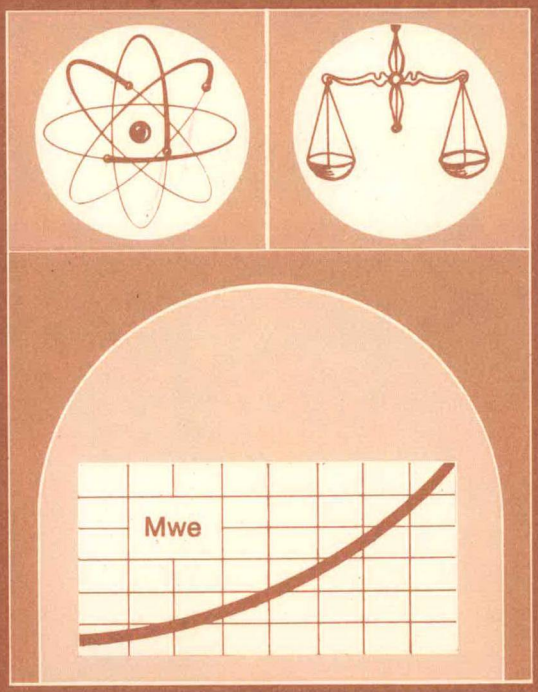
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NYO-3853-1

COMPETITION IN THE NUCLEAR POWER SUPPLY INDUSTRY



REPORT TO:

U.S. Atomic Energy Commission

U.S. Department of Justice

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This study and its underlying research and gathering of data were carried out under a contract for the U.S. Atomic Energy Commission and the Department of Justice. The central purpose of the study is to provide background information and economic data on the growing nuclear industry, which, in turn, should provide the Commission and the Department of Justice with a firmer factual basis for the possible development of the kind of determinations best designed to foster healthy competition in this industry. The study also reviews various possible objectives of the Government in developing a competitive industry and presents approaches that might be used in achieving desired objectives.

Any opinions contained in the report are the views of Arthur D. Little, Inc., and do not necessarily represent policies or views of either the Commission or the Department of Justice.

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COMPETITION IN THE NUCLEAR POWER SUPPLY INDUSTRY

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Report to

U.S. Atomic Energy Commission
U.S. Department of Justice

prepared by

Arthur D. Little, Inc.

☆

Contract No. AT (30-1)-3853

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December 1968

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PART ONE

I. PURPOSE AND SCOPE

Two fundamental policies of the Atomic Energy Act are that the use and control of atomic energy "be directed so as to make the maximum contribution to the general welfare" and to "strengthen free competition in private enterprise."

It is clear from the Act, notably Section 105, that the mandate upon the Atomic Energy Commission is intended to be carried out in a manner consistent with the antitrust laws and with the Department of Justice's administration of those laws. A specific provision in Section 105 (b) calls upon the Commission to report promptly to the Attorney General any information it may have concerning apparent violations or apparent tendencies toward violations of the antitrust laws in any utilization of special nuclear materials or atomic energy.

Having in mind the close cooperation between the Department and the Commission necessary to a full effectuation of the policies laid down by Congress in the Act and the antitrust laws, the Department and the Commission embarked upon this joint study so as to provide the basis for preparation and consideration of guidelines for the industry best designed to foster vigorous growth and to provide a sound basis for government action.

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II. BACKGROUND AND APPROACH

The development of the nuclear power supply industry, with the large-scale participation of the government, is unique in the annals of industry in the United States. Earlier academic research activities in theoretical physics led to the formation at the outset of World War II of the vast Manhattan Project, a national defense effort of the highest priority, which contributed importantly to the war effort and the understanding of nuclear fission. Following the cessation of hostilities, the government maintained a monopoly in the nuclear field, but placed control under civilian leadership by means of the Atomic Energy Act of 1946, which established the Atomic Energy Commission, and the formation of the Joint Committee on Atomic Energy of the Congress. While a large national defense effort continued, peaceful uses for nuclear energy were also stressed; and changes in the Atomic Energy Act during the 1950's permitted industry to participate in various ways, including the development of nuclear reactors for the purpose of generating power. It is estimated that the Atomic Energy Commission has expended approximately $2 billion, and industry $1 billion, on research, development, equipment, and facilities leading to the development of commercial nuclear power as we know it today. These figures do not include the even larger government expenditures in national defense and space programs, which have also contributed important knowledge to the development of nuclear steam supply systems; nor do they include vital facilities construction and operating expenditures such as those for enrichment plants. The government, therefore, obviously has a special interest in fostering a nuclear power supply industry that -- by its structure and performance -- can "make the maximum contribution to the general welfare."

Historically, the production and supply of electric power equipment and fuel in the United States have been private sector matters. The nuclear power supply industry follows this precedent, with the single present exception of the enrichment phase of the nuclear fuel cycle. Public policy in the United States favors private ownership and management regulated by the forces of competition.

This study is one of the first of its type in that it is designed to develop economic and technical information that will help the government promote the sound and competitive growth of an industry still in its formative stages, reducing the possibility that any remedial measures will have to be applied at a future time when undesirable structures or practices may have developed. The study relied on the cooperation of government and of the industry and its customers. Information was developed by a series of interviews with corporations in most segments of the nuclear power industry. We did not have the authority to subpoena records. To a large extent industry cooperation was

enhanced by assurances from the Department of Justice and the Atomic Energy Commission that confidential treatment could be accorded by Arthur D. Little, Inc., (ADL) to information provided by industry. The Department of Justice and the AEC stated that they would "not use ADL's files as a source of information for investigative purposes and do not intend to request from ADL detailed information in order to enforce laws subject to their jurisdiction. It would be the intent of both agencies to obtain information for such purposes directly from the companies and the individuals involved." Many of the major respondents in the interviewing program took advantage of the opportunity accorded to review drafts of this report for accuracy of the information recorded.

The study focuses on the industry that supplies nuclear-related goods and services to the utilities. In the course of this work we interviewed utilities to obtain information about the commercial practices of their suppliers and about their own purchasing policies. Specifically excluded was any investigation of how nuclear power might be related to antitrust issues surrounding the utilities themselves, a subject which at the present time is receiving attention elsewhere. By mutual agreement with the Department of Justice and the AEC, we also excluded from our study the AEC's uranium enrichment facilities, since the complex competitive and economic questions involved, and the national security aspects of the gaseous diffusion plants and their possible disposition, are now under separate study by the AEC and interested industry groups.

Our analysis of competition in the nuclear power supply industry focuses on five subjects customarily examined in industry studies of competition:

- *Product and market definition* – What may be appropriately defined as the various products comprising the nuclear power supply industry? What function does each of the products perform? Who are the buyers for the various products?

- *Market structure* – Who are the participants in the industry? What are their market shares? To what degree is there vertical integration and multi-product firm activity?

- *Trends in structure* – To what degree and in what way, if any, are market shares changing? What is the likelihood of new entry? To what degree do barriers to new entry exist?[1] What is the likelihood that present participants may go out of business?

- *Market performance* – What are the price trends? How can observed changes in prices be explained? What are the buying and selling practices and policies?

- *Innovation and progressiveness* – To what degree is innovation occurring? What are the incentives?

Following the condensed descriptions of our findings on these points in Part One of the report is a presentation of possible government policy objectives for the industry and a discussion of suggested approaches for meeting these objectives. Part Two of the report contains a series of technical papers describing in more detail the various segments of the industry.

For most of the analysis in this study we have used information available up to March 31, 1968. In any field undergoing the rapid commercial and technical changes occurring in the nuclear power supply industry important events inevitably take place during the writing, review, and editorial processes. In a number of instances we have been able to take these developments into account either in the text or in footnotes, but this report is substantially a document reflecting information available in early 1968.

1. The term "economies of scale," related to new entry and viability of marginal firms, has in some circles begun to be used as a general and seemingly self-evident justification of bigness in American industry, often with little documentation and with considerable reliance on not-too-carefully explained "managerial and organizational" economies. In this report we apply a stricter meaning to the term, with emphasis on physical and technological economies achievable by means of increases in single plant size and on fixed design, engineering, and R & D factors. The technical papers assembled in Part Two of this report carry the supporting evidence of economies of scale on which the summary observations in Part One are based.

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III. THE NUCLEAR POWER SUPPLY INDUSTRY

A. THE PRODUCTS AND THEIR COMPONENTS

The nuclear power supply industry is in its infancy. The total installed capacity today is approximately 2000 Mwe out of a total utility operated generating capacity of about 270,000 Mwe in the United States.

The first, more economical, large scale nuclear plants in the 800-1000 Mwe range are not expected to go into operation until 1970. Consequently, there is now limited experience for predicting the future performance of the industry; and it is impossible at this time to obtain the type of cost-price information one would expect to use in studying and analyzing a more mature industry. By the mid-1970's this situation will have changed materially. The AEC forecasts[1] that 145,000 Mwe of nuclear power will be installed in the United States by 1980 out of a total utility operated generating capacity of 580,000 Mwe. This would represent a nuclear power supply industry having annual domestic sales of approximately $5 billion.

It is assumed the reader wishing to become familiar with the technical details of nuclear power production will look to other references[2] and that a brief description of a nuclear reactor, as given in Figure 1, is sufficient for purposes of this report.

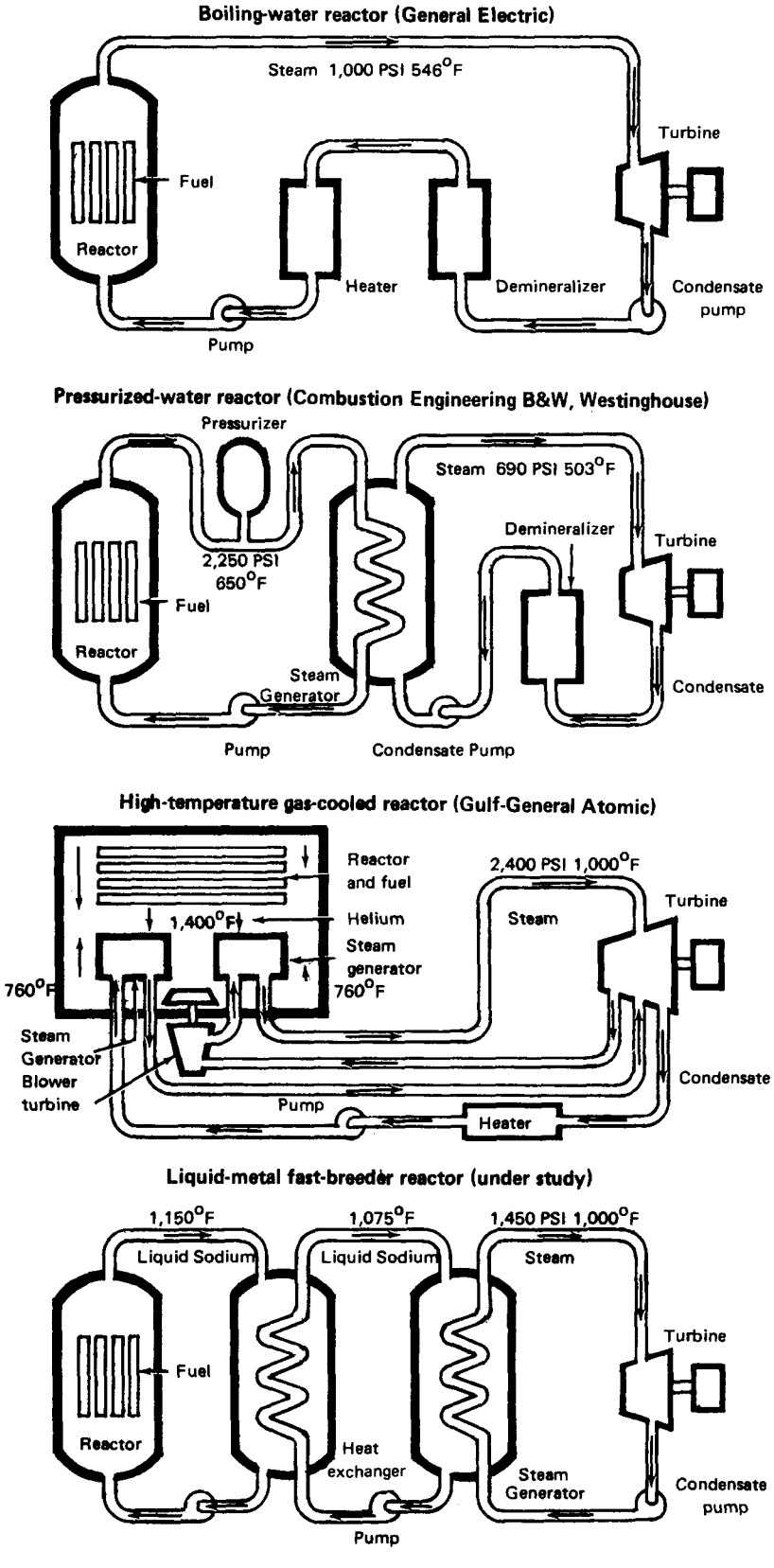
The nuclear power supply industry is a complex one which we have broken down into some forty segments for analysis. These forty segments are in turn grouped in four general industry sectors, which are roughly equal in annual dollar volume of business at this time:

- *Nuclear Steam Supply System (NSSS).* Reactor pressure vessel, steam generator (PWR's), primary pumps, and other components consisting of reactor internals, controls and instrumentation, valves, piping, tanks, and related equipment.

1. "Forecast of Nuclear Power Growth," WASH 1084, USAEC Division of Operations Analysis and Forecasting, December, 1967. By prior agreement with the AEC, calculations for this report are based on the median figures of this forecast.
2. *Nuclear Chemical Engineering,* by M. Benedict and T.H. Pigford, McGraw-Hill Book Co., Inc., 1957.

   Nuclear Reactor Engineering, by Samuel Glasstone and Alexander Sesonske Van Nostrand, 1963.

   Current Status and Future Technical and Economic Potential of Light Water Reactors, WASH 1082, by Jackson and Moreland, Inc., and S. M. Stoller Associates.



In the United States, commercial power reactors now use light water (as opposed to heavy water which has different neutron absorption characteristics and is the basis for other reactor designs) as a coolant and uranium oxide slightly enriched in the fissionable isotope U-235 and encased in zirconium tubes for the fuel. The water coolant is permitted to boil in the case of the Boiling Water Reactor (BWR) and the resulting steam produced in the core goes directly to the turbine generator. In Pressurized Water Reactor (PWR) designs the coolant is not permitted to boil in the core, the steam being produced in a separate steam generator. The High Temperature Gas-Cooled Reactor employs helium as a primary coolant and graphite fuel elements containing coated particles of highly enriched uranium plus fertile thorium. As in the PWR, steam for the turbine is produced by secondary heat transfer in a steam generator. Breeder reactors, a fourth type, hold promise of being able to produce more fissionable material than they consume. Most of the U. S. breeder research and development program is concentrated on the liquid metal-cooled fast-breeder reactor concept.

Source: *Chemical Week,* May 25, 1968; page 55, reproduced with permission.

FIGURE 1 NUCLEAR REACTOR SYSTEM FOR CENTRAL STATION POWER

- *Nuclear Fuel Cycle.* Uranium mining, milling (the concentration of ore to U_3O_8 in "yellow cake"), conversion (U_3O_8 to UF_6), enrichment (concentrating the U-235 fissionable isotope content of uranium), conversion (UF_6 to UO_2 powder), fuel fabrication (production of UO_2 pellets and fuel elements), and fuel reprocessing (recovery of residual fuel and other by-products).

- *Turbine-generator and associated equipment.*

- *Balance of plant, engineering and construction.*

Figure 2 is a simplified flow diagram of the industry. In order to provide an overview of the structure of the industry, we have used AEC nuclear power installation forecasts and our own estimates of unit prices to show the industry as we believe it will look in 1970. In each industry segment we have listed the dollar volume of domestic sales, the corporations participating or possibly in a position to participate, and the approximate market share (or capacity) that might be enjoyed by each, recognizing that market share estimates must be averaged over the first few years of 1970 in order to avoid the "lumpiness" of early deliveries in a thin market.

In 1970 these four parts of the industry will have similar dollar volumes. Later, as shown in Table 8, the fuel cycle becomes a far more significant and dominant cost because fuel is required for the installed population of reactors as well as new plants coming on line.[1] For the most part the other expenditures for a new plant are one-time expenditures, except for the normal purchases of repair services and replacement parts; the exceptions are some of the control equipment and instrumentation located inside the reactor – these take on some of the characteristics of the fuel cycle, though much smaller in dollar volume.

Table 1 shows the relative contributions of various components to total nuclear power plant costs and estimated 1970 market volumes for the various components.

Another way of placing the various segments of the industry into perspective is to show, as Table 2 does, the approximate contribution each makes

1. Fuel sales for new reactors constitute an initial inventory of three to five year's worth of annual consumption – the inventory being necessary to sustain the nuclear chain reaction. Some of this expended fuel must be replaced on an annual basis in order to maintain the inventory.

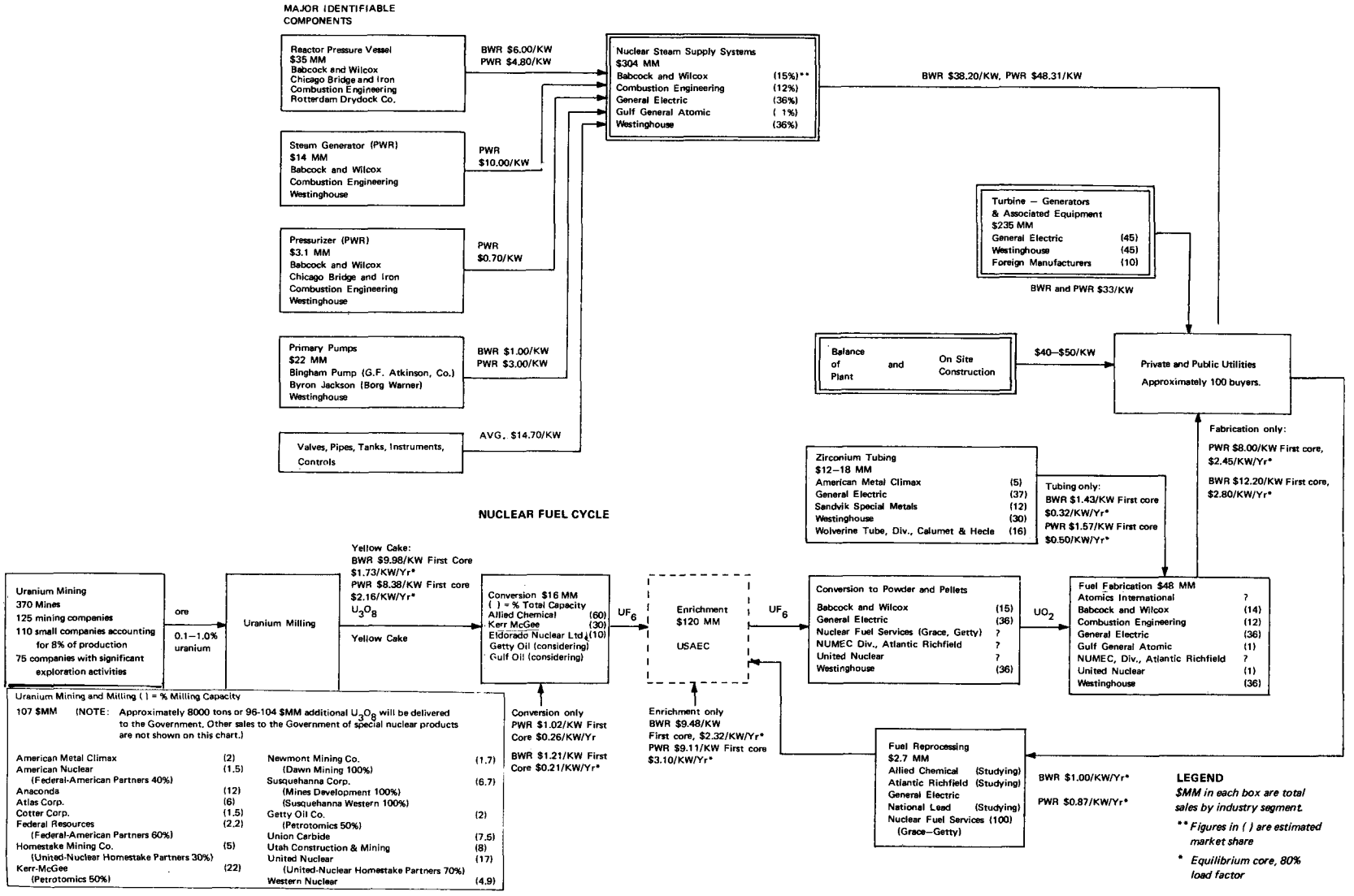


FIGURE 2 SIMPLIFIED OVERVIEW: THE NUCLEAR POWER SUPPLY INDUSTRY, 1970 ESTIMATE

TABLE 1

RELATIVE SIGNIFICANCE OF MAJOR NUCLEAR POWER SUPPLY INDUSTRY COMPONENTS AND MARKETS

For a 1000-Mwe Nuclear Plant

Product	Approximate 1967 Cost for Installing New Reactor Capacity ($/kw)	Percent of Avg. Total Plant Cost, Incl. Value of Initial Core[1]	Estimated Annual Volume of Business in 1970 (1967 dollars) $ million	Approximate Percent of Total 1970 Business
NSSS				
Major Components				
Pressure vessel	5.40	3.6%	35	3
Steam generator (PWR)	10.00	6.6	44	4
Pressurizer (PWR)	0.70	0.5	3	nil
Primary pumps	2.00	1.3	22	2
Instrumentation, control rods & drives, etc.	8.70	5.8	56	5
Valves, pipes, tanks	6.00	4.0	42	4
Other, incl. fabrication	10.20	6.7	102	9
Total (total cost avg. of PWR and BWR)	43.00	28.5%	304	27%
Nuclear Fuel				
U_3O_8	9.20	6.1	107	9
Conversion to UF_6	1.10	0.7	13	1
Enrichment	9.30	6.2	120	11
Fabrication (incl. conversion to UO_2 and zirconium tubing)	10.50	7.0	48	4
Total Initial Core Cost	30.10	20.0%	288	25%
Reprocessing	–	–	3	nil
Turbine-Generator	29.00	19.2	205	18
Associated condensor, feedwater heater, feed pumps, etc.	4.20	2.8	30	2
Total turbine-generator and associated equipment	33.20	22.0%	235	20%
Balance of Plant, Engineering and Construction	34-44	25.5	241-311	24
Containment	6.00	4.0	42	4
Total balance of plant and containment[a]	40-50	29.5%	283-353	28%
GRAND TOTAL, Nuclear Plant and Fuel[b]	146-156	100.0%	1113-1183	100.%

[a]The major portion of this item represents the cost of construction work at the plant site.

[b]Does not include interest during construction and owner's contingency. See Table 2 for analysis of nuclear generating costs on a mills/KWhr basis. See Table 3 for additional details on Fuel Cycle.

Source: ADL estimates.

TABLE 2

APPROXIMATE AT-THE-BUSBAR ELECTRICITY COSTS FOR A 1000-Mwe NUCLEAR REACTOR[a]

		Mills/KWhr (Range)
1. Charges based on Capitalized Costs		2.3 – 3.1[b]
2. Fuel Cycle Costs		1.5 – 2.0[c]
(For the effect of important variables on fuel cycle costs, see Table 3.)		
3. Operation, Maintenance, Insurance		0.3 – 0.4
Total	(rounded)	4.0 – 5.0

Notes:

[a] Based on 1967-1968 prices. (A plant ordered during this period would be expected to be completed and producing power by the beginning of 1973 or 1974.)

[b] This figure is directly proportional to the fixed charge rate assumed and inversely proportional to the load factor realized for the plant. The underlying capital costs may be estimated at $134 – $150/KWe, consistent with the Jackson and Moreland Report (WASH 1082), March, 1968; and this report, Table 1 and Figure 2.

[c] WASH 1082 gives a figure of 1.74 as typical for the first five years of operation.

Source: Arthur D. Little, Inc., estimates

to the cost of producing a kilowatt hour of electricity. The translation of capital and fuel cycle costs into precise mills per kilowatt hour requires that estimates of the three capital cost components of a plant be combined with estimates of load factor, assumptions about financing costs, and the translation of a series of assumptions for the initial and future costs of the various steps in the fuel cycle. Such an analysis is carried out in detail by a utility at the time it compares nuclear plant and fuel costs with related fossil costs. The sensitivity of fuel costs to changes in the costs of various components of the fuel cycle is illustrated in Table 3.

B. THE BUYERS: THE ELECTRIC UTILITY INDUSTRY

Electricity for the United States comes from several kinds of suppliers; the "electric utility industry" proper; net imports (the balance of transactions with Canada and Mexico, primarily hydroelectric imports from Canada); and self-generation from capacity owned by, and largely committed to, sizable commercial and industrial enterprises. But the "electric utility industry" is by far the most important source.

At the end of 1966 some 200 investor-owned operating utilities accounted for roughly 75% of the generating capacity of the industry; federal facilities, such as the TVA, the Bureau of Reclamation, and Corps of Engineers Projects, accounted for about 12.5%; the balance of the capacity was owned by municipal facilities, REA systems and cooperatives.

The investor-owned utility segment of the electric utility industry consisted of 212 operating companies which accounted for 99% of the revenues of the investor-owned sector. Of these 212 operating companies, 115 were independent, while 97 were wholly- or majority-owned subsidiaries of 28 holding companies. Thus the 212 operating companies represented 143 distinct decision-making entities.

Federal facilities consisted of 62 separate operating jurisdictions: 42 projects of the Department of Army's Corps of Engineers; 16 projects of the Department of Interior's Bureau of Reclamation; the Department of Interior's Bonneville Power Administration, Southeastern Power Administration, and Southwestern Power Administration; and the Tennessee Valley Authority.

The municipal facilities consisted of 492 municipal utilities, under the Federal Power Act definition of municipality as "a city, county, irrigation district, drainage district, or other political subdivision or agency of a State."

TABLE 3

ILLUSTRATION OF THE EFFECT ON NUCLEAR FUEL COST OF COMPONENT COST CHANGES[1]

Component	Price Chosen for Illustration	Contribution to Fuel Cost	Illustrative Price Change	Corresponding Change in Fuel Cost
U_3O_8	\$7.00/lb. U_3O_8	.503 mills/KWhr	+\$1.00/lb.	+.072 mills/KWhr[2]
U_3O_8 to UF_6	\$1.04/lb. U contained	.063	–\$ .25/lb	–.015
Enrichment	\$30/unit of separative work (1967)[3]	.521	–\$2/unit	–.035
Fabrication	\$90/kg U	.375	–\$10/kg U	–.042
Spent Fuel Transport	\$5/kg U	.021	+\$1/kg U	+.004
Reprocessing	\$33/kg U into reactor	.137	–\$3/kg U	–.013
Excess Uranium Credit	\$237.00/kg U at 3%	–.099	+\$1/lb. U_3O_8	–.007
Uranium Credit	\$42.84/kg U reprocessed	–.169	+\$1/lb U_3O_8	–.017
Plutonium Credit	\$8000/kg Pu[4]	–.214	+\$1000/kg	–.027
Working Capital Charge Rate	10%	.402	–4%	–.161
		1.540 mills/KWhr		

[1] Figures in the table are based on contemporary PWR designs, and assume relatively high burnups; the general principles also hold for contemporary BWR's.
[2] Increased uranium credit would reduce the change to +.048.
[3] Current AEC toll enrichment charge is \$26/kg, with 0.2% tails assay.
[4] Current AEC buyback price is \$9280/kg.

Source: R. L. Witzke, Westinghouse Electric Co. Based on a paper presented at the American Power Conference, 1967.

The REA system consisted of slightly more than 1000 currently-financed and former-borrower units; of these, slightly fewer than 50 were engaged in generation and transmission activity.

Although there were more than 800 separate operating units across all sectors of the electric utility industry, the presence of holding companies and centralization in the Departments of Interior and Army reduces the number of active decision-makers to well under 700. Moreover, virtually all Municipal and REA utilities are small systems that could not realistically absorb as individual utilities a large generating unit, nuclear- or fossil-fueled, into their system. Therefore, the number of utility decision-makers confronting the suppliers of electrical generating equipment in the 400 Mwe and above size categories was in the range of 100-150.[1]

Among these 100-150 decision-makers there is evidence of further consolidation, which would suggest a materially lower number of active and substantial utility buyers. The 35 largest private utility decision-makers, measured by total assets at the end of 1966, included 20 independent operating companies, and 15 holding companies with control over 58 subsidiary operating companies. Thus these 35 decision-makers, with control over 78 operating companies, represented all of the "big 70 electric utilities," (as well as an additional eight companies) and accounted for almost 70% of all assets held by the private utility sector. The ten largest private utilities accounted for over 35% of private sector assets.

U. S. generating capacity rose 12% in 1967. Over the long run the industry looks toward a doubling every 10 years – i.e., a 7% annual growth rate. However, growth is not uniform from year to year, and the cyclic nature of facility orders contributes to some of the problems we will discuss later.

Sales of electricity totaled $17.2 billion in 1967, up slightly more than 6% from 1966 revenue. The electric utility industry spent almost $8 billion on construction expenditures in 1967, about 40% of which was for generating facilities (the balance was for transmission and distribution). The private sector of the utility industry spent $2.5 billion in 1967 for electric generating facilities, a remarkable rise of 42% over the $1.8 billion spent in 1966.

1. Not counted here are about 10-15 consortia that, particularly in the case of nuclear power, have been formed to purchase and operate large generating stations and that may or may not reflect purchasing attitudes of their owner utilities.

Thus, it is in a context of sharply rising expenditures for generating capacity by the entire industry that this analysis of competition in the nuclear power supply industry is undertaken.

IV. ANALYSIS OF THE NUCLEAR POWER SUPPLY INDUSTRY BY MAJOR SEGMENTS

A. THE NUCLEAR STEAM SUPPLY SYSTEM (NSSS)

1. Product and Market Definition

The term "nuclear reactor" is sometimes used literally: i.e. to describe the pressure vessel and the nuclear fuel it contains. In other discussions "nuclear reactor" is used to describe the entire nuclear-powered generating station. The relevant article of commerce used in this report is the "nuclear steam supply system" (NSSS), consisting of the pressure vessel and its associated heat transfer equipment, pipes, and pumps, along with control and safety subsystems. This terminology has evolved over a series of nuclear power plant awards. Normally, fuel is not considered a part of the NSSS nor is the turbine-generator which, along with the containment structure and the plant housing all of the equipment, comprise the nuclear power plant. The overall cost of a nuclear power plant including the initial fuel loading is in the order of $150 per kilowatt, (1967 dollars)[1]; this translates into roughly $150 million for a thousand-megawatt plant. Of this total, the NSSS and field construction each contributes roughly $40-50 per kilowatt, while initial fuel and turbine-generator, along with the associated equipment, each contributes roughly $30-35 per kilowatt.

In contracts for the first 12 or so commercial plants ordered the reactor vendor assumed responsibility for having all the components of the NSSS and turbine-generator equipment assembled at the plant site and for constructing the elaborate concrete and steel structures that support and house these systems – that is, to deliver a fully constructed, operating power station. The industry refers to these as turnkey plants. However, in the non-turnkey scopes of supply, now universal in the light water reactor industry, components are shipped to the plant site for assembly by the owner or his constructors. Consequently, a significant portion of the value added in building a nuclear power plant is beyond the direct control of the NSSS manufacturer. Furthermore, many of the components of an NSSS are purchased as relatively standard industrial items from the wide range of the industries normally supplying such items as valves, heat exchangers, tanks, fittings, and instruments to the petrochemical and process industry. As much as $.50 of the NSSS sales dollar may be translated into purchased components by the less integrated NSSS manufacturers. In many respects the design and project management, the "software" aspects of a nuclear steam supply system, are the special and most valuable contributions made by NSSS manufacturers.

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1. Excludes owner's contingency allowance and interest during construction.

A realistic overview of the industry that furnishes nuclear power stations must, then, be preconditioned by the fact that this article of commerce has in its value a high percentage of goods and services purchased either by the vendor or his customer from sources that need not have a particularly strong, indeed if any, nuclear orientation.

A realistic view must also focus on the infancy of the industry. In early 1968 when nearly $10 billion worth of NSSS, turbine-generators, construction, and fuel had been committed to the nuclear alternative, operating experience was limited to three early-generation plants, only one-sixth the size of some of the full scale plants being ordered. Operating information from plants that will employ the more advanced technology characteristic of systems now in order backlog will not be available until the early 1970's. At the end of March, 1968, only one-third of awarded nuclear plants were under construction; only a few of these were as much as 50% complete. Thus, the industry has a very narrow base of experience on which to base projections of costs of manufacture and limited operating experience to validate the technical and economic aspects of designs now on paper.

With few exceptions the utility industry and its architect-engineers are satisfied with the current NSSS scope of supply, although these scopes tend to place some of the equipment selection and system design historically performed by the utilities or their architect-engineers in the hands of the reactor vendor. Generally, the utilities and their architect-engineers are unwilling to take the expense or risk of designing a nuclear steam supply system and selecting individual nuclear components. To do so would mean to assume the costs of obtaining AEC licensing, approval and also to bear the risk of the design's operating to specifications. (The NSSS that does not deliver as much steam as was expected penalizes not just the economics of the nuclear steam supply system; it also under-utilizes the turbine-generator and balance of plant; the NSSS that does not "burn" its fuel as efficiently as anticipated can show an economic penalty throughout its life.)

2. Market Structure

The four current U. S. suppliers of commercial nuclear steam supply systems are General Electric, Westinghouse, Babcock and Wilcox and Combustion Engineering. Their present shares of market are shown in Table 4. Note, however, market share figures such as these are subject to variation because of differences in interpretation as to: 1) what constitutes a firm order as opposed to an option; and 2) the megawatt rating the plant will achieve (especially in the earlier plant awards in which there was an allowance for "stretch" or operation at more than one capacity level depending on the technical successes achieved).

TABLE 4

MARKET SHARES, CURRENT U.S. SUPPLIERS OF COMMERCIAL NUCLEAR STEAM SUPPLY SYSTEMS*

	Share of Mwe all Nuclear Plants* Built or Awarded	Share of New Orders, (Mwe) during Year Ending March 30, 1968
General Electric	41.4%	45.5%
Westinghouse	35.7	26.9
Babcock and Wilcox	13.8	14.3
Combustion Engineering	9.1	13.3

*U.S. nuclear stations over 175 Mwe, as of March 30, 1968. Note these figures are based on megawatts, rather than the number of plants.

Source: ADL estimates

The successful technical demonstration of General Atomic's High Temperature Gas-Cooled Reactor at Peach Bottom, progress on the 330 Mwe Fort St. Vrain reactor, and the infusion of capital and additional talent now that General Atomic is a subsidiary of Gulf Oil Company makes General Atomic more likely than ever to sell a large scale nuclear steam supply system on a commercial basis. We see a strong likelihood of its receiving an order for a NSSS within the next year or two, so that a fifth participant (and, perhaps more important, a significantly different technology, as well as a buyer from a somewhat different group of second tier suppliers) will be added to the competition.

The Atomics International Division of North American Rockwell, which has provided utilities with reactor prototypes embodying various design concepts, does not now offer a NSSS on a commercial basis nor does it offer thermal reactor fuel. Its continuing efforts in the nuclear power supply industry are related principally to breeder reactors.

We do not expect additional domestic entrants into the light water reactor field. Nor is it likely that any foreign suppliers, many of whom are licensed under patents owned by U. S. suppliers, will make any significant entry into the U. S. market over the next ten years.

3. Trends in Market Structure

Despite the large dollar volume of the NSSS market, the high unit value (and consequently, the small number of plants built each year) places a severe limitation on the number of competitors active in the market. We estimate that

only 12-20 units per year will be built between now and 1980 (not allowing for cyclical buying). To some extent, increases in plant size will tend to offset the growth in numbers of units which would be expected from the normal 6-7% annual increase in demand for power.

Each NSSS manufacturer told us that in a general way he required an average level of activity of about three reactors per year in order to remain viable in the face of the high research, development, and engineering costs that are a critical part of this technologically-based industry. We were unable to obtain specific data to confirm these estimates. The amount of business required to achieve viability in the industry is obviously conditioned by a manufacturer's ability to spread research and engineering efforts over a broad sales base.

Viability is also influenced by a manufacturer's ability to convert the cyclic order influx into a more or less sustained rate of engineering effort and reactor delivery. On balance, it is difficult for us to visualize more than four or five viable participants in the field; and, in the foreseeable future, additional entrants might well force the retirement of one of the existing five.

The positions of GE and Westinghouse in the nuclear power supply industry are secure because of their head start in selling commercial reactors, the depth of their nuclear expertise, their experience and reputation as suppliers to utilities, their large corporate financial resources, their resolve to remain in the industry, and their leadership in producing and selling large size units.

B & W and CE have a substantial backlog of orders to provide momentum during the important startup phase. As major manufacturers of fossil boilers, both of these firms have traditionally been suppliers to utilities, and both appear resolved to compete in the nuclear field in order to maintain their traditional roles. They expect to achieve 20-25% of their sales in the nuclear industry. On the other hand, they have fewer orders, less experience, and smaller size units than GE and Westinghouse. They face the problem during the 1970's of obtaining a sufficient volume of orders in a thin and cyclical market to cover the heavy fixed research and engineering costs of a highly innovative industry.

All four current NSSS vendors are extensively vertically integrated as shown in Table 5. The extent of this integration is another indication of the probable viability of the companies. The degree of vertical integration of Gulf General Atomic is less certain at this time.

There are two major barriers to entry into the NSSS business. The first has to do with technical, managerial and financial resources. Although the cost of entry is high – a *minimum* of $50-60 million, and the amount could easily run

TABLE 5

VERTICAL INTEGRATION OF REACTOR MANUFACTURERS

Babcock and Wilcox	Combustion Engineering	General Electric	Gulf General Atomic	Westinghouse
PWR NSSS	PWR NSSS	BWR NSSS	HTGR NSSS	PWR NSSS
Pressure Vessel	Pressure Vessel		Concrete Pressure Vessel	
Steam Generator	Steam Generator		Steam Generator	Steam Generator
Pressurizer	Pressurizer			Pressurizer
				Primary Pumps
Reactor Internals	Reactor Internals	Reactor Internals		Reactor Internals
		Pressurizer Controls		Pressurizer Controls
		Pump Motors		Pump Motors
		Stainless Castings		
Control Rods	Control Rods	Control Rods	Control Rods	Control Rods
Excore Instruments	Excore Instruments	Excore Instruments	Excore Instruments	Excore Instruments
		Incore Instruments	Incore Instruments	Incore Instruments
Fuel Fabrication	Fuel Fabrication	Fuel Fabrication	Fuel Fabrication	Fuel Fabrication
Conversion to UO_2[(a)]	Conversion to UO_2[(a)]	Conversion to UO_2	Conversion to UC	Conversion to UO_2
		Zirconium Tubing[a]		Zirconium Tubing
		Fuel Reprocessing[a]		
		Fuel Transportation		Fuel Transportation
	Ore Exploration	Ore Exploration (Inactive)	Ore Exploration	Ore Exploration
		Turbine-Generator		Turbine-Generator
				Condensers
				Feed Water
			Primary Coolant Circulator	
			Gas Circulators	

[a]Announced only

Source: ADL, based on information from the five manufacturers.

twice this figure – this obstacle can presumably be overcome despite the shortage of nuclear physicists and engineers. The second barrier is one of a commercial character, and is perhaps more difficult to conquer. This barrier involves:

- *Establishing credibility as a nuclear supplier.* It is not easy for a new firm to demonstrate its capability in reactor physics and nuclear equipment design of high quality, nor is it easy to persuade prospective buyers that its nuclear steam supply system design will be acceptable to the AEC's safety and licensing authorities and will provide reliable power plant operation when installed.

- *Establishing credibility as a utility supplier.* Utilities want to buy equipment from suppliers with whom they have had experience and expect will remain in the business. From successful experience utilities not only gain confidence that equipment proposed by the vendor will meet its specifications and be delivered on schedule, but, more important, that the vendor will make – and continue to be able to make – a rapid and significant response in the event of equipment failure.

- *Establishing credibility as a translator of basic nuclear steam supply system design into detailed nuts, bolts, and valve designs and specifications necessary for construction.* Much of this work requires little or no nuclear knowledge; instead, it draws on years of experience of project engineers and draftsmen who know the strong points and shortcomings of the myriad of industrial products that must be assembled for performance at maximum reliability and minimum costs, under difficult field construction conditions.

Patents do not appear to pose an obstacle to new entry for domestic producers at this time. Much of the technology is publicly available through the AEC, who sponsored its development. In addition, there is a long tradition of licensing at relatively modest fees in the electric utility supply industry – a practice that seems to be continuing in the nuclear power field.

On the other hand, patents and know-how are important in establishing foreign license and affiliation arrangements, and each of the NSSS vendors has several such arrangements. Although it is expected that U. S. designs of reactors will play an important role in foreign nuclear power installations,[1] much of the

1. *The Growth of Foreign Power* by Arthur D. Little, Inc., TID 22973, April, 1966.

detailed engineering and most of the manufacturing will take place overseas. After the first two or three foreign installations have been made, most of the revenues accruing to U. S. companies will be in the form of royalty payments. For this reason, foreign sales of U. S. type reactors are not expected to represent a major contribution to the support of the large research, development, and engineering costs of the U. S. firms.

4. Market Performance

Because of the newness of the NSSS industry, the record provides a meager basis for evaluating competition or projecting performance. Even when we were able to obtain complete bid information, it is difficult to compare the prices of the NSSS vendors. There are three major reasons for this. First, final vendor selection has to be based on total costs, including items beyond the NSSS scope (balance of plant, engineering, construction, etc.). Second, a wide variety of fuel purchase methods is encountered, involving differing assumptions for present value calculations. Third, wide variations occur in warranty language and conditions. Utilities themselves vary greatly in their ability to evaluate bids; and, therefore, utilities often employ an architect-engineer-constructor firm as a consultant to assist in sorting out the intricacies of nuclear plant bids.

When NSSS vendors were first attempting to convince utilities to switch to nuclear power in order to establish the market and utilities were in a position to demand some sharing of the risks, prices were low. Through mid-1966 we estimate that 55% of the nuclear megawatts were sold on attractive turnkey terms, and an additional 25% were sold at bargain prices set to allow "buying" of first orders. Since 1966 NSSS prices have increased substantially. One NSSS manufacturer provided the following breakdown:

TABLE 6

APPROXIMATE CAPITAL COSTS FOR 1000-Mwe STATIONS

	$/Kwe
1966 on a Turnkey Basis	100
Early 1968 Plants with Equivalent Equipment, but with NSSS, Turbine-Generator, and Construction Purchased Separately	150
INCREASE	50
BREAKDOWN OF INCREASE	
Inaccuracy in 1966 Prices (Underestimate of both NSSS and construction costs)	$10-15
New Nuclear Safety Requirements	5-10
Construction Cost Escalations	15-25
Increases in the General Level of Equipment Selling Prices	10
TOTAL	$40-60

From the viewpoint of the limited directly relevant experience with large-scale, high-efficiency nuclear power plants, the large dollar commitment on the part of both the power supply industry and the utilities entails significant risk. The risk to the suppliers[1] can be put into perspective as follows: The current backlog of the smaller two LWR manufacturers, depending on definitions, equals 120-150% of stockholders' equity; for the larger two the percentage equals 40-80%. This does not include the total exposure to risk that derives from fuel commitments, an exposure difficult to put into dollar figures because of the imprecision of the fuel warranty language and differences between amounts spelled out contractually and what the NSSS manufacturers believe their actual liability might run. Obviously the suppliers assign a near zero probability to sustaining losses in their NSSS activities equal to their total dollar backlog. But there is a real risk that unforeseen technical problems could materially reduce or wipe out expected profit margins on this business. Unfortunate experiences in nuclear endeavors may have consequences far in excess of the particular investments. NSSS vendors correctly feel that their entire corporate reputation is at risk when they engage in such widely publicized undertakings.

Production costs are also uncertain at this stage, a time when many component designs have just come off the drawing boards, little standardization has taken place, and new production facilities are untried at the higher levels of throughput where economies are expected. In addition, the flood of orders has no doubt caused certain investment and manpower inefficiencies.

1. A framework for relating the return that U. S. industry earns for the risk it bears is being developed by researchers in the field. It is clear from probabalistic decision theory that, when evaluating individual risk, it is not sufficient merely to relate the actual or expected financial outcome of decisions to the uncertainty (or some corresponding measure of volatility); a comprehensive analysis must also relate the size of the investment, the amount at "stake" to the overall resources of the firm. Insofar as the size of the investment is concerned, the NSSS vendors may be undertaking a level of exposure paralleled only by commercial jet aircraft manufacturers and the U. S. computer manufacturers. The lack of predictability, or uncertainty of final outcome, is a primary determinant of the riskiness of investment decisions. For several discussions of risk and return see the following: "Risk/Return: U. S. Industry Pattern," by Gordon R. Conrad and Irving H. Plotkin, *Harvard Business Review,* March-April 1968, and Irving N. Fisher and George R. Hall, *Risk and Aerospace Rate of Return,* The Rand Corporation, Santa Monica, California, December 1967.

The risks borne by utilities are likewise considerable. At least one utility expects that 50% of its generating capacity will be nuclear by 1973, and others also have plans for a high percentage of nuclear capacity by the early 1970's. Nuclear plants are generally larger than conventional fossil-fueled plants, and experience with their operation is more limited. Accordingly, at this time there is greater risk associated with the use of nuclear plants than fossil-fueled plants. Any dollar damages the utility may recover in event of a brown-out are unlikely to compensate them fully for losses of revenue and public good will. In almost all cases financial penalties for purchase of power from neighboring utility systems, when available, are not included in the warranty of the NSSS manufacturer.

All four NSSS vendors obtain a greater volume of business by selling a nuclear power plant rather than fossil plant. This raises a question about pricing policies. Pressure to keep fossil prices competitive comes from at least two sources. First, both Babcock and Wilcox and Combustion Engineering have an important stake in the fossil boiler business, and thus both have reason to see that fossil remains competitive with nuclear. Second, Foster Wheeler Corporation and Riley Stoker Corporation, who together with Babcock and Wilcox, and Combustion Engineering constitute the fossil boiler producers, are not in the NSSS business and consequently have every reason to see fossil remain competitive. However, it is important to note that Foster Wheeler and Riley Stoker have not traditionally been the technological leaders in the fossil-boiler industry and together have only 20% of the market.

The competitive force of the fossil fuel option is, of course, influenced not only by the utilities' cost of fossil steam generators but also by the price they have to pay for coal, oil and gas and for transportation of these fuels to their plant sites. Because of the influence of transportation costs, as well as inherent differences in the cost of extracting these natural fuels, fossil fuel costs, unlike nuclear (which has a relatively low transportation dependence), are not uniform throughout the United States. About 30% of the steam generating capacity to be added during the 1970's will be for systems whose average cost of fossil fuels falls within the range of $.22-.27 per million Btu's – the range in which, at early 1968 prices, the nuclear-fossil competition is most keen. The specific point of cost equivalence is dependent upon generating station size, assumptions about differential costs between construction of nuclear versus fossil plants, as well as differences in capital cost (including controls for environmental pollution) and fuel cost estimates. The one-third portion of the total U. S. new generating capacity that low fossil cost utilities (below $.22 per million Btu's) will add during the 1970's represents a hard target for nuclear, although TVA's heavy commitment to nuclear in the face of its low coal costs shows that strong nuclear-fossil competition has occurred for certain large stations under the right circumstances. Another one-third of the stations will be built in areas with fossil

fuel costs above $.27 and will probably represent markets in which fossil fuels provide only weak competition for new steam generating plants, although the specifics of each station – particularly when the addition is a new unit of an existing coal-fired plant that already has coal handling facilities – may make it possible for fossil to take some of this high cost business.

Thus, the competitive influence of fossil fuels on nuclear, fostered by the fossil steam generator manufacturers who do not have direct participation in the NSSS business, seems probable in a wide enough base of bid situations to suggest a reasonably firm calibration of market prices. Utilities in high fossil fuel cost areas would probably look to market behavior consistent with Robinson-Patman Act anti-discriminatory pricing regulations to ensure them an opportunity to purchase nuclear equipment at prices generally comparable with the prices being received by utilities in regions where the nuclear-fossil competition is keener. Finally, it should be noted that the effect of fossil-nuclear competition works in both directions; there have been notable instances in which the availability of the nuclear option has brought lower fossil fuel bids to a utility, and we believe the two-way competitive mechanism will continue.

In studying utility buying and NSSS selling patterns the following points emerge:

- Over 55% of megawatts committed in the initial commercial nuclear sales period ending in mid-1966 were with utilities that have had nuclear experience through AEC or privately financed demonstration projects.

- Reactor sales have been concentrated in relatively large utilities; 45% of all megawatts have been placed among utilities with system sizes about 6000 megawatts; 80% of all megawatts have been placed among utilities with system sizes above 2000 megawatts.[1]

1. Distribution of utility system capacities show about 20% under 2,000 Mwe, 35% 2000-6000 Mwe and 45% over 6000 Mwe.

- Westinghouse and GE account for all sales to utilities above 6000 megawatts; these placements constitute 55-60% of overall Westinghouse and GE sales; conversely, B & W and CE placements are concentrated among smaller utilities, with CE having 100% of its sales to utilities with systems size below 4000 megawatts, and B & W 50% of its placements with such utilities.

- The dominance of Westinghouse and GE among large utilities may be explained in part by the earlier inability or unwillingness of other NSSS manufacturers to respond to unit size specifications above 1000 Mwe, or a corresponding unwillingness on the part of utilities to admit the smaller NSSS manufacturers to their qualified bidders' list.

- Nuclear sales have been heavily concentrated in utilities with high fossil fuel costs, with the principal exception of TVA.

Some commentary on the general purchasing behavior of the electric utility industry is necessary because of the impact of purchasing methods upon the competitive performance of the nuclear power supply industry. The remarks that follow are made for the purpose of illustrating some current issues and contentions on this subject. A full characterization of utility buying methods and determination of their relative merits is beyond the scope of the report.

Debates over the effectiveness of utility purchasing as a market regulatory mechanism usually fall in three categories: a) utility purchasing incentives; b) utility purchasing practices (which may or may not be in support of the incentives); c) utility performance as buyers.

a. Purchasing Incentives

Some contend that the incentive for utilities to buy capital equipment competitively is blunted by regulatory practice that allows utilities to earn up to a more or less fixed rate of return on their capital base; where the utility's weighted cost of capital is less than the allowable return, it is argued that profits to utility shareholders are maximized by the expansion of the utility's capital base. Regulatory machinery often does not concern itself with purchases; in cases where it does, the regulatory review is not timely.

Counter arguments in the extensive literature on the "rate base maximization" question are as follows:

Rate base lag – capital projects are admitted to the rate base considerably after the utility makes payments for them. Over-buying is said to penalize the shareholder, at least until the asset is incorporated into the rate base. (This is generally mitigated to some extent by "interest charged to construction.")

Demand elasticity for electricity – a lower rate structure is believed to attract additional load – higher utilization of electric energy as well as new customers. Many utilities believe that a high growth potential is necessary to maximize the value of their equity in the marketplace.

Competition among utilities – utilities compete in energy markets with other energy forms, particularly gas. Even in cases where one utility provides both gas and electricity (and therefore may or may not be sharply competitive within its territory), there is perceived competition among utilities in different areas for additional load, especially new industrial customers who in turn attract additional residential customers.

The yardstick effect of government-owned utilities – In the view of some, TVA, other government facilities, and municipal and cooperative utilities – utilities that presumably do not have incentive for maximizing their rate base – provide yardsticks by which private utility performance can be measured; private utilities, therefore, cannot permit themselves to purchase carelessly.

b. Purchasing Practices

1. *Disclosure of bid information* – most utilities decline disclosure of information about bids they receive from equipment suppliers. They give two reasons:

   - Clauses in the bids of many suppliers that make information proprietary to the supplier, except as public disclosure might be statutorily required.

- The utility believes that it is able to negotiate better than other utilities, and that disclosure of its "bargain prices" would nullify this advantage in the future. (Obviously, all utilities cannot be obtaining below-average prices; nevertheless, this belief is widely held.)

In order to overcome the first objection, we obtained release letters from the nuclear steam supply system vendors that authorized utilities to discuss details of non-current bids. Despite these releases, we were able to get price information from only a small number of utilities, a fact that may indicate the large importance of the second reason for their keeping bid information confidential. This result reduced our ability to fully describe NSSS commercial practice and price competition.

2. *Supplier qualification* – lists of prospective suppliers may be unnecessarily restrictive. Even though the number of suppliers of most utility heavy capital equipment may already be limited, some utilities narrow the list still further – sometimes to the point of having a demonstrably preferred vendor for each type of equipment. Utilities argue that specification writing, bid submission, and bid evaluation are expensive processes; and that both the utility and the vendor industry can save money by restricting invitations to those vendors in whom the utility has confidence and whose equipment capabilities best suit utility needs. However, it is interesting to note that several utilities have recently widened the scope of their supplier lists deliberately and are more actively seeking additional competitors.

3. *Foreign purchases* – historically, U. S. private utilities have infrequently bought major capital equipment from abroad, even when offered substantially better prices. Private utilities have claimed that their need for prompt service, a desire to be "good corporate citizens," and their greater confidence in U. S. suppliers have caused their noticeable "buy American" attitudes. The apparent success of such public utilities as TVA and the Los Angeles Department of Water and Power with foreign suppliers has, to some extent, backed the argument of critics who claim that utilities may not be overly concerned about what they pay for capital equipment. Nevertheless, as will be mentioned in the discussion of turbine-generators, within the last year there have been significant awards by private utilities for foreign turbine-generators; consequently, the historical pattern may be changing.

c. Past Buying Performance

Although during the course of this and other studies[1] we found that a spectrum of buying capabilities exists within the utility industry, the price-fixing conspiracy trial of 1960 called into question the general astuteness of the utility industry as buyers of electrical equipment during an earlier period.

5. Innovation and Technological Progress

Although we are unable to show the presence or absence of vigorous price competition, we can demonstrate a climate of intensive technological competition. The technical and economic benefits of this competition will not be seen in operating plants for one or more years, but the improvements will almost certainly be in the direction of lower capital and fuel cycle costs.

The effect of technological changes on the percent of NSSS commitments obtained by vendors is shown in Figure 3. While bidding strategy, backlog, and other factors may also have had significant effects, note how various technological improvements, which have increased equilibrium fuel burnup 40% and power density 50% since the Oyster Creek award of 1963, correlate with the swings in orders obtained.

The large investments of the NSSS vendors in research, development, and engineering are expected to continue and to provide a major competitive force in the marketplace.

B. NUCLEAR FUEL CYCLE

1. Uranium Mining and Milling

a. Product and Market Definition

The relevant activities in this industry segment are:

- Exploration and drilling to locate uranium deposits
- Development drilling to define and evaluate deposits, and to establish an appropriate approach to ore removal.

1. *Future Market for Utility Coal in New England,* Arthur D. Little, Inc. (1966) prepared for the Office of Coal Research, U. S. Department of the Interior.

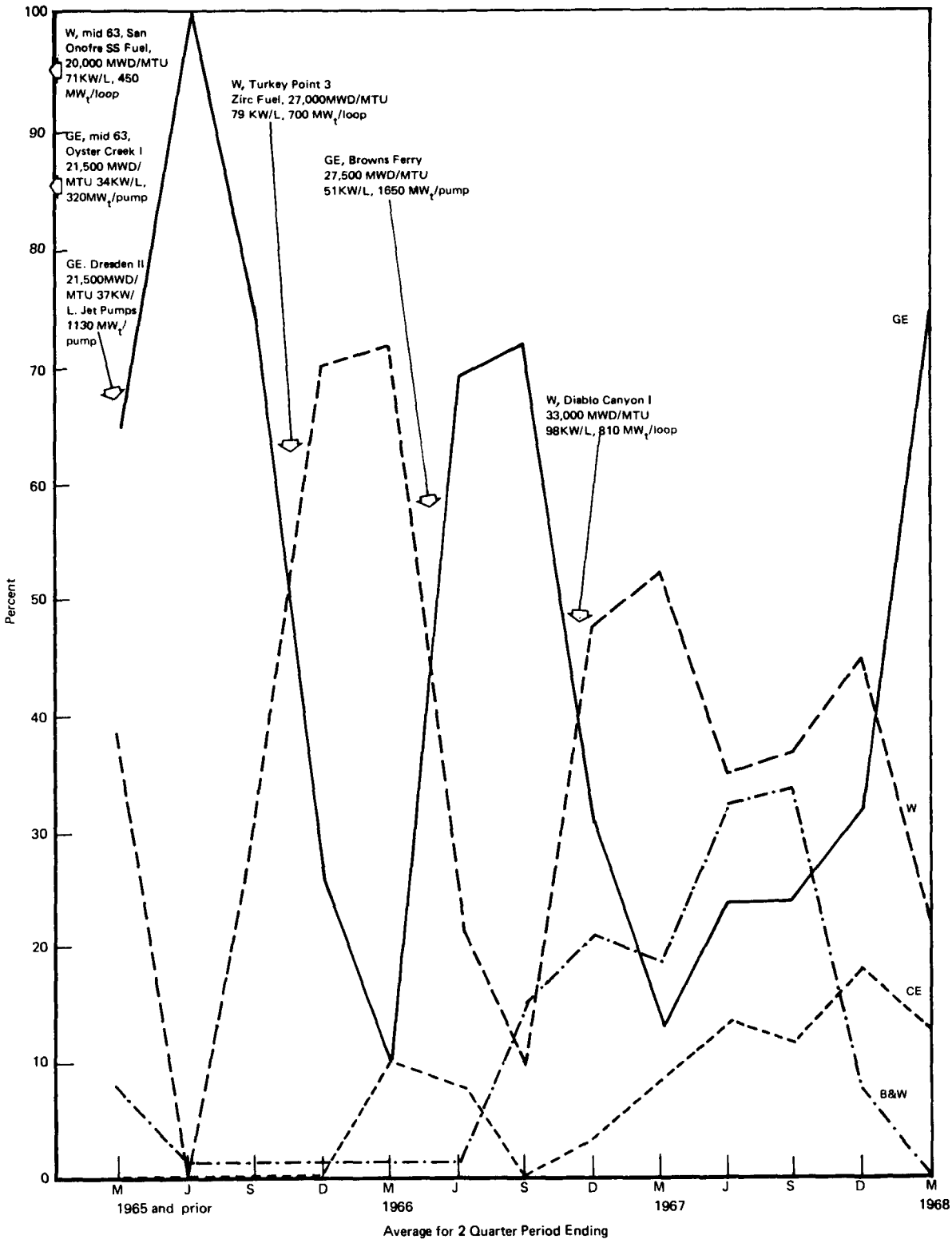


FIGURE 3 MOVING AVERAGE OF PERCENT Mwe AWARDED

- Mining the ore, which in the United States typically averages 0.20-0.25% uranium.

- Milling the ore to produce "yellow cake," which is essentially U_3O_8.

Exploration and development drilling are ordinarily carried out by mining companies intent on mining and milling any significant deposit uncovered. If this route is not economical, the mining companies sell ore to a miller or keep title to the ore while paying a miller for services. Depending on the situation, ultimate sales of ore or yellow cake may go to a fuel fabricator, a utility, a provider of fuel services, or a fuel leasing agency. Which will dominate in the future is not yet clear, and this will be discussed further under Nuclear Fuel Fabrication.

b. Market Structure

In 1967 about 125 mining companies produced ore from about 370 uranium mines in the United States. Approximately 110 companies operating 145 mines are small, independent mining firms that account for only 8% of the production. The other 225 mines, which account for 92% of the production, are owned or controlled by 15 integrated mining and milling corporations. Approximately 75 companies, including a number of major oil companies, are currently involved in significant exploration activities. The major integrated reactor manufacturers-fuel fabricators, with the exception of Babcock and Wilcox, are planning to enter, or have already entered, into uranium ore exploration and mining (GE is inactive at this time). And United Nuclear, an independent fuel fabricator, has a major position in uranium mining and milling. Kerr-McGee, one of the leading mining and milling companies, has decided to integrate forward into UF_6 conversion and is expanding its UO_2 powder and pellet conversion activity.

c. Trends in Market Structure

The number of companies involved in exploration may change as a result of the discovery rate and various market conditions, but it is not expected to decrease to a point where vigorous competition would be threatened in any way.

Consolidation has already occurred to some extent in uranium mining, and marginal operations are being weeded out of a commercially maturing industry. However, it is unlikely that the number of mining companies will decline to a small number, or that a few companies will dominate the market, since it is unreasonable to expect that a few companies could gain control over all uranium properties.

In the past there have been as many as 23 separate companies operating mills. A decline to 14 millers resulted from the decrease in uranium demand in the mid-1960's when the government curtailed the annual deliveries that it took. Although forward orders for the commercial market are large (about 60,000 tons), current deliveries are relatively small and have not been sufficient to fill the gap left by declining government purchases. As commercial demand increases, the total number of milling companies will probably increase. Economies of scale might prove important in planning new mills, but this is not always the case, since mill size must be tailored to the extent of the ore body, mining rate, mine life, ore grade, amenability of ore to processing, mine location, haulage distances, and market demand.

The recovery of uranium, like other mineral recovery activities, is eligible for a depletion allowance. For uranium this allowance is 23% and may be taken at the mining or milling stage. This tends to encourage vertical integration between mining and milling, and independent mining companies to keep title to the uranium ore and have it milled on a toll basis. The depletion allowance may also act as a force for further vertical integration in the fuel cycle, since this structure, if general in the industry, is conducive to maximizing the benefits of the depletion allowance. A parallel situation exists in the oil and other extractive industries eligible for the depletion allowance.

d. Market Performance

The only market for uranium in the past has been the government. Total AEC purchases to date from domestic sources of about 155,000 tons have been spread out over some 25 companies, with the top four (Anaconda, Atlas, Kerr-McGee, Union Carbide) having supplied about 51% of the total U_3O_8. The recent prices paid by the government for domestic yellow cake vary from a high of \$12-13/lb of U_3O_8 equivalent in the mid 1950's to \$8 in the mid-1960's. In 1969 and 1970 the government expects to pay an average of \$5.50-6.00. All factors point to a continued viable and competitive uranium mining and milling industry after government purchases are terminated in 1970, as is planned. In fact, we believe the industry would generally be viable and competitive even if government purchases were terminated earlier, although some of the smaller companies might leave the industry. Competitive conditions are likely to prevail, and we believe prices will be based on costs (with a reasonable rate of return included as a cost). It is our opinion that \$7-8/lb U_3O_8 equivalent (in constant dollars) is a reasonable estimate of the price through 1980, the period covered by this study.

Costs of foreign uranium appear unlikely to be significantly lower than domestic sources. Import restrictions are under constant review by the government. The government expects to have an eventual inventory of approximately 40,000 to 50,000 tons of U_3O_8[1] and has announced that "such stocks would be disposed of in a manner which would not adversely affect the general viability of the domestic uranium industry."

Proven uranium reserves are not sufficient to meet projected requirements through 1980. It is too early to determine if there will be an appreciable change in the rate of new finds per unit of effort; but if only one-half the past rate of finds is valid in the future, we estimate the current rate of exploration and development activity will be sufficient to develop adequate reserves.

e. Innovation and Technological Progress

New technology is important in uranium mining, largely through improved knowledge of uranium geology and exploration techniques. In milling, research and development will be aimed at decreasing costs and evolving new processes for the extraction of uranium from lower grades of ore. The government may well play a role through support of research in these areas. The advent of more companies, including the larger oil companies, in uranium exploration will probably mean increased technological competition in the exploration, mining and milling steps.

2. Conversion of Yellow Cake to UF_6

a. Product and Market Definition

The yellow cake (essentially U_3O_8) produced in the milling operation must be refined and converted to UF_6 for feeding into the gaseous enrichment plants now owned and operated by the government.

Conversion is usually a tolling service open to any company – domestic or foreign – that wishes to prepare U_3O_8 for enrichment.

b. Market Structure

At the present time the Allied Chemical Corporation has at Metropolis, Illinois, the only commercial refining and conversion plant. The government's large plant at Paducah, Kentucky, is designed to undertake the conversion step only.

1. Hearings on Uranium Enrichment Services, Joint Committee on Atomic Energy, 1966.

Because of certain government purchasing decisions and lack of commercial demand, the Allied plant was shut down for more than three years; it has recently reopened. Its original capacity when built in 1958 was 5000 tons per year of U_3O_8, and Allied expects to expand capacity to 10,000 tons per year of uranium by the end of 1969 to meet rising domestic and foreign commercial demands for UF_6. Total plant investment then will be about $25 million, but some of this has been written off. The price for UF_6 conversion is about $1.05-1.25 per lb of contained uranium.

c. Trends in Market Structure

In the anticipation of the growth of the market, Kerr-McGee has announced plans to build a 5000 ton per year conversion plant, which is scheduled for operation in 1970. It can be expanded to produce 10,000 tons of uranium per year. Getty Oil and Gulf Oil are also considering entry.

The fact that in the past the government was the largest buyer of UF_6 and also owned the largest conversion plant constituted a barrier to entry in the conversion business. Thus government decisions whether or not to buy, and whether or not to operate the Paducah plant had a major effect on potential industry markets. With the advent of larger commercial markets, this situation will change, and the present barriers to entry are the sizable capital requirements for plant construction coupled with the need to build a plant large enough to take advantage of economies of scale. Since a 10,000 ton per year plant is estimated to show a cost saving of 12-14% over a 5000 ton per year plant, and the projections of domestic industry requirements for conversion services do not indicate the need for a second 10,000 ton per year plant until about 1976, optimum capacity for entry obviously presents a strategic problem for a company like Kerr-McGee. Similarly, from 1976 to about 1981 only one or two more suppliers could enter at the economic plant scale level of about 10,000 tons per year. Government requirements for conversion services and foreign U_3O_8 requiring conversion could alter this market picture. Conversion services for foreign U_3O_8 are currently expected to reach 8500 tons in 1970.

Further competition, particularly for foreign business, is also facing U. S. industry with the announced entry of Eldorado Nuclear, Ltd.,[1] a Canadian crown corporation. Eldorado expects to have a 2500 ton per year plant of standard design on the line in Ontario by April 1, 1970. The capital cost is approximately $10 million, and the plant is designed for expansion, probably in 1972, to 5000 tons.

1. An affiliate of Eldorado Mining and Refining, Limited.

It appears probable that only a limited number of competitors will appear in this market because of its size in relation to economic plant sizes. As a result, conversion will not represent an attractive vertical integration step for many mining or reactor manufacturing companies.

d. Market Performance

It is estimated that a return on investment of 7%-10% after taxes can be achieved for 5000 to 10,000 ton per year plants operating near capacity and selling product at present prices. It appears that projected domestic and foreign competition will maintain prices reasonably related to costs.

Conversion of reprocessed uranium to UF_6 will also be undertaken commercially before 1973, and both Allied Chemical and General Electric have mentioned entering this field.

3. Nuclear Fuel Fabrication

a. Product and Market Definition

In its simplest form, fuel fabrication involves the nuclear and physical design of nuclear fuel elements, the physical construction of these elements by the packaging of uranium oxide in sealed zirconium tubes or fuel rods, and the assembling of these rods into fuel elements. The companies that carry out these fuel fabrication steps expect that in the future they will also perform the step immediately preliminary to fuel fabrication – the conversion of uranium hexafluoride from the AEC's gaseous diffusion plants into uranium oxide powder or pellets. The process is neither highly complex nor costly and is integrated with fuel fabrication for process and quality control reasons.

Fuel fabrication, including conversion of UF_6 to UO_2, is not always sold or purchased as a separate service. Utilities have several choices.

b. Market Structure

Four major nuclear steam system suppliers – B & W, CE, GE, and Westinghouse – have shared virtually all of the commercial reactor fuel fabrication market. United Nuclear, an independent fuel fabricator, is the only

other company that has won any awards for commercial nuclear fuel.[1] Gulf General Atomic is in the nuclear fuel business for the HTGR. Two other companies, Aerojet General and the Numec Division of Atlantic Richfield, have either reported that they are considering entry into the commercial fuel business or have made some steps in that direction; but we have found no instances of offers from these firms to utilities beyond initial conversations.[1] The Atomics International Division of North American Rockwell, a potential entrant in the breeder reactor period, is not currently offering fuel for light water reactors. Gulf General Atomic, if it were to sell a commercial scale HTGR, would provide the fuel for that reactor. There is no basis yet for predicting whether independent fuel suppliers might some years hence compete for reloads of HTGR's, although at least one is reportedly interested in the possibility.

Adequate information for deriving truly meaningful estimates of market shares of the fuel fabricators is not available. Reasonably comprehensive information about the extent or time duration of reload fuel contracts is often not released publicly at the time of the NSSS award. In some of these and other

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1. United Nuclear is supplying fuel for two small utility operated reactors built by Allis-Chalmers and, through its receipt of replacement business for Dresden 1 (which at 200 megawatts is on the borderline of commercial significance as the term is used in this report) has a much higher percentage of the *available* market for utility-consumed fuel fabrication in the later 60's than is indicated in Figure 2 for 1970. In July, 1968, United Nuclear received from Consolidated Edison its second major commercial award (the first was from American Electric Power) marking a significant improvement in its reload fuel fabrication contracts.

2. In addition, Kerr-McGee, National Lead and NFS are in various segments of the uranium fuel business and would be in a position to enter fuel fabrication.

instances, contractual provisions, including options for additional reloads, are not negotiated until well after the NSSS award is made. Nevertheless, several market characteristics are clear:

- To date the four NSSS suppliers have won all first fuel loads for their reactors.

- With one minor exception,[1] no NSSS supplier has won a reload contract for a commercial reactor other than his own.

- The only reload business won by a fuel fabricator other than the original reactor supplier has been won by United Nuclear.

- NSSS suppliers have acquired a substantial interest in replacement fuel; 60% of Westinghouse and GE's megawatts have been sold on a two-complete core basis.

- Reactor sales with fuel for more than one loading represent roughly 90% of Westinghouse and GE megawatts combined.

c. Trends in Market Structure

Three important matters that will affect the distribution of business among fuel fabricators are:

- Distribution of the nuclear steam supply system business;

- The degree to which NSSS manufacturers continue to capture first cores for their systems;

- The amount of reload business that goes to the original NSSS supplier.

Several factors suggest a continued strong linkage between NSSS and first core sale, although one independent – United Nuclear – has bid (unsuccessfully so far) on a first core and some exceptions may develop. The reason for the linkage is the intimate technical relationship between the design of a reactor and its fuel, which NSSS manufacturers say makes it nearly impossible to describe one without the other and hence warrant their performance separately. During the last three years rapid technological changes in systems design, coupled with lack of sufficient operating experience with either the reactor or its fuel, have provided

1. The Westinghouse reload for the 200-Mwe Babcock and Wilcox Indian Point 1 plant.

an even stronger technical reason why the NSSS and first fuel core were awarded to the same manufacturer. With more operating experience with advanced reactor designs and with the standardization that will inevitably occur as design features stabilize, there is a possibility that some first cores will be awarded to fuel fabricators other than NSSS manufacturers. We believe, however, that if utilities are to undertake separate contracts they will have to develop substantially stronger technical capabilities and greater willingness to assume financial risk.

Technical reasons for buying fuel cores from the NSSS supplier are not as strong in the case of reload cores as in the case of original cores. But the reload business over the next five or six years will be small, because few reactors will have reached the age at which they require reload fuel, and because of commitments that many utilities have already made with the original NSSS vendor for reload fuel.[1]

Some of the obstacles in obtaining reload core business that face companies other than the original core manufacturer include:

- The independent must overcome his lack of information about the NSSS and thus faces extra design costs. To an extent, utilities can help the independent overcome this barrier by contractually requiring certain design specifications from the NSSS vendor at the time of award;

- By the mid-1970's the NSSS supplier will have gained a significant advantage in fuel fabrication experience, not only for initial cores but for reload cores as well;

- Utility purchasers tend to require that independents establish the same credibility in engineering design and fabrication as they require of a NSSS vendor;

- Warranties provide problems because fuel reloading is staggered over several years, and no more than one-fourth to one-third of the fuel is removed at any given time. Since it may be difficult to assign responsibility in case of malfunction when the fuel comes from several sources, warranty becomes a problem. Although the problem may decrease in

1. It is difficult to know how strong a force these options will prove to be. Some are vaguely worded; others have definite cancellation provisions. Speaking of the "iron clad" reload contracts, one NSSS manufacturer told us: "It would be commercial suicide for us to insist on a strict legal interpretation of such contracts if the utility were convinced it could do better elsewhere. The utility would want to negotiate a change in contract conditions or escape entirely and we would have to go along."

the future as more experience and confidence are gained by buyers and sellers, at present they restrict the range of potential customers for independents to those utilities willing to bear the technological and price risk; and

- Commitments or options for future deliveries already obtained by original core suppliers restrict size of market available to new entrants.

If participation of independents continues to be small and NSSS manufacturers continue to reload their own reactors, the shares of the market would, of course, closely approximate the cumulative installed megawatts of the respective NSSS vendors, shown in Table 4, page 19. On the other hand, the four do not have uniform forward commitments for reload fuel. For example, proportionately more of the reloads for the megawatts of capacity to be furnished by Combustion Engineering remains open for competition in reload fuel than is the case with GE and Westinghouse.

Our analysis of fuel fabrication costs, the sensitivity of these costs to volume, and the prices currently being charged suggest that entry into fuel fabrication could be viable from the standpoint of the economics of production at a throughput of one metric ton per day.

d. Market Performance

Utilities have a variety of options for the purchase of fuel elements. In addition to their choice of the number of fuel cores for which they contract initially, they can select among the steps of the fuel cycle to be included in the contract with the fuel fabricator. The three basic service types are; 1) fuel fabrication service only; 2) initial fuel service; and 3) complete fuel cycle service. In the fuel fabrication service, the supplier provides only design and fabrication service – the latter generally including conversion of UF_6 to UO_2. In the initial fuel service, the procurement of U_3O_8, the conversion of U_3O_8 to UF_6, and enrichment are also provided. In the fuel cycle service, spent fuel transportation, reprocessing and responsibility for the reclaimed products are added; thus fuel cycle service includes all steps except ownership of the uranium while in a reactor and associated carrying charges.

Typical practices in respect to services purchased from the fuel fabricator are as follows:

- The predominant fuel mode is fuel fabrication only: 70% of Westinghouse megawattage, 60% of GE and virtually all of CE and B & W's have been committed in this manner. A large percentage of megawattage contracted in this mode is on a multiple core basis – 63% for Westinghouse and 53% for GE;

- Fuel service commitments other than "fuel fabrication only," including the basic "fuel cycle service," and "initial fuel service" occur in 21% of total nuclear megawattage (all NSSS manufacturers); 60% of such fuel service megawattage is concentrated among utilities with low fossil fuel cost (under 26 cents per million Btu);

- The fuel cycle service mode of contracting is concentrated among large utilities; 60% of this mode by megawattage occurs among utilities with system sizes of over 8000 megawatts while only 11% of this is among utilities of under 4000 megawatts.

The trend is toward more "fabrication only" type of contracts. In fact, at least one of the major reactor suppliers only offers now "fuel fabrication only." Based on our review of a number of technical studies, we estimate that prices for fuel fabrication services in the $60 to $80 per kgU range (where the low end of the range represents later years when volumes will have increased) will cover costs with a 20% after-tax return on investment. This may be compared with present quotations for these services ranging between $70 and $110 per kgU. We could not determine whether or not the range in which there is apparently a substantial premium over cost can be justified by the risk inherent in the fuel fabrication business and by contingencies for correcting unforeseen fuel performance problems.

4. Manufacture of Zirconium Tubing

a. Product and Market Definition

Zirconium tubing, which is used to contain the UO_2 fuel in a nuclear reactor because of its favorable corrosion resistance and thermal neutron capture cross section, is an important fuel element component of a light-water nuclear power plant. The cost of the tubing for a nuclear reactor is estimated to be

approximately 15% to 20% of the cost of fuel fabrication[1] and about 5% of total fuel costs. Zirconium tubing is an important factor in determining the cost of nuclear power because the physical properties of the tube play an important part in achieving higher reactor efficiencies.

The basic raw material for zirconium tubing is zircon sands, which are found in abundance in Australia and available elsewhere in the world. Zirconium sponge is produced from zircon sands and in turn is fabricated into tubing in the form of a zirconium alloy called zircaloy.

Nuclear reactor applications, primarily in the form of tubing, consume more than 95% of the present domestic zirconium sponge output. Currently more than half of the zirconium is consumed by the military, but this will decrease substantially in the next few years as the number of commercial reactors increases rapidly.

b. Market Structure

Zircon is in plentiful supply and is available at competitive prices. There are two producers of zirconium sponge in the United States – Wah Chang Albany Corporation, a subsidiary of Teledyne, which supplies two-thirds of the market and AMAX's Nuclear Division, which supplies the balance. AMAX is the only integrated company, manufacturing zirconium tubing as well as sponge. There is currently one other domestic producer of zirconium tubing that has actually made substantial commercial shipments as of this writing: the Wolverine Tube Division of Calumet and Hecla (now a subsidiary of Universal Oil Products). Wolverine has the largest share of the current tube market – 65% – and AMAX has the remainder.

c. Trends in Market Structure

Current consumption of zirconium in the United States is approximately 2 million pounds per year, of which about 0.4 million pounds per year ($8.5 million) is presently being consumed by commercial reactors. Total zirconium demand is expected to rise to 6 million pounds per year by 1980 when U. S. commercial reactors will use 4.6 million pounds worth some $115 million.[2]

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1. Fuel fabrication includes everything but uranium values and amounts to about 1/3 of the total fuel costs – the uranium values represent the remaining 2/3 of the total fuel cost.

2. One year's slippage or gain in reactor construction schedules in the next four years can decrease or increase these projections by *at least* 25%. There are indications that current production for commercial reactors is, due to slippage, in excess of consumption and that a slowdown in delivery schedules may be imminent.

Present fuel fabricator consumption of zirconium tubing is about 2 million feet per year. This is expected to rise to the range of 5 million feet per year in 1970 and 35 million feet per year in 1980. The break-even point for an efficient plant at today's costs is between ¾and 1½ million feet per year, depending upon sales price, the degree of integration in zirconium tubing manufacture, and the amount of tube products other than zirconium that can be put through such a specialized facility. At current price levels, which will probably be reduced, we anticipate that a producer manufacturing 2 million feet per year will be able to obtain a 10% after-tax return on initial investment.

General Electric, Westinghouse, and Sandvik Special Metals Company (a joint venture between United Nuclear and the Swedish steel company, Sandvik Steel) have all announced plans to manufacture zirconium tubing and have begun or completed construction of facilities. In fact, Westinghouse and Sandvik Special Metals are already in production. All three plants will be designed to operate efficiently at the 2 million feet per year range or larger. The entry of these new producers will most likely create over-capacity in the industry for a period reaching well into the 1970's. General Electric plans to produce all of its requirements and not solicit any outside business; if the company maintains its percentage of the reactor and fuel market, this will amount to about 1/3 of zirconium tubing consumption. Westinghouse, on the other hand, plans to manufacture somewhat less than total requirements for fuel it manufactures and to sell a portion of its production in the open market. Based on the above current plans, General Electric and Westinghouse will together have approximately 2/3 of the zirconium tubing market in the 1970's. The remaining 1/3 of the market will be adequate for the next few years to support profitably no more than one other efficient producer, whose facility is used exclusively for zirconium.

Because of their internal markets, General Electric and Westinghouse are likely to achieve highly economic levels of production earlier than an independent producer and it is estimated that with a production volume of 2-3 million feet per year, these companies will have a cost advantage of $.20 to $.30 per foot of tubing over the average independent manufacturer whose volume will be about 1-1/4 to 1-1/2 million feet per year. The advantage amounts to $1.10 to $1.70 per kilogram of uranium, which represents 1-1/2% of the total cost of a fuel loading.

The competitive ability of an independent would be improved if he could cover part of his fixed costs with other tubular products in addition to zirconium. The addition of General Electric and Westinghouse to the market can be expected to enhance the likelihood of technological advances in the development of improved zirconium alloys with increased physical strength and the attendant improvement in reactor economies.

There is efficiency in integration between sponge and tubing primarily because of the economics of scrap salvage. AMAX and Westinghouse are the only two producers who will have this capability (and AMAX is integrated even further to ore). Manufacturing costs for an extensively integrated plant with the capacity of 3 million feet per year can be $.50 per foot lower than a non-integrated plant operating at less than 1-1/2 million feet per year. However, the capitalization required for backward integration increases in a manner commensurate with decreasing costs.

d. Market Performance

Vertical integration into zirconium tubing by General Electric and Westinghouse will leave a market available to independents that is hardly large enough to profitably support more than one efficient independent tube producer until the early 1970's and no more than two companies until the mid-1970's. Failure by a single independent to obtain the bulk of the business not manufactured by GE and Westinghouse in the years immediately after their entry could prevent any one independent from reaching a viable level of production.

Price trends have been down in both zirconium sponge and tubing. Sponge is currently selling for $5.25 per lb, which is approximately $1 less than in 1959, and tubing has dropped from $6 per foot in 1962 to the present level of $3 per foot.[1] These price decreases are a result of increased volume, improved manufacturing technology, increased competition from new tube producers, and less severe technical specifications on the part of the NSSS manufacturers. Although the increase in zirconium consumption can be expected to result in even lower prices for zirconium tubing, the same probably cannot be said for zirconium sponge, unless the by-product hafnium – now used almost exclusively for control rods in military reactors – finds other significant applications. In fact, since the price of the hafnium by-product has a large influence on the price of zirconium sponge, the present price of zirconium sponge would increase by about $1.50/lb (i.e., 29%) if government purchasing of hafnium were to cease and other applications did not develop. Historically, purchasing policies for hafnium are such that contracts are placed on a competitive bid basis with either one zirconium producer or the other – orders are seldom split – thereby exerting a maximum of price pressure.

e. Innovation: Technological Progressiveness

The manufacturing processes now employed for zirconium tubing are in general highly efficient and are unlikely to be improved upon to a significant

1. Even at the time of this writing, there are market indications that the price is weakening and orders are being considered and taken at $2.80/foot and below.

degree. However, if a significant improvement in the mechanical-chemical properties of zirconium alloys were achieved, important cost savings might be effected in the production of nuclear power (for instance, by permitting the use of thinner walled tubes). An integrated reactor designer and tubing producer is probably in the best position to make these improvements in mechanical-chemical properties.

5. Reprocessing of Irradiated Fuel

a. Product and Market Definition

Reprocessing, strictly speaking, comprises the series of chemical separations operations performed on fuel discharged from a nuclear reactor in order to recover fissile and other valuable materials. For purposes of this study, we include spent fuel shipment, as well as radioactive waste management operations, when we speak generally about this segment of the nuclear fuel cycle. Reprocessing services will generally be offered to electric utilities, or to the owner of the discharged fuel, if not a utility. They account for 10-15% of the nuclear fuel cycle cost or roughly 0.2 mills/kwh.

Irradiated fuel transport – i.e., shipping of spent fuel from the reactor site to the reprocessing plant – is usually considered a part of the reprocessing operation from the standpoint of cost. Because of the intense radioactivity of spent fuel, these shipments require use of special shielded casks, designed for removal of decay heat, and provided with neutron-absorbing poisons to prevent criticality accidents. Rigorous government regulations cover their design and use. The cost of shipping spent fuel is probably the only transportation cost of significance in the fuel cycle, amounting to perhaps $4/kgU, which amounts to about 10% of the total cost of reprocessing.

b. Market Structure

The one current commercial reprocessor, Nuclear Fuel Services (NFS), has a plant capable of processing one metric ton[1] of uranium (contained in low-enriched LWR spent fuel elements) per day, which is in excess of currently available load. The AEC has given NFS a 5-year "base load" contract[2] to reprocess 95 metric tons per year of Commission-owned fuel, and NFS has several additional contracts for reprocessing from several private utilities.

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1. The overall cost of this plant was about $33 million. NFS estimated that plant capacity could be doubled for an incremental investment of $6 million or so. For details, see Appendix C in Part Two of this report.

2. This contract gives the AEC the right of access to technical and cost data, a significant part of which could be released to the public.

The Atomic Energy Authority of the United Kingdom offers reprocessing services in the Free World market. The commercial load outside the United States is minuscule, however, and attempts to sell UKAEA services in the United States have been unsuccessful. The Atomic Energy Commission stands ready to offer reprocessing services if services are not available from others or if the service is available from only one commercial firm at prices deemed, through the AEC's conceptual plant policy, to be "unreasonable."

c. Trends in Market Structure

The expected schedule for LWR fuel core replacement will result in a rate of spent fuel discharge of approximately 30 metric tons of uranium per year per thousand megawatts of installed nuclear generating capacity in the United States. This will result in a commercial demand for reprocessing of about 80 metric tons per year in 1970, rising to 3000-4000 metric tons per year – comprising perhaps in excess of $100 million/year of business – by 1980. Assuming an average annual addition to national nuclear capacity of about 20,000 megawatts per year over the period 1978-1983, reprocessing demand should then increase at a rate of approximately 600 metric tons per year. This translates into a requirement for 16 tons per day installed capacity by 1980, with additional plants or capacity planned such that two to three tons per day come on stream in the immediately following years.

Major economies of scale are indicated for a reprocessing plant based on the well known Purex process. Given the same cost of capital, and operating the same number of days per year, a 6 ton/day plant is estimated to have total costs per unit output of only about one-third those for a one ton/day plant. Larger plants may have further economies, but environmental and other considerations may set the maximum economic plant size at about 6-7 tons/day. Because of capital intensity, market size, and economies of scale – all resulting in the fact that one large plant could economically handle the maximum domestic commercial load well into the 1970's – the economics of reprocessing over the short term have certain characteristics of a natural monopoly, features that normally provide some basis for establishing a regulated public utility.

However, because the condition is temporary and price increases much above current costs are restricted, such regulation seems inappropriate. Demand will have reached such a high level by the late 1970's and will be increasing at such a rapid rate, that a number of additional plants of maximum economic size will be necessary in the following years. The fact that prices for reprocessing services, at least until the advent of breeder reactors, must be below the value recoverable in spent fuel in order for such services to be in demand acts as a restraint on possible price increases.

As may be expected from the exponential nature of load growth, and aggressive competition, current plans for new plant capacity far exceed short term demand. GE has begun construction of a one metric ton-per-day plant based on a somewhat different process than used by NFS. The GE plant, which is expected to come on stream in 1970 or 1971, will have the added feature of recovering uranium in the form of UF_6 (rather than uranyl nitrate hexahydrate, as in the straight Purex process) as a final product and a waste treatment system resulting in compact solid wastes (rather than liquid wastes). The GE plant will also be able to recover neptunium.

Both Allied Chemical[1] and Atlantic Richfield have announced plans to enter the business in the mid-1970's. We understand that Allied Chemical has filed a construction permit application for a five-ton-a-day plant. National Lead is studying the possibility of entry.

d. Market Performance

Nuclear Fuel Services, Inc. (affiliate of W. R. Grace Co. and recently, Getty Oil) has a current standard minimum price (determined by formula) for reprocessing of about $32 per kilogram of contained uranium, equivalent to approximately 0.2 mills per kwh of electricity generated in a light water reactor. The relationship of price to cost is difficult to assess, since costs are sensitive to several variables, including the fixed charge rate applied to plant investment, realized throughput, and economies of scale. In the general case, we estimate that prices of $20 to $30 per kilogram for a five-ton-per-day plant should show a rate of return after taxes of from 10-20% per year, if the plant operates near full capacity.

NFS is currently a nonintegrated participant in the commercial nuclear fuel business. Excluding General Electric Company, the prospective new entrants – Allied Chemical, Atlantic Richfield, and National Lead – would not be substantially more vertically integrated than NFS. NFS, Atlantic Richfield (Numec), and National Lead participate to some degree in the nuclear fuel element business with some capabilities in commercial oxide fuel, specialty fuels, and plutonium R & D. National Lead and Allied Chemical, like NFS, offer irradiated fuel transport services, competing with Atcor, Inc., GE, and to some extent, Westinghouse. Allied Chemical is also engaged in the conversion of U_3O_8 to UF_6, and is a joint owner of Idaho Nuclear, the operating contractor for the AEC chemical separations facilities in Arco, Idaho. Atlantic Richfield presently has an AEC contract for operating the chemical separations facilities at Hanford (Richland, Washington).

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1. Allied Chemical is planning to incorporate a "continuous dissolver," an innovation it hopes will reduce operating costs. Further details of Allied's plant should be available in the documentation provided with its construction permit application, expected shortly. Plant cost is estimated at $50-60 million.

Reprocessing constitutes a significant step in vertical integration in the fuel business for GE. GE has been offering utilities a buyback credit for spent fuel in certain of its contracts. In these cases GE sets a firm price schedule for buyback, and will take title to the spent fuel; the utility is paid a fixed sum in recognition of the value of the enriched uranium and plutonium recoverable, less a charge for reprocessing. This arrangement, along with the complete fuel cycle service contracts GE has in hand already, results in GE having a significant base load available for reprocessing. However, the reprocessing value of the contracts is highly sensitive to the value assigned to the plutonium recovered. GE maintains its buyback offering "was originated as part of initial fuel sales offerings to be responsive to the desires of a very few utilities who at one time wanted complete security on fuel costs. This was at a time when it was extremely uncertain whether GE would go into the reprocessing business." Other NSSS suppliers who have shown little interest in entering the reprocessing business also felt it necessary to make this type of offering – although unlike GE they did not publish buyback prices – and it is understood the first contracts placed on this basis were with suppliers other than GE. Effective July 1, 1968, GE is not normally offering a buyback arrangement as part of its fuel scope and warranty offering, "since what little utility interest there has been in buyback seems to be dwindling."

Because of the innovations planned by GE, its reprocessing plant design may not benefit from scale economies to the extent that competitors' plants would. It appears that GE's strategy is to try to offset this by offering product as UF_6 and standing ready to build small plants near load centers to reduce transportation costs.

Gulf General Atomic has underway studies of a plant for reprocessing HTGR fuel. There is presently no commercial capability for reprocessing such fuel, which consists of uranium-thorium carbide particles dispersed in annular graphite compacts or hexagonal graphite blocks. (The fissile material is a relatively small amount of highly enriched uranium; a relatively large quantity of thorium is present as fertile material, which results in the production of fissile U-233 in the reactor.) Indeed, one would not expect HTGR reprocessing capability until several HTGR's have been sold, and there were some prospects for a recurring spent fuel load. Under its conceptual plant policy,[1] the AEC may develop cost estimates for a conceptual HTGR reprocessing plant, and announce prices it would charge for HTGR fuel recovery until 1977, the currently established cut-off date. The absence of firm prices for reprocessing HTGR fuel is somewhat of a handicap to Gulf General Atomic's HTGR marketing posture. However, estimates can be made of the likely reprocessing costs; studies by GGA and the Oak Ridge National Laboratory suggest that on a mills/KWhr basis, they will be similar to those for LWR fuel. The HTGR concept offers very high burnups and/or high

1. The Federal Register, January 3, 1968.

recovered values; hence, fuel cycle costs are expected to be much lower than for LWR's. However, in either case, reprocessing costs will only be a fraction of a utility's total nuclear electric generating costs.

e. Innovation and New Technology

Incentives for innovation on the part of new entrants (e.g., GE and Allied Chemical) have been referred to elsewhere. Any significant demand for reprocessing HTGR fuel will provide additional incentives to reprocessors.

The complex problems of nuclear materials accountability and radioactive waste management will grow with the large increases in the amount of fuel reprocessed in future years. Uncertainties exist with respect to safety requirements that may be imposed retroactively and the manner in which international nuclear safeguards, inspections and nonproliferation-of-nuclear-materials treaties will be implemented.

The advent of breeder reactions will bring new challenges as well as new opportunities. In contrast to the light water reactor fuel cycle, a breeder reactor fuel cycle is meaningless without reprocessing. Hence, the demand for reprocessing services will be relatively inelastic in the context of fast breeder economics. Indications are that breeder core fuels will be of much higher fissile content and much more radioactive after exposure in the reactor; therefore, they are likely to be more difficult and costly to reprocess. Furthermore, because of the relatively high inventory value of irradiated breeder fuel – and depending on spent fuel shipping costs – fast breeder technology may involve on-site reprocessing to achieve rapid recycling. Finally, differences in composition, radioactivity, fissile content, etc. may result in the use of different (e.g., non-aqueous) separation techniques from those used for LWR's.

C. TURBINE-GENERATORS

1. Product and Market Definition

The steam produced by the nuclear steam supply system is expanded through a turbine that drives a generator to supply the electrical output of a nuclear power plant. The mechanism is the same as for a conventional fossil power station, except that the steam conditions differ so that nuclear turbine-generators are larger and operate at a slower speed (1800 rpm as against 3600 rpm).[1] For a 1000-Mwe plant, the massive turbine-generator would cost about $32 million, weigh some 5100 tons, and have a size of approximately 20 ft by 23 ft by 223 ft.

1. The HTGR nuclear plant would, however, use a 3600 rpm turbine-generator.

Although the turbine-generator is usually purchased separately from the NSSS and should be considered a separate business, it is included in this analysis because it represents about one-fifth the cost of a nuclear power station and because the two current domestic producers of turbine-generators – General Electric and Westinghouse – are also major integrated NSSS and fuel fabricators.

2. Market Structure

General Electric and Westinghouse, the only two domestic turbine manufacturers, have approximately equal shares of the United States nuclear turbine market. In general, the utilities would welcome a third domestic manufacturer, providing the company would be competitive in all phases – price, reliability, efficiency, delivery and servicing. A number of foreign turbine manufacturers actively bid on projects in the United States, including Associated Electrical Industries, C. A. Parsons and Company Ltd., English Electric – all of U.K.; Brown Boveri, of Switzerland; and Hitachi Ltd. of Japan. Nevertheless, foreign producers have made only a small penetration in the U. S. market to date. As this report is being prepared, discussions are in progress between North American Rockwell and Brown Boveri on the possibility of their jointly entering the domestic turbine-generator market as a third producer. The annual dollar volume of the U. S. market for large turbine-generators (over 100 megawatts in size) is approximately $500 million. This represents some 40 to 50 machines per year with an average size of 500 megawatts. The shop time for completion of a large turbine is about 24 months.

3. Trends in Market Structure

For many years GE had a significantly larger share of the domestic turbine market than Westinghouse. Following Allis-Chalmers' withdrawal from the turbine business and the development of the commercial nuclear power business, Westinghouse's share of the turbine market has grown to approximate that of GE. One factor influencing this change was the GE decision in 1966 to take no more orders for shipments for 1969. A second factor has been the early trend by utilities to order turbine-generators when possible from the company selected to supply the nuclear steam supply system. The fact that Westinghouse and GE have similar shares of the NSSS market has caused Westinghouse's share of the turbine market to rise. Both GE and Westinghouse are in the process of doubling plant capacity to 20,000 Mwe each to meet the growing turbine demand. When these expansions are completed in 1973, we estimate that the total capital investment of each company will be on the order of $350 million. Turbine-generator business now represents less than 10% of the overall business of each. There is little question of continuing participation of each in the turbine market.

The entry of additional companies into the turbine-generator business would be difficult and risky, although it is possible given the right combination of factors. For instance, Brown Boveri/North American Rockwell could be assisted by foreign business over which they might spread some engineering and research and development costs. Ten per cent of a market characterized by strong cyclical movements proved inadequate to support a viable business for Allis-Chalmers in an industry characterized by heavy capital investment and engineering expenses. The opinion in the industry is that a new entrant would have to achieve 20-25% of the U. S. market, unless it could allocate a substantial amount of engineering and administrative overhead to other sales, and the utilities would smooth out cyclic buying practices. Plant depreciation, engineering, research and development, field servicing, and other relatively fixed costs equal approximately 50% of the total cost in the turbine-generator business. A steep learning curve poses an additional problem to the new entrant. Since down-time for a turbine is very costly to the utility, reliability gained through learning curve experience is of great importance.

4. Market Performance

Data permitting a comparison of costs and prices for turbines and generators are unavailable. Available information shows that prices have increased by about 30% over the last four years and are now at about their 1953 levels. Reasons given for the increase are a recovery from abnormally depressed prices, lower rates of output and manufacturing facility utilization for the larger nuclear turbine-generators now being manufactured in increasing numbers, current construction of costly new facilities, and inflation. The abnormally depressed prices came about at the time of the Philadelphia trials in 1960, in which major electric equipment producers, including turbine-generator manufacturers, were found to have conspired to fix prices during the 1950's.

Prices of turbine-generators produced by GE and Westinghouse are publicly available in printed price lists, which are very detailed and nearly the same. They are sold at price less discounts, which have varied over the years. During the last few years of heavy backlogs, turbines have been sold with less negotiation of the discount. Firm ceiling prices are now given for shipment within 60 months from the date of order. Purchasers are also given the benefit of any lower price that may be quoted to another purchaser for a period of six months.

Until recently, U. S. turbine-generator manufacturers would not quote a firm price on an order for delivery beyond 36 months. Since advance orders for as long as five years were common in the recent high backlog period, purchasers experienced long periods of uncertainty. Because of this, the willingness of foreign turbine suppliers to quote firm prices at time of order, and the price escalation of domestic turbines, foreign turbine manufacturers made several large

sales in the U. S. market. This foreign competition coupled with utility pressure essentially forced domestic turbine-generator manufacturers to offer firm ceiling prices on orders accepted for 60-month delivery.

Early in 1968 foreign turbine price levels were reported to be from 15 to 20% below domestic quotations. Domestic turbine producers believe that at a 20-30% higher price domestic turbines are still more economical – at least for large sizes. Though disputed by some, the claim of domestic manufacturers is that they offer economies through greater reliability gained by a combination of better design, a more advanced position on the learning curve, and more effective servicing.

Buying and selling practices and policies with respect to turbine-generators generally militate against their being used to promote the sale of NSSS systems, and vice versa. Some of the pertinent aspects of buying and selling arrangements are as follows:

- In contracts for power plants the turbine-generator has been traditionally the subject of separate negotiations from the steam supply system. During the turnkey era, GE and Westinghouse sold plants complete with turbine-generators. Current practice has reverted to former methods. There is a trend toward purchasing the more complex NSSS system first and the turbine-generator later.

- The price of a turbine-generator is sufficiently large for top utility management to give careful attention to its purchase. Management appears generally sensitive to tie-in possibilities of NSSS and turbine sales and could be expected to move against any attempts by an integrated supplier to gain advantage by special arrangements covering purchase of the two items. Managements of the turbine suppliers also appear sensitive at this time to the potential tie-in problems and can be expected not to create any cause for concern on this score.

- A prospective buyer may reserve space on a producer's turbine-generator schedule before or after the award of the NSSS without prejudice as to which corporation wins the NSSS competition.

- Turbine-generators and nuclear steam supply systems are under different division management at both GE and Westinghouse. These divisions at both companies are separate profit centers, and each presumably has its own incentive for maximizing profits.

Neither Babcock and Wilcox nor Combustion Engineering believes it is at a disadvantage as an NSSS vendor by not also manufacturing turbine-generators.[1]

5. Innovation and Technological Progress

Technological improvements are most important in the turbine-generator business. We estimate that both General Electric and Westinghouse spend 10% of sales on research and development aimed at improved efficiency and reliability and lower manufacturing costs. For any competitor to become viable, he would need a share of the market large enough to support such necessary overhead activities.

D. BALANCE OF PLANT, ENGINEERING, AND CONSTRUCTION

1. Elements Involved

For analytical purposes we have divided the fourth and final part of the nuclear power plant into the following three segments:

- Characteristics of the balance of plant and nuclear plant construction
- Architect-engineers and engineer-constructor services
- Containment.

2. Characteristics of the Balance of Plant and Nuclear Plant Construction

The balance of plant includes those elements of the nuclear power plant (up to the transmission plant) not provided or assembled under the NSSS and turbine-generator suppliers' contracts – e.g., such items as site preparation, erection of structures and improvements, accessory electric equipment, various

1. In reviewing the draft of this report, one NSSS manufacturer said that since the time of our field interviews he had seen one instance in which he believed a utility based an award on an NSSS manufacturer's ability to build both the reactor system and the turbine-generator.

auxiliary systems, and on-site craft labor. These items may account for approximately one-third of direct power plant costs, according to AEC-FPC classification of power plant construction accounts. Additional elements that we include in the "balance of plant" category are such distributive (indirect) costs as architect -engineer and construction management services, licensing, and start-up, which may amount to 10% of direct plant costs.

Certain aspects of any power plant, conventional or nuclear, are similar. Some of the important features are the 4-6 year construction lead time, and the expenditure of millions of dollars before the plant produces any power. We have mentioned elsewhere the fact that, unlike other manufactured products, the power plant is shipped in pieces to the owner and erected at a site of his choice. A substantial engineering effort is involved, and usually includes the use of both in-house and outside engineers, construction personnel, and consultants.

The major difference between nuclear and fossil plant construction is the AEC safety and licensing function, which requires assurance that the plant can be constructed and operated safely on the part of the owner-operator before he may obtain a construction permit. Among other things, this requires proof of financial responsibility and arrangement for nuclear liability indemnification and insurance (under the Price-Anderson amendments to the Atomic Energy Act of 1954). Subsequently, the owner-operator must show that his plant design meets all AEC requirements before he may obtain a permit to operate the plant.

3. Architect-Engineers and Engineer-Constructor Services

a. Product and Market Definition

Architect-engineer services include balance of plant design and engineering, preparation of overall plant specifications for bids, supervision of bid invitation procedures, and bid evaluation. Certain consulting firms specialize in power plant problems, such as siting, fuel cycle cost analysis, fuel cycle services, and radioactive waste management. The engineer-constructor, often the same company as the architect-engineer, will normally have overall plant engineering and design responsibility, erect the balance of plant, and provide overall plant construction management. This involves, in coordination with the NSSS and turbine-generator suppliers and the utility, site preparation, erection of structures and improvements, auxiliary systems, and management of construction labor and scheduling of the project. The pattern of plant construction arrangements resembles that characteristic of traditional fossil plant procurement by electric utilities.

The professional engineering firms have a unique vantage point, since they frequently act as agents for, or consultants to, utilities. They are exposed to bid data, balance of plant procurement, and site construction of much of a nuclear or fossil-fueled generating plant.

Because most of the larger firms are engineer-constructors, and these firms have major responsibilities in the engineering and construction of approximately two-thirds of the nuclear generating capacity underway or announced as of mid-1968, we will discuss their roles in more detail.

b. Market Structure

The principal engineer-constructor participants – firms providing both architect-engineer and construction services – and their estimated rank or share of the nuclear plant construction work are indicated in Table 7.

c. Trends in Market Structure

The major participants, and their relative shares of the nuclear utility market for engineer-constructor services, correspond quite closely to those involved in fossil fuel power plant awards. Almost all the firms have been in business for many years and are well known professionally in several other fields of activity (e.g., oil refinery construction, chemical plants, special government projects, and pipelines).

New entrants have nevertheless appeared, not so much in the engineer-constructor (E-C) role, but rather as specialized consultants in areas peculiar to the nuclear field – e.g. siting, waste management, uranium procurement, and fuel cycle service. This development is expected to continue.

d. Market Performance

Value added may be taken as the cost of architect-engineering services, which typically represent 6% of direct plant construction cost. Roughly 10% of direct construction cost is represented by architect-engineering and construction management services combined. There are few economies of scale in this type of work, except in the case of building, say, three identical plants at the same site. (The only two examples of this – TVA's "Browns Ferry" and Duke Power's "Oconee" stations – do not involve outside A-E or E-C firms to any great extent.) Historical information on associations between architect-engineer or engineer-constructor firms and public and private utilities suggests that although there may be some preferences, the market is generally diverse and the possible preferences have no strong bearing on the competitive situation in the reactor business or fuel

TABLE 7

E-C PARTICIPATION IN COMMERCIAL NUCLEAR POWER PLANT CONSTRUCTION UNDERWAY IN 1967 OR ANNOUNCED AS OF MARCH 1968[a]

Engineer-Constructor Firm	Total Units	Approximate Mwe
Bechtel Corporation	16[b]	11,400[b]
United Engineers & Constructors	12	10,700
Stone & Webster Engineering	9	6,200
Burns & Roe	3	2,300
Ebasco Services	3	1,900
All others, n.e.c.	6	3,600
Utility Engineer-Constructor		
TVA	3	3,300
Duke Power Corporation	3	2,400
American Electric Power	2	2,200
Pacific Gas and Electric	2	2,100
E-C Not Yet Selected	8	7,600
Total	67	53,700

Notes:

[a]Excludes research reactors, small demonstration prototypes, and about 1600 Mwe in five completed central station plants.

[b]Excludes Oconee 1 and 2 (1600 Mwe) for which Bechtel is providing engineering assistance.

Source: Arthur D. Little, Inc.

cycle at this time. Competition among A-E's and E-C's appears to be adequate and comparable to that in fossil-fueled plant contracting.

Engineer-constructors are increasingly performing services as a utility's agent, under a cost-plus-fixed-fee arrangement, rather than on a fixed-price contract basis; in certain cases some of the larger firms will work under incentive contracts. The agency role seems to be generally preferred by both the utility and the E-C; it is one which has been traditional in the construction of conventional power plants. It is a professional relationship rather than a supplier-customer relationship. Furthermore, it is claimed that the relationship gives the E-C more flexibility to shop for components at the best price, and hence save the utility money. The agency role may also be more effective in limiting the NSSS manufacturer's scope of supply, a matter discussed elsewhere under the topic of NSSS vertical integration. On the other hand, it is an arrangement under which the E-C has relatively little financial risk due to construction cost escalations (on-site construction labor costs for large nuclear plants are estimated to be five to seven man-hours per kilowatt). This risk is shifted to the utility, which may be expected to be stronger financially and better able to bear it.

4. Containment

a. Product and Market Definition

A nuclear containment system comprises integrated subsystems and procedures for ensuring against uncontrolled release of radioactive products in the event of an accident and otherwise protecting the public against operational releases of radioactivity. The major discrete product is the containment structure, made of steel or concrete, that surrounds the reactor and its associated equipment. The 12 to 20 nuclear power plants that we expect will be ordered per year between 1968 and 1980 will each require a suitable containment structure, and it is likely that these will continue to involve some degree of custom engineering.

The containment structure differs from a pressure vessel in that it is not normally under pressure, it is provided with air-locks for entrance and exit, and it is not protected against overpressure by means of relief valves or rupture discs, since these would defeat its basic purpose.

1. The HTGR design embodies a pre-stressed, post-tensioned concrete pressure vessel with a steel liner, for both primary and secondary containment – i.e., there is no containment structure separate from the reactor pressure vessel.

b. Market Structure

Chicago Bridge and Iron Co. has supplied or is supplying approximately two-thirds of the steel containment structures ordered to date for reactors over 400 Mwe. The other awards have gone to Pittsburgh DesMoines Steel, Graver Division of Union Tank, General American Transportation, and Nooter Corp.

The four largest engineer-constructor firms are interested in reinforced concrete containment designs, which may or may not involve steel as a liner. The E-C's already provide the necessary concrete work associated with erection of a containment structure. The use of more concrete plus a steel liner would involve substantially less value added for steel plate fabricators than a free standing steel containment; however, the liner would most likely be ordered from the above listed companies.

The "value added" by the containment structure including site, labor, steel, concrete, etc., is about $6-7 million (1967) for a 1000-Mwe plant. The cost of the steel structure alone would be $1.50 to $3 per kilowatt. These costs are relatively small in comparison with total power plant costs.

c. Trends in Market Structure

New entry is facilitated on the one hand by standard specifications – e.g., for ASME Code pressure vessels. On the other hand, the importance of experience and reputation and of AEC safety and licensing requirements tends to make entry difficult. The special studies and demands of the AEC, arising out of its statutory concern for public safety, determine many of the features of containment design, and hence influence the type of firms that might enter the competition.

d. Market Performance

Containment on turnkey contracts was under subcontract to the plant prime contractor. The trend now is to make containment the responsibility of the customer-utility's architect-engineer or engineer-constructor.

Steel containment vessels are built on a firm fixed-price, lump-sum contract basis. Concrete vessels, on the other hand, are often built on a time-and-materials-plus-fee basis. We cannot generalize about price-cost relationship due to the absence of bid and cost data.

For all companies in the containment business, that activity represents a small part of their overall business. The processes involved in making a

containment vessel are similar to those associated with the non-nuclear work by these companies: viz., for metal plate fabricators, welding and inspection technology to high standards; in the case of concrete work, reinforced or pre-stressed concrete technology, construction labor management, and so on.

The nuclear containment business at this stage involves evolving buyer-seller relationships, changing designs, and very conservative specifications. The nature of competitive offerings may be said to be influenced by relatively sophisticated customers and by the controls exerted by the AEC.

The Westinghouse ice condenser, which could allow a smaller containment design – possibly saving $2 per kw of the $7 overall containment cost – may represent a significant containment innovation. It has already been specified for the twin 1100-Mwe nuclear plants that have been ordered by AEP. Much documentation has been submitted in connection with the construction permit application; but as of this writing, approval of the ice condenser containment is still under consideration by AEC's Division of Reactor Licensing.

e. Innovation and New Technology

In the near future, the nature of containment competition may be changed as a result of (1) any shift in the reactor mix toward more PWR's (or HTGR's) vs. BWR's, which would probably mean less steel fabrication value per megawatt; (2) increased competition from engineer-constructors; and (3) continued innovations such as the ice condenser. For the longer term, important developments are a possible trend toward underground containment because of urban siting, changes in material requirements imposed by much higher reactor ratings, and changes in containment concepts to match the requirements of fast breeder reactor plants.

E. TOTAL NUCLEAR POWER SUPPLY INDUSTRY

Having presented a segmented view, it is now appropriate to picture the nuclear power industry as a whole. We have prepared a detailed flow diagram of the industry in Figure 4. The figure divides the industry into some forty segments, and the names of the major participating corporations are recorded for each segment.

A summary picture of the industry based on our data – a picture that is necessarily limited by the newness of the industry – is given in Table 8. It includes price information, market concentration and projected sales for the major segments of the industry to 1980.

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FIGURE 4 FLOW DIAGRAM FOR LIGHT WATER REACTORS

The industry has been segmented on the basis of major components for Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR). By showing Gulf General Atomics, which offers only High Temperature Gas Reactors (HTGR), on this chart we indicate the functional areas in which they compete. However, the individual components of the HTGR are substantially different from Light Water Reactors.

We have attempted to show companies which now participate or are considered most likely to participate in a commercially significant way in the various sectors of the nuclear power supply industry.

In order to make the diagram a concise and meaningful description of certain commercial-competitive aspects of the industry, we have not shown all of the companies presently or potentially qualified to participate in the various sectors; nor have we included some companies which have participated in the past but have either become inactive or which now participate only in the supply of components for military or space systems. This is particularly true in the area of fuel fabrication where many companies have capabilities for producing fuel assemblies (usually for experimental or test reactors) but where few can fabricate light water reactor fuel on other than a laboratory scale.

The lineup of companies was edited from information obtained from the NSSS manufacturers, field interviews, and published sources. It has been necessary for us to make some arbitrary distinctions on the seriousness with which a potential entrant may be viewing the field and the attendant likelihood of his entry into it. Moreover, it is never possible to list all prospective entrants. Some companies will not disclose preparation and intent to enter and still other potential entrants may not yet have started to look at the field.

Detailed lists of current vendors and vendors under development are available for the four light water reactor system suppliers.

Foreign companies (F) have been shown only if they have obtained commercially significant orders for nuclear plants to be built in the United States.

\# Announced Firm Plans

* Projects Under Study

F Foreign Companies

Arthur D. Little, Inc.

September 1968

Manufacture of Heavy Steel Plate
Lukens
Limited Paticipation, See Text
ARMCO
Bethlehem
U. S. Steel

Production of Heavy Steel Forgings
Babcock & Wilcox
Bethlehem Steel
BLH
Camero Iron Works
Ladish
Midval Heppenstall
Pennsylvania Forge
U. S. Steel
Wyman-Gordon

Production of Inconel Tubing
International Nickel
Pacific Tube
Sandvik
Sawhill Tubular Products
Tube Methods
Westinghouse

Manufacture of Pressurizer Heaters and Controls (Pwr)
General Electric
Watlow Electric Mfg.
E. L. Wiegand

Manufacture of Pump Motors and Control
Allis Chalmers
General Electric
Westinghouse
Worthington Div., Studebaker

Manufacture of Stainless Steel Castings
Bonney Floyd
Esco (Electic Steel Co.)
General Electric

Manufacture of Other Steel Products
Most Steel Companies

Manufacture of Zirconium Plates and Shapes
AMAX (American Metals Climax)
Carpenter Steel
Jessop Steel
Latrobe Steel
Superior Tube
Wah-Chang Div., Teledyne

Manufacture of Zirconium Sponge
AMAX (American Metals Climax)
Wah-Chang Div., Teledyne

Fabrication of Reactor Pressure Vessel
Babcock & Wilcox
Chicago Bridge & Iron
Combustion Engineering
Rotterdam Dockyard Co. (F)

Fabrication of Steam Generator (Pwr)
Babcock & Wilcox
Combustion Engineering
Westinghouse

Fabrication of Pressurizer (Pwr)
Babcock & Wilcox
Chicago Bridge and Iron
Combustion Engineering
Westinghouse

Manufacture of Primary Pumps
Bingham Pump (G. F. Atkinson Co.)
Byron Jackson (Borg-Warner)
Westinghouse

Manufacture of Valves
Anchor
Atwood & Morrill
Black-Sivalls-Bryson
Crane
Darling
Hoke
Wm. Powell
Rockwell Manufacturing
Velan
Walworth

Manufacture of Pipe, Tanks
Associated Piping & Engineering
Babcock & Wilcox
Combustion Engineering
Dravo
Grinnell
Pine Fabrication & Supply
Southwestern Pipe
South West Fabricating & Welding
Struthers Wells

Fabrication of Reactor Internals
Babcock & Wilcox
Carpenter Steel
Combustion Engineering
General Electric
Mesta Machine
NUCOM Div., Sealol
Rotterdam Dockyard (F)
Westinghouse
Willamette Steel Div., G. F. Atkinson Co.

Manufacture of Zirconium Tubing
AMAX (American Metals Climax)
General Electric #
Sandvik Special Metals #
(50% Sandvik AB (F), 50% United Nuclear)
Superior Tube
Westinghouse #
Wolverine Tube Div., Calumet & Hecla (UOP)

Manufacture of Turbine Generators
Associated Electric Industries (F)
Brown Boveri (F)
English Electric (F)
General Electric
Westinghouse

Manufacture of Condensors
Foster Wheeler
Ingersoll-Rand
Maryland Dry Dock
Southwest Engineering
Westinghouse
Worthington Div., Studebaker
Yuba

Manufacture of Feed Water Heater
BLH
Foster Wheeler
Southwestern Engineering
Struthers Wells
Westinghouse
Yuba

Design and Manufacture of Nuclear Steam Supply System
Babcock & Wilcox
Combustion Engineering
General Electric
Gulf-General Atomics (HTGR)
Westinghouse

Manufacture of Control Rod Drives
Babcock & Wilcox
Combustion Engineering
General Electric
Marvel-Schebler Div., Borg-Warner
Reactor Controls
Westinghouse

Manufacture of Excore and Process Instrumentation
Bailey Meter Div., Babcock & Wilcox
Foxboro
General Electric
Hagan Div., Westinghouse
Honeywell
Leeds & Northrup
Tracerlab Div. of LFE

Manufacture of Other Components
INCLUDING FUEL HANDLING AND SERVICE EQUIPMENT
AMF
Babcock & Wilcox
Combustion Engineering
Gifford-Wood
National Annealing Box
Pittsburgh-Des Moines Steel
Programmed & Remote Systems
Schutte & Koerting
Stearns-Roger
Westinghouse

Fuel Channels (BWR)

Fabrication of Control Rods
Babcock & Wilcox
Combustion Engineering
General Electric
Gulf-General Atomics
NUCOM Div., Sealol
Westinghouse

Manufacture of Incore Instrumentation
General Electric
Gulf-General Atomic (HTGR)
Reuter-Stokes
Westinghouse

Construction Work

Additional Costs to the Utility
Interest on Construction
Site Acquisition and Preparation
Safety and Licensing
Operator Training
Public Information
Taxes

Manufacture of Cooling Towers
Fluor
Marley

Containment Structures
Steel
Chicago Bridge & Iron
CBT
Pittsburgh-Des Moines Steel
Union Tank
Concrete
Engineer-Constructor Firms

Manufacture of All Other Components for Plant

These Materials and Services Usually Purchased By A/E

Utility

Performance of Architect-Engineer and Construction Supervision Services
Burns and Roe
Gerstel
Ebasco Services
Gibbs & Hill Div., Dravo
Gilbert Associates
Pioneer Service & Engineers
Sargent & Lundy
Stone & Webster
United Engineers & Constructors
Others, Including the Utilities

These Materials Flow to First Core and Succeeding Reloads

MINING AND MILLING

American Metal Climax
American Nuclear
(Federal-American Partners 40%)
Anaconda
Atlas Corp.
Cotter Corp.
Federal Resources
(Federal-American Partners 60%)
Homestake Mining Co.
(United-Nuclear Homestake Partners
Kerr-McGee
(Petrotomics 50%)
Newmont Mining Co.
(Dawn Mining 100%)
Susquehanna Corp.
(Mines Development 100%)
(Susquehanna Western 100%)
Getty Oil Co.
(Petrotomics 50%)
Union Carbide
Utah Construction & Mining
United Nuclear
(United-Nuclear Homestake Partners 70%)
Western Nuclear

Uranium Mining
Approximately 125 Mining Companies Operating 370 Mines

Ore 0.1 to 1.0 % Uranium

Uranium Milling

U_3O_8 "Yellow Cake"

Conversion of U_3O_8 to UF_6
Allied Chemical
Eldorado Mining & Refining Ltd. #
Kerr-McGee #
Getty*

UF_6

Enrichment
U. S. AEC

Diffusion Plant Tails

UF_6

Conversion to Powder and Pellets
Babcock & Wilcox
Combustion Engineering #
General Electric
Kerr-McGee
Nuclear Fuel Services, Inc.
NUMEC Div., Atlantic Richfield
United Nuclear
Westinghouse

UO_2 Powder and Pellets

Fuel Fabrication
Aerojet-General *
Atomics Int'l Div., North American Rockwell *
Babcock & Wilcox
Combustion Engineering
General Electric
Gulf-General atomics
NUMEC Div., Atlantic Richfield
United Nuclear
Westinghouse

Fabricated Fuel Assemblies

Conversion to UF_6
Allied Chemical
U. S. AEC

UF_6

Plutonium as $Pu(NO_3)_4$

Uranium as UNH

Fuel Reprocessing
Allied Chemical #
Atlantic Richfield *
General Electric (through UF_6) #
National Lead *
Nuclear Fuel Services, Inc.
UKAEA (F)

Radioactive Waste

Irradiated ("Spent") Fuel

Irradiated Fuel Transport
Allied Chemical
Atcor, Inc.
General Electric (services)
National Lead (casks)
Nuclear Fuel Services, Inc.
Westinghouse

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TABLE 8

SIZE, NUMBER OF FIRMS, AND DEGREE OF CONCENTRATION OF NUCLEAR POWER SUPPLY INDUSTRY

	Estimated Annual U.S. Business Volume (millions of 1967 dollars)			Active U.S. Companies[a]	Approximate Share of Market for Top Four Participants
	1970	1975	1980	1968	1970
NSSS	304	582	1083	5	99%
Major Components[b]					
Pressure vessel	(35)	(68)	(126)	3	100
Steam Generator (PWR)	(44)	(85)	(157)	3	100
Pressurizer (PWR)	(3)	(6)	(11)	3	100
Primary pumps	(22)	(38)	(57)	3	100
Reactor internals	(6)	(13)	(23)	8	85
Control rod drives	(18)	(35)	(64)	5	95
Control rods	(8)	(16)	(31)	5	95
Instrumentation	(24)	(47)	(89)	8+	70
Valves	(21)	(40)	(76)	10+	40
Pipes, tanks	(21)	(40)	(76)	10+	40
Fuel Cycle[c]					
U_3O_8	107	292	563	15	60
Conversion to UF_6	13	35	67	3	100
Enrichment	120	358	714	1[d]	100
Fabrication	48	175	405	5	97
Conversion to UO_2[(e)]	(16)	(67)	(154)		90
Zirconium tubing[e]	(12-18)	(42)	(90)	4	95
Reprocessing	3	30	100	3	100
Turbine-Generator	205	390	730	2	100
Associated condensor, feedwater heater, feed pumps, etc.	30	57	106	6–7	Unknown
Balance of Plant, Engineering and Construction[f]	283–353	540–675	1007–1259	7	75
Containment	(42)	(81)	(151)	7	100
Grand Total	1113–1183	2459–2694	4775–5027		

Source: ADL estimates.

NOTE: Market volumes are based on shipments and reflect the effect of shipment lead times before plant start-up.

[a]Actively participating – excludes companies shown as "announced firm plans" or "projects under study" in Figure 4. also excludes foreign companies and those who to our knowledge have received no commercial orders.

[b]"Second Tier" products sold as part of NSSS.

[c]Annual market volume includes initial cores and reload; $/kw of fuel cycle in Table 1 refers to first core only. Annual demand for Fuel Cycle products runs approximately one-third to one-fifth of the first core. Irradiated fuel transport and reprocessing, part of the reload cycle only, adds another $1.00/kw to the fuel cycle (excluding credit for recovered plutonium).

[d]U.S. AEC-owned plants.

[e]"Second Tier" products sold as part of Fuel.

[f]The major portion of this item represents cost of construction work at the plant site. It does not include interest during construction nor owner's contingency. It includes cost of containment.

F. THE BREEDER REACTOR INDUSTRY

Breeder reactors (a breeder is a nuclear reactor that produces more fissionable material than it consumes) are still in the early research and development stage, so that a breeder industry is not expected to exist before the early to middle 1980's. Present indications are that the breeder industry structure will be similar to the present nuclear power industry, and most of the present corporate participants are expected to carry forward into the next generation of power reactors.

The AEC will play a strong role in structuring the industry, for it is expected to be a major source of research and development funds and also a substantial source of demonstration plant funds. Based upon its past and present performance, it is believed the AEC will select as major contractors those corporations best able to make meaningful and timely research and development contributions in the field, utilizing both government contract funds and private corporate funds. This will probably necessitate contracting largely with corporations already deeply involved in nuclear power development. And, through its announced policy of advocating and helping to support two or three different demonstration plants, the AEC is continuing its policy of encouraging industry competition among the highest qualified suppliers in the reactor field in order to maximize chances of success within the minimum cost and time schedule.

The AEC published in December 1967 its Liquid Metal Fast Breeder Reactor Program Plans. These outline the work to be performed in each of ten program elements, e.g., sodium technology, physics, safety, etc. The program is now being implemented and the AEC already has at least nine corporations under contract for work in each of the major component development areas. These include Atomics International, Babcock and Wilcox, Combustion Engineering, General Electric, United Nuclear, Westinghouse and other corporations already competent in the light water nuclear reactor field, as well as some new entrants.

Industry is also busy with its own breeder reactor development program. In order to become informed about the status of breeder reactor development and to acquire the ability to plan intelligently for the ultimate commercial installation of breeders, the utility industry has formed to date some eight groups that are investing in various studies, R & D, and construction projects. The groups vary in size from 4 to 24 participants; and, in all, over 95 utilities as well as some other types of companies are participating. The major groups include General Public Utilities (GPU), Southwest Atomic Energy Associates (SAEA), Empire State Atomic Power Development Associates (ESAPDA), Westinghouse Group, East Central Nuclear Group (ECNG), Southwest Experimental Fast Oxide Reactor

(SEFOR), the Gas Cooled Fast Reactor Group, and the Power Reactor Development Company (PRDC – operators of the Fermi Reactor).[1] Each group now has studies or other activities underway utilizing the design services of the major reactor design companies, such as General Electric, Westinghouse, Babcock and Wilcox, Combustion Engineering, Gulf General Atomic, and Atomics International.

Although it is not the province of this report to speculate on the structure of a breeder industry that will develop after 1980, it seems appropriate to conjecture that the problems of the light water reactor industry posed by thinness of market and concentration among manufacturers appear likely to persist.

1. *Fast Breeder Reactor Report,* Edison Electric Institute, April 1968.

V. THE NUCLEAR POWER SUPPLY INDUSTRY AND PUBLIC POLICY

A. GOALS OF PUBLIC POLICY

United States policy toward business and industry generally favors private ownership and management regulated by competitive market forces, not only because this situation maximizes the scope for individual action and initiative, but also because competition is widely accepted as being conducive to a number of desirable social and economic conditions. Among these desirable conditions are the following:[1]

- Company earnings sufficiently commensurate with risks to provide economic incentives without generating monopoly profits: i.e., prices reasonably consistent with costs;
- Enough alternatives for buyers so that they can choose freely among market-regulated suppliers;
- Substantial realization of economies of scale, with appropriate benefits passed on to consumers; and
- A sustained high rate of innovation.

In addition to seeking these desirable conditions for the nuclear power supply industry, U. S. policy makers have further objectives:

- A cheap, abundant, reliable flow of power, with assurance of environmental safety;
- A nuclear defense posture that serves as a deterrent to war or as a sufficient retaliatory capability.

Moreover, these goals are to be pursued in a context of general concern for national income, optimal resource allocation, full employment and other dimensions of social welfare.

It is apparent that what serves any one or any group of these goals does not necessarily serve them all. Policy is frequently a matter of compromise and trade-off, since preferences do not always point unambiguously in one direction; for example:

1. For a similar statement of the benefits expected to derive from competition, see the "Report of the Attorney General's National Committee to Study the Antitrust Laws" (U. S. Government Printing Office, March 31, 1955), pp. 317-8.

- Free enterprise is valued, but so is a system of handicaps designed to keep the race competitive.

- Competition is favored, but shows a tendency to eliminate the weak and compound the market strength of the winners.

- Economic growth, technological change, and cheap abundance are desired, but they call for a scale of operation that may squeeze out small firms and discourage new entrants.

- A self-policing market made up of many small firms may be inconsistent with the realization of economies of scale.

If a satisfactory mix of advantages is to be achieved in terms of national goals in the nuclear power supply industry, we must first see to what extent present conditions diverge from those desired, and then consider what effects could be brought about by various alternatives open to U. S. policy makers.

B. EVALUATING THE COMPETITIVENESS OF AN INDUSTRY

The evaluation of an industry for purposes of assessing its competitiveness basically calls for analysis of both its structure and its performance. In a nation that historically has preferred a minimum of governmental regulation and that this regulation to be impersonal and indirect, policy-making has tended to concentrate on structure rather than on performance. Good performance is to be had to the degree possible by sound structure.

To be effective, structure-oriented policy requires a cause-and-effect model of the dynamic relationships between different kinds of industrial organization and different performance characteristics. Classical and neo-classical economic equilibrium models have been relied on to supply this policy-formulating guidance, with structures of "pure monopoly" and "pure and perfect competition" serving as limiting cases. These models are too abstract and static to be relied on literally, but they have made policy makers sensitive to such elements as "numerousness" and "concentration" and "integration" – all of which are suggestive of the degree of self-discipline that may be expected to prevail in a given market.

To fill the large space between the extremes of pure monopoly and pure and perfect competition, models of imperfect competition have been developed. These newer models (embracing "monopolistic competition," "oligopolistic competition," and "dynamic competition") embody somewhat less abstract assumptions and often permit predictions more relevant to the performance data of the real world. For example, the new doctrines (unlike the old) accept both

technological change and changes in consumer preferences as functions *internal* to the business firm. Innovational competition and non-price competition can thus be seen as signs of competitive vigor, even when numbers of firms are low and "concentration" is high.

The new models have come into use because in the end it is performance that we experience and evaluate and direct our policy efforts toward changing. Those who evaluate performance are interested in the ways in which buyers and sellers are seen to interact, rates of growth and innovation, profit levels, cost-price relationships, levels of efficiency, and the quality of service available to consumers. Studies of market performance serve as "reality checks" on the structural models available to policy makers.

Nevertheless when sellers are very few in number, there is a strong presumption that competition, especially price competition, will be less vigorous and healthy than when they are numerous. This does not mean that price competition does not occur in markets having as few as two to five or six sellers. Nor does it mean that the product improvement and technological effort that is often substituted for price competition in so-called "oligopolistic" markets is not equally desirable. What the fewness of sellers does mean is that healthy and effective competition, including price competition, cannot be relied on with the degree of certainty the American public expects in a market-governed economy. Even the more sophisticated indices of concentration, such as the Herfindahl index[1], support no more than the presumption that high levels of concentration are *conducive* to monopolistic practices and that low levels are *suggestive* of competitive behavior. Performance is a function of more than just structure, and the theory of structure-performance relationships is too inconclusive to support simple inferences of competitiveness. Something akin to the "totality of conduct" doctrine in equity law should govern the evaluation of industrial organization for policy-making purposes.

Consequently, in assessing the degree of competitiveness in an industry, available evidence on all dimensions of structure and performance should be considered and not just the correlation of one structural element with one performance factor. It can be misleading, for example, to deduce from the coexistence of high concentration and high profits alone that a particular market is of necessity noncompetitive. The following are examples of other factors that bear on the competitiveness of an industry or that should be considered when evaluating its competitiveness:[2]

1. The Herfindahl index gives a summary measure of concentration *throughout* an industry, rather than a single-point reading, by using the sum of the squares of firm sizes measured as percentages of total industry size, e.g. when 4 firms each have 25% of the market the Herfindahl index is $\Sigma[(.25)^2 + (.25)^2 + (.25)^2 + (.25)^2] = .25$.
2. For a discussion of these factors, see the "Report of the Attorney General's National Committee to Study the Antitrust Laws," *op. cit.*, pp. 326-336.

- Opportunity for entry
- Independence of rivals
- Predatory, preclusive practices
- Rate of industry or market growth
- Incentives for competitive activity
- Degree of product differentiation
- Price rivalry
- Excess capacity
- Price discrimination.

Although classical theory requires the presence in all markets of numerous small firms if competitive ideals are to be realized, it is built upon a set of static economic assumptions no longer characteristic of U. S. manufacturing industries. Proponents of what is sometimes called the "new competition" have contended that a fairly high level of concentration is both desirable and inevitable. It is said to be desirable because the modern corporation must possess at least some degree of control over its respective markets before it will undertake the risky innovational activities that account for the strikingly high rate of industrial progress in the United States. It is said to be inevitable because the capital requirements, entry-deterring effects of the risks innovation involves, and the nature of demand all point to the viability of relatively few large firms. Recent investigations tend to support the general proposition that at least moderately high concentration is conducive to innovational effort.[1] In most industries, however, the level of concentration appears to be higher than that required for a satisfactory rate of innovation. Thus, while the new competition theories call for some qualification of the earlier theories (espousing low concentration and "numerosity"), they do not completely allay society's justifiable mistrust of unusually high levels of market concentration.

Although there is no hard and fast rule that permits one to determine the competitiveness of an industry simply on the basis of numbers of participants, measures of concentration are nevertheless useful as indicators of the degree of competitive potential. Concerning such measures as concentration ratios Professor Edward S. Mason has observed:

1. Cf. Frederic M. Scherer, "Market Structure and the Employment of Scientists and Engineers," *American Economic Review,* June 1967, pp. 524-30.

> "No one familiar with the statistics and other material pertaining to the performance of firms and industries would deny the extreme difficulty of constructing a water-tight case for or against the workability of competition in terms of tests such as these, but neither would one deny that reasonable judgments can be made."[1]

One widely-held view is that concentration ratios of 40% or less are not excessive;[2] that is, when the largest four firms in an industry have 40% or less of the relevant market, the prospects for effectively competitive behavior are fairly high. The emphasis is on the word "prospects"; measures of concentration are suggestive rather than determinative of the degree of competition in an industry. Fairly high levels of concentration have been found to be consistent with workable competition in a number of industries that have been the subject of recent empirical studies.[3]

Information from the 1963 Census of Manufacturers covering 417 four-digit S.I.C. Industries showed the concentration level for the top four firms in the various industries to be as follows:[4]

% Total Industry Shipments Accounted for by Four Largest Firms	Number of Industries	% of Total Industries	% of Total Value of Shipment**
76% – 100%	32*	8	8
51% – 75%	81	19	15
26% – 50%	161	39	39
0% – 25%	143	34	38

* Twenty-seven of the more highly concentrated four-digit industries in 1963 were: tirecord and fabric; cellulosic man-made fibers; organic fibers, noncellulosic; reclaimed rubber; flat glass; gypsum products; electro metallurgical products; primary copper; nonferrous forgings; steam engines and turbines; typewriters; carbon and graphite products; household laundry equipment; household vacuum cleaners; electric lamps; telephone and telegraph apparatus; electron tubes; cathode ray picture tubes; primary batteries; motor vehicles and parts; aircraft propellers; locomotives and parts; hard surface floor coverings; cereal preparations; chocolate and cocoa products; chewing gum; cigarettes.

** Value of shipments percentages based on 1958 data because 1963 data not yet calculated.

1. E. S. Mason, *Economic Concentration and the Monopoly Problem* Cambridge, Mass., Harvard Univ. Press, 1957, p. 368.
2. Cf. J. S. Bain, *Barriers to New Competition* Cambridge, Mass., Harvard Univ. Press, 1965, p. 218.
3. J. W. McKie, *Tin Cans and Tin Plate: A Study of Competition in Two Related Markets* Cambridge, Mass.: Harvard Univ. Press, 1959; C. F. Phillips, Jr., *Competition in the Synthetic Rubber Industry* Chapel Hill, N.C.: Univ. of N. Carolina Press, 1963; J. W. Markham, *Competition in the Rayon Industry* Cambridge, Mass.: Harvard Univ. Press, 1952; J. W. Markham and C. C. Slater, "Standards of Competition and the Food Industries" in American Marketing Assn., *Proceedings of the 1966 World Congress*, June 1966; pp. 19-45.
4. Source: *Concentration Ratios in Manufacturing Industry, 1963;* U. S. Dept. of Commerce, Washington, 1966.

Thus, in nearly 75% of all manufacturing industries grouped according to the four-digit classification the four largest firms account for 50% or less of total shipments; and in only 8% of the industries do the four largest firms account for 75% or more of total shipments. Consequently we see that the vast majority of U. S. industry grouped by the four-digit classification is "not excessively concentrated" according to the 40% criterion.[1]

The industries falling in the high concentration group appear to conform to no common pattern in terms of technological sophistication, capital requirements and similar industry features. They range from consumer goods such as cigarettes, chewing gum and cereal preparations to industrial goods such as locomotives and electro-metallurgical products. The areas of high concentration include steam engines, turbine-generators, and other heavy electrical equipment.

The fossil-fueled power supply industry has been characterized by high concentration. Four manufacturers have had virtually the entire market for large steam boilers and two of those companies have dominated that market. Three companies for many years supplied the turbine market, and the number declined to two a few years before the advent of nuclear power on a commercial basis.

Although many industries are characterized by a few dominant firms, the permanence of the market share of these firms is open to question. Both the theories and the facts relating to the durability of market control, once it has been obtained by one or two large firms, are conflicting. A large body of theory asserts that market dominance virtually assures its own survival[2]; however, an imposing body of literature propounds a conflicting theory.[3]

The facts on the point are equally conflicting: contrast the rise to dominance of the "big three" in the automobile industry after the 1920's with the erosion of market dominance over the same period for the United States Steel Corporation in steel (from over 50% of the market to approximately 25%), the American Viscose Company in rayon, and the "big four" in meat packing.

1. Any attempt to compare the degree of concentration of the nuclear power supply industry with general levels of concentration based on the four-digit industry classification must be undertaken cautiously. Within many of the industry groups are products that could hardly be considered substitutes for each other, which would cause the classification system to tend to understate the degree of concentration. On the other hand, some products with a high degree of substitutability are in different groups which would tend to cause bias in the opposite direction, and any finer classification would tend further in the direction of overstating the degree of concentration.
2. E.g. William Fellner, *Competition Among the Few* (New York, 1949), pp. 33-41; 198-229.
3. E.g. D. A. Worcester, "Why Dominant Firms Decline," *Journal of Political Economy,* (1957), pp. 338-346.

This diverse pattern of behavior apparently characterizes the entire manufacturing economy. Professor William G. Shepherd found in his study[1] of 26 highly concentrated industries over the period 1947 to 1958 that in 14 of them the level of concentration remained the same or increased while in 12 industries concentration declined. The industries registering a decline accounted for 57.5% of total employment in the 26 industries. He found further that declines were associated with growth industries (a finding that may be of significance in view of the projected rapid growth of the nuclear power supply industry), while increases in concentration were more closely associated with stable or declining industries. However, in an analysis of 35 well-known "oligopolies" over the same period, he found that concentration increased in 20, declined in 11, and remained unchanged in 4; on balance, the increases in concentration were more pronounced than the decreases.

While this factual evidence on the permanence of concentration, once it reaches high levels, is highly inconclusive, the evidence does seem to suggest that the turnover of the largest firms in specific industries is on the decline. Professor Lee E. Preston found in his recent study a weak but statistically reliable relationship between high concentration levels in specific industries and the absence of change in identity of the top four leading firms. As concentration increased, the identity of the top four firms appeared to be more permanent.[2]

C. STRUCTURE OF THE NUCLEAR POWER SUPPLY INDUSTRY

Bearing in mind the limitations of industrial concentration analysis that we have examined above, we now address the nuclear power supply industry to see what levels of concentration obtain within it, and what the significance of its structure is for policy-making purposes.

1. Less Concentrated Segments

The only segments of the nuclear power supply industry that meet the 40% criterion (i.e., have 40% or less of the market in the hands of the top four firms) are the segments producing valves, pipes and tanks. As can be seen by inspection of the industry profile set forth in Table 8, a few other segments have concentration indices in the 40% to 60% range. These are uranium mining and milling, architect-engineering services, ex-core instrumentation, and construction.

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1. William G. Shepherd, "Trends of Concentration in American Manufacturing Industries;" *Review of Economics and Statistics,* Vol. XLXI, No. 2 (May 1964) pp. 200-212.

2. Lee E. Preston, *Testimony* in *Economic Concentration,* Hearings Before the Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary, U. S. Senate, 88th Congress, 2d Session, Part I, pp. 56-76.

Uranium ore is mined by many firms, although some 15 integrated *mining and milling* companies currently account for approximately 92% of total ore production. Four companies (Anaconda, Atlas, Kerr-McGee, and Union Carbide) have accounted for approximately 50% of uranium sales to this time. Three of these companies (Anaconda, Kerr-McGee, and Union Carbide) plus one other (United Nuclear), currently have close to 60% of milling capacity. Approximately 75 firms are engaged in uranium exploration. High transport costs per unit of U_3O_8 in ore favor locating mills close to uranium mines, even though economies of scale in milling, at least up to a throughput of 3000 tons of ore per day, discourage the entry of mills to serve individual small mines. The general prospects in mining and milling are for a substantial number of firms and reasonably low levels of concentration.

Foreign uranium sources would, if permitted, introduce a new competitive factor into the mining and milling industry and, at times, might establish a uranium price with which the domestic industry would have to compete to avoid serious loss of business. Moreover, government uranium stockpile management can help to moderate price trends.

Architect-engineering and engineer-construction services for nuclear plants are provided by essentially the same firms that provide them for fossil fuel plant construction. Four architect-engineering firms, and seven engineering-construction firms (which also have architect-engineering capabilities) are participating in commercial nuclear plant construction. Some of the larger utilities, including TVA, Duke Power Corporation, and American Electric Power, also have engineer-construction capabilities that they are now applying to their own nuclear plants. Although the level of concentration is high when measured in terms of the share of business accounted for by the four largest firms, it is probably about as low as market size permits. In terms of total contracts awarded per year, the market is thin. The services, especially architect-engineering, are highly professional; the relationship between buyer and seller is of a fiduciary nature. Since the end of turnkey contracts, the trend in engineer-construction firms has been toward the kind of agency relationship with public utilities that has been traditional in the case of fossil plants.

Instrumentation for nuclear steam supply systems, a significant NSSS component in terms of value added, is provided by eight to ten firms, the top four of which have about two-thirds of the market. Half of the NSSS instrumentation value is for conventional equipment; the other half is at present mostly for highly specialized reactor monitoring and control instruments. Conventional process instrumentation for power plants is supplied in varying degrees by almost all these firms, while in-core nuclear instruments are mainly integrated into the operations of GE, Westinghouse and B & W. CE is currently developing its own capabilities.

Already a large number of firms in other markets are capable of supplying conventional instrumentation; and, as the demand for ex-core monitoring equipment grows in the nuclear field, there should be no lack of qualified potential entrants.

If the above cited segments of the nuclear power supply industry present any policy problems, these would appear to be the kinds of problems with which traditional antitrust policy has dealt: e.g., anti-competitive mergers, collusion and other illegal or unfair practices. The structures of these segments support expectations of reasonably competitive behavior. In sum, uranium mining and milling (in the raw materials sector), architect-engineering and construction (in the services sector), and ex-core instrumentation, valves, pipes, and tanks (among the second tier components) call for no special treatment and no new instruments of public policy for purposes of ensuring reasonably competitive performance.

2. More Highly Concentrated Segments

More complex policy issues are presented in the areas of nuclear fuel fabrication, conversion, reprocessing, the manufacture of major components for nuclear steam supply systems, the design and assembly of the systems, and the production of turbine-generators. These segments of the industry are characterized by relatively few sellers and hence by high levels of concentration. In most of the relevant components and finished assembly markets, sellers number from two to five or six. Table 8 shows the number of sellers and an approximate indication of the portion of total sales volume for each industry segment.

There are currently only four NSSS suppliers with commercial orders. The degree of concentration in the manufacture of a number of major NSSS components is similarly high – pressure vessels, steam generators, pressurizers and primary pumps have three participants in each segment; control rod drives and control rods have five participants, but the top four in each case have some 95% of the market; and reactor internals materials have eight participants, but the top four are estimated to have 85% of the market.

Fuel fabrication is, in terms of sales and future contractual commitments, structurally similar to the NSSS industry, since to date NSSS manufacturers have supplied virtually all the initial fuel, and, along with one independent,[1] each has been contracting to supply reload fuel for the nuclear plants it originally built. Although at least eight firms have fuel fabrication capabilities of varying degrees, only five have received any commercial orders for finished LWR fuel elements.

1. United Nuclear has won awards for a small percentage of the nuclear fuel market.

The downstream segments of the nuclear fuel industry vary in their degree of concentration. Mining and milling are relatively less concentrated, as has been described. There is little market currently for conversion service (yellow cake to UF_6); but when a market does develop, it cannot be expected to be large enough for more than three or four companies to participate in view of economies of scale. Enrichment is currently a government monopoly whose future direction is under study. As many as seven companies plan to offer conversion services to UO_2, including the four integrated NSSS manufacturers if present plans are carried out. Zirconium sponge and tubing are concentrated with two and five participants respectively. A single company now offers reprocessing services for the small market currently existing, although three additional companies have announced plans to enter the market with substantial additional capacity by 1973 when the market will be considerably larger.

Although the large turbine-generator market is one of the sectors with the highest level of concentration, the two domestic manufacturers supply both nuclear and fossil power plants. Concentration in the turbine-generator industry is not a phenomenon specifically related to the development of the nuclear power supply industry.

3. Sources of Potential Competition

Are the high levels of concentration prevailing in most major segments of the industry likely to be mitigated to some degree by competition from other sources? Three sources of actual or potential competition may have such an influence. They are:

- A possible fifth NSSS supplier, Gulf General Atomic;
- Foreign manufacturers; and
- Fossil-fuel power supply industry.

Gulf General Atomic appears likely to become a fifth NSSS supplier. If the company succeeds, it can be expected to offer fuel as well as nuclear steam supply systems. A fifth supplier not only would enhance the structural conditions for competition in the industry but its technologically different system may raise the strength of the competition.

As for foreign competition, there are a number of hurdles before sales to the U. S. will exist on any significant scale for nuclear steam supply systems, but some imports of NSSS components and turbine-generators are occurring. Several European and Japanese firms have demonstrated a capability in the manufacture

of nuclear steam supply systems, but they seem unlikely in the next decade to penetrate the U. S. market. A major obstacle is patents and licensing. Many foreign producers of light water reactors are using technology licensed from U. S. companies but restricted to use outside of the United States. A second obstacle is the reluctance of utility customers in the United States to apply to the AEC for safety and licensing approvals on foreign reactors. A third obstacle is the general reluctance of U. S. utilities (particularly investor-owned ones) to buy from foreign suppliers. Nevertheless, the development of large price differentials between domestic and foreign systems could be expected to place competitive pressures on U. S. suppliers, as occurred in the case of turbine-generators.

Among foreign competitors for the U. S. market, the United Kingdom Atomic Energy Authority with its Advanced Gas-Cooled Reactor, for which a U. S. engineering study was recently completed, may be farthest along. For some of the reasons stated above, plus skepticism by some U. S. observers over the economics of the AGR, entry into the U. S. market by the UKAEA does not at this time appear imminent.

Evidence that foreign competition in components may be significantly stronger than in the market for complete systems is Westinghouse's recent purchase of a Dutch-made pressure vessel for one of its systems and GE's purchase of reactor internals.

A significant breakthrough for foreign competition has recently occurred in turbine-generators for nuclear plants. American Electric Power purchased two units above 1000 megawatts from a European manufacturer and Consolidated Edison, one such unit from Europe. Contracts for two large units were also made to a foreign supplier for the Bolsa Island project, but the project is currently stalled and may not proceed. Evidence of an immediate effect upon competition in the U. S. market was a modification by the two domestic manufacturers in the terms of sale for turbines to provide greater price certainty to purchasers. Utilities considered the earlier conditions of sale unreasonable and had been trying to induce the manufacturers to change.

Fossil-fueled and nuclear power are competitive in some areas of the country. In the absence of price discrimination, the country as a whole benefits from this competition. It should tend to act as a restraint on energy prices and keep suppliers in both fields cost-conscious and efficient. However, fossil-fueled and nuclear power are not directly competitive in all areas of the country and the extent to which they are competitive is subject to variation, since the relative cost of the two methods of generating power may change over time. Moreover, many of the same companies supply power equipment for both markets (i.e., GE and Westinghouse for turbine-generators; B & W and CE for steam boilers and reactor

vessels). Therefore, the country cannot reasonably rely upon competition between nuclear and fossil industries alone to assure that the power supply market performs in the public interest. Policy on competition should basically treat the markets as separate.

Recent predictions[1] regarding coal and oil tend to support the expectation of a continuation of the present pattern of competitiveness of nuclear and fossil-fueled power. A proposal by Northern Natural Gas Company[2] illustrates the competitive forces in operation between various energy modes:

> "[The company] proposed to the Federal Power Commission a 'total energy systems service' rate it said would 'permit more vigorous competition between the natural-gas and electric-utility industries'. It defined 'total energy' as to the on-site use of natural gas to generate electricity, with the related heat available for on-site space heating and cooling, and for water heating...These rates...represent a major push by Northern Natural to compete with electric utilities. Under the total energy plan, customers would use natural gas to generate electric power, and thus would not have any need for service by the local electric company. The electric industry in recent years has embarked on a drive to get customers to go 'all electric' for power, heating and cooking facilities."

Competition between nuclear and fossil as a factor of significance in the energy market is dependent upon the existence of separate companies in the two fields. If the companies serving the two markets were to become the same by evolving into nuclear/fossil energy companies, the nature of competition between them would change significantly. The development of firms diversified in the energy field could pose a threat to inter-modal energy competition. Whether this in turn would impair competition in the overall energy market would depend upon the number of firms and levels of concentration in the overall market.

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1. Joseph Moody, President of the National Coal Policy Conference, forecasts that coal will continue to play a very strong competitive role in supplying the nation's energy needs. He notes that the production from coal of synthetic crude oil and synthetic pipe line gas will allow the use of coal reserves further and further from their source ("Competitive Aspects of Oil Shale Development," Hearings before the Senate Subcommittee on Antitrust and Monopoly, April and May 1967, Part I, p. 538). M. A. Adelman also predicts a substantial role for coal in the fuel market *(Ibid.* p. 525). While the future price of oil is more uncertain than that of coal, it is clear that the current market price of oil is for various policy reasons held above the competitive supply price, and that a deliberate drop in the market price would enhance oil's competitiveness in the total energy market.

2. See the *Wall Street Journal,* September 16, 1968; p. 11, col. 3.

Oil companies have a number of incentives to expand into various segments of the nuclear power supply industry. Some, already supplying utilities with gas or coal, could be expected to want to maintain or increase their shares of this market, as a significant part of the growth of power generation shifts to nuclear. Oil companies have some of the basic skills for success in the uranium industry, such as geological and mining experience. Finally, investment in the nuclear fuel field may promise above-average returns for big companies having large cash flows and willing to take above-average risks.

The data in Table 9 show that a number of major oil companies, by entering other energy-producing industries, are becoming full-line energy companies. Eleven of the top 20 oil companies are now in uranium exploration or mining, and five are in coal mining. Five of these diversified energy companies are among the top ten firms on *Fortune's* list of the 500 largest U. S. industrials.

4. Vertical Integration

In addition to the high degree of concentration in major segments of the nuclear power supply industry, there is substantial vertical integration. Each of the four NSSS suppliers is extensively vertically integrated in NSSS components, although these companies vary significantly with regard to the products in which integration occurs. For instance, of the four NSSS suppliers, only B & W and CE manufacture pressure vessels, and only GE and Westinghouse produce turbine-generators. The four NSSS suppliers are vertically integrated in nuclear fuel fabrication, and a number of companies in uranium mining and milling are either integrated to various degrees in the fuel cycle (Kerr-McGee and United Nuclear) or intend to expand in the fuel cycle (Gulf General Atomic, Getty Oil and Atlantic Richfield).

Table 5 gives a comparative picture of the nature and degree of vertical integration by the four NSSS suppliers.

The most significant areas of vertical integration or prospective integration from the standpoint of competition are:

- NSSS and fuel fabrication
- NSSS and reprocessing
- NSSS and zirconium tubing, and
- Uranium mining and milling and other up-stream fuel services.

TABLE 9

DIVERSIFICATION BY MAJOR PETROLEUM COMPANIES IN ENERGY-PRODUCING INDUSTRIES
(X means that company is engaged in activity)

Company	Assets in 1965 (in thousands)	Rank in assets		Crude oil production		Petroleum refining						
		Petroleum industry	Fortune's 500 largest industrials	Domestic	Foreign	Domestic	Foreign	Natural gas	Oil shale[1]	Coal	Uranium	Tar sand
Standard Oil (New Jersey)	$13,073,437	1	1	X	X	X	X	X	X		X	
Texaco	5,342,903	2	5	X	X	X	X	X	X	X[2]	X	
Mobil Oil	5,212,380	3	6	X	X	X	X	X	X		X	
Gulf Oil	5,210,833	4	7	X	X	X	X	X	X	X	X	
Standard Oil of California	4,165,825	5	9	X	X	X	X	X	X			
Standard Oil (Indiana)	3,514,102	6	12	X	X	X	X	X	X		X	
Shell Oil	2,671,464	7	15	X	X	X	(3)	(3)	X		X	
Phillips Petroleum	2,029,064	8	20	X	X	X	X	X	X		X	
Union Oil of California	1,758,516	9	24	X	X	X	X		X			
Sinclair Oil	1,694,519	10	27	X	X	X	X	X	X			
Continental Oil	1,679,473	11	28	X	X	X	X	X[4]	X	X	X	
Cities Service	1,635,417	12	30	X	X	X	X		X		X	X
Sun Oil	1,205,783	13	41	X	X	X	X	X	X	X[5]		X
Tidewater Oil	995,541	14	50	X	X	X	X	X	X		X	
Atlantic Refining[6]	993,849	15	51	X	X	X	X	X[4]	X	X	X	X
Marathon Oil	785,832	16	72	X	X	X	X	X[4]				
Sunray DX Oil	639,204	17	82	X	X	X	X					
Standard Oil (Ohio)	617,955	18	88	X	X	X	X		X			
Signal Oil & Gas	597,047	19	96	X	X	X	X	X				
Skelly Oil	420,339	20	128	X	X	X	X				X	

[1]Ownership of oil shale lands, exploration rights, or research.

[2]In Western Germany.

[3]By parent company.

[4]Part ownership of refineries in foreign countries.

[5]Ownership of coal-producing lands.

[6]In 1966, Atlantic Refining acquired Richfield Oil and changed its name to Atlantic Richfield. The combined assets of 2 companies in 1965 were $1,488,319,000.

Sources: The Fortune Directory, October 1966; Moody's Industrial Manual, 1966; Fortune 1966 Plant and Product Directory; Standard & Poor's; Listed Stock Reports; Business Week, Apr. 29, 1967; Chemical Engineering, Aug. 30, 1965; Department of the Interior; Atomic Energy Commission; and annual reports of the companies.

Source: Hearings before the U. S. Senate Subcommittee on Antitrust and Monopoly. Part 1. April 18, 19, 20, 25, 27; May 2, 5, 1967; p. 618

The interlocking directorate is a form of integration sometimes considered beneficial from a managerial point of view but sometimes thought to be potentially injurious to competition. We have made a detailed (though not exhaustive) examination of the corporate interlocks among the primary nuclear reactor/fuel suppliers and electric utilities, the results of which appear in an appendix to Part Two of this report. There are a number of corporate boards, typically those of financial institutions such as banks and insurance companies, on which officers or directors of utilities sit with officers or directors of nuclear power equipment or fuel suppliers. There are at least two companies in the nuclear power supply industry on whose board sits an officer and director of a supplier or potential supplier company. We do not presume to fully understand what effects these interconnections may have on competitive behavior, but we do consider a factual summary to be pertinent to any study of policy implications. Widespread interlocks have been described as "a feature in American corporate operations";[1] yet, especially in connection with the electrical industry, there is a statutory basis for wanting to be fully cognizant of the facts.[2]

5. Market Performance

Of the various dimensions of market performance that it is customary to examine, five are of major importance:

- Prices, costs and profits;
- Efficiency of production and economies of scale;
- Innovations and progressiveness;
- Distribution practices; and
- Buyer incentives and characteristics.

With respect to the first two of these aspects of market performance, data are seriously limited at this stage. We conducted our investigation on the basis of what could be learned on a voluntary, cooperative basis. The normal resistances and reluctance stemming from the commercial necessity of safeguarding proprietary information were encountered. In addition, as anticipated, the newness of the industry and the rapidity of basic changes in it tend to preclude

1. Staff Report on "Interlocks in Corporate Management," to the Antitrust Subcommittee of the Committee on the Judiciary of the U. S. House of Representatives, March 12, 1965, at p. 6.

2. See (a) Public Law 212, 63d Congress, 38 Stat. 730, 15 U. S. C. 12/et seq. (the Clayton Act); (b) 49 Stat. 856, Aug. 26, 1935; 16 U. S. C. 825d, 1958 (The Federal Power Act); and (c) 49 Stat. 838, Aug. 26, 1935; 15 U. S. C. 79, 1958 (The Public Utility Holding Company Act).

significant trend data that would reflect the force of any single variable or combination of variables. Finally, the fact that many firms in the nuclear power supply industry are highly diversified poses difficulties in determining the true costs and profits associated with their nuclear activities.

It is known that *pricing* at the outset had to be pegged at invitingly low rates to offset customer risk and to get in under fossil plant prices. The industry consensus, which we cannot validate or disprove, is that although turnkey plants were loss ventures (priced low, in part, deliberately to attract business; in part, in error because of unforeseen costs), it is reasonable to look forward now to profitable sales.

Inductive data about *efficiency of production* are confined to impressions gathered by experts who interviewed industry personnel. These impressions suggest that there has been reasonable "learning curve" progress in view of pressures to recoup losses, to remain competitive with fossil plants, and to survive against intra-industry competition. As the extensive technical papers in Part Two show, there is evidence that in many industry segments *economies of scale* are being pursued and realized and limit the number of companies likely to enter such segments.

The nuclear power supply industry appears to be functioning competitively to the degree that *innovations and improvements* both imply and beget competition. The two largest producers, GE and Westinghouse, offer technologically differentiated systems; while the prospective NSSS entrant, Gulf General Atomics, offers a third and more highly differentiated system, a high-temperature gas-cooled reactor. The marked differences between early nuclear plants and the most recent ones show a rapid rate of technological change, and the high level of R & D expenditures presages more of the same. That there is pressure to improve performance can reliably be deduced from such things as the 50% increase in power density and the 40% increase in equilibrium fuel burn-up over a 5-year period.

We turn next to *distribution practices*. Because of the high degree of vertical integration in the nuclear power equipment industry (i.e., between the NSSS and various components, the NSSS and fuel, the NSSS and turbine-generator and within the fuel cycle), there is widespread opportunity, and in many cases strong incentives, for "tie-in" or combination sales. Such sales can be anti-competitive. They can permit monopoly power in one market to be used in another and restrain the development of competitive sources of supply and independent market participants. The sale of some major items of the nuclear power plant in combination appears justified on the basis of technical and economic reasons – for example, the NSSS with various integral components and (at this time) the

sale of the original fuel core with the NSSS. On the other hand, other possible combination sales (such as the NSSS with turbine-generator) would seem to lack technical justification. Criteria are set out elsewhere in the report for assisting in distinguishing between unreasonable, anti-competitive tie-in sales and those that are not harmful to competition or are justified for technical or economic reasons.

Quite aside from the behavior of sellers in the area of prices, production, innovation and distribution, *the behavior of buyers* can enhance or diminish the competitive vigor of market performance. In the nuclear power supply industry there appear to be some institutional forces that tend to lessen the countervailing power that buyers might otherwise exert on the limited number of sellers. As mentioned earlier, these forces stem, in large part, from the fact that the typical buyer of a nuclear power plant, a utility, has a monopolistic position and operates within a publicly supervised rate-fixing system that may not necessarily favor cost-minimization. Moreover, in respect to purchasing nuclear power plants, utilities face a highly complex and rapidly changing technology which encourages them to stay with time-proven suppliers or with the first firms to establish credibility for new systems. The alternative, which many utilities may be hesitant to pursue, are burdensome investigations which may still be inconclusive. For these reasons, utilities as a general matter may be buying less competitively and with the exercise of less countervailing market power than desirable from the standpoint of the public interest.

D. AVAILABLE POLICY ALTERNATIVES AND THEIR APPROPRIATENESS

It is the task of those who make and apply the instruments of public policy to do so in ways – consistent with economic and political traditions – that will bring about a greater correspondence between existing conditions and national goals. This often requires that difficult and controversial trade-offs be made between increments of conflicting advantages, and it involves the development of new approaches for situations in which new conditions and issues do not fit readily into an existing policy framework.

Over the years the U. S. has evolved a general policy framework for dealing with questions of industry structure and performance in response to the needs and problems generated by the nation's economic development. Underlying this framework is a general presumption favoring a minimal role for government in the conduct of legitimate business and managerial affairs. Wherever there are "structural elements" or "market forces" that can be relied on to provide desired social controls without regular intervention by public authority, private enterprise enjoys wide freedom of action. These elements or forces are commonly

considered adequate if the number of firms in an industry is great enough to provide enough *known* alternatives to prevent buyers from being "victimized," and to provide a spur to any supplier who might be tempted to lapse into inefficiency. Whether the number is "sufficient" in any market of limited numbers of competitors, such as characterizes much of U. S. manufacturing, depends upon such factors as the ease with which new firms can enter the field, the promptness with which inefficient firms are weeded out, the degree of concentration of large market shares in the hands of a few firms in the industry, the rate of technological progress, the relation of cost to price, and so on.

In markets that are so structured as to be appropriately left to the discipline of competitive interaction of buyers and sellers, government policy as a general matter is restricted to preventing activities that would tend to upset the structure. When market forces alone cannot be relied upon to regulate a specific industry in the public interest, policy in the United States may involve one of four other approaches:

(1) Antitrust measures to eliminate unreasonable restraints of trade or modify non-competitive structures;

(2) Direct government regulation of private monopolies;

(3) Government ownership in a few special cases;

(4) "Guidance" policies to promote market behavior that is in the public interest.

We shall examine each of these approaches in turn, indicating whether it seems relevant to the present state of the nuclear power supply industry. Then we shall examine in greater detail the two approaches that seem most relevant. Under the general category of antitrust measures we consider both those that are preventive and those that are corrective.

1. *If business, in the exercise of its basic competitive freedom, achieves by fair or unfair practices a degree of monopolistic power that enables it unreasonably to restrain trade and reduce buyer options, the government generally intervenes by antitrust action to re-create or maintain a competitive environment.*

The enforcement of the antitrust laws is an extension of our basic commitment to a free, competitive market system, since enforcement seeks to maintain or to restore the competitive conditions whenever they are substantially violated. Until the enactment of the Sherman Act in 1890, the competitive forces of the marketplace were considered strong enough that they did not need to be

preserved or strengthened through public law. By 1890 it had become apparent that monopoly may occur through mergers and acquisitions, or internal growth, or "survival of the fittest." It may also result from "unfair trade practices" that significantly enhance one company's strength to the detriment of its rivals. Monopolistic growth through horizontal mergers and acquisitions, especially in recent years, has been the easiest to identify and control. It is more difficult to distinguish "unfair" from "fair" trade practices, or to define the precise circumstances in which vertical and "conglomerate" growth substantially lessen competition.

Some of the principal prohibitions of antitrust policy are agreements among competitors that restrain competition (especially price-fixing agreements); monopolization or attempts to monopolize that are not economically inevitable, even if the activities leading to market domination were "honestly industrial"[1]; mergers that tend substantially to restructure the market toward higher concentration or greater vertical integration by a dominant firm[2]; and certain anticompetitive practices such as tie-in sales, discriminatory pricing, requirements contracts, and false or misleading advertising.[3]

There is considerable scope and relevance for antitrust policy in shaping the future of the nuclear supply industry, but reliance on conventional antitrust enforcement policy alone is not believed to be sufficient to obtain the desirable industry performance described earlier. Taken in conjunction with other policies which we will describe, antitrust regulation, we believe, becomes sufficient.

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1. See U. S. v. Aluminum Company of America, 148 F. 2d 416 (2d Civ., 1945); U. S. v. United Shoe Mach. Corp., 110 F. Supp. 295 (D. Mass, 1953).

2. See 'Merger Guidelines" published by the U. S. Dept. of Justice, 30 May, 1968. For recent trends in court rulings note that in the *Von's Grocery* decision the market share declared illegal did not exceed 7.5% of a local retail market; and in the *Pabst Brewing Co.* decision a merger involving only 4.49% of the national market was declared illegal, although the court took into account that not only the total United States market but also "various sections thereof," in which the market shares involved were higher. In the *Brown Shoe* decision an essentially vertical merger involving less than 5% of the market was declared illegal. More recently in the *Proctor and Gamble* decision the harsher anti-merger policy was applied to "product-extension" mergers.

3. In general, the legal status of such practices depend on their effects on competition, on the particular market circumstances in which they arise, and on technical relationships. For example, the tying of the sale of business machines to their operation and to the punch cards they process has been held to be illegal; but a reactor sold with internals (excluding core) would not seem to have the elements of anticompetitive tie-in.

2. *When private capital is available in sufficient quantities to provide vital services that it would be foolish to duplicate and wasteful to provide except on a mass scale, monopoly is encouraged, but is subject to public regulation regarding what it can charge and what it must provide.*

The American predilection for competitive markets does not obscure the fact that, in some instances, lower costs and prices can be achieved by a few large firms or even a single firm, rather than by a larger number of smaller firms. These instances give rise to an uncomfortable ambivalence. We prefer competition because of its impersonal, downward impact on prices; yet lower prices are sometimes dependent upon the efficiencies of large-scale operations. In certain extreme cases of this type, when regulation by market forces is either impossible or undesirable, monopoly is countenanced, subject to public control through a regulatory commission (e.g., telephone service).

Before subjecting particular industries to positive regulation by public authorities, legislative bodies have tended to allow competitive market forces to operate for a long time to demonstrate whether or not market regulation was effective. Railroads had operated in the United States for 50 years before the Interstate Commerce Commission was established in 1887. Many privately-owned local and intrastate utilities had been in business for decades before the large majority of states established public utility regulatory agencies. While each of the industries that have gradually been placed under public control has its own peculiar characteristics, all have demonstrated over a considerable period of time that they function best under monopolistic conditions, and all provide virtually the entire citizenry with services that are needed on a regular and reliable basis (since consumers cannot carry inventories of such services to level out the vagaries of supply).

The nuclear power supply industry, including its various segments, would not appear to need this kind of direct regulation to keep it responsive to the public interest.

3. *When a vital social benefit would be likely to be denied to some citizens if its price tag equaled its full cost, including capital and entrepreneurial returns, government is prepared to own and operate an agency to provide such a benefit.*

The area in which the state has taken over the productive process is extremely limited in the essentially private enterprise economy of the United States. The conditions that have generally prompted states and federal governments to take this step are first, a clear demonstration of public need or necessity; and second, a clear demonstration that private capital either will not, or cannot, fulfill the need.

For example, the Federal Government serves as entrepreneur in matters of defense, space exploration, postal service, and multiple-purpose river development projects, when it is impossible or has been regarded unfeasible to divide the service into units independently salable to individual members of society.

Neither the nuclear power supply industry nor its various components satisfies these criteria now, nor does it appear likely that the industry or any of its segments will so evolve in the future as to satisfy them.

4. *When certain conditions or practices relating to industry structure and performance are regarded as contrary to the public interest, but do not violate the antitrust statutes, and do not warrant the use of policies reserved for industries considered permanently inappropriate for control by competitive market forces, the government may employ various means for guiding, steering or nudging the industry toward an adequate structure and a pattern of performance consistent with effective competition.*

For the nuclear power supply industry thin markets, strong economies of scale, high investment requirements, and complex and rapidly improving technology all militate against the existence of the classical competitive conditions of large numbers and easy entry. Antitrust can prevent mergers, acquisitions, and other corporate expansions from further reducing competition under such conditions and, to some extent, can mitigate the effects of the structural problems through surveillance of distribution practices; but we believe these regulatory activities need to be complemented by other government policies including information dissemination, business-government consultation, antitrust review procedures, and the indirect use for competitive purposes of government authority over such matters as R & D expenditures, procurement, imports, exports, and strategic resource management. A combination of antitrust policies and what we shall call "guidance policies" seems appropriate to us for ensuring the competitive vigor of the nuclear power supply industry.

E. APPLICATIONS OF ANTITRUST POLICY

Some of the principal anti-competitive activities or conditions with which antitrust policy can deal directly are:

(1) Agreements affecting prices or production;

(2) Mergers and acquisitions;

(3) Market concentration and vertical integration;

(4) Market-entry barriers including anti-competitive distribution practices; and

(5) Price discrimination.

1. Agreements Affecting Prices or Production

It is unrealistic to expect complete independence of action among the relatively few competitors that operate in most nuclear power equipment markets. When sellers are few in number, parallel action on prices and discounts, for example, may arise either out of unavoidable "conjectural interdependence" or out of collusion. It is essential, therefore, that firms in the nuclear power equipment industry be held to as high a standard of independent competitive action as possible. By this we mean that antitrust agencies should be especially alert to the possibility of collusive action such as that brought to light in the electrical equipment industry by the Philadelphia trials of 1960.

2. Mergers and Acquisitions

The publication by the Department of Justice of a comprehensive set of guidelines[1] pertaining to mergers and acquisitions serves useful notice to all industries of the criteria by which the legality of such combinations is to be judged. These guidelines are meant to promote price competition, innovative rivalry, and efficient methods of production, as well as to facilitate business planning and decision-making. Their general thrust is to ensure competitive behavior by preserving or restoring structural conditions relating to numbers of firms, relative sizes of market shares, entry of new firms, and degrees of integration.

The ordinary presumption concerning horizontal mergers and acquisitions in highly concentrated industries is that they tend to exacerbate anti-competitive conditions and are therefore against the public interest. The only general exception is for a company that is failing and is consequently not likely to remain an independent competitor in any event. The application of these criteria would mean, for example, that an NSSS manufacturer would have to be in failing condition before it would be permitted to acquire or be acquired by a firm operating in one of its markets. The fact that an acquisition would make a company a stronger, more viable competitor would generally not be reason enough to permit the increase in concentration inherent in the acquisition. However, it may be appropriate to consider whether a merger of two marginal firms in a market dominated by one or two giants might not better serve to increase effective competition than would an attempt to maintain lower concentration in the immediate short-run. The availability of other means such as "guidance policies" discussed later to strengthen the marginal companies may be relevant in reaching a decision.

1. *Merger Guidelines* released by the U. S. Department of Justice on May 30, 1968.

The rule with respect to purely vertical mergers can be somewhat more permissive because such integration does not itself directly increase market concentration. The following are important factors to be taken into account in determining the reasonableness of such integration: [1]

a. The effect upon non-integrated firms in the two markets involved;

b. The relative strength and degree of vertical integration of rivals;

c. The viability of each of the companies in the absence of the integration;

d. The degree of concentration in each of the markets involved;

e. The degree to which demonstrable technological and economic advantages exist for the integrated company.

Restricting vertical merger or acquisition may have the effect of reducing concentration in a market by prompting a new entry through internal expansion. Successful entry by means of internal growth that does not force another firm in the industry out of business will have this favorable effect. When, however, vertical integration promises significant technological or economic advantages, and cannot be achieved by merger, it is likely to be pursued by means of internal expansion. Firms realizing such efficiencies via internal expansion are likely to gain significant market advantages which their rivals, probably by similar means, must eventually seek to attain. This process confronts potential entrants with higher entry barriers but because of the general technological or economic benefits would not usually be against public policy for this reason alone.

Since nuclear and fossil fueled plants are competitive means for generating electric power in some parts of the country, a merger of a supplier of one type of equipment or fuel with a supplier of another type could reduce competition. The following factors are relevant in determining whether a merger between such companies is likely to be anti-competitive and consequently against the public interest:

a. *Industry concentration and market shares of the merging companies.* Mergers in the fuel sector (except perhaps those involving the largest firms) would probably not violate the recently announced Department of Justice *Merger Guidelines*, since the oil-coal-gas-nuclear fuel industry is not highly concentrated, and many suppliers have small shares of the market. The situation would appear substantially different on the

1. See Department of Justice *Merger Guidelines,* op. cit.

equipment side, where there is a large overlap of a limited number of suppliers to the fossil and nuclear industries (GE, Westinghouse, B & W and CE) and only a few other significant competitors (e.g., Foster Wheeler and Riley Stoker).

b. *Effect upon competitors.* Even though a merger does not involve sufficiently large market shares to be barred on this account, it may still be anti-competitive if it confers upon a company the power to expand its market share significantly without relying on such acceptable competitive devices as greater efficiency or superior product. An example is a company that might be able to overwhelm its competition and monopolize a market because of its greater resources relative to competitors. On the other hand, if a merged company were likely to raise the level of competition (with regard to prices, innovation or terms of sale, for example) by more aggressive behavior without posing a threat of monopolization, the merger would have a strong factor in its favor.

3. Market Concentration and Vertical Integration

The maintenance of competition raises not only the possibility of blocking mergers and acquisitions but also of breaking up existing companies to create new competition in a given market segment. The remedy of dissolution may also be considered in extreme cases of vertical integration.

When an industry (or various industry segments) is so highly concentrated as virtually to preclude further mergers and acquisitions, whether horizontal or vertical, it does not automatically follow that dissolution (vertical or horizontal) is appropriate or that growth by internal expansion should be restricted. A number of conditions in addition to high concentration must be present before dissolution becomes an appropriate remedy:

a. *Company divisibility.* There must be the possibility of dividing into separate *viable* organizations a company's plant or plants and its personnel including engineers, R & D staff, and management.

b. *Economies of scale.* Potential business must be adequate for all companies in the industry to have a reasonable chance to realize substantial economies of scale.

c. *Capital requirements, diversification and market acceptance.* The viability of split-up companies in the nuclear power supply industry can depend on such matters as: (1) how well a relatively undiversified company can fare in an industry characterized by diversification; (2) how likely a new company with limited access to large amounts of

capital is to survive in a high capital, large risk business; and (3) how a new company without a market position can overcome strong buyer preferences for traditional, time-proven suppliers.

d. *Technical and economic factors.* Consideration should be given to the effects of vertical dissolution on such activities or factors as research and development, innovation, and control over product quality.

e. *Market concentration, maturity and entry conditions.* Other relevant factors for evaluating the appropriateness of dissolution are the degree of concentration, the likelihood of its persistence and the probability of new entry.

In summary, the logic of antitrust is to move away from situations in which a few large firms make up a highly concentrated and integrated market toward ones in which a large number of smaller firms present buyers with a wider range of alternatives. This logic does not automatically apply to already highly concentrated and integrated industries, but can be presumed to apply unless the breakup of concentration or the dissolution of integration would interfere significantly with the provision of socially desired output.

To reduce concentration or integration through dissolution without unduly reducing output capability requires that the firm be economically and technologically divisible into viable units. This condition is not easy to identify. At the borderline between indivisibility and divisibility and between non-viability and viability, there is a risk of impairing the provision of desired output from the industry on the one hand, or of tolerating monopolistic conditions and their exclusory effects on the other. In the case of the nuclear power supply industry, now a technologically immature oligopoly for the most part, it may be advisable to mount a close watch on the conduct of highly integrated firms while demand and scalar conditions evolve further. Guidance policies can continue to be used to help steer the industry along a suitable evolutionary path, with dissolution measures for the most part held in reserve. This does not imply any relaxation of concern for the control of tacit or overt collusive behavior or other unreasonably restrictive market practices. As emphasized earlier, in the face of inevitable high concentration such behavior and practices merit special vigil.

4. Market Entry Barriers; Anti-Competitive Distribution Practices

Various forms of government assistance can help to reduce or overcome barriers to market entry. The government may, on the one hand, virtually set up a new company, arranging initial business and protecting it by restricting competitors. The aluminum and rubber industries provide examples of new entry

prompted by government initiative. The government, on the other hand, may only make certain that a potential entrant faces no "unreasonable" obstacles in the form of inappropriate distribution practices among existing competitors. It may also act to prevent vertical integration from constituting such an unreasonable obstacle.

If the government were to consider setting up a new competitor, most of the considerations relating to dissolution policy would apply. There must be "economic room" in the industry, and success for the new company must not drive another company out of business.

A principal anti-competitive entry barrier is a tie-in sale obligating a purchaser to take two or more different products of a supplier in combination. A variation of this arrangement is a "requirements contract," obligating a purchaser to a particular supplier for a product beyond a single order.

Such practices need not be anti-competitive or unreasonable in all instances. In fact, most articles of commerce are a combination of products or materials that might be said to represent tie-in arrangements. Yet we do not expect all of these articles to be sold in their most divisible forms. Consequently at the outset there is a difficult problem of product definition. Nevertheless some criteria are available for distinguishing unreasonable tie-in arrangements from those that are not harmful or are technically or economically justified.

a. *Market alternatives.* The general presumption that tie-in or package sale arrangements (under appropriate product definitions) tend unreasonably to reduce competition may be negated if it can be shown that buyers have credible alternatives in respect to purchasing arrangements. For instance, this would exist in markets where particular products were available on reasonable terms in both divided and tied-in form. A possible example from the nuclear power supply industry is the current arrangements for sale of fuel. A buyer may have alternatives worthy of consideration varying from relying on a single supplier for virtually all fuel cycle services at one extreme, to contracting separately for each service at the other extreme.

b. *Technical complexities and relationships.* The degree to which various products or parts of a product are technically related is part of the general problem of product definition. In any event, it may be said that a high degree of technical complexity and relatedness is a factor that tends to support the reasonableness of a particular package sale. Two examples from the nuclear industry may clarify this point. On the one hand, although nuclear turbine-generators and nuclear steam supply

systems are both highly complex products, they are not integrally related from a technical standpoint. Designing one to fit the other is not a great problem. Consequently, there would seem to be little or no technical reason for the products to be sold together. On the other hand, nuclear steam supply systems and fuel cores, as well as being highly complex technically, are integrally related in design and performance. There is far more reason for these products at this time to be sold as a package than for NSSS and turbines, at least with respect to the initial core, which involves completing a workable design for the system. This integral relationship between the NSSS and fuel core may change through time; e.g., the relationship could be affected by the development of standardization that would permit the easy matching of fuel and nuclear steam supply systems.

c. *Interconnected performance.* Another factor that may be relevant when evaluating package-sale arrangements is the degree of difficulty involved in identifying the way in which separate parts contribute to the performance of an overall system. A possible example of this factor, which is associated with the matter of technical relatedness, may also be seen in the relationship between the NSSS and fuel cores. At this stage of experience with nuclear power reactors, there may be considerable difficulty in identifying the separate contributions of the NSSS and fuel core to overall system performance and consequently determining, for example, whether a case of substandard performance or a performance failure was the result of one component or the other. Another example of this difficulty may be seen in "foreign" fuel supplied by a different company from the one which supplied the original fuel. In event of substandard fuel performance, it may be difficult or impossible to ascertain whether the reload fuel or the original fuel remaining in the reactor is responsible. Accountability is important in respect to such matters as warranties and the performance evaluation by customers of their suppliers.

Dynamic aspects. In evaluating package-sale arrangements, attention must be given to the matter of change. On the one hand, the government should be vigorous in promoting healthy development in new and emerging situations before unsound patterns become established. On the other hand, the government may be well advised to move slowly in situations where the course of events seems consistent with the development of sound patterns. Although these alternative policy directions are not necessarily inconsistent, they may often pose a considerable dilemma for policy. Distribution practices for the NSSS and fuel cores

again provides a case in point. Although the sale of reload cores in association with the NSSS and initial core sale is clearly a restraint on competition in the fuel market, it is not clear at this time that this is an unreasonable restraint. Before plant construction, utilities have typically sought to arrange fossil fuel contracts covering the life of the plant in order to provide some assurance on fuel costs. The fact that at least some utilities do this for nuclear fuel may be sound for the competitive performance of the industry. On the other hand, if universally practiced, it may become an unreasonable restraint.

5. Price Discrimination

Because of differences in the strength of fossil competition in various geographical areas, the nuclear power equipment industry is confronted with an incentive to engage in geographical price discrimination; that is, to charge lower prices on nuclear plants and fuel where nuclear confronts strong competition from fossil power than in areas where such competition does not exist. In markets characterized by oligopoly (or less than perfectly competitive conditions) modest price discrimination is probably inevitable and can be a desirable market factor when differences are small and exert a downward pressure on prices. Some price differences among nuclear plants and fuel are especially likely if, as we have urged elsewhere, utilities exert their maximum bargaining strength in transactions with nuclear power equipment suppliers. When such bargaining occurs it would be highly unlikely that all prices would be identical. Some of these differences would no doubt occur among geographical regions. We should emphasize that we found no definitive evidence on this point in our research. Nevertheless, a program to maintain the best possible information on prices and product characteristics is desirable for purposes of minimizing discriminatory pricing and raising the possibility that lower prices in an area will exert a generally downward pressure on prices. Publicity and government-industry discussion of apparent price differences should be conducive to sound practice in this area.

F. APPLICATIONS OF GUIDANCE POLICIES

We have given the name "guidance policies" to that collection of tools which we believe can supplement and complement traditional antitrust measures in shaping the nuclear power supply industry along workably competitive lines with desirable performance characteristics. Guidance policies represent ways of steering, nudging and assisting an industry into desirable channels and keeping it on a course that serves national goals.

Use of this approach in matters of U. S. industrial organization is relatively new. Its application, which has seldom been attempted on a systematic basis, began in a number of pragmatic responses by public authorities to certain conditions or practices relating to industry structure and performance regarded as contrary to the public interest, but not amenable to successful treatment by established policy methods. Situations of this kind do not clearly violate any of the antitrust statutes, nor do they warrant the imposition of policies reserved for industries regarded as permanently inappropriate for regulation by competitive market forces. Nevertheless, they pose conditions incompatible with the results we identify with effective or workable competition.

The AEC has recognized the need for, and value of, a guidance type approach for the young and evolving nuclear power supply industry. They have looked upon the use of guidance measures as an appropriate part of a "preventive medicine" policy. The AEC generally has encouraged the development of a competitive industry through use of government contracting power and the dissemination of information[1]. Examples of specific AEC guidance-type programs include:

- Contracting with private companies and with different private companies through time for the operation of government facilities, e.g., the U-235 production plants at Paducah, Portsmouth and Oak Ridge, and the plutonium production and fuel recovery installations at Hanford and Savannah River;

- Contracting with private companies for experimental and demonstration projects; e.g., the Power Reactor Demonstration Program;

- Guaranteeing a certain amount of business to a private company; e.g., partial load guarantees for private reprocessors;

- Helping stabilize market demand in temporary periods of weakness; e.g., the stretch-out program for AEC uranium purchases; and

- Influencing utility purchasers to buy competitively by holding information discussions.

The "guidance approach" embraces two fairly distinct categories that are not easily compressed into a single caption, since they differ in terms of the legal obligations they impose. The two categories are:

1. For a discussion of some of the government programs see James T. Ramey, "Competitive Vigor in Nuclear Power," *Harvard Business Review,* July-August, 1968, pp. 126-142.

(1) Policies favoring government-business consultation and voluntary compliance;

(2) Policies designed primarily to attain objectives other than influencing industry structure or performance in desirable ways, but yet capable of such influence.

1. Government-Business Consultation and Cooperation

Broadly defined, this sub-set of guidance policies consists of the government's stating certain objectives in anticipation of voluntary compliance on the part of private business firms consistent with the attainment of the objectives. This approach to public issues has come into more extensive use in recent years than is often recognized. It includes, among other examples, the following:

- the wage-price guidelines announced in 1962 by President Kennedy;

- the non-compulsory crude oil import quotas the government worked out with domestic petroleum refiners in the mid-1950's;

- the modification of contracts between the major automobile manufacturers and their dealers, to the latter's advantage, through Congressional committee hearings in 1954;

- certain aspects of the current government program to reduce the outflow of gold and dollars abroad;

- the voicing of Presidential disapproval of the automobile price increases announced by Chrysler Corporation in September, 1968, and of Presidential approval of the smaller price increases announced by General Motors and Ford;

- the Federal Government's urging of private businesses to train more of the hard-core unemployed for productive jobs;

- the confrontation between several recent administrations and the steel industry over steel capacity, prices and imports; and

- the public airing, through Senate Committee hearings, of ethical drug profits, prices and trade practices.

While these diverse actions by public authority appear to be disconnected pragmatic responses to various problems, they all have one important feature in common: in each instance the public action has arisen from the inapplicability, the inadequacy, or the inappropriateness of specific antitrust and other laws for dealing with a particular economic problem that urgently needed correction in the view of the public authority concerned.

The following detailed identification of the "voluntary" or cooperative aspect of the guidance approach is presented because it appears to be particularly appropriate for the nuclear power supply industry. Since the industry is entering what is often termed a "take-off" stage, the particular structural and behavioral conditions that now obtain in certain of its segments are not necessarily indicative of long-run equilibrium conditions. For example, in some of these segments the number of present competitors is, by conventional structural standards, insufficient for competitive performance. The small number of effective competitors and dangers to the survival of the weakest may be attributed to economic and technological constraints that may diminish as the industry grows; but, on the other hand, there is no assurance that this will be the case.

Furthermore, the optimum structure for the industry from the standpoint of the public interest is far from clear at this early stage in the industry's development. In such circumstances the likelihood of making serious errors in moving the industry in one direction or another is greatly reduced by making small, *ad hoc*, incremental policy moves that do not run the risk of being pre-emptive or irreversible or seriously de-motivating. The guidance approach lends itself to gradual adaptation as more is learned about the industry and about arrangements that reflect preferences of the marketplace.

A further reason supporting the guidance approach is the absence of good analytical tools for relating market structure and performance, a situation that is further complicated for the nuclear supply industry by the industry's early stage of development. Economists and lawyers in government know that it is a difficult matter to apply policy deduced from abstract equilibrium models to real world situations. As specialists in industrial organization they understand how tenuous the link is between observable market structure and observable market conduct.

These observations argue for policies that, proceeding incrementally and pragmatically, guide the industry into acceptable channels as it grows, develops, and matures, and its technological and commercial characteristics become clearer.

Although the nuclear energy program has, since its inception, moved more and more into the private sector – an important objective of the AEC – many strong and special ties have existed and still exist between the industry and the

government. By virtue of the many points at which its authority touches all nuclear activity, the government has a favorable strategic location for continuing to affect the nuclear power supply industry's future development as it has in the past. Nuclear technology is a product of public and private research efforts. The standards of safety employed in plant construction and operations and in waste disposal systems are "affected with a public interest." The government is involved in the purchasing of uranium for national security and has been the exclusive operator of enrichment plants. The customers of those who build nuclear plants are publicly regulated utility companies, licensed by the Atomic Energy Commission to operate nuclear power plants. The government has encouraged and facilitated the entry of additional companies into the industry, and has helped to keep them there in the interests of vigorous competition. The AEC has provided incentives to private enterprise to take over some functions previously exercised by government.

In sum, a special relationship between government and business in the nuclear field exists. This relationship continues both to justify and to provide the channels for a policy of public guidance and voluntary compliance. This kind of guidance bears some resemblance to the advisory opinions that some judicial and quasi-judicial bodies deliver to help businesses evaluate the implications of some of the options open to them. Such advice can be applied in advance of actions that might otherwise have to be modified or nullified. The purpose is not to second-guess management nor to pre-empt the rights of managers, but to encourage and help managers to avoid courses of action likely to lead to results that are not in the public interest. Of considerable importance in new and emerging industrial situations is the fact that this somewhat improvised policy approach can proceed incrementally, meeting temporary and transitional needs, incorporating new information, accommodating a broad range of new and different developments, and reserving generalization until it is appropriate, without having to stand still while conditions may deteriorate.

We do not consider it within the scope of this assignment to identify in detail all the policies that relate to the entire range of government-business interfaces, or to prescribe such policies. However, we do identify three lines of action that appear to be especially promising as ways of guiding the nuclear power supply industry toward a more competitive performance structure:

a. *Government can assist in the generation and dissemination of information that will improve the bargaining position of public utilities in dealing with nuclear plant suppliers.*

The theory behind this approach is that a well informed customer is in a better position to bargain with suppliers than is a poorly informed one. The government has a variety of means at its disposal to improve the amount and quality of technical and economic information that might flow to the utilities.

The government is itself a primary collector, compiler, and publisher of information. The annual report of the AEC Division of Industrial Participation and the large amounts of information maintained by the Raw Materials Division on uranium exploration, drilling and mining are examples of continuing information programs. Another area in which more complete, or at least well organized, information on a continuing basis might be constructive relates to the terms and conditions of power plant contract awards. The proprietary nature of this general type of information poses an obstacle, but more complete information than is currently available seems possible without interfering with the protection traditionally accorded private information in the U. S. Voluntary programs and government utilities represent two possible approaches to fuller information in the area.

The government is a frequent sponsor, promoter or undertaker of studies. It can order and finance a study by independent persons or groups. It can prompt private groups to undertake studies on matters of mutual interest to government and industry. It can undertake research projects through its own staff. Types of technical and economic information that may be useful are many and varied – manufacturing methods and costs, R & D activities and results, nuclear power plant design, cost and operating information, and so on. The AEC, Edison Electric Institute, Atomic Industrial Forum, the American Public Power Association, and various private companies have undertaken in the past technical studies covering such areas. An example of such a study is the report "Current Status and Future Economic Potential of Light Water Reactors" (WASH 1082), sponsored by the AEC.

These suggested ways of injecting useful information into the marketplace are difficult to reduce to a set of specific actions having general applicability. An example that illustrates the potential usefulness of the approach may be seen in a government program of the early 1930's to introduce highly concentrated phosphates for fertilizer production. Through research and information dissemination to manufacturers and buyers the government eventually overcame large obstacles confronting the program and achieved spectacular success.[1]

1. This is documented in Jesse W. Markham's *The Fertilizer Industry: Study of an Imperfect Market,* Vanderbilt University, Nashville, 1958.

   In the early 1930's the TVA undertook extensive research in highly concentrated phosphates for fertilizer production. Through its chemical, engineering, and argonomic research, it demonstrated that highly concentrated phosphatic materials were, for most parts of the country, far more economical sources of P_2O_5 than the ordinary superphosphates in general use in American agriculture; but the market did not bring about the substitution of the more efficient for the less efficient sources of P_2O_5 because American farmers were bound to the latter by custom. Because farmers did not demand them, commercial fertilizer manufacturers would not produce them.

   TVA and other governmental agencies concerned with agriculture broke down this barrier to efficient resource allocation by employing what we call guidance policy. They sponsored information programs explaining why P_2O_5 was less costly in highly concentrated phosphatic materials. TVA offered financial incentives to farmers to use the more concentrated materials, and to farmer cooperatives, and later to commercial distributors, to make them available to farmers. TVA made its technology and production know-how freely available to all chemical and fertilizer manufacturers that demonstrated a serious intent to enter the concentrated superphosphate business. These efforts created both a demand for, and a supply of, more efficient sources of P_2O_5. Between 1950 and 1963 the sale of P_2O_5 in ordinary superphosphate declined from 2.6 million tons to 1.2 million tons, while the sale of P_2O_5 in concentrated superphosphate increased from 315,600 tons to 1.1 million tons.

b. *Utility commissions, in their rate-making proceedings can pay more explicit attention to the question of how public utilities economize in plant procurement.*

In the discussion that follows we do not imply that most utility commissions do not already inquire into the capital purchasing procedures of utilities, but we suggest that a full awareness of the complex matter of the incentives of utilities could lead to a more effective use of the existing powers of utility commissions. No new powers are needed to ascertain the reasonableness of the efforts of utilities to obtain their nuclear (or fossil) plants at prices as competitive as possible.[1]

The matter of incentives is a complex one because forces of rate base maximization and of cost minimization can bear on the purchasing decisions of utilities and because conventions of joint cost accounting can obscure "true" maxima and minima.

Recent analysis of public utility operations suggests that the rate-making process can deprive the utility of some of the normal incentive to minimize its plant costs.[2] The argument, stated in its simplest terms, is as follows: a utility obtains rates before public commissions that allow it a given rate of return (R) on its rate base. At the same time it incurs a cost of capital (C) approximately equal to the class A bond rate. When R is greater than C, the utility has an incentive to *increase* its rate base. Since the rate base is measured in financial units, this increase can come about by substituting (sometimes uneconomically) capital for labor, or even by *not* obtaining plant at the lowest possible cost. The utility, therefore, may not bargain as hard as it otherwise might over the price for its nuclear plant.

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1. An example of how the Federal Power Commission might, under its existing authority, promulgate a rule favoring more competitive behavior, appears in the *Wall Street Journal* for September 16, 1968, p. 4, col. 4. "The proposed rule would let (electric and gas pipeline) companies choose from three methods of competitive procurement (for construction and service contracts) so long as the result is 'widespread public notification' to possible suppliers of major purchases...The companies would have to tell unsuccessful bidders why their proposals weren't accepted...A further provision would require a company to make available to the FPC a 'comprehensive statement' of its current procurement policies and practices...The FPC would review selections (of bids) only during its periodic audits of company books, 'at which point clear abuses of managerial discretion, if any, can be dealt with'." For the proposed rule see the Federal Register, September 19, 1968 (33FR14173).

2. See Averch and Johnson, "Behavior of the Firm Under Regulatory Constraint," American Economic Review, Vol. 52, No. 5, pp. 1052-1069 (1962) and F. Westfield, "Regulation and Conspiracy," *The American Economic Review,* Vol. LV, No. 3, pp. 424-443 (June 1965).

On the other hand, there are incentives for minimizing capital costs. Utilities may generally feel constrained by certain "yardstick" criteria by which rates and costs are judged. Capital projects are admitted to the rate base considerably after costs are incurred which would tend to penalize a utility that "overbought." Finally, utilities are generally interested in growth (for instance, to maximize the value of their equity in the marketplace), which is an incentive for keeping power rates low to attract additional load.

c. *The Department of Justice may use various business review or guideline-type procedures to promote the sound development of the nuclear power supply industry.*

The *Merger Guidelines* outlining Department of Justice policy criteria on mergers and acquisitions are relevant to the nuclear power supply industry and provide the government with a significant instrument for influencing behavior in the industry. Certain features of the industry that have been described (e.g., the high degree of concentration already present, product and demand characteristics of the market, the special government role in the development of the industry, and the regulated power market) suggest that a more-than-usual number of antitrust policy questions are likely to arise for which the general merger guidelines do not provide pertinent and satisfactory answers. Two possible policy approaches that might deserve emphasis under the circumstances are:

(1) *Special guidelines* – These would be issued in supplement of the general merger guidelines to cover situations of special concern in the nuclear power supply industry; for instance, possible cases of vertical integration by internal expansion that might be harmful to competition and not technically justified. Such guidelines could be made dependent upon an informal process of AEC, Department of Justice and business study and consultation with a view toward obtaining the greatest possible precision, understanding and acceptance for the results.

(2) *Business review procedures* – A more easily implemented method of covering areas of possible policy uncertainty is consultation between government and business (in this approach, generally a single company) on a case-by-case basis. On the one hand, the government may want to use such meetings only to clarify what it understands a law to mean and when it proposes to take action. An extension of this approach, possibly of special value with respect to the nuclear power supply industry because of the many uncertainties at this early stage in its development, would be for the government to use the process of consultation on a case-by-case basis to develop its policy positions as well as to make them known.

2. Coordination of Other Policies Affecting the Competitiveness of the Nuclear Power Supply Industry

In addition to the various voluntary-cooperative elements of guidance policy just described, there are other public policies which, though designed for other purposes, can provide leverage on the competitiveness of the nuclear power supply industry. When these policies are being used primarily for the purposes for which they were designed, they should be administered with full cognizance of their potential impact on market structure and performance; and when they are being applied to influence competition, their other effects must obviously be considered at the same time. Such policy applications therefore invariably call for trade-off analysis.

Examples of policies that were developed for purposes other than stimulating and maintaining competition, but can also be used for that purpose, are as follows:

- Allocation of government *R & D* funds to improve the competitive structure of the industry, or to avoid injury to competition, whenever the costs of doing so are not excessive.

- Contracting with *private companies* for the operation of government facilities to broaden private sector experience in the nuclear area and facilitate new entry.

- Administration of government *procurement* so as to enhance the survival and continued viability prospects of smaller firms.

- Adjustment of *import* restrictions and *export* incentives to enlarge markets.

- Modification of *depletion allowance* on uranium or method of calculating the depletion allowance to improve the market effects.[1]

- Administration of the uranium *stockpile* to compensate for unwanted market effects.

- Allocation and timing of government *orders* and other government activities in ways that might help to smooth out present cyclical fluctuations in utility nuclear placements.

1. There are, as this study shows, forces (e.g., transportation costs) making for the vertical integration of uranium mining and the milling of yellow cake. Even if these forces did not exist, the calculation of depletion allowances in terms of value of yellow cake now assures widespread vertical integration between mining and milling.

The list is not exhaustive because our purpose here is not to recommend but to elucidate. This purpose can perhaps be served by enlarging on the one or two examples.

a. Research and Development Contracts

From its inception the nuclear power supply industry has been strongly influenced by both public and private investment in research and development. The way such investments are made in the future will affect not only the rate of technological progress but the pattern of competition in the industry.

The optimum distribution of public R & D funds requires a careful balancing of short-run and long-run objectives. It can be reasonably expected that, at least in the short-run, the productivity of R & D dollars is highest in large technologically-based firms with demonstrated scientific capabilities. However, it must be borne in mind that these are also the firms most able and likely to allocate their own funds to promising R & D projects. Accordingly, especially after the initial impetus has been provided by government contracts, a continuing concentration of government R & D funds in such firms may simply result in their being substituted for internally financed R & D. When this substitution occurs on a significant scale, the awarding of most R & D contracts to the largest firms with demonstrated capabilities may reduce even the short-run productivity of government R & D policy.

Even when it is true that large firms with established R & D capabilities can produce more output from a given amount of R & D funds than small, untried companies, it does not necessarily follow that the allocation of funds exclusively to the large firms favors long-run R & D productivity. There is a strong presumption that technological competition among firms is itself an important source of technological progress, and that, at least up to a point, this competition increases as the number of firms grows larger. Hence, in the interests of maximizing the productivity of R & D funds in the long-run, the government may well consider awarding certain R & D contracts to smaller, less established firms. The lower probability that they will be immediately productive may be more than offset by the likelihood of their stimulating greater technological competition if they become viable entities in the nuclear power industry.

Such choices by government must be made under a high order of uncertainty in any case, since the nuclear industry is relatively new, and its technology far from stable or mature. Research and development is, by definition, attended by a high order of uncertainty. In these circumstances some sacrifice of *estimated* short-run productivity for an *estimated* increase in productivity and technological progress in the long-run is a policy worthy of consideration.

b. International Trade Policy

At the present time, various policy tools under the heading of international trade policy are being used with a view to mitigating a persistent imbalance in the U. S. balance of payments. Keeping the importance of this basic objective in mind, there may still be some latitude (and later on perhaps more scope) for the use of trade policy for the added purpose of maintaining competitive vigor in the nuclear power supply industry. In some nations, those in which the thinness of the nuclear market and the fewness of viable suppliers is even more pronounced than in the U. S., a calculated exposure to international competition has been the chosen device for securing domestic market discipline and stimulation. In specific circumstances the U. S. may wish to "broaden the market" in a comparable way by adjusting various import restrictions. If levels of concentration should rise in the U. S. due to the elimination of weaker firms or to a deliberate policy in pursuit of economies of scale, some of the effects of such increased concentration might be offset by making our domestic market more accessible to foreign firms.

Export promotion can also under some circumstances favorably affect competition. Expansion of markets by export development can help overcome undue restrictions on numbers of firms posed by economies of scale. Maintenance of leadership in nuclear power technology keeps the United States in a strong position for expanding nuclear exports not only to the possible improvement of competitive conditions in the nuclear industry but also to improve the nation's balance of payments.

c. Cyclical Smoothing Policy

The viability of some competitors can be adversely affected by limits to their ability to ride out "troughs" in the cyclical pattern of industry demand. To the degree that such cycles can be smoothed, firms that might otherwise quit or decline to enter an industry may be added to bolster the number of competitors. Administration of government uranium stockpiles, government procurement policy (especially for government owned power plants and their fuel) and timing of R & D contracts are examples of government devices that can possibly provide some leverage on damaging market fluctuations.

G. A NOTE ON THE ADL APPROACH TO POLICY IMPLICATIONS

It is neither proper nor possible for us to anticipate how, when and where each of the many elements of combined antitrust and guidance policies should be used. We have sought to show the need for such a complementary set of policies if the Atomic Energy Commission and the Department of Justice are to deal effectively with the special characteristics of the nuclear supply industry. We have also

indicated the range of such policies, some of the problem areas to which they can be usefully applied, and some of the trade-off implications arising from their application.

We have deliberately avoided making specific policy recommendations, confining our comments to the appropriateness of certain concepts of regulation, certain economic issues, certain classes of remedies, certain ramifications of policy measures, and certain opportunities and constraints facing policy-makers. When the facts of specific cases and the constitutional authority of certain officials are added to this policy framework, specific policy decisions can be made by the government with greater facility.

PART TWO

I. INTRODUCTION

A. BACKGROUND OF THE STUDY

Two fundamental policies of the Atomic Energy Act are that (subject to the paramount objective of national defense and security) the development, use and control of atomic energy be directed (1) so as "to make the maximum contribution to the general welfare" and (2) "to strengthen free competition in private enterprise."[1]

The Atomic Energy Commission in the performance of its developmental activities; in the establishment of policies governing the furnishing of services to the public; and in the execution of its regulatory responsibilities under the Atomic Energy Act performs functions that have a profound effect upon the competitive status of the nuclear power supply industry.

Moreover, it is clear from another provision of the Act – notably Section 105 – that the Atomic Energy Commission is to carry out its responsibilities in a manner consistent with the antitrust laws and with the Department of Justice's administration of those laws. A specific provision in Section 105 (b) calls upon the Commission to report promptly to the Attorney General any information it may have concerning apparent violations, or apparent tendencies toward violations, of the antitrust laws in any utilization of special nuclear materials or atomic energy.

To assist the Atomic Energy Commission and the Department of Justice in fulfilling their responsibilities relating to the encouragement of desirable patterns of growth in the rapidly expanding nuclear industry, the two agencies decided in May 1967 to initiate this study to produce up-to-date, accurate and comprehensive data on, and analysis of, the economic structure, conduct, and performance of the nuclear power supply industry.

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1. The Atomic Energy Act of 1954,"Chapter 1, Section 1. Declaration–Atomic energy is capable of application for peaceful as well as military purposes. It is therefore declared to be the policy of the United States that–

> "a. the development, use, and control of atomic energy shall be directed so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security; and
> "b. the development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise."

B. APPROACH

The Atomic Energy Commission–Department of Justice prepared a detailed tentative outline of the study, which served as a valuable basis for our initial discussions with the AEC and DOJ about the study and for planning the approach that was finally adopted.

At the outset we organized, under a project director and a project manager, a multidisciplinary team of twelve professional men skilled in such areas as nuclear engineering, electrical engineering, chemical engineering, metallurgy, market research, business research, economics, and legal aspects of antitrust. In addition, we arranged to utilize as special consultants Professor Manson Benedict of the Massachusetts Institute of Technology, for advice on nuclear technology; Professor Jesse Markham of Princeton University, for advice on antitrust policy issues; and NUS Corporation on certain aspects of fuel cycle and reactor technology and costs. Also, we established close liaison with the Atomic Energy Commission and the Department of Justice in order to keep both agencies informed of our progress, and to obtain information and guidance on key issues.

An overall plan of attack was formulated (see Figure I-1), which included three major phases:

Phase I. Data Acquisition

Carry out literature studies and in-depth field interviews to gain an understanding of all phases of operation of the nuclear power supply industry (reactor system and warranties, reactor vessels, reactor components, containment, architect-engineer-constructors, uranium mining and milling, conversion, fuel element fabrication, zirconium tubing, reprocessing, health, safety and licensing, breeders, etc.)

Undertake field interviews of the customers as represented by the public and private utilities and their agents (such as architect-engineer-constructors) to acquire an understanding of present and future methods of purchasing nuclear power systems and fuel. In order to obtain certain types of information and maintain the confidential nature thereof, arrangements were made to obtain appropriate release letters from the Government and the major reactor systems and core suppliers.

Construct a flow diagram of the nuclear power supply industry and formulate a list of suppliers within each component segment.

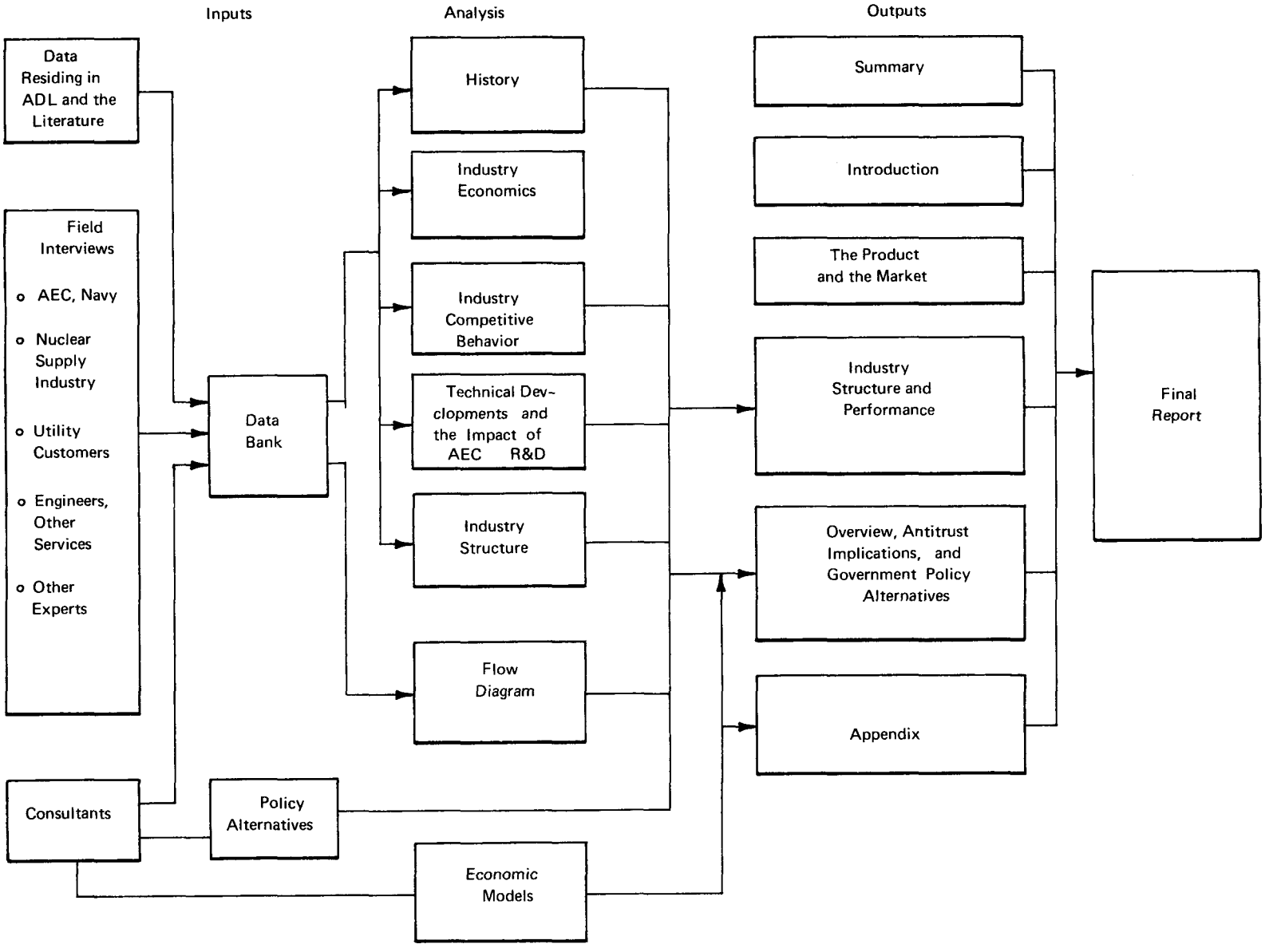


FIGURE I–1 CONCEPTUAL DESIGN OF THE STUDY

Obtain information on the history of the development of the nuclear power industry from the Atomic Energy Commission and industry.

Identify the major competitive issues and the policy alternatives available to the Atomic Energy Commission and the Department of Justice.

Organize the information in a data bank through the coordinating efforts of a core group of six men, including the Project Director and Project Manager.

Phase II. Analysis

Analyze the data gathered in Phase I from the standpoints of (1) the structure of the nuclear power supply industry, (2) the competitive behavior of the industry, (3) the economics of the industry, (4) technological developments, and (5) the formulation of an analytic framework.

Conduct further follow-up field interviews as may be necessary.

Analyze the major competitive implications and the policy alternatives open to the government.

Phase III. Reporting

Preparation of a draft report for comprehensive review by government and industry, and writing the final report.

II. HISTORICAL SUMMARY OF MAJOR TECHNOLOGICAL AND INSTITUTIONAL DEVELOPMENTS

A. INTRODUCTION

Any brief overview of the development of the nuclear power supply industry must begin with the formation of the U.S. Atomic Energy Commission on August 1, 1946. While the ultimate achievement of commercial power production from nuclear reactors seemed fairly obvious to many as a result of the nuclear developments made during World War II, many obstacles were to arise, and unforeseen amounts of money had to be expended.[1,2,3,4]

For the nuclear industry to grow so rapidly to reach a present volume of over $1 billion per year, many important events had to take place over the past 20 years. These events occurred particularly in three areas: policy and institutional developments, research and development programs on the part of both government and industry, and reactor development milestones.

For the period 1946 to the present we have collected from the literature and field interviews with representatives of AEC, professional society, university, and industry groups information on the more important events bearing upon the development of the thermal nuclear power supply system industry. (Breeder development will be discussed in a later section of this report.) These events were then arranged in a time series and recorded on Figure II-1. While not intended to be a complete record, the figure does provide an overall chronological history which can, with the assistance of the caption provided, be read and understood rapidly.

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1. "Man Harnesses the Atom," by Richard G. Hewlett, Historian USAEC *Technology in Western Civilization* Vol II, edited by M. Kranzberg and C.W. Purcell, Jr., University of Wisconsin, 1967.

2. *Industry and the Atomic Energy Commission,* by Richard G. Hewlett, Society for the History of Technology and Organization of American Historians, April 27, 1967.

3. *Nuclear Power, U.S.A.,* by Walter H. Zinn, Frank K. Pittman, and John F. Hogerton, McGraw-Hill, 1964.

4. "The Arrival of Nuclear Power," by John F. Hogerton, *Scientific American,* February 1968.

HISTORY OF THERMAL NUCLEAR POWER REACTOR DEVELOPMENT

Figure II-1 depicts the cumulative government and industry investment and the major chronological events in bringing about the growth of the thermal nuclear power supply industry. (Breeders are considered separately in a later section of this report .)

A brief explanation of various aspects of the figure follows.

- *Policy and Institutional Developments.* In the early days of the AEC it will be noted that the absence of international atomic energy controls, the Cold War situation, secrecy, and other problems slowed the formulation of a civilian power program. It was not until the Thomas proposal of 1950, the feasibility studies of 1952, the Eisenhower proposal of 1953, and the change in the Atomic Energy Act in 1954 that an aggressive civilian power program was developed. And the breakthrough in achieving commercialization did not occur until industry assumed great risks in promoting in 1964 large-scale, low potential power cost nuclear plants on a turnkey basis. Private ownership of special nuclear materials was passed in 1964, and the first big year of nuclear plant orders came in 1966, twenty years after the formation of the AEC. The Joint Committee on Atomic Energy has played a key role in policy developments.

- *Research, Development and Facility Expenditures.* The cumulative expenditures by the AEC for the development of civilian thermal nuclear power reactors of about $1.9 billion is shown in Curve A. Included are research, development, facilities and equipment expenditures. The total is an absolute minimum figure as it allows for no "fallout" to the broad nuclear power supply industry from the far larger expenditures by the AEC on military reactor development; diffusion plant design, construction and operation; uranium raw material process and exploration development; conversion and reprocessing development; etc.

The estimated cumulative expenditures for research, development, facilities and equipment by industry of over $1 billion is shown in Curve B. This is also a minimum total figure as not all industrial corporations could be covered, nor are corporate losses necessarily included.

Note the time delay between these combined minimum expenditures of approximately $3 billion and the advent of substantial megawatts of nuclear power as indicated by the projections shown by the cross hatched area in Curve C.

- *Reactor Development Milestones.* Some key technical events leading to commercial nuclear power include the MTR pressurized water and heat transfer concepts (1948); zirconium metal development (1948); the slightly enriched light water concept (1950); the BWR concept (1952); overcoming metal fuel element problems by going to oxides (1957); the lessons learned from the Shippingport PWR (1957), Dresden (1960) and Yankee (1961); the initial designs of large size nuclear plants (1963); the HTGR concept (1966); and the tremendous improvements in power density and fuel burnup achieved from 1955 to 1967.

To make these discoveries possible large numbers of scientists and engineers had to be trained in the many disciplines involved in the nuclear industry. And vast amounts of money had to be spent on laboratory, testing, and manufacturing facilities and equipment.

It is the nature of research and development on large complex systems that expenditures of great magnitude are required to create the environment to bring about the seemingly few key discoveries that ultimately spell success.

Finally, both government and industry undertook great financial risks to design and build the first large-scale, commercially competitive plants that have brought about the coming of age of nuclear power (1966).

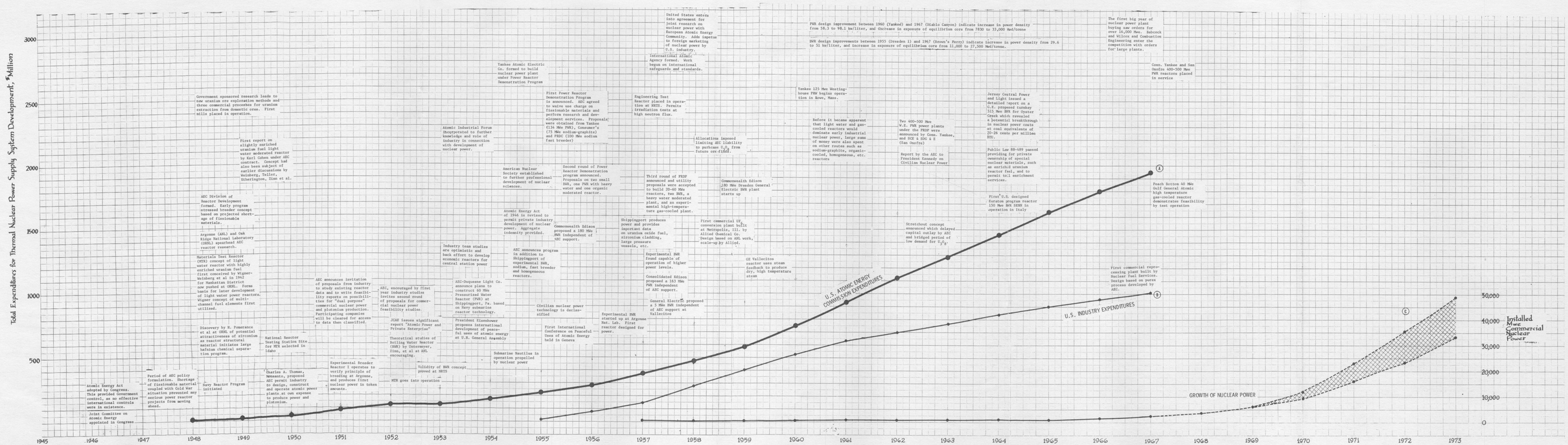


FIGURE II–1 HISTORY OF THERMAL NUCLEAR POWER REACTOR DEVELOPMENT

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B. MAJOR CONTRACTORS

Since a detailed study of USAEC contracting practices for research, development, and managerial services have been reported on by others, it is only necessary in this report to indicate a few points of major significance in this area as they apply to the growth of the nuclear power supply industry.

The most important point is that the Government decided, soon after the establishment of the Atomic Energy Commission, that rapid progress toward the development of nuclear power could best be achieved by careful selection of a few highly competent prime contractors to run major programs and installations. Such contractors offered the advantages of bringing into the program extensive scientific and engineering skills and background know-how, manufacturing facilities, and existing managerial capabilities that relieved the AEC of the necessity of staffing to handle myriads of administrative details. In addition, it was expected that these contractors would further contribute to the success of nuclear power by undertaking various developments at their own expense.

The major recipients of AEC prime contracts for the development of civilian nuclear power were Atomics International, Allis Chalmers, Babcock and Wilcox, Combustion Engineering, General Electric, Gulf General Atomic, United Nuclear, and Westinghouse. For two reasons it is difficult to determine in a meaningful way the extent of assistance received by each towards entry into the civilian power market. First, these same corporations also received large contracts for defense and space work in the nuclear field, such as the submarine propulsion, SNAP, and other programs. Second, typically 25–30% of prime contract funds find their way to subcontractors, and these same corporations were also major subcontractors. Thus it would be a lengthy undertaking to arrive at total contract dollar figures received by each. And, having done so, it would be almost impossible to determine the amount of knowledge and training so obtained that was directly applicable to the development of the numerous reactor concepts and components, out of which grew the present civilian nuclear power industry.

However, three things can be concluded from the investigation we carried out. First, through its careful selection of qualified contractors (carrying foward a tradition set by The Manhattan Project), the AEC heavily influenced not only the participants in, but the rapid progress of, the nuclear industry. Second, all the present major nuclear steam system suppliers received valuable experience through government contracts amounting to many, many millions of dollars. And, third, each of the successful entrants in the field also invested at least $60 million of its own corporate funds in order to acquire the capability of a qualified NSSS supplier.

C. SHIPPINGPORT

Much of the early work on light water reactors was directed at developing a submarine propulsion system. This high priority military program, which was initiated in 1948 and achieved remarkable success with the operation of the *Nautilus* in 1954, had an important influence on the later development of central station nuclear power. The program not only furnished the driving force for early reactor research and development, but also trained people and provided industry with valuable experience in the rigorous quality control environment of the nuclear age. Thus, it was not surprising that the first response to President Eisenhower's call in 1954 for peaceful atomic development was the establishment of the AEC Shippingport Project in which Vice Admiral H.G. Rickover, of *Nautilus* fame, was requested to head a power demonstration program to provide 60,000 kilowatts for the Pittsburgh area by the end of 1957. Westinghouse, which, along with General Electric, had been instrumental in the submarine reactor work, designed the pressurized water type reactor, and the Duquesne Light Company cooperated by supplying the generating facilities.

The main purpose of the Shippingport Project was to advance the technology of light water reactors. As the first nuclear plant in power supply service, Shippingport has been given credit by the Ad Hoc Committee to Evaluate the Shippingport Project[1] for the following contributions:

> "In fuels, the advancement of UO_2 and pellet technology; in physics and fuel economics, the development of the seed and blanket concept; in materials, the development of zirconium alloys. Other significant contributions are: in large reactor core design the development of data on heat transfer both within the fuel elements and from them to water; in mathematical analysis, the development of an extensive coding program involving many aspects of nuclear calculations; in components, the development and the bringing to successful conclusion of a program for the design and construction of large canned motor pumps. All of these constitute in totality an impressive list of research and developmental results and contributions to the pressurized water and the general civilian atomic power program. It is true that not all of these ideas originated with the Shippingport project, but all of them eventually found employment in PWR-1 where they were carried further than was elsewhere the case.
>
> "The achievements of Shippingport and its contributions as a prototype plant are in perhaps a different category. In many cases the contributions arose principally from the fact that Shippingport was the first large civilian power reactor. It therefore had the advantages and disadvantages associated with that

1. 1960 Hearings Joint Committee on Atomic Energy, 86th U.S. Congress.

circumstance. The project developed initial contact with manufacturers and fabricators. It worked out initial problems of safety of equipment with safety code agencies and health authorities. It also worked out health safety problems with such agencies. It developed design and specification standards on welds, valves, and other similar components. It worked out details in connection with the handling of radioactive wastes and their decontamination or general cleaning up when that was possible."

D. TECHNICAL MANPOWER

Obviously, the nuclear power supply industry could not reach a viable size until a sufficient number of scientists and engineers were educated and trained to perform the extensive multidisciplinary research, development, design, engineering and test work required to evolve nuclear reactor systems capable of producing power at prices competitive with fossil fuel plants. This process required time. For example, only about 6 universities offered nuclear engineering training prior to 1953, as compared to about 21 today. The AEC laboratories and the Navy reactor program played key roles in providing educational and training services in all phases of reactor technology. It was not until 1954 that the American Nuclear Society was established to provide a discussion forum for the many different professional disciplines required to make possible a nuclear industry.

While accurate manpower figures are difficult to obtain, we estimate from U.S. Department of Labor, AEC and Atomic Industrial Forum data that it required ten years for employment of scientists and engineers in the nuclear power reactor field to grow from about 1600 in 1956 to slightly over 5000 in 1966, the first year of substantial reactor orders. At the same time, the membership of U.S. industry representatives in the American Nuclear Society sections dealing with various aspects of nuclear reactor physics and engineering – who might be considered the cadre of industry professionals most capable of contributing to reactor design and specifications – grew from the small founding nucleus to approximately 2000 members.

E. THE BREAKTHROUGH TO COMMERCIALIZATION

Preliminary to the commercialization of nuclear power two stages of development occurred.

First, there was an experimental or demonstration plant stage from about 1953–63 that saw the 60 Mwe (Westinghouse Bettis PWR) Shippingport-Duquesne Light Company and the Yankee Atomic Electric Company 125 Mwe (Westinghouse PWR) reactors built under the AEC Power Reactor Demonstration

Program, and the Commonwealth Edison Company Dresden I 180 Mwe (General Electric BWR) and Consolidated Edison Company Indian Point No. 1 265 Mwe (Babcock and Wilcox PWR) reactors built with private funds. Then, two large plants were announced in 1963 under the PRDP, Connecticut Yankee and San Onofre, both 400-500 Mwe (Westinghouse PWR).

Second, it became apparent to General Electric that one route to achieving more rapid acceptance of nuclear power by the utiliities would be to design a large enough plant to achieve real economies, and to offer to sell such a plant on a fixed price, turnkey basis. This turnkey plan was carried out with the Jersey Central Power and Light Company Oyster Creek reactor. In February 1964 Jersey Central issued a report indicating that the proposed 515–620 Mwe BWR was expected to produce power competitively, under its particular contractual circumstances, with coal at 20-26 cents per million Btu's. This move entailed risk on the part of General Electric of a magnitude few companies could afford. But it represented a real breakthrough in projected nuclear power costs and, even though others issued somewhat more conservative cost estimates for Oyster Creek, the real impetus was forged for the sale of nuclear power in many parts of the world. Only a few other turnkey plants by General Electric and Westinghouse were needed to establish the nuclear power market before it was possible to revert to more conventional methods of selling central station power plants. (Incidentally, the same risk taking, turnkey route will probably have to be utilized by Gulf General Atomic in order to promote the sale of the first large HTGR type reactor to the utility industry.)

The third stage, the first big year of reactor orders, occurred in 1966. Over 16,000 Mwe of utility orders were placed, including the first receipt of large scale reactor orders by Combustion Engineering and Babcock and Wilcox. Through March 31, 1968 orders for commercial size units representing about 53,000 Mwe have been received by the four companies, as shown in Table II-1.

TABLE II-1

COMMERCIAL SIZE REACTOR ORDERS
(as of March 31,1968)

	No. of Units	Mwe
General Electric	31	22,409
Westinghouse	27	18,915
Babcock and Wilcox	9	6,863
Combustion Engineering	7	5,175

In addition, Gulf General Atomics has entered the competition with the order for a High Temperature Gas-Cooled Reactor (HTGR) for central station power in Colorado.

To arrive at this point required a combined Government-industry investment of over $3 billion, at an absolute minimum, as already shown in Figure II-1. The industry risk investment of over $1 billion has led to substantial improvements in power density, fuel burn-up and other design features resulting in viable economic nuclear power costs, and to increased competition between the four major nuclear steam supply system manufacturers. Further evidence of competition within the industry are recent announcements of new manufacturing facility investments exceeding $400 million planned over the next five years.

F. SIMILARITIES WITH THE FOSSIL FUELED ELECTRIC POWER INDUSTRY

A brief study was made of certain aspects of the development of the fossil fueled electric power industry to determine whether lessons applicable to the nuclear industry might be learned from this history. While some similarities do exist, it is the general belief of the nuclear steam systems suppliers most familiar with the fossil boiler business that the technological and manufacturing complexities of the nuclear industry place it in a separate category. However, the following ways in which the two industries are related or similar are worth noting:

1. For many years there have been only four suppliers for fossil steam plants, just as there are currently four suppliers for nuclear systems. Two of these, Babcock and Wilcox, and Combustion Engineering, are in both the fossil and nuclear industries.

2. The combined market shares of the two leaders in the fossil business, Babcock and Wilcox, and Combustion Engineering, are 70-80% (see Table II-2). Similarly, in the nuclear business the two leaders, General Electric and Westinghouse, enjoy 70-80% of the market.

3. Market shares of the two leaders in fossil steam plants have changed back and forth over the years (Table II-2). While a detailed study of the causes for this was beyond the scope of our assignment, the suppliers believe that these swings have been caused more by pricing practices and particular utility preferences for a given supplier than by technological advances by an individual supplier.

4. The two domestic suppliers of turbine-generators to fossil power plants, General Electric and Westinghouse, also supply the nuclear industry.

TABLE II-2

PERCENT MARKET SHARE OF FOSSIL FUELED STEAM PLANTS[a]

Year	Babcock and Wilcox	Combustion Engineering	Foster Wheeler	Riley Stoker	Total Mwe 2 Years
1953	56.8	35.3	2.6	5.3	10,000
1953–1954	46.2	43.6	4.5	5.5	18,073
1954–1955	38.3	50.6	6.6	4.3	12,940
1955–1956	46.0	42.2	8.1	3.5	17,038
1956–1957	40.1	41.5	11.9	6.3	29,197
1957–1958	33.5	45.5	13.2	7.7	20,489
1958–1959	20.6	45.7	14.2	19.3	65,209
1959–1960	27.1	48.1	10.0	14.6	24,654
1960–1961	38.6	50.8	4.5	6.0	21,287
1961–1962	43.5	39.7	9.9	6.8	14,496
1962–1963	30.7	45.2	10.9	13.1	15,839
1963–1964	30.3	52.3	8.1	9.1	22,921
1964–1965	34.5	48.3	10.4	6.9	25,741
1965–1966	39.0	39.3	16.4	5.1	27,630
1966–1967	42.9	30.7	19.5	6.7	31,691
1967	43.5	26.9	18.7	10.7	16,603

a. These are two year moving averages to smooth out year end fluctuations

5. The four major current suppliers of nuclear steam supply systems are all well known to the utility buyers as a result of having established reputations as suppliers of steam generating and electrical equipment over the years to the fossil power industry. Thus they know the complexities of the utility industry, and they enjoy the confidence of that industry with respect to the quality of their products and willingness to warrantee the proper functioning of these products.

6. Many second tier suppliers to the fossil industry also supply the nuclear power industry.

7. Both the fossil and nuclear power systems suppliers have the same underlying growth pattern and the same regulated, multi-customer structure for products.

There are, however, basic differences in the two industries, which appear to outweigh the similarities. Among the more important are the following:

1. The technological complexities of the nuclear power supply industry far exceed those of the fossil industry. As already pointed out, massive government research and development contract support as well as large corporate research and engineering investments were needed to bring the business to a point where still further corporate risks, generally feasible only by such large companies as General Electric and Westinghouse, were required to launch the industry through means of turnkey, no near-term-profit contracts. Furthermore, the technological complexities are compounded by the AEC licensing procedures, and the requirements for specialized manufacturing facilities and techniques to meet the stringent quality assurance and safety programs of the nuclear industry. The nuclear industry is, indeed, at or near the top of our most research-based industries.

2. While the larger suppliers in both the fossil and nuclear fields are the generally recognized leaders in pioneering technological advances, the effect of this leadership on market share might prove to be different in the two industries. With the lower research and engineering overheads of the fossil industry, Foster Wheeler and Riley Stoker were able to survive in a cyclical market with only

4-6% of the business in certain years (see Table II-2). It is possible that this share would be inadequate in the nuclear industry with its faster pace and greater expected impact of technological innovation.

3. The traditional utility practices involving selective buying of fossil plant components appear less applicable to the more complex systems aspects currently presented by the nuclear industry. The need for more sophisticated buying on the part of the utilities is discussed elsewhere in this report. This need extends to fuel as well as to basic plant purchases. Whereas fossil fueled plants can be designed or modified to burn coal, oil, or gas of varied, standard specifications, nuclear fuels are more narrowly limited by reactor designs. Such matters as nuclear fuel warrantees, ore costs, fuel burn-up, fuel fabrication costs, reprocessing costs, etc. must all be considered in the purchase of nuclear fuels. The preferred methods of purchasing or leasing are still in a highly fluid state. In fact, the only important similarity is that for both fossil and nuclear fuel the utility buyer is in a position to exert pressure toward the development of multiple sources of supply.

III. NUCLEAR STEAM SUPPLY SYSTEMS

A. THE NUCLEAR PLANT

The construction of any large power generating station, fossil or nuclear, is a complex engineering task. The site is prepared, an architecturally intricate building is erected, large sophisticated machines such as turbine-generators are shipped in parts for on-site assembly, and this and other equipment is interconnected with hundreds of pipes, valves, and miles of electrical wiring. Perhaps one-third of the cost of either a fossil or nuclear generating station is incurred in construction work including materials and labor.

Many parts of a nuclear power station are made by sectors of industry that have little or no nuclear expertise. With certain exceptions such as the reactor pressure vessel and some key system components such as primary circulation pumps, the bulk of the components for a nuclear generating station are products traditionally supplied by the hydraulic and heat transfer industries for use in a wide range of industrial processes. A tank in one of the safety systems of a nuclear station will undoubtedly be custom fabricated to a size specified by the nuclear steam supply system designer – but it will likely be fabricated by a company regularly custom fabricating tanks of similar dimensions and weights for other industries.

Even for the more integrated nuclear steam supply system manufacturers a major if not the largest value added lies in the engineering and design of the system and the willingness to bear the risks that these design and specification activities entail.

Economies of scale[1] come more from repeated use of all or portions of previous design rather than tooling, and not, as in the case of reprocessing, from efficiencies from rapidly decreasing capital facility costs per unit of throughput.

Even the highly integrated NSSS manufacturers will have to compete more on their ability to economically engineer and warrant systems rather than on their ability to manufacture the parts at less cost than their competitors.

In addition to a need to shift the concept of building a nuclear steam supply system away from traditional views of product manufacturing toward a concept of a system consisting of engineering services or software, parts, subassemblies,

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1. Throughout this chapter we are talking about economies in the size of the supplier's business, rather than the economies of size occurring in the nuclear station itself.

and substantial general contracting, we have found it important to emphasize to those outside the nuclear industry the infancy of that industry and the economic and technical uncertainties that manufacturers and utilities continue to face. There is an unfortunate tendency to equate reported commitments for nuclear plants with production experience and to consider progress payment revenues as shipments of goods. The fact is that utilities and manufacturers committed themselves to the installation of nearly 60,000 Mwe of generating capacity (representing an investment of over $10 billion) at a time when the only available operating experience with nuclear plants was limited to installations which were, in some cases, only one-sixth the size of the plants being ordered and having technical performance considerably less strenuous than the plants being ordered. At the end of March 1968, only one-third of the nuclear plants committed were under construction and only a few of those were as much as 50% complete. To date, the supply industry has probably spent more money on design than it has on hardware. Thus, the economists' definition of the costs of production is obscured by a lack of cost experience and a production cycle that spans many years.

Finally, the commitment to and acceptance of significant technical extrapolations before directly applicable operating experience has been obtained give rise to an element of risk which must be borne by someone – the utility or the manufacturer. This cost can be described conceptually, not quantitatively. This is not to say that nuclear power stations will not ultimately perform or that the extrapolations are unsound, but rather that unforeseen engineering difficulties or decisions can raise the cost over initial estimates. Although most contracts contain escalation provisions, there is always the possibility that these provisions will not accurately reflect the future costs of building the system even if the design were not changed at all. Obviously, such uncertainties are more severe for the commitments made further into the future.

So a product definition already blurred by the significant content of software and the bits and pieces approach that is used to furnish the NSSS is further complicated by the key role of the warranty and the provisions which it contains. The warranty is an attempt to draw the division between risk borne by the utility and the risks borne by the designer of the nuclear steam supply system. Because the warranty attempts to apportion the real costs of technical and economic uncertainties surrounding a complex product, we believe the provisions of the warranty and terms of sale must be considered an integral part of the goods and services that constitute the article of commerce in nuclear steam supply systems. Since warranty terms differ greatly from project to project, the definition of the product that has been sold also varies considerably from project to project.

B. PRODUCT/MARKET DEFINITION

In discussing the sale and manufacture of nuclear steam supply systems, we are referring to the goods and services that flow from the sector labeled "Design and Manufacture of Nuclear Steam Supply Systems" in the Light Water Reactor Flow Diagram (see Figure III–1). We also include the fabrication of control rods and the manufacture of incore instrumentation; components which, because they are used in the first and succeeding reloads, are shown for purposes of the flow diagram and the computation model as being transferred directly to the utilities, not through the nuclear steam supply system sector.

This flow chart, which distinguishes second tier suppliers along traditional industry and product lines, does not break down the nuclear steam supply system into functional subsystems. General Electric illustrates such a breakdown in its Atomic Power Equipment Department handbook, showing the functional subsystems of a nuclear power plant and describing which of them are normally included in GE's NSSS scope of supply (see Figure III–2). Such a chart, applicable as of March 27, 1967 but subject to periodic revision, is reproduced as Figure III–2.[1] NSSS offerings of other vendors would be roughly similar in scope to the subsystems shown by General Electric in the dark double lines in Figure III–2, making allowances, of course, for the technical differences of a PWR. Variations among standard scopes of supply of the NSSS vendors, as well as small differences in thermal outputs at which the vendors have optimized their designs, have an economic importance to the utilities' contribution to the complexities of the bid evaluation process.

The concept of a nuclear steam supply system as the principal article of commerce is the result of successive diminutions of the nuclear vendors' scope of supply. In the dozen or so turnkey nuclear projects, all equipment and subsystems (except power transmission plant) shown in Figure III–2, including site, labor, and materials, were supplied by the reactor vendor. The first reduction of scope of supply deleted the turbine generator equipment and much of the field work, leaving a "nuclear island" consisting of the reactor, containment, and all systems located within the containment structure. Several variations of the nuclear island scope were tried before the NSSS concept – which does not include containment or construction or much of the physical plant layout design – was settled upon as the preferred scope for buying and selling nuclear steam generation facilities. The nuclear steam supply system manufacturer designs the subsystems, manufactures the fuel and most of the hardware directly connected with the reactor

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1. APED Handbook, section 8800, page 3, reproduced with permission.

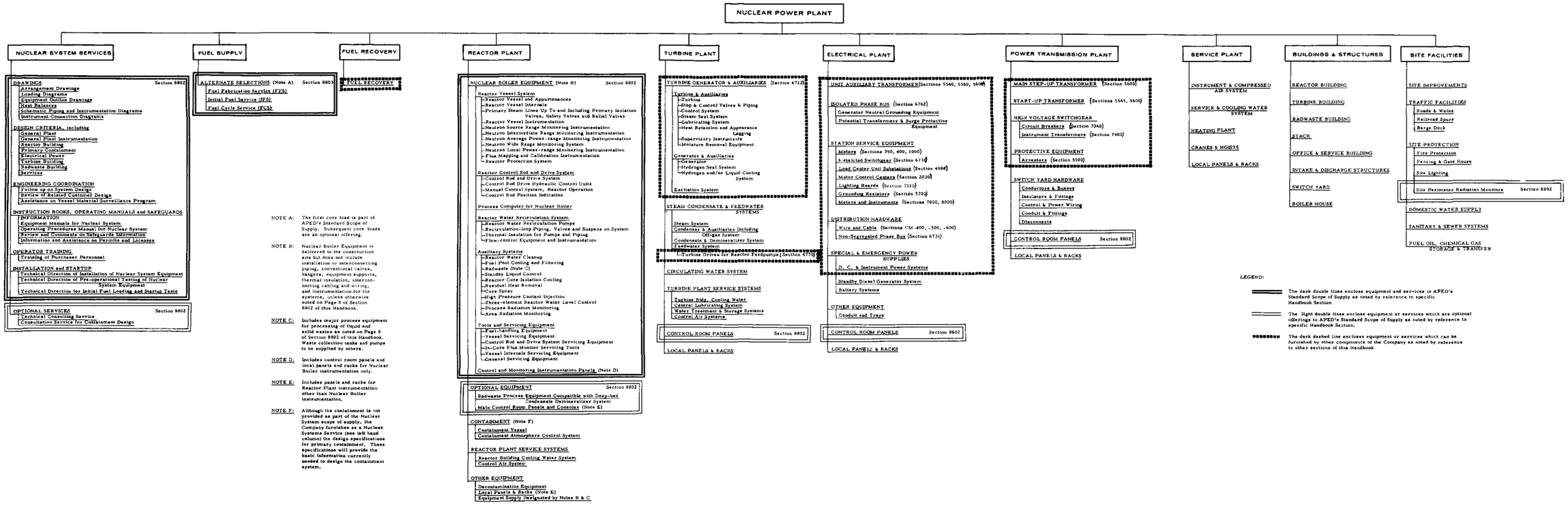
FIGURE III-1

Flow Diagram for Light Water Reactors

See Figure 4, page 61 of Part One

FIGURE III–2

Structural Chart of a Nuclear Power Plant



NOTE A: The first core load is part of APED's Standard Scope of Supply. Subsequent core loads are an optional offering.

NOTE B: Nuclear Boiler Equipment is delivered to the construction site but does not include installation or interconnecting piping, conventional valves, hangers, equipment supports, thermal insulation, interconnecting cabling and wiring, and instrumentation for the systems, unless otherwise noted on Page 8 of Section 8802 of this Handbook.

NOTE C: Includes major process equipment for processing of liquid and solid wastes as noted on Page 8 of Section 8802 of this Handbook. Waste collection tanks and pumps to be supplied by others.

NOTE D: Includes control room panels and local panels and racks for Nuclear Boiler instrumentation only.

NOTE E: Includes panels and racks for Reactor Plant instrumentation other than Nuclear Boiler instrumentation.

NOTE F: Although the containment is not provided as part of the Nuclear System scope of supply, the Company furnishes as a Nuclear Systems Service (see left hand column) the design specifications for primary containment. These specifications will provide the basic information currently needed to design the containment system.

Source: APED Handbook, Section 8800, page 3, Dated March 27, 1967, Reproduced with Permission

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vessel, inside and outside, and specifies and builds or procures the equipment directly associated with the reactor coolant and the principal safety subsystems, warranting the output and performance of the system. The utility, through its own engineering department or its architect-engineer, is responsible for determining the physical placement of the components, contracting for the foundation, and building and erecting the nuclear and electrical components of the station.

In terms of design and construction, the responsibilities falling to the utility for an NSSS are much the same as for a fossil steam generator, although of much higher complexity.

Some people connected with the nuclear industry have felt that the scope of supply for nuclear steam supply systems continues to be too comprehensive, that some of the subsystems could be specified and procured by the utilities' engineering arm. Under a reduced scope of supply, the utilities' engineering arm would take on additional design responsibility, and would specify and procure the major items of the nuclear system such as the presssure vessel, steam generators, pumps, and fuel much as it purchases condensors, turbine-generators. feed water heaters, and boiler teed pumps. The problem with tne reduced scope is the absence of the nuclear steam supply system manufacturers' warranty. (And, as discussed previously, we believe the warranty plays a key role in defining this product, more so than materials and workmanship warranties of the kind that normally accompany industrial products.)

We questioned manufacturers, utilities, and architect-engineers about their views of reduced NSSS scopes. With few exceptions, executives we talked with were satisfied with the scopes of nuclear steam supply systems as they are being offered by the four light water reactor manufacturers. In general, the utilities and their architect-engineers would be unwilling to assume the additional risks of nuclear steam supply system design that would be inevitable if they were to design the system and select individual components. Were they to involve themselves in system design, they would become responsible not only for the costs of obtaining licenses, but also for the risk that designs might not operate to specifications.

We can foresee some instances in which architect-engineers or utilities might take a larger role in nuclear system design, but during the 1970's we expect that the article of nuclear commerce will stay similar to today's NSSS.

C. THE MARKETS, FIRMS, AND MARKET SHARES

Table III–1 shows the five firms, ranked by overall size, actively participating in the commercial nuclear steam supply system market. Table III–2 estimates

TABLE III-1

1967 SIZE AND PROFITABILITY OF NSSS MANUFACTURERS IN PERSPECTIVE
(data from 1968 edition of the Fortune 500 Industrial Companies)

Rank in Sales	Company	1967 Sales ($ x 10^9)	1967 Assets ($ x 10^9)	RETURN On Sales Percent	On Sales Rank	On Capital Employed Percent	On Capital Employed Rank
4	General Electric	7.741	5.347	4.7	271	15.4	97
9	Gulf[a]	4.202	6.458	13.8	14	13.1	171
18	Westinghouse	2.901	2.075	4.2	300	10.3	298
130	Combustion Engineering	.689	.364	3.1	388	14.1	133
141	Babcock and Wilcox	.625	.439	5.3	226	11.9	221

a. Sales volume not including excise taxes.

Source: Fortune 500 Industrial Companies, 1968 Edition

TABLE III–2

IMPACT OF DIRECT NUCLEAR BUSINESS ON SALES OF THE FOUR LWR MANUFACTURERS
($ millions)

	General Electric	Westinghouse	Babcock & Wilcox	Combustion Engineering
1972				
NSSS Sales	153	217	130	77
Fuel Fabrication	47	32	13	7
Total	200	249	143	84
Company Sales[a]	10,344	3,486	817	1,069
Percent Nuclear	1.9	7.2	17.5	7.9
1977				
NSSS Sales	229	290	121	97
Fuel Fabrication	116	87	39	27
Total	345	377	160	124
Company Sales[a]	13,821	4,189	1,067	1,659
Percent Nuclear	2.5	9.0	15.0	7.5

a. Projected at the average yearly growth rate experienced by these companies from 1957 to to 1967. Total corporate sales projected in this way probably understate sales that the companies will achieve. Westinghouse, for example, announced to security analysts in June 1968 that it expects to reach $4 billion in sales in 1970. See also footnote (in Section G) that discusses different accounting conventions used in the reporting of sales having high purchased-material components. Nuclear-related sales volumes shown above were derived from megawattage and average selling price estimates and do not reflect differences in accounting practice.

Source: Arthur D. Little, Inc., estimates.

the contribution that direct nuclear activities[1] will make to the sales volume of these companies in the decade beginning in 1970. We have used our estimates of the share of the nuclear market these companies will capture and a projection of overall company sales based on historical growth rates and current dollars. Obviously such estimates are crude, particularly because there is no way of reliably projecting the total sales volume of these companies (nuclear dollar volumes are relatively more certain). Nonetheless, the projections show the surprisingly small role nuclear power may play in the overall activities of these companies.

D. MARKET SIZE

A description of nuclear steam supply system market volumes and market shares requires a good deal of elaboration for the field sufficiently complex to give rise to seemingly conflicting market statistics. Market shares can be expressed in terms of the number of nuclear steam supply systems (sales events), the megawatts of capacity involved, or dollar volumes. Moreover, a company's participation can be further broken down into the percentage of *new* orders captured, the percentage of the plants to be *started* within some time period, or the fraction of the *total* (accumulated) number of systems or amount of capacity that has been awarded, without regard to date of award or startup. New orders are more descriptive of the on-going market; the total number of systems is useful in describing an experience base and an exposure to risk.

We highlight several other complications in describing and measuring market shares:

- There can be disagreement on what constitutes a sale. The time at which the vendor or the utility recognizes an award does not necessarily coincide nor agree with public announcement of a plant. The problem is particularly difficult when options or formal or informal agreements are made for duplicate units at a given plant site. In many cases formal contracts that, for other products, might identify a sale follow many months after the market impact of a commitment – long after the vendor has begun his design and manufacturing cycle.

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1. The sales include NSSS and fuel fabrication and management, but not components sold to other NSSS manufacturers, non-nuclear equipment for these power stations, repair parts, or nuclear raw materials, separative work for reprocessing.

- We are dealing with, in any year, relatively few purchase events and relatively few startups. A commitment that has been formalized in, say, the months of November through February might be considered as an event in either the earlier or later year, and since there are not many purchase events, the time of recognition can have a noticeable effect on a vendor's market share and even on total industry volume. Similarly, slippage of the startup of a plant originally scheduled for December startup into January of the following year will make a noticeable difference on the total installed capacity estimates for these years. Consequently, we have found it convenient in some of our discussions to group reported commitments and startups by quarters and then make moving averages in an attempt to smooth market share data.

- Vendors differ in their accounting practices in the way they recognize major outside purchases as revenue, and in the way they treat progress payments. General Electric, for instance, treats as sales revenue its resale of components that it buys on behalf of a utility customer. Westinghouse does not usually consider as part of its corporate sales volume major components manufactured by others and shipped directly to the utility. Such components are significant, even for highly integrated NSSS vendors. There are also differences in the way in which progress payments are recognized and similarly in the time at which profits are recognized. The lengthy design and manufacturing cycle requires progress payments extending over several years and the differences in accounting practice can be significant.

In agreement with the AEC we used their forecasts for the growth of nuclear power as our base in talking about the likely size of the various sectors of the nuclear power supply market. This forecast[1] predicts an installed nuclear capacity in the United States of 145,500 Mwe in 1980. (We removed from this estimate

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1. Forecast of Growth of Nuclear Power, December 1965, WASH-1084, United States Atomic Energy Commission Division of Operations Analysis and Forecasting.

1200 Mwe of capacity represented by small reactors less than 200 Mwe in size.) This estimate, which represents the midpoint between the AEC's high and low projections, also falls about midway between pessimistic and optimistic industry projections, and its end point in 1980 coincides almost excactly with another detailed forecast recently compiled by S.M. Stoller Associates, although the shape of the Stoller growth curve differs from that of the AEC. We did not find in our field work any information that would drastically change the AEC's estimates.

In arriving at its estimates the AEC allowed for some slippage of reactor startups, particularly in the years 1970–1973 when, under present schedules, the industry will have a heavy schedule of completions. This raised for us the problem of adjusting announced startup dates of the individual projects so that in total they would match the AEC's forecast. We have had to be arbitrary about our adjustments, and our time series of installed megawatts does not precisely match that of the AEC in the early years. While we note this discrepancy, we do not believe serious distortion results from it. In fact, any description of a primary market as dynamic as this (growth running, in the early years, 40% per year compounded) and of the secondary markets that undergo similar rates of increase, several definitions of market size may well be appropriate for describing of industry behavior. Second tier suppliers may see orders that reflect announced startup dates. Because slippage occurs after they have made their own timely shipments, the announced startup dates may be relevant for them. On the other hand, some markets, particularly those related to reload fuel and the reprocessing of spent fuel, are keyed to the time at which utilities elect to remove a reactor from service for its first refueling. Any delays between anticipated and actual startup delays operation in achieving full power on a fairly continuous basis (such delays between startup and continuous operation have been experienced in several of the early plants now on-stream) significantly affect the timing of the markets tied to reloading.

Table III–3 shows a four-month moving average of the Mwe of new light water reactor awards made to the four vendors. Figure III–3 shows the time series of new awards, in this case a moving average of two quarters. As would be expected, averaging over the shorter time period gives a more volatile picture of market shares. We have also indicated in Figure III–3 the points in time at which General Electric and Westinghouse made significant technological improvements in the reactor system they offered.[1] We will talk later about the marked technical innovation that has taken place in the short span of two or three years. We note here that buyers seem to have responded favorably to design improvements.

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1. The evolution of Figure III-3 is interesting. A table of significant technical milestones was made on technical merits and independent of the peaks and valleys shown by the market share information. We discovered that the timing of the major technical milestones did in fact closely coincide with the seesaw in market shares of Westinghouse and General Electric in 1965 and 1966.

TABLE III–3

MOVING AVERAGE OF NEW LWR AWARDS BY VENDOR

MOVING AVERAGE OF FOUR QUARTERS ENDING AT TIME SHOWN

Quarter Ending	GE		W		C.E.		B&W	
	Mwe	Percent	Mwe	Percent	Mwe	Percent	Mwe	Percent
Thru Sept 1965[a]	897	60.8	505	34.2	0	0.0	73	4.9
Dec 1965	537	41.5	756	58.5	0	0.0	0	0.0
Mar 1966	537	27.9	1179	61.4	205	10.7	0	0.0
June 1966	1654	54.4	1179	38.8	205	6.8	0	0.0
Sept 1966	2004	50.4	1327	33.4	205	5.2	437	11.0
Dec 1966	2201	45.6	1642	34.0	325	6.7	655	13.6
Mar 1967	2262	39.3	2061	35.8	331	5.8	1101	19.1
June 1967	1834	27.0	2465	36.3	731	10.8	1761	25.9
Sept 1967	1149	18.7	2750	44.7	731	11.9	1524	24.8
Dec 1967	1702	27.4	2196	35.3	1011	16.3	1306	21.0
Mar 1968	2733	45.5	1619	26.9	800	13.3	860	14.3

a. Includes Dresden I, Yankee, and Indian Point 1

Sources: Project announcements and estimates by Arthur D. Little, Inc.

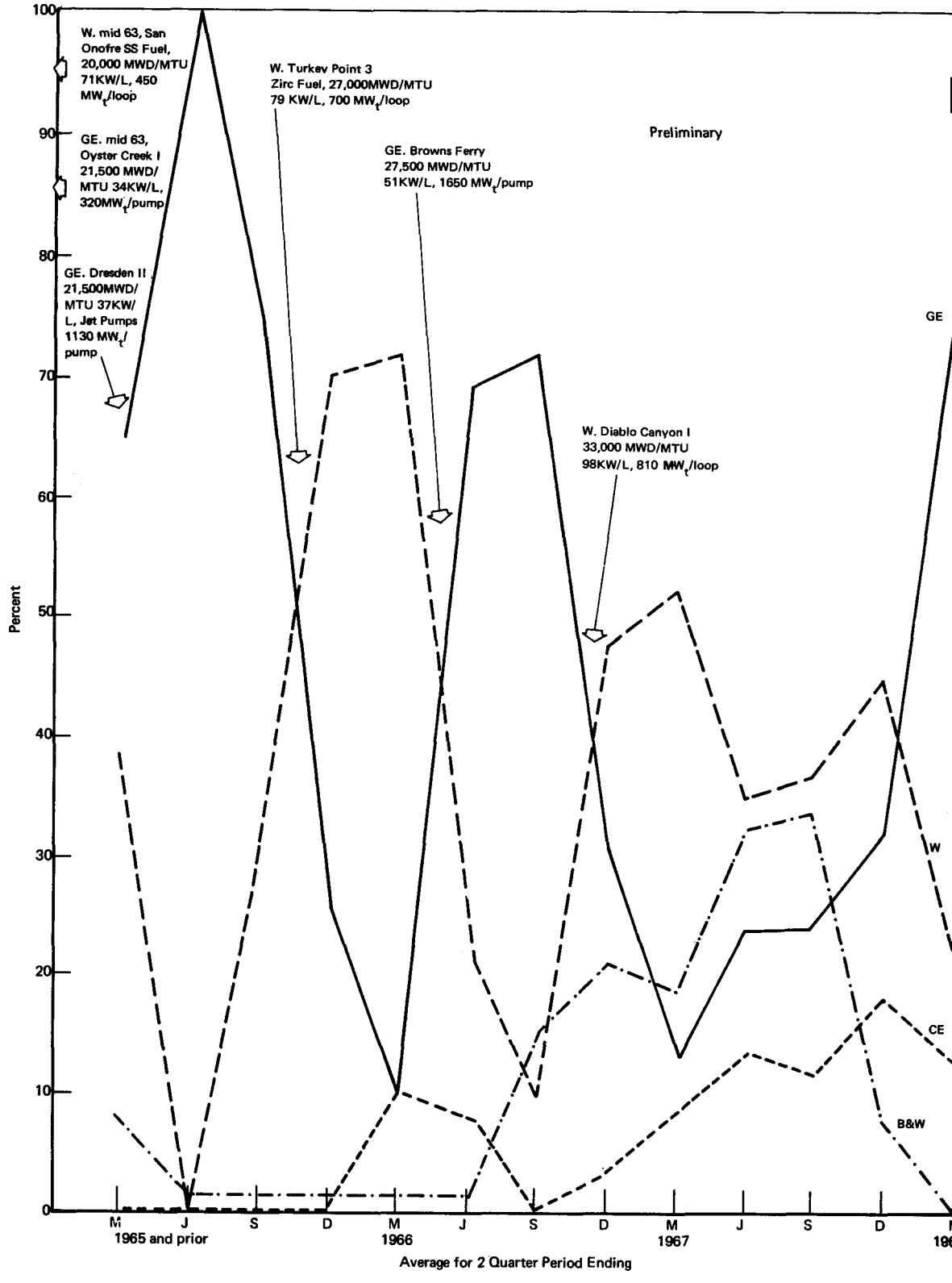


FIGURE III–3 MOVING AVERAGE OF PERCENT MW_e AWARDED

It is also meaningful to look at the cumulative awards as a function of time, as shown in Table III–4. Cumulative awards nearly equal the four companies' present backlogs and work in progress – since only some 3% of the committed nuclear megawatts have actually been started up. Figure III–4 displays cumulative backlog smoothed by a two month moving average – a cumulative statistic comparable to the rates plotted in Figure III–2.

In projecting individual companies' share of the market for the latter 1970's, a period for which few awards have yet been made, we used an arbitrary assignment of 35% of the market to General Electric and Westinghouse, with 16% to B&W and 14% to Combustion Engineering.

E. NSSS VENDORS

1. General Electric Company

GE became active in the nuclear field immediately after World War II, first as operating contractor at Hanford in 1946 and then a few years later as operating contractor for Knolls Atomic Power Laboratory. At Hanford, GE was involved in the design, construction and operation of the plutonium production reactors[1] as well as a variety of other activities in nuclear energy. Foremost among these were the plutonium recycle program for civilian power reactors (which included design, construction and operation of the plutonium recycle test reactor) and project management and startup of the N-reactor, a dual-purpose power and plutonium production reactor. GE began a phased withdrawal from Hanford in 1964; this was completed in 1967.

At KAPL, GE was responsible for the sodium cooled submarine reactor project, involving a land-based prototype and one submarine, the *Seawolf*, which was later converted to one of the Westinghouse PWR's that became universal in the nuclear submarine fleet. KAPL also had project responsibility for the following prototype reactors: (1) Submarine Advanced Reactor (startup 1958); (2) Destroyer Reactor (1962); and (3) Natural Circulation Test Plant (1965), which is located at the NRTS. All three of these reactors are PWR type.

GE started its commercial nuclear operation in California in 1956, its earlier work having been done in Schenectady. It selected the BWR concept, then under development at Argonne National Laboratory, as its prime effort. With its own funds, it constructed the Vallecitos Boiling Water Reactor, a prototype similar to the AEC's Experimental Boiling Water Reactor. VBWR was started up in 1957, less than one year after EBWR.

1. Reactors operated for the objective of plutonium production and from which thermal energy was an unwanted by-product.

TABLE III–4

CUMULATIVE AWARDS OF LWR ORDERS BY VENDOR
(through March 1968)

(INSTALLATIONS AND ORDER BACKLOG AT TIME SHOWN)

	GE		W		CE		B&W	
Quarter Ending	Mwe	Percent	Mwe	Percent	Mwe	Percent	Mwe	Percent
Thru 1964[a]	1440	43.9	1549	47.2	0	0.0	292	8.9
Mar 1965	2249	55.0	1549	37.9	0	0.0	292	7.1
June 1965	2249	55.0	1549	37.9	0	0.0	292	7.1
Sept 1965	3588	60.8	2019	34.2	0	0.0	292	4.9
Dec 1965	3588	42.5	4572	54.1	0	0.0	292	3.5
Mar 1966	4397	37.3	6266	53.2	821	7.0	292	2.5
June 1966	8864	54.6	6266	38.6	821	5.1	292	1.8
Sept 1966	11604	53.3	7326	33.6	821	3.8	2040	9.4
Dec 1966	12391	44.7	11140	40.2	1302	4.7	2911	10.5
Mar 1967	13446	38.6	14511	41.7	2147	6.2	4696	13.5
June 1967	16199	37.3	16126	37.2	3747	8.6	7335	16.9
Sept 1967	16199	34.9	18326	39.5	3747	8.1	8135	17.5
Dec 1967	19199	36.5	19926	37.9	5347	10.2	8135	15.5
Mar 1968	24379	41.4	20986	35.7	5347	9.1	8135	13.8

a. Includes Dresden I, Yankee, and Indian Point I

Sources: Project announcements and estimates by Arthur D. Little, Inc.

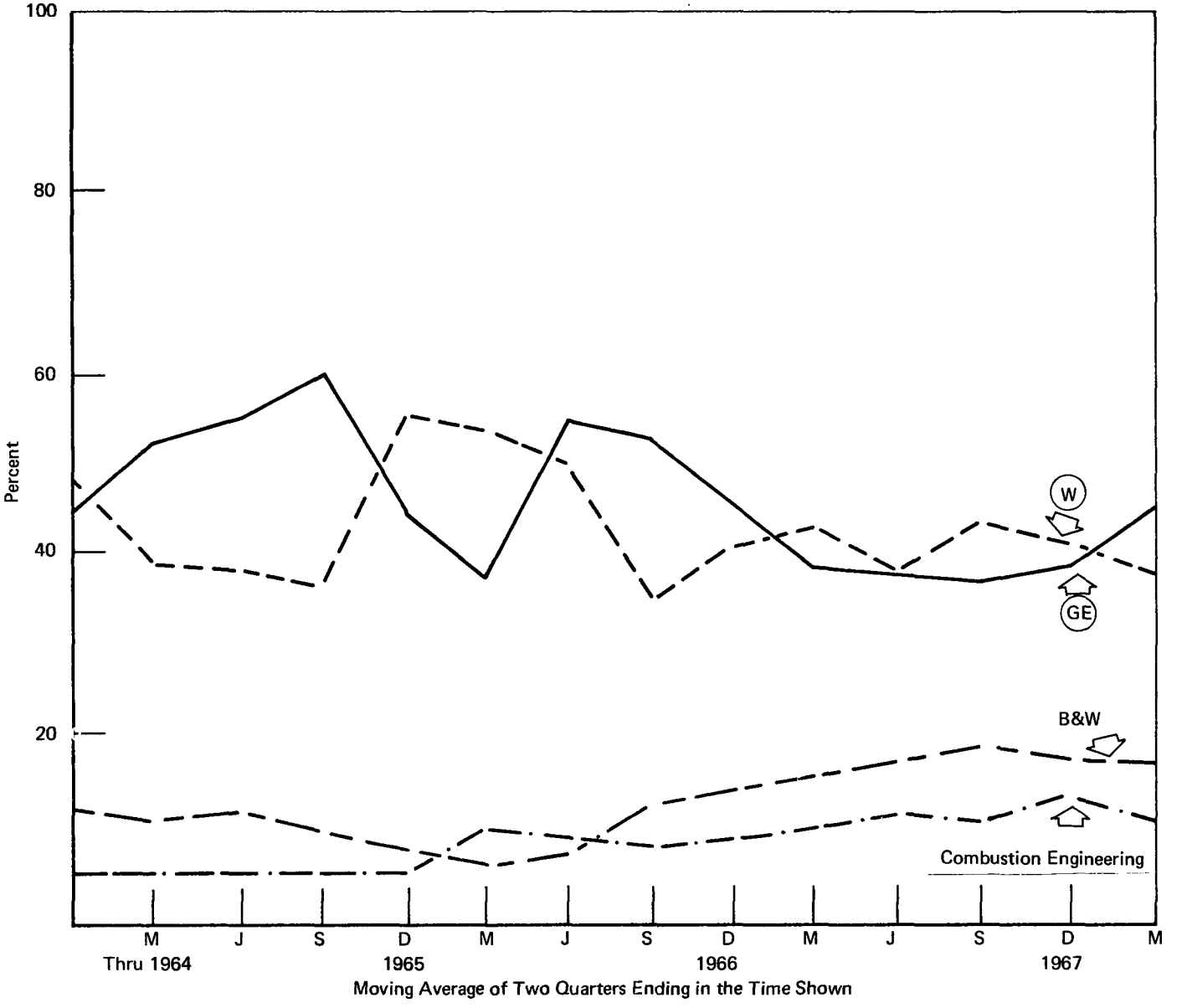


FIGURE III–4 PERCENT OF CUMULATIVE Mwe AWARDED (BACKLOG)

GE marketed the first commercial BWR plant (Dresden) in 1956, designed and built without government subsidy. To the AEC's request for proposals on a high power-density BWR demonstration plant, it responded with a proposal to Consumers Power Company.

The resulting plant, Big Rock Point, Michigan, was started up in 1962. GE also provided the NSSS for the Humboldt Bay Unit No. 3 of Pacific G&E, which was privately financed and which commenced operation in 1963.

In 1963, GE marketed the ~600 Mwe Oyster Creek and Nine Mile Point plants as commercial ventures. These projects are generally considered the turning point in favor of nuclear energy as an economically competitive energy source for producing electricity.

From boiling water reactors, GE turned its interest to superheated-steam cooled reactors. In 1963 it started up the Vallecitos Experimental Superheat Reactor, with financial support for its construction coming from a group of six New York utilities, called Empire States Atomic Development Associates (ESADA). Financial support for a sizeable R&D program on superheater fuel to be tested in this facility was received from the AEC. This program terminated and the EVESR was shut down in 1967.

GE has been active in the breeder reactor program for a number of years. In 1959 it was selected as a major AEC contractor (about $2.5 million per year) for the development of LMFBR ceramic fuel. With financial support from utilities and from West Germany, it is building the Southwest Experimental Fast Oxide Reactor (SEFOR) scheduled for operation in 1968. The AEC will financially support the experimental program on LMFBR physics to be conducted in SEFOR.

ESADA is financing, to the extent of $5 million, a demonstration LMFBR development program at General Electric and has obtained prior rights to the resulting prototype design until June 30, 1970.

2. Westinghouse Electric Corporation

Westinghouse entered the nuclear power field in 1949 as operating contractor of the Bettis Atomic Power Laboratory, the major facility for developing and building pressurized water reactors for submarine and aircraft carrier applications. Westinghouse also operates the Naval Reactor Facility at the National Reactor Testing Station where the land-based prototypes for these two reactor applications are located. In July 1953, BAPL was designed as the contractor to design, develop and construct the reactor for the Shippingport government-owned prototype for commercial power PWR's. In recent years, BAPL has been working on

the Light Water Breeder Reactor under the direction of the Naval Reactors Division of the AEC.

Westinghouse's major effort in the commercial nuclear power field has been in the design and supply of pressurized water reactor plants through its Atomic Power Division. WAPD marketed the Yankee reactor in 1955 as the first demonstration power plant. It continued to obtain AEC R&D support through the AEC's third round program for the San Onofre and Connecticut Yankee plants, contracted in 1960 and 1963, respectively. Its first sale of a plant not having direct government participation of some kind was the R.E. Ginna plant, in 1965.

WAPD has made some limited explorations into other reactor types. During the middle 1950's, it was involved in a study with Pennsylvania Power and Light of the aqueous homogeneous reactor concept pioneered by Oak Ridge. In response to the AEC's request for third round proposals, it acted as reactor designer for the Carolinas-Virginia Tube Reactor based on the heavy water reactor concept, and received AEC support for research and development specifically related to that project.

In addition to manufacturing facilities, Westinghouse constructed an R&D center, including a test reactor (1959 startup), partly in expectation of receiving AEC-supported irradiation programs. When this support did not materialize to the extent expected, the Westinghouse Test Reactor was shut down in 1962. Testing of fuel for commercial reactors and development of other features of the pressurized water reactor have mainly been done in the Saxton Nuclear Power Facility, built by Westinghouse for the Pennsylvania Electric Company.

In breeder reactors, WAPD has been working on LMFBR design studies, both with AEC and utility support. Utility support is also being given for component development for a demonstration plant, while AEC is funding work on carbide fuels, on LMFBR physics, and on component and instrumentation development. Westinghouse announced at the 1967 Authorization Hearings its willingness to commit $10 million of corporate funds and its facilities to LMFBR R&D.

3. Babcock and Wilcox

B&W was from the beginning of the program a major supplier of components such as pressure vessels and steam generators for naval reactors. B&W started its Lynchburg, Virginia, Atomic Energy Division in 1953 and started assembling a key group of physicists, reactor engineers, and other engineers. Its first major reactor project was the Consolidated Edison Indian Point Unit No. 1. This privately financed endeavor was started in 1955 and completed in 1962. The plant was beset with various constructional and operational difficulties. The use of thorium as fertile material in the core did not prove too successful from an economic standpoint and a replacement core was subsequently fabricated by

Westinghouse. In 1966, B&W sold the Oconee plants to Duke Power, marking the latter's entry into commercial nuclear steam supply systems.

Because of its traditional role as supplier to the maritime industry, B&W became interested early in nuclear propulsion for merchant ships. It supplied the reactor for the N.S. SAVANNAH, the first nuclear merchant vessel.

B&W originated the spectral-shift reactor concept, for which there was some limited AEC financial support (of the order of $2 million). When industry support failed to develop for a demonstration plant of this concept, it was dropped by both the AEC and B&W.

B&W acted as nuclear subcontractor to Ebasco Services in the design of the Advanced Test Reactor, whose construction was recently completed at the National Reactor Testing Station. When the operating contract at the NRTS came up for renewal, B&W was mentioned prominently as a candidate, but neglected to submit a proposal, apparently because its central station power commitments were finally beginning to develop.

Over the years, B&W has been a major component supplier for various reactor programs, and its R&D facilities have expanded to include fuel fabrication capability and a test reactor put into operation in 1964.

In the LMFBR program, B&W is conducting plant design studies with AEC support. It is also being funded by the AEC in steam generator and heat exchanger development, and in analytical work related to core physics. B&W is also developing fuel fabrication capability in mixed uranium-plutonium oxides, and in the past received utility support in a design study of the steam-cooled fast breeder concept.

4. Combustion Engineering

CE was a supplier of components for the Navy's Nuclear Program. It became a reactor vendor primarily through two major steps: (1) it was selected as developer of the Small Submarine Reactor Prototype (startup in 1959), and (2) it purchased General Nuclear Engineering Corporation of Dunedin, Florida.

GNEC was founded in the mid-fifties by senior personnel of Argonne National Laboratory who had been involved in the Manhattan project (design concept for the Hanford Production Reactors) and in early development of the LMFBR and BWR. GNEC designed the reactor for the BONUS plant, and also was involved in studies of other concepts such as the heavy water moderated, gas cooled reactor.

According to testimony at the FY–1967 AEC Authorization hearing, CE's landmark sale of the Palisades plant to Consumer's Power in 1966 marked the culmination of a three-year campaign to enter the commercial nuclear power field then supplied only by General Electric and Westinghouse. CE has capability in manufacturing the principal hardware of a nuclear steam supply system, especially reactor vessels and steam generators. It had closed out its Navy fuel work, but had developed and fabricated the fuel for BONUS. CE had no substantial support from the AEC in the design of reactors (only fixed-price hardware contracts), so the development of a product line nuclear steam supply system was entirely an internally funded effort.

CE and Atomics International formed a joint venture to spearhead, with AEC funding, the development of the Heavy Water Organic Moderated Reactor, but CE committed no funds of its own to the project during its two years of existence.

CE has not undertaken an active breeder program of its own nor has it solicited utility support for such an effort. It is conducting design studies in the AEC LMFBR program and, as a proposed subcontractor to AI, it has participated in the latter's effort to obtain the reactor design contract for FFTF.

5. General Atomic

Organized as a division of General Dynamics Corporation in the 1950's, GA pursued activities related to commercial nuclear technology, including the highly successful TRIGA research reactor; work in nuclear space propulsion (government financed); research on high-energy neutron physics, accelerators, controlled thermonuclear reactions and fusion reactors (the latter being largely privately financed); and development of devices for the direct conversion of heat to electricity (portions funded by itself, utilities, industry, the AEC, and by DOD agencies).

GA has concentrated its power reactor development efforts on the high-temperature gas-cooled reactor concept (HTGR), and in 1958 proposed the 40 Mwe prototype Peach Bottom plant as part of the AEC's Power Demonstration Reactor Program. The Peach Bottom unit was constructed, with Bechtel Corporation as prime contractor, on the Philadelphia Electric system. A group of approximately 50 utilities called High Temperature Reactor Development Associates (HTRDA) sponsored the project. The Peach Bottom plant became operational in 1967 and has operated continuously since then (with intermittent shutdowns for minor plant modifications) to demonstrate fuel performance.

In 1964, GA proposed with Rochester Gas & Electric to construct a 260 Mwe HTGR, again under the AEC demonstration program. Negotiations between the vendor and utility were terminated in early 1965, and shortly thereafter GA

teamed with Public Service of Colorado to propose to the AEC the 330 Mwe Fort St. Vrain plant. Two significant events regarding the Fort St. Vrain plant occurred in April 1968: first, the plant received ACRS approval of the Construction Permit application (significant because of several novel features of core design and the use of a single prestressed concrete vessel as both the pressure vessel and containment system); second was the reaffirmation of the 1965 contract, which had been subject to cancellation if Peach Bottom failed to demonstrate satisfactory performance or if the on-going R&D and plant design programs indicated that the HTGR lacked technical and economic feasibility.

In October 1967, Gulf Oil Corporation acquired GA. GA is currently actively marketing a 1000 Mwe HTGR, and has recently submitted a proposal for such a unit to a utility, Portland (Oregon) GE. GA is also actively developing a gas-cooled breeder concept with financial support from utility groups and the AEC. GA also has a cooperative agreement with the Swiss government to study this type of reactor.

6. Atomics International

In the early 1950's Atomics International Division of the North American Rockwell Corporation became active as a potential nuclear reactor supplier in three areas: (1) development of the organic-cooled reactor concept, (2) development of the sodium-graphite reactor concept, and (3) design, development and sale of a number of small solution-type research reactors for universities.

AI contributed its own corporate funds to the development of both power concepts, specifically to the construction of the proof-of-principle test for organic reactors, the Organic Moderated Reactor Experiment and the similar test of sodium graphite reactors, the Sodium Breeder Experiment. Both the SGR and OMR made it to the prototype stage, Hallam and Piqua respectively, with AI as the reactor vendor. In both cases, difficulties, delays with the prototypes, and lack of utility interest caused the AEC to withdraw further support of the concept. In both cases the technology and capability developed by AI was reoriented by the AEC to other programs. For about two years, until early 1967, the AEC supported a joint effort by AI and CE to develop the HWOCR concept, utilizing the organic coolant technology developed largely by AI.

The sodium technology work in support of SGR has been reoriented to the LMFBR program, and AI has been given additional responsibilities by the AEC, primarily in the supervision of component testing, both for LMFBR demonstration plants and the FFTF, at the Liquid Metal Engineering Center (LMEC). In addition, AI was one of the two bidders for the reactor design contract for FFTF. The AEC recently selected Westinghouse as the prime contractor, with AI designated as their principal subcontractors. In addition to studies for the AEC's

LMFBR program, AI is conducting development and design of a 300-500 Mwe sodium-cooled FBR. General Public Utilities is funding a substantial portion of this work, looking toward a decision on plant construction by 1970.

7. Allis-Chalmers

For a number of years, Allis-Chalmers pursued an aggressive program to become a competitive supplier of nuclear steam supply systems. It successively absorbed the nuclear reactor supply capability of ACF industries (1959) and of ALCO. Several of the key people in the ACF group had come from Argonne National Laboratory where they were involved in early Navy PWR work and the very early development of BWR plants.

A–C designed and placed into operation between 1958 and 1965 five fairly large research and test reactors, based on the Argonne CP–5 and on the Oak Ridge Research Reactor designs. Four of these were overseas, and two were in this country.

A–C was an active participant in the power demonstration program as reactor vendor on three plants: Elk River (obtained with the purchase of ACF's Nuclear Division), Pathfinder, and LaCrosse. Elk River and LaCrosse were small AEC-owned BWR plants for publicly owned utilities and involved no R&D support by the AEC. All three plants suffered from technical and construction delays. On a fourth demonstration plant, the ORNL Experimental Gas-Cooled Reactor, A–C was the nuclear reactor subcontractor (also inherited from ACF) to Kaiser Engineers. The EGCR project suffered from major construction delays and escalation of project costs, and was cancelled in 1965 prior to completion.

A–C was the first reactor vendor to venture into the design of fuel reprocessing plants, acting as designer for a thorium-bearing fuel reprocessing plant for Italy in the early 1960's.

During 1965, A–C was actively developing three reference designs for BWR central station power reactors in the 300-1000 Mwe range and was prepared to make firm price quotations in the 300-400 Mwe range.

In early 1966 A–C withdrew from contention for the operating contract at the National Reactor Testing Station. In March 1966 A–C announced its intention not to seek any further complete reactor projects, but to continue to manufacture components for the power industry. Allis-Chalmers stated that their decision was based on a long-range analysis of the building of nuclear power plants that indicated that sizeable additional losses would be necessary before achieving profitability in nuclear power.

F. PRICING PATTERNS AND COMMERCIAL PRACTICE

Heavy electrical equipment manufacturers designate as "proprietary and confidential" the technical and price proposals they submit to privately owned utilities (and some public utilities as well). If the utility honors this restriction the researcher is foreclosed from direct access to information on bid prices and, equally important, on warranty and terms of sale clauses.

Some information on the winning bid (price only) eventually enters the public domain when the nuclear station becomes operational and is incorporated into the utilities' rate base – but far too late to be of use in a study of this kind. Some price information is submitted by the utility as part of the financial capability data required by the AEC before a construction permit is granted. Unfortunately, utilities have varied widely in their responsiveness in supplying financial data; some perform considerable aggregation of unit prices – as, for instance, lumping together NSSS, turbine generators, associated equipment, and balance of plant equipment. In any event, price information by itself, without warranty and terms of sale language, and without a breakdown by constituents, is not too meaningful. And of course, none of these reports provides information on the *losing* bidders.

In order to gain some access to bid price and technical information in our interviews with utilities, we obtained from the NSSS manufacturers letters of access authorizing utilities to discuss with us details of bid submissions made to them.[1] A minority of the utilities we interviewed gave us part or all of the information on bid submissions which we sought; the majority refused. We found most utility executives feeling that disclosure of cost and warranty information would be giving away secrets that might either help their competitors (other electric utilities) or cause equipment suppliers to refrain from similar bargaining in the future. Obviously, all utilities can't do better than average, but the hope on the part of each that he is doing better is one of the reasons why full access to price data is difficult for the researcher to obtain.

Some people in the equipment supply industry and utilities suggested that the publicly announced bids of publicly owned utilities – TVA, the Los Angeles Department of Water and Power, and the Sacramento Utility District being notable examples – give a representative view of prices and terms being offered to both public and private utilities.

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1. Development of mutually satisfactory language for these releases and the ironing out of details concerning the confidentiality which would be maintained by ADL with information so obtained was an unforeseen and time consuming task which delayed our study.

However, there is a counter view that suggests that these may be atypical submissions because the vendors know in advance that prices will be publicly revealed. From the limited information we obtained, we are unable to adopt one view or the other – we merely point out the two lines of opinion.

Moreover, even if the basic bid submission data were freely available they would not be fully comparable. Bids received by the utilities must be "normalized" by them or their architect-engineers in order to put the different submissions on as nearly comparable a basis as possible. Normalization must take care of not only differences in a scope of supply and direct capital plant costs[1] but also estimated differences in the cost of constructing the plants (each of the four light water reactor vendors require somewhat different equipment layouts with attendant construction cost differences). The normalization must also consider the discounted future fuel costs (the present value of fuel) and, at least subjectively, differences in warranty provisions.

Factors that are considered in bid normalization are subject to engineering judgment and to opinion about future prices (escalation insofar as the NSSS is concerned; price trends of uranium and fabrication in fuel) future burnups, unit efficiency, and unit availability, etc. In many bid evaluations there may be no single, universally recognized low bid.

Table III-5 shows utility costs representative of a typical year-end 1967 product-line large light water reactor for delivery in the mid-1970's. The cost are all in 1967 dollars, but adjustments have been applied to vendor prices for nuclear steam supply systems, turbine-generator equipment, and construction cost estimates to reflect 1973-74 startup. These costs were obtained from recent construction permit applications. They were corrected for known differences in plant design (for instance, the use of cooling towers) and minor adjustments were made to return plants near 1000 Mwe to the 1000 Mwe base of Table III-5.

Reactor prices have gone through three observable stages:

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1. These differences are accentuated in the comparison of BWR and PWR NSSS prices. Typically, BWR's have a lower capital cost than PWR's but the BWR requires a higher inventory of fuel. The fact that BWR's and PWR's have each achieved a share of the market is a strong indication that in the final evaluation the two differing LWR systems offer similar economic performance, although the capital and fuel cost constituents may be different.

TABLE III-5

NUCLEAR POWER STATION PLANT INVESTMENT COST ESTIMATE
(PWR – 1000 MWe (Net) Single Unit)

Cost Category	Total Costs ($X000's)	Percent of DC, IDC	Percent of TPC	Unit Cost ($/kw)
A. Direct Costs (DC)				
Land	1,000	0.9	0.7	1.00
Structures & Improvements	15,500	14.2	10.5	15.50
Reactor Plant Equipment	49,000	45.0	33.3	49.00
Turbo-Generator Plant Equipment	36,500	33.5	24.8	36.50
Accessory Electrical Equipment	5,500	5.0	3.7	5.50
Miscellaneous Power Plant Equipment	1,500	1.4	1.0	1.50
Subtotal	109,000	100.0	74.0	109.00
B. Indirect Costs (IDC)				
Engineering Services[1]	8,500	22.4	5.8	8.50
Training	800	2.1	.6	.80
Contingency and Escalation	7,200	18.9	4.9	7.20
Administration and Legal[2]	1,200	3.1	.8	1.20
Construction Facilities	800	2.1	.6	.80
Interest During Construction[4]	19,500	51.4	13.3	19.50
Subtotal	38,000	100.0	26.0	38.00
Total Plant Cost (TPC)[3]	147,000	– –	100.0	147.00
First Core Cost (Fuel)	29,500	– –	20.1	29.50
Cost of NSSS[5]	34,000	– –	23.1	34.00
Turbine Generator (Without the Accessory Equipment That Makes Up "Turbo-Generator Plant Equipment")	29,000	– –	19.7	29.00

1. Includes Design, Procurement, Construction Management, Quality Assurance, and associated licensing activities.
2. Includes licensing and public relations costs associated with activities performed by personnel of the utility.
3. Excluding costs of substation and transmission equipment (typically $4-20 million).
4. Investor-owned utility interest rates.
5. That portion of the Chart of Accounts, "Reactor Plant and Equipment" corresponding to an NSSS scope of supply.

1. In the first stage, running from the last of the demonstration round of reactors through 1965 and reaching a low point in mid-1966 with the offerings to TVA that became the Brown's Ferry I and II stations, NSSS prices per kilowatt or total plant prices per kilowatt in case of turnkey offerings declined. To some extent this was the result of rapidly increasing unit sizes and a reflection of the economies of larger plants. In part, it reflected a period of strategic price cutting during which GE and Westinghouse sought to develop primary demand for nuclear stations.

2. For the following year to 18 months, there was a period of relative stability at prices slightly higher than those reached at the low point in mid-1966.

3 Rapid price rises became apparent in the summer of 1967, with NSSS prices rising as much as 25-30% from this period through the first quarter of 1968. (Note, however, that backlogs were extending rapidly and units sold at the higher prices were in many cases for much later delivery than those sold in mid-1966. There were in these prices provisions for several additional years of anticipated cost escalation.) In general, this was a period during which the first cost experience data for the large scale plants were beginning becoming available; a time when additional equipment requirements were emerging as the result of safety and licensing hearings; and a period of rapidly increasing labor and materials costs.

Superimposed on the general price levels in the market are pricing strategies of the individual companies. It is not unusual for a manufacturer seeking entry into the heavy capital equipment market to underprice[1] his first few offerings – in industry terms, to "buy" these orders. Such a strategy is designed to give the customer an incentive to take the additional risk of trying a new product or trying a new vendor. This under conditions in which losses to the buyer in the event of failure can be many times the original cost of the equipment. (Such amelioration of risk was also part of GE's and Westinghouse's strategy in offering to build turnkey plants rather than NSSS more closely approximating traditional fossil steam generator scopes of supply.)

It is difficult for an outsider to reconstruct the rationale of GE and Westinghouse's bidding strategy in the period from the Oyster Creek award (October 1963) to the present. Clearly, managers of the nuclear activities at General Electric and Westinghouse were under severe pressure to obtain business for their sizeable engineering organizations. (For example, we estimate that GE's commercial nuclear activities at San Jose were costing the company something on the order of $30-40 million per year in the early 60's although some of these costs were offset by AEC contracts.) Proposal activity in the early 1960's resulted in only two 600 Mwe plants in the latter part of 1963 (Oyster Creek and Nine Mile Point) but the next award was not until February 1965 (Commonwealth Edison, Dresden No. 2). Westinghouse during this time was probably spending somewhat less per year and had the advantage of Connecticut Yankee and San Onofre (roughtly the 450 Mwe class) to keep them busy during this period. However, their first truly commercial awards were also in the latter part of 1965 (the R.E. Ginna station of Rochester Gas and Electric and Consolidated Edison's Indian Point No. 2).

The price advantage for nuclear shown to the industry in Oyster Creek and the attendant willingness of GE and Westinghouse to assume the risks of construction costs in the turnkey arrangement did not produce a flood of nuclear orders from the utilities. During this period Westinghouse and General Electric continued to offer turnkey plants and developed considerable exposure through a number of formal and informal bids that ultimately led to the rapid influx of orders beginning in 1965.

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1. Or sometimes offer formal or informal warranty terms in excess of the "going" terms.

Although at the time of the Oyster Creek award, General Electric claimed it was making a sound commercial offering there was skepticism in the industry on how long prices representative of Oyster Creek could be maintained.[1] And General Electric has now publicly stated that it will incur substantial losses on Oyster Creek, based on an underestimate of construction costs and over-optimism that problems would not develop in the field (particularly: strikes and a need for design changes), not to mention technical problems that developed with the reactor pressure vessel.

1. Phillip Sporn, the president of American Electric Power, in his "Post Oyster Creek Evaluation of the Current Status of Nuclear Electric Generation," a paper addressed to the JCAE July 17, 1965, discussed the Oyster Creek price: "Given this intense competitive background the opportunity to bid for a nuclear plant at Oyster Creek called forth the effort to incorporate in one project simultaneously every available technological development, a number of which I have described, and every optimistic market projection based on the new pricings made possible by these developments, none of which, however, had passed the test of experience.... It is generally known that GE priced the Oyster Creek plant on the altogether reasonable assumption that three or more very similar units could be sold to minimize the financial risk of this particular plant.... It is still my personal judgment that one of the effects of the competitive pressures of the marketplace was to induce the manufacturer to risk somewhat greater uncertainty in the costs behind the turnkey price than might be tolerable repeatedly.... In addition, I am extremely doubtful even in the case of the most fortuitous maximization of the effects of the manufacturer's financial risk, whether the Oyster Creek sale will yield the same financial return as the manufacturer would normally require as a matter of sound business; the kind of return he requires for his conventional turbine business for example."

On the subject of price increases since 1966 one NSSS manufacturer provided the following breakdown:

APPROXIMATE CAPITAL COSTS FOR 1000 Mwe STATIONS

	$/Kwe
1966 on a Turnkey Basis	100
1968 Plants with Equivalent Equipment, but with NSSS, T–G, and Construction Purchased Separately	150
Increase	50

BREAKDOWN OF INCREASE

Inaccuracy in 1966 Prices (underestimate of both NSSS and construction costs)	$10-15
New Nuclear Safety Requirements	5-10
Construction Cost Escalations	15-25
Increases in the General Level of Equipment Selling Prices	10
	$40-60

G . TRENDS IN NON-PRICE, NON-TECHNOLOGICAL COMPETITION

In addition to competition based on price and reactor technology (discussed below) the NSSS vendors can compete to some extent on their willingness to meet the particular product requirement of individual utilities and in the commercial terms they offer. In the early, lean days perhaps through 1966, NSSS manufacturers were more responsive to individual utility request for station sizes,[1] optional features, and warranties. Now, having achieved large backlogs of orders and having built up formidable engineering workloads NSSS manufacturers are attempting to standardize on three station sizes, roughly: 600, 800–900, and 1000–1100 Mwe. And they are sticking to more clearly defined scopes of supply.

While on the surface this rigidity limits the options open to the utility it may also benefit them when they apply for a construction permit. Carbon copy stations trading on technical work already passed by the licensing authorities may enjoy shorter delays. Standardization could also work to the utilities' benefit in the procurement of replacement fuel, for an independent fuel fabricator is likely to concentrate his efforts on reactors that are part of a family of similar designs in order that his investment in fuel design and engineering be used for more than one fuel fabrication job.

NSSS vendors are now offering more clearly defined scopes of supply and their warranty language is becoming standardized. Earlier guarantees that an NSSS would be licensable are now couched in terms saying the system is guaranteed to meet licensing standards as they are shown at the time of purchase – changes in the standards that require additional equipment are the cost responsibility of the buyer.

H. NSSS INDUSTRY ECONOMICS

In our pilot interviews with the NSSS manufacturers we explored the kinds of cost information they might be willing to make available for this study. Responses varied. While some were willing to provide more production-related information than others (one extreme being categorical refusal to discuss any aspects of costs or value added), all were unwilling to provide sufficient cost data to enable us to make a meaningful comparative analysis of NSSS costs and prices. Cost information of this type is, of course, sensitive and proprietary. It also is information of a type that all manufacturers felt could not be properly assessed at this time. They pointed out that actual cost experience is extremely limited since the components that will go to the truly commercially reactors sold from 1966 onward are just now going through the shops. Some of these components were

1. Although through 1967, B&W, the notable exception, offered only an 850 Mwe plant.

first-of-a-kind and were not in the opinion of the NSSS manufacturers representative of second and third units that will follow. Therefore, in many instances we had to settle for qualitative information on costs and cost-volume relationships.

We examined a number of cost studies that have been made of the principal components of a nuclear station or in which station costs have been built up from estimates of individual components. Most of these studies cover PWR's, since BWR's, offered only by General Electric, pose a special problem in that such cost breakdowns are related to a specific company. Certain engineering differences among the PWR's made by the three companies – such as the number of coolant loops, or the configuration of a major component such as a steam generator – make typical figures for PWR's somewhat less sensitive to company restrictions. Three of the cost studies deserve mention:

1. A study for the AEC by The Kaiser Engineers published March, 1962 ("Guide to Nuclear Power Cost Evaluation," TID-7025) contains considerable component cost estimates in detail; unfortunately, most of the costs were estimated in 1961 and equipment sizes and configurations estimated differ considerably from the large reactors now under construction.

2. The Westinghouse (in association with Stone and Webster and Combustion Engineering [pressure vessels]) "1000 Mwe Closed Cycle Water Reactor Study" (WCAP-2385) done for the AEC and issued in March, 1963 gives a detailed breakdown of estimated equipment and field labor cost by AEC nuclear station account number the 1000 Mwe plant, was then considered to be a major step forward in technology (the largest plant that had been ordered was about 500 Mwe) requiring $10.5 million of R&D to bring it to fruition. (A contemporary report "1000 Mwe Boiling Water Reactor Plant Feasibility Study" (GEAP-4476) was issued February, 1964. The GE study does not have the detailed component cost, information that the Westinghouse study has.)

   Unfortunately, data in the Westinghouse study although it is more recent than the Kaiser work, is of limited usefulness in estimating today's costs. Technology of 1000 Mwe plants has advanced considerably from the unit they describe. In particular, the power per primary loop has been dramatically increased and the number of primary loops reduced from seven to four. This means that major cost components, such as steam generators and pumps (now controlled leakage instead of canned) are being built larger to exploit economies of scale.

3. The Jackson and Moreland study of the Future Light Water Reactors previously cited contains station cost estimates that were built up from individual system[1] costs combined with Jackson and Moreland's view of possible cost improvements coming from the learning curve and further technical evolution. Much of the component cost information was obtained by Jackson and Moreland on a confidential basis and could not be made available to us. We benefited in a general way from discussions with the AEC and the writers of this study but were unable to obtain accurate cost breakdowns.

For most components we were unable to obtain manufacturer's quotations; for these were the NSSS manufacturers with whom the data problems first arose. As shown in the industry flow diagram, the PWR industry is quite vertically integrated in those components that make the most significant contribution to the costs of a PWR NSSS.

Of the three PWR makers, B&W is probably most fully integrated, producing for itself all the major components of an NSSS except primary coolant pumps. Westinghouse produces pumps for its own use, but does not manufacture pressure vessels. Westinghouse has not announced any plans to fabricate its own pressure vessels but it should be noted that many of the shop facilities required for pressure vessel fabrication will be in place in its Tampa facility (to be completed in 1969).

General Electric is the least vertically integrated NSSS manufacturer and thus buys more of its major components on the outside. GE's BWR requires fewer major components (such as steam generators) than PWR's. GE's major purchased component is the pressure vessel, which is larger and more costly than the pressure vessel for PWR's. As much as 50% of GE's cost of furnishing an NSSS (meaning here all out-of-pocket costs except general and administrative and a return on investment) may consist of purchased components.[2] Substantial material and parts purchases to which General Electric would add manufacturing value would also be included in the remaining 50%.

By working with approximate market prices of major components and certain other information on the relationships between material and labor

1. A basis that does not always correspond to a component-by-component description.

2. For the most part, major components when purchased on the outside are shipped directly to the NSSS plant site and do not go to facilities of the NSSS designer for further manufacturing. General Electric and Westinghouse differ markedly in their corporate accounting treatment of such components. Westinghouse does not include such purchased components as part of its revenue, in a sense viewing its position with such purchases as that of an agent for its customer; General Electric, on the other hand, includes revenue for such components in its statements of sales.

constituents of the more intricate and highly machined subassemblies (such as control rod drives, instruments and instrumentation housings) one can estimate somewhere between 65% and 75% of current NSSS selling price is spent on purchased components or the materials, direct labor and indirect labor content of "made" hardware items. The remaining 35-25% would represent engineering and project management costs plus a contribution to corporate profit (return on investment), corporate overheads and research and development.

We asked the NSSS manufacturers and other key components manufacturers how their hardware costs – the 65-75% portion of the selling price – might vary as a function of production volume. Their answers were heavily conditioned by their assessment of shop mix and by the alternative products that might be displaced if production volume were increased. In general, we obtained the response that manufacturing costs would not be significantly dependent on volume; that average unit costs of 100% at 100% volume might drop to 95-97% at 200% volume.

The reason for this low sensitivity lies in the job shop nature of heavy equipment manufacturers. Implied in job shop operation is the building to order, in small lots – frequently one each – rather than for inventory.

Setup times represent a significant cost and because of the wide variety of work done on any one machine tool, jigs and fixtures give only moderate cost improvement. Production economies experienced in other industries when near–assembly line techniques can be employed are for the most part unavailable to the heavy machine shop.

Estimates of volume-cost relationships are complicated by the fact that many machine operations can be done in two or three different ways, depending on the machine tools that are in place and not otherwise occupied on another product at the time when they are needed for the NSSS part. At least in the short run there are few direct cost efficiencies that can be obtained by pushing more NSSS jobs through an existing facility and indeed an attempt to push higher volumes through the shop may reduce efficiency because of longer queuing time and because fewer of the machining operations can be done in the optimum way. In the long run, of course, a plant designed for higher throughput may well incorporate more sophisticated machine tools, thus lowering the unit costs of certain machine operations.

An example of specialized machine tools can be found in the operation of boring the thousands of holes in the header of a tube and shell steam generator. Here numerically controlled machine tools have produced efficiencies. In the places where such innovations have been made the manufacturers are, understandably, reluctant to talk about the cost impact of their innovations.

Several of the NSSS manufacturers told us that they believe they are now able to purchase major components in volumes that will give them lower unit costs. The component manufacturer can now plan to make several nearly identical units even though production may be spread over a couple of years. This is in contrast to the early days of nuclear power in the 1950's and early 1960's when each order for a component was an entirely new job. However, most of the NSSS manufacturers told us that they do not expect further significant reductions in purchased component prices.

If these admittedly general observations about the character of an NSSS cost function are valid, the principal determinant of the shape of the overall NSSS cost-volume curve is the proration of the heavy fixed cost component of NSSS engineering and research and development over a wider base of production. Indeed, a fairly wide range of assumptions about the cost performance of the "hardware" components of the plant will not significantly alter the overall curve. Table III-6 shows the index of selling prices that would generate an equal contribution to overhead and profit under different assumptions about the direct cost content of a product.

I. BARRIERS TO ENTRY

We will be talking about two kinds of barriers to entry: the first will be barriers in the usual sense of the hurdles which an outsider must clear if he wants to attain some minimal position in the market; the second type of barrier is not so explicit because it has to do with the outsider's perception, before entry is attempted, of what his long term rewards for having achieved entry might amount to. Clearly these two factors must be evaluated simultaneously. Higher long term expectations will justify an assault on more difficult initial barriers. Conversely, a less optimistic assessment of long range possibilities would make entry attractive only if the initial hurdles were somewhat lower.

We class initial hurdles as technical, financial, commercial, and managerial. We believe that of these, the technical hurdles are the least formidable or at least are the most easily overcome by investment. The established vendors have not attained their market shares by virtue of exclusive patent positions. While all have some features of their systems which they believe to be protected by their patents, much basic technology is in the public domain because of the AEC's original research and development in light water reactors. Also, there is a history in the heavy electrical industry of relatively frequent and inexpensive cross-licensing of these developments that have been awarded strong patents. Nor is this an industry in which trade secrets play a major role.

TABLE III-6

Illustrative Example

SELLING PRICE INDEX TO GENERATE EQUAL CONTRIBUTION TO OVERHEAD AND PROFIT

Production (units/year)	If Hardware Costs at 3 Units/Year Are: 65% of Total	75% of Total
1	170	150
2	118	113
3	100	100
4	91	94
5	86	90
6	82	87

Source: Arthur D. Little, Inc., estimates.

IV. URANIUM PRODUCTION

A. URANIUM MINING AND MILLING

1. Background

Although uranium had been produced for many years for use as a ceramic coloring agent, the uranium mining and milling industry began production on a large scale for the Manhattan project during the Second World War. The government obtained over 10,000 tons of U_3O_8 in the period 1943 through 1946. The material came from the three major sources of uranium ore known at the time: the Eldorado Mine (Great Bear Lake, Canada), the Shinkolobwe Mine (Katanga, Belgian Congo), and the Carnotite deposits of the Colorado Plateau. Domestic production, however, ceased in 1946. Government exploration activity dominated in the early period; commercial activity picked up in 1953, and government exploration ceased in 1956.

The AEC succeeded the Manhattan Engineering District, and in late 1947 began to buy uranium for the United States Government. The amount purchased reached a peak in fiscal year 1960, when concentrate containing over 34,000 tons of U_3O_8 was delivered to the AEC.

By 1957 it had become evident that the program to encourage exploration and exploitation of domestic uranium had been more successful than expected and, in order to limit its purchase commitments, the AEC announced in November 1958 that only properties which then had valid ore reserves would be eligible for future sales to the AEC. The stretchout program, offered in 1962, was designed to effect better balance between AEC receipts and requirements through 1970 and help provide a continuing industry to supply the anticipated future commercial markets. Now, in the late 1960's, the nuclear power industry is becoming a significant consumer.

2. Definition of Product and Market

This section deals with uranium exploration, development, mining and milling. Basic inputs to this segment of the industry are exploration funds, capital, and labor. The output is yellow cake, a variable complex uranium chemical generally reported in terms of the contained U_3O_8 equivalent. Yellow cake has been sold to the AEC to be processed to UF_6 in which form it can be enriched.

3. Market Structure

In 1967, 124 mining companies produced ore from 368 mines in the United States. Of these companies 15 were integrated producers having ore processing mills. These companies operated 223 mines and produced 92% of the ore; 109

independent mining companies operated 145 mines and produced 8% of the ore. During calendar year 1967, 75 companies actually conducted drilling to find more ore.

Table IV–1 presents a list of most companies currently active in uranium exploration or development drilling activity in the United States. Very few of these firms can be classed as predominantly involved in uranium; those that are, are small. Table IV–2 lists the milling capacity of the companies with uranium ore processing plants. There have been in the past as many as 23 integrated mining and milling companies.

To provide information on market share, listed in Table IV–3 are companies that have entered into stretch-out agreements, and their contracted 1967–70 deliveries. These data indicate that no one company dominates these deliveries; future market shares will depend largely upon which firms discover ore through exploration activity.

With the exception of Babcock & Wilcox, each of the four major integrated reactor manufacturers-fuel fabricators is either already engaged in uranium mining or exploration, or is planning to enter this phase of the industry (G.E., however, is inactive at this time). United Nuclear, the major independent fuel fabricator, is also in uranium mining. Several mining companies are contemplating integrating beyond milling to UF_6 production. Kerr - McGee has announced a plant for production of UF_6 to be in operation in 1970. The company already has facilities for conversion of enriched UF_6 to fuels.

Consolidation has taken place in the mining industry since its early days in the 1950's, and will doubtless continue although the consolidation is unlikely to raise concentration to unsatisfactory levels. In the beginning the deposits worked were on or near the surface, and mining in small units was natural. The AEC offered a steady market, and to encourage production from remote mines, the AEC allowed transportation charges of $0.06 per ton-mile up to a distance of 100 miles for hauling uranium ore to a mill.[1] The AEC also required that each mill save a portion of its capacity to process ore from independents. In some cases the independents sell the ore directly to the mill, and in others, they toll the ore through the mill and sell it as concentrate in order to get the added depletion allowance. The decision depends on ore mining costs.

A number of factors encouraged consolidation. As the industry developed, more money went into exploration, which resulted in major finds. With the development of larger deposits, the mining operation could economically support a mill for concentrating the ore to yellow cake. Since the cost of transporting

1. The AEC ended the transportation allowance for ores on March 31, 1962, and thereafter purchased only U_3O_8 in concentrates at $8 per pound.

TABLE IV–1

COMPANIES ACTIVE IN URANIUM EXPLORATION AND/OR DEVELOPMENT ACTIVITY

Amarillo Minerals, Inc.[b]
Amerada Petroleum Corporation[b]
American Smelting & Refining Company[a,b]
The Anaconda Company[a,b]
Atlantic Richfield Company[a,b]
Atlas Minerals, Div. of Atlas Corp.[b]
Bokum Corporation[a]
Buttes Gas & Oil Co.[a,b]
Can–Fer Mines Limited[a]
Can–New–Mex Uranium Mines Ltd.[a]
Cities Service Minerals Corporation[b]
Cleveland Cliffs Iron Company[a,b]
Climax Uranium Company[a,b]
Continental Materials Corporation[a,b]
Continental Oil Company[a,b]
Cordero Mining Company[a,b]
Cotter Corporation[a,b]
Dawn Mining Company[a]
Dennison Mines (U.S.) Incorporated[a,b]
Duval Corporation[a,b]
Farmers Union Central Exchange, Inc.[b]
Farris Mines[a]
Federal Partners[a]
Federal Resources Corp.[a,b]
Four Corners Exploration Company[a,b]
Getty Oil Company[b]
The Golden Cycle Corporation[b]
Gulf Oil Corporation[a,b]
Hecla Mining Company[a,b]
Homestake Mining Co.[a,b]
Homestake–Sapin Partners[a,b]
Humble Oil & Refining Company[a,b]
Page T. Jenkins[a]
Kern County Land Company[a]
Kerr–McGee Corporation[a,b]
Mobil Oil Corporation[b]
Newmont Mining Corporation[a,b]
Orion Oil Company[b]
Petrotomics Joint Venture[a]
Pinnacle Exploration, Inc.[a]
Ranchers Exploration & Development Corp.[a,b]
Rio Tinto Canadian Exploration Ltd.[a,b]
Shiprock Limited[a,b]
Standard Metals Corporation[a]
The Standard Oil Company[b]
Strategic Minerals Exploration Co.[a,b]
Sundance Oil Company[a,b]
The Susquehanna Corporation[a,b]
Teton Exploration Drilling Co., Inc.[a,b]
Texas Company[a]
Texas Gulf Sulphur Company[a]
Tidewater–Skelly–Getty Joint Venture[a]
Umont Mining, Inc.[b]
Union Carbide Corporation[a,b]
Union Pacific Railroad Company[a,b]
United Nuclear Corporation[a,b]
Utah Construction & Mining Co.[a,b]
Vanadium Corporation of America[a]
Vitro-Marathon Uranium Project[a,b]
Webb Resources, Inc.[b]
Western Nuclear, Inc.[a,b]
Wyoming Joint Venture[b]

a. Companies responding to May 1967 inquiry by GJO
b. Companies responding to April 1968 inquiry by GJO

Source: AEC Grand Junction Office

TABLE IV–2

URANIUM ORE PROCESSING PLANTS – WESTERN UNITED STATES

Company	Location of Mill	Approximate Milling Capacity[a] Tons Ore Per Day
American Metal Climax	Grand Junction, Colo.	500
The Anaconda Company	Grants, New Mexico	3000
Atlas Corporation	Moab, Utah	1500
Cotter Corporation	Canyon City, Colo.	400
Federal–American Partners	Fremont County, Wyo.	900
United Nuclear–Homestake–Partners[b]	Grants, New Mexico	3500
Kerr–McGee Corporation	Grants, New Mexico	6000
Mines Development, Inc.	Edgemont, South Dakota	650
Petrotomics Company	Carbon County, Wyo.	1000
Susquehanna–Western, Inc.	Falls City, Texas	1000
Union Carbide Corporation	Rifle & Uravan, Colo.	1000
Union Carbide Corporation	Natrona County, Wyo.	800
Utah Construction & Mining Company	Fremont County, Wyo.	980
Western Nuclear, Inc.	Jeffrey City, Wyo.	1200
Dawn Mining Company[c]	Ford, Washington	440
Foote Mineral Company[c,d,e]	Shiprock, New Mexico	500
United Nuclear Corporation[c,e]	Grants, New Mexico	1725
		25,095

a. AEC Compilation of Capacity from the most recently published sources.

b. This mill, 70% owned by United Nuclear Corp., processes ores of both Homestake and UNC.

c. Inactive.

d. Ceased operation 6/30/68.

e. Probably will not be reopened.

Source: AEC

TABLE IV–3

COMPANIES ENTERED INTO STRETCH-OUT AGREEMENTS, 1967-1970

Domestic Uranium Processing Mills Participating in Stretch-Out Program	Contracted Deliveries to AEC Under the Stretch-out Program, CY 1967–1970	
	Tons U_3O_8	% of Total
The Anaconda Co., Bluewater, N.M.	3000	9.2
Atlas Corp., Moab, Utah	3500	10.8
Federal–American Partners, Fremont Co., Wyo.	1500	4.6
Foote Mineral Company, Shiprock, N.M.[a]	1400	4.3
United Nuclear–Homestake–Grants, N.M.	4300	13.2
Kerr–McGee Corp., Grants, N.M.	6100	18.8
Union Carbide Corp., Uravan & Rifle, Colo.	3800	11.7
Union Carbide Corp., Globe, Wyo.	750	2.3
United Nuclear, Grants, N.M.	3850	11.9
Utah Construction, Fremont Co., Wyo.	2150	6.6
Western Nuclear, Jeffrey City, Wyo.	2150	6.6
	32,500	100.0

a. Shut down 6/30/68; currently inactive.

Source: AEC

There are in addition five domestic uranium processing mills operating primarily or entirely for private sales:

Climax Uranium, Grand Junction, Colo.
Cotter Corporation, Canon City, Colo.
Mines Development, Inc., Edgemont, S. Dakota
Petrotomics Company, Shirley Basin, Wyo.
Susquehanna–Western, Inc., Falls City, Texas

Source: AEC

U_3O_8 as ore is high, a mill usually is located within 15-20 miles of major ore sources, although this distance varies directly with the grade of ore and the cost of mining.

A feature of the depletion allowance encourages integration of mining and milling. The depletion allowance is calculated on the basis of the value of yellow cake rather than ore. Thus, it is an advantage for the integrated company to utilize its milling capacity with its own ore.

However, the uranium mining and milling industry is unlikely to become concentrated between now and 1980, a period during which the demand for uranium is expected to be increasing rapidly. As a result of the projected demand being substantially greater than known low cost reserves, exploration activity in the United States currently is increasing at a rapid rate. Approximately 75 companies are now involved in exploration and development. These include diversified mining companies, oil companies, uranium and nuclear companies, and some foreign companies.

At the exploration stage no one company or small group of companies can control the industry. The only way this could be done would be to control the land on which exploration is done. But the amount of potential land is so extensive, it is inconceivable that effective control could be obtained. The exploration industry is highly competitive now and only time will tell which of the companies will be successful in finding economic deposits of uranium ore. However, a few will not be successful fast enough and will drop out. Thus, we expect that when the current activity settles down there will be fewer than 75 companies involved in a continuing exploration program.

With a projected demand for almost 40,000 tons of U_3O_8 in 1980, one can hypothesize the number of milling operations that will exist under various circumstances. About 10 mills of the current maximum size mill (around 5000 tons of ore per day) would be required; about 125 mills of the smallest size (400 tons/day). While economics of scale might prove important in planning new mills, this is not always the case, as the mill size must be tailored to the extent of the ore body, mining rate, mine life, ore grade, amenability of ore to processing, mine location, haulage distances, market demand, and so forth.

4. Market Performance

a. Costs and Prices

(a) Price History. Table IV–4 lists the prices paid by the AEC per pound of U_3O_8 equivalent between 1947 and 1967. The trends in domestic concentrate price are evident – from \$7–9 in 1948 to \$12–13 in 1955 and then a gradual decline to \$8 in 1962, where they have remained. Prices paid for foreign concentrate were substantially lower in the early years but have been above

TABLE IV–4

TONS AND COST OF U_3O_8 DELIVERED TO AEC

Fiscal Year	Deliveries (tons)		Average Cost ($/lb)	
	Foreign	Domestic	Foreign	Domestic
1947	1,577	0	$ 2.50	$ 0
1948	1,895	116	3.77	7.14
1949	2,126	115	4.44	8.53
1950	2,740	323	4.18	8.92
1951	3,047	641	4.40	10.36
1952	2,833	825	6.80	11.83
1953	1,905	983	8.22	12.42
1954	3,238	1,451	10.79	12.63
1955	3,799	2,140	11.44	12.72
1956	6,232	4,210	10.88	11.59
1957	8,576	7,584	11.38	10.54
1958	16,132	10,243	11.17	9.56
1959	18,165	15,162	11.12	9.26
1960	18,015	16,566	11.29	8.82
1961	14,502	17,758	11.17	8.53
1962	12,107	17,255	10.50	8.19
1963	11,222	15,760	10.34	7.85
1964	6,071	12,583	10.36	8.03
1965	3,994	11,319	10.38	8.03
1966	2,317	10,109	10.42	8.03
1967	882	9,097	10.49	8.03

Source: AEC

domestic prices since 1957, primarily because of long-term commitments entered into with foreign suppliers with low uranium content ores in the early years of the industry.

Because of the nature of the early finds, and the relative ease of mining, there were many firms in the mining phase of the uranium industry right from the start and ore prices generally paralleled concentrate prices. In 1949, the average ore price to the AEC was $2.95 per pound of contained U_3O_8. This increased substantially in 1952 when the "circular 5 price revision" was instituted to supply sufficient incentive to find and exploit deposits. Between 1952 and 1962 the average price for ore was slightly over $4.00 per pound of contained U_3O_8 in the ore. In 1962 a uniform price of $8 per pound U_3O_8 equivalent in concentrate went into effect. The prices paid for ore under AEC purchase circulars were on a graduated scale depending on the grade of the ore, a premium being paid on ores containing over 0.20% U_3O_8.

(b) Costs. An analysis of actual costs, in the usual form of a breakdown between exploration, mining and milling is impossible for the uranium industry because of the lack of data. Even if data were available, the very wide variations in each of these segments experienced by different companies would make it difficult to develop any meaningful interpretation of the data. In view of this, we have chosen to analyze some actual financial data supplied to the AEC by companies operating in this industry.

The AEC data were divided into five general geographical areas: (1) Grants area, (2) Wyoming and Dakotas, (3) Uravan Mineral Belt, (4) Utah and Arizona, and (5) Other areas. The AEC supplied both balance sheets and overall profit and loss statements for the industry and for each area for the following periods: (1) inception to April 1, 1962, (2) April 1, 1962 to July 1, 1964, and (3) inception to July 1, 1964.

Using these industry figures, we were able to estimate the overall investment, operating costs, profitability, and rate of return by area and for the industry as a whole. We based our analysis on the AEC profit and loss statements for the period April 1, 1962 to July 1, 1964. As a conservative indication of the profitability during this period, we assumed that the invested capital was that at the end of the period. This tends to show the average return as being lower than it actually was due to probable increases in invested capital during the period. Also, since many of the mills had certificates of necessity permitting rapid write-off of the investments, the indicated return is lower than it would otherwise have been due to the higher income tax paid. During the period used for analysis, the industry probably was not operating at a uniform rate. In fact, it probably was at a declining rate of production due to some companies accepting stretchout contracts from the AEC. However, because of the lack of detailed data on this we assumed that the cash flow was constant over the period and thereby developed results which represent the average industry operation over this 27 month period (where appropriate the results were converted into an annual base).

In our analysis, rate of return or profitability is the cash flow after taxes for one year as a percentage of the total invested capital for the year ending July 1, 1964. The industry as a whole showed a rate of return of about 32%, which is equivalent to an investment payout of just over three years. The data used in determining these figures are presented in Table IV-5. The industry's relatively high profitability is further substantiated by the prevalence of stretchout contracts, which the AEC indicates will result in an average price well under the $8 per pound currently being paid.

We can now proceed with an analysis of the effect of rate of return on costs and thereby estimate the future price of uranium to supply power industry requirements in the United States as a function of time.

(c) Future Prices. When projecting the price of U_3O_8 it is essential to analyze the uranium industry as it is constituted today to determine whether (and if so, when) additional investment in any of the stages of industry development (i.e., exploration, development, mining, and milling) will be necessarv to supply the projected U_3O_8 requirements through 1980. If additional investment will be required to maintain a continuous supply of U_3O_8 certain economic criteria (the rate of return) must be used in evaluating this investment. Since the price received for the U_3O_8 produced must permit an adequate rate of return on the capital invested, the required rate of return will be significant in determining the long-term price at which U_3O_8 will continue to be supplied.

There is very little valid historical information available on which to base any U_3O_8 price projections. The pricing that has existed from the inception of the uranium industry (and that will exist through the stretchout) has been based almost entirely on negotiated prices with the AEC and has been quite artificial in terms of the supply-demand situation.

In November 1962, the AEC offered its contractors a stretchout program covering the period 1967 through 1970. At that time, all uranium purchase contracts were scheduled to end by December 31, 1966. Under this program, if a contractor were willing to extend the production and delivery period for the scheduled contract quantity for an additional two years – that is through 1968 – the AEC would agree to purchase in 1969 and 1970 an additional amount of U_3O_8 in concentrates equal to that on which deferral of deliveries was made from the 1963–66 period into 1967 and 1968. The price to be paid for the deferred deliveries would remain at $8.00 per pound as in the existing contracts. The price to be paid for the additional purchases in 1969 and 1970 would be a fixed price per pound of U_3O_8 in concentrates determined by a formula based on allowable production costs during the period 1963–68. The formula price is $1.60 plus 85% of the allowable production cost per pound, subject to a maximum price of $6.70 per pound. The companies stretching out deliveries under the AEC contracts generally reduced production rates by about one-third. The AEC's expressed intention was to obtain a better balance between supply and requirements, and to help provide for a continuing industry to supply the anticipated future commercial market. This situation has already resulted in, and we believe will continue to bring about, a consolidation of companies in the industry and of operations

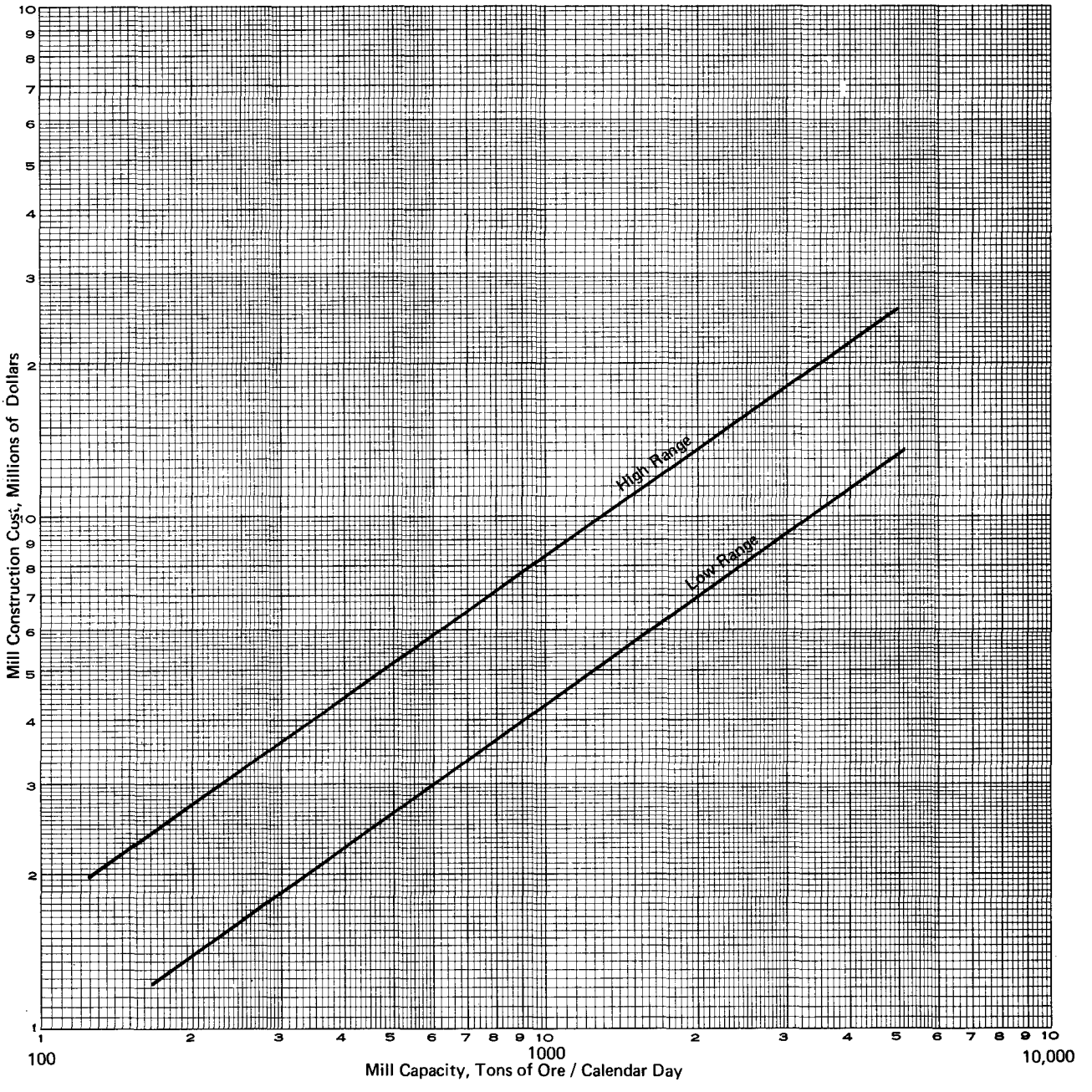
TABLE IV–5

U.S. INDUSTRY STATUS

	Grants Area	Wyoming and Dakotas	Uravan Mineral Belt	Utah and Arizona	Other Areas	Industry-Wide Total
Balance Sheet ($000's) July 1, 1964						
Net Current Assets	$ 60,474	$12,746	$ 8,351	$11,111	$ 2,437	$ 95,119
Net Property	46,786	21,925	2,881	15,687	2,223	89,502
Other Assets	26,045	5,777	5,813	4,161	2,953	44,749
Employed Capital	$133,305	$40,448	$17,045	$30,959	$ 7,613	$229,370
Profit & Loss ($000's except pounds) April 1, 1962 – July 1, 1964						
Net Profit Before Taxes	68,304	26,411	5,368	15,880	8,054	124,017
Depreciation, Depletion, and Amortization	14,190	19,179	12,417	19,628	7,371	72,785
Cash Flow Pretax	82,494	45,590	17,785	35,508	15,425	196,802
Pounds U_3O_8 Sold (000)	25,781	13,627	8,464	14,356	4,499	66,727
Cash Flow[a]/employed Capital	0.275	0.501	0.464	0.510	0.900	0.381
Cash Flow Adjustment for Taxes[a,b]/employed Capital	0.218	0.428	0.429	0.453	0.823	0.321

a. 12/27 of cash flow for period.

b. For purposes of calculation we assumed that the 50% of pretax profit triggering effect on depletion was controlling and that the effective tax rate was 50% on taxable income.



Source: AEC

FIGURE IV–1 URANIUM MILL CONSTRUCTION COST ADJUSTED TO 1/1/66

within companies to enable them to become as efficient as possible while operating under the limited government market. However, the uranium sales price expected for delivery in calendar years 1969 and 1970 under the stretchout program provides some clues on its long-term price.

As demand for U_3O_8 increases and additional investment in mining and milling is required, the industry's companies will seek a rate of return on this new investment commensurate with the risks involved. This risk will be reflected in the return on the investment that each company requires and, in aggregate, will determine the industry price level for uranium. The risk, and consequently the price for a major portion of the requirements, can and probably will be reduced by the development of long-term contracts with the power companies, at least in the early stages.

The current Free World capacity to mine and mill uranium is probably about 30,000 tons U_3O_8 equivalent per year, of which the United States currently represents about 15,000 tons. Although the industry will continue to operate for some time considerably below capacity, we believe it could increase production to a level of about 30,000 tons without significant investment in either mining or milling. The investment in the existing facilities has been written way down for tax purposes because of the uncertainty of the future. Therefore, depreciation charges are likely to be relatively low. On the other hand, new mills are in planning stages. United Nuclear plans to have a new mill at Churchrock, New Mexico, of about 2000 tons-per-day capacity in operation by mid–1970.

New investment in mining and milling (including capitalized average exploration costs) is generally estimated at \$12–14,000 (1968) per daily ton of ore for a 3000-ton-per-day operation, the size most frequently discussed for future operations (see Figure IV–1 for a generalized overall view of mill construction costs). On the basis of five pounds of U_3O_8 per ton of ore milled, this amounts to an investment of \$2400–2800 per daily pound of U_3O_8 equivalent, or \$8.00–9.33 per annual pound of U_3O_8. Since the ore body is much better defined at this point, the risk associated with the mining and milling operations is greatly reduced; the cost of developing a new deposit into a producing property can be estimated rather accurately; and the milling costs estimated even more accurately. Thus, at this stage of the venture, the market is the major risk-associated factor.

For most companies a pretax rate of return of 20–25% for new ventures is acceptable. A pretax rate of return of 20% on invested capital in the uranium industry would amount to capital charges of \$1.60–1.90 per pound of U_3O_8 equivalent; a rate of return of 30% would amount to charges of \$2.40–2.80 per pound. The 30% rate appears to be a reasonable upper limit in this case; any rate materially higher is likely to encourage excessive capital investment that, in turn,

will serve to limit the price, and therefore, the long-term rate of return. A lower rate of return could be justified if long-term contracts were available.

The stretchout pricing structure provides for the AEC to pay 85% of allowable production costs per pound plus a fixed allowance of $1.60. The AEC estimates that this will give U.S. industry an average sales price to the AEC during stretchout of $5.50–6.00 per pound, which is equivalent to allowable costs of approximately $4.60–5.20 per pound ($5.50–1.60/0.85 = allowable costs). Allowable costs are averaged costs (excluding capital charges) over a period of years. We have assumed that the average allowable costs will be those experienced in 1966 and, therefore, the costs must be escalated to reflect the situation in 1968. (We have escalated at 3% per year giving 1968 costs of $4.90–5.50.) Adding the capital charge associated with a 20% rate of return ($1.60–1.90) gives a free market price of $6.50–7.40.

We have already accounted for increased exploration and sales costs and have stated that it is reasonable that these may roughly be balanced by the improved economics of operating nearer to capacity. Thus, although there is a relatively high capital charge associated with a 30% rate of return, the difference between the capital charge and the fixed allowance of $1.60 would add only $0.80–1.20 per pound to the stretchout price to give a range of $7.30–8.30 per pound. We believe that a return of about 20% will be sufficient. This, coupled with the expected variation in capital cost, leads us to estimate a price level of approximately $7.00–7.50 per pound of U_3O_8 equivalent (in yellow cake; 1968 dollars).

The price was considerably lower than this until the industry came to believe that demand was actually growing at the projected rate. Any changes in the growth rate of demand will affect the time at which new capital will be required and, therefore, will affect the time when the price reaches the level of $7.00–7.50 per pound. Assuming that demand follows the projected growth curve, we estimate that the price of U_3O_8 equivalent will be $7.00–7.50 per pound (1968 dollars) through 1980.

(d) Stockpile. There are two major limits on price on the high side: (1) the cost of competitive fuels and (2) the AEC offer to sell enriched uranium on the basis of $8 per pound of U_3O_8 equivalent. We believe the first of these will not play a part in uranium pricing in the foreseeable future, since we believe that adequate U_3O_8 will be discovered at well below the comparable price of coal in one-third to one-half of the United States.

The AEC offer to sell uranium, which has recently been reaffirmed and clarified, will effectively place a limit on the free-market price in the early 1970's. Our projections of a price of $7.00–7.50 in 1968 dollars is equal to a price of

$7.65–8.20 in 1971 (assuming 3%/yr inflation). Although the question of escalation was raised in some of the comments received by the AEC on the Federal Register Notice of November 9, 1967, in its revised statement on uranium supply policies (Sept. 6, 1968) the AEC saw no need to make provisions for escalation (however, the Commission will consider the matter again if conditions warrant). If the AEC price offer remains a fixed price, with no escalation, it will effectively place an $8 limit on the price which any U.S. consumer will pay for yellow cake in the early 1970's.

(e) Imports. AEC import restrictions also may place a restriction on the U_3O_8 price on the low side, although we suspect that were the import restriction lifted the U.S. prices would not fall drastically. Canada appears to be the only major source of uranium that could be offered on a basis competitive with U.S. sources. Although some Canadian sales have been made at prices around $5/lb U_3O_8 equivalent, recently contracts have been about in line with similar U.S. contracts.

Some U.S. mining companies are undertaking a uranium exploration effort overseas to supply either or both the U.S. and overseas market. Most companies are merely maintaining cognizance of the foreign situation until the U.S. import restriction timing is clarified. Once it is known when this restriction will be lifted, more U.S. mining companies will explore overseas seeking lower-cost deposits than may be found in the United States. If such are found, the benefit to the U.S. nuclear industry would be a reduced price for U_3O_8. We believe, however, that there will not be a massive exodus of exploration funds from the United States into overseas territories, nor would we expect those foreign companies currently exploring in the United States automatically to lose interest in continuing their exploration activity. Indeed, the western part of the United States has been proved such a favorable area for uranium that it will continue to receive considerable exploration attention, regardless of the status of the import restrictions.

b. Buying and Selling Policies and Practices

Contractual arrangements vary widely; some are as short as one year, others extend up to 15 years. Table IV–6 presents some recent prices paid for uranium.

Generally, on the longer term contracts some type of escalation clause is included, usually specifically for labor and materials. In at least one case (Canadian), a significant portion of the contract was prepaid in a lump sum, which had the effect of increasing the effective contract value (on a present value basis).

In some instances, contracts are sought on more than one product, such as during the recent SMUD negotiations, during which prices were quoted on yellow cake (U_3O_8 equivalent) and UF_6. The major yellow cake producers have few

TABLE IV–6

SELECTED RECENTLY ANNOUNCED LONG–TERM URANIUM SALES CONTRACTS

Seller	Purchaser	Volume (tons U_3O_8 Equivalent)	Contract Period	Price[a] ($/lb)	Sources
Utah Construction	Nordostschweizerische	400	1967	na	A
	Oskarshamns	485	1968	5.39[b]–6.43[c]	A
	General Electric (2 contracts)	3,500	1968–75		
	General Electric	500	1972	na	C
	SMUD	500	1971	7.37	B,C
United Nuclear	Several	4,650	1969–75	6.14	A
Kerr–McGee	Several	3,500	1968–70	5.88	A
		4,150	1971–73	6.45	A
Dennison Mines	Tokyo Electric	10,500	1969–78	6.40[d]	B,E,
Rio Algom Mines	Kansai Electric	5,000	1969–78	7.10–7.60[e]	B,E,F,
	United Kingdom	11,500	through 1983	7.14	F
	Ontario Hydro	6,000			F

a. In many cases an escalation clause is also included.

b. Weighted average for first four years.

c. Weighted average for last four years.

d. Plus 20 cents per year; two $4 million prepayments, one in 1968, one in 1969.

e. $7.10 for 1969–73; $7.60 for 1974; no set price for 1975–78.

Sources:

A. Prospectus

B. *Nucleonics Week,* February 1, 1968

C. *Nucleonics Week,* December 14, 1967

D. *Nucleonics Week,* January 4, 1968

E. *Metals Week,* September 25, 1967

F. *Northern Miner,* September 21, 1967

qualms about processing their material further, provided the economics are sound. Most of them look on such processing as a defensive investment and will consider it seriously only if the demands of the customers are such that yellow cake becomes difficult to market. Others, notably Kerr-McGee, are taking an aggressive posture on the question and intend to be able to supply whatever the market dictates, without being forced into it by competitive pressures. We believe that in the future the two philosophies will continue in parallel: the oil companies and possibly other high-risk, market-oriented firms will assume an aggressive position; the high-risk, non-market-oriented companies (the typical mining company) will integrate forward only under pressure and not before it is necessary. The market-oriented firms will very likely integrate all the way to UO_2 tolling through the enrichment step if necessary. The typical mining companies will tend to form conglomerates to achieve economies of scale and, more importantly, to support the running of the operation by a technically competent group.

If the current rate of drilling activity continues, we believe adequate U_3O_8 reserves will be discovered to satisfy projected demand. However, because of the time required to develop ore properties, we believe that uranium will not become generally available until the mid–1970's. At this time customers can begin to consider the advantages of spot purchase rather than purchasing under long-term contract. However, the risks associated with spot purchases undoubtedly will predominate in many cases, at least in the early years, and for this reason we believe long-term contracts will prevail in the early years.

5. Uranium Reserves

The size of worldwide uranium reserves has several implications. Inadequate reserves – i.e., either an absolute scarcity or high cost – could influence the development of the nuclear power industry. The size of deposits found and their location also have implications for competition within the raw materials segment of the uranium industry.

We believe that the United States is unlikely – even during the light-water reactor period of rapidly rising demand for uranium – to run short of raw material. However, a great deal of new uranium ore must be located to keep up with demand.

In the exploration efforts of the 1950's, around 8 pounds of U_3O_8 equivalent were developed for each foot of surface exploration and development drilling. A number of factors will influence the future discovery rate. Today's geologists – with increased basic knowledge coupled with a background of experience in uranium exploration – can more quickly eliminate unpromising prospecting land and direct drilling activity to attractive geological settings than was the case historically. On the other hand, there is the possibility that drilling, although better directed, will not be so productive in the future. The need to go

deeper than was necessary in the past to find uranium is undisputed by the industry, and deep holes are more expensive per foot than shallow holes. However, uranium deposition and (natural) concentration is much better understood than it was in the 1950's. This results in more knowledgeable drilling, and more knowledge is gained per hole drilled than was the case earlier. Therefore, less drilling is required to make a rational judgment on an area's potential.

Industry representatives generally contend that a lower finding rate will be experienced in the future. Some suggest rates as low as 2 lbs U_3O_8/ft. We are inclined to believe that the historic rate of slightly less than 8 lbs U_3O_8/ft may continue to be achieved, although there certainly is a major possibility of a significantly lower finding rate. At the present time it is impossible to come to a definite conclusion on this matter. However, in April 1968, the AEC surveyed industry drilling plans for 1968 through 1971. Of the 65 companies responding, 47 provided estimates that totaled about 25 million feet in each year. The other 18 advised that plans had not progressed to the point of making definite estimates. Considering only the planned drilling activity, we estimate that a finding rate of 4 lb/foot or above will satisfy requirements. After considering that the finding rate currently reported by the AEC is slightly less than 3 lb/foot and recognizing the time lags involved in reporting new ore discoveries to the AEC, we believe that the planned rate of drilling activity may be more than sufficient to meet demand.

Current drilling activity generally is in those states with greatest current reserves. Industry opinion is divided as to the probability of locating ore in various areas. The majority indicates that areas such as Texas and Wyoming's Powder River Basin could well become highly important. Although uranium occurrences have been noted in a very large number of areas (the AEC has records of some 7000 individual occurrences), only a few producing areas have become important. Most companies currently undertaking exploration activity believe that major new finds will be made both in areas that have had substantial historical production and in areas that have had little or no production. Kerr–McGee's recent announcement of a major discovery in the Powder River Basin supports the contention that all the ore has not been found yet and that new areas will become important.

Many areas in which uranium occurrences were located during the original uranium boom were not developed into mining districts because insufficient ore was discovered. However, exploration and drilling during this period usually were confined to surface anomalies. The current re-examination and re-appraisal of such areas in the light of improved understanding of uranium geology and ore habits are expected to result in substantial deposits being found close to areas previously abandoned. In fact this has happened in the past. Companies have discarded uranium finds as being unmineable (for instance, because of a probable problem with too much water) only to have others succeed in bringing in a profitable mine. This underlines the importance of having a thorough understanding of mining to be successful in the uranium exploration and mining industry.

B. CONVERSION OF U_3O_8 TO UF_6

1. Product and Market Definition

Conversion of U_3O_8 to UF_6 is a chemical process that is a necessary step in the U.S. commercial fuel cycle. This step refines and then converts the U_3O_8 concentrate into a form that can be used by a gaseous diffusion plant for enrichment. Since light water reactors require enriched uranium for an economical fuel cycle, the future need for conversion is assured.

2. Market Structure

Presently there is one supplier for conversion, Allied Chemical. The Allied plant is located in Metropolis, Illinois, and resumed operation in 1968 after a four-year shutdown. Prior to the shutdown this facility had a capacity of 6000 tons per year. The plant is expected to reach an eventual capacity of 10,000 tons per year. A brief description of the history of this facility is contained in the next section.

Kerr–McGee Corporation has announced plans to build a five- to ten-thousand ton per year plant near Gore, Oklahoma. The plant is scheduled to begin operation by 1970.

Getty and Gulf Oil are studying the feasibility of building plants sometime in the future. The sizes of these facilities and the date of startup have not been announced.

Under the assumption that Kerr–McGee enters the conversion market in 1970 with a 5000 ton per year plant and doubles its capacity by about 1973, one can compare the installed capacity with the projected requirements for conversion services. This comparison is given graphically in Figure IV–2. The projected requirements were calculated assuming an installed capacity of 145,000 Mwe by 1980 and no plutonium recycle. Conversion of foreign ore supplements the domestic market rather substantially. For example, total production is expected to reach 7000 tons in 1969 and 8500 tons in 1970.

This curve shows that overcapacity will probably exist when the Kerr-McGee plant begins operation and will continue for a few years. The entry of a third supplier in the early 1970's would be done at the risk of substantial idle capacity, unless foreign conversion loads are high.

Competition for this foreign ore conversion business is facing U.S. industry with the announced entry of Eldorado Nuclear, Ltd., a Canadian crown corporation. Eldorado expects to have a 2500 ton per year plant of standard design on the line by April 1970. The capital cost is about $10 million, and the plant is designed for expansion, probably in 1972, to 5000 tons.

3. History of the Allied Plant

In 1956 the Atomic Energy Commission entered into a contract (No. AT(40–1)–1198) with Allied Chemical Corporation, which resulted in construction of a facility at Metropolis, Illinois, and delivery of uranium hexafluoride containing 4240 tons of uranium annually for a five-year period expiring March 31, 1964. At the end of this contract the requirements for UF_6 had decreased to a point well below the requirements in 1956. The AEC could not then justify a new contract with Allied, and the plant was shut down. At that time commercial nuclear power was not a big customer for enriched uranium.

With the arrival of economical nuclear power came the need for both enriched uranium and UF_6 conversion services. While the Metropolis plant was idle, Allied management decided to expand the facility. The plant will start up in 1968 at a nominal 7500 tons per year capacity and reach an eventual 10,000 tons per year capacity by 1969.

4. Construction and Operating Costs of a 5000 ton per year Plant

A construction cost estimate will be based on figures published by Allied and Kerr–McGee. The exact cost of the construction of the initial Allied plant has not been made public, but available information indicates a capital cost of $12 million.

When Allied announced its expansion plans in April 1967, it stated that the two stage program would cost $10 million. Since the total expansion will add 5000 tons per year capacity to the plant, it appears that doubling the capacity almost doubles the construction costs.

Kerr–McGee's announcement stated that it plans to spend $25 million on a five- to ten-thousand ton per year plant. Based on the Allied statements, one must assume that Kerr–McGee will spend up to $25 million, a figure which probably relates to a 10,000 ton per year facility. It appears that the capital investment in a 5000 ton per year plant comes to a minimum of $12 million, a figure that will be used in this analysis.

The annual operating costs will be broken down into four categories: (1) capital write-off and debt retirement, (2) labor plus overhead costs, (3) taxes and insurance, and (4) material costs. The approach used in the following paragraphs will be to use information published about the conversion business, and from this information to construct the costs of a 5000 ton per year plant.

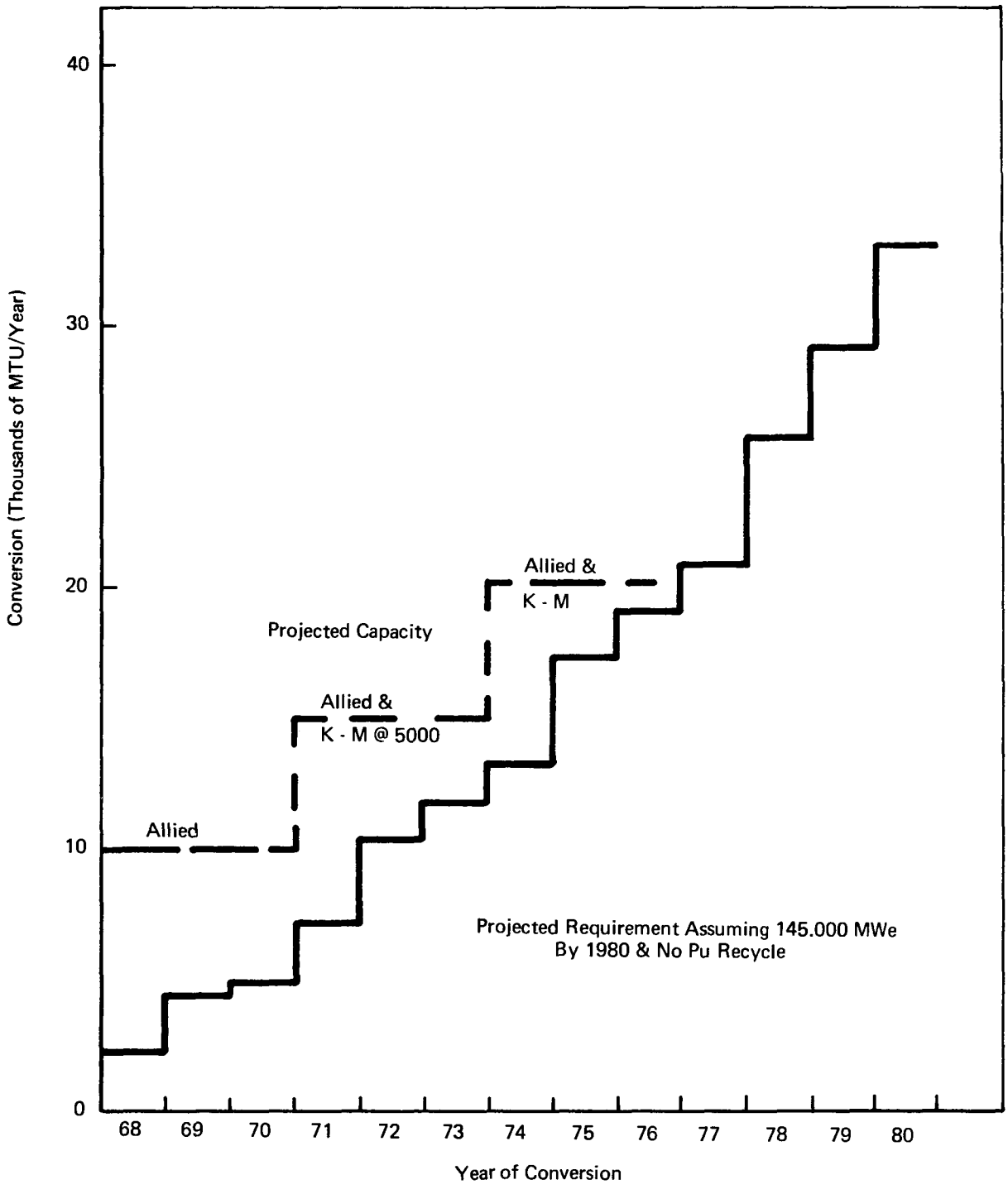


FIGURE IV–2 PROJECTED DOMESTIC CONVERSION REQUIREMENT AND CAPACITY

It is assumed that all financing is done by equity capital, so that annual costs will not include debt retirement. Instead, a rapid (five-year) write-off of plant and equipment will be included in the annual costs. This approach yields an effective 20% capital recovery charge irrespective of any profit.

With respect to the size of the labor force, reference 7, gives 250 people as the total employment of the Allied plant under the AEC contract. This figure includes direct labor, indirect labor, supervisory, and management personnel. Total labor costs including overhead will be based on $15,000 per employee. Taxes and insurance are placed at roughly 2% of the capital investment plus inventories. With a three-month backlog of inventories at $8 per pound of U_3O_8, taxes and insurance came to about $500,000 per year.

The principal contribution to material costs is from fluorine. The effect of the cost of fluorine on the final product cost depends on the process used, among other things. Two-thirds of the fluorine in the UF_6 comes from HF. One-third comes from the reaction of UF_4 and fluorine gas, the latter being produced by electrolysis of HF. It is calculated that the contribution of fluorine to the total cost of UF_6 is $0.20 per pound of uranium.

Table IV–7 summarizes the preceding information and indicates a unit cost of $0.87 per pound of uranium in UF_6 from a 5000 ton per year plant operating at full capacity.

5. Economies of Scale

The published information on capital costs of a conversion plant is not detailed enough for one to predict the economies of scale in this area. The published figures indicate that doubling the capacity doubles plant investment. But it is not at all clear (1) whether these figures represent actual costs, (2) whether cost escalation is a factor in the latest numbers, (3) whether all of the cash quoted for construction by Kerr–McGee will be used, or (4) whether any of the $10 million for Allied's expansion goes into modification of existing facilities. *For this study, economies of scale in plant and equipment will be treated by an exponential scaling law.*

It is expected that there will be savings in labor costs in a larger facility. Most modern chemical plants are well automated and labor requirements are held to a minimum. A UF_6 facility should be representative of a well automated and modern chemical plant.

In order to extrapolate costs from 5000 tons per year, the contribution to unit costs ($/lb U) from both plant and labor will be scaled down by the same exponential factor. (See equation below.)

The cost of fluorine will be treated differently. It will be assumed that fluorine costs between five and ten thousand tons a year are constant. In other words, the raw material costs of fluorine in UF_6 does not vary with plant size. This treatment of raw material costs is analogous to the treatment of fuel fabrication, in which the cost of zircaloy was assumed to be independent of the fabrication plant throughput.

Under these assumptions, conversion costs can be represented by an equation of the form

$$C = C_o \left(\frac{T^{-0.3}}{5000}\right) + C_1$$

C_o = Plant, equipment, labor and overhead at 5000 tons/yr, \$/lb U

T = Plant capacity, STU/yr

C_1 = Fluorine cost, \$/lb U

The exponent of -0.3 is an approximate number which has been found to be typical of U.S. industry. It was not derived specifically for the conversion business.

Using the results of the previous discussion, which are summarized in Table IV–7, the equation becomes:

$$C = 0.67 \left(\frac{T^{-0.3}}{5000}\right) + 0.20$$

For instance, at a throughput of 10,000 tons per year, one finds

$$C = 0.55 + 0.20$$
$$C = \$0.75/\text{lb U}$$

We see from this result that labor plus overhead comprise about 41% of the total cost at 10,000 tons per year. As a point of reference, typical escalation terms in conversion contracts assign a wage escalation to 30% of the price. Escalation of 60% of the price is tied to the wholesale price index for the Industrial Commodities Group, with 10% fixed. Although the split between labor and materials may not be accurately treated by the equation generated above, this equation does give approximate agreement with the breakdown of costs implied by the escalation clause.

TABLE IV–7

CONVERSION COSTS AT 5000 TONS PER YEAR

Facility Cost	$12,000,000
Annual Operating Costs	
Building and Equipment @ 20%	$ 2,400,000
Labor plus Overhead, (250 people @ 15,000/year)	$ 3,750,000
Taxes and Insurance	500,000
	$ 6,650,000
Fluorine ($/lb U)	$ 0.20
Tons/year	5000
Operating Costs:	
Excluding Material	$ 6.65×10^6
Fluorine Cost/year	2.0×10^6
Unit Cost ($/lb U)	~ $ 0.87

Sources: NUS Corporation and Arthur D. Little, Inc.

The public information on prices made available so far apply to the Allied operations. These prices may be summarized as being $1.23 per pound of U at a nominal 5000 tons per year throughput and $1.04 per pound of U from a plant with twice that capacity.

However, it is unlikely that the conversion plants will operate a full capacity for several years (see Figure IV–2). In 1972 the total domestic business available amounts to 11,000 Mtu or slightly more than two-thirds of the industry capacity. Presumably the $1.04 price includes some contingency for the expected low capacity operation. In the mid–1970's it is possible that converters will be able to operate at capacity. If this happens, price reductions below $1.04 per pound of uranium are possible.

The cost of conversion is not the only factor to consider when comparing the relative costs of obtaining UF_6. Other costs are concentrate shipping, concentrate sampling and weighing, and UF_6 shipping. These items are discussed below.

Present AEC practice is to put nearly all UF_6 feed material into their Paducah enrichment facility, across the river from Allied's Metropolis plant. While this location gives Allied an apparent shipping cost advantage over Kerr-McGee, differences in the cost of shipping U_3O_8 must also be considered.

Assuming fluorine gas is obtained by hydrolysis, electrical power is an important cost factor in conversion. The power consumed in electrolysis of HF is 11.3 kw–hr/lb F. A difference of 0.1 mil per kilowatt hour translates into $0.001 per pound of fluorine, which is less than $0.001 per pound of U in the form of UF_6. Since power costs of Gore, Oklahoma and Metropolis, Illinois appear to be almost identical, Allied and Kerr–McGee should have similar production costs.

The capacity of the Kerr–McGee conversion plant exceeds that of Kerr–McGee's own U_3O_8 milling capacity, so that it will be competing with Allied and Eldorado for roughly one half its throughput. We expect that prices will be competitive and reasonably related to costs.

V. NUCLEAR FUEL FABRICATION

A. PRODUCT AND MARKET DEFINITION

Nuclear fuel is offered to utilities in a wide spectrum of comprehensiveness or scope of supply. These scopes tend to cluster around the three shown in Table V-1. In the most comprehensive fuel cycle service (FCS), the utility is virtually relieved of any responsibility or authority in the specification of, contracting for, and delivery, price, and performance risks attendant to the four principal steps of the fuel cycle:

1. Procurement of uranium ore as "yellow cake" (U_3O_8) and the conversion of the U_3O_8 to the gaseous uranium hexafluoride (UF_6) suitable for feed stock to the AEC's gaseous diffusion plants.

2. Providing for enrichment of the uranium through contracts with the AEC.

3. Conversion of the UF_6 to uranium oxide (UO_2), sintering it into pellets, loading the pellets into zirconium tubes to form fuel rods, sealing the tubes by welding, and fabrication of the rods into clusters or fuel elements. Associated with this fabrication step of the fuel cycle is the nuclear and physical design of the fuel (for instance, specification of uranium quantities and enrichments as well as method of assembly) and the warrantying of its performance.

4. Reprocessing the spent fuel after it has been irradiated in the reactor.

When all four of these principal steps are procured from the fuel fabricator (or when the interface with reprocessing is by means of a spent-fuel "buy back" arrangement) the utility usually pays for energy produced. The cost of energy is warranted by the fuel manufacturer – often with escalation and de-escalation clauses covering the fuel fabricator's principal cost elements (purchased materials and labor) and sometimes with provisions for bonuses and penalties if the performance of the fuel differs from expectations at the time the contract is written.

At the other end of the spectrum, the utility itself may purchase each of the four principal components of the fuel cycle (sometimes further dividing its purchases by, for instance, purchasing U_3O_8 from one vendor and having it converted to UF_6 by another). In this case the producer of nuclear fuel may supply only fabrication and related services (step 3).

TABLE V-1

GE's DEFINITION OF TYPES OF FUEL OFFERINGS AND SUMMARY STATEMENT OF ITEMS WARRANTED

NOTE: Only General Electric, of the four light water nuclear steam supply system manufacturers, publishes a nuclear fuel price list. Until October 1967 the GE price list included a comprehensive description of the scope of supply for the three variations typical of the bulk of the nuclear fuel orders that have been placed with any manufacturers. It also gave an example of the complexities attendant to definition of scope of supply and the specification of warranty language. In July 1968 GE replaced this section of its handbook with pages offering only Fuel Fabrication Service. We have shown above only the introductory portion of the earlier General Electric nuclear fuel price list; far more detailed information is available from General Electric upon request.

TYPES OF FUEL OFFERINGS

General Electric is prepared to sell nuclear fuel with three scopes of supply as outlined in this section. The three scopes of supply are best explained with the chart below which defines the responsibilities of the Company and the Purchaser with each type of offering. The three types of fuel offering are FUEL CYCLE SERVICE, INITIAL FUEL SERVICE, and FUEL FABRICATION SERVICE.

Fuel Cycle	Fuel Cycle Service	Initial Fuel Service	Fuel Fabrication Service
	Fuel Cycle Responsibility[1]		
Procurement of U_3O_8	GE	GE	P
Conversion of U_3O_8 to UF_6	GE	GE	P
Enrichment	GE	GE	P
Fuel Design	GE	GE	GE
Conversion UF_6 to UO_2	GE	GE	GE
Fabrication	GE	GE	GE
Operation	P	P	P
Carrying Charges[2]	P	P	P
Spent fuel transportation	GE	P	P
Recovery of uranium, plutonium and other isotopes	GE[3]	P	P
Resale or recycle of reworked products	GE	P	P

[1] GE indicates General Electric responsibility; P indicates Purchaser responsibility.

[2] Carrying charges are defined as inventory carrying charges on fuel while in possession of the Purchaser.

[3] Arrangement for other reprocessor is optional under this scope of supply.

TABLE V-1 (continued)

Fuel Cycle Service

This offering consists of the Company taking responsibility for all fuel cost factors, except for financing during the period the fuel is owned by Purchaser. The Company will provide for procurement of uranium, conversion, enrichment, fuel design, fabrication, and shipping of fuel bundles to Purchaser at an agreed price. Purchaser will buy the fuel from the Company and utilize its heat content over whatever reasonable time period desired. After Purchaser removes the fuel from the reactor upon depletion of reactivity, the Company will repurchase the fuel at the agreed price. The buyback price is adjusted to insure achievement of the Company's warranty on the fuel by means of warranted calculated fuel cost.

Initial Fuel Service

This offering consists of providing for procurement of uranium, conversion, enrichment, fuel design, fabrication and shipping the complete fuel bundles to the Purchaser at an agreed price. The Purchaser owns the fuel while it is in his reactor. Responsibility for the disposition of spent fuel (recovery and sale of uranium and plutonium) remains with the Purchaser.

Fuel Fabrication Service

This offering consists of the design and fabrication of the fuel at an agreed price. Ownership of the uranium and the responsibility for its procurement, conversion, and enrichment, as well as recovery and sale of residual uranium and plutonium remains with the Purchaser and is not included in the Company's scope of supply.

WARRANTIES FOR EACH SCOPE OF SUPPLY

The warranties for each scope of supply take the form of a warranted calculated fuel cycle cost that incorporates a combined warranty on the technical and economic factors for which the Company takes responsibility in the scope of supply. For example, the Fuel Cycle Service warranty covers uranium weight and heat content, fuel bundle mechanical integrity, and uranium and plutonium buyback price; thus, with a firm price for the initial supply of a complete fuel bundle, the Purchaser is at risk for only the inventory charges and proper handling of the fuel during his ownership. Similarly, Fuel Fabrication Service warranty covers the technical factors of the fuel design such as uranium weight and energy content, mechanical integrity, actual isotopic content and quantity of discharged fuel. None of the individual factors are warranted such as heat content, discharged uranium or plutonium, but the combined net dollar value of these factors is warranted in full by means of the warranted calculated fuel cycle cost.

Source: *General Electric Atomic Power Equipment Division Apparatus Handbook,* October 24, 1966, (in effect until October 1967). Section 8803, p. 7. Reprinted with permission.

In characterizing the market, we use the latter more limited fabrication-only definition of the nuclear fuel supply business, because of the technological uniqueness of fuel fabrication and the corresponding technological, manufacturing, financial, and commercial resources required of this business as well as to reflect the utilities' view of what the "good of commerce" is and who the competitors are. Under this definition a firm which offers comprehensive fuel cycle services does so by purchasing on its own account materials and services for the other steps of the fuel cycle as an adjunct to this firm's principal value added.

We also restrict our definition of the market for fuel fabrication to commercial light water reactors above 100 Mwe. This removes from the marketplace perhaps half a dozen firms that have made or currently are manufacturing fuel for nuclear reactors of some type. Many of these are low-power research and development reactors, some are special purpose production reactors operated by the AEC to produce special nuclear materials, and others are for space applications. Although in principal some of these firms have the necessary facilities for dealing with radioactive materials and the technical skills to fabricate fuel elements which can be used in light water reactors, utility customers tend to exclude most of the special purpose fuel fabricators from their lists of acceptable vendors and companies which now supply commercial light water reactor fuel fabrication and do not include special purpose fabricators in their definition of potential com petitors. To be considered as a commercial nuclear fuel supplier, these laboratory-scale fabricators must first produce light water fuel elements which pass utilities' qualification tests and then they usually must build single-purpose facilities capable of volume production.

Under present commercial practice, the fuel fabricator has three major functions:

1. *Design the Fuel* – which extends from the broad thermal and nuclear physics calculations that establish the enrichment and configuration of the pellets within the rods and the rods within the elements, to the engineering and production of detailed shop drawings having the kind of tolerance information that enables a fabrication shop to build the elements. This design process is complex and costly;

2. *Fabricate the Elements* – do the actual factory work, which may or may not include conversions of UF_6 to UO_2 and sinter and grind the pellets to tolerance, but which always includes fabrication, inspection, and assembly into fuel rods.

3. *Warrant* the performance of the fuel in the reactor. Such a warranty covers at minimum factory materials and workmanship, but under present commercial practice it usually also includes guarantees that are related to the basic nuclear and thermal design of the fuel elements and the amount of energy which this fuel will generate.

B. FIRMS AND MARKET SHARES

To date, the four light water nuclear steam supply system manufacturers have captured virtually all of the light water fuel fabrication market. United Nuclear is the only independent to have been awarded reload fuel: its first contract (for Commonwealth Edison's Dresden #1, 200 Mwe GE BWR) was awarded in June, 1966 and will be loaded in five installments from 1968 through 1972; its second (for American Electric Power Company's Donald Cook #2, 1100 Mwe Westinghouse PWR), for two replacement cores to be delivered in segments from 1973 through 1978; its third, for an undetermined quantity (believed by industry sources to exceed one full reload core) of fuel for Consolidated Edison's 1115 Mwe GE BWR(s), delivery in the mid-1970's.

Three other independents, Aerojet General, Gulf General Atomic[1] and the NUMEC Division of Atlantic Richfield have said they are considering entry or have made some initial steps in that direction. However, we found no instances of offers from these firms to the utilities beyond initial, tentative conversations; we found no situations in which these potential independents had made bona fide bids for specific reloads. The Atomics International Division of North American-Rockwell is not currently offering fuel for light water reactors.

Although we saw some recent instances of bidding by an NSSS manufacturer for fabrication of fuel to be used in an NSSS built by a competitor, all significant fuel fabrication so far has been for first core or reloads for reactors of their own manufacture. The single exception was a Westinghouse contract to supply second and third cores for the B & W designed Indian Point #1 reactor. But this is a demonstration round reactor, the basic fuel cycle of which was changed from thorium to uranium in the second and third cores, and is not a truly representative case of one NSSS manufacturer supplying fuel for another's reactor.

The shares of the fabrication market captured by the various NSSS manufacturers is not fully known. In the first place, details on the extent or time

1. Gulf General Atomic, of course, makes commercial fuel offerings with its high temperature gas reactor. Because of the infancy of this reactor type in full-scale commercial competition, there is virtually no information on Gulf-General Atomic's HTGR fuel bids. Likewise, Gulf-General Atomic does not yet have competition in this area, although at least one company has expressed interest in competing for HTGR fuel once a market is established.

duration of reload fuel contracts is not often publicly released at the time the NSSS is awarded. In some cases the contractual provisions of fuel contracts have not been hammered out at the time the NSSS award is announced by the utility. Moreover, many of the contracts contain options (in some cases for fewer reload regions than the base contract; in others, for reloads in addition to the base contract) that further complicate the estimation of market shares. It is difficult to know how strong a force these options will prove to be. Some are vaguely worded; others have definite cancellation provisions. Even of the "iron clad" reload contracts one NSSS manufacturer told us: "It would be commercial suicide for us to insist on a strict legal interpretation of such contracts if the utility were convinced it could do better elsewhere. The utility would want to negotiate a change in contract conditions or escape entirely and we would have to go along."

Table V-2 shows an estimate of the fuel fabrication demand that might be met by the current LWR NSSS participants. These estimates were based on information from our interviews and public announcements, but in some cases the data were slim. These estimates were prepared principally to give an idea of the size of fabrication facilities that the NSSS vendors might require. In fact, some of the indicated demand will be met by independents and perhaps NSSS vendors refueling reactors other than their own.

The *reload* market that is in fact available to independents (or for that matter, available to NSSS manufacturers other than the builder of the reactor to be refueled) is not only small for the next five or six years – because the major portion of the reactors now committed will just be coming on line and will not require reload fuel in this interval – but is also reduced even in the mid-, and potentially the latter, 1970's, by commitments that utilities have already made to their NSSS vendors for reload fuel. Figure V-1 shows our estimates of the fuel commitments made so far. Figure V-1 shows as part of the committed reload business all types of fuel offerings, some for fabrication alone, some including uranium and other segments of the fuel cycle. (Elsewhere, we discuss the uranium and reprocessing commitments that may be contained in the reload fuel commitments.) We have shown the fuel purchasing patterns by the number of reloads which have been committed because it is from such information that uncommitted fuel fabrication demand can be computed. The differences between General Electric and Westinghouse in the 4-8 reload area arises from the number of reloads that constitute the replacement of an entire core. A first core plus six reloads commitment to Westinghouse is equivalent to these cores; a first core plus eight reload commitments to General Electric is also equivalent to three cores because of the slightly different pattern of fueling used for BWR's.

We can speculate on a number of reasons why utilities have made what seem to be extensive forward commitments for fuel, often without having thrown the reloads open to serious competition from independents or other NSSS manufacturers. For example:

TABLE V-2

APPROXIMATE FUEL FABRICATION DEMAND FOR THE FOUR LWR NSSS VENDORS

Metric Tons/Day Demand

	B & W	CE	GE	W
1970	.1	.3	1.3	.7
1975	1.2	.8	4.0	2.8
1980	3.1	2.2	9.2	7.1

For the industry as a whole, initial cores represent the following percent of the total industry fabrication demand shown above:

1970	88%
1975	48%
1980	41%

NOTES: Total fabrication demand for initial and reload cores for the time series which reaches 145 Mwe installed nuclear capacity in 1980. Assumes for convenience no participation by independents and that the four NSSS manufacturers supply fuel solely for new and installed reactors of their own manufacture.

Assumes a one ton/day fabrication facility produces 250 MTU/year.

As noted in the text, independents can be expected to capture some of this market; United Nuclear has already done so.

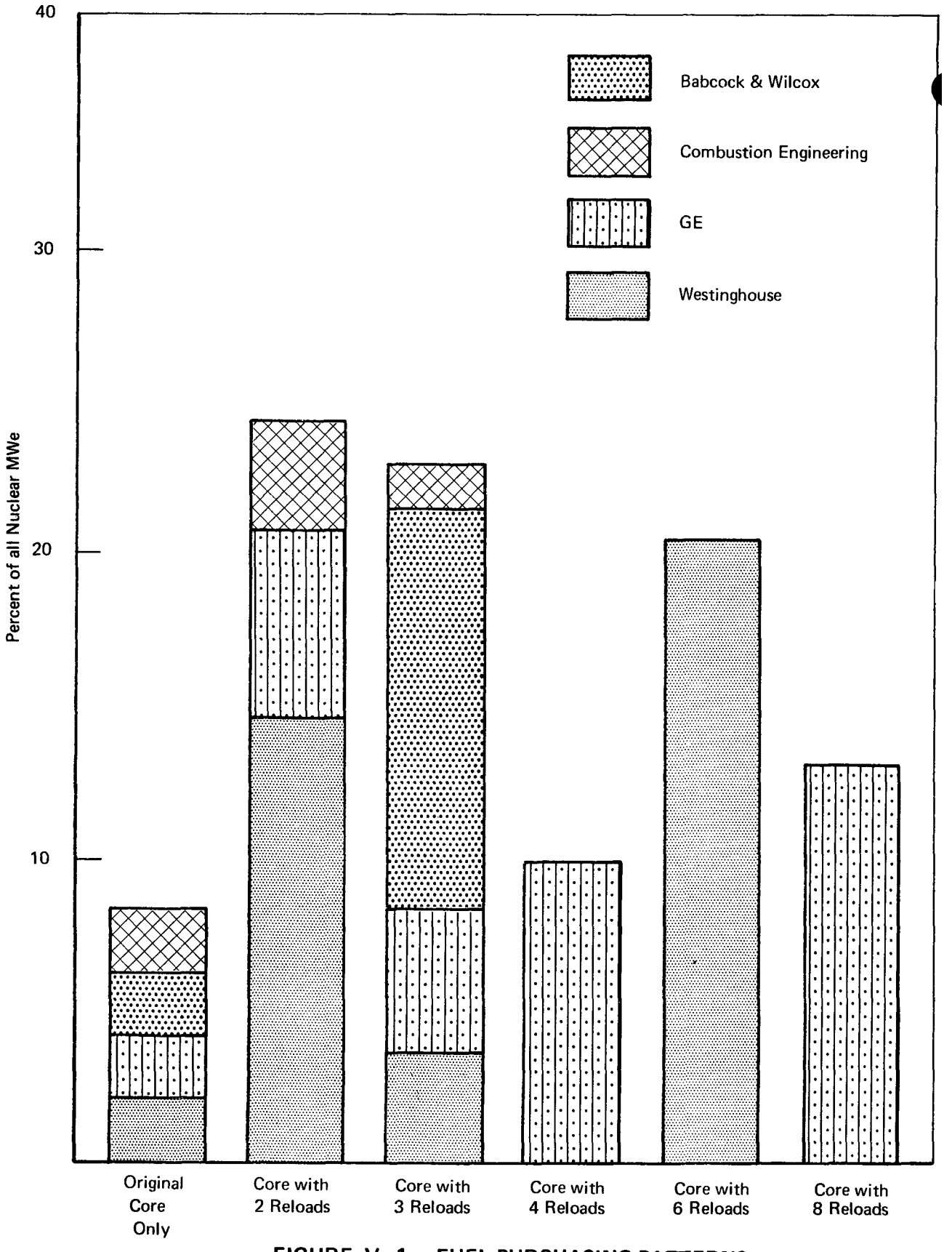


FIGURE V–1 FUEL PURCHASING PATTERNS

- In some cases the fuel fabricator has combined fabrication with what to the utilities were favorable terms for the reload uranium that they would otherwise have had to buy. For those utilities that felt disadvantaged because of a lack of experience in dealing with the uranium miners the NSSS manufacturers' willingness to supply uranium for the reload fuel may have been perceived as both a technical as well as, in some cases, a price advantage.

- Some utilities believe there will be substantial fuel design changes often with the possibility that the design improvements can be retrofitted to nuclear plants of earlier design and they consider the NSSS manufacturers to be the best qualified to undertake these design revisions in the course of providing follow-on fuel. It should be noted that even in the event that additional technical advances are not made, the design of the nuclear fuel undergoes change until the core reaches "equilibrium" – sometimes as long as 10 years after reactor startup.

- In some cases (TVA as a notable example) utilities have felt an obligation to compare guaranteed costs of nuclear fuel for some period of time longer than the life of the initial core in order to satisfy themselves that a valid comparison with long-term fossil alternatives has been made. The growing commercial practice of entering into long-term coal contracts, often from dedicated mines, has led some utilities to believe that they required similarly long contracts for nuclear fuel, even though the underlying technical reasons are not as pressing as they are for coal.

- Perhaps more important than any of these reasons, the utilities have had only limited opportunity to "shop around." Technical personnel at NSSS manufacturers have been so overburdened with design of fuel for their new NSSS that they have not as yet actively pursued the fabrication of fuel for one another's reactors. And to date, independents have been represented only by United Nuclear, a company that has found it necessary to be selective in the number of situations on which it bids. In general, potential independent fabricators have found it difficult to compete actively now for business that will not be available in meaningful quantities until the mid- and latter 1970's. For such companies the

path of business activities during the time from award to fulfillment of a commercial fuel fabrication contract entered into today may lead away from such pursuits altogether and therefore they have not wanted to tie themselves to such contracts.

Thus, most utilities have placed fuel commitments which have included first core as well as some reload business. Figure V-2 shows our estimates of the uncommitted reload fuel business that will be available in the 1970's. Much of this business is uncommitted because the reactors in which the reload fuel will be used have not yet been purchased. In order to see how the continuation of the historical patterns of utility nuclear fuel buying might affect the volume of business available to independent or competing NSSS manufacturers, the figure shows that portion of the currently uncommitted fuel business in the latter 1970's that would go to the NSSS manufacturer if utilities continue to follow past purchasing practices at the time the NSSS is awarded.[1]

C. THE ECONOMICS OF FUEL FABRICATION

As in the case of NSSS we were able to obtain only limited general information from the five active fuel fabricators. However, the economics of nuclear fuel fabrication are more susceptible to analysis from the outside, without access to data from the participants.

First, the process is amenable to study operation by operation, through the building of paper and pencil models of hypothetical plants devoted solely to fabrication of commercial LWR fuel fabrication. Estimating the costs of such a plant differs from estimating the cost of production of nuclear steam supply systems.

Second, the fabrication of commercial light water nuclear fuel is somewhat akin to the fabrication of other nuclear fuel, for instance, the AEC's production reactors and naval reactors. These fabrication process layouts and costs, as well as the costs of fabricating commercial reactor fuel itself, have been the subject of a number of comprehensive studies by AEC National Laboratories and outside AEC contractors.

1. Recent awards suggest a trend toward shorter reload commitments with the initial system but there are no sufficient bids even to talk about a statistically significant change.

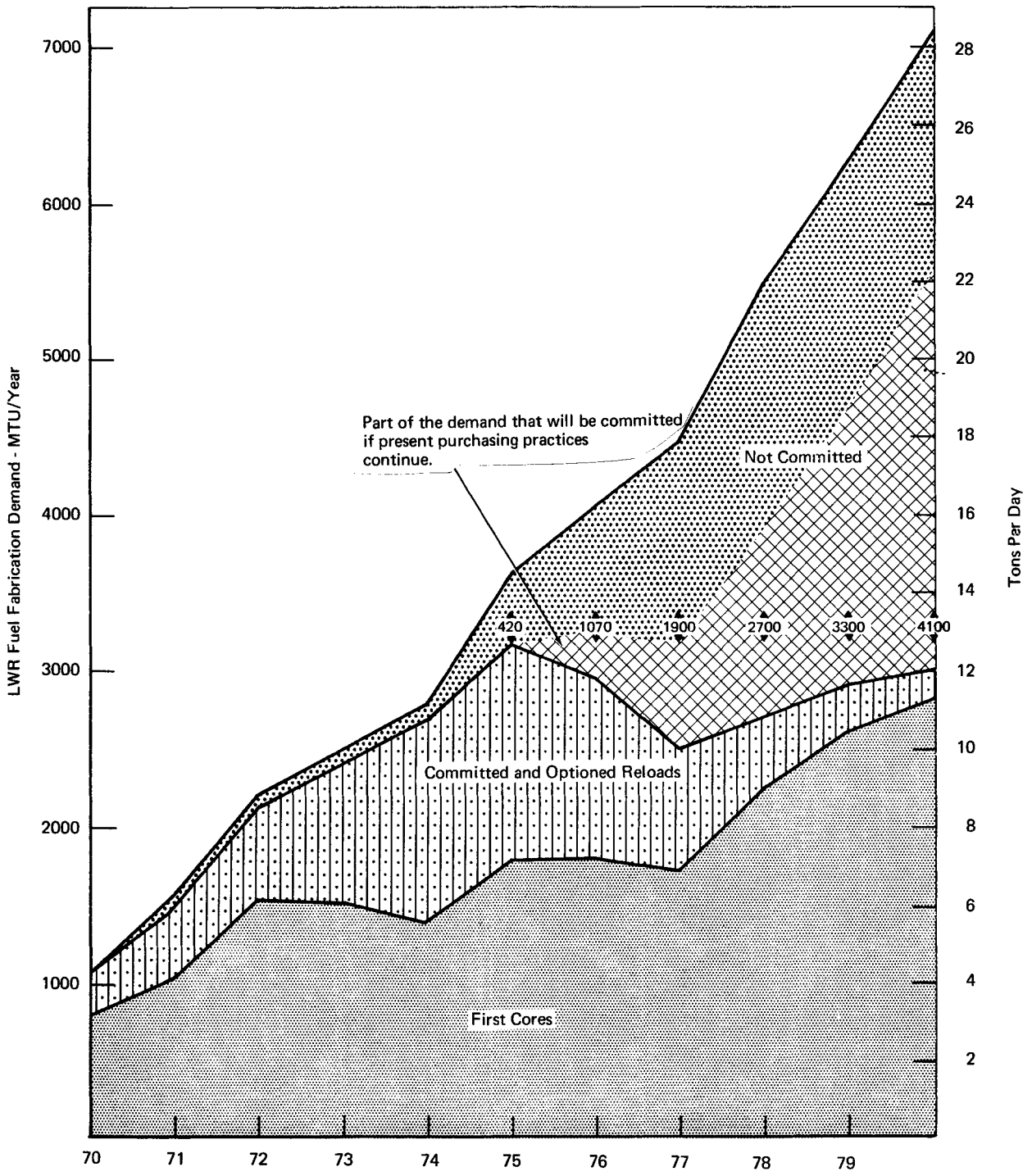


FIGURE V–2 U.S. LWR FUEL FABRICATION DEMAND

One of these, by Batelle Northwest Laboratories (BNWL-273),[1] estimated the costs of fabricating one ton per day of enriched uranium and plutonium enriched LWR fuels using several fabrication processes. A later work[2] (BNWL-SA-1079) estimates scale effects. Costs of fuel fabrication are also reported by A. L. Lotts[3] using higher amortization rates (i.e., approaching those more typical of commercial manufacturing enterprises). Costs of fuel fabrication versus plant size are also discussed in some length in the Jackson and Moreland and S. M. Stoller Associates study,[4] modifying a study by Washburn at Oak Ridge.

As part of this project we have also had fuel fabrication cost estimates prepared by the NUS Corporation. (Elsewhere we discuss some of the similarities and differences among these reports.)

Finally, the costs of LWR nuclear fuel fabrication have been examined in detail by companies with nuclear fuel fabrication experience as part of their review of business opportunities in the commercial fuel market. These studies, some of which we have had an opportunity to examine, are significant not only because they show how some of the most likely potential entrants view the commercial fuel fabrication as a business, but also because they represent informed appraisal by private industry of AEC paper and pencil designs.

1. Capital Costs

Compared with other parts of the nuclear fuel cycle, fuel fabrication has low capital intensity. Estimates for a plant capable of fabricating one ton of contained

1. Burnham, J. G., Merker, L. G. and Deonigi, D. E., *Comparative Cost of Oxide Fuel Elements, Vol. I, II, and III and Appendix,* BNWL-273, July 1966.
2. Keenan, J. P., Goldsmith, S. and De Halas, D. R., *Fabrication and Irradiation Factors Influencing Plutonium Recycle Economics,* BNWL-SA-1079, January 1967.
3. Oak Ridge National Laboratory, *A Comparative Evaluation of Advanced Converters,* ORNL-3686, January 1965.
4. "Current Status and Future Technical and Economic Potential of Light Water Reactors," Wash. 1082.

uranium[1] per day range from $3.8 million to $6 million, with additional increments of capacity once the central facilities have been built, costing about $2-3 million per ton per day.[2] A one-ton-per-day plant will generate $18.75 million worth of fabrication service revenue per year at a fabrication selling price of $75/KgU; $3 to $9 of annual sales per dollar invested in capital facilities.

BNWL-273 estimated space requirements for a one-ton-per-day-pelletized-uranium LWR fuel fabrication facility at 30,500 square feet for active manufacturing; 7000 square feet for offices. This does not include space for conversion of UF_6 to UO_2 powder (under the assumption that this conversion would be done by others and the fabrication plant would purchase UO_2 powder). Also, the BNWL-273 did not include what can broadly be termed corporate overhead costs such as selling, general, and administrative costs; overheads they included were more representative of costs at the manufacturing plant level. (Office space may be underestimated for this reason but this would have negligible impact on the total capital facilities required.)

By way of comparison, Babcock & Wilcox claims it will be spending $2 million to add 40,000 square feet for fuel fabrication facilities devoted to commercial fuel at its Lynchberg (Virginia) site, which now manufactures nuclear fuel for the Navy. Westinghouse has announced that its Columbia (South Carolina) plant, which will be in operation the third quarter of 1969, will have 210,000 square feet of manufacturing space and 50,000 of office and laboratories. This plant, being built at a cost of $20 million (including a 1155 acre site), will carry UF_6 through finished fuel. Westinghouse has said the plant will employ 600 in 1969 rising to 1200 in 1973. (BNWL-273 would have required 135-150 production workers, depending on assumptions on the mix of skills required. Another unpublished study estimated 216 production employees plus 29 general and administrative people for a one-ton-per-day plant.) This is probably at least a five-ton-per-day facility, which would indicate, at most, an average investment of $4 per ton per day (in contrast to an average investment of $2.80 per ton per day derived from an estimate of $6 million for initial capacity and $2 million for each incremental ton per day.)

1. We have chosen contained kilograms of uranium or "heavy metal" (a term used in the case of mixed plutonium-uranium fuels) as the unit of fuel fabrication output, cost, and price. Some studies (i.e., those done by the Battelle Northwest Laboratories) have been based on kilograms of contained oxide. Since such reports spread fabrication costs not only over the weight of the uranium, but also the oxygen, it is necessary to multiply figures based on oxide by 1.13, the ratio of the molecular weight of UO_2 to the molecular weight of uranium metal. It is usual practice of the industry to exclude the contribution made by the zirconium tubing to the weight of the fabricated fuel, although about .25 kilograms of zirconium tubing is used for each kilogram of contained uranium.

2. Relatively low investment in capital facilities per annual sales dollar is required for incremental capacity once a plant of one ton per day has been built to include radioactive material storage and handling equipment, inspection facilities, quality control laboratories, etc.

In doing these analyses it is convenient to formulate return on investment as a cost element which can be added to the factory costs of fabricating 1 KgU of fuel. When a similar charge is made for general and administrative costs, there results a selling price which includes profit. The charge for capital facilities must include the effects of the depreciation tax shield, the owner's required after-tax return on investment, and income taxes.

We are not prepared to suggest a target rate of return on investment for fuel fabrication. In general, it is desirable that the rate of return on any enterprise be equivalent to the rate required by the competitive money markets for ventures having similar risk characteristics. But, such a definition is extremely hard to put into operational terms for an industry undergoing rapid growth, where technological change is significant and frequent, and where even the risks that may be encountered by the entrepreneur are still not well understood. In Table V-3 we have developed three capital-related costs at rates of return which would most probably span the risk adjusted competitive rate, if it could be defined.

This approach to handling fixed charges is similar to that used in many other studies. However, in these studies it is often difficult to determine exactly what has been included in the fixed charge rates. How is depreciation handled? What assumptions on tax are used? What are the time periods? In Table V-3 we have set forth the assumptions we use in developing a capital-related cost which might be applied to fuel fabrication.

Table V-3 is developed for a one-ton-per-day plant similar to that in the BNWL-273 study – comprised of $3.8 million worth of building and $2.2 million worth of equipment. BNWL depreciated buildings in 20 years and equipment on a per element fabricated basis, with most equipment depreciated in 10 years at designed throughput; some in 5 years. In our work we have removed depreciation charges from operating costs and handled them as part of the capital charge because in a discounted cash flow analysis depreciation charges are significant only as a means of reducing the income taxes; they should not carry the connotation of "recovering the original investment" or "making provisions to replace worn out equipment." In Table V-3 we have shown the highest present value of the depreciation tax shield permissible under IRS regulations writing off all equipment in 5 years, buildings in 20, using double declining balance accelerated depreciation for both classes of asset.

In finding a yearly charge which will provide the assumed rate of return we have postulated a plant which will be operable and technologically viable for 10 years and that cash flows from operations will last for 10 years. At that time operations would cease with building and equipment having no residual or scrap value. This somewhat severe assumption may understate the return from the enterprise.

TABLE V-3

TRANSLATION OF CAPITAL AND ENTRY COSTS FOR A 1 TON/DAY LWR ENRICHED URANIUM FUEL FABRICATION PLANT INTO FIXED CHARGE RATES AT SELECTED RATES OF RETURN

(millions of dollars)

	10%	20%	30%
CAPITAL FACILITIES			
Building	$3.80	$3.80	$3.80
Present Value of Depreciation Tax Shield[a]	-0.98	-0.64	-0.48
	$2.82	$3.16	$3.32
Equipment	$2.20	$2.20	$2.20
Present Value of Tax Shield (5-Year Double Declining Balance)	-0.89	-0.75	-0.64
	$1.31	$1.45	$1.56
After-Tax Present Value of Outlay	$4.13	$4.61	$4.88
10 Year After-Tax Annual Cash Flow Needed to Recover this Present Value	$ .64	$1.00	$1.38
Pre-Tax Annual Cash Flow Needed	$1.28	$2.00	$2.76
$/KgU Fabricated at 250 Tons/Year	$5.12/KgU	$8.00/KgU	$11.04/KgU
Yearly Pre-Tax Cash Flow As % of Initial Investment	21%	33%	46%
EXPENSED COSTS OF ENTRY			
Yearly Net Pre-Tax Outflow Assumed	$2.00	$2.00	$2.00
After-Tax	$1.00	$1.00	$1.00
"Present Value" or Amount to Which These After-Tax Outflows Accumulate at Time Operation Starts	$6.41	$8.16	10.34
10-Year After-Tax Cash Flows Needed to Recover This Present Value	$ .99	$1.77	$2.92
Pre-Tax Annual Cash Flow Needed	$1.98	$3.55	$5.84
$/KgU Fabricated at 250 Tons/Year	$7.92/KgU	$14.20/KgU	$23.36/KgU

[a]Twenty-year double declining balance and transfer to straight line; for simplicity, 50% corporate income tax rate. See tables such as Bracken, H. J., Jr., and Christenson, Charles: Tables for the Analysis of Capital Expenditures, Harvard Business School, 1961.

Of course, significant investments in research, engineering, and commercial development activities must be made to launch a viable fabrication business. We have made only rough estimates of the expenditures required for these non-capitalized items, and necessarily, such computations never adequately reflect the "opportunity cost" or the fact that the highly skilled personnel who develop such an enterprise do so in lieu of other profitable activities within their firms.

Our best estimate of the non-capitalized costs to an independent with general nuclear capability entering the field is that net pre-tax outflows in the range of $1-2 million per year would have to be sustained for about 5 years, but this estimate could be low. In calculating the financial performance of such an enterprise we have assumed that the five year tooling up would be followed by the construction of a one-ton-per-day plant and that as the result of previous work capacity would be reached at the end of the first year of operation. Obviously, ours is not a detailed financial projection for such a venture but it provides a rough measure of the dollar magnitudes involved and, more important, gives us a way to see how such startup costs would have to be reflected in fabrication prices to achieve various returns on investment.

The range of startup costs we have assumed is supported to some extent by the NSSS manufacturers' comments on our profile of entry into the NSSS business; in part, by other confidential information given to us in the study; and to some extent, by looking at the magnitude of costs shown in United Nuclear's February 1968 prospectus particularly at those items connected with fuel fabrication rather than uranium mining.

In that prospectus, United Nuclear stated that its research and development center currently employs 175 persons, of whom 75 had engineering degrees, including 40 with graduate degrees. The figure of $40,000 per year per engineer (to cover the man's salary, fringe benefits, and support personnel and materials) would suggest that United Nuclear has expended about $3 million per year in research and development. Some of this has been paid research and development carried out on a contract basis for others. This prospectus shows that in the years 1963-1965 United Nuclear received R & D revenues of $4-4.8 million per year, although by 1966 and 1967 these revenues for research and development had fallen to approximately $2.9 million per year.

Some general and administrative personnel in United Nuclear's Nuclear Fuel Division (presently making naval reactor fuel) who contribute to United Nuclear's ability to compete for LWR fuel have not represented a direct investment attributable to establishing a position in commercial fuel fabrication. Then, too, United Nuclear's orders for fabricating fuel for light water reactors such as Pathfinder and Elk River have provided some offset to the cash outflows for

commercial fuel research and development and general and administrative costs in the early years.

It is more difficult to estimate the costs which an NSSS manufacturer would attribute to entry into fuel fabrication. Much of the initial design engineering, the technical tooling up, is part and parcel of the NSSS design itself. The steam system supplier has an opportunity to amortize selling expenses, special nuclear technical skills and test facilities over a wider base than does an independent entering the business. Moreover, the NSSS manufacturer will undoubtedly supply duplicate or near-duplicate first cores for several reactors of a size and thus enjoy some economies of scale not available to the independent by spreading his engineering costs over more KgU's of fuel produced.

2. Operating Costs

Table V-4 shows our estimates, based on BNWL-273, for the costs of operating an independent fabricating business at the one-ton-per-day level (250,000 KgU per year). The principal adjustments in the ex-plant costs are in the price of zirconium tubing, which we have based on the work reported here and in the contribution of total costs made by interest on money tied up in the enriched uranium while it is undergoing fabrication. To these ex-plant costs we have added engineering, corporate overheads, and the return on capital facilities as well as on money spent to achieve entry into the business.

In Table V-5 we have made a very simple calculation of economies of scale that might be achieved at any point in time. We changed only fixed and semi-variable costs as a function of plant throughput. We have not shown any changes in variable costs; improvements that might come about because of larger scale operations. The large 56% of factory costs of fabricating fuel consisting of purchased materials and services (32% by zirconium tubing, 14.3% by purchased UF_6 to UO_2 conversion) leave relatively little contribution to the total ex-factory cost under the direct control of the fuel fabricator and susceptible to economies of scale.

In their study, "Current Status and Future Technical and Economic Potential of Light Water Reactors," Jackson and Moreland and S. M. Stoller Associates started with the curve shown in Figure V-3 and then also developed costs which might be expected if a 90% learning curve were applied to these total costs (that is, they assumed total costs would drop an additional 10% for each doubling of plant capacity from 1 to 4 tons/day). Benefits from learning are not strictly dependent on volume; they are also dependent on experience and time. In the natural growth of the industry costs could be expected to come down due both to volume and to experience, it being difficult to separate the two causes.

TABLE V-4

BASIC COST COMPONENTS OF 1 KgU OF PWR FUEL FABRICATED IN A 1 TON/DAY FACILITY

	$/KgU		% of Ex-plant Costs (Based on ADL Adjusted Values
	From BNWL	Adjusted By ADL	
Direct Materials			
Zirconium Tubing[a]	$11.64	$17.28	31.9
Conversion UF_6 to UO_2	7.75	7.75	14.3
Other Direct Material (Includes $.46 Zirconium Parts)	5.18	5.18	9.6
Costs of Ordinary Material Due to Rejects	.08	.08	–
	$24.65	$30.29	55.8
Direct Labor	5.45	5.45	10.1
Rework Labor	0.15	0.15	0.3
"Use Charge" on Nuclear Materials[b]	1.84	4.14	7.6
Costs of Nuclear Materials Due to Rejects	2.92	2.60	4.8
Indirect Material and Equipment	7.30	7.30	13.5
Building & Equipment (Depreciation)	0.90	–	–
Occupancy Charge w/o Depreciation	0.96	0.96	1.8
Fixed Manufacturing Costs	1.93	1.93	3.6
Fixed Non-Manufacturing Cost[c]	0.84	0.80	1.5
Working Capital (12%/year)	0.56	0.56	1.0
Ex-plant w/o SG&A, Engineering, and Return on Investment	$47.50	$54.18	100.0
Fuel Management Engineering (6% of Ex-plant Costs)		3.25	
Fuel Design and Warranty for a Specific Reactor Type[d] (12% of Ex-plant Costs)		6.50	
$2 MM/Year G&A (Represents 8.4% of Selling Price)		8.00	
		$71.93	
Capital-Based Charge to Cover Return (at 20% After Tax) on:			
Facilities } See Table V-3		8.00	
Costs of Entry } See Table V-3		14.20	
		$94.13	

TABLE V-4 (continued)

NOTES: [a]BNWL was fabricating a hybrid fuel element representative of the three regions of fuel in the March 1963 Westinghouse "1000 Mwe Closed Cycle Water Reactor Study" (WCAP-2385). It had a tube O.D. of .402 inch, a wall of .022 inch, and active fuel length of 132 inches. The cost of this tubing was estimated at $11.46/KgU. (Tubing at $25/lb zirconium.)

Diablo Canyon (Westinghouse, 1972 startup, 160 Mwe), by contrast, has a tubing O.D. of .422 inch, a wall thickness of .0243 inch, and an active fuel length of 144 inches. This tubing is currently selling for $3 per foot, or approximately $30/lb zirconium. The Diablo Canyon tubing is thicker and we have allowed 12 inches of inactive tubing in each rod. We estimate the contribution of zirconium tubing cost to the fabrication of a fuel element at $17.28/KgU. We estimate an equivalent zirconium tubing cost for BWR's at $10.19/KgU. (However, costs for BWR fuel fabrication cannot be obtained merely by substituting this value for tubing because the size of the pellets is different.)

[b]BNWL based its charge for holding nuclear materials during fabrication on the then-current AEC valuation of $254.30/KgU for 3% enriched material. At that time these materials were leased from the government at a charge of 4.75% per year. We have based our estimate on privately owned 3% enriched material worth of $226.24/KgU ($U_3O_8$ at $7/lb; conversion to UF_6 at $1.04/lb separative work at $26/KgU, tails assay .002) and have used a 12% working capital charge on nuclear material.

[c]This small difference between BNWL and us arises because we have backed out the depreciation of office buildings which appears in the original program as part of the fixed non-manufacturing costs.

[d]These costs are for initial design of the fuel for a single specific reactor and probably decrease to half this value per reactor if the design can be used for additional identical NSSS.

TABLE V-5

COST COMPONENTS OF FUEL FABRICATED IN A 2- AND 4-TON/DAY FACILITY

	Capacity		
	1 Ton (Table IV 4C-4a)	2 Ton/Day	4 Ton/Day
	($/KgU)	($/KgU)	($/KgU)
Ex-plant Costs	54.18	54.18	54.18
Adjustment for Lower Residence time of Nuclear Materials	0	-2.07	-3.11
Adjustment for Shorter Time for Working Capital	0	- .28	- .42
Adjusted Ex-plant Costs	54.18	51.83	50.65
Fuel Management Engineering	3.25	3.25	3.25
Fuel Design (Assume 30% Duplicates)	6.50	5.40	5.40
G & A	8.00	6.00	4.00
	71.93	66.48	63.30
CAPITAL BASED CHARGES (20%)			
Facilities @ $2 MM/Incremental Ton	8.00	5.33	4.00
Costs of Entry	14.20	7.10	3.53
TOTAL	94.13	78.91	70.83

NOTE: This table does not assume any improvement in plant efficiency, but merely spreads fixed and semi-variable costs over a wider base.

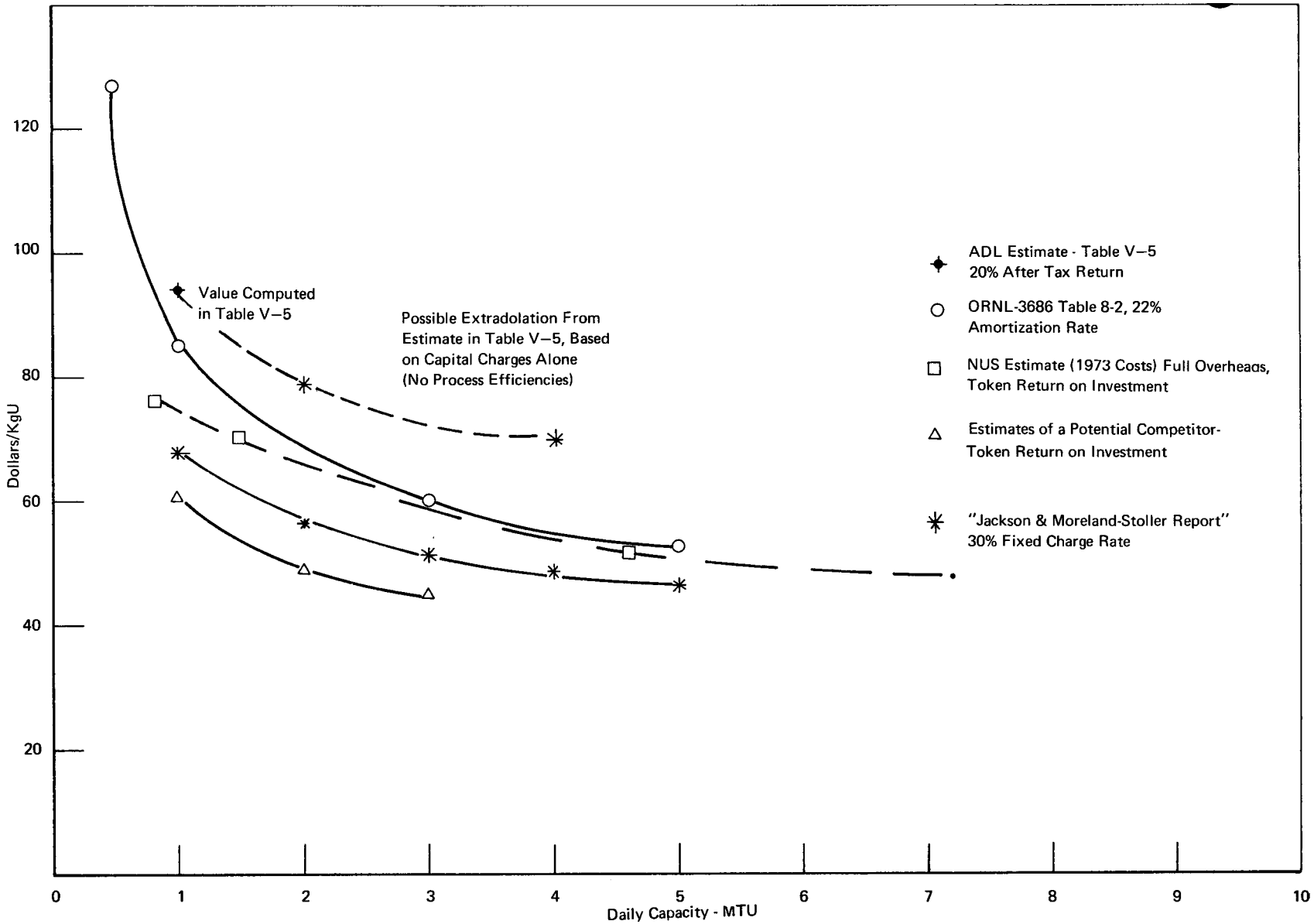


FIGURE V–3 ESTIMATES OF PWR FUEL FABRICATION COSTS
(Would Represent Price at Return Shown)

There will also be some economies of scale for the industry as a whole in addition to those of the individual plant, economies such as reduced zirconium tubing prices as the throughput of zirconium sponge is increased.

Studies by BNWL, by NUS, and some unpublished work we have examined in the course of our project, suggest that fabrication costs are not particularly sensitive to the extent of automation employed. Nor are there significant operating advantages for two- or three-shift-per-day operations (BNWL used an average of 1.43 shifts per day).

Figure V-3 shows estimates from several sources on the cost of fabricating PWR fuel. Costs[1] shown as ADL estimates are similar to those of ORNL-3686 and the NUS estimate when adjusted to include engineering, general and administrative costs, and a return on the independent's investment required to enter the business. In Figure V-3 we have made the notation that some of the cost estimates have included a token return on investment. By this we mean the original investment in capital facilities was recaptured through depreciation charges but, as we have pointed out, this is only a small part of the cash flows needed to yield a rate of return close to one that might be required by the money markets.

There is no way for us to compare these cost estimates with the costs now being experienced by the four NSSS manufacturers or their estimates for their new, larger fuel fabrication facilities. Actual experience may show extraordinary startup expenses, and when experience with production volumes is obtained, the cost experience may depart significantly from the estimates shown in Figures V-3 and V-4.

3. Prices

We have shown in Figures V-5 and V-6 what we believe to be representative prices being quoted today for fuel fabrication to be performed at the time shown. This pricing information must be viewed with considerable caution:

1. It is based on relatively few data points. Information for somewhere between 10 and 20 bid situations were obtained, but they varied considerably in their specificity. We did not obtain sufficient price information to determine whether there has been, over the last several years, an upward or downward price trend for commercial LWR fabrication services.

1. Costs would also represent prices at the rates of return assumed.

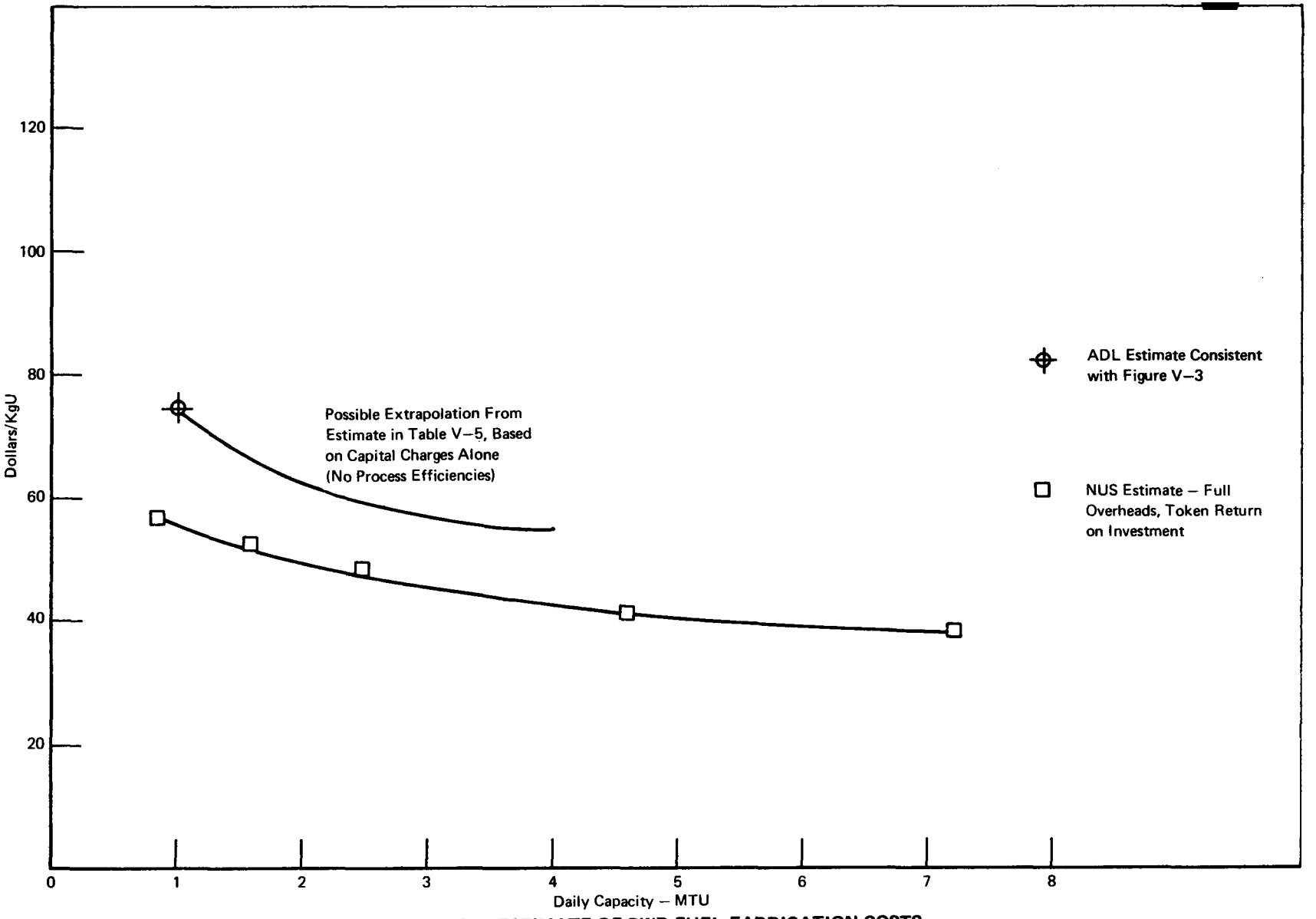


FIGURE V–4 ESTIMATE OF BWR FUEL FABRICATION COSTS
(Would Represent Price at Return Shown)

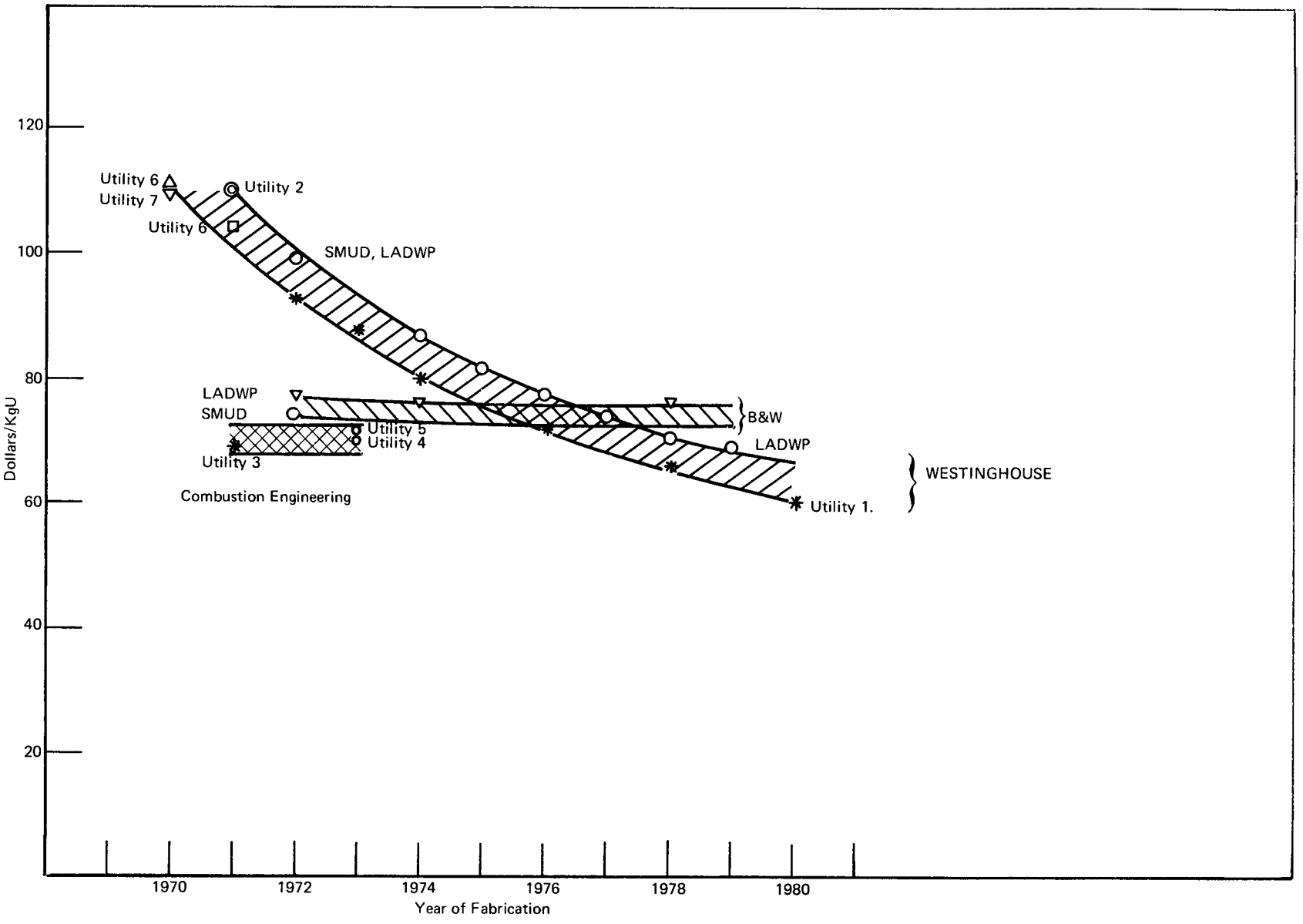


FIGURE V–5 TYPICAL PWR FUEL FABRICATION PRICES

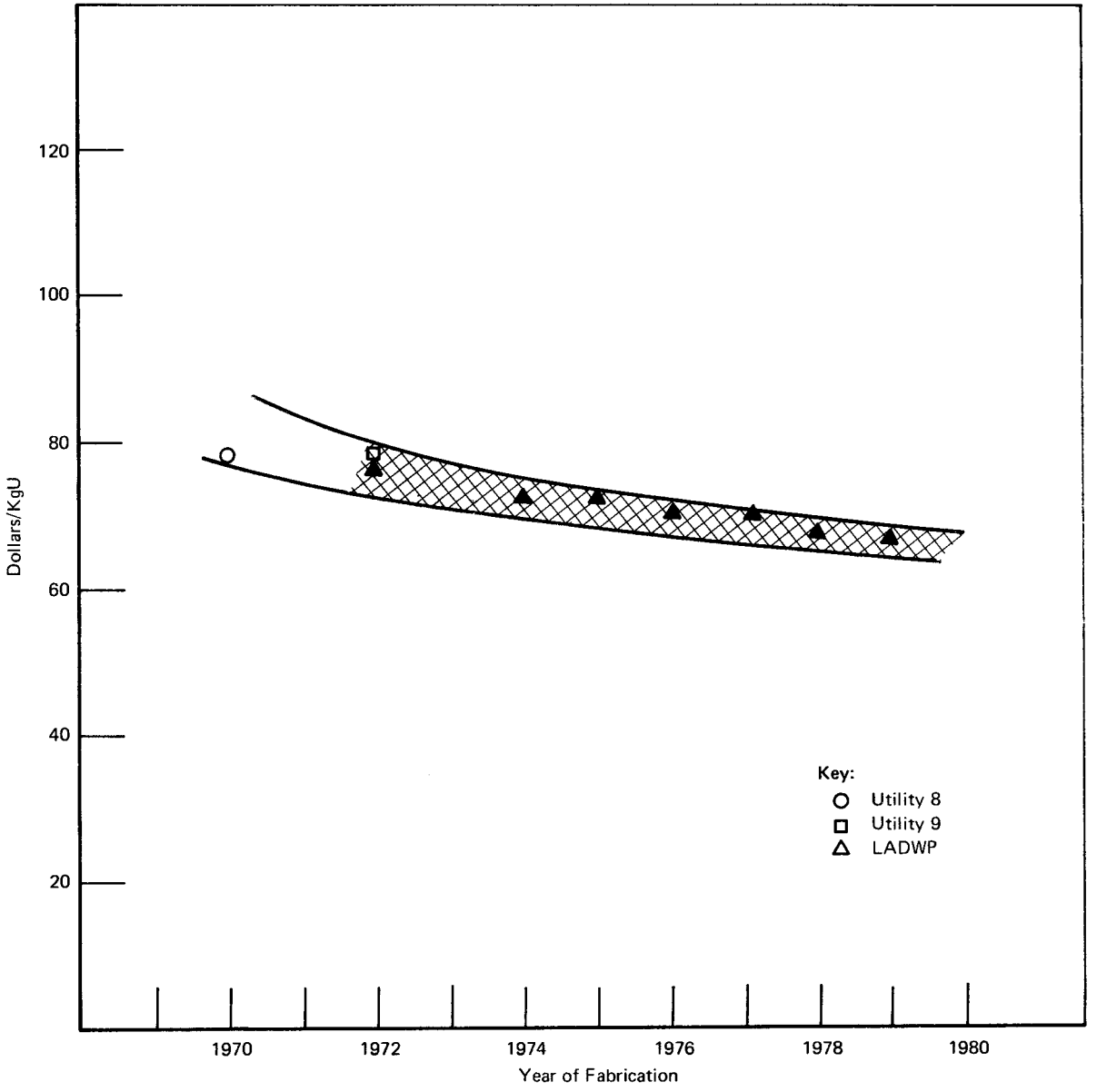


FIGURE V–6 TYPICAL BWR FUEL FABRICATION PRICES

2. Curves in Figures V-5 and V-6 are intended to show the approximate levels of PWR and BWR fabrication prices but more important – differences in pricing philosophy. Westinghouse has considerable taper, or price reduction in future years; GE less taper; and B & W and Combustion appear not to employ the taper concept. It must be remembered that the final cost of generation that the utilities use in selecting equipment and fuel options is made up of the present value of the expected fuel costs as well as the capital cost of the station. Hence, it is not meaningful to look at Figures V-5 and V-6 and say with any certainty that any one of the PWR manufacturers has a competitive edge over the others.

3. The prices do not fall on a single line. We did not find what we considered reliable prices lying outside the band indicated. We regard this spread between the upper and lower prices shown at any time for any single company to be within the range that might be expected because of differences in warranty wording, escalation provisions and, in some cases a discount for a second identical core being sold to a utility. The data do not justify a conclusion that the fabricators were exhibiting price discrimination or favoritism, although that possibility cannot be entirely discounted.

4. Prices and Their Relation to Estimated Costs

Both B & W and Combustion Engineering seem to be pricing their fabrication services at a level at which (if their costs of entry into the fuel portion of their business were similar to those we assumed for an independent) would provide about a 20% after-tax return on investments. It would appear that the Westinghouse tapered price approach would earn substantially higher returns for them, particularly in the next five or six years.

D. BARRIERS TO ENTRY

In summary, the problems confronting an outsider considering entry into the fuel fabrication market are as follows:

- The market is extremely small, almost non-existent, until the mid-1970's when reactors representing the massive orders of 1966-1968 have come on stream and been operated for the year before their first reloading.

- Much of the initial reload business has been committed to the NSSS manufacturer.

- The outsider must expend engineering effort to overcome his lack of information about the system and to carry out the nuclear design. This will necessarily be more expensive for the outsider than for the NSSS manufacturer, who not only has considerable information available from the first core design but also has an excellent opportunity to spread his design efforts over more than one reactor of a given size and design. To an extent utilities can help the outsider overcome these barriers by demanding the appropriate kind of data from the NSSS manufacturers at the time the NSSS is awarded.

- The outsider will be competing against the NSSS manufacturers who, by the mid-1970's, will have achieved significant fuel fabrication throughputs not only for initial cores but also the reloads which they have won.

- Utility attitudes place on the outsider many of the requirements for establishing credibility of engineering competence and commercial relationships required of the NSSS vendor. (These were described in connection with NSSS.)

- Entry into the field of reload fuel fabrication is complicated by the problems of "foreign fuel" warranty. These are not insurmountable but at least at the present time they restrict the range of potential customers to those utilities which are more willing to bear technological and price risks.

Our analysis of fuel fabrication costs, the sensitivity of these costs to volume, and the prices currently being charged in the market suggest that entry into fuel fabrication should be possible, and economically viable, at a throughput of one ton/day. The cost characteristics are nowhere near as sharply declining with volume as reprocessing and the magnitude of the investment needed to reach one ton/day is considerably less. The net result is that financial considerations are not so much of a barrier to entry as is the unavailability of market, the problem of achieving utility acceptance of the product, and the creation of technical ability to carry out engineering which will cause the product to meet its warranty commitments.

E. PLUTONIUM RECYCLE

So far we have confined our discussion to enriched uranium fuel; uranium in which naturally fissile U_{235} has been concentrated to give better nuclear

properties. Fuel having somewhat similar nuclear characteristics can be made by combining plutonium recovered from spent fuel reprocessing with uranium having its natural concentration of U_{235} or perhaps uranium recovered from reprocessing. Use of fuel made this way is known as plutonium recycle.

At present plutonium is not being recycled on a commercial basis. The AEC currently has title to plutonium produced in its leased fuels and has offered to buy back at the beginning of the era of private ownership in 1969 $9.28 per gram plutonium produced in commercial reactors. This buy-back program ends December 31, 1970. At that time operating reactors will be producing a valuable nuclear material which utilities can sell for use in breeder reactors or which, alternatively, can be recycled in lieu of some of the enriched uranium otherwise required for reload fuel.

Plutonium is extremely toxic and considerable additional care and facilities are required to safely fabricate plutonium bearing fuel rods. Glove boxes and remote-controlled operations are used for safe handling of plutonium. These techniques were developed by the AEC in weapons programs and for fuel for specialized research reactors. The problem facing the LWR fuel fabrication industry is, then, to translate applicable portions of this technology to the volume production of commercial fuel at costs which continue to give economic incentive to the use of plutonium. The costs of the special handling of plutonium acrue largely before the individual fuel rod is welded closed. After that the rod can be combined with similar rods containing enriched uranium to form a fuel element which is actually a combination of plutonium bearing and enriched uranium fuel. At that stage in the process, special handling and toxicity considerations are no different from uranium bearing fuel – except that if by any remote chance mechanical damage to the plutonium bearing rods should occur toxicity precautions would have to be taken.

Light water reactors produce far less plutonium than breeders. Under the equilibrium conditions in which all plutonium produced in light water reactors were being recycled, plutonium bearing rods would constitute only 20% or so of the industry's total reload fuel volume.[1] In practice, much of this plutonium will probably be destined for breeders which are able to use it more efficiently than are light water reactors, so plutonium bearing fuel fabrication will be an additional, not supplanting, technology during the 1970's. In addition to the special handling costs of unsheathed plutonium there are additional costs attendant to engineering the mixed fuel elements and in warranting their output. The output of current research and development programs being sponsored by the utilities and the nuclear vendors, as well as operating results from commercial reactors employing experimental plutonium bearing fuel, will be required before fuel

1. The remaining 80% of the rods would contain enriched uranium.

fabricators will know enough about plutonium fuel to specify precisely its performance in terms of cents/million BTU's generated. The extra handling and engineering and warranty costs associated with plutonium recycle are usually regarded as a premium which can be added to the basic cost of designing and fabricating an enriched uranium fuel element. Current estimates are that the fabrication premium for plutonium bearing rods may be over 100% (i.e., the cost of fabricating a plutonium bearing rod would be in excess of 200% of the enriched uranium equivalent). However, the premium applies only to that percentage of the fuel rods which actually contain recycled plutonium. Present costs are due to the extremely low volumes, laboratory scale really, being fabricated for experimental purposes. Some estimates suggest that the fabrication premium may be reduced to 20% when plutonium recycle becomes a standard practice.

F. INFLUENCE ON COMPETITION AMONG FUEL FABRICATORS

It has been argued that technical knowhow to handle plutonium will serve as a means for the entry for some companies not now actively in the commercial light water fuel fabrication business. It is probably fair to say such skills are currently more highly developed in companies other than the NSSS manufacturers. But all five commercial light water fuel vendors have under study or have announced firm plans to develop the capability to fabricate plutonium bearing fuel.

Without denying the possibility that plutonium skills may help outsiders enter, we do not see entry based solely on such skills and, on balance, we are not overly optimistic about the advent of commercial-scale plutonium recycle having a major influence on the structure of the light water fuel fabrication market as it is seen by the utilities, for the following reasons:

- We expect the five enriched uranium fuel fabricators to develop the necessary technology of plutonium fuel fabrication and offer plutonium bearing fuels to utilities. Some of the five may subcontract the plutonium bearing rods but this second tier of fabrication in itself will not necessarily offer utilities a wider selection of vendors.

- The volume of plutonium bearing fuel will be low for the next 10-15 years – perhaps an industry-wide total of one ton per day in 1975, 2.5 tons per day in 1980 (assuming no drain of plutonium to breeders). To offer mixed reload fuel the independent will need to fabricate enriched uranium fuel at a competitive price, since such fuel may represent 20% of his throughput.

- Outsiders, whether or not they know how to work with plutonium, will continue to face the barriers to entry in connection with enriched uranium fuel. Technical skills in dealing with plutonium will not easily translate to commercial advantages meaningful to utility customers, particularly if established fuel fabricators are also willing and able to handle the utility's plutonium.

VI. REPROCESSING OF IRRADIATED FUEL

A. THE MARKET FOR REPROCESSING

1. Product and Market Definition

Reprocessing comprises the series of chemical separations and recovery operations performed on fuel discharged from a nuclear reactor. Reprocessing services are generally offered to electric utilities and other owners of discharged fuel. For the purposes of this study, we have included spent fuel shipment and radioactive waste management as part of the reprocessing segment of the nuclear power supply industry.

2. Background

a. General

Light water reactor (LWR) fuel management will result in ~30 MTU/year discharged per 1000 Mwe installed.

The primary objective of a reprocessing plant is to recover the fissile material remaining in the irradiated or "spent" fuel, decontaminate it from fission products, and convert it into a usable form. The cost of spent fuel reprocessing is about 0.2 mills/kwh (or 10–15% of the total nuclear fuel cycle cost), and could account for over $100 million/year of commercial business by 1980.

After suitable decay cooling and spent fuel shipment, the principal operations are (a) decladding and/or dissolution, (b) chemical separations, (c) product packaging and shipment, and (d) radioactive waste management. Several chemical separations techniques have been studied:[1]

Aqueous
- Solvent Extraction
- Ion Exchange
- Precipitation

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1. M. Benedict and T. Pigford, *Nuclear Chemical Engineering,* McGraw-Hill, New York, 1957, pp. 304-360.

Non-Aqueous

Fluoride distillation
Liquid metal or fused salt extraction
Vacuum volatilization of molten metals
Oxidative slagging
Electrorefining

The technical literature on reprocessing, including spent fuel shipment and radioactive waste management, is extensive. (For example, cf. the *Proceedings of the United Nations Conferences on Peaceful Uses of Atomic Energy* (1956 and 1964), or the list of references, contained in the AEC's bibliographies.[1]

The techniques of aqueous solvent extraction and ion exchange for separation or uranium, plutonium, and fission products have seen extensive development over the last fifteen years, under the sponsorship of the AEC. The so-called Redox and Purex solvent extraction processes (aqueous nitrate feed solution contacted with organic solvent) for low-enriched fuels (e.g., from the plutonium production reactors) and variations of these processes for highly-enriched fuels (e.g., various NRTS and Naval reactor cores) have been in operation at AEC facilities at Hanford, Washington, and Savannah River, South Carolina, as well as the National Reactor Test Station in Idaho. U.S. and foreign reprocessing plants are listed in TableVI–1.

Commercial reprocessing plants that have been announced will also rely heavily on aqueous processing technology – as does the only privately-owned commercial plant in existence today, that of Nuclear Fuel Services, Inc., in West Valley, N.Y. (about 30 miles southwest of Buffalo). This plant is designed to be multi-purpose, with a chop-leach, head-end, Purex-type solvent extraction process, and silica gel absorption for uranium and anion exchange product purification and concentration for plutonium. Other features of the plant are described in detail in the literature[2] and will not be repeated here.

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1. *An Annotated Bibliography of Reprocessing of Irradiated Fission Reactor Fuel and Breeding Materials,* USAEC Report TID-3312, 1958.
2. "Chemical Reprocessing Plant," transcript of a hearing before the Joint Committee on Atomic Energy, Eighty-Eighth Congress, First Session, May 14, 1963. "NSF: First Fuel Reprocessor," *Nucleonics,* December 1965, pp. 26-29.

TABLE VI–1

UNITED STATES AND FOREIGN REPROCESSING PLANTS

Owner	Location	Started	Enrichment	Capacity (kg/day)
USAEC	Hanford, Wash.[a]	1944	Low	N.A.
USAEC	Savannah River, S.C.[b]	1954	High and Low	N.A.
USAEC	Arco, Idaho[c]	1953	High	N.A.
NFS	West Valley, New York	1966	High and Low	1000[d]
UKAEA	Dounreay, Scotland	1958-60	High	10
UKAEA	Windscale, England	1963-66	Low	7000 (est.)
French CEA	Marcoule	N.A.	Low	
French CEA	LaHague	1966	Low	4000 (est.)
Eurochemic	Mol, Belgium	1966	High and Low	400
Japan Atomic Fuel Company	Tokai Mura	1972	Low	700-1000
Indian AEC	Trombay, India	1964	Low	350
GWK	Karlsruhe, Germany	1969	Low	100
PCUT	Rotondella, Italy	1967	Low	15

Notes:

a. Chemical separations facilities operated by Atlantic Richfield-Hanford under AEC contract. Handles spent fuel from (Pu) production reactors.

b. Operated by Du Pont under AEC contract. Handles a variety of AEC-owned fuels.

c. Chemical separations facilities operated by Idaho Nuclear, joint venture of Allied Chemical and Aerojet-General, under AEC contract. Handles Navy, NRTS, and other enriched fuels.

d. Processing rate for low-enrichment LWR fuels.

Shipping of spent fuel (from the reactor site to the reprocessing plant) is usually considered along with reprocessing economics. Because of the intense radioactivity of spent fuel, these shipments require the use of special lead-shielded casks, which are designed for removal of decay heat and provided with neutron-absorbing poisons to prevent criticality accidents. Rigorous government regulations cover their design and use. The cost of shipping spent fuel is probably the only transportation cost of significance in the fuel cycle, amounting to perhaps $4/kgU. This represents about 10% of the cost of reprocessing.

b. Historical Development of a Competitive Reprocessing Industry

The literature relating to the history of commercial reprocessing in the United States is extensive, but less so than that relating to the technology. The U.S. Atomic Energy Commission has had a long interest in this subject, and AEC records embody most of the pertinent details.

A most important historical document is the printed record of the "Chemical Processing Plant Hearing," held before the Joint Committee on Atomic Energy (88th Congress, First Session) May 14, 1963; and materials incorporated therein by reference. We summarize below most of the key events:

1954	The Atomic Energy Act of 1954 was passed.
1956	AEC gave a position paper on role of commercial processing.
1957	AEC announced its conceptual reprocessing plant policy, one effect of which was to place a ceiling on prices for commercial reprocessing. Conceptual plant charges of $15,300 per day (subject to increase) were based on a hypothetical $20 million plant with no allowance for profit. AEC would not offer reprocessing if private prices were no more than 15% above AEC's prices.
1959	The Industrial Reprocessing Group (IRG) was formed.
1961	G.E. proposed use of Hanford for commercial service.
1962	Davison Chemical, a division of W.R. Grace, proposed the first private plant.
	AMF (22%) and Grace (78%) joined to form Nuclear Fuel Services, Inc., which applied for a license to build and operate the first privately-owned multi-purpose reprocessing plant.

1963	AEC signed base-load contract with NFS. IRG members also signed reprocessing contracts. NFS was granted a construction permit.
	Allied and G.E. began fluoride volatility studies.
	AEC announced availability of Commission information on fluoride volatility processes.
1964	GE decided to explore feasibility of a commercial Aquafluor® plant.
1967	Allied Chemical and other firms expressed interest in large plants, AEC and others revised their spent fuel forecasts upwards. GE received construction permit for plant to go on-stream in 1970.
Early 1968	Allied Chemical announced intention to build 5 tons per day Purex-type plant for 1973. Getty Oil and its Skelly affiliate indicate plans to acquire an interest in Nuclear Fuel Services, Inc., from AMF and W.R. Grace. National Lead confirms interest in a 5 ton per day plant for the mid-1970's. Atlantic Richfield also is expected to enter.

The government's position with respect to establishing a competitive reprocessing industry was made quite clear during the 1963 Joint Committee Hearings. Of particular significance is the correspondence between the USAEC and the Department of Justice, especially that exchanged between the AEC's General Counsel and the U.S. Assistant Attorney General, Anti-Trust Division. This correspondence is reproduced as Appendix C. Also of interest was a statement of Commissioner James. T. Ramey, commenting on the proposed AEC base load contract with Nuclear Fuel Services Inc., also reproduced in Appendix C. More recently, at the May 1967 Conference on Fuel Reprocessing held in Augusta, Georgia, AEC Commissioner Ramey commented:

> I think that we might all agree with one or two possible exceptions – that there might be broader competition if chemical companies, rather than equipment firms, or firms with equipment supply capability, furnish reprocessing service. It is the old problem of vertical integration. We want to have firms strongenough to remain viable in a competitive market but not so strong in all phases of the industry that they are able to unduly affect competitors who work only in a portion of the nuclear supply industry.

. . .utilities will play an extremely important part in deciding who will succeed in the reprocessing business.

3. Market Structure

Nuclear Fuel Services' $33 million reprocessing plant went on-stream in mid–1966, with a nominal capacity of 1 MTU per day. Allowing for shutdown and turnaround time, this was estimated to be equivalent to 300 MTU per year, based on contemporary light-water reactor fuel designs. Under its five-year base load contract, AEC will make available about 95 MTU per year of Commission-owned spent fuel (e.g., NPR). In addition, NFS entered into 15-year contracts with each of the IRG utilities, to handle fuel discharged from Dresden-1 (Commonwealth Edison), Fermi (PRDC), Indian Point-1 (Consolidated Edison), Pathfinder (northern States Power) and Yankee (Yankee Atomic). Both "Fermi" and "Pathfinder" are presently shut down. This load was estimated at 40–50 MTU per year, so that NFS started with a load well under plant capacity. However, even if more load were available, initial problems of maintenance and repairs have caused substantial downtime. NFS and AEC statements indicate that the NFS West Valley plant could break even at a load equivalent to about 182 MTU per year, given the minimum standard charges of $31.3 per KgU (subject to increase). (This is computed by a formula: $23,500 per plant day with a minimum number of days specified for cleanup. Note, however, that as long as there is a commercial reprocessing monopoly, the AEC has substantial influence over the prices NFS may charge through the recent extension of its conceptual plant policy authority.)

The most recent ADL forecast of spent fuel from domestic power reactors indicates that NFS's full capacity will not be needed before 1972 when the AEC base load contract will be completed. In the meantime, GE has received a construction permit to build a one-ton per day plant for operation in late 1970. GE has a certain captive market available to it as a result of present fuel contracts with some utilities – notably, TVA. Other companies who plan to enter the market in the 1970's are Allied Chemical (a joint operator of the AEC's reprocessing facilities at the NRTS, Idaho), National Lead, and Atlantic-Richfield (the new operator of Hanford separation works). It is not yet clear what return on investment can be expected from these commercial plant ventures.

Table VI–2 presents ADL estimates of commercial reprocessing capacity through 1980, and Table VI–3 compares private domestic commercial loads and capacities over the same time period; in both tables, we have given a "high" forecast of load for comparison.

TABLE VI–2

ESTIMATED BUILD–UP IN COMMERCIAL SPENT FUEL
PER REPROCESSOR CAPACITY–MTU PER YEAR

Year	NFS[a]	GE	Allied	Nat'l Lead	Atl.-Rich	Total Capacity	ADL High Demand Forecast
1968	300					300	20
1969	300					300	45
1970	300					300	80
1971	300	300[b]				600	165
1972	300	300				600	340
1973	300+	300	300[c]			900	617
1974	300+	300	600			1200-1500	960
1975	300+	300	900	?[d]	[e]	1800-2400	1401
1976	300+	300+	1200	?	?	2400-3000	1715
1977	300+	300+	1500	?	?	3000-3600	2059
1978	300+	300+	1500	?	?	3000-3600	2516
1979	300+	300+	1500	?	?	3600-3900	3088
1980	300+	300+	1500	?	?	3900-4500	3717

NOTES:

a. NFS has contract now for 125 days/year AEC base load, plus 5 utility contracts totaling ~60 days/yr. However, breakeven estimates @ 240 days/yr (80% capacity). Charges are based on total days, comprising processing days @ 1 MTU/day plus turnaround time.

b. Estimated capacity when plant on-stream – in 1971. (Near Dresden, Ill.)

c. Initial operation in 1973, building up to 5 MTU/day in 1977. (Near Savannah River Plant.)

d. Operating details not formally announced.

e. Participation by Atlantic Richfield expected on West Coast (Hanford Complex ?) in this time frame.

Source: Arthur D. Little, Inc., estimates.

TABLE VI–3

PRIVATE DOMESTIC REPROCESSING LOAD VERSUS CAPACITY

Year	Estimated Reprocessing Load[a] (MTU/year)		Estimated Operable Capacity (MTU/year)
	Probable	High	
1968	20	20	300
1969	45	45	300
1970	80	80	300
1971	131	165	600
1972	240	340	600
1973	457	617	900
1974	666	960	1200-1500
1975	943	1401	1800-2400
1976	1344	1715	2400-3000
1977	1744	2059	3000-3600
1978	2116	2516	3000-3600
1979	2602	3088	3600-3900
1980	3088	3717	3900-4500

a. Based upon the AEC forecast of 145,000 Mwe of nuclear generating capacity by 1980.

Source: Arthur D. Little, Inc., estimates.

4. Value Added

The value added in the reprocessing step is approximately the same as the charge for reprocessing, since the costs of materials and utilities are only 10–15% of total costs. In terms of fuel cycle, the value added by this step is the cost to utilities of reprocessing services (including waste management), which is presently about $32 KgU. An additional amount of $4–5/kgU represents the cost of spent fuel handling and shipment.

5. Economies of Scale

The economies of scale in reprocessing are quite striking. This has been confirmed by several early studies, especially those by Farrow at Du Pont; C.M. Slansky, and J.A. McBride at Phillips Petroleum, and, more recently, by the work of J.T. Roberts, W.E. Unger, and the current AEC Reprocessing Task Force headed by W. McVey.[1]

The most important technical factors influencing scale economies are the need for expensive instrumentation, radiation shielding and remote maintenance and handling equipment, regardless of plant size; and plant design to insure against a critical mass of fissile material accumulating anywhere in the process. Indications are that today it costs over $20 million for a minimum viable plant. The nature of the process is capital-intensive, with unit costs inversely proportional to throughput.

Our studies show that the capital costs of reprocessing facilities is expected to vary approximately as the 0.35 power of plant rating; the operating costs are taken as proportional to both the capital cost and the throughput. A good discussion of the influence of burnup, specific power, spent fuel cooling time (generally 120–150 days), the split between processing days and turnaround days, and other factors, has been presented by Roberts.[2]

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1. W. Farrow, Jr., "Radiochemical Separations Plant Study – Part II: Design and Cost Estimates," USAEC Report DP-556, March 1961.

   C.M. Slansky and J. A. McBride, "The Case for Small Reprocessing Plants," *Nucleonics,* September 1962.

   J.T. Roberts, "Spent Fuel Processing Costs," USAEC Report ORNL–3686, pp. 116-132, 1965.

   W.E. Unger, et al, "On-Site Fuel Processing and Recycle Plant Design Study," USAEC Report ORNL–3959, 1967.

2. Roberts, *op cit.*

Figure VI–1 shows the economies of scale for a single operator whose plant has approximately an 80% load factor, and operates roughly 300 days per year (processing and turnaround time); it is based on available data on NFS plant costs, the studies by Roberts in ORNL–3686, plus cost extrapolations to 5 MTU per day. The actual number of processing days is quite important, but it is a function of batch size and turnaround time. We have used NFS and ORNL calculations for the1–, 2–, and 4–MTU per day costs; for the 5 MTU per day, we assumed 200 processing days per year as a reasonable calculation for the purposes of this illustration.

The differences between NFS's current price ($31.3 per kgU) and the values in Figure VI–1 may be explained by several factors:

- Higher capital and operating costs for NFS than originally estimated[1] (but there is little flexibility to raise prices under existing contract and AEC policy).

- An unusually low fixed charge rate (about 12%) is applicable to NFS plants because of very high debt-equity ratio and use of leased N.Y. State facilities.

- NFS is willing to accept a modest return (perhaps even a loss) in the early years in exchange for long-term benefits. It was estimated that the plant capacity could be doubled for an additional $6 million investment, bringing charges down from $23.5 per kgU to $15.2 per kgU for reprocessing. (Adding turnaround changes, to be consistent with Figure VI-1, these would translate into $31.3 per kgU and $20.3 per kgU respectively.)

Based on the JCAE hearings and various conference papers presented by T.C. Runion, president of NFS, we estimate that at full capacity the NFS plant could realize a conventional accounting return of 9–14% after taxes on stockholders' investment. However, it is apparent that the load of a given plant is a function of its price, as well as the total potential load. Furthermore, the price to capture a certain future load is a function of the estimated price competitors will charge, which in turn depends on the size of their plants, their risk-return criteria, cost of capital, and the time value of money.

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1. An AEC-picked review team, in its December 1962 report to the Commission, felt NFS cost estimates were too optimistic. One of the major differences was in number of employees, although NFS specified 45% more than the AEC conceptual plant. Despite several uncertainties, and after a few modifications, NFS, AEC, and IRG signed commercial reprocessing contracts.

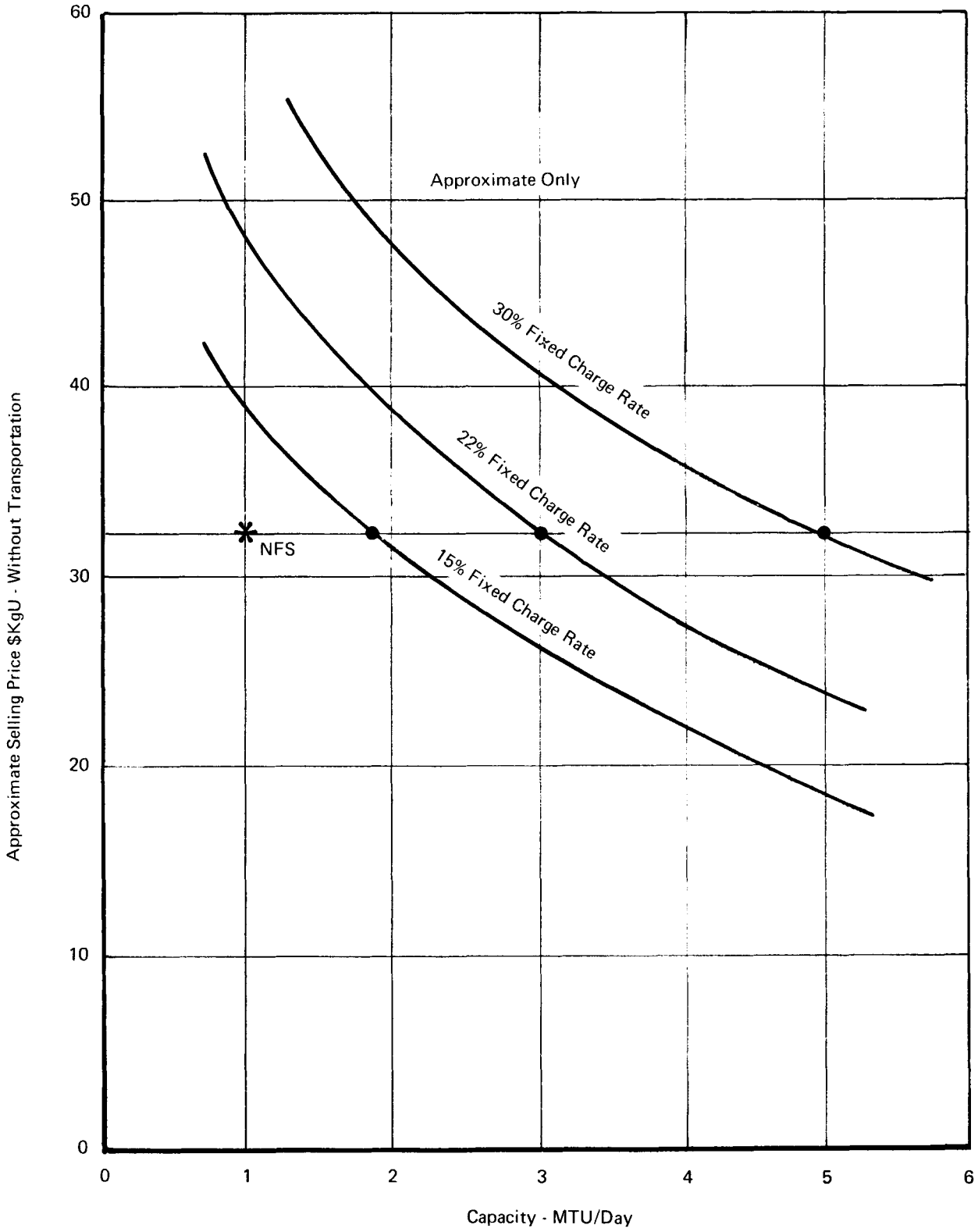


FIGURE VI–1 SINGLE PLANT ECONOMIES OF SCALE

6. Importance of Fixed Charges and Rate-of-Return Criteria

In spite of the pronounced economies of scale *at a given fixed charge rate* (which is a function of the cost of money to the investor), Figure VI–1 shows that the market could see virtually the same price for reprocessing services, depending on the type of firm owning the reprocessing plant, and the size of its plant. Thus, Figure VI–1 suggests that perhaps traditional chemical company financing and venture analysis on a 5-ton per day plant would result in reprocessing charges about the same as for a smaller plant owned by a firm with different risk-return criteria and/or a much lower cost of capital. We may also note here that despite certain similarities, there are major financial and technical differences in reprocessing vis-a-vis traditional chemical industry operations.

B. LIMITS ON PLANT SIZE

1. Site Limitations

Ultimate plant sizes are influenced primarily by proximity to population centers and also by such factors as site climate, geology, hydrology, etc. Site limitations in reprocessing may arise as a result of the maximum permissible release levels of radioactive waste gases in fuel element dissolution and of radioactive tritium contamination in cooling basin waste water. The waste gases of importance here are iodine (I–131), krypton (Kr–85), and to some extent, xenon (Xe–133). Iodine can be removed by scrubbing solution or filter, and the noble gases can be absorbed on carbon or silica gel in stack filters; in practice, off-gas control is affected by a hold-up-and-release procedure. Adequate stream dilution factors can control radioactive tritium contamination, and the plant can also be designed to release tritium (H–3) in gaseous form through the stack.

The NFS plant may be limited to 3 tons per day capacity at the West Valley site. Allied's proposed plant near Savannah River anticipates no difficulties at 5 tons per day. At Oak Ridge, AEC has estimated that 6 tons per day would be feasible.

2. Criticality Limitations

Criticality in reprocessing plants has been controlled by designing equipment with "always safe" geometry, by concentration control, by batch size limits, and by the use of such neutron-absorbing materials as cadmium-covered vessels, borated steels, and soluble poison (e.g., boric acid) in process solutions.

The Reprocessing Task Force has apparently leaned toward a view that a 10 ton per day reprocessing plant would be feasible for light water reactor spent fuels, although some experts feel that parallel lines would be required above 5 tons per day. In either case, it may be that site limitations will restrict plants to 6 tons per day in the U.S.

3. Cost Equation and Relation of Costs to Number of Plants

The capital costs of a reprocessing plant depend upon plant capacity, and the operating costs depends on both plant size and throughput. The nature of reprocessing is such that there is a large dollar investment per dollar of sales. Hence, fixed charges are quite important.

Combining estimates and data in the literature, we have developed an equation for estimating reprocessing costs (R) as a function of fixed charge rate (F), nominal plant size (P) in metric tons per day, and number of processing days per year, (D). Note that the calculated cost includes land, working capital, and return on investment.

$$R(\$/kgU) \simeq \frac{32{,}000\,(F + 0.084)\,(P)^{0.35} + 0.5}{(P)\,(D)}$$

The number of processing days per year (D), must be less than 310 for about an 85% availability factor. Its actual number will depend on the number of plants, as well as turnaround time.

As an illustration of scale economies and the influence of the number of plants, we calculated the costs that would obtain under the assumption that, for any given demand, each plant is either approximately the same size as every other plant or achieves the same total annual throughput. The rationale here is that in the 1975–80 market period, two large plants could probably handle the entire U.S. load without running into site or criticality control problems. The unit cost could be so low in these plants that no smaller plant could compete. This rationale may be an oversimplification, but the calculations will illustrate correctly some of the policy implications with which we must deal.

Table VI–4 presents the results of our calculations given a certain number of plants (N) and using 250–300 days as the upper reasonable limit on (D). Note that F = 15% per year has been used as typical of private utility financing, while F = 30% would be low for typical chemical industry ventures using 100% equity capital. The inherently greater capital intensity of reprocessing suggests some debt financing in the capital structure, and a fixed charge rate of 22% seems a realistic compromise. Using the 22% rate, Table VI–4 shows that, in the 1980 fuel economy, 5 plants each handling 3 MTU per day for 250 days per year would give reprocessing costs of about $20 per kgU.

Three plants operating at 5 tons per day each, however, would give costs of about $14 per kgU. For comparison, note that a one-ton per day plant processing 300 days a year would have costs of $33 per kgU. We estimate that the *marginal* cost of operating the present NFS plant 300 days per year in 1980 will be $21 per kgU at one-ton per day capacity and $15 per kgU at two tons per day (both in constant dollars for comparison). This will obviously influence any NFS decision concerning expansion or retrenchment.

TABLE VI–4

AN ILLUSTRATION OF SCALE ECONOMIES AND THE INFLUENCE OF THE NUMBER OF PLANTS

CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.30				CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.22				CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.15			
N	D	P	R	N	D	P	R	N	D	P	R
1	150.	10.00	18.84	1	150.	10.00	15.02	1	150.	10.00	11.68
1	175.	8.57	17.88	1	175.	8.57	14.26	1	175.	8.57	11.09
1	200.	7.50	17.08	1	200.	7.50	13.63	1	200	7.50	10.61
1	225.	6.67	16.41	1	225.	6.67	13.10	1	225.	6.67	10.20
1	250.	6.00	15.84	1	250.	6.00	12.64	1	250.	6.00	9.85
1	275.	5.45	15.33	1	275	5.45	12.24	1	275.	5.45	9.54
1	300.	5.00	14.89	1	300.	5.00	11.89	1	300.	5.00	9.27
2	150.	5.00	29.28	2	150.	5.00	23.28	2	150.	5.00	18.04
2	175.	4.29	27.77	2	175.	4.29	22.09	2	175.	4.29	17.12
2	200.	3.75	26.52	2	200.	3.75	21.10	2	200.	3.75	16.36
2	225.	3.33	25.47	2	225.	3.33	20.27	2	225.	3.33	15.72
2	250.	3.00	24.57	2	250.	3.00	19.55	2	250.	3.00	15.17
2	275.	2.73	23.78	2	275.	2.73	18.93	2	275.	2.73	14.68
2	300.	2.50	23.08	2	300.	2.50	18.37	2	300.	2.50	14.26
3	150.	3.33	37.96	3	150.	3.33	30.15	3	150.	3.33	23.32
3	175.	2.86	35.99	3	175.	2.86	28.60	3	175.	2.86	22.13
3	200.	2.50	34.37	3	200.	2.50	27.31	3	200.	2.50	21.14
3	225.	2.22	33.00	3	225.	2.22	26.23	3	225.	2.22	20.30
3	250.	2.00	31.82	3	250.	2.00	25.30	3	250.	2.00	19.59
3	275.	1.82	30.80	3	275.	1.82	24.48	3	275.	1.82	18.96
3	300.	1.67	29.89	3	300.	1.67	23.76	3	300.	1.67	18.41

TABLE VI–4 (Continued)

CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.30				CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.22				CALCULATIONS FOR 1975–1976 FIXED CHARGE RATE = 0.15			
N	D	P	R	N	D	P	R	N	D	P	R
4	150.	2.50	45.66	4	150.	2.50	36.25	4	150.	2.50	28.02
4	175.	2.14	43.29	4	175.	2.14	34.37	4	175.	2.14	26.57
4	200.	1.88	41.33	4	200.	1.88	32.83	4	200.	1.88	25.38
4	225.	1.67	39.68	4	225	1.67	31.52	4	225.	1.67	24.38
4	250.	1.50	38.26	4	250.	1.50	30.40	4	250.	1.50	23.51
4	275.	1.36	37.03	4	275.	1.36	29.42	4	275.	1.36	22.76
4	300.	1.25	35.93	4	300.	1.25	28.55	4	300.	1.25	22.09
5	150.	2.00	52.71	5	150.	2.00	41.83	5	150.	2.00	32.31
5	175.	1.71	49.96	5	175.	1.71	39.66	5	175.	1.71	30.64
5	200.	1.50	47.71	5	200.	1.50	37.87	5	200.	1.50	29.27
5	225.	1.33	45.80	5	225.	1.33	36.36	5	225.	1.33	28.10
5	250.	1.20	44.16	5	250.	1.20	35.06	5	250.	1.20	27.10
5	275.	1.09	42.73	5	275.	1.09	33.93	5	275.	1.09	26.23
5	300.	1.00	41.46	5	300.	1.00	32.93	5	300.	1.00	25.46
CALCULATIONS FOR 1980				CALCULATIONS FOR 1980				CALCULATIONS FOR 1980			
2	200.	9.25	14.97	2	200.	9.25	11.96	2	200.	9.25	9.32
2	225.	8.22	14.39	2	225.	8.22	11.49	2	225.	8.22	8.96
2	250.	7.40	13.88	2	250.	7.40	11.09	2	250.	7.40	8.66
2	275.	6.73	13.44	2	275.	6.73	10.75	2	275.	6.73	8.39
2	300	6.17	13.06	2	300.	6.17	10.44	2	300.	6.17	8.15

TABLE VI–4 (Continued)

CALCULATIONS FOR 1980 FIXED CHARGE RATE = 0.30				CALCULATIONS FOR 1980 FIXED CHARGE RATE = 0.22				CALCULATIONS FOR 1980 FIXED CHARGE RATE = 0.15			
N	D	P	R	N	D	P	R	N	D	P	R
3	150.	8.22	21.33	3	150.	8.22	16.99	3	150.	8.22	13.19
3	175.	7.05	20.23	3	175.	7.05	16.12	3	175.	7.05	12.53
3	200.	6.17	19.33	3	200.	6.17	15.41	3	200.	6.17	11.98
3	225.	5.48	18.57	3	225.	5.48	14.81	3	225.	5.48	11.51
3	250.	4.93	17.92	3	250.	4.93	14.29	3	250.	4.93	11.11
3	275.	4.48	17.35	3	275.	4.48	13.84	3	275.	4.48	10.77
3	300.	4.11	16.84	3	300.	4.11	13.44	3	300.	4.11	10.46
4	150.	6.17	25.61	4	150.	6.17	20.38	4	150.	6.17	15.80
4	175.	5.29	24.29	4	175.	5.29	19.34	4	175.	5.29	15.00
4	200.	4.63	23.21	4	200.	4.63	18.48	4	200.	4.63	14.34
4	225.	4.11	22.29	4	225.	4.11	17.75	4	225.	4.11	13.78
4	250.	3.70	21.50	4	250.	3.70	17.12	4	250.	3.70	13.30
4	275.	3.36	20.81	4	275.	3.36	16.58	4	275.	3.36	12.88
4	300.	3.08	20.20	4	300.	3.08	16.10	4	300.	3.08	12.51
5	150.	4.93	29.53	5	150.	4.93	23.48	5	150.	4.93	18.19
5	175.	4.23	28.01	5	175.	4.23	22.28	5	175.	4.23	17.26
5	200.	3.70	26.75	5	200.	3.70	21.28	5	200.	3.70	16.50
5	225.	3.29	25.69	5	225.	3.29	20.44	5	225.	3.29	15.85
5	250.	2.96	24.78	5	250.	2.96	19.72	5	250.	2.96	15.29
5	275.	2.69	23.98	5	275.	2.69	19.09	5	275.	2.69	14.81
5	300.	2.47	23.28	5	300.	2.47	18.53	5	300.	2.47	14.38

Note: This table presents calculations of R in $/kg for the equation in the text, R = f (D,P,F). In each block of calculations, throughput is constant, i.e., $P_j D_j = M/N$, where:

N = The number of plants serving market
D = Number of days of operation per year
P = Nominal capacity of each plant, MTU/day
F = Fixed charge rate applied to the investment
M = Total demand, MTU/year, estimated at 1500 metric tons in 1975–1976 and 3700 metric tons in 1980

and the subscript j denotes a particular plant.

The table presents idealized values of R for various numbers of competing plants at the same F; or alternatively, indicates R for specified values of F, P, and D.

4. The Reprocessing Investment Decision

Figure VI–2 illustrates the striking economies of scale that are possible in reprocessing, assuming the plant owner makes use of a reasonable amount of capacity. Table VI–4 illustrates the impact of the number of competing plants on capacity utilization and reprocessing charges.

Thus, reprocessing is an activity in which greater competition does not necessarily result in lower charges for services. This is due to the sensitivity of costs to throughput handled (market capture), as well as the sensitivity to fixed charges. The lower the throughput and the higher the fixed charge rate, the higher must be the charge for reprocessing.

A firm contemplating entry into reprocessing will have to make assumptions about its probable market capture; and it should also select an "economic" plant size and engage in preliminary discussions with potential customers. It will also have to estimate the load build-up, plant availability factor, etc., in order to calculate the financial outcome of such a venture. A discounted cash flow analysis can be performed to indicate the internal rate of return, which is the discount rate (r) producing zero net present value for the investment opportunity.[1] This will yield the internal rate of return corresponding to a given price. When the cost of capital is high, the D.C.F. calculation for reprocessing offers an important refinement to the analysis in Table VI–4, which employs a uniform fixed charge rate. This occurs because of the effect of the time value of money on the heavy early cash outlays and the relatively slow buildup in offsetting cash inflows from a reprocessing plant.

We have performed such an analysis for the cases of one-ton per day and 5-ton per day plants. The capital and operating costs were estimated by us, based on the references already cited. The key assumptions are that

1. A one-ton per day plant will cost $32 million current dollars; a 5-ton per day plant, $56 million.

2. The number of processing days builds up from 100 per year in the fifth year to 300 per year in the ninth year; it will remain at that figure until the 16th year and then decline to zero in the 20th year, when the plant is shut down and scrapped.

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1. Solving the equation, Net P. V. $= \sum_{i=1}^{n} \frac{\text{net cash flow in year i,}}{(1+r)^i}$ for (r).

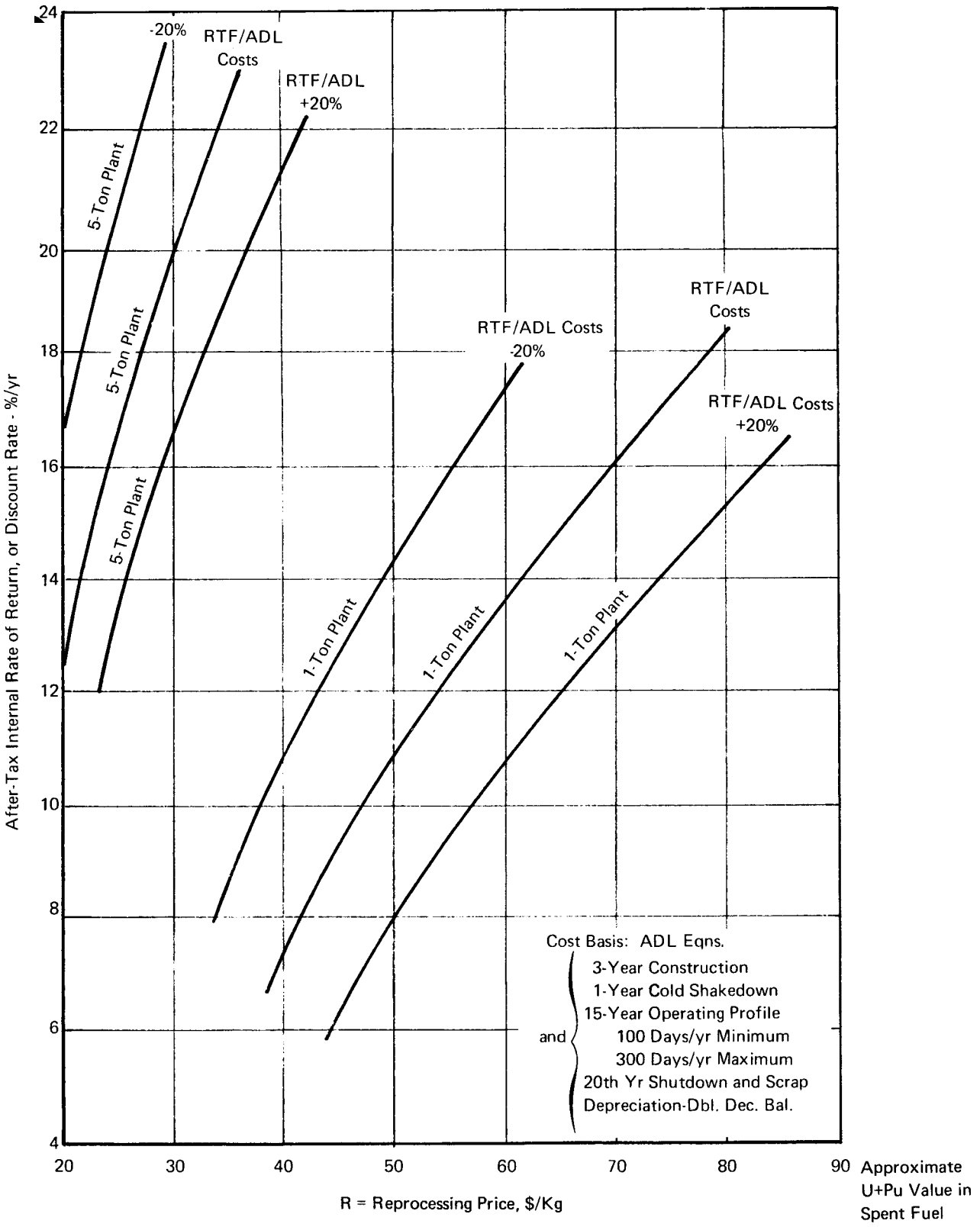


FIGURE VI–2 SCALE ECONOMIES - D.C.F. ANALYSIS

3. For both the one-ton per day and 5-ton per day ventures, capital investment and annual operating costs were varied by ±20%,

4. For calculations of Federal income tax liability, double declining balance depreciation was assumed, together with a 50% effective corporate tax rate.

The results are plotted in Figure VI–2. They indicate after-tax returns of 10–20% per year, at charges of $20–30 per kg, for 5-ton per day plants; but these returns are well below the municipal bond rate for one-ton per day plants with such charges. We believe the load profile assumed is reasonable, although unforeseen competition or maintenance problems would reduce available processing time, and hence return on investment. Conversely, more adverse assumptions would require a higher charge for reprocessing, other things being equal.

It may be feasible in the short run to accomplish reprocessing with one large central plant, although this plant might be up against site limitations and larger transportation costs. Indeed, in view of the theoretical scale economies, high fixed-to-variable costs, etc., reprocessing seems to have some characteristics of a public utility; i.e., a natural monopoly.

The foregoing discussion and calculations – in conjunction with Figure VI–1, Figure VI–2, and Table VI–4 illustrate the economies of scale in reprocessing. Their implications for the government policy questions can be seen in the following passage:[1]

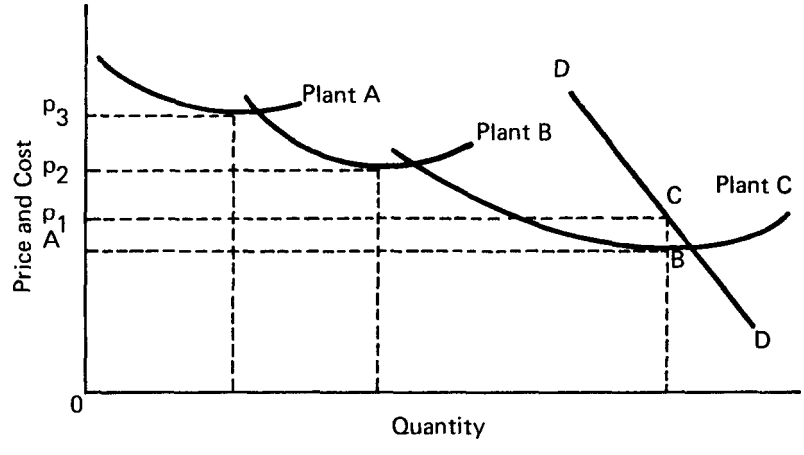
> In some fields, regulation is predicated on the idea that such enterprises can achieve a lower cost of operation if they are placed in the position of a monopolist in a market. Assuming a given state of technology, one firm can thus produce at a lower average cost than can two or more competing firms. Such a situation is illustrated in Figure VI-3. If four firms of equal size were competing in a market, the long-run price could not be less than P_3 (plant A). If two firms of equal size were serving the market, minimum average costs would fall to P_2 (plant B). But the situation would still be unstable, for if economies of scale permitted one of the firms to double its plant, it would be able to supply the entire market (plant C), charging price P_1 and earning a monopoly profit equal to P_1CBA.*

1. Charles Phillips, *The Economics of Regulation,* Richard D. Irwin, pp. 21-22, 1965.

*Long-run decreasing costs can also result from new technological advances or managerial techniques. Historically, such factors have been of major importance in explaining decreasing costs in American industries. The theoretical treatment, however, is the same as depicted in Figure 2-1: over time, only one firm of optimum size will survive in a market.

The true natural monopoly situation, therefore, is determined by economies of scale. Competition may exist for a time, but only until bankruptcy or merger leaves the field to one firm. Competition is self-destructive and results in a waste of scarce resources. Conceivably, the two or three firms could make an agreement to share the market. Neither the firms nor the public would benefit should this occur. The firms would be high-cost producers and the consumers would be denied the benefits derived from economies of scale. Moreover, nonprice rivalry between inefficient plants does not lead to an efficient allocation of resources. When economies of scale permit only one optimum-size producer in a market, it is highly desirable for public policy to allow a monopolistic supplier to operate. But the mere fact that a monopolist is allowed to exist does not assure the public of obtaining the benefits of whatever lower costs are achieved. In fact, the monopolist might absorb not only the benefits resulting from the lower cost but also might raise prices. Consequently, the presence of a monopolist calls for some degree of public regulation.

Figure VI-3 The Natural Monopoly Situation



5. Trends in Market Structure

a. Barriers to Entry

(1) *Technical.* Experience in handling highly radioactive materials, criticality control, and radioactive waste management is essential. Senior personnel of all companies active or interested in reprocessing have worked for AEC or its operating contractors. On the other hand, Union Carbide and Du Pont, with their long association with radiochemical operations at ORNL and Savannah River, have not yet shown an interest in building a private reprocessing plant.

(2) *Financial.* Capital intensity is approximately comparable to that of an electric utility plant, in terms of revenue per dollar of plant and also absolute dollars of plant cost compared to a 1000 Mw boiler or reactor.

(3) *Regulatory.* Federal, state, and local permission is required. AEC licensing is the major legal factor.

(4) *Buyer-Seller Relationships.* Excluding the federal government, only electric utilities, reactor fuel fabricators, or financial intermediates are logical customers for reprocessing services. The principal customers are expected to be utilities, and their relationship with reactor/fuel fabrication vendors could conceivably be a barrier to entry of a chemical company or some other type of company into reprocessing. This would result either because utilities prefer to deal with traditional steam system suppliers, or because NSSS suppliers may offer attractive "packages" that favor certain reprocessing plants or locations as the result of volume and transportation cost considerations.

The AEC has called attention to the issue of vertical integration in reprocessing, and the case of General Electric Company is of particular interest to this study. GE has offered utilities a buy-back credit for spent fuel in certain of its contracts; conditions were published in Section 8803 of the APED Handbook in October 1966. One concern is that GE can offer utilities a firm price for spent fuel, thereby shifting the risk of higher reprocessing charges and lower residual fuel values (U+Pu) from the utility to the General Electric Company. The utility is also relieved of spent fuel management responsibility. In any event, GE has a captive market for the recovered uranium and plutonium. If reprocessing charges decline and spent fuel values increase, GE will enjoy the benefits (even though they will be deferred until some time after the buy-back contract has been negotiated, and must therefore be discounted to present value).

To the extent that GE or another NSSS vendor's offer of a buy-back is attractive to utilities, the reprocessing market could shift into the hands of such vendors. Independent reprocessors may then have only a handful of customers

instead of 50 or so nuclear utilities; another possibility is that, to compete for reprocessing load, the independent plant would also have to stand ready to take title (buy-back) to spent utility fuel, thereby incurring a huge working capital burden without a captive resale market (such as the integrated NSSS vendor might have).

There is implicit in the buy-back price a three-way relationship among the values of recovered uranium, the value that GE (or other reactor manufacturer/fuel fabricator) assigns to plutonium, and the cost assigned to reprocessing services. We tested the price GE charges (implicitly) for reprocessing to see if it is too low, given an assumption about the maximum value of plutonium. From the data and our analysis, we were unable to show that GE's buy-back price was unreasonable in any respect.

b. Uncertainties

(1) *Market.* There is a significant uncertainty in the amount of spent fuel expected to be available in a given year, due to delays in plant construction and/or operation, burnup which can be achieved, fuel shuffling schemes, etc. Table VI–5 highlights the market uncertainty. (Note that a 15% error in the 1980 load equals the capacity of two NFS-type plants.)

(2) *Competitors.* The indications are that there will be more than enough capacity rather than too little. We expect the market to develop geographically, with GE in the Midwest, NFS and Allied on the East Coast, and Atlantic Richfield on the West Coast. However, decisions regarding entry must be made about 5 years in advance of operations, due to the long lead time required for a reprocessing plant.

Although we have not made the calculation, it seems clear that in a freely competitive market the optimal strategy for those interested in commercial reprocessing would take into account: (1) timing of plant availablity, (2) size of plant, (3) price of reprocessing services, (4) location, (5) risk-return criteria. There are also several constraints in the solution, e.g., only a given amount of spent fuel will be available in any year, and the reprocessing price to reprocess it cannot exceed the value recoverable in the spent fuel. Other constraints are the limits on plant size, discussed earlier.

(3) *Regulatory.* Uncertainties exist with respect to safety requirements imposed retroactively by AEC and/or other regulatory agencies. In particular, the manner of implementing international nuclear safeguards inspection and non-proliferation-of-nuclear-materials treaties has not been settled.

TABLE VI–5

ESTIMATED AVAILABILITY OF SPENT FUEL

Year	ADL High Forecast (3/68)	MTU AEC Forecast (5/67)	AEC Forecast (12/67)	Duke Power Company Forecast (5/67)
1970	80	100	110	143
1975	1401	1000	1100	1660
1980	3717	3400	3600	4190

6. Market Performance

a. General Motives for Entry

The market has long-term attraction because of the recurring demand from existing plants, plus the additional demand from growth in nuclear generating capacity. GE's motives are most interesting and important to understand. We speculate that they are not all "profit-maximizing." Even if doubled to two tons per day, the nature and size of GE's proposed plant,would not necessarily result in the most attractive reprocessing cost, in comparison with Allied's plant or NFS's marginal cost. However, GE now has a captive market available under various fuel cycle contracts with utilities, (notably, TVA). It may be in a position to offer assurances to utilities, particularly Commonwealth Edison in the event NFS has continuing difficulties. Furthermore its experience with Pu ion-exchange and fluoride volatility could be very valuable in preparaton for Pu-recycle work and breeder reactor development and pricing, respectively.

GE maintains its buy-back offering "was originated as part of initial fuel sales offerings to be responsive to the desires of a very few utilities who at one time wanted complete security on fuel costs. This was at a time when it was extremely uncertain whether GE would go into the reprocessing business." (Other NSSS suppliers who have shown little interest in entering the reprocessing business also felt it necessary to make this type of offering – although unlike GE they didn't publish buy-back prices – and it is understood the first contracts placed on this basis were with suppliers other than GE.) Effective July 1, 1968, GE is not normally offering a buy-back arrangement as part of its fuel scope and warranty offering, "since what little utility interest there has been in buy-back seems to be dwindling."

Because of the innovations planned by GE, its reprocessing plant design may not benefit from scale economies to the extent that competitors' plants would. It appears GE's strategy is to try to offset this by offering product as UF_6, and standing ready to build small plants near load centers to reduce transportation costs.

b. GE's Process versus NFS and Allied Chemical

We have stated that all three processes employ aqueous processing, with primary separation by solvent extraction. GE and Allied have apparently optimized their plants for low-enrichment uranium oxide fuels. NFS's present plant is better able to handle higher enrichments (although at lower rates). None of them is presently suitable for HTGR or LMFBR fuels.

The uranium and plutonium recovered by the Purex process are in the form of nitrate solutions. If the uranium is to be further enriched, it must be converted to UF_6 in the gaseous diffusion plants. Presently, this can be done only in small AEC facilities, at a charge of $5.60 per kg, which is based on nitrate solutions. However, another method would be calcine the nitrate to UO_3, and fluorinate the oxide at the reprocessing site. General Electric's proposed plant is taking this route (Plutonium, as well as neptunium, are still recovered as nitrate solutions). Thus GE's reprocessing charge, whatever it is, will have a conversion value included in it. This may be advantageous other things being equal, to the utility or fuel fabricator who is planning on re-enrichment (as opposed to blending with plutonium or other uranium for refabrication). Allied Chemical is reportedly prepared to offer a conversion option for fuel that will be reprocessed by its Purex-type plant; further details are not available. In the long run, under private ownership, we would expect shipment from NFS-type plants as UO_3,with conversion to UF_6 at the GDP site, as the preferred method for product recycling. Fluorination in a separate process can most probably be done at a price about half the AEC's current price, as commercial volume builds up. Although cost bases are not strictly comparable, some industry experts point to Allied Chemical's charge for conversion of ore concentrates (U_3O_8), which is dropping to $2.19 per kg at its Metropolis, Illinois plant. Other things being equal, GE's reprocessing charges can be expected to be higher than, say, NFS's, by the value of nitrate-fluoride conversion.

c. Value of Neptunium in Spent Fuel

Successful economic use of Pu-238 as an isotopic power source will create a demand for the reactor intermediate product neptunium (Np-237), from which Pu-238 may be produced by neutron irradiation. Over the short term, there will be a significant demand for fueling NASA space-power test shots. If there is a long-term demand, it seems clear industry is prepared to add the requisite

recovery facilities to separate Np-237 from spent fuel. GE and the New York State Atomic and Space Development Authority already are moving in that direction. The value of Np-237 recovery has been estimated at perhaps $50 million (1967 dollars) by 1980, which would be equivalent to a significant reduction in net reprocessing costs.

d. Control Over Reprocessing Load

Utilities hold the key to competitive reprocessing. Table VI–6 indicates the commercial reprocessing market controlled by reactor vendors *in toto* to be only about 20% of the total available load through 1977. Most of the utilities realize they have a few years at least before committing themselves, and many apparently expect lower effective costs for reprocessing services. At the other extreme, if reprocessing costs rise relative to the value of fissile and other isotopes recovered, utilities may refuse reprocessing. This possibility seems remote at present.

7. Innovation and Technological Change

Future innovations in reprocessing will be required for economical handling of advanced converter and breeder reactor fuels. No commercial capability yet exists to reprocess the U-Th-graphite matrix HTGR fuel, and one cannot be expected until the prospects for a significant load become clear.

Gulf-General Atomic has underway studies of a plant for reprocessing HTGR fuel, which consists of carbon-coated uranium-thorium particles dispersed in annular graphite compacts or hexagonal graphite blocks. (The fissile material is a relatively small amount of highly enriched uranium; a relatively large quantity of thorium is present as fertile material, which results in the production of fissile U-233 in the reactor.) Under its conceptual plant policy (cf. the Federal Register, January 3, 1968), the AEC may be expected to develop cost estimates for a conceptual HTGR fuel recovery until 1977, the currently established cutoff date. The absence of firm prices for reprocessing HTGR fuel is somewhat of a handicap to Gulf-General Atomic's HTGR marketing posture. However, GGA's estimates bracket the likely reprocessing costs; GA's and independent studies by ORNL suggest that, on a mills/kw hour basis, they will be similar to those for LWR fuel. The HTGR concept offers very high burnups and/or high recovered values; hence, fuel cycle costs are expected to be much lower than for LWR's. However, in either case, reprocessing costs will only be a fraction of a utility's total nuclear electric generating costs.

The large increase in the amount of spent fuel reprocessed in future years will bring with it stringent requirements for nuclear materials accountability, and radioactive waste management. These functions will be under special surveillance by a number of government agencies. Uncertainties exist with respect to safety

TABLE VI–6

REACTOR VENDOR SPENT FUEL LOAD FORECAST, 1967–1977
(discharge from reactor)
Metric Tons Uranium

Year	GE	W	B&W	Total	ADL Utility Market Forecast	Reactor Vendors' Percent of Total Forecast
1967-72	30	20	–	50	530	10
1973	50	54	53	157	457	33
1974	80	78	67	225	666	33
1975	118	78	80	276	943	30
1976	104	79	91	274	1344	20
1977	112	78	83	273	1744	16

Note:

Data as of 15 August 1967, when approximately 42,000 Mwe nuclear had been ordered (48,000 Mwe announced). We have been told that perhaps 3–5000 Mwe more recently ordered involve an option to place reprocessing under reactor vendor control via a buy-back arrangement.

Sources: USAEC and Arthur D. Little, Inc., estimates. (Data have not been verified by reactor vendors, nor by all utilities concerned.)

requirements imposed retroactively, and the manner in which international nuclear safeguards, inspections, and nonproliferation-of-nuclear-materials treaties will be implemented.

Breeder fuels will be of much higher fissile content and much more radioactive after exposure in the reactor; consequently, they will be more difficult and costly to reprocess. Fast breeder reactor technology may involve on-site reprocessing, since the high inventory value of irradiated breeder fuel places a premium on rapid reprocessing and fuel recycling. Differences in composition, radioactivity, fissile content, etc., may result in the use of non-aqueous separations techniques. There may be certain important dis-economies of scale. In any case, we expect the demand for reprocessing to be inelastic in the context of fast breeder economics.

8. Government Influence on Industry

Federal Government policies and requirements having significant influence on reprocessing competition include:

a. Conceptual Plant Policy

The AEC conceptual plant policy allows the Commission to accept private fuel for reprocessing if NFS charges are determined to be unreasonable.[1] This policy, for LWR's is expected to remain in effect until 1971, or until there is another firm offering commercial reprocessing services. After the expiration of its AEC contract in 1971, NFS is theoretically free to make some changes in its pricing on new business. This will be about the time GE's plant is scheduled to come on stream.

b. Foreign Reprocessors

The United Kingdom Atomic Energy Authority (UKAEA) plant at Windscale is the largest in the world offering full commercial reprocessing services. Under a revised bilateral agreement on nuclear safeguards, U.S. utilities could send fuel out of the country for reprocessing (UKAEA's charges reportedly are $20 per kgU, plus $12 per kgU for transportation and handling, for a total price competitive with NFS's). However USAEC at this time does not intend to amend the bilateral agreement to permit foreign reprocessing of U.S. fuel.

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1. "AEC Conceptual Plant Policy," remarks of Mr. George Quinn, USAEC, at Conference on Nuclear Power Fuel Reprocessing, Augusta, Georgia, May 11-12, 1967.

c. Government Fuel

The Government could contract with commercial firms to handle more AEC fuels, or Naval reactor cores, in private facilities. The latter would require considerable advanced planning.

d. Transportation Regulations

ICC regulations and Department of Transportation policies can affect the economics of fuel shipment, and hence reprocessing costs. The indications are that scale economies are more pronounced in reprocessing than in spent fuel shipment; transportation charges would become more important if reprocessing costs decline substantially. For example, freight costs are now about 5% of the total reprocessing costs plus spent fuel shipment charges, if total reprocessing costs decline from $37 per kg to $19 per kg, the same freight cost would then be 9% of the total. This would still be a minor cost. Changes in regulations concerning spent fuel shipment cask design could also have some influence on costs,[1] as discussed further in the next section.

9. Notes on Spent Fuel Shipping

Large power reactor spent fuel shipments use rail, barge, truck, or steamship. The heavy shielding of the shipping casks adds enormous weight. (The original Yankee cask, provided by Westinghouse and designed by Edlow Lead Company, weighed 70 tons and had a duplicate cooling system and standby power source.) Rail casks for contemporary reactors are being designed to accommodate up to about 12 PWR or 24 BWR fuel elements, with a total cargo weight up to 100 tons.

A concise treatment of significant historical developments which have a bearing on the competitive situation in spent fuel shipment may be found in the "Chemical Reprocessing Plant" hearing.[2] In 1964 ORNL prepared a detailed shipping cost study, including the relation of cost to burnup;[3] and foreign experience (Italy, UK) was discussed in several UN conference papers. The technical and regulatory progress in spent fuel shipment gives some reason for so

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1. "The Nuclear Industry, 1967," Division of Industrial Participation, USAEC, pp. 172-178.
2. "Chemical Reprocessing Plant," *op cit.*, pp. 216-218.
3. R. Salmon, "A Comparative Evaluation of Advanced Converters," AEC Report ORNL-3686, pp. 135-145, 1965.

much discussion, but the cost of spent fuel shipment will be a minor factor in LWR economics. However, shipping costs will influence plant location, number, and load potential. Also, the manner in which shipment services are offered by, and/or integrated with, reprocessors' services is relevant to the study of competitive aspects of buyer-seller relationships.

The investment required for casks, and cask utilization rates, are principal factors in shipment costs. A large rail cask may represent an investment of $500,000; a smaller truck cask about one-half of this amount.

The AEC is currently working on a study program for a light-weight spent fuel shipping cask using laminated depleted uranium. In a paper presented at the 1966 AIF Conference, the National Lead Company indicated that total costs for shipping irradiated fuel are about $5.00 per kilogram of uranium; these costs include loading and unloading, shipping equipment and shipping costs, lease charges and insurance. National Lead is studying a cask design that shows promise of reducing the turnaround time in the loading and unloading pools. The design employs lead, steel, and uranium. National Lead also has under preliminary study shipments by barge using water for shielding and heat transfer. In about 10 years there may be adequate volume for such a system to function economically and yield shipping costs below $1 per kg of fuel for 1000-mile distances.

The 1967 conference on chemical reprocessing held at Augusta, Georgia, brought forth the following information concerning spent fuel shipping:

- Nuclear Fuel Services, Inc., cited total shipping costs in the range of $4 – $10 per kg of uranium fuel, as a factor favoring regional reprocessing plants.

- Commonwealth Edison Company gave the following breakdown of costs for shipping Dresden No. 1 spent fuel assemblies to NFS during 1966-67 for reprocessing:

Assemblies	Mode	Freight Cost/Assembly	$/kgU
319	Rail	$176	$1.45
165	Truck	$245	$2.00

Based on our studies, the following breakdown of costs appears reasonable for the mixed-transportation, mixed-reactor fuel economy of the 1970's:

	Contribution to Spent Fuel Shipping Cost ($/kgU)
Freight (500-1000 miles)	1.65
Insurance and Licenses	.50
Handling	.15
Fixed Charges on Cask (depreciation, taxes, profit)	1.95
	$4.25

Private firms licensed and active in the transport of radioactive materials include:[1]

Broad Capabilities	Specialized
ATCOR, Inc., Hawthorne, N.Y.	Samuel Edlow, Columbus, Ohio (casks)
General Electric Company	Long Island Nuclear Services, Bellport, New York (waste disposal)
Nuclear Fuel Services, Inc., West Valley, New York	Nuclear Engineering Company, Walnut Creek, California (waste disposal)
Westinghouse Electric Corporation	Tri-State Motor Transit Company, Joplin, Missouri (carrier)
	International Transport, Inc., Rochester, Minneapolis (carrier)
	Transnuclear, Inc., New York, New York (carrier)
	National Lead Company, New York, New York (casks)

1. "The Nuclear Industry, 1967," *op cit.*

The most relevant service for this discussion is a "package" comprising provision of casks and related equipment for power reactor fuels, either by sale or lease, and arrangements for shipment by licensed carrier. GE, Westinghouse, NFS, and ATCOR are in a position to offer this service now. We expect Allied Chemical and National Lead to develop further "systems" capabilities, commensurate with their interest in reprocessing.

Shipments of radioactive material are covered by the regulations of several Federal Agencies, including the AEC, the Interstate Commerce Commission, the Coast Guard, the Federal Aviation Agency, and the Post Office Department. The AEC is coordinating its regulatory control in this area with these other agencies. In a Memorandum of Understanding between AEC and ICC, signed on March 21, 1966, the agencies agreed that AEC will adopt regulations applicable to preparation for shipment of fissile material and large quantities of radioactive material, and, as necessary, for radioactive material when its shipment is outside the jurisdiction of ICC. ICC will adopt regulations consistent with AEC standards for transportation of all radioactive material for preparation for shipment of radioactive material other than fissile material and large quantities of radioactive material.

The ICC issued a revision of its regulations (ICC Order No. 70) with an effective date of July 12, 1966, which for the first time, provides rules for shipping fissile material as a routine commodity in transportation. The AEC's regulations govern the packaging of radioactive materials for transport and are contained in the U.S. Code of Federal Regulation, Title 10 Part 71. A revision to 10 CFR Part 71 became effective on August 21, 1966. At the same time an AEC manual chapter (AECM-0529) was issued that placed AEC contractors under identical packaging requirements, thus establishing a common standard that all shippers of fissile and large quantities of radioactive material can use in designing shipping packages. AEC contractors shipping packages must be in compliance with AECM-0529 by July 1, 1968.

10. Concluding Comments

The commercial demand for reprocessing of fuel discharged from central station nuclear power plants is expected to increase from about 80 metric tons per year in 1970 to 3000-4000 metric tons per year in 1980. Assuming an average annual addition to nuclear capacity of 20,000 Mwe per year in the years 1978-1983, reprocessing load will increase at an average rate of 600 tons per year for several years beyond 1980. This demand would be satisfied by a capacity of 16 tons per day through 1980, with approximately 7 tons per day additional capacity under construction to go on-stream in 1983-84.

Although there is only one commercial reprocessing venture at the moment (NFS's one-ton per day plant), available load is below capacity. GE has announced a one-ton per day plant, with a modified process, for operation in 1970. Allied Chemical and Atlantic Richfield have announced plans to enter the market in the mid-1970's; and National Lead's participation is expected. Thus, we see perhaps 3000 metric tons per year capacity by the mid-1970's, although the potential domestic reprocessing load might be less than half that much. However, due to the exponential growth of load and the long lead-time for construction and shakedown, periods of over-capacity, particularly in the early years, are what one might expect.

Theoretically, because of economies of scale, the most efficient way to meet the load buildup described above would be large plants – each of which should begin operation at such a time that initial capacity is well utilized. Increments to capacity can be added at relatively small cost. Theoretical economies of scale indicate that probably most efficient plant size is about 10 tons per day, but site and/or criticality considerations lower the maximum economic plant size to about 6-7 tons per day. In any case with the development of reprocessing by private industry in a freely competitive market, a variety of plants and schedules can be expected.

The large size plants (compared to current and near-term demand) are evidence that substantial economies of scale are expected. Such economies tend to minimize any threat to competition posed by vertical integration of reactor manufacturers into reprocessing, as long as their share of market does not justify their building the largest plants in the industry, or plants substantially larger than independent firms. However, because of the capital intensity of reprocessing plants and the sensitivity of costs to fixed charges and realized plants throughput, there is no easy way to predict the short-run impact of the entry of Allied and National Lead on prices. Given the same cost of capital, and operating the same number of days per year, a 6 ton per day plant is estimated to have total costs per unit output of only about one-third of those for a one-ton per day plant.

Because of capital intensity, economies of scale, and the fact that a few very large plants could handle the entire domestic commercial load until 1980, the reprocessing industry today had certain features characteristic of a natural monopoly, which normally provides some basis for establishing regulated public utilities. (It may be noted that, as long as the AEC conceptual plant policy is in effect, there is a type of regulation by possible government price competition.) However, because of site and/or criticality limitations, plants are likely to be smaller than dictated by economies of scale at least for the next 20 years, and several plants are likely during this period. Furthermore, because the demand for reprocessing services contracts sharply as prices go up – until the advent of breeder reactors – there is a strong built-in restraint on price increases. Finally,

although there is currently a commercial monopoly, no "monopoly profits" are yet in prospect for the industry because of the small market relative to efficient levels of production.

If some commercial fast breeder reactors appear, the reprocessing situation could be quite different after 1980, depending on the technology finally adopted and the related economies (dis-economies) of scale. The demand for reprocessing is inelastic in the context of fast breeder economics, and radiochemical processing operations are likely to involve much broader questions of the public interest than in the case of LWR's.

VII. ZIRCONIUM

A. INTRODUCTION AND BACKGROUND

Zirconium metal is produced from the mineral zircon ($ZrSiO_4$) which is found in certain types of beach sands. Zircon is so abundant and so widely available that having control over a source of concentrates is of little importance in establishing the competitive position of a zirconium metal producer. Domestically, Florida and Georgia beach sands contain abundant amounts of zircon—but a combination of favorable price, high hafnium content, and low contaminant level make Australian beach sands the primary source for zirconium producers.[1]

Zirconium metal is used almost exclusively in nuclear reactor applications; for example, at least 95% of the approximately 2-½ million lbs produced in the United States in 1967 was used thusly.[2] The only other major application for zirconium metal has been in photographic flash bulbs, where about 40,000 lb of zirconium foil were used in 1966. Small amounts of zirconium are also used in the production of military flares, as "gettering" in vacuum tubes, and as an alloying addition for aluminum, magnesium, and steel. Little zirconium is used in the chemical process industries, because titanium has approximately the same corrosion resistance and is considerably less expensive.

The most important developments in the use of zirconium occurred after World War II as a result of the United States Government's nuclear weapons and naval reactor programs—both of which helped to accelerate the growth of zirconium technology. The commercial sector of the economy assisted the Federal Government in meeting its zirconium requirements by constructing new plant and equipment and by developing the manufacturing methods needed to meet the AEC's specifications for purity and physical properties. Private enterprise made the investment in the expectation that a commercial, as well as government, market for zirconium would materialize.

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1. Only a minor portion of the zircon dredged from beach sands is used in the production of zirconium metal. More than half the zircon consumed in the United States is used as mold material by the foundry industry. The next largest market for zircon is in the production of cast refractories.

2. All zirconium employed in U.S. commercial and military nuclear reactors is actually an alloy called "zircaloy," which contains more than 98% zirconium. The remainder is tin, chromium, iron, and nickel. The alloy has improved corrosion and strength properties. The terms "zirconium" and "zircaloy" are used interchangeably in this report.

From 1958 to 1963 zirconium producers were sustained by three major Atomic Energy Commission procurement contracts for annual deliveries of more than 2 million lb of zirconium sponge. This material was to be used primarily in naval nuclear reactors and plutonium production reactors. The naval reactor design was subsequently changed and less zirconium was required. Simultaneously, plutonium production requirements were in large measure filled, and there was a great deal of disillusionment within the industry during the early 1960's when significant commercial applications for zirconium, either in nuclear power or the chemical industry, failed to materialize. Faced with the loss of the AEC contracts, reduced markets, and price competition for mill products, a major zirconium supplier, Reactive Metals, Inc., formally deactivated its sponge producing facilities early in 1965, thereby reducing the considerable overcapacity that existed within the industry. Columbia-National's Plant in Pace, Florida was shut-down prior to the Reactive-Metals closing. The Carborundum Metals Company and Wah Chang Corporation were the remaining U.S. producers. In 1966, however, it became obvious that the future of commercial nuclear power was extraordinarily bright and the use of zirconium would grow with it.

B. PRODUCT AND MARKET

Currently, naval and plutonium production reactor requirements for zirconium still dwarf commercial reactor usage, but future growth in the consumption of zirconium metal will be almost entirely dependent on its use in commercial boiling (BWR) and pressurized water (PWR) nuclear reactors (see Table VII-1). We anticipate that the commercial market will grow very rapidly, while military applications will remain static or decrease (see Table VII-2 and Figure VII-1). Although the accuracy of the military requirement forecast[1] is crucial to the 1968 zirconium consumption, its effect on 1980 projections is small because the commercial requirement then will account for more than 80% of the total consumption. Predicted zirconium sponge production (Figure VII-1) exceeds metal consumption because (1) scrap must be recycled through the beneficiation process, and (2) sponge is now being manufactured for reactors not scheduled to come on-stream until 1970. Both considerations are quantified in footnotes to Figure VII-2. Note that we believe there will be a temporary reduction in the growth rate of zirconium sponge production in the next few years, caused primarily by slippage in reactor construction schedules.[2]

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1. The military requirements shown on Table 2 and Figure 1 are informal estimates of the Atomic Energy Commission. Since military requirements are dependent upon world political conditions, they are very difficult to project.

2. Reactor construction slippage or gain of one year can change these projections by ± 25%. A major industry leader is of the opinion that our projections are a bit low, but we attribute this disagreement to different opinions on the subject of the most probable slippage in the next few years.

TABLE VII-1

U.S. ZIRCONIUM CONSUMPTION[d] BY FUEL FABRICATORS FOR COMMERCIAL REACTORS

Year of Fuel Fabrication	Metric Tons Enriched Uranium[a]			Zirconium Tubing[b]			Zirconium Sheet and Bar[c]	
	New Cores	Reload Cores	Total	lb millions	feet millions	$ millions	lb millions	$ millions
1968	291	47	338	.186	1.70	5.10	.060	.720
1969	485	65	550	.303	2.78	8.34	.110	1.320
1970	733	145	878	.484	4.438	13.32	.189	2.268
1971	1024	277	1301	.717	6.57	19.71	.213	2.556
1972	1380	478	1858	1.024	9.39	28.17	.269	3.216
1973	1369	758	2127	1.172	10.75	32.25	.275	3.300
1974	1046	1136	2182	1.202	11.02	33.06	.264	3.168
1975	1401	1510	2911	1.604	14.71	44.13	.381	4.572
1976	1779	2180	3959	2.182	20.01	60.00	.449	5.498
1977	1779	2667	4446	2.451	22.48	67.44	.457	5.609
1978	2253	3153	5406	2.979	27.32	81.96	.581	7.125
1979	2689	3640	6249	3.444	31.58	94.74	.665	8.152
1980	2673	4256	6929	3.819	35.02	105.06	.738	9.056

a. 35% of uranium used in BWR reactors, 65% in PWR reactors. Kilowatt estimate based upon modifications to Washington 1084 AEC publication December 1967. Most recent AEC projections. Present reactor mix may be heavier in BWR construction and therefore 1968 sheet estimate may be low.

b. 5.76 ft Zr tube required for each Kg uranium used in PWR.
3.40 ft Zr tube required for each Kg uranium used in BWR.
PWR tube $30/lb $3.00/ft 0.425" O.D. x 0.025 wall 0.1 lb/ft
BWR tube $20/lb $3.00/ft 0.563" O.D. x 0.032 wall 0.15 lb/ft

c. PWR and BWR reactors require 1 lb of bar for every 10 lb of tube
BWR reactor requires 7 lb of sheet for every 10 lb of tube in new cores only
Sheet requirements in reload cores are minimal
Price of sheet = $12/lb. Price of bar = $12/lb;

d. Fuel fabricators generally receive tubing 12 months before reactor installation.

TABLE VII-2

TOTAL ZIRCONIUM CONSUMPTION[d]
(millions of lb)

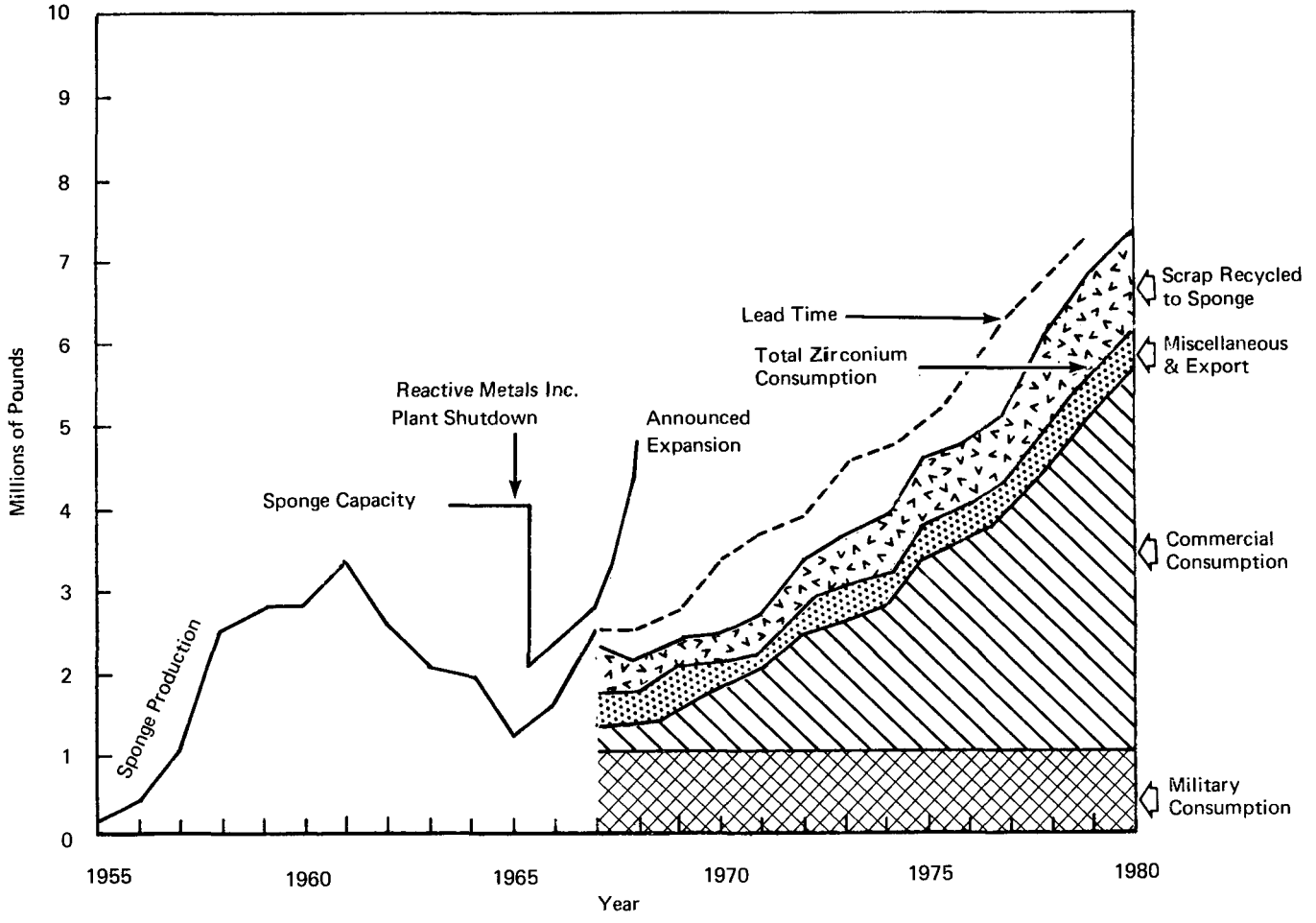
Year of Fuel Assembly Fabrication	Commercial Reactors[a]	Naval and Plutonium Reactors[b]	Other Applications	Export (Nuclear)[c]	Total Zirconium Consumption by Fuel Fabricators
1968	.246	.971	.090	.350	1.657
1969	.413	1.021	.100	.275	1.809
1970	.673	1.021	.110	.175	1.979
1971	.930	1.021	.120	.125	2.196
1972	1.293	1.021	.140	.125	2.579
1973	1.447	1.021	.160	.125	2.753
1974	1.466	1.021	.180	.125	2.792
1975	1.685	1.021	.200	.125	3.031
1976	2.631	1.021	.220	.125	3.997
1977	2.908	1.021	.240	.125	4.294
1978	3.560	1.021	.280	.125	4.986
1979	4.109	1.021	.310	.125	5.565
1980	4.557	1.021	.340	.125	6.043

a. Source: See Table VII-1.

b. Includes: 338,000 lb/yr taken from government stockpiles in the years 1967-1969 inclusive.
Source: AEC estimates.

c. Source: Arthur D. Little, Inc., estimates and Bureau of Mines. Data does not include any hafnium-free zirconium oxide which may be produced for export.

d. Data does not include inventory build-up of scrap recycle.



Special Notes:

1. In 1967, 1968, and 1969 sponge production will be or was augmented, by 340,000 lbs./year of released from government stockpiles.
2. In 1968 the amount of time which transpires from the manufacture of sponge to the reactor criticality date is taken to be 24 months. We have assumed that this time will gradually dwindle to 12 months in 1980.
3. Scrap that must be recycled to sponge = 20% consumption.
4. Each sponge producer may have an additional capacity to produce hafnium free zirconium oxide for export as a raw material for foreign zirconium sponge producers.

FIGURE VII–1 ZIRCONIUM SPONGE CONSUMPTION, PRODUCTION AND PLANT CAPACITY

It is unlikely that zirconium will be used as a cladding material in high temperature epi-thermal breeder reactors which, we assume, will dominate new reactor construction in the early 1980's. Therefore, the growth of the zirconium industry will be greatest in the late 1970's and will be dependent almost entirely upon the future of thermal neutron reactors.

Both General Electric's BWR and Westinghouse's PWR reactor utilize zircaloy in the form of small diameter tubing as a cladding for uranium oxide fuel pellets and in the form of bar, as fuel tube end plugs. The tubing in both reactors—although not exactly the same—is approximately ½" in diameter, with about a 0.03" wall, and is approximately 13 feet long. The G.E. reactor also uses a great deal of zircaloy 0.083" sheet formed into 6" x 6" round-cornered square tubes that contain 49 fuel tubes. These fuel channels are not replaced with each new core loading; hence they represent a "one-time" expenditure. Table VII-1 includes a projection of zirconium consumption for new as well as reload cores from 1967 through 1980. By 1980, the commercial reactors will consume, in the form of tubing, bar, and sheet, approximately 4.6 million lb of zirconium per year, which amounts to approximately $115 million in today's currency and at present prices. This contrasts to the approximately 0.17 million lb required in 1967 (for a total value of $4 million).

The export market for zirconium has been composed primarily of Canada, and to a lesser degree, the United Kingdom. A Canadian producer of zirconium will soon be supplying its own country's requirements, and Ugine Industries of France is rapidly capturing the English market. Occasional orders from Europe for zirconium tubing have been garnered by U.S. firms.

Reliable industry participants suggest that U.S. zirconium sponge producers probably have a capacity, in addition to that stated in Table VII-1 and Figure VII-1, to produce hafnium-free zirconium oxide. This product can be consumed as a raw material by European zirconium sponge producers that do not have adequate hafnium separation facilities.

Exports of this material are considered temporary and so are not included in our projections.

C. MARKET STRUCTURE

Three companies currently have together more than 90% of the zirconium, sponge, and tubing market in the United States: Wah Chang, the largest sponge producer; Wolverine Tube, the largest tubing producer; and AMAX, the only supplier of tubing who is integrated back to ore.

1. Sponge

Zirconium sponge, the most basic form of zirconium metal, is produced by only two manufacturers in the United States. Wah Chang Albany Corporation, a Teledyne Company, in Albany, Oregon supplied about two-thirds of the market and AMAX the remaining third. The plant capacity and market share of each of these organizations are shown in Tables VII-3 and VII-4. Considerable expansion of sponge manufacturing capacity has taken place in the past year and further announced expansion is under way. One can see from Figure VII-1 that by the end of 1968, there will be enough sponge capacity in existence to supply zirconium requirements until 1974.

No other American companies have announced any intention of manufacturing zirconium sponge. Naturally, the extraordinarily rapid growth that will be encountered in the next several years has generated much interest on the part of large chemical companies who might have the technology required to become sponge producers. However, the relatively limited market for sponge (only about $30 million in 1980) and the announced plant expansions of current producers, have prevented any new American entries.

Eldorado Mining and Refining, Ltd. of Canada, has announced the construction of zirconium sponge production facilities in Port Hope, Ontario, probably to supply a portion of the United States market. This facility will use zirconium oxide (baddeleyite ore) as a feed material. Ugine-Kuhlmann, S.A., of France, has expanded its sponge production facilities to 1-½ million lb per year and will probably capture most of the European market.

A Japanese company has approached several non-integrated American zirconium consumers with proposals to supply them with zirconium sponge. (Actually, a zirconium tube producer that does not have zirconium sponge production facilities usually purchases machined zircaloy billets rather than sponge. A great deal of scrap is generated in the manufacture of billet, and a sponge producer is more capable of utilizing scrap effectively.)

2. Tubing

The Wolverine Tube Division of Calumet and Hecla supplied almost two-thirds of all the zirconium tubing manufactured in the United States in 1967 (see Table VII-4). The remaining one-third was manufactured almost exclusively by AMAX's nuclear division. There are some peripheral suppliers (such as Superior Tube and Harvey Aluminum Company) whose share of the commercial reactor tubing market is substantially less than 10% but who possess a large fabrication capacity for manufacturing zirconium tubing. Table VII-1 shows that in 1968, 1.7

TABLE VII-3

PLANT CAPACITIES FOR THE PRIMARY ZIRCONIUM SPONGE AND TUBE PRODUCERS OF THE UNITED STATES[a]

	Sponge Capacity (millions of lb)		Tube Capacity (millions of feet)	
	Current	End of 1968	Early 1968	End of 1968
AMAX Specialty Metals	0.8	1.3	1.2	1.8
Wah Chang Albany Corp. Div. of Teledyne, Inc.	2.5	3.5	--	--
Wolverine Tube Div.[c] Calumet Hecla	--	--	1.3	2.6
Sandvik Specialty Metals United Nuclear/Sandvik Steel venture	--	--	--[b]	1.3
Westinghouse Electric	--	--	0.5	2.5
General Electric	--	--	--	2.0
Total	3.3	4.8	3.0	10.2

a. Harvey Aluminum, Chase Brass and Copper, and Superior Tube Company are not in this listing because, in the case of Harvey and Chase, they manufacture only large diameter plutonium production reactor tube and Superior's market share is so small as to be judged unimportant.

b. S.S.M. is actually now in production and has about a 1 million ft capacity. However, shipments will not begin until late 1968.

c. Calumet & Hecla was recently purchased by Universal Oil Products.

TABLE VII-4

APPROXIMATE MARKET SHARE OF DOMESTIC ZIRCONIUM SPONGE AND COMMERCIAL REACTOR TUBE SHIPMENTS

	Sponge		Commercial Reactor Tubing	
	1967	1968	1967	1968
AMAX	30%	30%	20%	35%
Wah Chang	70%	70%	0%	0%
Wolverine	0%	0%	80%	63%
Sandvik Special Metals	0%	0%	0%	2%
Total	100%	100%	100%	100%

Source: Arthur D. Little, Inc., estimates.

million feet of zircaloy tubing will be used by fuel fabricators; in 1969 this will increase to 218 million feet. Manufacturing capacity early in 1968, about 3.0 million ft per year, is being rapidly augmented by expansion programs by current suppliers and by the entry of United Nuclear/Sandvik Steel, Westinghouse, and General Electric. By the end of 1968, it is anticipated that production capacity will be increased to about 10 million ft per year. In 1972, about 11 million ft of zircaloy tubing will be assembled into fuel bundles, but tubing must be manufactured about one year prior to its use in cores. Therefore, the total expansion of tube manufacturing facilities is not out of line with tubing requirements in the near or immediate future. In fact, tube manufacturing capacity is more closely balanced to consumption than sponge production capacity is to its consumption. (By the end of 1968, sponge manufacturers will be capable of supplying 1974's requirements.) This situation does not mean, however, that there is enough of a market to keep all producers operating at a profitable level.

In Europe, there are now three producers of zirconium tubing: Cefilac-Vanllourec Div. of Ugine-Kuhlmann S.A., Vereinigte Deutsche Metallwerk A.G. Division of Metallgesellschaft A.G. and Sandvik Steel. All these organizations are relatively small producers of zircaloy tube and, at this moment, cannot compete effectively in the U.S. market. Three Japanese manufacturers have announced plans for entry into zirconium tubing production–Kobe Steel Ltd., Sumitomo Metal Industries Ltd., and Mitsubishi Metal Mining Co. Kobe has reportedly already submitted tubing for fuel irradiation tests in Japan and Norway.

3. Strip and Bar

Zirconium strip is used extensively in naval reactors and in General Electric's BWR reactor. Bar is used as end caps for PWR and BWR fuel tubes. These product forms account for a relatively small proportion of the total zirconium requirement. Wah Chang is probably their largest single manufacturer and AMAX is the second. Because strip and bar represent a relatively minor portion of the business (less than 10% of the 1980 dollar volume), little attention was given to them in this study. However, it should be noted that the capacity to manufacture sheet provides an outlet for zirconium metal that may not be acceptable for tubing production. This outlet offers a degree of flexibility that can be effectively utilized to improve an organization's profitability. One pound of bar, for use as end caps, is consumed for every 10 pounds of tubing in both new and reload cores in BWR and PWR reactors. Seven pounds of 0.083" sheet is consumed for every ten pounds of tubing in new BWR cores only.

D. CHANGES IN MARKET STRUCTURE: NEW ENTRIES

Three companies not now manufacturing zirconium tubing have begun construction of production facilities in the United States. They are Westinghouse, General Electric, and Sandvik Special Metals Company, a joint venture on the part of United Nuclear and the Swedish company, Sandvik Steel. The planned capacities, capabilities, market goals, and stated motivation of each of these entries is discussed below.

1. General Electric

General Electric Company is installing facilities for the reduction of extruded tube hollows to finished tubing at Wilmington, North Carolina. (At one time General Electric considered the purchase of an existing sponge producer, but abandoned the idea. We understand that the Government raised the question of possible anti-trust implications.) The facility has been designed to produce approximately 2 million ft per year of zircaloy tube. No metals other than zirconium and its alloys will be processed. In addition to tubing, G.E. plans to manufacture end plugs, spacers, channel pre-forms, and channels. It is anticipated that the plant will be in operation sometime around the end of 1968. There will be no arc melting or extrusion equipment included in the facility; G.E. will purchase extruded tube blank directly from the sponge producers, who will have to toll convert it from billet. The hollows will subsequently be processed in G.E.'s Wilmington facility. General Electric intends to supply, within the capacity of its plant, its own zirconium tubing requirements. They do not plan to become a zircaloy tubing supplier to others. G.E. has decided to produce finished tubing in order to secure improved costs, primarily through better quality and schedules.

2. Westinghouse Electric Company

Westinghouse's Materials Manufacturing Division (MMD), which has produced several million pounds of zircaloy fuel cladding in plate and sheet form in the past ten years, has decided to enter the zircaloy tubing business. MMD currently has arc melting and extrusion facilities which adjoin the 38,000 sq ft tube mill that is being constructed in Blairsville, Pa. Westinghouse's existing zircaloy tube capacity is approximately 0.5 million ft per year. By the end of 1968 this will be expanded to approximately 2.5 million ft per year. Whether or not this new facility will be used for metals other than zirconium alloys, we do not know. Westinghouse will continue to produce zircaloy sheet and bar, however. Westinghouse will most likely be the only tube manufacturer (besides AMAX) capable of melting sponge and scrap. It will be the only zircaloy tube producer (besides Wolverine) with its own extrusion facilities.

Westinghouse is–and intends to continue–soliciting tube business from consumers other than itself, although its Nuclear Fuel Division has purchased the greater part of its tubing requirements, through 1970, from non-Westinghouse suppliers. Westinghouse's Nuclear Fuel Division has purchased significant quantities of zircaloy tubing from the Westinghouse Materials Manufacturing Division and these purchases were, according to Westinghouse, made at prices, and under terms of sale, substantially equivalent to those involving outside suppliers. Westinghouse has stated that they will continue to purchase significant quantities of tubing from competitive non-Westinghouse suppliers.

To summarize, Westinghouse apparently intends to manufacture more than half its own requirements and purchase the balance from outside vendors in order to protect itself from problems such as strikes, shortages, technological breakthroughs by competitors, and other difficulties that might be encountered by being dependent upon a single source of supply. Westinghouse would plan to solicit the requirements of other reactor manufacturers to keep their plant at full capacity.

Although Westinghouse has purchased a good portion of its tube requirements to 1970, it should be remembered that there is currently a 12 to 18 month lead time on tube manufacture, and Westinghouse would appear to be less than conservative to expect its newly installed facilities to manufacture all of this tube.

As one of its objectives, Westinghouse is trying to develop new manufacturing procedures, processes, tools, and equipment which hopefully will result in lower production costs and/or higher performance tubing.

3. Sandvik Special Metals Company

This joint venture of the United Nuclear Corporation and the Sandvik Steel Corporation has announced plans to spend approximately $3.5 million in the construction of a tube reducing facility to manufacture 1.3 million ft per year of finished zircaloy tubing from extruded tube hollows. The facility will not have any arc melting or extrusion capabilities. It should be noted that with a minor increase in investment the operation can be expanded to 2 million ft per year if market conditions warrant. Sandvik will purchase machined billet from either of the sponge producers and will have it extruded by an outside vendor. The company will also have to recycle its scrap through either AMAX or Wah Chang.

Sandvik Steel produces zircaloy tubing in Sweden and has developed the manufacturing techniques required. Their technology is being employed in the Sandvik Special Metals plant, but Sandvik Steel will continue to manufacture zircaloy tubing in Europe. The research efforts of this joint venture will be a conglomerate of contributions-mechanical process improvement and metallurgy by Sandvik Steel, and reactor environmental testing and nuclear design by United Nuclear.

Although the joint venture will solicit business where it is available, it expects that its primary sales volume will be tubing used in reload cores, a market segment that will not become significant until the mid-1970's. A capability to convert other metals besides zirconium in this facility will most likely be developed in an effort to defray fixed costs.

E. COMPETITIVE FACTORS

1. Prices and Costs

a. Sponge

The manufacturing cost of zirconium sponge is highly volume dependent, caused in part by large fixed costs. The capitalization required for a 2 million lb per year sponge plant is approximately $15 million. The current price of sponge is one dollar less than the $6.25 per lb price in 1959, and industry leaders indicate that in the mid-1970's, when 5–6 million lb per year of zirconium sponge must be manufactured (consumption on the order of 4 million lbs) the price can drop to $3.50–$4 per lb in today's dollars if a market can be found for the extra hafnium that will be produced. The recent price reductions have taken place in a period when zircon concentrates have gone from $45 per ton (in 1959) to approximately $55 per ton (in 1967).

Recent publicity releases have alluded to a new process for the manufacture of zirconium. The new process avoids the liquid-liquid separation of hafnium, but purportedly employs another less expensive type of separation process. The new process was developed by Japan's Ishizuka Research Laboratories. Ishizuka has joined with Mitsui and Company, Ltd., and Wah Chang Albany Corporation to consider constructing such a facility in the United States. If the process is successful, it will probably lead to further price reductions.

A capability of selling hafnium extracted from zirconium is crucial in determining an organization's sponge manufacturing costs–hence, its competitive position. Approximately one pound of hafnium is produced for every 50 lb of reactor grade zirconium manufactured. The principal market for hafnium has been as a control rod in naval reactors, and the U.S. demand for the metal was about 40,000 lb in 1967. The hafnium requirement in 1967 was just about in balance with zirconium sponge production (1/50 x 2.5 million lb = 50,000 lb hafnium output), but as zirconium needs accelerate, this balance will no longer exist. Some producers are trying to develop uses for hafnium in carbide cutting tools, high temperature alloys, and commercial power reactor control rod materials (currently a silver–cadmium–indium alloy). It does not appear likely that the new uses for hafnium at similar prices will develop at the rate at which zirconium production will be expanding. Therefore, the price of zirconium sponge will probably stay close to its present levels even though increased production volume will affect substantial economies of scale.

Hafnium sponge purchase contracts (approximately $75 per lb) are let by organizations supplying the U.S. Government, almost exclusively on the basis of price. Placing hafnium purchase contracts gives the Federal Government some degree of leverage with zirconium producers. For example, if a producer were not able to sell his hafnium sponge, he would have to raise the price of his zirconium sponge approximately one-fiftieth of $75—or $1.50 per lb—to $6.75 per lb in order to realize the same income.

b. Tubing

The price of zirconium tubing for commercial nuclear reactors has dropped from $7 or $8 per ft in 1959 ($6 per ft in 1962) to its present level of about $3 per ft.[1] This amounts to approximately $20 per lb for thick-walled BWR reactor tubing and approximately $30 per lb for thin-walled PWR tubing. This significant price decrease in tubing was primarily a result of increased volume, improved manufacturing techniques, the introduction of more competitors and less severe technical specifications and has primarily been due to the work of independent tube producers.

Our estimate of the distribution of manufacturing costs for the production of zirconium tubing on a per-foot basis is shown below:

	BWR	PWR
Sponge	27%	18%
Production of ingot from sponge	6%	4%
Production of drilled and scalped extrusion billet from ingot	6%	7%
Fabrication of tube from extrusion billet	45%	55%
Final testing of tube	16%	16%
Total	100%	100%

If a producer of zirconium tubing is not integrated back to ore, he generally will purchase a drilled billet ready for extrusion. He usually purchases this billet at a price of $7 to $9 a lb, depending on its size and, in particular, the diameter of the hole drilled in its center.

1. Orders have recently been considered and taken at approximately $2.80 per ft. There are indications of even lower prices to be forthcoming.

The production of scrap during the various manufacturing steps is a cost so significant that it can be a distinct competitive disadvantage to a non-integrated producer of tubing. In manufacturing machined extrusion billets from zirconium sponge, one obtains approximately 70 pounds of billet from 100 pounds of sponge. About half the scrap generated–lathe turnings and drill chips from scalping and boring–can be recompacted into electrodes and remelted. The balance must be recycled as ore. Once the machined billet is shipped to a tube fabricating plant, approximately 25 pounds of scrap and 75 pounds of tubing are produced from every 100 pounds of billet. Twenty pounds of this scrap can be remelted into acceptable ingot at a cost of about $1.50 per lb to the tube converter. Five pounds represents a total loss and is either sent back through the ore cycle or sold to scrap dealers for the production of ferro-master alloys or hydride flares. AMAX, the only fully integrated (with the exception of extrusion) zirconium producer, is potentially in the best competitive position to minimize the costs of scrap generation.

The capital investment in a zirconium tube plant is wholly dependent upon the number of different fabrication operations performed within it. Minimum operations are a tube rocking and vacuum annealing plant. The equipment investment for a 2 million ft per year plant is approximated below:

$2.30 million[1]	"Rocking" equipment
.15 million	Vacuum annealing furnace
.15 million	Pickling facility
.40 million	Inspection and misc. equipment
.05 million	Straighteners
.40 million	Building and land
$3.45 million	Total

Several tube producers–Wolverine, Westinghouse, and AMAX–also have extrusion/forging presses and/or arc melting facilities. This equipment would add between $1 and $2 million to the above total. (It is doubtful that any tube producer will have enough volume in five years to justify such a facility for zirconium alone.)

1. This is conservatively stated and could be as much as $1 million lower.

The cost of producing zircaloy tubing from extrusion billet is highly volume dependent. There is a certain minimum size tube rocking plant (2 million ft per year capacity) required to achieve a reasonable balance of equipment capabilities and minimum manufacturing cost. A plant can be constructed at the outset with this capacity, or the major items can be installed and gradually augmented to achieve a volume of at least 2 million ft per year. With the current price structure of zircaloy tubing adequate profitability and return on investment will not be realized until a volume of about 2 million ft per year is achieved. The listing of plant capacities in Table VII-3 corroborates this, for all the plants, except Sandvik Special Metals, will have close to or more than 2 million ft per year capacity by the end of 1968. Sandvik has stated that their facility is designed for an immediate scale-up to 2 million ft per year as soon as they are in a market position to do so.

Manufacturing cost estimates calculated by Arthur D. Little, Inc., and also disclosed to us by mature industry participants, are shown in Figure VII-2. One can conclude from these data:

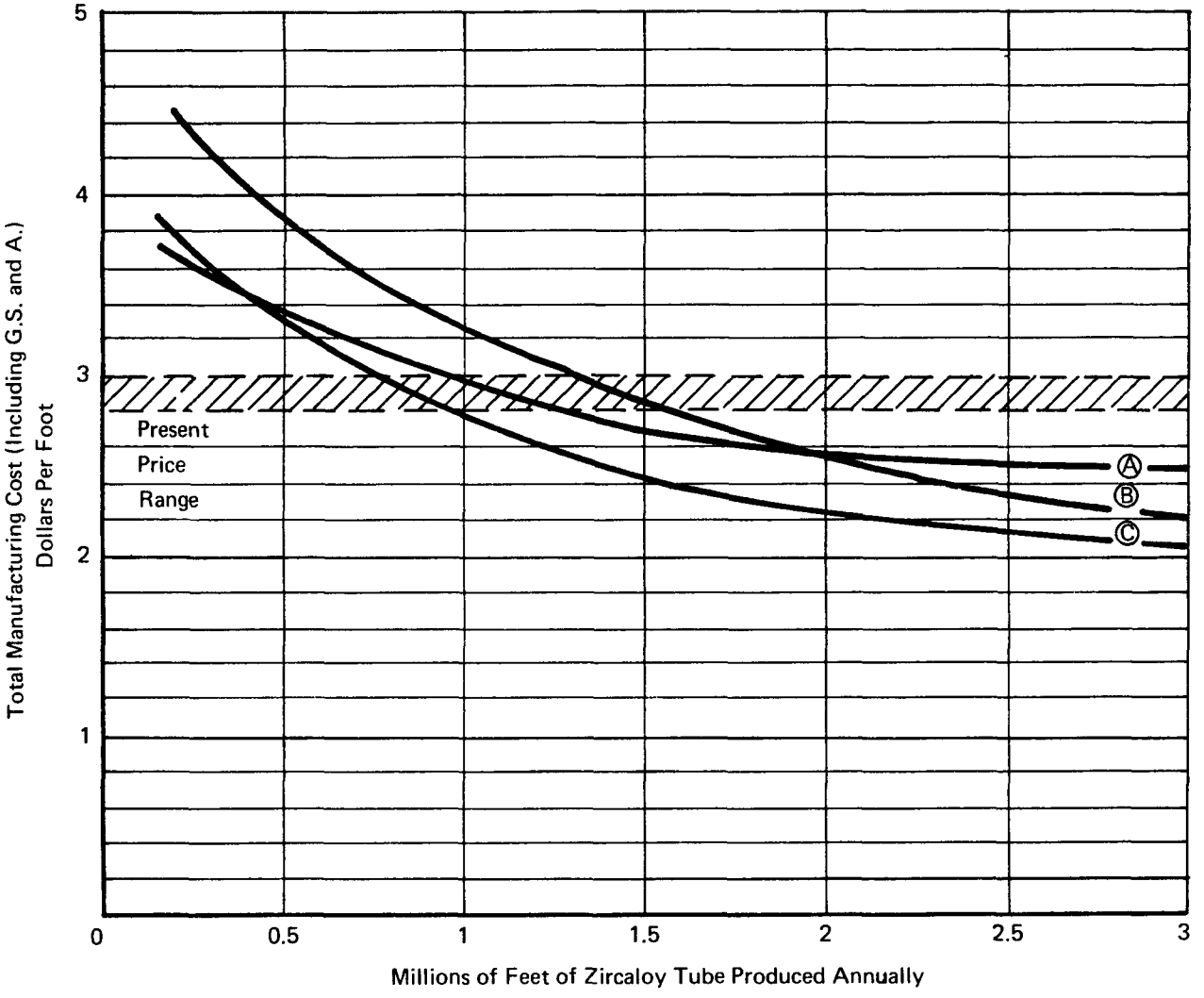
- The breakeven point for a zircaloy tube plant at today's prices is approximately ¾ to 1-½ million ft per year of zircaloy tubing, depending upon sales price, the degree of integration and the amount of metal tube, other than zircaloy, the plant can produce.

- Total manufacturing costs for a partially integrated 3 million ft per year plant can easily be 50 cents per foot lower than a non-integrated plant operating at 1.25 million feet per year.

- If a tubing producer can sell about 2 million feet per year at a price about 35cents/ft above his manufacturing costs, his after tax return on initial investment would be approximately 10%.

- Optimum manufacturing costs can best be achieved by a high degree of integration and augmented by a large non-zircaloy business.

Therefore, it appears that if a zircaloy tube manufacturer cannot achieve a sales volume of at least 1.5–2 million feet per year, he will not remain competitive. And, if he does not achieve sales in excess of 2 million feet per year, he will not be able to provide a reasonable return on his investment.



A Plant with only tube rocking and annealing facilities – represents the minimum degree of integration – such as G.E. and Sandvik Special Metals.

B Plant with rocking, extrusion and arc melting facilities that manufactures only Zircaloy Tube.

C Same as B but with significant (35%) sales volume of other metal tube to help defray fixed costs. Westinghouse would probably fit between B and C.

Note: A producer integrated back to sponge has the potential of even lower manufacturing costs.

FIGURE VII–2 TOTAL MANUFACTURING COSTS (INCLUDING G.S. AND A.) VERSUS VOLUME FOR VARIOUS TYPES OF ZIRCALOY TUBE PLANTS.

2. Buying and Selling Policies and Practices

Present zirconium tubing suppliers do not publish a price list. All major sales are made on a negotiated bid basis and several long-term contracts have been let. For example, Westinghouse and at least one other reactor manufacturer have signed purchase contracts for almost all their tube requirements until 1970. The total amount of dollars and feet associated with each major purchase are generally announced publicly.

The ability of a vendor to deliver acceptable tubing on schedule is as important to a purchaser as price. The extremely important task assigned to zircaloy tubing, i.e., containment of the fuel, justifies the reactor manufacturers' great concern over the ability of a vendor to deliver acceptable tubing.

It is dificult to state more specifically what the buying and selling characteristics of the industry are since only about four major purchases have been made to date.

F. TECHNOLOGICAL IMPROVEMENTS

After the Bureau of Mines developed the Kroll process for zirconium in the mid-1940's, industry research turned primarily to improving the physical and chemical properties of zirconium. Specifically, pure zirconium can adequately withstand the corrosive attack of water at temperatures up to 500°F. Above this temperature, however, behavior is erratic, and for this reason the zircaloy alloys were developed. Considerable effort was also placed upon understanding the role of hydrogen in the materials embrittlement. Little, if any, of this critical work was accomplished by the present zirconium sponge or tube producers; rather, it was done by various government contractors, especially reactor designers. Following these developments, public zirconium research and development efforts slowed. Commercial tubing producers then began to bring their metalworking experience to bear on the development of economical production processes for zircaloy tubing.

It is our opinion that the manufacturing processes now employed in the production of zircaloy tubing, with the exception of the amount of scrap generated in the formation of billet, are very efficient and not likely to be improved upon to any considerable degree. Although we anticipate significant price reductions for zirconium sponge, this will not have a substantial effect upon the price of finished zircaloy tube.

A large increase in the mechanical strength of zircaloy tubing will probably not result in an important increase in the burn-up achieved in most nuclear reactors. The limiting factor in determining burn-up is not the tendency of the zirconium tubing to burst, but instead, the carrying cost associated with the increased degree of fuel enrichment needed to achieve higher fuel burn-up. The investment required for greater enrichment does not appear to be commensurate with the potential gain.

However, if a large improvement in the mechanical properties (especially at higher temperatures) of zircaloy were achieved, significant cost savings would be effected because of considerations other than burn-up. First, assuming adequate corrosion characteristics, a reactor might be able to operate at higher temperatures with the attendant improvement in efficiency and second, the wall thickness of the zirconium fuel tube could be reduced almost in direct proportion to the increase in strength. This reduction would make nuclear power more economical because less zirconium would be employed in the core of a reactor and the neutron economies achieved would allow a reduced degree of enrichment to realize a given burn-up. It is true that the amount of zirconium sponge to produce a foot of tubing would also be reduced; however, this might not result in any saving because the production of thinner wall tubing would result in a higher per-foot manufacturing cost. Comparing BWR and PWR tubing price schedules reveals a perfect example of this trade off. Fuel tubes for both reactors cost $3 per ft; however, the PWR tube has a substantially thinner wall and weighs approximately 0.05 lb per ft less than BWR tubing. Here, increased manufacturing costs associated with the thinner wall tube are equal to the savings in zirconium metal costs.

Consideration has been given to increasing zircaloy's effective operating strength by placing any hydride particles in a pattern transverse to the tube axis rather than parallel to it. In zircaloy, tube cracks are believed to originate at the hydride platelets, and since the internal hydrostatic pressure developed by the production of fission gases causes hoopstress, the hydride platelets should be oriented in a direction which is not perpendicular to the tensile forces developed; i.e., they should be transverse to the axis to the tube.

There is some discussion within the industry about manufacturing zirconium tubing by continuous welding of strip. Several industry leaders expressed considerable doubt about the economic potential of this process in relation to current manufacturing techniques, since the price of strip is not that much less than that of tubing.

To summarize, we believe that the research and development within the industry can most profitably be spent on improving the functional performance of zircaloy tubing, rather than on reducing its manufacturing costs: Specifically, the development of higher strength alloys.[1] The original reactor manufacturers, with their large research staff and in-reactor test capability, probably have a better chance of success than present tube or sponge manufacturers in the development of new high performance zirconium alloys. However, among the independents, AMAX has an active research effort aimed at achieving this goal.

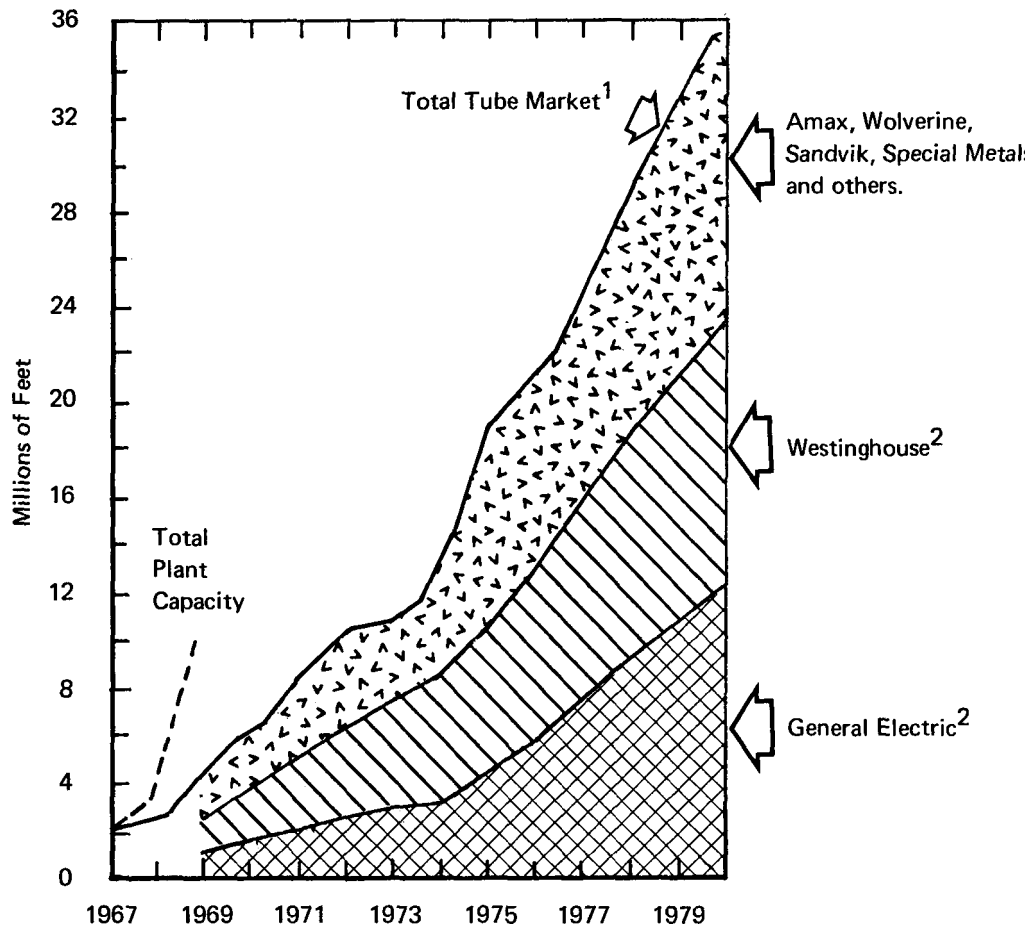
G. IMPLICATIONS OF PROSPECTIVE NEW ENTRIES

1. Effects on Present Manufacturers of Zircaloy Tube

The entry of General Electric, Westinghouse, and Sandvik Special Metals Company into the zirconium tubing business will create overcapacity in the industry which, based on our projections, will probably not be eliminated by a corresponding growth in the market until 1971. See Figure VII-3. The data presented in this figure is based upon total zirconium tube requirements, as shown in Table VII-1, and the probable market division among reactor producers based on the reported plans of the new producers described elsewhere in this report.

If, as estimated in Figure 3, General Electric produces 100% of its own tubing requirements and Westinghouse the equivalent of 75% of its needs, together they will in the future provide approximately two-thirds of the total U.S. zircaloy tube requirements. The balance of the market will be left to the independents of which there are currently three (AMAX, Wolverine, and Sandvik Special Metals). Based on the minimum economic plant size (1-¼ million feet per year results in about a breakeven situation, and 2 million feet per year yields about a 10% return on initial investment) this leaves a small market to the independents until the mid-1970's—only about 2 million feet in 1969, but growing to 8 million feet in 1975.[2] Wolverine and AMAX currently share a market of somewhat less than 2 million feet (excluding minor exports). Actually, Sandvik Special Metals Company, although they are currently manufacturing tube, will not really be shipping until late 1968, and even then it will not have the opportunity to solicit from the independent market, as indicated in Figure VII-3, because almost all of this business has already been contracted for until late 1969. According to how both domestic and export business is divided among the three independents, there is at least the possibility that one or more might achieve reasonable economies of scale, i.e., more than 2-½ million feet per year, before the mid-70's. If other companies were to enter the market, and/or if Westinghouse manufactures more than 75% of its requirements, comparable economies of scale might not be achieved by any existing independent until the late 1970's.

1. It should be noted that one of the major new entries into the field (a reactor manufacturer), who has not yet had significant tube production experience, is of the opinion that manufacturing costs can be reduced significantly.
2. This assumes that the independents are not able to develop and retain a significant export market for tubing.



NOTES:

1. Assuming production of zircaloy tubing is 18 months ahead of reactor installation in 1968, and this lead time is assumed to decrease to 6 months in 1980.
2. Assume G. E. manufactures 100% of its requirement and Westinghouse manufactures at least 50% of its requirement plus some of other reactor suppliers.

FIGURE VII–3 PROJECTED ZIRCALOY TUBE MARKET AND PLANT CAPACITY

Because they will probably achieve more economic levels of production, G.E. and Westinghouse may be expected to have a cost advantage in the production of zircaloy tubing until approximately 1974. We estimate this cost advantage, relative to the independent producers, might reasonably be approximately 25 cents per foot in 1970. The present selling price for zircaloy tubing is about $3.00 per foot. This advantage would be greater or would last longer if either G.E. or Westinghouse should occupy a larger part of the market than has been projected.

At the moment Wolverine probably has a competitive advantage over General Electric and Westinghouse because of its long experience in the manufacture of tubing. This experience is attested to by the fact that organizations such as Westinghouse and AMAX have hired away supervisory Wolverine personnel. On the other hand, it can be expected that in time the new zircaloy tube producers will gain experience that will reduce Wolverine's advantage to a minimal level. Wolverine, however, will most likely make a substantial effort to produce other tubular products, such as titanium, on its extrusion and tube rocking facilities which will help equalize their manufacturing costs with those of Westinghouse and G.E. This is easily achieved in the extrusion operation, but is more difficult in rocking, where contamination may occur more easily. It should be noted that due to its tubing production and marketing experience, Wolverine is in an excellent position to achieve this goal.

AMAX's primary advantage is achieved by virtue of the fact that they are the only zircaloy tube producer integrated back to sponge; hence, they are capable of obtaining maximum utilization of scrap. AMAX may be in almost as good a position as Wolverine to utilize its metallurgical and marketing capabilities in the production and sale of tubing other than zirconium. Significant success in such an effort would help to defray fixed manufacturing costs for their facility but profit margins might not be completely satisfactory due to the extra costs associated with facilities clean-up to avoid contaminating zircaloy tube.

Sandvik Special Metals Company may be in the most difficult competitive position of the zircaloy tube producers. It is the only independent producer of zircaloy tubing which cannot extrude and/or arc melt. On the other hand, it is affiliated with United Nuclear[1] whose demand for tubing could become significant if they are successful as an independent fuel fabricator. Moreover, even

1. While this report was being written it was announced that Combustion Engineering was acquiring a 22% interest in United Nuclear. Quoting from a June 25, 1968, United Nuclear Annual Meeting notice: "Combustion Engineering, Inc., is purchasing uranium oxide pellets from the Corporation and zirconium tubing from Sandvik Special Metals Corporation, a 50% owned subsidiary of the Corporation, with deliveries scheduled into 1969 in the case of the pellets and into 1973 in the case of the tubing. Total sales delivered since April 1, 1967 or presently under firm orders aggregate approximately $4,500,000, and Combustion Engineering has options to purchase additional tubing at a total price of approximately $3,000,000." It should also be noted that Sandvik Special Metals currently possesses some long-term (1970) orders from Babcock & Wilcox for zircaloy tubing and is thus in an excellent position to become *the* major supplier of the minor reactor manufacturers. The C.E. purchase of 22% of U.N. is likely to strengthen the buyer-seller relationship between the two.

though Sandvik is just commencing its start-up period, it does have some significant orders for tubing over the next several years.

S.S.M., through its special relationship with Sandvik Steel, may be able to use that company's U.S. sales organization as a marketing organization for tubing of metals other than zircaloy which it may produce.

2. Effects on Non-Integrated Reactor Manufacturers

Combustion Engineering and Babcock & Wilcox will, in the future, have the choice of buying zircaloy tubing from their competitors (G.E. and Westinghouse) or from one or more of several independent tube suppliers. It is thought that the independents may be able to claim a small premium for their products over what the integrated manufacturer may obtain because of the reluctance of a company to buy from a competitor. This tendency will be especially helpful to the independents during the early 1970's when they will most likely be at a significant cost disadvantage.

Both Babcock & Wilcox and Combustion Engineering have considerable experience in the tube manufacturing business and each could probably enter the zircaloy tubing business without too much difficulty. However, if they were to enter the market they would most likely do so by the purchase of an existing producer.[1] Their problem would be the same one, although probably to a lesser degree, encountered by the existing independent tubing suppliers. Could they reach the sales volume required to be competitive with Westinghouse and G.E.? Unlike the independent tube producers however, Combustion Engineering and Babcock & Wilcox would have a substantial internal market for the product. If either one of the non-integrated reactor manufacturers decides to produce zircaloy tubing, the market available to independent suppliers would significantly decrease and certainly would not be large enough to profitably support more than one independent producer until the mid-70's.

Regarding the position of the four reactor manufacturers relative to each other, it should be noted that G.E. and Westinghouse are largely, but not exclusively, dependent upon Babcock & Wilcox and Combustion Engineering for pressure vessels and Babcock & Wilcox and Combustion Engineering are similarly dependent upon G.E. and Westinghouse for turbines. In time, G.E. and Westinghouse will be in a position to offer zircaloy tubing to Babcock & Wilcox and Combustion Engineering, further strengthening this existing interdependence. While we foresee no reason to expect reciprocal buying pressures to develop, the structural relationship for such an occurrence exists.

1. The possibility of Combustion Engineering entering the zircaloy tubing business is probably now negligible since its recent acquisition of a considerable portion of United Nuclear's equity.

The question arises as to whether or not the integrated reactor manufacturers might have a significant cost advantage in the NSSS over the non-integrated manufacturers because of the cost advantages achieved in the large scale product production of zircaloy tubing. We believe that by the early to mid-1970's General Electric and Westinghouse will most probably have a manufacturing cost advantage over the independent tube producers (and, consequently, over Babcock & Wilcox and Combustion Engineering) of 20 cents to 30 cents per foot of tubing or $1.10 to $1.70 per kilogram of uranium, which amounts to approximately 1-½% to 2% of the fabrication cost of a new fuel loading and 1/3% to 1/2% of the total cost.

3. The New Manufacturers

Entry into the manufacture of zircaloy tubing has several advantages for General Electric and Westinghouse. Each will probably be able to obtain cost savings over the alternative of outside purchases by (1) early realization of efficient scales of production and (2) perhaps more favorable purchase arrangements for sponge by virtue of large quantity purchases. In addition to these advantages, good profits will probably be possible on sales in the open market. Finally, when General Electric and Westinghouse begin to manufacture their own tubing the gradual simplification of specifications which when taken place will probably be accelerated, by virtue of increased familiarity and experience. Many of the costly procedures necessitated by the reactor manufacturers' own specifications which, in the opinion of several producers, are overly stringent will be eliminated. More importantly, they may also, through skill in alloy development, be able to make technological improvements in zircaloy which would lead to increased physical strength and an attendant improvement in reactor economics.

Tube inspection costs are unlikely to be reduced by G.E. and Westinghouse's entry since both organizations currently employ resident inspector systems in the plants of current tube producers. There is presently little, if any, duplicate inspection.

We have pointed out that the major reactor manufacturers are entering the zircaloy tube business and that there is considerable incentive for them to do so. Wah Chang, the leading sponge producer, might also have a substantial incentive to enter the tubing market. Although Wah Chang will probably continue to supply the great majority of all zirconium sponge consumed in the United States, this will amount to an annual market of less than $40 million in 1980. This contrasts sharply with the annual market, at that time, for zirconium mill products (tube, sheet and bar) in commercial reactors alone which we estimate to exceed $110 million. Wah Chang, as an integrated producer with the maximum capability of recycling scrap and with strong metallurgical capabilities, should be

capable of becoming a low cost producer, assuming that they could obtain an adequate market to support an efficient-sized plant. In fact, several industry participants have stated that Wah Chang is presently evaluating this course of action.

H. DESCRIPTION OF MANUFACTURING PROCESSES

It is essential that a brief description of the manufacturing processes employed in the production of zirconium tubing be available to those individuals whose purpose is to understand and monitor the changes which occur from time to time within the industry. One must understand the outstanding strengths and weaknesses of the process in order to properly evaluate the potential benefits or penalties associated with the entry of a new producer.

1. Sponge Production

The production of zirconium in the United States starts with the purchase of a concentrate produced from Australian beach sands. The sands are subjected to electrostatic concentration procedures to produce a zircon ($ZrSiO_4$) concentration of approximately 65%. The sands generally contain about 2 to 2-½% as much hafnium as zirconium. (High hafnium contents are desirable, for the entire product must go through a hafnium separation process, and a producer might as well extract as much hafnium as possible.) The zircon concentrates are mixed with carbon and reacted in an electric arc furnace to produce a golden yellow material commonly referred to as zirconium carbon nitride. This is subsequently chlorinated to produce zirconium tetrachloride ($ZrCl_4$).

Silicon, titanium, and aluminum are eliminated in the chlorination step. Zirconium tetrachloride differs from other tetrachlorides in that it does not go through a liquid phase but sublimes from the solid at about 300°C. The tetrachloride is hydrolyzed with water and converted to a zirconyl chloride aqueous solution, which is contacted with a hexone containing ammonium thiocyanate. The latter step is the liquid-liquid hafnium extraction. About 90% of the zirconium remains in the aqueous phase, with all of the hafnium and some of the zirconium going into the organic hexone phase. The zirconium is stripped from the hexone phase with dilute hydrochloric acid, and the hafnium is subsequently recovered from the organic by washing it with a strong sulphuric acid. Washing places the hafnium in a separate aqueous solution, which enables the organic solvents to be recycled.

Various recoveries are made of the materials in the zirconium aqueous solution, and the zirconium is precipitated as an acidic sulfate, phthalate, or salicylate, which is converted to a hydroxide and calcined to oxide. The zirconium oxide is then mixed with lampblack, briquetted, and chlorinated, producing a high purity tetrachloride that is fed into a Kroll reduction cell using molten

magnesium and covered with a chloride vapor and helium gas. The product of the Kroll reaction is called sponge because its physical appearance is similar to the marine creature. The sponge is contaminated with magnesium chloride and some magnesium metal, both of which are distilled off in a vacuum furnace after removal from the Kroll cell.

2. Billet Production

The pure zirconium sponge is then pressed into electrodes and double melted into increasingly larger ingots in a vacuum arc furnace weighing as much as several thousand pounds. The 1-½% tin and small amounts of nickel, chromium, and iron to produce zircaloy are added during the initial double arc melting procedures, by mixing chips of a "master alloy" directly with the pure sponge. The final ingot is scalped and *hot* forged into billet of the shape and size desired. After forging, the billet is scalped again and machined precisely to the dimensions required for extrusion billet and/or rolling ingot. The scalping, turning, and boring chips generated contain a great deal of metal which was contaminated in the forging operation and that must be recycled through the entire purification process. This is probably the largest single source of scrap. Since more than 80% of the zirconium used in nuclear reactors is in the form of tube, the manufacturing process for this product form will be the only one described.

3. Tube Production

A round extrusion billet, generally about one foot long and five inches in diameter, with a hole drilled down the center, is sent to an extrusion plant where it is clad entirely in a copper jacket, evacuated and welded shut. The copper clad billet is then hot extruded to a tube approximately 2-¼ or 1-¼ inches in diameter (depending on the reduction equipment available) by about 12 feet long. The copper cladding is removed by nitric acid pickling, the end defects are cut off, and the tube is carefully inspected. The tubing is then given a thorough surface conditioning, a light etch in a hydrofluoric acid solution, and is cleaned and vacuum annealed. Following the vacuum anneal, it is cooled in a vacuum chamber, removed, and tube reduced or "rocked" directly to final dimensions. Several sizes of tube rockers are employed in order of descending size.

It should be noted that many vacuum annealing steps are interspersed in the tube reducing cycle, as required, to restore ductility and workability. The tube must be cleaned prior to each vacuum anneal to remove lubricant, and then acid etched to insure chemical cleanliness. The tube must be inserted into the vacuum annealing furnace in a completely dry condition to prevent contamination of the equipment and the metal itself. The vacuum annealing takes place at a temperature of about 1450°F. Following the reduction to final size, the tube is given a fairly heavy hydrofluoric acid etch, which removes 3% to 7% of the metal.

Depending upon the specifications and the manufacturer's capabilities, a final finishing operation by means of a tube drawing or sinking process may be utilized for sizing.

At various stages throughout fabrication, scrap is generated. The largest single source of scrap in the manufacture of tube from machined billet is probably encountered when the extrusion ends are trimmed. Approximately 12 pounds of scrap is generated for every 100 pounds of extrusion billet. Almost all of this scrap is shipped back to an arc melting facility, where it is compacted into an electrode and remelted. The tube fabricator must be extraordinarily careful in keeping his scrap clean. The arc melter—generally the original zirconium supplier—produces ingot from the fabricator's scrap for approximately $1.50 per lb. After the melting operation, the ingot is analyzed chemically to determine whether or not it meets nuclear specifications. The tube fabricator must pay the $1.50 per lb melting charge regardless of the outcome of the chemical analysis. This pricing system certainly provides the fabricator with the incentive to maintain clean scrap. If the chemical analysis is such that the material does not qualify as reactor grade zircaloy, the metal must be diverted into other commercial applications or recycled directly into the beneficiation process as zirconium oxide.

After achieving the dimensional characteristics required, the tubing is then straightened and cut to its final length. The non-destructive and destructive tests are hydrostatic, pneumatic, eddy-current, ultrasonic, dye-penetrant, and visual examination. The destructive tests are a flare or expansion test, flattening, burst, tensile, rockwell hardness, dye-penetrant on deformed sections, corrosion, metallographic examination, and chemical analysis. Naturally, the dimensions of the tube are carefully checked as well. All tubing shipped is certified with voluminous data obtained during the processing, final inspection, and quality assurance testing.

It is reasonable to state that the most modern fabrication methods have been used in producing an extraordinarily high quality seamless tubing manufactured under stringent processing specifications and lot control. The manufacturing techniques are very similar to those developed and used for many years on aircraft quality stainless steel and high alloy seamless tubing. The processes for manufacturing zircaloy tubing from billet were substantially refined by Wolverine Tube Divison of Calumet Hecla as an outgrowth of their technology as the largest U.S. manufacturer of non-ferrous tubing. The basic production process was probably first reduced to large scale commercial operation in the Mallory-Sharon Metal Corporation facility—now Reactive Metal, Inc.—around 1958 in conjunction with the Dresden reactor program. Sandvik Steel Co. appears to have developed their own technology independently of other producers.

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VIII. BALANCE OF PLANT, ENGINEERING, AND CONSTRUCTION

A. ELEMENTS INVOLVED

For analytical purposes we have divided the fourth and final part of the nuclear power plant into the following three segments:

- Characteristics of the balance of plant and nuclear plant construction
- Architect-engineers and engineer-constructor services
- Containment

B. CHARACTERISTICS OF THE BALANCE OF PLANT AND NUCLEAR PLANT CONSTRUCTION

1. Background

The balance of plant includes those elements of the nuclear power plant (up to the transmission plant) that are not provided and/or assembled under the NSSS and turbine-generator suppliers' contracts – e.g., site preparation, erection of structures and improvements, accessory electric equipment, various auxiliary systems, and on-site craft labor. These items may account for approximately one-third of direct power plant costs, as reported according to AEC-FPC classification of power plant construction accounts. Additional elements we include in the "balance of plant" category are such distributive (indirect) costs as architect-engineer and construction management services, licensing, and start-up, which may amount to± 10% of direct plant costs.

Certain aspects of any power plant, whether conventional or nuclear, are similar. Some of the important features are the 4–6 year construction lead time, and the expenditure of millions of dollars before the plant produces any power. We have mentioned elsewhere the fact that, unlike other manufactured products, the power plant is shipped in pieces to the owner and erected at a site of his choice. A substantial engineering effort is involved, which usually includes the use of both in-house and outside engineers, construction personnel, and consultants.

The major difference between nuclear and fossil plant construction is the AEC safety and licensing function, which requires assurance that the plant can be constructed and operated safely on the part of the owner-operator before he may obtain a construction permit. Among other things, this requires proof of financial responsibility and arrangement for nuclear liability indemnification and insurance

(under the Price-Anderson amendments to the Atomic Energy Act of 1954). Subsequently, the owner-operator must show that his plant design meets all AEC requirements before he may obtain a permit to operate the plant.

During the period 1954–1967, we witnessed a variety of contracting practices among the NSSS vendors, architect-engineer/construction firms, and utilities. Until 1966, there were only two commercial NSSS suppliers, and the predominant instrument of negotiation between utility and plant supplier was the so-called turnkey contract. The trend is now away from turnkey contracting for nuclear plants, and toward contracts characteristic of traditional utility fossil-fueled plant procurement: i.e., an architect-engineer (A/E) firm and/or engineer-constructor (E–C) assist the utility in (1) system planning, preliminary design engineering (2) bid evaluation, (3) procurement, (4) plant construction of non-nuclear portion of the generating station, and (5) overall construction management.

The licensing process and its relation to plant construction and operation, and the roles of utility, A/E, and NSSS vendor, are shown schematically in Figure VIII-1.

The AEC still treats reactors as developmental rather than commercial products. Section 102 of the Atomic Energy Act of 1954, as amended, provides that whenever the Commission has made a finding in writing that when any type of reactor has been "sufficiently developed to be of practical value for industrial or commercial purposes the Commission may thereafter" issue commercial licenses. In its 1964 "Oyster Creek" application, Jersey Central filed under the developmental section of the Act, but in its application stated that if the type of reactor for which it sought a construction permit should be found to be of practical value under Section 102 of the Atomic Energy Act, its application should be considered an application for a commercial license. Oyster Creek, like all other power reactors to date, was considered developmental by AEC.

In his foreword to the 1968 Jackson & Moreland/Stoller Associates report on "Current Status. . .of Light Water Reactors," Mr. Milton Shaw, Director of AEC's Division of Reactor Development and Technology, echoed the sentiment of recent AEC legal briefs (filed in the U.S. Court of Appeals) in support of its position on the matter of practical value, stating that

> ...it must be remembered that the purchase of pressurized water and boiling water reactors in unanticipated numbers by the electric utility industry is an established fact. These purchases have been made on the basis of warranties and economic extrapolations furnished by the. . .manufacturers. It should also be noted that the technology and economics of the large light water reactor plants now under construction have yet to be demonstrated.

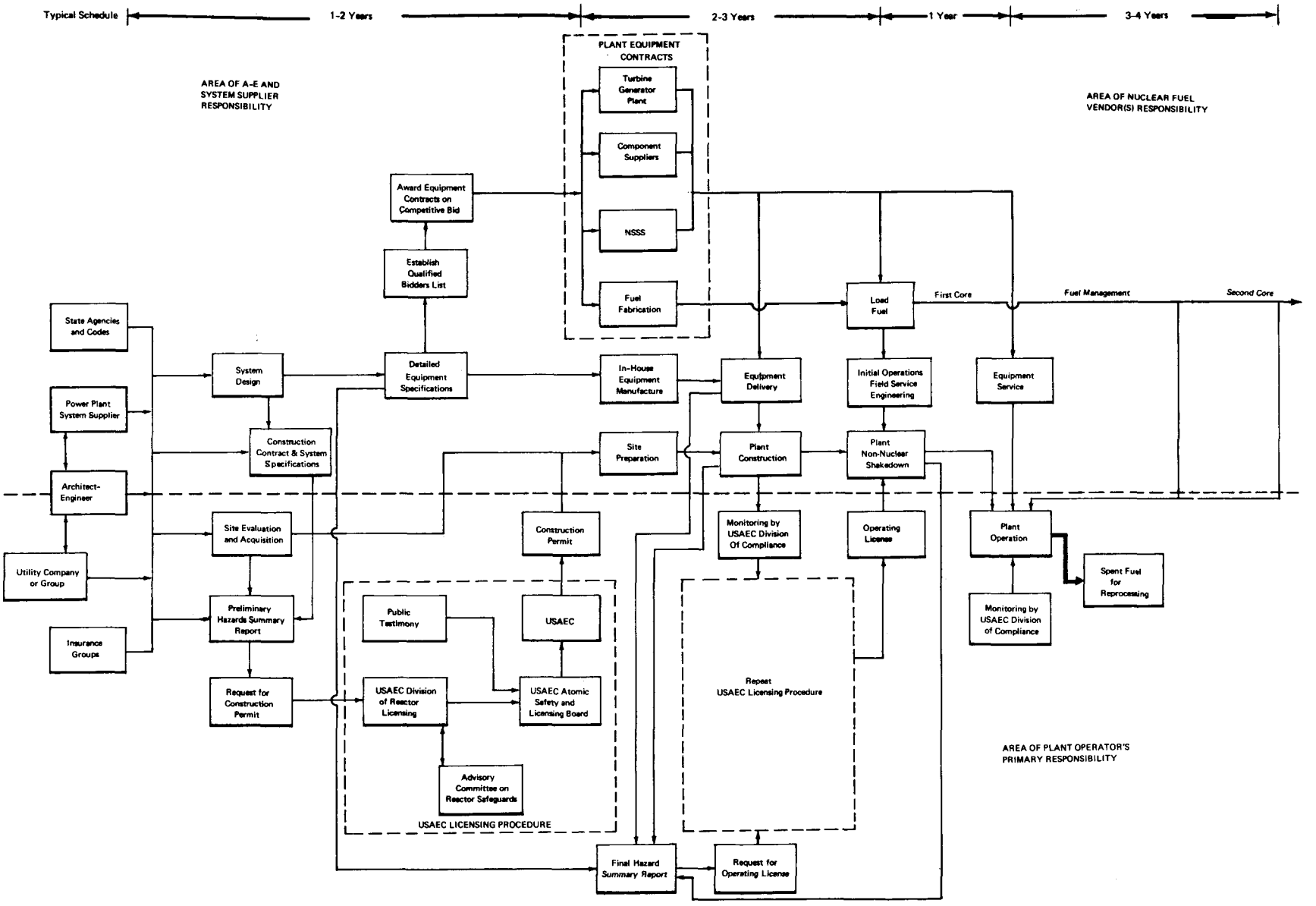


FIGURE VIII–1 DIAGRAM FOR NUCLEAR PLANT CONSTRUCTION

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If a "finding of practical value" were made, then licensing automatically opens the proceedings to mandatory review on antitrust matters by the Department of Justice under present law.

Currently there is controversy on the subject between investor-owned and small public/municipal utilities, the latter claiming that present AEC licensing procedures favor large private utilities and consortia, allowing the latter groups to benefit from the scale economies of nuclear power plants. Their expectation is that DOJ review would open up participation in nuclear projects. New legislation governing the actual scope of AEC's regulatory authority over construction of power reactors and the role of DOJ in the licensing process is presently being worked out in various congressional committees.

2. Influence of AEC classification of Construction Accounts

Before discussing those aspects of nuclear plant construction that have an obvious bearing on competition in the nuclear power supply industry, we shall briefly examine the AEC's classification of construction accounts, which are often used in the industry for estimating nuclear power plant costs, and the importance of utility accounting for such costs.

Utility plant investment, and hence buying practices can be influenced by what acceptable accounting, tax and/or regulatory practice encourage with regard to cost accounting for an investment. In the case of utilities, what is capitalized versus expensed is a key area of management and utility commission concern, since it can affect the rate base, period rate of return, and ultimate charges for electric power.

Table VIII-1 presents the AEC's uniform system of accounts for estimating and reporting construction costs for nuclear power and related transmissions and general plant facilities. This system was designed by AEC Headquarters, Office of the Comptroller, to provide a means for standard distribution of costs for nuclear power plants and to facilitate the comparative economic analyses of various nuclear power plant concepts.

The direct cost accounts have been keyed to the Electric Plant Accounts established by the Federal Power Commission[1]. The principal difference between the AEC system of accounts and that of the FPC is that the latter is designed for

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1. FPC Uniform System of Accounts prescribed for Public Utilities and Licensees (Class A and Class B), subject to the provisions of the Federal Power Act, effective January 1, 1961.

TABLE VIII–1

SUMMARY–CLASSIFICATION OF CONSTRUCTION ACCOUNTS
NUCLEAR POWER PLANTS

Account Number		
	NUCLEAR PRODUCTION PLANT	
20	Land and Land Rights	
	201	Land and Privilege Acquisition
	202	Relocating Highways and Railroads
	203	Relocating Telephone and Power Lines
21	Structures and Improvements	
	211	Ground Improvements
	212	Buildings
	218	Stacks
	219	Reactor Containment Structure
22	Reactor Plant Equipment	
	221	Reactor Equipment
	222	Heat Transfer Systems
	223	Fuel Handling and Storage Equipment
	224	Fuel Processing and Fabricating Equipment
	225	Radioactive Waste Treatment and Disposal
	226	Instrumentation and Control
	227	Feed-water Supply and Treatment
	228	Steam, Condensate and Feed-water Piping
	229	Other Reactor Plant Equipment
23	Turbine-Generator Units	
	231	Turbine-generators
	232	Circulating Water Systems
	233	Condensers
	234	Central Lubricating System
	235	Turbine Plant Boards, Instruments and Controls
	236	Turbine Plant Piping
	237	Auxiliary Equipment for Generators
	238	Other Turbine Plant Equipment

Account Number		
24	Accessory Electric Equipment	
	241	Switchgear
	242	Switchboards
	243	Protective Equipment
	244	Electrical Structures
	245	Conduit
	246	Power and Control Wiring
	247	Station Service Equipment
25	Miscellaneous Power Plant Equipment	
	251	Cranes and Hoisting Equipment
	252	Compressed Air and Vaccum Cleaning Systems
	253	Other Power Plant Equipment
	TRANSMISSION PLANT	
50	Land and Land Rights	
51	Clearing Land and Rights-of-Way	
52	Structures and Improvements	
	521	General Yard Improvements
	522	Substation Buildings
	523	Outdoor Substation Structures
53	Station Equipment	
	531	Switchgear
	532	Protective Equipment
	533	Main Conversion Equipment
	534	Conduit
	535	Power and Control Wiring
	536	Station Service Equipment
54	Towers and Fixtures	
55	Poles and Fixtures	

TABLE VIII–1 (Continued)

Account Number	
56	Overhead Conductors and Devices
57	Underground Conduit
58	Underground Conductors and Devices
59	Roads and Trails
	GENERAL PLANT
97	Communication Equipment
	DISTRIBUTIVES
98	Indirect Construction Costs
	981 Engineering, Design, and Inspection
	982 General and Administrative
	983 Other Indirect Costs
	984 Earnings and Expenses during Construction
	985 Interest during Construction
99	Miscellaneous Construction Costs
	991 Construction Inventories
	992 Temporary Construction Facilities
	993 Construction Equipment and Tools
	994 Construction Clearing Accounts
	CONTINGENCY

Source: Guide to Nuclear Power Cost Evaluation, TID–7025, USAEC (1962).

use in recording costs of completed plants, after the allocation of indirect construction costs. The AEC system, on the other hand, is designed for use during the construction period prior to the allocation of indirect construction costs and, therefore, provides separate accounts for these costs (Accounts 98 and 99).

The above classification of accounts, drawn up before private ownership of nuclear fuel, is obviously incomplete to the extent that utilities will treat nuclear fuel, or at least its fabrication cost, as a capital investment[1].

The accounts do provide an idea of the complexity of a modern power plant, and the scope of responsibility implied by the term 'balance-of-plant" – in this report, everything but the nuclear reactor and its associated, vendor-supplied equipment.

The accounts also provide a framework for the subsequent discussion of architect engineers and engineer-constructors. Professional engineering fees and fees for construction supervision are considered indirect or distributive costs; construction labor, however, is a direct cost usually paid by the utility or paid by the E–C reimbursed by the utility.

The accounts are also used by utilities in presenting their plant cost estimates to AEC when filing for a construction permit. AEC has to rule on the "financial responsibility of the applicant," and the AEC Division of Construction submits a statement saying in effect that "the estimated installed cost per kilowatt is (is not) in a reasonable range." This procedure possibly has the desirable effect of intensifying competition "by exposure," since the filings are part of the public record. Unfortunately, it can also lead to distortions by the trade press, since frequently no effort is made to adjust total plant costs as filed so that fair comparisons can be made with costs reported for other plants. Two items of indirect cost, in particular, can be troublesome in this respect: interest during construction, and contingency allowance.

1. A study is currently underway by the FPC and a committee of Edison Electric Institute to resolve some of the special problems that utilities face in setting up accounting principles for nuclear fuel under private ownership.

The following breakdown, taken from information submitted recently by Virginia Electric & Power Company to AEC and made public in connection with the 1694 Mwe, 2-unit Surry nuclear power plant construction permit application, illustrates these points:

CONSTRUCTION ACCOUNT	COST ESTIMATED MARCH 1, 1968 ($ millions)
Land and Land Rights	0.38
Structures and Improvements	30.94
Reactor Plant and Equipment	71.66
Turbogenerator Units	58.17
Accessory Electric Equipment	7.92
Miscellaneous Power Plant Equipment	2.23
Subtotal, Direct Costs	171.30
Engineering, Design, Inspection	8.73
Startup	0.24
Contingencies	5.40
Interest during Construction	25.79
Other Indirect Costs	43.80
Subtotal, Indirect Costs	83.96
Grand Total	255.26
Less: Interest Charged to Construction	-25.79
Estimated Cash Requirement	229.47

The Surry station is being constructed for VEPCO by Stone & Webster Engineering. Westinghouse is providing the NSSS and turbine-generator. Based on the above information, the plant has an indicated "book cost" of $255 million. The estimated cash outlay, obtained by subtracting interest charged to construction, is $229 million over the 1967–72 construction period.

C. ARCHITECT-ENGINEERS AND ENGINEER-CONSTRUCTORS

1. Product/Market Description

These firms provide professional engineering services to industry and government. They have a unique vantage point as agents for and/or consultants to utilities. They are exposed to bid data, balance of plant procurement and site construction of much of a nuclear or fossil-fueled generating plant.

To distinguish between the two types of firms, the AE provides professional engineering services that may include conducting bid invitations, furnishing general specifications, bid normalization, and balance of plant design and assistance. (Certain firms, e.g. NUS, Stoller Associates, have specialized in fuel cycle analysis, and also may be brought in as consultants.) The construction of the plant is the responsibility of another organization. For example, Commonwealth Edison has Sargeant and Lundy as AE, and United Engineers as construction manager on Dresden 2 and 3. The engineer-constructor (E–C) offers an integrated service to the customer. This type of firm can provide both the architect-engineering services and plant construction. Stone & Webster Engineering has this role on VEPCO's Surry station.

2. Market Structure

Market structure information is summarized in Tables VIII-2 and VIII-3. There is some evidence, as well as some financial history, relating certain utilities to certain AE's. However, utilities tend to choose AE'S the way one would choose a law firm or a dentist. (Engineering firms don't like to think of themselves as engaging in price competition, as this is considered unethical. They provide a professional service and bill for such.) The pattern for nuclear plants appears to be very similar to that for fossil – fueled plants; in fact, almost exactly the same firms are represented. The rank ordering is approximately the same in both cases, with the five leading firms responsible for the lion's share of the available engineering and/or construction business as of the beginning of 1968. However, the drop in Ebasco Services' position, from No. 1 in fossil to No. 5 in nuclear, is striking. We will comment on Bechtel, which holds the No. 1 position in nuclear, later in this section.

AE charges for professional services (design/engineering) typically amount to 6%, and E–C charges for engineering and construction management, 10% of the direct plant construction cost. These are added to the latter as an item of indirect construction cost in the utility accounts. Construction management generally includes scheduling, procurement, inspection, and providing craft labor at the site. All of the major engineering-constructor firms also have the ability to design,

TABLE VIII–2

APPROXIMATE RANK BY Mwe UNDER CONSTRUCTION
(January 1968)

	AE		E–C	
Rank	**Fossil**	**Nuclear**	**Fossil**	**Nuclear**
1	Sargeant & Lundy	Sargeant & Lundy	Ebasco	Bechtel
2	Gilbert Associates	Gilbert Associates	Bechtel	United Engineers
3	Black & Veatch	Pioneer Service	Stone & Webster	Stone & Webster
4	Pioneer Service	Commonwealth Associates	United Engineers	Burns & Roe
5	Commonwealth Associates		Brown & Root	Ebasco
6			Burns & Roe	J. A. Jones
7			Gibbs & Hill	Gibbs & Hill

TABLE VIII–3

E–C PARTICIPATION IN COMMERCIAL NUCLEAR POWER PLANT CONSTRUCTION UNDERWAY IN 1967 OR ANNOUNCED AS OF MARCH 1968[a]

ENGINEER–CONSTRUCTOR FIRM	TOTAL UNITS	APPROXIMATE Mwe
Bechtel Corporation	16[b]	11,400[b]
United Engineers & Constructors	12	10,700
Stone & Webster Engineering	9	6,200
Burns & Roe	3	2,300
Ebasco Services	3	1,900
All others, n.e.c.	6	3,600
UTILITY ENGINEER–CONSTRUCTOR		
TVA	3	3,300
Duke Power Corporation	3	2,400
American Electric Power	2	2,200
Pacific Gas and Electric	2	2,100
E–C NOT YET SELECTED	8	7,600
	67	53,700

a. Excludes research reactors, small demonstration prototypes, and about 1600 Mwe in five completed central station plants

b. Excludes Oconee 1 and 2 (1600 Mwe), for which Bechtel is providing engineering assistance.

Source: Arthur D. Little, Inc.

engineer, and construct a significant part of the auxiliary facilities at a nuclear plant site – cleanup systems, fuel storage, waste handling, and so forth. The engineering firms may be in a better position than the NSSS suppliers to handle complete auxiliary subsystems; there is thus an area of "value added" in nuclear plant design and/or construction in which the NSSS supplier and the engineering firms may offer competing services or expertise.

a. Viability

To the extent that neither reactor manufacturers nor utilities have the background and experience to perform power plant construction on the scale that will be required in the years ahead, demand for AE and E–C services should be strong. However, E–C's will feel competition from the increasing number of sophisticated utility systems with in-house AE and construction management capabilities. On the other hand, because of their unique professional role and broad base of activities, AE and E–C firms should be able to attract and hold the required personnel, and there should be no question about the viability of such firms.

b. Barriers to Entry

The barriers to entry are primarily: lack of experience and reputation, insufficient technical manpower, economic resources, and detailed design information required by the AEC in licensing. Because AE's and E–C's help utilities and work with manufacturers in submitting the preliminary safety analysis report to the Division of Reactor Licensing at AEC (required for a construction permit), substantial experience has been built up in these organizations. The safety and licensing process, if anything, enhances their abilities to gain business. The shift away from turnkey contracting has in this and other ways, been beneficial to the early firms. It has also tended to spur design innovations.

c. New Entry

Recently there have been several new AE entrants specializing in the problems peculiar to nuclear plants (e.g., siting, waste disposal, fuel cycle services). In the case of E–C's, it might seem that the larger, well-established, firms would have an advantage over new entrants with a relatively small capitalization, because of financing requirements for construction. Our expectation, however, is that a new entrant acting as agent for the utility would have no problem of this type because of the utility's credit and financial stature. In any event, capitalization is only one of the elements affecting new entry; others are procurement capability, labor relations, and a recognized ability to perform on schedule.

3. Market Performance

Historical information on both public and private utilities, showing what architect-engineer or engineer-constructor firms, if any, they tend to associate with, suggests that, while there are some preferences, they have no strong bearing on the competitive situation in the reactor business or fuel cycle at this time. There appears to be adequate competition among AE's and E–C's comparable to that in fossil-fueled plant contracting.

Engineer-constructors are increasingly performing services as a utility's agent, under a cost-plus-fixed-fee arrangement, rather than on a fixed-price contract basis. In certain cases some of the larger firms will work under incentive contracts. The agency role seems to be generally preferred by both the utility and the E–C; it has been traditional in the construction of conventional power plants. It is a professional relationship rather than a supplier-customer relationship. Furthermore, the claim is made that it gives the E–C more flexibility to shop for components at the best price, and hence save the utility money.

The agency role may be more effective in limiting the NSSS manufacturer's scope of supply, a matter discussed elsewhere in this report under the topic of NSSS vertical integration. On the other hand, it is an arrangement under which the E–C has relatively little financial risk due to construction cost escalations. This risk is shifted to the utility, which may be expected to be much stronger financially. (In most cases, any construction cost escalations would eventually be incorporated into the rate base; however, there are factors to consider other than rate base maximization to determine whether, in specific cases, a utility could consider such construction cost escalations salutary.)

Both nuclear and fossil plant construction costs increased sharply during the last 12–18 months. This raises the major question of how much control the customer utility has over its plant construction costs, due to the nature of E–C and manufacturers' contracts, and labor relations practices among the craft unions across the country. This question is relevant, not only to the labor intensity of nuclear vis-a-vis fossil plants, but also to the impact of a large change in plant construction costs on the nuclear industry.

(At the same time, certain decisions depending on labor union regulations [e.g., field fabrication of piping], can affect the economics of a pressurized water reactor vis-a-vis a boiling water reactor.)

It appears that, except on turnkey contracts, the utility is bearing the brunt of the large and increasing labor costs associated with nuclear plant construction. Most manufacturers are assuming that site labor costs will increase. It would be encouraging if there were some talk of productivity increases to offset such wage

rate escalation, but we have found no evidence of this at this juncture. (Some of the industry feel that the AEC licensing process is discouraging any innovations – including some means for increasing productivity.) As an example of what is involved, we learned that the Oyster Creek project, excluding the repair of welds between the stub tubes and control rod drive housings in the reactor pressure vessel, is expected to require 4 million manhours of craft labor at the site; Nine-Mile Point, a similar plant, will require the same amount. This is equivalent to 7–8 manhours/kilowatt of plant, worth perhaps $40/kw – a very significant portion of total generating plant costs.

On Peach Bottom 2 the estimate is roughly 5 manhours/kw of field labor (an 1100 megawatt plant). However, a plant of this size has not been constructed yet. TVA is apparentlv budgeting for an average of 5–6 manhours/kw on Browns Ferry (3–1100 Mwe units), based partially on its experience with fossil plants of comparable size.

While there is probably more site labor involved in erecting a fossil boiler than a nuclear boiler of the same rating, the additional complexity, quality control, and auxiliary systems required in the nuclear plant probably make for larger site labor requirements. If the labor factor continues to worsen, because of union provisions, manufacturer's escalations, etc., the market for nuclear plants could be affected, other things being equal. The situation could be aggravated further by delays in construction necessitated by AEC safety and licensing procedures. Indeed, one prominent utility spokesman, with considerable nuclear experience, recently estimated that such delays alone could add $10–15/kw to nuclear plant costs.

4. Bechtel Corporation

Bechtel is probably the largest engineering-construction firm in the U.S., and also has the most nuclear plant work to date. A brief examination of the firm seems in order.

Bechtel considers itself an "engineer-manager organization." Operations include engineering, design, procurement, construction, and conducting economic and feasibility studies for a multitude of government and industrial clients worldwide. It is a private corporation, and trade estimates are that Bechtel handles approximately $1 billion worth of engineering and construction work per year. Operations are divided into eight major divisions, most of which are based in San Francisco, where Bechtel employs some 4000 engineers. (Another 1000 are scattered worldwide in its various area and field offices.) The largest is the Refinery and Chemical Division, with more than 1600 staff. Other divisions include the Power and Industrial, Vernon, International, Pipeline, Hydro and Transportation, and Mining and Metals. The great bulk of Bechtel's nuclear work is domestic.

Bechtel's interest in the nuclear field dates back to 1949. It grew out of a determination after WW II of Bechtel's management to gain a stronger participation in the utility business. Electric power was viewed as a growth industry and nuclear power an exciting field, which offered promise of ultimately having commercial application. In 1949 Bechtel constructed the experimental fast breeder (EBR–1) reactor facility in Idaho for the AEC. In 1951 it was invited to participate in one of four AEC studies of power-and-plutonium reactor plants. It formed a team with its neighbor Pacific Gas and Electric. Three other teams were Commonwealth Edison-Public Service of Northern Illinois (they subsequently merged); Union Electric-Monsanto; and Detroit Edison-Dow Chemical.

In the early 50's developments at the Savannah River Plant set back the concept of power-and-plutonium reactor plants; however, they stimulated private companies to look at power-only reactors. In 1953, Bechtel, Pacific Gas and Electric, and Commonwealth Edison, among others, formed the Nuclear Power Group, Inc., which contracted for Dresden-1 in 1955. This was the first power reactor (a GE BWR) to be financed entirely by private capital. Bechtel performed the engineering and construction management of Dresden-1. It also did the chemical processing plant at Arco, Idaho, (the national reactor test site) and designed and constructed the commercial spent-fuel reprocessing plant of Nuclear Fuel Services, Inc. Bechtel has worked with all major reactor manufacturers on every type of commercially offered and/or prototype plant. It also has an impressive cross-section of utility customers, both public and private, in its nuclear business.

D. CONTAINMENT FOR NUCLEAR STEAM SUPPLY SYSTEMS

Containment refers to the overall system comprising a physical barrier and heat transfer and fluid flow components designed to protect against uncontrolled release of radioactive products to the environment in the event of an accident. The principal design consideration is to contain a "maximum loss of coolant" accident, with its attendant energy release and pressure surge. The containment structure per se is the physical barrier, and surrounds the nuclear reactor and associated equipment.

The containment structure differs from a pressure vessel in that it is not normally under pressure. It is provided with air-locks for entrance and exit, and is not protected against overpressure by means of relief valves or rupture discs, since these would defeat its basic purpose. [1]

1. The HTGR design embodies a pre-stressed, post-tensioned concrete pressure vessel with a steel liner, for both primary and secondary containment – i.e., there is no containment structure separate from the reactor pressure vessel.

1. Product/Market Description

Containment structures are made of steel, concrete, or a combination of steel and concrete. The steel is fabricated by manufacturers of large metal plate structures in conformance with the ASME boiler and pressure vessel code. Concrete work – involving supporting and reinforced concrete for structural and shielding purposes – is generally provided by the engineer-constructor organization.

Containment structures may roughly be compared to large, complex gas storage tanks in terms of the nature of the product. The "product" is not homogeneous in the usual economic sense; i.e., each structure is custom designed to a certain extent. Moreover, while part of a larger product whose demand is relatively elastic, the demand for a containment structure is inelastic once a nuclear plant is chosen. However, the total cost of a containment structure is only about 4–6% of the present total cost of a nuclear power plant.

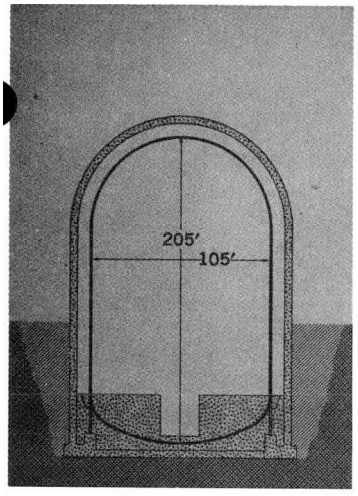
2. Market Structure

Approximately 56 nuclear units over 400 Mwe have been ordered through 1967. Depending on the nature and extent of nuclear power growth, we would expect about 12-20 orders for containment structures per year for the period 1970–1980. Chicago Bridge and Iron Company, a leading metal-plate fabricator and construction concern with annual sales of about $200 million, has constructed or has under construction about 25 steel containment structures for commercial central station plants. (Figure VIII-2 presents CB&I's Bulletin 8500 and illustrative material in order to show the scope of CB&I's work in the nuclear field.)

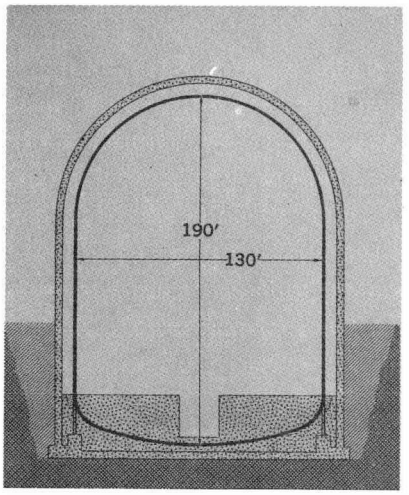
CB&I's product is a metal tank structure. It has competition from Pittsburgh-Des Moines Steel Company, the Graver Division of Union Tank Car Company, and Nooter Corporation and General American Transportation Corporation. CB&I lost out to competition in TVA's Brown's Ferry (3 units), Florida Power and Light's Turkey Point (2 units), Wisconsin's Point Beach (2 units), and a few miscellaneous prototype or research reactors. The containment suppliers for several more recent plant awards have not yet been announced. CB&I can expect increasing competition from such engineering-construction firms as Bechtel, Stone & Webster, Ebasco, and United Engineers & Constructors.

a. Value Added

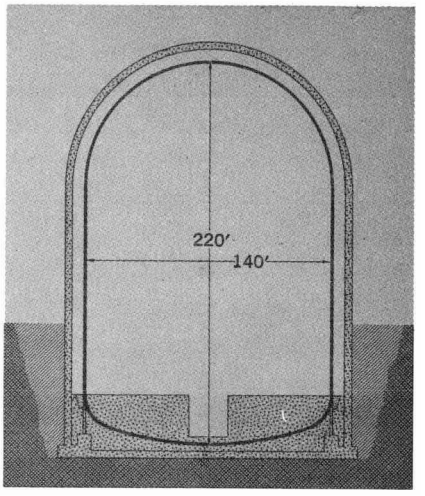
The total cost of containment for a 800–900 Mwe plant is ~$5–6 million today, ($6+/kw) for either BWR or PWR In the PWR, the steel liner alone may cost $1.50/kw. In a BWR, the large free-standing steel pressure suppression containment would cost about $3/kw. The cost of materials is only a fraction of the total cost, since there is a high skilled labor and engineering content.



500 MWe PLANT



800 MWe PLANT



1100 MWe PLANT

FULL PRESSURE - FREE STANDING - STEEL CONTAINMENT

TAILORED FOR INDIVIDUAL PWR PLANT REQUIREMENTS

- FIRM PRICE
- FIXED SCHEDULE
- SINGLE RESPONSIBILITY
  - DESIGN
  - FABRICATE
  - DELIVER
  - CONSTRUCT
  - TEST

- Low—0.10 per cent—leakage rates.
- Design conforms to Section III ASME Code for Unfired Pressure Vessels.
- Equipment openings of 24′ to 30′ diameter are provided.
- Steel vessel design is readily adapted to earthquake requirements.
- Polar crane may be hung directly from the shell. There is no need for a separate support structure.
- Typical steel construction schedule of 13 months may be shortened to 10 months by double shift operation.
- Steel vessel offers improved heat sink characteristics in containment system design.
- Simplified shield wall concrete.
- Vessel provides weather protection when placing internal concrete and equipment.
- Double containment capability.

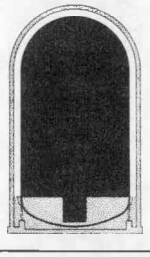
FIGURE VIII-2 CB&I CONTAINMENT AD-PWR's

VERTICAL CONTAINMENT VESSELS
CYLINDRICAL SHELL WITH FORMED TOP AND BOTTOM



LOCATION	VOLUME CU. FT.	DESIGN psi INTERNAL (EXTERNAL)	DIMENSIONS	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT	REACTOR TYPE
DAYTON, OHIO	744,700	16 (TEST)	82'-8"Ø 159'-4"OA	9/16"-1" A201-A300	NO	1957	POOL REACTOR
LAGOONA BEACH, MICHIGAN	415,800	32 (2)	72'Ø 120'OA	1.03"-1.25" A201-A300	VIII	1957	FBR
ELK RIVER, MINNESOTA	415,000	21 (0.5)	74'Ø 115'OA	0.70"-.875" A201-A300	VIII	1959	BWR
FORT GREELEY, ALASKA	89,600	15 (NOT Spec.)	40'8"Ø 79'OA	0.25"-0.50" A201-A300	NO	1960	PWR
PLEASANTON, CALIFORNIA	202,600	58 (1)	48'Ø 128'OA	0.513"-1.015" A201-A300	VIII	1961	BWR
TRINO* VERCELLESE, ITALY	1,295,900	33.7 (0.9)	100'Ø 190'OA	0.616"-1.50" A201-A300	NO	1962	PWR
PEACH BOTTOM, PENNSYLVANIA	1,141,500	8.0 (0.2)	100'Ø 162'OA	5/16"-0.703" A201-A300	VIII	1964	HTGR
LA CROSSE, WISCONSIN	364,800	52 (0.5)	60'Ø 144'OA	0.60"-1.16" A201-A300	VIII	1964	BWR
FAYETTEVILLE, ARKANSAS	215,200	30 (1)	50'Ø 105'-6"OA	A212-A300	VIII	UNDER CONSTR.	BWR

VERTICAL FULL PRESSURE CONTAINMENT VESSELS
WITH EXTERIOR SHIELD WALL CONCRETE



LOCATION	VOLUME CU. FT.	DESIGN psi INTERNAL (EXTERNAL)	DIMENSIONS	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT	REACTOR TYPE
PRAIRIE ISLAND, MINNESOTA (2 vessels)	1,559,750	41.4 (0.8)	105'Ø 206'-4"OA	A516-70 A300	III	UNDER CONSTR.	PWR
KEWAUNEE, WISCONSIN	1,455,000	41.0 (0.8)	105'Ø 194'OA	A516-70 A300	III	UNDER CONSTR.	PWR

*Built by Chicago Bridge Limited (CB&I Subsidiary)

FIGURE VIII-2 Continued

STEEL LINERS FOR CONCRETE CONTAINMENT VESSELS



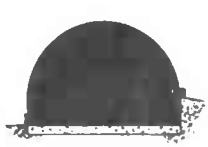
LOCATION	DIMENSIONS	MATERIAL	YEAR BUILT	REACTOR TYPE
HADDAM, CONNECTICUT	135'Ø 188'-6"OA	A442-GR60 SHELL 3/8" DOME 1/2"	1967	PWR
ROCHESTER, NEW YORK	105'Ø 149'-6"OA	A442-GR60 MOD. SHELL 3/8" DOME 1/2"	1967	PWR
INDIAN POINT, #2 NEW YORK	135'Ø 209'-6"OA	A442-GR60 MOD. SHELL 3/8" DOME 1/2"	1968	PWR
INDIAN POINT, #3 NEW YORK	135'Ø 209'-6"OA	A442-GR60 MOD. SHELL 3/8" DOME 1/2"	UNDER CONST.	PWR
SANDUSKY, OHIO	136'Ø 158'OA	A285-GRC FBX SHELL 1/4" DOME 1/4"	1966	PWR
HARTSVILLE, SOUTH CAROLINA	130'Ø 191'OA	A442-GR60 SHELL 3/8" DOME 1/2"	UNDER CONST.	PWR
MIDDLETOWN, PENNSYLVANIA	130'Ø 192'-4"OA	A283-GRC SHELL 3/8" DOME 3/8"	UNDER CONST.	PWR

VERTICAL CONTAINMENT VESSELS
CYLINDRICAL SHELL, FORMED TOP AND FLAT BOTTOM





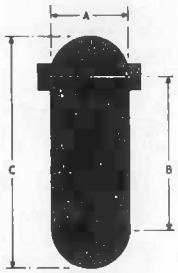




LOCATION	VOLUME CU. FT.	DESIGN psi INTERNAL (EXTERNAL)	DIMENSIONS	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT
LIVERMORE, CALIFORNIA	257,500	2 (.083)	80'Ø 38'TL	1/4" SHELL A283	NO	1957
CAMBRIDGE, MASSACHUSETTS	258,700	2 (.1)	74'Ø 48'TL	3/8" SHELL A283	NO	1958
ATLANTA, GEORGIA	263,500	2 (0.2)	82'-2"Ø 71'OA	7/16" to 1.75" A201-A300	NO	1962
LYNCHBURG, VIRGINIA	542,000	5 (0.4)	33' 66'-3"OA	1/4" SHELL A201-A300	NO	1964
AIKEN, SOUTH CAROLINA	214,000	24 (.25)	70'Ø 67'OA	.375"-.67" A201-A300	NO	1960
RINCON, PUERTO RICO	1,780,000	5 (.25)	166'-8"Ø 109'-4"OA	0.40" SHELL 5/16" A201-FGP	NO	1961

FIGURE VIII-2 Continued

REACTOR PRESSURE VESSELS



LOCATION	ASSEMBLY	TYPE SIZE MWe	DESIGN PRESS. PSIG	DIMENSIONS A IN.	B FT.	C FT.	Avg. Thick IN.	MATERIAL SHELL / CLADDING	ASME CODE STAMP SECTION	YEAR BUILT
MONTICELLO, MINNESOTA	SITE	BWR 545	1250	205	46	63.9	5-1/16	A553-CL.1-GR.B / Type 304	III	UNDER CONSTR.
VERNON DAM, VERMONT	SITE	BWR 545	1250	205	46	63.9	5-1/16	A533-CL.1-GR.B / Type 304	III	UNDER CONSTR.
TO BE ANNOUNCED	SHOP	BWR 800	1250	220	51	69.5	5-3/8	A533-CL.1-GR.B / Type 304	III	UNDER CONSTR.
TO BE ANNOUNCED	SHOP	BWR 800	1250	220	51	69.5	5-3/8	A533-CL.1-GR.B / Type 304	III	UNDER CONSTR.
TO BE ANNOUNCED	SITE	BWR 800	1250	220	51	69.5	5-3/8	A533-CL.1-GR.B / Type 304	III	UNDER CONSTR.

RADIOACTIVE WASTE STORAGE TANKS

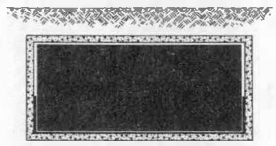
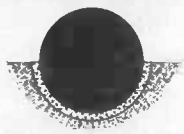
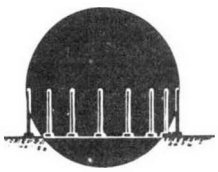
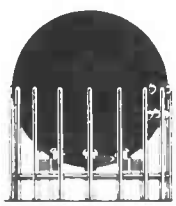
	LOCATION	DIMENSIONS	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT
	ARCO, IDAHO 7 VESSELS	12'Ø x 42'6"	304SS	VIII	1965
	SPRINGVILLE, NEW YORK 2 VESSELS (PWHT)	70'Ø x 27' VESSELS 75'Ø x 5'3" PANS	A201AFBX	VIII	1964
	HANFORD, WASHINGTON	62'6" SPHERE	A441	VIII	1963
	HANFORD, WASHINGTON	40'Ø x 10'6"	A283	NO	1961

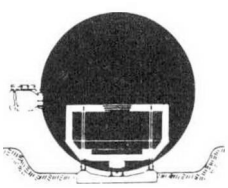
FIGURE VIII-2 Continued

SPHERICAL CONTAINMENT VESSELS

LOCATION	VOLUME CU. FT.	DESIGN psi INTERNAL (EXTERNAL)	DIAMETER	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT	REACTOR TYPE
W. MILTON, NEW YORK	6,000,000	20 (.8)	225'	.9"-1.1" A201-A300	NO	1953	SIR
DRESDEN, ILLINOIS	3,600,000	29.5 (1)	190'	1.25"-1.4" A201-A300	VIII	1958	BWR
INDIAN PT., NEW YORK	2,140,000	25 (1.25)	160'	.89"-1.03" A201-A300	VIII	1959	PWR
CHARLEVOIX, MICHIGAN	1,150,000	27 (.5)	130'	.702"-.774" A201-A300	VIII	1960	BWR
SAN ONOFRE, CALIFORNIA	1,435,000	46.4 (2)	140'	A212-A300	VIII	1965	PWR
GARIGLIANO,** ITALY	2,140,000	26 (1)	160'	.832"-.947" A201-A300	NO	1961	BWR
ROWE, MASSACHUSETTS	1,020,000	31.5	125'	.875"-1.25" A201-A300	VIII	1959	PWR
DOUNREAY,* SCOTLAND	1,290,000	18 (TEST) (4) TEST	135'	1"-1.75" Coltuf	NO	1956	GCR



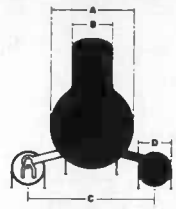




*Built by Motherwell Bridge & Engrg. Co., Inc. (CB&I Licensee)
**Built by Chicago Bridge Limited (CB&I Subsidiary)

FIGURE VIII-2 Continued

PRESSURE SUPPRESSION CONTAINMENT VESSELS



LOCATION		TOTAL VOLUME (CU. FT.)	DESIGN PRESSURE (PSI) INT	EXT	DIMENSIONS (FT.) A	B	C	D	MATERIAL	ASME CODE STAMP SECTION	YEAR BUILT	REACTOR TYPE
TARAPUR, INDIA 2 VESSELS	DRYWELL		45	2	65	23			A201-A300	NO	1965	BWR
	SUPPRESSION CHAMBER		STEEL LINED BY OTHERS									
OYSTER CREEK, NEW JERSEY	DRYWELL	440,000	62	2	70	33			A212-A300	VIII	1965	BWR
	SUPPRESSION CHAMBER		35	5			101	30	A212-A300			
OSWEGO, NEW YORK	DRYWELL	440,000	62	2	70	33			A212-A300	III	1965	BWR
	SUPPRESSION CHAMBER		35	1			124	27	A201-A300			
DRESDEN, ILLINOIS NOS. 2 & 3	DRYWELL	440,000	62	2	66	38			A212-A300	III	NO. 2 1966 NO. 3 1967	BWR
	SUPPRESSION CHAMBER		62	1			109	30	A212-A300			
MILLSTONE POINT, CONNECTICUT	DRYWELL	420,000	62	2	64	34-2			A516-GR70 A300	III	1967	BWR
	SUPPRESSION CHAMBER		62	1			102	29-6	A516-GR70 A300			
MONTICELLO, MINNESOTA	DRYWELL	430,000	56	2	62	33			A516-GR70 A300	III	1968	BWR
	SUPPRESSION CHAMBER		56	1			98	27-8	A516-GR70 A300			
VERNON DAM, VERMONT	DRYWELL	430,000	56	2	62	33			A516-GR70 A300	III	UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	1			98	27-8	A516-GR70 A300			
CORDOVA, ILLINOIS 2 VESSELS	DRYWELL	440,000	56	2	66	37			A516-GR70 A300	III	NO. 1 1968 NO. 2 UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	1			109	30	A516-GR70 A300			
PLYMOUTH, MASSACHUSETTS	DRYWELL	420,000	56	2	64	34			A516-GR70 A300	III	UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	2			102	30	A516-GR70 A300			
EASTON STATION, NEW YORK	DRYWELL	430,000	56	2	67	39			A516-GR70 A300	III	UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	2			112	31	A516-GR70 A300			
PEACH BOTTOM, PENNSYLVANIA 2 VESSELS	DRYWELL	480,000	56	2	67	39			A516-GR70 A300	III	UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	2			112	31	A516-GR70 A300			
COOPER STATION, NEBRASKA	DRYWELL	388,000	56	2	65	36			A516-GR70 A300	III	UNDER CONST.	BWR
	SUPPRESSION CHAMBER		56	2			102	29	A516-GR70 A300			

FIGURE VIII-2 Continued

b. Economies of Scale

There may be some economies of scale to the extent that one could spread head office engineering and inspection equipment over a large volume of work. However, design has not standardized, and there is a very large labor component to absorb on each job. Thus, there are few scale economies.

c. Barriers to Entry

The existence of the ASME pressure vessel code theoretically allows any firm to bid on a job to code specification. However, experience and reputation are important for long-term participation in this business. The NSSS suppliers and/or utility customer have responsibility for guaranteeing that the containment conforms to code, or, if not a "Code Vessel" (e.g., all concrete), that it meets AEC safety and licensing requirements. On new containment designs, or those not covered by code, the AEC necessarily becomes, at least for a while, a type of barrier to entry because of the time required to prepare and present documentation demonstrating safe design.

3. Changes in Market Structure

The steel containment business appears particularly sensitive to what happens to the boiling water reactor (Figure VIII-3). The BWR's larger volume per Mwe and GE's extensive use of the "inverted lightbulb" pressure suppression containment, translate into a relatively large value of steel fabrication work in such systems. Pressurized water reactors, on the other hand, generally involve a cylindrical concrete containment structure enclosing a steel liner; they use less containment steel per megawatt. The concrete structure will be furnished by the engineer-constructor at the plant site.

Recently the large engineer-constructor firms have endeavored to use prestressed concrete containment for both PWR and BWR systems. (A thin steel liner may still be incorporated.) CB&I has countered with a "free-standing steel vessel for PWR's,"(although the PWR would be surrounded by concrete shielding); and the firm has stressed certain advantages of integrating field fabrication of the reactor pressure vessel with the erection of a steel containment structure, particularly for BWR's at remote sites. Thus, despite its past success and wealth of plate welding experience, CB&I's participation could diminish substantially if the reactor mix shifts toward more PWR (and HTGR) systems and if concrete is more widely used in containment.

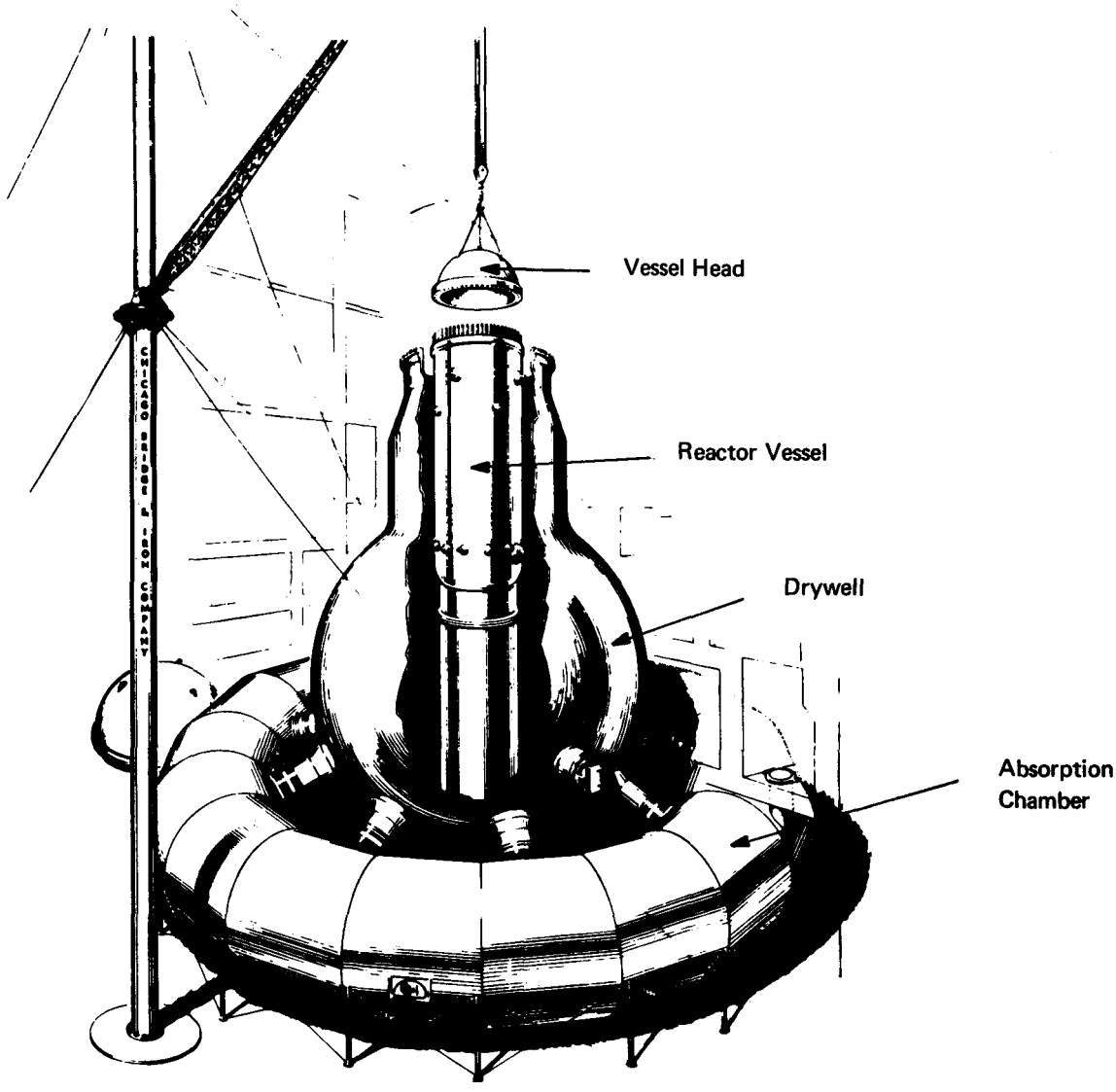


FIGURE VIII-3 PRESSURE SUPPRESSION CONTAINMENT – BWR

The trade publication *Nucleonics Week,* in its March 14,1968 edition, commented (italics supplied):

> The familiar inverted light bulb description of a BWR seems to be on its way out. At least two utilities are planning their nuclear plant containments as truncated cones of reinforced concrete. Principal advantages are the savings of several months and significant costs in the concrete construction as against fabrication of the traditional steel drywell. Some of these savings are attributed to more efficient use of structural materials and a vessel that would not have to be as thick as one made of steel.
>
> *Stone & Webster,* architect-engineer for Long Island Lighting Company's Shoreham station, is working on an over-under concept, with the pressure-suppression pool directly beneath the floor of the concrete cone. *New York State Electric & Gas Corporation* and its A/E, *United Engineers & Constructors,* have a different design for the Bell station: a truncated cone through most of the height of the vessel, changing to almost cylindrical near the base and becoming a monolith with the upper third of the torus. The torus, rectangular in cross-section, will be stepped out as it goes down to 40 feet below grade, forming a 142-foot-diameter doughnut. *The containments for both plants will be lined with thin steel plate.*
>
> Both utilities are keeping AEC abreast of their design progress. The Shoreham preliminary safety analysis report is expected to be submitted early in May and New York State E&G will be filing its construction-permit application about the same time. Both plants are scheduled for 1973 operation. *AEC and the Advisory Committee on Reactor Safeguards will have to be satisfied on the soundness of structural design,* soils and seismic problems and, particularly, the design of penetrations for the main steam lines and the stresses to which the concrete will be subjected by these lines.

4. Market Performance

a. Buyer-Seller Relationships

There is an interface between the reactor supplier and the containment system designer: the former must provide heat transfer and composition data so that the latter may calculate volume, pressure, temperature, and stress – quantities that are consistent with safe overall containment design. In the past,

on turnkey contracts, the containment structure was normally supplied under subcontract to the reactor system prime contractor. With the termination of turnkey contracting in mid–1966, the trend has been to make containment the responsibility of the engineer-constructor firm that handles the balance of plant construction and performs overall construction management services for the customer utility.

There appears to be an appreciable "software" contribution required at this stage of the business, so that steel fabrication prices and field labor experience in welding and testing will not, of themselves, provide a basis for competitive selection of a steel containment-structure supplier. Containment design and erection must satisfy AEC safety and licensing requirements, giving an edge to firms with special know-how relating to penetrations, isolation systems, and emergency cooling systems.

b. Selling Practices

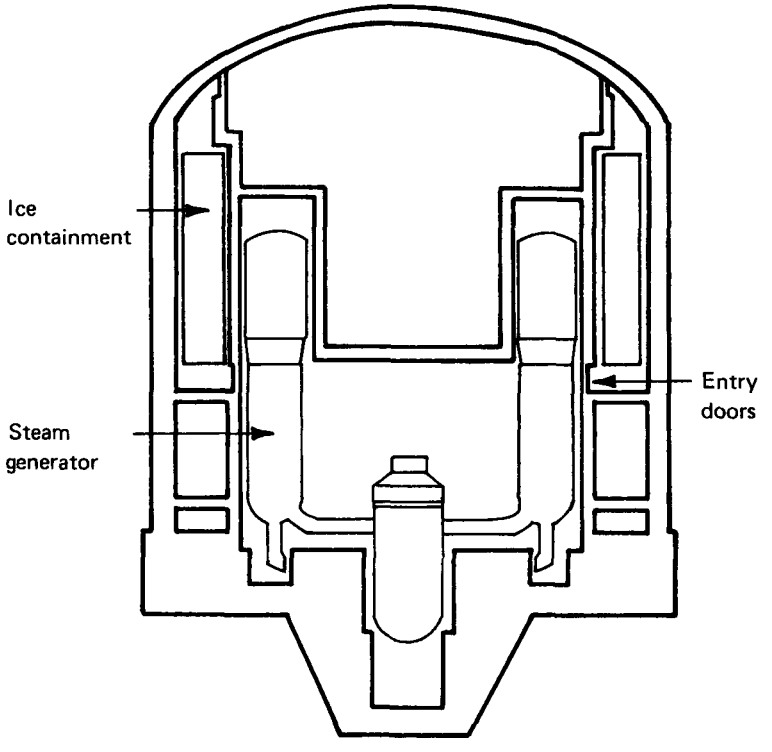
Steel containment vessels are built on a firm price, lump-sum contract basis. Concrete vessels are often built on a time and materials basis plus fee.

A more closely-related area now is the fabrication of large steel reactor pressure vessels. CB&I entered this market with orders for two field-fabricated vessels. It has also announced it will market fully shop-fabricated vessels in competition with Combustion Engineering and Babcock & Wilcox. This move may be attractive from both CB&I's and the customer's point of view, since (according to CB&I) there can be economies involved in having the schedule, fabrication, erection, and post-weld heat treatment of the reactor vessel and steel containment structure coordinated by the same organization. This seems particularly true in the case of the BWR.

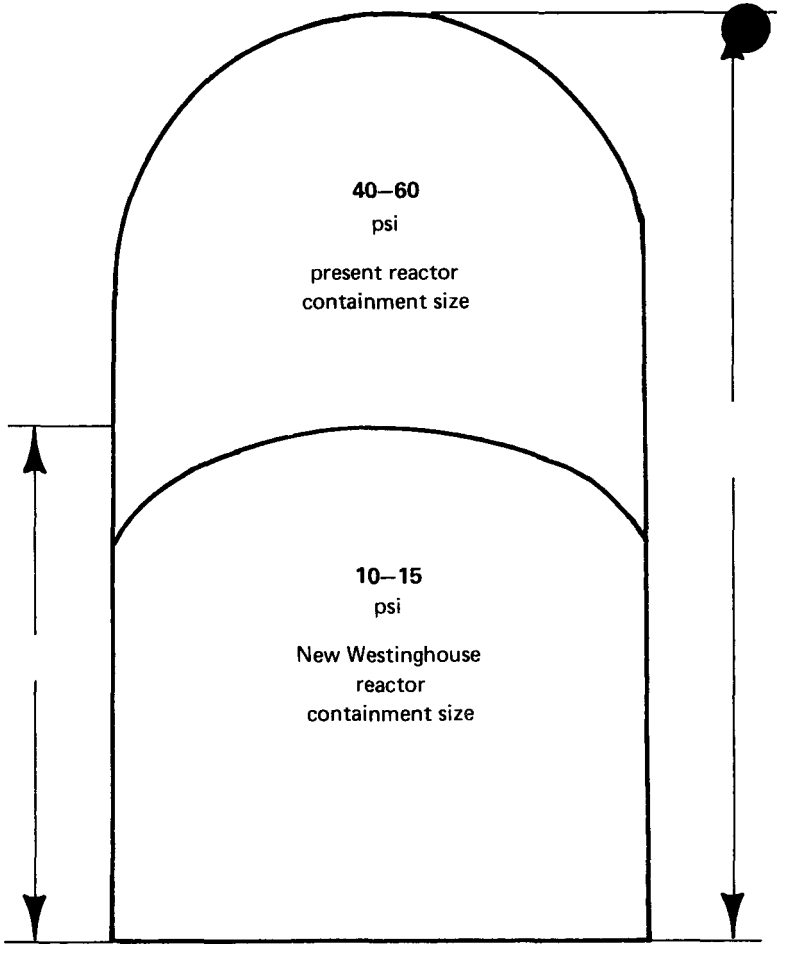
5. New Technology

The Westinghouse "ice condenser" is perhaps a significant containment innovation (see Figure VIII-4). It may allow a smaller containment volume, possibly saving $2/kw of plant costs. American Electric Power has specified the system for its 2 x 1100 megawatt "Donald Cook" (Bridgman, Michigan) plant, to be completed ca. 1972, but the AEC has not approved the concept yet.

Our picture of the current state of competition is incomplete to the extent that it does not anticipate the requirements of new technology. Changes in the nature of competition could be brought about by significant changes in containment design. Two areas of potential concern here may be (a) underground containment due to urban siting, and (b) radiation embrittlement of steel at the very high temperatures and neutron fluxes associated with the next generation of



Source: Westinghouse Electric Corporation Advertisement – 1967 AIF Conference



Reduced cost of construction

The smaller, more reliable containment is designed to withstand pressures of 10 to 15 psi, instead of the 40 to 60 psi formerly necessary. The savings in construction time and materials represent an important reduction in capital investment.

FIGURE VIII-4 WESTINGHOUSE ICE CONDENSER CONTAINMENT SYSTEM

reactors. In any case, as reactors get larger, there may be economic incentives (assuming safety can be assured) to use pre-stressed (and post-tensioned) concrete in both the containment and pressure vessel for light water reactors. These matters are now being studied both in this country and abroad. Alternatively, one of the ways to get around problems caused by very large, thick steel plate required in the larger nuclear pressure vessels would be to go to a multi-layer weld technology. This is not qualified according to the ASME code, nor has it been approved by AEC except in a special case.

IX. TURBINE–GENERATORS

The steam produced by the nuclear steam supply system is expanded through a turbine which drives a generator to supply the electrical output of a nuclear power station. The mechanism is thus similar to the conventional fossil power station, although the turbines differ in design because of the differing steam conditions encountered. Thus the lower steam temperatures produced by light water nuclear reactors require a larger, slower (1800 rpm) turbine than the fossil turbine (3600 rpm).[1] A turbine-generator for a 1000 Mwe nuclear plant is a huge piece of equipment – i.e. about 20 feet by 23 feet by 223 feet and weighing 5100 tons. After test it must be disassembled and shipped in pieces, the largest piece weighing about 350 tons.

While the turbine-generator is usually purchased separately from the nuclear steam supply system by the utility and should be considered as a separate business from the nuclear power supply industry, for the sake of completeness the turbine-generator is included in this report. Power transformers, power circuit breakers and other such equipment, however, are essentially the same irrespective of the type of steam supply system utilized, and therefore are not included in this report.

A. MARKET STRUCTURE

The only two manufacturers of large turbine-generators in the United States are General Electric and Westinghouse.[2] In general, the utilities would welcome a third domestic manufacturer providing said company would be competitive in all phases – price, reliability, efficiency, delivery and service. In addition, several foreign suppliers bid and occasionally sell in the United States market: e.g., Associated Electrical Industries, Brown Boveri Corporation, C.A. Parsons and Company Ltd., Hitachi Ltd., and English Electric.

Table IX-1 shows data on the share of market for fossil fuel power plants of 100 Mwe and above obtained by the various turbine-generator manufacturers since 1953. As the table indicates, Allis Chalmers was not able to acquire more than about 10% of the market. Finding it impossible to remain competitive with such a small share of the business, Allis Chalmers announced in December 1962 its withdrawal from the business. The table also shows that few turbine-generators of over 100 Mwe in size are purchased from foreign suppliers. Finally, the two leaders, General Electric and Westinghouse, now have close to an equal share of the market.

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1. The HTGR nuclear plant would, however, use a 3600 rpm turbine-generator.

2. As this report went to print North American Rockwell and Brown Boveri were still discussing the possibility of jointly entering the domestic turbine-generator market as a third supplier.

TABLE IX–1

PERCENTAGE DISTRIBUTION OF TURBINE–GENERATOR ORDERS FOR FOSSIL FUEL POWER PLANTS OF 100 Mwe AND OVER IN SIZE

	MARKET SHARE					
Year Ordered	Westinghouse	General Electric	Allis Chalmers	Brown Boveri	C.S. Parsons	Total Mwe
1953	47.9	51.1	1.0	0	0	10,010
1954	33.7	64.8	1.5	0	0	8,069
1955	36.8	57.1	6.1	0	0	4,877
1956	23.8	69.2	7.0	0	0	12,171
1957	33.7	57.5	8.8	0	0	17,381
1958	39.5	56.0	4.5	0	0	3,463
1959	41.7	49.7	5.7	3.6	0	11,231
1960	28.8	58.8	12.4	0	0	12,908
1961	32.6	55.6	0	5.9	5.9	8,379
1962	23.9	42.9	26.7	6.5	0	7,117
1963	30.0	59.7	10.3	0	0	9,649
1964	51.5	48.5	0	0	0	12,799
1965	32.1	67.9	0	0	0	12,542
1966	37.5	62.5	0	0	0	15,028
1967	48.9	51.1	0	0	0	16,134

Table IX-2 shows that the market for large turbine-generators for nuclear plants is also shared approximately equally by General Electric and Westinghouse, with some small recent penetration by foreign suppliers.

Based on current prices and capacities, the annual dollar volume of the United States market for large turbine-generators is approximately $500 million. If one assumes an average turbine-generator size of 500 Mwe, this volume entails the delivery of only 40-50 machines per year.

Sales to foreign markets by United States suppliers average only about 10–15 percent of output per year due in large measure to import restrictions, particularly by European nations.

B. CHANGES IN MARKET STRUCTURE

Since the withdrawal of Allis Chalmers in 1962, the increase in turbine-generator orders beginning in 1963, and the advent of large nuclear power plant orders in 1966, Westinghouse has moved into a market share position about equivalent to General Electric (see Tables IX-1 and IX-2). One factor influencing this change was GE's decision in 1966 to close out shipments for 1969. A second factor has been the early trend by utilities to order turbine-generators from the company selected to furnish the nuclear steam supply system. Thus Westinghouse received turbine orders for essentially all its PWR steam systems to boost its share of business. While General Electric also sold turbines for almost all the early BWR steam systems, both companies believe that future utility purchasing will show much more flexibility. Foreign suppliers have been able to penetrate the market in the last year when domestic backlogs were high and foreign prices low.

While the market for turbine-generators should be predictable from the 6-7% steady growth rate of the utility industry, such is not the case. As Table IX-3 shows, there evidently was a period of underordering by the utilities in 1961 and 1962 which – coupled with later increases in margins for power pooling following the blackout problems – led to a rush of orders in 1966 and 1967. Even with the added industry capacity[1] it will take some time to eliminate the present backlog. Orders and shipments will probably be in better balance by about 1971 as Westinghouse and General Electric build toward their planned capacity of 20,000 Mwe each.

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1. Capacity varies according to size and type of turbine-generator order. We have tried to normalize capacity figures based on the projected nuclear power plant capture ratio and increasing turbine-generator size.

TABLE IX–2

PERCENTAGE DISTRIBUTION OF TURBINE–GENERATOR ORDERS PLACED THROUGH DECEMBER 1967 FOR NUCLEAR POWER PLANTS

Year Operation	Westinghouse	General Electric	Brown Boveri	Associated Electrical Industries	Total Mwe
1967	100	0	0	0	912
1968	0	100	0	0	1,240
1969	50.7	49.3	0	0	2,964
1970	45.6	54.4	0	0	6,093
1971	32.2	67.8	0	0	9,751
1972	64.5	35.5	0	0	10,737
1973	40.5	40.2	9.6	9.7	11,504
1974	42.1	57.9	0	0	1,382

TABLE IX–3

DOMESTIC TURBINE–GENERATOR INDUSTRY DATA[a]
(rounded numbers)

Year	Total U.S. Capacity Mwe	Orders (Mwe) Total	Orders (Mwe) Foreign Manufacturers	Shipments (Mwe) Total	Shipments (Mwe) Foreign Manufacturers
1959	15,000	10,500	1,500	8,300	
1960	15,000	8,500		9,300	230
1961	15,000	9,400	460	6,200	730
1962	15,000	8,500		9,700	730
1963	15,000	14,200		10,100	230
1964	13,000	20,500		10,500	
1965	13,000	26,000		10,900	
1966	17,000	42,300		16,700	
1967	21,000	55,100	6,400	21,100	
1968	28,000			24,800	
1969	29,000			26,100	
1970	29,000			30,300	3,100
1971	29,000				
1974	38,000				
1978	40,000				

a. Turbine-Generator Units 100,000 KW and larger.

There is plenty of evidence to indicate that General Electric and Westinghouse intend to remain viable competitors in turbine-generators. To reach their planned total capacity of approximately 20,000 Mwe of generating equipment each, we estimate that GE and Westinghouse will have invested in old and new plants about $325-375 million each. These are highly dedicated, capital intensive, specially engineered plants with heavy, complex tooling and material handling equipment. Improvements in plants are expected to provide increased efficiency so that production costs can be kept in line despite increasing labor and material costs. To back up the production and sales activities, each also has large research, development and engineering staffs, representing about 15-20 percent of the total employees. While turbine-generators represent less than 10% of the business of the two corporations, and thus is not critical to corporate survival despite cyclical buying by the utilities, such buying practices do, nevertheless, represent a serious economic problem for which a solution must be sought.

The entry of any new corporate competition into the turbine-generator business can be both complicated and expensive, and a number of important factors must be taken into consideration. A new plant of minimum size would require a capital investment of over $100 million and a capacity of the order of 4000 Mwe. In addition, the new entrant would have to obtain more than the 10% share of a non-viable Allis Chalmers in order to support its capital and engineering overhead and smooth out its shop production schedule in cyclical buying periods. This cyclical buying of the utility industry was the single most important cause of the demise of Allis Chalmers. We estimate in such a cyclical industry any new entrant would have to obtain 20-25% of the market unless it could allocate a substantial amount of engineering and administrative overhead to major foreign sales, as might possibly be the case with the Brown Boveri-North American Rockwell proposition under discussion.

Two other factors are important to a new entrant: first, the corporate entity must be acceptable and known to the utility industry as a reliable supplier able to stand behind and service its product; second, experience. In the latter case, for example, there is the so-called "learning curve barrier." That is, turbine unavailability drops materially, on the order of 50 – 80% along a smooth curve, as experience is gained over a five- to eight-year period with about twenty of the same size machine. Thus a new entrant even at the earliest possible future date, say 1973, must expect to face both a General Electric and a Westinghouse at the advanced, flat portion of the nuclear plant turbine-generator learning curves.

Plant output is important in turbine generator manufacture because fixed costs including plant depreciation, engineering, supervision and other such essentially fixed costs are close to 50% of the total. Therefore, it is essential to keep shop load high or, as in the case of Allis Chalmers, it is impossible to survive.

We were not able to obtain definitive data on value added by manufacturing. Out of a total cost of a nuclear power plant of about $150/kw, the turbine-generator represents a cost of about $30/kw. Thus the price of a turbine-generator for a 1000 Mwe power plant is approximately $30 million.

C. MARKET PERFORMANCE

We have no real data on the relationships of prices to costs. However, prices seem to have been depressed in the recent past. Thus in the last four years prices have been raised nearly 30% and are back up to about the 1953 level in terms of $/kw. Reasons given for increasing prices in addition to recovery from recent low return on investment include low initial cost estimates for the larger, slower speed nuclear plant turbine-generators, lower rate of output and manufacturing facility utilization for the larger turbine-generators; need to design and construct new facilities; and inflation.

This increase in price coupled with longer delivery dates, because of the recent high ordering rate by utilities, has caused a number of utilities to place orders with foreign firms. Prices for foreign turbine-generators are reported to be 15-20% below quotations. It is not clear at this time of very limited manufacturing and no operating experience with these large machines whether all of these foreign prices provide for a reasonable profit or represent buy-in attempts to establish a foothold in the U.S. market. One U.S. manufacturer forced to buy components in the European market in order to meet delivery schedules in this high backlog situation reports component prices in Europe to be no lower than U.S. prices.

Prices of turbine–generators produced by General Electric and Westinghouse are publicly available in printed price lists and are essentially identical. These lists present in detail basic machine standard features and accessories prices. In the past these price lists left a fairly large area for negotiation. Following the antitrust actions, the price lists were in 1963 made more detailed with respect to accessories to the point that little room for negotiation beyond established discounts exists. Two other pricing developments are worth noting:

1. As a result of recent utility buying pressure in the face of long lead times, the following policy has been established on prices for shipments beyond 36 months:

   "Quoted prices are based on shipment within 36 months from date of order and are firm for shipment within such time. For shipments longer than 36 months but within 48 months from date of order, the price, terms of payment

and other conditions of sale will be the price, terms of payment of other conditions of sale in effect 36 months prior to shipment but will not exceed the quoted price by more than 4%. For shipments longer than 48 but within 60 months from date of order, the price, terms of payment and other conditions of sale will be the price, terms of payment and other conditions of sale in effect 36 months prior to shipment but will not exceed the quoted price by more than 8%. For shipment beyond 60 months the Corporation's established price, terms of payment and other conditions of sale in effect 36 months prior to shipment will apply."

2. A price protection policy has been instituted by one manufacturer, as follows:

"If the Company quotes a steam turbine-generator unit rated 44,000 kw or larger to any Purchaser for use within the fifty United States at a lower price level, all orders received by the Company between the date of the new quotation and the same day of the sixth preceding calendar month will be reduced to the lower level."

Whether such firm prices would prevail were the market to drop precipitously in another utility cyclical buying period is a matter of conjecture.

An obvious question to ask in buyer-seller relationships is whether the turbine-generator sale is somehow associated with the NSSS sale, particularly when it is recognized that in only 2 instances out of 57 to date have Westinghouse turbine-generators been sold for use with a General Electric NSSS, and vice versa. The two corporations are, of course, well aware of this situation and the legal restrictions with respect to tie-in sales. While at the outset of the nuclear power age utilities might be expected to give much weight to buying the complete, highly complex plant from one responsible buyer with appropriate overall warranties, the manufacturers expect and are encouraging a trend toward more conventional utility buying in which the steam and turbine-generator systems are traditionally separate negotiations. Technical differences between PWR and BWR turbine-generator designs can be met easily by either manufacturer.

The manufacturers are well aware of the legal restrictions involved and point out that buying and selling practices protect against tie-in sales in the following ways:

1. There is a trend toward buying the more complex NSSS portion of a nuclear power plant first, and then later

requesting bids on turbine-generators, which are by comparison considered mature, more or less standard, pieces of equipment. The price is sufficiently high so that the purchase of the turbine-generator receives detailed attention of top utility management, all of whom are sensitive to any tie-in sales aspects. As an indication of lack of tie-in, a single turbine manufacturer has already received orders for machines to match all types of NSSS provided by all five successful corporate NSSS bidders. And, as shown in Table IX-4, General Electric and Westinghouse both supply turbine-generators to utilities buying PWRs from Babcock and Wilcox and Combustion Engineering.

Not all advantages in turbine negotiation and sales reside in the seller. A limited number – less than 100 – of big utilities comprise the major market. These buyers have general information on prices available to them and although there are only two domestic sources for turbines, the suppliers depend upon repeat business and have incentive not to push an advantage in one sale to face the consequence of losing future sales not only in turbine-generators but other electrical equipment.

2. Any prospective utility buyer may reserve a space on the turbine-generator production schedule before or after the award of the NSSS without prejudice as to which corporation wins the NSSS competition.

3. The divisions of those companies supplying both NSSS and turbine-generators have separate division managers, with incentives to maximize their own division profits. Thus there is little or no incentive for either division manager to shave his prices to favor a sale by another division of his own company as against sale to an outside customer at the higher quoted market price.

In addition to price competition, the more important factors affecting competition are turbine-generator availability, service, efficiency and delivery data.

Above all, a utility strives to maintain electrical supply to its customers on a continuing basis throughout the year, as downtime on a 1000 Mwe plant costs about $50,000 per day. Turbine-generator reliability includes a combination of availability, efficiency, and maintenance and servicing. Perhaps the major

turbine-generator selling point is reliability and this involves not only the points just noted coupled with learning curve experience of the manufacturer, but also the confidence of the utility gained through past experience with the manufacturer's machines. It is the combination of all these factors which makes domestic manufacturers confident they can compete with foreign suppliers, even at possible first price disadvantages. In effect, this is a competitive game played against the projected risk to the utility.

Delivery date can obviously affect choice of turbine-generator supplier when backlogs are as high as they are at the present time. Usually, this does not represent a controlling factor in supplier selection.

D. NEW TECHNOLOGY

New technology is of great importance in the turbine-generator field. To remain competitive both General Electric and Westinghouse expend a high percent of sales – we estimate about 10% – on research and development aimed at improved efficiency, reliability and lower costs.

The inability of a competitor with only a small share of the market to invest such a large effort in technological advances (as was the case with Allis Chalmers) is a definite barrier to viability.

TABLE IX–4

PERCENTAGE DISTRIBUTION OF TURBINE–GENERATOR ORDERS[a] TO MATCH BABCOCK AND WILCOX AND COMBUSTION ENGINEERING NUCLEAR STEAM SUPPLY SYSTEMS

	MARKET SHARE		
NSSS	General Electric	Westinghouse	Total Mwe
Babcock and Wilcox	57	43	6,078
Combustion Engineering	72	28	2,902

a. Placed through December 1967

X. UTILITY PURCHASING CHARACTERISTICS

A. PATTERN OF NUCLEAR FUEL COMMITMENTS

1. Definition of Data Scope

The source of data drawn upon to analyze the pattern of nuclear fuel commitments is the universe of "light water reactors above 400 Mwe." Technologies such as gas and liquid metal have been excluded, because wide-scale commercial application of these has not been demonstrated to date. Light water reactors below the 400 Mwe capacity level have been excluded because typically the purchase of such reactors has been an experimental venture into nuclear technology, frequently with AEC assistance through the Power Demonstration Reactor Program (PDRP),[1] rather than a commercial decision based upon the comparative economics of alternative fuels. The PDRP consisted of an AEC effort in the mid-50s facilitate the "commercialization" of nuclear power for civilian use, by sharing with the utilities the early technical risks. There were three types of AEC support available, through three types of "rounds":

- A first round, launched in 1955, where the AEC helped meet the R & D project costs, and waived the lease charge for initial fuel; this applied principally to PWR and LWR technologies.

- A second round, launched in 1955, where the AEC owned the reactor, helped meet R & D costs, and absorbed the costs of initial core fabrication; this was aimed at publicly-owned utilities venturing into advanced technologies such as sodium.

- A third round, launched in 1957, where the AEC under terms similar to those of round one encouraged privately-owned utilities to invest in advanced-technology reactors.

The projects reported by the AEC in 1967 as PDRP-backed, and operating, under design, or under construction, are listed in Table X-1. The AEC's early attempt to broaden the reactor supplier base by backing four manufacturers in addition to the traditional "Big Two" should be noted.

1. Admittedly, three LWR projects about 400 Mwe are PDRP-backed; one of these, however, has encountered siting problems which may preclude action; the other two projects comprise less than 2% of the megawattage under consideration, and therefore do not affect materially the "commercial" character of the data base.

TABLE X-1

POWER DEMONSTRATION REACTOR PROGRAM, PROJECTS IN OPERATION, UNDER DESIGN, OR UNDER CONSTRUCTION

Contract Awarded	Project Name	Reactor Supplier[a]	New Mwe	PDRP-Round
1956	Yankee Nuclear Power Station	West	175	1
1957	Fermi Atomic Power Plant	PRDC	61	1
1957	Pathfinder Atomic Power Plant	A-C	59	3
1958	Elk River Nuclear Plant	A-C	22	2
1958	Peach Bottom Atomic Power Station	GA	40	3
1959	Piqua Nuclear Power Facility	AI	11	2
1959	Big Rock Point Nuclear Power Plant	GE	70	3
1960	B.O.N.U.S.	CE	17	2
1962	LaCrosse Boiling Water Reactor	A-C	50	2
1962	Connecticut Yankee Atomic Power Plant	West	462	3
1963	Malibu Nuclear Plant[b]	West	462	3
1963	San Onofre Nuclear Generating Station	West	430	3
1965	Fort St. Vrain Nuclear Generating Station	GA	330	3

NOTES:

[a] A-C: Allis-Chalmers
AI: Atomics International, North American Rockwell
CE: Combustion Engineering
GA: General Atomics, Gulf
GE: General Electric
PRDC: Power Reactor Development Corp. (consortium of 21 utilities and manufacturers)
WEST: Westinghouse

[b] Project delayed due to siting problem.

The purpose of limiting the data base to sizeable LWR projects is to focus the analysis upon the segment of nuclear energy technology which most closely approximates commercial viability and genuine competitiveness. Under conditions of viability and competitiveness, it may be assumed that the emerging patterns of fuel commitments result from objective and analytical efforts to appraise the merits of alternative fuels, and it may be further assumed that in the absence of major circumstantial changes, such as in technical or economic performance, the emerging patterns can be projected into the future as broad indicators.

Admittedly major changes in the technical and economic performance of LWR or competitive non-nuclear technologies could make the patterns of LWR commitments irrelevant to future energy market developments. Concerning major LWR changes, however, it has been suggested that the last five years have constituted a major breakthrough era for that technology, and radical change is consequently improbable. Moreover, given the current differences of opinion concerning the genuine long term economics of LWRs (as distinguished from commercial offering price levels), and given the differences concerning the feasibility of extrapolating experience with small units to the currently-marketed size ranges above 1000 Mwe, it appears that an interval of consolidation and standardization may be expected before another round of radical innovation. The major benefits of LWR technology, realization of high power density levels and burnup rates, appear to have been achieved, or are foreseen and planned for inclusion in many of the LWRs under consideration or construction. On balance, therefore, the LWR universe defined earlier can be taken as descriptive of the reactors on the commercial market in the near future, say 3-5 years hence.

Concerning major changes in the performance of competitive non-nuclear fuels, which could alter significantly the comparative economics of nuclear and non-nuclear fuels, and make a projection of past experience irrelevant, the most destabilizing change from the nuclear power industry viewpoint would be a "significant" reduction in the cost of delivered coal. This, if it materialized, would probably result from business strategy motives rather than reflect a technical breakthrough. However, it appears at this date that the economic response[1] of the coal companies is and may well continue to be one of adaptation to the prevailing energy costs, rather than one of concerted effort to underprice competing fuels. In fact, since 1966 it appears that the price of delivered coal has been trending upwards, concurrently with the price increases for nuclear steam supply systems.

1. Any generalization about the prospective competitiveness of nuclear and fossil energy is vulnerable, yet a judgment about competitive response is necessary. Mr. Philip Sporn's recent reference to "this semi-competitive atmosphere," in describing to the J.C.A.E. the transition from fossil fuel to nuclear fuel, seems knowledgeable and persuasive.

The long-term outlook for nuclear and non-nuclear fuels is, of course, a highly complex issue. It is not the purpose of this discussion to resolve that issue but to determine whether any major changes in their comparative economics are readily apparent; this does not seem to be the case.

The LWR universe which results from the above scope definition amounts to some 45,000 megawatts of generating capacity, operating, under construction, or committed firmly to a NSSS manufacturer. Options that are pending, but have not been exercised, are excluded.

This universe coincides in large measure with all of the nuclear central station orders placed in the interval 1965-1967. LWR orders placed earlier, which have progressed to construction, account for only 4% of the megawattage within the scope definition. Orders placed in 1968 have been excluded because the bidding and negotiating processes usually overlapped the data-gathering effort, thus precluding the disclosure of information by utility respondents.

2. Data Sources

Much of the information which underlies this analysis has been obtained from personal interviews with utility executives; typically, several individuals within a single utility were interviewed. In the aggregate, the utilities interviewed comprised 60% of the LWR generating capacity under consideration. A consulting firm provided parallel data on utility fuel commitments; this was used to amplify the interview data, and to provide coverage for the 40% of the universe that was not interviewed. Conversations were also held with Architect-Engineer firms to elaborate some information.

It should be recognized that detailed information on utility fuel commitments is frequently unavailable. In many instances, while general agreement on the type of fuel service has been reached, implementing details have not been specified. In other cases, although the contractual detail is comprehensive, the utility need not commit to a particular fuel option for some time. Finally, there is occasional reluctance to disclose even the broad nature of a commitment either because of concurrent negotiations with independent suppliers, or because of traditional policies concerning disclosure.

3. Data Format

The information that was derived from personal interviews was frequently made available by the utility respondents upon the condition that in analysis and presentation there would be sufficient aggregation to prevent particular patterns from being linked to individual utilities. Because of this stipulation, and because

of the sharp variations in the level of detail disclosed by the respondents, a very generalized format has been used. This format is strongly conditioned by the degree of cooperation received from respondents, and by the requirement for data aggregation.

The main measures used in this format are distributions of capacity, in net electrical megawattage, along the following major dimensions of market performance:

- *Supplier selling strategies,* for each major NSSS manufacturer, as evidenced by the duration of fuel commitments made (number of reload regions committed beyond the original core); by the nature of fuel commitments made (within the spectrum of "fabrication-services-only" to a contract for "complete-fuel-cycle-services"); and as evidenced by the general type of utility customer, in terms of system size (through a "small-to-large" array of relative system capacities), and in terms of geography (through a "low-cost-to-high-cost" array of regional energy cost levels).

- *Buyer preferences,* as evidenced by fluctuations in supplier market share within intervals of the "small-to-large" array of utilities, and by changes in the type of fuel commitments within the array.

- *Secular trends,* as evidenced by changes over the 1965-1967 interval in the duration of fuel commitments made, in the nature of fuel commitments made, and in the selling strategies of the major NSSS manufacturers.

4. Supplier Selling Strategy

The 45,000 Mwe which comprise the LWR universe under consideration are distributed among the NSSS manufacturers in the proportions shown in Figure X-1. Westinghouse and General Electric orders account for slightly less than 80% of the megawattage, roughly the overall level of their combined market share in all LWR sizes to date.

a. NSSS Manufacturers: Duration of Fuel Commitments

The measure used here is the number of reload regions committed. In a few instances, where the commitment was for fuel cycle services for a fixed number of years, rather than for stated quantities of fuel, it was necessary to estimate the number of reloads equivalent to the life of the contract.

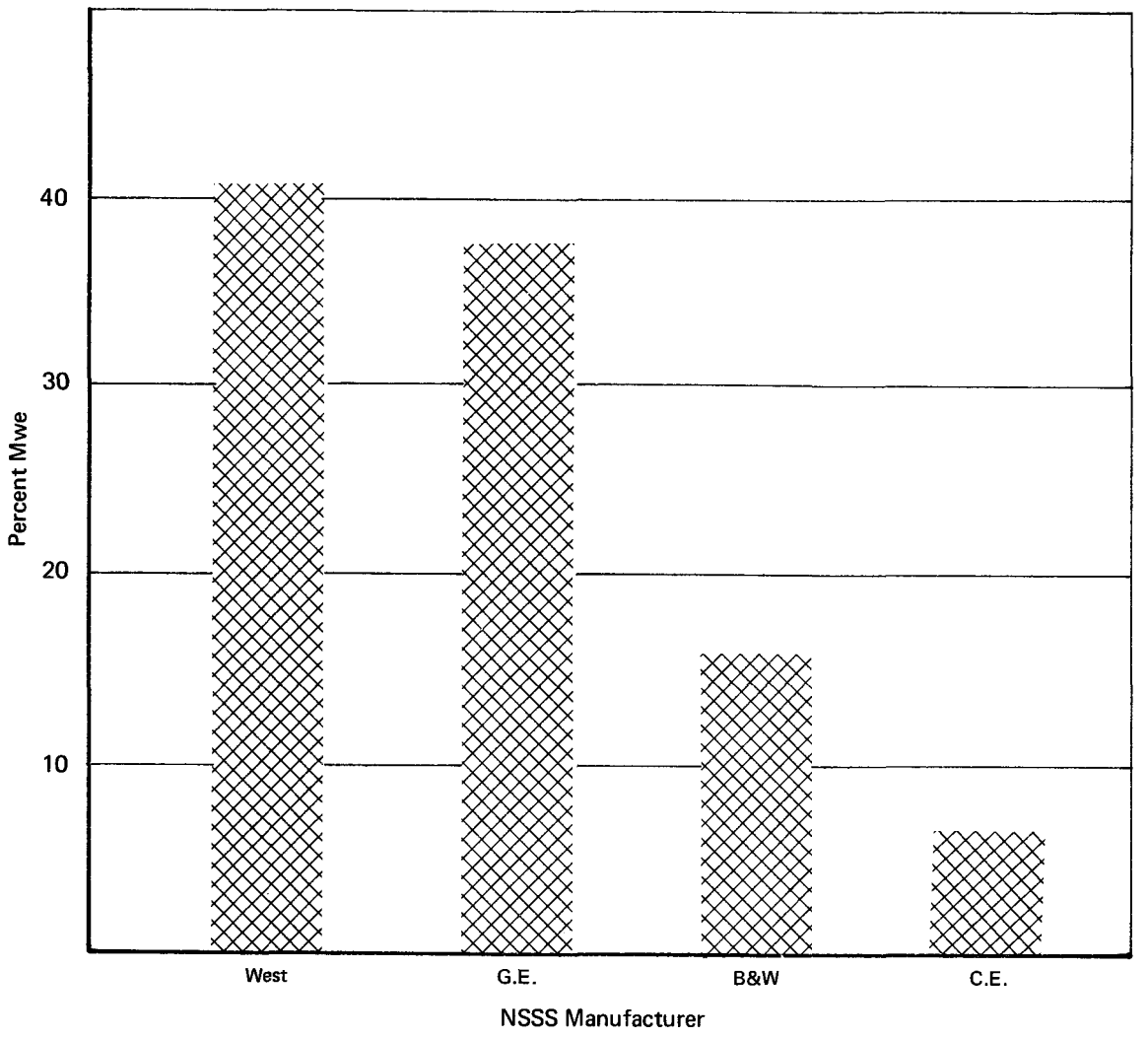


FIGURE X–1 DISTRIBUTION OF Mwe BY NSSS MANUFACTURER

Figures X-2 through X-5 show for each NSSS manufacturer the distribution of his own orders. It should be noted that for the PWRs, three regions have been assumed to correspond to a full core, whereas for the BWRs the assumption has been four regions to a complete core.

Not surprisingly, Figures X-2 through X-5 confirm that the NSSS manufacturers have an active interest in the replacement fuel market. By Table X-2, it appears that roughly 60% of the Westinghouse and G.E. capacity has been sold with at least one complete replacement core. The corresponding figure for B & W, 87.5%, may not be significant because it applies to a much smaller amount of business, and could be diluted to the 60% level by a very few additional orders placed on a "less than one complete replacement core" basis.

Westinghouse, with half of its order capacity on a three-complete-core basis, appears to have the strongest interest in long-duration replacement fuel commitments; G.E. has roughly one third of its capacity on an equivalent three-complete-core basis. Moreover, of G.E.'s three-complete-core megawattage, well over half is accounted for by the TVA Browns Ferry units; the prices quoted and the general bidding conditions pertaining to the Browns Ferry 1 and 2 awards appear to have been unique to the circumstances of an "infant market," rather than constituting the pattern for subsequent G.E. offerings. The comparable three-complete-core percentage of G.E. megawattage, therefore, adjusted to reflect recurring selling practices, is probably no more than half of Westinghouse's 50%.

It is clear from Table X-2 that only a small percentage of the megawattage sold by the two major manufacturers has been committed on an original-core-only basis, roughly 6% of their placements. This suggests that in the 1965-1967 interval, the accepted marketplace concept of LWRs as commercial product packages definitely extended beyond reactors as hardware and beyond the initial core loading. Several reasons for selecting long-duration fuel commitments were cited by utility respondents. Typically, the decisive factors were some combination of receptivity toward price inducements for multiple-region orders, and utility demand for warranted burnup rates, which were usually contingent upon and coterminous with the use of the NSSS manufacturer's fuel. The demand for burnup warranties seems to have been a function of a new technology, and a resulting degree of risk-aversion on the part of buyers.

b. NSSS Manufacturers: Nature of Fuel Commitments

The spectrum of fuel modes includes: fabrication services only; fabrication services with U_3O_8; "initial fuel services," the delivery of contained uranium, with no responsibility for removal and reprocessing; and "fuel cycle services," usually but not always warranted as an energy contract between the manufacturer and the utility. The fuel commitments analyzed here pertain only to arrangements

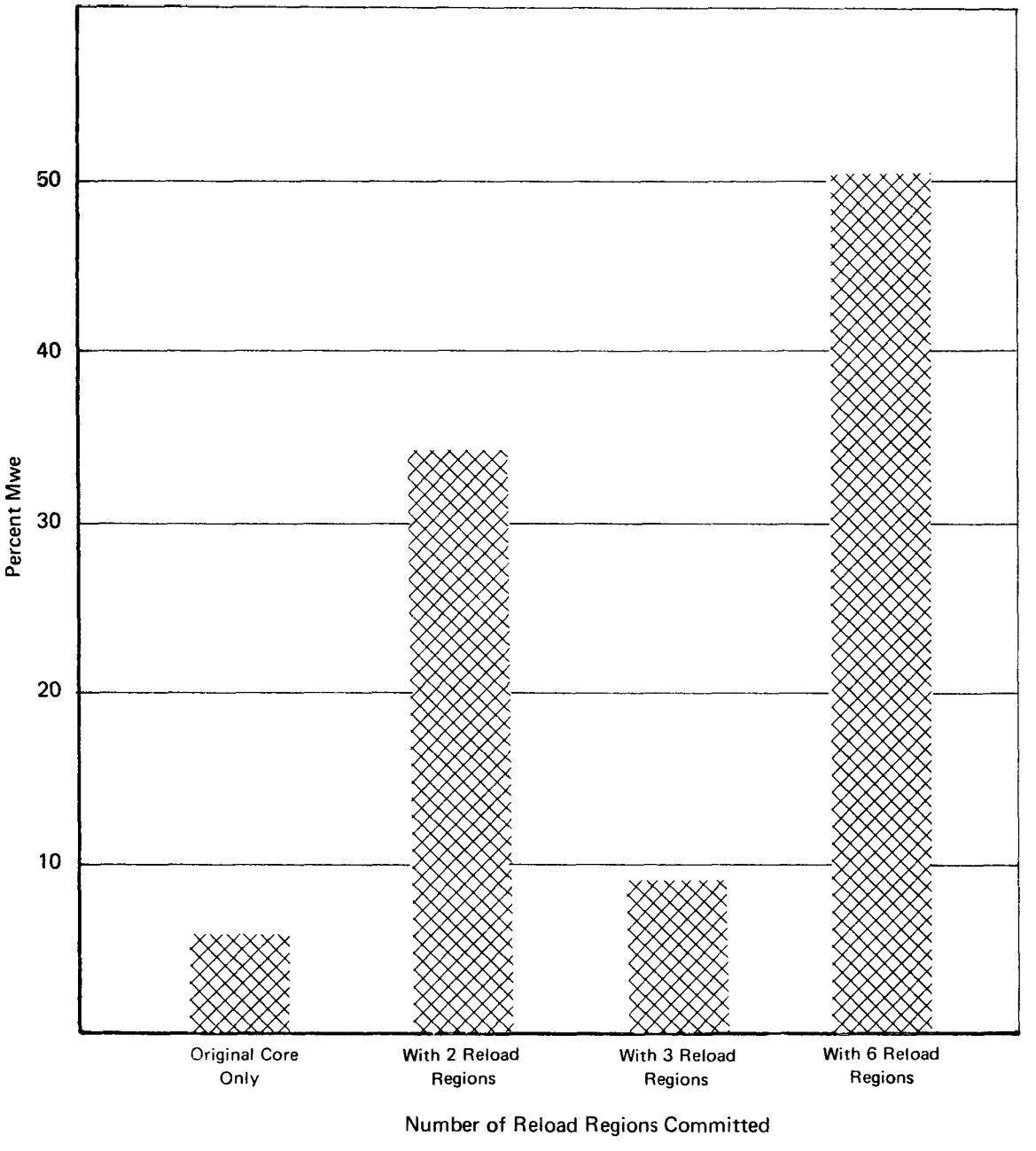


FIGURE X–2 DISTRIBUTION OF WESTINGHOUSE Mwe BY NUMBER OF RELOAD REGIONS COMMITTED

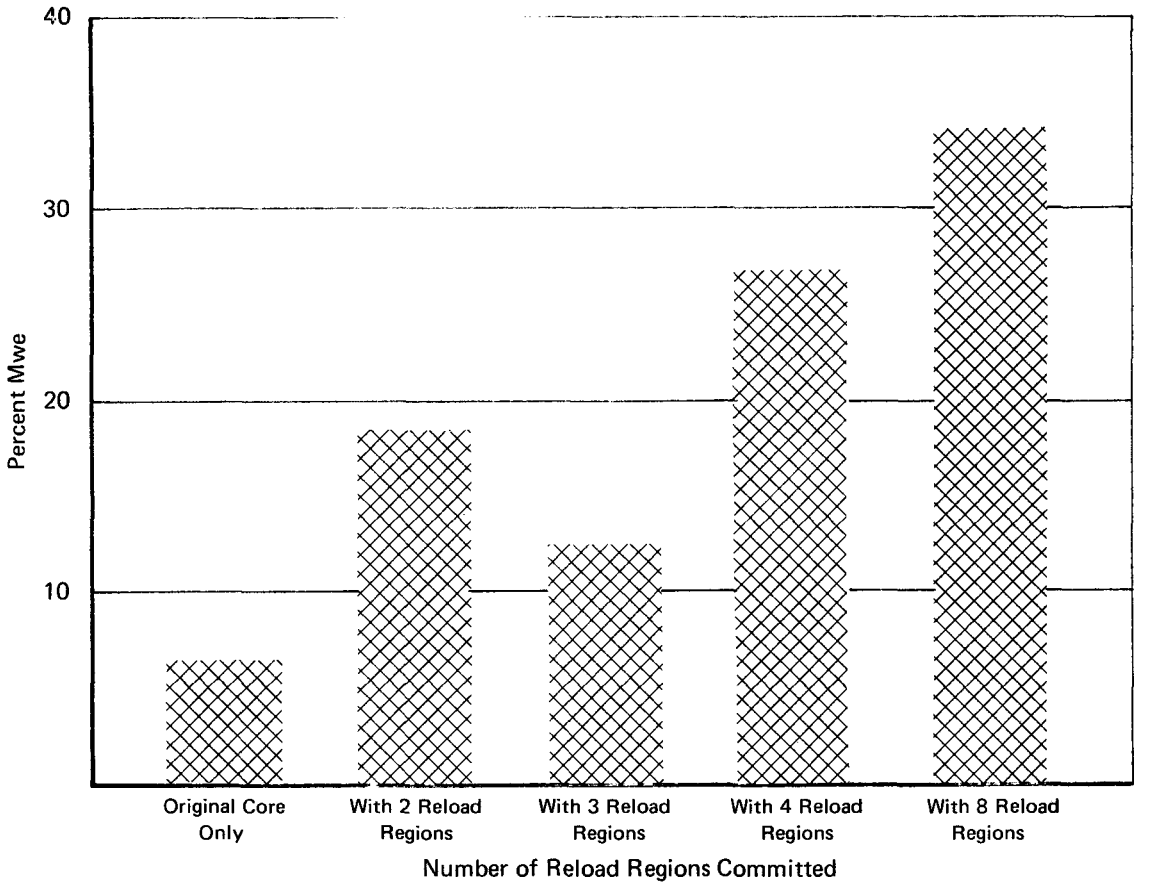


FIGURE X–3 DISTRIBUTION OF G.E. Mwe BY NUMBER OF RELOAD REGIONS COMMITTED

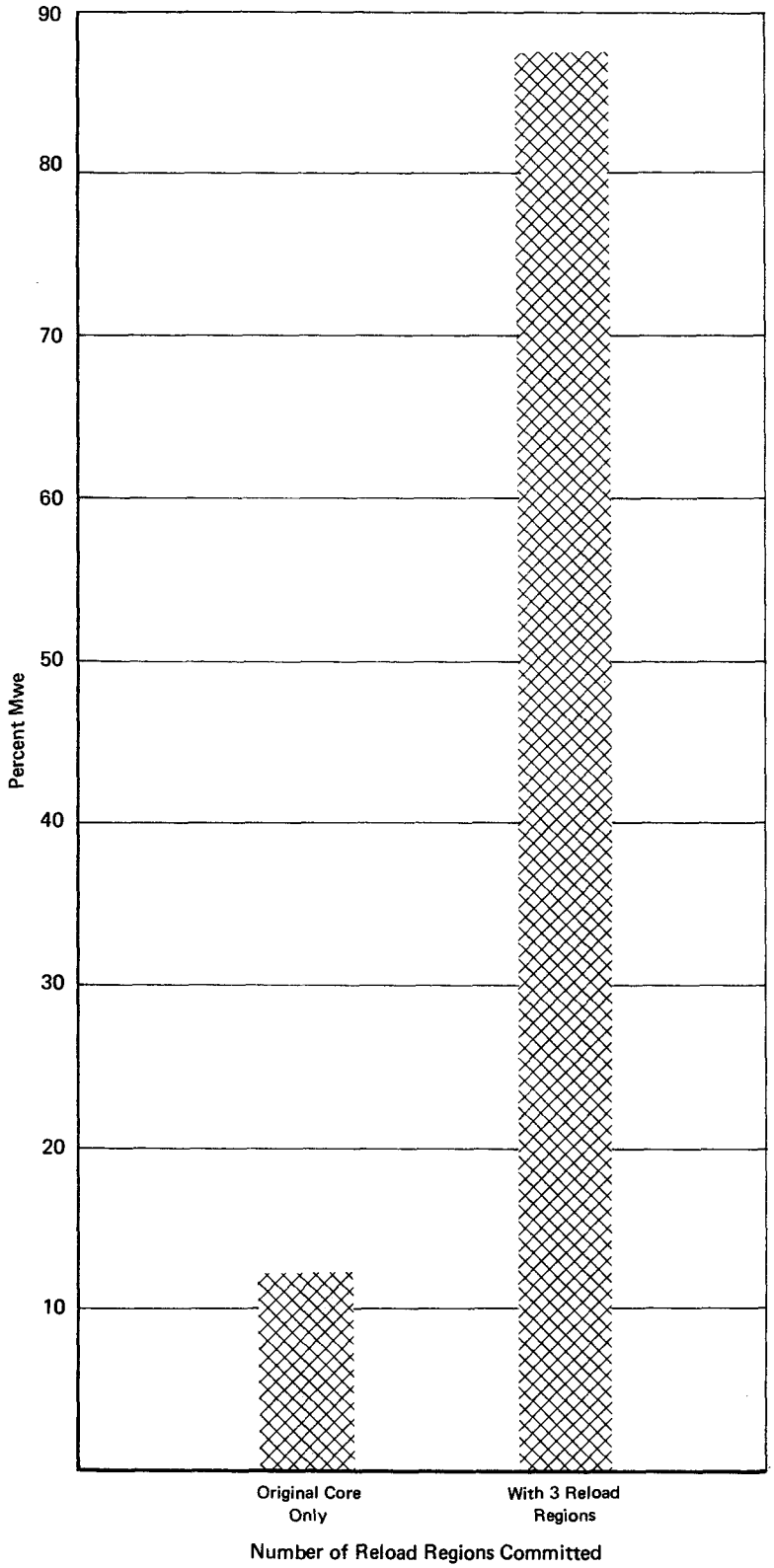


FIGURE X–4 DISTRIBUTION OF B&W Mwe BY NUMBER OF RELOAD REGIONS COMMITTED

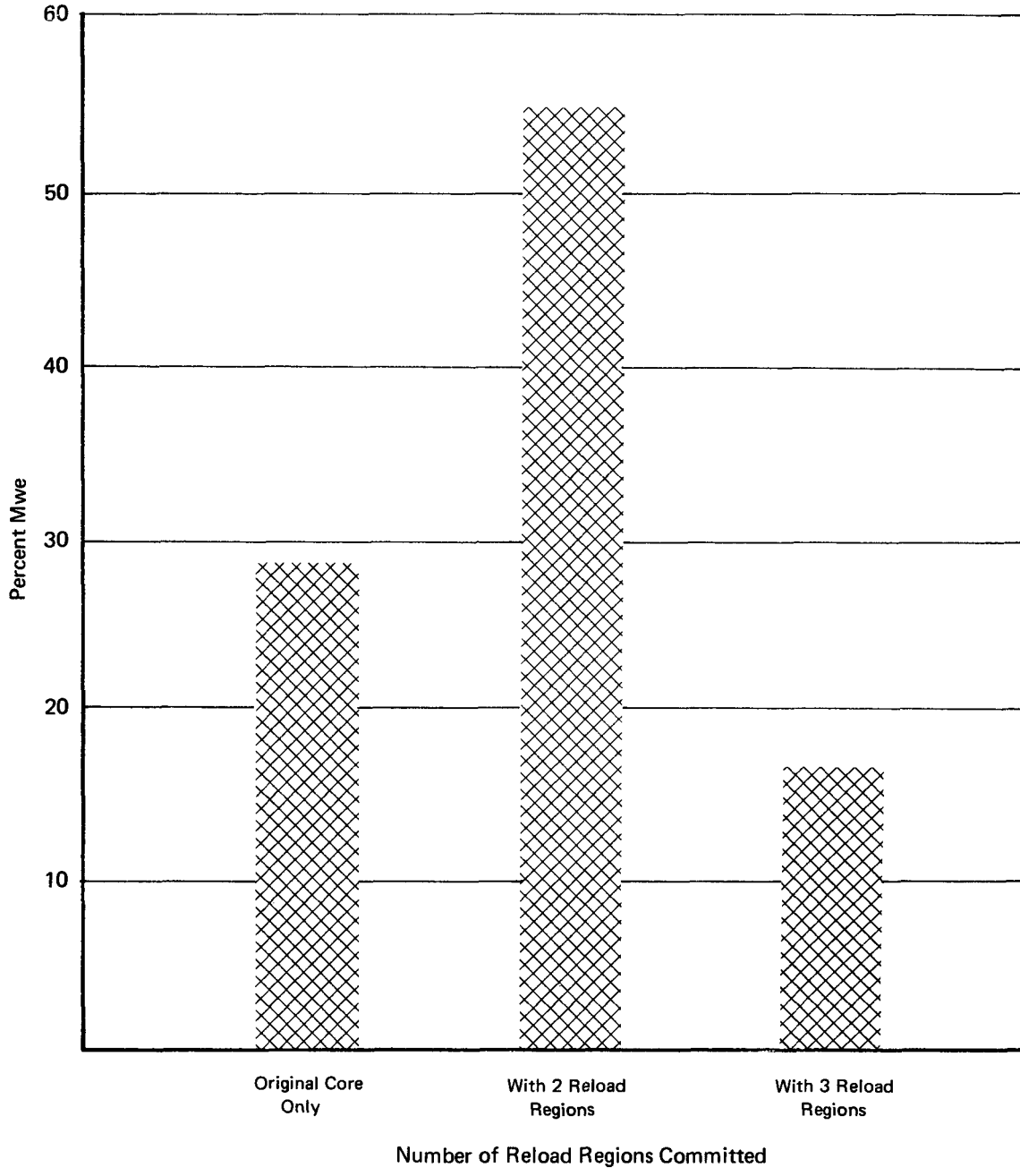


FIGURE X–5 DISTRIBUTION OF C.E. Mwe BY NUMBER OF RELOAD REGIONS COMMITTED

TABLE X-2

DISTRIBUTION OF NSSS MANUFACTURERS Mwe BY REPLACEMENT CORES COMMITTED

	WEST	G.E.	B & W	C.E.
Original core with two complete replacement cores	50.7%	34.9%	–	–
Original core with one complete replacement core	8.8%	27.0%	87.5%	16.5%
Original core with partial replacement core (PWR: less than 3 regions; BWR: less than 4 regions)	34.4%	31.4%	–	55.1%
Original core only	5.9%	6.5%	12.5%	28.2%

between NSSS manufacturers and utilities. Leases from the AEC, ore contracts between mining companies and utilities, and direct utility commitments with fuel processors and independent fabricators are not included. The reason for thus restricting the scope of the analysis is that the pattern between NSSS manufacturers and utilities is probably of most immediate regulatory interest and relevance. Moreover the AEC leasing program is scheduled to terminate in the near future. Finally, the direct commitments between utilities and NSSS-independent suppliers, with only a handful of publicized exceptions, are not readily discussed by respondents.

The "initial fuel services" and "fuel cycle services" modes indicate implicitly the type of reprocessing commitments made. In the fabrication services modes, however, the reprocessing inference cannot be drawn; in the majority of such cases, negotiations for reprocessing loads are currently active or open, and consequently firm indications were not given.

Figures X-6 through X-9 array for each NSSS manufacturer his fuel commitments by fuel mode. The data are summarized in Table X-3. The prevalence of the fabrication-services-only mode is obvious. This pattern might be challenged as misleading, in that many respondents indicated that they had options for U_3O_8 from the NSSS manufacturers, typically with some risk of price escalation upon the utility. For the present, however, these options have not been exercised. Moreover, the intent of many utilities, from respondent remarks, is clearly to be "masters of our own fuel destiny," rather than delegators of the fuel cycle management responsibility. The U_3O_8 options are described in this context as insurance against a uranium shortage which is not really foreseen, and – occasionally – as a bargaining device in negotiating with mining companies.

Therefore, while the fuel mode pattern reflected in Figures X-6 through X-9 may be altered by the overhang of current U_3O_8 options, on balance it seems that the utilities who hold these options intend to purchase their ore elsewhere, independently.[1] It appears more reasonable to assume that this will be feasible, than to postulate an ore shortage which would force the exercise of the U_3O_8 options.

1. It was suggested earlier that the long-duration pattern of fuel commitments was explained, in part, by the utilities demand for warranted burnup rates; the prevalence of fabrication services commitments might appear to negate this suggestion, if it is assumed that the warranties are contingent upon use of the NSSS manufacturer's ore. In fact, under current contracting arrangements the warranties are not usually jeopardized by the use of "foreign" (i.e. non-NSSS manufacturer source) U_3O_8 providing that specifications are met. On the other hand, the use of fabricated fuel elements of "foreign" origin does raise considerable problems for the NSSS manufacturer burnup warranties.

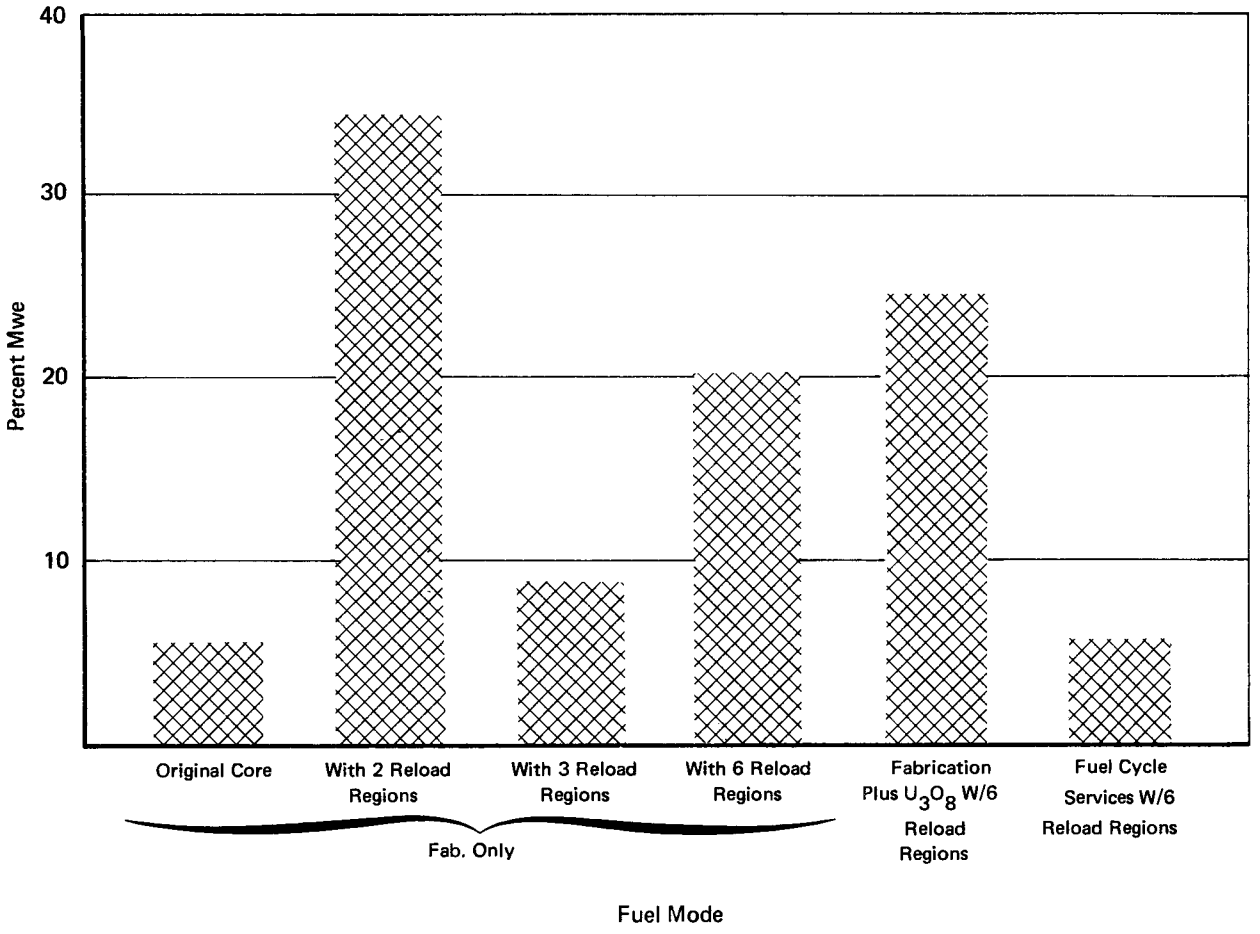


FIGURE X–6 DISTRIBUTION OF WESTINGHOUSE Mwe BY FUEL MODE

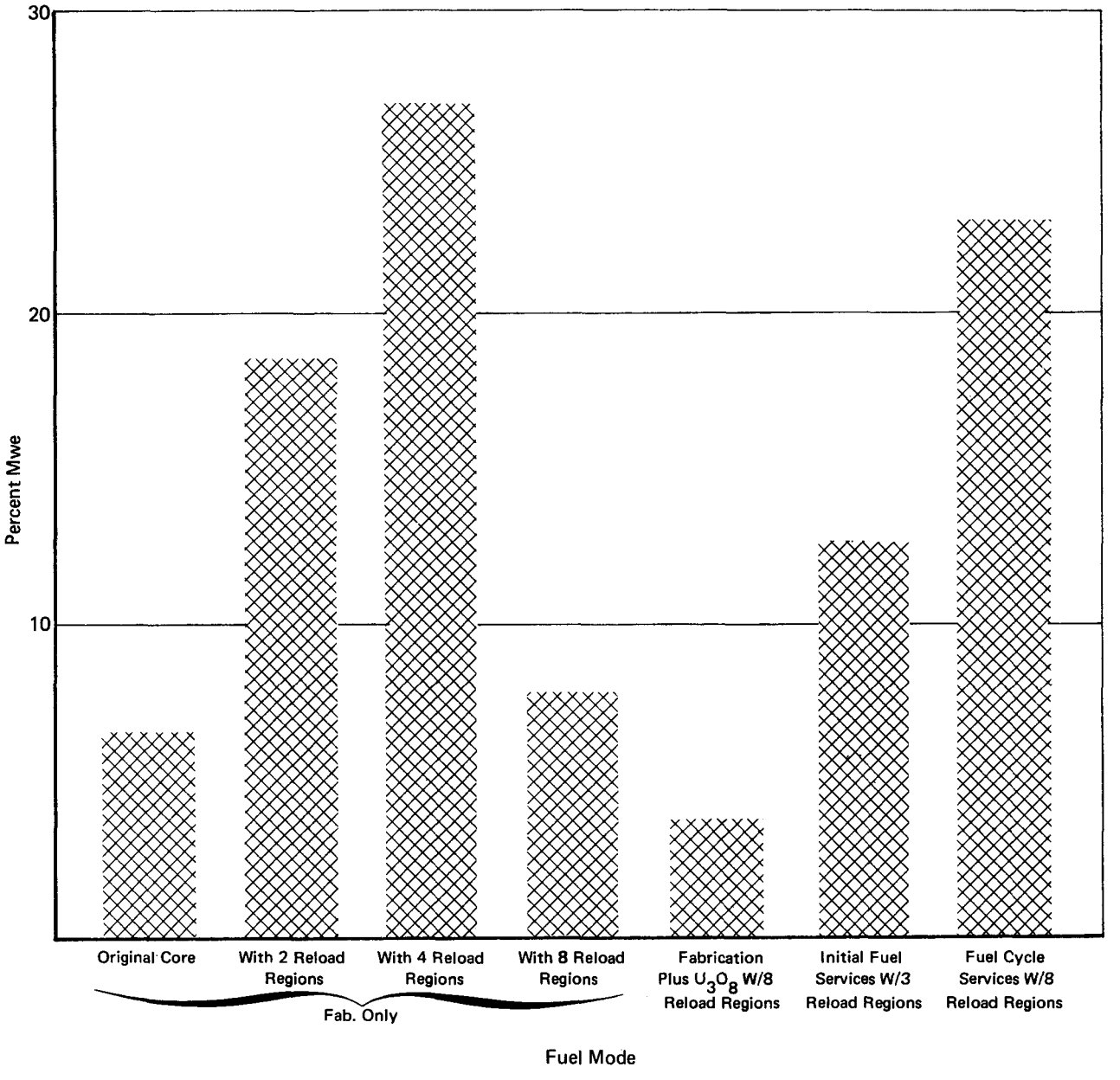


FIGURE X–7 DISTRIBUTION OF G.E. Mwe BY FUEL MODE

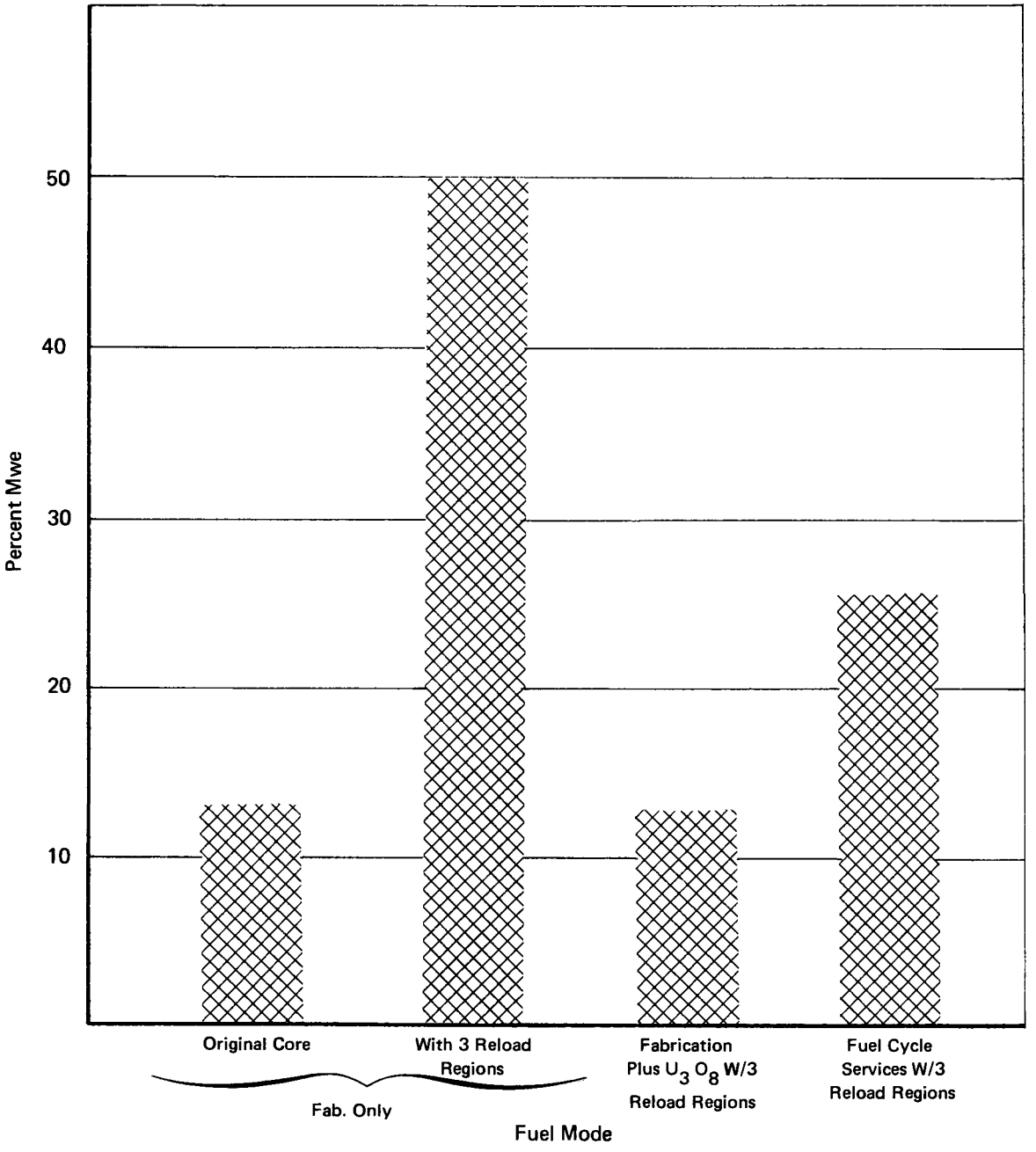


FIGURE X–8 DISTRIBUTION OF B&W Mwe BY FUEL MODE

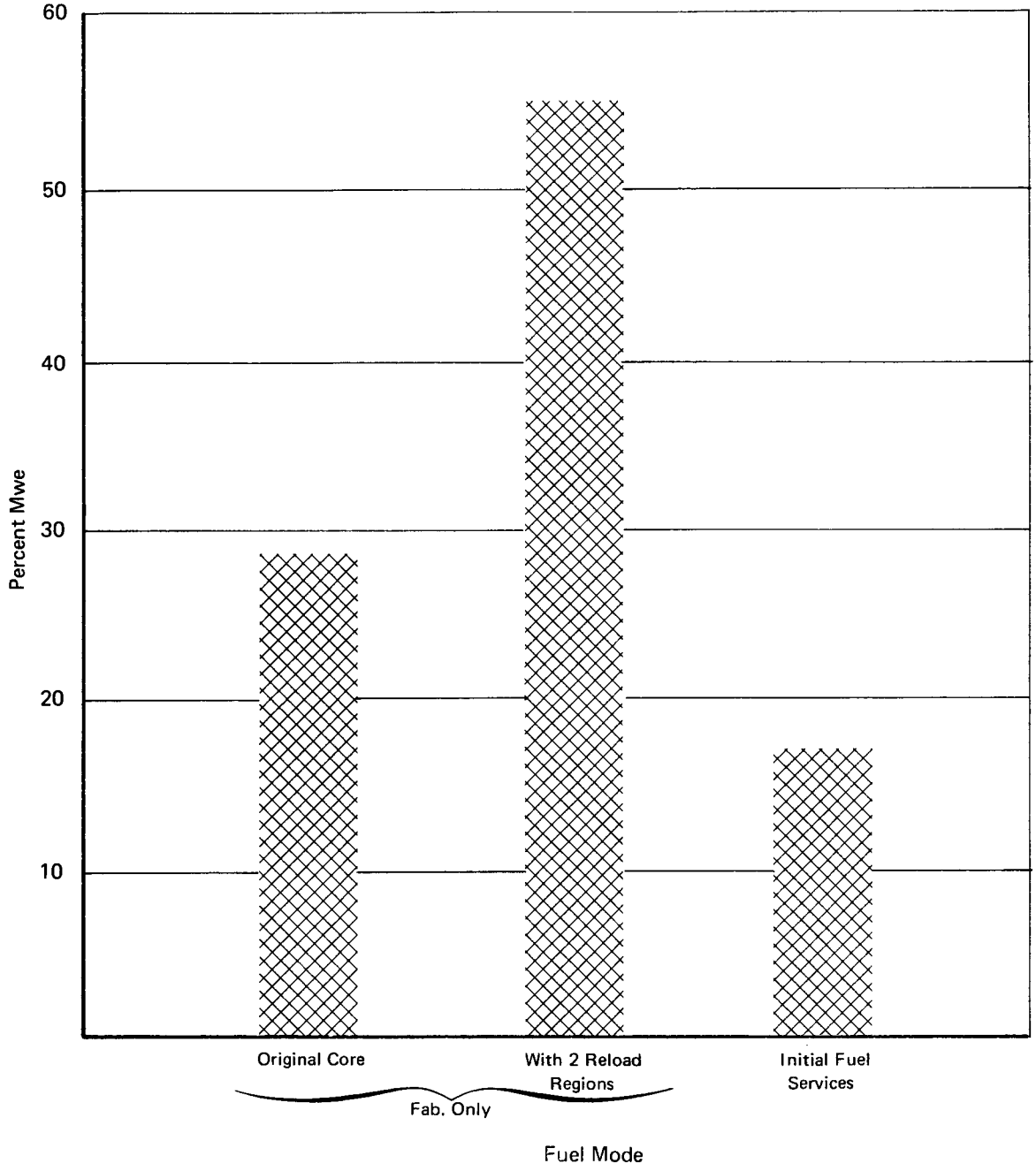


FIGURE X–9 DISTRIBUTION OF C.E. Mwe BY FUEL MODE

TABLE X-3

DISTRIBUTION OF NSSS MANUFACTURERS Mwe BY FUEL MODE

	WEST	G.E.	B & W	C.E.
Fabrication services only	69.3%	59.8%	62.2%	83.3%
– Original core only	5.9%	6.5%	12.5%	28.2%
– With reload regions	63.4%	53.3%	49.7%	55.1%
Fabrication plus U_3O_8[a]	24.7%	3.8%	12.5%	–
Initial fuel services[a]	–	12.8%	–	16.5%
Fuel cycle services[a]	5.7%	23.3%	25.1%	–

[a]With the exception of C.E.'s initial fuel services orders, all of this capacity has been committed with at least three reload regions beyond the original core.

Focusing upon the characteristic fuel modes of the two major NSSS manufacturers, Westinghouse is discernibly more committed to the fabrication-only concept than G.E., roughly 70% of megawattage vs 60%. In both instances, the majority of fabrication-only orders applies to reload regions as well as the original core; in fact, the 6-7% of capacity which is on a "fabrication services only-first core only" basis for Westinghouse and G.E., amounts to only one order for each manufacturer. These orders have been placed by two of the largest utilities in the U.S., whether measured in terms of system capacity or magnitude of nuclear orders awarded; in addition both utilities can be considered pioneers in sponsoring and implementing new technical concepts.

Thus, both because of small magnitude, and because of the uniqueness of the buying utilities, the "fabrication-only-original core" fuel mode does not appear to be typical of current fuel modes.

The "fuel services" modes, initial and complete cycle, do not represent a major portion of the Westinghouse and G.E. awards if an adjustment of the G.E. distribution is made. Although the "fuel cycle services" mode comprises nearly one fourth of G.E. business, this mode consists entirely of the Browns Ferry units which were earlier characterized as unique, and probably not indicative of long run selling strategy.

In summary, it appears that the prevailing fuel mode is a "fabrication services only" commitment which typically includes the original core and reloaded regions. Table X-4 elaborates the data in Table X-3, showing the distribution of megawattage in the "fabrication services only" mode by the number of reloads; over 80% of such megawattage involves commitments for 2-6 reload regions.

c. NSSS Manufacturers: General Type of Utility Customer

(1) System Size

The measure of system generating capacity has been used as a way of drawing some distinctions within the utility universe. Generating capacity is defined as all sources of power, including hydroelectric, for all applications, baseload or peak, in operation as of the end of 1967.

The definition of system size for consortia presents a problem, whether to use aggregate consortium capacity or the capacity of the major participant. Since the purpose here is to indicate for particular awards a

TABLE X-4

DISTRIBUTION OF "FABRICATION SERVICES ONLY" Mwe BY NUMBER OF RELOAD REGIONS COMMITTED

Original core only	13.0%
With two reload regions	37.3%
With three reload regions	17.0%
With four reload regions	15.4%
With six reload regions	12.5%
With eight reload regions	4.4%

rough measure of the economic strength of the buying group, and look for differences along this dimension, the measure of total consortium capacity seems more relevant than a less comprehensive measure.[1]

By this criterion, two separate system capacity figures can apply to a single utility if the utility has both wholly-owned and consortium projects; this, for example, is true of Commonwealth Edison.

The overall pattern of megawattage, distributed by system capacity increments ranging from over 10,000 Mwe to under 1000 Mwe, is shown in Figure X-10; Figures X-11 through X-14 show similar distributions for each NSSS manufacturer; Table X-5 summarizes the data.

On an overall basis, approximately 45% of the megawattage ordered has been placed with utilities or consortia of over 6000 Mwe. The two major NSSS manufacturers account for all of these placements. As a result, for Westinghouse and G.E. individually the percentages of business represented by the "large system" (over 6000 Mwe) buyers are well above the overall manufacturer average, amounting to 55% and 60% respectively versus the overall figure of 45%.

The concentration of C.E. awards among utilities with systems under 4000 Mwe, the "small" segment of the utility universe, is noticeable. Half of B & W's capacity is in the next highest interval, 4000-5999 Mwe. However, three-fourths of such capacity, roughly 40% of all B & W awards, is accounted for by one utility. The supplier's success with this middle-size utility, winning first a two-unit order, and later a follow-on unit for the station, undoubtedly reflects his own competence and resourcefulness. Coincidentally with the first award of two units, however, a separate bidding round to which B & W was not a party, was underway; this award involved one of the largest utilities in the country, and was a major landmark in the fossil/nuclear energy confrontation. It is possible, therefore, that the resources of other NSSS manufacturers had to be split between these two bidding events, with some dilution of these manufacturers' marketing efforts in their competition with B & W.

1. The Yankee groups raise special issues of classification. They can be distinguished from other consortia by several features: The large number of utility participants; the small participation taken by several investing utilities, amounting to a nominal presence in many cases; the separate legal and organizational existence of the consortium technicians (unlike most of the other consortia where a major participant utility has project management responsibility, for which it draws upon its own organization); and the recent regulatory interest in the membership criteria. Because of these complexities, the Yankee projects have been excluded from this part of the analysis.

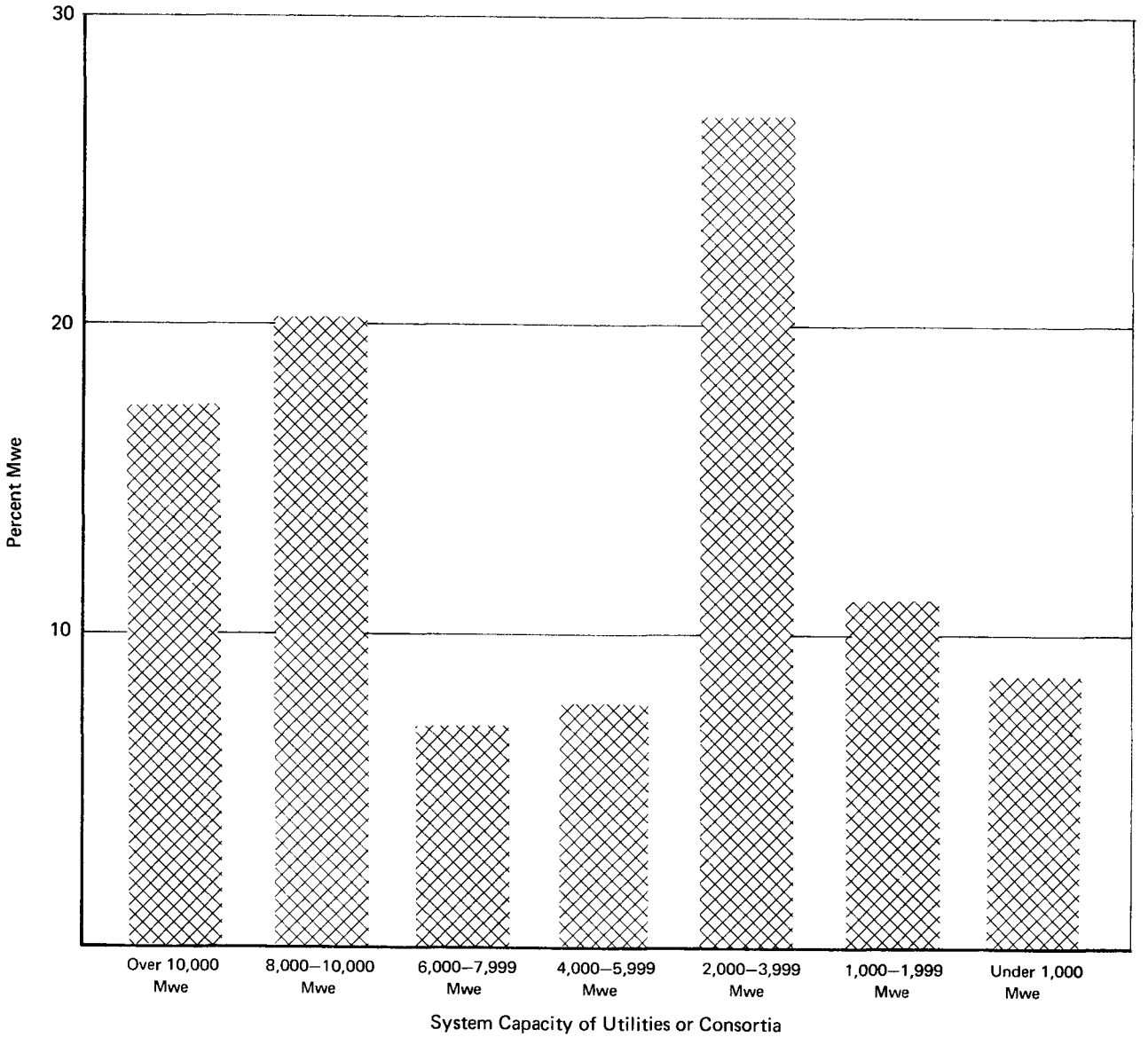


FIGURE X–10 DISTRIBUTION OF Mwe BY SYSTEM CAPACITY OF UTILITIES OR CONSORTIA

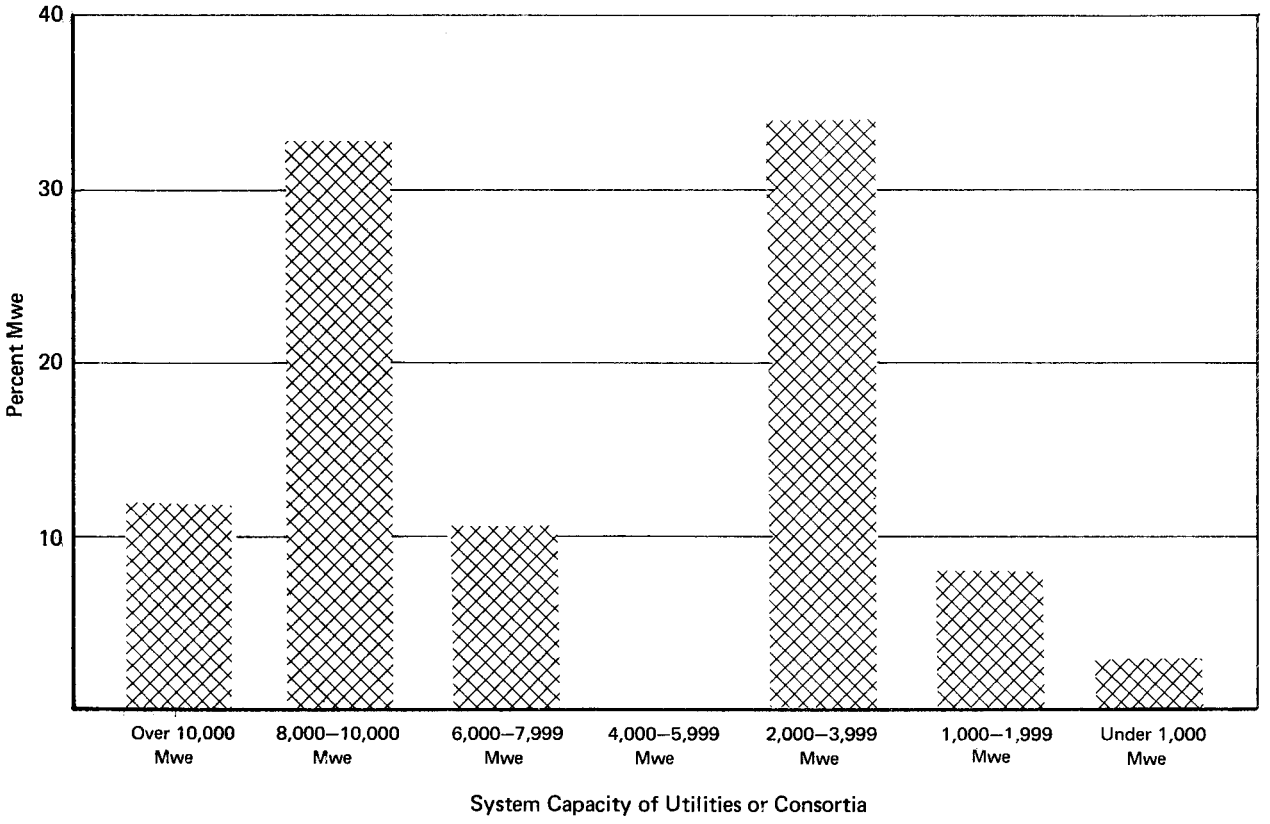


FIGURE X–11 DISTRIBUTION OF WESTINGHOUSE Mwe BY SYSTEM CAPACITY OF UTILITIES OR CONSORTIA

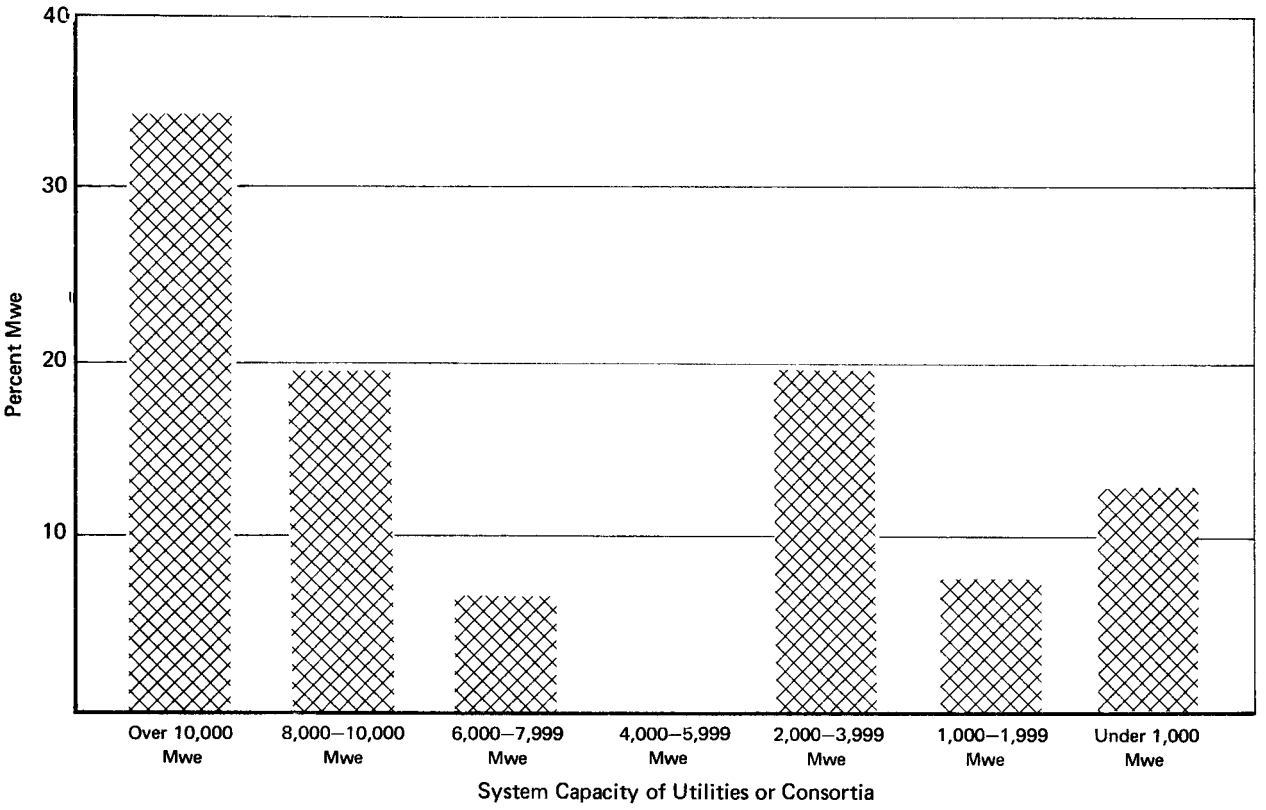


FIGURE X–12 DISTRIBUTION OF G.E. Mwe BY SYSTEM CAPACITY OF UTILITIES OR CONSORTIA

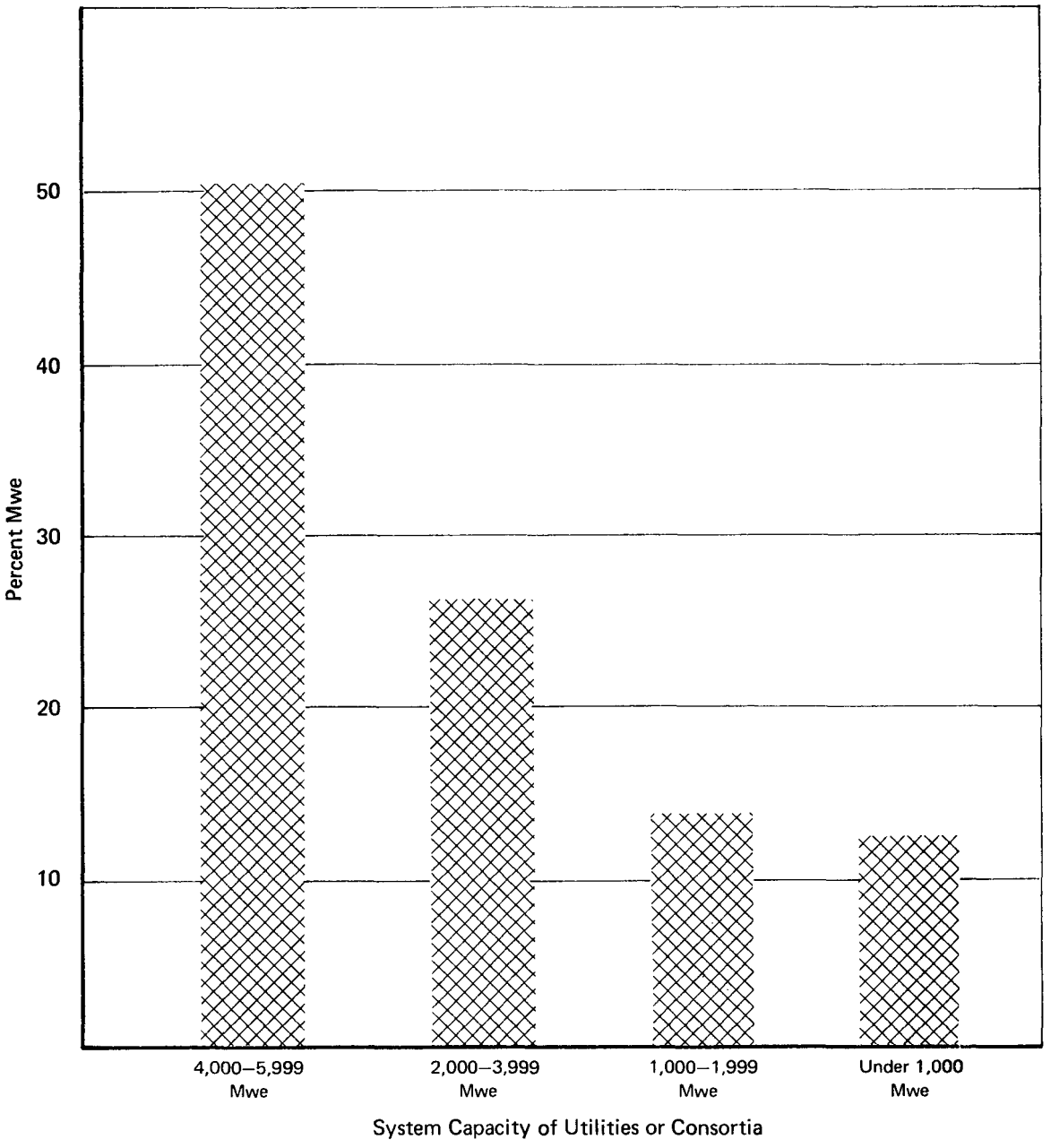


FIGURE X–13 DISTRIBUTION OF B&W Mwe BY SYSTEM CAPACITY OF UTILITIES OR CONSORTIA

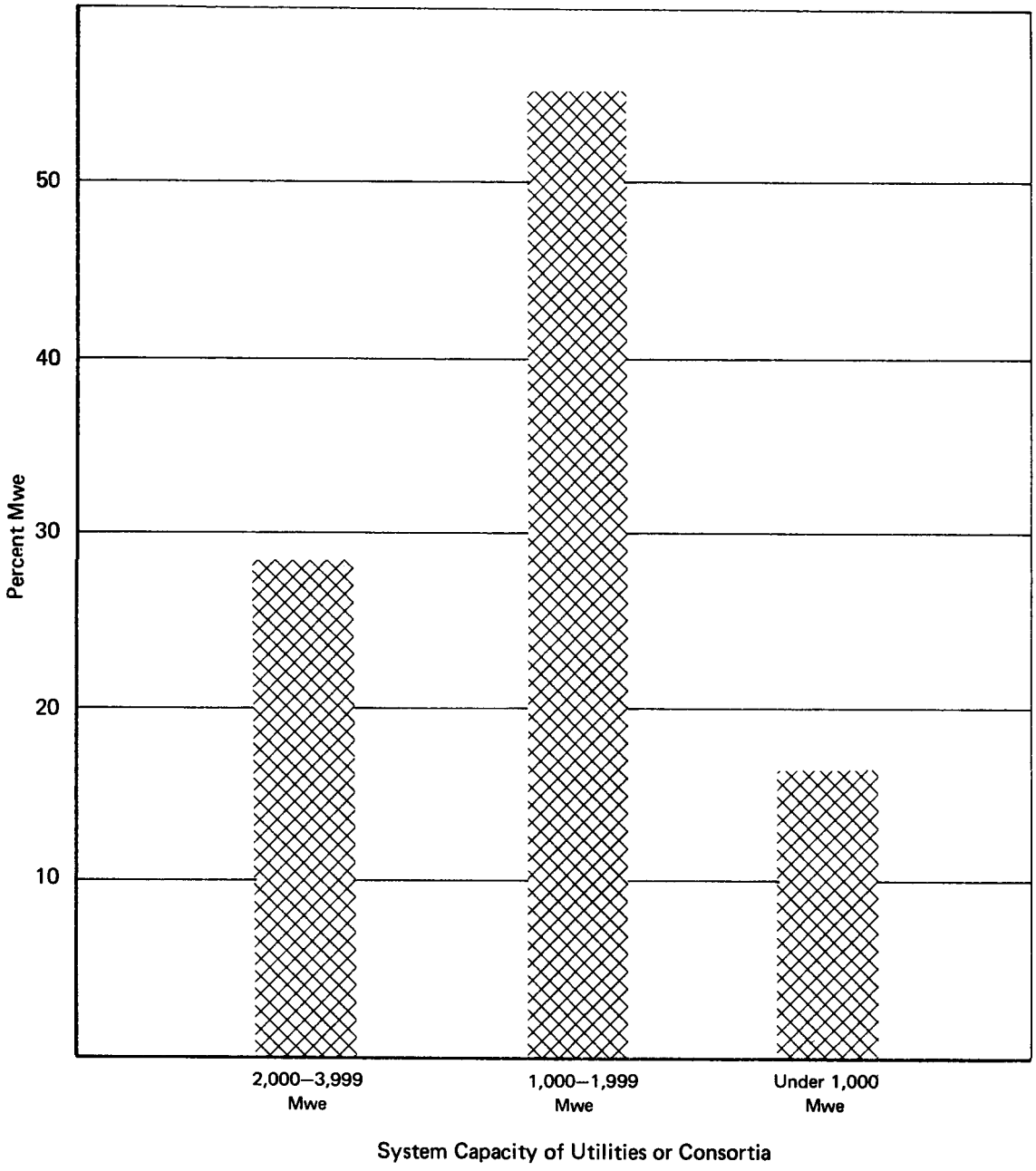


FIGURE X–14 DISTRIBUTION OF C.E. Mwe BY SYSTEM CAPACITY OF UTILITIES OR CONSORTIA

TABLE X-5

DISTRIBUTION OF Mwe BY SYSTEM CAPACITY

	Overall	WEST	G.E.	B & W	C.E.
Over 10,000 Mwe	17.5%	11.7%	34.1%	–	–
8,000 – 10,000 Mwe	20.4%	32.7%	19.5%	–	–
6,000 – 7,999 Mwe	7.1%	11.4%	6.7%	–	–
4,000 – 5,999 Mwe	7.8%	–	–	50.3%	–
2,000 – 3,999 Mwe	26.7%	33.6%	19.4%	25.4%	28.2%
1,000 – 1,999 Mwe	11.4%	7.7%	7.4%	12.7%	55.1%
Under 1,000 Mwe	8.7%	2.6%	12.7%	11.4%	16.5%

Under this assumption, the major entry of a third NSSS manufacturer into the "large-and-middle" utility universe of the two dominant manufacturers may have been facilitated to an indeterminate degree by a diversion. This hypothesis, if correct, would suggest even more strongly than the figures in Table X-5 that approximately half of the megawattage put out to bid in the interval 1965-1967 involved buyer group sizes that were somehow beyond the reach of the other two NSSS manufacturers.

This conclusion is not startling or remarkable if two factors are kept in mind: the typical unit size requirements of large utility systems, and the upper size limits of the reactors marketed by B & W and C.E. during the interval in question. Subsequent sections will show a secular increase in the size of unit purchased, whether nuclear or fossil, by the utilities which have made nuclear commitments. This increase had the effect, independently of supplier selling strategies, of frequently escalating the unit size specifications beyond the technical ability of some prospective bidders.

(2) Regional Energy Cost Levels

Regional differences in prevailing fossil energy costs within the contiguous United States are an important market dimension, defining a series of sub-markets with distinctive local energy costs. An estimate has been made of the "local" fossil energy costs, using a composite measure of the average fossil fuel costs[1] throughout a single state, or a few contiguous states. This has been derived from the Edison Electric Institute's *Statistical Yearbook for 1966:* Table 43S, "Analysis of Fuel for Electric Generation. Total Electric Utility Industry." This method has been selected because it coincides roughly with the geographical breakdown used in the AEC's recent *Forecast of the Growth of Nuclear Power;* the Forecast describes future capacity additions on an aggregated "Power Supply Area" basis, which frequently encompasses more than one state.

The Forecast provides a region-by-region estimate of megawattage to be added in the interval 1974-1980; capacity scheduled for 1973 and earlier may be considered firmly committed, for all practical purposes.

1. The composite fossil fuel cost represents the average of coal, gas and oil, weighted by the relative magnitudes of fuel consumed. No adjustment has been made for the differences in capital costs among coal, gas and oil generating units, which would affect the overall costs of power generation.

By describing both the amount of capacity to be added in a region, and the currently-prevailing fossil energy costs, an estimate can be made of the "fossil cost profile of future demand." By similar methods, the nuclear megawattage committed over the 1965-1967 interval can be arrayed to show the "fossil cost profile of recent nuclear demand."

The two cost profiles provide a way of dividing demand into "low," "medium" and "high" cost components which reflect the relative magnitudes of underlying demand. These magnitudes are important determinants of supplier strategy because they quantify market demand within intervals of fossil fuel costs. The comparison of profiles for "recent" and "future" demand provides a rough indication of changes in the structure of demand, measured in terms of fossil cost experience.

Figure X-15, "Profile of Fossil Fuel Costs," represents a distribution of electrical generating capacity; the solid line applies to future capacity, forecast for 1974-1980; the dotted line describes nuclear capacity added during 1965-1967. It appears that generally the fossil energy costs of the "nuclear capacity" utility group are higher than the current fossil energy costs of the "future capacity" group. This assumes, of course, that the current fossil fuel cost profile will not change appreciably. Under this assumption, it is probably that the NSSS-manufacturers will feel more competitive pressure from fossil energy alternatives; whereas, for example, half of the 1965-1967 placements were made in the under 29.3 cent range, half of the 1974-1980 demand will result from utilities in the under 26.6 cent range.

The "nuclear capacity" distribution in Figure X-15 has been used to divide the 1965-1967 megawattage into "low-cost," "middle-cost" and "high-cost" intervals. The demarkation points taken are 25.9 cents/MBTU and 30.3 cents/MBTU, yielding three roughly equal blocks of nuclear megawattage. The first demarkation point, which places the "low-cost" interval below 25.9 cents, occurs close to the upper limit of the cost range for "large" reactors, those at 800 Mwe and above; these reactors at current handbook prices, with several assumptions about load profile, site preparation, construction cost escalation, and cost of capital, translate to an energy cost range of 22-27 cents. Hence the "low-cost" interval is the area of severest fossil competition for NSSS-manufacturers. With the exception of utilities virtually astride of natural gas and coal deposits, however, whose energy costs are presumably below the 22 cent level, NSSS offerings in the large reactor sizes can compete on an energy cost basis with fossil alternatives. The other demarkation point, 30.3 cents, is slightly above the upper limit of the cost range for "small" reactors in the 400-600 Mwe area. By a set of

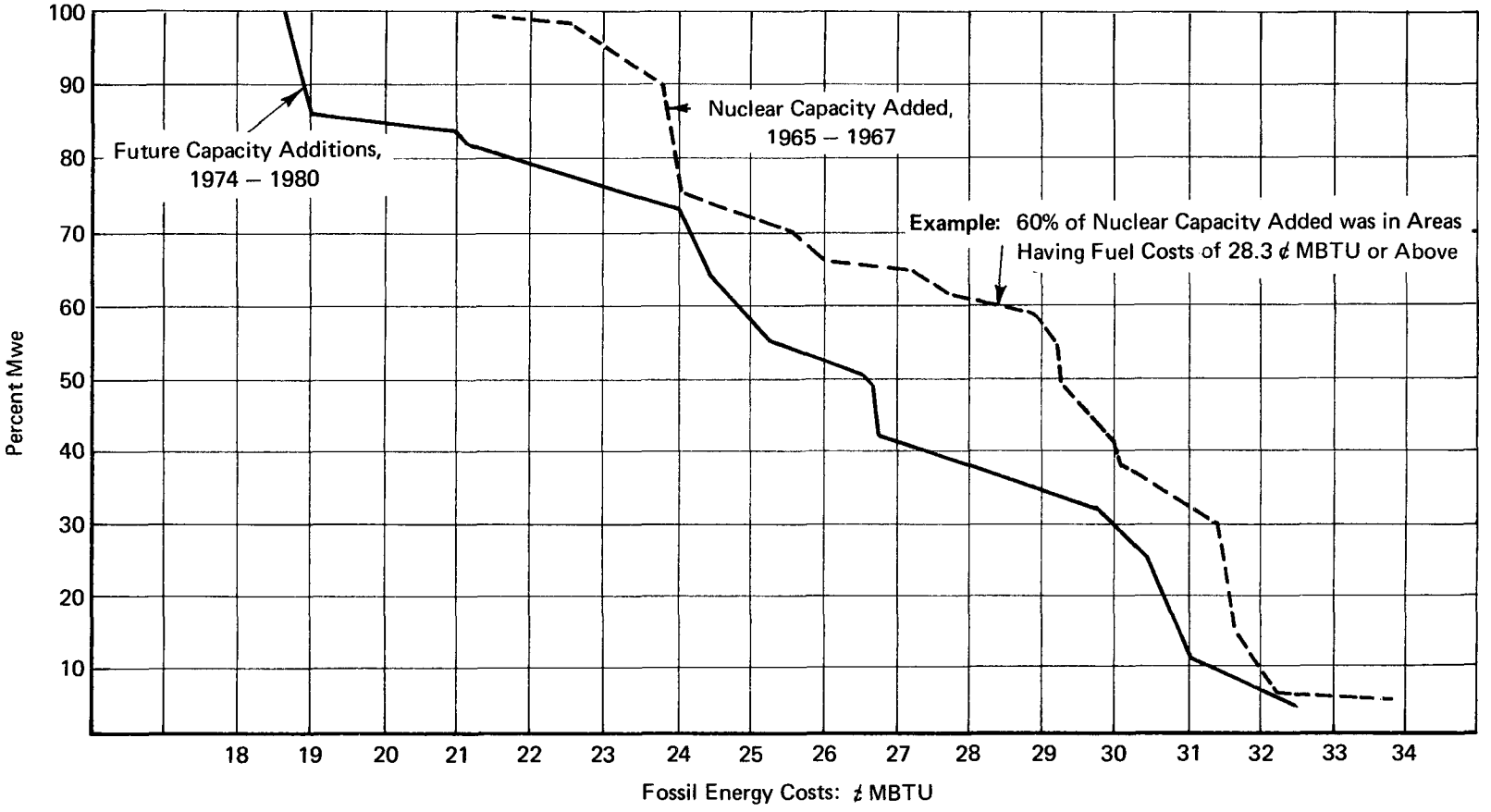


FIGURE X–15 PROFILE OF FOSSIL FUEL COSTS

assumptions such as those indicated above, the energy cost range for these reactors is 27-30 cents. Within the "medium-cost" interval defined by the two demarkation points, reactors in the large sizes have a pricing advantage; while reactors in the small sizes have price characteristics roughly equivalent to fossil alternatives. Above the 30.3 cent level, there is a price advantage for reactors in all sizes.

Within the three fossil fuel cost categories, which correspond approximately to market conditions of fossil/nuclear parity, nuclear large-unit advantage, and overall nuclear advantage, differences in selling strategy are apparent. Table X-6 shows for the three fuel cost categories the nuclear fuel mode distribution of each. The "fabrication only" mode is roughly constant, between 59% and 65% of capacity in each category. Other fuel modes, however, show significant variations. The two "fuel services" modes (initial fuel services and fuel cycle services) are more widespread among "low cost" utilities than among "high cost" ones, 36% v. 8%; offsetting this, the "fabrication and ore" mode has a higher incidence among "high cost" utilities than among "low cost" ones, 31% v. 5%. The prevalence of "fuel services" commitments among "low cost" utilities is confirmed by putting the Table X-6 data in a different perspective: distributing the "fuel services" megawattage across all fuel cost categories, 60% of it falls within the "low cost" category. These patterns suggest that the "fuel services" modes are priced more competitively to the "low cost" utilities than to others. In fact, the modes themselves, somewhat independently of price, constitute a competitive technique, because they tend to fix or bracket the nuclear energy costs for the buying utility; this reduction of uncertainty can be very attractive in the context of a new technology and unit-size extrapolations.

5. Buyer Preferences

a. Nature of Fuel Commitments

Figure X-16 and Table X-7 show the distribution of fuel modes by size of utility systems; Figure X-16 shows all fuel modes for each system size interval, while Table X-7 recasts the data to show for each fuel mode its individual distribution by system size.

The "fabrication only" mode, which by Table X-3 was shown to be the prevalent one for all NSSS manufacturers, is distributed among utilities in a proportion roughly paralleling the overall distribution of megawattage (regardless of fuel mode). Thus, for example, utilities above 8000 Mwe account for 38% of capacity sold, and 36% of the fabrication-only commitments; for those below

TABLE X-6

DISTRIBUTION OF FUEL MODE Mwe BY FOSSIL FUEL COST CATEGORY

	Low-Cost (Under 25.9¢)	Medium-Cost (25.9–30.3¢)	High-Cost (Over 30.3¢)
Fabrication only	58.8%	64.8%	60.5%
Fabrication & U_3O_8	5.4%	18.4%	31.5%
Initial Fuel Services	13.9%	2.9%	–
Fuel Cycle Services	21.8%	13.6%	7.8%

TABLE X-7

DISTRIBUTION OF FUEL MODE Mwe BY SYSTEM SIZE

	Overall Mwe	Fuel Modes			
		Fab	Fab & U_3O_8	IFS	FCS
Over 10,000 Mwe	17.5%	7.6%	–	83.0%	51.3%
8,000 – 10,000 Mwe	20.4%	28.7%	–	–	15.1%
6,000 – 7,999 Mwe	7.1%	3.9%	29.4%	–	–
4,000 – 5,999 Mwe	7.8%	3.0%	12.8%	–	25.6%
2,000 – 3,999 Mwe	26.7%	26.2%	57.6%	–	7.8%
1,000 – 1,999 Mwe	11.4%	18.1%	–	–	–
Under 1,000 Mwe	8.7%	12.2%	–	17.0%	–

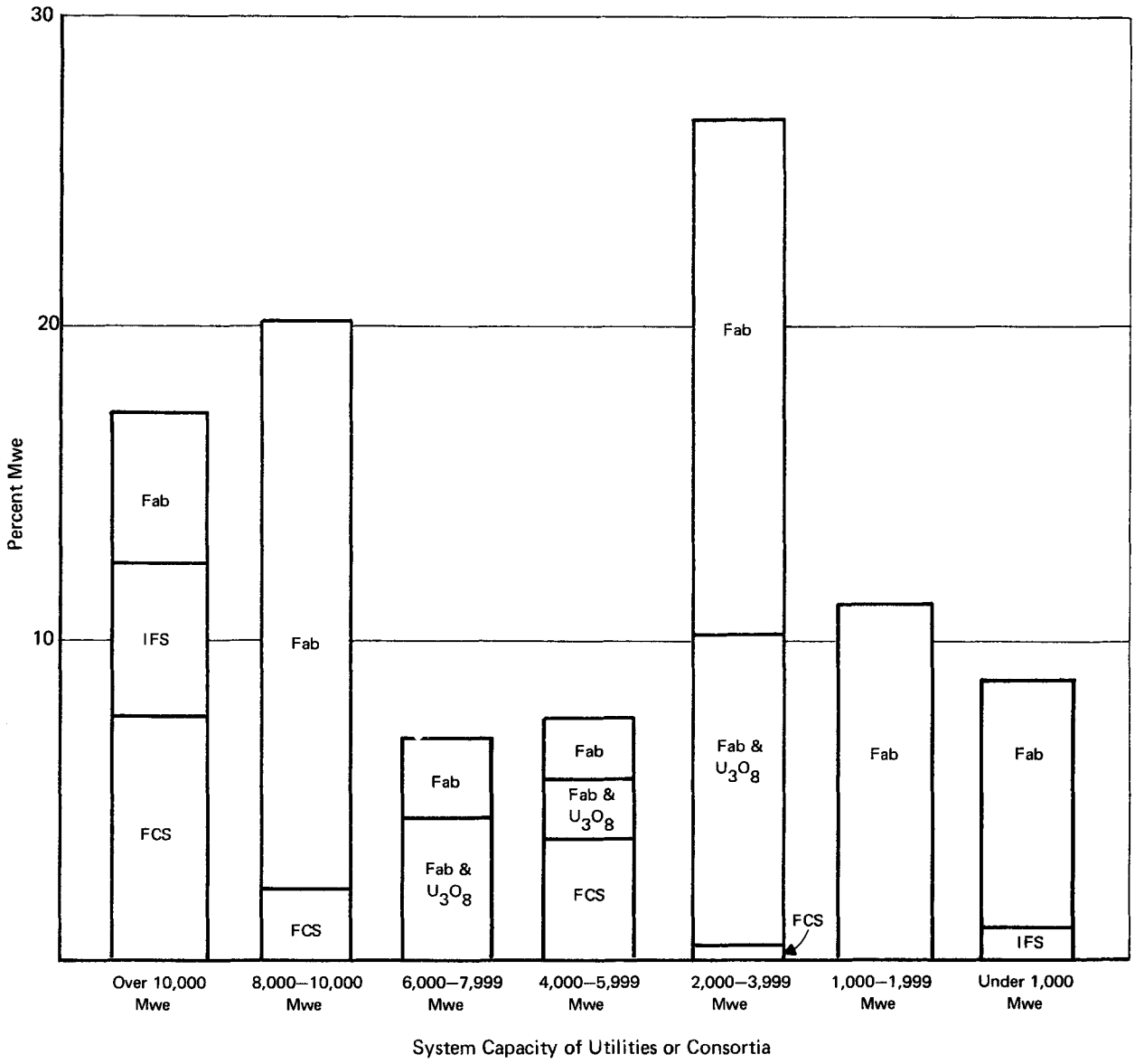


FIGURE X–16 DISTRIBUTION OF Mwe BY SYSTEM SIZE AND BY FUEL MODE

4000 Mwe, the figures are 47% and 56% respectively. This suggests that fabrication-only mode is a popular one among all sizes of utility, rather than being promoted to or demanded by a particular size of utility.

If it is hypothesized that system size might correlate very roughly with financial and technical resourcefulness, one might have expected to find the fabrication-only megawattage clustered within a few high intervals of the distribution, rather than being spread out in parallel with the overall megawattage distribution; the expected cluster would presumably have resulted among the large, resourceful utilities who could take the risk of bringing U_3O_8 up to the fabrication phase. Since the cluster is not in evidence, one cannot postulate an undue large-utility preference for the fabrication-only mode, vis-a-vis smaller utilities. A previous finding was advanced, to the effect that "fuel services" offerings were concentrated heavily among "low-cost" utilities. If it is assumed that the "low cost" utilities are – roughly speaking – the "large" utilities (whose system sizes permit scale economics in power generation), then one might conclude from the fuel mode distribution of Table X-7 as follows:

- In the matter of nuclear fuel management, the "large" utilities were not appreciably more risk-prone than the "small" utilities, as demonstrated by fuel commitments during the 1965-1967 interval.

- Alternatively, special vendor offerings to "low cost" (and "large") utilities induced these utilities to select fuel modes which, for other reasons, were also favored by "small" utilities.

The two conclusions are by no means mutually exclusive.

The pattern of fuel services commitments, initial services and complete cycle services, confirms indirectly the above conclusions. Table X-8 aggregates the system size intervals into "large," "medium" and "small" utility classifications. Within each of these, a division of "fabrication" and "fuel services" modes is shown. This division reflects differences in risk to the utility. In the "fabrication" mode, whether with or without U_3O_8, the utility usually bears some risk for changes in the cost of separative work and conversion. There may also be some uncertainty concerning the eventual price of U_3O_8 to the utility, when the commitment is for a physical quantity, with a price-determining formula containing escalatable variables.

On the other hand, a "fuel services" commitment, whether initial services or full cycle services, typically limits the future price uncertainty by fixing the price

TABLE X-8

FABRICATION MODE VS. FUEL SERVICES MODE BY SYSTEM SIZE

		Fabrication (fab only, and fab with U_3O_8)	Fuel Services (initial and complete cycle)
Over 10,000 Mwe 8,000 – 10,000 Mwe	"large"	60%	40%
6,000 – 7,999 Mwe 4,000 – 5,999 Mwe 2,000 – 3,999 Mwe	"medium"	88%	12%
1,000 – 1,999 Mwe Under 1,000 Mwe	"small"	95%	5%

level for certain fuel cycle components, and by bracketing with a formula the fluctuation range for other components. Admittedly, there are "fuel services" contracts where all components are formula-variable, and thus uncertain rather than fixed, but in the few instances observed directly, the formulas were so written as to place an upper limit upon the total price to the utility.

Generally, a commitment in the "fuel services" classification is a way of limiting future price uncertainty, and therefore a way of limiting risk when compared to a "fabrication" commitment. If an earlier assumption is accepted, to the effect that "large" utilities might be more resourceful and consequently more risk-prone than "small" utilities, it is surprising to find the pattern of Table X-8: the "large" utilities are proportionately more receptive[1] to the "fuel services" mode than smaller utilities.

b. NSSS Manufacturers

It was shown earlier that the megawattage of the major two NSSS manufacturers, G.E. and Westinghouse, is concentrated within the "large" utility universe. The conclusion can also be reversed, to the effect that all of the "large" utility megawattage is concentrated within the "major" NSSS manufacturer universe, as shown in Figure X- 17.

Table X-9 shows that the average reactor size increases with the system size of the buying utility.[2] The plausible interpretation of this phenomenon is that as system size increases, the "digestive" ability of the buyers increases. In fact, by the measure of average reactor size purchased to average system capacity, the larger utilities seem to have less difficulty in absorbing the unit sizes offered, than the smaller utilities, as shown in Table X-10; for the smallest utilities, under 1000 Mwe, the purchase of a reactor involves a new technology as well as a doubling of system capacity.

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1. In earlier discussion, it was suggested that the Browns Ferry awards were not genuinely indicative of patterns that might be expected in the future; consequently, adjustments were made to some computations by eliminating the Browns Ferry megawattage. If such an adjustment is made to the data in Table X-6, for "large" utilities the division between the "fabrication" and "fuel services" classifications is 76%-24% rather than 60%-40% as shown. The 76% incidence of "fabrication awards" is still materially lower than the 88% and 95% for "medium" and "small" systems.

2. The megawattage analyzed here has been restricted to those orders placed between mid-1966 and the end of 1967, to take into account the fact that B & W and C.E. (ex-Palisades) did not win any large (above 400 Mwe) orders until that time; C.E.'s Palisades award, received in early 1966, has been included. Consequently, the figures in Table X-9 (and Table X-10 as well) represent those awards that pertain to the size preferences of utility buyers during the interval when all four NSSS manufacturers were active bidders.

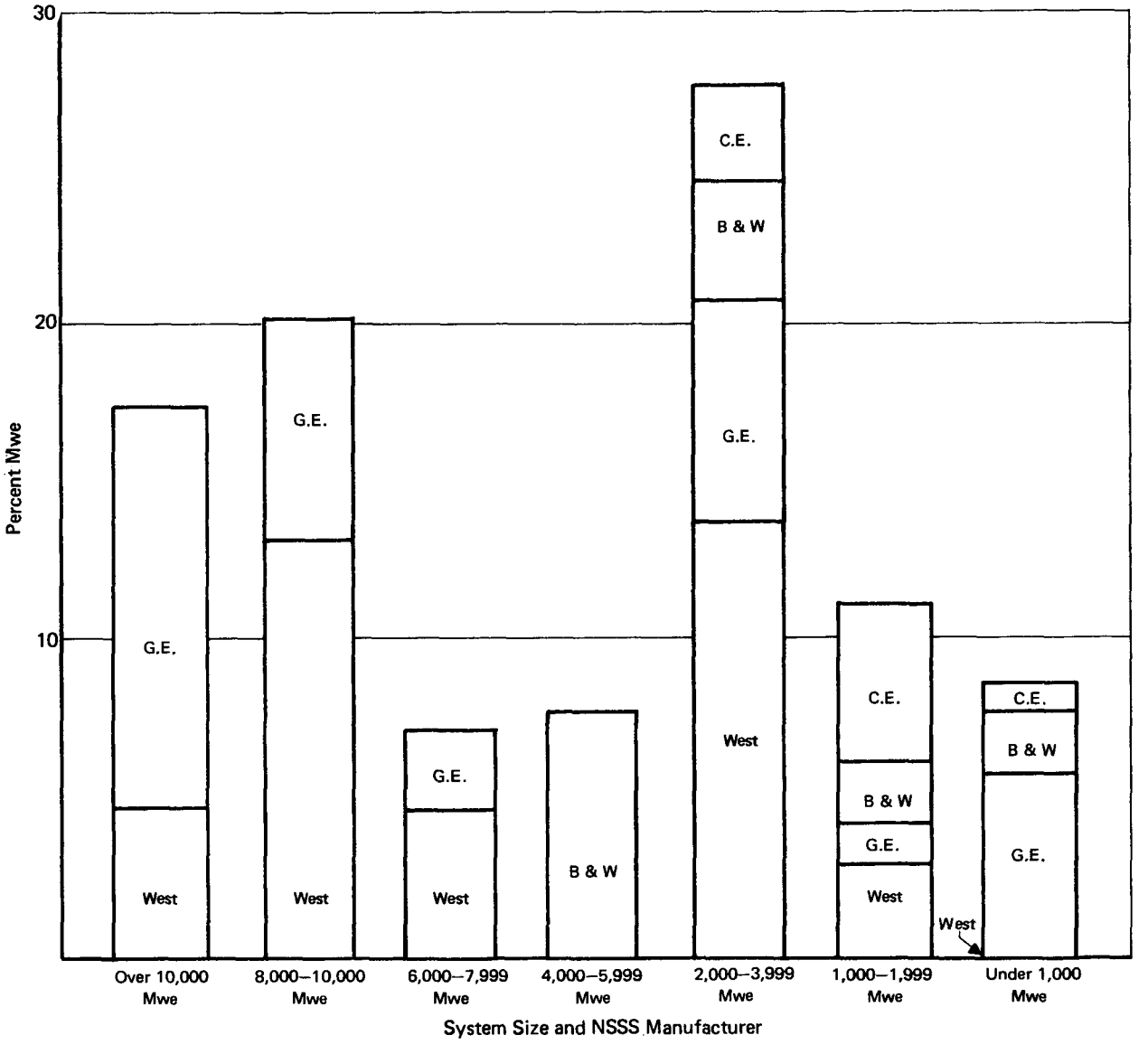


FIGURE X–17 DISTRIBUTION OF Mwe BY SYSTEM SIZE AND BY NSSS MANUFACTURER

TABLE X-9

AVERAGE SIZE OF REACTOR PURCHASED, BY UTILITY SYSTEM CAPACITY INTERVALS

	Average Reactor Size, Mwe
Over 10,000 Mwe	1,094
8,000 – 10,000 Mwe	1,092
6,000 – 7,999 Mwe	1,074
4,000 – 5,999 Mwe	875
2,000 – 3,999 Mwe	780
1,000 – 1,999 Mwe	735
Under 1,000 Mwe	680

TABLE X-10

RATIO OF AVERAGE REACTOR SIZE TO SYSTEM CAPACITY

	Average Reactor Size/System Size
Over 10,000 Mwe	8.4%
8,000 – 10,000 Mwe	12.7%
6,000 – 7,999 Mwe	14.1%
4,000 – 5,999 Mwe	19.2%
2,000 – 3,999 Mwe	28.4%
1,000 – 1,999 Mwe	46.5%
Under 1,000 Mwe	104.1%

For large utilities, those with system capacity above 6000 Mwe, the average size of reactor purchased is well above 1050 Mwe, as shown in Table X-9. By Table X-10, the ratio of average reactor size to system size for these utilities is at or below 14%. Adding capacity in increments of this magnitude is clearly no great burden for such utilities in terms of idle plant if they are experiencing rapidly-growing loads; in the case of most large utilities, a 14% increment probably represents no more than two years of load growth; for several, with annual growth rates between 8-10%, a 14% addition could be fully utilized when on line by the combination of one year's new load retirements of obsolete plant.

However, the measure of average unit size added is only a partial test of a utility's "digestive" ability; an additional measure of aggregate capacity added is also needed. Table X-11 provides this measure through the ratio of aggregate additions to system capacity. The largest utilities still appear better able to absorb their nuclear orders; for utilities above 8000 Mwe, the additions total less than 30% of the existing system capacity, whereas for virtually all other utilities, additions are between 40% and 55% of their systems.

Given, therefore, the greater inherent ability of large utilities to absorb capacity increments, and given that 1000 Mwe units are not disproportionate to this ability, the 1050-1100 Mwe unit sizes offered by Westinghouse and G.E. appear to have been well-tailored to the unit size needs of the buyers; the buying response confirms this. Implicitly, the inability of B & W and C.E. to respond to unit size specifications beyond 1000 Mwe served effectively to restrict the large utilities to the two major suppliers, although four qualified NSSS manufacturers appeared to be in evidence.

6. Secular Trends

a. Nature of Fuel Commitments

The 1965-1967 interval has been divided into three phases, each of which accounts for approximately one third of the megawattage under consideration. The first phase begins in 1965 and ends with the Browns Ferry 1 & 2 award in mid-1966; the second phase runs into early 1967; and the third phase includes the balance of the 1967 year. By Table X-12, there are changes in the fuel mode patterns over time: the "fabrication only" mode rises from over half of the megawattage to three fourths, while the "fuel services" modes peak at almost 40% in the second phase, and then drop drastically. This suggests that the "fuel services" modes were used in the early phases as a way of converting skeptics to the energy nuclear concept; in Phase III, with a backlog of committed nuclear

TABLE X-11

RATIO OF AGGREGATE NUCLEAR CAPACITY PURCHASED TO SYSTEM CAPACITY

	Aggregate Purchases/Capacity
Over 10,000 Mwe	29.8%
8,000 – 10,000 Mwe	26.6%
6,000 – 7,999 Mwe	42.0%
4,000 – 5,999 Mwe	48.1%
2,000 – 3,999 Mwe	51.5%
1,000 – 1,999 Mwe	55.1%
Under 1,000 Mwe	104.1%

TABLE X-12

DISTRIBUTION OF FUEL MODE Mwe BY DATE OF COMMITMENT

	Phase I	Phase II	Phase III
Fabrication only	53.3%	54.8%	74.4%
Fabrication & U_3O_8	27.7%	6.1%	18.4%
Initial Fuel Services	–	19.0%	–
Fuel Cycle Services	18.8%	19.9%	7.0%

capacity, some of it secured in land mark confrontations with fossil alternatives, the function of the "fuel services" modes in minimizing uncertainty became less important, hence the incidence of the "fuel services" modes dropped.

b. Duration of Fuel Commitments

It is difficult to find a consistent pattern in the trend of the duration of fuel commitments. Generally, by Table X-14, it appears that the early phase reliance upon at least two complete cores has been loosened; however, at least 40% of the megawattage has always been on this long term basis, and in the most recent phase the proportion has risen to approximately half of the megawattage committed. It is too early to judge whether the recent rise in "original core only" commitments, from trivial levels to roughly one fifth of megawattage committed, is a durable trend. Certainly, with only 20% of recent commitments theoretically available in the near future to independent fuel fabricators, the "independent" fuel market is a severely circumscribed one.

c. NSSS Manufacturer Strategies

The data in Table X-12 have been refined into an array of Westinghouse and G.E. orders, by phases, and by fuel modes; this is summarized in Table X-13. It becomes clear from the refinement that the strategy of early phase commitments in the "fuel services" modes is more descriptive of G.E. than Westinghouse. Westinghouse's strategy seems to have been a rather consistent reliance upon the "fabrication" or "fabrication with ore" modes.

A similar refinement has been made of the data in Table X-14 to show the duration of Westinghouse and G.E. fuel commitments; this is shown in Table X-15. For the first two phases, the duration of Westinghouse and G.E. commitments is roughly similar: in Phase I, all of the megawattage for each is committed on a two or three core basis; and in the second phase, 80% of each manufacturer's megawattage slips to a partial replacement basis. In Phase III, however, the patterns diverge: G.E. megawattage continues to slip into shorter duration intervals, with three fourths of it placed on a partial replacement or no replacement basis; almost two thirds of Westinghouse megawattage, however, is committed to a two complete replacement cores basis.

B. NUCLEAR PLANT COMMITMENTS: EVALUATION AND SELECTION PROCESS

1. Commitment to Nuclear Energy

In the typical utility process whereby a utility arrives at a choice of power plant supplier, the normal sequence of events is to proceed from a determination

TABLE X-13

DISTRIBUTION OF WESTINGHOUSE AND G.E. FUEL MODE Mwe BY DATE OF COMMITMENT

	Phase I		Phase II		Phase III	
	W.	G.E.	W.	G.E.	W.	G.E.
Fabrication only	36.9%	59.9%	82.5%	45.5%	68.7%	73.9%
Fabrication & U_3O_8	63.1%	7.5%	–	–	31.2%	–
Initial Fuel Services	–	–	–	54.4%	–	–
Fuel Cycle Services	–	32.8%	17.5%	–	–	26.1%

TABLE X-14

DISTRIBUTION OF REPLACEMENT CORE Mwe BY DATE OF COMMITMENT

	Phase I	Phase II	Phase III
Original core with two complete replacement cores	58.3%	7.5%	33.7%
Original core with one complete replacement core	36.0%	33.8%	15.7%
Original core with partial replacement core (PWR: less than 3 regions; BWR: less than four regions)	–	58.5%	31.5%
Original core only	5.4%	–	18.9%

TABLE X-15

DISTRIBUTION OF WESTINGHOUSE AND G.E. Mwe BY DURATION AND DATE OF COMMITMENT

	Phase I		Phase II		Phase III	
	W.	G.E.	W.	G.E.	W.	G.E.
Original core with two complete replacement cores	71.1%	55.8%	17.5%	–	63.5%	26.1%
Original core with one complete replacement core	28.9%	44.2%	–	19.5%	–	–
Original core with partial replacement core (PWR: less than 3 regions; BWR: less than four regions)	–	–	82.5%	80.5%	20.2%	48.5%
Original core only	–	–	–	–	16.1%	25.2%

of the need for additional capacity, to the selection of a supplier, without an extensive intermediate phase of analyzing potential energy sources. The operating experience and the geography of the utility usually serve to pre-screen various energy sources, excluding some without the need for elaborate analysis. The utility's evaluation process can, therefore, usually focus upon fine differences among suppliers of a single type of energy. For this evaluation, *bona fide* bids with hard data are required, rather than generalized comparisons of alternative energy sources.

As nuclear energy moved beyond the experimental, small-scale applications of the 1950's toward commercial applications in large unit sizes, it faced the prospect of competing with mature technologies, from its own condition of uncertain technical and economic performance estimates grounded upon extrapolated data. Moreover, for utilities with little or no nuclear experience, the process of evaluating and refining the nuclear performance estimates could be a complex and expensive one.

The typical unit size of fossil power plant that was being purchased in the early sixties had escalated noticeably. Table X-16 shows that from the base year of 1953, the average unit size purchased by utilities that ultimately made nuclear commitments had more than doubled from 150 Mwe to a 1963 level of 383 Mwe. Thus by 1963, the time of the first sizeable nuclear commitments such as Connecticut Yankee, Malibu (since delayed in licensing), and Oyster Creek, the fossil size offerings favored by the large utilities were between 350-400 Mwe, far above the typical levels of earlier PDRP Round 1 or 2, or privately-financed experimental reactors.

Among the many difficulties posed by the competition from large fossil units of demonstrated or demonstrable economics, it appears that two major issues had to be resolved as a precondition for a nuclear commitment:

- Utilities had to be convinced in rough, aggregate fashion that the fossil/nuclear alternatives were within the same broad cost range, before they would undertake the expensive, refined analysis necessary to evaluate commercial bids.

- The evaluation of commercial bids would have to generate findings that demonstrated nuclear energy's competitiveness, and were sufficiently creditable to justify a multi-million dollar commitment to a nuclear option that might – at best – be only marginally preferable to the fossil alternatives.

TABLE X-16

ESCALATION IN FOSSIL POWER PLANT UNIT SIZES, 1953-1963[a]

Year of Order	Average Size of Unit[b] (Mwe)
1953	150
1954	142
1955	152
1956	177
1957	235
1958	185
1959	226
1960	286
1961	415
1962	302
1963	383

[a]These units represent the fossil power plant commitments of those utilities which during the 1963-1967 era bought LWR units in sizes above 400 Mwe.

[b]Units rated beneath 100 Mwe have been excluded, since these were typically committed for standby or peak applications.

These issues, of course, were eventually resolved in favor of nuclear power, as evidenced by the commercial breakthrough in large-unit orders placed since 1963. Under current circumstances, the utilities' process of moving from a determination of capacity need to the selection of a supplier follows the "normal" pattern, with the nuclear option as viable as the fossil options throughout most of the contiguous United States. In the early phases of the commercial breakthrough, however, some special factors operated to meet the unique difficulties of a technology in its commercial infancy. The "early phase" can be defined as the period 1963 to mid-1966, spanning the Connecticut Yankee, Malibu and Oyster Creek awards on one side, and ending with the Browns Ferry 1 and 2 award on the other side; with the Browns Ferry commitment, price competitiveness under severe competition was demonstrated by nuclear power, and the 15,000 Mwe mark of large-unit size nuclear orders placed was passed.

The "special factors" which operated during the 1963-1966 interval, although by now inoperative, are relevant to an understanding of the large-scale commercialization of nuclear energy. Although several factors could be cited, it appears that four factors were decisive:

- The availability of fixed-price turnkey bids, many of which on a substantially non-escalatable basis.

- For awards with high visibility throughout the utility industry, price quotations that had the primary aim of bringing nuclear power into the commercial market, and somewhat secondarily the aim of recovering full factor costs.

- Supplier approaches generally focussed upon major utilities in areas of high fossil fuel cost, where the fossil competition would not be overly severe.

- The accumulated experience of utilities which had participated in PDRP projects, or in privately-financed consortia.

a. Availability of Turnkey Bids

From interviews among utility respondents, it appears that at least until 1963, and frequently until 1965, a utility evaluated nuclear energy through a review of general cost data, rather than through the solicitation of commercial bids. Typically, the practice seems to have been one of estimating from the utility's own experience with fossil plant procurement the current fossil cost levels; these estimates were frequently supplemented by informal discussions with transportation, fuel, and equipment suppliers. These fossil estimates were then usually translated into capital and operating costs reflecting the utility's individual circumstances, by the utility's own technical staff.

It appears that from the early sixties, and certainly no later than the Oyster Creek award, many major utilities as a matter of informal policy reviewed their fossil estimates to determine whether the effort and expense of analyzing a nuclear alternative seemed warranted. It is hard to generalize about the method and thoroughness of these early comparisons. In several cases, it seems to have been a rather summary derivation of capital and fuel cost measures, grounded upon informal discussions with architect-engineers and suppliers, and reinforced – where applicable – by the utility's own experience in early PDR or privately financed programs. Not surprisingly, what typified these analytical efforts was a strong sense of uneasiness about the reliability of the quantitative estimates. In these circumstances, the attractiveness of a turnkey bid was self-evident. Given the necessity of relying upon extrapolated data in pricing an 800 Mwe or 1100 Mwe unit, it is not difficult to understand the technical risk-aversion of utility management. In addition, utility experience with inflation of construction labor costs, and the prevailing utility view of nuclear plants as more capital and construction-labor intensive than fossil plants, both highlighted the price escalation risk of a nuclear commitment. There were, however, exceptions among utilities in their general receptivity to and reliance upon turnkey bids. For example, the Yankee Nuclear Power Station project (Mass. Yankee), built with AEC PDRP – Round 1 assistance, was not awarded on a turnkey basis; rather, it was essentially a cost-plus-fixed fee project which significantly underran the estimate.

Generally, while the utilities welcomed the opportunity to transfer the technical and price-escalation risks to the supplier, it was still necessary for those taking on the turnkey responsibility to demonstrate financial and technical ability, and – more generally – to be known to the utilities as credible and reliable. The extensive background of Westinghouse and G.E. in electrical generation equipment was an obvious and useful facilitating factor. Although the point is now moot, several utility respondents suggested that because of the considerable complexities in making a large-scale commercial application of nuclear energy, somewhat independently of the allocation of financial risk the utilities needed the reassuring presence of known suppliers who had demonstrated through past fossil projects technical resourcefulness in coping with unforeseeable difficulties, and reasonableness in sharing with the utilities the consequent burden of these difficulties. It also appears that well-publicized difficulties of other NSSS suppliers in the middle 50's, both in civilian and military nuclear programs induced caution among the utilities, and possibly among the suppliers themselves in risking an over-commitment to a large experimental project.

It should be kept in mind that while the utilities generally managed to avoid technical and price-escalation risks by turnkey commitments, a residual risk of schedule slippage and power availability remained upon them. In no instance among utilities interviewed was there evidence of acceptance of "consequential damages" liability by the NSSS supplier, where the utility might be compensated

for the unavailability of power due to project schedule slippage. However, in the LaCrosse Boiling Water Reactor project, AEC PDRP–Round 2 and Dairyland Power Cooperative, actual damages were paid by the AEC to the utility for failure to have firm power available to meet the utility's power pool commitments. Moreover, in a few other instaces of new technology and high risk projects, it is rumored that an arrangement amounting to a provision for consequential damages was agreed upon, as an inducement for the utility in question.

Nonetheless the general utility industry view appears to have been that a consequential damages clause was unprecedented and probably infeasible: it would require an off-setting clause compensating the supplier for anticipated availability, and would necessitate a definition of Acts-of-God clearly beyond the supplier's responsibility. More generally, in the traditional manner of doing business with long-standing suppliers of proven competence, it was typically felt by utilities that these suppliers would continue to take best-effort remedial action when necessary, and nothing more precise than a "rule of reason" could be stipulated in advance.

It is difficult to measure the overall impact upon the power supply market of turnkey pricing. As a rough indication, recognizing that several other factors were also relevant, one may consider the percentage of 1963 – mid-1966 commitments made on a turnkey basis. By Table X-17, it can be seen that well over half of the megawattage committed during the 1963 – mid-1966 interval, some 55%, was placed on a turnkey basis.

As described above, it is clear that turnkey commitments had a tangible monetary value to utility buyers; it is difficult, however, to quantify this factor because the main variables are the actual construction cost experience, which has not yet been completely incurred for plants above 800 Mwe, and the administrative economies of delegating project responsibility to the turnkey supplier, which hinge upon the cost and depth of the utility's own staff. In the case of one utility contacted, a detailed comparison of turnkey and non-turnkey bids had been prepared, and was made available. This admittedly covers the experience of one somewhat unique utility, but it is a useful and informed illustration; the detail is given in Table X-18. To protect the confidentiality of the information, the figures shown are based upon a turnkey project cost of "100 units." It can be seen that of the total project cost variance between the two bids of 18 units, half is accounted for by the project overhead variance of 9 units; in turn, most of the project overhead variance is accounted for by the engineering staff variance. This engineering staff variance translates to a dollar figure considerably above $10 M, and is, therefore, of absolute as well as marginal importance in the evaluation. It could be argued that the variance is not a legitimate one, since in-house technical staff costs are typically not variable on a project-by-project basis. This might be true in cost accounting theory, but it appears that the utility in question was (and

TABLE X-17

TURNKEY[a] VS. NON-TURNKEY PROJECTS, 1963-1966

Project/Unit Name		Net Mwe
Connecticut Yankee		462
San Onofre		450
Nine Mile Point		600
Oyster Creek	Turnkey	640
Dresden No. 2	Turnkey	809
R. E. Ginna	Turnkey	470
Pilgrim		687
Millstone Point No. 1	Turnkey	652
Turkey Point No. 3		760
Turkey Point No. 4		760
Indian Point No. 2	Turnkey	1,033
Dresden No. 3	Turnkey	809
Point Beach No. 1	Turnkey	497
Point Beach No. 2	Turnkey	497
H. B. Robinson No. 2	Turnkey	700
Palisades No. 1		821
Monticello	Turnkey	545
Quad Cities No. 1	Turnkey	809
Quad Cities No. 2	Turnkey	809
Browns Ferry No. 1		1,152
Browns Ferry No. 2		1,152
Total Turnkey Mwe		8,305
Total Project Mwe		15,114
Turnkey Mwe/Total Mwe		55%

[a]All Turnkey designations were verified with the suppliers; many of the Turnkey projects were substantially on a no-escalation, broad supply-scope basis.

TABLE X-18

COMPARISON OF SELECTED COST COMPONENTS, TURNKEY VS. NON-TURNKEY BIDS

	Turnkey Bid	Non-Turnkey Bid
Total Project Cost	100[a]	118
Power Plant	82	89
NSSS	21	22.5
Project Overhead	14.0	23.0
Interest on Construction	8.5	8.8
General Administration	.6	1.2
Engineering Staff	4.9	13.0

[a]All dollar amounts have been normalized to a turnkey project cost of "100 units."

still is) engaged in a rapid expansion of capacity, as were most other utility respondents; under these circumstances, the assumption of engineering responsibility by the NSSS supplier released the utility's staff for other high-priority projects and for specialized instruction. The variance appeared as a real one to the utility, which is ultimately the best judge of the opportunity cost of its staff time.

With several reservations in mind, centering around the uniqueness of an individual utility's own staff costs and its perceptions of these costs, the quantified turnkey advantage is revealing when it is put in the context of fossil/nuclear price differentials. Assuming that the turnkey advantage is $10/kw, which is perhaps conservative in view of probably sharp construction labor cost escalation and technical difficulties which turnkey suppliers may encounter, its potential effect upon a nuclear/fossil comparison can be seen in Figure X-18. The data represent actual bids received by a single utility, evaluated by the staff and translated to an "expected ultimate cost: $/kw"; the four projects, two fossil and two nuclear, represent four separate sites evaluated over a period of 18 months. For "fossil-1," the dotted arrow represents an uncertain penalty superimposed upon the project cost figure for unallocated use of unit train facilities; the solid arrow extending above "fossil-2" represents an estimate for unusual siting and environmental protection costs. The nuclear projects were quoted on a turnkey basis; the lines extending above them represent the assumed $10/kw turnkey advantage. Because of the proprietary nature of the data in Figure X-18, it is not possible to elaborate the capital cost ranges with the underlying assumptions, and adjustments for expected fuel costs. Consequently, the array can be taken as only a very general and simplified indication of the impact of turnkey bids upon a fossil/nuclear capital cost evaluation by a utility.

b. Attractive Prices

A factor of obvious efficacy in facilitating the arrival of nuclear energy was the quotation of "attractive" prices for nuclear power plants. The two most discussed instances appear to have been the Oyster Creek and Browns Ferry awards. With some remonstrations from the supplier in question, it seems to be the prevailing view that the capital costs announced for these two projects at stretch capacity, $104 and $116 respectively, were not reflective of the general price levels anticipated by suppliers for the majority of their placements. The uniqueness of the prices covering these awards need not be argued lengthily: the price on a virtually identical Browns Ferry follow-on unit, No. 3, rose to $130-135/kw in an interval of less than one year, an increase of almost 15%; for the nuclear steam supply system alone, it appears that the quoted prices rose by some 30%. In another instance discussed by a utility respondent in some detail, an initial turnkey placement was made at $105/kw; some 18 months later, an identical follow-on unit bid by the original supplier for the same site on a turnkey basis, priced out at $160/kw, an increase of well over 50%.

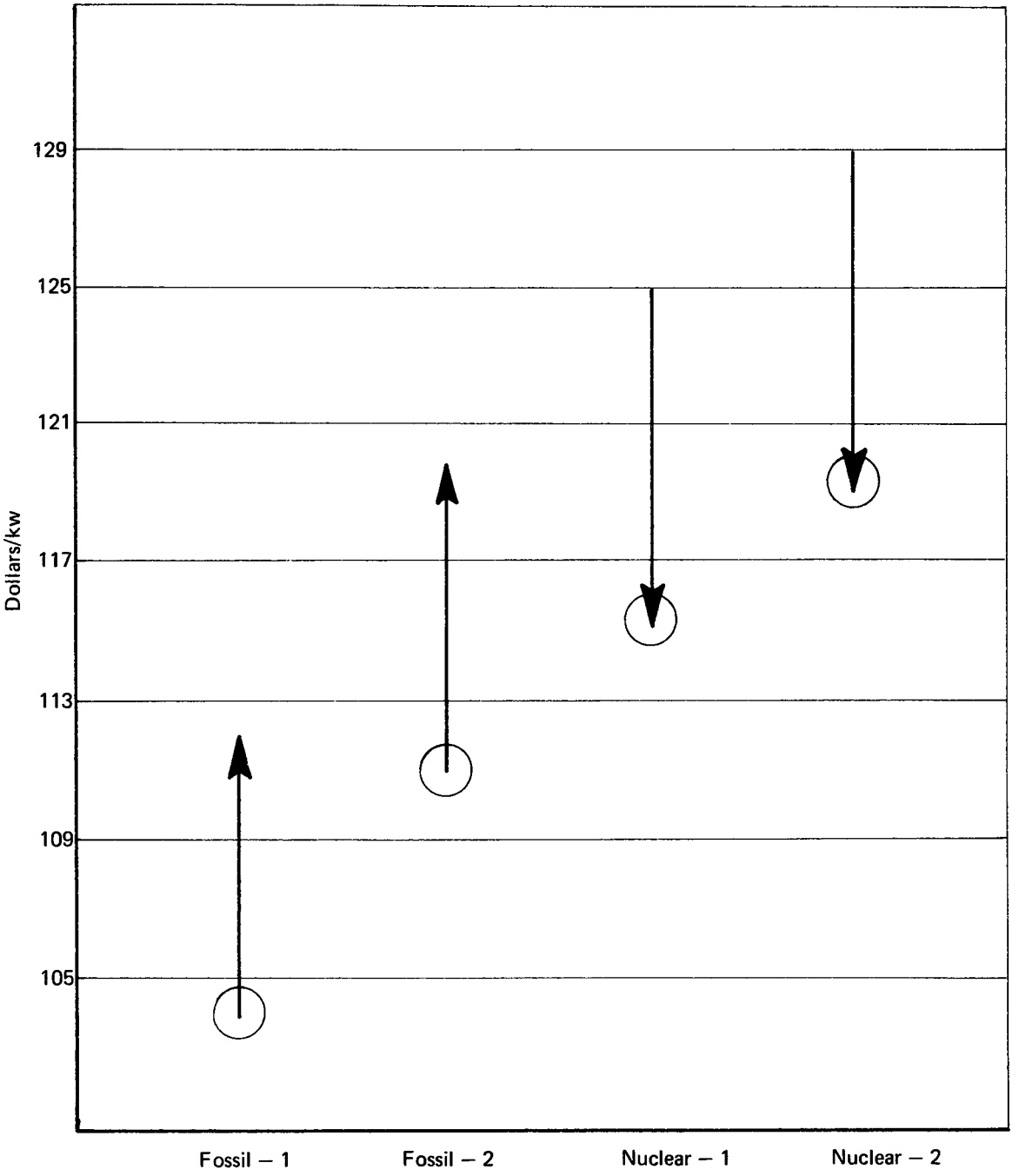


FIGURE X–18 IMPACT OF TURNKEY BIDS

Concurrent with this follow-on bid at $160/kw, the supplier in question submitted to another large utility a proposal with capital costs of $145/kw; other bids received ranged between $145/kw and $155/kw. The difference between the $160/kw bid and the $145/kw bid may reflect differences in site and equipment specifications; the size specification for the two bids, however, was virtually identical.

Admittedly, the escalation from $105/kw to the $145-160/kw range, for a particular unit size, may have been caused by factors other than a simple NSSS price movement. Nonetheless, with evidence of current capital costs in the range of $145/kw to $160/kw, it is clear that the attractively-priced offerings such as the Oyster Creek and Browns Ferry awards, quoted well below $120/kw, are simply not available today, whatever the reason for the intervening price escalation. Consequently, from today's perspective the Oyster Creek and Browns Ferry awards can be properly described as uniquely and attractively priced.

The significance of attractive price levels during the 1963-mid-1966 era is twofold. The most obvious effect was the public impact of an "epochal" commitment such as Oyster Creek, and the "defeat of coal in its own backyard" through Browns Ferry. Of equal importance, these commitments represented a sizeable percentage of the 1963-mid-1966 placements. If the Nine Mile Point award, also "advantageously priced," is added to the other two mentioned above, it appears that almost one fourth of the placements, roughly 23% of total megawattage, were the beneficiaries of attractive price levels.

c. High Fossil Fuel Cost Utilities

Several commentators have identified in the pattern of early nuclear placements a prevalence of awards among utilities with relatively high fossil fuel costs. With the exception of the Browns Ferry commitment, it is not surprising to find that the apparent supplier strategy was to confront competing energy sources in areas where they were most vulnerable; in this context, the Browns Ferry commitment takes on the appearance of a temporary excursion, rather than a firm precedent.

Borrowing from a display technique devised by Mr. John Hogerton, the major placements of the 1963-mid-1966 period have been arrayed in Figure X-19. For each of 16 utility nuclear commitments, the range of fossil fuel costs for the utilities' three most efficient plants has been plotted; mine-mouth plants have been excluded as unrepresentative of generally-available fossil alternatives. The fossil fuel costs have been drawn from the National Coal Association's "Steam-Electric Plant Factors, 1965"; they represent the cost of coal, F.O.B. plant. Two

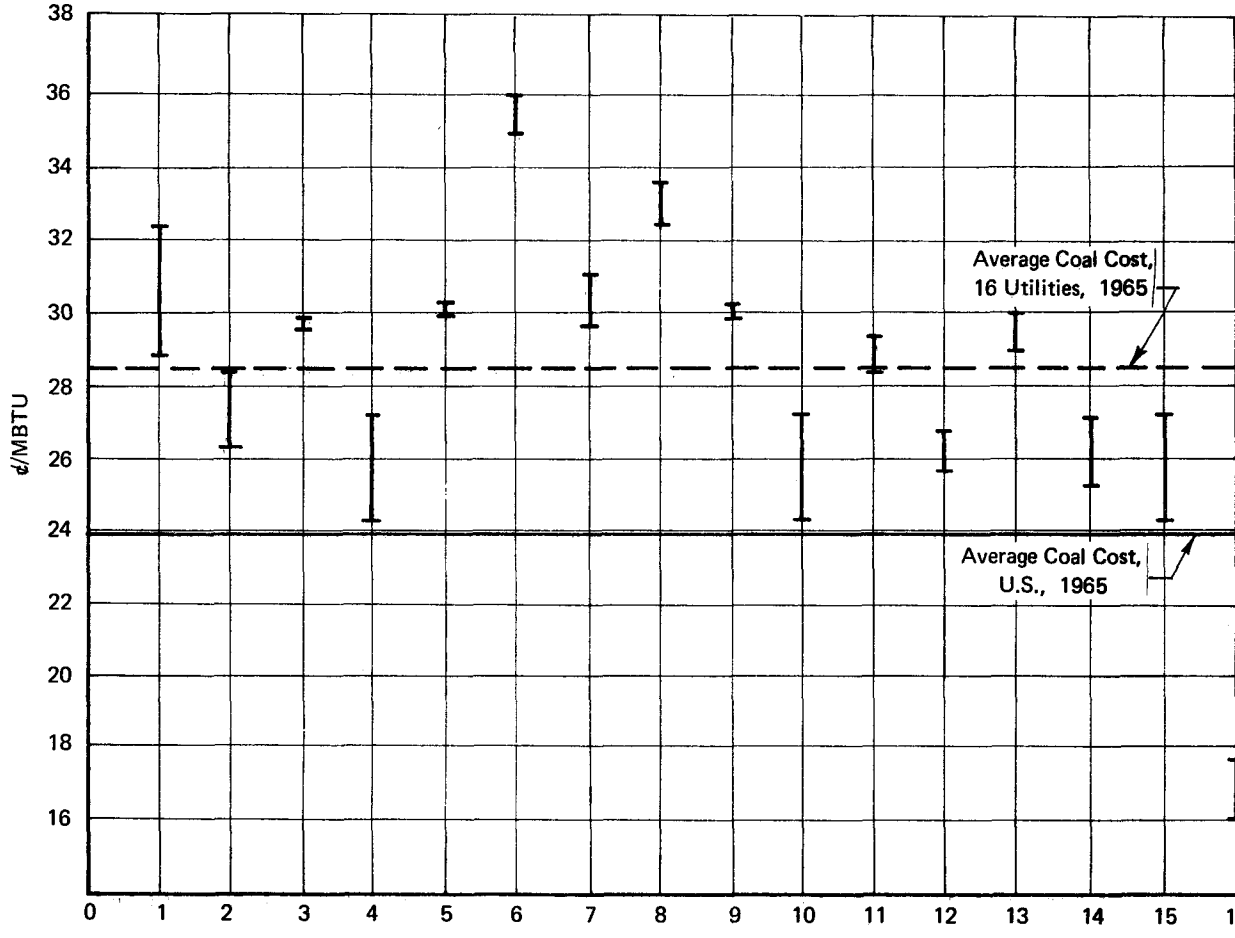


FIGURE X–19 SIXTEEN NUCLEAR AWARDS PLACED DURING 1963 – 1966; ARRAYED BY FOSSIL FUEL COSTS OF UTILITY BUYERS

lines have been drawn across the array: the solid line represents the cost of coal, F.O.B. plant, for all power plants in the contiguous United States as a whole; the dotted line represents the average cost of coal for the buyer utilities arrayed.

From Figure X-19, as might be expected, it is clear that virtually all placements were made among utilities with coal costs well above the national average. From a different perspective, assuming that an aggregation of 16 awards would average out the errors of estimates, unreliability, or uniqueness of any individual award, it appears that nuclear energy was competing successfully with "28 cent coal," with an average unit size placed of roughly 700 Mwe. This confirms the view of such observers as Mr. Philip Sporn, who, in written testimony to the JCAE in late 1967, stated that "the Oyster Creek plant and similar plants following might actually be competitive with coal prices at about 27 cents per million British thermal units, plus or minus 2 cents." A contrary view by a supplier, to the effect that a reactor in the 600 Mwe range can be competitive with "coal at 23 cents," does not seem to be substantiated by the average fossil fuel cost circumstances of the early phase utility buyers.

d. Backlog of Nuclear Experience

While turnkey prices served as one method for facilitating credible nuclear/fossil comparisons, the backlog of nuclear experience was also an operative factor. If the definition of "nuclear experience" is limited to major involvement through the PDR program, or privately-financed experimental projects, by these criteria it appears that more than 57% of the megawattage committed between the Connecticut Yankee and Browns Ferry awards came from utilities with prior experience. Utility respondents emphasized the vital importance of this early involvement in facilitating their eventual commitments. Most importantly, perhaps, the prior experience meant that major utilities had on their staffs individuals with nuclear expertise and motivation; their sponsorship and advocacy of the eventual commercial commitments to nuclear energy were considerably more credible within their organizations than similar recommendations from outsiders, even with the alleged impartiality of a consultant or an architect-engineer.

Every one of the awards made during the 1963-mid-1966 period was affected by at least one of the four factors cited above: 55% of placements were on a turnkey basis; 23% of placements were attractively priced; 85% of placements were among high fossil fuel cost utilities; and 57% of placements were among utilities with prior nuclear experience. The two factors most readily within the pricing discretion of suppliers, turnkey bids and attractive prices, were operative for almost 75% of the capacity awarded during the interval.

2. Preparation of Bid Specifications

a. General Specification Parameters

In a matter as complex as the purchase of a large nuclear steam supply system, the preparation of bid specifications is typically an elaborate and lengthy task. The characteristics of the supplier's standard offering must be matched to the utility's circumstances, a highly unique combination of system geography, plant site environment, operating practices, and local regulatory philosophy. Among the many relevant technical parameters that have to be considered by a utility in the evaluation of bids, a few major ones have been repeatedly cited by utility respondents. These parameters, summarized below, are typically the subject of extensive supplier-utility discussions before the drafting of specifications, and are frequently incorporated into the formal bid specifications as functional requirements, quantified where appropriate as an acceptable range of performance or a single performance figure:

- Guaranteed rating expressed in thermal or electrical megawattage, with a plus/minus allowance; or expressed in terms of steam delivery at specific conditions of temperature, pressure and moisture; a series of alternate ratings may be included.

- Scope of equipment and services supply, typically including:

  -- Reactor vessel;
  -- Reactor internals; excluding fuel, but including neutron sources and internal instrumentation;
  -- Control rod drives and auxiliary drive mechanisms;
  -- Coolant or recirculation system;
  -- Auxiliary reactor systems, including devices for supplementary reactivity control, coolant chemistry control, and water level control.

- Schedule of payments and delivery; terms for contract extension, suspension and termination.

- Terms of price escalation, including the selection and weighting of escalation formulas, with allocation of exposure between supplier and utility.

- Warranty terms and scope; remedies and methods for settlement; penalty and bonus clauses for variations around a warranted level.

- Licensing responsibility, including allocation of exposure between supplier and utility for unforeseeable licensing-induced plant modifications.

- Safety margin requirements.

- Balance-of-plant criteria.

- Educational services to be provided to utility staff by supplier.

- Miscellaneous legal: patent indemnity, insurance, taxes, title transfer.

These ten parameters represent only the most obvious considerations; in actuality, the specification document is frequently much more extensive. Table X-19 shows the Table of Contents of a specification document soliciting bids for an 800 Mwe NSSS.

b. Unit Size Specification

The detail concerning the specification writing process is overwhelming, and not immediately relevant to a consideration of competition in the nuclear power supply market. One facet, however, the preparation of the unit size specification, is of some interest because of its impact upon second-tier suppliers. It appears that two sets of factors, one pertaining to the utility industry and the other to the major NSSS suppliers, have operated in mutually-supporting fashion to push up the size of nuclear units on the market.

3. Utility Factors

Several utility respondents indicated that around 1964-1966 they readjusted their load growth forecasts substantially upward. The causes for this revision are widely discussed throughout the industry, and need only be mentioned: the cumulative momentum of the economic boom of the early and middle sixties, the public impact of the 1965 blackout and subsequent brownouts, and the drop in generating reserve margins which occurred between 1964 and 1966. One of the major utilities interviewed, for example, stated that between December, 1963, and July, 1966, it raised its growth forecasts from 7.0 to 7.24%, then 7.38%, and finally 7.5%; the impact upon their facility planning was "substantial." The general effect upon large utilities was to raise the size specification for units about to be committed to meet the growing generation requirements, and the revised (post blackout) margin criteria. At the same time, of course, some accelerated or pre-emptive buying started to materialize.

TABLE X-19

TABLE OF CONTENTS; SPECIFICATIONS FOR AN 800 Mwe NSSS

Section	Contents
I	INVITATION FOR BIDS
II	INSTRUCTIONS TO BIDDERS
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	Withdrawal or Modification of Bids
	Form of Bid and Manner of Submission
	Examination of Invitation and Explanation to Bidders
	Qualification of Bidders
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	Bidding Schedules
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V	GENERAL CONDITIONS
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	Passing of Title
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	Packing and Shipping
	Inspection and Expediting
	Shop Tests
	Notice, Permits and Applicable Statutes and Regulations
	Patent Indemnity
	No Waiver
	Prohibition Against Assignments

TABLE X-19 (Continued)

Section	Contents
	Indemnity
	Right to Operate Unsatisfactory Equipment
	Final Examination and Acceptance
VI	SPECIAL CONDITIONS
	Scope of Work
	Guaranties
	Terms of Payment
	Escalation
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VII	NUCLEAR STEAM SUPPLY SYSTEM TECHNICAL PROVISIONS
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	Division of Responsibility for Pressurized Water Reactor – Nuclear Steam Supply System
	Pressurized Water Reactor – Nuclear Steam Supply System
	Division of Responsibility for Boiling Water Reactor – Nuclear Steam Supply System
	Boiling Water Reactor – Nuclear Steam Supply System

As a veritable stampede got underway, a sharp escalation in the average size of units purchased manifested itself. Table X-20 illustrates this: for the "nuclear" utilities, those that made nuclear commitments by 1967, the average size of unit ordered, whether fossil or nuclear, rose noticeably between 1965 and 1966. During this interval, it appears that nuclear suppliers were beginning to concentrate their offerings around three roughly standardized sizes: 500 Mwe, 800 Mwe, and 1100 Mwe. It might seem that the gap between the 500 Mwe and 800 Mwe offerings was too broad, since it represented an increase of 60% from the 500 Mwe base which in 1965 was clearly above the historical fossil unit size average; even with the upward revision of load growth, a 60% increase appears formidable.

Nonetheless, several utility respondents indicated that while their aggregate system size and the traditional size unit purchased might militate against acceptance of unit-size escalation, a combination of three circumstances made acceptance feasible, and even desirable:

- Scale economies, reflected in $/kw advantage, for the larger nuclear units over smaller units;

- Reluctance of major suppliers to respond to awkward size specifications in the intermediate ranges;

- Rapid growth of interconnections, whereby the excess capacity can be firmly committed to other systems.

Less explicitly, perhaps, another factor within utility management discretion facilitated the acceptance of size escalation: the load factor assumption pertaining to the proposed nuclear unit. The general practice seems to have been one of treating the nuclear unit as a base-load plant, with load factors between 70-90%, reflecting the initial ten year operating profile. Some observers have criticized this procedure, suggesting that a system-wide load factor should be used instead; a few assert that "there is no such thing as a base-load plant." The point is moot, since the utility evaluations proceed under a high load-factor assumption. Whether legitimately or otherwise, this does indeed favor large-sized nuclear units for obvious reasons:

- The greater capital intensity of nuclear units over fossil units;

- The scale economies, already cited, which are realized in larger units over small ones, under heavy load.

4. Supplier Influences

While the utilities were generally predisposed to larger unit sizes for the reasons described above, it appears that the two major NSSS suppliers were also

TABLE X-20

ESCALATION IN FOSSIL AND NUCLEAR POWER PLANT UNIT SIZES, 1963 - 1967[a]

Year of Order	Average Size of Unit (Mwe)		Combined Fossil/Nuclear Unit Average
	Fossil[b]	Nuclear	
1963	383	477	402
1964	430	---	430
1965	375	529	426
1966	582	791	708
1967	490	807	710

[a]These units represent the commitments of those utilities which during the 1963-1967 era bought LWR units in sizes above 400 Mwe.

[b]Fossil units rated beneath 100 Mwe have been excluded, since these were typically committed for standby or peak applications.

active in promoting their large units. Several utility respondents have mentioned that as they discussed their size specifications with prospective suppliers, before issuing the formal request-for-proposal, the two major suppliers tended to emphasize the performance and desirability of their largest offerings, which incorporated their latest advances. Several utility respondents, in describing mid-1966-1967 bidding rounds under specifications above 1000 Mwe, made it clear that the specified size necessarily restricted the number of qualified bidders to two.

5. Utility/Architect-Engineer Relations

A separate section of this report addresses the topic of architect-engineers and engineer-constructors in terms of product/market definition, number of firms and market share, barriers to entry, and performance. From the different perspective of this section, that of the utilities which have made nuclear commitments, what emerges from a review of utility practices is a general pattern of concentrated sourcing of architect-engineer services from a few firms.

Rather than retrace the pattern of architect-engineer services for nuclear plant evaluations, described elsewhere, it appears more useful to consider instead the pattern of architect-engineer/utility relations for fossil plant evaluations. While the fossil and nuclear practices are not necessarily analogous, the accumulated patterns and traditions of architect-engineer participation in fossil plant evaluations may serve as rough indicators of what might ultimately emerge in nuclear plant evaluations. Moreover, the extrapolation of future trends from the history of nuclear evaluations alone is hazardous, since the data only stretch back five years, and cover roughly 55 awards; with the use of fossil evaluations as admittedly-imperfect analogues, some 16 years of activity covering hundreds of awards can be drawn upon.

Table X-21 describes the pattern of architect-engineer services, as sourced by a highly distinct group of utilities. This group has been assembled from the general universe of utilities that have made nuclear commitments; among these, the utilities that had a long history of numerous fossil plant awards over the interval 1963-1967 have been identified and arrayed in Table X-21. This group of 16 major utilities is a highly significant segment of the "nuclear" utility universe, since the group accounts for roughly 45% of the nuclear megawattage committed between 1963 and 1967. Furthermore, of the total megawattage awarded, some 12-15% did not require extensive architect-engineer services because the utility in question did substantially all of the architect-engineer work through its own staff; removing this megawattage, as inherently not on the architect-engineer market, the 16 utilities of Table X-21 account for over half of the remaining nuclear megawattage.

From the data in Table X-21, it can be seen that eight of the 16 utilities relied exclusively upon a single architect-engineer firm for their fossil evaluations;

TABLE X-21

FOSSIL PLANT EVALUATION FOR 16 MAJOR UTILITIES[a] -- CONCENTRATION OF Mwe AMONG PRIME A/E, 1953 - 1967

Number of Utilities	% of Fossil Mwe Handled by Utility's Prime A/E	Total Fossil Mwe Awarded
8	100	12,637
2	99-90	10,116
2	89-75	11,091
3	74-60	6,573
1	50	650
16		41,067

[a]These 16 utilities comprise roughly half of the 30 utilities or consortia which made nuclear commitments during the 1963-1967 interval.

another four gave at least 75% of the fossil evaluation work to a single firm. Altogether, of roughly 41,000 fossil Mwe considered, over 80% was placed by utilities which relied exclusively or substantially upon a single architect-engineer firm over a 16-year interval.

As several utility respondents have pointed out, the sourcing of architect-engineer services is a highly complex matter. It cannot be intelligently resolved on the basis of a bidding procedure, project by project, any more than the placement of contracts for outside legal services could be based upon a recurring bidding procedure. The long-term advantages of using the most competent professional help, and building effective working relationships between internal and external technical specialists are undeniable to those who appreciate the complexity of evaluating power plant bids, and supervising their construction. One of the utilities among those in Table X-21, for example, has had an agency agreement for over 30 years with an architect-engineer firm, whereby the firm has participated continuously, automatically, and exclusively in all of the utility's major fossil awards.

While a concentrated pattern of utility/architect-engineer relations may be inherent, or even necessary, given the complexity of the tasks jointly undertaken, a question frequently arises about the effect of architect-engineers strategically close to major utilities, upon the pattern of equipment awards; implicitly, of course, there is a hypothesis about architect-engineer preference for, or reliance upon, a single equipment supplier.

A review of fossil plant awards between 1963 and 1967 has been made, to determine whether accumulation of awards over several years, arrayed by architect-engineer participants, would reveal any pattern of unusual preference. Table X-22 is a compilation of all the fossil awards by major utilities, whether "nuclear" or "non-nuclear," 1963-1967; these awards have been traced to the participant architect-engineer, with the nine largest firms arrayed; for each architect-engineer firm, the total megawattage evaluated has been distributed by steam-supply system manufacturer.

The presence of two dominant steam-system suppliers is clear, but this is the result of several market factors which go far beyond architect-engineer preferences. Rather than a measure of supplier market share, the relevant test of architect-engineer influence is the variation between the supplier market share arrayed by individual architect-engineers, and the overall supplier market share; moreover, since a hypothesis of "undue" preference for particular suppliers is being tested, the variation traceable to architect engineer influence should be in the direction of substantial concentration of awards to a particular equipment supplier. A valid and rigorous definition of "substantial concentration" will not

TABLE X-22

MARKET SHARE OF FOSSIL STEAM-SYSTEM SUPPLIERS, FOR AWARDS[a] EVALUATED BY NINE MAJOR ARCHITECT-ENGINEER FIRMS, 1953 - 1967

A/E Firm	% Mwe Share of Fossil Steam-System Suppliers			
	A	B	C	D
#1	38	47	3	10
#2	55	38	5	--
#3	59	40	--	--
#4	23	36	16	23
#5	35	24	18	22
#6	69	9	4	16
#7	15	64	10	9
#8	42	42	13	1
#9	58	28	9	3
TOTAL	44	33	11	11

[a]The data cover evaluations performed by each A/E for all of its major utility customers, whether "nuclear" or "non-nuclear" utilities.

be attempted here, since the overall market pattern is a highly concentrated one. It can only be suggested that in the overall context of a quasi-duopoly, with three instances of architect-engineer concentration figures above 60%, there does not seem to be evidence to support the hypothesis of "undue" preference.

6. Bid Evaluation Schedule

Figure X-20 illustrates the typical sequence of events in proceeding from bid solicitation to the commercial operation of a 1000 Mwe nuclear power plant. Although individual projects may vary somewhat from the indicated schedule, the elapsed times indicated in Figure X-20 are adequate rough measures of typical projects. The importance of the "bid evaluation and negotiation" phase is obvious; by Figure X-20, it can be seen that this phase typically precedes by two years the beginning of work, and precedes by nearly six years the major functional reactor tests. Consequently, the uncertainties and approximations in the evaluation are considerable.

By the Figure X-20 timetable, the evaluation phase takes four months. Utility respondents generally consider this a tight schedule; while they have usually had prior familiarity with the bidders offerings, and preliminary discussions about technical performance, the process of normalizing several bids to a uniform base, and adapting the bids to the utility's specific operating circumstances, is a very complex one. The four month evaluation interval, therefore, has been frequently described as "barely adequate."

In this situation of tight early-phase scheduling, the actual experience of several utilities is of interest because in these instances the four month interval has been compressed. Figure X-21 arrays the bid evaluation scheduling experience of 11 utilities, covering 13 reactor awards during 1965-1967. For each award, a line has been drawn indicating elapsed time between formal submission of all bids, and a firm utility decision to award; the end-point is the date of the utility's decision rather than the date of award announcement, because the announcement frequently lags the decision. Special notation has been used to describe follow-on units, i.e. reactors substantially identical to previously-bought reactors, installed in an existing nuclear station; optioned units are similar to follow-on units, with the added feature of an option price-in-effect for a stated interval.

Follow-on and option awards have been identified separately because the evaluation process benefits from the prior evaluation of a substantially-identical reactor, and the evaluation can therefore be accelerated. Even with this refinement, however, it appears that for several awards, the evaluation phase was a drastically short one. Under these circumstances, such intangibles as bidder reputation, previous experience with the bidder, and ability of the bidder to meet unforeseen contingencies, become especially important.

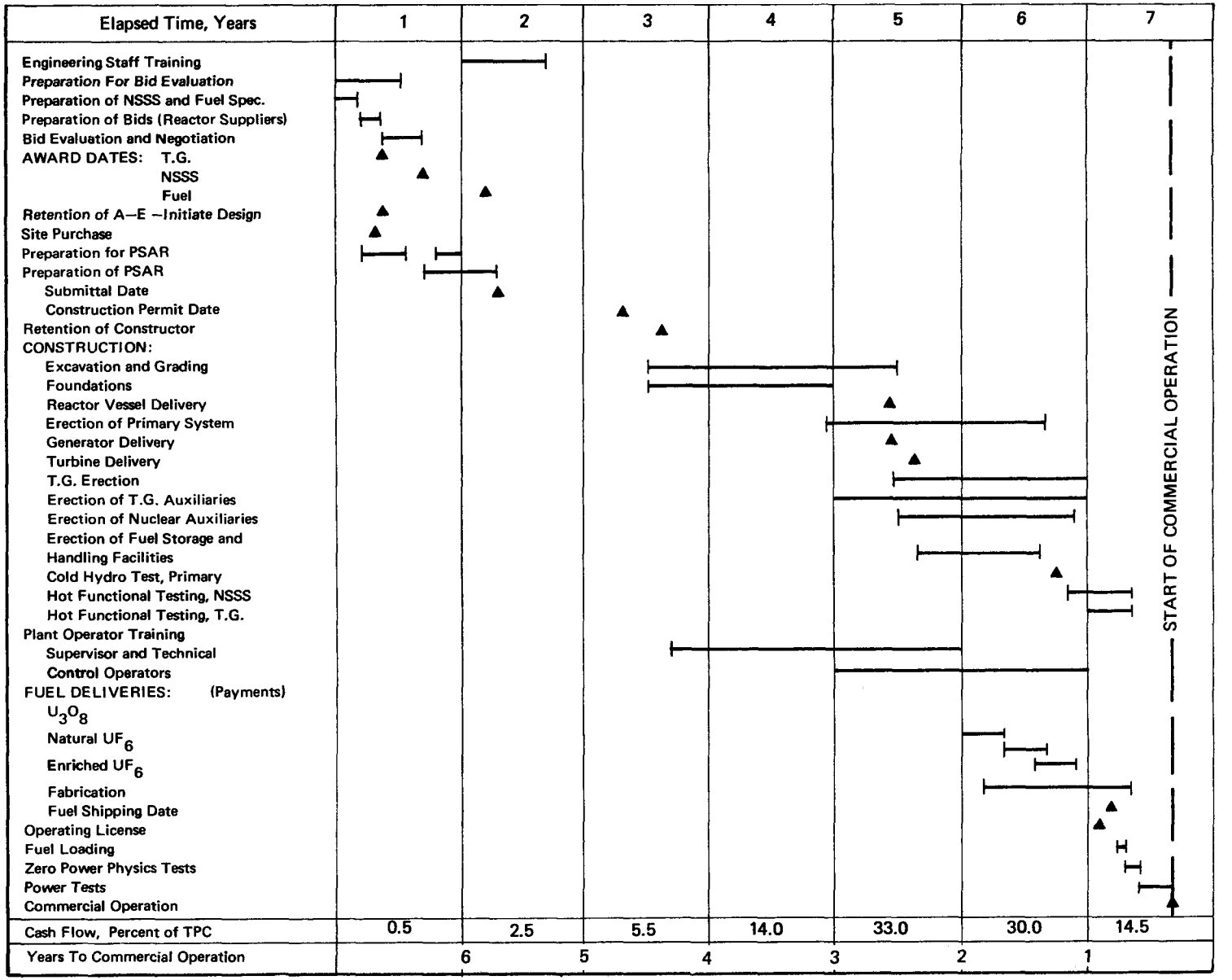
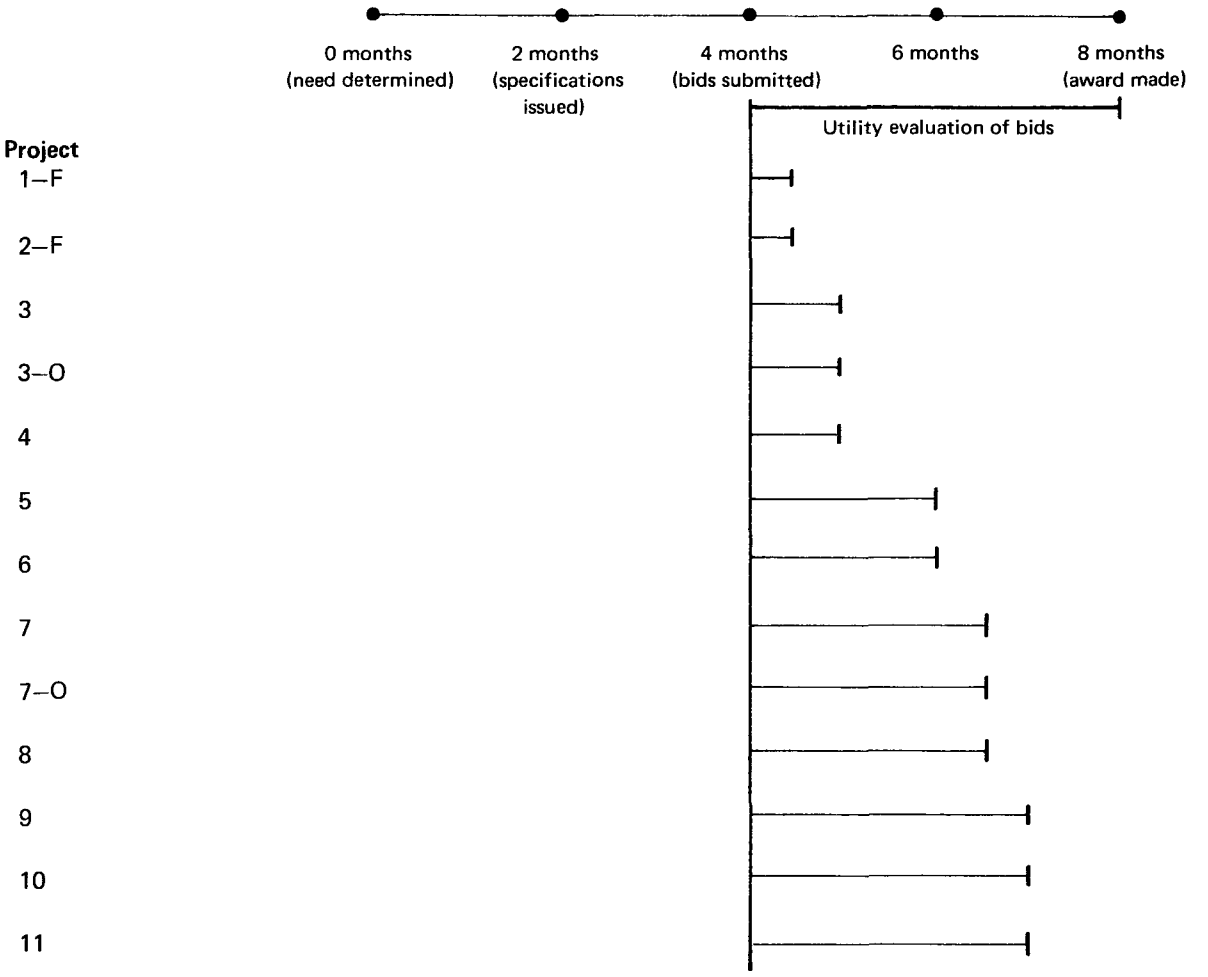


FIGURE X–20 PROJECT SCHEDULE FOR 1000 Mwe NUCLEAR POWER PLANT



Note: The suffix "F" denotes a follow-on unit for a multi-unit station. The suffix "O" denotes an option which the utility has received, contingent upon a firm award made during the indicated interval.

FIGURE X–21 LENGTH OF BID EVALUATION PERIOD, THIRTEEN NUCLEAR PLANT AWARDS

Some respondents have indicated that a major factor in compressing the bid evaluation interval was the need to secure a timely turbine-generator delivery date. To the extent that this was a factor during 1965-1967, it will probably ease in the near future: a considerable amount of the capacity awarded during 1965-1967 was placed "pre-emptively," for delivery beyond the normal five year waiting interval; thus, the pre-emptive awards of 1965-1967 should diminish future awards.

7. Major Bid Evaluation Parameters

Previous sections have described the pattern of nuclear fuel commitments, and the price competitiveness of fossil and nuclear energy. These are clearly dominant considerations in a utility's evaluation of bids. Residually, there are some other considerations which are also influential, and have been mentioned frequently by utility respondents: warranties, disclosure, and price escalation.

a. Warranties

The major warranties concerning a nuclear power supply system pertain to full-power operation and fuel performance. The full-power operation warranty appears to be a standard offering of 100 hours at stipulated operating levels. Most of the utility respondents indicated that there is no appreciable difference among suppliers in this matter, and that the warranty is satisfactory to them as currently offered.

Fuel warranties, on the other hand, are a much more complex matter. They can vary considerably, depending upon (among other things) the scope of the fuel commitment made: a commitment for fabrication services only, for example, could be warranted by the supplier for the mechanical integrity of the fabrication process, but would not necessarily be warranted for the price or performance of the contained uranium, since these would typically lie beyond the supplier's scope of responsibility.[1] To simplify the analysis, it will be assumed here that a commitment has been made for "fuel services," whereby the supplier is responsible for the delivery of contained uranium. Under these circumstances, there are two general types of fuel warranty, one covering mechanical integrity, the other covering performance. The mechanical integrity warranty is not a matter of great dispute: in simple terms, it is usually no more than a warranty of good workmanship. The performance warranty, however, applies to the heat properties of the

1. G.E. is an apparent exception to this, since it has been customary for them to warrant the energy output of the fuel under a "fabrication scope" of fuel supply. However, G.E. does not bid on a "fabrication services only" scope which excludes design responsibility. Hence, under the "fabrication services only" scope, with no supplier responsibility for design, it is the general case that only a mechanical integrity warranty is written.

fuel in the reactor as ultimately evidenced by the measure of "thermal megawatt days/ton of fuel." In this case, buyer and seller are trying to agree on a reasonable expected level of performance from a system which has perhaps never been operated before in the envisaged size, with factor costs subject to considerable uncertainty.

From the utilities interviewed, it appears that three different solutions to the performance warranty problem are emerging: a warranty expressed in terms of thermal power output, with maximum or complete risk upon the supplier; a warranty expressed in terms of a formula, with an allocation of risky variables between buyer and supplier; and no performance warranty at all.

Concerning the first solution, maximum risk upon the supplier, it seems that utilities now recognize the considerable hidden costs of such an arrangement: the supplier in legitimate self-protection against risk may either underwarrant, or adjust his price to reflect the risk of high warranty; some suppliers may also insist upon a bonus for performance above a stipulated level. More basically, if the supplier is bound by a performance warranty he will probably insist upon a voice in the fuel management of the unit, for which he has financial responsibility. His prime interest of meeting the performance target through *unit* management may be at variance with the utility's *system* management philosophy.

The second solution, allocation of risk, attenuates somewhat the undesirable features of the first solution, but does not remove them completely. To the extent that significant risk remains upon the supplier, his price and warranty level will reflect this risk, and he will retain an interest in the unit's management, possibly at odds with the interests of the utility. Moreover, the complexity and detail of the formulas may be a source of disagreement rather than clarification.

The third solution, no performance warranty, may be indicative of future developments: General Electric in the spring of 1968 announced a simplification of its warranty provisions, eliminating the "target fuel warranty" concept along with its performance formulas, and bonus provisions. Furthermore, spokesmen for some of the major utilities have indicated publicly their preference for minimal warranties, such as mechanical integrity.

A further complexity in the matter of fuel performance warranties is emerging, as the prospect materializes of buying replacement fuel from someone other than the original core supplier. In this case, a fuel "foreign" to the fuel originally in the reactor is inserted; the issue, then, is whether the performance of the original fuel is affected by foreign fuels, and how the warranty should be adjusted. Not surprisingly, the general position taken by the utilities is that if the foreign fuel is sourced from a reputable supplier, and properly specified, the

performance of the original fuel will not be materially affected; conversely, suppliers tend to suggest that their core performances are highly proprietary, and vulnerable to the introduction of foreign fuel.

One compromise solution cited by respondents provides for tight specifications on foreign fuel, and the retention of the original core performance warranty until more than half of the fuel assemblies in the core are from a foreign source. It is more probable, however, that as the practice of giving performance warranties subsides, the issue of foreign fuel effect will become moot.

b. Disclosure

There is a separate issue, which is increasingly affecting the negotiating fuel commitments, concerning the disclosure of information from supplier to buyer. As in the case of fuel performance warranties, this issue applies primarily to utilities which have committed for fuel services. Under these circumstances, there are two general kinds of relevant information: data on the core assembly, including configuration, dimensions and tolerances; and data on the core's performance, including the fuel code and the accumulated physics data from core performance.

While some of this information is automatically made available to the utility, suppliers may treat other information as proprietary. Yet unless there is rather complete information on the core's physical characteristics, its physics and its history, it may be very difficult for the utility to secure a replacement fuel bid at a competitive price from another supplier; this supplier, in these circumstances, would have to try to derive the fuel code for himself, and might not have the advantage of the physics data reflecting the operations to date of the core. If he could bid at all, his price might be higher than that of the original core supplier, to reflect the necessary technical overhead. To illustrate the complexity of the required information, Table X-23 has been assembled: this represents the specific data needs of an independent fuel supplier, bidding replacement fuel to a utility.

There appears to be no standard utility practice in writing a disclosure specification. Some utility respondents indicated that they felt it necessary and prudent to put a specific, affirmative clause into the final contract, and that the wording of this clause was the subject of prolonged negotiating with the supplier. Other respondents felt that suppliers would cooperate to the fullest possible extent as a matter of "good business practice": some of these respondents recognized that a supplier would probably not volunteer something as proprietary as fuel code, but they thought they could make the derivation themselves, and solicit competitive replacement bids from other suppliers.

On balance, it seems that with a utility trend away from comprehensive fuel services commitments, and with a parallel trend away from fuel performance

TABLE X-23

REPLACEMENT FUEL BIDDING -- INFORMATION REQUIREMENTS

A. Core Composition

(1) Isotopic composition of all original supplier and reload fuel.

(2) Initial total mass of uranium (and plutonium) per cluster, batch, and whole core of original supplier fuel and any subsequent reload fuel.

(3) Fuel clad materials, nominal dimensions, volumes, and masses (or data from which these items can be calcaulated reliably).

(4) Coolant and moderator volumes.

(5) Shroud and fuel rod spacer materials and volumes.

(6) Control rod locations, control rod materials, dimensions and composition.

(7) Burnable poison location, composition, and masses, if any.

(8) Fixed shim locations, control material, dimensions and composition.

(9) Nature and composition of side and end reflectors.

(10) Fuel pellet diameter.

The above is required to permit determination of the nuclear characteristics of the fuel remaining in the core, and the nuclear characteristics of the control rods to be used in conjunction with the new fuel batches to be supplied. This information is not substantially different from that normally provided in Safety Analysis Reports submitted to the AEC.

B. Reactor Operating History
(including projections up to time of reload of proposed replacement fuel)

(1) Power level history.

(2) Control rod insertion

The control rod locations at all times of power operation are required to help determine burnup distributions.

(3) Soluble poison concentration at all times of power operation.

(4) Fuel management history.

Location of each fuel element used in the core during the whole history of power operation is required for calculating relative burnups.

(5) New core layout.

The fuel elements which will remain in the core will have to be identified and, if the utility is placing any restrictions on the layout of the reloaded core, these restrictions and the locations of the remaining fuel must be given.

(6) Alternate burnup information.

In lieu of (2) and (4) above, detailed documented burnup information for each fuel element which is to remain in the core at reload time would be acceptable. This information should consist of the measured or calculated axial distributions of exposure for each of the remaining fuel elements, and description of the methods used.

The above is required because of the influence of exposure distribution in the remaining fuel on power and exposure distribution of the new fuel.

C. Core Thermal-Hydraulics Information

BWR's

(1) Inlet and outlet plenum operating pressures and temperatures.

(2) Coolant flow rates at operating conditions (corresponding to Item C-1) in each type of fuel element which will remain in the core for shrouded elements. These data should be given for each orifice, if any, that is used on a given type fuel element.

(3) Flow rates and flow areas of moderator external to shrouded fuel elements are required.

(4) Any restrictions on orificing imposed by the utility should be specified.

(5) Coolant flow rate versus relative power in the remaining fuel elements is required.

(6) Primary flow rate history.

PWR's

(1) Pressure drop characteristics (pressure changes at operating flow rates) of the fuel assemblies remaining in the core.

(2) Flow areas within remaining fuel assemblies are required at lower and upper nozzle locations, at lower and upper grid plate locations, at spacer locations and at locations between spacers. Total coolant flow area in the core as well as coolant flow areas through thermal shields, entrance and exit plenums are also required.

(3) Primary system flow rates.

(4) Inlet and outlet operating mixed mean coolant temperatures.

The above information is required because of the influence of the above thermal hydraulic data on enthalpy distribution and hence thermal margins affecting core power capability.

D. Data Affecting Loss of Flow and Potential Startup Accidents

(1) Coolant pumps flow coast-down characteristics as supplied by pump manufacturer.

(2) Delay time between initiation of scram and control rod motion.

(3) Control rod drop velocity.

(4) Maximum rod withdrawal speed.

The above information is required to permit evaluation of the safety of the new fuel should the new fuel be sufficiently different from the remaining fuel to warrant a re-examination of loss of flow and startup accidents.

E. Mechanical Design Information

(1) Drawings of installed fuel.

As a minimum, data on envelope and alignment requirements which replacement fuel must meet are required. This should include external and internal requirements such as:

a. Upper and lower end fitting interface dimensions and tolerances.

b. Control rod channel detailed dimensioning.

c. Instrument channel dimensions and tolerances.

d. Proximity of thermocouple instrumentation, if applicable.

e. For cluster control type fuel assemblies;
   (1) Design of rod channel plug assembly.
   (2) Deceleration force required for design of control cluster stop pad on upper end fitting.

(2) Drawings of fuel element supports.

These data are required to insure that the replacement fuel assembly envelope and existing support fittings will be compatible.

(3) In-core instrumentation and lead locations.

Dimensional data are required on the in-core instrumentation leads and channels adjacent to the core to assess potential interference problems.

(4) Control rod drawings and locations.

Interface fits and clearances to insure that the replacement fuel is compatible with the control rod system. This information need not include proprietary data (see also paragraph A(6) above).

(5) Drawings of fuel handling tools.

Drawings of fuel handling tools to verify the compatibility of the replacement fuel end fitting design with existing handling tools.

F. Systems

(1) Water chemistry.

Operating limits of pH, O_2, H_2, Cl and total solids are required.

This is essential to determine the compatibility of the new fuel supplied with water chemistry practices normally employed in the plant.

(2) Reactor protection set points and related instrument errors.

G. Materials Information

(1) Full descriptions of materials exposed to primary coolant (pressure vessel, core supports, control rods, piping, primary coolant pumps, valves including seat materials, steam generator tubes and tube sheets) are required.

The purpose of the above is to insure compatibility of materials used in the replacement fuel with those existing in the reactor.

H. License Documents

(1) Complete safety analysis reports and other documents submitted to the AEC in justification of reactor safety are required.

warranties which put maximum risk upon the supplier, the utilities are accepting the primary role and responsibility in fuel cycle management. Consequently, they are moving toward a position of expertise, where hopefully disclosure constraints of suppliers can be overcome, and the necessary data derivations can be made economically. It is, nonetheless, worth noting that during 1965-1967, under the circumstances of a new and formidably complex technology, several utilities with very meager in-house nuclear expertise felt that an unwritten tradition of good business practices would protect their interests in the crucial area of fuel management.

c. Price Escalation

With the discontinuance of fixed-price bids, the subject of price escalation has become an important one. Table X-24 shows the formula allocation between labor and material indices, used in a major recent NSSS bid. It can be seen that in all cases, 10% of the NSSS price is firm; three of the four manufacturers tie well over half of the NSSS price, 55-60%, to labor indices which are generally viewed as more volatile than material indices.

Table X-25 shows the price escalation formulas for fuel, presented in the same bid described in Table X-24. Only two manufacturers are shown: the third manufacturer bid a fuel fabrication formula identical to that of manufacturer No. 2 in Table X-25; the enriched uranium was bid on a firm price basis. The fourth manufacturer bid the fabrication and enriched uranium on a firm price basis. Without knowledge of the base prices to which the formulas pertain, it is impossible to judge the relative attractiveness and rationale of the four price-escalation arrangements. Understandably, utilities seek to minimize the proportion of labor indices, because of the previously-mentioned view of greater volatility; manufacturers #1 and #2 are viewed as loading their formulas with disproportionate labor content. The detail of manufacturer #1's replacement fuel formula is welcomed, because two thirds of the price is tied to the price of separative work and U_3O_8; it is assumed that government policy in these areas will keep a ceiling on price.

Several utility respondents commented unfavorably on the practice of making fuel fabrication prices subject to escalation. Their objection stems from the belief that economies of scale will be realized by fuel fabricators, and that these benefits should be shared with utilities. These respondents recognize that some of the suppliers drop their prices for fabrication of replacement fuel ordered concurrently with original fuel; however, they feel that the price benefit should not be made contingent upon an original-and-replacement order: in their view, the scale benefits will flow, regardless of the date on which a contract was signed, if – as seems certain to them – annual fabrication activity increases sharply over the next several years.

TABLE X-24

PRICE ESCALATION FORMULAS FOR NSSS, 1967 BIDS

	Mfr. #1	Mfr. #2	Mfr. #3	Mfr. #4
Labor Index %	55	55	45	60
Material Index %	35	35	45	30

TABLE X-25

PRICE ESCALATION FORMULAS FOR NUCLEAR FUEL, 1967 BIDS

Mfr. #1	First Core	Replacement
Firm	7.0%	3.0%
Labor - Chemical	18.9%	8.9%
Labor - Electrical	17.5%	6.5%
WPI - Industrial	15.4%	7.1%
Steel Mill Products	11.2%	4.2%
Separation Work ($26/Kg Base)	30.0%	34.0%
U_3O_8 ($8/lb base)		36.3%
Mfr. #2	**All Cores**	
Fabrication		
Firm	10.0%	
Labor	60.0%	
Material	30.0%	
Enriched Uranium		
Firm	10.0%	
WPI - Industrial	50.0%	
Labor	30.0%	
Mater	10.0%	

C. GENERAL CHARACTERISTICS OF THE UTILITY PURCHASING PROCESS

In analyzing utility purchasing characteristics for nuclear power plants and fuel, some general characteristics of the utility purchasing process emerged either as topical issues or as forcefully-made contentions about the electric utility industry. It is unreasonable to attribute this full set of characteristics to any particular utility during a single purchase decision, particularly if the attribution is made as part of a general attack on the utility industry. Moreover, some of the imputed "characteristics" are in the nature of hypotheses held by groups external to the utility industry, with distinctly different perspectives, motivations and criteria.

It is not the purpose of this report to characterize definitively the general purchasing behavior of the electric utility industry. The following remarks, therefore, are made for the purpose of illustrating some current issues and contentions; determinations of right-and-wrong are beyond the intended scope of this discussion.

There are considerable industry and regulatory interest in the following areas:

- The utilities' process of accepting prospective suppliers as qualified bidders.
- The utilities' disclosure of bid information received, to other utilities, to regulatory bodies, and to the general public.
- The utilities' attitude toward foreign sources of supply.
- The utilities' incentives in purchasing major capital items in an economic manner.
- The past performance of the utilities as vigorous and knowledgeable buyers.

1. Supplier Qualification

The Federal Power Commission has recently intervened in the area of supplier qualification by utilities. The Commission's intended result, as reported in the financial press, is "widespread public notification" to a large number of potential bid respondents. Underlying this FPC concern, apparently, is a feeling that "some lists of prospective suppliers . . . appear to be unnecessarily restrictive."

The question of supplier qualification is a very complex one, even when considered on the narrowest technical grounds. Furthermore, the technical question can be compounded by other issues, ranging potentially from a utility view that vital management prerogatives are being interfered with, to a regulatory view that some purchasing events consist of nothing more than oral negotiations with a single prospective supplier. Under these circumstances, the derivation of an objective finding concerning a proper and equitable technique for qualifying prospective suppliers is very difficult indeed.

Observations during the course of fieldwork for this assignment suggest that, generally, major purchases by the leading utilities are made after a formal and lengthy process of drafting preliminary specifications; discussing these with major prospective suppliers; refining and finalizing the specifications into a formal request-for-bid; taking sealed bids; and analyzing the bids carefully to normalize them for comparability. Since the process is a lengthy and complex one, it appears that utilities are not eager to proliferate the number of bid submissions which they will have to analyze, particularly if they do not have a high level of confidence in some of the bid respondents.

Confidence in this context is usually a function of a utility's own past experience with the supplier under scrutiny. If the utility has not had experience with the supplier, then the experience of the supplier with similar or contiguous utilities may serve as a determinant. Finally, if no relevant prior experience exists, the utility is likely to evaluate the supplier by the supplier's general level of financial and technical resources, the scope of his commercial activities, and his reputation in the trade. All of the above, of course, can become highly subjective. More importantly, the general effect seems to be one of favoring a continuation of past patterns of procurement, unless strong evidence to the contrary emerges.

2. Disclosure of Bid Information

In most instances, the utilities contacted in the course of this study indicated that they did not disclose detailed purchase price information as a matter of policy. Two reasons were generally mentioned:

a) Affirmative clauses in bids submitted by major prospective suppliers, making all the information in the bid proprietary to the suppliers in question, except as public disclosure might be statutorily required by the state commissions, the FPC, and the AEC.

b) A general belief that by hard bargaining, the utility in question had secured from the supplier an advantageous set of conditions which, if broadcast throughout the trade, would trigger a universal demand for similar conditions, and thus nullify the utility's advantage.

The first reason, supplier restrictions on disclosure, becomes somewhat circular when it is discussed with suppliers. There are several legitimate reasons which induce suppliers to protect themselves against the indiscriminate release of technical and economic information pertaining to their innovations. However, some suppliers have gone beyond this kind of explanation, and have suggested that the restrictive clauses are a generally-accepted condition of doing business, traditionally demanded by the utilities. Our interviews in several instances confirmed this hypothesis: although comprehensive release letters had been secured by the major NSSS suppliers, and a cover letter from the AEC and the Department of Justice stipulated that data furnished during field research would not be drawn upon by the government in regulatory proceedings, many of the utilities declined to discuss in meaningful detail their price experience. Undoubtedly, reasons other than the ones specified above may have been relevant; nonetheless, it was frequently the case that as quickly as the general constraint of supplier restrictiveness was relaxed, a subsequent constraint emerged.

The second reason, the belief in individual astuteness and advantage, is not logical when it is held as universally throughout the industry as appears to be the case: virtually everyone "scored" himself as appreciably above the average. While this is an understandable individual impulse, it is not a plausible interpretation of the industry's overall buying performance.

3. Utilities and Foreign Supply

This issue is most relevant in the case of foreign-made turbine-generator sets, and is discussed elsewhere in this report.

Clearly, there are some very legitimate reasons for distinguishing between products of U. S. and overseas origin, even in the very unlikely instance that price, performance and delivery factors are identical. These reasons are well known, ranging from fear of unreliability of after-sale parts and service, to a general objective of being a "good corporate citizen" and operating as extensively as possible within the economy of one's service area.

However, the unbending application of these reasons to every situation encountered, particulary when the combined price, performance and delivery factors of foreign suppliers are appreciably better than those of alternative U. S. suppliers, can result in some visible instances of undesirable market performance, from the perspective of the utilities *themselves*. Most strikingly, for example, throughout 1967 as delivery positions for U. S.-made turbine-generator sets tightened, and open-ended price escalation clauses were quoted by the U. S. suppliers, in the course of several interviews several utilities in virtually the same

breath would decry the practices of U. S. suppliers, and reaffirm their unwillingness to even talk to prospective foreign suppliers who were ready to quote on a firm-price basis. Some major utilities, of course, pursued a very different course, and probably caused the discontinuance of open-ended escalation clauses. Other utility respondents interviewed in late 1967 and early 1968 volunteered that they welcomed the change that had been effected, but they themselves would not have considered taking measures as radical as foreign procurement.

4. Utility Purchasing Incentives

In regulatory economics, there is a theory to the effect that allowing a publicly-regulated utility to earn a more-or-less fixed rate of return on a capital base removes the incentive for economical purchasing of capital goods. The argument is sometimes refined to allow for the impact of regulatory commission review in safeguarding against gross excesses; even with refinements, however, some feel that in marginal situations which are difficult to detect, under the guise of safety and reliability, a utility may "overbuy."

The further contention is made that this purchasing behavior may appear quite rational to a utility, if the utility is currently earning at the limit of its allowable rate, and its cost-of-capital is below its allowable rate (whether the proper measure of cost-of-capital is a weighted one, or the marginal cost to finance the proposed purchase is a further complexity that can be avoided here). In effect, the capital cost of the venture is lower than its anticipated return, and in the process the capital base of the utility is enlarged to accommodate a greater earnings flow; hence the price quoted is not of crucial importance.

This contention of "rate-base maximization" is a frequent one from some circles; the literature and supporting detail on both sides of the contention are extensive. In response to the contention, there are some analytical reasons which may have merit in specific instances:

a) *Demand elasticity for electricity* – The response of customers to a lower rate structure may be increased consumption which will result in greater revenue to the utility under the lower rate structure; therefore, the utility will buy economically, to enable the rate structure to be brought down.

b) *"Yardstick" effect of government-owned utilities* – With large government generating stations in operation, the private electric utility industry cannot afford to get too far out of line with the rate structure of these government facilities; consequently, frozen into a prevailing rate structure, private utilities have to control their costs rather than pass

them along. The merit of this argument hinges on the feasibility of comparing systems and rate structures. The exercise is a complex and controversial one, compounded by the partisan interests of those making the comparison.

c) *Competition among utilities* – Although franchised monopolies in their service areas, some utilities compete with one another in trying to attract new industrial loads into their territory, along with significant secondary retail demand. Several utilities suggested that the ability to offer an advantageous rate schedule to an industrial prospect, and thus lure him away from an alternative site and service area, depends in large measure on the utility's plant purchasing effectiveness "since we do not like to give power away." Others, outside the utility industry, question the impact of rate schedule differentials upon a decision process as complex as industrial site selection.

d) *Performance of the utilities securities* – In keeping their cost of capital down, several utilities have come to believe that a major determinant of the investment community's appraisal of their new issues is the utility's growth potential. This, in their view, depends upon load growth, and their ability to attract new load through an advantageous rate structure. Others concede that the investment community's appraisal of growth is indeed important, but feel that it is determined primarily from factors beyond the utility's control, such as basic demographic and economic trends.

e) *Corporate climate* – Some of the major utilities with a demonstrable record of innovation and efficiency, have suggested that it is not feasible to run a large organization with dual objectives of cost consciousness and cost laxity, depending upon the accounting circumstances of the moment.

5. Past Utility Performance as Buyers

Some observers believe that with the exception of a few major utilities, the industry has generally proven itself incapable of generating the requisite countervailing power that economic theory ordinarily anticipates as an autonomous device to discipline supplier behavior. They usually refer to the price-fixing conspiracy of the middle and late 1950s as evidence for their contention.

XI. BREEDER REACTORS[1]

A. INTRODUCTION

Essentially all of the experts we interviewed predicted that breeder reactor prototypes will not be authorized before 1971–72, will not be constructed until 1975–77, and that commercial breeders will not appear until a decade later – i.e., in the early to middle 1980's. These predictions are based on the expected rate of expenditure of research, development, and construction funds; the difficulty of the technical problems to be overcome; the large testing program required to achieve safety and reliability standards; and the availability of technical manpower. Beyond this it must be remembered that improvements in thermal reactors will represent a moving target to the introduction of commercial breeders. Thus, we have not included the breeder in our model of the present industry, which ends in 1980. However, the government does face in the years ahead many decisions with respect to the breeder industry and for this reason it is important to consider the matter briefly at this time.

The breeder industry will evolve based upon the investments in research, development, equipment, and facilities by both the AEC and industry. As in the case of the thermal reactor industry described earlier in this report, the major share of the funds will probably come from the government. Thus the selection of industrial contractors by the AEC to carry out the nearly $1 billion program projected from 1967 through 1973 will have a very important bearing upon which corporations enter and remain in the field.

We have collected for the period 1946 to date from the literature[2,3] and from field interviews information on important events bearing upon the development of breeder technology. These events together with the past and projected total development expenditures, are presented chronologically in Figure XI–1. The caption provides assistance in gaining a rapid perspective of breeder history.

1. A breeder is a nuclear reactor that produces more fissionable material than it consumes.
2. *Fast Reactor Technology: Plant Design* by John G. Yevick, Editor, A. Amorosi, Associate Editor, The M.I.T. Press, 1966.
3. Various Hearings before the Joint Committee on Atomic Energy, Congress of the United States.

Figure XI–1 depicts the major chronological events to date and the cumulative investment by government and industry in the development of breeder reactors.

Policy and Milestone Developments

In the early days of the AEC emphasis was placed on research on breeder concepts for nuclear power because of the then limited known uranium ore resources. Thus the first token amount of nuclear power produced in the world was by Experimental Breeder Reactor I built and operated by the Argonne National Laboratory December 20, 1951. By this time, however, the improvement in the uranium supply outlook and the priority pressures of the Navy submarine project changed the nature of the government's program to one dominated by thermal, light water reactors. Only one breeder type reactor APDA Fermi, was authorized under the Power Reactor Demonstration Programs in 1955, and it did not reach criticality until 1963. Thus, until the advent of the Liquid Metal Fast Breeder Reactor Program in 1966, only a limited research effort existed. Now, again, the development of fast breeder reactors has top AEC priority.

Research, Development, and Facility Expenditures

The cumulative expenditures to date by the AEC for the development of breeder reactors in Commission and industry laboratories has been only about $225 million. However, a sharp increase in effort is contemplated over the next few years (see curve A in Figure XI–1). By 1973 it is estimated the investment will exceed $1 billion.

Industry expenditures for breeder reactor development to date are estimated to be at least $150 million (curve B). No collective industry data are available on future investment plans, but a marked increase in development effort is clearly contemplated.

Judging solely on the basis of costs encountered in the development of thermal power reactors (see Figure II–1) total investments of the order of $3 billion might possibly be required before the breeder industry is fully established in the early to middle 1980's.

FLOW DIAGRAM FOR BREEDER REACTORS

While there is no breeder industry as such today, we have attempted to segment the potential breeder industry to show companies expected to participate in a commercially significant way to the development of the various segments. It is not possible to be certain that all participating companies are listed, but this presentation represents a starting point from which more accurate diagrams can be constructed as the industry evolves.

\# Announced Firm Plans

* Projects Under Study

Production of Stainless Shapes
Many

Production of Low Alloy Tubing
Babcock & Wilcox

Manufacture of Pump Motors and Control
Allis Chalmers Div., Signal Oil & Gas
General Electric
Westinghouse
Worthington Div., Studebaker

Manufacture of Stainless Pipe
Many

Manufacture of Stainless Steel Alloys
Many

Manufacture of Sodium-to-Air Heat Exchanger
Atomic International
Atomic Power Development Assoc.
Babcock & Wilcox
Baldwin Lima Hamilton
Chicago Bridge & Iron
Combustion Engineering
Struthers Wells
Westinghouse

Manufacture of Feed Water Heater
Babcock & Wilcox
Basco
Baldwin Lima Hamilton
Foster Wheeler
Struthers Wells
Southwestern Engineering Co.
Westinghouse

Fabrication of Reactor Vessel
Babcock & Wilcox
Chicago Bridge & Iron
Combustion Engineering
Foster Wheeler

Fabrication of Steam Generator
Atomics International
Atomic Power Development Assoc.
Babcock & Wilcox
Baldwin Lima Hamilton
Combustion Engineering
Foster Wheeler
United Nuclear
Westinghouse

Fabrication of Intermediate Heat Exchanger
Atomics International
Atomic Power Development Assoc.
Babcock & Wilcox
Baldwin Lima Hamilton
Chicago Bridge & Iron
Combustion Engineering
Struthers Wells
Westinghouse

Manufacture of Sodium Pumps
Byron Jackson Div., Borg-Warner
Combustion Engineering
Westinghouse

Manufacture of Sodium Valves
Westinghouse
Rockwell Mfg. Co.
Fisher Governor
Lunkenheimer
Aerojet

Manufacture of Sodium Piping

Fabrication of Reactor Internals
Babcock & Wilcox
Carpenter Steel
Combustion Engineering
General Electric
Mesta Machine
NUCOM Div., Sealol
Westinghouse

Manufacture of Pure Sodium
du Pont

Manufacture of Turbine Generators
General Electric
Westinghouse

Manufacture of Condensor

Design and Manufacture of Nuclear Steam Supply System
Babcock & Wilcox
Combustion Engineering
General Electric
Gulf-General Atomic
Westinghouse

Manufacture of Control Rod Drives
Babcock & Wilcox
Bendix
Combustion Engineering
General Electric
Marvel-Schebler Div., Borg-Warner
Reactor Controls
Westinghouse

Manufacture of Excore and Process Instrumentation
Atomic Power Development Assoc.
Bailey Meter Div., Babcock & Wilcox
Foxboro
General Electric
Hagan Div., Westinghouse
Honeywell
Leeds & Northrup
Millitron
Mine Safety Associates
N. Wood
Reuter-Stokes
United Nuclear
Westinghouse

Manufacture of Other Components Including Fuel Handling and Service Equipment
Atomics International
General Electric

Fabrication of Control Rods
Babcock & Wilcox
Combustion Engineering
General Electric
Gulf-General Atomic
NUCOM Div., Sealol
Westinghouse

Manufacture of Incore Instrumentation
Babcock & Wilcox
General Electric
Reuter-Stokes
Westinghouse

Architect-Engineer and Construction Work
Burns & Roe
Bechtel
C. F. Braun
Ebasco Services
Gibbs & Hill Div., Dravo
Kaiser Engineers
Stone & Webster
United Engineers & Constructors
Others, including the utilities

Manufacture of Cooling Towers
Fluor Corp.
Marley

Manufacture of Containment Structures
Chicago Bridge & Iron
Pittsburgh-Des Moines Steel

Manufacture of all Other Components for Plant

Sodium Instrumentation
Atomics International
Atomic Power Development Associates
Babcock & Wilcox
Mine Safety Associates
Reuter-Stokes
United Nuclear

Performance of Services
Atomic Power Development Assoc.
United Nuclear
Others, including the utilities

These Materials and Services Usually Purchased by A/E

Utility

These Materials Flow to First Core and Succeeding Reloads

Manufacture of Stainless Tubing
Babcock & Wilcox
Carpenter Steel
Columbia Summerill
Combustion Engineering
Handy & Harmon
Harvey Aluminum
Pacific Tube
Plymouth Tube
Sandvik Special Metals (Sandvik, United Nuclear)
Superior Tube
Trent Tube
Tube Methods
Uniform Tubes
Wall Tube Metal Products
Westinghouse #
Whittaker
Wolverine Tube Div., Calumet & Hecla

Uranium Mining
Approximately 125 Mining Companies Operating 370 Mines

Ore 0.1 to 1.0% Uranium

Uranium Milling

U_3O_8 "Yellow Cake"

Conversion of U_3O_8 to UF_6
Allied Chemical
Kerr-McGee #
Getty

UF_6

Enrichment
USAEC

Diffusion Plant Tails

UF_6

Conversion to Powder and Pellets
Babcock & Wilcox
General Electric
Nuclear Fuel Services (Grace, Getty)
NUMEC Div., Atlantic Richfield
United Nuclear
Westinghouse

UO_2 Powder and Pellets

Fuel Fabrication
Aerojet-General *
Atomics International
Babcock & Wilcox
Combustion Engineering
General Electric
National Lead *
NUMEC Div., Atlantic Richfield
United Nuclear
Westinghouse

Fabricated Fuel Assemblies

Conversion to UF_6
Allied Chemical #
USAEC

UF_6

Plutonium as $Pu(No_3)_4$

Uranium as UNH

Fuel Reprocessing
Allied Chemical *
Atlantic Richfield *
General Electric # (through UF_6)
National Lead *
Nuclear Fuel Services (W. R. Grace, Getty)

Radioactive Waste

Irradiated ("Spent") Fuel

Irradiated Fuel Transport
Atcor, Inc.
General Electric (services)
National Lead (casks)
Nuclear Fuel Services (Grace, Getty)

Arthur D. Little, Inc.
May 1968

FIGURE XI–2 FLOW DIAGRAM FOR BREEDER REACTORS

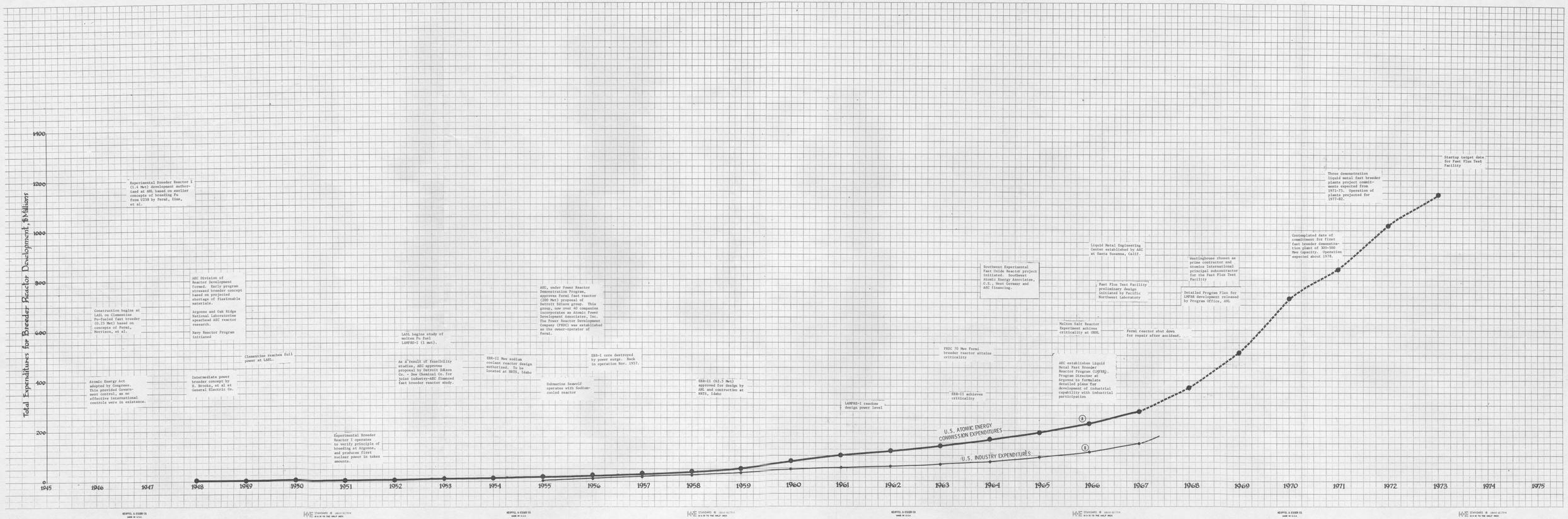


FIGURE XI–1 HISTORICAL DEVELOPMENT OF BREEDER REACTORS

Since there is not yet a breeder industry as such, but only a research and development program, it is not possible to produce a flow diagram of value added by segment as was done earlier in this report for the thermal reactor industry (Figure II–1). However, it is possible to show, as in Figure XI–2, the segments of the breeder industry as they are expected to develop and to list in each those companies now known to be performing research and development or offering to supply services within each segment. From this, one can begin to build an understanding of the probable future competitive structure of the breeder industry as it evolves. A model such as this could be readily updated to follow the competitive trends.

As might be expected, many corporations now involved in the nuclear power supply industry are also engaged in the development of breeders. In fact, the five current thermal reactor manufacturers are all participating in breeder reactor design and development. At least part of the reason for this is that in order to be considered progressive suppliers by current utility industry customers, it is almost essential that these manufacturers also participate in the development of expected future generation reactor types. The same is true for participants in a number of other segments of the industry that will carry over into next generation reactors. Thus it will be noted that many corporate names appear both in Figure II–1 and in Figure XI–2, and new segments such as sodium and stainless steel technology bring in new corporate participants.

B. AEC PROGRAM PLAN

The AEC has given high priority to the development of fast breeder reactors and has established a Liquid Metal Fast Breeder Reactor (LMFBR) Program Office at the Argonne National Laboratory.

We have been informed by the LMFBR Program Office that it is responsible for the development of a Program Plan with the following objective:

> "The primary objective of the civilian power reactor development program in the United States is to achieve widespread use of nuclear energy for the production of heat and electricity while fully exploiting the energy available in our resources of uranium and thorium. The U.S. Atomic Energy Commission's objective also includes fostering the development of an efficient and competitive nuclear industry – the objective of the Liquid Metal Fast Breeder Reactor (LMFBR) Program is the development of a safe, reliable, and economic power plant for the utility environment."

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APPENDICES

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A detailed Program Plan[1], on which industry comments have been invited, has been prepared. It is broken down into the following ten elements:

1. Overall Plan
2. Plant Design
3. Components
4. Instrumentation and Control
5. Sodium Technology
6. Core Design
7. Fuel and Materials
8. Fuel Recycle
9. Physics
10. Safety

Research and development on each of these elements will be carried out in AEC, university, and industry laboratories. Many special facilities will be required, some of which are now in existence, and some of which are proposed.

There are many indications that the AEC will continue its practice, developed under the thermal reactor program, of selecting capable and experienced contractors for receipt of its program funds in the breeder field. For example, Table XI–1 shows broad participation by many competent government and industry organizations is already going forward under the AEC research and development program. As further evidence, Westinghouse has recently been selected as prime contractor, with Atomics International as principal subcontractor, for the design and construction of the Fast Flux Test Facility.

In addition to the LMFBR Program, the AEC is supporting work on competing breeder concepts. The U–233 fueled Molten Salt Reactor Experiment (MSRE) has operated successfully at ORNL at a temperature of 1200°F without encountering significant corrosion problems. ORNL is also investigating, as an outgrowth of the water desalting program, an Unclad Metal Breeder Reactor (UMBR) using a 73% thorium, 16% uranium, 6% plutonium, 5% fission product fuel.

C. INDUSTRY PROGRAM

The genesis of the industry program was the large program on the design, construction, and operation of the 200 Mwt Fermi fast breeder initiated in 1955 by Atomic Power Development Associates, Inc. (APDA). This group, now consisting of over forty companies, began work on the project under the First Round Invitation of the AEC's Power Reactor Demonstration Program. The nuclear portion of the plant, which went critical in 1963, is owned and operated by the Power Reactor Development Company, which is made up of 20 utilities and reactor manufacturing companies. To date some $115 million has been spent on

1. Liquid Metal Fast Breeder Reactor Program Plans, LMFBR Program Office, Argonne National Laboratory, December 1967.

TABLE XI–1

AEC LIQUID METAL FAST BREEDER REACTOR PROGRAM PARTICIPANTS

	Fuels & Materials	Fuel Recycle	Physics	Safety	Na Tech.	Compnts	Instr.	Plant Design	Core Design
Direct	AI	ANL	AI	ANL	AI	AI UNC	AI	B&W	B&W
	GE NUMEC	PNL	GE	PNL	APDA	APDA	APDA	AI	AI
	UNC	ORNL	W	GE	GE	BLH	UNC	CE	CE
	B&W W	B&W	B&W	W	MSA	B&W	LMEC	GE	GE
	ANL		APDA	CE	LMEC	LMEC	PNL	W	W
	PNL ORNL		ANL	B&W	ANL	W	ANL	PNL	ANL
	PRDC		ORNL	AI		B–J	ORNL	ANL	PNL
	LMEC		PNL					APDA	
								LMEC	
Indirect	BMI		AI	AI	AI	ANL	AEROPROJ		
	B&W GE		GA W	GE	ANL	AI	B&W		
	ANL		RPI	APDA	SRI	GE	GE		
	PNL ORNL	PNL	PNL	LASL	LASL	MTI	ANL		
	DOW BNL	ANL	ANL BNL	PNL		PNL	ORNL		
	NUMEC	ORNL	ORNL		PNL		PNL		
	LASL		INC	ANL	BNL		UNC		
	GE–NMPO			BNL	UNC		MSA		
	AMES				W		PHILLIPS		
	Q				ORNL		PARAMETRICS		
	Q				AMES		MILLETRON		
	Q						MARQUARDT		

Plus International Program and Facilities

a. Direct: Directly funded under Civilian Power and Power Demo. Prog.

b. Indirect: Funded under other RDT programs.

the project by the participating companies, The Detroit Edison Company, which owns the steam generators and turbine-generator, and APDA. The AEC has also contributed about $9.5 million in research funds and waiver of fuel use charges. Despite some unfortunate accidents, work on this project is continuing and it could provide valuable experience.

The Edison Electric Institute has recently published a report[1] that details electric utility activities in the fast breeder reactor field. Thus it is necessary here only to summarize some of the important points.

In order to become informed about the status of breeder reactor development and to acquire the ability to plan intelligently for the ultimate commercial installation of breeders, the utility industry has formed to date about eight groups that are investing in study, research and development, and construction projects. The groups vary in size from about 4 to 24 participants, and, in all, over 95 utilities and some other types of companies are participating. The major groups include General Public Utilities (GPU), Southwest Atomic Energy Associates (SAEA), Empire State Atomic Power Development Associates (ESAPDA), Westinghouse Group, and East Central Nuclear Group (ECNG), and the Gas Cooled Fast Reactor Group.

Each group now has studies underway utilizing the design services of the major reactor design companies such as General Electric, Westinghouse, Babcock & Wilcox, Combustion Engineering, Gulf General Atomic, and Atomics International. The studies cover not only sodium coolant, but also steam (recently cancelled) and gas cooled breeders. While the amount of money now being spent on studies by the utilities is modest – about $5–8 million per year – it is expected that this will expand manyfold when demonstration size plants are authorized.

One group has a design, construction, and operation project, the 20 Mwt Southwest Experimental Fast Oxide Reactor (SEFOR). This group, which has a $15 million commitment, consists of the southwest Atomic Energy Associates ($5.9 million), Karlsruhe Nuclear Research Center and European Atomic Energy Community ($5.0 million), and General Electric Co. ($4.1 million). The reactor is expected to go critical in 1968 and its operation will be directed at providing information for the design, licensing and operation of future fast reactors.

These study, design, construction, and experimental operation activities by the utility industry as continued and expanded over the next 20 years, should provide the utility industry with the proper background to buy intelligently on a

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1. *Fast Breeder Reactor Report,* Edison Electric Institute, April 1968.

basis that will tend to foster competition within the breeder reactor supply industry when it comes into being. Furthermore, as pointed out in the EEI report, the utilities should be able to achieve economies in fuel costs in the period 1980–85 through utilization, in fast breeders, of the plutonium generated in thermal reactors.

In addition to the utility actions just summarized, there has also been considerable investment in the development of breeder reactors by the five current reactor manufacturing companies. These have entailed contributions to the aforementioned studies made for the utilities, and investment in facilities, equipment, and research and development. But the major expenditures will probably not be faced until large demonstration plants (300–500 Mwe) are built, and the first, high capital intensive, commercial size breeders (probably 1000 Mwe or larger) are ordered.

The large monetary risks involved, coupled with the somewhat limited market in terms of numbers for the larger-sized breeder type reactors, will likely dictate that only a small number of giant reactor manufacturing corporations can and will enter the race. And we may well see the use of the turnkey concept reappear in order to provide the impetus for utilities to accept the transition to breeders.

5. Foreign Breeder Development

Competition for the U.S. breeder reactor industry may develop overseas as many foreign nations are spurred to undertake breeder research because of the absence of adequate indigenous uranium deposits. The United Kingdom has had an extensive breeder development program for more than 10 years, and research is also going on in France, Russia, West Germany, Netherlands, Spain, Japan, Belgium, Italy, and other nations. The extent to which these efforts might affect the structure and performance of the U.S. breeder industry will probably depend largely on the availability of the huge sum of risk capital required when the time for decision on foreign demonstration plant construction is reached.

APPENDIX A

ADL COMPUTER MODEL OF THE NUCLEAR POWER SUPPLY INDUSTRY

The estimation of future sales volumes for various components of nuclear power plants and the nuclear fuel cycle is complicated by the fact that some components are used not only in the initial construction of the plant but also, in varying quantities, in fuel reload or in the replacement of certain key components during the life of the reactor. A further complication is that the relative quantities of these components are dependent on reactor technology: improved burnup, for example, reduces not only the amount of fuel fabrication required but also the attendant reprocessing. Finally, estimates of market volumes are rendered difficult by the long and widely differing lead times between components and fuel cycle sales and the startup of the station.

In order to facilitate estimation of market volumes for the various components of nuclear plants and the fuel cycle, given differing assumptions on installed capacity, reactor technology, and unit costs, we constructed a simplified FORTRAN model of this industry following in concept the relationship of the segments shown in the Industry Flow Diagram (Figure 2).

The principal input to this program is an estimated time series of installed nuclear capacity. The program computes the market value of goods and services required to meet the implied schedule of capacity additions in each year as well as to service the annual requirements of in-place stations, basing these market values on input assumed unit prices and delivery times relative to startup time. Because the program computes the value of the principal component and raw material inputs to each segment, as well as the market value of the output of each segment, it is possible by subtraction to compute a crude "value-added" for each. However, it is important to recognize that while we have supplied a program with the principal flows of goods and services, these do not necessarily form an exhaustive list of the transfers that take place to and from the various segments in the actual industrial setting. In some segments of the industry this tends to overstate or understate the value-added as computed by the program. Nor does the value-added computation of the program adjust for changes in inventory level or in differences in accounting conventions.[1] We have found that the value-added computed by the program is a reasonable first approximation to the significance

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1. In particular: differences among the NSSS manufacturers in the way they treat major purchased components for purposes of reporting sales; and differences in progress payment schedules and the rate at which work in progress is credited toward the finished product.

that the segment has to the overall nuclear industry; but again we must caution that the value-added as computed by the model would not necessarily correspond to that developed by the Department of Commerce Census of Manufactures.

The program uses three sets of input data:

1. A year-by-year forecast of installed nuclear generating capacity and an estimated division of the market by reactor type (BWR, PWR, etc.).[1]

2. Diffusion plant tails assay, optional provision for plutonium recycle and technical parameters for each reactor type's initial cores and annual replacement requirements, such as degree of enrichment and burn-up. We have used technical parameters typical of reactors coming on line in the early and mid 70's, as presented in Table 7 of the AEC "Forecast of Growth of Nuclear Power" dated December 1967 (WASH-1084), issued by the Division of Operations Analysis and Forecasting. The only major divergence in assumptions is in our assumed load factor of 80% in contrast to the figure of 85% presented in the referenced table; we have also assumed a constant production of 0.17 g Pu/year per 1000 MW(e) and a relative fissile worth of 1.3 g Pu/g U-235.

3. Coefficients for transfers between pairs of industry segments, relating the units and dollar volume of these transfers and their timing to installed nuclear capacity. Provision is made for separate consideration of initial cores and replacement core requirements.

   The unit and dollar volume of any transfer between industry segments can be scaled to (1) the installed nuclear capacity,

1. The program was written to accommodate four reactor types. Our study makes computations only for BWR's and PWR's—since little unit cost information was available for High Temperature Gas Reactors. The fourth reactor type, "CAND," carried in the program as column headings, has been used in other projects to represent a natural uranium reactor based on the Canadian "CANDU" design. When run with coefficients for only the three industry segments, the program is well suited to the complex calculation of aggregate enrichment (separative work) demands and uranium and conversion requirements to support a nuclear economy containing a mixture of reactors. Such computations on a worldwide basis must include light water, gas, and natural uranium reactors.

(2) the required annual tonnage of enriched uranium, (3) the annual tonnage of natural uranium feed, (4) the annual separative work requirement, or (5) the annual reprocessing load.

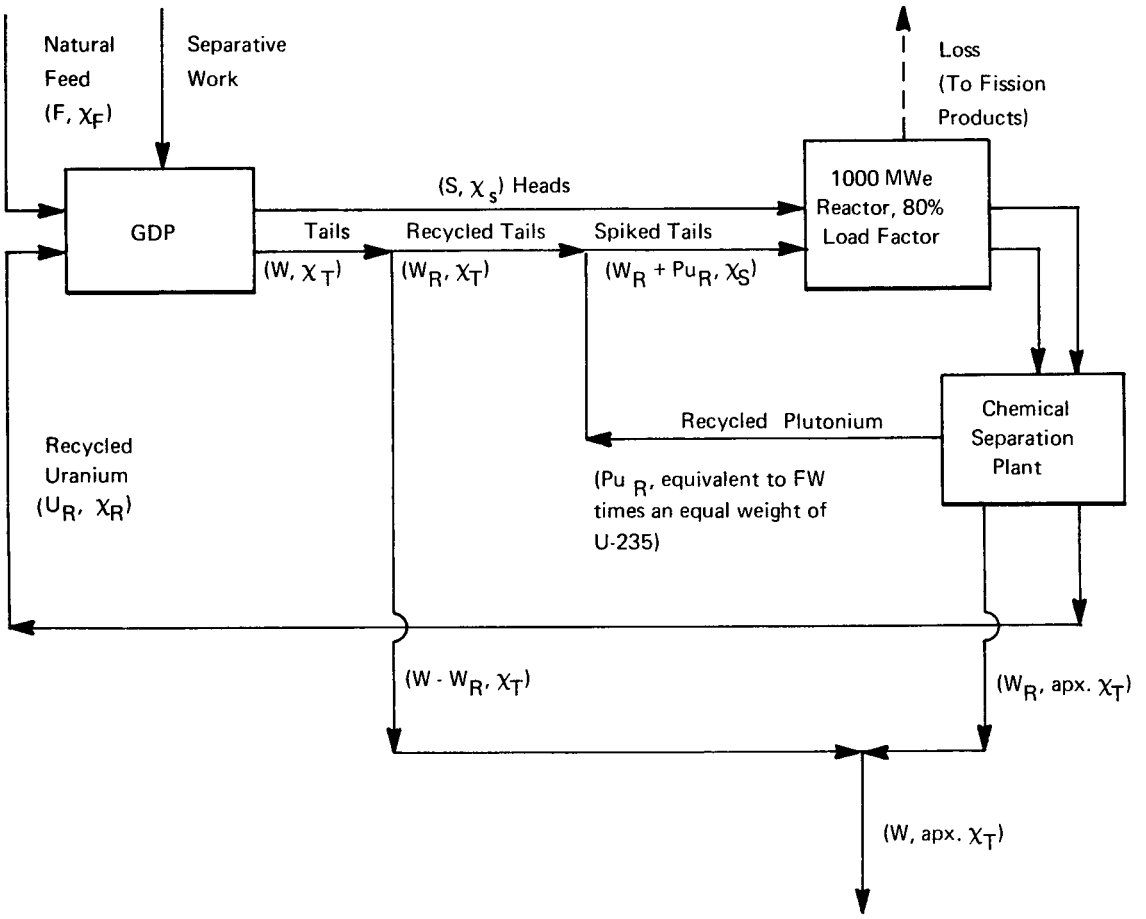
The model incorporates a sub-program that calculates the natural uranium and separative work required, year by year, for any projected mix of four reactor types. The basis for the calculation of separative work and natural feed requirements is shown in Figure A-l, which outlines the provision for recycling spent uranium to the gaseous diffusion plant and for recycling the plutonium to separate fuel elements in which it is mixed with recycled diffusion plant tails.

The model can be used to calculate the sensitivity of various industry segments to changes in any of the input parameters listed above. Output includes;

1. Two summary tables regarding assumed reactor constants and annual requirements of uranium feed and separative work for the nuclear demand projected. (See Tables A-l and A-2 for examples of these.)

2. Component transfer tables showing the projected magnitude of all intra-industry transfers (see Table A-3).

3. A summary table for each industry segment showing the algebraic sum of all transfers into and out of that segment ("value-added"), keeping in mind the qualifications stated above (see Table A-4).



Note: Nomenclature is as given on the drawing; in each case, the letter(s) preceding the comma refer to the weight of the stream, and the letter(s) following the comma refer to the U-235 concentration of the stream.

GIVEN:

Reactor Feed = $(S + W_R + Pu_R)$ MTU/yr
Equivalent Concentration of Reactor Feed = χ_S, gU-235/gU
Pu Recycle = Pu_R, MTU/yr
Pu Equivalence = FW, gU-235/gPu
Loss to Fission Prods. = Loss, MTU/yr
Concentration of GDP Tails = χ_T, gU-235/gU
Concentration of Recycle U = χ_R, gU-235/gU
Concentration of Natural Feed = χ_F = 0.00711 gU-235/gU

CALCULATE:

$W_R = Pu_R [(FW - \chi_S) / (\chi_S - \chi_T)]$
$S = (S + W_R + Pu_R) - W_R - Pu_R$
$U_R = S - Loss$
$F = [(S)(\chi_S) - (U_R)(\chi_R) - (Loss)(\chi_T)] / (\chi_F - \chi_T)$
$W = F - Loss$

FIGURE A–1 ANNUAL REPLACEMENT CORE CALCULATIONS - 1000 Mwe REACTOR MODEL FOR COMPUTING FRESH FEED AND HEADS REQUIREMENTS; PU BLEND WITH TAILS ONLY

BASIS FOR CALCULATIONS FOR 1000 MWE REACTORS

ASSUMED GDP TAILS ASSAY = .002000
ASSUMED ANNUAL LOSS TO FISSION PRODUCTS = .90 MTU
ASSUMED GDP LEAD TIME = 2 YEARS

	.....INITIAL CORES.....				.....	ANNUAL REPLACEMENT REQUIREMENTS.....						
REACTOR TYPE	ASSUMED INITIAL CORE, MTU	ASSUMED CONCN, INITIAL CORE	CALCD NATURAL REQMNT, MTU	CALCD SEP WORK REQMNT, MTU	ASSUMED PU RECYCLE, MT PU	ASSUMED REL REACTIVE WORTH OF PU	ASSUMED REPLACEMENT CORE, MTU	ASSUMED CONCN, REPLACEMENT CORE	ASSUMED CONCN, U RECYCLE TO GDP	CALCD U RECYCLE, MTU	CALCD NATURAL REQMNT, MTU	CALCD SEP WORK REQMNT, MTU
BWR	139.9	.0220	547.6	364.0	.17	.769	32.1	.0260	.00800	25.8	95.0	89.1
PWR	90.5	.0280	460.5	350.3	.17	.769	28.1	.0340	.00900	23.1	118.8	119.3
HTGR	3.7	.9300	671.9	871.5	.00	.769	.7	.9300	.65000	.5	65.1	81.7
CAND	190.0	.0071	190.0	0.0	.17	.769	73.3	.0071	0.00000	0.0	73.3	0.0

ASSUMED NEAREST WHOLE NUMBER OF YEARS OPERATION ON INITIAL CORES
2 YEAR(S) FOR BWR
2 YEAR(S) FOR PWR
2 YEAR(S) FOR HTGR
1 YEAR(S) FOR CAND

NOTE THAT THE NATURAL FEED AND SEPARATIVE WORK REQUIRED FOR THE FIRST REPLACEMENT CORES FOR EACH REACTOR WILL DIFFER FROM THOSE OF LATER REPLACEMENT CORES BECAUSE OF LACK OF RECYCLE. ALLOWANCE HAS BEEN MADE HERE FOR THE FIRST TWO ANNUAL REPLACEMENT CORES FOR EACH REACTOR TO BE PREPARED BY THE GDP FROM NATURAL FEED.

TABLE A-1

ASSUMED REACTOR CONSTANTS

CALCULATED RESULTS FOR ASSUMED REACTOR PROPORTIONS AS FOLLOWS-
BWR = 35 PCT , PWR = 65 PCT , HTGR = 0 PCT , CAND = 0 PCT
TOTAL PU RECYCLE
GDP TAILS ASSAY = .002000

		.....INITIAL CORES.....			.....REPLACEMENT CORES.....							
YEAR	CAPY OF ABOVE TYPES, GW	GDP HEADS, MTU	CONSUMPTION OF NATURAL URANIUM, MTU	SEPARATIVE WORK, MTU	GDP HEADS, MTU	REPROCESSING LOAD, MTU	NET CONSUMPTION OF NATURAL URANIUM, MTU	NET SEPARATIVE WORK, MTU	TOTAL ANNUAL CONSUMPTION OF NATURAL URANIUM, MTU	CUMULATIVE CONSUMPTION OF NATURAL URANIUM, MTU	TOTAL ANNUAL SEP WK REQMNT AT GDP, MTU	CUMULATIVE SEP WK REQMNT AT GDP, MTU
1967	2.8	291	1326	959	70	29	411	349	1737	1737	1308	1308
1968	3.9	345	1571	1136	97	51	550	476	2121	3858	1612	2920
1969	6.6	722	3289	2379	165	80	944	812	4234	8092	3191	6111
1970	9.8	733	3338	2415	245	112	1417	1211	4755	12847	3626	9737
1971	16.5	1046	4762	3445	412	189	2384	2039	7146	19993	5483	15221
1972	23.3	1509	6873	4972	581	280	3339	2867	10212	30205	7839	23059
1973	33.0	1509	6873	4972	823	472	4580	3996	11454	41659	8967	32027
1974	47.0	1401	6382	4617	1173	666	6535	5696	12917	54576	10312	42339
1975	61.0	1832	8346	6037	1522	944	8325	7324	16671	71247	13361	55700
1976	74.0	1832	8346	6037	1846	1344	9704	8712	18050	89297	14749	70450
1977	91.0	1725	7855	5682	2270	1745	11752	10635	19607	108904	16317	86766
1978	108.0	2264	10310	7457	2695	2116	13856	12582	24166	133070	20039	106805
1979	124.0	2587	11783	8523	3094	2603	15567	14296	27350	160420	22819	129624
1980	145.0	2803	12765	9233	3618	3089	18113	16678	30878	191298	25911	155535

TABLE A-2

SAMPLE COMPUTATION OF NATURAL URANIUM AND SEPARATIVE WORK REQUIREMENTS

COMPONENT TRANSFER

ORIGIN - NSSS DESIGN AND MFG

DESTINATION - ELECTRIC UTILITIES

UNITS - MEGAWATTS NSSS

REACTOR TYPE	$/UNIT	INITIAL CORES UNITS/GWE	INITIAL CORES MOS LEAD	REPLACEMENT CORES UNITS/GWE	REPLACEMENT CORES MOS LEAD
BWR	38200.0	1000.0	12	0.0	0
PWR	48309.0	1000.0	12	0.0	0
HTGR	0.0	1000.0	12	0.0	0
CAND	0.0	1000.0	12	0.0	0

	NUMBER OF UNITS					DOLLAR VOLUME		
YEAR	FOR BWR REACTORS	FOR PWR REACTORS	FOR HTGR REACTORS	FOR CAND REACTORS	TOTAL	NEW CORES	REPLACE-MENT CORES	TOTAL
1967	385.0	715.0	0.0	0.0	1100.0	49247935	0	49247935
1968	945.0	1755.0	0.0	0.0	2700.0	120881295	0	120881295
1969	1120.0	2080.0	0.0	0.0	3200.0	143266720	0	143266720
1970	2345.0	4355.0	0.0	0.0	6700.0	299964695	0	299964695
1971	2380.0	4420.0	0.0	0.0	6800.0	304441780	0	304441780
1972	3395.0	6305.0	0.0	0.0	9700.0	434277245	0	434277245
1973	4900.0	9100.0	0.0	0.0	14000.0	626791900	0	626791900
1974	4900.0	9100.0	0.0	0.0	14000.0	626791900	0	626791900
1975	4550.0	8450.0	0.0	0.0	13000.0	582021050	0	582021050
1976	5950.0	11050.0	0.0	0.0	17000.0	761104450	0	761104450
1977	5950.0	11050.0	0.0	0.0	17000.0	761104450	0	761104450
1978	5600.0	10400.0	0.0	0.0	16000.0	716333600	0	716333600
1979	7350.0	13650.0	0.0	0.0	21000.0	940187850	0	940187850
1980	8400.0	15600.0	0.0	0.0	24000.0	1074500400	0	1074500400

TABLE A-3

EXAMPLE OF A COMPONENT TRANSFER TABLE

NET DOLLAR VALUE ADDED -- NSSS DESIGN AND MFG

ALLOWING FOR GOODS AND SERVICES TO
ELECTRIC UTILITIES

ALLOWING FOR GOODS AND SERVICES FROM
IN-CORE INSTMN MFG
CONTROL ROD FABN
CNTRL ROD DRIVE MFG
REACTR PRESS VSL MFG
STEAM GEN FABN
PRESSURIZER FABN
PRIMARY PUMP MFG
REACTR INTERNLS FABN
FUEL CHANNEL MFG

NET ANNUAL DOLLAR FLOW

YEAR	NEW CORES	REPLACE-MENT CORES	TOTAL
1967	23382736	-164318	23218418
1968	65276716	-263659	65013057
1969	70677960	-376889	70301071
1970	164606666	-610187	163996480
1971	160626915	-932692	159694223
1972	228754129	-1527114	227227015
1973	344434825	-2244150	342190675
1974	346734825	-3176133	343558692
1975	310632337	-4517493	306114844
1976	418242287	-6000527	412241760
1977	420542287	-7410578	413131709
1978	382139800	-9079615	373060185
1979	509752237	-10880443	498871795
1980	585859700	-12608286	573251414

TABLE A-4

EXAMPLE OF A VALUE-ADDED TABLE

APPENDIX B

CORPORATE RELATIONSHIPS THROUGH DIRECTOR AFFILIATIONS

An interest in corporate relationships among competing equipment and/or fuel suppliers, actual and potential electric utility customers, and potential sources of financing – e.g., commercial banks, insurance companies, large institutional investors – resulting from their director affiliations is logically a part of any study of competition in the nuclear power supply industry. There are statutory bases for such an interest, embodied in the Clayton Act, the Public Utility Holding Company Act, and the Federal Power Act.[1] Such relationships in some instances could comprise a form of vertical or horizontal integration and according to the circumstances amount to an unreasonable restraint of competition. On the other side, in many cases such relationships may contribute to managerial efficiency.

We examined these types of interrelationships among firms and institutions in the nuclear power supply market which existed in early 1967, and which, for the most part, have continued into late 1968 – covering the period of our study. It is important to note that most of these relationships also existed in 1966, so that we have at least a fair picture of this element of management's decision-making environment in the years 1966 and 1967, when a relatively large number of nuclear megawatts were committed.

Figure B–1 shows the interrelationships we found. These are a matter of public record, and were obtained from Poor's Register of Corporations, Directors, and Executives; Moody's Handbook of Corporate Managements; company proxy statements, and annual reports.

The figure contains various symbols to denote the position or title held by an individual in one organization who also serves as a director of one or more additional corporations. These symbols are explained in the Legend. The lines drawn between the various names of individuals and organizations denote the nature and direction of such relationships. These lines are in different colors to help the reader distinguish various clusters of director relationships. This enables one to readily see, for example, the relatively large number of director affiliations associated with several large banks and insurance companies, so that institutionally, if not through individuals, these firms hold an intermediary position between a number of utilities and NSSS suppliers. There are at least two companies in the nuclear power supply industry on whose board sits an officer and director of a supplier or potential supplier company.

1. See (a) Public Law 212, 63d Congress, 38 Stat. 730, 15 U.S.C. 12/et seq. (The Clayton Act); (b) 49 Stat. 856, Aug. 26, 1935; 16 U.S.C. 825d, 1958 (The Federal Power Act); and (c) 49 Stat. 838, Aug. 26, 1935; 15 U.S.C. 79, 1958 (The Public Utility Holding Company Act).

The relationships shown are subject to change as directors' terms expire, resignations occur, corporate managements shift, and mergers and acquisitions may change corporate ownership.

Changes that are pending or that took place during the study (e.g., Gulf's purchase of General Atomic from General Dynamics, with the attendant resignation of the Chairman of Gulf from the Westinghouse board) are noted by a dashed line or a break in a line.

We wish to emphasize that our study of interrelationships is not exhaustive. Additional information could have been incorporated, but its usefulness would not contribute appreciably to the results, which already show a large and complex set of relationships. By this study of interrelationships we do not want to imply that they are peculiar to the nuclear industry or necessarily harmful to competition. As suggested by a House subcommittee staff report, they may reflect a "feature of American corporate operations."[1] A case-by-case examination is necessary to evaluate any competitive consequences.

1. Staff Report on "Interlocks in Corporate Management," to the Antitrust Subcommittee of the Committee on the Judiciary of the U.S. House of Representatives, March 12, 1965, p. 6.

Legend:

- (U) Nuclear Electric Utilties
- (N) Nuclear Reactor/Fuel Cycle Supplier
- (A-E) Architect-Engineer Firm

Abbreviations:

Chm. - Chairman
D - Director
LM - Life Member
A - Affiliate
S - Subsidiary
P - Partner
Pr. - President
T - Trustee
Tr. - Treasurer
V.P. - Vice President
C.E.C. - Chairman Executive Committee
C.F.C. - Chairman Finance Committee
M - Member of Corporation

(U) Commonwealth Edison Company — J. Harris Ward, Chm.; Gordon R. Corey, C.F.C.

(U) Consumers Power Co. of Michigan

(U) Consolidated Edison Co. — Thomas C. Fogarty, Continental Can; Richard S. Perkins, Chm. Exec. Comm.; Henry C. Alexander, Chm. Ex. Com., Morgan Guaranty Trust Co.

(U) Long Island Lighting Co. — Eben W. Pyne, Sr. V.P.

(U) Rochester Gas and Electric — Hulbert W. Tripp, Sr. V.P.

(U) Duke Power Co. — D.W. Jones, V.P.

(U) Philadelphia Electric Co. — Chm. Roy Rincliffe

(U) Public Service Co. of Colorado

(N) Kerr-McGee Corp. — Dean A. McGee, Chm.

Beatrice Foods — B. W. Cannon, V.P.

Vulcan Materials Co. (Ala.) — B. A. Monaghan, Pr.

(U) General Public Utilities

Chm., Thomas C. Fogarty — Continental Can Company — Charles Stauffacher, Ex. V.P. — To Cons. Edison

Allied Chemical Corp. — E. Newton Cutler, Jr., Sr. V.P.; John J. McCloy

Continental Illinois National Bank — David M. Kennedy, Chm.; Donald M. Graham, V. Chm.

Insurance Co. of North America — John A. Diamond, Chm. Ex. Com.

American Airlines, Inc.

Minot Milliken, V.P. — Deering Milliken, Inc. — Roger Milliken, Pr.

(N) General Electric Company

J.P. Stevens and Co. — Robert T. Stevens, Pr.

(N) Utah Construction and Mining Co. — Edmund W. Littlefield, Pr.

(U) William Webster, Chm. — New England Electric System

- Yankee Atomic Electric Co.
- Connecticut Yankee Elec. Co.
- Maine Yankee Elec. Co.
- Vermont Yankee Elec. Co.
- New England Power Svc. Co.

W. R. Grace Co. — J. Peter Grace, Chm.

First National City Bank of N.Y.

Thos. S. Gates, Chm. — Morgan Guaranty Trust Co. — Elmore C. Patterson, V. Chm.; Edward M. Lamont, V.P.; John M. Meyer, Pr.

Ropes and Gray, Atty's — Ed. B. Hanify

(U) Northeast Utilities — Sherman Knapp, D

North American Rockwell — W.F. Rockwell, Jr., Chm.

Francis Burr M — Charles Coolidge M (Ret.) — The Corporation of Harvard College — George F. Bennett, Treas.

Pres. and Dir. — Paul C. Cabot, Chm. — State Street Investment Corp. — Mayo A. Shattuck, V.P.

Scovill Manufacturing — Malcolm Baldridge, Pr.

(U) Duquesne Light Co. — Philip A. Fleger, Pr.

(N) Westinghouse Electric — Pr. - Donald Burnham

Frank Denton, V. Chm. — Mellon NB and Trust — R.K. Mellon, Chm.; Edgar Lewis, V.P.

Middle South Utilities (U)

(A-E) Stone and Webster, Inc. — Whitney Stone Chm.

Gulf Oil Corp. — Ernest Brokett, Chm.; William Whiteford, D

Niagara Mohawk Power (U)

James Lawrence and Co. — Mr. John E. Lawrence

Harris, Upham and Co. (Members NYSE) Partners

Eastern Gas and Fuel Assoc.

Great American Insurance Co.

Cabot Corporation — Louis W. Cabot, Pres.; Thomas D. Cabot, Chm.

(U) American Electric Power

Owens Corning Fiberglas Corp. — Harold Boeschenstein, Chm.

The Corporation of Massachusetts Institute of Technology — Gwilym A. Price, Esq.; James R. Killian, Jr., Chm.

Chase Manhattan Bank — William W. Higgins; David Rockefeller, Pres.

Consolidation Coal — Chm., D — George Love — C.E.C.

Chrysler Corp. — Lynn Townsend (Chairman)

Procter and Gamble Co. — Neil McElroy, Chm.; Howard Morgens, Pres. (Also Director of Morgan G.T.)

National Distillers and Chem. — John Bierwith, Chm.

John J. McCloy, Esq. — Ptr. Milbank, Tweed, Hadley and McCloy

International Nickel Co. Ltd. — J. R. Gordon, Ch. Exec., D — George C. Sharp

Malcolm P. Aldrich — Equitable Life Assurance Soc. of U.S.

General American Investors — Boylston Tompkins

Amer. Tel. and Tel. Co. — Ben S. Gilmer, Pres.; James B. Fisk, BTL

Sullivan and Cromwell — Stoddard Stevens

Henry S. Wingate, Chm. Inco and also Dir. Morgan Guaranty

Manfr's. Hanover Trust Co. — Robert E. McNeil, Jr., Chm.

Diamond Alkali Co. — Raymond F. Evans, Chm.

Babcock and Wilcox Co. (N)

Electric Bond and Share Co. — George G. Walker, Pres. — Ebasco Services (A-E)

D. H. McLaughlin, Chm. Homestake Mining Co.

J. R. Dilworth A — Rockefeller Bros., Inc. — T. Walkowicz A — L. Rockefeller, Chm.

Eaton Yale and Towne, Inc. — John C. Virden, Chm.

Youngstown Sheet and Tube

The Corporation of Yale University — Ch. F.C.

Olin Mathieson Chemical Co. — Gordon Grand, Jr., Pres.; Harlow J. Reed, V.P.

Florida Power and Light Co. — McGregor Smith, Chm.

Detroit Edison Company — Walter Cisler, Chm.

Cleveland Electric Illuminating — E. L. Lindseth, Chm.

United Nuclear Corp. — Walter F. O'Connell (Chm.)

Combustion Engineering (N)

Cummins Engine Co., Inc. — J. Irwin Miller, Chm.; Eugene R. Black, Esq.

To Ptr Milbank, Tweed, Hadley and McCloy

To Detroit Edison

Sources: Moody's Handbook of Corporate Management, 1967; Company proxy statements, and annual reports. Standard and Poor's Register of Corporations, Directors, and Executives, 1968.

Note: See page 417 of Appendix B for further explanation of the construction of this diagram.

FIGURE B-1 CORPORATE RELATIONSHIPS THROUGH DIRECTOR AFFILIATIONS

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APPENDIX C

1963 JOINT COMMITTEE HEARINGS: CORRESPONDENCE BETWEEN THE AEC'S GENERAL COUNSEL AND THE U. S. ASSISTANT ATTORNEY GENERAL, ANTI-TRUST DIVISION

U. S. Atomic Energy Commission,
Washington, D.C., July 2, 1963

Hon. Robert F. Kennedy,
The Attorney General.
(Attention: Hon. William H. Orrick, Jr., Assistant Attorney General.)

DEAR MR. KENNEDY: The Atomic Energy Commission is planning, in the near future, to execute a contract with Nuclear Fuel Services, Inc. (hereinafter referred to as "NFS"), calling for NFS to provide chemical processing services for irradiated fuel elements from nuclear reactors owned by the United States, licensees of the AEC and foreign governments. From the outset of the development of this arrangement, the Commission has had in mind certain possible monopoly aspects due to the fact that the small amount of private reactor fuels available for reprocessing during the first few years of operation would make the operation of two competing private reprocessing plants economically impracticable. The Commission has taken precautions both to see that industry had a fair chance to compete for the establishment of this first private plant and that every opportunity would be provided for the entry of a competing enterprise into the field as soon as the quantity of private fuels available would justify construction of a second plant, which should be within a period of 6 to 10 years. The Commission has been negotiating this arrangement over an extended period with the purposes of providing maximum opportunity for the establishment of a competitive private industrial position and has taken certain steps toward that end which are described below; however, we would appreciate your review of the proposed arrangements from the standpoint of any inconsistency with the anti-trust laws.

In order to assist you in reaching your conclusions, we would like briefly to review the history of chemical processing of irradiated fuel elements, the background of the proposed NFS–AEC contract, the essential terms of the proposed NFS–AEC contract, the contemplated arrangements between NFS and its customers other than the AEC, the prospect of early development of a competitive plant, and the AEC's relationship to NFS, its potential customers and others apart from the proposed NFS–AEC contract.

Fuel elements which have been irradiated in nuclear reactors become unusable after a period of time and must be removed and replaced with new fuel elements. However, there remains a considerable amount of valuable special nuclear material (e.g., uranium enriched in U^{235} and/or U^{233}, and/or plutonium) in these removed fuel elements. To recover and separate these special nuclear materials, the irradiated fuel elements must be chemically processed to get rid of the radioactive fission products.

The AEC leases special nuclear material to private reactor operators for use as fuel, and is required to pay a "fair price" for special nuclear material produced by licensees in private reactors. Under section 161m. of the Atomic Energy Act of 1954, as amended, AEC is authorized to provide for chemical processing services for special nuclear material utilized or produced by licensees in private reactors at prices which provide reasonable compensation to the Government and which will not discourage the development of sources of supplies independent of the AEC.

The AEC has constructed a number of Government-owned plants at AEC sites for the chemical processing of irradiated fuel elements from AEC's plutonium production, and certain other highly enriched reactors. However, in the mid-1950's, when the first private nuclear reactor projects were getting underway, there was not available, either from the AEC or from private industry, a chemical processing service for these private reactors. Neither was there available any specific information on the costs of chemically processing the type of fuels discharged from these reactors.

Accordingly, in March 1957, a policy was announced under which AEC offered, under individually negotiated contracts, to accept irradiated nuclear fuel from licensees for financial settlement. The settlement included charges for chemical processing. In announcing this policy, the AEC made clear its desire to continue to encourage the development of a commercial capability for irradiated fuel processing – by stating that in implementing this policy, contractual arrangements between AEC and licensees would expire on June 30, 1967, or earlier if the AEC determined that the required processing services would be commercially available at "reasonable" charges. As a basis for the charges AEC would make for chemical processing services for power reactor fuels where the technology had not been developed or demonstrated, a hypothetical multipurpose chemical processing plant was conceived by the AEC. The estimated costs associated with this so-called conceptual plant (which was preliminarily designed for the purpose of establishing charges, but which was never built) were the basis for the establishment of AEC's charges for chemical processing services. The AEC considered that such charges were reasonable in that they were not so high as to discourage the growth of nuclear power; nor were they so low that a private chemical processing service would be indefinitely deferred, in the light of the continuing development of chemical processing technology and the

then-anticipated growth in availability of fuels which would require processing services.

The AEC has a fourfold objective in encouraging the development of a private chemical processing capability, viz,

1. To have privately owned processing plants in operation as it becomes necessary to process different types of fuel elements from privately owned and other power reactors.
2. To eliminate the responsibility of the AEC to the reactor industry to provide for the processing of private reactor fuels.
3. To have available a private capacity for processing certain fuels from Government reactors, in order to supplement existing Government facilities and to avoid additional capital expenditures for storage and processing facilities.
4. Finally, and perhaps most important of all, to demonstrate as soon as practicable in a privately owned facility the economics of chemical processing of different types of fuels for privately owned reactors in order to bring to bear the potential and capabilities of private industry in lowering the cost of this part of the fuel cycle.

In connection with the fourth objective noted above, chemical processing is an important part of the AEC's goal of achieving nuclear powerplant designs which will produce economically competitive power in the United States. To attain this goal, the AEC has spent considerable sums on the total reactor program and undertaken a number of reactor demonstration projects. The cost of chemical processing must be considered at an early stage in the conceptual design of a nuclear reactor as it could have a significant influence on the total cost of the power. Accordingly, in order for the reactor industry to be able to base its design decisions on true economics, it is important that the economics of fuel processing be known accurately at an early date.

Such knowledge would not be forthcoming if power reactor fuels were processed at the large Government facilities designed basically for the processing of very large quantities of irradiated fuels from the Commission's reactors that are utilized for the production of military materials and fuels from the Commission's reactors used for research and development purposes. The private reactor fuels, if so processed, would be of such small volume compared to the Government processing load that unit processing costs, with the advantage of a broad base for allocation of charges for depreciation and overhead, would be unrealistically low. Addition of auxiliary facilities (in the magnitude of several million dollars) to the Government processing plants would be necessary to permit handling the different types of private fuels, but amortization of such facilities, as well as determining appropriate allocation of amortization for the existing large facilities would present substantial problems and lead to further distortions. In addition, the costs of operation of the Government facilities would not be a meaningful index as to the cost of a private operation. Examples of costs that would be

different in these Government facilities versus a private plant are taxes, insurance, and administrative costs. Furthermore, in view of the intimate association of the large Government facilities with the military and other programs, and the possibility of wide fluctuations in the utilization of these facilities for Government purposes, private reactor operators would be faced with considerable uncertainty concerning the future availability of these facilities for the processing of private reactor fuels, and the charges that the Government might make for processing of private fuels in these facilities. These were some of the problems which caused the AEC to formulate its chemical processing charges on the basis of a "conceptual plant," as discussed above.

The Commission considers it necessary for the future development of the nuclear power industry that those considering the construction of nuclear plants be able to make their decisions on the basis of reliable industrial experience that will have established, under normal industrial conditions, the actual cost of chemical processing of fuel elements of various designs and compositions. The Commission would expect further that the early entry of private enterprise into this field would bring to bear industrial management capabilities and incentives that should effect efficiencies and economies leading to reduction in the cost of this element of the nuclear powerplant fuel cycle. Such participation, in the Commission's opinion, would serve to further the national policy established in the Atomic Energy Act that "the development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise."

In 1956 and 1957, when it appeared to the AEC that the area of irradiated fuel processing was likely to continue to be a gap in a broadly based commercial nuclear industry, AEC undertook to discuss with industry representatives the AEC program of encouraging the development of a competitive, industrial irradiated fuel processing capability. In soliciting expressions of industry interest in the construction and operation of a private chemical processing plant, the AEC made known that it would consider as "reasonable" charges by industry on the order of 15 percent higher than the AEC charges based on the conceptual plant. That is, AEC would not offer its own services in competition with a private plant whose charges were on the order of 15 percent higher than conceptual plant charges. As another element of encouragement to the industry, AEC announced its willingness to make available, as a baseload to a private chemical processing venture, certain quantities of irradiated fuels to be discharged from Government-owned reactors. In 1957, AEC conferred with representatives of approximately 34 companies, including a number of leading chemical and refining firms, concerning possible private industrial participation in the chemical processing field. However, it soon became clear that most interested members of the industry considered the potential commercial load for such a facility to be inadequate to justify its early construction. As a result, AEC made preliminary plans to modify

AEC chemical processing facilities to carry out power reactor fuel processing, but indicated its continued willingness to consider proposals from industry.

In 1959, however, a new industrial interest in chemical processing developed. The present NFS venture is the culmination of studies by five electric utilities building nuclear powerplants – Yankee Atomic Electric Co., Commonwealth Edison Co., Consolidated Edison Co., Northern States Power Co., and Power Reactor Development Co. – and the Davison Chemical Co., division of W. R. Grace & Co. (hereinafter referred to as "Davison"). These companies constituted themselves as the Industrial Reprocessing Group, or IRG, which was formed in 1959. On the basis of the industrial interest reflected by the IRG study, the AEC deferred proceeding with planned modifications of AEC facilities to permit power reactor fuel processing. The IRG continued its studies through 1961.

II. BACKGROUND OF THE PROPOSED NFS–AEC CONTRACT

In January 1962, Davison outlined to the AEC its plans for constructing the first privately owned chemical processing plant. Davison informed the AEC that the IRG had terminated its existence prior to that date, since its basic studies had been completed. Davison proposed to construct its plant on the condition that it could obtain, among other things, long-term contracts with utilities and a 5-year baseload contract from AEC. The AEC considered the Davison proposal and concluded that it appeared to hold promise of satisfying AEC's basic objectives noted above. Accordingly, in March 1962, the AEC notified Davison that its proposal to provide the commercial service, involving a baseload of Government fuels to supplement the fuels that would be supplied by licensees and others, constituted a satisfactory basis for further negotiation and development of definitive plans. Soon thereafter, NFS, a Maryland corporation organized and owned jointly by W. R. Grace & Co. and the American Machine & Foundry Co., replaced Davison as the entity to undertake the venture.

NFS would own, in addition to the proposed irradiated fuel processing plant, (i) an existing fuel fabrication facility previously owned by American Machine & Foundry Co. and located at Port Hope, Ontario, Canada, and (ii) an existing facility for the chemical processing of unirradiated uraniums, previously owned by Davison and located at Erwin, Tenn. NFS proposed to enter into a contract with the Bechtel Corp. for the design and construction of the new plant. In addition to the $8 million cash equity of the stockholders, NFS sources of funds include $13.3 million in bank loans and a $2 million grant from the Empire State Atomic Development Associates, Inc., a group of New York State utilities. The NFS plant would be located on a site in western New York State leased to NFS by the New York State Atomic Research and Development Authority (hereinafter referred to as "ARDA"), a public corporation of the State of New York. ARDA would also own and lease to NFS certain portions of the plant complex. The

ARDA site and facilities are valued at $8.5 million. Since November 1962, negotiation of an NFS–AEC contract for the baseload of Government fuels has been actively underway.

III. ESSENTIAL TERMS OF THE PROPOSED NFS–AEC CONTRACT

As currently drafted, the proposed contract calls for AEC to deliver and NFS to process irradiated fuels equivalent to approximately 125 "revenue units" annually over a 5-year period ending no later than June 30, 1971. A "revenue unit" is equivalent to about 1 day's work in the NFS plant, at design rates. In addition, AEC would deliver, for processing, certain irradiated fuels previously delivered to AEC by licensed reactor operators under the terms of AEC's March 1957 announcement. NFS would construct a chemical processing plant, and would process the irradiated fuels delivered by AEC essentially for a fixed charge. NFS would agree to provide chemical processing services, within the capability of its plant, for any licensee of the AEC or foreign government, during the term of the AEC contract, at charges and upon terms and conditions which, taken as a whole, are no less favorable than those contained in any contract between NFS and any of its other customers. The patent provisions in the proposed contract are essentially in the standard form set forth in the Atomic Energy procurement regulations, insofar as AEC reserves the right, in the Government, to take title to patents on all inventions. This is consistent with the provisions of section 152 of the Atomic Energy Act of 1954, which vest in AEC title to all inventions made or conceived in the course of or under an AEC contract, when the inventions are useful in the production or utiliztion of special nuclear material or atomic energy, except as AEC may waive its rights. It is the usual AEC policy to retain all rights in the Government in any inventions useful in the production or utilization of special nuclear material or atomic energy, and to grant royalty-free licenses in those inventions to members of the public. The contractor is sometimes permitted to retain certain licensing rights in inventions for use for purposes other than in the production or utilization of special nuclear material or atomic energy, in cases in which such inventions relate only incidentally to research and development work of the AEC and are in a field in which the contractor has an established industrial or patent position. In addition, AEC would have the right of access to all technical and cost data developed in the course of design, construction or operation of the plant, and could disseminate to the public including potential competitors of NFS, without charge for use, the more significant portions of these data.

IV. CONTEMPLATED ARRANGEMENTS BETWEEN NFS AND ITS CUSTOMERS OTHER THAN THE AEC

Concurrently with the development of the proposed contract with AEC, NFS has been negotiating processing contracts with the IRG members. To keep AEC informed and at AEC's request, NFS has furnished AEC with copies of its draft contracts with these utility companies, and we have been informed that there is now substantial agreement on their content although there may well be changes in these documents before they are executed. . . . .

(Remainder of letter not reprinted.)

Joseph F. Hennessey, Esq.
General Counsel, U.S. Atomic Energy Commission
Washington, D. C.

U. S. Department of Justice
Washington, D.C., August 9, 1963

Joseph F. Hennessey, Esq.
General Counsel, U. S. Atomic Energy Commission
Washington, D.C.

Dear Mr. Hennessey:

This will acknowledge your letter and enclosures of July 2, 1963, dealing with certain proposed contractual arrangements for the establishment of a privately owned chemical processing plant for treating irradiated fuel elements from nuclear reactors owned by the United States, licensees of the Atomic Energy Commission, and foreign governments. You have requested that we review the proposed arrangements "from the standpoint of any inconsistency with the antitrust laws." We summarize below the considerations which you have placed before us:

The plant in question would begin operations in 1966 and would be owned by Nuclear Fuel Services, Inc., which is the joint venture of W. R. Grace & Co. and American Machine & Foundry Co. Nuclear Fuel Services, Inc., proposes to enter into a contract with AEC for a 5-year period and a contract with five utility companies for a 15-year period.

While AEC has chemical processing facilities of the type in question, Nuclear Fuel Services, Inc., proposes to establish the first privately owned processing plant of that nature. Moreover, that plant will be able to process certain materials which AEC would not be able to handle without a plant expansion involving the expenditure of several million dollars.

The proposed plant will require an investment of $25 or $30 million in a new and uncharted field; and, if there has been any mistake in the calculations, it can develop into an unprofitable venture. In order for Nuclear Fuel Services, Inc., to break even, the new plant will have to perform about 220 days of processing operations per year, but the utilities' processing needs will require only about 90 days of work per year during the first 5 years (1966-70). To get the plant built at this time, it is essential that AEC give the plant 125 days of processing work during the first 5 years. Because of the limited amount of private work available during that period, it would be impracticable for more than one private plant to be established at this time. AEC has undertaken to assure that processing charges will not impose unreasonable or unfair financial burdens on the nuclear power industry and its consumers during the interim period when the proposed plant will be the sole private processing facility.

The private demand for processing services is expected to increase rapidly after 1970. In 5 years or so, a competitor could begin construction of a plant planning to enter the field in the 1970's, in anticipation of receiving, from AEC,

the same volume of Government business that is being given the currently proposed plant. The proposed processing plant would be established in western New York State. And, while the ratio of transportation cost to processing cost would be about 11 percent for a Massachusetts utility, it would be about 22 percent for a California utility. This, of course, would serve to encourage the development of a plant on the Pacific coast in the 1970's. AEC would seek to encourage such development by a company other than Nuclear Fuel Services, Inc., or its parent corporations.

In light of the present state of the art of processing irradiated nuclear fuel elements, and in light of the assurances you have given with respect to current and anticipated developments in that industry, we conclude that the joint venture of W. R. Grace & Co. and American Machine & Foundry Co., the proposed 5-year contract between Nuclear Fuel Services, Inc., and AEC, and the proposed 15-year contracts between Nuclear Fuel Services, Inc., and the five utility companies, should not be deemed impermissible from the standpoint of antitrust law or policy. However, we do believe that fewer problems of an antitrust nature would arise if the proposed plant were the undertaking of a single company rather than being a joint venture shared by two very large firms. We think you will agree that it is desirable that the Government encourage as much independence of action as possible on the part of firms capable of entering this processing field on an individual basis. Moreover, while there may be justification for 15-year commitments in the initial contracts between Nuclear Fuel Services, Inc., and the five utility companies, antitrust problems are less likely to arise in the future if subsequent processing contracts involve commitments for 5 years or less. We would hope that, at such time as the total demand for processing services becomes large enough to warrant the establishment of a competing processor, the entry of such a competitor will not be frustrated because the potential customers are virtually all tied to Nuclear Fuel Services, Inc., by long-term contracts.

Sincerely yours,

William H. Orrick, Jr.
Assistant Attorney General, Antitrust Division

DEVELOPMENT OF A COMMERCIAL COMPETITIVE SERVICE

Representative Price. What is your feeling as to what the Nuclear Fuel Services project would do in the area of promoting competition? Do you think it will encourage competitors to get into the field, or discourage others from getting into the field?

Mr. Ramey. I think certainly they will be in a quasimonopoly situation at the start, with the Commission having the right to provide service if a new utility can't get reasonable charges. We hope that the technical and economic information developed through the operation of the project will get around so that other potential competitors will see what the real costs are, especially for larger load, and that they will be able then to calculate whether it is to their interest to go into the business.

As Commissioner Wilson mentioned, probably the next place would be the west coast to have a facility.

Representative Price. If another competitor did enter the field, would the AEC be able to provide an additional baseload for another plant within the next 10 years?

Dr. Wilson. Yes, they would.

Mr. Ramey. Our obligation is just for 5 years on this one.

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