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THE DEVELOPMENT OF NUCLEAR POWER

Review of nuclear power costs

Report of the Board of Governors

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List of abbreviations

ACEC	Ateliers de Constructions Electriques de Charleroi
AEG/KEA	Allgemeine Elektricitaets Gesellschaft-Kernenergieanlagen
aux.	auxiliary
BTU	British thermal unit
BW	boiling-water reactor type
D	deuterium
d	day
fig.	figure
GCE	gas-cooled, enriched-uranium reactor
GCN	gas-cooled, natural-uranium reactor
GEC	General Electric Company
hr	hour
HV	high voltage
HWN	heavy-water, natural-uranium reactor
kg	kilogram
kwe	kilowatt electrical
kwh	kilowatt-hour
mills	thousandths of a US dollar (= tenths of a cent)
misc.	miscellaneous
Mwd/t	megawatt days per metric ton
Mwe	megawatt electrical
N.A.	not available
nat.	natural
O	Oxygen
OCHWN	organic-cooled, heavy-water-moderated, natural-uranium reactor
OM	organic-moderated and organic-cooled reactor
Pu	plutonium
PW	pressurized-water reactor
SS	stainless steel
U	uranium
US	United States
USAEC	United States Atomic Energy Commission
vol.	volume
WPC	World Power Conference
yr	year

I. INTRODUCTION

1. At its third regular session the General Conference adopted a resolution requesting the Board of Governors to submit to it at its fourth regular session a report on the economics of nuclear power in the light of the latest technical and economic developments and the specific studies made by the Agency on this subject. [1]

2. The range of topics thus defined is extremely wide. Taken literally, it would involve not only a study of the present and anticipated costs of nuclear power plants and fuels, and their comparisons with conventional alternatives, but also of the economic development of the power system for which nuclear plants are intended and of the country as a whole where they are expected to operate.

3. The relevance and complexity of this comprehensive approach has been fully recognized by some of the Member States which have elaborated their own nuclear programs. It involves evaluating of all costs incurred in developing a national industrial infrastructure for nuclear power and comparing them with the investment that would be required to supply an expansion of conventional capacity.

4. The Agency's program to implement resolutions GC(II)/RES/27 and GC(III)/RES/57 provides for studies of all of these interrelated subjects but their variety and breadth makes it necessary to adopt a step-by-step approach. This first report has therefore been mainly restricted to the present costs of nuclear power plants and fuels with some tentative extrapolation of their probable future trends. The report has further been designed to facilitate a preliminary evaluation by less-developed countries of power plants using nuclear instead of conventional fuels. In this connexion it will be noted that it does not deal with cost comparisons between nuclear and hydroelectric power. The latter source of power may be cheap, plentiful and still unharnessed in a number of under-developed areas and it is assumed that, before attempting any refined comparison of the advantages of generating electric power in nuclear and conventional thermal plants, a country will first carry out an extensive investigation of its hydroelectric potential.

5. Consequently this study should be considered as a first step towards wider investigations which would take into account the introduction of nuclear power within a mixed thermal and hydroelectric system, as well as the full economic implications of its development within a given country. The Secretariat is already engaged in studies of the latter type in Finland and expects this year to initiate a preliminary nuclear power survey in the Philippines. [2] It is confident that the results of these studies will provide useful guidance to many Member States although it should be recognized that, because of their specific nature, they cannot have the same character of continuity that was expected by the General Conference of the present analysis. The Secretariat intends to keep the present cost study up to date by revising and adding to the tables of data and diagrams any substantive information it may receive from Members over the next years.

6. It must be emphasized that the cost data and figures presented in this report refer essentially to projected nuclear power costs and not to the costs of reactors now in operation or under construction. They are the best estimates based upon the latest technological developments for nuclear power plants which would be commissioned about 1965. The reliability of these estimates will only be demonstrated by the actual construction and operation of these plants.

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[1] GC(III)/RES/57, paragraph 5.

[2] See document GC(IV)/122, paragraphs 17 - 18 and 20 - 22 respectively.

7. The present report represents only part of the activities of the Agency in general nuclear power economics. In addition, specialized panels of experts will be called upon to prepare more detailed documents on the various aspects of the subject. The first of these panels began its work in 1960 and is expected to produce a detailed report on the present methods of nuclear power costing.

8. It will be noted that the report is primarily centred on moderate- and large-sized power reactors, although some extrapolations and cost data on smaller sizes are also given. This emphasis results from the fact that technical data for power reactors in the small and medium size range is at present insufficient to permit cost estimates of comparable reliability for larger sizes to be made, but it is known that engineering studies are being carried on in several countries. It may be noted that USAEC has invited the Agency to participate in the design, construction and operation stages of a number of reactor projects in connexion with its development programme for small and medium nuclear power plants and the final arrangements are being made to take advantage of this offer. [3] The Agency's Conference on Small and Medium Power Reactors to be held in September 1960 will also serve to elicit technical and economic information on these subjects. These activities are expected to provide for subsequent reports a firmer basis than now exists for cost estimates of comparable quality over the whole range of possible power reactor sizes.

II. GENERAL CONSIDERATION OF AVAILABLE INFORMATION

9. Several factors must be borne in mind when reviewing and assessing published information on nuclear power costs so that the correct emphasis can be given to the various data and valid comparisons hence made. These factors are discussed in the remaining paragraphs of this section.

10. The first is the significance of the data, since it is found that meaningful information, particularly for small nuclear power plants is limited and difficult to obtain. Although cost information on many Government-supported reactors is available, the experimental nature and the methods of financing and operating these reactors makes the data of limited use for the assessment of the true cost of a nuclear station constructed and operated commercially for the sole object of producing power. It is also often difficult to allocate - or even to ascertain the magnitude of - research and development expenditures in connexion with specific reactor projects or types, when such expenditures were spread over a number of years and were made at different laboratories and centres. Furthermore, for those power reactors at present under commercial construction there is in many cases a natural reluctance on the part of industrial manufacturers to release detailed information or estimates which may affect their competitive position.

11. It must be borne in mind when examining published cost data that, as yet, there is not a great deal of experience in the operation of nuclear plants on a commercial basis solely for the production of power. Many of the nuclear plants in operation today are either for plutonium production, with electricity as a useful by-product, or are experimental plants where the economic production of electricity is of secondary importance. Also with fuel manufacture and reprocessing, since this is often carried out on a semi-experimental scale, there is uncertainty as to the potential cost and performance of fuel manufactured or reprocessed on a commercial scale. Improvements here are important, since low fuelling costs can substantially offset the higher capital investment needed for nuclear power plants.

12. Also of importance when examining published costs is the method which has been used to derive the results from the basic data. Available cost data are presented in so many different ways that precise identification of the various components of the costs is not always

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[3] Ibid., paragraph 32.

possible. The proper allocation of labor and indirect costs, the inclusion or exclusion of interest on capital during construction, start-up costs, allowances for escalation [4] and contingencies, miscellaneous fees, first core costs and research and development costs are items of prime importance for accurate evaluation; but it is not known just which items are in fact included in much of the published cost data.

13. Probably the most important consideration when reviewing published information on nuclear power costs is that in most cases the cost data given is specific to one situation only, generally in the country of publication, and is conditioned by local accounting procedures. Before any direct comparison can be made between different schemes for nuclear power construction, all data must be reduced to a common basis. Considering the difficulty inherent in presenting cost information which would be directly applicable to all Member States, an attempt has been made in the following section to indicate to interested Member States how they can extrapolate the cost information given later in this report to suit their own specific conditions and accounting practices.

III. EXTRAPOLATION OF AVAILABLE DATA TO SPECIFIC SITUATIONS

14. The correct extrapolation of data from one situation to another is a matter for experts with a knowledge of the local conditions in both situations, but reasonable approximations can be made by considering the factors involved and these approximations will probably be as accurate as most of the basic information used.

15. Nuclear power costs expressed in terms of cost per kilowatt hour are in themselves of limited value because of their direct dependence on the specific local conditions of financing and plant utilization. Hence, efforts have been made to compile information on the various components of electric power generation cost, rather than merely quoting total cost per kilowatt hour, so that the information may be more easily extrapolated to suit other conditions. To this end data are given in the remainder of this section as a function of plant output for:

(a) The initial investment cost per net kilowatt of capacity;

(b) Fuel replacement cost as cost per kilowatt hour; and

(c) Annual operating and maintenance cost per net kilowatt of capacity.

A. Initial investment cost

16. The largest capital expenditure is that needed for the design and construction of the nuclear power plant, and when considering this element the first essential step is to ensure that any quoted figures include all the necessary items of cost. Here the breakdown of capital costs given in Figures 3, 4, 5 and 6 should prove useful. Additional items of cost specific to local situations may have to be added as, for instance, the cost of earthquake precautions. A detailed breakdown of cost items is being prepared by the Secretariat.

17. The breakdown of capital cost, whether specific to the reactor plant being studied or general for that type of reactor plant, is essential when extrapolating that data to any other situation. The cost of each separate item should be examined and extrapolated as necessary, and at the same time an estimate made as to the amounts of domestic and foreign capital which will be required according to whether the item can be obtained locally or must be imported. In addition allowances should be made for the cost of transport of imported plant and for any export or import duties which may be charged.

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[4] This term means an increase in the costs of labor or materials.

18. The next largest capital expenditure is for the initial fuel charge for the reactor and for the working stock of fuel which must be kept available for normal operation and for emergencies. The size of the reserve fuel stock will need to be carefully estimated, taking into account the availability of the particular fuel at the manufacturing plant and the time taken to transport it to the power station site. Naturally if the fissile material is on loan or is to be paid for by a deferred payment loan, the amount of capital to be found will be reduced to the sum of the fuel fabrication cost and the transport and insurance charges. It is also possible that transport and insurance charges may be payable in domestic currency.

19. Finally, it is usual to provide a small amount of working capital, some of which would be used for spares and supplies not included in the capital cost of the power station and the remainder for the day-to-day operation of the plant.

20. Having estimated the total amount of foreign and domestic capital necessary to construct the plant and supply the initial fuel charge and working stock, it is then necessary to estimate the annual charges which this borrowed capital would incur. Briefly these are:

(a) Interest or dividends;

(b) Depreciation (the amount depending on the interest rate, the expected life of the plant and the method of accounting);

(c) Insurance (both normal plant insurance and also nuclear liability insurance);

(d) Taxes, for example, income or enterprise tax and local tax; and

(e) Interim replacements which may be allied to the depreciation factor but may in some countries be classed as an operating expenditure.

It must be pointed out that no hard and fast rules can be laid down on this subject; each situation must be examined separately.

B. Fuelling cost

21. The fuel component of electricity generating cost depends on the price of new fuel less any credit available for spent fuel and on the estimated burn-up which can be achieved. The addition of transport and insurance charges to the price of new fuel has already been mentioned and corresponding adjustments must be made to the credit available for spent fuel, bearing in mind the relatively high cost of transporting the highly radioactive irradiated fuel. If it is proposed that spent fuel should be discarded, then an allowance must be made for the cost of its disposal or long-term storage.

22. Burn-up estimates are usually given by the designer but they may have to be revised in the light of experience. The fissile material content of spent fuel must then be adjusted and the correct credit calculated.

C. Annual operating and maintenance costs

23. The extrapolation of quoted operating and maintenance costs from one situation to another, especially in the case of a less-developed area, must take into account a number of factors, such as:

(a) The possible need for foreign specialists with high salaries and allowances;

(b) The possible lack of specialized skills and equipment;

(c) A possible lack of specialized repair facilities and services which are readily available at short notice in more advanced countries; and

(d) The transport costs of special materials such as organic liquids, heavy water or helium and of specialized spares and other operating materials.

D. Computation of generating cost

24. After the capital cost, capital charges, fuelling cost, and operating and maintenance cost have been extrapolated the electricity generating cost can be computed for the specific situation being studied. [5] The foregoing information will also be required to make other calculations of the effect of varying the installed nuclear capacity, the plant factor and the financing system. The effect of each of these changes should be studied for each of the reactor proposals under consideration.

25. The estimates of costs presented in this report are based on the extrapolation of cost experience with reactors which have been built and the present development stage of the nuclear technology. This compilation of cost figures can be considered an initial effort and will undoubtedly be altered in the light of information which is expected to be obtained from the operation of power reactors recently commissioned, and the cost experience of reactors currently under construction. The figures should, therefore, be periodically reviewed and brought up to date.

26. In spite of its limitations the present survey of nuclear costs should prove helpful in the making of a preliminary assessment of the economic merit of nuclear power for a specific application, based upon the present status of technology and the assumptions on which the present estimates are based. In order to obtain a more realistic appraisal, further work would be needed which would involve more precise information on costing procedures, the further examination of cost figures, a study of the influence of the integration of a power plant within a system, and an examination of the present worth of trends in the current movements of nuclear and conventional fuel costs.

IV. PRESENT STATUS OF NUCLEAR POWER

27. The reactor types for which this report is of relevance are limited to those the technology of which is relatively well developed and which have been operated or are about to be operated on an industrial scale. Examples are the pressurized and boiling-water reactors, the gas-cooled, the organic-moderated and the heavy-water reactors. Advanced reactors such as fast breeders or homogeneous reactors are not dealt with here, nor is any attempt made to compare the economics of reactors of different types. The possibility of using enriched uranium provides considerable flexibility in the design of reactors, especially in smaller sizes where the smaller cores require correspondingly less capital investment; enrichment can also be used to provide increased fuel burn-up and permits a wider choice of materials for the core. Counterbalancing these advantages are the cost of enrichment, the increased cost of the fabricated fuel and dependence on the source of fuel enrichment. Hence the interest in the use of reactors which operate on natural uranium such as the gas-cooled graphite-moderated and the heavy-water reactors, although both these types appear to be economically more suitable in larger sizes. In general their capital costs are higher than those of reactors using enriched uranium, but their fuelling costs are lower.

28. Much information has been published on the construction, fuelling and operating costs of nuclear reactors, but in many cases it is not clear which items were included in these costs, for what period of time the estimates would remain valid, what assumptions were made in preparing the cost data and what was the experience on which the costs were based. For these reasons caution has been exercised in selecting the sources of information and in presenting the information itself. The conclusions to be drawn from data from

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[5] The Annex provides examples of such generating cost computations.

some sources may not be in accord with those derived from information from others. In this respect the Agency would welcome further information which would improve the evaluation of the present status of nuclear power costs.

29. The three following sub-sections deal with construction costs, fuel costs and operating and maintenance costs. In every case an effort is made to indicate future trends of costs and to suggest reasons for possible decreases in the costs of various items. Attention is drawn, however, to the fact that progress in nuclear technology often arises from difficult compromises between efforts to obtain the maximum advantage from numerous, and sometimes conflicting, technical possibilities. In many cases an improvement which would lead to a decrease in one cost factor would have an unfavourable impact on another. For this reason one cannot merely add up the possible savings but must exercise critical judgment in combining them.

A. Initial investment in a nuclear power station

30. The data given in Tables 1 and 2 and presented graphically in Figure 1 show the estimated construction costs of small and large nuclear power stations which could be constructed in the United States of America on the basis of present technology and which could be operative by 1964-65. The data given in Table 1 and shown in Figure 1 as solid lines are normalizations, made by a contractor for USAEC, of the results of design studies carried out by five other contractors of USAEC. These results are based on the experience available from many experimental reactors which are being operated on behalf of USAEC. The data given in Table 2 and shown as individual points in Figure 1 represent estimates made by reactor designers and manufacturers in response to a request from USAEC for information on small size power reactors. It will be seen that the estimates for small nuclear power stations are lower than might have been expected from an extrapolation of the estimates for the larger stations and it is difficult to find technical justification for this fact. The data for the small stations were developed from individual studies, all of which were not based on the same criteria and it appears that the estimates for these stations do not include all the cost factors.

31. The data given in Table 3 and presented graphically in Figure 2 show the estimated construction costs of large and small nuclear power stations built in the United Kingdom of Great Britain and Northern Ireland. The figures for the gas-cooled reactor power stations are based on an averaging of the estimated costs of the latest large commercial power stations being constructed at present. The figures for the small power stations using slightly enriched uranium as fuel are from manufacturers in the United Kingdom and in some cases are based on designs from the United States. The estimates based on the design of the advanced gas-cooled reactor at present being constructed for the Atomic Energy Authority at Windscale indicate that a large power station of this type could be built in the United Kingdom for a cost of US $220 to US $250 per kwe during the period 1962 to 1966.[6] At the World Power Conference in 1960 a construction cost of US $280/kwe was quoted for a nuclear plant consisting of two 250 Mwe reactors for commissioning in 1965.[7]

32. Table 4 gives estimates of construction costs of nuclear power stations received from Belgium, Canada, and the Federal Republic of Germany in reply to a questionnaire sent by the Director General to Member States. It is also understood that Canada intends to release information about another heavy-water reactor in the near future. The estimates are still being evaluated by the Secretariat and no comment can yet be offered.

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[6] FLETCHER, P.T., Atom (February 1960).

[7] VAUGHAN, R.D., Technical and Economic Development of the Gas-Cooled Reactor, WPC, Madrid, paper IVB/11(1960).

33. To assist in the extrapolation of these construction costs to other situations, construction cost breakdowns given in the original references are shown in Table 5 and diagrammatically in Figures 3, 4 and 5. This presentation should also facilitate a rough estimation of those costs which could be met in a country's own currency, thus saving foreign exchange. For comparison purposes the breakdown of the estimated cost of a typical conventional power station constructed in the United States is shown in Figure 6.

34. From Figures 3, 4, 5 and 6 it will be seen that unless comparable steam conditions are achieved, the cost of turbogenerators and auxiliary power equipment will be higher for nuclear plants than for conventional plants of similar sizes. Building and civil works with special concrete shielding and containment structures cost substantially more for a nuclear power plant; the heat transfer system and the reactor part of a nuclear power plant will cost more than the conventional steam generating equipment. It can therefore hardly be expected that the capital cost of a nuclear power plant could fall below that of a conventional station.

35. However, there is a promise of a reduction in the costs of the items referred to in the preceding paragraph in the coming years. Conservative containment structures which represent a substantial part of the civil works at present considered necessary may progressively be reduced or entirely eliminated. Simpler pumps and more conventional piping materials will bring down some of the coolant circuit costs, while structural materials in the reactor proper should become cheaper through improvements in manufacturing methods. Higher power densities should also bring a significant reduction in the cost of the reactor itself.

36. The estimates for large nuclear plants to be built in the next five years indicate that the cost per kwe installed will exceed that of conventional stations of similar size by a factor of 1.5 or more, but the potential reductions mentioned above may subsequently bring this ratio down to about 1.3.

37. No general answer can be given to the question of whether these figures would be different for less-developed countries. The lower wages for unskilled labour would make for lower construction costs, but the higher salaries of foreign technicians required for construction and start-up would substantially offset this advantage. The possibly lower prices of some of the domestically produced materials would have to be balanced against the transport charges for the main plant components and the cost of the larger stock of spare parts that would be required. The degree of industrialization of the country would condition possible further savings, but the general conclusion would seem to be that nuclear power plant construction costs in a less-developed country are not likely to be lower than in the country of manufacture. To a large extent these considerations also apply to conventional thermal stations.

B. Fuel costs

38. The five types of reactor which are at present considered potentially most suitable for use in less-developed countries utilize the following types of fuel: enriched or natural uranium metal or oxide, clad in stainless steel, zirconium alloy, beryllium, aluminium or magnesium alloy. The uranium oxide is used in the form of sintered pellets, sealed in thin walled tubes, bundles of which are then assembled to form the fuel element. The uranium metal is utilized in the form of plates or cast rods sealed in tubes with extended heat transfer surfaces.

39. The available fuelling cost data for most of the reactors discussed in paragraphs 30 - 37 above are presented in Figure 7. The costs have been quoted under certain specified conditions of power station efficiency, reactor size and expected fuel life. For natural uranium fuel obtained from the United Kingdom costs of US $56/kgU for the fabricated fuel elements and US $14/kgU credit for the spent fuel elements have been quoted. Where possible the

costs have been sub-divided to indicate fabrication and running costs separately. The balance includes burn-up cost and reprocessing cost less the credit for plutonium produced, omitting the shipping charge and inventory cost, which would differ in each particular case. The costs shown are indicative of what can be achieved at the present time with present knowledge; they do not reflect possible price reductions which may occur during the lifetime of the reactor. For example, according to the Canadian Atomic Energy Commission Limited, if a burn-up of about 10 000 Mwd/t were achieved for the heavy water natural uranium reactor with a fabricated fuel cost of US $60/kg, the spent fuel being discarded, the fuelling cost could be as low as 1 mill/kwh.

40. Every component of fuel costs offers room for substantial reductions in the near future. With regard to natural uranium, the price of U_3O_8 in concentrates offered by the Agency has now dropped to about US $18/kg while there have been offers of nuclear uranium metal around US $35/kg. Both figures indicate a trend to lower prices which is unlikely to be reversed in the next few years. A recent study made in the United States of the prices of enriched uranium produced in diffusion plants in that country indicates that they are free of any Government subsidy and suggests that they will not be increased but may conceivably be reduced. Further, the present capacity of diffusion plants in the United States appears sufficient to meet the inventory and burn-up requirements of a nuclear power plant capacity of about 40 000 Mwe.[8] It is also known that other methods of isotopic enrichment of uranium which may possibly lead to equal or lower production costs are being investigated in various countries.

41. Even larger economies may be expected in the fabrication of fuel elements where standardization of designs and larger batch production may cause a 30 - 40 per cent reduction in costs. To quote but one example, the fabrication cost of a certain type of fuel element for a pressurized-water reactor is expected to decrease from US $110 to US $70 per kgU over the next few years.[9]

42. No less important is the trend towards higher burn-up which may be expected to lead to reductions of more than 0.5 mills per kwh (or about 15 per cent of the present total fuel costs) in certain enriched systems.

43. Finally, decreases in processing costs for irradiated fuel may occur, especially where continuous processing can replace batch treatment.

44. Should all of these possible developments occur, reductions of up to 30 per cent in total fuel costs in the next five to ten years could be expected, even if a possible decrease in credit for plutonium is taken into account.

45. This encouraging picture may appear attractive to less-developed countries, but the following factors should be taken into account. With regard to natural-uranium systems, although the mining of ores and production of concentrates are relatively simple processes, they involve considerable investment. Similarly the production of uranium metal of nuclear purity in small amounts is quite feasible, but the fabrication of fuel elements for use at high temperature is a very difficult undertaking. The unit investment cost of a processing plant for irradiated fuel elements increases substantially for smaller throughputs, and a plant of this kind would hardly be economic unless a very substantial nuclear power programme were contemplated on a national or regional basis. Finally, the cost of an enrichment plant running into several hundred million dollars clearly rules out this type of development for any country taking its initial steps towards the utilization of nuclear power.

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[8] Forum Memo (December 1959).

[9] Nucleonics (April 1960).

46. In spite of the factors which augur a substantial reduction in fuel costs in the near future, such as abundant supplies of uranium, the economies to be achieved by fabricating larger lots of more standardized fuel elements and the spare capacity in existing processing and enrichment plants, the economic advantages for the less-developed countries of establishing domestic nuclear industries in the immediate future are nevertheless limited. However, in the case of a country with a sufficiently large total industrial output and a large nuclear power development programme, planning for domestic fabricating and processing plants would appear to be important if its expenditure in foreign currency on nuclear power is to be kept to a minimum.

C. Operating and maintenance costs

47. The annual cost of operating and maintaining a conventional power station, excluding depreciation and fuel costs, includes the cost of supervisory, operating and maintenance personnel and the cost of the materials and external services which are required. The same items of cost would be involved in operating and maintaining a nuclear power station. In making cost comparisons it is desirable to show the annual cost of operation only (e.g. as dollars per kilowatt per year) and to exclude the effect of the plant factor.

48. As yet there is still insufficient information on the operating and maintenance cost of a nuclear power station used solely for the production of electricity, although estimates have been made by analogy with conventional stations or by inspection of nuclear station designs. For example it is still uncertain what staff is required. Estimates for water reactors have been given in the United States ranging from 0.3 to 0.5 employees per Mwe for a 200 - 300 Mwe station to about 1 to 1.5 employees per Mwe for a 50 - 75 Mwe station.[10] The corresponding figures would be significantly higher for smaller nuclear stations. In the United Kingdom the estimate for a 500 Mwe gas-cooled two-reactor station is about 0.6 employees per Mwe.[11] If the station were operated in an isolated area, all these figures would probably be higher.

49. The estimates of operating and maintenance costs which have been made in the United States are presented in Figures 1 and 2. It should be noted that the annual cost per kilowatt is strongly influenced by the size of the power station. These data indicate that for enriched-water reactor plants, normal operation and maintenance costs vary from US $20/kwe for a 20 Mwe station to US $4/kwe for a 300 Mwe station. At an 80 per cent plant factor this corresponds to 3 mills to 0.6 mills per kwh respectively. For the large gas-cooled natural uranium station in the United Kingdom operating and maintenance costs are expected to be US $5 and US $4 per kwe respectively for 300 and 500 Mwe stations, which corresponds to 0.7 and 0.6 mills per kwh at 80 per cent load factor.

50. Reductions in operating staff, increased automation and lower repair bills are a likely expectation and, together with greater experience in safety requirements, will all contribute to lower operating and maintenance costs. Considering, however, that this item represents less than 10 per cent of the total nuclear power costs, even a 20 per cent saving in operating and maintenance costs would imply only a two per cent overall saving.

51. In the case of less-developed countries a relatively lower wage and salary bill (provided local operating staff have been trained) would have to be balanced against the cost of the larger stock of spare parts which would necessarily have to be carried for repairs in the initial stages. It can, therefore, hardly be expected that a lower wage and salary bill in such countries would lead to any significant difference in the unit price of the electricity generated.

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[10] USAEC, Power Cost Normalization Studies, SL-1674.

[11] IAEA, Directory of Nuclear Reactors: Vol. 1. Power Reactors, STI/PUB. No. 4 (1959), page 162.

V. SUMMARY OF THE REPORT AND FUTURE TRENDS IN NUCLEAR POWER COSTS

52. It is evident that nuclear power is still in its early phase of development, and important cost reductions are envisaged as a result of technical advances based upon the continuous research and development which is being carried on. Present day designs of relatively developed systems will be further improved to incorporate the experience being gained with the first and second generation plants, and some other reactor concepts now in the experimental stage may prove successful. Of great significance will be the possible reductions in fuel cycle costs; these will result from reductions in fabrication and reprocessing charges, the achievement of higher burn-ups and the lowering of uranium prices. Considerable work is being carried out to develop inexpensive reactor materials with good nuclear properties and capable of withstanding high temperatures; such material will help to prolong the useful life of nuclear plants. Sizeable savings can be expected from the standardization and improvement of reactor components such as pumps, valves and heat exchangers which represent a large fraction of total investment. Lack of extensive experience in reactor safety has led to conservative and costly designs for containment shells, control mechanisms and instrumentation; with better understanding of essential safety requirements and the use of improved techniques, containment and control of reactors will be simplified without sacrificing reliability and safety. Most of the nuclear power plants now under construction are one of a kind; when several plants of essentially the same design are built, the engineering development expenses will be spread out and the cost per unit will decrease.

53. It has been estimated that the cost of generating power with the large gas-cooled reactor in the United Kingdom will be 7 mills/kwh in 1964, levelling off to 5 mills/kwh after 1974, at a 75 per cent plant factor and with an annual capital charge of about 8 per cent.[12] Conventional fuel is predicted to level off at US $0.49/million BTU, and the conventional generating costs are expected to decrease from 6.3 to 5.8 mills/kwh in the same period and for the same plant factor. Nuclear power is, therefore, likely to become competitive with conventional power about 1966.

54. According to a recent USAEC evaluation which assumes a 14 per cent annual capital charge, an 80 per cent plant factor and no changes in USAEC's present schedule of uranium prices nor in its purchase price of plutonium, the generating cost of power produced from slightly enriched uranium in a 200 Mwe capacity reactor, which on the basis of present technology would fall between 11 and 14 mills/kwh, [10] is expected to decrease later into the 9 - 10 mills/kwh range.[13]

55. Assuming that improvements in the efficiency of conventional thermal power plants are levelling off and under the conditions specified, the cost of power generated in a large nuclear power plant to be installed towards the end of the next decade would become competitive with conventional thermal power in areas where conventional fuel costs were above US $0.55 per million BTU (US $2.20 per million kilocalories).

56. It is interesting to note that, if in the above computation the annual rate of capital charge is taken as 7 instead of 14 per cent, the power generating costs from a similar 200 Mwe nuclear reactor (which on the basis of present technology would fall between 8 and 10 mills/kwh) might come down later into the 6.5 - 7.5 mills/kwh range. At that time and under these assumptions, such power costs would become competitive with conventional thermal power in areas where conventional fuel costs were above US $0.45 per million BTU (US $1.80 per million kilocalories).

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[12] HINTON, Sir C. et al., The Economics of Nuclear Power in Great Britain, WPC, Madrid, Paper IV B/8 (1960).

[13] Computations based on data in the source cited in footnote 10, and on the Statement of the United States Atomic Energy Commission to Joint Committee on Atomic Energy, as summarized in Nucleonics (April 1960), pages 71 et seq.

57. The foregoing calculations demonstrate the importance of but one of the key factors which will in the future determine the conditions under which nuclear power may become competitive. It is therefore obvious that as such characteristics as types and sizes of plants, plant factors and rates of annual capital charges change, the limits of competitiveness will correspondingly vary substantially; and it is the purpose of this report to facilitate the making by Member States of preliminary estimates of the nuclear power costs that will apply in their specific situations. [14]

TABLE 1

Initial investment and operating and maintenance costs for medium and large nuclear power stations based upon recent United States studies a/

Type of station	Capacity (Net Mwe)	Initial investment (US $/kwe)			Operating and maintenance cost (US $/kw/y)
		Plant only	Fuel only b/	Fabricated fuel b/	
PW	75	435	115	145	9.6
	200	282	95	120	5.5
	300	242	95	120	4.1
BW	75	470	60	100	9.7
	200	311	40	75	5.6
	300	263	32	57	4.2
OM	75	350	28	130	13.1
	200	241	97	130	9.0
	300	220	96	120	7.6
HWN c/	75	640	14	31	12.7
	200	425	5.5	12.4	8.0
	300	360	4.3	9.6	6.4
GCN	75	675			9.7
	200	452	64	88	5.6
	300	380			4.2

a/ USAEC, Power Cost Normalization Studies, SL-1674, relating only to planned reactors.

b/ In the core.

c/ The costs of the heavy water inventory are included in the figures for this reactor.

[14] As mentioned in paragraph 8 above, there is as yet too little reliable information on the economics of small power reactors for a sound extrapolation to be made to small power units.

TABLE 2

Initial investment and operating and maintenance costs for small nuclear power stations in the United States based upon estimates of reactor designers and manufacturers[a]

Identification number	Type of station	Capacity (Net Mwe)	USAEC report number	Initial investment (US $/kwe) Plant only	Fuel only[b]	Fabricated fuel[b]	Operating and maintenance cost (US $/kw/y)	Remarks
1	PW	11.7 23.6	TID-8513	660 480	152 135	210 184	20 14	
2	PW	23.5	TID-8508	445	76	96	10	Includes 29 Mw of conventional superheat.
3	PW	10.5	TID-8513	1 030	102	233	26	Identical in design with and of approximately the same cost as the BR-3 station under construction at Mol, Belgium.
4	BW	23.5 32.9	TID-8510	372 350	28 26	51 49	N.A.	Includes 20 and 27 Mw of conventional superheat for the two stations respectively. Many indirect costs omitted.
5	BW	23.5	TID-8508	465	29	74	10	Similar to number 4, but includes additional indirect costs such as profits, contingency and interest during construction.
6	BW	19.1	TID-8510	451	45	84	N.A.	Similar to number 4, but includes nuclear instead of conventional superheat. Many indirect costs omitted.
7	BW	19.1	TID-8510 SL-1674	640	45	84	N.A.	Based on the same data as number 6, but using "Sargent and Lundy" ratio of total costs to construction costs.

a/ The figures given are provisional estimates relating only to planned reactors. See also the remarks in paragraph 30.

b/ In the core.

TABLE 3

Initial investment for nuclear power stations based upon recent United Kingdom studies[a]

Identification number	Type of station	Capacity (Net Mwe)	Reactors per station	Initial investment (US $/kwe)[b]	
				Plant only[c]	Fabricated fuel[d]
1.	GCN[e]	50	1	700	45 to 60
2.	GCN[e]	300	1	280	45 to 60
3.	GCN[e]	250	2	295	45 to 60
4.	GCE[f]	30	1	475	50
5.	GCE[f]	60	1	335	45
6.	GCE[f]	150	1	255	35
7.	PW[g]	20	1	450	N.A.
8.	PW[g]	60	1	335	N.A.
9.	OM[g]	20	1	308	155

a/ The figures given are provisional estimates relating only to planned reactors.

b/ At US $2.80 = £1 sterling.

c/ Does not include interest during construction or power company's charges.

d/ One core loading only: total inventory would entail about 1.3 core loadings.

e/ Source of information: FLETCHER, P.T., *Atom* (February 1960).

f/ Information from a private source.

g/ Source of information: *Engineering* (15 April 1960).

TABLE 4

Initial investment for nuclear power stations based upon estimates received from Belgium, Canada and the Federal Republic of Germany[a/]

Country and manufacturer	Type of station	Capacity (Net Mwe)	Initial investment (US $/kwe)		
			Plant only	Fuel only	Fabricated fuel
BELGIUM					
ACEC	PW	200	300	N.A.	24
CANADA					
Canadian Atomic Energy Commission Limited	HWN	200	328[b/]	7.7	23
Canadian Westinghouse	HWN	132	386[b/]	11.4	32
Canadian GEC	OCHWN	55	435[c/]	5.9	17
GERMANY, FEDERAL REPUBLIC OF					
Interatom	OM	16	520	82	101
Siemens	HWN	49	400	N.A.	40
AEG/KEA	BW	15	500 to 565	N.A.	60[d/]
German Babcock and Wilcox	GCE	35	485	N.A.	13[d/]

a/ The figures given are provisional estimates relating only to planned reactors.

b/ Does not include US $60/kwe for D_2O investment.

c/ Includes D_2O investment.

d/ Fabrication costs only, fuel costs not included.

TABLE 5

Breakdown of the costs of power stations[a]

Identification number and item of cost	PW				BW				GCN	HWN				CONVEN-TIONAL	
	75 Mwe		300 Mwe		75 Mwe		300 Mwe		300 Mwe	132 Mwe		200 Mwe[c]		235 Mwe	
	$/kw	%	$/kw	%	$/kw	%	$/kw	%		$/kw	%	$/kw	%	$/kw	%
I. Buildings and civil works															
Site preparations and improvements	17	4	5	2	19	4	5	2				7	2		
Containment and civil works	44	10	12	5	52	11	29	11	N.A.	N.A.		26	8	N.A.	
Other structures and civil works	26	6	9	4	23	5	11	4				36	11		
Sub-total	87	20	26	11	94	20	45	17	25	77	20	68	21	32	18
II. Reactor and auxiliary equipment															
Reactor equipment	61	14	27	11	75	16	29	11	21	39[b]	10[b]	54[b]	16[b]		
Fuel handling	13	3	5	2	14	3	5	2	1	11	3	8	3		
Waste disposal	5	1	2	1	5	1	3	1	1	15	4	4	1		
Instrumentation	17	4	5	2	23	5	8	3	1	8	2	22	7		
Sub-total	96	22	38	16	117	25	45	17	24	73[b]	19[b]	88[b]	27[b]		
III. Heat transfer and steam generation equipment														) Boiler equipment	
Primary coolant equipment	65	15	41	17	52	11	29	11	12	54	14	17	5		
Water supply and treatment	4	1	5	2	9	2	5	2	4	8	2	8	2		
Steam generation equipment	48	11	29	12	52	11	34	13	14	39	10	15	5		
Sub-total	117	27	75	31	113	24	68	26	30	101	26	40	12	63	36
IV. Turbo-generator and miscellaneous power equipment															
Turbo-generator and auxiliaries	61	14	55	23	71	15	58	22	19	66	17	42	13	63	36
Condensor and water system	17	4	15	6	19	4	13	6	1	19	5	15	4		
Auxiliary and miscellaneous power plant equipment to high voltage line	26	6	15	6	23	5	16	5	1	23	6	29	9	6	3
Sub-total	104	24	85	35	113	24	87	33	21	108	28	86	26	69	39
V. Interest during construction	31	7	18	7	33	7	18	7	27	27	7	46	14	12	7
GRAND TOTAL	435	100	242	100	470	100	263	100	100	386[b]	100[b]	328[b]	100[b]	176	100

a/ The figures given for nuclear plants are provisional estimates relating only to planned reactors. All indirect costs such as those for engineering, contingencies and start-up have been proportionately shared between the various items of cost shown in this Table.

b/ The cost of the D_2O moderator is not included in this figure.

c/ The information for this station was received at a late date. In the time available it has not been possible to reconcile some of the figures for the station with those for other stations, particularly those relating to heat transfer and steam generation equipment.

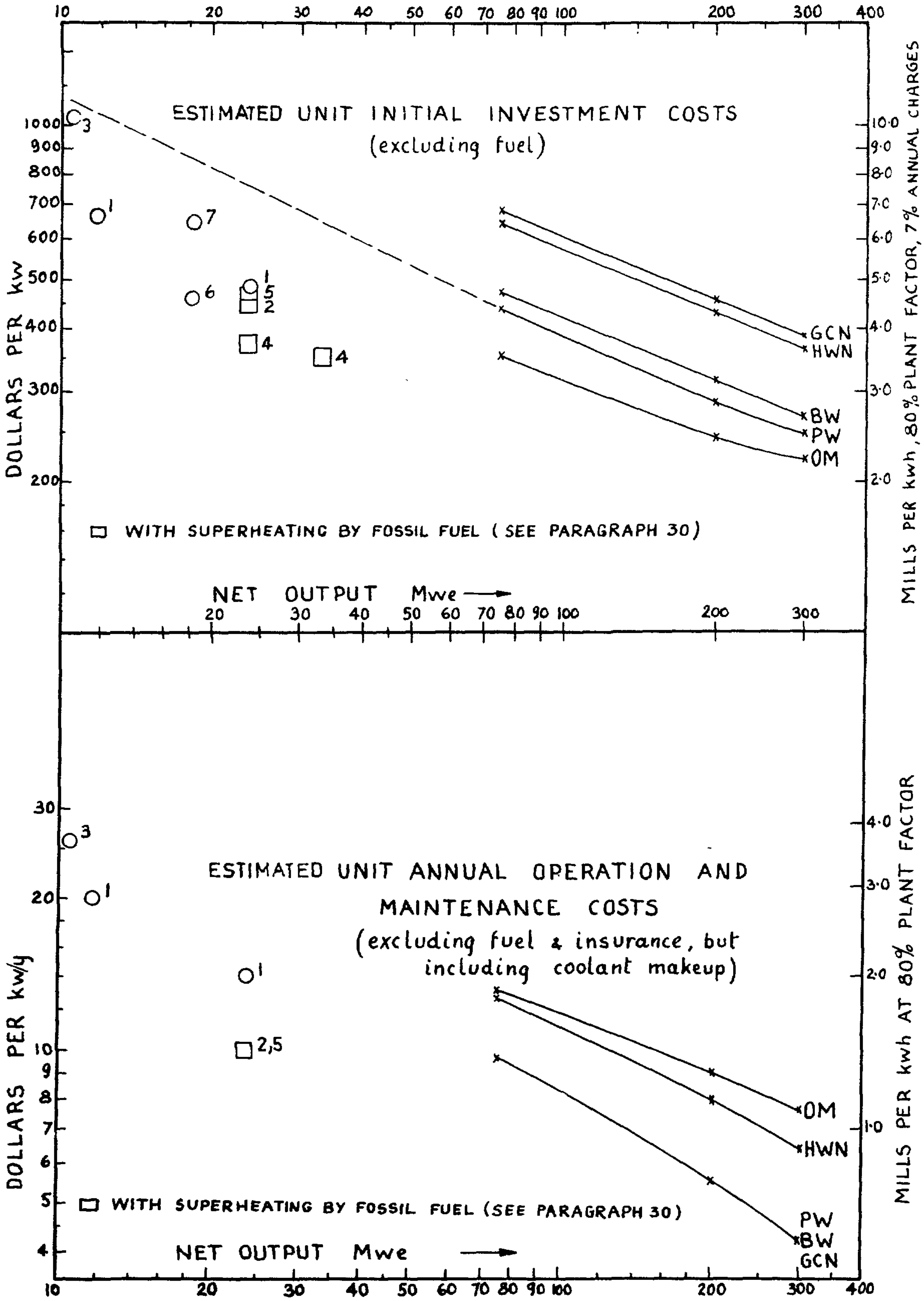


FIGURE 1

ESTIMATED PLANT AND OPERATING COSTS IN THE UNITED STATES BASED ON PRESENT TECHNOLOGY
(according to Tables 1&2)

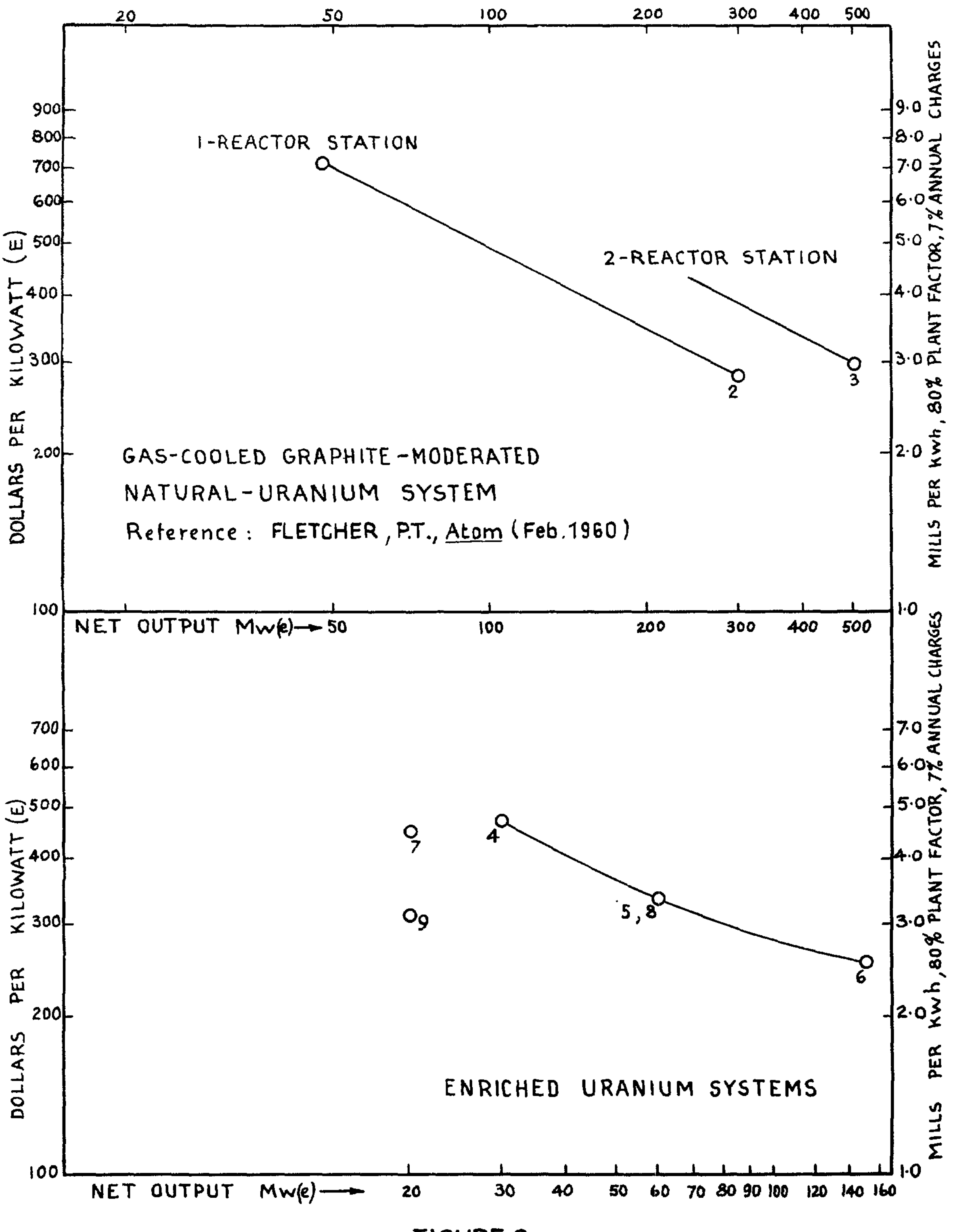


FIGURE 2

ESTIMATED PLANT COSTS IN THE UNITED KINGDOM BASED ON PRESENT TECHNOLOGY (according to Table 3)

Notes: Fuel & land costs excluded
£1 = $ 2·80 : 1d = 11·7 mills

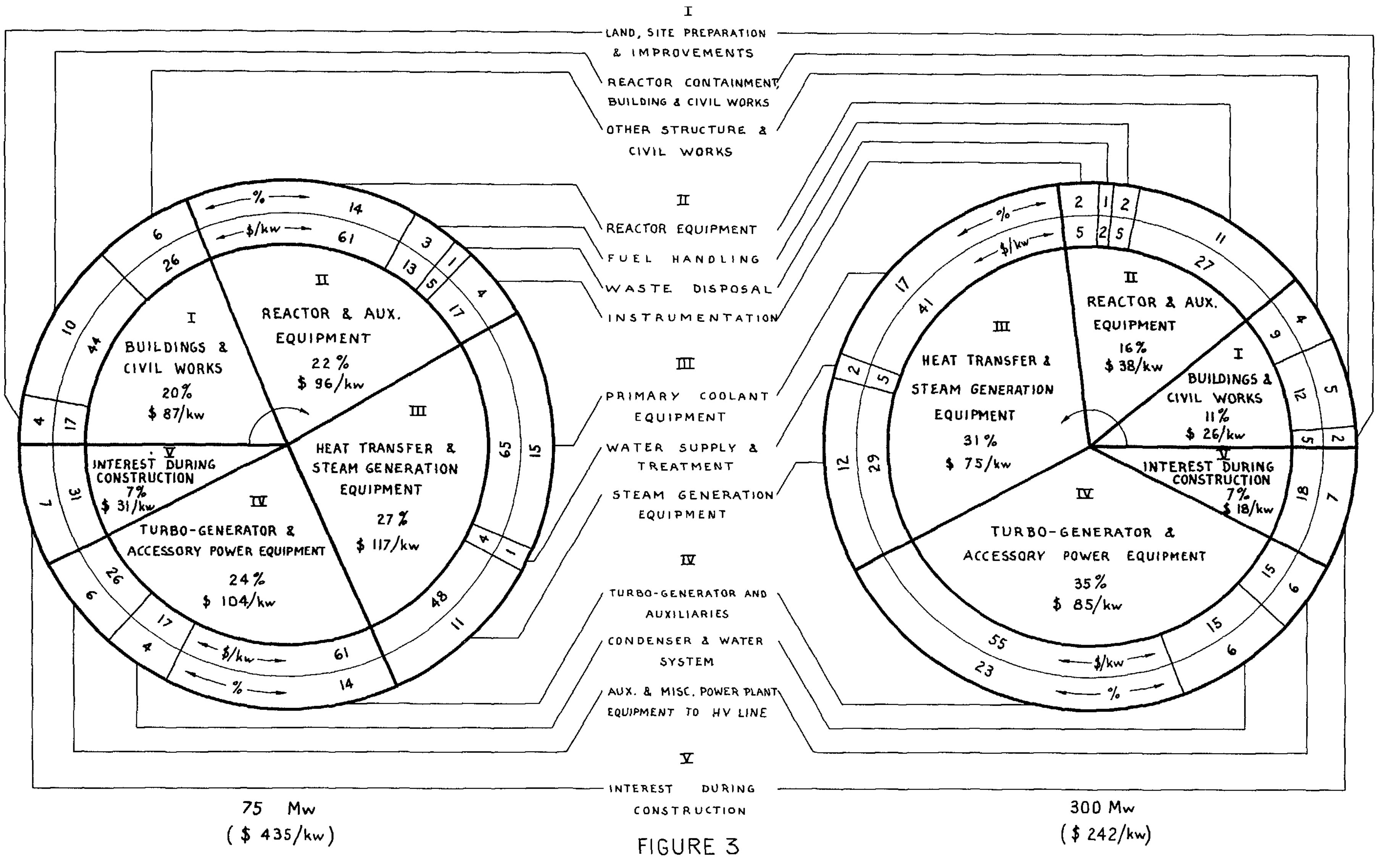


FIGURE 3

BREAKDOWN OF NUCLEAR POWER PLANT COSTS FOR PLANNED PRESSURIZED-WATER REACTORS

Note: Percentages adjusted to whole numbers

Reference Sargent & Lundy, USAEC report SL-1674

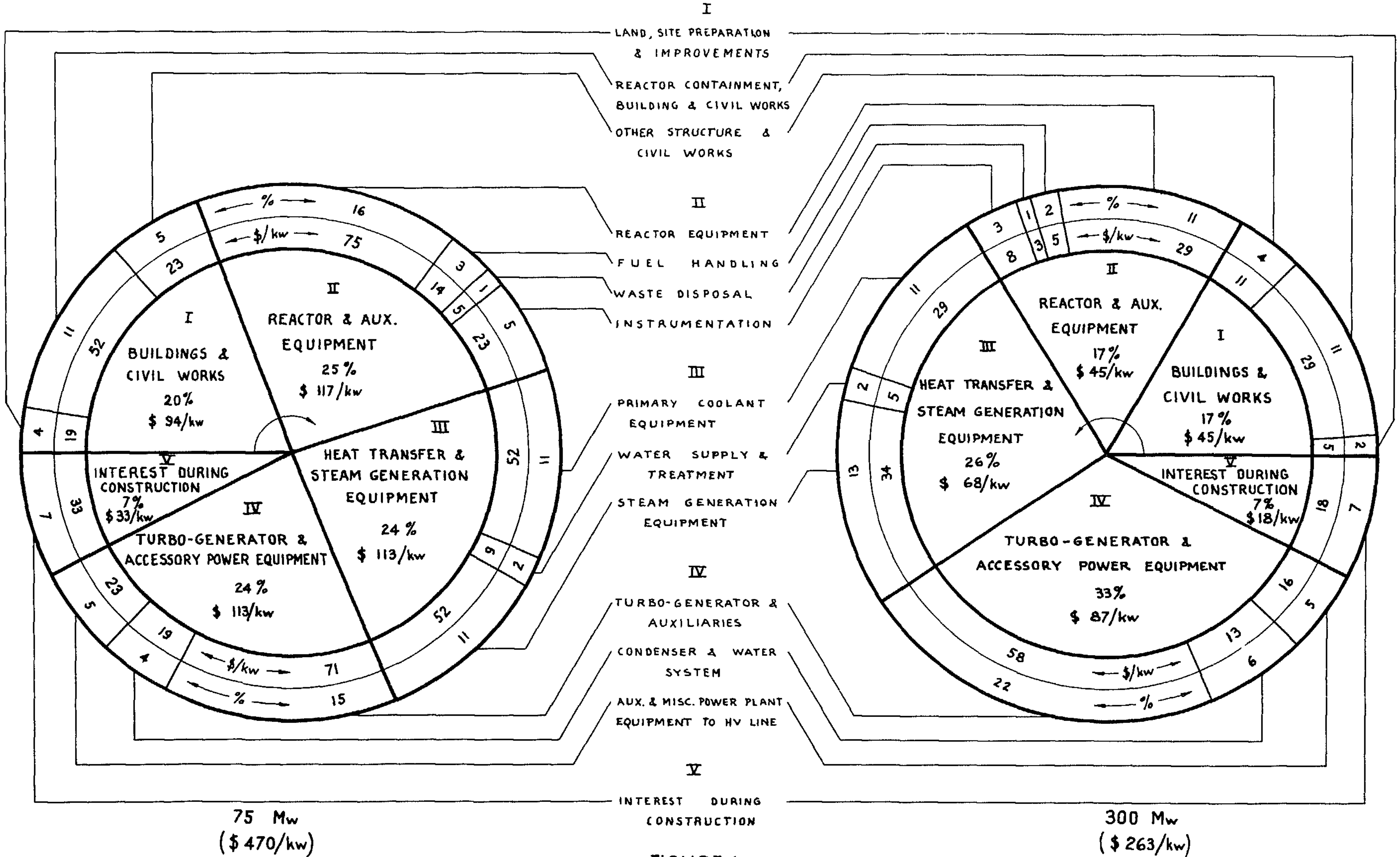
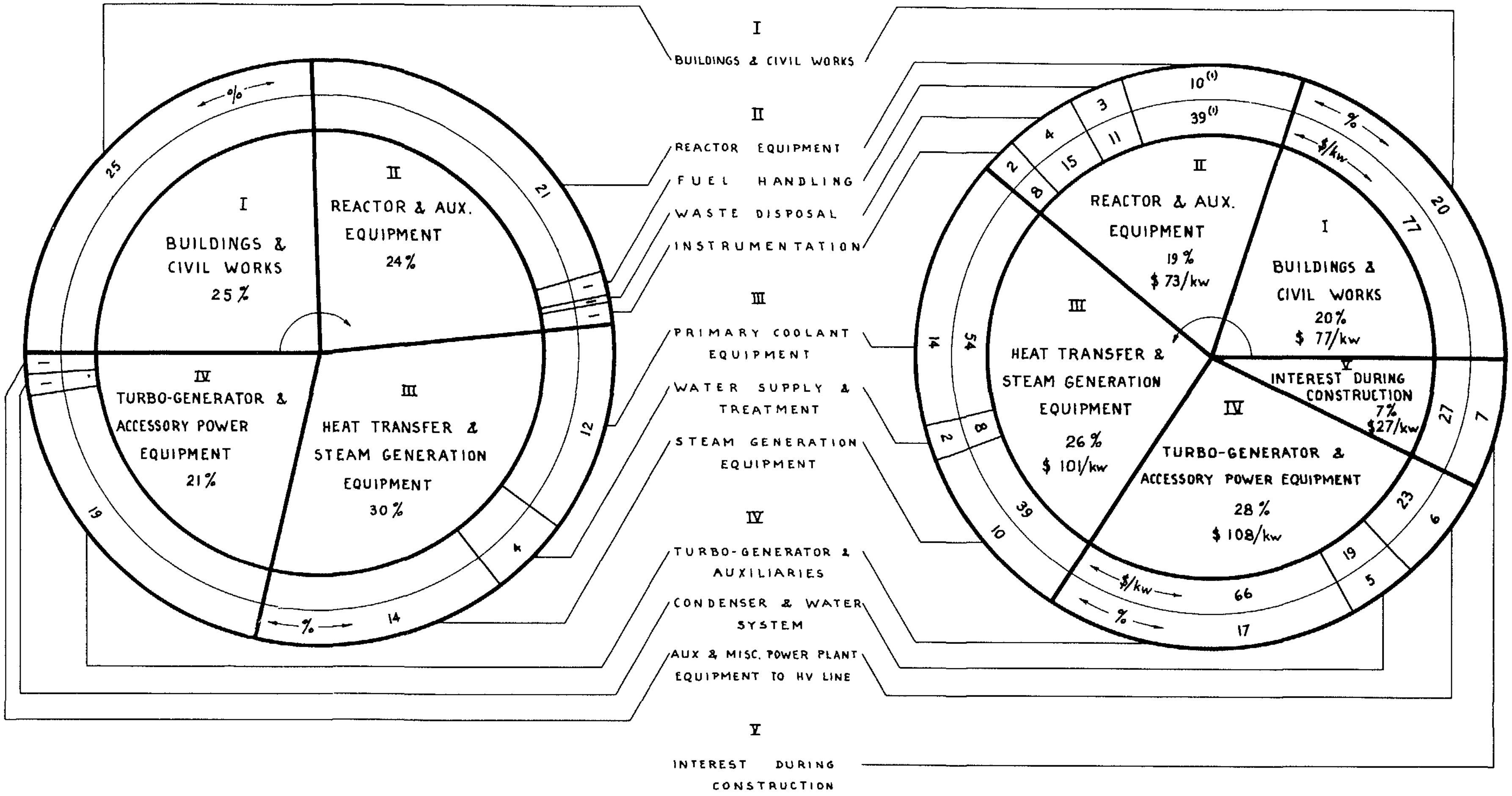


FIGURE 4

BREAKDOWN OF NUCLEAR POWER PLANT COSTS FOR PLANNED BOILING-WATER REACTORS (DUAL CYCLE)

Note: Percentages adjusted to whole numbers
Reference Sargent & Lundy, USAEC report SL-1674



PLANNED GAS-COOLED REACTOR
(U.K., > 300 Mw)

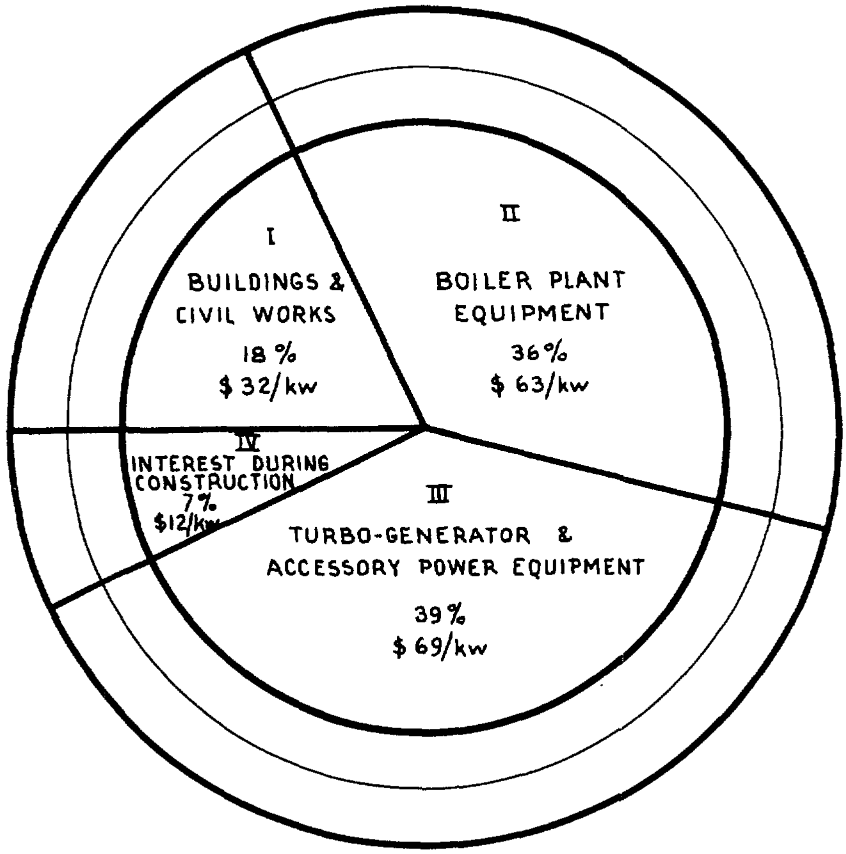
FIGURE 5

PLANNED HEAVY-WATER REACTOR
(CANADA. 132 Mw, $386/kw)

BREAKDOWN OF NUCLEAR POWER PLANT COSTS

Notes (1) Excludes D_2O moderator
Percentages adjusted to whole numbers
Cost of land excluded

References: U K Atomic Energy Authority
Canada: Private communication

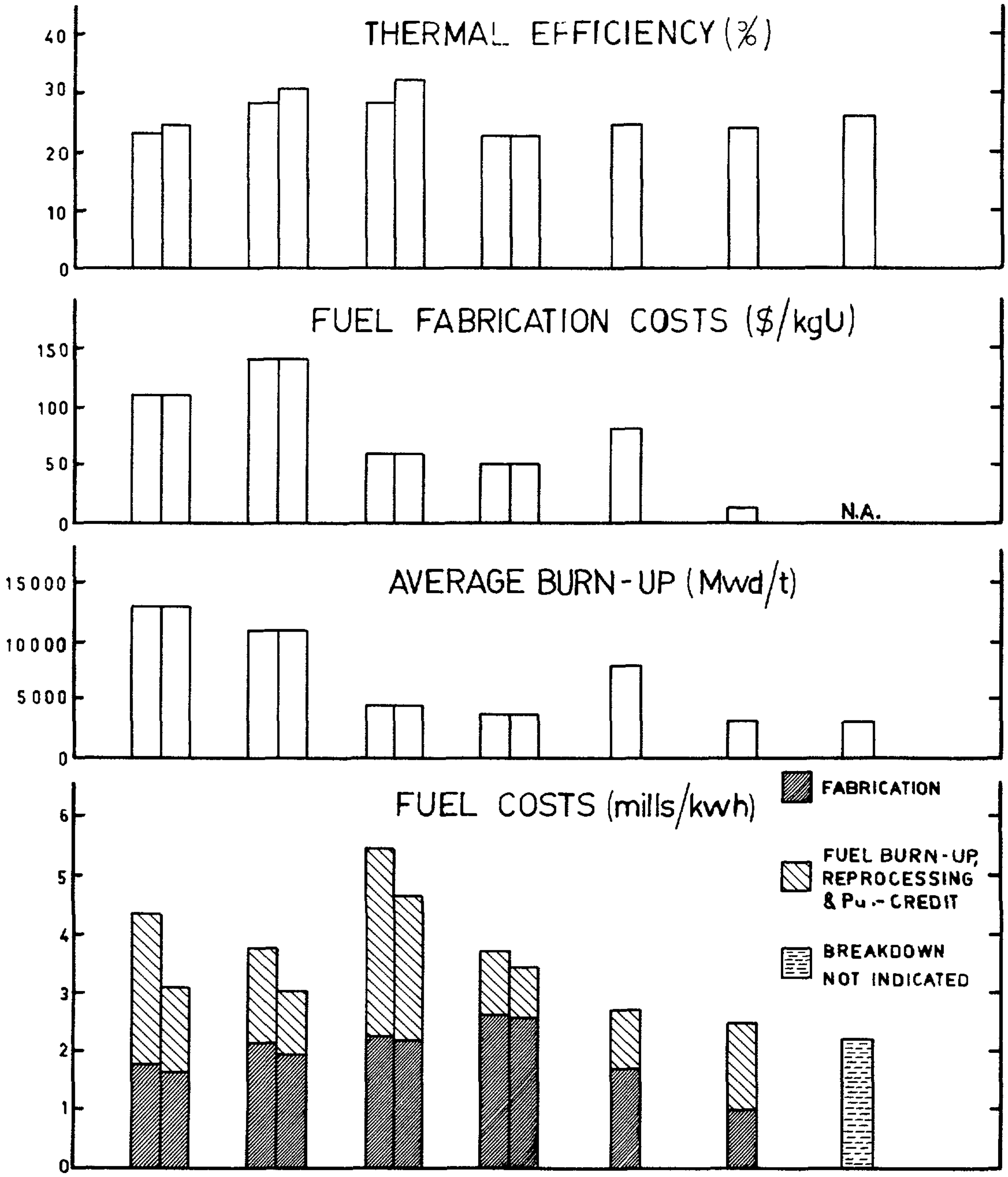


235 Mw
($176/kw)

FIGURE 6

BREAKDOWN OF TYPICAL CONVENTIONAL POWER PLANT COSTS IN THE UNITED STATES

Reference: STONE and WEBSTER to USAEC, COMMUNICATION SWI.



POWER (Mw)	20 230	20 300	20 350	100 300	132	230	250
FUEL	UO_2	UO_2	U	U	UO_2	U	U
CLADDING	S.S.	Zr	Al	Zr	Zr	Magnax	Magnax
REACTOR	PW	BW	OM	HWN	HWN	GCN	GCN
COUNTRY	U.S.	U.S.	U.S.	U.S.	CANADA	U.S.	U.K.
REFERENCE	1	1	1	1	3	1	2

FIGURE 7.

ESTIMATED NUCLEAR FUEL COSTS
BASED ON PRESENT-DAY PRICES

Notes: For planned reactors, plant factor 80%
Shipping and inventory costs excluded
References: 1. USAEC, Power Cost Normalization Studies, SL-1674
2. FLETCHER, P.T., Atom (Feb. 1960)
3. Private communication

ANNEX

Examples of approximations of the cost of generating electric power in nuclear stations

1. As indicated in paragraphs 14, 15 and 24 of the foregoing report, extrapolation of data to specific local circumstances is rather complicated and considerably influenced by the costing procedures used. It has been thought, nevertheless, of interest to provide a few simple examples of reactor cost computations as a guide to those countries that may wish to undertake on their own a very preliminary assessment of the relative merits of nuclear power. At a later stage of an eventual nuclear plant project, the receipt of tenders should be expected to give more precise cost information.

2. The examples which follow give estimates of the cost of generating electric power in nuclear stations under assumed specific conditions. To the extent possible, use has been made of the cost data presented in the report. Simplified procedures have been used for the cost calculations and the results rounded off to the nearest unit.

3. Any of the estimates could serve for a rough evaluation in a preliminary study for the eventual construction of a nuclear power plant, provided that appropriate extrapolations were made for the different cost components taking into consideration the local conditions, construction time and costs, cost of money and other variables that apply in the country in question.

4. It should be emphasized that the examples are hypothetical and do not relate to nuclear plants actually under construction or in operation. Therefore, the relative differences in the total costs of generation given should not be considered as indicating the relative merits of the different reactor systems. The costs given would change considerably with the size of the reactor, the specific financing arrangements, the plant utilization factor in the network, and other particular conditions and circumstances.

5. Examples are given for the following reactor types and systems:

   I. Large graphite-moderated reactor fuelled with natural uranium (500 Mwe);

   II. Large pressurized-water-moderated reactor fuelled with slightly enriched uranium (200 Mwe);

   III. Small pressurized-water-moderated reactor fuelled with slightly enriched uranium (20 Mwe); and

   IV. Large heavy-water reactor fuelled with natural uranium, the spent fuel being discarded (130 Mwe).

I. Estimated costs in US dollars of generating electric power in a large graphite-moderated reactor fuelled with natural uranium (500 Mwe)

A. Type of reactor

Large gas-cooled, graphite-moderated reactor fuelled with natural uranium and built in Europe.

B. Fuel

Fuel is assumed purchased from the United Kingdom and spent fuel returned thereto. The fuel is continuously charged into and discharged from the reactor.

C. Operating parameters

Power output: 500 Mwe net (from 2 units of 250 Mwe each).
Net plant efficiency: 26%.
Burn-up at equilibrium: 3 000 Mwd/t U.
Ratio of total fuel inventory to fuel in reactor: 1.3.
Plant factor: 80% (7 000 hr/yr).

D. Cost parameters

Plant investment costs:	$295/kwe. This figure is obtained from the data given under identification number 3 in Table 3, or from Figure 2. The estimate is for a nuclear plant built under United Kingdom conditions. Cost of money, construction time and local conditions and requirements would, of course, alter this estimate for construction in another European country, but probably not very substantially. Figure 5 could be used to indicate an approximate distribution of the construction costs, and by extrapolation permit a crude evaluation of possible foreign currency savings.
Cost of fabricated fuel:	$56/kgU (taken from paragraph 39).
Cost of initial core loading:	$60/kwe (taken from Table 3, identification number 3).
Value of spent fuel:	$14/kgU (taken from paragraph 39) or $15/kwe.
Operating and maintenance cost:	$4/kwe/yr (taken from paragraph 49).
Transport cost:	$10/kgU. This is the assumed cost of shipping spent fuel elements to the United Kingdom. This high cost is due to the need for heavy containers for radiation shielding. The shipping weight of spent fuel can be taken as 30 times the weight of uranium.
Annual capital charges, including cost of money, depreciation and taxes (if any):	7%/yr and 14%/yr (assumed values).

E. Calculation of generating costs

Annual capital charge	14%/yr	7%/yr
1. Plant investment $\frac{\$295/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	5.9	3.0 mills/kwh
2. Operating and maintenance $\frac{\$4/kwe/yr}{7\ 000\ hr/yr}$	0.6	0.6 " "
3. Fuel $\frac{\$56/kg - \$14/kg}{24\ hr/d \times 26\% \times 3\ 000\ kwd/kg}$	2.2	2.2 " "
4. Spent fuel transport $\frac{\$10/kg}{24\ hr/d \times 26\% \times 3\ 000\ kwd/kg}$	0.5	0.5 " "
5. Total, excluding fuel inventory	9.2	6.3 mills/kwh
(a) Fuel inventory considered as part of plant investment		
6. Fuel inventory 1.3 x $\frac{\$60/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	1.6	0.8 " "
7. Total cost	10.8	7.1 mills/kwh
(b) Fuel inventory based upon average value of fuel in the reactor		
8. Total, excluding inventory (line 5 above)	9.2	6.3 mills/kwh
9. Fuel inventory 1.3 x $\frac{\$(60+15)/kwe}{2}$ x $\frac{1}{7\ 000\ hr/yr}$ x (6% and 5%)/yr	0.4	0.3 " "
10. Total cost	9.6	6.6 mills/kwh

II. Estimated costs in US dollars of generating electric power in a large pressurized-water-moderated reactor fuelled with slightly enriched uranium (200 Mwe)

A. Type of reactor

Large pressurized-water-moderated reactor fuelled with slightly (3.2%) enriched uranium and built under conditions similar to those prevailing in the United States of America.

B. Fuel

Fuel is assumed purchased from the United States and spent fuel returned thereto.

C. Operating parameters

Power output: 200 Mwe net.
Net plant efficiency: 25%.
Burn-up at equilibrium: 13 000 Mwd/tU.
Ratio of total fuel inventory to fuel in reactor: 1.5.
Plant factor: 80% (7 000 hr/yr).

D. Cost parameters

Plant investment costs:	$282/kwe. This figure is taken from Table 1 or Figure 1. The estimate is for a nuclear plant built under United States conditions. Cost of money, construction time, local conditions and requirements, different from those in the United States, may alter this figure substantially.
Cost of fabricated fuel:	$517/kgU. This figure represents the official United States price of 3.2% enriched uranium, plus assumed charges of $110/kg for fabrication.
Cost of initial core loading:	$120/kwe (Taken from Table 1).
Value of spent fuel:	$251/kgU (or $58/kwe). This is the United States price for 2.2% enriched uranium. A credit for the plutonium produced and a debit for the reprocessing cost, together with other factors affecting fuel costs, have been taken into account in arriving at the fuel cost given in part E, line 3 below.
Operating and maintenance cost:	$5.5/kwe/yr (Taken from Table 1).
Transport cost:	$20/kgU (Assumed cost of transporting spent fuel).
Annual capital charges, including cost of money, depreciation and taxes (if any):	7%/yr and 14%/yr (Assumed values).

E. Calculation of generating costs

Annual capital charge	14%/yr	7%/yr
1. Plant investment $\frac{\$282/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	5.6	2.8 mills/kwh
2. Operating and maintenance $\frac{\$5.5/kwe/yr}{7\ 000\ hr/yr}$	0.8	0.8 " "
3. Fuel (taken from Figure 7)	3.1	3.1 " "
4. Spent fuel transport $\frac{\$20/kg}{24\ hr/d \times 25\% \times 13\ 000\ kwd/kg}$	0.2	0.2 " "
5. Total, excluding fuel inventory	9.7	6.9 mills/kwh
(a) Fuel inventory considered as part of plant investment		
6. Fuel inventory 1.5 x $\frac{\$120/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	3.6	1.8 " "
7. Total cost	13.3	8.7 mills/kwh
Annual capital charge		
(b) Fuel inventory based upon average value of fuel in the reactor		
8. Total, excluding inventory	9.7	6.9 mills/kwh
9. Fuel inventory 1.5 x $\frac{\$(120 + 58)/kwe}{2 \times 7\ 000\ hr/yr}$ x (6% and 5%)/yr	1.1	1.0 " "
10. Total cost	10.8	7.9 mills/kwh

III. Estimated costs in US dollars of generating electric power in a small pressurized-water-moderated reactor fuelled with slightly enriched uranium (20 Mwe)

A. Type of reactor

Small pressurized-water-moderated reactor fuelled with slightly (3.3%) enriched uranium and built under conditions similar to those prevailing in the United States of America.

B. Fuel

Fuel is assumed purchased from the United States and spent fuel returned thereto.

C. Operating parameters

Power output: 20 Mwe net.
Net plant efficiency: 25%.
Burn-up at equilibrium: 13 000 Mwd/tU.
Ratio of total fuel inventory to fuel in reactor: 1.6.
Plant factor: 80% (7 000 hr/yr).

D. Cost parameters

Plant investment costs:	$800/kwe. This figure is taken from Figure 1, dotted line. The estimate is for a nuclear plant built under United States conditions, based upon extrapolation of the projected costs of large reactors. Cost of money, construction time, local conditions and requirements, different from those in the United States, may alter this figure substantially.
Cost of fabricated fuel:	$533/kgU. This figure represents the official United States price of 3.3% enriched uranium, plus assumed charges of $110/kg for fabrication.
Cost of initial core loading:	$185/kwe (taken from Table 2, under identification number 1).
Value of spent fuel:	$220/kgU (or $76/kwe). This is the United States price for 2% enriched uranium. A credit for the plutonium produced and a debit for the reprocessing cost, together with other factors affecting fuel costs, have been taken into account in arriving at the fuel cost given in part E, line 3 below.
Operating and maintenance costs:	$20/kwe/yr (taken from paragraph 49).
Transport cost:	$20/kgU. Assumed costs of transporting spent fuel.
Annual capital charges, including cost of money, depreciation and taxes (if any):	7%/yr or 14%/yr, (assumed values).

E. Calculation of generating costs

Annual capital charge	14%/yr	7%/yr
1. Plant investment $\frac{\$800/\text{kwe}}{7\ 000\ \text{hr/yr}}$ x (14% and 7%)/yr	16.0	8.0 mills/kwh
2. Operating and maintenance $\frac{\$20/\text{kwe/yr}}{7\ 000\ \text{hr/yr}}$	3.0	3.0 " "
3. Fuel (taken from Figure 7)	4.4	4.4 " "
4. Spent fuel transport $\frac{\$20/\text{kg}}{24\ \text{hr/d} \times 25\% \times 13\ 000\ \text{kwd/kg}}$	0.3	0.3 " "
5. Total, excluding fuel inventory	23.7	15.7 mills/kwh
(a) Fuel inventory considered as part of plant investment		
6. Fuel inventory 1.6 x $\frac{\$185/\text{kwe}}{7\ 000\ \text{hr/yr}}$ x (14% and 7%)/yr	5.9	3.0 " "
7. Total cost	29.6	18.7 mills/kwh
(b) Fuel inventory based upon average value of fuel in the reactor		
8. Total, excluding fuel inventory	23.7	15.7 mills/kwh
9. Fuel inventory 1.6 x $\frac{\$(185 + 76)/\text{kwe}}{2 \times 7\ 000\ \text{hr/yr}}$ x (6% and 5%)/yr	1.8	1.5 " "
10. Total cost	25.5	17.2 mills/kwh

IV. Estimated costs in US dollars of generating electric power in a large heavy-water reactor fuelled with natural uranium, the spent fuel being discarded (130 Mwe)

A. Type of reactor

Large heavy-water-moderated reactor, pressure-tube type fuelled with natural uranium and built in Canada. It should be noted that there is as yet no operating experience of such a pressure-tube type reactor, contrary to the case of pressure-vessel type reactors.

B. Fuel

Fuel is assumed to be fabricated in Canada, and spent fuel discarded.

C. Operating parameters

Power output: 130 Mwe net.
Net plant efficiency: 25%.
Burn-up at equilibrium: 7 800 Mwd/tU.
Ratio of total fuel inventory to fuel in reactor: 1.3.
Plant factor: 80% (7 000 hr/yr).

D. Cost parameters

Plant investment costs:	\$446/kwe (taken from Table 4 and including \$60/kwe heavy water inventory).
Cost of initial core loading:	\$32/kwe (taken from Table 4).
Operating and maintenance cost:	\$10/kwe (Assumed value based on paragraph 49 and including heavy water losses).
Annual capital charges, including cost of money, depreciation and taxes (if any):	7%/yr and 14%/yr (assumed values).

E. Calculation of generating costs

Annual capital charge	14%/yr	7%/yr
1. Plant investment $\frac{\$446/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	8.9	4.5 mills/kwh
2. Operating and maintenance $\frac{\$10/kwe/yr}{7\ 000\ hr/yr}$	1.4	1.4 " "
3. Fuel (taken from Figure 7)	2.7	2.7 " "
4. Spent fuel transport	-	-
5. Total, excluding fuel inventory	13.0	8.6 mills/kwh
(a) Fuel inventory considered as part of plant investment		
6. Fuel inventory 1.3 x $\frac{\$32/kwe}{7\ 000\ hr/yr}$ x (14% and 7%)/yr	0.8	0.4 " "
7. Total cost	13.8	9.0 mills/kwh
(b) Fuel inventory based upon average value of fuel in the reactor		
8. Total, excluding fuel inventory	13.0	8.6 mills/kwh
9. Fuel inventory 1.3 x $\frac{\$32/kwe}{2 \times 7\ 000\ hr/yr}$ x (6% and 5%)/yr	0.1	0.1 " "
10. Total cost	13.1	8.7 mills/kwh