIR FILTER ROOM
BASEMENT FLOOR PLAN
TURBINE BUILDING
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FOR U.S ATOMIC ENERGY COMMISSION
LOCATION CHICAGO OPERATIONS OFFICE
SMALL NUCLEAR POWER PLANT STUDY
100 MW OCMR NUCLEAR ISLAND
JOB No. 3554
DWG. No. 205 A
R-0

Operations Office. The layout was somewhat changed by relocating in the turbine plant those features that need not be located in the nuclear island.

6. The BWR

The nuclear island for the 50 MWe BWR is based upon the 50 MWe BWR Humboldt Bay design, but modified to reflect some changes that appeared desirable from actual operating experience.

5.4 Cost Estimates

General

The objective of the cost estimates in this study is to identify all cost components and elements, and to produce two sets of cost figures upon which a meaningful comparison among alternative plans can be made. First, one needs to know the total capital required for a particular plant. Second, one needs to know the unit cost of power generation from that plant in mills/kwh.

Generally, when an electric utility begins long range plans for expansion of generating facilities, several alternative sites are available, the level of current equipment prices and labor costs are known, and the levels of future labor costs can be estimated with fair accuracy. Moreover, load projections are also available, and therefore the expected annual energy production from the proposed new power plant can be forecasted for the ensuing ten years.

In the absence of such specific data in this study, the simplifying assumption was made that the annual energy production from the new nuclear plant will be the same in each of the ten years following start-up. This assumption introduced a small negative bias, since in reality the annual energy send-out from a new plant in a small electric system is likely to increase. (This may not be true for a large system where the newest plant would be base loaded at 90% plant factor for the initial years.) Similarly, no allowance was made in this study for an increase in operating and maintenance costs over the 10-year period considered in this study. In the case of fuel cycle costs, however, the cost calculations took into account the variations arising from "batches" and hence varying annual fuel cycle costs were obtained.

The Cost Structure

A standard method was followed to determine the unit cost of generation of electrical energy for each plant. Basically it consisted of an estimate of the required capital investment, the application of a fixed charge rate to that capital to annualize the investment, an estimate of annual operation, maintenance, fuel cycle and nuclear insurance costs, and dividing the sum of all annual costs by the estimated annual net energy send-out. The resulting unit power generation cost in mills/kwh serves as a yardstick to measure the economic merit of each of the various power plants. Table 1 (presented in the Summary at the beginning of this section) shows the cost structure as described above.

In order to facilitate an assessment of the potential cost reductions (see Section 6.0), the cost structure was arranged to permit modification of those cost elements considered to be susceptible to reductions.

Construction Cost Estimate

1. Uniform System of Accounts

The first step in the cost structure was the establishment of a construction cost estimate in general in accordance with the FPC classification of accounts per AEC's TID-8531, "Costs of Nuclear Power," with certain groupings to eliminate unnecessary detail. An itemized "Classification of Accounts" is provided in Appendix B. The construction cost estimate covers the following accounts:

321	Structures and Improvements
322	Reactor Plant Equipment
323	Turbine Generator Unit
324	Accessory Electrical Equipment
325	Miscellaneous Power Plant Equipment
398	Contractor's Distributable Field Costs

The sum of these costs is the Direct Construction Cost; i.e., the amount of money payable to the contractor(s) for furnishing and installing all items and facilities. Nuclear engineering is included in Account 322.

2. Basic Premises

In order to maintain as much consistency as possible, the following basic premises were used:

a. Plant construction will start in 1967 and the plant will begin commercial operation on January 1, 1970.

b. Capital costs include all equipment up to the low voltage side of the step-up transformer.

c. Construction costs for the main transformer and switchyard are excluded.

d. The costs of initial surveys to establish background radiation of air, water and vegetation in vicinity of site are included in construction costs. The cost of subsequent surveys during plant operation are included in operating costs.

e. Spare parts of warehouse type are not shown as a separate item because they are included in the provision for working capital.

f. The costs of steam piping including main and auxiliary steam piping (e.g., the steam piping from the reactor to the turbine and turbine extraction lines, etc.) all condensate piping, feedwater piping, drain and vent piping, etc., are reported under cost account No. 322.7.

g. Cost account No. 321.9 is used for the reactor containment structure.

h. Indirect construction costs and other indirect costs were computed as a fixed percentage of the sum of direct construction costs. In determining these percentages, the cost of land and land rights was not included as a direct construction cost.

3. Nuclear Engineering

Nuclear engineering and design will be provided by the reactor vendor; it is included in the Reactor Plant Equipment in Account No. 322.8. Nuclear engineering includes core physics analyses, reactor systems design, instruction books, operation and maintenance manuals, review and comments on safeguards information, assistance and information on permits and licenses, and a training program for owner operating personnel. The vendor's cost of the training program includes the furnishing of instructors, classrooms and training facilities, but excludes the cost of the living expenses, travel, etc., for the owner's personnel being trained. The latter costs are included under "Owner's Costs."

4. Nuclear Island and Other Plant

It may be of interest to permit comparison of the effect upon unit power generation costs arising from different types of reactors. Therefore, the concept of the "nuclear island" was followed and the costs associated with or due to the reactor were grouped under the nuclear island. It should be noted that all items except piping in Account No. 322, "Reactor Plant Equipment," are entirely a part of the nuclear island. Of the piping (Account No. 322.7) approximately 20% is deemed to be a part of the nuclear island. All of the reactor building, all of the radioactive waste building, 50% of the accessory electrical equipment (Account No. 324) and 50% of the communications equipment (Account No. 325.3) are also considered part of the nuclear island. In the absence of detailed design drawings an exact grouping cannot be made; therefore, the costs of the nuclear island derived in this cost analysis are approximate only. Reference to the classification of accounts in Appendix B will show the specific items deemed to be in the nuclear island. Table 2, "Construction Cost Estimate," also shows the percentage of each major subaccount deemed to be a part of the nuclear island.

The nuclear island concept does not, however, account for all cost differences arising from different reactors. Some of these costs show up in other accounts. For example, the BWR uses a higher priced saturated steam turbine than the standard machine used for the OCMR. The BWR power plant uses two feedwater heaters; the OCMR uses four. The cost differences--which are due to the differences in the reactor type--show up in Account No. 323, "Turbine-Generator Unit."

As a general approach, the nuclear island includes the nuclear boiler (or nuclear steam supply system), plus the containment structure and treatment facilities, all reactor auxiliaries and safeguards systems, nuclear and safety instrumentation and associated control cabinets and consoles, procéss instrumentation associated with the reactor and its auxiliaries, the reactor building, all plant radiation monitors, electrical power supply for the reactor systems, and all reactor building support equipment and systems such as building cranes, lighting, and utility systems within the reactor building, and the radioactive waste treatment building and storage vault.

Those facilities not included in the nuclear island are the turbine-generator, exciter, condenser, feedwater heaters, condensate and feedwater pumps, power plant auxiliaries, circulating water system, compressed air supply, raw water and demineralizer water supply, electric power supply and distribution (including emergency power) external to the reactor building, the radioactive waste disposal building, and all plant buildings, structures and improvements excluding the reactor building and the radioactive waste disposal building and storage vault. These plant buildings, structures and improvements normally include the turbine-generator building, an office building if separate, the control room, cooling towers, roads, parking, fencing, sanitary sewage treatment facilities, shops and a warehouse.

5. Construction Cost Estimate

The construction cost estimates for the five nuclear power plants are shown in Table 2. For convenience, the costs of Land and Land Rights (Account No. 320) are also shown, but are not included in the total construction costs summarized on Sheet 4 of the table.

Owner's Costs

1. General

"Owner's Costs" are grouped in Account No. 399 and consist of those costs that are neither direct construction costs, nor considered part of the Architect-Engineer's costs.

2. Interest During Design and Construction

Account No. 399.1 covers the net cost of funds (other than fuel purchase) used for the project. The net cost is the capitalized value of the interest payments during the project period. For the construction of a single plant, or the first of a series of "identical" plants, the total estimated project duration for design and construction is assumed to be 40 months. For a typical municipally owned utility, an interest rate of 3.74% per year is assumed for revenue bonds (see "Financing" in this section). Based on a normal rate of expenditure for design and construction, the total net payment for interest during the design and construction period is 5.5% of the sum of the construction and Architect-Engineer's costs. It is assumed that payback of principal is deferred until the start of the second year of plant operation.

The total design and construction period of 40 months is used for all three plant ratings (25, 50 and 100 MWe). It includes the total elapsed time from project inception until achievement of full-power operation. This design and construction period is applicable to presently available nuclear power plants.

3. Procurement, Accounting and Administrative Costs

These are included in Owner's cost account number 399.2, and cover general administration, accounting, purchasing, and other related activities of the owner in connection with the construction project.

4. Owner's Liaison Engineering Costs

As a general rule, the owner will utilize his engineering staff in a liaison and/or a supervising capacity during the design and construction of the power plant. These costs are accounted for in Account No. 399.3.

5. Safeguards Report and Licensing Costs

Account No. 399.4 covers all owner costs of preparing (or having prepared) the Safety Analysis Report (SAR) and submitting it to the ACRS, and all other costs required to obtain construction permits and operating licenses.

6. Operator Training Costs

Account No. 399.5 covers all owner costs of training operating personnel prior to the start-up period. This item includes the salaries and expenses of owner's personnel assigned primarily for training purposes to other installations prior to start-up. An estimate of these costs is shown in Table 3.

7. Start-Up Costs

The net start-up costs for a nuclear power plant were estimated at 35% of the annual operating and maintenance costs, including supplies but excluding fuel costs. This is shown in Account No. 399.6.

8. Cost of Efficiency and Capability Tests

Subsequent to start-up but prior to commercial operation, the plant will be tested for overall efficiency and maximum capability. The net cost to the owner for these tests; i.e., total cost less credit for power sold, is assumed to be 20% of the start-up costs, and is shown in Account No. 399.7.

9. Other Costs

Other owner costs not covered elsewhere are included in Account No. 399.8.

10. Estimate of Owner's Costs

Table 4 lists the estimated cost elements comprising the "Owner's Costs."

Architect-Engineer Services and Costs

These services consist of preliminary investigations, engineering, design and preparation of plans and specifications, expediting, inspection and procurement of materials and equipment, inspection of construction work to secure compliance with plans and specifications, engineering consultant services, and engineering supervision in connection with construction work. Costs of all A/E services are included in Account No. 393.

The cost of A/E services were estimated in the following manner: from past experience the A/E costs for conventional power plants of 25, 50 and 100 MWe sizes were used as a base. This is shown in Tables 5, 6, and 7 as the cost of A/E services for the non-nuclear plant. Then, the A/E costs for the design of the reactor building, the radioactive waste building, etc., were estimated. Added to this was an estimate of costs arising from the A/E's contribution to the safeguards report and license application and certain other costs deemed to be a function of the type and size of reactor. The sum of these costs is shown in Tables 5, 6 and 7 as cost of A/E services for the nuclear island. Nuclear engineering is not part of the A/E services; it is part of the reactor vendor's scope of supply; the nuclear engineering costs are included in Account No. 322.

Contingency

To account for unforeseen expenses, a contingency allowance was added to each capital cost estimate. This amount was based upon a percentage of the depreciable capital cost; i.e., all capital cost other than land and working capital. The choice of a percentage value is based upon judgment. For this study, the lowest contingency percentage (5%) was applied to the 50 MWe BWR, because it is the only plant that is actually in operation (Humboldt Bay). Moreover, the entire BWR concept is fully developed, and thus this plant has the least uncertainties. The 100 MWe BWR represents an extrapolation upward from

Humboldt Bay--or downward from Dresden--hence a slightly higher contingency percentage (5.5%) was used.

Because the 50 and 100 MWe OCMR's represent considerable extrapolations from the 11.4 MWe Piqua Nuclear Power Facility, higher contingency percentages were applied: respectively 8.5% and 10%.

A 10% contingency percentage was used for the PWR-CNSG also since it represents a land based extrapolation of a shipboard reactor.

Working Capital (Excluding Fuel Cycle)

The estimated working capital required for plant operation and maintenance (but excluding the fuel cycle) was computed as the sum of:

1. 2.7% of the sum of the annual fuel cost and the annual operating and maintenance costs. (Line 12, Table 17).

2. The average value of materials and supplies in inventory, other than nuclear fuel. This value is assumed to equal 25% of the sum of operating and maintenance supplies (Line 5, Table 17) and chemicals and resins (Line 6, Table 17).

The foregoing method yielded a working capital that appears somewhat low for small electric systems. It can be justified on the basis that legal and other expenses incurred prior to a bond issue for the new plant would be paid out of a general fund.

Summary of Capital Costs

Based on the foregoing capital cost components, Tables 5 through 7 were prepared showing the total capital investment required for each of the five plants. The six cost items comprising the "Total Direct Construction Costs" are those given in greater detail in Table 2. When the costs for the Architect-Engineer services are added to the Direct Construction Costs, the resultant total is referred to as "Total Before Owner's Costs." When the owner's costs, contingency, land and land rights (Account No. 320), and working capital are added to the "Total Before Owner's Costs" the resultant sum is the "Total Capital Cost" required for the plant, excluding the capital cost (working capital) for the fuel cycle.

Fuel Cycle Costs

1. General

   Toll enrichment of privately-owned uranium in government-owned gaseous diffusion plants becomes available in 1969, with private ownership becoming mandatory in 1971. Thus, for a nuclear power plant which would achieve commercial operation in 1970, private ownership of the fuel was assumed to apply throughout the plant's lifetime. Under private fuel ownership, the fuel cycle cost elements are:

   a. Purchase of uranium ore concentrate.

   b. Conversion of ore concentrate to uranium hexafluoride.

   c. Toll enrichment of the uranium.

d. Fabrication into fuel assemblies and shipment to plant.

e. Spent fuel storage and shipment.

f. Chemical processing and reconversion.

g. Credit for the value of recovered uranium and plutonium.

In addition to the above elements of fuel cost, the fixed charge on the working capital required for the fuel cycle throughout the first ten years of operation was included as a part of the fuel cycle cost. As a further simplification, the interest on the capital required for the first core (which requires a lead time of about two years before start-up) has been spread over the ten year operating period. Thus, the fuel cycle cost tables show a constant working fuel capital and hence a constant annual cost for the use of that working capital. The constant annual cost is an average cost, but it is also sufficient to recover the interest paid on the first core capital investment prior to start-up. Strictly speaking, working capital for the fuel cycle should be included under "Working Capital;" however, it is included as a fuel cost in order to provide a more complete analysis by presenting in one place all of the costs associated with nuclear fuel.

Fuel cycle costs were calculated for the five reactor plants. Two sets of economic ground rules, designated as "conservative" and "optimistic," were used for such factors as cost of uranium ore, cost of converting ore to UF_6 and spent fuel recovery. The Ground Rules are summarized in Appendix A. The conservative ground rules apply to the fuel cycle costs expected under present conditions; the optimistic ground rules plus anticipated reductions in fuel fabrication costs were applied to the fuel cycle costs expected under "Potential Cost Reductions" discussed in Section 6.0. For reasons of convenience and ready comparison fuel costs based on both sets of economic ground rules are shown in the Fuel Cost Analysis Tables included in this section (Present Power Costs).

All of the reactors studied use fuel management schemes involving partial core refueling; i.e., periodically the reactor is shut down, a portion of the remaining fuel--ranging from one-fifth to one-half for the cases studied --rearranged, new fuel assemblies added, and the plant restarted. The quantity of fuel added and removed during each refueling is called a fuel "batch." After the first few years of operation an equilibrium is reached and each new fuel batch has the same composition as the previous batch and each spent fuel batch also has the same composition as the previous spent batch. Tables 8, 10, and 13 show a breakdown of the nuclear fuel costs for a typical equilibrium batch of fuel for the 25 MWe PWR-CNSG, the 100 MWe OCMR, and the 50 MWe BWR, respectively.

If a reactor is partially refueled once a year, the total cost per batch would also be the annual fuel cost. Since the reactors studied do not use once-a-year refueling, the annual fuel costs were computed as follows:

a. The total cost per batch (without capital charges) was divided by the total power production per batch (over the appropriate period of time) to obtain the unit fuel cost contribution to total unit energy costs. Thus, for the 25 MWe "Conservative Assumption" case in Table 8:

$$\frac{\$688,000/\text{batch} \times 1,000 \text{ mills}/\$}{3.103 \times 10^8 \text{ kwh/batch}} = 2.22 \frac{\text{mills}}{\text{kwh}}$$

b. The unit fuel cost per batch was multiplied by the net energy send-out per year. Thus for the same case as above, the net energy send-out is 131 x 10^6 kwh/yr (see Table 9), and the annual fuel cost is:

$$\frac{2.22 \text{ mills/kwh} \times 131 \times 10^6 \text{ kwh/yr}}{1,000 \text{ mills}/\$} = \$292,000/\text{yr}$$

This is the equilibrium annual fuel cost shown on line 3 of Table 9 for the years 1973 and beyond. (During the first three years of operation, the core will achieve equilibrium and the fuel costs will be higher.)

In a similar manner the average fuel cycle working capital for the plant can be computed from the data for a single batch.

c. The process from uranium ore through fabrication of fuel elements, shipment, exposure, storage, and reprocessing encompasses many steps and requires a time span of perhaps two years. During that interval, money expenditures of various magnitude are made at various times. Therefore, rather than charge the sum of these expenditures at the onset of the fuel cycle, the costs were charged as they occur by plotting a time vs investment curve.

For the same example cited above, the area under the time vs investment curve is computed to be 3,175,800 \$-years. Applying the fixed charge rate for working capital of 5.54%/yr and the power production per batch of 3.103 x 10^8 kwh, the contribution to the unit power cost of fuel cycle working capital was computed as follows:

$$\frac{3,175,800 \text{ \$-yr} \times 0.0554/\text{yr} \times 1,000 \text{ mills}/\$}{3.103 \times 10^8 \text{ kwh}} = 0.56 \frac{\text{mills}}{\text{kwh}}$$

d. By multiplying the unit power cost contribution (made by the fuel working capital) by the annual net energy send-out, we obtained the annual cost of the fuel cycle working capital (Line 2 in Table 9) as follows:

$$\frac{0.56 \text{ mills/kwh} \times 131 \times 10^6 \text{ kwh/year}}{1,000 \text{ mills}/\$} = \$73,000/\text{yr}$$

The cost of fuel cycle working capital for the years prior to achieving equilibrium is somewhat higher than for the equilibrium batch; the average over the first ten years was estimated to be \$75,000/yr as shown on Line 2 of Table 9. This is equivalent to an average working capital of \$1,350,000.

2. Net Plant Heat Rates

For a nuclear plant as for a fossil-fueled plant fuel costs are a function of plant overall heat rate. Heat rates provided by the reactor vendors are usually full-load heat rates or optimum heat rates and do not take into account part-load operation. In addition, they are usually based upon 1.5 in. Hg abs turbine exhaust pressure, whereas, over the course of a year, a 2 in. Hg abs backpressure may be more realistic. Also, auxiliary power is usually based upon river or seacoast locations, whereas in this study the use of a cooling tower (resulting in higher auxiliary power) was assumed. In view of the foregoing, the heat rates provided by the reactor vendors were adjusted as follows:

	PWR	OCMR		BWR	
	25 MW	50 MW	100 MW	50 MW	100 MW
Best Net Plant HR by Vendor	-	10,650	10,420	11,860	-
Avg Net Plant HR Used	11,900	11,800	11,600	13,100	13,100

3. Fuel Cycle Costs for the PWR

The reactor core for the 25 MWe PWR power plant is made up of 37 fuel assemblies. Each fuel assembly, in turn, contains about one hundred 3/8 in. diameter by 4.5 ft to 5 ft fuel rods. These rods are made up of UO_2 (uranium dioxide) pellets, clad with zircaloy; a combination which has become the standard selection for water cooled nuclear reactors. Fuel management employs an outside-in two-zone shuffle in which the reactor is shut down and the inner zone, consisting of 18 fuel assemblies and the central fuel assembly, are removed once every two to two and a half years at a 60% plant capacity factor. Fuel assemblies in the outer zone are then moved into the inner zone, and new assemblies are added to the outer zone and central core position. The group of fuel assemblies inserted into and/or removed from the reactor during each refueling is called a fuel batch.

A summary of the cost elements for a typical batch of fuel assemblies for a 25 MWe PWR is shown in Table 8 for the conservative and optimistic assumptions. Using this and similar data for the batches comprising the first core, annual and unit fuel costs were computed for the first ten years of operation, as shown in Table 9.

4. Fuel Cycle Costs for the OCMR

The fuel elements for organic cooled and moderated reactors are made of partially enriched uranium carbide fuel, clad with SAP (Sintered Aluminum Product).

Hyperstoichiometric uranium carbide has been selected as the fuel for this type of ractor on the basis of uranium density and optimum nuclear and thermal characteristics. It exhibits good radiation stability at long burnups and fuel temperatures in excess of 2,000°F. It is chemically compatible with both the SAP cladding and the organic coolant. On the other hand performance of uranium carbide fuel material has not been completely demonstrated. Should problems arise to prevent the large scale use of uranium carbide reactor fuel, the organic cooled and moderated reactor concept could readily be adapted to use uranium dioxide fuel material, now successfully employed in large PWR and BWR power plants.

The SAP fuel rod cladding is an aluminum powder metallurgy product alloyed with aluminum oxide and iron which exhibits better mechanical properties at elevated temperatures than conventional aluminum alloys. SAP has demonstrated excellent compatibility with both fuel and coolant over the proposed operating temperature range. Its mechanical properties are virtually unaffected by radiation at exposures of interest.

The fuel elements are similar to those used in the proposed second core for the Piqua Nuclear Power Facility and consist of spiral finned fuel rods arranged in two annular rings between inner and outer stainless steel shroud tubes. The 50 MWe design contains 110 fuel assemblies, 4.75 ft long, and the 100 MWe design contains 175 fuel assemblies, 6 ft long.

The reactor is refueled by shutting down the reactor and replacing spent fuel. During a burnup cycle, the change in average core burnup will be 5,000 MWD/MTU, after which spent fuel elements will be replaced with new elements. Approximately 25% of the core will be replaced during each shutdown, which occurs about once a year at a 60% plant capacity factor. The group of fuel assemblies inserted into and/or removed from the reactor each year is called a "fuel batch."

A summary of the cost elements for a typical batch of fuel assemblies for a 100 MWe OCMR is shown in Table 10 for both conservative and optimistic assumptions. Using this and similar data for the batches comprising the first core, the annual and unit fuel costs were computed for the first ten years of power plant operations, as shown in Table 11 for the 50 MW OCMR and in Table 12 for the 100 MW OCMR.

5. Fuel Cycle Costs for the BWR

The fuel element assemblies for the natural circulation boiling water reactor consists of a bundle of 49 fuel rods. Each of the fuel rods is comprised of high density uranium dioxide (UO_2) pellets contained within Zircaloy-4 tubing. The fuel rods are held in position by intermediate spacers and by tie plates at the end of the rods. The assemblies are provided with fittings at the top and bottom to position the assembly in the core and to permit removal during refueling. Surrounding the bundle of fuel rods are Zircaloy channels. These channels are metallic shrouds around the fuel assembly which serve four functions:

a. Increase structural rigidity of the fuel assembly.

b. Provide guide surfaces for control elements.

c. Protect fuel elements from damage during fuel handling operations.

d. Provide a channel for natural circulation of the coolant.

After the first core loading, approximately one-fifth of the core will be replaced at the end of each normal fuel cycle. The depleted fuel is removed from a randomly distributed (scatter) pattern within the core. Based on a 60% annual plant operating factor, the first batch, comprising approximately one-fifth of the core, will be removed two and a quarter years after achieving commercial operation.

Thereafter, refueling will occur at nine-month intervals. The average exposure for the first five batches discharged will be 16,500 MWD per metric ton of uranium (15,000 MWD/short ton). The design equilibrium exposure also is 16,500 MWD/short ton.

A summary of the cost elements for a typical batch of fuel assemblies for the 50 MW BWR is shown in Table 13 for both conservative and optimistic assumptions. Using this and similar data for batches comprising the first core, annual and unit fuel cycle costs were computed for the first ten years of operations, as shown in Table 14 for the 50 MW BWR and in Table 15 for the 100 MW BWR.

Operation and Maintenance Costs

1. Supervision, Operating and Maintenance Labor

The number of people required to operate, maintain and supervise a small nuclear power plant is likely to be the same whether the plant is rated at 25, 50 or 100 MWe. Therefore, one "Manning Table" (Table 16) was prepared, based on a survey of plant personnel at the Humboldt Bay and Piqua Nuclear Power Plants.

Labor costs comprise a high proportion of the total annual costs for a power plant and, since these costs are nearly constant regardless of plant size, the smaller the plant the heavier their impact upon the energy costs from that plant.

2. Other Operating Costs

Other annual operating costs were computed on the following basis:

Contract Maintenance	22.5¢/kw
Radiation Protection	$1,200
Operating and Maintenance Supplies	30¢/kw + $120,000
Chemicals and Resins	
BWR and PWR	9¢/kw
OCMR	5¢/kw + 0.016¢/kwh
Waste Disposal	5¢/kw
Communications	7.5¢/kw
Consulting Services	$5,000

3. Summary Cost Table

Table 17 shows the costs calculated for each item, the total cost, and the unit cost in mills/kwh for Operation and Maintenance. This annual cost was assumed to remain constant for the 10-year period considered in this study.

Nuclear Insurance Costs

1. General

The annual cost of nuclear insurance is comprised of nuclear liability insurance purchased from private insurance companies, and nuclear indemnity insurance purchased from the U. S. Government.

The cost of government-provided nuclear indemnity insurance is $30 per year per thermal megawatt of plant rating.

The required private liability insurance coverage, $74 million for plants with a net electrical capacity of 100 MWe and larger. For the smaller plants, the required insurance coverage was assumed equal to $185 times the reactors maximum thermal rating in kilowatts, times a population factor, P. For the assumed site on the outskirts of a medium-sized California community the population factor, P, was taken as 1.2. Basing the private insurance coverage on $185 per thermal kilowatt makes allowances for a possible increase which the AEC is considering for plants rated at less than 100 MWe.

After the utility has received its construction permit, representatives of the utility make a presentation to the nuclear liability insurance pools. The Safety Analysis Report is made available, along with drawings of the planned facility. Following this presentation, nuclear liability insurance pools arrive at a "base rate" for the first one million dollars of nuclear liability coverage. Among the factors considered in arriving at a premium rate for negotiations are the following:

a. Type of reactor.

b. Use to which reactor will be put.

c. Power level.

d. Population distribution.

e. Degree of containment.

After a "base rate" is negotiated between the utility and the nuclear liability insurance pool, it is applied to arrive at the total annual premium:

Amount of Coverage	Premium Rate
First $1,000,000	Base Rate
Next $4,000,000	50% x base rate
Next $5,000,000	20% x base rate
Next $10,000,000	10% x base rate
Next $20,000,000	5% x base rate
Next $20,000,000	2.5% x base rate
Next $14,000,000	1.25% x base rate

In applying the above schedule to arrive at an annual premium, it should be noted that the premium rate never drops below an established minimum of $1,000/million dollars coverage.

There may be a considerable variation in the "base rate" negotiated, depending on the five factors enumerated above. For instance, the "base rate" for a nuclear plant located near a large eastern metropolitan area is $41,000/million dollars coverage, while the "base rate" for a small nuclear power plant on the outskirts of a medium-sized California city is $14,500/million dollars coverage. The latter value was selected for use in the present study since the conditions more nearly approach those applicable to a utility which might install a small nuclear power plant.

The nuclear liability insurance pools have an "industry credit rating plan" under which a certain portion of the annual premium is paid into a reserve fund. The utility pays the established negotiated premium rate for the first ten years. If for the eleventh year of operation, the industry's experience has been good (i.e., few claims have been paid), up to 60-70% of the first year's premium is refunded to the utility. Again, in the twelfth year, up to 60-70% of the second year's premium could be refunded, etc. To date, the safety record of the nuclear industry has been exceedingly good and only a handful of claims have been paid. It is reasonable to anticipate that this experience will continue to be favorable in the future. Therefore, in order to make a realistic appraisal of the cost of nuclear liability insurance, credit was taken for the present worth of the anticipated future reserve premium refund of 60% of each year's premium.

2. Summary Cost Table

Table 18 shows the annual cost of nuclear liability and indemnity insurance computed for each of the five plants considered in this study.

Financing

1. General

Investor-owned and local public power systems usually obtain their capital from the private money market, whereas Rural Electric Cooperatives have access to low-cost REA loans. Investor-owned utilities may have a financing plan consisting of 50% of the capital requirements in bonds, 15% in preferred stock and 35% in common stock. Local public power systems generally obtain their capital funds from the sale of general obligation bonds or revenue bonds. Currently, the cost of money borrowed through bonds is 3 to 4% for most public systems.

2. Fixed Charge Rate

The following fixed charge rates are generally accepted as representative:

	REA		Municipal		Investor-Owned Public Utility	
	Dep	Nondep	Dep	Nondep	Dep	Nondep
Interest Charged	2.00	2.00	3.74	3.74	-	-
Minimum Return Required	-	-	-	-	6.75	6.75
Depreciation*	2.46	-	1.86	-	1.11	-
Interim Replacements	0.35	-	0.35	-	0.35	-
Property Insurance	0.40	0.40	0.40	0.40	0.40	0.40
Federal Income Taxes	-	-	-	-	3.40	3.40
State and Local Taxes	0.80	0.80	1.40	1.40	2.45	2.45
Total	6.01	3.20	7.75	5.54	14.46	13.00

*Based on a 30-year Sinking Fund. This does not imply creation of actual sinking funds, but is merely a convenient way to state the cost of repayment of the bond principal.

Since the largest group of potential customers is small municipal systems, the fixed charge applicable to them has been used in this study. Reference to Table 10 of the APPA material supplied to the AEC shows a fixed charge rate of 7.6% for the City of Los Angeles Malibu Nuclear Power Plant. This compares well with the 7.75% fixed charge rate in this study. The slightly higher rate is justified on the basis that many of the smaller municipal systems may not be able to sell their bonds at quite the same rates as the City of Los Angeles.

Cost Summary

The final step in the determination of the cost of power is the computation of the total annual costs. The cost elements comprising the total annual cost are as follows:

Cost of depreciating capital investment without fuel

PWR-CNSG: Table 5

OCMR: Table 6

BWR: Table 7

Cost of nondepreciating capital investment without fuel

Tables 5 through 7

Nondepreciating capital for fuel

Fuel Cycle Costs

25 MW PWR-CNSG: Table 9

50 MW OCMR: Table 11

100 MW OCMR: Table 12

50 MW BWR: Table 14

100 MW BWR: Table 15

Operating and maintenance costs

Table 17

Cost of Nuclear Insurance

Table 18

The unit cost of power generation in mills/kwh is computed by dividing the sum of the annual cost elements by the annual net energy send-out. In order to see more clearly the contribution of each cost element to the total cost, it is also useful to divide each annual cost element by the annual net energy send-out. This has been done in Table 1, presented at the beginning of this section.

TABLE 1

SUMMARY OF CAPITAL AND POWER GENERATING COSTS
PRESENT COSTS

(Capital & Annual Costs are in Thousands of Dollars)

		PWR-CNSG	OCMR		BWR	
		25 MWe	50 MWe	100 MWe	50 MWe	100 MWe
	Capital Costs					
1.	Depreciable Capital Costs (w/o Fuel)	$14,850	$18,750	$24,600	$19,270	$27,650
2.	Non-Depreciable Cap. Costs (w/o Fuel)	150	250	400	230	350
3.	Total, Capital (w/o Fuel)	$15,000	$19,000	$25,000	$19,500	$28,000
4.	Unit Capital Cost, $/KW Net	600	380	250	390	280
5.	Non-Depr. Capital for Fuel*	1,350	2,320	4,450	3,360	6,290
6.	Total Capital Required	$16,350	$21,320	$29,450	$22,860	$34,290
	Annual Costs					
7.	Depr. Capital (Line 1) @ 7.75%	1,151	1,453	1,907	1,493	2,170
8.	Non-Depr. Capital (Line 2) @ 5.54%	8	14	22	12	20
9.	Fuel Cycle Cost (10-Yr. Average)*	381	783	1,414	941	1,677
10.	Operation & Maintenance	705	887	1,083	743	800
11.	Nuclear Insurance	42	51	83	59	85
12.	Total Annual Cost	$ 2,287	$ 3,188	$ 4,509	$ 3,248	$ 4,752
	Unit Power Generation Costs, Mills/kwh					
13.	Annual Net Energy Send-Out @ 60% P. F. Million KWH	131	263	526	263	526
14.	Unit Cost for Plant, Mills/kwh	8.85	5.58	3.66	5.72	4.16
15.	Unit Cost for Fuel Cycle	2.90	2.98	2.69	3.58	3.19
16.	Unit Cost for Operation & Maintenance	5.38	3.37	2.06	2.83	1.52
17.	Unit Cost for Nuclear Insurance	0.32	0.19	0.16	0.22	0.16
18.	Total Unit Energy Cost	17.45	12.12	8.57	12.35	9.03

*Based on "Conservative" Assumptions.

	Unit Power Generation Costs at 80% PF, Mills/kwh					
19.	All Unit Costs Except Fuel Cycle Costs	10.91	6.86	4.41	6.58	4.38
20.	Unit Costs for Fuel Cycle**	2.90	2.98	2.69	3.58	3.19
21.	Total Unit Energy Cost	13.81	9.84	7.10	10.16	7.57

**Effect of Increased Plant Capacity Factor upon fuel inventory has been excluded.

Note: PF = Plant Capacity Factor

TABLE 2 SHEET 1 OF 4

CONSTRUCTION COST ESTIMATES

Thousands of Dollars

Account No.	Item	Notes	Nuclear Island % of Cost	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
320	Land & Land Rights							
.1	Land Acquisition			$ 75	$ 125	$ 200	$ 125	$ 200
.2	Clearing Land	Not Required		--	--	--	--	--
.3	Surveys	Aerial & Environmental		20	20	20	20	20
.4	Fees, Etc.	Incl. in Land Acquis.		--	--	--	--	--
.5	Easements	Incl. in Land Acquis.		--	--	--	--	--
.6	Preliminary Grading	Incl. in Acct. 321.1		--	--	--	--	--
	Total Account 320			$ 95	$ 145	$ 220	$ 145	$ 220
321	Structures & Improvements							
.1	Improvements to Site			$ 240	$ 240	$ 240	$ 240	$ 240
.2	Reactor Building		100%	500	600	750	650	910
.3	Radioactive Waste Bldg.		100%	160	175	175	225	225
.4	Turbine Building			650	700	900	790	1,000
.5	Administration Bldg.	Part of Turbine Bldg.		--	--	--	--	--
.6	Service Building	Part of Turbine Bldg.		--	--	--	--	--
.7	Misc. Yard Building			20	20	20	20	20
.8	Stack	Included in 321.2		--	--	--	--	--
.9	Reactor Contain. Struct.	Included in 321.2		--	--	--	--	--
	Total Account 321			$1,570	$1,735	$2,085	$1,925	$2,395

TABLE 2 SHEET 2 OF 4

CONSTRUCTION COST ESTIMATES

Thousands of Dollars

Account No.	Item	Notes	Nuclear Island % of Cost	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
322	Reactor Plant Equipment							
.1	Reactor Equipment		100%	$2,900	$1,900	$2,800	$3,360	$5,830
.2	Heat Transfer Systems		100%		1,000	1,500	280	460
.3	Fuel Handling & Storage		100%	260	360	400	60	100
.4	Radioactive Waste Treatment		100%	160	100	120	225	250
.5	Instrumentation & Control		100%	400	490	490	400	400
.6	F. W. Supply & Treatment			180	400	425	350	400
.7	Steam, Cond. & F.W. Piping		20%	300	350	500	415	600
.8	Nuclear Engineering		100%	1,700	2,000	2,000	1,700	1,700
	Total Account 322			$5,900	$6,600	$8,235	$6,790	$9,740
323	Turbine Generator Unit							
.1	Turbine Generator			$1,350	$2,200	$3,500	$2,800	$5,400
.2	Condenser & Auxiliaries			200	350	650	400	700
.3	Circulating Water System			235	635	950	665	1,000
.4	Lubricating Oil Equip.			10	10	10	10	10
.5	T-G Pedestal			40	60	90	60	90
.6	Turbine Plant Piping			20	35	65	40	70
	Total Account 323			$1,855	$3,290	$5,265	$3,975	$7,270

TABLE 2 SHEET 3 OF 4

CONSTRUCTION COST ESTIMATES

Thousands of Dollars

Account No.	Item	Notes	Nuclear Island % of Cost	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
324	Accessory Electrical Equip.		50%					
.1	Switchgear			$ 200	$ 280	$ 370	$ 260	$ 330
.2	Switchboards			10	20	20	15	20
.3	Protective Equipment			5	10	10	5	10
.4	Electrical Structures			5	10	10	10	10
.5	Conduit							
.6	Power & Control Wiring			300	400	500	350	450
.7	Station Service Equipment			40	60	90	60	90
	Total Account 324			$ 560	$ 780	$1,000	$ 700	$ 920
325	Misc. Power Plant Equipment							
.1	Turbine Building Crane			$ 180	$ 210	$ 300	$ 230	$ 270
.2	Station Air System			25	35	45	35	45
.3	Communication System		50%	30	30	30	30	30
.4	Annunciations & Alarms			5	5	5	5	5
.5	Misc. Equipment			30	30	30	30	30
	Total Account 325			$ 270	$ 310	$ 415	$ 330	$ 380
	Subtotal Direct Construction Costs	Excludes Land & Distr. Const. Costs		$10,155	$12,715	$17,000	$13,720	$20,705

TABLE 2 SHEET 4 OF 4

CONSTRUCTION COST ESTIMATES

Thousands of Dollars

Account No.	Item		PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
	Distribution of Other Contractor's Field Costs						
321 thru 325	Nuclear Island		$6,435	$7,100	$9,150	$7,360	$10,470
	All Other (Except Land)		3,720	5,615	7,850	6,360	10,335
398	Other Contractor's Field Costs:	Nuclear Island	500	800	900	800	900
		All Others	300	500	800	600	900
	Totals						
	Nuclear Island -:		$6,935	$7,900	$10,050	$8,160	$11,370
	All Others (Except Land) -:		4,020	6,115	8,650	6,960	11,135
	Total Construction Cost* -:		$10,955	$14,015	$18,700	$15,120	$22,505

*Includes: Nuclear Engineering Costs (Account 322.8)

Excludes: Land & Land Rights (Account 320)

Architect-Engineering Costs

All Owner's Costs

TABLE 3

OWNER'S COSTS FOR OPERATOR TRAINING

Basis: Piqua Nuclear Power Facility Program - Per COO-284, Volume I, Section 12

1. Train 20 people for 3 months each				
1	Plant Superintendent	@ $1300/mo		$ 3,900
1	Asst. Superintendent	@ $1100/mo		3,300
1	Operations Engineer	@ $800/mo		2,400
1	Instrument Engineer	@ $900/mo		2,700
1	Mech-Electrical Eng	@ $885/mo		2,655
1	Process Engineer	@ $850/mo		2,550
6	Shift Supervisors	@ $866/mo		15,585
4	Chief Operators	@ $750/mo		9,360
4	Reactor Operators	@ $710/mo		8,520
			Subtotal	$ 50,970
2. Special Orientation Training - 1 month each for 4 people				
1	Health Physics Engineer	@ $750/mo		$ 750
1	Laboratory Technician	@ $300/mo		300
1	Electronics Technician	@ $606/mo		610
1	Mech-Elec Technician	@ $650/mo		650
			Subtotal	$ 2,310
3. Lecture Program During Plant Start-Up (entire staff for 80 hours)				$ 16,000
		Subtotal Labor		69,280
		Payroll Additives @ 25%		17,320
		Total Payroll Costs		$ 86,600
4. Travel Expenses in Connection with above				
20 people x 6 weeks @ $110/wk				$ 13,200
4 people x 4 weeks @ $110/wk				1,800
24 trips @ $200/trip				4,800
			Subtotal	$ 19,800
Total Owner's Cost for Training				$106,400
		Say		$110,000

Note: Costs of lecturers, etc., are included in "Nuclear Engineering" portion of direct costs.

TABLE 4

ESTIMATE OF OWNER'S COSTS

Thousands of Dollars

Account No.	Item	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
399.1	Interest on Debt During Construction (5.5% of "Total Before Owner's Costs")	$ 670	$ 860	$1,100	$ 920	$1,320
399.2	Procurement, Accounting, Administrative	50	70	100	70	100
399.3	Liaison Engineering	150	150	150	150	150
399.4	Safeguards Report and Licensing	100	100	100	100	100
399.5	Operator Training	110	110	110	110	110
399.6	Start-Up Costs @ 35% of Annual O&M Costs	220	280	340	230	250
399.7	Efficiency & Capability Tests @ 20% of Item 399.6	40	60	70	50	50
399.8	Other Costs	10	20	30	20	20
	Total Account 399	$1,350	$1,650	$2,000	$1,650	$2,100

TABLE 5

SUMMARY OF CAPITAL COST FOR 25 MW PWR

Thousands of Dollars

	25 MW PWR-CNSG		
	Nuclear Island	Non-Nuclear Plant	Total
A. Depreciable Items			
321 Structures & Improvements	$ 660	$ 910	$ 1,570
322 Reactor Plant Equipment	5,480	420	5,900
323 Turbine-Generator Equipment	--	1,855	1,855
324 Accessory Electrical Equipment	280	280	560
325 Misc. Power Plant Equipment	15	255	270
398 Distributable Construction Costs	500	300	800
Total Direct Construction Costs	$6,935	$4,020	$10,955
393 A-E Services	400	800	1,200
Total Before Owner's Costs	$7,335	$4,820	$12,155
399 Owner's Costs			1,350
		Total Before Contingency:	$13,505
		Contingency @ 10%:	1,345
		Total Depreciable Items:	$14,850
B. Non-Depreciable Items			
320 Land & Land Rights			95
Working Capital (Excluding Fuel Cycle)			55
		Total Non-Depreciable Items:	150
		Total Capital Costs:	$15,000

TABLE 6

SUMMARY OF CAPITAL COST FOR OCMR

Thousands of Dollars

	Organic Cooled and Moderated Reactor					
	50 MW			100 MW		
	Nuclear Island	Non-Nuclear Plant	Total	Nuclear Island	Non-Nuclear Plant	Total
A. Depreciable Items						
321 Structures & Improvements	$ 775	$ 960	$ 1,735	$ 925	$ 1,160	$ 2,085
322 Reactor Plant Equipment	5,920	680	6,600	7,710	525	8,235
323 Turbine-Generator Equipment	--	3,290	3,290	--	5,265	5,265
324 Accessory Electrical Equipment	390	390	780	500	500	1,000
325 Misc. Power Plant Equipment	15	295	310	15	400	415
398 Distributable Construction Costs	800	500	1,300	900	800	1,700
Total Direct Const. Costs	$ 7,900	$ 6,115	$14,015	$10,050	$ 8,650	$18,700
393 A-E Services	600	1,000	1,600	600	1,000	1,600
Total Before Owner's Costs	$ 8,500	$ 7,115	$15,615	$10,650	$ 9,650	$20,300
399 Owner's Costs			1,650			2,000
Total Before Contingency:			$17,265			$22,300
Contingency (@ 8.5%):			1,485		(@ 10%):	2,300
Total Depreciable Items:			$18,750			$24,600
B. Non-Depreciable Items						
320 Land & Land Rights			145			220
Working Capital (Excluding Fuel Cycle)			105			180
Total Non-Depreciable Items:			250			400
Total Capital Cost			$19,000			$25,000

TABLE 7

SUMMARY OF CAPITAL COST FOR BWR

Thousands of Dollars

	Boiling Water Reactor 50 MW Nuclear Island	50 MW Non-Nuclear Plant	50 MW Total	100 MW Nuclear Island	100 MW Non-Nuclear Plant	100 MW Total
A. Depreciable Items						
321 Structures & Improvements	$ 875	$ 1,050	$ 1,925	$ 1,135	$ 1,260	$ 2,395
322 Reactor Plant Equipment	6,120	670	6,790	8,860	880	9,740
323 Turbine-Generator Equipment	--	3,975	3,975	--	7,270	7,270
324 Accessory Electrical Equipment	350	350	700	460	460	920
325 Misc. Power Plant Equipment	15	315	330	15	365	380
398 Distributable Construction Costs	800	600	1,400	900	900	1,800
Total Direct Const. Costs	$ 8,160	$ 6,960	$15,120	$11,370	$11,135	$22,505
393 A-E Services	600	1,000	1,600	600	1,000	1,600
Total Before Owner's Costs	$ 8,760	$ 7,960	$16,720	$11,970	$12,135	$24,105
399 Owner's Costs			1,650			2,100
Total Before Contingency:			$18,370			$26,205
Contingency		(@ 5%):	900		(@ 5.5%):	1,445
Total Depreciable Items:			$19,270			$27,650
B. Non-Depreciable Items						
320 Land & Land Rights			145			220
Working Capital (Excluding Fuel Cycle)			85			130
Total Non-Depreciable Items:			230			350
Total Capital Costs			$19,500			$28,000

TABLE 8

FUEL CYCLE COST ANALYSIS - 25 MW PWR

GENERAL DATA

Reactor Type	PWR	Batch Number	"Equilibrium"
Net Electrical Rating	25 MWe	Reactor Thermal Rating	80 MWt
Average Net Electric Output	15 MWe	Average Reactor Thermal Output	52.0 MWt
Exposure, MWD/MTU	27,000	Batch Loading, KgU (2 Batches/Core)	1,660
Power Production per Batch, KWHr	3.103×10^8	Batch Lifetime, Months	56.5

COST ANALYSIS

Operation	Quantity	"CONSERVATIVE ASSUMPTIONS" Unit Cost	Total Cost	"OPTIMISTIC ASSUMPTIONS" Unit Cost	Total Cost
Ore Purchase	14,010 KgU	\$20.80/KgU (\$8.00 lb/U_3O_8)	\$291,000	\$13.00/KgU (\$5.00 lb/U_3O_8)	\$182,000
Conversion to UF_6	14,010 KgU	\$2.70/KgU	38,000	\$2.20/KgU	31,000
Enrichment	1,660 Kg @ 4.12%	\$181.11/KgU (\$30/Kg sep. wk)	301,000	\$181.11/KgU (\$30/Kg sep. wk)	301,000
Fabrication	1,660 KgU	\$145/KgU	241,000	\$145/KgU*	241,000*
Spent Fuel Shipping	1,601 KgU	\$10/KgU	16,000	\$5/KgU	8,000
Chemical Processing	1,600 KgU	\$47.00/KgU	76,000	\$31.40/KgU	50,000
Reconversion	1,590 KgU	\$5.60/KgU	9,000	--	--
Uranium Recovery	1,590 KgU @ 1.76%	\$121.62/KgU	(193,000)	\$86.50/KgU	(138,000)
Fissile Pu Recovery	9.08/Kg	\$10,000/Kg	(91,000)	\$8,200/KgPu	(74,000)
Total Cost Without Capital Charges, \$			\$688,000		\$601,000
Unit Power Cost Without Capital Charges, Mills/KWHr			2.22		1.95
Fuel Cycle Working Capital Amount/Batch, \$-Yrs.			3,175,800		2,882,000
Annual Charges on Fuel Working Capital/Batch, @ 5.54%/yr.			\$175,900		\$160,000
Unit Power Cost of Working Capital, Mills/KWHr			0.56		0.51
Total Unit Power Cost, Mills/KWHr			2.78		2.46

*No "optimistic" estimate was made of fuel fabrication costs; such reductions were assumed to be the result of multiple orders only (see Section 6.0).

TABLE 9

ANNUAL FUEL CYCLE COSTS FOR THE 25 MW PWR

Fuel Cost Assumptions: Conservative
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,900 Btu/kwhr		131	→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $1,350,000		75	→								
3	Other Fuel Cycle Costs, $/Yr		$361	$361	$314	$292	$292	→				
4	Total Annual Fuel Costs, $/Yr	$381*	$436	$436	$389	$367	$367	→				
5	Unit Fuel Costs, Mills/kwh		3.31	3.31	2.95	2.78	2.78	→				
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.90					

*10-Yr Average.

TABLE 10

FUEL CYCLE COST ANALYSIS - 100 MW OCMR

GENERAL DATA

Reactor Type	OCMR	Batch Number	"Equilibrium"
Net Electrical Rating	100 MWe	Reactor Thermal Rating	315 MWt
Average Net Electric Output	60 MWe	Average Reactor Thermal Output	204.3 MWt
Exposure, MWD/MTU	20,000	Batch Loading, KgU (4 Batches/Core)	3960
Power Production per Batch, KWHr	5.582×10^8	Batch Lifetime, Months	51.0

COST ANALYSIS

		"CONSERVATIVE ASSUMPTIONS"		"OPTIMISTIC ASSUMPTIONS"	
Operation	Quantity	Unit Cost	Total Cost	Unit Cost	Total Cost
Ore Purchase	20,536 KgU	\$20.80/KgU (\$8.00/lb U_3O_8)	\$ 427,000	\$13.00/KgU (\$5.00/lb U_3O_8)	\$ 267,000
Conversion to UF_6	20,536 KgU	\$2.70/KgU	56,000	\$2.20/KgU	45,000
Enrichment	3960 KgU @ 2.63% U-235	\$91.97/KgU (\$30/Kg Sep. Wk)	364,000	\$181.11/KgU (\$30/Kg Sep. Wk)	364,000
Fabrication	3960 KgU	\$120.00/KgU	475,000	\$120.00/KgU*	475,000*
Spent Fuel Shipping	3850 KgU	\$10.00/KgU	39,000	\$5.00/KgU	19,000
Chemical Processing	3850 KgU	\$35.70/KgU*	138,000	\$31.40/KgU	121,000
Reconversion	3810 KgU	\$5.60/KgU	21,000	--	--
Uranium Recovery	3800 KgU @ 0.94% U-235	\$42.39/KgU	(161,000)	\$25.06/KgU	(195,000)
Fissile Pu Recovery	18.48 Kg Pu	\$10,000/Kg Pu	(180,000)	\$8,200/Kg Pu	(151,000)
Total Cost Without Capital Charges, \$			\$1,179,000		\$1,045,000
Unit Power Cost Without Capital Charges, Mills/KWHr			2.12		1.89
Fuel Cycle Working Capital Amount/Batch, \$-Yrs.			4,590,000		3,655,000
Annual Charges on Fuel Working Capital/Batch, @ 5.54%/Yr			254,300		202,500
Unit Power Cost of Working Capital, Mills/KWHr			0.46		0.36
Total Unit Power Cost, Mills/KWHr			2.58		2.25

*Assumes processing of 4 Batches (1 core) simultaneously.

*No "optimistic" estimate was made of fuel fabrication costs; such reductions were assumed to be the result of multiple orders only (see Section 6.0).

TABLE 11

ANNUAL FUEL CYCLE COSTS FOR THE 50 MW OCMR

Fuel Cost Assumptions: Conservative
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,800 Btu/kwhr		$263	——————→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $2,320,000		129	——————→								
3	Other Fuel Cycle Costs, $/Yr		$820	$744	$644	$612	$615	$623	——————→			
4	Total Annual Fuel Costs, $/Yr	$783*	$949	$873	$773	$741	$744	$752	——————→			
5	Unit Fuel Costs, Mills/kwh		3.61	3.32	2.94	2.82	2.83	2.85	——————→			
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.98					

*10-Yr Average

TABLE 12

ANNUAL FUEL CYCLE COSTS FOR THE 100 MW OCMR

Fuel Cost Assumptions: Conservative
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,600 Btu/kwhr		$526	→	→	→	→	→	→	→	→	→
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $4,450,000		247	→	→	→	→	→	→	→	→	→
3	Other Fuel Cycle Costs, $/Yr		$1466	$1330	$1151	$1093	$1099	$1114	→	→	→	→
4	Total Annual Fuel Costs, $/Yr	$1414*	$1713	$1577	$1398	$1340	$1346	$1361	→	→	→	→
5	Unit Fuel Costs, Mills/kwh		3.25	2.99	2.65	2.54	2.55	2.58	→	→	→	→
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.69					

*10-Yr Average

TABLE 13

FUEL CYCLE COST ANALYSIS - 50 MW BWR

GENERAL DATA

Reactor Type	BWR	Batch Number	"Equilibrium"
Net Electrical Rating	50 MWe	Reactor Thermal Rating	178 MWt
Average Net Electric Output	30 MWe	Average Reactor Thermal Output	115.1 MWt
Exposure, MWD/MTU	16,500	Batch Loading, KgU (5 Batches/Core)	1920
Power Production per Batch, KWHr	1.979×10^8	Batch Lifetime, Months	45.6

COST ANALYSIS

		"CONSERVATIVE ASSUMPTIONS"		"OPTIMISTIC ASSUMPTIONS"	
Operation	Quantity	Unit Cost	Total Cost	Unit Cost	Total Cost
Ore Purchase	24,800 lb U_3O_8	\$8.00/lb U_3O_8	\$ 198,000	\$5.00/lb U_3O_8	\$ 124,000
Conversion to UF_6	9,570 KgU	\$2.70/KgU	26,000	\$2.20/KgU	21,000
Enrichment	1,920 KgU @ 2.54%	\$87.60/KgU (\$30/Kg Sep. Wk)	168,000	\$87.60/KgU (\$30/Kg Sep. Wk)	168,000
Fabrication	1,920 KgU	\$145/KgU	278,000	\$145/KgU	278,000*
Spent Fuel Shipping	1,875 KgU	\$10/KgU	19,000	}	}
Chemical Processing	1,875 KgU	\$36/KgU	68,000	\$36.40/KgU	68,000
Reconversion	1,801 KgU	\$5.60/KgU	10,000	}	}
Uranium Recovery	1,801 KgU @ 1.15% U-235	\$61.40/KgU	(110,000)	\$40.50/KgU	(73,000)
Fissile Pu Recovery	8.30/KgPu	\$10,000/KgPu	(83,000)	\$8,200/KgPu	(68,000)
Total Cost without Capital Charges, \$			\$ 574,000		\$ 518,000
Unit Power Cost without Capital Charges, Mills/KWHr			2.91		2.62
Fuel Cycle Working Capital Amount/Batch, \$-Yrs			2,440,000		1,800,000
Annual Charges on Fuel Working Capital/Batch, @ 5.54%/Yr			135,000		100,000
Unit Power Cost of Working Capital, Mills/KWHr			0.68		0.50
Total Unit Power Cost, Mills/KWHr			3.59		3.12

*No "optimistic" estimate was made of fuel fabrication costs; such reductions were assumed to be the result of multiple orders only (see Section 6.0).

TABLE 14

ANNUAL FUEL CYCLE COSTS FOR THE 50 MW BWR

Fuel Cost Assumptions: Conservative
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 13,100 Btu/kwhr		$263	→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $3,360,000		186	→								
3	Other Fuel Cycle Costs, $/Yr		$770	$770	$770	$717	$725	$754	$765	→		
4	Total Annual Fuel Costs, $/Yr	$941*	$956	$956	$956	$903	$911	$940	$951	→		
5	Unit Fuel Costs, Mills/kwh		3.63	3.63	3.63	3.43	3.46	3.57	3.61	→		
6	10-Year Average Unit Fuel Costs, Mills/kwh						3.58					

*10-Yr Average

TABLE 15

ANNUAL FUEL CYCLE COSTS FOR THE 100 MW BWR

Fuel Cost Assumptions: Conservative
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 13,100 Btu/kwhr		$526	——————————→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $6,290,000		348	——————————→								
3	Other Fuel Cycle Costs, $/Yr		$1367	$1367	$1367	$1261	$1267	$1320	$1335	——————→		
4	Total Annual Fuel Costs, $/Yr	$1677*	$1715	$1715	$1715	$1609	$1615	$1668	$1683	——————→		
5	Unit Fuel Costs, Mills/kwh		3.26	3.26	3.26	3.06	3.07	3.17	3.20	——————→		
6	10-Year Average Unit Fuel Costs, Mills/kwh						3.19					

*10-Yr Average

TABLE 16

PLANT MANNING TABLE - 25 TO 100 MWe NUCLEAR PLANT
PRESENT COSTS

No. of Employees	Function	Rate	Annual Direct Cost $/Year
	SUPERVISION (4)		
1	Superintendent	$1300/mo	$ 15,600
1	Assistant Superintendent	$1100/mo	13,200
2	Secretaries	$260/mo	6,200
		Subtotal	$ 35,000
	TECHNICAL & FINANCIAL STAFF (8)		
1	Accounting Analyst	$750/mo	$ 9,000
1	Nuclear Engineer	$1000/mo	12,000
1	Health Physics Engineer	$850/mo	10,200
1	Health Physics Technician	$650/mo	7,800
1	Process Engineer	$850/mo	10,200
1	Process Chemist	$800/mo	9,600
1	Lab Technician	$583/mo	7,000
1	Operations Engineer	$850/mo	10,200
		Subtotal	$ 76,000
	OPERATION (19)		
5	Shift Supervisors	$200/wk	52,000
4	Chief Operators	$180/wk	37,400
4	Reactor Operators	$164/wk	34,200
2	Relief Operators	$154/wk	16,000
4	Shift Helpers	$122/wk	25,400
		Subtotal	$165,000
	MAINTENANCE (16)		
1	Instrument Engineer	$900/mo	$ 10,800
1	Maintenance Foreman	$173/wk	9,000
1	Electronics Technician	$140/wk	7,300
1	Instrument Technician	$140/wk	7,300
2	Pneumatic Technician	$130/wk	13,500
1	Mech-Elect Engineer	$885/mo	10,600
1	Mech-Elect Technician	$150/wk	7,800
1	Electrician	$150/wk	7,800
1	Insulator	$140/wk	7,300
2	Mechanics	$150/wk	15,600
2	Pipefitters	$150/wk	15,600
1	Helper	$120/wk	6,200
1	Utility Man	$100/wk	5,200
		Subtotal	$124,000
47			$400,000
		Payroll Additives @ 25%	100,000
		Total Payroll	$500,000

TABLE 17

ESTIMATED ANNUAL OPERATION & MAINTENANCE COST (EXCL. FUEL)
(Present Conditions)

Thousands of Dollars

Line		PWR-CNSG	OCMR		BWR	
		25 MW	50 MW	100 MW	50 MW	100 MW
1	Net Energy Send-Out, MWH	131,000	263,000	526,000	263,000	526,000
2	Supv., Oper. & Maint. Labor	500	500	500	500	500
3	Contract Maintenance	6	11	23	11	23
4	Radiation Protection	1	1	1	1	1
5	Operating & Maintenance Supplies	128	135	150	135	150
6	Chemicals & Resins*	2	148	291	5	9
7	Waste Disposal	1	3	5	3	5
8	Communications	2	4	8	4	8
9	Consulting Services	5	5	5	5	5
10	Subtotal	$645	$807	$983	$664	$701
11	Overhead on Total @ 10%	60	80	100	80	100
12	Total O&M	$705	$887	$1083	$744	$801
13	Unit Cost, Mills/kwh @ 60% C.F.	5.38	3.37	2.06	2.83	1.52

*Includes Moderator Make-Up for OCMR.

TABLE 18

ESTIMATED ANNUAL COST OF NUCLEAR INSURANCE

Thousands of Dollars

Line		PWR-CNSG	OCMR		BWR	
		25 MW	50 MW	100 MW	50 MW	100 MW
1	Net Energy Send-Out, MWH	131,000	263,000	526,000	263,000	526,000
2	Nuclear Liability Insurance*	40	46	74	54	74
3	Nuclear Indemnity Insurance	2	5	9	5	11
4	Total, Nuclear Insurance	$42	$51	$83	$59	$85
5	Unit Cost of Insurance, Mills/kwh	0.32	0.19	0.16	0.22	0.16
6	10-Year Average Unit Cost, Mills/kwh	0.32	0.19	0.16	0.22	0.16

*Includes credit for present worth of estimated reserve premium refund.

6.0 REDUCED ENERGY COSTS

6.1 Summary and Conclusions

General

In Section 5.0 the cost of energy was determined for small nuclear power stations under presently existing conditions. Although the estimated unit cost of energy from nuclear plants below 100 MWe is too high to compete with fossil-fueled stations except in unusual circumstances, this is in marked contrast to the attractively low costs anticipated for larger (300 MWe) nuclear power plants. The latter have become competitive with fossil fuels in many parts of the country. The differences in the fossil-vs-nuclear energy costs between small and larger power plants can be attributed to the high percentage of size-independent high cost items in nuclear power plants. These costs (which result from the need for special engineering analyses, complex regulatory requirements, and the relatively small scale of manufacturing operations), when spread over the annual energy production of a 500 MWe unit, add but little to the unit power cost. For example, if two additional engineers are required in a nuclear power plant to prepare reports required by the AEC, it adds over 0.1 mill to the unit power cost in a 50 MWe nuclear power plant but only 0.01 mill in a 500 MWe nuclear power plant.

An examination of the cost elements in Section 5.0 indicates that there are five areas susceptible to cost reductions, with the first four offering the greatest potential. They are:

1. The high capital cost of the Nuclear Island. Cost reductions can be achieved through development of a standardized nuclear island from one reactor vendor.

2. The cost arising from AEC regulations requiring extensive and time consuming studies and presentations for each application. Cost reductions can be achieved by acceptance of the standard Nuclear Island and by simplifying siting application requirements.

3. High labor costs arising from larger plant organization. Reduction in staff can be achieved by eliminating dual functions, by substantially reducing reporting activities presently required of the plant personnel, and by pooling certain service functions.

4. A plant capacity factor usually ranging from 50% to 60%. The costs of energy from nuclear plants, by virtue of their higher capital cost (and lower fuel cost) are more sensitive to plant capacity factor than those from a fossil-fueled plant. Therefore, improvements in plant capacity factor through pooling or interchange arrangements are essential for a nuclear plant.

5. Technological improvements, "stretch," and reduced fuel cycle costs offer additional reductions in capital and in operating costs. These reductions will probably not be as significant as the others outlined above.

The area and magnitude of cost reductions which can be realized by each of these factors are discussed in this section. While some of the potential savings may be achieved through the continued development and growth of larger nuclear power plants (greater than 100 MWe), in most cases positive action by the smaller utilities, including the construction and operation of nuclear power plants, is necessary in order to achieve the maximum projected cost savings.

Estimates of the achievable reductions in investment cost, fuel cost, operating and maintenance cost - resulting in reduced unit power costs - are presented for the same five cases covered in Section 5.0.

Summary of Reduced Capital and Power Generation Costs

Table 1 summarizes the reduced capital and power generating costs, for the five nuclear plants considered, that may be achieved by a major effort to achieve low cost nuclear power for the smaller utilities. To facilitate comparison with present unit energy cost, estimated in Section 5.0, the table is in the same form as that summarizing costs for single plants under existing conditions, as presented in Section 5.0. The major sources of cost reductions are those of multiple plant orders, provision for joint services, and regulatory simplifications. Additional savings are the result of technological improvements and reduced fuel costs resulting from larger nuclear fuel industry operation and consequent increased exploration for and development of new ore deposits. It can be seen by comparing the costs in Table 1 of this section with those in Table 1 of Section 5.0 that the reduction in power cost resulting from all of these factors is approximately equal to the reduction resulting from an increase in the plant factor from 60% to 80% for plants built under existing conditions. With a combination of increased plant factor and the other cost reductions, a power generation cost of about 6 mills is achievable for 100 MWe plants and a cost of about 8 mills is achievable for 50 MWe plants.

Further Cost Reduction Due to "Stretch"

In addition to the cost reductions resulting from the implementation of steps for joint action, technological improvements, regulatory simplifications, etc., there is the potential cost reduction arising from the "stretch" capability of the reactor. Stretch capability is nothing more than an initial "under-rating" of the reactor due to conservative design. In other words, a reactor rated at 100 MW may be expected to produce 115 MW after the initial operating period. This extra capability can be utilized by initially designing the turbine plant somewhat larger to accommodate the extra reactor capability. Clearly, the extra capability is worth money, because it permits deferment of installing additional generating capacity at some point in the future. Another way of evaluating stretch is to consider the extra capability as a saleable commodity. Either way, the extra capability produces an income to the utility, thus lowering power generation costs. Only a detailed analysis considering the electric system's load growth, existing generating facilities, power contracts, etc., can establish the true worth of stretch for each particular situation. In this study an approximation has been made, showing that at a 60% plant factor the cost reduction due to stretch amounts to nearly 0.2 mill/kwh.

Conclusions

The economic advantage - or lack of it - of a nuclear plant can be determined only by comparing the unit energy costs from the nuclear plant with that from the same size fossil-fueled plant. In the summary of Section 5.0, it was stated that a reasonable yardstick for unit energy costs from a fossil-fueled plant ranges from 7 mills/kwh for a 100 MW station to 11 mills/kwh for a 25 MW station. (There are always exceptions to this, of course.) From Table 1, it can be seen that, even after a substantial cost reduction program, at a 60% plant capacity factor, only nuclear plants above 50 MW can achieve unit energy costs that approach those of a fossil-fueled plant. If an 80% plant capacity factor can be achieved, the unit power costs of the 100 MW plants fall well below the 7 mills/kwh yardstick, and even the 25 MWe nuclear plant will "compete" with a fossil-fueled plant with a unit power cost of 11 mills/kwh. This latter conclusion is somewhat optimistic since at an 80% plant capacity factor the unit power cost for the fossil plants would also be reduced. Nevertheless, it is safe to conclude that achievement of the "Reduced Power Costs" and an 80% plant capacity factor for nuclear power plants in the 50 to 100 MWe range will result in these plants showing a decided economic advantage over fossil-fueled units in many parts of the country. Only very special circumstances, however, would result in a 25 MWe nuclear power plant showing a similar economic advantage.

6.2 Cost Reductions Through Joint Action

General

It was indicated earlier that if the smaller utilities would jointly purchase several identical nuclear plants and jointly perform some of the special functions required for nuclear power plants, substantial cost reductions could be achieved. This would result from spreading the size-independent costs associated with nuclear power over several units, thus reducing the cost for each unit.

It has been hypothesized that the interested utilities would first set up an ad hoc committee together with other interested participants, followed later by incorporation of the utilities into a group for joint action, as the mechanism by which this joint participation would be accomplished. It has been assumed that the group would be composed of five electric utilities each requiring new generating capacity of about the same size within the same time period (e.g., 1970 - 1972). Through the group the utilities would engage one engineering firm to prepare specifications for five substantially identical nuclear islands, evaluate the bids and select the single most suitable contractor for this portion of the power plant. The remainder of the power plants, exclusive of the Nuclear Island, could also be contracted through the group or could be contracted separately by each of the utilities using its normal engineering and business practices. The group would represent the utilities in dealing with the Atomic Energy Commission and other regulatory agencies as may be appropriate, both during plant construction and during subsequent plant operation. It would secure consulting services, coordinate and monitor radiation protection activities, and arrange for joint purchasing of nuclear fuel elements and other fuel cycle services.

Joint Action Before Operation

1. Joint Plant Purchases

   The area of greatest potential cost reduction through joint action by several utilities is that of a multiple plant order. If several utilities place a joint order for identical nuclear islands from a single reactor vendor, a substantial price reduction per nuclear island can be made by the reactor vendor. This reduction results from reduced costs on the part of the nuclear island supplier, due to:

a. Reduced costs for equipment such as reactor vessels, control rod drives, etc., due to multiple orders.

b. Reduced nuclear engineering and project management costs (including assistance in licensing and training).

c. Reduced architect-engineer costs for identical (or nearly identical) reactor and auxiliary buildings.

In addition, the utility's costs for liaison engineering, for obtaining licenses and permits from the AEC, and for personnel training would be appreciably reduced. Nuclear fuel costs would be reduced because of lower fabrication costs due to the increased scale of operations and reduction of reprocessing costs by combining batches of spent fuel.

The principal manufacturer of organic reactors has estimated that for a 50 MWe power plant one order of five identical nuclear power plants will reduce each plant by 21% to 25% of the cost for a single plant of this type; for 100 MWe OCMR power plants the savings under similar circumstances are 15% to 19%. Although there is a small (about 4%) decrease in the reactor equipment cost, the major savings are in engineering costs, project management costs and distributable construction costs resulting from a foreshortened construction schedule for the second and subsequent units of the series. This assumes that the units start up at about 6-month intervals.

Similarly the principal boiling water reactor manufacturer has estimated a 12 to 15% decrease in investment costs resulting from a multiple order of five to ten BWR power plants. As with OCMR reactors, there is only a 4% decrease in equipment costs, the major decrease being due to a reduction in engineering and design costs.

2. Joint Fuel Element Purchase

For OCMR power plants in the range from 50 to 100 MWe, it has been estimated that nuclear fuel fabrication costs can be reduced by about 33% when fabricating fuel for five identical plants rather than for one; spent fuel reprocessing costs for these plants would be reduced by 20 to 25% if spent fuel from five plants could be combined and reprocessed together (based on the conservative fuel cycle assumptions). The overall effect for OCMR power plants is a reduction of fuel cycle costs by 0.40 to 0.45 mills/kwh.

The fuel assemblies for 50 MWe and 100 MWe BWR power plants are sufficiently similar to those employed in larger BWR plants so that fabrication costs for a single BWR already reflect, to some extent, a substantial scale of operations due to the large number of large BWR plants presently on order. The 100 MWe plants show a further reduction in fabrication costs, below present values, of about 10% by 1977 because of further increases in fabrication load.

It is not unreasonable to assume that fuel fabrication costs for 50 and 100 MWe BWR power plants would show an additional 10% reduction if orders were placed for five identical plants. In addition, reductions in fuel reprocessing cost of about 20 to 25% can be achieved by combining the output from five reactors. The overall effect for BWR plants is a reduction of about 0.3 mill/kwh.

3. <u>Joint Licensing and Safeguards</u>

Apart from savings which could be realized by regulatory simplifications, it is anticipated that certain savings in the costs for licensing and safeguards review could be made through joint action. For example, it might be possible to have the nuclear island pre-licensed. This could be accomplished by presenting to the AEC the portion of the safety analysis reports dealing with the "identical" reactor and nuclear island separately from the portions dealing with the site and the balance of the plant. Thus one group of the regulatory staff and one Atomic Safety and Licensing Board might be assigned to review the safety of the nuclear island. For five "identical" nuclear islands, however, it is not expected that the cost per plant of preparing the nuclear island information would necessarily be one-fifth of that for a single plant. This is based on the assumption that the application for pre-licensing the nuclear island would receive closer scrutiny, with more questions being raised, than would be the case for a single plant. This cost, however, would be spread over five plants.

Much of the work of preparing descriptions for the balance of the power plant, site characteristics, etc., would be prepared by the group staff, working closely with the individual utilities, their architect-engineers and the reactor vendor. Some of the information would have to be generated for each site; other information might be useable for more than one site. In any event, having one group responsible for gathering ecological, hydrological and meteorological data for each site, for preparing the facility and site descriptions, and for computing radiological doses, would result in some savings because of the increase in efficiency after the first such site report had been prepared. The group could later form a cadre for conducting operator training programs and providing continuing consulting services on fuel cycle management, health physics, etc.

It is estimated that the licensing and compliance cost per unit could be reduced to one-half of the cost for a single unit, if five identical units were procured through the group. This estimated saving takes no credit for any regulatory simplifications. In fact, it assumes that the effort required to get the reactor pre-licensed would be double that for a single plant.

However, if both multiple unit procurement and regulatory simplification were accomplished, the savings would not necessarily be additive.

4. <u>Personnel Training</u>

It is expected that most of the plant management, engineers, operating and maintenance personnel for a nuclear power plant would be drawn from a utility's personnel, experienced in the operation of conventional fossil-fueled units. The training program to equip them to take over operation of a nuclear station would consist both of classroom instruction and operational experience at a nuclear power plant.

Generally all plant personnel should receive some training in radiation protection. Engineers receive rather extensive training in reactor operations, radiation protection and coolant chemistry. All control operators and their supervisors must receive AEC reactor operator's licenses. Operators must become familiar with normal and emergency plant operations. The operators should receive both orientation training (familiarization with the plant organization, manuals), and operating experience under the supervision of a shift foreman experienced in nuclear power plant operation.

Maintenance personnel should receive training and experience in the radiation protection aspects of their work.

Some reactor vendors provide a training program for utility personnel as a part of their scope of supply. The savings in personnel training costs through the group would not be very large. A major portion of personnel training costs consists of salaries, transportation and expenses of employees during the training period. These costs remain fairly constant as long as the number of personnel, course content and training duration are the same. Some savings might be realized through the use of a common course of instruction, instructors and training equipment. Also, certain common services would be provided through the group, which would reduce the number of required plant personnel. It is estimated that a savings of 10% in the cost of personnel training might be realized in this manner.

Aside from cost savings, certain other advantages would accrue through joint action. After the first nuclear power plant had been started up, it would be possible to assign several key operating or supervisory personnel from each of the other utilities to the first station. This would give them experience in operating a reactor identical to that which they would operate later. Also, it might become economically feasible to acquire a reactor simulator for use in training operating personnel for all five plants. It probably would not be economical to obtain a reactor simulator for training the operators for a single station.

Joint Action During Operation

1. Waste Disposal

On-site facilities are provided for the collection, processing, storage or disposal of radioactive liquid wastes. Similarly, facilities are provided for the treatment, monitoring, hold-up and dispersal of gaseous effluents.

Temporary on-site storage is provided for low-level solid wastes generated during operation of a nuclear power plant. These radioactively contaminated solid wastes generally consist of paper, rags, defective parts, insulation material and spent radioactive waste filter elements. The amount of such materials accumulated may amount to 500 to 1000 cu ft per year. These low-level wastes usually are disposed of by land burial. The volume of contaminated solid materials generated can be handled by approximately one truckload per year. The U. S. AEC will not license the disposal of wastes on land not owned by the State or Federal Government. At the present time a number of private firms are licensed either by the State or Federal Government to handle low-level wastes. Three firms provide land burial services. Due to the relatively small volume of solid wastes accumulated and the availability of commercial firms offering such land burial services, it is not felt that the group should attempt to perform waste disposal services for the member utilities. However, it might be possible to negotiate a somewhat lower charge for solid waste disposal through the group, by taking advantage of the larger volume of business represented by a group of utilities. It is estimated that this saving might amount to 15% of the annual cost of solid waste disposal.

2. Radiation Protection

The plant organization for a nuclear power station usually includes a health physicist or radiation protection engineer plus a health physics technician. If five identical plants were procured through joint action it would be possible to eliminate the health physicist from each plant organization, and use one health physics consultant instead. This health physics consultant would be available for consulting at any time and would visit each of the plants approximately once a month. If this were done, it is estimated that annual savings of $6,000 could be realized in the cost of radiation protection for each plant.

As a part of the radiation protection program, plant operating personnel are issued a film badge and a pocket ionization chamber to measure individual exposures to various ionizing radiation. Most nuclear power plants presently use a commercial firm for processing these film badges and mail the film packets to the firm. This is probably more economical than having the group take on this responsibility.

3. Fuel Cycle Management

With respect to fuel cycle management, the principal function of the group is the coordination of the purchase of fuel elements (including ore purchase, conversion to UF and fabrication) and the other fuel services (shipping, reprocessing and disposal of recovered plutonium) in order to obtain the maximum cost saving from the increased scale of operation.

The group staff would include a nuclear engineer to provide consultation on special nuclear problems as they arise at the operating plant. One of the consultant's duties would be to receive the records from each plant on reactor operating power, control rod patterns, etc., and to perform computer calculations on fuel element depletion. These computations would be used to optimize the fuel cycle program so that the lowest overall generation cost is achieved by the utilities. This work would include optimization of the fuel loading and unloading schedules, ore procurement, fuel fabrication and spent fuel processing. In addition, this consultant would generate the information necessary for reports to the U. S. AEC on all receipts, transfers and inventories of fissionable materials. Such accounting of nuclear materials will be required of licensed users of special nuclear material.

Among the nuclear consultants' early duties would be participating in the preparation of safety analysis reports and planning the training program for plant operating personnel.

Nuclear consulting services are available from a number of the reactor vendors, in addition to private consultants. Probably very little, if any, savings would be effected by having a consultant on the group staff. However, the utilities probably could receive more immediate and detailed attention to their specific problems from their own consultant -- who will be intimately familiar with their own problem -- than by employing an outside organization. The staff nuclear consultant would be more intimately familiar with the operations and requirements of the member utilities.

6.3 Other Cost Reductions

Technological Improvements

Because of the three-to-four year period required for the design, fabrication, construction and startup of a nuclear power plant, it is clear that a plant whose production is required by 1970 must be ordered in 1966, and the investment cost, therefore, will reflect present technology. Moreover, in the absence of a market for nuclear power plants with capacities less than 100 MWe, only minor technological improvements -- those which can be achieved as spin-offs from the large nuclear power plant developments -- can be anticipated in the next few years. Although certain technological improvements which are achieved for large nuclear power plants can also be applied to plants of smaller capacities (for example, development of improved instrumentation and control systems, elimination of certain standby systems), many of the technological improvements developed for larger nuclear power plants are not applicable to plants of less than 100 MWe capacity. (For example, jet recirculation pumps recently introduced for large Boiling Water Reactors are not applicable for plants of 100 MWe or less which employ natural circulation.)

Although investment costs of plants constructed for operation in the early 1970's are of necessity based on present technology, certain technological improvements which result in decreased fuel or operating and maintenance costs can be incorporated into an operating plant. One example of this latter type of technological improvement is the development of a "coolant reclaimer," for organic-cooled reactors, which will regenerate useable organic coolant from the high boiler material, presently a waste product. Provision could be made in the plant layout for the later installation of a coolant reclaimer, which would result in a net reduction in operating costs of about 0.3 mill/kwh.

Fuel Cost Savings

It is generally anticipated that decreases in nuclear fuel cost will be realized during the useful plant life of any nuclear power plant coming into operation within the next few years. These predicted savings have three bases: (1) technological improvements, (2) cost reduction due to larger scale operations and (3) long term cost trends for uranium ore and the value of by-production plutonium produced. These factors are discussed below.

During the early period of nuclear power development there were major technological improvements in the nuclear fuel cycle. These included the development of uranium oxide fuel material, the development of zirconium alloys for fuel cladding, the development of fabrication techniques which permit long fuel exposures without loss of structural integrity, the development of fuel management schemes (such as multi-zoned cores with fuel shuffling) which resulted in a more uniform power distribution and a longer reactivity lifetime for the fuel. Developments are still proceeding in most of these areas; for example, development of vibratory compacted fuel elements -- as contrasted to pelletized fuel -- and the use of fluoride volatility techniques for spent fuel reprocessing. A continuation of the substantial cost reductions in fuel cycle costs due to technological improvements cannot be expected, but it is not unreasonable to anticipate that technological developments will result in a further reduction of overall fuel cycle costs of about 0.1 to 0.2 mill/kwh.

The second basis for appreciable fuel cost savings in the future is that of an increased scale of fuel fabrication and reprocessing. For example, certain firms engaged in fuel fabrication have predicted that a 10-fold increase in the annual through-put of a fuel fabrication plant would lead to a $50/Kg reduction in the cost of fabrication of fuel assemblies. This decrease is equivalent to approximately 0.35 mill/kwh for fuel with a 20,000 MWD/ton burnup. Similar decreases can be expected in the cost of spent fuel reprocessing, the unit cost of which is quite sensitive to plant capacity and batch size.

Finally there is the more speculative type of fuel cycle cost decreases which involve factors such as the cost of uranium ore. The present average cost to the U. S. AEC for uranium ore (as yellow-cake) is $8/lb of contained U_3O_8, but the present free world market price is less than $5/lb. Certain fuel-cost prognosticators claim that this $5/lb cost is typical of the long term price of uranium ore (excluding effects of inflation) and that the exhaustion of present reserves of low cost ore by the expanding nuclear power industry will be more than offset by the discovery of new uranium ore deposits. An opposing school of thought holds that it is unduly optimistic to predict discovery of major new sources of readily recoverable uranium ore. Consequently they predict that the cost of uranium ore will, in fact, rise as the low cost supplies are consumed during the 1970's and 1980's, so that uranium costs will rise to $10 to $12/lb of U_3O_8 before the end of the century. The fuel cost estimates contained in Section 5.0 are based upon this more conservative assumption; the average cost of uranium ore during the life of the plant was assumed to be $8/lb.

Another area of potential fuel cycle cost reduction which falls in the speculative category, is the value of the plutonium produced in the reactor. Although there is general agreement that fissile plutonium has a value of approximately 80% of the cost of highly enriched uranium for use in a thermal reactor (like a BWR, PWR or OCMR), its value is undoubtedly considerably higher for use in a fast breeder reactor.

In evaluating this reduced fuel cycle cost, as summarized in Table 1, only the effects of increased scale of operations on fabrication, UF_6 conversion and spent fuel reprocessing, as well as the assumption that the cost of uranium ore remains at its present $4.50 to $5.00/lb level, were included. The other factors, should they be realized, would result in further reductions of fuel cost over the plant lifetime.

Regulatory Simplifications

Regulatory simplifications could affect the cost of power in two ways. The first is the capital cost of the power plant, which includes the cost of obtaining the construction permit for the facility and of obtaining an operating license. The second area of costs which could be affected by regulatory simplifications is "compliance" after the facility has gone into operation. The cost of satisfying the AEC Division of Compliance that the facility is being operated in a safe manner is an operating expense.

Before a utility can commence construction of a nuclear power plant, it is necessary to obtain a construction permit from the AEC, in addition to the customary building permits and licenses. Information prepared by the reactor vendor, architect-engineer and the utility owner is assembled into a "Preliminary Safety Analysis Report." This report is submitted by the utility to the AEC along with its request for a construction permit. Presently, three different groups within the AEC are primarily involved with reviewing the safety of a proposed nuclear power plant. The first such group is the "Advisory Committee on Reactor Safeguards (ACRS)". The ACRS is charged by statute with the mandatory requirement of reviewing every proposed nuclear power plant for safety. The second group is the regulatory staff of the Division of Reactor Licensing. This regulatory staff makes a detailed review of the safety characteristics of a proposed nuclear power plant. The third group is the "Atomic Safety and Licensing Board." The Board holds public hearings on the safety of a proposed facility. This Board performs a quasi-judicial function in conducting these hearings, hearing testimony from the regulatory staff, the applicant and any intervenors who may be protesting the safety of the proposed facility.

After the construction permit has been granted and the plant construction is nearing completion, the utility makes application for an operating license. Before the operating license is granted it is necessary for the applicant to submit a "Final Safety Analysis Report" together with the "Technical Specifications" for the facility. The Final Safety Analysis Report contains much the same information as that required for the Preliminary Safety Analysis Report. Both reports describe the reactor, the site, various hypothesized accidents and the consequences of these accidents on public and plant safety. The Technical Specifications contain a detailed listing of the plant design specifications and operating parameters.

To date, each of the above groups, the ACRS, the regulatory staff, and the Atomic Safety and Licensing Board have tended to make their own independent appraisal. This has resulted in a multiplicity of safety reviews which has imposed a considerable burden and expense on the applicant for a construction permit or operating license. Further, during the course of these multiple reviews many questions are generated which must be satisfactorily answered by the applicant or his consultants.

Further, even after the utility has obtained an operating license, a considerable continuing effort must be devoted to acquisition of data, preparation of routine reports, and visits by representatives of the AEC's Division of Compliance. It is estimated that at the present time this can amount to the equivalent of three man-years of effort per year in order to satisfy compliance requirements.

In 1965, the AEC appointed a seven-man panel to review the Commission's licensing and regulation responsibilities, and the decision-making process in the AEC regulatory program. Among the major recommendations of the Regulatory Review Panel were:

1. The primary responsibility for making a detailed review of the safety of the proposed facility should be vested in the regulatory staff.

2. The ACRS should be relieved of its statutory obligation to review every proposed plant. It should devote its efforts to establishing criteria and standards, and to reviewing non-routine applications.

3. The hearing board should not attempt a thorough-going review of the safety of a proposed plant. It should merely satisfy itself that the regulatory staff has adequately reviewed the application, and hear testimony from interested parties.

4. The contents of safety analysis reports and technical specifications should be simplified and restricted to matters relevant to safety.

It was estimated that, if the preceding recommendations were put into effect, the minimum time required to obtain a construction permit might be reduced from one year to six months. The AEC has already requested legislation to eliminate the mandatory ACRS review.

It is estimated that regulatory simplifications could reduce the cost of licensing to approximately one-half of present costs.

In the area of compliance, certain reductions could be expected if greater latitude were given in plant parameters, and if the routine reports were limited to essential information. Further, the utilities should be given the opportunity to take more responsibility for compliance. It is estimated that a savings of one-third, or the equivalent of one man-year per year, might be realized through such regulatory simplification.

Stretch Capability

Nuclear power plants constructed to date have demonstrated a capability of achieving appreciably higher power densities and power outputs than their initial rating. This capability has been termed "stretch." It results from a combination of factors. The first is the margin which the designer provides between the design point and the warranted rating. Another factor is that, after one or two years' operation, the coolant flow and neutron flux distribution within the core will have been accurately determined by actual measurement. Experience has shown that design factors assumed by the designer to account for these distributions have been more conservative than those measured during actual operation. Therefore, it has been possible to increase the core output without increasing the upper limits on core design parameters. Finally, it may become possible to increase the operating limits for certain parameters as more operating experience and experimental data are acquired.

It is estimated that presently offered nuclear boilers have a potential maximum stretch capability of 15%. It is reasonable to assume that the turbine plant equipment will be capable of exceeding nameplate ratings by 5%. Thus, if advantage is to be taken of the potential uprating of the nuclear boiler, the initial ratings of the turbine plant equipment will have to be increased by approximately 10%. Certain reactor auxiliary systems also will have to be designed initially to accommodate the anticipated increase in power output. These systems include those such as the shutdown cooling, safety injection and emergency cooling systems whose ratings are established by reactor decay heat. The reactor decay heat, produced by radioactive decay of fission products in the core, is directly related to reactor power.

6.4 Reduced Energy Costs

General

Previously, several areas were discussed where energy costs for plants of less than 100 MWe capacity can be reduced as a result of a cooperative effort by the utilities, and the anticipated cooperation of the Atomic Energy Commission and the reactor manufacturers, should a real market develop for plants of this capacity. A re-estimate of the cost of energy was prepared for the same five cases examined in Section 5.0, assuming that there would be such a cooperative effort and that the benefits described above would be realized.

In the estimates of "Reduced Energy Costs," the plant designs and technical characteristics are identical to those of the plants described in Section 5.0. The cost estimates, moreover, were prepared on the same bases as those in Section 5.0, except for those specific areas in which cost reductions were anticipated because of multiple plant orders, anticipated regulatory simplifications, etc. The reduced investment costs, nuclear fuel costs, operating and maintenance costs, and the resulting total unit power generation costs are tabulated and explained below. In addition, a minimum value for savings due to stretch capability of the reactor is also derived.

Investment Costs

The reduced values of investment cost are shown for the 25 MW PWR power plant on Table 2, for the 50 MW and 100 MW OCMR power plants on Table 3, for the 50 MW and 100 MW BWR on Table 4. It can be noted from these tables that the only Direct Construction Cost accounts which differ from the corresponding estimates under "existing conditions" (see Section 5.0, Tables 5, 6, and 7) are Accounts 322 and 398, "Reactor Plant Equipment" and "Distributable Construction Costs," respectively. Within Account 322, the cost of the equipment items within the Nuclear Island (see Section 5.0, Table 2) was reduced by about 4%, to reflect an order for five identical plants; the "Nuclear Engineering Costs," Account 322.8, were reduced to about one third of that for a single plant. The latter was estimated by assuming the first plant of the five would have the same nuclear engineering and management costs as a single plant order and that these costs for the remaining four plants would be reduced to about $300,000 each; it was further assumed that the savings achieved in this manner would be distributed evenly among the five units. The Distributable Construction Costs, Account 398, for the Nuclear Island were reduced by about 25% to account for the reduced construction schedules (were a corresponding reduction in field overhead) and somewhat more efficient construction techniques on the second and subsequent identical units.

The cost of architect-engineer (A-E) services, Account 393, for each of the Nuclear Islands subsequent to the first of the plants, was estimated to be approximately $50,000 for adaption to the various sites; the savings for this items were assumed to be distributed evenly among the five units. The cost of A-E services for the non-nuclear portion of the plant was reduced by about $110,000 compared to the costs estimated for a single unit. For the single plant, this item included the cost of preparation of specifications and bid documents for the Nuclear Island, bid evaluation and Nuclear Island Contractor selection, and coordination of the Nuclear Island design within the remainder of the plant. For the multiple unit order, this work would be performed by the engineers and the cost for each of the five plants reduced substantially.

The computation of Owner's Costs, Account 399, for the reduced power cost case is shown on Table 5. Account 399.1, "Interest on Debt During Construction," is reduced for two reasons: (1) construction and engineering costs are reduced and (2) because of the shortened construction period, the equivalent interest rate is also reduced. Accounts 399.2, 399.3 and 399.4 were all reduced somewhat because of the savings attributed to coordination of all of the work associated with the Nuclear Island. The cost attributed to Operator Training, Account 399.5, was reduced by virtue of the reduced staff requiring training (see "Operation and Maintenance Costs" below); similarly, the start-up costs and cost of efficiency and capability tests were reduced because of the reduced annual operating expense. The overall reductions in Owner's Costs are 25% to 35%.

The other items of Capital Cost, Contingency and Non-Depreciable Costs, are unchanged from the cost estimates under existing conditions.

Nuclear Fuel Costs

Tables 6 through 10 show the reduced nuclear fuel costs for the 25 MW PWR plant, the 50 MW OCMR, the 100 MW OCMR, the 50 MW BWR and the 100 MW BWR, respectively. These reduced costs result from multiple plant purchase, joint arrangements for fuel cycle services and optimistic assumptions as to uranium ore cost and fuel reprocessing costs. Thus, the fuel cycle cost elements are similar to those shown in the "optimistic assumptions" column of Section 5.0, Tables 8, 10 and 13, except that the fabrication costs were reduced as a result of the increased volume when fabricating fuel for five identical plants. The overall fuel cycle cost reductions from those for a single plant using conservative assumptions, and for multiple plants using the more optimistic fuel cost assumptions, range from 0.5 to 0.8 mills/kwh.

Operation and Maintenance Costs

With the assumed simplification in AEC regulatory requirements, increasing familiarity with nuclear power by the utilities, additional automation, coordination of regulatory compliance and provision of joint radiation protection services, substantial reductions in plant staffing requirements can be achieved. Table 11 shows a Plant Manning Table under these assumed conditions. It can be noted, by comparison with Section 5.0, Table 16, that the total plant staff can be reduced from 47 to 29 and annual payroll costs reduced from $500,000 to $300,000. Total estimated annual Operations and Maintenance Costs for these reduced cost conditions are shown in Table 12. The only additional cost reduction, in addition to payroll, is that of chemical and resin costs for the OCMR power plants.

It was assumed that the cost of organic make-up for these plants will be halved as a result of successful completion of the development (now in progress) of a high-boiler-residue reclaimer and/or reduction of the cost of organic coolant make-up as a result of the greatly increased market. The annual cost of "Consulting Services," $10,000, represents a prorated share of the cost of joint services.

Unit Energy Costs

The annual fuel cycle costs, annual operation and maintenance costs, fixed charges on capital investment and annual nuclear insurance costs -- the latter unchanged from the costs shown in Section 5.0, Table 18 -- are combined in Table 1 to obtain the Total Annual Cost of the busbar, and corresponding Unit Power Cost. The basic estimates were prepared for a 60% plant factor. By assuming that the unit cost for nuclear fuel is unchanged when the plant factor is changed from 60% to 80% and that the other unit costs are inversely proportional to plant factor, the unit energy costs for 80% plant factor shown at the bottom of Figure 1 were computed.

Stretch Capability

Previously in this section, the potential power capability increase due to stretch in the reactor was discussed. It was also pointed out that a rigorous analysis of the cost and benefits of stretch would have to be made for each specific case. It is possible, however, to make an approximate evaluation of potential cost reduction achievable through the stretch capability of the reactor, based on the fact that extra power capability -- even in the absence of any energy generation with that extra capability -- is a saleable commodity and, hence, has a value. Using an annual capability credit of $10/kw, the annual income can be computed and expressed as a reduction of the unit cost of power. This has been done in Table 13 based upon the following assumptions:

1. A 15% stretch in power production capability.

2. The incremental capital cost for the reactor plant is assumed to be $5/kw for the PWR and the BWR, and $10/kw for the OCMR.

3. A 10% increase in rating of turbine plant can accommodate the 15% reactor stretch.

4. The incremental capital cost of the turbine plant and associated equipment to accommodate nuclear boiler stretch is $60/kw, but only for two thirds of the total capability increase.

5. Annual operating and maintenance costs after stretch remain the same as for the initial rating.

6. The nuclear fuel costs, in mills/kwh, remain constant.

7. Annual nuclear liability and indemnity insurance cost increases are small and can be neglected.

As can be seen, the income from the stretch -- even though it is not generating energy -- is worth nearly 0.2 of a mill/kwh at 60% plant factor. In other words, the unit power costs could be reduced by that amount. When energy is generated with this additional capability, maintenance and other costs would have to be increased slightly. The incremental kwh generated with the extra capability would also be lower in cost because the capital cost component of the energy cost would be lower. It should also be noted that when the annual income due to stretch is divided by the annual net energy send-out at 80% plant factor, the cost reduction per unit of power generated is three quarters of that at 60% plant factor.

TABLE 1

REDUCED COSTS
SUMMARY OF CAPITAL AND POWER GENERATING COSTS

(Capital and Annual Costs are in Thousands of Dollars)

		PWR-CNSG	OCMR		BWR	
		25 MWe	50 MWe	100 MWe	50 MWe	100 MWe
	Capital Costs					
1.	Depreciable Capital Costs (w/o Fuel)	$12,450	$15,700	$21,400	$16,700	$24,800
2.	Non-Depreciable Cap. Costs (w/o Fuel)	150	250	400	230	350
3.	Total, Capital w/o Fuel	$12,600	$15,950	$21,800	$16,930	$25,150
4.	Unit Capital Cost, $/KW Net	510	320	220	340	250
5.	Non-Dep. Capital for Fuel	1,230	1,840	3,490	2,350	5,000
6.	Total Capital Required	$13,830	$17,790	$25,290	$19,280	$30,150
	Annual Costs					
7.	Depr. Capital (Line 1) @ 7.75%	965	1,236	1,659	1,312	1,949
8.	Non-Dep. Capital (Line 2) @ 5.54%	8	14	22	12	20
9.	Fuel Cycle Cost (10-Year Average)*	317	602	1,157	739	1,399
10.	Operation & Maintenance	500	589	717	519	566
11.	Nuclear Insurance	42	51	83	59	85
12.	Total Annual Cost	$ 1,832	$ 2,492	$ 3,638	$ 2,641	$ 4,019
	Unit Power Generation Costs, Mills/kwh					
13.	Annual Net Energy Send-Out @ 60% P. F. Million KWH	131	263	526	263	526
14.	Unit Cost for Plant, Mills/kwh	7.43	4.75	3.19	5.03	3.74
15.	Unit Cost for Fuel Cycle	2.42	2.29	2.20	2.81	2.66
16.	Unit Cost for Operation & Maintenance	3.82	2.24	1.36	1.97	1.08
17.	Unit Cost for Nuclear Insurance	0.32	0.19	0.16	0.22	0.16
18.	Total Unit Energy Cost	13.99	9.47	6.91	10.03	7.64

*Based on Optimistic Assumptions

	Unit Power Generation Costs at 80% PF, Mills/kwh					
19.	All Unit Cost Except Fuel Cycle	8.67	5.38	3.53	5.41	3.73
20.	Unit Costs for Fuel Cycle**	2.42	2.29	2.20	2.81	2.66
21.	Total Unit Energy Cost	11.09	7.67	5.73	8.22	6.39
	Unit Power Generation Costs Reduced by Stretch, Mills/kwh					
22.	Total Unit Energy Cost @ 60% P. F.	13.81	9.30	6.74	9.84	7.45
23.	Total Unit Energy Cost @ 80% P. F.	10.95	7.54	5.60	8.08	6.25

**Effect of Increased plant capacity factor upon fuel inventory has been excluded.

NOTE: PF = Plant Capacity Factor

TABLE 2

REDUCED COSTS
SUMMARY OF CAPITAL COST FOR 25 MW PWR

Thousands of Dollars

	25 MW PWR-CNSG		
	Nuclear Island	Non-Nuclear Plant	Total
A. Depreciable Items			
321 Structures & Improvements	$ 660	$ 910	$ 1,570
322 Reactor Plant Equipment	4,180	420	4,600
323 Turbine-Generator Equipment	--	1,855	1,855
324 Accessory Electrical Equipment	280	280	560
325 Misc. Power Plant Equipment	15	255	270
398 Distributable Construction Costs	400	300	700
Total Direct Construction Costs	$ 5,535	$ 4,020	$ 9,555
393 A-E Services	115	680	795
Total Before Owner's Costs	$ 5,650	$ 4,700	$10,350
399 Owner's Costs			970
		Total Before Contingency:	$11,320
		Contingency @ 10%:	1,130
		Total Depreciable Items:	$12,450
B. Non-Depreciable Items			
320 Land & Land Rights			95
Working Capital (Excluding Fuel Cycle)			55
		Total Non-Depreciable Items:	150
		Total Capital Costs:	$12,600

TABLE 3

REDUCED COSTS
SUMMARY OF CAPITAL COST FOR OCMR

Thousands of Dollars

	Organic Cooled and Moderated Reactor					
	50 MW			100 MW		
	Nuclear Island	Non-Nuclear Plant	Total	Nuclear Island	Non-Nuclear Plant	Total
A. Depreciable Items						
321 Structures & Improvements	$ 775	$ 960	$ 1,735	$ 925	$ 1,160	$ 2,085
322 Reactor Plant Equipment	4,420	680	5,100	6,160	525	6,685
323 Turbine-Generator Equipment	--	3,290	3,290	--	5,265	5,265
324 Accessory Electrical Equipment	390	390	780	500	500	1,000
325 Misc. Power Plant Equipment	15	295	310	15	400	415
398 Distributable Construction Costs	600	500	1,300	650	800	1,450
Total Direct Construction Costs	$ 6,200	$ 6,115	$12,315	$ 8,250	$ 8,650	$16,900
393 A-E Services	160	885	1,045	160	890	1,050
Total Before Owner's Costs	$ 6,360	$ 7,000	$13,360	$ 8,410	$ 9,540	$17,950
399 Owner's Costs			1,110			1,490
Total Before Contingency:			14,470			19,440
Contingency (@ 8.5%):			1,230		(@ 10%):	1,960
Total Depreciable Items:			$15,700			$21,400
B. Non-Depreciable Items						
320 Land & Land Rights			145			220
Working Capital (Excluding Fuel Cycle)			105			180
Total Non-Depreciable Items:			250			400
Total Capital Cost			$15,950			$21,800

TABLE 4

REDUCED COSTS
SUMMARY OF CAPITAL COST FOR BWR

Thousands of Dollars

	Boiling Water Reactor					
	50 MW			100 MW		
	Nuclear Island	Non-Nuclear Plant	Total	Nuclear Island	Non-Nuclear Plant	Total
A. Depreciable Items						
321 Structures & Improvements	$ 875	$ 1,050	$ 1,925	$ 1,135	$ 1,260	$ 2,395
322 Reactor Plant Equipment	4,820	670	5,490	7,460	880	8,340
323 Turbine-Generator Equipment	--	3,975	3,975	--	7,270	7,270
324 Accessory Electrical Equipment	350	350	700	460	460	920
325 Misc. Power Plant Equipment	15	315	330	15	365	380
398 Distributable Construction Costs	600	600	1,200	650	900	1,550
Total Direct Construction Costs	$ 6,660	$ 6,960	$13,620	$ 9,720	$11,135	$20,855
393 A-E Services	160	890	1,050	160	895	1,055
Total Before Owner's Costs	$ 6,820	$ 7,850	$14,670	$ 9,880	$12,030	$21,910
399 Owner's Costs			1,210			1,610
Total Before Contingency:			$15,880			$23,520
Contingency (@ 5%):			820		(@ 5.5%):	1,280
Total Depreciable Items:			$16,700			$24,800
B. Non-Depreciable Items						
320 Land & Land Rights			145			220
Working Capital (Excluding Fuel Cycle)			85			130
Total Non-Depreciable Items:			230			350
Total Capital Costs			$16,930			$25,150

TABLE 5

REDUCED COSTS
ESTIMATE OF OWNER'S COSTS

Thousands of Dollars

Account No.	Item	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
399.1	Interest on Debt During Construction (5.0% of "Total Before Owner's Costs"*)	$ 520	$ 670	$ 900	$ 730	$1,100
399.2	Procurement, Accounting, Administrative	30	40	60	40	60
399.3	Liaison Engineering	90	90	90	90	90
399.4	Safeguards Report and Licensing	70	70	70	70	70
399.5	Operator Training	70	70	70	70	70
399.6	Start-Up Costs @ 35% of Annual O&M Costs	150	180	220	160	170
399.7	Efficiency & Capability Tests @ 20% of Item 399.6	30	40	50	30	30
399.8	Other Costs	10	20	30	20	20
	TOTAL ACCOUNT 399	$ 970	$1,110	$1,490	$1,210	$1,610

*Reflects shortened construction schedule.

TABLE 6

REDUCED COSTS
ANNUAL FUEL CYCLE COSTS FOR THE 25 MW PWR

Fuel Cost Assumptions: Optimistic and orders for Multiple Plants
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,900 Btu/kwhr		131	→	→	→	→	→	→	→	→	→
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $1,230,000		68	→	→	→	→	→	→	→	→	→
3	Other Fuel Cycle Costs, $/Yr		$295	$295	$254	$235	$235	→	→	→	→	→
4	Total Annual Fuel Costs, $/Yr	$317*	363	363	322	303	303	→	→	→	→	→
5	Unit Fuel Costs, Mills/kwh		2.77	2.77	2.46	2.31	2.31	→	→	→	→	→
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.42					

*10-Year Average.

TABLE 7

REDUCED COSTS
ANNUAL FUEL CYCLE COSTS FOR THE 50 MW OCMR

Fuel Cost Assumptions: Optimistic and orders for Multiple Plants
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,800 Btu/kwhr		263	———	———	———	———	———	———	———	———	→
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $1,840,000		102	———	———	———	———	———	———	———	———	→
3	Other Fuel Cycle Costs, $/Yr		$648	$579	$490	$461	$463	$471	———	———	———	→
4	Total Annual Fuel Costs, $/Yr	$602*	750	681	592	563	565	573	———	———	———	→
5	Unit Fuel Costs, Mills/kwh		2.85	2.59	2.25	2.14	2.15	2.18	———	———	———	→
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.29					

*10-Year Average.

TABLE 8

REDUCED COSTS
ANNUAL FUEL CYCLE COSTS FOR THE 100 MW OCMR

Fuel Cost Assumptions: Optimistic and orders for Multiple Plants
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 11,600 Btu/kwhr		526	→	→	→	→	→	→	→	→	→
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $3,490,000		193	→	→	→	→	→	→	→	→	→
3	Other Fuel Cycle Costs, $/Yr		$1,258	$1,106	$943	$896	$896	$912	→	→	→	→
4	Total Annual Fuel Cost, $/Yr	$1157*	1,415	1,299	1,136	1,089	1,089	1,105	→	→	→	→
5	Unit Fuel Costs, Mills/kwh		2.69	2.47	2.16	2.07	2.07	2.10	→	→	→	→
6	10-Year Average						2.20					

*10-Year Average.

TABLE 9

REDUCED COSTS
ANNUAL FUEL CYCLE COSTS FOR THE 50 MW BWR

Fuel Cost Assumptions: Optimistic and orders for Multiple Plants
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 13,100 Btu/kwhr		263	→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $2,350,000		129	→								
3	Other Fuel Cycle Costs, $/Yr		$628	$628	$634	$584	$586	$613	$621	$610	$605	$592
4	Total Annual Fuel Costs, $/Yr	$739*	757	757	763	713	715	742	750	739	734	721
5	Unit Fuel Costs, Mills/kwh		2.88	2.88	2.90	2.71	2.72	2.82	2.85	2.81	2.79	2.74
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.81					

*10-Year Average.

TABLE 10

REDUCED COSTS
ANNUAL FUEL CYCLE COSTS FOR THE 100 MW BWR

Fuel Cost Assumptions: Optimistic and orders for Multiple Plants
Plant Capacity Factor: 60%

Thousands of Dollars

Line	Item	Note	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	Net Energy Send-Out Millions KWH Average Heat Rate of 13,100 Btu/kwhr		526	→								
2	Average Annual Cost of Fuel Cycle Working Capital @ 5.54% of $5,000,000		277	→								
3	Other Fuel Cycle Costs, $/Yr		$1,164	$1,164	$1,164	$1,080	$1,085	$1,127	$1,133	$1,117	$1,106	$1,096
4	Total Annual Fuel Costs, $/Yr	$1399*	1,441	1,441	1,441	1,357	1,362	1,404	1,410	1,394	1,383	1,373
5	Unit Fuel Costs, Mills/kwh		2.74	2.74	2.74	2.58	2.59	2.67	2.68	2.65	2.63	2.61
6	10-Year Average Unit Fuel Costs, Mills/kwh						2.66					

*10-Year Average.

TABLE 11

REDUCED COSTS
PLANT MANNING TABLE - 25 - 100 MWe NUCLEAR PLANT

No. of Employees	Function	Rate	Annual Direct Cost, $/Year
	SUPERVISION		
1	Superintendent	$1300/mo	$15,600
1	Assistant Superintendent	$1100/mo	13,200
1	Secretary	$260/mo	3,100
		Subtotal	$31,900
	OPERATION (16)		
1	Nuclear & Results Engineer	$1000/mo	$12,000
1	Health Physics Technician	$650/mo	7,800
1	Lab Technician	$550/mo	6,600
4	Shift Supervisors	$200/wk	41,600
4	Reactor Operators	$164/wk	34,200
1	Relief Operator	$154/wk	8,000
4	Shift Helpers	$120/wk	25,000
		Subtotal	$135,200
	MAINTENANCE (10)		
1	Maintenance Foreman	$173/wk	9,000
1	Electronics Technician	$140/wk	7,300
1	Instrument Technician	$140/wk	7,300
1	Electrician	$150/wk	7,800
1	Insulator	$140/wk	7,300
2	Mechanics	$150/wk	15,600
1	Pipefitter	$150/wk	7,800
1	Helper	$120/wk	6,200
1	Utility Man	$100/wk	5,200
		Subtotal	$73,500
29			$240,600
	Payroll Additives @ 25%		60,100
		Total Payroll:	$300,700
		Use:	$300,000

Note: There are only 4 shift crews of 3 men each. Each crew works 5 days/week making a total of 20 shifts. Since there are 21 shifts per week the electronics and instrument technicians and the electrician are used as operators for 1 day (i.e., 1 shift) per week instead of working on maintenance.

TABLE 12

REDUCED COSTS
ESTIMATED ANNUAL OPERATION & MAINTENANCE COST (EXCL. FUEL)

Thousands of Dollars

Line		Note	PWR-CNSG 25 MW	OCMR 50 MW	OCMR 100 MW	BWR 50 MW	BWR 100 MW
1	Net Energy Send-Out, MWH		131,000	263,000	526,000	263,000	526,000
2	Supv., Oper. & Maint. Labor		300	300	300	300	300
3	Contract Maintenance		6	11	23	11	23
4	Radiation Protection		1	1	1	1	1
5	Operating & Maintenance Supplies		128	135	150	135	150
6	Chemicals & Resins*		2	75	150	5	9
7	Waste Disposal		1	3	5	3	5
8	Communications		2	4	8	4	8
9	Consulting Services		10**	10**	10**	10**	10**
10	Subtotal		450	539	647	469	506
11	Overhead on Total @ 10%		50	50	70	50	60
12	Total O&M		500	589	717	519	566
13	Unit Cost, Mills/kwh @ 60% C. F.		3.82	2.24	1.36	1.97	1.08

*Includes Moderator Make-Up for OCMR.

**Prorated Share of Costs of AFJA Services.

TABLE 13

ANNUAL COST SAVINGS DUE TO STRETCH CAPABILITY AT 60% PLANT CAPACITY FACTOR

Thousands of Dollars

Item	PWR-CNSG	OCMR		BWR	
	25 MW	50 MW	100 MW	50 MW	100 MW
1. Increase in Stretch Capability @ 15% MW	3.75	7.5	15	7.5	15
2. Additional Reactor Plant Investment	19	75	150	38	75
3. Additional Turbine Plant Investment @ $60/KW for 2/3 of the Capability Increase	150	300	600	300	600
4. Total Additional Investment	169	375	750	338	675
5. Annual Cost of Investment @ 7.75%	13	29	58	26	52
6. Annual Capability Credit @ $10/KW	37	75	150	75	150
7. Annual Income from Stretch, $/Yr	24	46	92	49	98
8. Annual Net Energy Send-Out @ 60% P. F. (Same as Before), Million KWH	131	263	526	263	526
9. Unit Cost of Income from Stretch, Mills/kwh	0.18	0.17	0.17	0.19	0.19

7.0 MARKET SURVEY

7.1 General

The objective of this section is to survey the smaller utilities to determine which, if any, might be "candidates" for a nuclear power plant. While the choice of "Nuclear" or "Fossil" may be influenced by many factors, the major consideration will be unquestionably an economic one. Consideration of a nuclear alternative in a system expansion study is basically an evaluation of alternate plant sizes and types to determine, by means of economic differences, which plant will show the lowest energy cost. As pointed out in the Introduction, such an economic comparison must be made, in detail, whenever a system expansion is considered. It is usually well worthwhile to go beyond the simple method of comparing nuclear and conventional units on a straightforward mills-per-kwh basis. A more sophisticated method consists of establishing the optimum loading pattern (i.e., economic dispatch) on unit incremental costs. This results in determining the plant loading; i.e., plant capacity factor, as a function of economic dispatch. If the system is large enough to have several units in operation, such a study may show a higher capacity factor for the nuclear unit than for a conventional unit.

7.2 Basis for Selecting Utility Candidates

For this Market Survey, "candidates" for a nuclear power plant can be found by a very simple process. This study assumes the new nuclear plant would start operation in 1970, hence all utilities whose load growth warrants the addition of a 100 MW unit are potential candidates. Since load forecasts are uncertain at best, it seems reasonable to use a five-year period; i.e., to say that all utilities whose load forecasts show the need for installing a 75 to 125 MW unit in any one of the years between 1968 and 1972 may be considered potential candidates.

The next step consists of examining the fuel costs currently paid by the potential candidates and to delete those whose fuel costs are too low to warrant consideration of a nuclear plant. This step presupposed a certain fuel cost as a "break-even" fuel cost. The break-even fuel cost can be established by estimating the unit cost of energy exclusive of fuel for a new conventional unit, and then adding a unit fuel cost of sufficient magnitude (the break-even fuel cost) to make the total unit energy cost from the conventional unit equal to the total unit energy cost from the same size nuclear unit. If fossil fuel costs for the utility are higher than the break-even fuel cost, the utility can be considered a candidate for nuclear power. The following calculations will make this method clear.

Cost Basis for a Conventional 100 MW Plant

	I	II
Fuel Burned	Gas	Coal
Type of Construction	Enclosed	
Average capital cost w/o switchyard, $/kw (El. World, 14th Steam Station Cost Survey)	$115	$140
Capital Cost, Thousands of Dollars	$11,500	$14,000
Average Net Plant Heat Rate, Btu/kwh	$11,000	
Annual Generation @ 60% PF, 10^6 kwh/yr	526	

Next, the costs for a nuclear power plant must be established. In this study, the costs obtained in Section 6.0, "Potential Cost Reductions," for the 100 MW OCMR will be used. Table 1 in Section 6.0 provides the unit power generation costs for municipal financing. Unit power generation costs for cooperative and private financing can be adjusted as shown in Table 2 of this section.

The next step consists of establishing the fossil fuel cost that will, when added to the other annual costs above, make the total unit energy cost from the conventional plant the same as that from a nuclear plant. (Refer to Table 3.)

Since it may be assumed that both gas and coal prices will increase during future years, it is not unreasonable to say that whenever a cooperative or public power potential candidate pays present gas prices of 30¢ per million Btu and present coal prices of 27¢ per million Btu, he might be included in the list of candidates. For an investor-owned utility the break-even fossil-fuel prices would be 43¢ per million Btu for gas and 37¢ per million Btu for coal.

7.3 Selection of Potential Utility Candidates

The last step consists of analyzing the load forecast for all utilities in the range of 44 to 125 MW units. This has been done in Table 4. A circle around the fuel cost indicates that the utility pays a fuel price high enough to be considered a potential candidate for a nuclear power plant.

7.4 Conclusion

The foregoing evaluation should be used with great caution. Load forecasts are subject to considerable changes with the passage of time. Moreover, there are considerable uncertainties that make a prediction as to future capacity conditions very speculative. The formation of pools, of inter-changes, etc., may well change the predictions made herein. For example, Public Service of New Mexico is shown to be adding a 100 MW unit in 1970. This may or may not happen depending on the extent to which that utility will draw on the very large power stations being installed by Western Energy and Transmission System, of which it is a member. On the other hand, this list does not include potential industrial generation. Moreover, the concept of looking for potential candidates might be expanded to include those in Canada. Also, the selection of "potential" candidates based upon fossil-fuel cost is, at best, only a first approach to finding interested candidates. There are many other considerations, besides fossil-fuel costs, that will determine whether or not a particular small electric utility may be a candidate for a nuclear plant.

It can be concluded that there is a fair chance of being able to locate five small utilities where a nuclear power plant could be competitive. The validity of this conclusion depends, of course, on the willingness of the utilities to cooperate for joint action and it depends on the support and encouragement of industry associations and responsible governmental agencies.

TABLE 1

ANNUAL COSTS W/O FUEL FOR A FOSSIL-FUEL 100 MW PLANT

Thousands of Dollars

	COOP		MUNICIPAL		INVESTOR	
Fixed Charge Rate on Capital	6.01%		7.75%		14.46%	
	GAS	COAL	GAS	COAL	GAS	COAL
Capital Cost	690	840	890	1,090	1,660	2,020
Operation & Maintenance	400	500	400	500	400	500
General & Administrative	100	100	100	100	100	100
Total Annual Cost w/o Fuel	1,190	1,440	1,390	1,690	2,160	2,620
Annual Generation @ 60% P. F.	←		$525 \times 10^6 \frac{kwh}{yr}$		→	
Annual Generation @ 80% P. F.	←		$700 \times 10^6 \frac{kwh}{yr}$		→	
Unit Cost w/o Fuel @ 60% PF, $\frac{Mills}{kwh}$	2.26	2.74	2.64	3.21	4.10	4.98
Unit Cost w/o Fuel @ 80% PF, $\frac{Mills}{kwh}$	1.70	2.06	1.99	2.42	3.09	3.75

TABLE 2

UNIT ENERGY COSTS FROM A 100 MW OCMR

(With Credit for Stretch)

Costs in Dollars

		Coop	Municipal*	Investor
1.	Fixed Charge Rate, Depreciating Capital	6.01%	7.75%	14.46%
2.	Fixed Charge Rate, Non-Depreciating Capital	3.20%	5.54%	13.00%
3.	Annual Cost, Depreciating Capital	$1,286,000	$1,659,000	$3,094,000
4.	Annual Cost, Non-Depreciating Capital	13,000	22,000	52,000
5.	Annual Operating and Maintenance	717,000	717,000	717,000
6.	Annual Nuclear Insurance	83,000	83,000	83,000
7.	Total Annual Cost w/o Fuel	$2,099,000	$2,481,000	$3,946,000
8.	Less, Credit for Stretch	(90,000)	(90,000)	(90,000)
9.	Net Annual Cost w/o Fuel	$2,009,000	$2,391,000	$3,856,000
10.	Fuel Cycle Capital Charges ($3,490,000 x Fixed Charge Rate Non-Depreciating Capital)	112,000	193,000	454,000
11.	Other Fuel Costs @ 60% PF	964,000	964,000	964,000
12.	Total Annual Fuel Cost (Lines 10 + 11)	$1,076,000	$1,157,000	$1,418,000
13.	Total Annual Costs @ 60% PF (Line 9 + Line 12)	$3,085,000	$3,548,000	$5,274,000

*See Table 1, Section 6.0

Unit Power Generation Costs at 60% PF, Mills/kwh (526,000,000 kwh/yr)

		Coop	Municipal	Investor
14.	All Unit Costs Except Fuel Cycle	3.82	4.54	7.33
15.	Unit Costs for Fuel Cycle	2.05	2.20	2.70
16.	Total Unit Energy Cost	5.87	6.74	10.03

Unit Power Generation Costs at 80% PF, Mills/kwh (701,000,000 kwh/yr)

		Coop	Municipal	Investor
17.	All Unit Costs Except Fuel Cycle	2.87	3.40	5.50
18.	Unit Costs for Fuel Cycle**	2.05	2.20	2.70
19.	Total Unit Energy Cost	4.92	5.60	8.20

**Effect of increased plant capacity factor upon fuel inventory cost has been excluded.

TABLE 3

BREAK-EVEN FOSSIL FUEL COST FOR 100 MW OCMR WITH STRETCH

60% PF	Coop Nuclear	Coop Gas	Coop Coal	Municipal Nuclear	Municipal Gas	Municipal Coal	Investor Nuclear	Investor Gas	Investor Coal
Unit Cost w/o Fuel, mills/kwh	3.82	2.26	2.74	4.54	2.64	3.21	7.33	4.10	4.98
Fuel Cost, mills/kwh	2.05	3.61	3.13	2.20	4.10	3.53	2.70	5.93	5.05
Total Unit Energy Cost, mills/kwh	5.87	5.87	5.87	6.74	6.74	6.74	10.03	10.03	10.03
Break-Even Fossil Fuel Cost in ¢/MBtu at Net Plant Heat Rate of 11,000 $\frac{Btu}{kwh}$									
Gas	$\frac{3.61}{11,000} \times 10^5 = 32.8$¢/MBtu			$\frac{4.10}{11,000} \times 10^5 = 37.3$¢/MBtu			$\frac{5.93}{11,000} \times 10^5 = 53.9$¢/MBtu		
Coal	$\frac{3.13}{11,000} \times 10^5 = 28.5$¢/MBtu			$\frac{3.53}{11,000} \times 10^5 = 32.1$¢/MBtu			$\frac{5.05}{11,000} \times 10^5 = 45.9$¢/MBtu		
80% PF									
Unit Cost w/o Fuel, mills/kwh	2.87	1.70	2.06	3.40	1.99	2.42	5.50	3.09	3.75
Fuel Cost, mills/kwh	2.05	3.22	2.86	2.20	3.61	3.18	2.70	5.11	4.45
Total Unit Energy Cost, mills/kwh	4.92	4.92	4.92	5.60	5.60	5.60	8.20	8.20	8.20
Break-Even Fossil Fuel Cost in ¢/MBtu at Net Plant Heat Rate of 11,000									
Gas	$\frac{3.22}{11,000} \times 10^5 = 29.3$¢/MBtu			$\frac{3.61}{11,000} \times 10^5 = 32.8$¢/MBtu			$\frac{5.11}{11,000} \times 10^5 = 46.5$¢/MBtu		
Coal	$\frac{2.86}{11,000} \times 10^5 = 26.0$¢/MBtu			$\frac{3.18}{11,000} \times 10^5 = 29.0$¢/MBtu			$\frac{4.45}{11,000} \times 10^5 = 40.5$¢/MBtu		

TABLE 4 SHEET 1 OF 4

FORECAST OF GENERATION ADDITIONS

(44 MW to 150 MW)

Utility	Type P.I.C.	Size MW	Year Installed	Fuel	Fuel Cost ¢/MBtu
Alabama					
Alabama Electric Cooperative	C	66	69	Coal	24
		66	73		
Alaska					
Chugach Electric Association	C	44	72		
Arizona					
Arizona Electric Power Cooperative	C	75	70	Gas	33
California					
Burbank Public Service Department	P	100	70	Gas/Oil	35
Glendale Public Service Department	P	66	71	Gas/Oil	35
Imperial Irrigation District	P	100	73	Gas/Oil	44
Pasadena Municipal Light & Power	P	75	73	Gas/Oil	35
Colorado					
Colorado Springs Dept. of Public Util.	P	100	72	Gas/Coal	22/24
Southern Colorado Power	I	44	69		
		44	73	?	?
Florida					
Gainesville Utility Department	P	66	69	Gas	33
		100	73		
Lakeland Light & Water Dept.	P	66	69	Gas/	33/
	P	100	72	Oil	41
Tallahassee Power Plant	P	44	71	?	?
Georgia					
Savannah Electric & Power Company	I	100	71	Gas/Coal	29/31

TABLE 4 SHEET 2 OF 4

FORECAST OF GENERATION ADDITIONS

(44 MW to 150 MW)

Utility	Type P.I.C.	Size MW	Year Installed	Fuel	Fuel Cost ¢/MBtu
Hawaii					
Hawaiian Electric Company	I	125	70	Oil	35
		125	72		
Illinois					
Springfield Water, Light & Power Dept.	P	44	71	Coal	26
Central Illinois E&G	I	66	69	Gas/Coal	21/33
Indiana					
Richmond Power & Light Dept.	P	44	71	Coal	28
Iowa					
Corn Belt Power Cooperative	C	66	71	Coal	30
Kansas					
Kansas City Board of Public Util.	P	100	70	Gas/Coal	24/26
Central Kansas Power	I	44	72	Gas	22
Western Light & Telephone Company	I	150	71	Gas	22
Kentucky					
East Kentucky Rural Electric Coop.	C	100	69	Coal	22?
		150	73		
Louisiana					
Lafayette Utilities System	P	100	70		
Monroe Utilities Commission	P	44	70		

TABLE 4 SHEET 3 OF 4

FORECAST OF GENERATION ADDITIONS

(44 MW to 150 MW)

Utility	Type P.I.C.	Size MW	Year Installed	Fuel	Fuel Cost ¢/MBtu
Michigan					
Lansing Board of Water & Light	P	100	71	Coal	32
Upper Penninsula Power Company	I	66	70	Coal	34
Minnesota					
Rochester Electric Department	P	44	70	Coal	37?
Missouri					
Central Electric Power Cooperative	C	100	70	Gas	22
M & A Electric Power Cooperative	C	100	70	Gas	22
North-East Electric Power Cooperative	C	44	69	Gas	22
North-West Electric Power Cooperative	C	100	69	Gas	22
Springfield City Utilities	P	100	69	Gas	22
Nevada					
Nevada Power Company	I	125	69	Gas/Oil	38/56
		125	71		
		150	74		
Sierra Pacific Power	I	100	70	Gas/Oil	38/56
		100	73		
New Mexico					
Lea County Electric Coop	C	66	70	Gas/Oil	?
Public Service of New Mexico	I	100	70	Gas/Oil	22/30
North Dakota					
Central Power Electric Coop	C	44	72	Lignite	32?
Minnekota Power Coop	C	100	73	Lignite	32?

TABLE 4 SHEET 4 OF 4

FORECAST OF GENERATION ADDITIONS

(44 MW to 150 MW)

Utility	Type P.I.C.	Size MW	Year Installed	Fuel	Fuel Cost ¢/MBtu
Oklahoma					
Western Farmers Electric Coop	C	100	71	Gas/Oil	20
South Carolina					
S. Carolina Public Power Authority	P	2-100	72	Coal	(30)
Texas					
Brazos Electric Power Coop	C	150	72	Gas	?
Brownsville Public Utility Board	P	44	69	Gas	16
Bryan Municipal Electric System	P	44	71	Gas	22
Denton Municipal Utilities	P	66	72		?
Garland Power & Light	P	150	70	Gas	22
Lubbock Power & Light	P	100	72	Gas	18
Medina Electric Corp.	C	44	71		?
South Texas Electric Coop	C	44	69		?
Vermont					
Green Mountain Power Coop	I	44	70	Coal	(40)
Wisconsin					
Madison Gas & Electric Company	I	75	71	Gas/Coal	(32)/(34)

8.0 APPENDIX A

GROUND RULES FOR EVALUATING

SMALL NUCLEAR POWER PLANTS

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8.1 General

This evaluation of Small Nuclear Power Plants is focused upon the needs and problems of the smaller electric utility systems and is based upon the ground rules set forth below. These ground rules ensure a uniform evaluation of nuclear power generating plant proposals. In placing all proposals upon a uniform basis, the intrinsic value of one type of nuclear plant can be compared with another type, and differences in the busbar cost of power will be due to differences in first cost and performance, rather than upon different methods of bookkeeping or different approaches in calculating performances.

In the absence of a specific site and specific conditions - as would be the case when a utility solicits proposals for a power plant - such specific conditions have to be defined, and a specific (though hypothetical) site has to be stipulated. This enables the user of this report to convert the cost estimate for the plant at the hypothetical site and conditions to a cost estimate for his site and conditions by making appropriate adjustment. While it is not suggested that the cost data thus established be deemed a definitive estimate, nevertheless, it will serve as a good "first cut" and a useful guide as to whether or not a particular nuclear power plant merits further investigation.

8.2 Site Data

A "hypothetical site" has been adopted for the Small Nuclear Power Plants Study.

Area, Cost and General Characteristics

1. Required Area

   For nuclear plants, the area requirements are set by hazards considerations rather than by functional requirements of plant arrangement. Based upon AEC publication 10 CF 100, "Reactor Site Criteria," and a companion document TID-14844, "Calculations of Distance Factors for Power and Test Reactor Sites" (containing a sample calculation for exclusion area radius, low-population zone distance, population center distance based on a postulated maximum credible accident, and assumptions applicable to boiling or pressurized water reactors using pressure type containment structures), the minimum exclusion area has been calculated.

   For existing reactors, however, a comparison of minimum to actual exclusion areas shows that the ratio of the actual exclusion area radius to that calculated in TID-14844 varies from 0.62 to 4.2.

   Tabulated below for each plant capacity are the minimum areas corresponding to the TID-14844 exclusion distances and the areas recommended for the Small Power Reactor Study. Each of the recommended areas is approximately twice the area which one would need based on the exclusion distance in TID-14844. This provides a margin to account for the fact that the site will not be circular, and to accommodate operation at reactor stretch capability.

Plant Capacity (MWe, Net)	Thermal Power (MWt)	Site Area (Circular) Based On TID-14844 (Acres)	Recommended Site Area for Study (Acres)
25	88	61	150
50	174	143	250
100	348	263	500

The above numbers should not be deemed final. There may be considerable variation in the required exclusion distance, depending on the safeguards incorporated in the plan, including the type of containment system.

2. Cost

The cost for the hypothetical site shall be assumed to be:

Nominal Plant Rating (MWe)	Land Area (Acres)	Land Cost (Per Acre)
25	150	$500
50	250	$500
100	500	$400

Land surrounding the site is generally available at the same cost. It is assumed that no easements are necessary.

3. Location

The site consists of level terrain and is located at the outskirts of a medium sized city in California. It is adjacent to a river that will supply cooling water. It is not required that the river be navigable, as shipment of the reactor vessel (the largest piece of equipment) can be made overland.

4. Access

Highway access is provided to the hypothetical site by a secondary road from a state highway. This road is in good condition and needs no additional improvements. A railroad team track with an unloading dock is located within five miles of the site.

All equipment shipments will be made overland, either by railroad or by truck. No railroad spur is required to the plant as all heavy equipment such as the reactor pressure vessel and generator stator can be trucked to the site by a low-boy trailer from the nearest railroad siding.

5. Population Distribution

The sample calculation contained in TID-14844, "Calculations of Distance Factors for Power and Test Reactor Sites," gives the low population zone distance and the distance to the nearest boundary of a densely populated area with more than about 25,000 residents. These computed distances are based on a water-type reactor with a pressure-type containment and a postulated maximum credible accident with certain stated assumptions. The low population zone is an area immediately outside the plant exclusion area, which is of such size and population density that the plant operator and local authorities could take appropriate measures to protect residents in the event of a serious accident. The population center distance is arbitrarily taken as one and one-third times the outer radius of the low population zone. Tabulated below are the low population zone distance and population center distance (from TID-14844), as functions of the electrical and thermal rating of the nuclear power plant.

Reactor Thermal Power (MWt)	Plant Net* Electrical Capacity (MWe)	Low-Population Zone Distance (Miles)	Population Center Distance (Miles)
50	14	1.4	1.9
100	29	2.2	2.9
200	58	3.4	4.5
300	86	4.5	6.0
400	115	5.4	7.2

*Based on estimated thermal efficiency of a natural circulation boiling water reactor.

From the above, it is seen that for nuclear power plants rated at 25, 50 and 100 MWe the distances from the reactor building to the outer boundary of a densely populated area, with more than about 25,000 residents, should be approximately 2.7, 5.5, and 7 miles, respectively.

6. Utilities

An emergency power source in the plant is necessary, as the distribution system in the area is a single source transmission. Natural gas is available at the site boundary as a fuel for an emergency diesel generator.

Communication lines shall be furnished to the site boundary at no cost. Cost for communications within the site shall be in accordance with standard utility company practice.

An adequate amount of 480 v, 3-phase, 60-cycle construction power is available at the site to the contractor. The contractors connect to this source, and furnish, install and maintain the wiring systems, as well as pay the cost of power.

Power for the station startup auxiliary transformer is available at 138 kv from a transmission system in the vicinity of the site.

Meteorology and Climatology

1. Temperature

The daily average temperature ranges between 40°F and 60°F, with a design maximum of 90°F and a design minimum of 30°F.

2. Temperature Inversions

It is assumed that the frequency and duration of temperature inversions are such that no difficulty will be experienced in obtaining adequate dispersal of any gaseous effluents, released either during normal operation or following certain hypothesized accident situations.

3. Wind Variation

Prevailing surface winds in the region surrounding the hypothetical site blow from the south through west quadrant, at speeds varying from 4 to 15 miles per hour throughout the year. There are no large daily variations in wind speed or direction. Observations of wind velocities at altitude indicate a gradual increase in mean speed and a gradual shift in prevailing wind direction, from southwest near the surface to westerly aloft.

A maximum wind velocity of 100 miles per hour has been recorded at the site.

Hydrology

1. Precipitation

Average annual rainfall at the site is over 27 inches.

2. Surface Water

The river, at a mean temperature of 60°F, provides an adequate source of raw make-up and condenser cooling water for the ultimate station capacity. The average river water maximum temperature is 75°F, and the average minimum is 40°F. The river is sufficiently large to absorb the heat rejected by the plant without exceeding the allowable temperature rise specified by the state.

3. Drainage

Natural drainage of the site is provided by the land contours.

4. Ground Water

Adequate ground water for domestic use and plant make-up is available from wells within 250 ft below grade.

Geology and Seismology

1. Soil Load Bearing Characteristics

The soil consists of medium stiff clay with a load bearing capacity of 6,000 lb/sq ft. This value has been selected as a representative average value for soil load bearing characteristics. The ground is assumed to be easily excavated down to a depth of 100 ft. Dewatering and pilings are not required.

2. Seismology

This is a Zone 1 site, as designated by the Uniform Building Code.

Radioactive Waste Disposal

1. Sewage

All sewage must receive primary and secondary treatment prior to dumping into the river.

2. Volatile Wastes

Maximum permissible concentrations or dosages shall be within the limits as prescribed in:

a. Code of Federal Regulations Title 10, Part 20, "Standards for Protection Against Radiation."

b. National Bureau of Standards Handbook 69, Maximum Permissible Body Burdens and Maximum Concentration of Radionuclides in Air and in Water for Occupational Exposure.

In the event of conflict between items a. and b. above, item a. shall govern.

3. Liquid Wastes

Maximum permissible activity of water entering the river shall be as prescribed in the reference listed under "Volatile Wastes" above. The activity level of the liquid effluent shall be measured as it leaves the plant. No credit for dilution in the river will be assumed.

4. Solid Wastes

Storage on site for decay shall be permissible but no ultimate disposal on site shall be made.

Labor

Labor availability for plant construction and operation at this site is adequate, and travel pay is not required. Costs are based upon California labor rates and working agreements, and a normal eight-hour day and forty-hour week.

8.3 Design Data

Plant Sizes

Outline designs and cost data shall be prepared for nuclear power stations with net electrical power ratings of 25 MW, 50 MW and 100 MW. This analysis shall be based on presently offered plants of proven technology.

Stretch Capability

The natural circulation boiling water reactor has demonstrated capability to achieve considerably higher power densities than those corresponding to the initial plant rating. Advantage can be taken of this inherent capability, known as "stretch," if the turbine-generator, power plant auxiliaries, and containment are initially designed to accommodate the reactor's uprated capability.

Turbine-Generators

Single turbine-generator units rated at an exhaust pressure of 1.5 in. Hg abs shall be used for all plants.

Condensers

The turbine condenser shall be designed to maintain a back pressure of 1-1/2 in. Hg abs with maximum throttle flow to the turbine, based on a 60^{o}F circulating water temperature and normal extraction of steam for feedwater heating. Units for direct cycle boiling water reactors shall be equipped with deaerating type hot wells. The tubes shall either be rolled into the tube sheet and equipped with O-rings or rolled and welded to the tube sheet. Indirect cycle reactor plants may be optionally designed for feedwater deaeration in the condenser or in an open, deaerating heater.

Codes and Standards

Materials and construction, style of architecture, etc., shall be designed and estimated in accordance with AEC manual, Part 6300, plus ASTM, ASME, ASA, AIEE and the National Board of Fire Underwriters' codes and standards where applicable.

Design Criteria

The U. S. Atomic Energy Commission recently proposed general design criteria to serve as a basis for the evaluation of applications for nuclear power plant construction permits. [1]These criteria have been evolved over the years and are particularly applicable to water cooled and moderated reactors. These criteria shall be utilized in assessing the adequacy and completeness of the nuclear reactors and auxiliaries proposed for application to nuclear power plants considered in this study.

Containment

The plant conceptual design, arrangement and costs shall be based on the application of pressure suppression containment for the presently available boiling water reactors.

8.4 Operating Data

Plant Capacity Factor

The annual power generation shall be based on an annual plant capacity factor of 60% of the net power rating. The fuel management program, where used, shall be such that the total annual shutdown time, including scheduled outages for fuel reloading, fuel reshuffling and scheduled inspection and maintenance, will not exceed 870 hr/year.

Operation and Maintenance

A manning table and an organization chart shall be developed for each plant size based on experience to date with plants presently operating, taking advantage of as much organizational simplification as possible.

The following assumptions shall be used in arriving at an operation and maintenance organization.

1. The essential functions are organized in a manner consistent with conventional station practices.

2. A single reactor is operated, not associated with other nuclear or conventional stations at the same site.

3. The staff provides for normal power plant operations only. It does not include personnel required for initial startup or major overhaul.

4. Day shift maintenance coverage is provided; supplemental personnel will be provided from outside the station for major overhaul, when required.

5. The technical personnel are provided for maintenance and routine operations; special test programs or operating requirements will be provided from outside the station as necessary.

6. The standard work week is 40 hours, and the staff size is large enough to provide coverage for vacations and sickness.

7. Services such as film badge processing, laundering of contaminated clothing, instrument calibration and radiobiological analysis are performed under contract.

8. For multiple identical power reactors operated by different utilities at separate locations, use will be made of common technical support organizations working on a contract basis.

The plant organization shall be arranged into the following functional groupings:

1. Management Staff - Station superintendent and assistants, clerks, storekeepers, etc.

2. Technical Staff - Nuclear and results engineers, health physicist, laboratory and instrument technicians, etc.

3. Operating Staff - Shift supervisors, control and equipment operators, watchmen, janitor, etc.

4. Maintenance Staff - Supervisor, electricians, machinists, pipe fitters, welders, mechanics, etc.

Fuel and Fuel Management

1. Boiling Water Reactors

The warranted average fuel exposures (or burnup) for presently offered, commercially available, boiling light water reactors rated at 200 MWe and above are:[2]

Core	Loading	Warranted Average Exposure (MWd/metric ton U)
1	1970-1971	16,500
2	1972-1976	22,000
3	1976-1981	22,000

These represent exposures presently achievable without exceeding metallurgical or reactivity limits, utilizing uranium oxide fuel clad with a zirconium alloy (Zircaloy-4). The economic optimum exposure is close to 22,000 MWd/metric ton of uranium.[3]

For small nuclear power plants (less than 100 MWe) of interest in this study, the average fuel exposures (set by economics) will be lower. The average exposure at discharge will be taken as that proposed by the reactor vendor. The economical average fuel exposures should be in the range of 13,000 to 16,500 MWd/metric ton of uranium.

2. Other Reactor Concepts

For the purpose of estimating potential fuel cycle cost with advanced reactor concepts, the average fuel exposures achievable using fuel management schedules are tabulated below:

Reactor Type	Fuel	Clad	Average Fuel Exposure (MWd/metric ton U)
Advanced PWR	UO_2	Zr/SS	27,000
Organic-cooled	UC	sintered aluminum product	20,000

The exposures tabulated above correspond to estimated maximum fuel exposures achievable without exceeding metallurgical or reactivity limits. Average fuel exposures proposed by the reactor vendors shall be used for computing potential fuel costs, if those exposure levels do not exceed those tabulated.

8.5 Data for Fuel Cycle Cost Calculations

Fuel Cycle

1. General

The estimate of working capital for nuclear fuel cycle operations shall be based on the average value of nuclear fuel in inventory. If sufficient information is available for the presently available water reactors, the average working capital shall be computed for each of the first ten years of the power plant's operation. If detailed core loading and repositioning schedules are not available, it shall be assumed that equilibrium fuel cycle conditions prevail. The interest on the capital required for the first core shall be spread over the first ten years of operation. Spare fuel on hand at all times shall be taken as 1% of the reactor inventory, rounded upward to the next complete fuel assembly. The term "nuclear fuel in inventory" includes the following items:

a. New fuel in process of manufacture, in transit and in storage at the reactor site.

b. All fuel in the reactor.

c. Spare fuel on hand.

d. Spent fuel in storage, in transit, and being reprocessed.

To determine the average value of nuclear fuel in inventory, for the study and evaluation of nuclear power plants, separate estimates shall be made covering the core fabrication cost components and the nuclear materials cost component, as follows.

2. Core Fabrication

This cost component shall be computed on the basis of all costs incurred in the chemical conversion and fabrication of nuclear material into useable form for the reactor, but not including the cost of nuclear materials such as thorium, plutonium, and enriched, natural or depleted uranium, except that the cost of such nuclear materials which is lost during the conversion and fabrication processes will be included. The estimate shall provide for the fabrication of a complete core for the reactor and include allowances for spare fuel on hand and for new fuel in process of manufacture. If factual data are not available, the average value of the core fabrication cost component of nuclear fuel in inventory as described above, shall be assumed to be 60% of the core fabrication cost.

3. Nuclear Materials

Private ownership of uranium and other nuclear materials shall be assumed to apply throughout the lifetime of the nuclear power plant. If a project were initiated in 1967, full power operation could be achieved in 1970 or

1971. Since under Public Law 88-489, "Private Ownership of Special Nuclear Materials Act," private ownership with toll enrichment services will become available in 1969, with private ownership becoming mandatory in 1971, it is reasonable to assume private ownership throughout the project lifetime.

This cost component shall be computed on the basis of all nuclear material purchased for chemical conversion and fabrication into forms useable in the reactor, including recycled scrap. The estimate shall include the average value of the nuclear material in the reactor, allowances for spare fuel on hand and new fuel in the process of manufacture, and the value of purchased nuclear material remaining in spent fuel until completion of reprocessing.

Fuel Operating Costs

1. General

The nuclear fuel cycle costs shall be based on private ownership of the nuclear materials throughout the lifetime of the plant. The use charges which were made when the nuclear fuel was leased from the AEC are no longer applicable as a part of the fuel cycle costs. The cost of financing the nuclear fuel cycle operations is included as a fixed charge on working capital. Enriched uranium is assumed to be obtained by toll enrichment by the AEC. The principal elements of cost are the cost of feed material - which includes purchase of uranium ore concentrates and subsequent conversion to UF_6 - toll enrichment, fuel fabrication, fuel recovery costs, and credit for uranium and plutonium recovered. Fuel cost estimates shall be based on the following assumptions.

2. Plant Factor

The annual plant operating factor shall be taken as 60%.

3. Feed Material Prices

The feed material provided to the AEC for toll enrichment is in the form of uranium hexafluoride. The cost of this material is dependent on two factors: the price of natural uranium ore concentrate (U_3O_8) known as "yellow-cake," and the cost of converting the ore to uranium hexafluoride.

For the conservative assumptions the price of yellow-cake shall be taken as \$8/lb of U_3O_8, and the cost of conversion to UF_6 will be taken as \$2.70/kg of contained uranium.

For the optimistic assumptions the cost of yellow-cake shall be taken as \$5/lb of yellow-cake through December 1974 and \$4.50 thereafter. The cost of converting the ore concentrate (U_3O_8) to uranium hexafluoride shall be taken as:

	Up to 12/31/74	After 12/31/74
Conversion to UF_6	\$2.20/gU	\$1.10/gU

4. Toll Enrichment

On October 1, 1965, the AEC published proposed criteria for toll enrichment services pursuant to Public Law 88-489, "Private Ownership of Special Nuclear Materials Act." These criteria provide for a guaranteed ceiling charge for enrichment services subject to upward escalation for labor and power costs.

The ceiling charge as of July 1, 1965, which is the base date for such escalation, was set at $30 per kilogram unit of separative work, and this charge shall be used for this study.

5. Fabrication

For presently available reactors, fuel fabrication costs include the cost of fuel element design, conversion of uranium hexafluoride to uranium dioxide, processing of the powder, incorporation of the uranium dioxide into zirconium alloy clad fuel assemblies, insurance, fuel warranty, and transportation of the completed fuel assemblies to the plant site. Fuel fabrication costs shall be based on the estimates and/or quotations of the particular reactor suppliers.

6. Recovery Cost

The cost of recovering uranium and fissile plutonium from irradiated fuel includes the cost of transporting the spent fuel from the power plant to the reprocessing plant, the cost of recovering the uranium and plutonium by solvent extraction, losses during the irradiated fuel reprocessing, and the cost of converting the uranyl nitrate to uranium hexafluoride suitable for re-enrichment in a gaseous diffusion plant.

For the conservative assumptions, the cost of spent fuel shipping shall be taken as $10/KgU. The cost of chemical processing shall be based on present prices set by Nuclear Fuel Service, Inc., as follows:

> The processing cost consists of a base charge of $23,500/day. For low-enrichment fuel (less than 3% U-235), the daily through-put is one metric ton per day. Thus, the base charge for processing low-enrichment fuel is $23,500 per metric ton. In addition to the base charge, there is a turn-around charge which takes into account the time required to clean up the plant after processing a batch of fuel. The minimum turn-around charge corresponds to two days. For batches of less than two metric tons, the turn-around charge is 2 x $23,500, or $47,000. For batches between two and eight metric tons, the turn-around charge is equal to the number of metric tons times the daily charge of $23,500. From 8 to 24 metric tons the turn-around charge is constant at eight times the daily charge. For batches above 24 metric tons, the turn-around charge is the number of metric tons divided by three, times the daily charge of $23,500.

The cost of reconversion of uranyl nitrate to UF_6 shall be taken as $5.60/KgU.

For the optimistic assumptions, the total recovery costs, including shipping, chemical processing and reconversion, shall be taken as $41.50/KgU for fuel recovered before 1979 and $36.40/KgU thereafter.

7. Uranium Depletion

The credit for recovered uranium is the value of the uranium at the enrichment discharged from the reactor. The value of uranium at a given enrichment is obtained from the cost of feed material plus the toll enrichment charge that would be required to enrich natural uranium feed material to that isotopic concentration of U-235.

8. Plutonium Credit

The value of fissile plutonium (Pu-239 and 241) in the nitrate form recovered from the fuel processing plant shall be assumed to be equal to 85% of the value of the U-235 contained UF_6 of 90% enrichment.

9. Fuel Cycle Schedule

If sufficient information is available on the refueling program for the reactor, including the initial and discharge concentrations, the fuel cost shall be estimated for each of the first ten years of the plant's operation. Otherwise, equilibrium fuel cycle cost shall be estimated. The estimated duration for various portions of the fuel cycle are tabulated below:

Item	Duration (Months)
Procurement of ore concentrate	3
Toll Enrichment	3
Fabrication	9
Transportation of new fuel assemblies to plant site	1
Cooling of fuel following discharge	4
Transportation of irradiated fuel to reprocessing plant	1
Reprocessing	1

It will be assumed that spent fuel is sold at the completion of reprocessing and a completely new supply of uranium ore procured for subsequent re-enrichment when required for core fabrication.

8.6 Nuclear Insurance

Nuclear Insurance may be considered to consist of two parts, viz. nuclear liability insurance purchased from private insurance companies, and nuclear indemnity insurance purchased from the U. S. Government.

The amount of financial protection required of AEC reactor licensees is determined in accordance with provisions of "Title 10 - Atomic Energy, Chapter 1 - Atomic Energy Commission, Part 140 - Financial Protection Requirements and Indemnity Agreements, Sub-part B, amended," published in the 25 Federal Register 2944, April 7, 1960.

Under Part 140, licensees of power reactors with rated capacity less than 100 MWe are required to maintain a total amount of nuclear liability insurance, or other financial protection, equal to $150 times the maximum power level, expressed in thermal kilowatts, times a population factor, P, subject to a minimum requirement of $3,500,000 and a maximum requirement of $60,000,000. The population factor shall be assumed to be 1.0 for the hypothetical site described herein.

The AEC amended its regulations (30 FR 14779, Nov. 30, 1965) pursuant to Public Law 89-210 which extends the Price-Anderson provisions of the Atomic Energy Act, to provide that the amount of the Government Indemnity ($500 million per nuclear incident) will be reduced by the amount by which the required financial protection exceeds $60 million. For reactors with a power rating of 100 MWe or greater, financial protection must equal the maximum amount available from private sources. Effective January 1, 1966, the two nuclear liability insurance pools (Nuclear Energy Liability Insurance Association and Mutual Atomic Energy Liability Underwriters) will increase the available private insurance coverage from $60 million to $74 million.

The AEC also announced (30 FR 14814, Nov. 30, 1965) that it is considering making a proportional increase (of approximately 23%) in the amount of financial protection required for facilities having a rated thermal capacity less than 100 MWe.

Thus, for the 25 MWe and 50 MWe nuclear power plants, the required private insurance coverage shall be $74 million. The liability insurance costs shall be based on the premium rates for privately available insurance.

The fee for government indemnification is charged at the rate of $30 per year per megawatt thermal.

8.7 References

1. "General Design Criteria for Nuclear Power Plant Construction Permits," issued for comment, U. S. AEC Press Release No. U-252, November 22, 1965.

2. General Electric, Atomic Power Equipment, Price Bulletin 8805, "Nuclear Fuel."

3. "Nuclear Fuel Cost Trends Under Private Ownership," Richard H. Graham, presented at the American Power Conference, April 1965.

APPENDIX B

CLASSIFICATION OF ACCOUNTS

The following is a condensed uniform system of accounts for use in the Small Power Reactor Study. For a detailed listing of all accounts as well as a brief description of what each account includes, refer to sections 105, 106 and 130 through 135 in Volume 1 of the Guide to Nuclear Power Cost Evaluation, TID-7025.

SUMMARY OF MAJOR ACCOUNTS

320	Land and Land Rights
321	Structures and Improvements
322	Reactor Plant Equipment (Less Fuel)
323	Turbine-Generator Unit
324	Accessory Electrical Equipment
325	Miscellaneous Power Plant Equipment
393	Engineering Costs
398	Distributable Construction Costs
399	Other Owner's Costs

Note: The symbol NI denotes that the item is part of the "Nuclear Island." Where NI is preceded by a percentage (e.g. 50% NI), only the percentage shown of the total cost is charged against the "Nuclear Island."

320 LAND AND LAND RIGHTS

320.1 Land Acquisition

First cost of acquisition including mortgages and other liens assumed.

320.2 Clearing Land

Includes first cost of clearing land of brush, trees and debris and of tree trimming.

320.3 Surveys

Includes all preliminary surveys in connection with acquisition of land.

320.4 Fees, Etc.

Includes fees, commissions and salaries to brokers, agents and others in connection with the acquisition of land.

320.5 Easements

Includes taxes, title expense, etc.

320.6 Preliminary Grading

Includes preliminary grading of land.

321 STRUCTURES AND IMPROVEMENTS

321.1 Improvements to Site

321.11 Clearing and Grading
321.12 Storm and Sanitary Sewer System
321.13 Yard Fire Protection System
321.14 Non-process Service Water System
321.15 Service Water Structures
321.16 Roads, Walks and Parking Areas
321.17 Fences and Gates
321.18 Yard Lighting
321.19 Cathodic Protection

NI 321.2 Reactor Building (Excluding Containment)

321.21 Substructure
321.22 Superstructure and Interior Finish
321.23 Building Services

NI 321.3 Radioactive

321.31 Substructure
321.32 Superstructure and Interior Finish
321.33 Building Services
321.34 Contaminated Waste Storage Vault

321.4 Turbine Building

321.41 Substructure
321.42 Superstructure and Interior Finish
321.43 Building Services

321.5 Administration Building

321.51 Substructure
321.52 Superstructure and Interior Finish
321.53 Building Services

321.6 Service Building

321.61 Substructure
321.62 Superstructure and Interior Finish
321.63 Building Services

321.7 Miscellaneous Yard Buildings

NI 321.8 Stacks

NI 321.9 Reactor Containment Structure

322 REACTOR PLANT EQUIPMENT

NI 322.1 Reactor Equipment

322.11 Vessel, Support and Internals
322.12 Controls
322.13 Shielding
322.14 Auxiliary Cooling and Heating System
322.15 Container (Within Building)
322.16 Moderator and Reflector
322.17 Cranes and Hoists

NI 322.2 Heat Transfer Systems

322.21 Reactor Coolant System
322.22 Intermediate Coolant System
322.23 Steam Generators and Superheaters
322.24 Coolant Receiving, Supply and Treatment
322.25 Moderator Auxiliary Systems
322.26 Coolant, Initial Charge

NI 322.3 Fuel Handling and Storage

322.31 Reactor Building Cranes and Hoists
322.32 Special Tools and Servicing Equipment
322.33 Spent Fuel Storage
322.34 Shipping Casks

NI 322.4 Radioactive Waste Treatment

322.41 Liquid Waste
322.42 Gaseous Waste
322.43 Solid Waste

NI 322.5 Instrumentation and Control

322.51 Reactor Plant Control System
322.52 Heat Transfer Systems
322.53 Fuel Handling and Storage
322.54 Radioactive Waste Systems
322.55 Radiation Monitoring
322.56 Steam Generator Controls
322.57 Control and Instrument Piping, Tubing and Wiring

322.6 Feedwater Supply and Treatment

322.61 Raw Water Supply System
322.62 Make-Up Water Supply
322.63 Steam Generator Feedwater Purification and Treatment System
322.64 Feedwater Heaters
322.65 Feedwater Pumps and Drives

20% NI 322.7 Steam Condensate and Feedwater Piping

NI 322.8 Nuclear Engineering

323 TURBO-GENERATOR UNIT

323.1 Turbine-Generator

- 323.11 Turbine-Generator Equipment
- 323.12 Direct Connected Exciters
- 323.13 Hydrogen and CO_2 Systems
- 323.14 Lubricating Oil System
- 323.15 Excitation Control Equipment

323.2 Condenser and Auxiliaries

- 323.21 Main Condenser
- 323.22 Steam Jet Air Ejector and Hogging Ejector
- 323.23 Condensate Pumps

323.3 Circulating Water System

- 323.31 River Intake Structure
- 323.32 Pumps, Screens, Trash Racks, Valves
- 323.33 River Outfall Structure
- 323.34 Circulating Water Ducts
- 323.35 Chemical and Acid Feed System
- 323.36 Chlorinating Equipment

323.4 Lubricating Oil Equipment

- 323.41 Lube Oil Pumps
- 323.42 Lube Oil Storage Tank
- 323.43 Lube Oil Filtering Equipment
- 323.44 Lube Oil Piping

323.5 Turbo-Generator Pedestal

- 323.51 Reinforcing Steel
- 323.52 Concrete Forms
- 323.53 Miscellaneous Iron (Embedded in Concrete)
- 323.54 Concrete
- 323.55 Anchor Bolts

323.6 Turbine Plant Piping

50% NI 324 ACCESSORY ELECTRICAL EQUIPMENT

324.1 Switchgear

- 324.11 Generator Switchgear
- 324.12 Station Service Switchgear

324.2 Switchboards

- 324.21 Main Electrical Systems Control Board
- 324.22 Auxiliary Power, Battery and Signal Boards
- 324.23 Motor Control Centers

324.3 Protective Equipment

- 324.31 Station Grounding System
- 324.32 CO_2 Fire Protection System

324.4 Electrical Structures

- 324.41 Concrete Cable Tunnels
- 324.42 Cable Trays and Supports
- 324.43 Piped Steel Frames and Supports

324.5 Conduit (Except Lighting and Heating for Building Services)

- 324.51 Conduit
- 324.52 Concrete Envelopes
- 324.53 Manholes and Covers

324.6 Power and Control Wiring

- 324.61 Main Power Cables
- 324.62 Control Auxiliary Power and Excitation Wiring

324.7 Station Service Equipment

- 324.71 Station Service Transformer
- 324.72 Batteries, Charging Equipment and MG Sets
- 324.73 Insulating Oil Storage and Treating Equipment
- 324.74 Emergency Power Generation

325 MISCELLANEOUS POWER PLANT EQUIPMENT

325.1 Station Cranes

- 325.11 Turbine Building Crane with Auxiliary Hoist

325.2 Station Air System

- 325.21 Compressors and Auxiliaries
- 325.22 Air Piping

50% NI 325.3 Communication System

- 325.31 Telephone Equipment
- 325.32 Telephone Conduit
- 325.33 Telephone Wire
- 325.34 Intercom System

325.4 Annunciators and Alarms

325.5 Miscellaneous Equipment

- 325.51 Machine Shop Equipment
- 325.52 Laboratory Equipment
- 325.53 Office Furniture and Equipment
- 325.54 Instrument Shop Equipment
- 325.55 Personnel Lockers and Equipment
- 325.56 Portable Turbine Shelter
- 325.57 Spare Battery Charger

393 ENGINEERING COSTS

(Reimbursable Cost Plus Sliding Fee Basis)

393.1 Engineering and Design

393.2 Fabrication Inspection Services

393.3 Jobsite Inspection

393.4 Estimating, Cost Control and Scheduling

393.5 Expenses

393.6 Other Costs

393.7 Fee(s)

398 DISTRIBUTABLE CONSTRUCTION COSTS

The accounts in this series will be used to accumulate field costs which cannot reasonably be charged directly to a specific work item.

398.1 Temporary Construction Facilities

398.2 Miscellaneous Construction Services

398.3 Construction Equipment, Tools, Supplies and Utilities

398.4 Field Office Costs

398.5 Preliminary Operations and Testing

398.6 Other

(Field Superintendence, General and Administrative, Field Engineering, Accounting, Purchasing and other related activities incurred by the contractors.)

399 OWNER'S COSTS

The following accounts are to be used to accumulate charges made to the job by the Owner, which are not to be considered as part of the Engineer's costs.

399.1 Interest on Debt During Construction (Except First Core Fuel)

399.2 Procurement, Accounting and Administrative

399.3 Liaison Engineering Costs

399.4 Safeguards Reports and Licensing Costs

399.5 Operator Training

399.6 Start-Up Costs

399.7 Efficiency and Capability Tests

399.8 Other Costs

These pages replace the same number in report COO-284(Vol.3).

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