TITLE

NUCLEAR PROCESS HEAT AND THE PAPER INDUSTRY—
With Special Reference to New England

by

ARUN JOSHI

B.S., University of Kansas
(1958)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1960

Signature of Author . . . . . . Signature redacted . . . . . .
School of Industrial Management

Certified by . . . . Signature redacted
Faculty Advisor of the Thesis

Professor Philip Franklin
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "Nuclear Process Heat and the Paper Industry - with Special Reference to New England."

I would like to take this opportunity to express my gratitude to my thesis committee, Prof. Carroll L. Wilson and Prof. W.A.W. Krebs, for their guidance and counsel in the preparation of this thesis.

Thanks are also due to the Federal Reserve Bank of Boston for facilitating this study through a research grant.

Sincerely yours,

Signature redacted

Arun Joshi

ABSTRACT

NUCLEAR PROCESS HEAT AND THE PAPER INDUSTRY - WITH SPECIAL REFERENCE TO NEW ENGLAND

by

Arun Joshi

Submitted to the School of Industrial Management in partial fulfillment of the requirement for the degree of Master of Science.

Ever since 1945, study of nuclear technology and economics has been largely restricted to the problem of power generation. Very recently, however, attention has also been directed on such uses as process steam and space heating.

The first phase of this thesis is devoted to an analysis of nuclear steam costs from existing reactor systems. Cost threshold, where nuclear systems become competitive with fossil fuel boilers, is derived.

In the second phase we apply this cost threshold to the New England pulp and paper industry to determine the potential for nuclear reactors in the region. To put it another way, we tried to estimate the market for nuclear reactors in the New England pulp and paper industry over the next decade.

We find that the existing reactor designs are quite suitable for the generation of steam. Steam produced from such reactors would be competitive with conventional steam in regions where fossil fuels roughly cost 50¢ per million B.T.U. or more. Since New Hampshire and Maine, which are best wuited for paper plant location, fall in such a high fuel cost region, nuclear process steam should be considered as a definite alternative to conventional boilers. A market of 80,000 K.W. (thermal) of atomic reactor capacity exists in New England if 30% of the new pulp and paper plants, over the next ten years, use nuclear process steam.

Thesis Advisor: Carroll L. Wilson

Title: Professorial Lecturer
School of Industrial Management

TABLE OF CONTENTS

LIST OF TABLES

LIST OF EXHIBITS

Page

CHAPTER I

CHAPTER II

CHAPTER III

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF EXHIBITS

LIST OF EXHIBITS (Cont.)

CHAPTER I

INTRODUCTION

The Problem and Its Setting

Ever since the first nuclear pile went critical, scientists, engineers, economists, as well as the common man,have seen in the atom a gateway to endless reserves of energy. Years of hard experience and experimentation have rubbed some of the romanticism off the staggering discovery, but atomic energy still remains one of the hopes of mankind in the long future. Indeed, for many of the less-developed nations of the world which are not endowed with such fuel deposits as coal or oil, atomic energy is the only hope for a source of abundant energy. Countries like India, with high coal costs on one hand and with thorium deposits on the other, can gain immensely if nuclear energy becomes commercially feasible. Intense interest given to this field in that country is an evidence of the future potentialities of atomic power.

All these years, research and development in the field of peaceful uses of atomic energy were centered mainly on electric power generation. Installations like the Experimental Boiling Water Reactor, the Shippingport Atomic Power Station, the Calder Hall reactors, etc., were designed and built for the production of electric power. Of course, radioisotopes have also been in use but their consumption was somewhat limited. Only very recently did the engineer and the economist turn their attention to such uses of nuclear energy as process heat for industry and heating the home.

This study proposes to deal with the problem of the potential use of nuclear energy in the generation of process heat for industry. Process heat comprises a very large portion of the total energy input in many industrial operations. In all of the United States' manufacturing industries, nearly 80% of the total energy used is in the form of process heat and 20% for electricity. Table 1.1 gives a measure of the share of process heat in total energy used.

Although the industries in Group II (Table 1.1) use large amounts of process heat, the temperature requirements are much above what is now feasible with

TABLE 1.1

PER CENT OF TOTAL ENERGY CONSUMED AS PROCESS HEAT IN MANUFACTURING INDUSTRIES IN 1939, 1947, AND 1954

	1939	1947	1954
Group I (steam heat)			
Food and kindred products	78.7	76.7	81.0
Chemicals and allied products	65.1	67.6	67.2
Paper and allied products	56.2	59.2	62.5
Petroleum refining	93.0	92.8	93.0
Total	76.4	76.6	78.1
Group II (furnace heat)			
Stone, clay and glass products	85.0	84.9	86.2
Iron and steel	88.7	85.2	83.6
Nonferrous metals	50.1	42.0	37.3
Fabricated metal products	73.7	66.7	67.9
Total	84.2	79.8	77.8
Group III			
Others	66.8	69.8	63.9
TOTAL	78.2	76.5	74.6

Source: Perazich, George, "Nuclear Process Heat in Industry" (Washington National Planning Association, 1958) nuclear reactors. While industries such as the steel and cement utilize temperatures ranging from 1500°F. to 3000°F., nuclear reactors developed so far are unable to produce usable temperatures higher than 1000°F. Furthermore, some of the fuels also serve as chemical agents; this role nuclear fuels, of course, would be unable to play. For these two reasons, therefore, it seems that the potential for nuclear process steam lies in the industries of Group I, which use low temperature, low pressure steam heat. Many of the power reactors, which prove non-competitive these days because they are unsuitable for producing high temperature steam, would be quite appropriate to produce the low temperature process steam needed by these industries.

This study is made especially with the New England pulp and paper industry in mind. The New England paper industry appears particularly promising to us so far as the use of process steam reactors is concerned. This is for two reasons: 1) Firstly, it is one of the most important industries in the economy of New England and 2) New England is the most expensive area in the

United States so far as conventional fuels are concerned; therefore, it is in this region that nuclear reactors stand the best chance of becoming competitive. The best locations for pulp and paper mills are near the forests of Maine and New Hampshire. In these regions, costs of conventional fuel soar as high as sixty cents per million B.T.U. A reactor would make the paper mill completely independent of the problems of fuel haulage.

Because of the above two reasons, we decided that a more detailed analysis should be made of the nuclear process steam costs and its potential advantages to the New England paper industry should be determined.

Method of Research

To solve the above problem, research had to be done in three major fields:

A. Economics of nuclear process steam

B. Possible expansion of pulp and paper industry in New England over the next decade, and the probable location of new plants.

C. Health, legal, and administrative problems of commercial use of process steam reactors.

A. Before determining the economics, it was necessary to select the reactor types that might possibly be used for producing process steam. While most reactors are capable of producing steam from the engineering viewpoint, they are prohibitive economically. Such reactor types as the Fast Breeder Reactor and the High Temperature Gas-cooled Reactor were obviously ruled out because of their general inappropriateness to the problem of process steam generation.

Others, like the Sodium Graphite Reactor and the Aqueous Homogeneous Reactor, while capable of producing process steam, are relatively more complicated and undeveloped to inspire confidence in businessmen.[1]

---

[1] A recent survey of businessmen conducted by the Atomic Industrial Forum, entitled "A Growth Survey of the Atomic Energy Industry 1958-1968," listed the following criteria in descending order of importance:

1) The extent of total experience.
2) The number of large prototypes built and operated.
3) The number of pilot units which have been built or are being built.
4) The degree to which formal research programs have been undertaken.

After considering all the relevant factors, we decided on three reactor types that might possibly be feasible in the near future. They are (1) pressurized water reactor, (2) boiling water reactor, (3) organic moderated reactor.

Having decided upon the reactor types, we proceeded to derive the costs of process steam from these reactors. Since the costs vary widely with the size of the reactor, they had to be derived separately for each size. In Chapter II we found that, depending upon the size of the pulp and paper plant, the required reactor size would vary from 20 Mwt to 100 Mwt. To cover the entire range, we decided to derive cost estimates for three sizes: 20 Mwt, 40 Mwt, and 100 Mwt and over.

Anyone who has dealt with nuclear economics is probably aware of the plethora of cost figures that exists in this field. There were only two ways of selecting the most accurate figures out of this mass: we could either start from scratch and do an engineering and economic study on each reactor type and size; or we could base our process steam cost on existing nuclear systems. Since the former approach would have involved much more time and skill than we had at our disposal, we elected to use the latter approach.

As pointed out earlier, no actual data exist specifically pertaining to the generation of nuclear process steam. We, therefore, had to depend upon the data for power generation. After selecting an existing power reactor for each reactor type and range, we converted the power costs into process steam costs under certain assumptions. Costs for the 40 Mwt range were taken directly from Argonne National Laboratory designs for process steam reactors. Nuclear process steam costs were then compared with the costs of conventional process steam and a fuel-cost threshold was established at which nuclear steam becomes competitive with conventional steam. All of this was the subject of Chapter III.

B. Since the future expansion of the New England paper industry is the sine qua non of industry's interest in process steam reactors, we tried to forecast the future expansion in New England pulp and paper production. Basing our analysis on a U.S. Paper Consumption Forecast made by the Department of Commerce (see Chapter IV), we first estimated the future production of paper in New England. Estimates of pulp production followed therefrom.

To determine the probable location of new paper plants, we conducted interviews; we also considered such factors as wood resources, labor costs, and fuel costs.

C. To give a realistic picture of the health hazards of atomic energy, we gathered data on nuclear accidents, not only in America but also in the United Kingdom and Canada. Nuclear energy poses some rather peculiar problems for the commercial user. To understand them, we analyzed the pertinent section of the Atomic Energy Act of 1954. We also gave a brief summary of the methods of obtaining nuclear insurance open to the paper manufacturer.

Conclusions

1. After comparing the cost of nuclear process steam with conventional process steam, we concluded that

a 40 Mwt process steam reactor becomes competitive with conventional steam under the following circumstances:

Reactor Type	70% Load 15% Chg.	80% Load 15% Chg.	90% Load 15% Chg.	80% Load 8% Chg.
	Conventional fuel @ (per mill. B.T.U.)			
PWR	62¢	56¢	50¢	38¢
BWR	-	-	-	60
OMR	-	70	60	50

2. Although New England's share in the national paper production has been steadily decreasing over the past years, it should be expected to maintain its niche in specialties. According to our estimates, paper capacity should increase by 1,700 tons per day in 1965 and 2,300 tons per day by 1970. Corresponding figures for pulp capacity are 500 tons per day in 1965 and 800 tons per day in 1970.

Abstracting from fuel costs, the best location for this new capacity is in Maine and New Hampshire. New pulp and paper plants would need nearly 15 X 10^8 thermal K.W.H. per year. This means 240,000 K.W.T. of new steam capacity. If 30% of this capacity utilizes nuclear process steam, potential market in New England for process steam reactors amounts to 80,000 K.W.T.

3. Should a paper manufacturer decide to replace conventional boilers by atomic reactors, he would face no difficult problem from the viewpoint of public health. Stipulations of the Atomic Energy Commission, although strict, are easy to comply with. With the formation of Nuclear Insurance Syndicates and the passage of the Indemnification Act, the problem of insurance has also been solved.

Recommendation

Considering the above factors, it is strongly recommended that a paper manufacturer setting up a plant of 400 tons per day or more capacity, should give some thought to the installation of a nuclear reactor, if his plant happens to be located where fossil fuels cost 50 - 60¢ per million B.T.U. Admittedly, it would be a pioneering effort, but the game promises to be worth the candle.

CHAPTER 2

PAPER TECHNOLOGY [1]

Before we proceed with the task of deriving the cost thresholds for nuclear process heat, it is pertinent to give a very general description of the pulp and paper manufacturing process. Our interest here lies in the u usage rate of steam, the pressures, the temperatures and other variables that might be relevant to our study. the following paragraphs, therefore, should be studied from this perspective.

Conversion of Wood into Pulp

Over 90% of paper making fibers have their source in wood pulp. However, where wood is scarce, or special qualities need to be imparted to the paper, other materials are also used. Briefly, these are the main sources: Wood, rags, bagasse, bamboo, manila rope, cereal straw, flax straw, waste paper etc.

Since wood is the dominant raw material, we would describe the pulp manufacture process with special reference to wood.

---

[1] This chapter is largely based on personal interviews and the following two sources:

- i. Calkin, John B. *Modern Pulp and Paper Making* (New York: Reinhold, 1957)
- ii. Organization for European Economic Cooperation, *Pulp and Paper Industry in the U.S.A.* 1957.

Wood consists of 50% cellulose, 30% lignin and the remainder is hemi-cellulose, pentosans, and sugar. Lignin is the binding material and it must be removed before pure cellulose can be produced.

As a first step towards the manufacture of pulp the logs are barked. These days it is mainly done by exposing the revolving logs to jets ranging from water to superheated, high pressure steam. The pressure goes as high as 1400-1500 psi when water is used as the medium. There are other methods of barking like mechanical barking, drum barking, chemical barking, but none of uses steam in any significant way.

After barking, the logs are chipped. The multi-knifed chipper is the most common device for this purpose. Size of the chips produced varies from process to process. After wood has been chipped, it is ready for the digesters.

The various means of producing pulp might be classified as follows:

1. Mechanical Pulp,
2. Sulfite Process,
3. Soda Pulp,
4. Sulfate Pulp,
5. Semi-chemical Pulps,

and 6. Chemical Conversion Pulps.

In the following pages we would very briefly discuss these different processes. Our emphasis, it should be recalled, is on steam conditions and consumption and not on the mechanical or chemical details.

Mechanical Pulp: Logs or blocks of wood are ground against a revolving abrasive stone in presence of water. It is a very economical process since only 7% of the raw material is lost against 50% or more for chemical p processes. The fiber produced is short and is an ideal mix for long fibers to produce newsprint,bag paper etc. Unless the logs are steamed before grinding, very little steam is used in this process.

Sulfite Process: This pulp is made by cooking chips, usually from low resin content woods, under pressure and at an elevated temperature in a solution of calcium, magnesium or ammonium bisulphite with an excess of SO_2. A cooking cycle might be scheduled as follows using the hot acid system now employed in most sulfite mills:

Time of cook	9 hrs.
Digester Capacity	20 tons of wood.
Initial temperature	60 to 70 degrees centigrade.
Initial pressure	40 psi.

The first part of the cooking operation is the penetration period. This is so because of the fact that the acid constituent of the cooking liquor penetrates the wood more rapidly than the basic constituent. The temperature is slowly raised to 110°C and the penetration period is maintained for approximately 2 hrs. At the end of the penetration period the temperature should be

110°C and the pressure higher than 75 psi, if possible. The temperature is then gradually raised to 140°C. Around the fifth hour the temperature is 130°C and the pressure around 75 psi. Near the seventh hour the temperature is raised to 140°C and the pressure reduced to 40 psi. At temperatures much in excess of this figure the rate of reaction of acid and cellulose constituent of the fiber increases, resulting in loss of yield.

Very large amounts of steam are used in the sulfite process. For every ton of pulp nearly 9000 pounds of steam and two tons of wood are required. If the acid is introduced at a higher initial temperature(around 80°C) cooking time is cut by nearly two hours and a reduction of 2000 pounds of steam per ton might also be brought about.

Soda Process: Soda process is an alkaline process of converting wood into pulp. Chips are cooked with cooking liquor made up of sodium hydroxide. Normal cooking pressure varies from 100 to 110 pounds and maximum temperature is between 340 and 360°F. Steam required per ton of pulp also varies from 4000 to 6000 pounds.

Sulfate Process: This is also an alkaline process. Maximum temperature employed is in the proximity of 340°F. Length of time the digester is maintained at the maximum temperature varies from ½ to 2½ hours. The amount of steam required in a rotary digester is 3000 pounds per ton of pulp. In stationary digesters as much as 4000 pounds of steam are used for every ton of pulp.

Semi-chemical pulping: Increasing wood costs lead certain firms to devise means of getting higher yields from hardwoods. The research ended in semi-chemical processing of woods. In the batch cooking process, the temperature is around 340 to 350°F and pressure around 700 psi. In the continuous process the pressure is 140 to 170 psi. The amount of steam used is nearly 2000 pounds for every ton of pulp.

Before pulp is converted into paper it is bleached and given mechanical preparation to improve its quality. Both these operations use rather insignificant amounts of steam and it is enough for our purpose to know that stages like these exist.

Conversion of Pulp into Paper: Describing the transformation of pulp into paper is to describe the fourdrinier. Essentially, a fourdrinier converts pulp into paper by pressing and by removing water. Operations on the fourdrinier are shown in Ex. 2.1. The diagram is self-explanatory for our purpose.

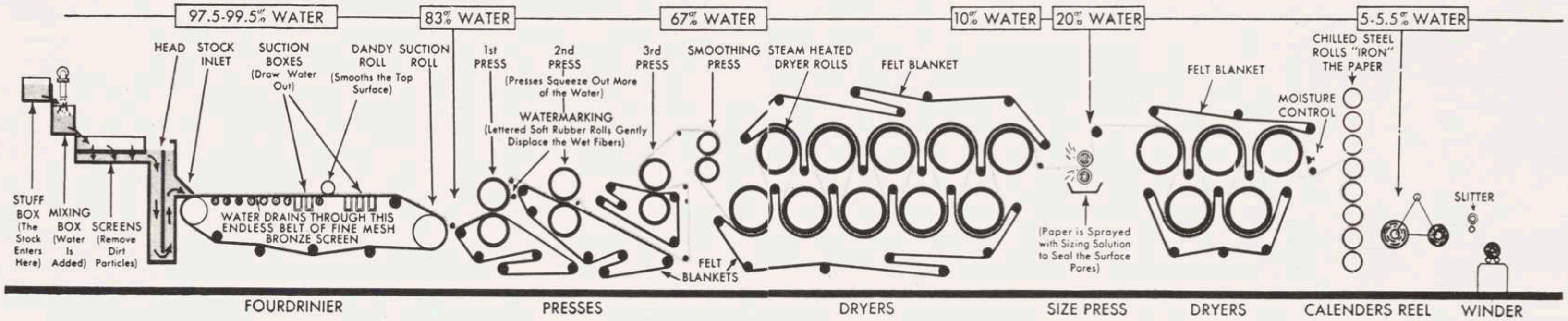
The moisture content of the sheet, which was between 60 and 70% as it emerged from the press section, depending on the type of paper, is reduced to 4 to 7% as it leaves the dryer section. The actual weight of the water removed is extremely large. For example, drying a sheet having 66% water to one having 7%, requires the removal of two tons of water for every ton of dry paper. To put it another way, a mill making 200 tons a day must provide enough heating facilities for the removal of 400 tons of water.

Removal of this water must follow an established path. At the beginning temperature of the drying cylinder should not exceed 180°F. The temperature of the last cylinder may be as high as 250°F.

Power Range of Steam Plants needed by Pulp and Paper Mills

Since most drives are electrical these days, use of steam is mostly required for process heat. As outlined above digesters and dryers are the two major users of process steam. Also, if the mill merely produces pulp, it needs steam to dry the pulp before shipping. Of course, pulp can be shipped wet-lap. Wet-lap, however, has higher transportation costs.

So far we have merely described the temperatures and pressures at which steam is used in pulp and paper manufacture; we have deliberately refrained from specifying the exact steam conditions. The fact of



Courtesy Hammermill Paper Co.

Ex. 2.1 THE FOURDRINIER

the matter is that there are many ways of achieving the requisite conditions. Each plant has its own method. From our interviews we gathered the following information:

The digesters use steam around 125-175 psi. Steam for dryers is around 40 psi. Many of the plants in the vicinity of New England were found to use process steam around 125 psi. Some plants, however, produce steam at higher pressure and run it through an extraction turbine. Pressure of steam is gradually lowered and the steam is extracted at different pressures as necessary.

In the previous discussion we have seent that consumption of steam in the manufacture of pulp and paper varies according to the process. While the sulfite process requires six to nine thousand pounds of steam per ton of pulp, the alkaline process requires only four thousand pounds. Here we would use a general figure of 6000 pounds of steam per ton of pulp. This amounts to nearly 5.4 million B.T.U. heat input per ton. Since an average pulp or paper mill produces around 250 tons per day, total annual heat requirements(on a 310 day basis) come to about 130 million thermal kilowatts(kwt).[1]

---

[1] Mr. Perazich comes to a substantially similar figure in his study Nuclear Process Heat in Industry, National Planning Association; 1958. See p. 28.

In other words, an average pulp and paper plant needs a steam plant of approximately 20 thermal megawatts (Mwt) capacity, assuming the load factor is 80% or so.

The largest plants, however, produce as much as 1200 tons per day. They can, at 80% load, use steam plants of nearly 100 Mwt capacity.

The range, then, in which nuclear steam plants are potentially applicable is

20 Mwt to 100 Mwt.

In the next chapter, we would study the cost of generating process steam from reactors in this range.

CHAPTER III

ECONOMICS OF NUCLEAR PROCESS STEAM

To a considerable extent, nuclear power has risen to its present importance through sheer faith in its eventual economic feasibility. Much has been written in this field that is without a rigorous scientific base. This is not to deny the existence of hundreds of millions dollars worth of nuclear technology, nor is it to cast a bad reflection upon workers in this field; the problem lies in the paucity of actual experience with nuclear systems.

Over the past three or four years, economics of power generating reactors have become clearer because of the actual operation of such reactors. These data also provide us with a starting point in the matter of nuclear process steam. Admittedly, gaps exist in our cost structure, gaps that have to be filled by certain assumptions.

After giving the structure of nuclear energy cost, we will outline the assumptions under which the subsequent cost estimates are derived. We will then scan the data available for Pressurized Water Reactors, the Boiling Water Reactors, and the Organic Moderated Reactors. Subsequently, we derive the cost of conventional process steam, which is then compared with nuclear steam costs.

Structure of Nuclear Energy Costs

Costs of generating process steam through nuclear reactors, or for any other form of nuclear energy utilization, can be classified as follows:

A. Capital costs
B. Fuel costs
C. Operating and maintenance

A. Capital costs: From the engineering viewpoint, almost all reactors are capable of producing process steam. It is in the cost of generating steam that the hitch lies. Since capital costs comprise by far the largest portion of the total costs, nuclear engineers have tried to reduce them in order to make nuclear reactors competitive with conventional boilers. Writing in 1958, Mr. Mayer estimated that the capital costs of a 40 Mwt reactor must fall around two million dollars in order to produce steam at sixty-five cents per million B.T.U.[1] He does not give any details of his cost estimates, but probably he includes conventional fuel at thirty cents per million B.T.U. or so. For high fuel regions, therefore, nuclear reactors could be a little bit more expensive and yet be competitive.

Capital costs vary immensely with reactor type and size. Table 3.1 should give some idea as to the difference in capital costs of the different reactor types. To do justice to the role of capital costs in steam generation, we would like to break them down into still smaller components. They might be said to be comprised of:

1) Site
2) Reactor building
3) Reactor vessel and the internals
4) Reactor instrumentation

1) Site: In the early days of atomic energy, scientists and engineers were very conscious as to the health hazards of nuclear fission. Consequently, they were somewhat over-cautious in their recommendations

---

[1] Mayer, Karl M., "The Market for Heat Reactors," <u>Nucleonics</u>, Vol. 16, No. 9 (Sept. 1958).

TABLE 3.1

CAPITAL COSTS OF DIFFERENT REACTOR TYPES[1]

Reactor Type	Cost per Kw thermal
Pressurized Water Reactor	$ 50
Boiling Water Reactor	70
Organic Moderated Reactor	140
Fast Breeder Reactor	150
Sodium Graphite Reactor	160
Aqueous Homogeneous Reactor	180
Sodium Cooled Heavy Water	215

[1] Source: United States Atomic Energy Commission, "Atomic Energy Facts," 1957, p. 100.

as to distance of a nuclear plant from inhabited districts. In 1950, for example, it was thought that a 180 MW reactor would need 220 square miles of area. At $50 per acre this amounted to $40 per KW. In 1955, due to experience and use of containment structure, the cost was brought down to $3 per KW, and on land closer to urban areas costing around $500 per acre.[1] In future, as more information becomes available, it is quite likely that some stipulations against possible health hazards would prove unnecessary. Even though site costs are higher for nuclear plants than for conventional plants, they form only 2% of the total costs of a process steam generation plant.[2]

For paper mills located in remote areas the site element in total capital costs might be even less significant. For some already established plants, the alternative cost of land might be negligible.

---

[1] Maxson, R.D., "Trends in Nuclear Power Costs," National Industrial Conference Board, Minutes of the 4th Annual Conference on Atomic Energy in Industry (New York Board: 1955) p. 99.

[2] *Ibid.*, p. 97.

2) Reactor building: Cost of site has been reduced partly through improved shielding and containment structure. The shield, along with instrumentation, is thought to be one of the items which costs about the same whether the reactor is 10 MW or 100 MW. Since we are dealing primarily with small reactors, the cost of shield per kilowatt of capacity is likely to run quite high.

3) Reactor vessel and the internals: Selection of structural materials for the reactor vessel and piping, etc., is important from two points of view. Firstly, dangers of corrosion and irradiation would be very much enhanced if a wrong choice is made. This danger is further aggravated in view of the fact that less than satisfactory knowledge is available in certain fields of nuclear technology. Secondly, structural materials have a significant bearing on the costs. Indeed, choice of structural materials is perhaps the area in which most significant cuts in capital cost can be effected.

By structural materials we mean cladding material as well as the material used for the pressure vessel and the primary system. Considering the limited performance demanded from a process-heat reactor (in regard to pressure and temperature) carbon or low alloy steel can be used to construct the pressure vessel, piping, heat exchanger, pumps, etc. In water-cooled systems carbon steel will, of course, corrode at a faster rate than stainless steel, but it is possible to maintain the pH under 10-11. This can be achieved by reasonably sized additions to the water quality control system. For Organic Moderated Reactors, however, there is no problem of corrosion.

For cladding the nuclear fuel, aluminum and zirconium are the two choices. At present, aluminum is the cheaper of the two. Under pressures of 30 psi or so a combination of aluminum cladding and carbon steel can perhaps be used. However, at a steam pressure of 200 psi, which is the requirement of a paper plant, the conditions might be too alkaline for aluminum cladding to be feasible. Under these conditions, the more expensive zirconium has to be used as the cladding material. It should be remembered, however, that aluminum cladding is economical only so long as the price differential between aluminum and zirconium exists. As the differential shrinks, the better corrosion characteristics of zirconium would definitely make it a better choice.

It is, perhaps, pertinent to point out here that no carbon steel systems have actually been operated. All past experience lies in the field of stainless steel systems. It was partly due to the fact that the cost differential between carbon steel and stainless steel was not important enough in a power reactor. For this reason, certain research and developmental work might be called for if carbon steel is to be used. It has been shown by many tests, however, that corrosion rate can be made acceptable by using standard methods of water quality control.[1]

4) Instrumentation and control: Because of the experimental stage of nuclear systems, they are characterized by somewhat elaborate instrumentation and control apparatus. Investment on such things tends to remain the same whatever the power level of the reactor might be. After greater experience with nuclear reactors, and after

---

[1] Argonne National Laboratories, "Study of 40 Mwt PWR, BWR and OMR for Production of Process Steam," (ANL 6009, 1959) P. 15.

they are more widely understood, it would be possible to dispense with a part of the instrumentation and share another small part between many reactors. These days, for example, the designer constructs self-sufficient plants. Structures like the overhead cranes for replacing fuel elements are, however, used very little. Under these circumstances, it is quite possible to design mobile cranes that would service a number of reactors.

In conclusion, we might say that even though the cost of instrumentation remains the same irrespective of the size of the reactor, there is ample likelihood that the need for such instrumentation will decrease as men become more familiar with nuclear systems.

B. Fuel costs: Choice of fuel lies between natural uranium and uranium oxide. They might, of course, be enriched with U_{235} to any desired degree, depending on the reactor design.

Difference between metallic uranium and UO_2, so far as the nuclear properties of the reactor are concerned, is very little. On the other hand, UO_2 has certain very definite advantages with regard to corrosion damage.

Uranium and thorium corrode badly in high temperature water. For slightly enriched reactors, it is very difficult to find a low-cross-section alloy that will make these materials corrosion-resistant. For water-cooled reactors, there are the following solutions to the corrosion problem:

1) High alloying
2) Use of UO_2

1) High alloying: We might give an excerpt from the proceedings of the Atomic Industry Forum that very aptly sums up the situation in this respect:

> It is highly unlikely that cladding can be sufficiently perfect to never expose the uranium to the coolant water...The other possible solution is to add something to the uranium to improve its characteristics, which can be done by making a uranium alloy, such as uranium-molybdenum, uranium-silicon, uranium-niobium...
>
> All alloying elements that improve the radiation damage resistance or the corrosion resistance properties of uranium alloys tend to give poor neutron economy, inasmuch as the alloying elements have a relatively high cross-section for capture of neutrons. Even if neutron economy is ignored, none of the alloys are suitable from both a corrosion-resistant and radiation-damage viewpoint. This means that either the life is seriously limited by radiation damage or by corrosion damage

> or both. The radiation may cause a rupture of the cladding and subsequent failure of one element due to corrosion, or the corrosion may be initiated by cladding defect. In either event, after several days of exposure to the hot water all of the uranium alloy and the contained fission products in the affected fuel might be released in the coolant stream.[1]

2) Use of uranium oxide: While alloying of uranium is full of the complicated problems outlined above, uranium oxide, because of its resistance to corrosion provides an excellent fuel. To draw once again from the proceedings of the Atomic Industry Forum:

> Uranium dioxide is an excellent material for the natural uranium fuel element because it is completely inert in high temperature water and is also satisfactory from a radiation damage viewpoint for a relatively high burn-up. The uranium oxide can readily be cold compacted into pellet form and then sintered to increase the density to in excess of 90% of theoretical density. By mass production techniques, the dimensions can be ground to extreme accuracy and the uranium dioxide loaded into zincaloy tubing. The enter temperature of the uranium oxide fuel elements may be as high as 2200°F. [2]

---

[1] As quoted in <u>Etherington Nuclear Engineering Handbook</u> (New York: McGraw-Hill, 1958) p. 12-61.

[2] <u>Ibid</u>., p. 12-62.

A discussion of fuel costs would be incomplete without giving a word about enrichment, even though full justice cannot be done to this topic in a study such as ours.

The economics of enrichment are essentially a question of balancing advantages that high enrichment offers in the field of reactor design, size and longer burn-up against the higher costs of enriched fuel.

Natural uranium reactors have to maintain an extraordinary neutron economy in order to remain critical. Because of this they are usually large in size. Since a process steam reactor should be compact, natural uranium is not well-suited for our purpose. Furthermore, natural uranium reactors must use such low cross-section materials as D_2O and graphite. To the extent that the incremental cost of these expensive materials is more than the incremental cost of U_{235}, for given design parameters, enrichment would prove more economical. It might also be pointed out that enrichment need not be very high to bring about a significant increase in neutron yield. As a matter of fact, the steepest gains in the neutron yield are made in the range of 0.7% - 5%. (See Ex. 3.1)

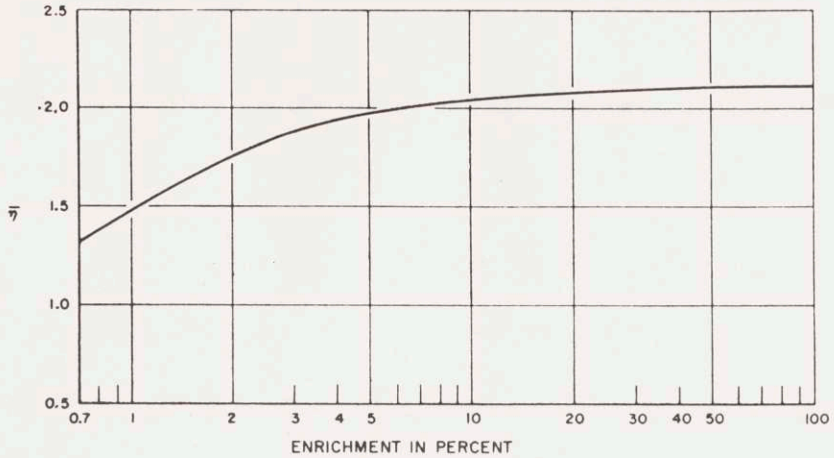
Another advantage of slight enrichment lies in the fact that increased burn-up cuts down actual reprocessing and fuel refabrication costs. Thus, doubling the fuel life, halves these costs.

These advantages of slight enrichment must be weighed against the higher costs of enrichment. Ex. 3.2 [1] gives an idea of how costs of fuel vary with enrichment.

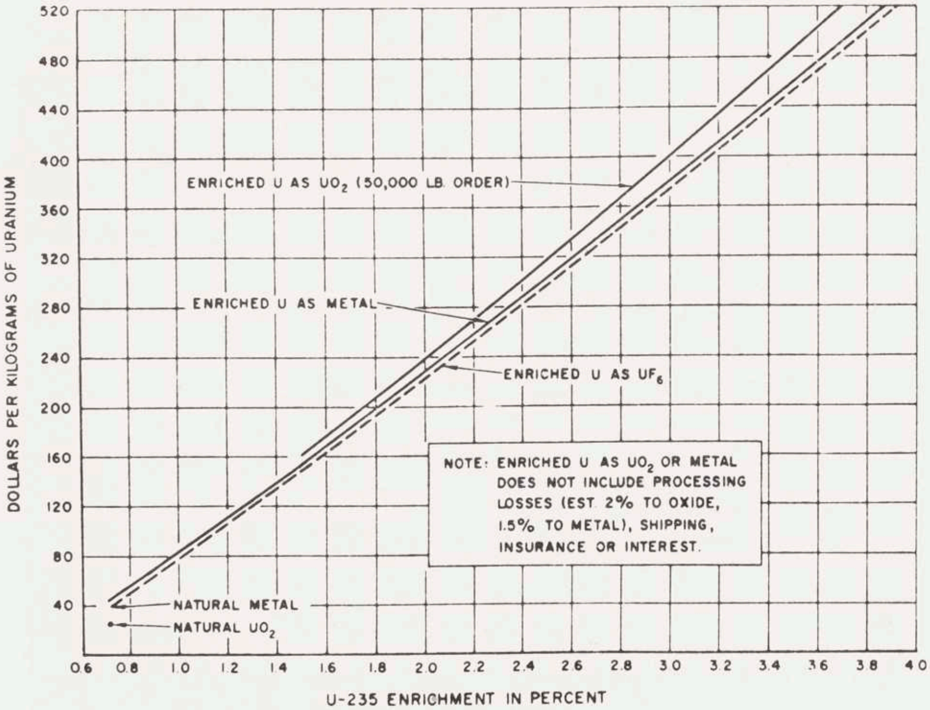
Briefly, then, these are the factors that should determine the percentage of U_{235} in the fuel. General opinion seems to be in favor of slight enrichment as against natural uranium. The exact percentage of U_{235} can, however, only be determined after the design is known. As Mr. Starr puts it, "First, he (the reactor designer) must determine the optimum enrichment for his reactor concept and the subsequent power costs associated

---

[1] Both Ex. 3.1 and Ex. 3.2 are taken from: Starr, Chauncey, "Fuel Enrichment and Reactor Performance," <u>Progress in Nuclear Energy</u>, Series VIII (New York: McGraw-Hill, 1959) pp. 213-215.



Ex. 3.1
Neutron Yield as a function
of U^{235} enrichment



Ex. 3.2
Cost of uranium as a function of
U^{235} enrichment

with optimum design, and then compare this cost with that of other systems."

C. Operating and Maintenance: Operating costs of an atomic reactor should not be expected to be any different from the operating costs of a conventional boiler.

Although some of the research staff that have been on the payroll of nuclear reactors up to this time, would not be needed once a process steam reactor design is confirmed, a greater number of specialists would be required to operate an atomic plant as compared to a conventional boiler. However, the total staff would perhaps be smaller. It might be pointed out here that even if the costs for a reactor are different from those of a boiler, it makes only a slight difference to the steam costs per million B.T.U.

Maintenance costs of a nuclear reactor, in general, depend on the complexity of the system. It might be very expensive to repair a part that was designed as inaccessible. Besides simplicity of design, use of standard parts can also cut down maintenance expenses.

Basis of Process Steam Costs

Selection of reactor types and power range:

In Chapter I, we considered the reactor types that might conceivably be used for process steam generation. They were: a) the pressurized water reactor, b) the boiling water reactor, and c) the organic moderated reactor.

In Chapter 2, we discussed the steam requirements of a pulp and paper mill. An average pulp or paper mill, we said can use a 20 megawatt (thermal) plant at 80% load factor, while the largest mills might use reactors of as much as 100 megawatt (thermal) capacity. From our interviews, we gathered that very few pulp mills would go above 500 tons per day. Such a mill would need a 40 Mwt steam plant at 80% load factor.

As we have pointed out earlier, the size of the reactor plant has a very significant effect on the capital costs per kilowatt (thermal), and thus on the annual capital charges. It is essential, therefore, for us to study the costs in each power range separately. In the following pages we would consider three reactor sizes: 20 Mwt, 40 Mwt, and 100 Mwt and over. These reactor sizes are merely meant to represent broad power ranges. While the first category is most easily found in industry, it is the second category which technically lends itself to economies of size as well as reactor material.[1]

The third category, even though it does not permit the use of such materials as carbon steel and aluminum cladding, has the lowest capital cost per kwt. Use of such reactors is, however, limited in the pulp and paper industry because of their size.

Not only must we differentiate reactors by size, but we must also consider each type separately. In the past literature, different reactor types have very often been grouped together so far as their economies go. This is somewhat misleading since there are substantial differences in the cost structures of different reactors. Such differences are important even for such similar types as the PWR and the BWR. Our task is then to consider the three reactor sizes in each reactor type. Unfortunately, this cannot be done with respect to the Organic Moderated

---

[1] Ritzman, Robert W., "History, Objectives and Program of Experimental Low-temperature Process Heat Reactor," USAEC No. IN-31, 1959, p. 1.

Reactors. It is only recently that they have come on the nuclear scene and very little is known about their actual costs. We shall consider only one 40 Mwt Organic Moderated Reactor for which reasonably reliable design and cost figures are available.

Most of the data in the field of nuclear technology pertain to power generation. There are two somewhat different ways of arriving at process steam costs from these data: We can either start from the basic design and consider the changes that would have to be made, and their effect on the costs, in order to generate process steam with the same apparatus; or, we can take particular reactors with operational experience and attempt to reduce their power costs to process steam costs under certain assumptions.

The first approach is out of the question because of time considerations, not to mention the author's lack of ability. It is the second approach that is used here. For greater accuracy we have based our cost estimates on reactors that have either been in actual operation for some time or that have been designed with a certain degree of thoroughness. Thus, costs for -

20 Mwt PWR are derived from a 1958 study based on APPR (Army Package Power Reactor).

40 Mwt PWR are derived from an ANL Process Steam Reactor design.

100 Mwt PWR are derived from the Yankee Atomic Reactor.

20 Mwt BWR are derived from the American Hydrotherm study.

40 Mwt BWR are derived from the ANL Process Steam Reactor design.

100 Mwt BWR are derived from the Dresden Atomic Reactor.

40 Mwt OMR are derived from the ANL Process Steam Reactor design.

Before deriving the cost estimates for these reactors, we must establish certain assumptions under which power costs are to be reduced to process steam costs as well as other assumptions with respect to the interest rate, rate of return, etc. This will be the subject of the next few paragraphs.

Assumptions underlying the cost analysis: With the above framework of costs in mind, we are ready to get down to individual reactors. Before doing that, however, it is wise to clearly state the assumptions under which the costs are arrived at. They are:

1) The load factor for all our estimates is assumed at 80%. Since the load factor in a pulp or paper plant is close to 90%,[1] ours is quite reasonable an assumption.

2) Next we must make an assumption as to the thermal efficiency between the reactor and the electric generator. George Perazich uses a figure of 35% for his calculations.[2] Considering the fact that almost all reactors operating in the United States (or, in other parts of the world, for that matter) have net efficiencies less than 30%,[3] or thermal efficiencies of about 30%, a figure of 35% seems a bit too high to us. Fortunately, for most of the reactors considered below actual thermal efficiency is available and we need not

---

[1] Dobrow, Morris C., "Paper Production and Capacity Survey," <u>Paper Trade Journal</u>, Vol.142, (February 24, 1958), p. 39.

[2] Perazich, George, "Nuclear Process Heat in Industry," Washington National Planning Association, 1958. p. 13.

[3] "Directory of Nuclear Reactors," International Atomic Energy Agency, Vol. 1, 1959.

enter into any conjectures. In those circumstances where actual information is not obtainable, we would use the figure of 30%.

3) We must also make certain assumptions regarding the annual charge per year. Again, for many of the following reactors, we would use the rates arrived at by the respective authorities. For others, we would use 15% as annual capital charge, including the rate of return on equity capital. This represents 7% for depreciation, 5% for cost of money, and 3% for insurance and taxes.

4) For some of the reactors considered below, capital costs for the reactor plant are aggregated with the power plant. We must therefore find some means to divide them between the two. We would use the following formula to estimate the power plant costs.[1] By subtracting

---

[1] It might be of interest to note the effect of a 10% error in the capital cost estimates, on the annual capital charge. Take the example of a 40 Mwt nuclear power plant that costs $4 million. If the costs of the reactor are assumed at 60% of the total, capital charge per year (at 15% and 80% load factor, 20 year life) comes to 40¢. If the reactor share is assumed at 70%, annual capital charge per year is 46-1/2¢.

3-21

the costs thus obtained from the total costs we would estimate the capital cost of the nuclear plant. Here is the formula:[1]

$$C = 2{,}250\ E^{0.76} + 330{,}000$$

where,

C = Capital cost of the power plant in dollars

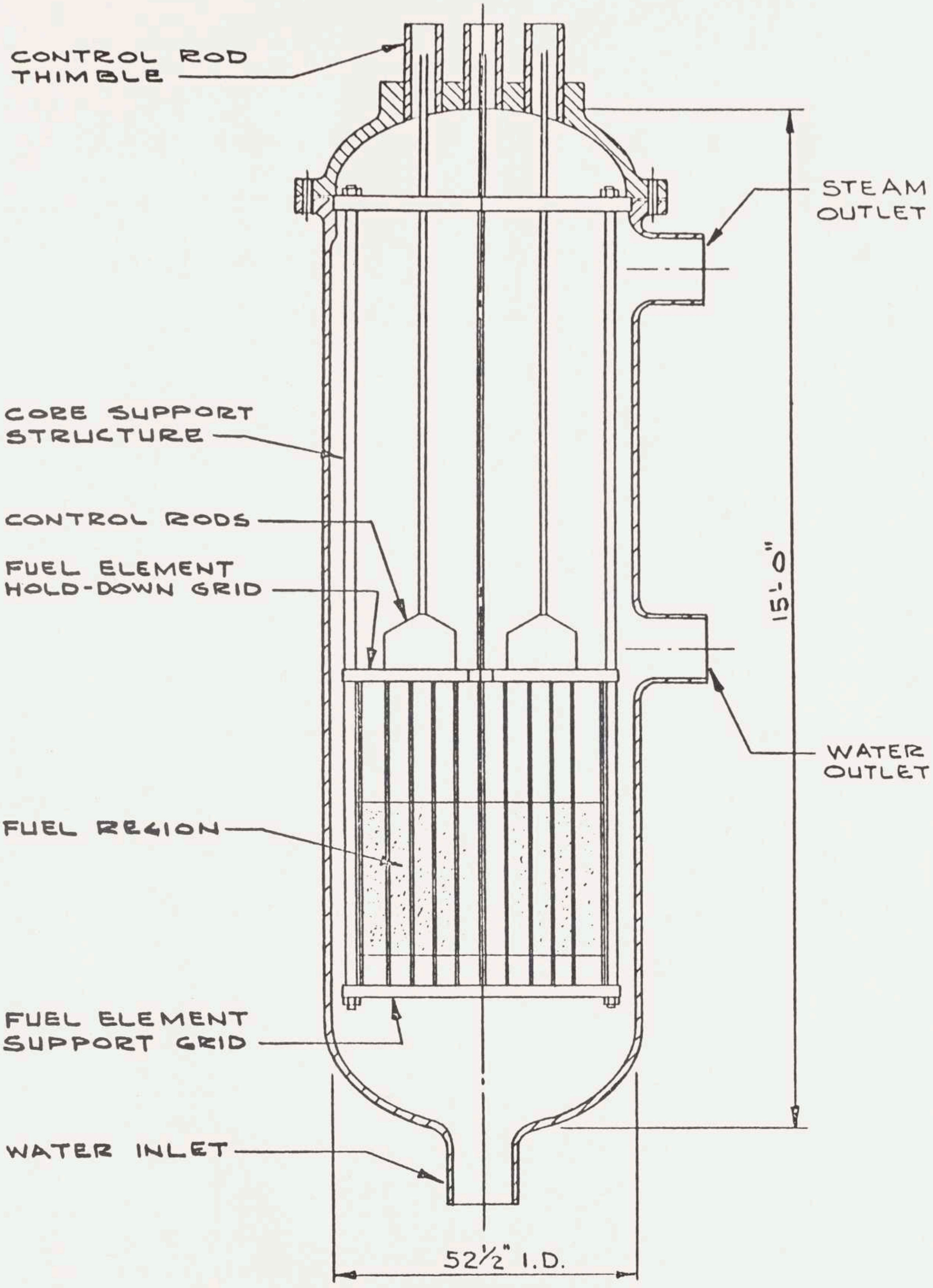
E = Rating of the power plant in electrical kilowatts

We also need to make some assumption as to the allocation of operating costs. Elimination of the power plant cannot be expected to bring about a proportionate reduction in all the overhead items. Most of the high-salaried specialists would remain, even if no power is generated. Under these circumstances, a reduction of one-third of the total operating costs seems to be the most likely.

5) The last, but one of the most important assumptions, pertains to those pulp and paper mills which generate their own electricity. Costs for process

---

[1] Williams, Donald G., "The Economics of Small Military Nuclear Power Plants," Management and Atomic Energy, (NICB, 1958). p. 91.



Ex. 3.3

REACTOR VESSEL SECTION

steam derived here are pertinent only to those mills which buy their electric power. To obtain reasonable figures for others, we would have to allocate a plethora of overhead costs between electric power and process steam. While this can be done for specific plant designs, no generalized analysis can be made that would be useful. However, costs derived here should be of interest to all mills as first approximations in the field of nuclear process steam.

Cost of Process Steam from Pressurized Water Reactor

Army Package Power Reactor:[1] Designed for the production of heat and electricity for remote locations, it went into operation in April, 1957, at Fort Belvoir, Virginia. It uses highly enriched fuel (93%) and it can operate without refueling for a year. As we would

---

[1] For more information, see:

Power Reactors, USAEC, 1958

Nucleonics, Vol. 15, No. 8, August, 1957.

presently see, steam produced with this reactor is very expensive. Its cost structure is nonetheless of interest to us since it is one of the few low-output pressurized water reactors in operation.

The following cost data are based on an article by Colonel Donald G. Williams.[1] Capital charges follow from the equation:

$$C = 300H^{0.91} + 570,000$$

where,

C = Capital cost in dollars

H = Rated heat output in thermal kilowatts

Total capital cost amounts to $1.8 million. Annual capital charges are obtained at 15% and the plant life is assumed at 25 years. Operation costs are derived from power costs for small reactors given in the same article.

Fuel costs, if enriched uranium is used, are 110 cents per million B.T.U. (based on 15 mills per electric K.W.H.). Such a high enrichment was necessitated by the

---

[1] Williams, *Op. cit.*, pp. 90-94.

special purposes for which the reactor was designed. The reactor design can be varied, without significantly adding to the capital costs, to use slightly enriched uranium. Consequently, in the estimates below we would use the fuel cost estimated for the 40 Mwt Argonne National Laboratory Reactor Design.[1]

Cost Estimates for a 20 Mwt
Pressurized Water Reactor
(Based on APPR-1)

Item	Cents/mill. B.T.U.
Capital Charge (including initial fuel inventory)	96
Operating Costs	39
Fuel	21
Total	156

40 Mwt Argonne National Laboratory Pressurized Water Reactor for Process Steam[2]

Description of the reactor: Under a request from the AEC, the Argonne National Laboratory made a specific

---

[1] See page

[2] This discussion is primarily based on two sources:
a) Argonne National Laboratory, "Study of

study of process steam reactors. A product of expert and thorough design, this is the best available information source in the field of process steam. We would, therefore, describe it in much greater detail than we have done in the case of the small APPR or the Yankee Atomic Reactor. Especially, we would like to point out those features of this reactor that have contributed to a reduction of costs of process steam.

General Plant Design: Ex. 3.4 and Ex. 3.5 describe the general plant design. The reactor is enclosed by a containment vessel 56 feet in diameter and 70 feet in height. All the primary equipment is installed in the containment vessel. The process steam condensate deaeration, and feedwater treatment plus the demineralized water make up for the primary circuit are located outside the containment vessel. All other operating equipment is installed in a room adjacent to the containment vessel.

The entire plant is located in an area of little more than two acres. It is assumed that access roads,

---

40 Mwt PWR, BWR, and OMR for Production of Process Steam" (ANL-6009, 1959).

b) ANL-6009, Addendum.

plenty of electricity and service water at 60°F. are available in the neighborhood.

A summary of the most salient data for the reactor is given in Table 3.2. Some of the features would be given greater attention in the following paragraphs.

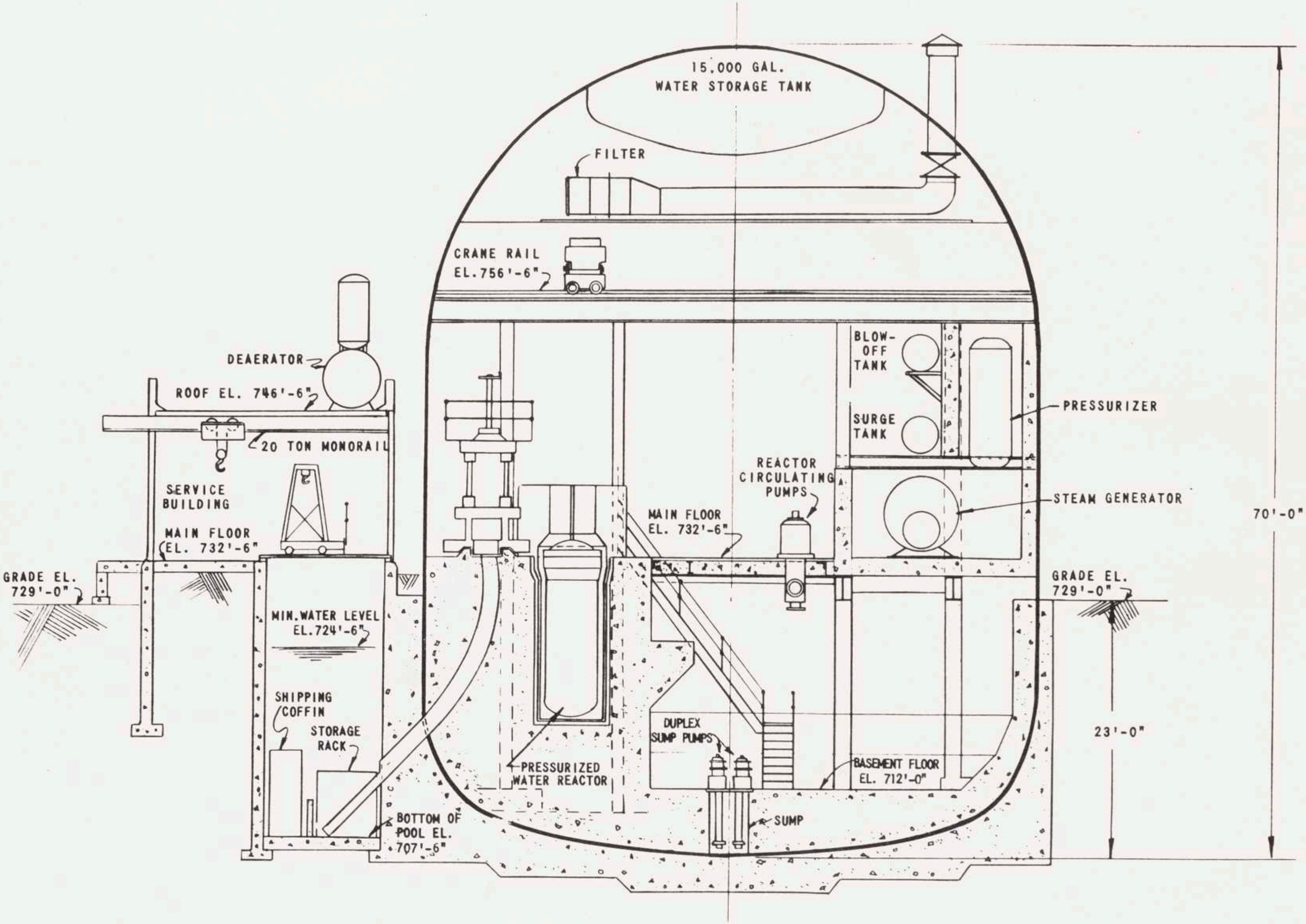
Fuel: One of the basic design criteria of the reactor core was low enrichment and high burnup. This was primarily done through a high non-water to core water ratio.

The fuel used in this reactor is uranium oxide in pellet form with 1.8% enrichment. Although UO_2 is expensive, the authors of the ANL study expect its price to go down with growing demand and with new techniques such as oxides swaged in tubes. Eighty-four UO_2 pellets are enclosed in a zircalloy tube of 0.5" O.D., 0.02" wall thickness, and 43.875" long. There is some debate as to the suitability of aluminum as cladding. But general consensus of opinion seems to indicate that corrosion rates of aluminum-with carbon steel system-would be intolerably high at a pressure of 196 psia. If the steam pressure is around 30 psia, as might be the case in a

TABLE 3.2

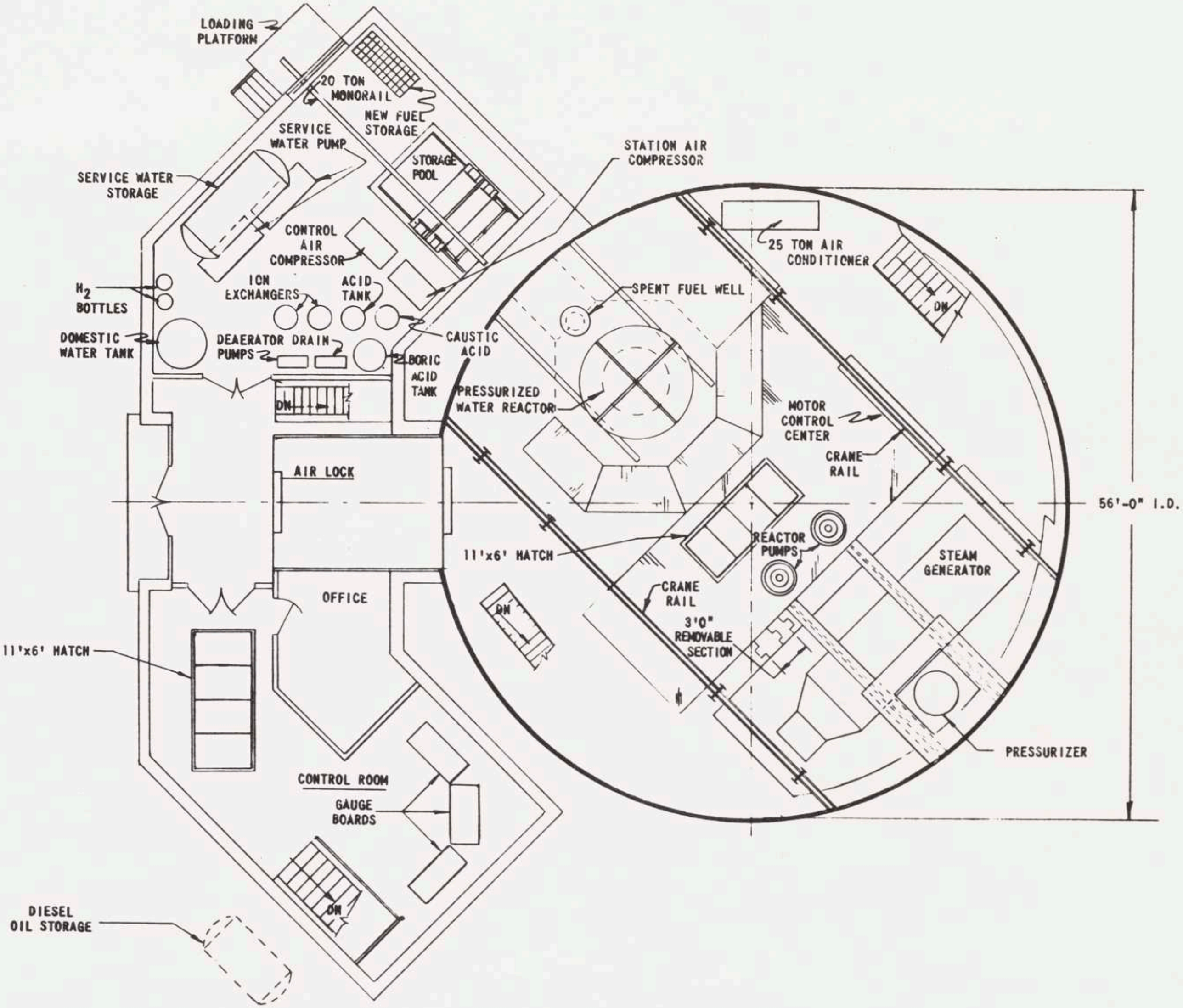
SALIENT DATA FOR 40 Mwt PWR

Power, Mwt	40.6
Core diameter, inches	42
Core length, inches	42
Core volume, liters	953
Coolant	Water
Primary flow rate, lb./hr.	4.22×10^6
Inlet temperature, °F.	400
Outlet temperature, °F.	430
Pressure, psia	900
Enrichment, %	1.8
Initial loading of uranium, Kg	3,380
Burnup, Mwd/M.T.	17,200
Process Steam Conditions	
Flow rate, lb./hr.	1.25×10^5
Temperature, °F.	380
Pressure, psia	196

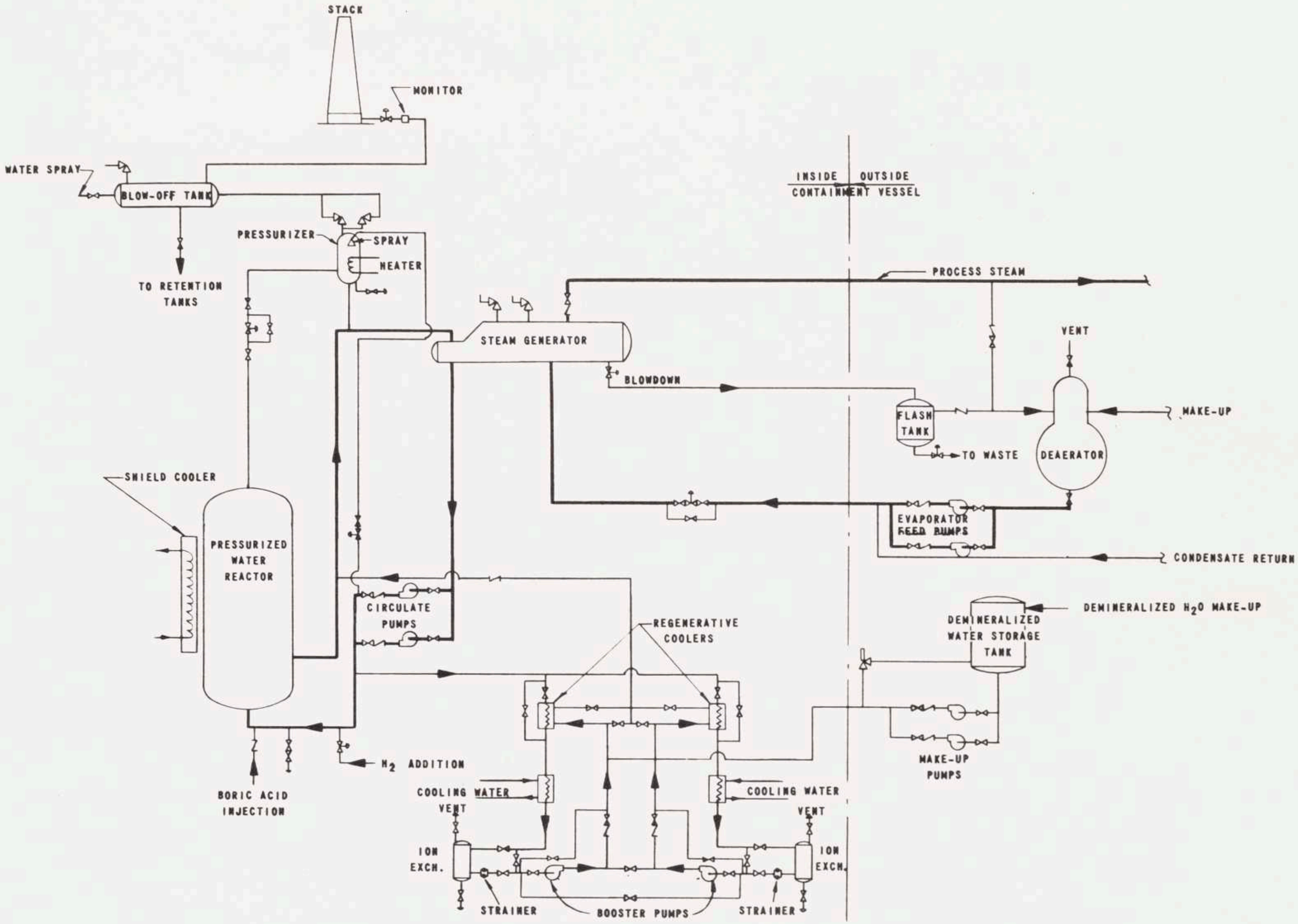


Ex. 3.4

PWR ELEVATION



Ex. 3.5
PWR MAIN FLOOR



Ex. 3.6
PWR Flow Diagram

non-integrated paper mill where steam is only desired for the dryers, aluminum cladding can be used to bring about a further reduction in the capital costs. Sixty-four such fuel rods make up one sub-assembly, and the core is made up of fifty-two sub-assemblies. The initial loading in the core is 3380 kg.

Pressure Vessel and other Internals: It is in the construction of the pressure vessel and the internal structure that most of the capital cost savings are accomplished. Emphasis is primarily placed on inexpensive structural material and a simplicity in design.

The pressure vessel is 56" inside diameter, 168" deep by 2.5" thick, and is made of SA212B carbon steel. (See Ex. 3.4) The upper and side thermal shields are made of 1% boron steel. The fuel containment frame is made of 0.125" thick zircalloy formed and welded into an assembly of 52 fuel cavities and 12 control rod cavities. The thermal shields, lower grid, and fuel containment frame may be assembled outside the reactor and lowered into position. The control rods are comprised of 2% boron stainless steel blade and a zircalloy clad UO_2

3-29

follower. As might be expected, it has been designed for rugged conditions under minimum of servicing. Since the control rods are made after proved design, they should be expected to assure the safety of the reactor under extreme conditions.

Primary Cooling System and Water Quality Control: Wherever possible standard parts are utilized to make up the primary cooling system. The system is designed and built according to ASME codes, under certain pressure and temperature specifications.

The steam generator is a two-pass shell and U-tube type heat exchanger approximately 84" O.D. and 25' long. The heat transfer surface is made up of 975 Monel tubes per pass. Monel is used for the tubes because of its ability to stand high chloride concentrations and corrosion.

The pressurizer vessel is made up of carbon steel. Pressure is always maintained above the saturation pressure.

Ion exchangers are used to maintain the purity of the water. The water is maintained at a high pH by lithium, potassium or ammonium cation resins. Hydrogen gas is dissolved in the reactor coolant to induce recombination of the water dissociated in the reactor core.

Full arrangements have been provided for the disposal of wastes from the plant. All wastes are collected in two 3000 tanks where they are monitored before being released to the plant sewer.

The shielding: Inside, to protect the pressure vessel, thermal shields of boron steel are used. Outside, 3" of steel and 4' of concrete are provided to absorb all radiation. Height of the concrete outside the vessel is 13.5 feet. Steel is chosen instead of lead or other materials because of the ease with which it can be fabricated, it is self-supporting and has good strength characteristics. The shielding above the core is provided by about 6 feet of water which takes care of the fast neutrons, and 4" of borated steel which keeps down the capture gammas. Below the core, the shielding is provided by a 3" steel plate which is also used to support the vessel. Since there is danger of primary cooling system becoming radioactive, all the primary system components are provided with a concrete shield of 2 feet thickness.

Instrumentation: Authors of the ANL study recommend a certain change in the control philosophy. According to them more emphasis should be placed on annunciators that would alert the operators rather than provide automatic control. The instrumentation in this reactor is, therefore, simpler than the instrumentation in most power reactors. The primary system has also been made simpler by providing only one loop and a minimum of motor operated valves.

The Secondary System: There is nothing unusual about the secondary system. It is of conventional design based on a return condensate temperature of 150°F. and 25% make-up (35,000 lb./hr.) at 60°F. Of course, the make-up might have to be varied in a pulp or paper mill. This would depend upon the amount of water that is absorbed by the materials in process, or lost. The secondary system is composed of a deaerating make-up water heater, two deaerating heater drain pumps, and a steam generator blowdown flash tank.

Containment: For the safety of the personnel and the neighborhood in the event of an accident, a containment vessel is provided. Designed according to ASTM standards, it will hold pressures of up to 27 psig. This is the pressure that would result if the water in the primary system were instantly released to the containment vessel.

Costs of Process Steam

Capital costs: Capital costs for the simple reactor design described above were made by Sargent and Lundy in consultation with the Argonne National Laboratories. The costs are largely based upon quotations. Since a large number of standard parts were used, such quotations were easy to get. Table 3.3 gives the capital cost estimates for the system. Table 3.4 gives the annual charge per million B.T.U. under different assumptions.[1] We have chosen the costs that fit in with our original assumptions, viz., 80% load factor, and 15% annual charge. There might be some argument as to our use of the carbon steel costs. In the past, only stainless steel systems

---

[1] Original cost estimates were given in cents per thousand pounds of steam. To convert these costs into cents per million B.T.U. we made the assumption that a pound of steam roughly equals a thousand B.T.U.

TABLE 3.3

40 Mwt PWR Capital Costs

	Stainless Steel	Carbon and low alloy Steel
A-Land	Not Incl.	Not Incl.
B-Structures	$ 561,000	$ 561,000
C-Equipment, Piping etc.	1,489,450	1,270,750
D-Electrical	112,000	112,000
E-Misc. Equipment	22,000	22,000
F-Personnel Training	Not Incl.	Not Incl.
G-Startup Supervision	Not Incl.	Not Incl.
H-Contractor's overhead and Profit	Incl. above	Incl. above
Sub-total(A to H)	2,184,450	1,965,750
I-Contingency, 10%	218,550	196,250
J-Top Charges-15%	360,000	324,000
K-Allowance for Escalation	Not Incl.	Not Incl.
Grand Total	$2,763,000	$2,486,000

TABLE 3.4

CAPITAL INFLUENCE ON STEAM COSTS
(Cents/million B.T.U.)

Annual Capital Chgs.	8%		15%		25%		Total Plant Capital Cost
Plant Factor	90%	70%	90%	70%	90%	80%	
PWR - Stainless Steel	22	29	42	54	70	90	$ 2,763,000
- Carbon Steel	20	26	38	49	63	81	2,486,000
BWR	18	23	34	44	56	73	2,226,000
OMR	18	24	34	44	57	74	2,260,000

have been used since it was thought that stainless steel did not make too much difference to the total costs of a nuclear power plant. Although, greater experience has been gathered with stainless steel systems, we believe carbon steel is quite compatible with zircalloy clad fuel elements.

Fuel costs: Fuel charge is independent of the load factor; it only depends upon the burnup. At a burnup rate of 17,200/Mwd/M.T., the PWR would have a fuel charge of 20¢/10^6 B.T.U. The factors considered in its calculation are price of uranium as UF_6, conversion of UF_6 to oxide or metal, processing charge, including conversion of uranium and plutonium nitrates to UF_6, and plutonium metal and finally credit is taken for the residual values of uranium and plutonium in the spend fuel.

Fuel inventory: Fuel inventory is made up of the following components--in addition to the fuel in the reactor:

1) one month's supply of fuel in fabrication.
2) six months' supply of new fabricated fuel
3) six months' supply of partially spend fuel waiting to be reloaded.
4) three months' supply of spent fuel in the decay storage, and one month's supply of spent fuel in shipping and in process.

For purposes of determining an inventory charge:

1) Total quantity of uranium is assumed to have a rental charge of 4%, based on its original value as UF_6.
2) A 6% money charge is placed on all fuels fabricated ahead of the reactor.
3) The fabricated value of the fuel in the reactor is treated as a capital item and is charged off at 8% or 15%. For our purpose, of course, we would use 15%.

Under the above conditions, assuming the load factor is 80%, fuel inventory charges for the PWR come to 13¢/million B.T.U.

Operating costs: Operating costs for the PWR are estimated as follows:

Labor - direct	$ 70,000
- indirect	15,000
Supplies and Maintenance	40,000
Manufacturing Expenses	25,000
	$150,000

At 80% load factor the operating costs come to 17¢/10^6B.T.U.

Adding all the different components of nuclear process steam costs, we come up with the following estimate of costs per million B.T.U.

Cost Estimates for 40 Mwt Pressurized Water Reactor
(Based on ANL Reactor design for 40 Mwt PWR Reactor)

Item	Cents/million B.T.U.
Capital costs	43
Operating costs	17
Fuel	20
Fuel inventory charge @15%	13
Total	93

Yankee Atomic Reactor[1]

Description of the Plant: Rated at 500 thermal Mwt, this reactor is our source for cost estimates for 100 Mwt and over range. It was designed by Westinghouse and it is scheduled to go into full operation in 1960 at Rowe, Massachusetts.

Fuel used in the Yankee Reactor is slightly enriched (3.4%). One hundred fifty sintered UO_2 pellets clad with stainless steel form the fuel rod. Approximately 300 such rods comprise the core. The core itself is a right circular cylinder 74" diameter and 90" high. The reactor

---

[1] For more information see:

Power Reactors, USAEC, 1958.

Geneva Paper, P/1038, 1958.

vessel is 31.5' in height and 9'1" in inner diameter. It is clad with stainless steel on the inside. Shielding is provided with a combination of steel (15" thick) and water. Concrete is used for biological shielding.

Cost of Process Steam:[1] Estimates of capital costs made in 1959 for this reactor are as follows:

Reactor plant	$ 29,900,000
Initial Core and working capital	5,100,000
Total	$ 35,000,000

To convert these capital costs into charge per million B.T.U., 80% load factor, 40 year life and a 14% annual charge was assumed. These are also the numbers used by the company to calculate power costs. Fuel costs for process steam were converted on the basis of 28% thermal efficiency which is the thermal efficiency of the reactor. Operating costs were also converted in the same way and then reduced by one-third to take into account the removal of power generating plant. Under these conditions, total steam costs came to be as follows:

---

[1] Based on data provided by International Atomic Energy Agency in the Directory of Nuclear Reactors, 1959.

Item	Cents/mill. B.T.U
Capital charges for reactor	41.0
Fuel replacement	28.7
Operation and maintenance	11.5
Total	81.2

Cost of Process Steam from Boiling Water Reactor

American Hydrotherm Corporation Reactor Design for 20 Mwt Boiling Water Reactor:[1] Our cost estimates for a 20 Mwt BWR are based upon a reactor design produced by the American Hydrotherm Corporation, under contract with the USAEC.

Description of the Plant: Designed specifically for producing process steam, this reactor would have a steam send-out capacity of 68 million B.T.U. per hour. The steam temperature and pressure are 400°F. and 250 psig, respectively.

To give a general idea of the engineering features of this plant, it is perhaps best to quote directly from the Hydrotherm study:

---

[1] This discussion is based on Geiringer & Goodfriend's Potential Applications of Nuclear Energy for Process and Space Heat in the United States, 1958.

> The reactor will consist of a vertical pressure vessel (designed to withstand pressures up to 600 psig) in which the fuel element core is arranged...All primary loop components in direct contact with the coolant are fabricated out of stainless steel...The fuel elements, containing partly enriched uranium, are set in a regular square pattern separated by control rods...M-388, an alloy of nickel-iron-silicon and aluminum with small admixtures of copper, lithium, cadmium and boron, has been chosen as the element cladding material...Present expectancy is that the reactor core would be replaced after every 2-3 years of operation, although this interval will probably be lessened as reactor technology advances.
>
> A containment vessel shall enclose the entire reactor and heat exchanger. The only lines leaving the containment vessel shall be those lines carrying the steam or high temperature water of the secondary system...Extensive use is made of ordinary concrete as shielding material in the plant. Radial shield around the reactor is 8' thick.[1]

Cost of Process Steam: Since this reactor design was especially created for process steam generation, we expect its cost estimates to be much more accurate than those for the 20 Mwt Pressurized Water Reactor, which was based upon the Army Package Power Reactor. Table 3.5

---

[1] *Ibid.*, p. 40, 41, and A-18.

TABLE 3.5

Estimated Investment Cost for 20 Mwt BWR

Item	Cost	
Site Preparation	$ 41,500	
Reactor Building	235,500	
Service Building	32,000	
Reactor and Primary System	533,200	
Auxiliary Systems	287,800	
Direct Cost		$1,130,000
Contingency	282,500	
Engineering SErvices	353,100	
Profit	176,600	
TOTAL		$1,940,000

gives the detailed capital costs for this plant. Although operation and maintenance costs for this reactor were also calculated with equal accuracy, we would refrain from giving their details here. In the study of Hydrotherm Corporation, the annual capital charges were made on a rate of 6.3%; we have converted them to 15%. We have also modified the fuel inventory charges in light of the Argonne study.[1] A blanket rate of 4% used in the Hydrotherm study does not take into account the different kind of inventories, and seems rather low to us.

Under 80% load factor, 15% annual charge, using low-enrichment fuel, we have the following estimates for the 20 Mwt process steam reactor:

Cost Estimates for a 20 Mwt BWR
(Based on Hydrotherm Reactor Design)

Item	Cents/million B.T.U.
Capital charge	55
Operating cost	31
Fuel	28
Fuel inventory	18
Total	132

---

[1] Argonne National Laboratories, *Op. cit.*, pp. 109-110.

40 Mwt Argonne National Laboratory Boiling Water Reactor for Process Steam[1]

Description of Plant: Our cost estimates for the 40 Mwt BWR are based on the ANL design. Designed especially for the generation of process steam, this reactor is based on proved BWR design. It can be built without further research and development, although some items, such as the use of carbon steel instead of stainless steel, might be further clarified with greater information.

Before giving the cost estimates for process steam, we would like to give more details about this reactor design.

General Plant Design: The reactor is contained in a vessel 56' in diameter and 77' over-all height. A general idea of the inside of the reactor building can be obtained from Ex. 3.7 to Ex. 3.8. A brief summary of the reactor characteristics is given in Table 3.6.

Fuel: UO_2 in pellet form and clad with Zr-2 is used as fuel in this reactor. The rods have an outer

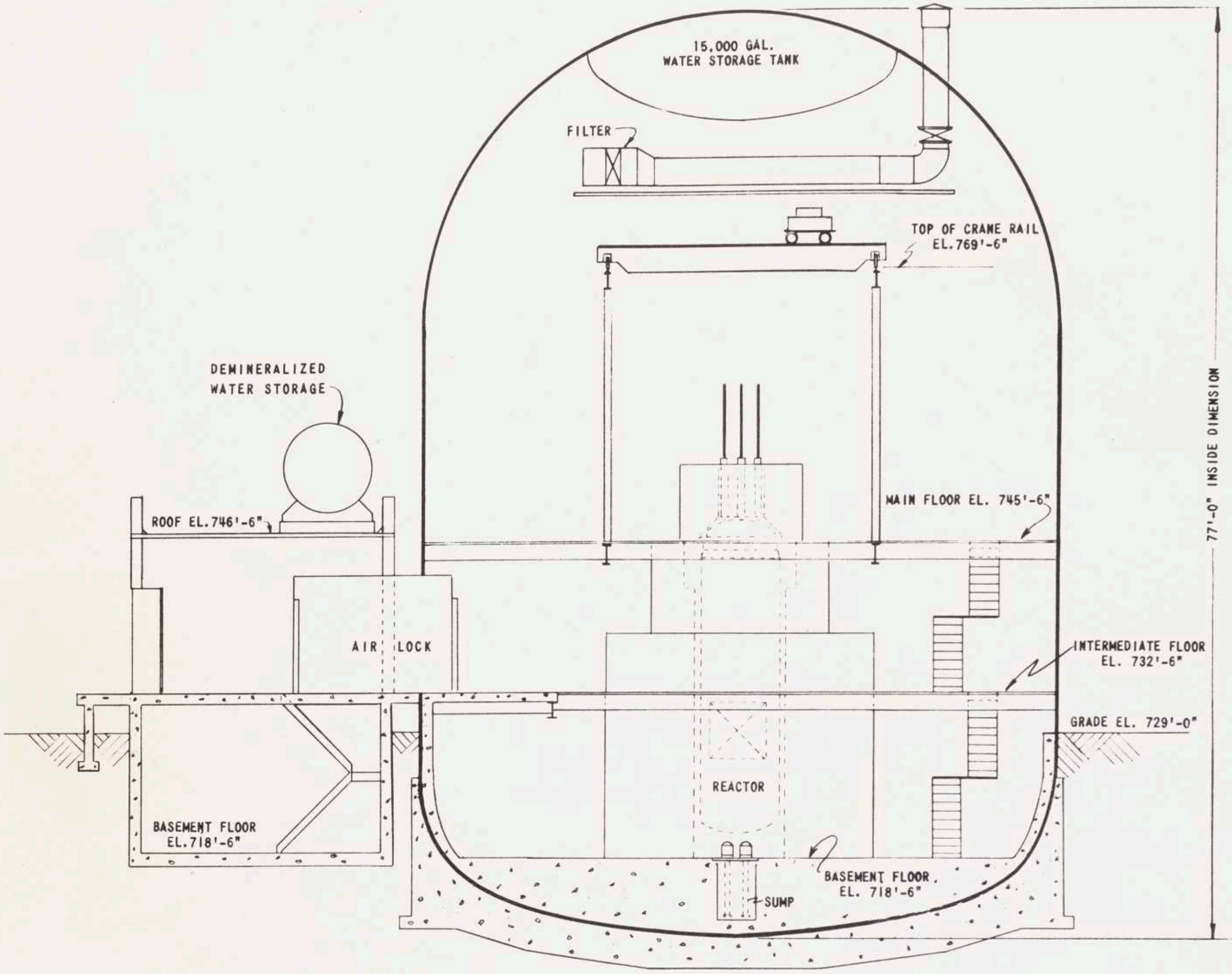
---

[1] Argonne National Laboratories, Op. cit., pp. 41-71.

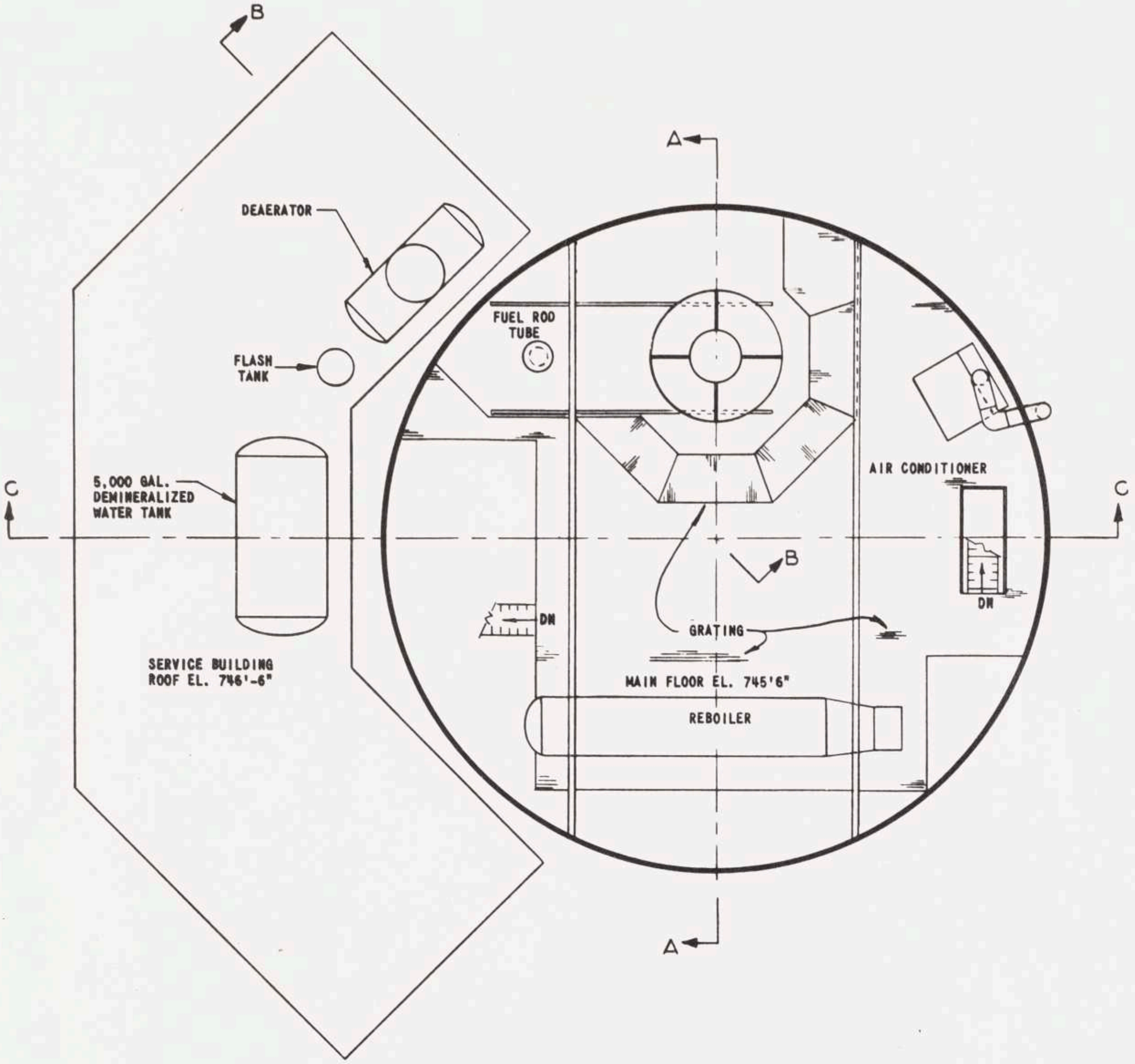
TABLE 3.6

SALIENT DATA FOR 40 Mwt BWR

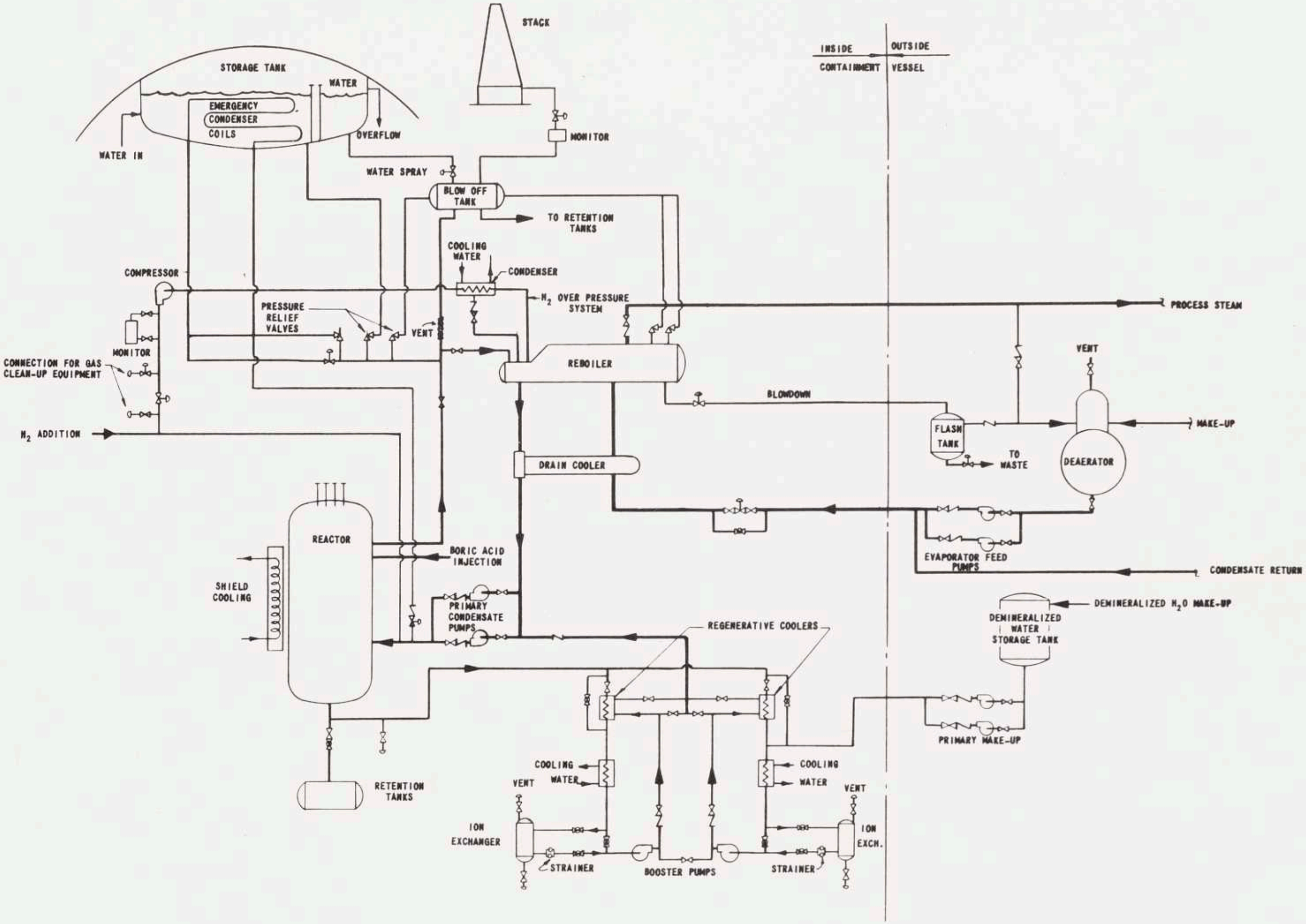
Power, Mwt	40.6
Core diameter, inches	56.3
Core length, inches	60
Core volume, liters	2442
Coolant	water
Primary flow rate, lb./hr.	1.39×10^5
Inlet temperature, °F.	239
Outlet temperature, °F.	427
Pressure, psia	333
Enrichment, %	1.5
Initial loading of uranium, Kg	10,300
Burnup, Mwd/M.T.	12,300
Process Steam Conditions	
Flow rate, lb./hr.	1.25×10^5
Temperature, °F	380
Pressure, psia	196



Ex. 3.7
BWR ELEVATION



Ex. 3.8
BWR - MAIN FLOOR



Ex. 3.9

BWR – FLOW DIAGRAM

diameter of 0.555" and a length of 60". The fuel element consists of a 9 X 9 array of fuel rods. In the core itself a total of 60 fuel elements is used under normal conditions.

<u>Pressure Vessel and other Internals</u>: Design of the pressure vessel is of maximum importance for a boiling water reactor. In this case the pressure vessel has been designed according to the Boiler Safety Act of 1952, which gives specific instructions as to the design of nuclear boilers. The pressure vessel is made of carbon steel with a lining of 0.1875" thick stainless steel. The vessel has a nominal inside diameter of 84" with a height of 25'3". The core is supported by a 6" thick grid. The top surface of the grid is located 6' above the bottom of the vessel. There are nine control rods to ensure the safe operation of the reactor. All of them are made of 2% boron steel.

<u>Primary cooling system</u>: The primary system is made of stainless steel. The reboiler, which does not have as intense corrosion problems as the primary system is made of carbon steel. The reboiler is a horizontal

shell and tube 58" in diameter and 32' long. The primary system is cooled inside 816 tubes, 0.75" in O.D., 27' long Monel tubes.

Shielding: Enough shielding is provided to accomplish a radiation level of 100 mr/hr (outside of the unpenetrated shield). The entire vessel is surrounded by 3" of insulation and 1" of lead bonded to 0.5" of carbon steel plate. Besides providing shielding, the steel also provides a support for the lead. At the very outside, 4' of ordinary concrete are placed. Around the reactor the concrete thickness is 7'. Water, steel, and removable concrete blocks are used to provide protection in the axial-up direction.

Instrumentation, Secondary System, and Containment: All of these in the case of the BWR are exactly similar to those for the PWR. The containment is designed to take account of the water in the primary system as well as a zirconium-water reaction involving 25% of the zirconium.

Capital Costs: Capital costs for the 40 Mwt BWR are given in Table 3.7. Just like the PWR, they have been based on quotations. The charge per million B.T.U. is

TABLE 3.7

BWR CAPITAL COSTS

A-Land	Not included
B-Structures	
1. Ground Improvements	$ 25,000
2. Reactor plant structure	390,000
3. Service building	167,000
4. Lighting	13,500
5. Misc. Permanent Structure	17,000
6. Electrical for structures	5,000
Total Structures	$ 617,500
C-Equipment, Piping etc.	
1. Equipment	$ 759,050
2. Piping and Insulation	150,000
3. Instrumentation	118,500
4. Total Equipment, Piping etc	$1,027,550
D-Electrical	
1. Auxiliary equipment	$ 80,000
2. Temporary Power and light	7,000
3. Misc. Power Plant equipment	6,000
Total Electrical	$ 93,000
E-Miscellaneous Equipment	
1. Health-Physics	$ 17,000
2. Office and locker room	3,500
3. Machine shop	not included
4. Fire Fighting Equipment	1,500
Total Misc. Equipment	$ 22,000
F-Personnel Training Program	Not Included
G-Start-up Supervision	Not Included
H-Contractor's Overhead & Profit	Included above
Sub-total(A through H)	$1,760,050
I-Contingency-10%	175,950
Sub-total	$1,936,000
J-Top Charges	290,000
K-Allowance for Escalation	Not included
Grand Total	$2,226,000

given in Table 3.4. Costs under 80% load factor and 15% annual charge are 39¢/10^6 B.T.U.

Fuel Costs, Inventory Costs, and Operating Costs: All these costs are derived under exactly similar conditions as those for the PWR. They are as given below:[1]

Cost Estimates for a 40 Mwt Boiling Water Reactor
(Based on ANL Design for 40 Mwt Reactor for Process Heat)

Item	Cents/million B.T.U.
Capital charges	39
Operating cost	17
Fuel	28
Fuel inventory	36
Total	120

Dresden Nuclear Power Station:

Our cost estimates for process steam from reactors in the 100 Mwt and over range are based on the Dresden Nuclear Power Station in Grundy County, Illinois.

Description of Plant: Rated at 626 thermal Mwt, this reactor is designed by the General Electric Company.

---

[1] For more information see:

Power Reactors, USAEC, 1958.

Geneva Paper, P/2372, 1958.

It uses sintered UO_2 of 1.5% enrichment in pellet form. Aircalloy-2 is used to clad the fuel elements. The reactor vessel is made of carbon steel with 0.375" cladding of stainless steel on the inside. It has an inner diameter of 12' and a height of 40'. Enough shielding is provided in the form of steel and concrete.

Cost of Process Steam: Since the reactor is not scheduled to go into operation until 1960, only capital costs are available at this moment. Even they are lumped together so that there is no way of separating the capital cost of the power plant. We have, therefore, used the equation[1]

$$C = 2,250\ E^{0.76} + 330,000$$

to obtain the capital cost of the power plant. By subtracting this from the total, we came up with a capital cost of \$22 million for the reactor plant.[2] The capital charge per million B.T.U. was made on the basis of 80% load factor, 15% annual capital charge, and 40 years plant life.

---

[1] See page

[2] Based on data provided by International Atomic Energy Agency in the Directory of Nuclear Reactors, 1959.

Since the reactor uses fuel of the same enrichment as the ANL design for 40 Mwt BWR, we have used the same fuel costs in the both cases. The operating costs can readily be estimated from the experience of the Yankee Atomic Reactor, which is also rated over 100 Mwt.

After generating data from such different sources, we arrived at the following cost estimates:

Cost Estimates for a 100 Mwt (and over) BWR
(Based on Dresden Nuclear Power Station)

Item	Cents/million B.T.U.
Capital charges	21
Fuel inventory	36
Fuel cost	32
Operating costs	12
Total	101

Cost of Process Steam from Organic Moderated Reactor

40 Mwt ANL Organic Moderated Reactor Design for Process Heat:[1] This design has been based on the Piqua Organic Moderated Reactor. Modifications have been made to take account of the lower temperature requirements.

---

[1] Argonne National Laboratories, Op. cit., pp. 71-93.

TABLE 3.8

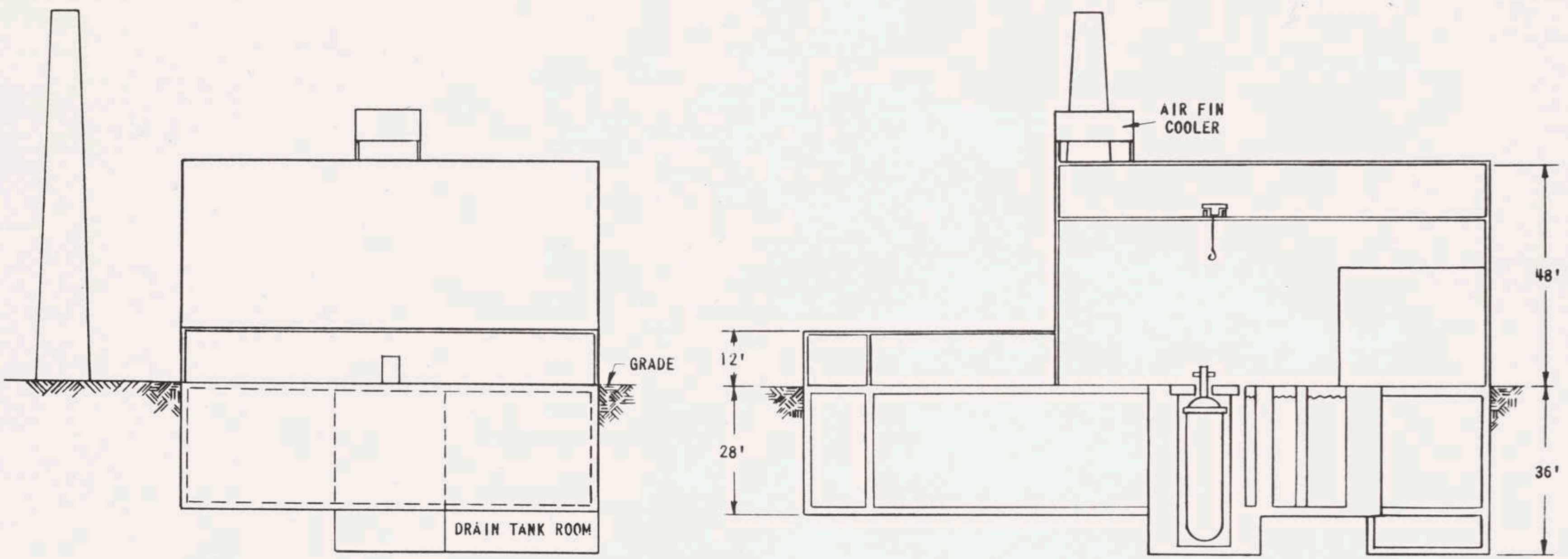
SALIENT DATA FOR 40 Mwt OMR

Power, Mwt	40.6
Core diameter, inches	48
Core length, inches	48
Core volume, liters	1.475
Coolant	Diphenyl
Primary flow rate, lb./hr.	7.9×10^6
Inlet temperature, ^{o}F	421
Outlet temperature, ^{o}F	450
Pressure, psia	75
Enrichment, %	1.5
Initial loading of uranium, Kg	7,650
Burnup, Mwd/M.T.	8,900
Process Steam Conditions	
Flow rate, lb/hr.	1.25×10^5
Temperature, ^{o}F	380
Pressure, psia	196

Some of the more important features of this design are given in Table 3.8. The building illustrated in Ex. 3.10 and Ex. 3.11 is made of steel and concrete.

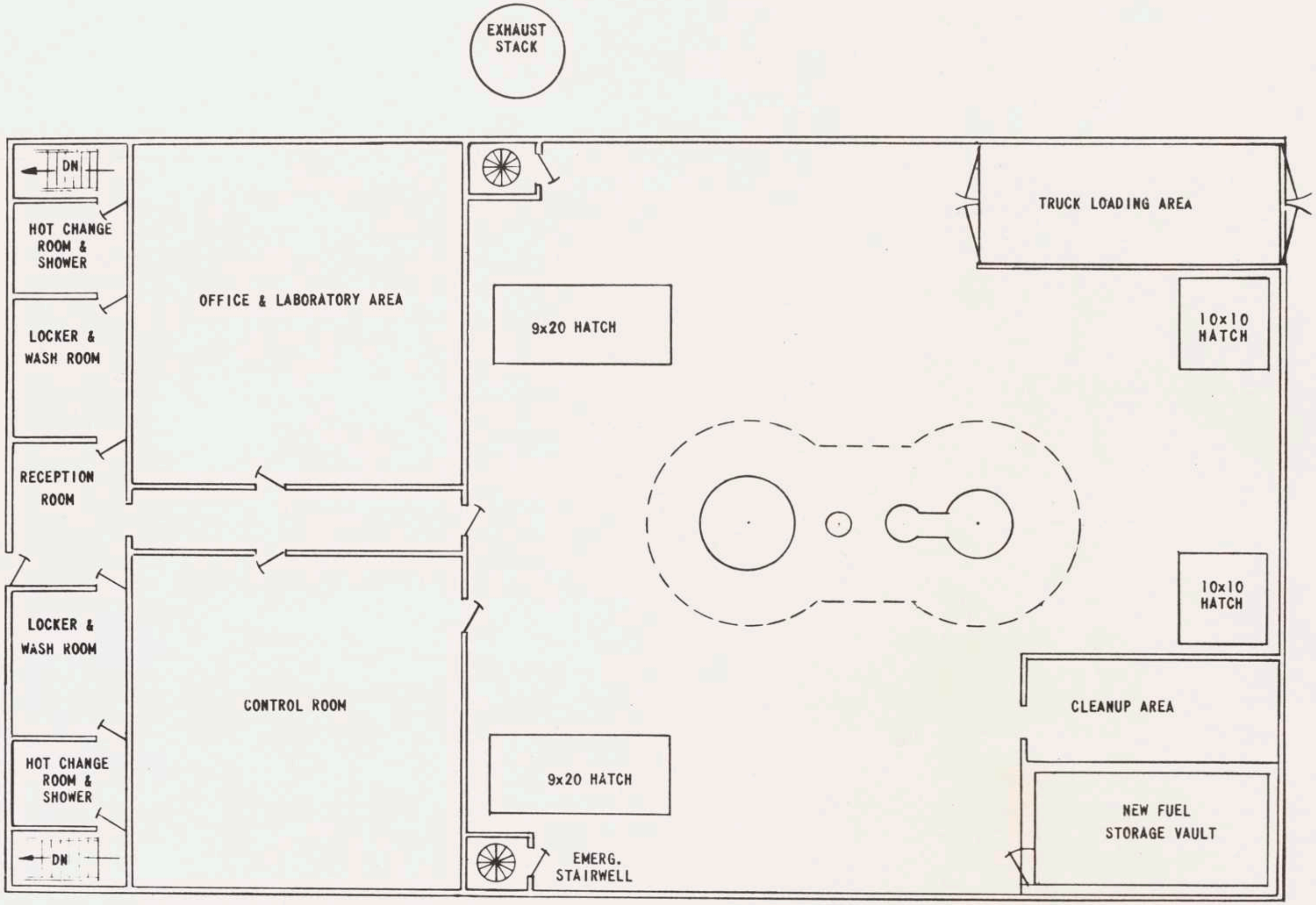
Fuel: As pointed out in the ANL study, the fuel for organic reactors is not very well established. There are two ways in which the fuel problem in an organic reactor differs from that in the water-cooled reactors: firstly, the organic moderator requires more surface for heat transfer than water; and, secondly, organic coolant permits the use of aluminum cladding as contrasted to zirconium for the PWR and the BWR. The heat transfer problem is solved by using uranium metal in the form of plates instead of UO_2. To minimize the irradiation damage to the metal and to give it greater strength, it is alloyed with molybdenum (see page). The alloy is clad with 2S aluminum. Life of the fuel is limited by radiation damage. High enrichment would be needed to prevent that. Cost of such enrichment would, of course, be high.

A fuel sub-assembly consists of 48 plates located in a 6 X 6" stainless steel box. The core itself consists



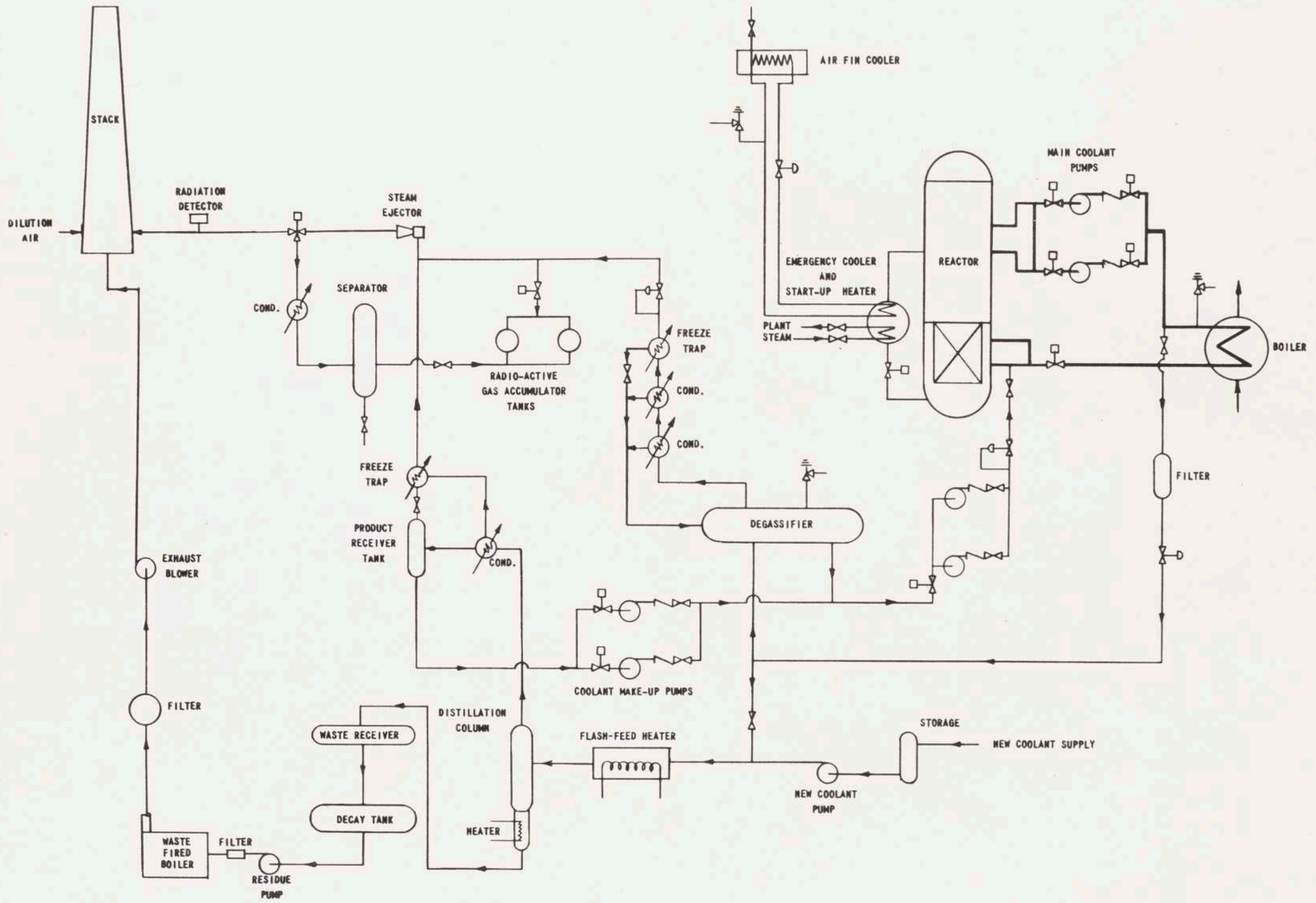
Ex. 3.10

MSR- REACTOR ELEVATION



Ex. 3.11

OMR – MAIN FLOOR



Ex. 3.12

OMR - FLOW DIAGRAM

of 52 such fuel sub-assemblies.

Pressure Vessel and other Internals: Because of the organic coolant, this reactor has no structural material problem. In spite of the aluminum cladding for the fuel, carbon steel is quite suitable for the pressure vessel and the primary system. The reactor vessel is, therefore, made of carbon steel. The vessel is 0.625" thick and approximately 30' in height. The inner thermal shield supports the core structure. The control rods, just as in the case of the water-cooled reactor, are made of 2% boron steel.

The Primary Cooling System: Diphenyl was chosen as a coolant because of its better heat transfer characteristics, its low pumping power requirements, and its low melting point. The authors of the ANL study are not, however, completely satisfied with the coolant. The effort is directed toward reducing the cost of the organic coolants and decreasing the decomposition rate. It is pointed out that a favorable combination of these two can decrease the costs of steam from 10% to 5%.

Steam is produced in a conventional boiler with the organic coolant on the tube side and water and steam on the shell side. The boiler is a two-pass shell made of carbon steel. The tubes are 0.625" in O.D. Monel tubes.

Coolant, or new injections of the organic liquid, is purified through a process of continuous distillation using the standard oil refinery techniques.

Shielding: The inner shield is 1.5" thick. Outer shielding is provided by a carbon steel cylinder 6" thick Biological shielding is ensured by a column of ordinary concrete 8' thick. The organic liquid and concrete blocks provide the shielding above the reactor vessel.

Containment: Since a rupture does not turn the coolant into vapor, nor is there any reaction between the fuel and the organic coolant, the purpose of containment is to prevent any damage which might accompany the use of organic liquids. The hot coolant, for example, is a serious fire hazard. To prevent this from happening, a sprinkler system is provided and all electrical equipment is vapor proof.

Capital cost: Capital costs for the OMR were not studied in as much detail as those for PWR and the BWR.

TABLE 3.9

OMR CAPITAL COSTS

A-Land	Not included
B-Structures	$ 561,000
C-Equipment, piping etc.	1,090,000
D-Electrical	112,000
E-Miscellaneous Equipment	22,000
F-Personnel Training Program	Not included
G-Startup supervision	Not Included
H-Contractor's Overhead & Profit	Included above
(Sub-total A through H)	$1,785,000
I-Contingency-10%	179,000
Sub Total	1,964,000
J-Top Charges-15%	296,000
K-Allowance for Escalation	Not included
Grand Total	$2,260,000

As a matter of fact, little change is made from the estimates for the PWR. The only change made from the PWR costs is in the item of equipment, piping, etc. These costs have been based on the Piqua organic moderated reactor. Table 3.9 gives the capital costs per million B.T.U.

Fuel, Fuel Inventory Costs, and Operating Costs:

Fuel and fuel inventory cost for the OMR are derived from the same conditions that were applied to the PWR and the BWR. The operating costs are slightly different from those for the water-cooled- reactors. The difference comes in because of the organic coolant make-up. Costs per million B.T.U. for the 40 Mwt OMR are given below:

Cost Estimates for a 40 Mwt OMR for Process Heat
(Based on ANL MOR Design for 40 Mwt Reactor)

Item	Cents/million B.T.U.
Capital charges	39
Operating costs	23
Fuel	24
Fuel inventory	20
Total	106

Cost of Process Steam from Conventional Boilers

Cost of process steam from conventional boilers can be divided into three parts:

1) Capital Costs
2) Operating Costs
3) Fuel Costs

1) Capital Costs: Capital cost of boilers varies from industry to industry, and no data are readily available. Even within an industry there are wide variations depending upon the conditions in particular plants. Our capital cost estimates for conventional boilers are based on the study of Mr. Perazich.[1] He based his costs partly on information derived from power plant equipment manufacturers, since many of them produce boilers for process steam as well. Excluding all electrical equipment, Mr. Perazich estimated the cost of a steam plant at $65 to $80 per electrical kilowatt. At 35% efficiency this amounts to $23 to $28 per Kwt. These costs are, however, for very large boilers producing high quality steam at 1000°F. or so. To produce steam at low temperatures and pressures, many of the auxiliaries would prove unnecessary.

---

[1] Perazich, George, Op. cit., pp. 13-20.

After adjusting for these different factors, Mr. Perazich estimates the following capital costs for conventional boilers:

10 - 40 Mwt	$30/Kwt
50 - 100 Mwt	25/Kwt
200 Mwt and up	20/Kwt

2) Operating costs: According to "generally accepted practices in conventional power plants," Mr. Perazich varies his operating cost estimates for difference in boiler size. He establishes a range of 3.2 mills per electrical kilowatt for small units and 1.6 mills for large units. Assuming 25% thermal efficiency, this amounts to .8 mills per Kwt for small boilers and .4 mills for large ones.

3) Fuel: Cost of fuel is the variable element in our calculations. In a sense, this is the most important factor that would determine the use of nuclear process steam reactors. In Table 3.10, where we bring the different cost elements together, we arrive at different cost estimates depending upon the difference in fuel costs.

TABLE 3.10

PROCESS STEAM COSTS FOR A CONVENTIONAL BOILER

Size Range	Capital cost @ 80% load	Operating Cost	Total cost with fuel at (per mill. B.T.U.)				
			30¢	40¢	50¢	60¢	70¢
10 - 40[1]	16.4¢	23.6¢	70	80	90	100	110
50 - 100	13.7	17.6	61	71	81	91	101
200 and over	11.0	11.7	53	63	73	83	93

---

[1] It is interesting to note that Prehn and Tarrice arrive at substantially similar estimates in their study, Process Heat Generation and Consumption, 1939-1967. (1958). The authors estimate total steam costs, less fuel, @13% annual charge and 80% load factor, for a 150,000 lb./hr. boiler (approximately 40 Mwt) at 42¢/million B.T.U.

TABLE 3.11

Costs of Nuclear Process Steam per mill. BTU

	Reactor size	Oper. cost	Fuel	Fuel inv.[1]	Capital charge	Total
	20 Mwt	39¢	21¢	---	196¢	156¢
PWR	40 Mwt	17	20	13	43	93
	100 Mwt	12	29	---	41	82
	20 Mwt	31	28	18	55	132
BWR	40 Mwt	17	28	36	39	120
	100 Mwt	12	32	36	21	101
OMR	40 Mwt	23	24	20	39	106

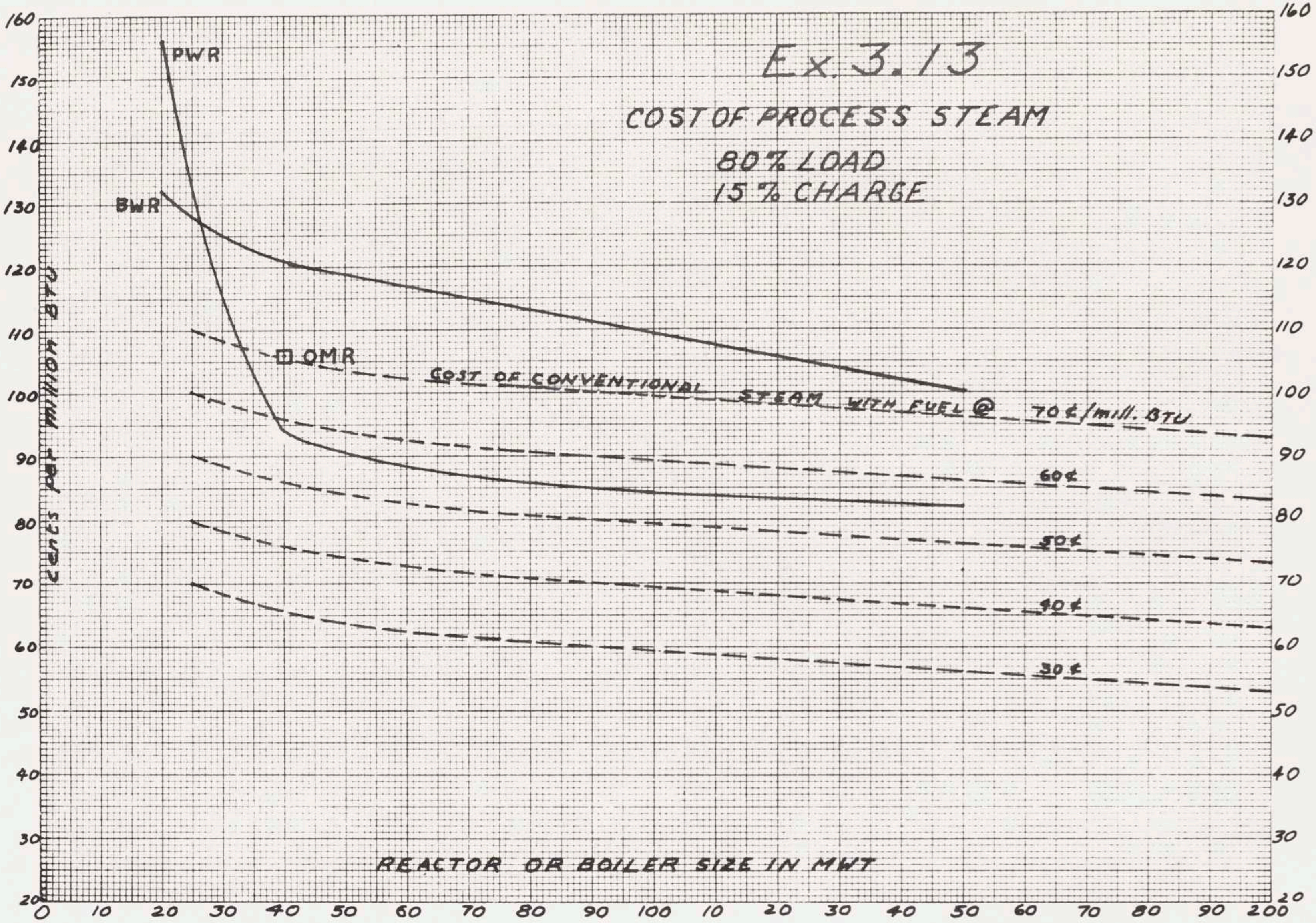
[1] For reactor sizes which do not give the fuel inventory charge, the fuel inventory costs are included in the capital charges.

Comparison of Nuclear and Conventional Process Steam Costs:

Our comparison of nuclear and conventional process steam costs is essentially done graphically through Ex. 3.13, and then through Ex. 3.14 to Ex. 3.16, which are drawn under different assumptions as to the load factor and the capital charge.

In Ex. 3.13, we have simply put Table 3.10 and 3.11 on the graph paper. Table 3.11, it will be noticed, is nothing more than a summary of cost figures derived previously in this Chapter. On the horizontal axis on the graph, we have reactor or boiler size in megawatts; on the vertical axis, we have cost of process steam in cents per million B.T.U. Cost points for each reactor size are plotted in the case of the PWR and the BWR. All the points are then joined with a free-hand curve. Cost for the OMR is only a point since we have estimates only for the 40 Mwt reactor.

It should be pointed out here that not all cost points deserve the same emphasis. While the cost estimates for the 40 Mwt reactors, derived by the Argonne National Laboratories, and the 20 Mwt Boiling Water


Ex. 3.13
COST OF PROCESS STEAM
80% LOAD
15% CHARGE
PWR
BWR
OMR
COST OF CONVENTIONAL STEAM WITH FUEL @ 70¢/mill. BTU
60¢
50¢
40¢
30¢
cents per million BTU
REACTOR OR BOILER SIZE IN MWT
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
80
90
200

Reactor (designed by Hydrotherm), are products of expert research, cost figures for other reactors are derived from power plant data, and involve extrapolation in their estimation.

The horizontal lines, slightly sloping from left to right are the costs of a million B.T.U. of heat from conventional boilers. They are plotted from Table 3.10.

It is apparent from the graph that, under the present assumptions, the Boiling Water Reactor is out of the range of economic feasibility. The organic moderated reactor is just competitive in the 40 Mwt range when fuel cost is 70¢/million B.T.U.; there is very little likelihood of its being competitive in the smaller category. For higher ranges, however, it would be more than competitive if the cost of fuel remains at 70¢/million B.T.U. The Pressurized Water Reactor seems to be the most economical of all. It becomes competitive with 60¢/million B.T.U. in as small a range as 38 Mwt or a paper plant producing approximately 350 tons per day.

Before we close this section, a word is due as to the use of this graph. It is meant to give a general impression and rule out the most obvious cases. In a region like the southern part of the United States, for example, nuclear process steam reactors are clearly out of the picture. In areas like New England, on the other hand, the competition between the conventional and the nuclear fuels becomes closer. For a plant located in a corner of New Hampshire or Maine, cost of fuel might be 60¢/million or more. (This point will be considered in more detail in Chapter IV.) A chart like ours gives an indication as to when a more refined engineering and economic analysis might be fruitful for a given plant location.

Effect of Changing the Assumption on Process Steam Costs:

Initially, we started with an assumption of a 80% load factor and 15% capital charge. Since paper plants have been operating around 80% load for quite some time, it is not an unreasonable assumption. In individual cases, however, a manufacturer might expect a load factor of 70% or 60% or less. For him, the economics of process steam would be substantially altered as is shown in Ex. 3.14. As a matter of fact, both the OMR and the BWR are thrown out. Even the PWR in the 40 Mwt range is competitive only for fuel costs of 63¢/million B.T.U. and up. A 90% load factor, of course, has the reverse effect (Ex. 3.15). Although BWR is still out of the range of economic feasibility, OMR is competitive at 60¢, and PWR at 50¢.

An annual charge of 15% was assumed to be composed of 7% depreciation, 5% cost of money, and 3% for insurance and taxes. We do not have a precise idea as to the cost of capital for paper companies, but for some companies, it might conceivably be 3% or so.

Ex. 3.16 gives the cost of process steam under 8% annual charge and 80% load. As might be expected, the effect is much more drastic than in the first two cases. A 40 Mwt PWR is competitive at as low a fuel cost as 38¢/million B.T.U. A 40 Mwt BWR is competitive at 60¢/million B.T.U. And an OMR is competitive at 50¢/million B.T.U.

TABLE 3.12a

Cost of Process Steam @ 70% load, 15% Chg.

	Reactor size	Capital charge	Oper. cost	Fuel	Fuel inv.[1]	Total
	20 Mwt	110¢	45¢	21¢	---	176¢
PWR	40 Mwt	49	20	20	14	103
	100 Mwt	46	14	29	---	89
	[2] 20 Mwt	63	35	28	18	144
BWR	40 Mwt	44	20	28	40	132
	100 Mwt	24	14	32	40	110
OMR	40 Mwt	44	26	24	22	116

TABLE 3.12b

Cost of Process Steam @ 90% load, 15% Chg.

	20 Mwt	85	35	21	---	141
PWR	40 Mwt	38	15	20	12	85
	100 Mwt	36	11	29	---	76
	20 Mwt	49	28	28	18	123
BWR	40 Mwt	34	15	28	32	109
	100 Mwt	19	11	32	32	94
OMR	40 Mwt	34	21	24	17	96

TABLE 3.12c

Cost of Process Steam @ 80% load, 8% Chg.

	20 Mwt	70	39	21	---	130
PWR	40 Mwt	23	17	20	10	70
	100 Mwt	24	12	29	---	65
	20 Mwt	29	31	28	12	100
BWR	40 Mwt	20	17	28	26	91
	100 Mwt	13	12	32	26	83
OMR	40 Mwt	21	23	24	13	81

---

[1] For reactor sizes which do not give the fuel inventory charge, the fuel inventory costs are included in the capital charges.

TABLE 3.13a

Boiler Steam Costs at 70% load, 15% Charge

Boiler Size (Mwt)	Capital charge (¢ per mill.BTU)	Operating Cost (¢ per mill.BTU)	Total cost with fuel @ (per mill. B.T.U.)				
			30¢	40¢	50¢	60¢	70¢
10-40	19	24	73¢	83¢	93¢	103¢	113¢
50-100	16	18	64	74	84	94	104
200 & Over	13	12	55	65	75	85	95

TABLE 3.13b

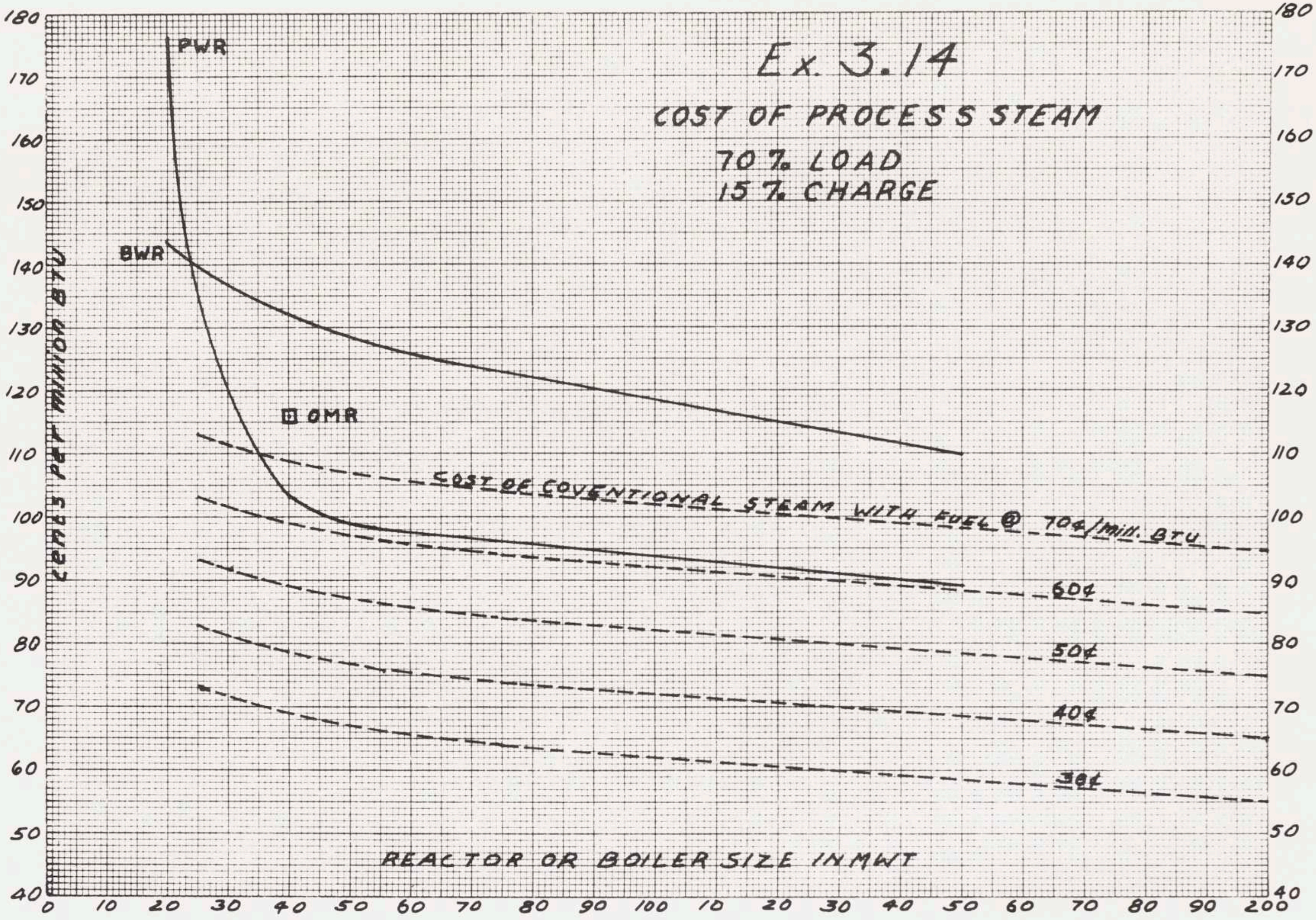
Boiler Steam Costs at 90% load, 15% Charge

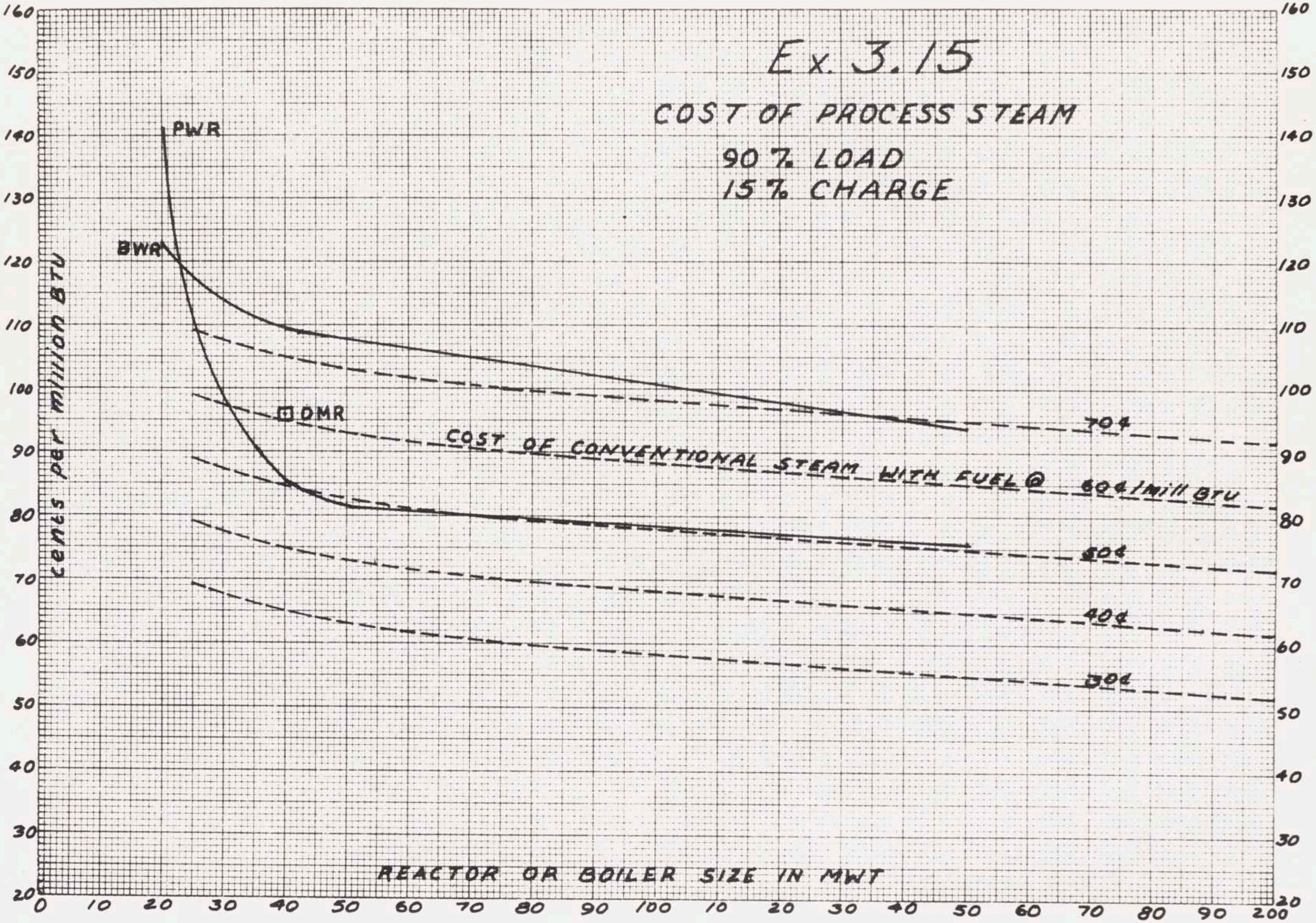
10-40	15	24	69	79	89	99	109
50-100	12	18	60	70	80	90	100
200 & Over	10,	12	52	62	72	82	92

TABLE 3.13c

Boiler Steam Costs at 80% load, 8% Charge

10-40	10	24	64	74	84	94	104
50-100	8	18	56	66	76	86	96
200 & Over	7	12	49	59	69	79	89

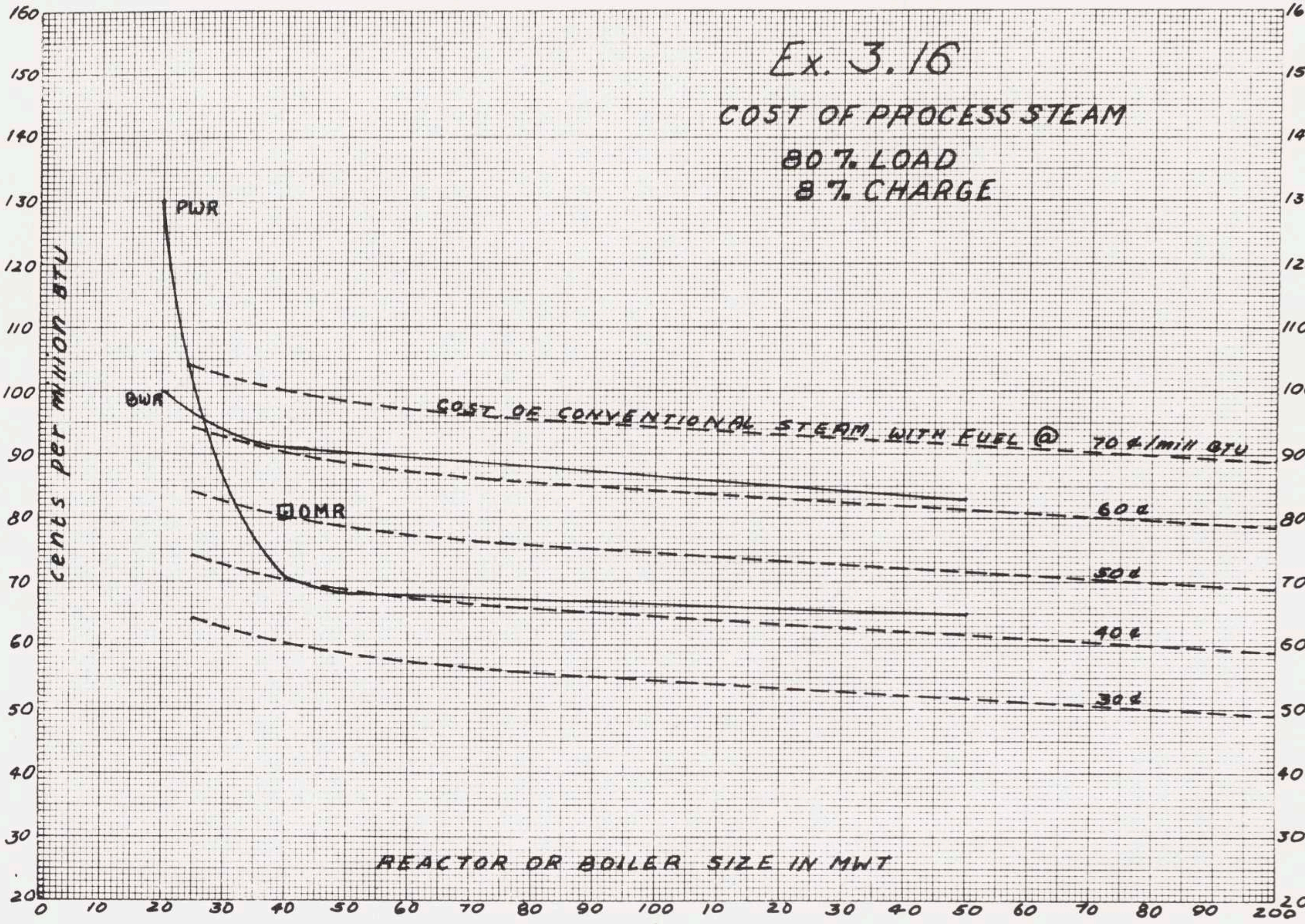

Ex. 3.14
COST OF PROCESS STEAM
70% LOAD
15% CHARGE
PWR
BWR
OMR
COST OF COVENTIONAL STEAM WITH FUEL @ 70¢/MILL. BTU
60¢
50¢
40¢
30¢
CENTS PER MILLION BTU
REACTOR OR BOILER SIZE IN MWT
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
80
90
200



Ex. 3.15

COST OF PROCESS STEAM

90 % LOAD
15 % CHARGE



Ex. 3.16

COST OF PROCESS STEAM

80% LOAD
8% CHARGE

CHAPTER 4

Whether nuclear process steam reactors would be of any interest to the New England paper industry in the future, depends upon two factors.

First of all, is there any chance at all for further expansion of the paper industry in New England? Although New England's share of the total U.S. production has been steadily decreasing over the years, we believe that the paper industry in the region will expand because of the specialized nature of its production, its wood resources and its lower labor costs. In a later portion of this chapter we give more detailed attention to this matter. First we derive the expected increase in pulp and paper production in the USA from 1960-1970, and New England's share of it. We then estimate the increase in New England's capacity that would be needed to satisfy this demand.

Assuming that a certain increase in pulp, paper and board production will take place, the second point that would determine the industry interest in process steam reactors is the cost of conventional fuel. In the following pages we consider this point in greater detail.

Ex. 4.1

SOURCE: US DEPT. OF COMMERCE

Factors affecting the demand for paper & board.

In order to provide a setting for the demand for paper in the context of the entire economy, we would briefly like to describe the factors that affect it. In the following paragraphs, therefore, we analyze the different factors that might be said to affect the demand for paper and board. Although we would consider almost all categories, we would give special attention to newspring, printing paper and fine paper; these three have a special place in New England. From Table 5-1 it would be noticed that tonnage-wise, these three comprise more than fifty percent of the total paper and board production in New England.

Newsprint. Demand for newsprint is, of course, closely tied with the expansion of the newspaper industry and the reading habits of the people. Newspaper circulation depends upon the shift of population from rural to the urban areas, by the proportion of the adult population in the country and individual family income. All these three have been increasing in the post war years and there is no sign of their abating. Nearly 70% of newspaper revenue is, however, derived from advertising and the role of newspapers as advertising medium is very significant for the growth of the industry.

Since 1945 newspaper advertising dollar volume has more than tripled even though its share of the total advertising expenditure has decreased. In our economic system advertising has become an integral part of the process of production and distribution. Although various other media have emerged over the years, each of them has a special niche of its own and newspaper advertising should be expected to keep its pace as the GNP and the disposable income expands.

Printing Papers. While one cannot tie down this grade of paper to any specific product, its relationship with the level of literacy and disposable income is obvious. The following distribution is estimated for the consumption of printing paper: Periodicals--34%; books--10%; other publications--9.5%; all other printed products--46.5%.

Substantially the same reasoning applies to periodicals that applied to the newspaper industry. Circulation of all general and farm magazines belonging to the Audit Bureau of Circulations in 1956 was 183.2 million per issue. From 1949 to 1955 advertising expenditure in periodicals -- which forms 60% of their revenue -- has shown an annual increase of 10% and the increase is continuing.

TABLE 4-1

PRODUCTION OF PAPER AND PAPERBOARD MILLS IN NEW ENGLAND AND THE UNITED STATES

(1954-in tons)

	1954	% Total N.E.	% of U.S.	1954	% of U.S.
Newsprint	487,946	16.94	40.6	1,202,413	4.47
Tissue				226,342	.84
Ground wood					
Book	771,345	26.78	21.5	3,587,360	13.35
Fine	334,067	11.60	28.5	1,284,526	4.78
Coarse	233,696	8.11	6.8	3,461,611	12,88
Special Industrial	137,096	4.76	27.4	500,525	1.86
Absorbent					
Sanitary	179,492	6.23	13.0	1,385,895	5.16
Container Board	110,119	3.82	1.7	6,487,984	24.14
Bending Board	296,891	10.31	8.3	3,579,867	13.32
Nonbending Board	103,527	3.59	11.2	922,569	3.43
Special Paper Bound Stock					
Cardboard	71,359	2.48	5.9	1,200,370	4.47
Wet Machine Board	54,614	1.90	4.0	135,910	.51
Building Paper	99,753	3.46	3.4	2,900,870	10.79
Building Board					
TOTAL	2,879,905	100.00	--	26,876,242	100.00

Source: U.S. Census of Manufacturers, 1954.

Consumption of books should be definitely expected to go up with the increase in school enrollment. Based on tentative estimates of the U.S. Office of Education the school enrollment should be expected to reach 54 million in 1965 as against 4.3 million in 1958.

With the advent of fast data processing machines and the fact that more and more of the business work is done on paper, the expenditures on commercial printing should go up with the expansion of industry.

Summarizing..."the tonnage of printing and fine papers used in books, periodicals and other printed products (commercial printing) has been rising over the postwar years, a trend that should continue. Our rapidly increasing population, expanding school enrollments, rising level of education, higher personal income, increased leisure, scientific and technological advances that create new products and, individually and collectively, are widening the market for books, periodicals, and other printed products........As our economy continues to use printed products, adapting them to meet new requirements, signs of accelerating growth may be noted. Among the factors that may be responsible is an increased use of printed advertising and promotional material, particularly periodical advertising, direct mail advertising, and catalogues."[1]

Fine Papers. The fine paper group includes such papers as rag writing paper, chemical wood pulp writing paper, bristols, cigarette paper, etc. It is evident that the use of fine papers, which are extensively used for social purposes besides providing the paper for commercial printing, would grow with the population and the standard of living.

Course and Special Industrial Paper. One of the fields in which paper has replaced many existing materials is the field of industrial paper. Paper has replaced such materials as jute sacks. Industrial paper should show a significant correlation with the index of industrial production.

Container Board. Container board comprises 25% of all domestic production of paper and paperboard. Use of container board is chiefly in the manufacture of containers and shipping boxes. It was during the War that the qualities of durability of container board were realized more strongly than ever, and ever since, container board has been in an increasing use. Its growth

---

[1] Committee on Interstate and Foreign Commerce, "Pulp, Paper and Board Supply - Demand - 1957", Home Report, No. 573, p. 73-74.

should be expected to continue with the rise in industrial production.

Demand for Paper and Paperboard in the U.S., 1960-70.

Our long range projections of pulp and paper demand in the U.S.A. are based on a study of the Department of Commerce entitled "Pulp Paper and Board Supply--Demand". This is perhaps the best available estimate of the future demand for the paper industry.

The original study was made in 1956 and demand was forecasted through 1965. "The projections were made of the level of general economic activity as measured by gross national product--the output of all goods and services in the economy; real disposable income--an overall measure of real purchasing power; and industrial production--an index of the output of the manufacturing and mining industries. On the basis of past relationships shown between changes in domestic demand for each grade group of paper and board and changes in the most general measure of economic activity, it was possible to project demand for paper and board."[2]

Regression equations were evolved for each of the various kinds of paper and board. Disposable income and

---

[2] Ibid., p. 32.

production indices were used as the independent parameters. They were, however, based upon the estimates of gross national product.

In addition to the individual grade forecast, aggregate demand for paper and board was also forecast. This provided an independent check on the grade forecasts. In every case the totals obtained from these two sources were strikingly similar.

As we stated earlier, the original Department of Commerce forecasts were made only up to 1965. We ventured to make the forecast for the year 1970 by using the same regression equations. Estimates of the disposable income and the production index for 1970 were obtained from the studies of the Stanford Research Institute.[3] It can perhaps be argued that the Department of Commerce study is a bit obsolete and that the demand forecasts should be adjusted in light of the experience in the last two or three years. However, as pointed out in the study, the forecasts are designed to give a general trend of the demand and not forecast demand in any particular year. Moreover, the study is based on

---

[3] Stanford Research Institute, "Production Trends in the U.S. through 1975" (1957) and "Income Trends in the U.S. through 1975" (1957).

experience of almost three decades and divergence from it is more likely to be an occasional deviation rather than a significant change in the long range trend.

The long range projections are given in Table 4-2.[4] The heading, it will be noticed, is "Apparent Consumption". Apparent consumption is defined as production plus imports minus exports. With the exception of newsprint it is unadjusted as to inventory changes.

Demand for Pulp in the United States.

Estimates of pulp requirements follow directly from the paper and paperboard projections. However, the process is somewhat complicated by the fact that many different kinds of pulp are used in the same grade of paper. The authors of the Department of Commerce study have adopted the following solution to this problem: "A more refined technical approach to calculating

---

[4] In the April 28 issue of the Paper Trade Journal, Mr. Kenneth A. Breggs made certain forecasts for the paper industry which are of interest to us. Mr. Breggs estimates a population of 191 million in 1965 and 205 million in 1970. It would have an income of about 25% more than in 1958. Basing his projections on these, Mr. Breggs expects paper and board consumption to be 49 million tons in 1965, and 58 million tons in 1970. For more detailed information see: K.A. Breggs, "How Much Will Our Industry Grow by 1970?", Paper Trade Journal, Vol. 142, No. 17 (April 28, 1958), pp. 20-24.

TABLE 4-2

PAPER AND BOARD, UNITED STATES PROJECTED DEMAND, 1960, 1965, and 1970

(Thousands of short tons)

ITEM	PROJECTED DEMAND 1960	 1965	 1970
Total paper and board	40,810	48,560	57,300
Total paper	20,530	23,550	27,300
Newsprint	7,325	8,250	9,800
Printing papers	4,445	5,035	6,000
Fine papers	1,685	1,965	2,300
Coarse & special industrial papers	4,975	5,700	6,000
Sanitary & tissue papers	2,100	2,600	3,200
Total paperboard	16,585	20,550	23,900
Container board	8,530	10,230	12,000
Bending board	3,185	3,725	4,000
Special food board	1,900	3,120	4,300
Nonbending & other paperboard	2,970	3,475	3,600
Total building paper & board	3,695	4,460	6,100
Building paper	1,805	2,185	3,400
Building board	1,890	2,275	2,700

Source: Committee on Interstate and Foreign Commerce, "Pulp, Paper and Board -- Supply & Demand, 1957" House Report, No. 573.

woodpulp requirements by grade groups for the domestic manufacture of paper and board through as far as 1965 would be to estimate, based upon general industry knowledge and expectations, the likely changes in pulp ratios for individual grades of woodpulp by individual grades of paper and board. This procedure was discussed with industry leaders, and it was concluded that, although subject to uncertainties, this was the most logical approach from the standpoint of making reasonable estimates for the future."[5]

As the authors readily admit, the determination of the pulp ratios is most difficult on the national basis even though individual manufacturers have a fairly good idea as to their own practice. The problem is also aggravated by the fact that a slight error in the ratio can have a large effect in the estimate of pulp requirements.

Since there is no quantitative way of projecting the pulp ratios through 1965, the authors relied primarily on "general industry judgment and expectations". Starting from the ratios in 1954, a trend was established.

---

[5] Committee on Interstate and Foreign Commerce, "Pulp, Paper and Board -- Supply & Demand, 1957", House Report, No. 573, p. 90.

Thereafter two extreme estimates were obtained for wood pulp -- one depending upon the 1954 ratios and the other on the growth trend. These are given in Table 4-3 and Table 4-4. For the year 1970 we used the same pulp ratios as in 1965.

To the domestic demand for pulp for paper and board was added the demand for pulp for other uses and exports. The latter two categories are, however, rather insignificant since they form only 5% of the total demand.

New England's Declining Share in the National Output.

New England led the United States in the manufacture of pulp and paper. With the replacement of rags, straw, etc., as the raw material, by wood, New England began to lose its leading position. But even until 1929 Maine was the leading state in wood pulp production in the country. Table 4.5 gives an idea of the changing share of New England in the nation's pulp and paper production. The industry has grown 2½ times as fast nationally as it has in New England.

For the region, however, pulp and paper manufacture has an important place. In 1954, paper and paper products formed nearly 6% of the total value added in New England, employed 6% of the production workers and paid out more than 7%[6] of the wages. For states like Maine and New Hampshire the significance of the paper industry is still greater.

There is a considerable difference between the grade composition of the national output and that of New England. New England produced 40% of the total U.S. newsprint production in 1954. (Table 4-1)

Traditionally, New England then specialized in book, fine and specialty. With its lower wages and historic experience, New England is particularly suited for high quality work that often has high manpower requirements. On the other hand, southern mills are more interested in large orders and they tend to leave the specialized work for the others. As the A.D. Little Report pointed out in 1952, New England's greatest opportunity lies in the field of high grade and specialty papers.[7] The Report also brought attention to the neutral sulphite semichemical press which can bring New England's huge hardwood pulpwood resources into use.

---

[6] U.S. Census of Manufacturers, 1954.

[7] A.D. Little, Inc., "Report on a Survey of Industrial Opportunities in New England to the Federal Reserve Bank of Boston", pp. 302-313. (August, 1952).

TABLE 4-3

TOTAL WOODPULP (1954 RATIO BASIS) ESTIMATED REQUIREMENTS FOR PAPER AND BOARD PRODUCTION, 1960, 1965, 1970

(Thousands short tons)

		1960		1965		1970	
GRADE GROUPS	RATIO PULP TO PAPER	PAPER PRODUCTION	REQUIRED PULP	PAPER PRODUCTION	REQUIRED PULP	PAPER PRODUCTION	REQUIRED PULP
Total paper & board	---	36,514	26,316	43,872	31,650	57,300	43,890
Total Paper	---	15,874	14,779	18,282	17,000	27,300	26,290
Newsprint	1.007	2,475	2,666	2,700	2,908	9,800	10,550
Printing papers	.812	4,470	3,630	5,085	4,129	6,000	4,870
Fine papers	.910	1,733	1,579	2,023	1,840	2,300	2,090
Coarse & special industrial papers	.984	6,086	5,004	5,860	5,767	6,000	5,900
Sanitary & tissue papers	.901	2,111	1,902	2,614	2,356	3,200	2,880
Total Paperboard	---	21,060	9,449	21,060	12,128	23,900	14,360
Container board	.788	8,810	6,941	10,610	8,360	12,000	9,460
Bending board (except special food board)	.176	3,255	573	3,825	673	4,000	700
Special food board	.927	1,900	1,762	3,120	2,892	4,300	3,990
Nonbending & other paperboards	.058	2,965	173	3,505	203	3,600	210
Total building paper & board		3,710	2,088	4,485	2,522	6,100	3,240
Building paper	.321	1,895	1,582	2,200	706	3,400	1,090
Building board	.795	1,895	1,506	2,285	1,816	2,700	2,150

Source: Committee on Interstate and Foreign Commerce, "Pulp, Paper & Board -- Supply & Demand, 1957", House Report, No. 573.

TABLE 4-4

TOTAL WOOD PULP--(GROWTH TREND RATIO BASIS ESTIMATED REQUIREMENTS FOR PAPER AND BOARD PRODUCTION, 1960, 1965, 1970

(Thousand short tons)

	1960			1965			1970		
Grade Groups	Ratio Pulp to Paper	Paper Production	Required Pulp	Ratio Pulp to Paper	Paper Production	Required Pulp	Ratio Pulp to Paper	Paper Production	Required Pulp
Total paper & board	0.727	36,516	26,564	0.737	43,827	32,308	----	57,300	44,630
Total paper	--	15,874	14,799	---	18,282	17,000	----	27,300	26,290
Newsprint	1.077	2,475	2,666	1,077	2,700	2,908	1.077	4,800	10,550
Printing papers	.812	4,470	3,630	.812	5,085	4,129	.812	6,000	4,870
Fine papers	.910	1,733	1,577	.910	2,023	1,840	.910	2,300	2,090
Coarse and special industrial papers	.984	5,085	5,004	.984	5,360	5,767	.984	6,000	5,900
Sanitary and tissue papers	.901	2,111	1,962	.901	2,614	2,356	.901	3,200	2,880
Total paperboard	--	16,930	9,697	--	21,060	12,786	----	23,900	15,100
Container board	.816	8,810	7,189	.850	10,610	9,018	.850	12,000	10,200
Bending board	.176	3,255	573	.176	3,825	673	.176	4,000	700
Special food board	.927	1,900	1,762	.927	3,120	2,892	.927	4,300	3,990
Nonbending & other paper boards	.058	2,965	173	.058	3,505	203	.058	3,600	210
Total building paper & board	--	3,710	2,088	---	4,485	2,522	----	6,100	3,240
Building paper	.321	1,815	582	.321	2,200	706	.321	3,400	1,090
Building board	.795	1,395	1,506	.795	2,285	1,816	----	2,700	2,150

Source: Same as Table 4-3.

TABLE 4-5

NEW ENGLAND'S SHARE IN U.S. PULP, PAPER AND PAPERBOARD PRODUCTION: 1914, 1947, 1954

YEAR	NO. of PLANTS			NO. of PROD. WKRS. (000's)			PAPER & PAPERBOARD OUTPUT (in millions of tons)		
	U.S.	N.E.	NE as % of U.S.	U.S.	N.E.	NE as % of U.S.	U.S.	N.E.	NE as % of U.S.
1914	718	222	31	885	30.5	34	5.3	1.6	30
1947	921	167	18	174.1	30.6	18	21.1	2.7	13
1954	932	161	17	183	30	16	26.9	2.9	11

Source: Census of Manufacturers and H.B. Shepard, *Op.cit.*

So much for the qualitative aspects of the New England paper industry. Here, we are primarily interested in the additional capacity that might conceivably be opened in New England over the next decade. Toward the end we would first establish New England's future share in the national production.

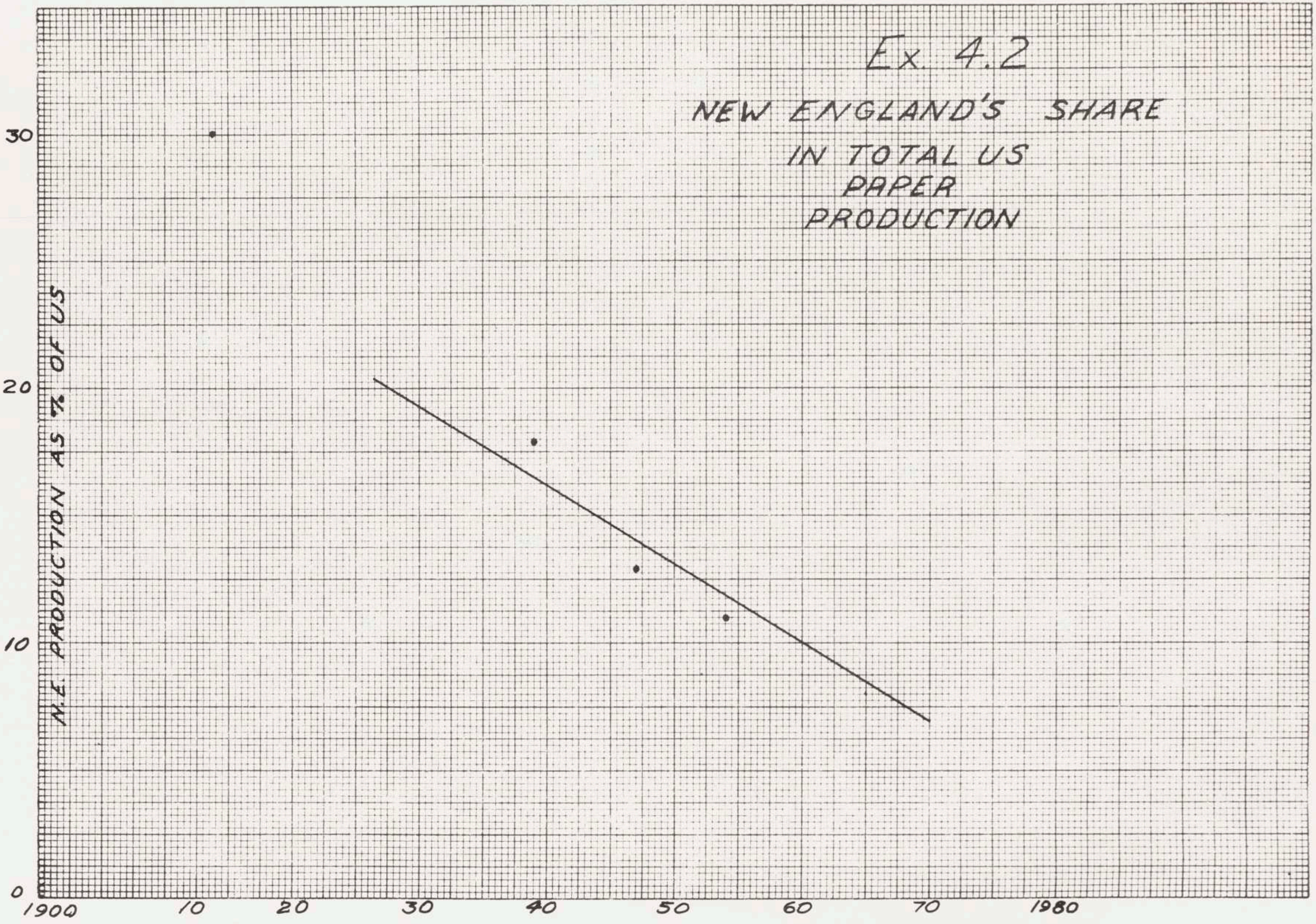
As pointed out earlier, growth of the New England paper industry should not be expected to match the national growth. There is an downward trend in New England's share of the total U.S. production. To establish this trend quantitatively is, however, much more difficult. By individual grades, we have data for just two years -- 1947 and 1954. By aggregate paper production we have more data. Since we are more interested in total capacity requirements, irrespective of specific grades, we have used the latter approach of production in New England and production in the U.S. Ratios for four years -- 1914, 1939,[8] 1947 and 1954 -- are plotted and a trend line is established. The ratios are given in Table 4-6 and plotted in Exhibit 4-2.

New England's Share of National Paper Production: 1960-70.

Assuming that the imports and exports of paper

---

[8] Ratio for 1939 is charged as Value Added rather than actual tonnage.



Ex. 4.2

NEW ENGLAND'S SHARE IN TOTAL US PAPER PRODUCTION

TABLE 4-6

RATIO OF PAPER & BOARD PRODUCTION IN NEW ENGLAND TO TOTAL U.S. PRODUCTION
1914 - 1954

YEAR	N.E. PROD./U.S. PROD.
1914	30%
1939	18%
1947	13%
1954	11%
1965*	7%
1970*	6%

*Forecasted

Source: Census of Manufacturers, 1939, 1947, 1954 and H.B. Shepard, "Hardwood Pulp..Its Manufacture and Use" (Published by the New England Council, 1956).

---

remain substantially the same over the next decade -- imports of 5 million tons and exports of 1 million tons, or 4 million tons net imports -- U.S. paper industry will have to provide 45 million tons of paper and bond in 1965 and 54 million tons in 1970. Applying the 1965 and 1970 ratios derived in Table 4-6 we get the following estimates for New England's production of paper and board:

1965..........3.66 million tons
1970..........3.8 million tons

Assuming that the composition of New England paper and board industry remains unchanged it would approximate the structure shown in Table 4-7.

TABLE 4-7

COMPOSITION OF NEW ENGLAND PAPER & BOARD INDUSTRY IN 1965 and 1970, USING 1954 RATIOS

(in 1000's of short tons)

	1965	1970
Newsprint	620	630
Bulk paper	900	1,030
Fine paper	420	440
Course & Industrial paper	470	490
Sanitary	230	240
TOTAL Paper	2,730	2,830
Container Board	140	150
Bending Board	370	390
Others	420	430
TOTAL Paperboard	930	970
TOTAL PAPER & BOARD	3,660	3,800

Probable Expansion in New England Paper & Board Manufacturing Capacity: 1960-1970.

In 1958 New England produced nearly 3.1 tons of paper and board.[9] In other words, an expansion of .5 million tons in annual capacity in 1965 and .7 million tons by 1970 should be expected in the New England paper industry. On the basis of a 310 day year, this amounts to an addition of 1700 tons/day by 1965 and 2,300 tons/day by 1970.

---

[9] Extrapolated from U.S. data.

Production of Pulp in New England: 1960-1970.

The amounts of pulp that would be required to produce the above quantities of paper and paperboard -- 3.66 million tons in 1967 and 3.8 million tons in 1970 -- are given in Table 4-8 and Table 4-9.

Starting with the estimates in Table 4-7, we applied the pulp ratios (amount of pulp required per ton of paper) arrived at by the Department of Commerce[10] to obtain the quantities of woodpulp that would be required by the New England paper industry. Just as in the case of the national estimates, two estimates were derived...one based on the 1954 ratios and the other based on the ratio trend. (Table 4-8 and Table 4-9) Except for the case of newsprint and container board, there is not any difference between the pulp ratios in 1954 and those derived from the trend of the container board ratio is upward because there is a tendency to use increasing amounts of virgin woodpulp (in place of Kraft wastepaper, and straw) in the manufacture of liners and corrugating medium.[11]

Probable Expansion in Pulp Manufacturing Capacity: 1960-70.

Thus, we have seen above that in 1965 New England

---

[10] Ibid., p. 94 & 96.

[11] Ibid., p. 91.

TABLE 4-8

TOTAL N.E. WOODPULP REQUIREMENTS (1954 BASIS) ESTIMATED REQUIREMENTS FOR PAPER & BOARD PRODUCTION - 1965 & 1970

(Thousands of short tons)

GRADE GROUP	RATIO PULP TO PAPER	1965		1970	
		PAPER PRODUCTION	REQUIRED PULP	PAPER PRODUCTION	REQUIRED PULP
Total Paper & Board		3,360	2,660	3,800	2,780
Total Paper		2,730	2,470	2,830	2,570
Newsprint	1.007	620	620	630	630
Book Paper	.812	990	800	1,030	840
Fine Paper	.910	420	380	440	400
Coarse & Industrial Paper	.984	470	460	490	480
Sanitary	.901	230	210	240	220
Total Paperboard	---	930	190	970	210
Container-Board	.788	140	110	150	120
Bending Board	.176	370	60	390	70
Others	.058	420	20	430	20

TABLE 4-9

TOTAL N.E. WOODPULP REQUIREMENTS (TREND BASIS) ESTIMATED REQUIREMENTS FOR PAPER & BOARD PRODUCTION - 1965 & 1970

(Thousands of short tons)

GRADE GROUP	RATIO PULP TO PAPER	1965		1970	
		PAPER PRODUCTION	REQUIRED PULP	PAPER PRODUCTION	REQUIRED PULP
Total Paper & Board		3,660	2,719	3,800	2,839
Total Paper		2,730	2,520	2,830	2,620
Newsprint	1.077	620	670	630	680
Book paper	.812	990	800	1,030	840
Fine paper	.910	420	830	440	400
Coarse & Industrial paper	.984	470	460	490	480
Sanitary	.901	230	210	240	220
TOTAL BOARD	-----	930	Q199	970	219
Container Board	.850	140	119	150	128
Building Board	.176	370	60	390	70
Others	.058	420	20	430	20

paper industry would probably be producing in the neighborhood of 3.5 million tons of paper and board, annually. To do so it would need 2.7 million tons of pulp. How much of this pulp could be produced <u>in</u> N.E. is a difficult conjecture. It is quite possible that paper industry in N.E. would be limited by a scarcity of pulpwood. On the other hand, a technological innovation might swing the pendulum back to the northeastern United States.[12]

There is no point in forecasting the share of New England pulp mills in the manufacture of the required pulp, since there are no data to go on. To the writer the ratio existing in 1954 seems as good as any other.

In 1954, 3 million tons of paper and board were produced in the New England area. Assuming that .72 tons of pulp are required for each ton of paper produced, the above output utilized 2.2 ton of pulp. In the same year New England pulp mills produced 1.6 million tons of pulp.[13] This comes to about 70% of the total.[14]

---

[12] See for example, H.B. Shepard, <u>Op</u>.<u>cit</u>., p.24

[13] <u>Ibid</u>.

[14] Following a different source we come to a somewhat different figure. In 1954, according to Lockwood's

If the same pattern continues, New England would produce nearly 1.9 million tons in 1965 and 2 million tons of pulp in 1970.

In 1958, New England pulp mills produced approximately 1.75 million tons of pulp.[15] An expansion in annual capacity of .15 million tons by 1965 and .25 million tons in 1970 would be needed if New England is to produce its present share of pulp for its paper mills. On the basis of 310 day year, the capacity requirements approximate an addition of 500 tons/day in 1965 and 800 tons/day in 1970.

Over the next decade, then, we can expect 800 tons/day of new capacity to be opended in pulp mills and 2,300

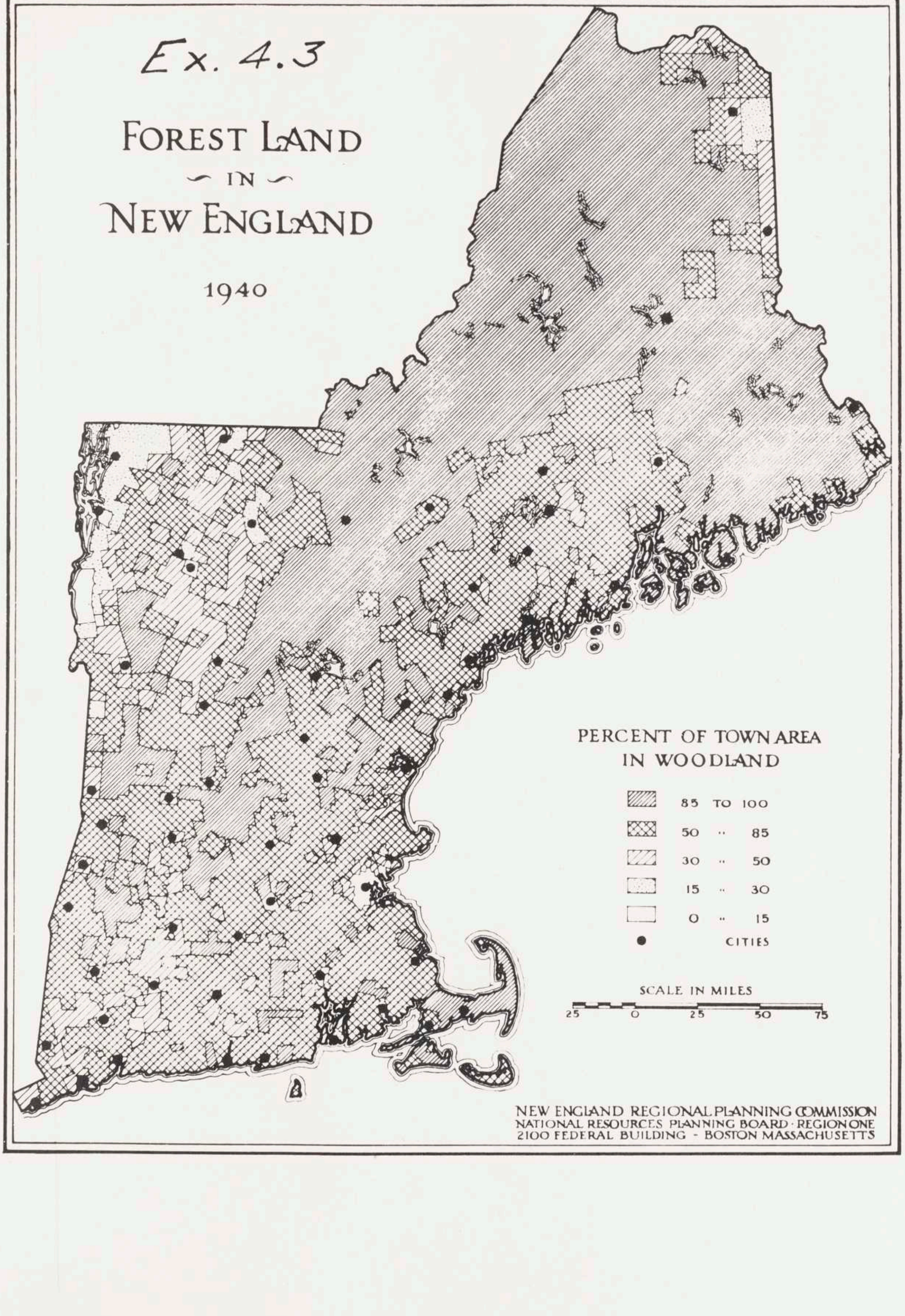
---

directory, 107 non-integrated paper mills existed in New England, producing less than 40% of the total output. Since all the pulp mills, (except one), were integrated with paper mills, these non-integrated mills presumably got their pulp supply from outside New England. Or, in other words, little less than 40% of the total pulp requirements were met from out-of-state sources.

[15] This figure has been extrapolated from the U.S. data.

Ex. 4.3

FOREST LAND
IN
NEW ENGLAND
1940



NEW ENGLAND REGIONAL PLANNING COMMISSION
NATIONAL RESOURCES PLANNING BOARD · REGION ONE
2100 FEDERAL BUILDING - BOSTON MASSACHUSETTS

tons/day in paper and board mills. Presumably, paper mills can be opened independently of pulp mills. In doing so, however, they suffer certain disadvantages. They have to pay for the transportation of pulp. If the pulp is dry lap they also have to beat it into usable shape. Relative slow growth of employment and output in the non-integrated paper mills of southern New England as compared to Maine and New Hampshire is an evidence of their disadvantages. These days the trend is toward greater and greater integration; and the site of the paper or board mill is pretty much determined once the pulp mill is located.

The following factors are usually considered in the location of a pulp mill.

Raw Material Source: Historically pulp industry has been resource oriented. In 1954, 20 out of the 30 pulp mills operating in New England were located in Maine.[16] Maine, as will be indicated in Exhibit 4-3, also has the biggest forest resources.

Cost of soft woods (which are used for fine paper) in New England are more than those in the south, but they are quite at par, or even less, with such other states

---

[16] Census of Manufacturers - 1954.

as Wisconsin, Michigan. (see Table 4-10) In hardwoods, New England has a disadvantage to all other states. The differntial is historic and it should not be considered an extraordinary handicap as long as N.E. restrict itself to its specialized field. However, the cost differential might prove prohibitive if the pulp plants are moved too far away from the forests. From the point of view of pulpwood costs, Maine and N.H. seem to be the best locations for pulp paper plants. Of course, they would have additional transportation costs of the final product but the cost would be much less, since a great reduction in weight takes place during the conversion of wood into paper.

Labor Costs: New England has an advantage in low labor costs. In 1954 average wages in pulp, paper and board industry were $1.80 in New England as against $1.94 in the U.S. and $2.10 in the Pacific region. In high quality paper, in which N.E. specializes, labor content is large enough to give N.E. a significant edge over other states. From the viewpoint of labor costs it does not really matter where the pulp plant is located in New England: wages are about the same in the region.

Fixed costs: In New England, there is a decided disadvantage in the matter of fuel costs. Costs of

4-37

TABLE 4-10

DELIVERED PULPWOOD COST PER CORD IN NEW ENGLAND, LAKE STATES, AND THE SOUTH, AND NEW YORK AND PENNSYLVANIA, 1947 AND 1954

	All Softwoods		All Hardwoods	
	1947	1954	1947	1954
NEW ENGLAND	\$23.66[1]	\$25.75[1]	\$21,17	\$22.73
Maine	n.a.[1]	25.60[1]	n.a.	20.63
New Hampshire	n.a.[1]	25.84[1]	n.a.	25.59
Wisconsin	24.84[1]	33.33[1]	17.14	19.34
Michigan	n.a.	35.94[2]	n.a.	15.23
MIDDLE ATLANTIC	n.a	30.39[1]	n.a.	20.82
Pennsylvania	n.a.	34.02[1]	n.a.	19.82
THE SOUTH	14.32[2]	17.88[1]	12,45	15.11

[1] Predominantly spruce fir

[2] Predominantly pine

Source: R. Eisenmenger (An unpublished manuscript of Mr. Eisenmenger of the Federal Reserve Bank of Boston).

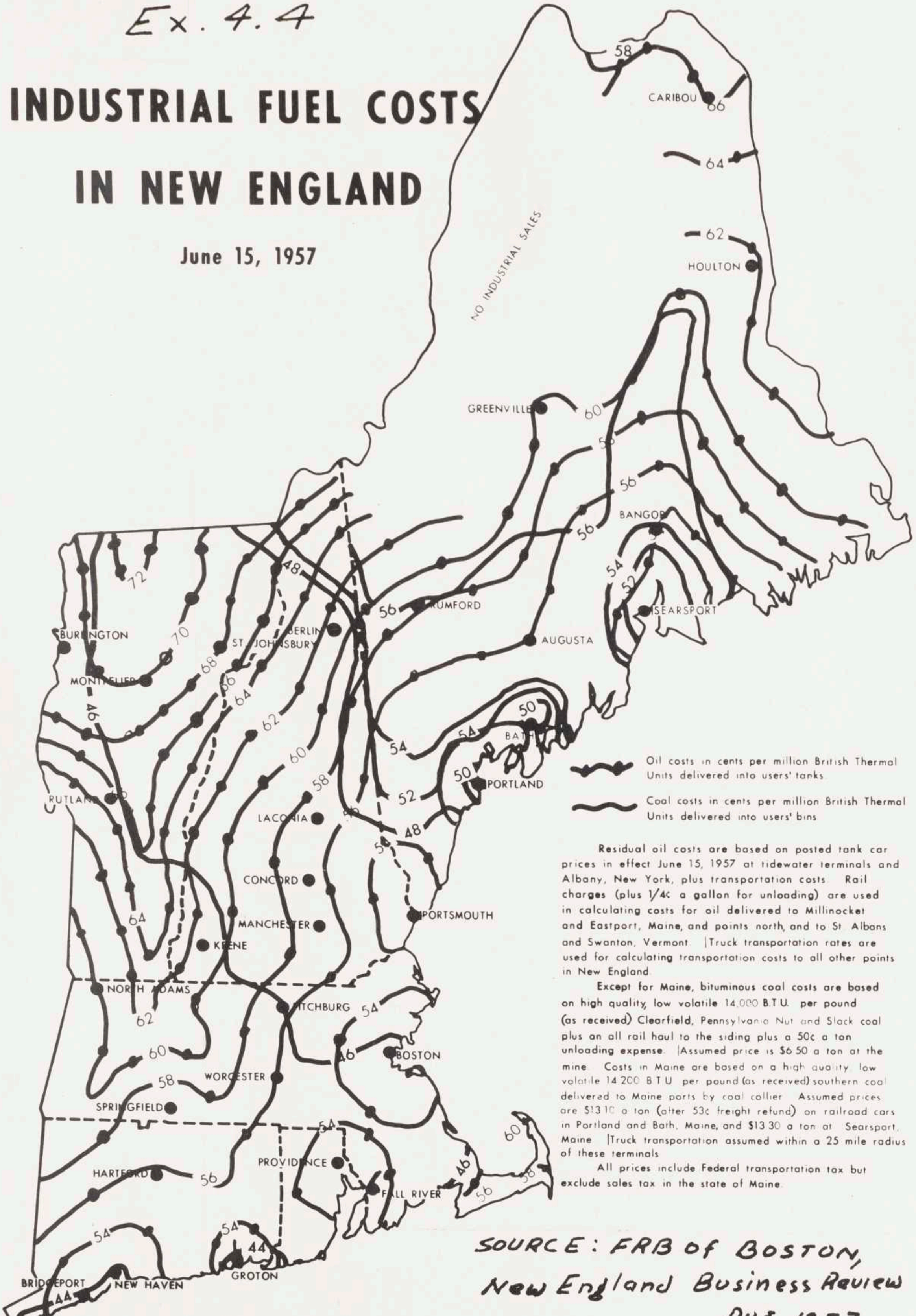
industrial fuel in N.E. are higher than any other region in the U.S. and about 50% higher than the Country as a whole. Exhibit 4-4 gives the cost of fuel per million BTU in the N.E. area. It will be noticed that Maine and N.H. -- the regions best suited for the location of pulp mills -- also have the highest fuel costs.

Conclusion: Except for the fuel costs, New Hampshire and Maine seem to be the best locations for establishing future pulp and paper capacity. The fuel disadvantage might be overcome through the use of nuclear reactor. As we tried to show in the last section at 80% load factor and 8% annual charges a pressurized water reactor of 40 MWT capacity is competitive with fuel costs at 40¢/10^6 BTU; at 90% load factor and 15% annual charge 40 MWT PWR is competitive with 50¢/10^6 BTU. It is apparent from Exhibit 4-4 that fuel costs in N.H. and Maine are quite close to 60¢/10^6 BTU. Nuclear Process Steam should, therefore, very definitely be considered when future expansion in pulp and paper capacity takes place in the New England region.

Ex. 4.4

INDUSTRIAL FUEL COSTS IN NEW ENGLAND

June 15, 1957



Oil costs in cents per million British Thermal Units delivered into users' tanks.

Coal costs in cents per million British Thermal Units delivered into users' bins

Residual oil costs are based on posted tank car prices in effect June 15, 1957 at tidewater terminals and Albany, New York, plus transportation costs. Rail charges (plus 1/4¢ a gallon for unloading) are used in calculating costs for oil delivered to Millinocket and Eastport, Maine, and points north, and to St. Albans and Swanton, Vermont. Truck transportation rates are used for calculating transportation costs to all other points in New England.

Except for Maine, bituminous coal costs are based on high quality, low volatile 14,000 B.T.U. per pound (as received) Clearfield, Pennsylvania Nut and Slack coal plus an all rail haul to the siding plus a 50¢ a ton unloading expense. Assumed price is $6.50 a ton at the mine. Costs in Maine are based on a high quality, low volatile 14,200 B.T.U. per pound (as received) southern coal delivered to Maine ports by coal collier. Assumed prices are $13.10 a ton (after 53¢ freight refund) on railroad cars in Portland and Bath, Maine, and $13.30 a ton at Searsport, Maine. Truck transportation assumed within a 25 mile radius of these terminals.

All prices include Federal transportation tax but exclude sales tax in the state of Maine.

SOURCE: FRB of BOSTON,
New England Business Review
Aug. 1957

CHAPTER V

HEALTH HAZARDS AND ADMINISTRATION OF NUCLEAR REACTORS[1]

General

In the minds of men nuclear reactors have come to be associated with nuclear weapons. It is feared that an accident in a nuclear plant might result in some kind of nuclear explosion, exposing whole localities to radiation. What is more, probability of such an explosion is placed quite high. The evidence, however, is clearly in the other direction. Here are some figures: from 1943 to 1954, twenty-five reactors operated in the United States for a total of 606,686 operating hours and 17,799,000 man hours. During this period no time was lost due to radiation injuries.

---

[1] The author has mainly depended upon the following sources for the facts used in this Chapter:

"Economics of Nuclear Power," Progress in Nuclear Energy, Series VIII (New York: McGraw-Hill, 1957).

"Law and Administration," Progress in Nuclear Energy, Series X (New York: McGraw-Hill, 1959).

A similar record has been established in the United Kingdom. During an operation history of some 50,000 man years, no death due to radiation has been reported; the safety rate with respect to internal hazards is a very small percentage of the best industrial rate, not a single case of temporary or permanent injury due to external radiation has occurred.

The breakdown of the Canadian NRX reactor in 1953, due to the failure of the control system, is very interesting from the point of view of public health. Even though the reactor was considerably damaged and large quantities of radioactive material were released, no one was significantly affected by radiation. There was no mechanical damage outside the reactor, and after the precautionary decontamination, the personnel returned to work on the next working day. According to the Canadian authorities, the NRX accident showed that "large amounts of radioactivity can be handled safely even though they are spread over large areas and throughout a complicated industrial plant."

In this country, to come back to the United States' experience, the record of lost-time injuries amongst the Atomic Energy Commission employees is inferior only to the communication industry. Here are the figures:

Industry	Lost-time Injury per mill. man-hr.
Electric Utilities	11.0
Nonferrous metals	10.0
Avg. for all industries	8.2
Misc. Manufacturing	6.1
Chemicals	5.5
AEC	2.3
Communication	1.8

Admittedly, experience gathered so far in the nuclear field is somewhat atypical. Extraordinary measures and expenditures have been undertaken through this period of experimentation. The above record, therefore, is not meant to be used as an argument for complacency; it is only meant to dispel the exaggerated fears that have prevailed in the mind of the public ever since the days of Hiroshima. Operating experience shows that radiation can be kept within tolerance limits if proper precautions are taken. It has been done in the past as the data in the following section show and there is no reason why nuclear reactors for paper plants should prove hazardous for the health of the employees or the public.

Hazards of Atomic Energy

Hazards of atomic energy can be divided into three groups:

A. External radiation
B. Internal radiation
C. Genetic effect

A. External radiation: Hazards of external radiation have been known for a considerable number of years, and there is a fairly general consensus as to the tolerance levels. Furthermore, external radiation can easily be detected and therefore controlled. Control can easily be established through films and other personnel monitoring devices. Table 5.1 goes a long way to show that external radiation hazards can be definitely controlled.

B. Internal radiation: Control in the field of internal radiation is much more difficult. As a matter of fact, great uncertainty exists as to the tolerance levels. Design of the plant is very important so far as the avoidance of internal radiation is concerned. Knowledge of the tolerance levels, although important is not enough; key to safety lies in good design and enlightened

TABLE 5.1

EXTERNAL RADIATION RECEIVED BY EMPLOYEES OF THE UKAEA

57% received an average dose less than 1/20 of the max. permissible weekly dose.
82% received an average dose less than 1/10 of the max. permissible weekly dose.
96% received an average dose less than 1/4 of the max. permissible weekly dose.
99.6 % received an average dose less than 1/2 of the max. permissible weekly dose.
100 % received an average dose less than 1 of the max. permissible weekly dose.

TABLE 5.2

RADIATION RECEIVED BY THE GONADS FROM DIFFERENT SOURCES

	Genetically significant radiation per annum to the population of England, Scotland, and Wales
Radiation from natural sources	2,100,000 r
Radiation to employees of UKAEA	2,000 r
Radiation received in high altitude flight	
(a) At present heights of 20,000 feet	30 r
(b) Corresponding total at 40,000 feet would be	300 r
Radiation resulting from routine diagnostic X-ray examination	about 50,000 r

---

Source: Farmer, F.R., "Safety Criteria in Atomic Energy," *Progress in Nuclear Energy*, Series VIII (New York: McGraw-Hill, 1957) p. 392 and p. 389.

management. As our past experience shows, both of these have been readily available in the developmental stage of nuclear power.

In the United Kingdom regular air samples were taken to detect α-, β-, and γ-ray contamination. Of the 33,000 air samples taken only 2% gave evidence of dust concentration requiring protective action. This result has an upward bias since more samples were taken from potentially dangerous zones. Periodic urine examinations were also given to the personnel. Of the 10,000 samples taken only four cases showed slightly significant execretion rates.

C. <u>Genetic effect</u>: The genetic effect of radiation has gathered somewhat of a nightmarish aura about itself. As a matter of fact, radiation received by the public, due to nuclear activities, is much less than the radiation received from many other sources. In Table 5.2 we reproduce the figures given by F. R. Farmer in his article in the <u>Progress in Nuclear Energy</u>, Series VIII, 1957. This is the radiation received by the gonads before reaching the age of thirty. It is obvious from the above figures that genetic effect of well-designed nuclear reactors is much less than that of routine X-ray examinations.

The Atomic Energy Act of 1954

We have tried to show above that with proper care radiation hazards can be admirably taken care of. In the United States, Congress and a few state legislatures have passed laws that enforce the proper care of atomic installations; therefore, a paper plant, if it uses a nuclear reactor, will have to obey these regulations. By far the most important among these regulations is the Atomic Energy Act of 1954.

This is a complex piece of legislation and we do not see any need to go into all its provisions here. We would consider only those aspects of the Act which bear upon the use of nuclear reactors by pulp and paper mills. From this point of view, the Act, through the agency of the Atomic Energy Commission, exercises control in two fields: control of information, and regulation of the design and operation of nuclear installations.

Control of information: The Act has labeled a considerable area of nuclear information as "Restricted Data." Access to this area can be obtained only after getting security clearance. The AEC, however, is directed to declassify as soon as possible as much information as national security permits.

Now, a businessman would like to gather as much information as possible before making a decision, and to this extent the Act might be said to impede progress in certain fields of nuclear science. But here we are dealing with just one field, i.e., the replacement of conventional boilers by nuclear reactors. The point is--does the businessman have enough data to compare a nuclear reactor with a conventional boiler? Our answer to this question is in the affirmative, as we have tried to show in the earlier parts of this study. Such paucity of data as ixists is due to the developmental state of nuclear technology rather than any restrictions on information that have been imposed by the Atomic Energy Act.

Regulation of design and operation of nuclear installations: In the matter of design, the AEC exercises substantial control over nuclear reactors. The main theme of the Act of 1954 was the safeguard of national security and public health. The Act bestows considerable discretionary powers on the AEC to adopt stringent measures where these two matters are concerned. In some circles, these powers of the AEC are rather excessively bemoaned as arbitrary. Before cursing the AEC, bell, book and candle, we must remember its heavy responsibilities in an uncertain, and potentially dangerous field, as atomic energy is.

A pulp and paper manufacturer must obtain two kinds of licenses from the AEC if he desires to use a nuclear reactor in his mill. First of all, the nuclear plant design must be approved by the AEC. This is to ensure that proper safety features are introduced in the structure. Secondly, after the plant has been built, the manufacturer must get a license to operate the facility. Theoretically, the AEC can refuse the permission to operate the reactor after it has been built. In practice, however, it is almost impossible if the proper design criteria are observed.

Commercial licenses are usually tailor-made to fit the particular situation. They may be issued for as long as forty years, and they can be renewed at the end of that period. Section 186, however, authorizes the government to revoke any license for "false statement in application" or "violation of, or failure to observe any of the terms and provisions of this Act or of any regulation of the Commission." The license can also be amended under certain circumstances. Section 187 of the Act states:

> The terms and conditions of all licenses shall be subject to amendment, revision, or modification, by reason of amendments of this Act or by reason of rules and regulations issued in accordance with the terms of this Act.

The Act, although it deleted government ownership of nuclear reactors, still specifies rights to all fissionable material would be vested in the government. Fissionable material can thus only be leased by the paper manufacturer. Moreover, fuel prices are to be fixed by the AEC. The prices would, however, be quite reasonable since the government is deeply interested in the development of nuclear energy.

These are just the beginnings of Atomic Law. It will take many court rulings before a definite pattern emerges. In the meantime, "The legal doctrine which will be applied in licensing program, is the administrative law, with a good deal of statutory interpretation added on. The Forum would be initially the AEC and the Federal courts."[1]

The state legislation, as it stands now, does not impose any more restrictions on the paper manufacturer than those imposed by the Atomic Energy Act. The Massachusetts Statute, and it is very similar to those enacted in other New England states, states that:

> No person shall manufacture, construct, produce, transfer, acquire or possess any special nuclear material, by-product material, production facility, or utilization facility within this commonwealth unless he shall have first obtained a license or permit for the activity in which he proposes to engage from the United States Atomic Energy Commission if, pursuant to the Atomic Energy Act of 1954, the Commission requires a license or permit to be obtained by persons proposing to engage in activities of the same type over which it has jurisdiction.[2]

---

[1] Ramney, J.T., "Atomic Energy and Government Institutions," Atomic Industrial Forum Inc., Vol. 1 No. 12 (1955) p. 52.

[2] Krebs, W.A.W., "Atomic Energy and State Law," Atomic Industrial Forum Inc., Vol. 1, No. 12 (1956) pp. 63-64.

A word would be pertinent here with regard to the future role of the states in the field of commercial nuclear energy. If the Atomic Energy Act is amended, as the AEC proposed, the states would be allowed to adopt and enforce standards "not in conflict with those adopted by the Commission." By "not in conflict with", the Commission means that the "states cannot relieve anyone from compliance with the Commission's radiation standards, but could impose, if they so chose, more restrictive standards."

Liability for Nuclear Accidents

Since no special statutes have as yet been enacted for atomic energy, the usual tort law would most probably be applied in the case of an incident. Tort laws are generally the business of the states and no definite rules can be laid down here. We would restrict ourselves to summarizing the views of A. W. Murphy as given in his article in Progress in Nuclear Energy.[1]

Generally, a person is not held liable under tort law unless he is at fault. Under the "rule of strict

---

[1] Murphy, A.W., "The Problem of Liability for Atomic Accidents and Insurance Against Them," Progress in Nuclear Energy, Series X (New York: McGraw-Hill, 1959).

liability," however, proof of his fault is quite immaterial. In Murphy's opinion, the latter rule would most probably be applied to reactor operators if an accident happens. The suppliers, however, would be held responsible only if their negligence is proved. "But even if the rules of strict liability are not applied," Murphy goes on to say, "neither the operators nor the suppliers can be certain that they will not be held liable for a nuclear accident, however careful they may be. Courts have increasingly...left negligence cases to juries; and juries generally have favored claimants. This practice is not, of course, universal, but whether a particular court will follow it in a particular case is less important to the atomic industry than that a procedure exists whereby liability can be imposed on the operator or a supplier, essentially without regard to fault."[1]

---

[1] Ibid., p. 62.

Insurance for Nuclear Installations

The problem of insurance against nuclear installations has been a much debated topic for a number of years. So long as most reactors were owned or contracted by the government, the risks were borne by the government in one form or another. Insurance of a reactor by a paper company, however, is a somewhat complicated problem, mainly because the possible (as opposed to probable) damage caused by the accident can be enormous in this field.

Some years ago, the insurance industry appointed a study group made up of insurance executives. After a thorough study of the problem, they came up with the following conclusions:[1]

> 1. The catastrophe potential of atomic energy, although remote, is more serious than anything now known in industry.
>
> 2. The possibility of a serious catastrophe seems very remote because of: a) substantial progress made in development of controls to prevent dangerous incidents; b) the development of features for containment of the

---

[1]

> results of a reactor failure should the multiplicity of controls all fail.
>
> 3. The insurance capacity for the physical hazards as now applicable to more hazardous types of chemical operations appears to be adequate to cover atomic reactor plants. If, however, the reactor should be located in proximity to large existing industrial plants, the increased exposure of the latter may be beyond the capacity of the insurance industry. This question would require further study.

After wrestling with the problem for some years, the industry has formed two syndicates to provide insurance for nuclear hazards: Nuclear Energy Liability Association, and Mutual Atomic Energy Liability Underwriters. Between themselves, the two pools would provide insurance up to sixty million dollars. It should be pointed out, however, that sixty million dollars is the top limit on the insurer's commitment no matter how many accidents occur over the life of the reactor. The insurance would cover all parties concerned, i.e., the supplier, the designer, etc. Policies issued by the syndicates are continuous. They do, however, have a cancellation clause. The policy only covers the nuclear hazard; the conventional hazards are to be insured in the regular way. The discovery period for claims, including genetic claims, is unlimited so long as the policy remains in force, and two years after it has been canceled. The policy does not cover damage to the reactor itself or to the employees.

Insurance premiums are to be paid annually. They are likely to be high in the first few years because of two reasons: firstly, no data exist as to the probable sums that the pools might be called upon to pay; and, secondly, the insurance industry would want to accumulate a fund out of which such payments can be made. Also, for the first few million dollars of insurance the rates are going to be higher than the average. According to the insurers, fifty million dollars coverage might cost as much as $50,000 a year in the case research reactor to $250,000 a year on 250,000 kw reactor.[1] For sparsely populated regions like Maine and New Hampshire, the rates might be relatively lower.

Private liability insurance becomes meaningful

---

[1] *Ibid.*, p. 68.

only when considered in the light of government indemnification as embodied in Public Law 85-256, also known as the Indemnification Act. Passed by the Eighty-fifth Congress to solve the problem of public liability for nuclear facilities, it became effective in September, 1957.

This law requires the nuclear operator to have a certain amount of financial protection from private insurance agencies. Over and above this basic financial insurance the government indemnifies the operator for 500 million dollars. Congress has also specified an upper limit as to the public liability--it is the sum of the basic financial protection and the 500 million dollars as indemnified by the government. The Act provides:

> The aggregate liability for a single nuclear incident of persons indemnified, including the reasonable cost of investigating and settling claims and defending suits for damage, shall not exceed the sum of 500 million dollars together with the amount of financial protection required of the licensee or contractor.

Between the private insurance syndicates and the government indemnification, the paper manufacturer can be quite sure of getting the required insurance.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

We find that nuclear process steam reactors are competitive with conventional boilers even under some very unfavorable assumptions.

We find that a 20 Mwt reactor, which might possibly be required in an average paper mill, is not economical at fuel costs below approximately 65¢ per 10^6 B.T.U. Since fossil fuels may not become that expensive in the next decade or so, nuclear technology would have to cut down the costs of small reactors to make small reactors competitive.

Process steam reactors of 40 Mwt size and over have a much more promising future. Table 6.1 gives the fuel cost threshold at which 40 Mwt reactors become competitive. For paper plants producing more than 400 tons per day or more, nuclear process heat should prove of considerable interest. Some of the largest plants producing up to 1200 tons per day can save as much as 15¢

TABLE 6.1

FUEL COST THRESHOLDS FOR 40 Mwt STEAM REACTORS

Reactor Type	70% Load 15% Chg.	80% Load 15% Chg.	90% Load 15% Chg.	80% Load 8% Chg.
	(Conventional fuel @ per mill. B.T.U.)			
PWR	62¢	56¢	50¢	38¢
BWR	-	-	-	60
OMR	-	70	60	50

per 10^6 B.T.U. in regions where fossil fuels cost as much as 60¢ per 10^6 B.T.U.

If a paper manufacturer decides to install a nuclear reactor, he should not expect extraordinary problems in his dealings with the Atomic Energy Commission. Indeed, he should draw upon the vast pool of expert knowledge that is embodied in that agency, and in private engineering firms with experience in reactor technology.

Problems of insurance have also been solved. Although the initial rates will be more than those for conventional boilers, they will be quite reasonable and would make a very slight effect on the total cost of steam produced. As yet, specific insurance rates are not available. This is one of the primary reasons why insurance charges are not included in the cost of nuclear reactors. (See Chapter III)

Turning our attention to the New England pulp and paper industry, we find that its share in the national production has been declining over the last twenty years or so. However, despite this declining rate, an expansion in New England pulp and paper capacity of nearly 3000 tons per day should be expected by 1970. Traditionally, we find the pulp and paper industry has been resource-oriented. We expect this trend to continue.

Abstracting from fuel costs, New Hampshire and Maine appear to be the best locations for new pulp and paper plants. These states are also the costliest in the United States from the point of view of fossil fuel costs. We conclude, therefore, that plants located in this region are the most promising for the use of nuclear process steam reactors.

Recommendations

The previous pages are only a general description of the problems of reactor use in the paper industry, and only a general analysis of their economics. They are merely meant to give an indication when a more precise analysis might be fruitful.

We recommend that paper manufacturers intending to open plants in Maine and New Hampshire give due consideration to the alternative of replacing conventional boilers by nuclear reactors for their process steam requirements.

BIBLIOGRAPHY

American Society of Mechanical Engineers. "A Glossary of Terms in Nuclear Science and Technology".

Argonne National Laboratory. Study of 40 MWT PWR, BWR and OMR for Production of Process Steam. ANL-6009, 1959.

______________________. ANL-6009, Addendum, 1959.

Atomic Industrial Forum, Inc., 1955-58.

______________________. "Atomic Energy, a Realistic Appraisal". (proceedings of a meeting of members, New York, 1955).

______________________. "Commercial and International Developments in Atomic Energy". (proceedings of a meeting for members and guests, New York,1956).

______________________. "*A Growth Survey of Atomic Industry, 1955-1965.* (New York, 1958).

______________________. "Management Economics & Technology for the Atomic Industry". (proceedings of the annual conference for members and guests, New York, 1956).

______________________. "Management and Atomic Industry, 1958". (proceedings of a conference sponsored by Atomic Industrial Forum and Nuclear Congress, New York, 1958).

______________________. "The New Atomic Energy Law: What It Means to Industry". (proceedings of a meeting for members and guests, New York, 1954).

______________________, and Stanford Research Institute. "Atomic Energy: The New Industrial Frontier". (proceedings of a meeting, New York, 1955).

Beggs, A. Kenneth. "How Much Will Your Industry Grow by 1957". Paper Trade Journal. No. 142 (April 28, 1958).

Calkin, J.B. Modern Pulp and Paper Making (New York: Reinhold, 1957).

Committee on Interstate and Foreign Commerce. "Pulp, Paper and Board Supply -- Demand", House Report, No. 573, (1957).

Cronan, Calvin S. "Paper Industry Reappraises Supply-Demand", Chemical Engineering (November, 1957).

Dobrow, M.C., "Paper Production and Capacity Survey", Paper Trade Journal, No. 142 (February 24, 1958).

Ely, O. "Atomic Power Costs", The AEC versus the Utilities, Public Utilities 52 (Dec., 1953).

Etherington. Nuclear Engineering Handbook (New York: McGraw Hill, 1958).

Gerringer & Goodfriend. "Potential Applications of Nuclear Energy for Process and Space Heat in the United States", American Hydrotherm, Inc. (1958).

Goldring, Mary. Economics of Atomic Energy. (1957)

Hecht, Selig, "Explaining the Atom. (New York: The Viking Press, 1949).

Hogencamp, Heinz. "Energy Consumption in the Drying of Paper", Abstract, B.I.P.C. 29:52: Chemical Abstracts (C.A.) 53:1710.

Hughes, D.J. "On Nuclear Energy. (Cambridge: Harvard University Press, 1957).

International Atomic Energy Agency. Directory of Nuclear Reactors, 1959.

Isard, W. and Whitney Vincent. Atomic Power -- An economic and Social Analysis.

Little, Arthur D., Inc. "Report on a Survey of Industrial Opportunities in New England to the Federal Reserve Bank of Boston, 1952".

Lockwood Directory of Pulp and Paper Mills, 1954, 1958.

McSweeney, Edward. "Pulp and Paper Trends Coming of Age", *Chemical Processing*, No. 21 (January, 1958).

Moise, W.L. "Some Investment Aspects of Paper Industry Today", *Paper Trade Journal*, No. 142, (May 12, 1958); B.I.P.C. 28:1598.

__________. "Paperboard Industry Expects Improved Demand", A.B.I.P.C. 29:188.

Murray, R.L. "Introduction to Nuclear Engineering",1954.

National Industrial Conference Board, Atomic Energy in Industry. Minutes of the 2nd conference, Oct. 1953.

______________. Minutes of the 3rd conference, Oct. 1954.

______________. Minutes of the 4th conference,Oct.,1955

______________. Minutes of the 5th conference, 1956.

______________. New York Board, 1957.

Organization for European Economic Cooperation. "pulp and Paper Industry in the U.S.A. " (1951).

Pederson, W.H. "Pulp, Paper and Board: An Economic Review", B.I.P.C. 28:1598.

Perazich, G.C. "Nuclear Process Heat in Industry". National Planning Association (1958).

Pickard, J.K. *Nuclear Power Reactors*. (Princeton: Van Nostrand, 1957).

Prehn & Tarrice. *Process Heat Generation and Consumption. 1939-1967.* (Stanford Research Inst., Menlo Park, Cal., 1958).

Progress in Nuclear Energy. "Economics of Nuclear Power", Series VIII, 1957 & 1959 (New York: McGraw Hill).

Schurr & Marschak, *Economic Aspects of Atomic Power* (1950)

Shepard, H.B. "Hardwood Pulp -- Its Manufacture and Use", New England Council, 1956.

Smyth, Henry de Wolf. *Atomic Energy for Military Purposes.* (Princeton: Princeton University Press, 1945).

Stanford Research Institute. "Production Trends in the U.S. through 1975". (1957).

________________.j "Income Trends in the U.S. through 1975" (1957).

United States Atomic Energy Commission. "Atomic Energy Facts"., 1957.

________________. *The Experimental Boiling Water Reactor*. Argonne National Laboratory.

________________. *Reports to the Atomic Energy Commission.*

________________) . *Source Book on Atomic Energy*, by Samuel Glasstone (2d Ed., 1958).

________________. *Atomic Power and Private Enterprise*. (Princeton: Van Nostrand)

________________. Hearings before the joint Committee on Atomic Energy, 83rd Congress. (Washington: U.S. Printing Office.).

________________. "*Atomic Power Development and Private Enterprise*. (Washington: U.S. Gov't. Printing Office, 1952).

United States Atomic Energy Agency. "History, Objectives and Program of Experimental Low Temperature Process Heat Reactor", *USAEC No. IN-31*, p. 1 (1959).

________________. *Power Reactors* (1958).

U.S. Dept. of Commerce. "Census of Manufacturers, 1939. 1947 and 1954".

Woodbury, D.O. "Atoms for Peace", 1957.