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A 37,500 KW POWER REACTOR WITH COMPETITIVE POSSIBILITIES

Reactors – P.W.R

ATOMIC ENERGY COMMISSION ★ UNITED STATES OF AMERICA ★

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AEC, Oak Ridge, Tenn.

WALTER KIDDE NUCLEAR LABORATORIES, INC.
975 Stewart Avenue
Garden City, New York

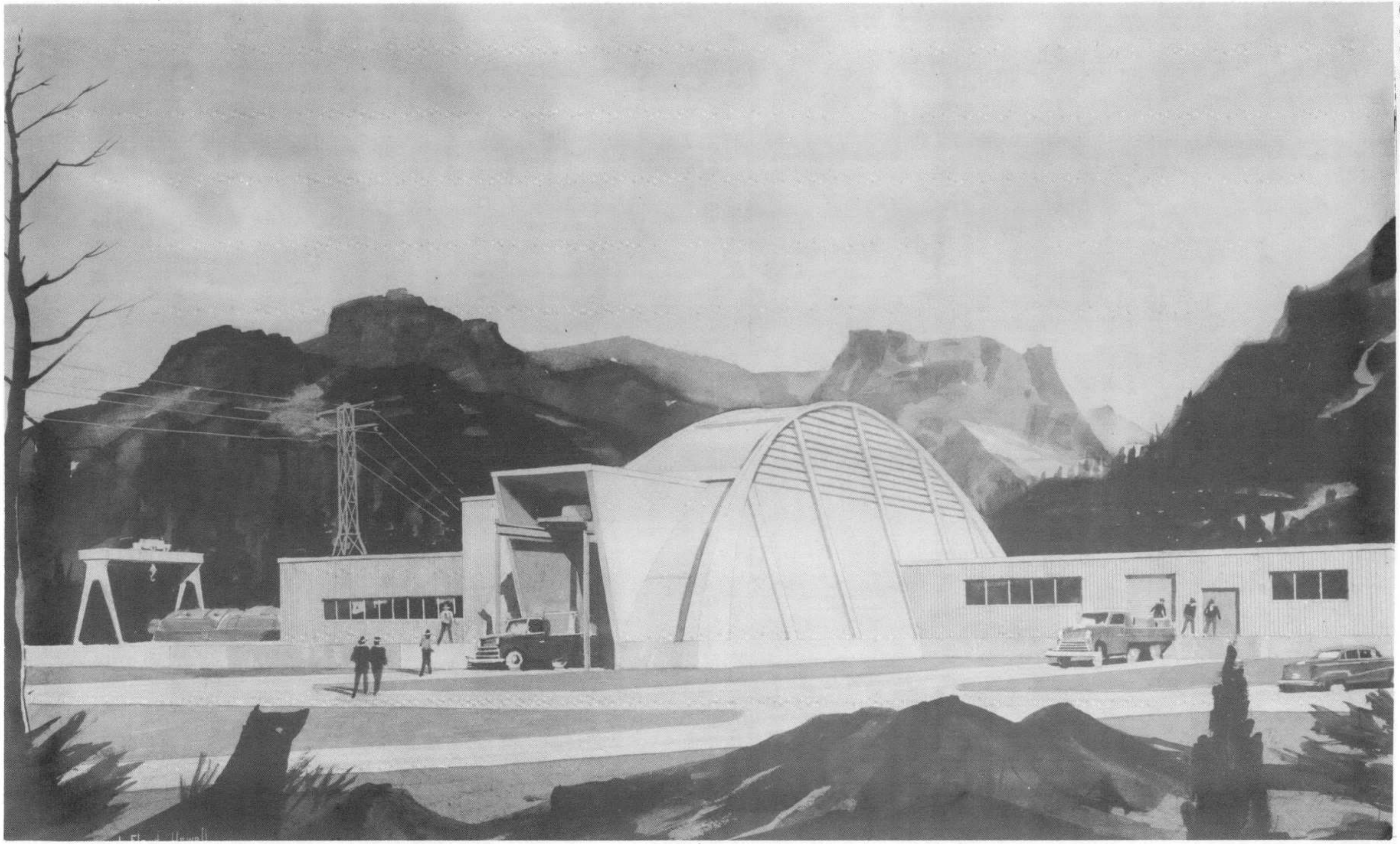
A 37,500 KW POWER REACTOR WITH COMPETITIVE POSSIBILITIES

W. I. Thompson
Chief Engineer

Karl Cohen
Vice President

Contract No. AT(30-1)-1374, Task IV
with
U. S. Atomic Energy Commission
New York Operations Office

February 26, 1954



DESIGNED BY WALTER KIDDE CONSTRUCTORS, INC

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FOREWORD

The present study on economics of nuclear power generation using a light water reactor was conducted by Walter Kidde Nuclear Laboratories, Inc. for the Atomic Energy Commission under contract number AT(30-1)-1374, Task IV.

Application of the light water reactor to other uses had already been considered in a series of reports as follows:

12/24/49	HKF-102	Low Enrichment Reactor for Naval Propulsion.
3/15/50	HKF-103	Neutron Production by Light- and Heavy-Water Moderated Reactors Using U-235 at Low Concentration.
6/1/50	HKF-105	High Performance Reactor for Neutron Production.
6/30/52	HKF-117	Low Cost Production Reactor.
9/30/53	NYO-3924 (WKNL-15)	Light Water Moderated Reactors in Cross Flow.

The possibility of low cost construction suggested its use for commercial power generation in package units to compete in relatively high fuel cost areas.

The scope of work was originally defined in a letter of April 24, 1953 from Dr. V. L. Parsegian substantially as follows:

> Design study for 30 MW net output capacity plant for isolated area, using reactor cooled and moderated by light water. Cost basis: power only reactor (i.e., no credit for plutonium), government ownership of land, reactor and generating equipment.

Other more specific instructions are included in the above letter.

The scope was subsequently extended to include more detailed engineering and to permit vibration testing on a model lattice under the proposed operating conditions.

In performing this work, we received valuable consulting assistance from a number of other firms, notably as follows: Walter Kidde Constructors, Inc.--architectural and layout; American Gas and Electric Service Corporation--power circuit specifications and utility economics and accounting; and Sylvania Electric Products, Inc.--fuel element design and fabrication cost. Principal suppliers included General Electric Company--turbine for low pressure saturated steam; Griscom-Russell Company and Babcock and Wilcox Company--boilers and pressure vessels; and Allis Chalmers and Ingersoll-Rand for high pressure water circulating pumps. The courtesies of these companies are gratefully acknowledged.

Chapter I

INTRODUCTION & SUMMARY

The basis of this report is the request by the AEC for a study of the economics of a light water moderated, slightly enriched uranium reactor as a 30,000 kw "package" power plant for service in remote locations.

Since our first report on the light water, slightly enriched reactor for submarine propulsion five years ago, there have been a large number of studies on the economic potentialities of this reactor type. Some or all aspects have been studied by WAPD, North American Aviation, ANL, KAPL, Commonwealth Edison - Public Service of N. Illinois, Project Dynamo, and doubtless others. A few of these studies have been reported in satisfactory detail. Commonwealth Edison and Project Dynamo both have reported design studies for cost estimating purposes. Project Dynamo is reasonably sanguine that power can be produced from light water low enrichment reactors within a decade or two at a price of 6.2 ± 0.6 mills/kwh. However, Westinghouse states the economic future of this power plant is obscure*, and has not quoted prices.

After all these studies, what are the points of departure of the present one? They are closely related to the immediacy of the atomic power problem. They are as follows:

1. The power plant is designed on the basis of already existing technology. Suppliers exist for every item of equipment, including the fuel elements.

2. We are designing a small power plant, which is below the ultimate economic size of a reactor power plant, as it is below the economic size of present-day coal-steam plants.

3. We are entering a transition period, at the beginning of which the government possesses all the processing plants and controls the market for all raw and finished materials of nuclear reactors. This situation will not be fundamentally altered until private nuclear power production is on a very substantial scale, say 2,000,000 kw of developed power.

4. Fuel element technology is rapidly improving. While the present assured lifetime of uranium fuel elements is not over 1,000 MW days per ton, the concensus of scientific opinion is that it will be increased to about 10,000 MW days per ton in about five to ten years.

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* Hearings before Joint Committee on Atomic Energy, July 9, 1953.

There are three problems facing the reactor designer today. He must design a reactor which will be fully competitive with coal-steam plants when improved fuel elements and adequate reactor operating experience are a reality. He must show how a reactor of this type, built of today's materials, can be financed and operated. And he must overcome the special difficulty that the commercial nuclear power industry is not yet established in sufficient volume to maintain its own ancillary facilities. The last two problems imply the need for some form of AEC assistance.

We cannot expect that one 35,000 kw power plant can support an entirely independent chain of auxiliary facilities -- ore processing plants, isotope separation plants, chemical reprocessing plants, and so forth. It will have to depend for many products and services on the existing AEC facilities. The costs of these products and services are crucial in the economic balance.

Determining the proper prices is not easy, for two main reasons: (1) the services or products may not be part of the AEC's standard operations, and hence may be on an uneconomically small scale for the existing facilities, and (2) the commercial power customer should not be burdened with costs which have been incurred to meet military schedules and specifications. There is just as great a danger of <u>under</u>pricing. Since it is the national interest to foster a strong commercial nuclear power industry, it is proper to expect AEC assistance in pricing to overcome temporary difficulties associated with low volume. But it must be demonstrable that once a reasonable scale of operations is attained, there will result a financially self-sustaining industry.

The need for AEC assistance is associated with our present technological difficulties (almost entirely the radiation sensitivity of the fuel element) and with the low volume of an infant industry. But these difficulties suggest their own solution. We shall propose a pricing policy and fuel rental policy for the AEC, by which it will be possible for private firms to invest now in reactors which will produce power in a competitive price range. What is more important, through the development of technique and the increase in volume, the necessity for a favorable AEC pricing policy will disappear. It will be far cheaper for the government to encourage the development of commercial nuclear power by the suggested policies than to adopt a "tough" pricing policy and be obliged, as a result of it, to support completely the development of power reactors.

The policies which are suggested are as follows:

1. The AEC should rent reactor fuel at a nominal rate. We suggest 4% per annum of the actual production costs.

2. The AEC should chemically reprocess spent low enrichment reactor fuels, at its present rate for reprocessing irradiated natural uranium.

The technical and economic justification for these policies is discussed in detail immediately below.

The reactor is designed around a low alloy* uranium fuel element with stainless steel jackets. The specific properties required of the element are:

1. That failures due to radiation damage will not be frequent before an average irradiation of 1,000 MWD/ton.

2. That the corrosion rate of the exposed slug after jacket failure will not be immeasurably large.

These specifications can be met with fuel elements deliverable in quantity in 30 months.**

If we accept that fuel elements have limited lives, of the order of 1,000 MWD/T, we are obliged to provide for periodic reprocessing of the fuel elements. The reactor must be designed so that removal and replacement of fuel elements is fairly convenient. And the reprocessing itself must be reasonably priced.

There are presently two types of chemical reprocessing in current AEC operation. One is reprocessing, in ton lots, of irradiated natural uranium: the costs are reckoned in dollars/pound. The other is reprocessing, in kilogram lots, of irradiated U-235 alloys: the costs are reckoned in dollars/gram. There is no facility which currently reprocesses intermediate low concentrations (such as the 1.5 per cent U-235 used here). We obviously cannot justify economically a special facility for one 35,000 kw power plant, whose requirement for chemical reprocessing is only 150 kg/day, or even less as the quality of the fuel element improves.

If we were to construct a special facility, it would not be a chemical reprocessing plant. What is needed is physical re-establishment of the fuel element -- metallurgical reforming rather than chemical change. The cost of this operation has been estimated for us by Sylvania Electric Products Company. For a scale of operations of 1,500 kg/day, they estimate a price, including normal profit, of $5/lb.

For the first power plant we envisage the use of the bulk facilities of the AEC for chemical reprocessing. Allowance has been made in our fuel economy for fairly high losses resulting from this operation. The economic worth of fuel element reforming by way of chemical reprocessing, which is more thorough than required, is then $5/lb. This price incidentally, is

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* That is, 10 or less atom per cent inert elements.

** We have given some consideration to high alloy uranium fuel elements (50 or more atom per cent inert elements), which might resist radiation damage to the limit of the reactivity cycle and be corrosion-proof without jackets. Even if we could be assured of delivery of fuel elements to these specifications in 30 months, it is not clear that they would be superior to the low alloy fuels, because of parasitic losses, fuel replenishment charges, and assembly problems.

approximately the present cost of recovering fuel elements from irradiated natural uranium. We suggest that it is the appropriate AEC price for the service.

The necessity for this service will disappear either by simple increase in the volume of operations, or by an improvement in radiation stability of fuel elements. When we have a fuel element which will last 10,000 MWD/ton, we could almost afford to discard the fuel without any chemical processing at all. More practically, since chemical reprocessing will now be much less frequent, we can certainly afford to pay far higher prices for the chemical recovery process.

The power plant suffers in other ways from being small, being one of its kind, and having sensitive fuel elements. We have been obliged, since fuel is reprocessed every 100 days, to provide for two* complete fuel charges, one in the reactor and one for replacement. It is possible to imagine more ingenious, and more economical, fuel replacement programs than the one adopted of replacing the whole charge each time, and reprocessing as a batch (thus mixing over- and under-exposed rods). However, on our small scale of operations, each 15 ton batch is barely of economical size for individual processing.

The fuel concentration is high because neutron leakage is appreciable from the small reactor core. The use of zirconium jackets is not feasible, wholly apart from the question of a reliable supply of tubing, because of the frequent reprocessing. The stainless steel jackets likewise increase the U-235 concentration. A larger reactor using zirconium would require about 1.2 per cent U-235, instead of the 1.46 per cent chosen. Thus, not only is the inventory large, but the U-235 concentration and hence the unit price is high.

The obvious way of reducing the inventory is to increase the specific power, or kilowatts per kilogram of fuel in the reactor. Our design flux is 1.4×10^{13} neutron/cm^2 sec:

by current standards of power reactor design, it is retrograde. But in the present instance, there are several reasons why higher specific power is not advisable. The replacement schedule at 1,000 MWD/ton burn-up, is once every 100 days. For remote operations, which is a possible end use of the package power plant, we would prefer to extend this schedule. We confidently expect to accomplish this through better fuel elements, but we can't make use of the improvement before we have it. Again, higher specific power requires smaller dimension fuel elements and coolant channels, and more finicking mechanical assembly. Finally, as has been mentioned, the core is already uncomfortably small so far as neutron leakage is concerned.

How can we avoid excessive fuel charges from our high fuel investment? Let us suppose for a moment that we purchase the fuel at the start of operations and discard it after it has completed its first reactivity cycle, which we estimate to be at 10,000 MWD/ton. If we had a fuel element

---

* Actually 2.2.

which could support 10,000 MWD/ton irradiation without physical damage, we would thus avoid chemical reprocessing problems altogether. However, even with such a superior fuel element, the fuel charge under this program (including the cost of money) is over 3.3 mills/kwh for our case.

But there is no reason to discard fuel after 10,000 MWD/ton, particularly since we are apt to reprocess far oftener than this anyway because of irradiation damage. Although the fuel needs enriching after 10,000 MWD/ton to maintain reactivity, it is far cheaper to do so than to purchase a fresh charge. In many ways fuel after 10,000 MWD/ton is superior to the initial charge. Over the first reactivity cycle, we burn on the average more U-235 than U-238. At 10,000 MWD/ton, we can burn equal parts of each, and as the concentration of higher Pu isotopes builds up we eventually* arrive at a point where we can burn 5 atoms of U-238 to one of U-235. What is more, the total concentration of fissionable elements (U-235, Pu-239, and Pu-241) gradually increases -- in fact doubles. And Pu-239/240/241 mixtures are eminently useful in fast reactors.

It is more reasonable to keep the original fuel charge as a non-depreciating asset, and to begin paying a fuel make-up charge after the first reactivity cycle. In our case the make-up charge begins at 1 mill/kwh (feeding in small quantities of 4.5 per cent U-235), which gradually decreases to 0.4 mill/kwh.** It is possible to make provision for constant fuel charges over the life of the plant. The plan suggested however has the important advantage of minimum fuel charges for the first (7.5 year) reactivity period. After this, we expect that reductions in reprocessing charges (surely we shall be able to irradiate to 2,000 MWD/ton in 10 years) and other operating improvements will absorb the increased fuel price. Of course, if there is any breeder reactor market, we may have other options.

In the financing plan which we propose, the plant is not unduly penalized by its high fuel investment. The reactor fuel is not now a suitable commodity for private investment. There is only one source of supply (the AEC); we cannot verify the supplier's costs, and the supplier has no stable pricing policy. The present and projected future prices of natural uranium are based on persistence of an insatiable military demand, which the U. S. government is attempting to eliminate by international accord. We even lack assurance that fuel which must be purchased today may not be given away tomorrow.

It is therefore logical to leave the fuel the property of the supplier. Since he must himself raise money to stockpile fuel, the rental should be the interest and the handling charges, which we round off at 4 per cent. Use of the above procedure to arrive at charges on fuel investment does not give an artificial picture of atomic power costs. For it is clear from the previous discussion that in subsequent and larger scale reactors the fuel investment (here taken as $133/kw) may be reduced by a factor of three through the use of higher specific power and improved

---

* After 10 10,000 MWD/ton cycles.

** Eventually we can use natural uranium feed.

scheduling. Low cost public financing of reactor fuel is only a temporary bridge to private financing, when the obstacles to the latter have been eliminated.*

One more word on financing. In calculating the price of power, we assume that the cost of money and the amortization rate for a reactor power plant are the same as those for a coal-steam plant. In reality we could only expect these conditions to apply after years of operating experience have shown that the risks of plant failure, and the lifetime of the plant components, are comparable for the two cases. There is reason to expect that these conditions will be met in the long run: we shall not insist here on how to achieve the eventual capital charges now. We turn now to the results.

The base case studied was a single reactor core whose heat output was taken as 150 MW. We chose this case at the beginning of the studies, expecting that the net conversion efficiency might be as low as 20 per cent. It has since been apparent, since the plant power output is 37,500 kw, that the efficiency is 25 per cent.

A single core, 37,500 kw plant would be most suitable as one unit of a system whose total output might be 100 to 150,000 kw. It is probably not appropriate as a reliable source of 30,000 kw in a remote location. Two or three separate 15,000 kw units would be better.

Since the ultimate utility of small power units of this type may depend on adaptation to special requirements of flexibility and availability of power, we have considered two possible alternate arrangements. First is a highly flexible unit in which full reactor output is assured at all times by providing three reactors, two of which can handle the full output. A second, somewhat less flexible alternate was studied in which two reactors are provided, each of which will supply half the full output. In each of these cases, a 2,500 kw diesel-electric unit is provided for start-up.

Table 1.1 gives estimated investment costs for the three cases. In Case I, the original base case, the investment, including contingency, amounts to $286/kw, based on an output of 37,500 kw of electric power. The very flexible Case II, with three reactors and two generators amounts to $397/kw, based on 37,500 kw output. Of course, the maximum output in this case would be considerably greater. The slightly less flexible Case III amounts to $328/kw. Table 1.2 gives details of reactor core, weight and costs of fuel inventory and make-up.

The total power costs for these different cases are given in Table 1.3, showing a range from 9.6 mills/kwh for the base case, to 12.9 mills/kwh for the most flexible unit, Case II. For comparison, estimated costs are also given for new coal-steam plants in an area where coal is $10/ton; for example, New England. The estimated cost for coal power is in the range from 8.3 to 10 mills per kwh. The base case will be about a stand-off with new coal plants in the New England region, and the lower

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* Contrast with the <u>permanent</u> high investment costs of hydroelectric plants, which achieve low carrying charges and putative low prices only through public financing.

fuel cost (2.6 mills vs. 4.24 mills/kwh) would suggest that the nuclear plants be operated at higher load factors at the expense of existing coal units.

The cost figures just given are perhaps not as inspiring as the figures for reactor power plants of the same and other types projected for some indefinite future date. However, they show that, with a suitable AEC pricing policy, we are in a competitive position with coal at $10/ton. This means there are economic outlets even in this country, and a fortiori abroad.

Finally, in Table 1.4 we give a breakdown of estimated power costs for a plant of the same general design based on a 10,000 MWD/T fuel element. Here we take a somewhat larger plant (125,000 kw of power), remove the contingency from the plant investment and improve scheduling of fuel replacement. On the other hand, we adopt private financing of the fuel inventory and double the cost of chemical reprocessing. It is clear that this plant, with a power cost of 7.2 mills/kwh, would be economically viable without assistance from the AEC. What further improvements might be possible through refinement of design, increase in primary system pressure, etc. cannot be fairly evaluated at this time; but they should be considerable.

To summarize, we present in this report a reactor design which is capable, through foreseeable stages of development, of competing favorably with coal-steam plants in many parts of the United States. We likewise propose an AEC pricing policy which makes possible the investment of private funds in nuclear reactors and their development. It is debatable whether the proposed pricing policy represents a subsidy or not: in any event the policy is automatically self-liquidating. Most importantly, we emphasize that we are talking about today.

We conclude with a brief review of the Case I reactor design. The details will be found in the body of the report.

The reactor assembly consists of a core of 5' uranium rods, arranged in a hexagonal lattice 4.5 feet in diameter. The water/uranium volume ratio is 1.5/1. The core is surrounded by a one foot thick graphite reflector. The rods are made up of cylindrical slugs of uranium containing 3 weight per cent Nb, 8" long and 0.5" in diameter, flashed with copper, and bonded to each other and to a .013 stainless steel tube which serves as a jacket. (This assembly is based on the powder metallurgy techniques of the Sylvania Electric Products Company). The rods are assembled, with the aid of spacers, into equilateral triangular arrays, which are encased in heavy (0.10") zirconium plates. The triangles are slightly truncated at the corners, and where they nest together there is a hexagonal gap at each intersection of six triangles. This space is occupied by a stainless steel control rube. Control is effected by a variable level of mercury. The core rests on top of the 19 control tubes which in turn are bolted to the bottom grid. Connections to the 19 control tubes are made through this grid. The upper surface is thus free, and bundles may be removed from above without disengaging control rods. (See Figs. 2.1 and 2.3).

The primary water coolant is pumped in a single pass parallel to the rods and upwards, thence to the tube side of a shell-and-tube boiler. The boiler tubes are double thickness stainless steel. The shell is carbon steel. The average water temperature in the reactor is 460° F, and the operating pressure is 850 psi. These limits were chosen, partly because studies showed little cost advantage to higher pressures in the steam cycle, partly to ease materials problems in the reactor and reactor vessel.

The temperature rise of water through the reactor is 30° F. The water velocity in the lattice is 10.3 f.p.s. The heat transfer coefficients are based on recent data taken at Garden City and not previously reported. The pumping rate is 35,400 gpm and the power requirement is 1,100 kw. Further details of the process design of the primary loop are given in Chapter III.

The reactor vessel (following a design suggested by the Babcock and Wilcox Company) is of 3" stainless clad steel, 19' long, 7' in diameter, with a bolted hemispherical head. There are no openings in the head. The seal is based on controlling leakage between a double gasket (see Fig. 5.1). Fabrication of the vessel is feasible with present equipment.

Besides the mercury control system, which is used for the safety system, additional control is accomplished by poisoning the primary coolant. The reactor has a large negative temperature coefficient of reactivity, and is self-stabilizing.

The U-235 concentration is 1.46 per cent. The initial conversion ratio of the reactor at 500° F is 0.95, allowing for equilibrium Xe and Sm losses. The reactor will lose criticality after 11,400* MWD/ton: the make-up rate will then be 960 gm/day of 4.5 per cent U-235, assuming losses of .6 per cent of the reactor charge at each reprocessing. The ratio of average to maximum neutron flux is 1:2.25. In addition, there is peaking of 17 per cent near the boundaries of the bundles, caused by excess water. The reactor physics is treated in more detail in Chapter II.

The power cycle is based on 308 lb. saturated steam.** The turbine and generator (tandem compound double-flow unit operating at 3,600 rpm) were quoted by the General Electric Company's turbine division for our specified steam condition. Architectural features and general layout of the power plant are shown in Figures 5.5 to 5.10 prepared by Walter Kidde Constructors, Inc.

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* We have used 10,000 MWD/ton in the economic studies.

** For the design and economics of the power cycle we are indebted to consultants furnished by the American Gas & Electric Service Corporation.

Table 1.1

Cost of Plants

Case	I	II	III
No. Reactors	1	3	2
Heat per Reactor, MW	150	75	75
No. Turbogenerators	1	2	1
Gross Power per Generator, KW	41,200	30,900	41,200
Auxiliary Power Unit, KW	—	2,500	2,500
Cost of Plant - $ Thousands			
Boiler Plant Equipment	2,698	3,422	3,100
Turbogenerator Units	2,759	3,985	2,759
Auxiliary Power Unit	—	600	600
Miscellaneous Equipment	127	155	140
Structure and Improvements	796	1,045	810
Outside Facilities	1,340	1,600	1,400
Total	7,720	10,807	8,809
Design Cost	754	997	860
Contractors Overhead and Fee	974	1,426	1,183
Contingency	1,252	1,670	1,448
TOTAL INVESTMENT	10,700	14,900	12,300
$/KW Based on Nominal Output*	286	397	328

* 37,500 KW

Table 1.2

Design Bases

Case	I	II	III
Reactor			
Number	1	3	2
Core Length, ft.	5.4	4.8	4.8
Core Diameter, ft.	4.5	3.0	3.0
Fuel Inventory per Reactor, Metric Tons	15	7.5	7.5
Heat Output per Reactor, MW	150	75	75
Boilers			
Number	6	6	6
Turbogenerator Units			
Number	1	2	1
Maximum Output per unit	41,200 KW	30,900	41,200
Fuel			
Total Inventory, Metric Tons	33	40.5	33
Inventory Enrichment	1.46%	1.56%	1.56%
Total Inventory Cost	$5,230,000	$7,100,000	$5,800,000
Make-Up Fuel*			
Rate gm/MWD Heat	6.42	7.55	7.55
Enrichment, % U-235	4.5%	4.5%	4.5%

*At end of initial reactivity period.

Table 1.3

A. Cost of Nuclear Power - Mills/KWH

80% Service Factor

Case	I First 7.5 Years	I After 7.5 Years	II First 9.2 Years	II After 9.2 Years	III First 7.5 Years	III After 7.5 Years
Capital Charges at 14%	5.72	5.72	7.94	7.94	6.56	6.56
Fuel Rental at 4%	0.80 (2.2 Charges)	0.60 (1.65 Charges)	1.38 (5.4 Charges)	1.38	0.89 (4.4 Charges)	0.89
Operating Costs	1.60	1.30	1.60	1.30	1.60	1.30
Fuel Reprocessing and Transportation						
(1000 MWD/ton Fuel Life)	2.00		2.00		2.00	
(2000 MWD/ton Fuel Life)		1.00		1.00		1.00
Fuel Make-Up Cost	---	1.00	---	1.18	---	1.18
TOTAL, NUCLEAR PLANT	10.12	9.62	12.92	12.80	11.05	10.93

B. Cost of Power from Coal

	Optimistic	Pessimistic
Capital Charges		
$160/KW	3.20	
$225/KW		4.50
Operating Expense	1.30	1.30
Fuel at $10/ton:		
10,000 Btu/KWH	3.85	
11,000 Btu/KWH	—	4.24
TOTAL, COAL PLANT	8.35	10.04

Table 1.4

Nuclear Power Costs in Larger Plant
with
Improved Fuel Elements

Design Bases: Heat Output - 500 MW
Total Fuel Inventory - 41 metric tons
Inventory Enrichment - 1.2%
Inventory Cost - $5,000,000
Plant Investment - $30,000,000 (= $240/kw)
Fuel Reprocessing Cost - $10/lb.
Service Factor - 80%
Power Output - 125 MW

	mills/kwh
Capital charges at 14%	4.8
Fuel inventory charges at 12%	0.7
Operating expenses	0.5
Fuel reprocessing and transportation (10,000 MWD/ton fuel life)	0.4
Fuel make-up (2nd cycle)	0.8
	7.2

Chapter II

REACTOR AND PRIMARY CIRCUIT

The reactor core consists of a lattice of uranium fuel rods in water, surrounded by a graphite reflector. The weight of the core is supported by a bottom grid which rests on supports welded to the interior of the reactor vessel. Nineteen mercury control tubes are provided for dynamic control and scram. Shim is accomplished by poisoning the water.

Figure 2.1 shows the general layout of core and reflector. The bottom grid and control tube piping are permanently installed in the pressure vessel. The 19 control tubes are bolted to the bottom grid and form the support for the fuel bundles. Each triangular fuel bundle (Fig. 2.2), containing 63 fuel rods, is supported at the top by the three adjacent control tubes and may be pulled out of the reactor by means of lifting lugs at the top. The reflector, which will be removed less frequently than fuel bundles, is composed of blocks of graphite jacketed in zirconium, which are supported directly by the vessel wall. Figure 2.3 shows the subdivision of the reflector.

Cooling water enters the bottom inlet, passes upward parallel to the fuel rods, and leaves by two exit ports at the top. All heat generated within the reactor, including reflector and control rods, is removed by this coolant.

The core is enclosed in a stainless clad cylindrical pressure vessel with wall thickness of 3 in., diameter 7 ft. and length 19 ft. The top of the pressure vessel is an ordinary convex closure which is bolted down with no unusual devices.

Each control tube consists of an outer mercury annulus and an inner vent tube which communicates with the annulus by radial tubes at the top (Fig. 2.4). The outer annulus is connected through a control system to a mercury head tube which supplies the pressure for scram. In case of scram, the head tube is opened directly to the control tube and mercury flows in at a rate limited only by pressure drop. In order to prevent the mercury from overshooting, the radial connections between the mercury annulus and the inner vent tube are made of a size which will permit rapid air flow but will permit only a trickle of mercury.

During normal operation, the mercury level is positioned by a pump and check valve system (see Fig. 2.5) with position indicated by the level in the head tank. The reading corresponding to full in can be used for calibration, since at this point the level will be gradually dropping with valves in scram position.

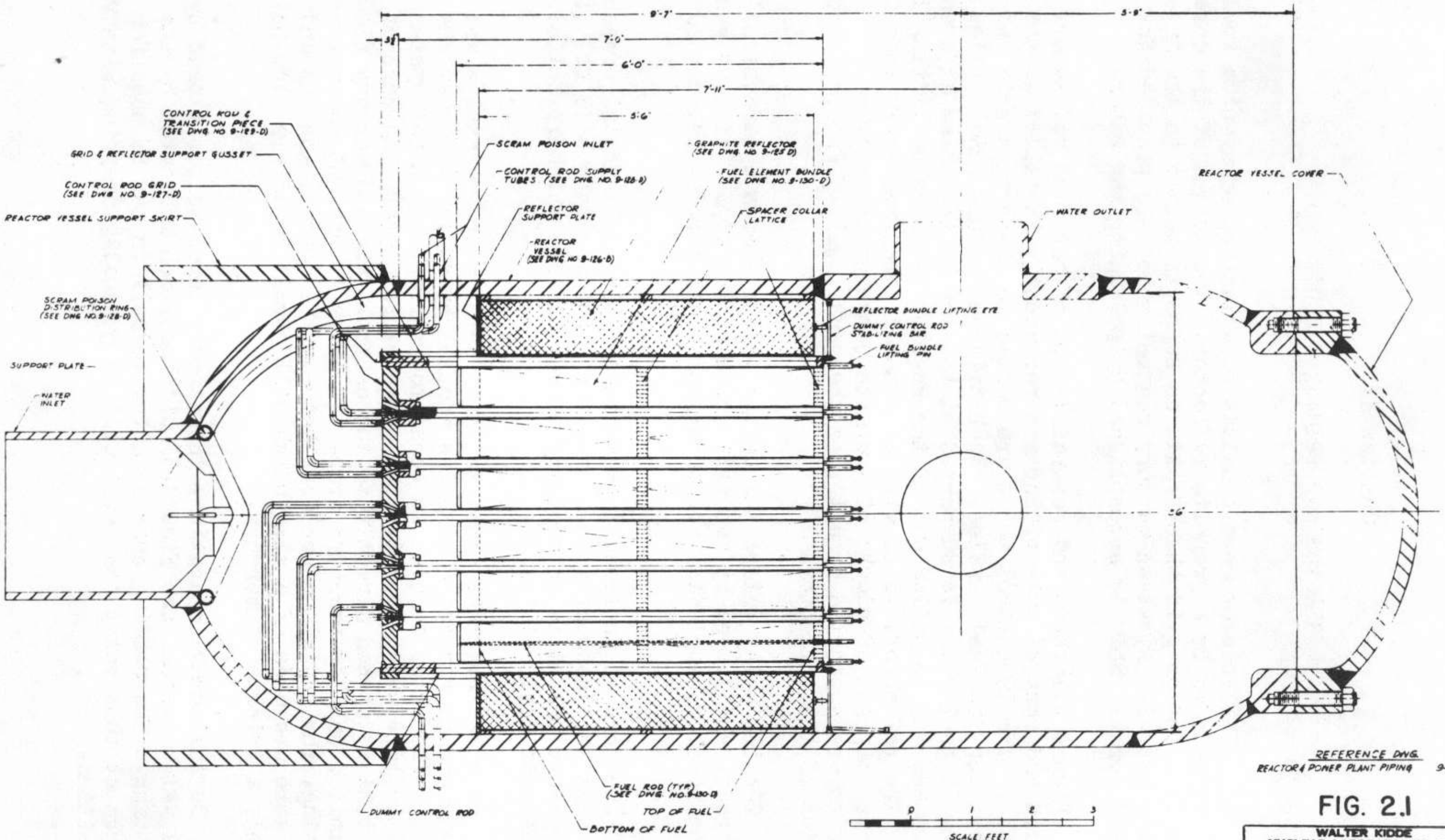


FIG. 2.1

WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y.

REACTOR-SECTIONAL ELEVATION

BY W.G.B. DATE 12-29-53	APP BY DATE	SCALE ¼" = 1'-0"	DRAWING NUMBER 9-124-D

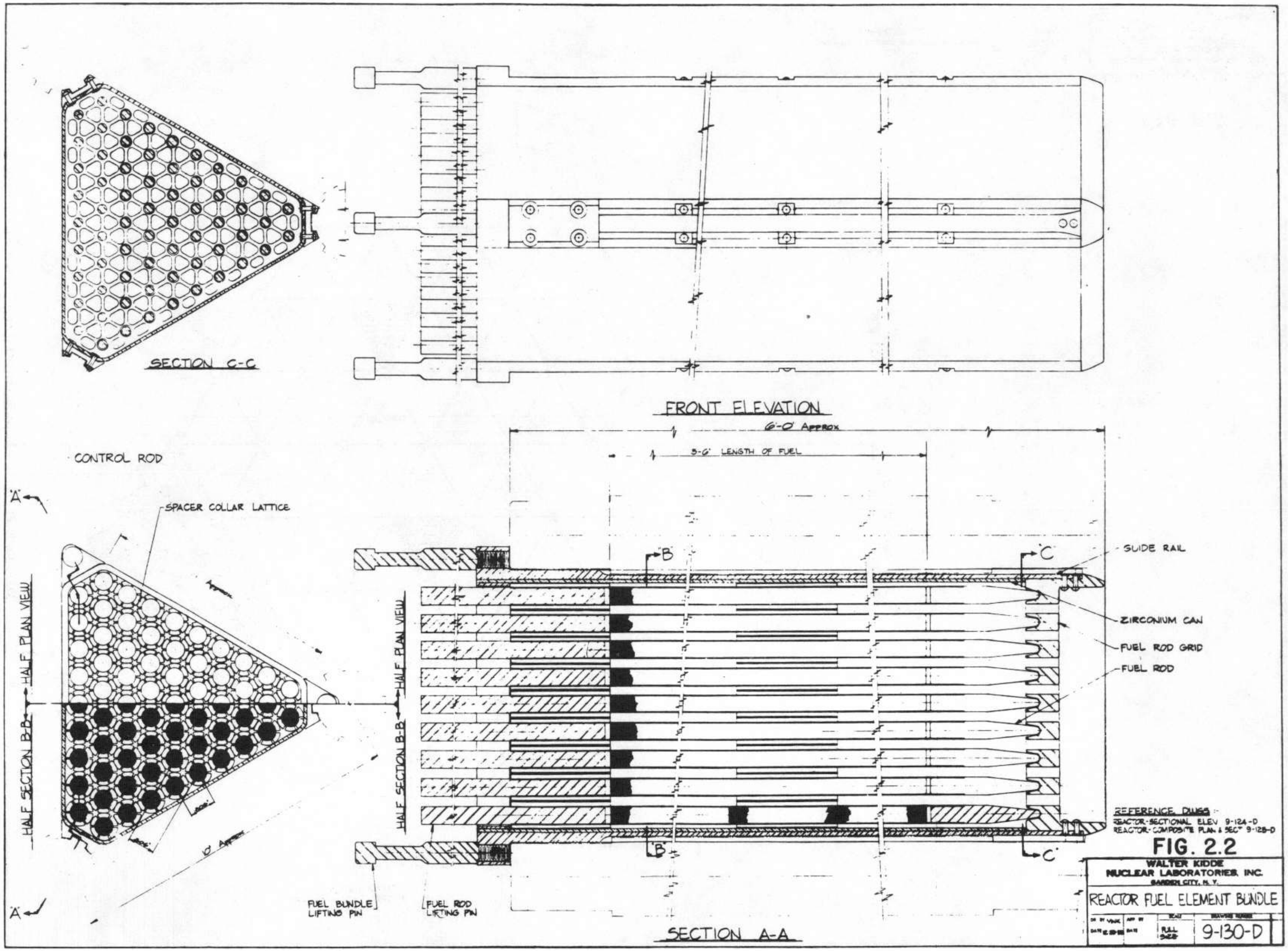


FIG. 2.2

REACTOR FUEL ELEMENT BUNDLE

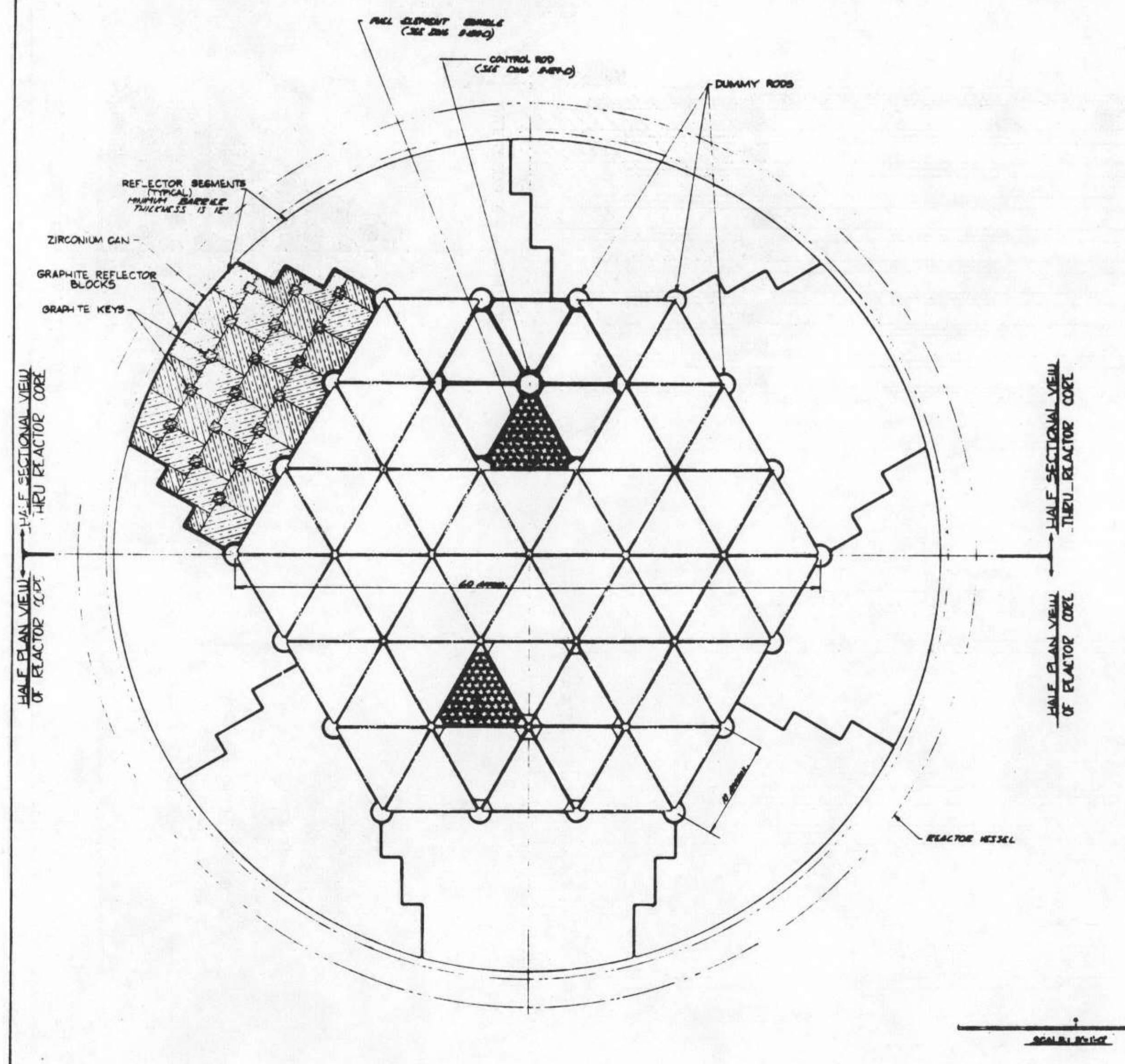


FIG. 2.3

REFERENCE DWG
REACTOR SECTIONAL ELEVATION

WALTER KIDDE NUCLEAR LABORATORIES, INC.
GARDEN CITY, N.Y.

- REACTOR COMPOSITE -
- PLAN & SECTION -

9-125-D

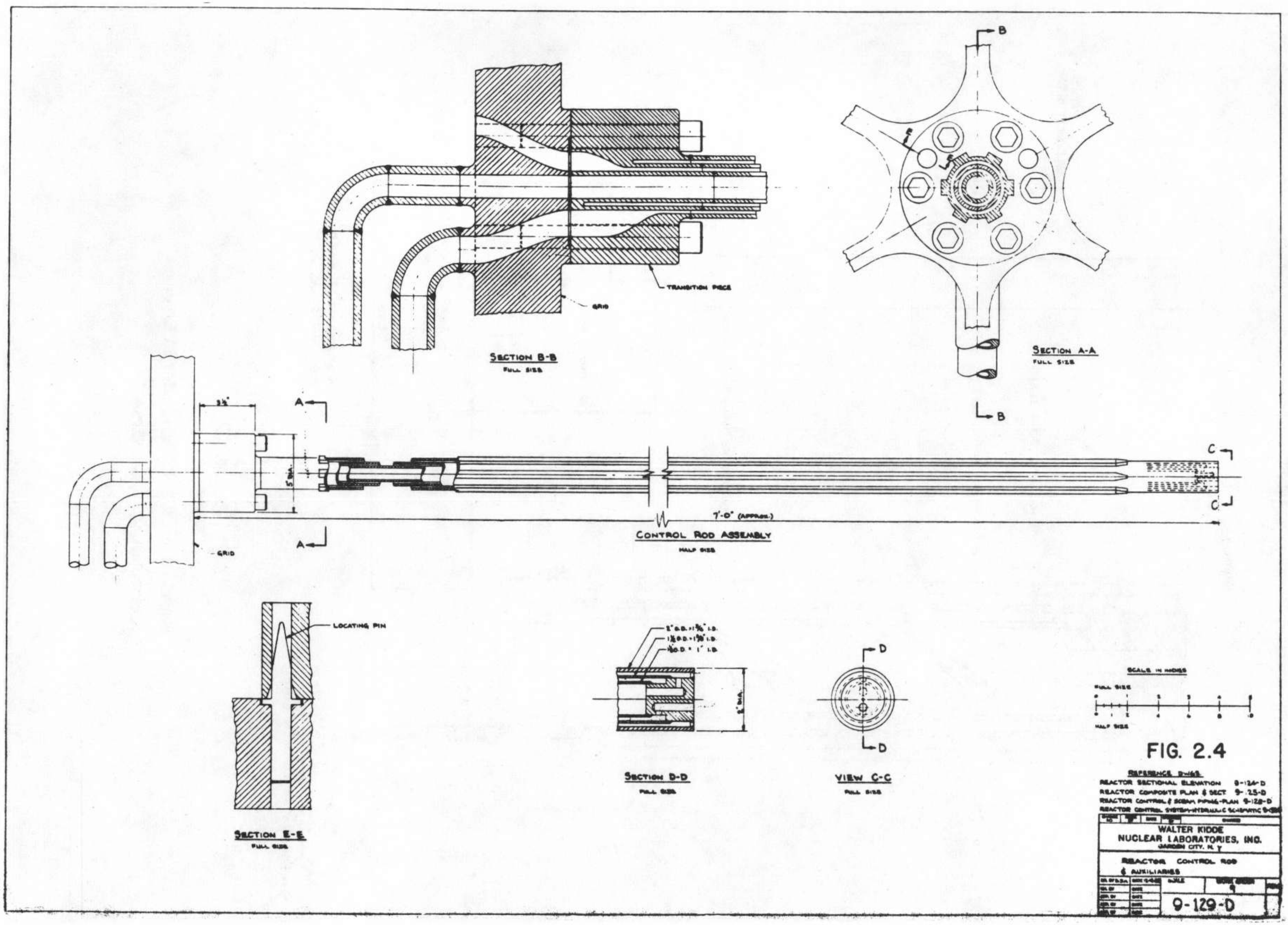

B
TRANSITION PIECE
GRID
SECTION B-B
FULL SIZE
SECTION A-A
FULL SIZE
A
7'-0" (APPROX.)
C
CONTROL ROD ASSEMBLY
HALF SIZE
GRID
LOCATING PIN
SECTION E-E
FULL SIZE
SECTION D-D
FULL SIZE
D
VIEW C-C
FULL SIZE
SCALE IN INCHES
FULL SIZE
HALF SIZE
REFERENCE DWGS.
REACTOR SECTIONAL ELEVATION 9-124-D
REACTOR COMPOSITE PLAN & SECT. 9-125-D
REACTOR CONTROL & SCRAM PIPING-PLAN 9-128-D
WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y.
REACTOR CONTROL ROD
& AUXILIARIES
9-129-D

FIG. 2.4

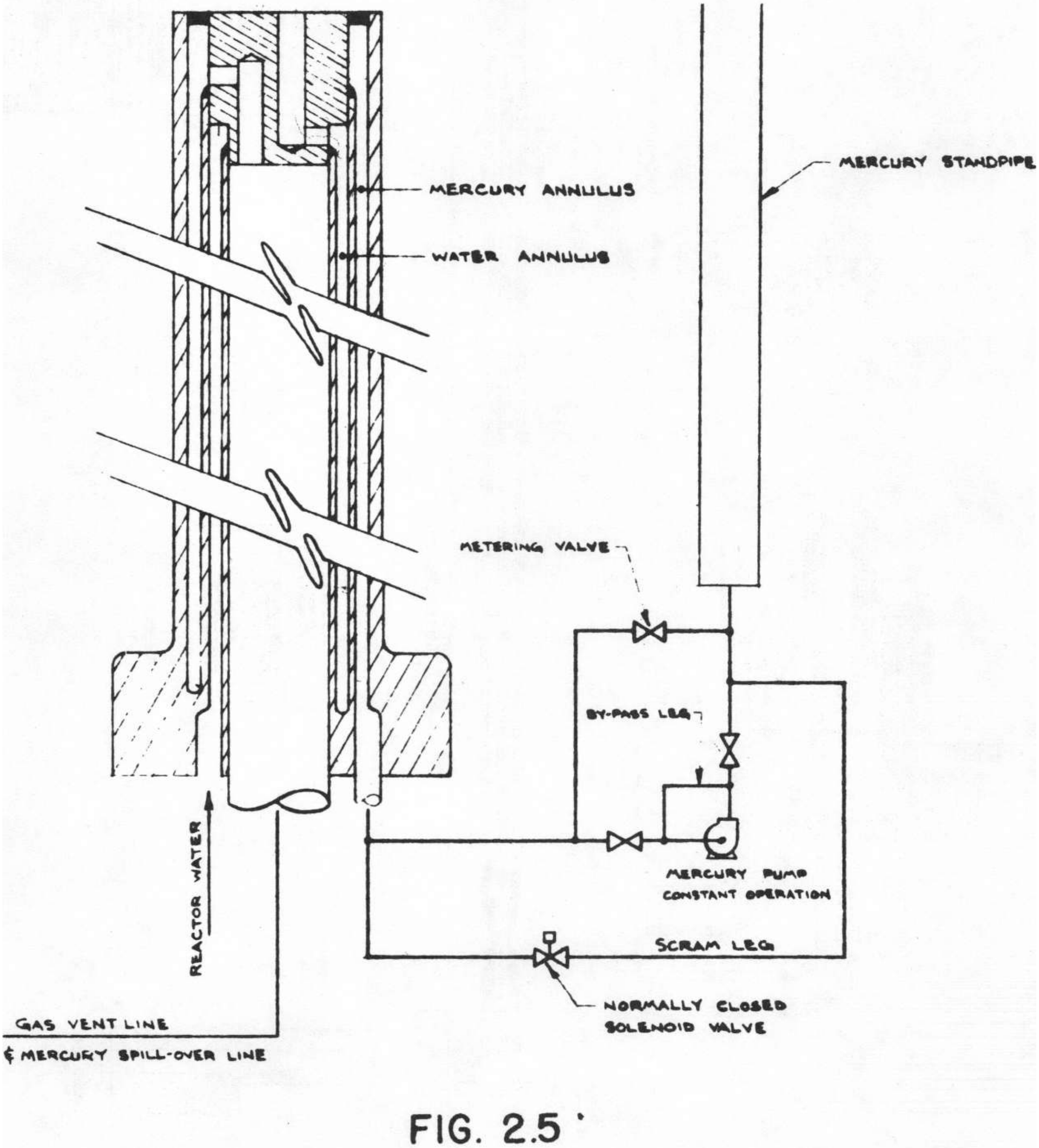


FIG. 2.5

REACTOR CONTROL SYSTEM
HYDRAULIC SCHEMATIC

The mechanical design of the core is summarized in Table 2.1.

Table 2.1

Core Dimensions

(Case H)

Fuel Rod Diameter (uranium)	0.511 in.
Jacket Thickness (stainless steel)	0.020 in.
Spacing Center to Center (triangular)	0.806 in.
Water to Uranium Volume Ratio	
Within Bundle	1.5
At Bundle Edge	1.59
Overall for Core	1.76
Fuel Rod Length (uranium)	5.4 ft.
Total Number of Fuel Rods	3402
Number per Bundle	63
Number of Control Rods	19
Control Rod, O.D.	2 in.
Core Volume	28 ft^3
Core Outer Diameter (across corners)	5 ft.
Core Outer Diameter (across flats)	4.3 ft.
Reflector Thickness - (minimum)	1 ft.
Total Weights, Metric Tons	
Uranium	14.75
Zirconium	1.68
Stainless Steel (inside reflector)	1.09
Water (500°F) (inside reflector)	1.16

Lattice Reactivity and Conversion

Table 2.2 gives details of the lattice design for Case H, the reference design. Results are also shown for an alternate design (Case B) which was carried along to show the effect of reactor temperature. Each case is designed to produce 150,000 KW of heat.

Table 2.2

Lattice Constants for Alternate Designs

150,000 KW Heat Output

	Case H	Case B
Ave. Water Temperature, °F	460	540
Core Height, ft.	5.4	6.5
Core Diameter (corner to corner of hexagon), ft.	5.0	5.0
Fuel Rod Diameter, cm.	1.33	1.33
Volume Ratio Water to Uranium	1.5	1.5
Reflector Thickness (graphite), ft.	1.0	1.0
Uranium in Core, Metric Tons	14.75	17.76
Enrichment, % U-235	1.46	1.66
k_∞ cold, clean (70°F)	1.157	1.192
k_∞ hot, clean	1.085	1.088
Radial Maximum to Average Flux	1.5	1.5
Axial Maximum to Average Flux	1.44	1.47
Lattice Constants (hot, clean)		
η	1.610	1.648
p	0.704	0.681
f	0.912	0.918
ϵ	1.050	1.052
neutron temperature, ev.	0.077	0.083
τ cm.^{2}	42.6	49.4
L^2 cm.^{2}	3.2	3.3
λ_{th} cm.	0.848	0.920
λ_f cm.	2.77	2.86
Initial Conversion Ratio	0.946	0.961

The initial charge (Case H) will remain reactive, as described below, throughout the core reactivity period which is estimated at 11,400 MWD/ton irradiation. After this period, makeup fuel, enriched uranium, must be added at regular intervals to maintain reactivity. Eventually, a steady state will be approached in which concentration in the reactor will be constant. Table 2.3 shows estimated reactivity and fuel composition at the start, after initial reactivity period, and at final equilibrium with steady processing and feed makeup. Nuclear constants used in calculating these reactivities are also listed in Table 2.3.

Table 2.3

Reactivity vs. Time

	Cold Clean	Hot 400 Hrs. (170 MWD/Ton)	Hot 11,400 MWD/Ton	Hot Equil. Composition
k_{∞} *	1.1568	1.0848	1.0848	
Radial Leakage	- .0264	- .0342	- .0342	
Axial Leakage	- .0105	- .0137	- .0137	
Xenon	0	- .0287	- .0252	
Samarium	0	- .0070	- .0070	
Burn-Up and Pu Gain	0	+ .0050	+ .0007	
Boron, Residual**	- .0037	- .0037	- .0032	
Control Tubes***	- .0025	- .0025	- .0022	
Total	1.1137	1.000	1.000	
Fuel Composition, mol. %				
U-235	1.46		0.655	0.372
U-236			0.147	0.037
U-238	98.54		96.4	97.4
Pu-239			0.454	0.773
Pu-240			0.211	0.864
Pu-241			0.035	0.342
σ_f (U-235)	584	293		
σ_f (Pu-239)	1020	604		
σ_f (Pu-241)	1200	604		

* Except for other items in table.
** At minimum boron concentration of 0.05×10^{-3} $\frac{\text{atom B}}{\text{mol } H_2O}$
*** At point of maximum sensitivity.

Losses in processing are taken at 0.6 per cent per cycle with processing at the rate of one metric ton per 1000 MWD of heat output. Figure 2.6 shows makeup rates and compositions estimated for the steady state. The time required to reach this steady state, however, is probably quite long. It is roughly estimated at 200,000 MWD/ton exposure, so that we will be chiefly concerned with the earlier periods.

The makeup feed will be somewhat greater at the end of the core reactivity period in order to maintain reactivity. The required concentration of

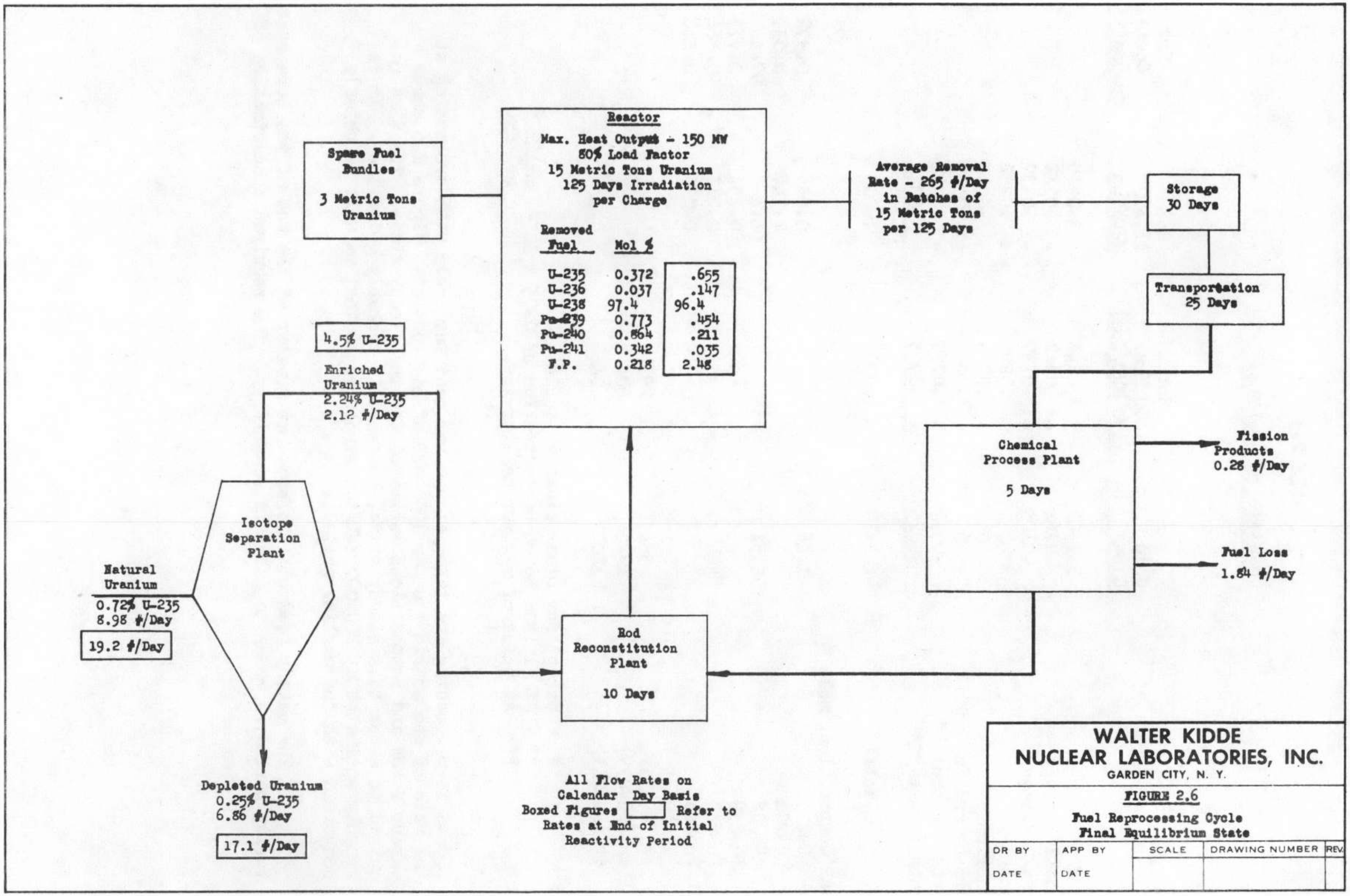


FIGURE 2.6
Fuel Reprocessing Cycle
Final Equilibrium State

feed is about 4.5 per cent U-235 (corresponding to 0.29 gm U-235 per MWD), which compares with the value of 2.24 per cent U-235 (or 0.143 gm U-235 per MWD) when equilibrium has been reached. The required feed concentration will gradually drop toward the equilibrium value, though the rate of drop is so low that it will probably have little effect during the plant amortization period.

A corollary of this progressive change in feed requirement is that, after the initial reactivity period, the reactor inventory will gradually increase in value because of the contained plutonium isotopes.

Calculation Basis

The first reported experiments on a water moderated uranium lattice were performed at Oak Ridge in 1944 (2.1). Further exponential experiments were carried out at Brookhaven under the guidance of the Ferguson Atomic Energy Division (2.2), and the results have recently been analyzed (2.3). As a result of these studies, a calculation procedure was devised using the most reliable information and having due regard for internal consistency. The critical masses, reflector effectiveness and initial conversion ratios have been computed by this means. Long-term reactivity effects, and fuel utilization have been determined with particular attention to the effect of uncertainties in the basic constants. Control requirements and limitations have been calculated in the usual fashion.

Core Reactivity Period

In general, if a reactor lattice is just barely critical with a fresh uranium charge,it will tend to become more reactive at first and will return to its initial reactivity after a certain period. We designate this as the core reactivity period. The core reactivity period depends on lattice volume ratios, rod diameter, temperature, and amount of foreign absorbing material which may be present as part of the structure.

The determination of the core reactivity period requires accurate knowledge of the basic nuclear constants as well as the neutron velocity spectrum, since this type of calculation tends to magnify variations. We have made a point of selecting a spectrum which results in conservative constants for this purpose, although it is possible that the constants may be even less favorable. Table 2.4 shows the effect on calculated reactivity period of various assumptions on basic constants.

(2.1) CP-2842, "Water Lattice Experiments", A. M. Weinberg and H. Jones, June 30, 1945.

(2.2) BNL-log-C-6687, "Exponential Experiments on Light Water Moderated, 1% U_{235} Lattices", H. J. Kouts, J. Chernick, I. Kaplan.

(2.3) NYO-3924, "Light Water Moderated Reactors in Cross Flow", Karl Cohen, September 30, 1953.

Table 2.4

Effect of Various Assumptions
on
Allowable Irradiation Time

Rod Diameter - 1.3 cm.
Water to Uranium Ratio - 1.5
Reflector - Graphite

Case Designation		Fuel Life - MWD/Ton
$\sigma_{f.p.}$ (.025) = 110 b,	$\alpha_{pu} = 0.60$	9,200
$\sigma_{f.p.}$ (.025)* = 110 b,	$\alpha_{pu} = 0.65$	7,000
$\sigma_{f.p.}$ (.025) = 110 b,	$\alpha_{pu} = 0.55$	11,000
$\sigma_{f.p.}$ (.025) = 50 b,	$\alpha_{pu} = 0.60$	11,400
$\sigma_{f.p.}$ (.025) = 120 b,	$\alpha_{pu} = 0.60$	8,900

*Per fission; 55 b per average atom.

In Table 2.4, the first item is based on the constants which we have chosen as a basis for detailed design, which leads to a reactivity period of 9,200 MWD/Ton.* Other choices of constants could conceivably reduce this period to as low as 7,000 MWD/Ton.

The absolute value of this reactivity period is important in planning reactor processing operations. However, it is not a direct measure of the utilization of fuel, since fuel utilization will depend on the entire fuel cycle. Moreover, it may be necessary to carry out some kind of processing after shorter period irradiations of the order of 1,000 to 2,000 MWD/Ton, in order to restore physical properties of the fuel. During this processing, removal of fission products will probably occur, based on considerations wholly aside from the maintenance of reactivity.

Figures 2.7 to 2.10 summarize the results of intermediate calculations used in arriving at the reactivity period.

*The figure used elsewhere (11,400 MWD/Ton) is based on removal of fission products at 5000 MWD/Ton intervals rather than 10,000.

FIG. 2.7

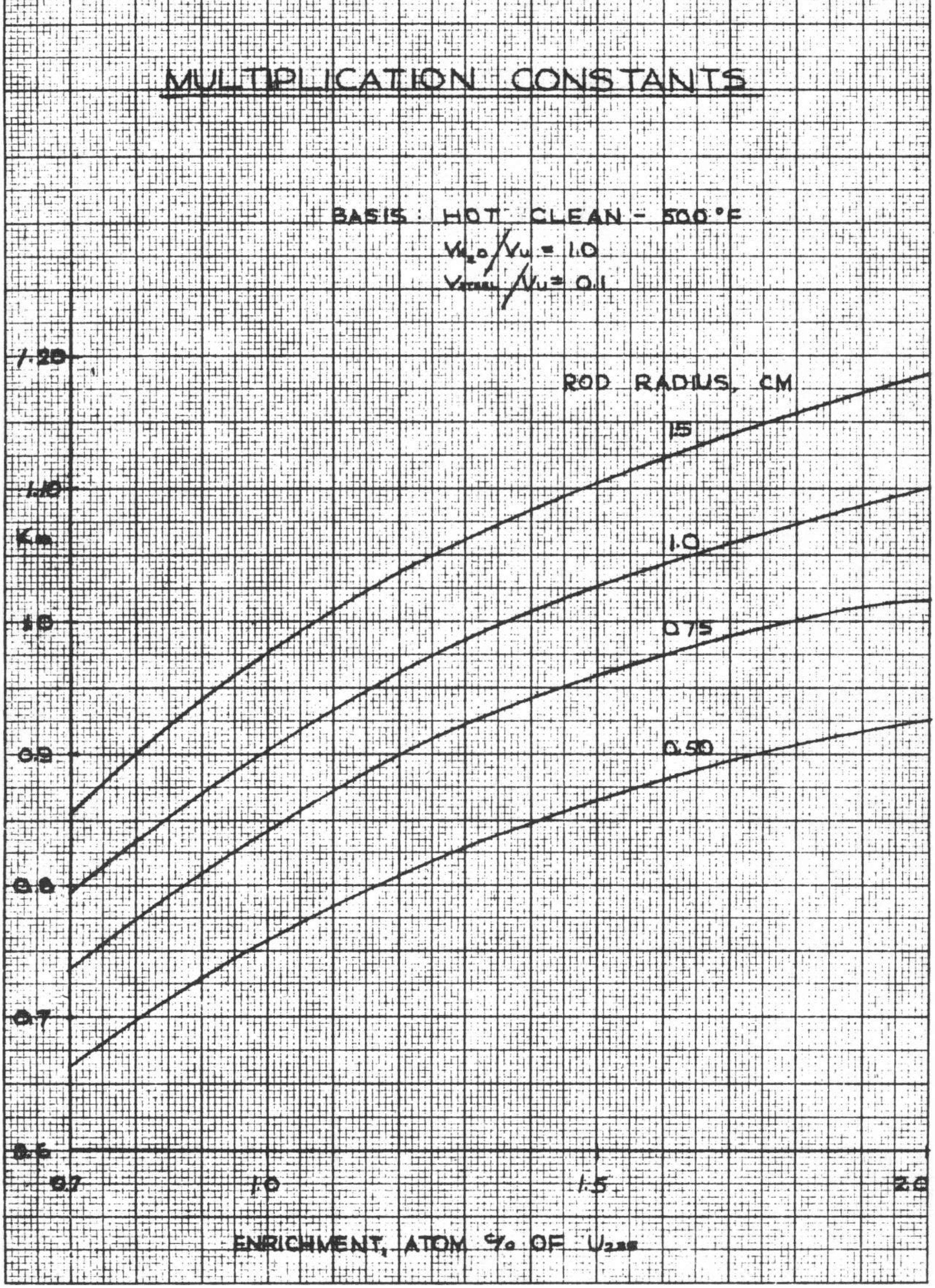

MULTIPLICATION CONSTANTS
BASIS: HOT CLEAN - 500°F
V_{H_2O}/V_U = 1.0
V_{STEEL}/V_U = 0.1
ROD RADIUS, CM
1.5
1.0
0.75
0.50
1.20
1.10
K∞
1.0
0.9
0.8
0.7
0.6
0.7
1.0
1.5
2.0
ENRICHMENT, ATOM % OF U_{235}

FIG. 2.8

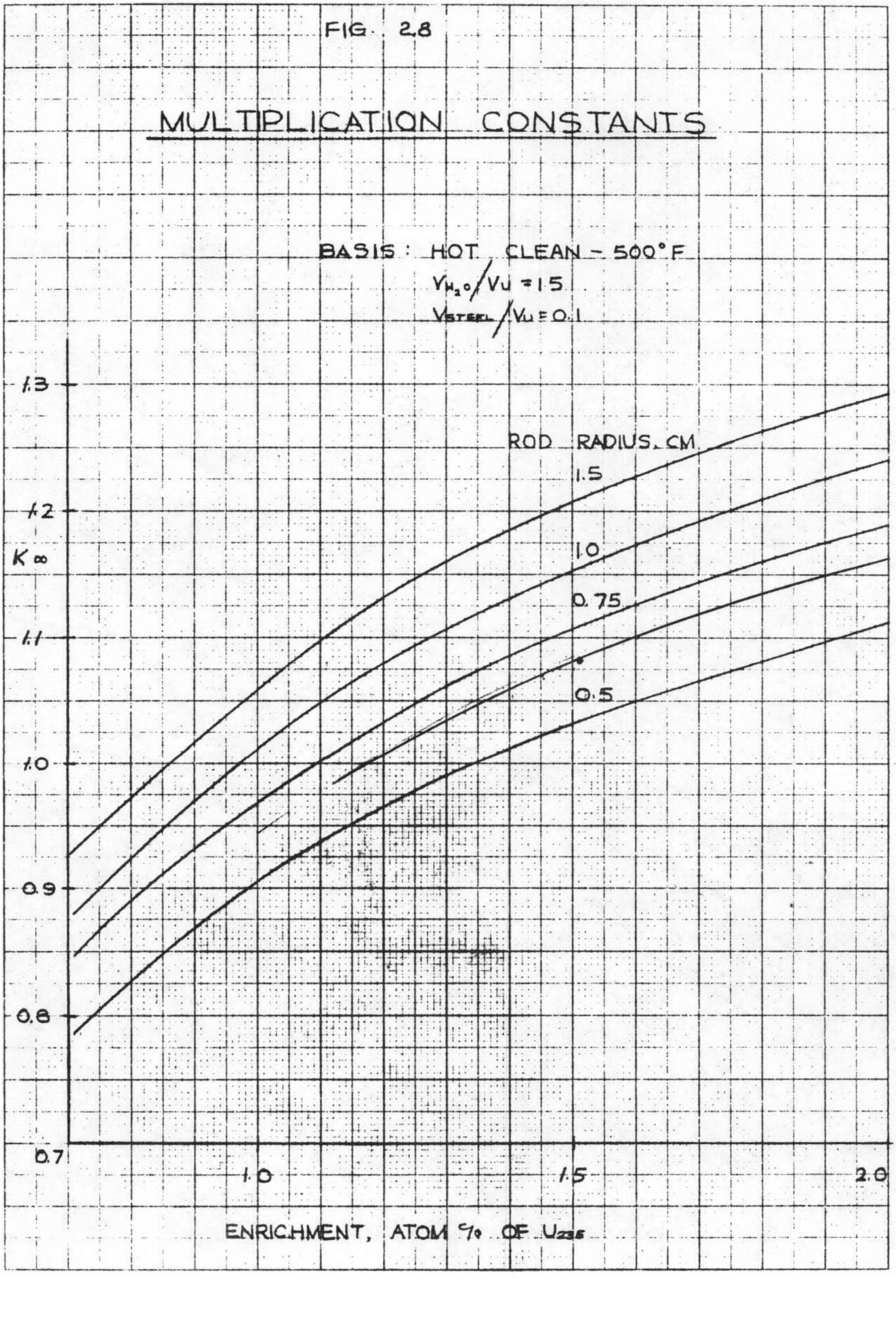

MULTIPLICATION CONSTANTS
BASIS: HOT CLEAN - 500°F
VH2O/VU = 1.5
VSTEEL/VU = 0.1
ROD RADIUS, CM
1.5
1.0
0.75
0.5
K∞
1.3
1.2
1.1
1.0
0.9
0.8
0.7
1.0
1.5
2.0
ENRICHMENT, ATOM % OF U235

FIG. 2.9

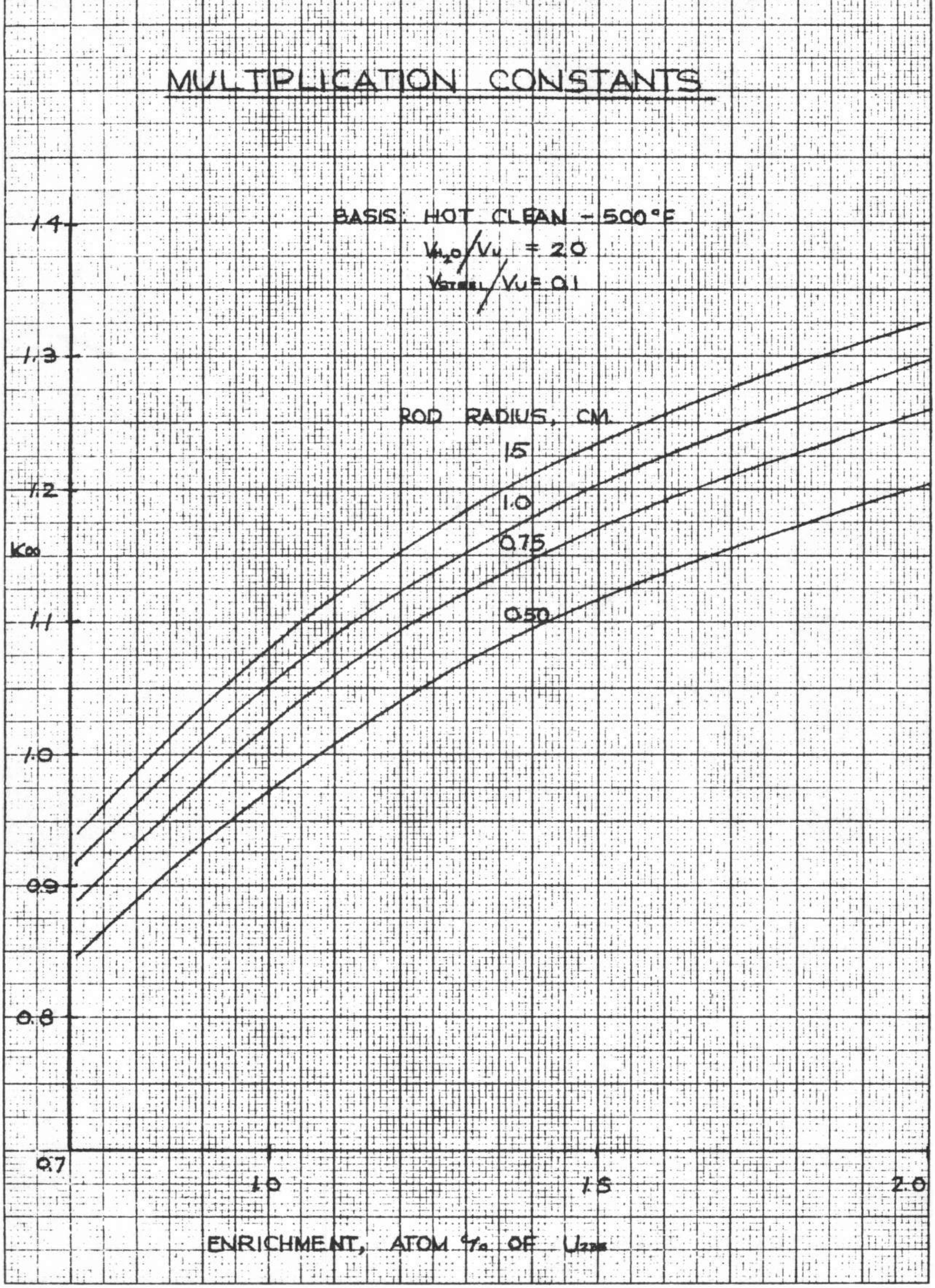
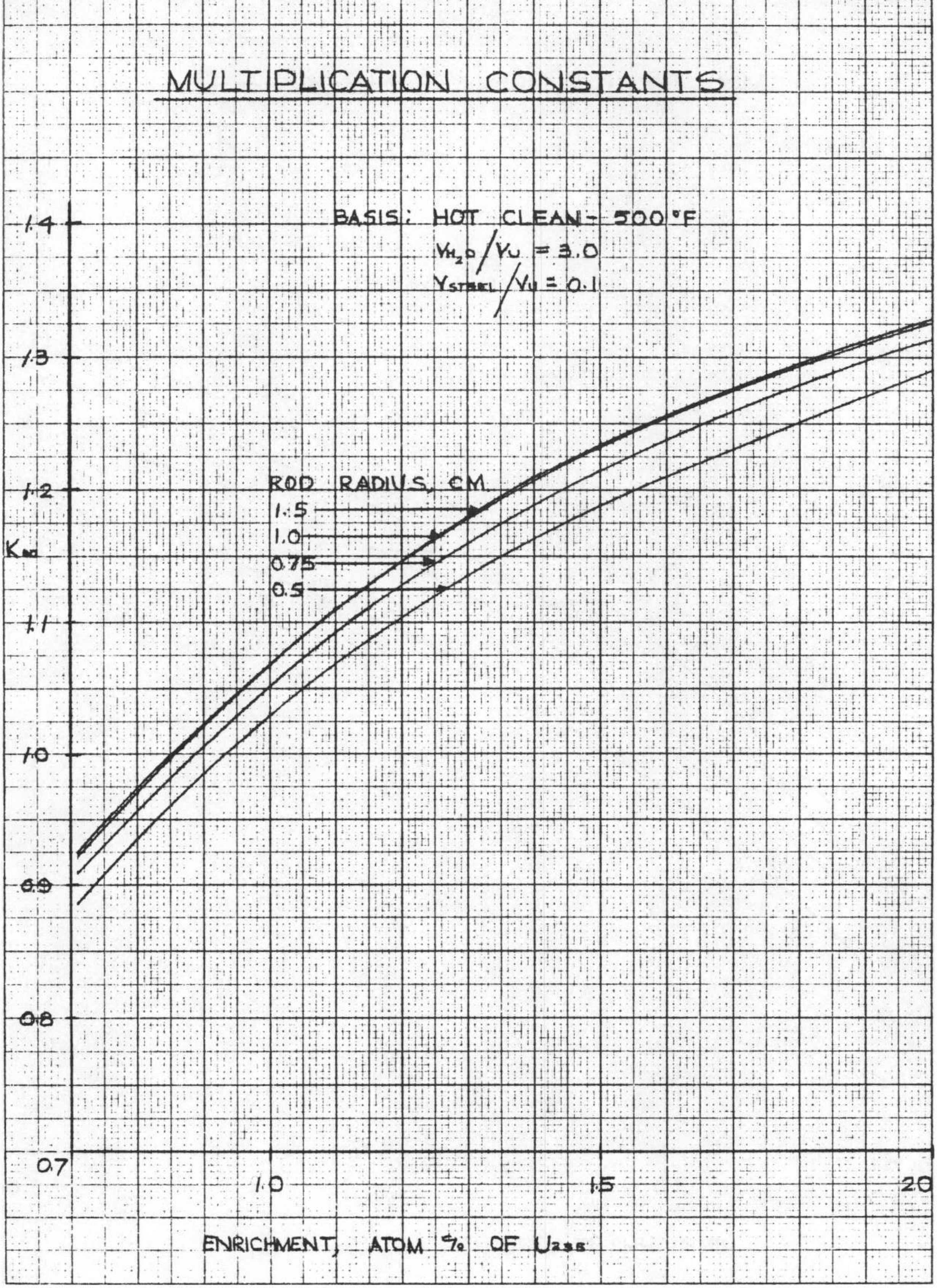

MULTIPLICATION CONSTANTS
BASIS: HOT CLEAN - 500°F
VH2O/VU = 2.0
VSTEEL/VU = 0.1
ROD RADIUS, CM.
1.5
1.0
0.75
0.50
K∞
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
1.0
1.5
2.0
ENRICHMENT, ATOM % OF U235

FIG. 2.10


MULTIPLICATION CONSTANTS
BASIS: HOT CLEAN - 500°F
$V_{H_2O}/V_U = 3.0$
$V_{STEEL}/V_U = 0.1$
ROD RADIUS, CM.
1.5
1.0
0.75
0.5
1.4
1.3
1.2
K_∞
1.1
1.0
0.9
0.8
0.7
1.0
1.5
2.0
ENRICHMENT, ATOM % OF U_{235}

Operating Temperature

The operating temperature affects reactor properties in two primary ways. In the first place, the temperature affects the moderator density. In the second place, the temperature affects neutron velocity and, consequently, the capture to fission ratio of plutonium, which is strongly dependent on neutron velocity. Figure 2.11 shows the effect of temperature on enrichment required for criticality, with other conditions representing the reference design. Above a temperature of 500°F, the required enrichment increases rapidly.

Reflector Design

The simplest solution to the reflector problem would be a water reflector, since this would require only a few inches additional space around the core and no extra materials. However, water as a reflector is not very effective in flattening the neutron distribution, which is desirable both in fuel handling and in heat removal.

Figure 2.12 shows the ratio of maximum to average flux as a function of reflector thickness, using a graphite reflector. At a thickness of one foot, which is about as far as it is reasonable to go, the ratio of maximum to average flux is about 1.57. The corresponding ratio for a one foot water reflector is about 1.86, which is about 19 per cent greater. The penalty for the water reflector would be a 19 per cent greater fuel processing rate and correspondingly lower heat output for a given lattice.

Referring to Figure 2.12, a one foot graphite reflector will reduce the enrichment required from 1.68 per cent to 1.54 per cent. Either reflector material reduces the enrichment required for criticality, graphite being slightly better.

Figure 2.13 shows the effect of the geometry of the core on flux ratio and enrichment required. For a core volume of 81.5 cu. ft., the radius for minimum enrichment would be about 2.2 ft., although this would not be the optimum, since it would correspond to a high maximum to average ratio. The combined considerations lead to a choice of a core which is relatively long and narrow.

Neutron Balance

In Table 2.5, the neutron balance is given for the time when the fuel is at its lowest reactivity point (400 hrs. after clean start-up).

FIG. 2.11

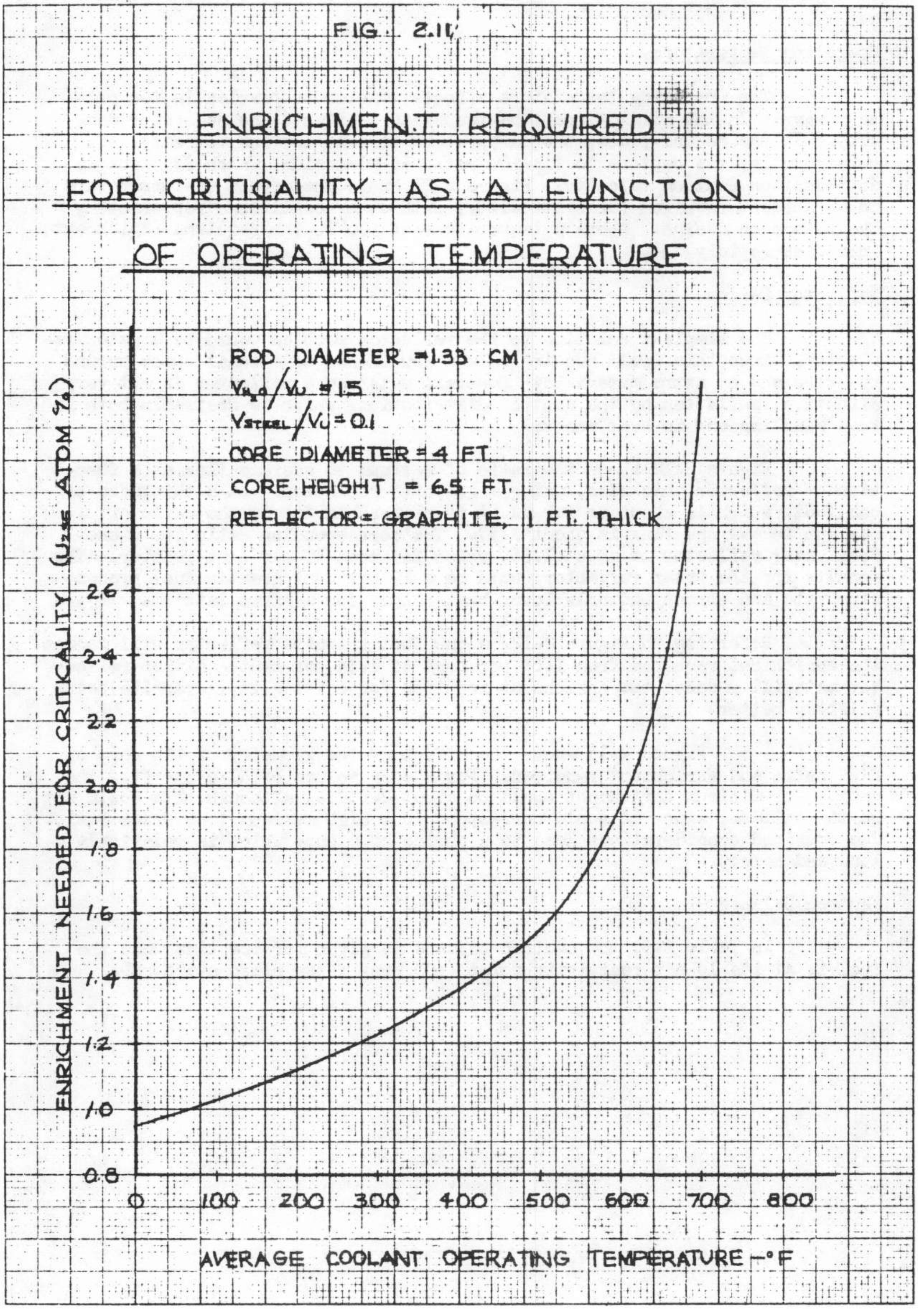

ENRICHMENT REQUIRED
FOR CRITICALITY AS A FUNCTION
OF OPERATING TEMPERATURE
ROD DIAMETER = 1.33 CM
V_{H_2O}/V_U = 1.5
V_{STEEL}/V_U = 0.1
CORE DIAMETER = 4 FT.
CORE HEIGHT = 6.5 FT.
REFLECTOR = GRAPHITE, 1 FT. THICK
ENRICHMENT NEEDED FOR CRITICALITY (U_{235} ATOM %)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
100
200
300
400
500
600
700
800
AVERAGE COOLANT OPERATING TEMPERATURE – °F

FIG. 2.12

EFFECTS OF VARYING REFLECTOR THICKNESS

BASIS: GRAPHITE REFLECTOR
CORE VOLUME = 81.5 FT^3
CORE DIAMETER = 4.7 FT
ROD DIAMETER = 1.33 CM
$V_{H_2O}/V_U = 1.5$
$V_{[illegible]}/V_U = 0.1$
AVERAGE COOLANT TEMP = 500°F

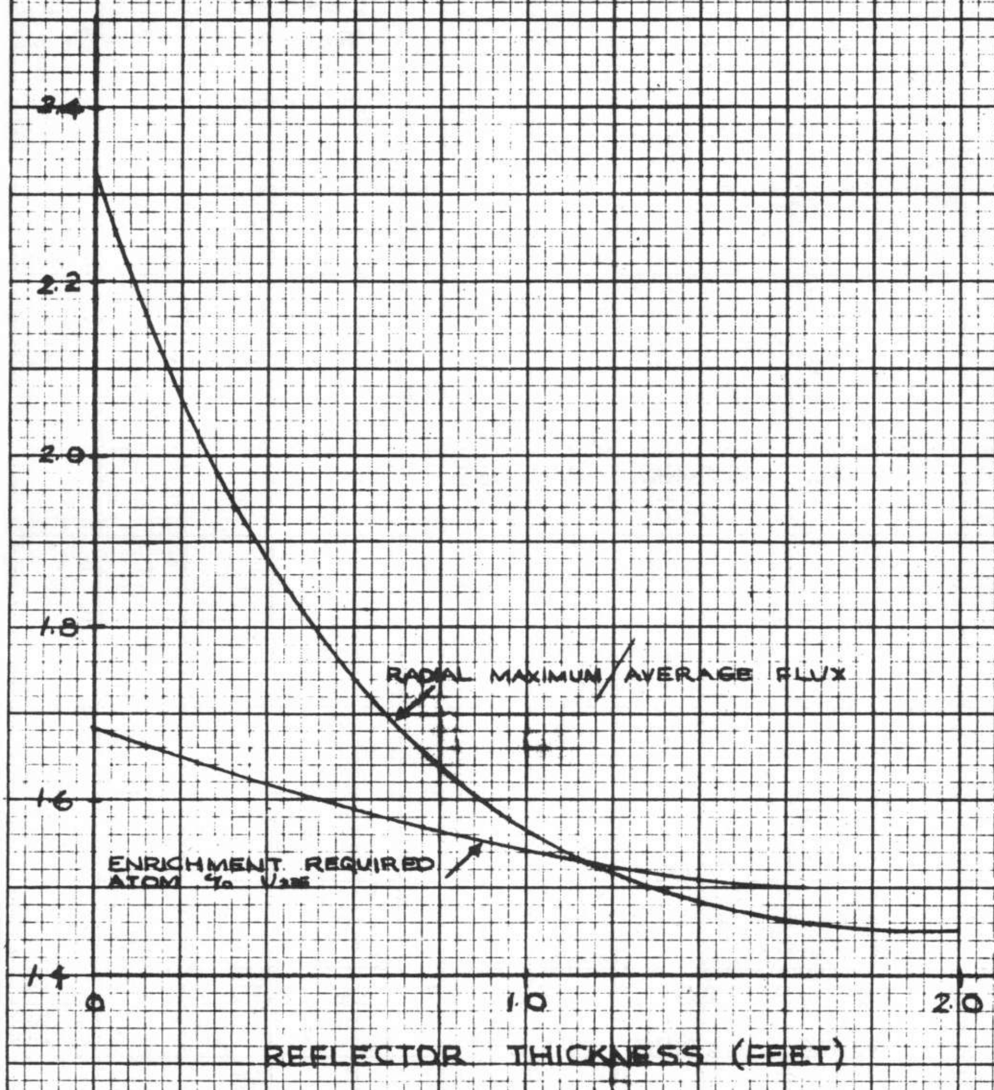


FIG. 2.13

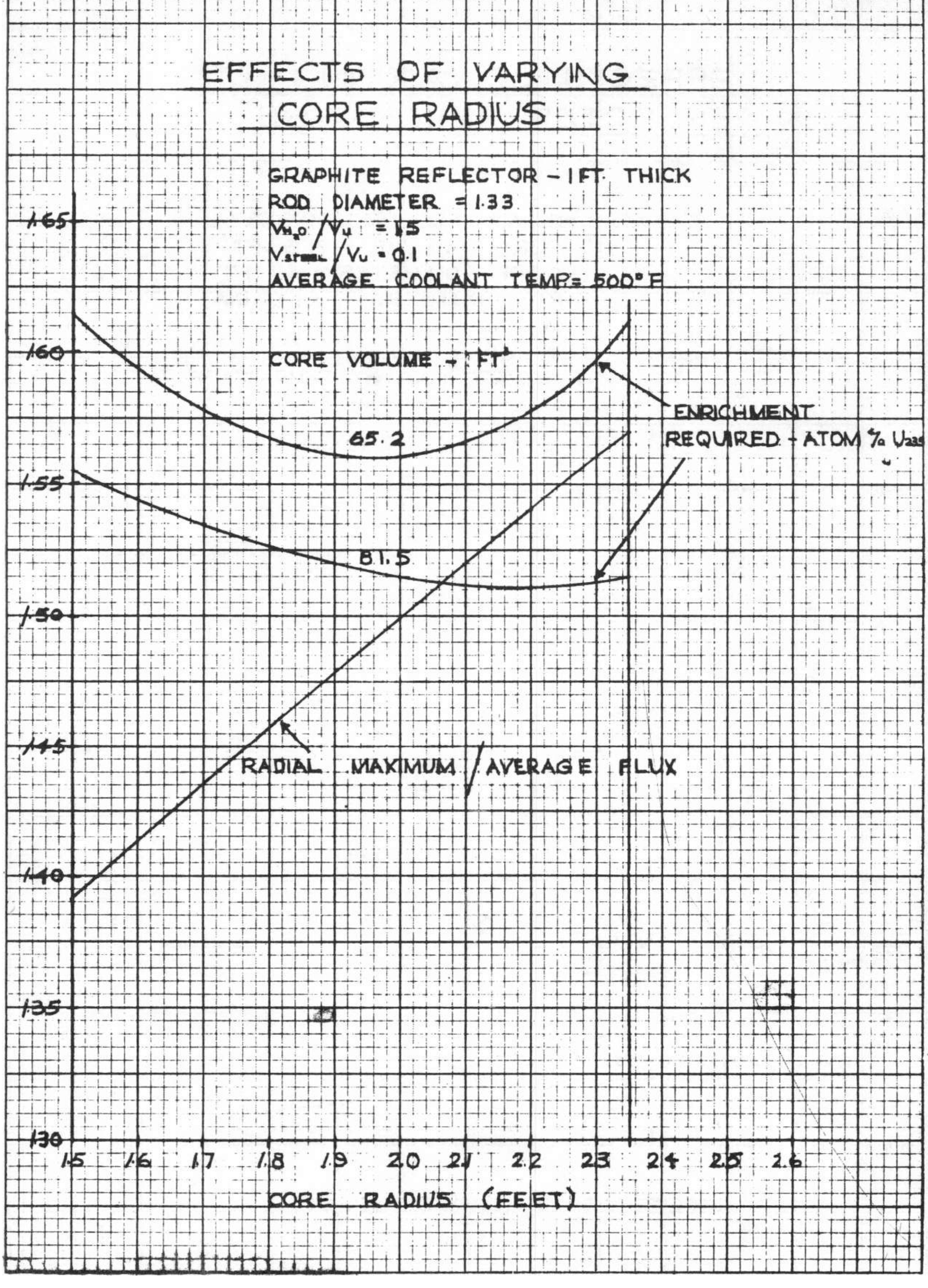

EFFECTS OF VARYING
CORE RADIUS
GRAPHITE REFLECTOR - 1 FT. THICK
ROD DIAMETER = 1.33
V_{H_2O} / V_U = 1.5
V_{STEEL} / V_U = 0.1
AVERAGE COOLANT TEMP = 500° F
CORE VOLUME - FT³
65.2
81.5
ENRICHMENT
REQUIRED - ATOM % U_{235}
RADIAL MAXIMUM / AVERAGE FLUX
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
CORE RADIUS (FEET)

Table 2.5

Detailed Neutron Balance 400 Hrs. after Clean Start-Up
Case H

Each Thermal Fission in U-235 Produces	2.510 neutrons
Net Neutrons Produced by Capture and Fission, in Pu, and Fission Product Capture	0.010
Net Neutrons Produced by Fast Capture and Fission in U-238	0.126
Total Neutrons per Thermal Fission	2.646
Resonance Capture in U-238	0.744
Thermal Capture in U-238	0.372
Total Pu Production	1.116
Thermal Fission Capture in U-235	1.000
Radioactive Capture in U-235	0.180
Total U-235 Destruction	1.180
Leakage	0.104
Water Capture	0.087
Xenon Capture	0.062
Samarium Capture	0.015
Steel Jackets, Control Tube Sleeves, Spacer Collars	0.069
Total Losses	0.337
Residual Boric Acid in Coolant	0.008
Control Tubes Inserted to Maximum Sensitivity	0.005
Total Capture in Control System	0.013
Total Captures per Thermal Fission	2.646

Fluxes

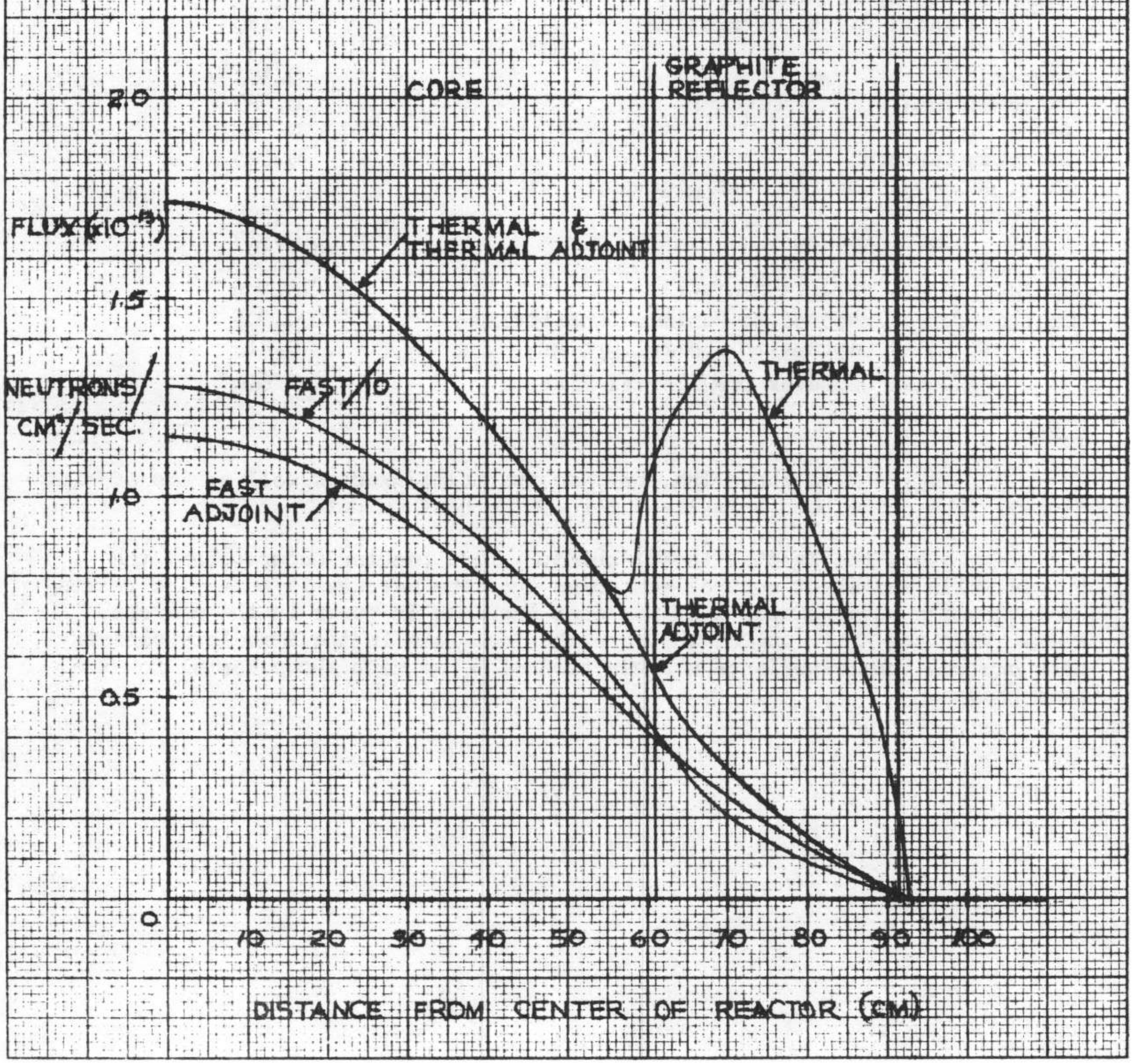
Figure 2.14 shows the fast and thermal fluxes as well as the adjoint fluxes. They have been normalized for 150 MW heat output.

Since the lattice is not uniform, flux peaking occurs about the bundle walls and about control rod holes when the mercury is out. The peaking at the bundle edges causes a 17 per cent increase in power in the nearest rods. When the Hg is out of the core the fuel rods in the immediate vicinity of a control tube experience a power rise of 8 per cent above normal for the same reason.

FIG. 2.14

FLUXES IN REACTOR

POWER LEVEL = 150 MW



Time Dependent Reactivity Changes

The variation of reactivity with time may be divided into rapid and slow processes. The rapid variation is due to the build-up to equilibrium of fission products having high cross sections and/or short half-lives. The slow variation is due to the build-up of all other fission products as well as the build-up and burnout of high atomic weight elements which are capable of fission or radioactive capture.

Figure 2.15 shows the variation of reactivity with time. The increase of reactivity as Pu^{239} builds up is controlled by the boron shim system. To conserve neutrons, however, it may be practicable during shutdowns imposed by radiation damage to control excess reactivity by replacing some of the fuel rods with thorium rods.

Control

Two control systems are built into the reactor. One consists of 19 hydraulically activated control tubes using mercury as the control medium. These are used for start-up and safety. The other is a system for injecting boron into and displacing boron from the coolant loop. This will be used for shim control. An auxiliary boron safety system is also provided. The control tubes amount to 2 per cent in k; the boron system is capable of controlling 30 per cent in k for shim and an additional 10 per cent in k for scram. These values apply to the initial reactor charge, cold and clean. The effectiveness gradually decreases as plutonium builds up and is about halved at the limiting steady state.

Normally, all scramming will be done with the mercury tubes. For complete shutdown, or if the mercury scram fails, the boron system will be called upon.

The reactor is extremely stable because of high negative temperature coefficients of reactivity. The instantaneous coefficient of reactivity (due to metal temperature) is $-3.6 \times 10^{-5}/^{\circ}C$; the equilibrium coefficient of reactivity (due to water temperature) is $-3.3 \times 10^{-4}/^{\circ}C$. Figures 2.16–2.19 show the effect of temperature on various constants. Because of this stability, transients present no problems. Pressure pulses are small, and the interaction of pressure, temperature, and reactivity produces no instability.

The possibility of inducing short pile periods in a start-up accident is dangerous, since a run-away on a fast period may damage the fuel rods before the scram system has come into play. For this reason, the mercury tubes are designed so that they can withdraw mercury no faster than 1 ft/min; the boron system is designed to limit the rate of boron withdrawal to 5×10^{-7} atoms of B per H_2O molecule per second. If the mercury (all 19 tubes simultaneously) or boron were removed from the system at these maximum

FIG. 2.15

VARIATION OF K_∞ OF LATTICE DURING OPERATING PERIOD

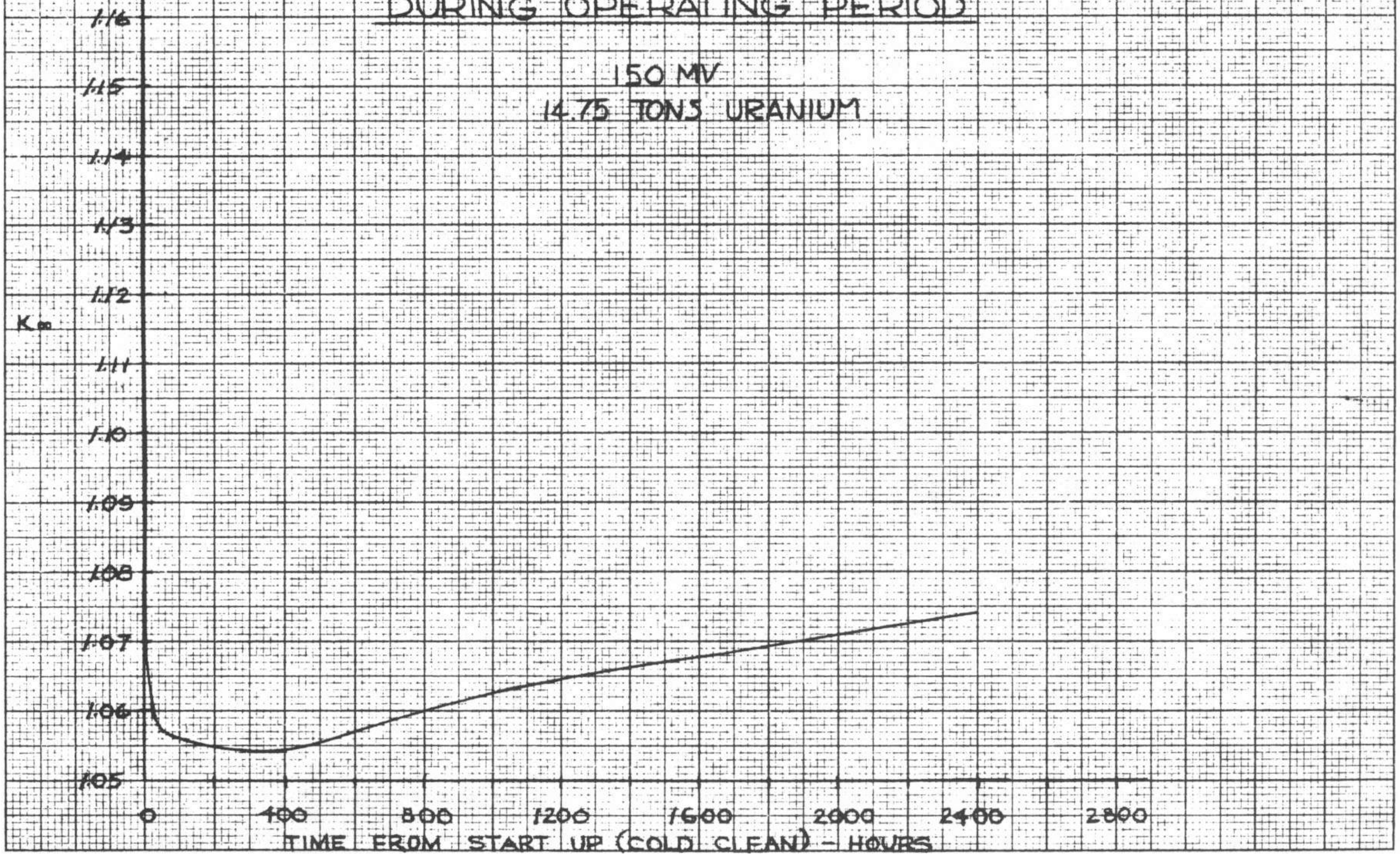


FIG. 2.16

VARIATION OF K_{EFF} CLEAN MULTIPLICATION CONSTANT WITH TEMPERATURE

BASIS: NO Pu IN FUEL

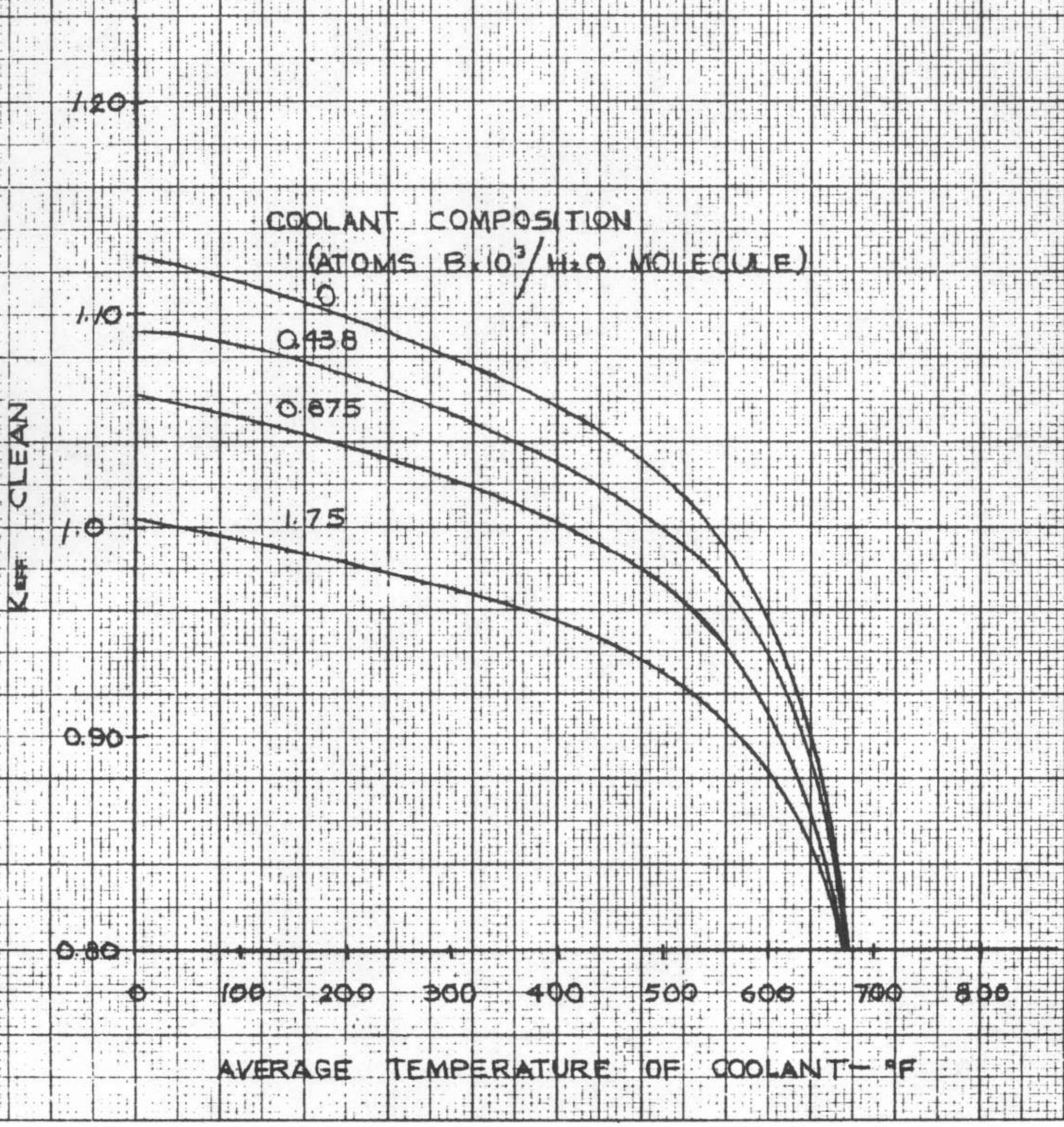


FIG. 2.17.

VARIATION OF K_{EFF} DIRTY MULTIPLICATION CONSTANT WITH TEMPERATURE

BASIS: NO Pu IN FUEL

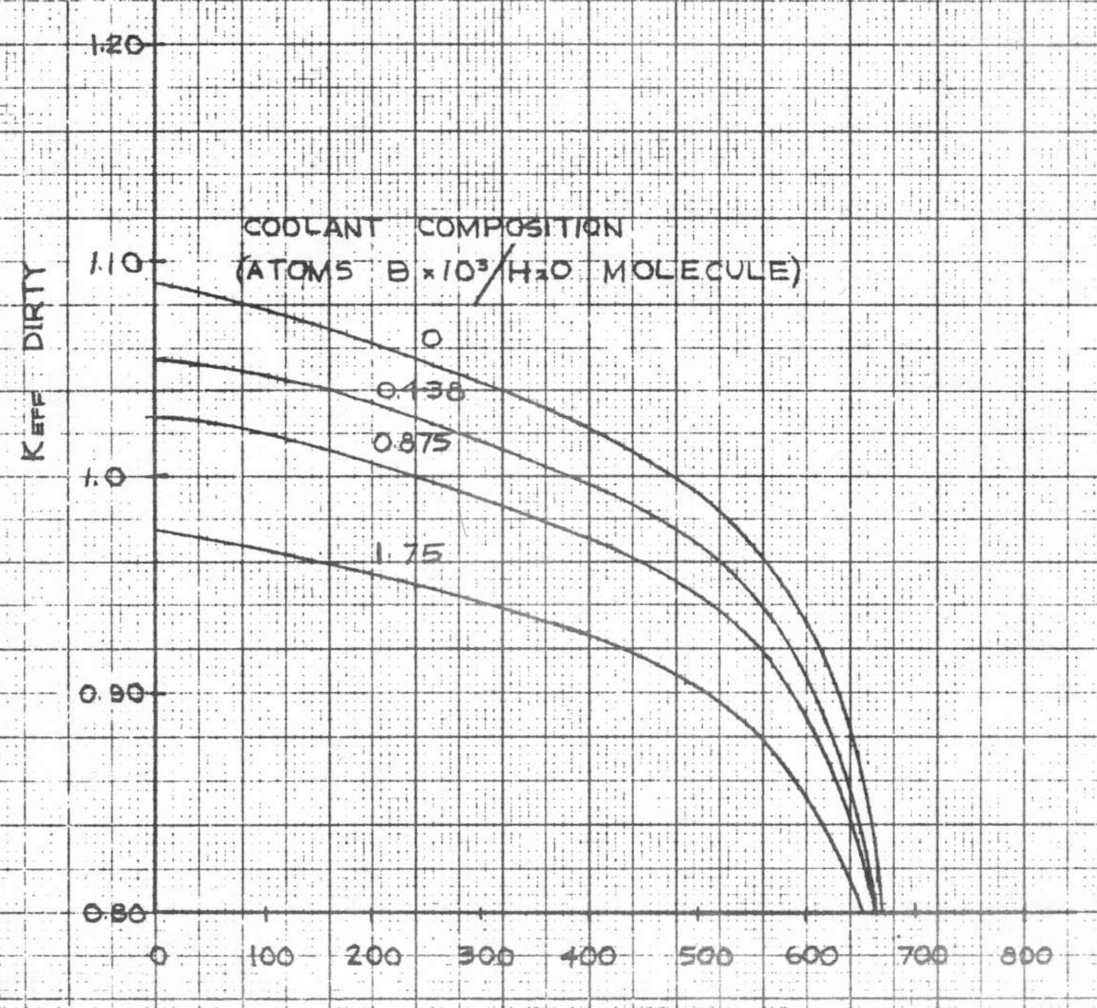


FIG. 2.18.

VARIATION OF τ & L^2 WITH TEMPERATURE

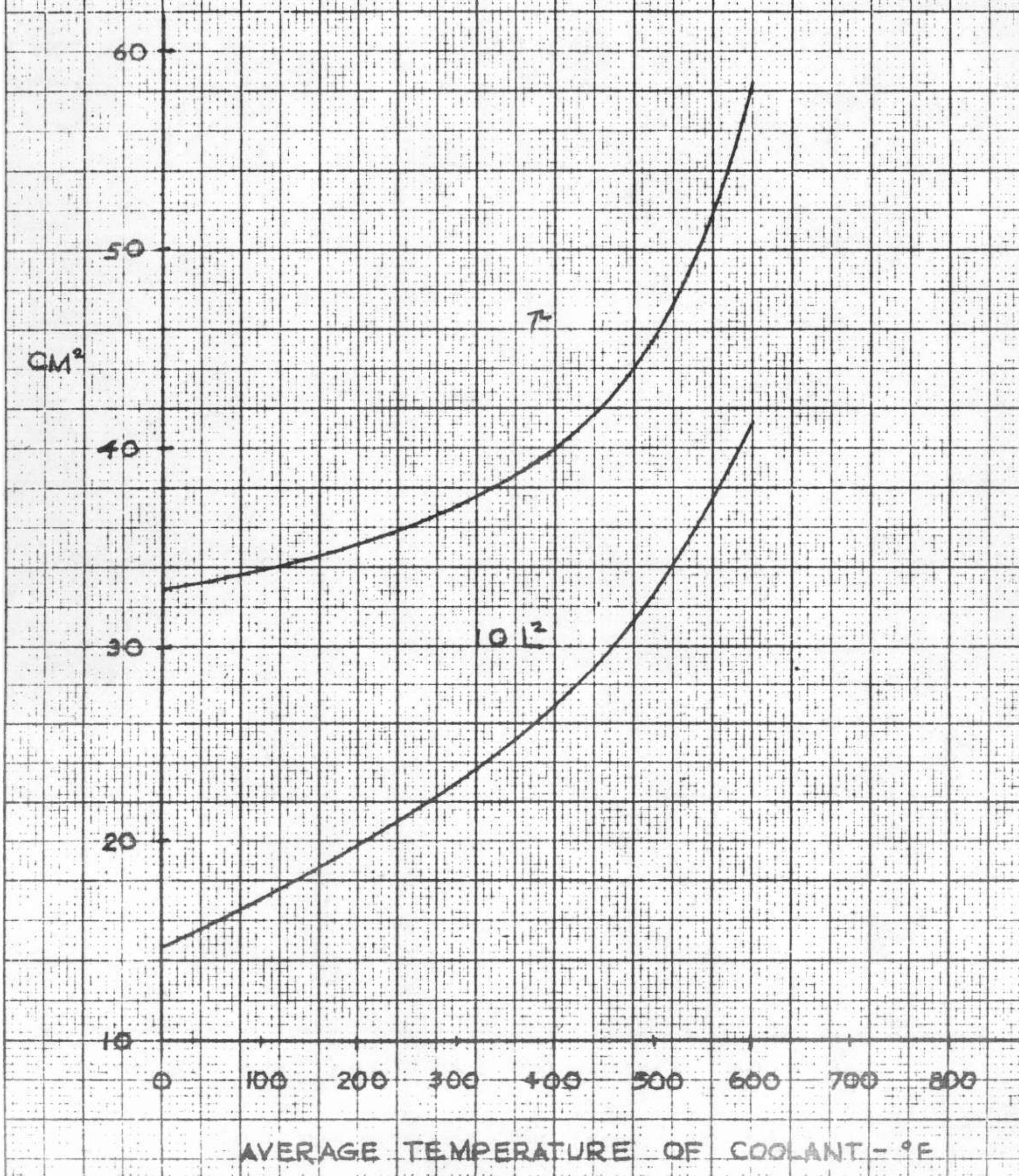
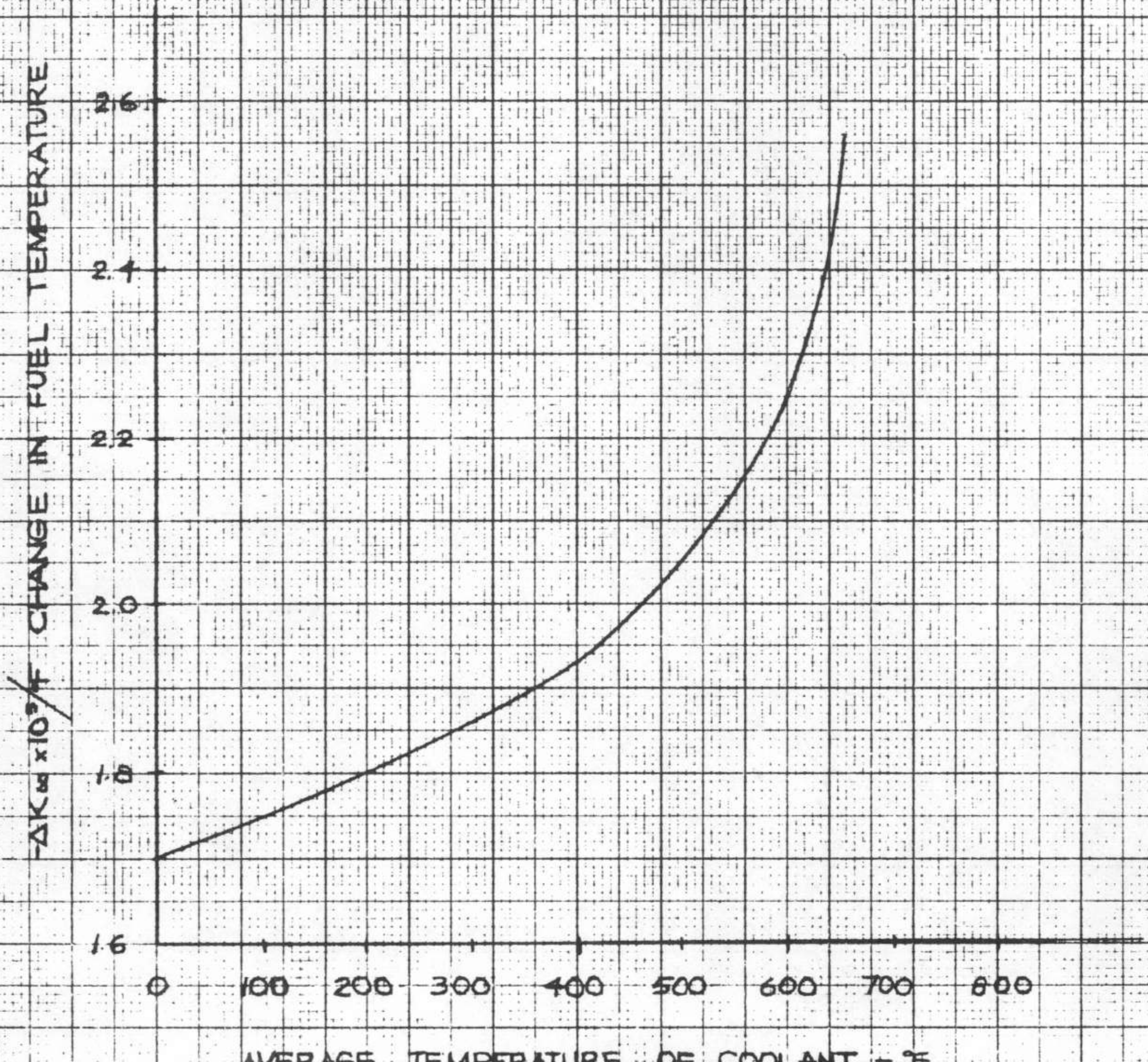


FIG. 2.12

VARIATION OF THE INSTANTANEOUS TEMPERATURE COEFFICIENT WITH COOLANT TEMPERATURE



rates after criticality were reached, the power overshoot would be, at most, 1.5 times full power, and the maximum rod temperature overshoot would be 10°C before the scram system would shut the reactor down. The large negative temperature coefficient is the major factor in damping any overshoot.

Shielding

Water and concrete are used for the shielding materials. The amount of shielding required to reduce radiation to laboratory tolerance levels is shown on the architectural sections, Figure 5.8.

Heat Transfer in Reactor Core

Coolant velocities and temperatures for the reference design are shown in Table 2.6. Heat transfer coefficients from fuel rods to water are based on data taken in this laboratory on similar lattices.

Table 2.6

Reactor Core Heat Transfer

150,000 KW Heat

No. Rods	3402
No. Bundles	54
Free Flow Area, ft^2	
1. Between Rods and Bundle Walls	2.14
2. Remainder of Bundle Interior	5.96
3. Between Bundles	0.308
Water Flow Rate, GPM Entering	
1. Between Rods and Bundle Walls	7500
2. Remainder of Bundle Interior	27,700
3. Between Bundle	430
Water Temperature Entering, °F	444
Average Water Temperature Rise, °F	30.6

Maximum Rod Conditions*	Within Bundle	Bundle Wall
Water Flow per Rod, lbs/hr	4350	4040
Temperature Rise, °F	47	58
Volume Uranium Heat Flux, Btu/ft^3 hr	4.42×10^7	5.16×10^7
Jacket Surface Heat Flux, Btu/ft^2 hr	4.36×10^5	5.10×10^5
Temperature, Reactor Center, °F		
Water	464	469
Jacket Surface	533	550
Uranium Surface	669	709
Uranium Center	991	1085

* Radial maximum to average = 1.5. Overall maximum to average = 2.25.

Lattice dimensions used for the heat transfer calculations are shown in Figure 2.20. The most critical zone is close to the wall of a central zirconium bundle, where the slightly greater water to uranium ratio produces flux peaking amounting to 17 per cent greater heat output.

Jacket temperatures at the critical points will exceed the water saturation temperature (525°F at 850 psia), so that there may be some tendency toward incipient boiling. However, this should be a very small effect, since the bulk water temperature is well below the saturation value, and the effect will tend to correct itself by virtue of the higher heat transfer coefficient associated with incipient boiling.

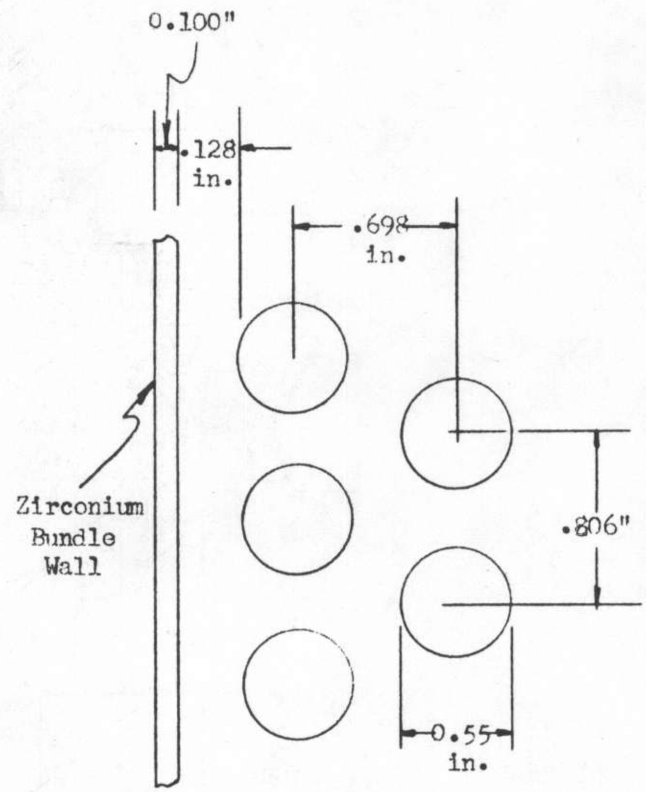
Auxiliary Process Systems

The operation of the reactor and power generating equipment requires a number of process systems for controlling water composition in both primary and secondary loops. Figure 2.21 shows the systems which must be provided at the plant for this purpose. The primary coolant loop is continuously purified by a cation removal system. Boron for control or scram may be injected into the loop or purged out by displacing with demineralized water. Radioactive waste is handled by a waste treatment system and concentrated radioactive impurities are ultimately sent to permanent storage. The supply water, which is obtained from deep wells, is handled by three separate systems. Most of the water is merely acid-treated for makeup to the cooling tower loop. A somewhat smaller portion is softened, chlorinated and stored for sanitary use and fire protection. A third portion is completely demineralized and stored for use in the reactor primary loop.

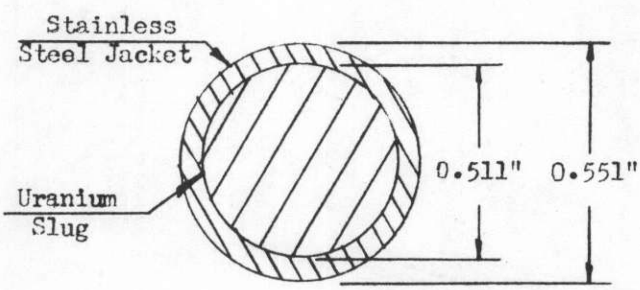
Figure 2.22 shows the primary process systems in greater detail. Demineralized water is first saturated with hydrogen at a relatively low pressure (about 100 psig) and is then pumped into the primary system, as required. Overflow from the system is removed in a surge and overflow loop which is also provided with a vent in case it is necessary to remove gases formed in the reactor. Effluent from the overflow system goes to the waste disposal system. Boron for shim control is ordinarily pumped in from a mixing and storage system containing a nearly saturated solution (about 0.5 lb/gal. of boric acid at about 100°F. In an emergency, more concentrated boron solutions can be prepared in this system by using potassium tetraborate instead of boric acid. An entirely separate system is provided for emergency insertion of concentrated potassium tetraborate solution for scram. The radiation level of the primary system, as affected by corrosion products circulated through the high neutron flux, is reduced by maintaining a continuous purge stream through a purification system and back into the primary loop. This purification system includes a cation exchanger and sulfuric acid regenerating system. Waste solutions from this system are sent to the waste disposal system. The volume of the primary loop is approximately 30,000 gallons.

FIGURE 2.20

Reactor Core Design



Lattice Dimensions



Fuel Rod

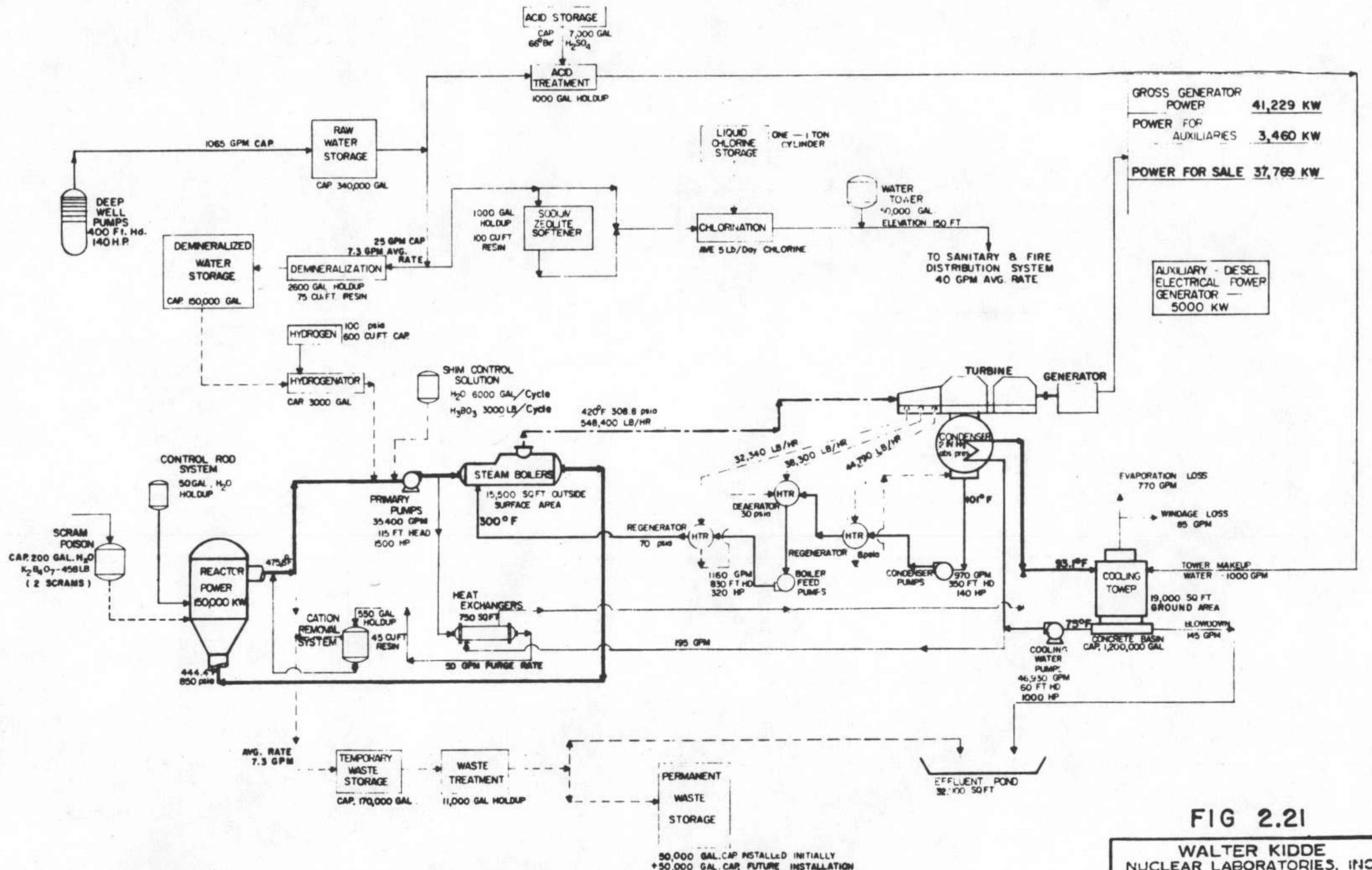


FIG 2.21

WALTER KIDDE NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y.

PROCESS FLOW SHEET ON SITE FACILITIES

9-117-C

PROCESS FLOW SHEET REFERENCE LIST:-

DWG. No.	TITLE
9-112-B	PRIMARY SYSTEM
9-113-D	WASTE TREATMENT
9-115-B	RAW WATER
9-114-B	DEMINERALIZATION
9-116-C	HEAT & POWER BALANCE

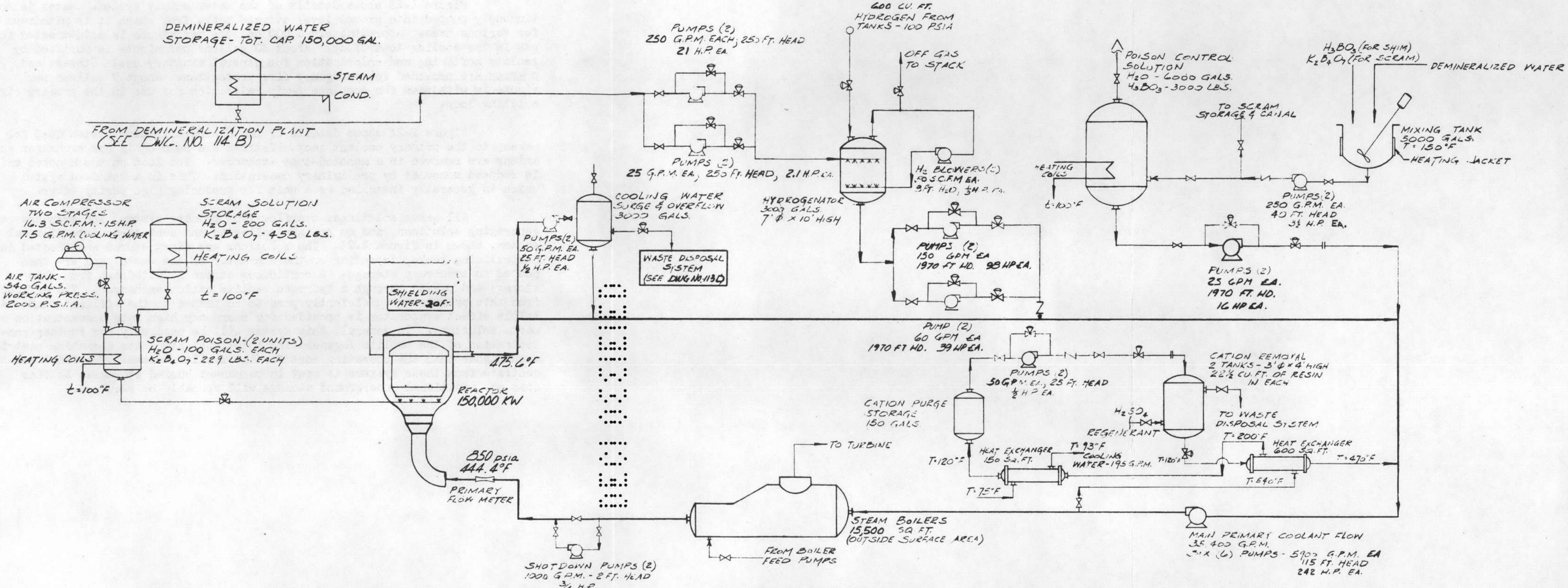


FIG. 2.22

PROCESS FLOW SHEET
PRIMARY SYSTEM

Figure 2.23 shows details of the water supply system. Water is continuously pumped into ground level storage tanks from which it is withdrawn for various uses. Approximately 1,000 gallons per minute is acid-treated for use in the cooling tower loop. About 40 gallons per minute is purified by zeolite softening and chlorination for general sanitary use. Storage and pumping are provided for emergency fire protection. About 7 gallons per minute is withdrawn for complete demineralization for use in the primary circulating loop.

Figure 2.24 shows details of the demineralization system used for makeup to the primary coolant loop. Cations are removed in one exchanger and anions are removed in a monobed-type exchanger. The load on the monobed unit is reduced somewhat by preliminary deaeration. This is a standard system which is generally installed as a unit for producing high purity water.

All waste solutions, overflow from primary system, ion exchange regenerating solutions, and so on, are collected and sent to a waste disposal system, shown in Figure 2.25. The solutions are first stored and treated in neutralizing tanks, depending on the character of the waste, and are then pumped to temporary storage. A continuous stream is withdrawn from this storage and passed through a hydrogen zeolite cation exchanger. The effluent from this process is sufficiently pure to be pumped to the effluent pond. A triple effect evaporator is provided for emergency high rate concentration of waste solutions. In general, this system will be used only for further concentration of the zeolite regenerating solutions, since its operating cost is much higher than the operating cost for the zeolite system. The final concentrate from these systems is sent to permanent buried storage. As time goes on, additional underground storage will probably be required.

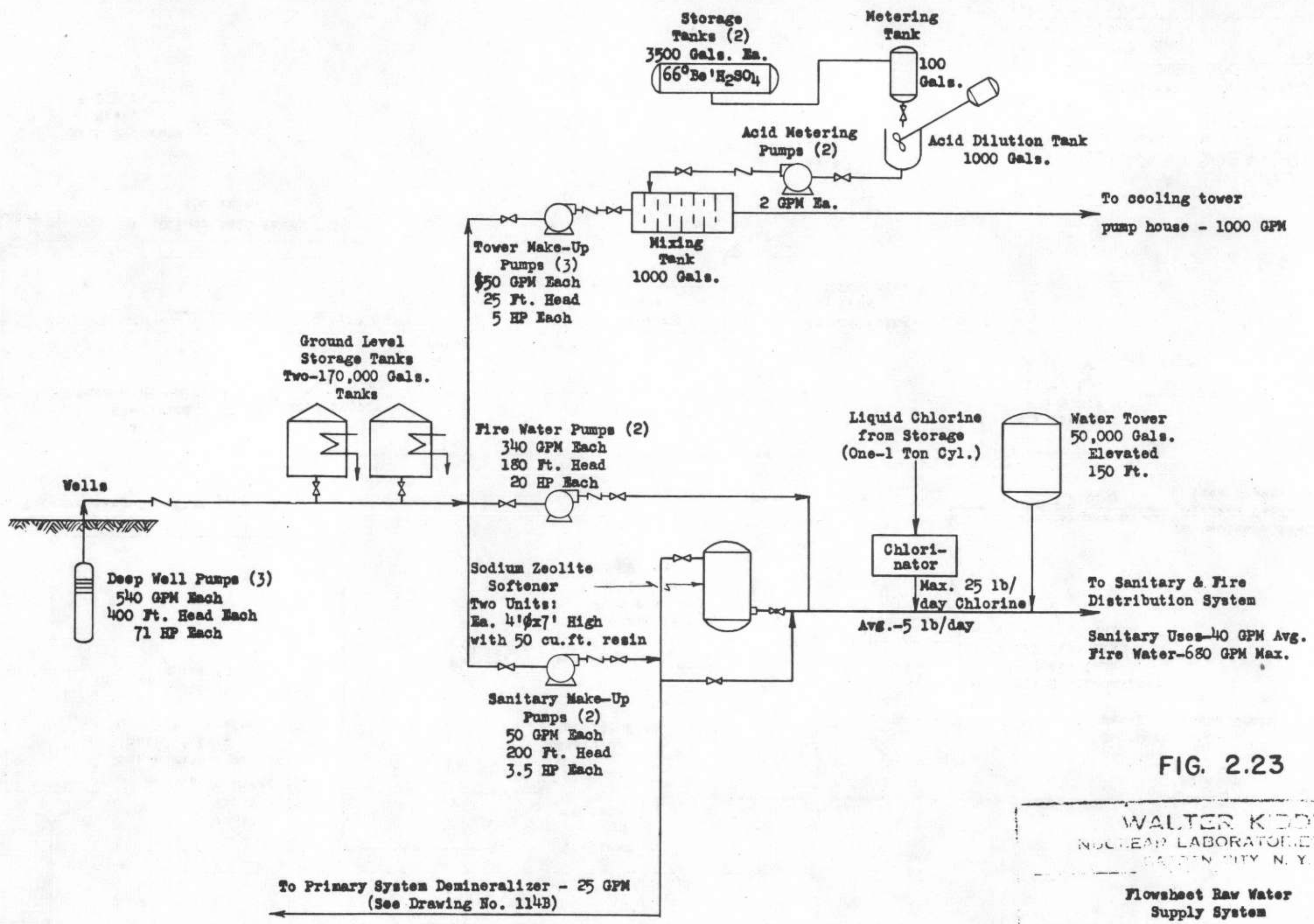


FIG. 2.23

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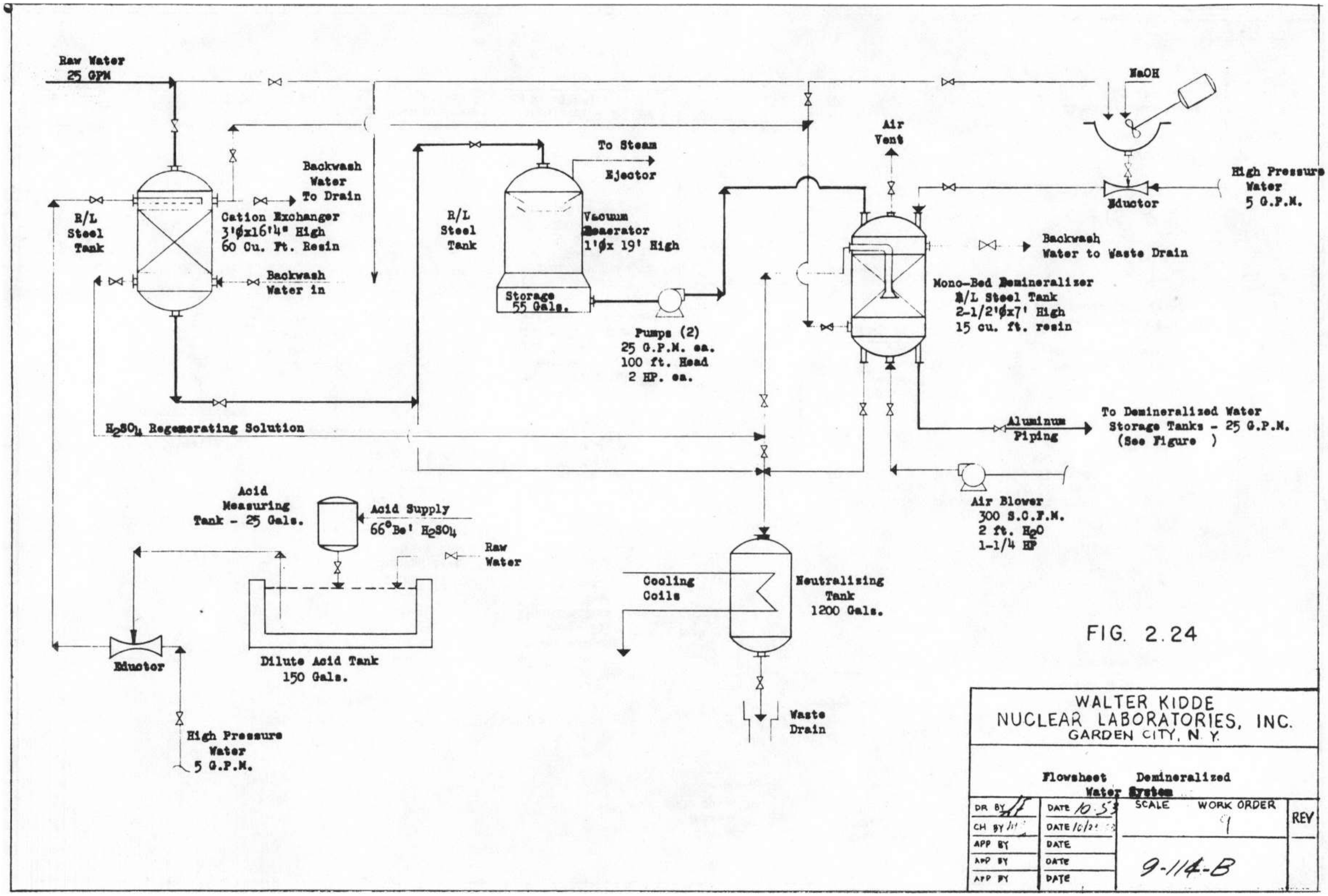
GARDEN CITY, N. Y.

Flowsheet Raw Water Supply System

D.J.M. 1/4/54

9-115-B



Raw Water
25 GPM
NaOH
To Steam
Ejector
Air
Vent
High Pressure
Water
5 G.P.M.
Backwash
Water
To Drain
R/L
Steel
Tank
Cation Exchanger
3'ϕx16'4" High
60 Cu. Ft. Resin
Backwash
Water in
R/L
Steel
Tank
Vacuum
Deaerator
1'ϕx 19' High
Eductor
Backwash
Water to Waste Drain
Storage
55 Gals.
Mono-Bed Demineralizer
R/L Steel Tank
2-1/2'ϕx7' High
15 cu. ft. resin
Pumps (2)
25 G.P.M. ea.
100 ft. Head
2 HP. ea.
H2SO4 Regenerating Solution
Aluminum
Piping
To Demineralized Water
Storage Tanks - 25 G.P.M.
(See Figure)
Acid
Measuring
Tank - 25 Gals.
Acid Supply
66°Be' H2SO4
Raw
Water
Air Blower
300 S.C.F.M.
2 ft. H2O
1-1/4 HP
Cooling
Coils
Neutralizing
Tank
1200 Gals.
Eductor
Dilute Acid Tank
150 Gals.
Waste
Drain
High Pressure
Water
5 G.P.M.
WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y.
Flowsheet Demineralized
Water System
DR BY
DATE 10-53
SCALE
WORK ORDER
REV
CH BY
DATE
APP BY
DATE
APP BY
DATE
APP BY
DATE
9-114-B

FIG. 2.24

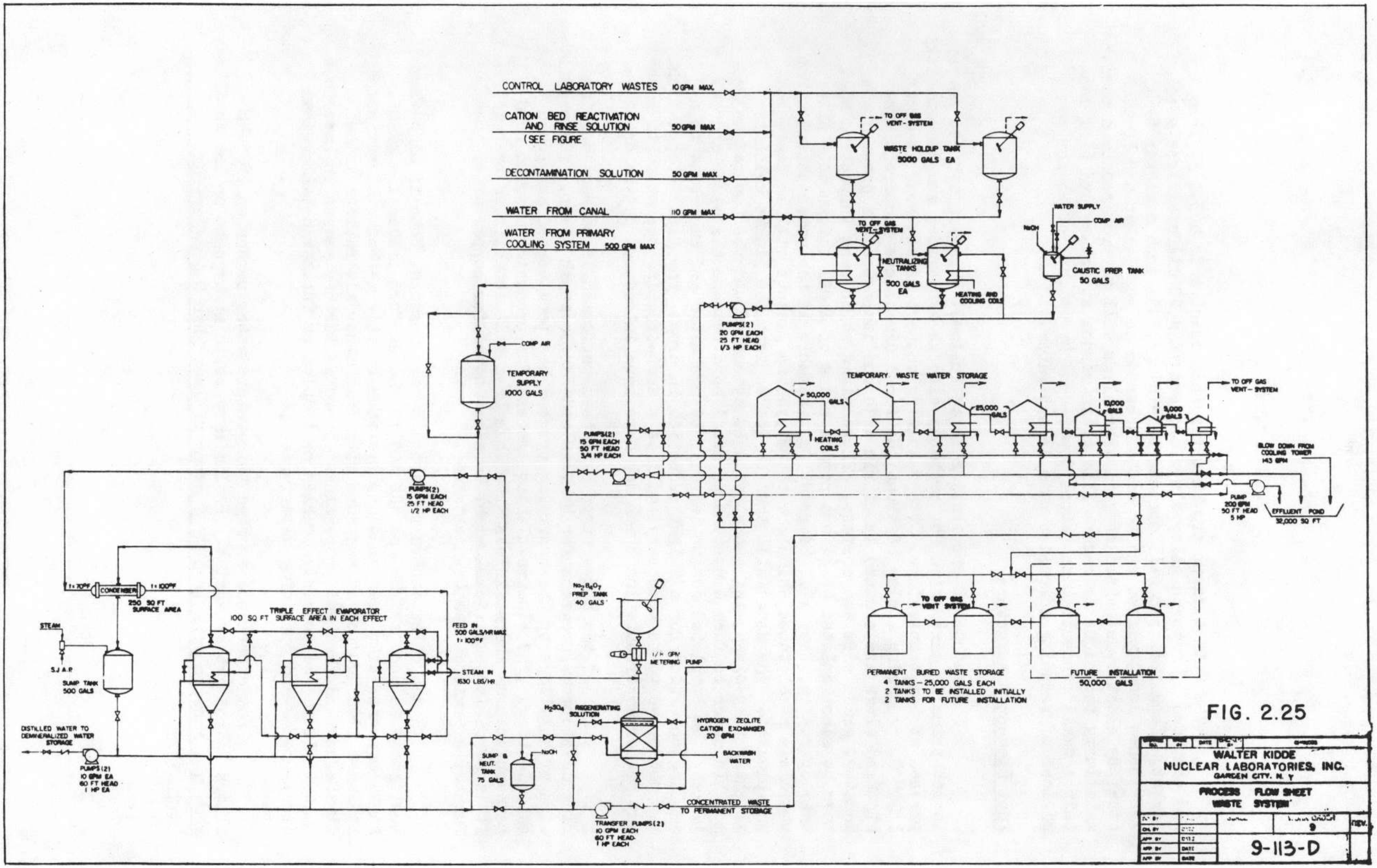

CONTROL LABORATORY WASTES
10 GPM MAX.
CATION BED REACTIVATION AND RINSE SOLUTION (SEE FIGURE
50 GPM MAX
DECONTAMINATION SOLUTION
50 GPM MAX
WATER FROM CANAL
110 GPM MAX
WATER FROM PRIMARY COOLING SYSTEM 500 GPM MAX
TO OFF GAS VENT-SYSTEM
WASTE HOLDUP TANK 5000 GALS EA
TO OFF GAS VENT-SYSTEM
NEUTRALIZING TANKS
500 GALS EA
HEATING AND COOLING COILS
WATER SUPPLY
COMP AIR
NaOH
CAUSTIC PREP. TANK 50 GALS
PUMPS(2) 20 GPM EACH 25 FT HEAD 1/3 HP EACH
COMP AIR
TEMPORARY SUPPLY 1000 GALS
TEMPORARY WASTE WATER STORAGE
50,000 GALS
HEATING COILS
25,000 GALS
10,000 GALS
5,000 GALS
TO OFF GAS VENT-SYSTEM
PUMPS(2) 15 GPM EACH 50 FT HEAD 3/4 HP EACH
PUMPS(2) 15 GPM EACH 25 FT HEAD 1/2 HP EACH
BLOW DOWN FROM COOLING TOWER 143 GPM
PUMP 200 GPM 50 FT HEAD 5 HP
EFFLUENT POND 32,000 SQ FT
CONDENSER
t = 70°F
t = 100°F
250 SQ FT SURFACE AREA
TRIPLE EFFECT EVAPORATOR
100 SQ FT SURFACE AREA IN EACH EFFECT
STEAM
SJAP
SUMP TANK 500 GALS
FEED IN 500 GALS/HR MAX t = 100°F
STEAM IN 1530 LBS/HR
DISTILLED WATER TO DEMINERALIZED WATER STORAGE
PUMPS (2) 10 GPM EA 60 FT HEAD 1 HP EA
Na2B4O7 PREP TANK 40 GALS
1/4 GPM METERING PUMP
H2SO4 REGENERATING SOLUTION
HYDROGEN ZEOLITE CATION EXCHANGER 20 GPM
BACKWASH WATER
SUMP & NEUT. TANK 75 GALS
NaOH
TRANSFER PUMPS (2) 10 GPM EACH 60 FT HEAD 1 HP EACH
CONCENTRATED WASTE TO PERMANENT STORAGE
TO OFF GAS VENT SYSTEM
PERMANENT BURIED WASTE STORAGE
4 TANKS - 25,000 GALS EACH
2 TANKS TO BE INSTALLED INITIALLY
2 TANKS FOR FUTURE INSTALLATION
FUTURE INSTALLATION
50,000 GALS
WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y
PROCESS FLOW SHEET
WASTE SYSTEM
CH. BY
APP BY
DATE
9
REV.
9-113-D

FIG. 2.25

Chapter III

FUEL ELEMENT

The fuel element proposed for this reactor is a 5.4 ft long rod composed of uranium alloy slugs encased in a 20 mil stainless steel jacket. Each fuel rod will contain nine slugs, .51 inch diameter by 7.2 inches long, placed end to end and bonded to the jacket and to each other by electro-deposited copper. The slugs will be prepared by a powder metallurgy technique to assure fine grain random structure and will contain a small concentration (about 5 per cent by weight) of Nb for the purpose of reducing corrosion rate in hot water.

Fuel Element Manufacture

The method of preparation is as follows. Uranium hydride powder is mechanically mixed with Nb, probably also as a hydride, and mechanically pressed at low temperature. The resulting compact is sintered at about 1100° C, producing a slug of about the final dimensions required. The sintered slugs are cleaned in nitric acid and inspected for dimensions, density, grain size and surface. Those slugs which pass inspection will then be electroplated to give a copper plate of 1 mil thickness. After this operation, they will be ready for assembly in the outer jacket. The stainless steel tubes which are to be used as jackets will be degreased and pickled. The slugs will then be loaded into the jacket which is slightly over-sized; the jacket will be evacuated and the top cap welded on. In order to form a continuous metal bond between the slugs and the jacket, the completed assemblies will be preheated and subjected to a drawing operation for a slight reduction in area. The final step, which may not prove to be necessary, will be a heat-treating operation to remove any preferred orientation which may have been introduced by the drawing.

All of the above steps have been performed in connection with slug development programs for Hanford and for Savannah River. The preparation of Nb alloys by the hydriding process has been tested and found to be satisfactory. The electro-plating process for producing a sound bond between uranium and stainless steel has been well established by practice. It is possible that nickel might be substituted for copper after some further experience has been obtained.

Based on extensive radiation damage testing, both in high flux test reactors such as MTR and NRX and in the Hanford production plant, it is expected that uranium slugs prepared by this method will withstand at least 1000 MWD/ton of exposure with only minor alterations inthe dimensions and physical properties. There is further reason to hope that this limit can be possibly doubled or tripled by further metallurgical developments and operating experience.

The experience in high temperature water corrosion of U-Nb alloys is not yet extensive. Preliminary tests at Argonne on low Nb alloys show a corrosion rate in 500° F water of less than 0.4 $mg/cm^2/hr$.*

* ANL-5078

Fuel Element Failure Problems

We have given considerable thought to the problems which might arise in case of failure of a slug jacket. In spite of the careful inspection, bonding and stainless steel jackets, there is some possibility that pin holes will develop on occasion. The main problems seem to be as follows:

1. Spread of radioactive contaminant throughout the primary system and consequent extra shielding and decontamination procedures.
2. Detection and removal of failed fuel rod.
3. Rapid or explosive corrosion of exposed uranium in hot water.

The first two items have been analyzed with the best information on corrosion rates and fission product activities. The third item, catastrophically high corrosion rate, is probably eliminated by the use of Nb alloy.

Let us assume that a pin hole will form at the reactor start-up time and will increase during the 100-day operating period to 2 cm^2 in area. In the first place, the amount of uranium loss will be about 1 gm, which would obviously be too small an amount to cause serious distortion to the corroded rod. The resulting buildup in fission product activity throughout the primary system will depend on the rate and efficiency of the continuous clean-up system which removes cations from a by-pass stream. If no ion removal is provided, the activity at reactor shutdown will amount to 470 Mev/sec/cm^3, which will persist with a relatively low decay rate. With an efficient purge system which completely purifies a 50 gpm by-pass stream, the activity buildup in the system at reactor shutdown will amount to 60 Mev/sec/cm^3. Since the short-lived N^{16} activity during reactor operation amounts to something in the order of 1,000,000 Mev/sec/cm^3, the additional activity due to fission products will obviously not affect the shielding design.

In case a piece of equipment in the primary loop must be serviced, for example, a boiler or a pump impeller, it will be necessary to decontaminate the part to be worked on. The maximum total amount of fission product activity, under the conditions assumed above, would amount to about 1.5 curies. Assuming that one per cent of this were present at the point where servicing had to be carried out, this amount of activity would give a dosage rate of 70 mr/hr at one foot, which could be reduced to a tolerable level by a decontamination factor of 10. Decontamination of this order is not generally a difficult problem and can probably be accomplished by flushing with an appropriate solution. For example, Argonne chemists have demonstrated the effectiveness of .01 molal alkali peroxide solutions for removal of solid uranium corrosion products.

The detection of a failed fuel rod at the rates of corrosion assumed here will be difficult by any method of sampling at the outlet of the reactor, since the change in uranium concentration at any point will be very small. However, the consequences of operating with such a failure do not appear to be serious and it will probably be sufficient to have a method which will detect the existence of a failed element, so that proper precautions can be taken at shutdown time. The concentration of uranium in the coolant at time of shutdown would amount to 7×10^{-11} gms/cm^3 with the corrosion rate assumed here. This concentration is about the lower limit of the fluorometric method of uranium analysis. A system of daily fluorometric tests would be sufficient to sense the corrosion danger. A negative test would indicate either no failure or a failure which is not troublesome. A positive result which increases with time would indicate a fuel element failure which might require clean-up measures at the next shutdown. The exact point where a concentration is considered troublesome would depend on the degree of localized separation of solid contaminants. The above analysis is based on homogeneous distribution of contamination.

Metallurgical Reprocessing

With a fuel exposure limit of 1000 MWD/ton, it will be necessary to reprocess the fuel elements, metallurgically at least, a number of times before it will be necessary to remove fission products or to re-enrich. The reformation of fuel elements by hydriding and powder metallurgy technique would be satisfactory for this purpose from the reactivity standpoint and would produce slugs which are the physical equal of fresh fuel. Since the fuel rods are highly radioactive and since the hydriding process does not remove most of the contaminants, it would be necessary to conduct all reprocessing operations by remote control.

The cost of a reprocessing system, based on hydride process, has been estimated by Sylvania Electric Products Corporation, assuming that a continuous remotely operated plant would be set up for this operation alone. Table 3.1 shows the condensed results of this study giving the final overall cost of processing, including profit, for various plant sizes and operating procedures.

Table 3.1

Estimated Fuel Reprocessing Price

	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
Capacity	218,000 lbs. elements/yr (2 reactors) 1-2 shifts/day	218,000 lbs. elements/yr (2 reactors) 3 shifts/day	1,092,000 lbs. elements/yr (10 reactors) 3 shifts/day	10,920,000 lbs. elements/yr (100 reactors) 3 shifts/day
Total Plant Cost	\$5,643,000	\$4,187,000	\$8,367,000	\$20,501,000
Manufacturing Cost Per Lb.	\$7.08	\$6.70	\$2.95	\$1.16
Estimated Selling Price Per Lb.	\$13.65	\$11.61	\$4.91	\$1.65

The price of this reprocessing operation is obviously very strongly affected by the amount of material handled. At a rate of reprocessing corresponding to continuous operation of 2 reactors, the price would be in the neighborhood of $12 per pound. At a rate of 10 reactors, the price would drop to about $5 per pound, and still larger plants would continue to show cost advantages.

Figure 3.1 shows the operations which are included in this cost estimate. The fuel rod jackets would be loosened by thermal shocking and slit open to remove the slugs. The copper plate would then be dissolved by a nitric acid treatment and the cleaned and dried slugs would be sent to the hydriding furnace. After hydriding and dehydriding, the resulting powder would be crushed to break up loose agglomerates and mixed in a continuous blender to assure uniform mixture of uranium, niobium and plutonium. The powder would then be compacted, sintered, cleaned, inspected, copper-plated, and reassembled into new stainless steel jackets as described above for the fresh fuel elements.

This process appears to be feasible, although the details of remote operation would require some equipment development. The method of loosening the jacket by thermal shocking is based on a routine destructive test now in operation to determine the quality of bond between a slug and a can. The hydriding and dehydriding operation has been tested on various alloys, including a 4 atom per cent Nb alloy. The presence of Pu is not expected to cause trouble whether or not it hydrides. Electroplating techniques are quite well established for producing the copper bonding. The exact method for slug and can assembly and subsequent drawing would have to be established by a test program. Such test work is already under way as part of a general fuel rod program.

It should be noted that a very considerable allowance has been made in estimating the plant investment cost for the possible occurrence of accidents which could not be remedied until extensive decontamination had been carried out. Equipment is over-sized and more than the usual provision is made for spares.

Chapter IV

POWER CYCLE

The heat removed from the primary coolant circuit generates saturated steam in a set of straight tube boilers. The steam is used without superheat in a conventional turbogenerator to produce electric power, exhausting condensate at 2" mercury pressure. Cooling towers are specified for removing the heat of condensation, although direct cooling might be preferable where large amounts of cooling water are available.

Steam is withdrawn at three intermediate points in the turbine for boiler feed preheating, as shown in Figure 2.21. This particular cycle was arrived at by a study of various possible steam cycles.

Table 4.1 summarizes the results of a preliminary cost analysis of nine power cycles. Cycles A, B, E and G (Case I) are based on 1543 psia reactor pressure, 681 psia steam at the turbine throttle and various combinations of reheat and regeneration. Cycles C, D and F (Case II) are based on the same reactor pressure (1543 psia) but lower turbine throttle temperature (382 psia) as a result of decreased primary circuit temperature and flow rate. Cycles H and I are based on lower reactor pressure (848 psia) and correspondingly lower turbine throttle pressure (309 psia). All cases are calculated for a reactor heat output of 150 megawatts.

The variation in cost among these cycles, expressed as dollars per kilowatt of generator output, is relatively small. The maximum variation is from $103/kw for Cycle A to $114/kw for Cycle F. Therefore, these costs can only serve to differentiate between cases in which the remaining parts of the plant are identical. That is, they will serve to choose the proper cycle for each reactor case.

Referring to Case I, Cycle A, which includes three stages of feed water preheat, is superior to Cycle B, which includes no feed water preheat, although the difference is small. Cycles E and G, which include reheat between high and low pressure stages of the turbine in addition to feed water preheat, show a definitely higher investment cost. Comparison of Cycles C, D and F (Case II) confirms this slight advantage of feed water preheat and disadvantage of interstage reheat. Cycles H and I also show the advantage of feed water preheat. The choice, then, is narrowed to Cycles A, C and H by study of steam cycles only.

The choice between these three cycles was based on further studies of the reactor. Cycle H was finally chosen as a compromise between cost of the power generating equipment and cost and feasibility of the reactor circuit. The comparative low pressure in the reactor makes possible a very simple pressure vessel which can be closed by an ordinary bolted cover. The lower reactor temperature also aids in reactivity and control which begin to show difficulties above 500° F.

The use of saturated steam in such a relatively low pressure cycle introduces the problem of moisture in the final stages of the turbine

Table 4.1

Study of Power Generation Cycles

REACTOR COOLANT CIRCUIT CONDITIONS	CASE I				CASE II			CASE III	
Temperature of Coolant - Out °F	547°	547°	547°	547°	497°	497°	497°	467°	467°
Temperature of Coolant - Return °F	533°	533°	533°	533°	463°	463°	463°	453°	453°
Temperature Drop - °F	14°	14°	14°	14°	34°	34°	34°	14°	14°
Reactor Vessel Pressure - psia	1,543	1,543	1,543	1,543	1,543	1,543	1,543	848	848
Coolant Flow - gpm	77,000	77,000	77,000	77,000	31,500	31,500	31,500	77,000	77,000
Reactor Heat Available - kw	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000
Pressure Drop through Reactor Piping to Heat Exchanger - psi	30	30	30	30	15	15	15	---	---
STEAM CYCLES	A	B	E	G	C	D	F	H	I
Pressure at Turbine Throttle - psia	681	681	681	681	382	382	382	308.8	308.8
Reheat Pressure to Reheat Turbine - psia	---	---	142 p.	142 p	---	---	86 p.	---	---
Reheat Temperature - °F	---	---	500°F	500°F	---	---	500°F	---	---
Number of Feed Water Heaters	3	0	3	4	3	0	3	3	0
Feed Water Temperature - °F	355°	102°	350°	414°	300°	102°	414°	300°	102°
Vacuum - " Hg	2"	2"	2"	2"	2"	2"	2"	2"	2"
SUMMARY OF CYCLE STUDIES	A	B	E	G	C	D	F	H	I
Heat Rate (Btu/net kwh)	11,213	12,527	10,944	10,910	11,956	13,210	11,840	12,456	13,627
Efficiency (3,415/heat rate)	30.44%	27.25%	31.19%	31.28%	28.55%	25.84%	28.83%	27.40%	25.06%
Net Generation - kw	45,657	40,867	46,780	46,930	42,820	38,756	43,238	41,100	37,570
Main Steam Flow (lbs./hr.)	585,600	453,400	499,300	543,010	547,700	451,700	491,100	548,400	452,050
Reheat Steam Flow (lbs./hr.)	---	---	436,100	429,360	---	---	441,990	---	---
Heat Exchanger Surface (sq. ft.)	12,700	10,250	13,250	14,480	12,930	11,010	14,210	13,177	11,255
kw/ft.² of Heat Exchanger Surface	3.60	3.99	3.38	3.24	3.31	3.52	3.04	3.12	3.34
% Moisture at Exhaust at 2" Hg	22.2%	22.2%	12.3%	12.3%	20.3%	20.3%	11.5%	19.6%	19.6%
Power/10 psi Drop - kw	440	440	440	440	184	184	184	440	440
COST STUDY									
Cost of Heat Exchanger F.O.B.	$191,000	$154,000	$207,500	$216,500	$194,000	$165,000	$213,000	$197,500	$169,000
Installation Cost	167,000	154,800	180,500	188,500	170,000	145,000	187,000	174,500	148,000
Cost of Turbo-Generators	1,736,425	1,617,000	1,993,400	1,997,900	1,690,500	1,588,900	1,912,140	1,647,500	1,559,250
Cost of Installation of Turbo-Generator	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000
Cost of Condenser	369,600	302,400	333,600	362,400	356,000	300,000	307,000	364,800	301,200
Feed Pump Installed	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000
Valves & Piping Installed	390,000	348,000	398,000	400,000	364,000	330,000	368,000	350,000	320,000
Cooling Tower Installed with Auxiliary	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000
Cost of Feedwater Heaters	63,000	---	63,000	84,000	63,000	---	63,000	63,000	---
Cost of Reheat Heat Exchanger	---	---	137,500	132,500	---	---	140,000	---	---
Building & Foundation Cost	460,000	460,000	460,000	460,000	460,000	460,000	460,000	460,000	460,000
Plant Elect. Cost	400,000	358,000	410,000	411,000	375,000	340,000	378,000	360,000	329,000
Distribution Equipment Cost	183,000	163,000	187,000	187,500	171,000	155,000	173,000	164,000	150,000
TOTAL COST	4,701,025	4,298,200	5,111,500	5,180,800	4,594,500	4,224,900	4,942,140	4,528,300	4,228,450
COST/KW	103	105	109	110	107	109	114	110	112

which might lead to excessive erosion of turbine blades. For example, Cycle H would result in 19.6 per cent moisture at the turbine exhaust, if no provision were made for moisture removal, and there was some thought that interstage reheat might be required on this basis in spite of the higher cost.

This point was discussed thoroughly with representatives of General Electric Company, Steam Turbine Division. Mr. C. W. Elston, Manager of Engineering, described devices which have already been successfully developed and tested for removing moisture at points where steam is extracted for feed water preheat. This is accomplished by grooves in the blades which channel the moisture to the tips where a fraction is removed with the steam bleed. Mr. Elston stated that moisture could be reduced by this means to a point where it would cause no undue erosion.

The turbogenerator unit proposed by General Electric Company for this service is a tandem compound double flow unit operating at 3600 RPM. No reheat is used between stages and bleed steam for feed water preheat is withdrawn at three points, which will also serve as moisture removal points.

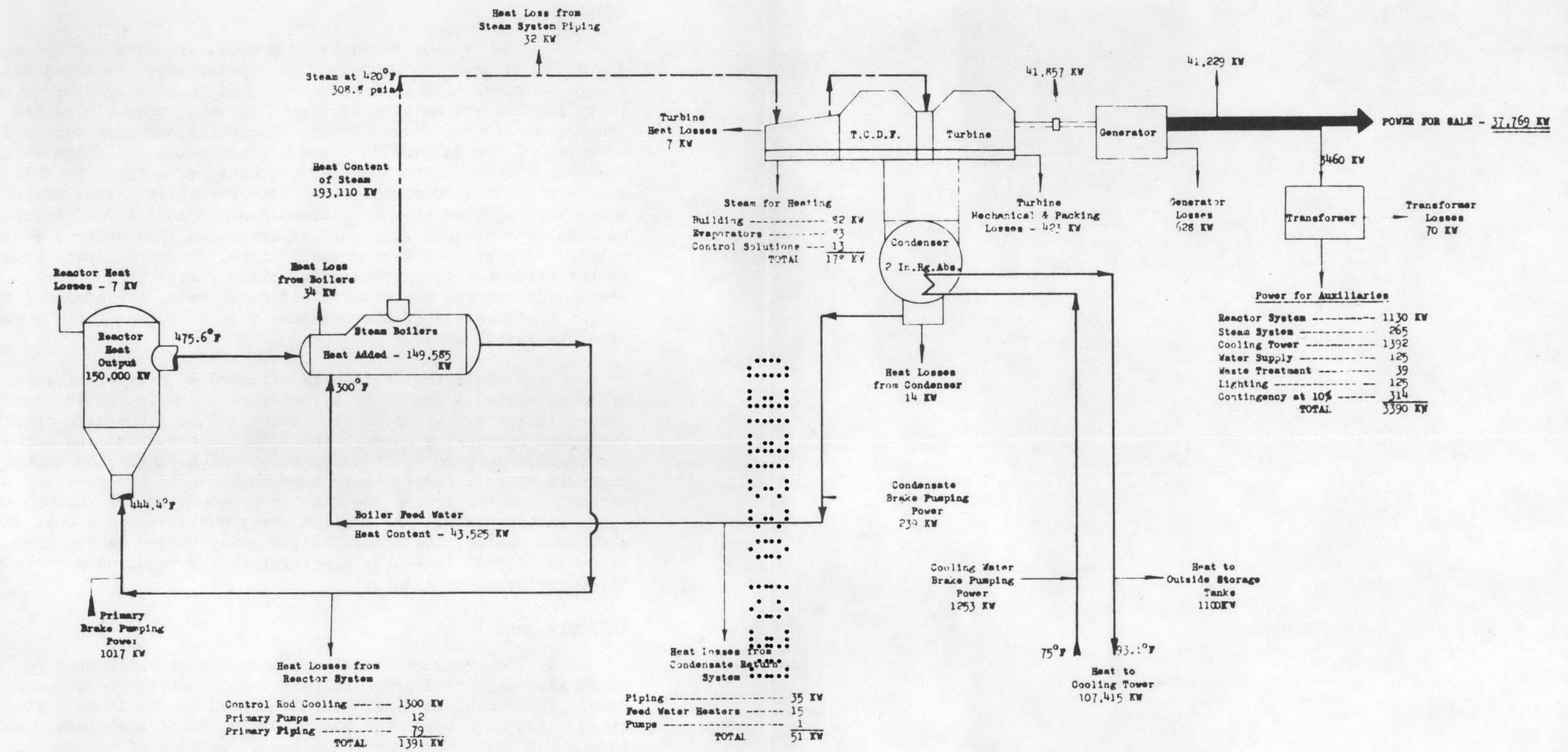
Boilers

The boilers consist of straight tube heat exchangers with the primary coolant on the tube side. Condensate is fed to the shell side at a rate equal to the vaporization rate and flows countercurrent to the primary coolant until it reaches the boiling point. Scale formation is controlled by close control of condensate make-up composition and by occasional flushing of the shell side surface.

The required surface is estimated at 16,000 ft^2 for the normal full load. This capacity is provided by 5 shells, with a sixth shell and circulating pump to permit full load operation while servicing one boiler. Cost and performance of these units is based on information from the Griscom-Russell Company.

The equipment specifications and costs given in Table 4.1 are based on early design information and serve only as a basis for cycle selection. Final choices of equipment are described in Chapter V.

Overall performance of the power plant is shown in Figure 4.1. The generator is sized to produce 42,000 kw of electric power. Auxiliary use of power within the plant amounts to 3,390 kw, the bulk of which is for the primary and secondary circulating pumps. The net power production at the plant bus bar is estimated at 37,769 kw.



$$\text{Gross Generating Efficiency} = \frac{41,229}{150,000} \times 100 = 27.5\%$$

$$\text{Net Generating Efficiency} = \frac{37,769}{150,000} \times 100 = 25.2\%$$

FIG. 4.1

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NUCLEAR LABORATORIES, INC.
GARDEN CITY, N. Y.

HEAT AND POWER BALANCE

DR BY AF	APP BY	SCALE	DRAWING NUMBER	REV.
DATE 12-53	DATE		9-116-C	

Chapter V

EQUIPMENT AND BUILDING SPECIFICATIONS AND COST ESTIMATE

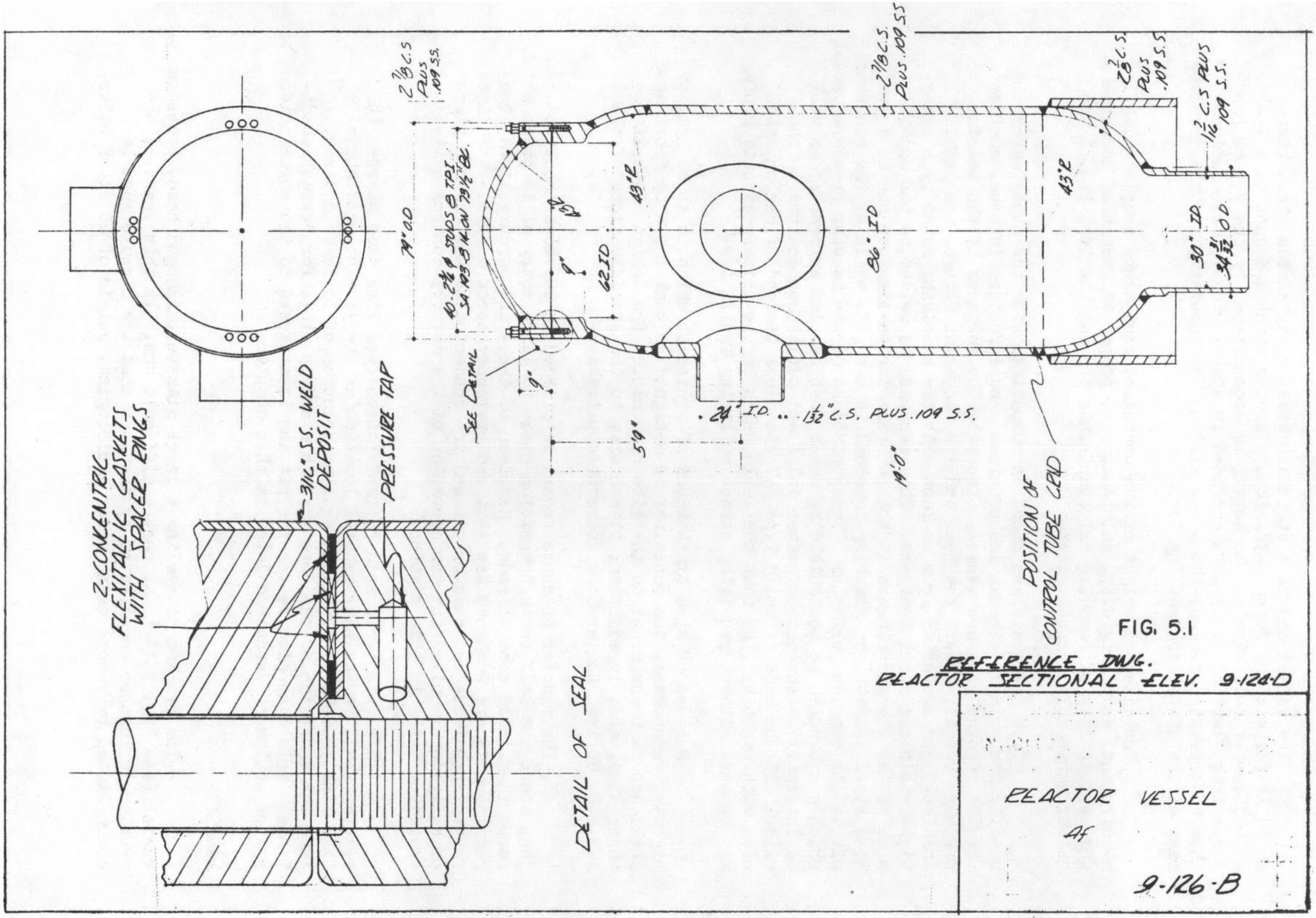
Reactor

The reactor consists of a core, graphite reflector, core carrying grid and pressure vessel. The reactor core, in turn, consists of 3402 stainless steel clad fuel rods set in 54 bundles of 63 rods per bundle. These bundles are encased in zirconium cans, open at the top and bottom, and are set in the core with their longitudinal axes vertical. The assembly of the 54 bundles forms a right hexagonal prism which is enveloped vertically by a zirconium clad graphite reflector. In this reactor, nineteen control rods made up of concentrically nested stainless steel tubes and eighteen stainless steel "dummy" rods form the core structure on which the grouped fuel bundles are hung. The control rods are dispersed within the core on a triangular lattice, while the dummy rods are set on the perimeter of the hexagonal prism formed by the core. A stainless steel grid carries the control and dummy rods, transferring the core weight to the walls of the pressure vessel through gussets welded to the pressure vessel walls.

A biological shield is effected by a layer of water covering the pressure vessel. The depth of water over the top of the reactor pressure vessel is approximately 20 ft. Reactor fuel recharging operations are performed by working through the shield water. Cooling and moderation of the reactor core is provided by water which enters the bottom of the reactor pressure vessel, flows upward through the grid and past the parallel array of fuel rods and leaves the reactor pressure vessel through two outlet ducts in the shell. The coolant water contains boric acid in solution as a control medium, the concentration being varied as required. Reactor power is 37.5 MW (saleable electricity) and requires a coolant flow of 35,400 gallons per minute.

Pressure Vessel

The pressure vessel shown on Figure 5.1 houses and supports the core, zirconium clad graphite reflector, control rods, dummy rods and grid. The vessel is a weldment of formed carbon steel plates 2-7/8 in. thick which have been clad with .109 in. thick stainless steel. The stainless steel cladding forms the internal surface of the pressure vessel. When completed, the vessel forms essentially a right circular cylinder 86 in. inside diameter by 19 ft high, measured from the gasketed closure at the top to the support apron at the bottom. The pressure vessel is supported on a circular steel skirt carried on the support apron which is, in turn, a reinforced concrete ring at the bottom of the reactor pit. A 30 in. inside diameter primary water inlet duct is welded to the hemispherical bell mouth transition section at the bottom of the vessel. Two 24 in. inside diameter outlet primary water ducts are located 5 ft 9 in. below the closure line. The closure flange at the top of the vessel is 62 in. inside diameter and is joined to the main shell of the vessel by a hemispherical transition piece.



2-CONCENTRIC FLEXITALLIC GASKETS WITH SPACER RINGS
3/16" S.S. WELD DEPOSIT
PRESSURE TAP
DETAIL OF SEAL
SEE DETAIL
POSITION OF CONTROL TUBE GRID
2 7/8 C.S. PLUS .109 S.S.
2 7/8 C.S. PLUS .109 S.S.
2 C.S. PLUS .109 S.S.
1 1/16 C.S PLUS .109 S.S.
79" O.D
43"R
43"R
62 ID
86" ID
30" ID
34 31/32 O.D
24" I.D.
1 1/32" C.S. PLUS .109 S.S.
5'9"
19'0"
9"
REFERENCE DWG.
REACTOR SECTIONAL ELEV. 9-124-D
REACTOR VESSEL
9-126-B

FIG. 5.1

The vessel cap is a stainless steel clad, carbon steel piece which is fastened by forty 2-3/4 inch diameter studs and nuts on a 73-1/2 inch diameter bolt circle. Gasketing is accomplished by the use of two concentric Flexitallic Gaskets confined in spacer rings. Calculations show that prestressing of the studs will not be necessary for the development of the gasket compressing force.

The size and weight of the contained equipment, coupled with requirements as to rigidity, maintenance of proper alignment of components, and desirability of removing all components through the top, led to the rather substantial vessel shown.

Type 347 stainless steel is compatible with the other materials used in the primary circuit and provides a satisfactory internal surface for the reactor pressure vessel. The exterior surfaces of the reactor pressure vessel, except the head and its companion flange, are heavily insulated and protected from contact with the shielding water by a water-tight stainless steel membrane. This membrane is welded to the under side of the flanged closure at the membrane inside diameter and to a stainless steel water-tight flashing imbedded in the side walls of the concrete pit at its outside perimeter. Those portions of the reactor pressure vessel which are exposed to the shielding water must be clad externally as well as internally. The primary water inlet and outlet connections to the vessel will be made of solid Type 347 stainless instead of carbon steel clad with stainless, so that the field welds to the primary circuit piping may be made without requiring stress relieving facilities.

Because of size limitations of equipment which is to be rail or highway transported, the container is designed so that the shop fabricated shell can be transported to the site "in toto." The design accomplishes these aims, and, in addition, it conforms to the specifications of the A.S.M.E. Unfired Boiler Code wherever applicable.

The reactor pressure vessel is pierced in its lower section just above the bell mouth transition piece to allow entry of 38 pipes which serve the liquid control rods. Nineteen of these are mercury lines, the remaining 19 are combined gas vent and emergency mercury spill-over lines. These lines leave the reactor pit and are connected to the various pieces of equipment required for the operation of the mercury control system described later in this chapter.

A single boric acid "scram" poison feed line also pierces the reactor shell in the same general location as the 38 mentioned above. This line feeds a concentrated aqueous solution of boric acid directly into the underside of the core through a sparge ring, for "scram" conditions. This line also leaves the pit and is attached to the scram poison system equipment described later in this chapter.

Closure

The problem of sealing a large diameter, flanged head, pressure vessel (see Fig. 5.1) is at best a difficult one. In this reactor, the problem is further complicated by the fact that the closure must be accomplished by remote means under a biological shield of 20 ft of water.

Unlike most pressure vessels used in industry, this one will have its closure seal broken quite often (approximately every 100 days). The entire fuel recharging cycle including time for effecting a tight closure and test will be limited to three days. This specification requires an extremely efficient sealing method. A thorough review was made of existing closure methods including various quick opening types. None were found which were considered superior to the bolted closure design finally adopted. The size of this bolted closure is limited by the torsional strength of the bolts, where the maximum allowable bolt diameter is determined by the capacity of commercially available impact wrenches. The fact that the closure has to be "made-up" under water precludes the possibility of using the technique of heating the bolts during tightening, and allowing the subsequent cooling and shrinkage to develop the necessary pressure.

The flanged cap is hemispherical in shape, and made of carbon steel, stainless steel clad on all surfaces. The flanged cap is 79 in. O.D. by 62 in. I.D. Forty 2-3/4 in. diameter studs and nuts (material SA-193-814) are used on a 73-1/2 in. diameter bolt circle. A pressure tap connection leading to the annulus between the concentric flexitallic gaskets insures that any leakage will be towards the inside of the vessel.

It was the opinion of Babcock and Wilcox engineers that this closure is a practical device which will require little or no further development. The diameter of this closure lies well within the range of actual field tested equipment.

<u>Internal Supports</u>

Eighteen stainless steel gussets are welded to the inside of the pressure vessel. These gussets serve to carry the control rod grid and the reflector barrier on shelves which in turn are welded to the gussets (see Fig. No. 5.2).

<u>Grid</u>

The control rod grid shown on Figure 5.2 is a stainless steel Type 347 casting in the shape of a hexagonal prism 60 in. across corners and three in. thick. Fifty-three triangular shaped cored passages running through the grid create a waffle-like structure to permit the passage of cooling water upwards through the reactor core. Nineteen finish machined bosses, five inches in diameter provide the mounting surface for the control rods. Each of these bosses provides the following features:

a) A recessed, machined gasketing surface.

b) Six equally spaced 3/4" tapped holes on a 3-3/4 inch diameter bolt circle.

c) Two control rod locating pins on a 3-3/4 inch diameter bolt circle.

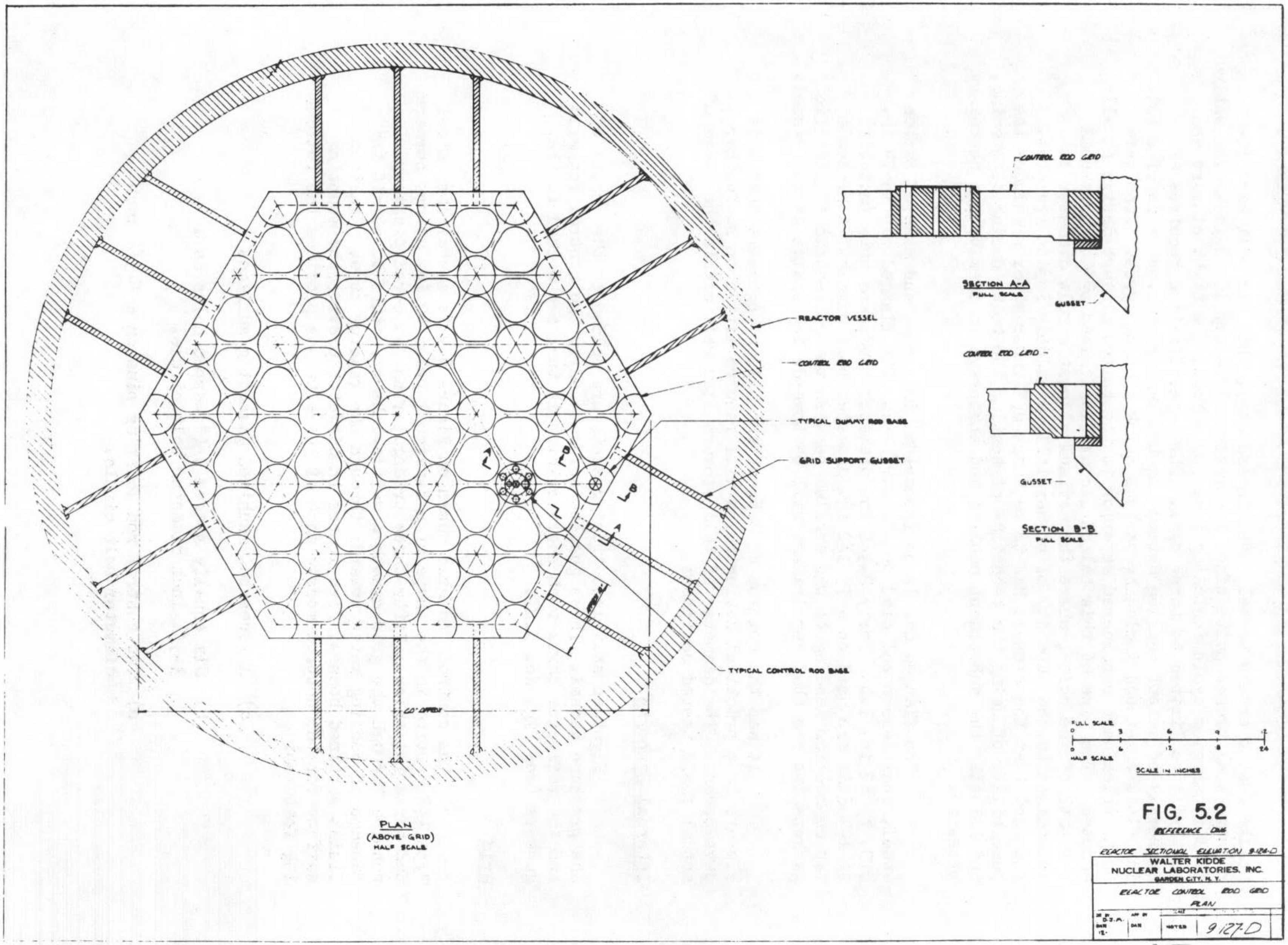

CONTROL ROD GRID
SECTION A-A
FULL SCALE
GUSSET
REACTOR VESSEL
CONTROL ROD GRID
CONTROL ROD GRID
TYPICAL DUMMY ROD BASE
GRID SUPPORT GUSSET
GUSSET
SECTION B-B
FULL SCALE
TYPICAL CONTROL ROD BASE
60" OPPOS
PLAN
(ABOVE GRID)
HALF SCALE
FULL SCALE
0 3 6 9 12
0 6 12 18 24
HALF SCALE
SCALE IN INCHES
REFERENCE DWG
REACTOR SECTIONAL ELEVATION 9126-D
WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N.Y.
REACTOR CONTROL ROD GRID
PLAN
9127-D

FIG. 5.2

d) Three cored holes passing through the boss to provide passageways for mercury, cooling water and vent gas.

Eighteen additional finish machined bosses, five inches in diameter on top of the grid provide the mounting surface for the dummy rods. These dummy rod bosses provide only a precision machined hole for a plug and socket type of connection between dummy rod and grid. The bottom of the grid has a finish machined strip, three inches wide running around the perimeter of the grid. This strip and the finish machined bosses on the top of the grid are held in close parallelism to insure vertical "plumbness" of the control rods.

Reflector

The 5.5 ft high reflector shown in Figures 2.1 and 2.3 forms a right circular cylinder on its 84 inch outside diameter and a right hexagonal prism approximately 60 inches across corners on its inside perimeter. The reflector consists of nine major segments dovetailed together to eliminate straight paths for neutron leakage. Each segment consists of an assembly of keyed four inch square by 2 ft 9 inch long graphite blocks completely enclosed in an air-tight, welded, evacuated zirconium can. The cans are made of .100 inch thick zirconium sheet and are provided with lifting lugs. The assembled reflector is supported by a shelf which encompasses the inside of the pressure vessel as part of the reactor internal supports. The dovetail joint construction of the reflector is so designed as to allow the removal of this assembly through the 62" diameter flanged opening in the pressure vessel. The grade of graphite selected for reflector construction is type AGHT. The blocks are machined with their "C", or principal growth axis parallel to the vertical centerline of the core so that the minimum growth axis is parallel to the width of the block.

Control Tubes

The 7 ft long reactor control tube shown on Figure 2.4 is made up of three concentrically nested stainless steel tubes. The innermost tube is 1-1/8 inch O.D. by 1 inch I.D.; the center tube is 1-1/2 inch O.D. by 1-3/8 inch I.D.; the outermost tube, 1-3/4 inch I.D., differs from the other two in that it has six integral longitudinal keys equally spaced about its external periphery. These keys locate the fuel bundles which are described later in this chapter. The annuli formed by the nested tubes are dis-associated from each other at the bottom of the control rod by a cast transition piece to which the three tubes are welded. This transition piece has a finish machined surface which it mates with the grid, providing both a gasketing and aligning surface. Six equally spaced bolt holes on a 3-3/4 diameter bolt circle are provided in the transition piece to permit fastening of the control rod to the grid. The tightening and loosening of the bolts may be accomplished by the use of impact wrenches operated from above the water shield. Two precision machined locating pin holes on a 3-3/4 inch diameter bolt circle permit accurate and reproducible positioning of the control rods on the grid from a distant station.

The outermost annulus is a mercury passage and is supplied by an independent tube which pierces the reactor pressure vessel and connects to the mercury control system located in the auxiliary equipment room. The second annulus is open to reactor water for cooling. The central or innermost passageway is a gas vent line. The control rod and cap, shown at "Section D-D" on Figure 2.4:

a) Provides a passageway between the outermost (mercury) annulus and the central vent. This passageway is also designed to act as a mercury flow throttling orifice to limit the rate of mercury overshoot on scram.

b) Permits the upward flow of reactor cooling water through the control rod.

The "dummy" rods are single stainless steel tubes which correspond to the outermost tube of the control rods with these exceptions:

1. There are only three integral longitudinal keys spaced 60 degrees apart on its external periphery with a total included angle of 120 degrees.

2. The connection between dummy rod and grid is of the plug and socket type instead of the bolted connection used for the control rods. Reactor cooling water passes through these dummy rods.

Fuel Rods

A 6.3 ft long fuel rod is shown as part of Figure 2.2. It is an assembly of uranium slugs .550 inches O.D., encased in a .013 inch thick stainless steel tube which is swaged down to provide a good thermal bond. A stainless steel end piece seals the end of the tube so that a gas-tight jacket is formed about the uranium. In addition, the bottom end piece acts to guide the fuel rod into position when it is being loaded into a fuel bundle, and to laminate the flow of reactor cooling water past the fuel rod. The top end piece provides a place to grip the fuel rod during the loading and unloading of the fuel bundle. Details of fuel rod fabrication are given in Chapter III.

Fuel Element Bundle

The fuel element bundle is shown on Figure 2.2. Each bundle is made up of:

a) Sixty-three stainless steel clad fuel rods.
b) A stainless steel fuel rod grid support.
c) 126 stainless steel spacer collars.
d) A zirconium can.
e) Three zirconium guide rails.
f) Three lifting pins.

The zirconium can is an equiangular triangular prism approximately 7 inches on a side and 6 feet long. It consists of three separate formed sheets which are riveted along each vertex of the triangular prism to the zirconium guide rails. These guide rails have keyways which engage the keys on the control and dummy rods to insure the proper orientation of each fuel element bundle. An overhanging lip is formed near the top of each guide rail through which the weight of the fuel bundle is transferred to the control tube. Lifting pins are fastened to these lips for loading and unloading bundles in the reactor. At the bottom of each can a cast stainless steel grid is riveted to the guide rails. The bottom end pieces of the fuel rods nest in countersunk holes in this grid. The .806 inch triangular lattice on which the fuel rods are based is maintained throughout the fuel bundle by these countersunk holes and two sets of spacer collars. One set of spacer collars is roughly at the mid-point of the fuel bundle and the other is at the top. These collars are stainless steel springs, spot-welded one to another, forming a compact which allows for thermal expansion of the rods without change in alignment.

Canal and Locks

The canals and canal locks form an integral part of the Reactor Material Handling and Storage System. They are shown on Figure 5.5. An examination of this drawing shows three locks which isolate four major areas:

a) The normal storage area for spent fuel bundles and new fuel bundles.

b) The transfer canal

c) The emergency storage area for damaged component isolation.

d) The reactor pit.

All transfer operations in these areas will be done under the biological water shield. For this reason, special lighting, viewing and handling equipment will be installed in these areas.

The sequence of operations runs as follows: Fuel bundles will be stored in the normal storage area. When it is necessary to load bundles into the reactor, the bundles will be picked up and moved through the lock into the center section of the canal and the lock closed behind them. The bundles will be carried to the other end of the canal through the lock leading to the reactor pit (while loading is being performed). The spent fuel cans will follow this sequence of operations in reverse. In the event that a bundle is removed from the reactor and found to be damaged, it will move from the reactor pit into the center canal area and through a third lock into the emergency storage area for special decontamination and disposal.

The canal will be tile-lined to afford ease of cleaning and good reflective surface for the submarine lighting at its bottom.

The steel lock gates or doors are hydraulically operated. A rubber inflatable gasket effects a seal to isolate the different areas

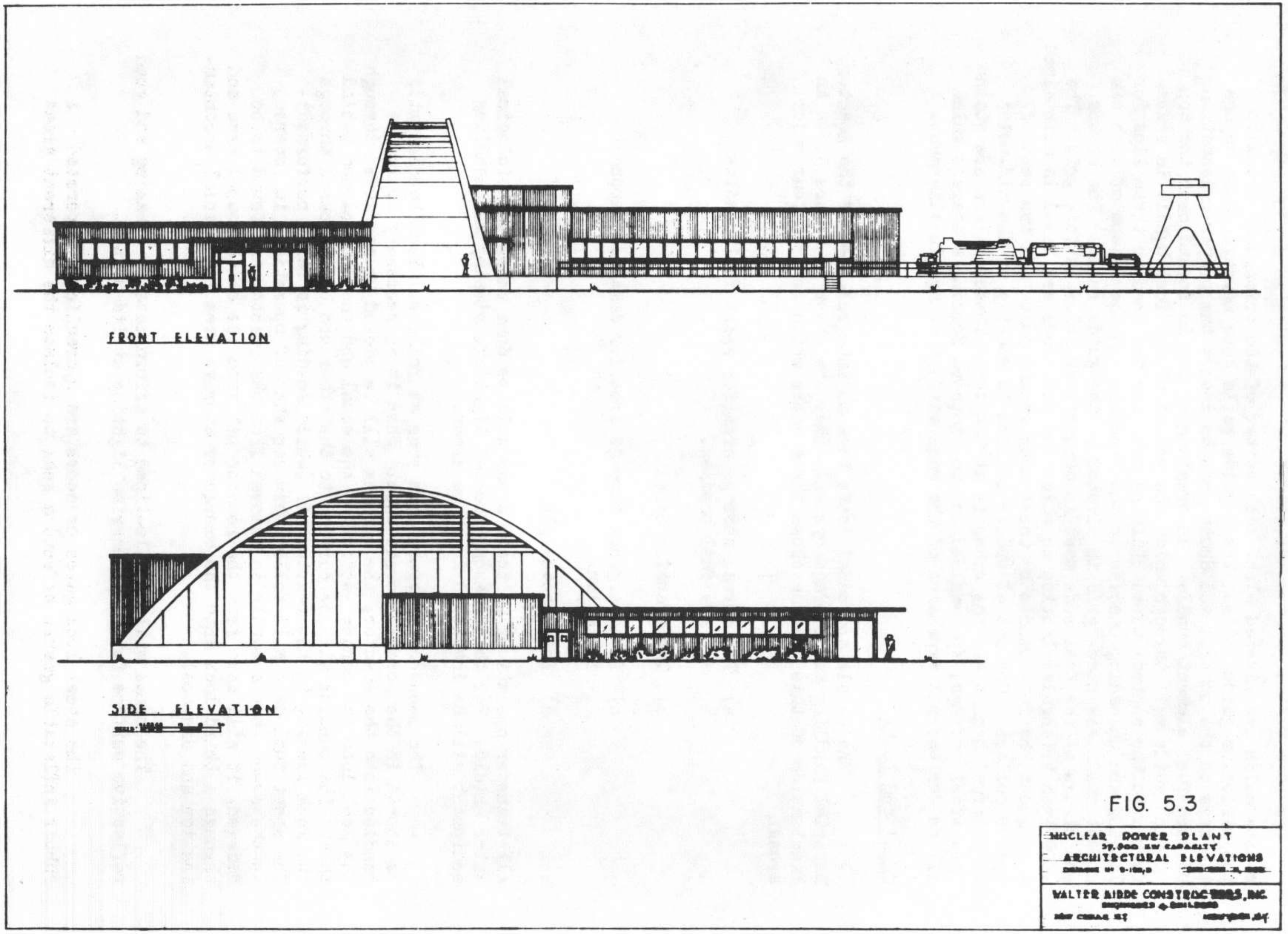

FRONT ELEVATION
SIDE ELEVATION
NUCLEAR POWER PLANT
ARCHITECTURAL ELEVATIONS

FIG. 5.3

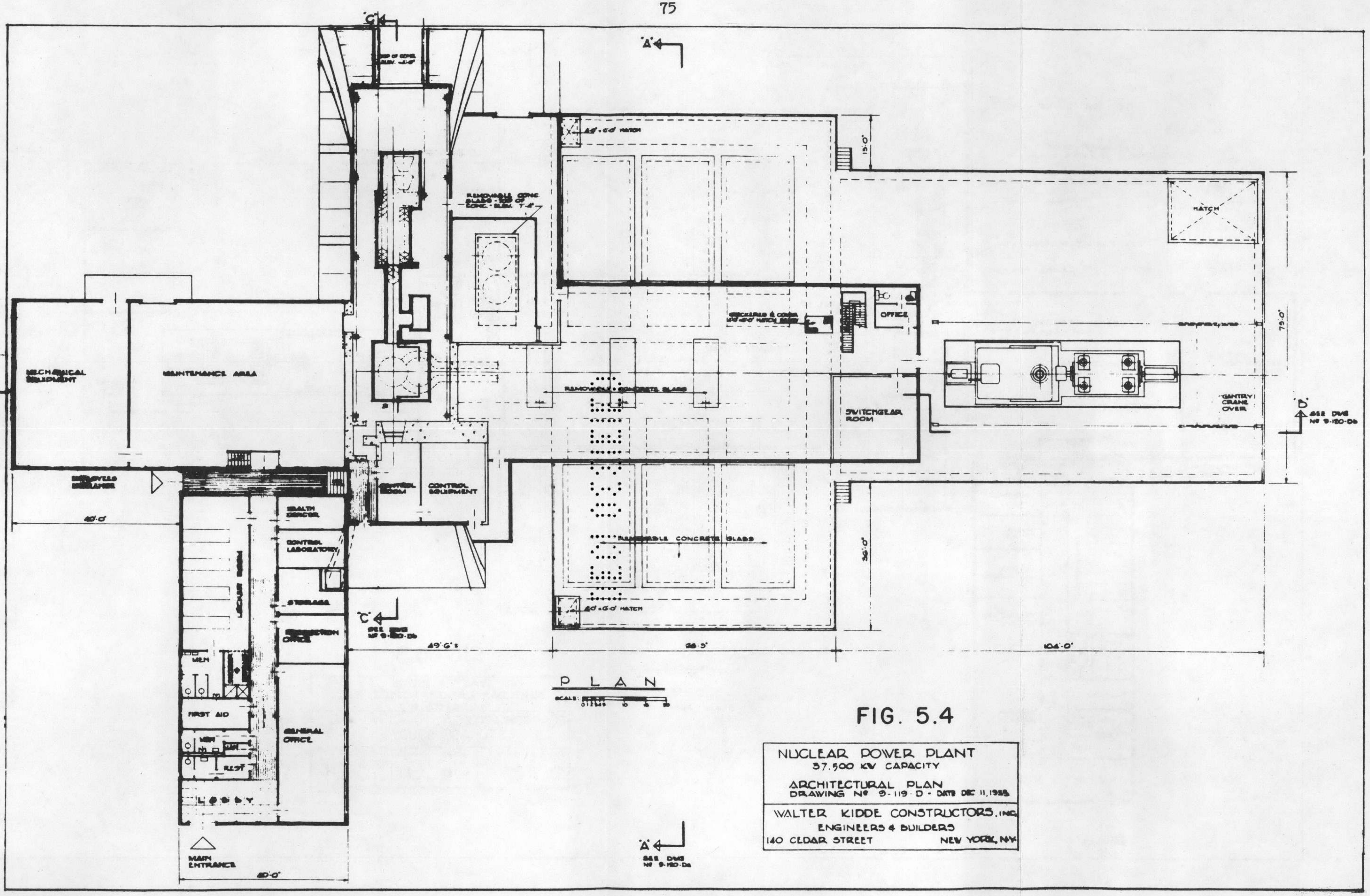

MECHANICAL EQUIPMENT
MAINTENANCE AREA
CONTROL ROOM
CONTROL EQUIPMENT
HEALTH DIRECTOR
CONTROL LABORATORY
STORAGE
FIRST AID
GENERAL OFFICE
LOBBY
MAIN ENTRANCE
MEN
REST
OFFICE
SWITCHGEAR ROOM
HATCH
GANTRY CRANE OVER
REMOVABLE CONCRETE SLABS
PLAN
NUCLEAR POWER PLANT
37,500 KW CAPACITY
ARCHITECTURAL PLAN
DRAWING Nº 9-119-D - DATE DEC 11, 1953
WALTER KIDDE CONSTRUCTORS, INC.
ENGINEERS & BUILDERS
140 CEDAR STREET NEW YORK, N.Y.

FIG. 5.4

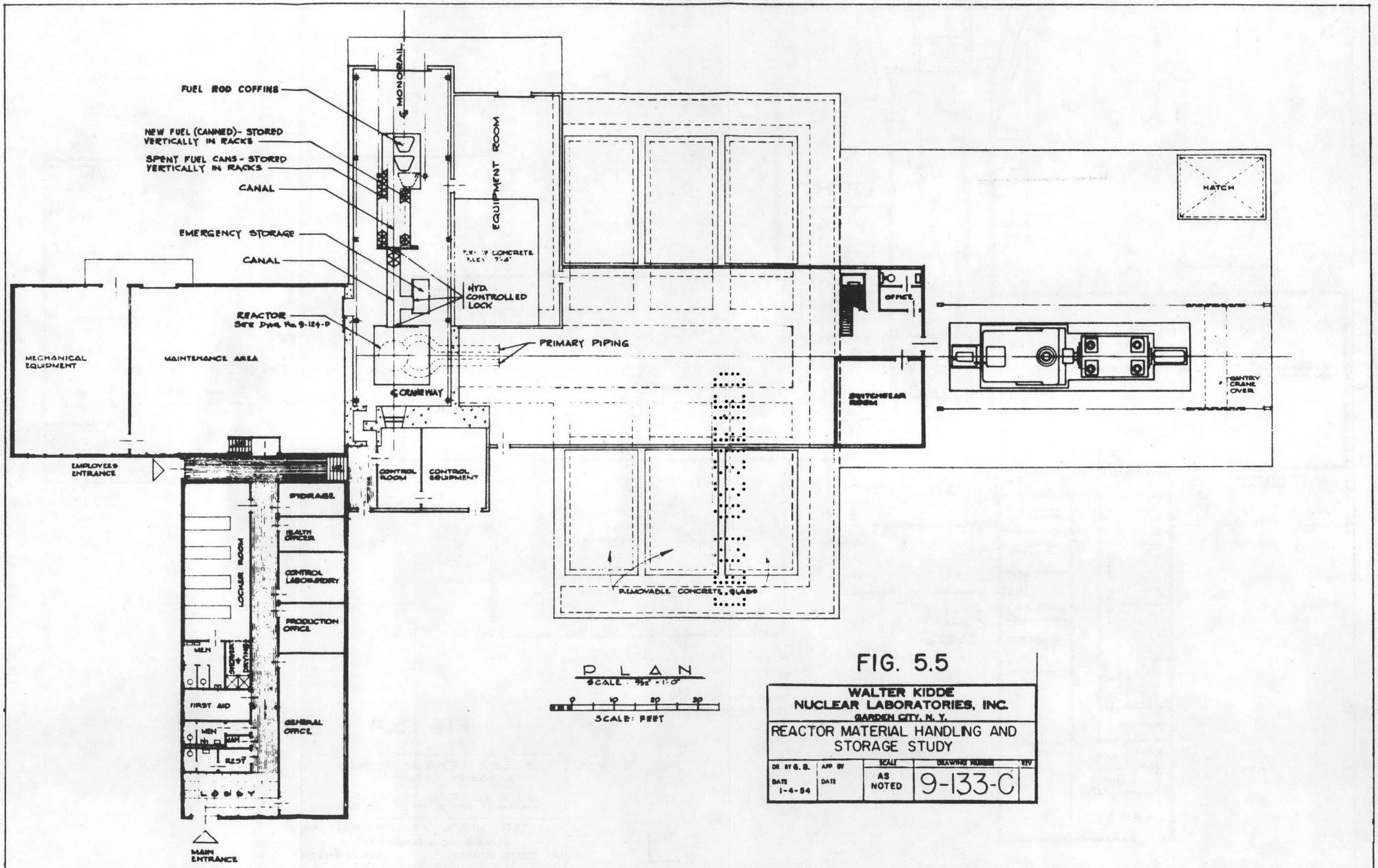


FIG. 5.5

WALTER KIDDE NUCLEAR LABORATORIES, INC. GARDEN CITY, N. Y.			
REACTOR MATERIAL HANDLING AND STORAGE STUDY			
DR BY G. B. DATE 1-4-54	APP BY DATE	SCALE AS NOTED	DRAWING NUMBER 9-133-C

from each other. The water in each of these areas may then be changed by introducing make-up water and pumping out the contaminated water.

The overhead crane system which services the reactor canal area, has a capacity of 5 tons and is supported from a trolley travelling on a bridge. The span between the bridge runway rail is approximately 22 ft. The runway rails traverse the length of the building over the canal area. The crane has been designed to clear a distance of 13 ft above the floor elevation. The crane operation will be controlled by a pendant, floor controlled unit. The hoist will accommodate lifts from a depth of approximately 34 ft below the reactor area floor to a height of 13 ft above the floor level. The monorail system within the reactor area is provided for handling fuel coffins weighing 35 tons each. It serves the railroad loading dock platform to facilitate ease of railroad car loading and unloading.

The Control Room

The control room is situated adjacent to the reactor area and directly opposite the reactor access pit. A five foot thick concrete wall, fitted with a shielded viewing window separates the two areas. Under normal operating conditions, this amount of shielding is not necessary. However, it may be necessary to exclude personnel from all areas but the control room in order to carry out a particularly hazardous operation. Control room shielding is adequate to protect personnel from the radiation of a spent fuel bundle suspended in the air above the access chamber. The control room houses a console and instrument panel for reactor control. Other control room system equipment is located in an adjoining room having the same shielding provisions as the control room.

Heating & Ventilating

The entire building is ventilated with filtered and tempered air. A positive flow of air is maintained from the "cold" areas to the "hot" areas in order to check the spread of radioactive contamination throughout the building. This is accomplished by controlling the inlet dampers and exhaust fans by a static pressure regulating device. Ventilation of the reactor access pit, the hot canal area and the emergency bay is achieved by exhausting air through continuous slots in the pit walls just above the water line. The purpose of this system is to protect operating personnel by drawing off water vapor rising from the surface of the shield water. Additional local ventilation can be provided for personnel if required.

Building Structure

The building is fabricated of structural steel with aluminum panel siding provided with aluminum architectural projected sash. The roof is constructed of pre-cast concrete roof slabs with a conventional weatherproof cover. The curved roof over the reactor area is fabricated of sandwich-type panels with an exterior surface of corrugated aluminum and the interior flat surface of steel with 1-1/2 inches of fiberglas-type insulation between them. (See outline specifications at end of Chapter).

Primary Pump and Heat Exchanger Area

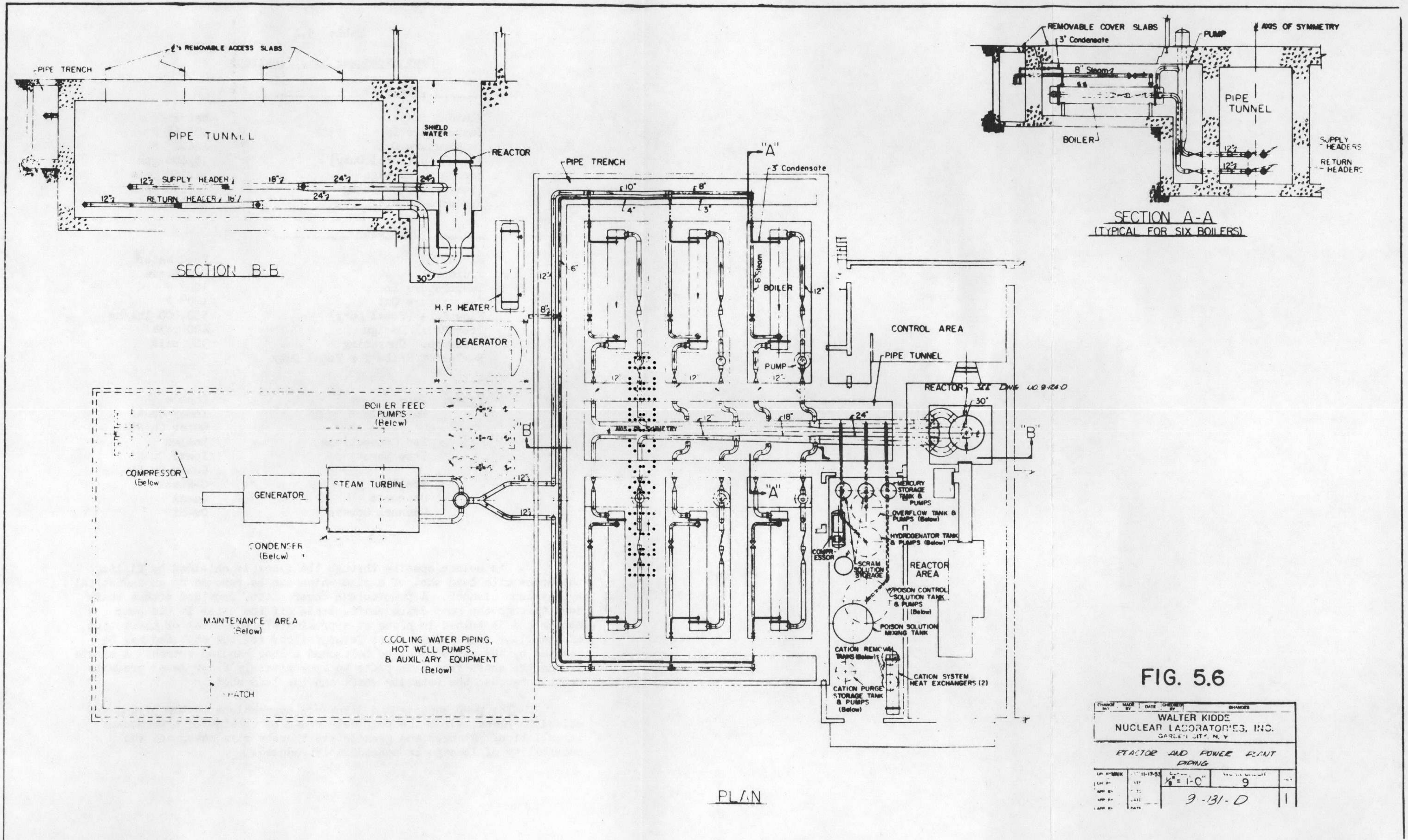
The Primary Pump and Heat Exchanger area shown on Figure 5.6 and described in the area outline specifications, Table 5.3, covers 8,750 sq. ft. (125 ft by 70 ft). It is located close to the reactor area to reduce the volume of the primary system. The area is designed to provide adequate radiation protection for operating personnel and at the same time to provide maximum ease of maintenance, repair, and replacement of equipment. The entire primary system within the structure is located below five feet thick concrete floor slabs. The only exceptions are the primary pump motor drives. Removable floor slabs are provided at the ends of all tunnels for access and for replacement of equipment. Access to the pump cells is provided by means of removable step floor plugs in each cell. The building superstructure consists of a steel frame with aluminum panel siding and aluminum architecturally protected window sash. The roof is constructed of pre-cast concrete roof slabs with a conventional weatherproof cover. A railroad loading dock is provided at one end of the building for the loading and unloading of heavy equipment. In addition to the pipe tunnels and pump cells, there are two banks of three pits, each 40 ft long by 14 ft wide by approximately 22 ft deep. Each pit is separated from the next by 5 ft thick concrete walls. These pits contain the heat exchangers together with the necessary piping, valves, etc.

Heat Exchangers

The heat exchangers are of the shell and tube type and constructed of copper-nickel alloy steel tubes, copper-nickel heads and tube sheets, and carbon steel shell. Each exchanger is approximately 25 ft long between tube sheets and has a shell diameter of 4 ft. The exchangers are arranged in two separate banks, each of which occupies a concrete pit, the dimensions of which have been previously described (see Fig. 5.6). Any five of these exchangers may be used for normal operations, the remaining one being a standby. The exchangers rest on steel supports. If it becomes necessary to remove a heat exchanger, the unit is blocked off, drained, flushed and decontaminated, if required. Each exchanger is fed by one primary pump with a flow rate of 7,100 gpm. The secondary system water travels through the heat exchangers in a counterflow arrangement at the rate of 240 gpm/per exchanger. The heat exchanger specifications are given in Table 5.1.

Main Pumps

The six main primary system pumps, one of which may be used as a standby unit, are of the vertical mixed flow pull-out type, having a capacity of 7,100 gpm each at a head of 115 ft. They are of stainless steel construction. They will be designed to enable the maintenance crew to uncouple the motor and remove an entire pump assembly while working from the main floor level without exposure to high radiation levels. The pull-out feature eliminates the necessity of unbolting connecting pipe flanges and removing the pump column.



SECTION B-B
PIPE TRENCH
4'± REMOVABLE ACCESS SLABS
PIPE TUNNEL
SHIELD WATER
REACTOR
12" SUPPLY HEADER
18"
24"
RETURN HEADER 16"
30"
SECTION A-A
(TYPICAL FOR SIX BOILERS)
REMOVABLE COVER SLABS
3" Condensate
PUMP
AXIS OF SYMMETRY
8" Steam
BOILER
PIPE TUNNEL
SUPPLY HEADERS
RETURN HEADERS
PLAN
"A"
3" Condensate
PIPE TRENCH
10"
8"
4"
3"
6"
12"
8" Steam
BOILER
H. P. HEATER
DEAERATOR
PUMP
CONTROL AREA
PIPE TUNNEL
REACTOR
AXIS OF SYMMETRY
BOILER FEED PUMPS (Below)
"B"
COMPRESSOR (Below)
GENERATOR
STEAM TURBINE
CONDENSER (Below)
MERCURY STORAGE TANK & PUMPS
OVERFLOW TANK & PUMPS (Below)
HYDROGENATOR TANK & PUMPS (Below)
COMPRESSOR
SCRAM SOLUTION STORAGE
REACTOR AREA
POISON CONTROL SOLUTION TANK & PUMPS (Below)
POISON SOLUTION MIXING TANK
CATION REMOVAL TANKS (Below)
CATION SYSTEM HEAT EXCHANGERS (2)
CATION PURGE STORAGE TANK & PUMPS (Below)
MAINTENANCE AREA (Below)
COOLING WATER PIPING, HOT WELL PUMPS, & AUXILIARY EQUIPMENT (Below)
HATCH
WALTER KIDDE
NUCLEAR LABORATORIES, INC.
GARDEN CITY, N.Y.
REACTOR AND POWER PLANT PIPING
1/8" = 1'-0"
9
9-131-D
1

FIG. 5.6

Table 5.1

Heat Exchanger Specifications

Tube Side	
Fluid	Water
Temperature In	475.6° F
Temperature Out	444.4° F
Flow Rate (Total Duty)	35,400 gpm
Pressure: Design	1,150 psia
Pressure: Operating	850 psia
Pressure Loss	10-20 psi
Shell Side	
Fluid In	Feed Water
Fluid Out	Dry Steam
Temperature In	300° F
Temperature Out	420° F
Flow Rate (Total Duty)	550,000 lbs/hr
Pressure: Design	400 psia
Pressure: Operating	309 psia
Number of Units for Total Duty	5

Tubes:	Type	Double
	Material	Inner Cu-Ni Outer Cu-Ni
	End Connections	Rolled
	Tube Sheets	Inner Cu-Ni Outer Cu-Ni
	Shell	C-Steel
	Channels	Cu-Ni
	Channel Covers	Cu-Ni

The column opening through the floor is shielded by filling the space with lead shot of a size which can be removed by an industrial type vacuum cleaner. A pump column cover plate, provided with a shaft seal through the pump drive shaft, seals off the water in the pump column and is bolted in place at approximately the level of the bottom of the floor slab. This plate forms a floor for the shot and may be removed by the use of captive bolts and a long handled wrench. A sleeve around the shaft from this plate to approximately floor level prevents contact between the rotating shaft and the lead shot.

The pump suction and discharge connections to the piping are welded in place, since the pump column can be considered a permanent installation. Flanges and gaskets are thereby eliminated and the possibility of leakage is considerably reduced.

The pump drives are directly coupled 300 HP vertical, drip-proof, squirrel cage induction motors mounted at floor level. Maintenance of these motors is easily achieved without exposure of personnel to radiation. They are also readily uncoupled and removed.

Shutdown Pumps

Immediately after shutdown of the reactor, it is necessary to maintain a portion of the normal rate of flow in the primary system. To accomplish this, two shutdown pumps are supplied. Each pump is a stainless steel submersible type unit capable of delivering 1000 gpm at a low head. At shutdown, the main primary pumps are stopped and simultaneously all valves in this system closed, with the exception of those in a preselected heat exchanger unit. At the same time, the shutdown bypass valves open and the shutdown pumps are started.

In the event that the main power feeder failure is the cause of the shutdown, the controls of these small pumps are arranged to receive power from the emergency power unit.

Piping

The primary piping will be shop-fabricated because of strict process specifications. The piping will be fabricated from SA-212 grade B steel, internally clad with .109, Type 347, stainless steel. All welded joints will be stress-relieved, all welds zygloed, and longitudinal and girth welds 100 per cent x-rayed.

Primary System Auxiliaries

There are five associated systems which, for the purpose of this report, are considered as parts of the primary system. They are: the Demineralized Water System Hydrogenator, Cooling Water Surge and Overflow System, Liquid Poison Control System and the Cation Removal System. The physical descriptions of these systems are outlined below. Functions and flowsheets are given in Chapter II.

Scram Poison System

The boron solution storage tank will supply a measured charge of 200 gallons of solution of $K_2B_4O_7$. The scram reservoir and storage tank are equipped with remote indicating liquid level gauges; indicators are located on the control room panel. The scram reservoir is gas-pressurized over the liquid solution to a pressure slightly higher than system pressure.

A two-stage, 16.3 SCFM 15 HP air compressor will be the driving force to introduce the scram poison into the system. The scram solution storage tank will be fabricated of Type 347 stainless steel and will have a capacity of 200 gallons. Heating coils will bring the temperature to approximately 100° F. The scram poison storage system will actually be two units, each of 100 gallon capacity fabricated of stainless steel Type 347.

Shim Poison System

The shim poison system is provided with a five thousand gallon capacity batch tank, fabricated of carbon steel and internally coated with vinyl paint to prevent rust. Agitation is accomplished by the use of a 7-1/2 HP lightning mixer with stainless steel shaft and propeller. Two 250 gpm 40 ft head stainless, Type 347, centrifugal pumps driven by 5 HP motors serve the solution tank. The solution tank has a capacity of 6,000 gallons. It is fabricated with steel, internally coated with vinyl paint and heated by steel coils. The solution feed line to the primary system is 3 in. stainless steel Type 347. Two stainless steel triplex pumps delivering 25 gpm against a 1,970 ft head feed the solution to the primary system. (See Fig. 2.22).

Cation Removal System

A cation removal system is provided to restrict the radioactivity of the primary system due to activated cation. Equipment for the cation removal system includes: two tanks 3 ft by 4 ft high with an 850 lb working pressure, fabricated of stainless steel, Type 347; one sulphuric acid storage tank of 3,000 gallons capacity horizontally mounted, fabricated of steel; one heat exchanger of 600 sq ft and a second exchanger of 150 sq ft. (See Fig. 2.22).

Demineralized Water System

The demineralized water system supplies all the makeup water to the primary system through the hydrogenator. The equipment involved consists of tankage, pumps, water treatment units, etc., and is housed in a small structure adjacent to the reactor area. A schematic flowsheet describing this equipment is included in Chapter II. (See Fig. 2.23).

Hydrogenator

The function of the hydrogenator system is twofold: it maintains hydrogen pressure in the primary coolant and introduces demineralized water into the primary system to dilute the boric acid poison. A schematic flowsheet describing this equipment is included in Chapter II. (See Fig. 2.22).

Cooling Water Surge and Overflow System

The cooling water surge and overflow system operates in conjunction with the hydrogenator to remove an amount of primary coolant equal to that added by the hydrogenator and controlled by liquid level control in the surge tank. A schematic flowsheet describing this equipment is included in Chapter II. (See Fig. 2.22).

Cooling Towers

Two cooling towers are required each having a cooling duty of approximately 25,000 gpm of water to be cooled from 93.1° F to 75° F based on a 65° wet bulb temperature. These units will be California redwood cased of the twin flow induced draft type. Each tower has overall dimensions of 87 ft by 151 ft by 44 ft high and a pumping head at the base of the tower of approximately 37.5 ft. Each tower will be equipped with 10 cast aluminum alloy fans each operated through a gear reducer by a 75 HP totally enclosed fan-cooled motor. The concrete basin below these towers will have a capacity of 1,200,000 gallons. The cooling water pumps required to handle the flow will have a total capacity of 46,930 gpm at 60 ft head and require approximately 1,000 HP. For actual process requirements, see Figure 2.21.

Controls and Instrumentation

The controls and instrumentation furnish indications for start, normal operation, and shutdown or scram. Start and normal operation can be manually controlled. Power is indicated by flux density and also monitored by means of coolant temperature measurements. Safety devices include automatic highspeed control rod insertion, coolant poison and a manually operated coolant poison reserve system. Additional devices accomplish various monitoring functions. The various systems are listed in Table 5.2.

Waste Handling System

The waste handling system consists of temporary and permanent waste storage tanks, effluent pond, pumps, piping, and waste treatment equipment. All these components, with the exception of the effluent pond, are slightly removed from the reactor area in a small building. The underground piping connecting these units with the reactor complex is installed in concrete trenches buried with sufficient cover of earth for shielding. The temporary waste storage tank farm consists of two 50,000 gallon steel tanks with heating coils, two 25,000 gallon tanks, one 10,000 gallon tank, and two 5,000 gallon tanks. The permanent buried waste storage tanks consist of two tanks of 25,000 gallons each. Provisions will be made for two additional tanks for future installation. The neutralizing system consists of two 5,000 gallon waste holdup tanks and two 500 gallon capacity neutralizing tanks, served by a 50 gallon caustic preparation tank. The vapor recompression evaporators concentrate waste solutions and return the distilled water to the demineralized water storage tank. This evaporator is a triple effect type, each effect having a surface area of approximately 100 sq ft.

The demineralizer system for the treatment of contaminated waste water consists of a 40 gallon $Na_2B_4O_7$ preparation tank, metering pump, a 20 gpm hydrogen zeolite cation exchanger, a 75 gallon neutralizing tank, and two transfer pumps.

The off-gas scrubbing and filtering system receives gases vented from all waste processes and storage tanks. The effluent pond is a shallow basin located somewhat removed from the process waste system building. It receives cold waste such as cooling tower blowdown, decayed and neutralized radioactive waste, and other miscellaneous inactive waste. It covers an area of approximately 32,000 sq ft. A flow sheet describing these facilities is included in Chapter II. (See Fig. 2.25).

Table 5.2

Plant Instrumentation

	Function or Description	No. of Units or No. of Channels
	GROUP I - REACTOR CONTROLS	
Control Rods	Control Random Power Variations	19
Power Level Emergency Trip	Main Over-Power Protection Device	1
Poison Scram System	Chemical Poison Emergency Shutdown System	1
Dilution Shutoff System	Poison Dilution Emergency Shutoff System	1
	GROUP II - REACTOR INSTRUMENTATION	
Power Level Indicator	Indicates Reactor Power Level	1
Counting Rate Meters	High Sensitivity Flux Level Device for Low Power	1
Period Meters	Measures Reactor Power & Period	1
Core Temperature Indicator	Indicates Reactor Internal Temperature	1
Coolant Contamination Level Indicator	Indicates Secondary System Gamma Level	1
Coolant Temperature Indicator	Multi-point Secondary Water Temperature Indicator	1
Personnel Protection Radiation Monitor	Monitors Area for Biologically Hazardous Levels	2
Primary System Flowmeter	Measures Primary Flow	1
Secondary System Flowmeter	Measures Secondary Flow	1
	GROUP III - PROCESS CONTROLS	
Demineralized Water Transfer Pumps	Liquid-Level Gauge	1
Dilution Water Pumping	Liquid-Level Gauge	1
Waste Water Pumping	Liquid-Level Gauge	1
Cation Removal	Flowmeter	1
Shutdown Solution Pumping System	Flowmeter	1
Primary Water Pumping System	Flowmeter	1
Secondary Water Pumping System	Flowmeter	1

Yard Piping

The water requirement for the reactor complex and supporting facilities is supplied by three 540 gpm 400 ft head deep-well pumps driven by 75 HP motors. The well water is pumped through underground mains to two 170,000 gallon capacity tanks which are ground level storage tanks. These ground level storage tanks supply a pump house in which the twoer makeup pumps, fire water pumps, sodium zeolite softener pumps, and sanitary pumps are installed. A flowsheet of the raw water supply system is included in Chapter II. (See Fig. 2.23).

Steam Lines

Steam supply from the steam plant to the other facilities is run underground. These lines are insulated, supported and installed in a covered concrete trough. Manholes are provided at all branch take-off points for access to valves.

Sanitary Sewers

The sanitary sewers consist of a system of vitrified tile pipes with the necessary number of manholes. The main sewer terminates in a disposal basin which is located southeast of the reactor complex and outside the perimeter fence.

Steam Generating Equipment

Chapter IV contains details on selection of the steam cycle. The steam generator unit consists of a tandem compound, double flow, 3,600 rpm turbine generator, including a 45,000 sq ft two-pass condenser, twin element steam jet air ejector, two circulating water pumps, two hot well pumps, and two priming ejectors. The turbine capacity is approximately 40,000 kw with initial steam conditions of 308.8 psia dry saturated steam for a steam flow of 548,000 lbs/hr with three stages of feed water heating. The generator capacity is 51,200 kva 0.85 power factor, 0.64 SCR at 30 lbs hydrogen pressure. The building outline specifications for this area are included in this report.

Emergency Power Generators

The emergency power generator starts and picks up its electrical load automatically in the event of reactor shutdown or failure and is located adjacent to the steam generating plant area. This unit will be a 5,000 kw diesel driven generator and will include the necessary switch gear and control features.

Stack and Fan House

The stack and fan house provide for discharge of reactor area ventilation air at a point on the facility remote from and normally downwind of the various buildings. The ventilation air discharged by the stack comes from the decontamination station and a special system provided to sweep filtered air across the reactor access pit, emergency bay and canal. While it is expected that the exhaust air from this special ventilation system will not be normally hazardous, it might be desirable to ventilate these portions of the reactor building and discharge the exhaust air at a point remote from the rest of the facility. The stack is constructed of mild steel painted on the inside surface with acid-resistant paint. It is 150 ft high. 5 ft in diameter and must be adequately guyed.

Maintenance Area

A small maintenance area will include a pipe shop, electrical shop, machine shop and store room and is located adjacent to the reactor area.

Laboratory

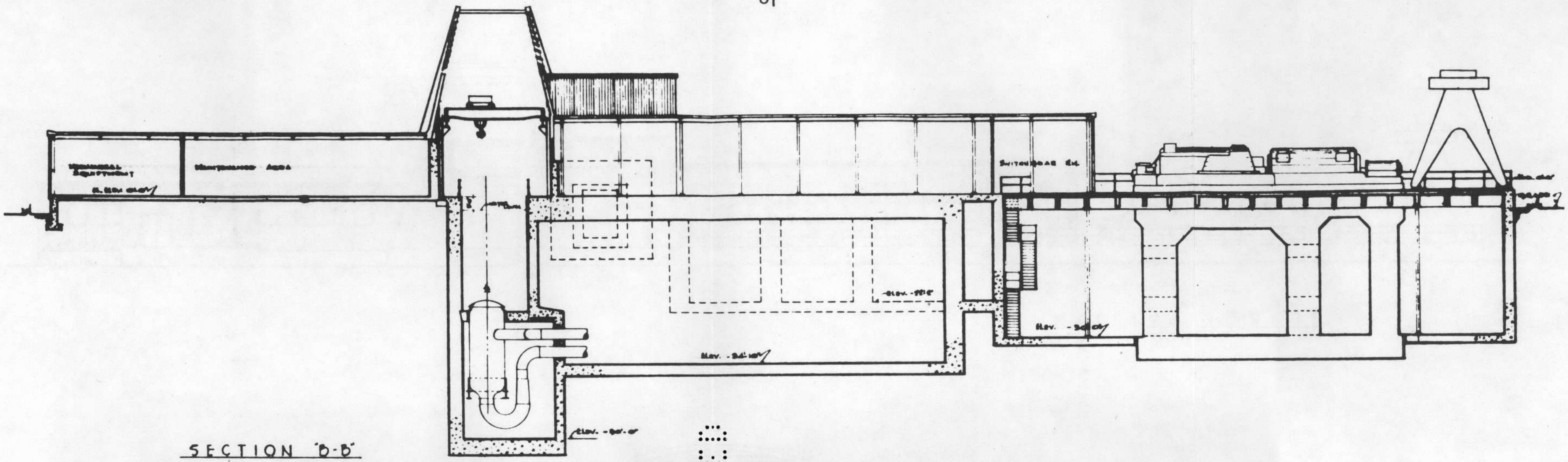
A small office will be provided to serve as a control laboratory.

Administration Area

The administration area, adjacent to the reactor area, will provide space for administrative offices, reception area, health physics office, etc.

Yard Facilities

Yard facilities will include fencing, a short railroad spur serving the reactor and heat exchanger area, black top service roads to the various isolated areas, parking space, etc.



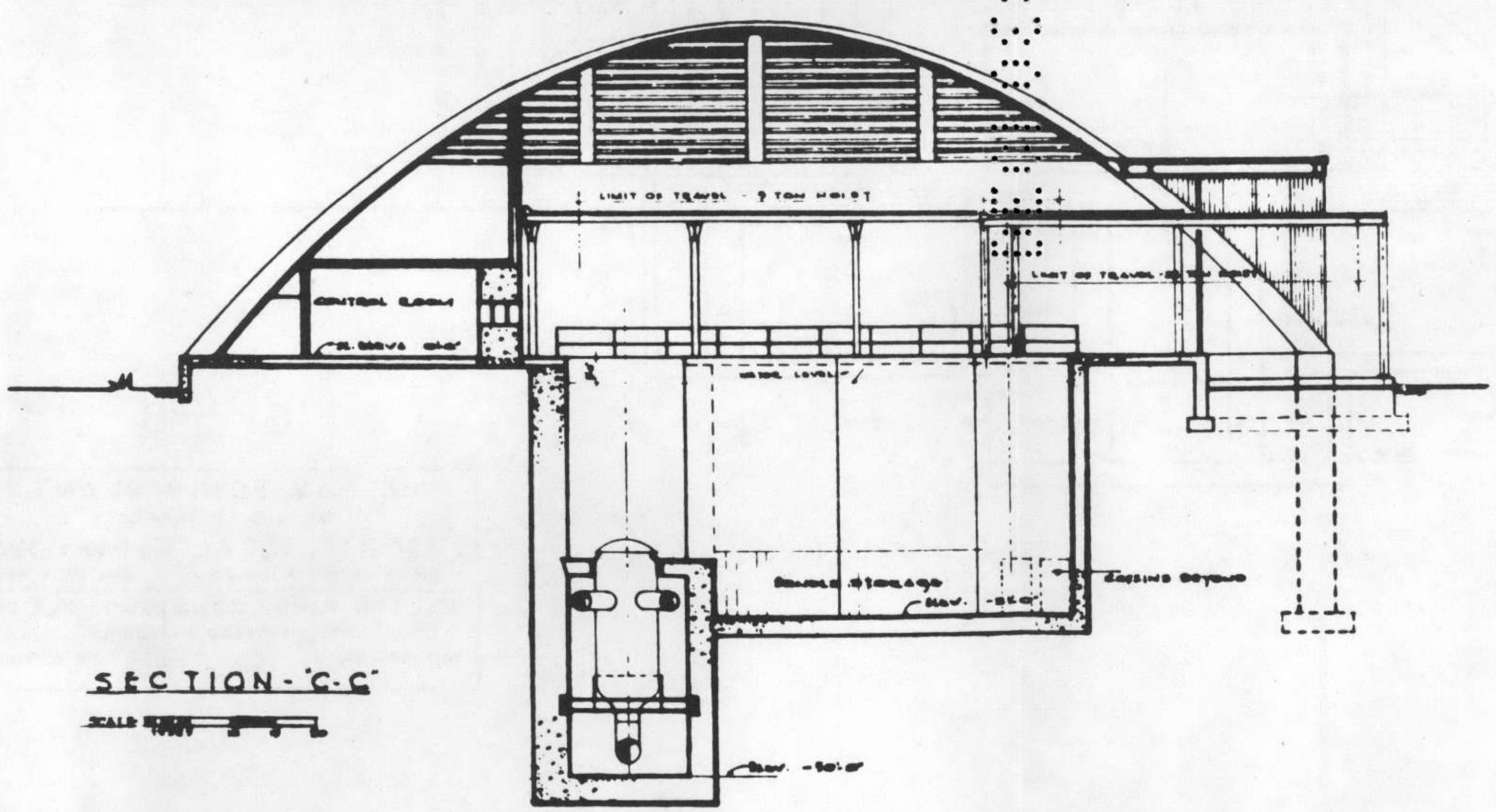
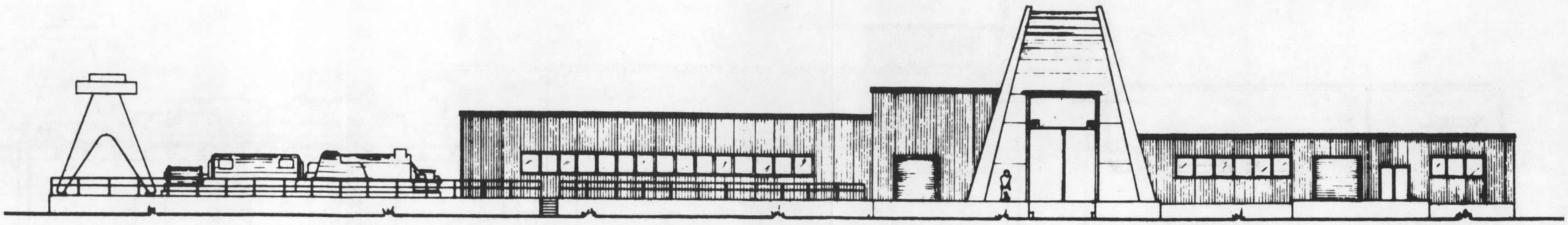


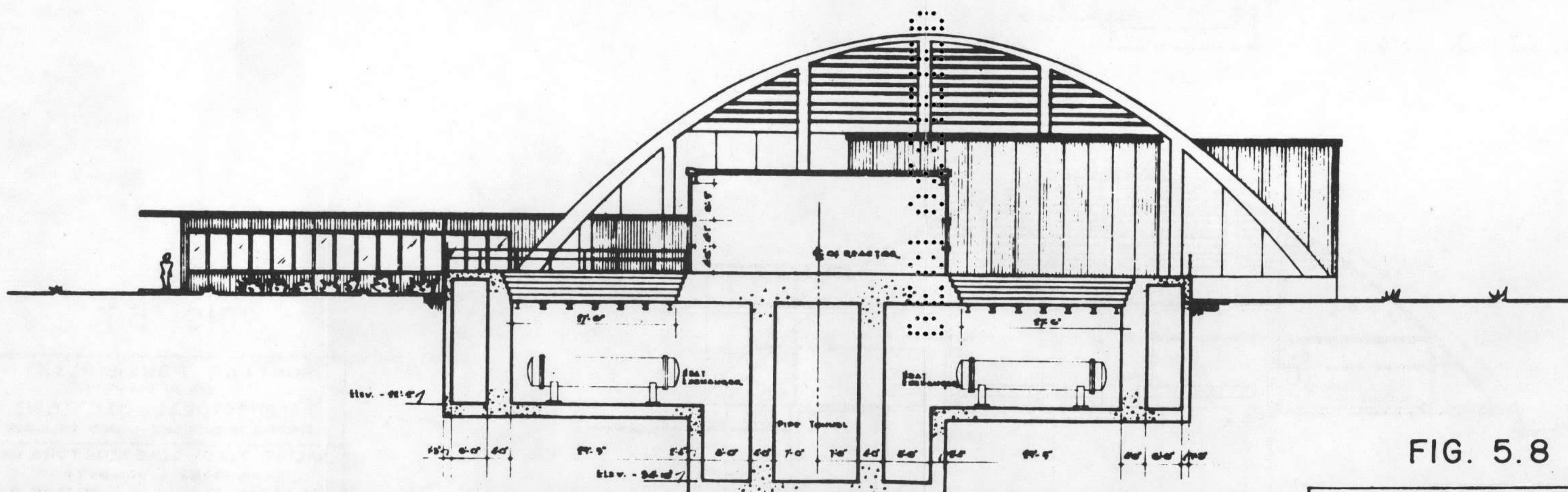
FIG. 5.7

NUCLEAR POWER PLANT
37,500 KW CAPACITY
ARCHITECTURAL SECTIONS
DRAWING Nº 9-100-Db DATE: DEC. 11, [illegible]

WALTER KIDDE CONSTRUCTORS, INC.
ENGINEERS & BUILDERS
140 CEDAR ST. NEW YORK, N.Y.



REAR ELEVATION

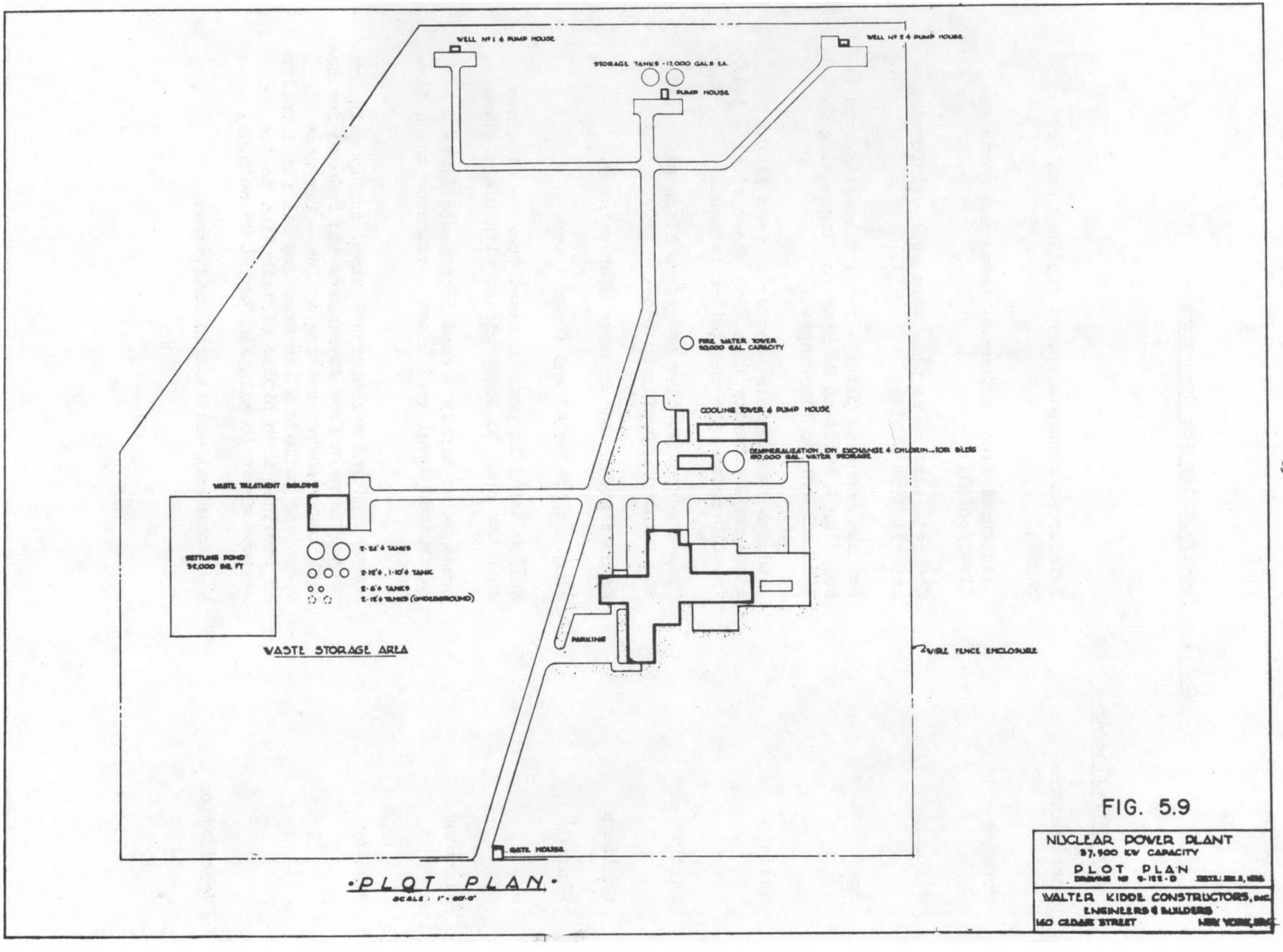


ELEVATION 'A-A'

FIG. 5.8

NUCLEAR POWER PLANT
37,500 KW CAPACITY
ARCHITECTURAL ELEVATIONS
DRAWING NO 9-120-Da [illegible]

WALTER KIDDE CONSTRUCTORS, INC.
ENGINEERS & BUILDERS
140 CEDAR ST. NEW YORK, N.Y.



WELL Nº 1 & PUMP HOUSE
WELL Nº 2 & PUMP HOUSE
STORAGE TANKS - 17,000 GALS EA.
PUMP HOUSE
FIRE WATER TOWER
50,000 GAL. CAPACITY
COOLING TOWER & PUMP HOUSE
DEMINERALIZATION, ION EXCHANGE & CHLORIN...TOR BLDG
150,000 GAL. WATER STORAGE
WASTE TREATMENT BUILDING
SETTLING POND
32,000 SQ. FT
2 - 24' ⌀ TANKS
2 - 12' ⌀, 1 - 10' ⌀ TANK
2 - 6' ⌀ TANKS
2 - 12' ⌀ TANKS (UNDERGROUND)
WASTE STORAGE AREA
PARKING
WIRE FENCE ENCLOSURE
GATE HOUSE
·PLOT PLAN·
NUCLEAR POWER PLANT
37,500 KW CAPACITY
PLOT PLAN
DRAWING Nº 9-122-D
WALTER KIDDE CONSTRUCTORS, INC.
ENGINEERS & BUILDERS
140 CEDAR STREET
NEW YORK, N.Y.

FIG. 5.9

Table 5.3

Outline Specification for Structures

Administration Area

Substructure	Reinforced concrete spread footings and grade beams.
Framing	Structural steel columns - beams and girts un-fireproofed.
Floor	Concrete slab on earth - wire mesh reinforcing - asphalt tile finish.
Roof	Precast concrete plant - 1 in. fibreglas type insulation - built-up 20 year roofing - slag finish - 16 ounce copper flashings.
Walls	Sandwich type panels - exterior face fluted aluminum - interior face flat sheet steel - 1-1/2 in. fibreglas type insulation between.
Partitions	Cinder concrete, clay or gypsum block plastered and painted - preformed base.
Ceilings	Exposed steel and concrete slab painted.
Windows	Aluminum projected and fixed types.
Doors	Hollow metal in pressed steel bucks - aluminum entrance door to lobby glazed with plate glass.
Plumbing	Brass water supply - cast iron waste lines - galvenized steel vent lines - vitreous china fixtures.
Heating	Convectors and enclosures - steam supply main connected to main from exchangers and reduced for use with low pressure heating system - for non-operating periods a low pressure oil fired boiler is provided with piping distribution to the various areas to maintain 70° at 0° outside.
Ventilation	No mechanical ventilation considered.

Table 5.3 -- Administration Area (Cont.)

Air Conditioning	No air conditioning considered.
Lighting	Fluorescent fixtures - 35 footcandle intensity.
Sprinklers	Dry type normal hazard system.
Painting	Priming and two (2) coats throughout interior.
<u>Maintenance Area</u>	
Substructure	Reinforced concrete spread footings and grade beams.
Framing	Structural steel columns - beams and girts un-fireproofed.
Floor	Concrete slab on earth - wire mesh reinforcing monolithic finish with hardener.
Roof	Precast concrete plant - 1 in. fibreglas type insulation - built-up 20 year roofing - slag finish - 16 ounce copper flashings.
Walls	Sandwich type panels - exterior face fluted aluminum - interior face flat sheet steel - 1-1/2 in. fibreglas type insulation between.
Partitions	Cinder concrete or clay block painted.
Ceilings	Exposed steel and concrete slab painted.
Windows	Aluminum projected and fixed types.
Doors	Hollow metal in pressed steel bucks - overhead doors to platform.
Plumbing	Brass water supply - galvanized steel roof drainage lines.
Heating	Steam unit heaters - system as described under "Administration Area".
Ventilation	No mechanical ventilation considered.

Table 5.3 — Maintenance Area (Cont.)

Air Conditioning	No air conditioning considered.
Lighting	Fluorescent fixtures - 25 footcandle intensity.
Sprinklers	Dry type normal hazard system.
Painting	Priming and two (2) coats throughout interior.
<u>Reactor - Heat Exchange & Turbo Generator Areas</u>	
Substructures	Reinforced concrete spread footings, piers, grade beams and walls outside canal, lock and pit areas. Reinforced concrete walls and foundation floors for canal, locks and pits — all concrete waterproofed.
Framing	Structural steel columns, beams, girts and arches unfireproofed.
Floors	Reactor Area: Concrete slab on earth - wire mesh reinforcing monolithic finish with hardener. Heat Exchange Area: Heavy reinforced concrete shielding slab over supply and return line gallery and transfer pits - monolithic finish with hardener - removable concrete slabs over exchanger pits - removable steel beam supports - metal tee bar expansion joints. Concrete slab over steam main gallery - membrane waterproofing - asphalt block wearing surface. Turbo Generator Area: Reinforced concrete foundation floor increased in thickness at column locations - monolithic finish with hardener. Deck at generator level of reinforced concrete slab, beam and column construction - membrane waterproofing - asphalt block wearing surface.

Table 5.3 - Reactor - Heat Exchange & Turbo Generator Areas (Cont.)

Roofs	Flat roofs of precast concrete plank - 1 in. fibreglas type insulation - built-up 20 year roofing - slag finish - 16 ounce copper flashings.
	Curved roof over Reactor Area of sandwich type panels - exterior surface corrugated aluminum - interior flat sheet steel - 1-1/2 in. fibreglas type insulation between.
Walls	Sandwich type panels - exterior face aluminum corrugated for Reactor Area and fluted for Heat Exchange Area - interior face flat sheet steel - 1-1/2 in. fibreglas type insulation between.
Partitions	Control and control equipment spaces in Reactor Area cinder concrete, clay or gypsum block plastered and painted - preformed base.
	Other partitions in Reactor Area and Heat Exchange Area cinder or clay block painted. Concrete shielding walls of 2 and 5 foot thickness between reactor and control, maintenance and heat exchange spaces.
Ceilings	Exposed steel and concrete slab painted.
Windows	Aluminum projected and fixed types.
Doors	Hollow metal in pressed steel bucks - overhead type auxiliary equipment space to platform - Bi-parting motorized from Reactor space to truck dock - sliding steel shielding motorized, from Reactor to Maintenance Area.
Gates	Special design mechanically operated, at ends of lock and from lock to emergency chamber.
Plumbing	Brass water supply - cast iron waste lines - galvanized steel vent and drainage lines - vitreous china fixtures.
Heating	Steam unit heaters - system as described under Administration Area.

Table 5.3 — Reactor - Heat Exchange & Turbo Generator Areas (Cont.)

Ventilation	No mechanical ventilation considered.
Air Conditioning	No air conditioning considered.
Lighting	Reactor Area: Fluorescent fixtures - 50 footcandle intensity. Heat Exchange Area: Fluorescent fixtures - 25 footcandle intensity. Turbo Generator Area: Fluorescent fixtures - 25 footcandle intensity. Flootlight standards at generator level.
Sprinklers	Dry type normal hazard system.
Painting	Priming and two (2) coats - interiors of all superstructures - basement of Turbo Generator Area - steel stairs, hatches and pipe railings - miscellaneous items of steel or wood.

Cost Estimate

Since the site for the erection of the proposed nuclear power plant has not been selected, certain assumptions were made to facilitate analysis of the cost figures presented herein. These are:

Labor rates would be equivalent to those published in current issues of the Engineering News-Record Formula for Construction Costs in large urban areas in northeastern U.S.A. (say, New York City).

The site would be approximately 100-200 miles from a fairly large construction labor market.

The cost of a temporary construction camp with commissary and sleeping facilities for construction labor is not included in this estimate.

Estimated major equipment costs include shipping charges from an F.O.B. point within a radius of 1000 miles from the plant site.

Mass materials such as lumber, gravel, sand, cement, etc. would be available for purchase within a radius of 100 miles.

The scheduled work week would be 40 hours and some small allowance is provided for premium time in the case of continuous concrete placement, finishing, start-up of equipment, etc.

Heavy equipment such as cranes, bulldozers, compressors, etc. would be available for rental within a 500 mile radius.

Costs for temporary offices and supply sheds are included in this estimate under construction overhead.

Costs for some of the main items of equipment, such as the primary pumps and piping system, reactor vessel (less internals), heat exchangers, cranes, turbogenerator and auxiliaries, and the cooling towers are based upon actual bids procured from nationally known manufacturers.

Steel and alloy tankage and vessels were estimated upon a cost per pound basis.

Costs of pumps and their auxiliaries are based upon actual figures published in various technical bulletins and magazines.

Some system costs are based upon scaled down estimates of similar facilities prepared by this group in some detail.

Table 5.4

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
310.0	LAND & LAND RIGHTS						
311.0	STRUCTURES & IMPROVEMENTS						
	ADMINISTRATION AREA						
311.1a	Substructures				4,895		
311.2a	Superstructures				23,360		
311.3a	Heating				2,750		
311.4a	Lighting				3,805		
311.5a	Plumbing & Water Supply				9,060		
311.6a	Sprinkler System				1,695		
311.7a	Interior Partitions				14,085		
	SUBTOTAL					59,650	
	MAINTENANCE AREA						
311.1b	Substructures				4,538		
311.2b	Superstructures				18,[illegible]96		
311.3b	Heating				2,550		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
311.4b	Lighting				2,550		
311.5b	Plumbing & Water Supply				1,000		
311.6b	Sprinkler System				1,595		
311.7b	Interior Partitions				1,415		
	SUBTOTAL					32,844	
	REACTOR AREA						
311.1c	Substructures				14,478		
311.2c	Superstructures				87,600		
311.3c	Heating				11,150		
311.4c	Lighting				8,280		
311.5c	Plumbing & Water Supply				1,185		
311.6c	Sprinkler System				3,850		
311.7c	Interior Partitions				5,855		
	SUBTOTAL					132,398	
	HEAT EXCHANGE AREA						
311.1d	Substructures				6,626		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
311.2d	Superstructures				24,955		
311.3d	Heating				3,190		
311.4d	Lighting				2,975		
311.5d	Plumbing & Water Supply				2,995		
311.6d	Sprinkler System				1,840		
311.7d	Interior Partitions				1,875		
	SUBTOTAL					[illegible]	
	TURBO GENERATOR AREA						
311.1e	Substructures				154,463		
311.2e	Superstructures				———		
311.3e	Heating				12,910		
311.4e	Lighting				7,545		
311.5e	Plumbing & Water Supply				945		
311.6e	Sprinkler System				3,445		
311.7e	Interior Partitions				———		
	SUBTOTAL					179,308	

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
	EQUIPMENT FOUNDATIONS						
311.8	Exchanger Pits				235,636		
311.9	Canal & Locks				139,950		
311.10	Turbo Generator Equipment Foundations				49,710		
	SUBTOTAL					425,296	
311.11	Design Cost				84,000		
311.12	Contractors Overhead & Fee				96,000		
	SUBTOTAL					180,000	1,054,652
312.0	**BOILER PLANT EQUIPMENT**						
312.1	Reactor Shell	1	75,000	5,000	80,000		
312.2	Insulation & Water Membrane	1	18,000	5,000	23,000		
312.3	Zr Fuel Bundles	135	209,500	10,000	219,500		
312.4	Zr Reflector Bundles	9	73,000	2,000	75,000		
312.5	Control Rod Assembly	19	20,000	30,000	50,000		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
312.6	Internal Grid & Accessories	1 Syst.	15,000	5,000	20,000		
312.7	Remote Loading & Unloading Equipment	1 Lot	25,000	6,000	31,000		
312.8	Primary Pumps & Drives	6	279,600	8,000	287,600		
312.9	Primary Piping, Supports, Insulation	1 Syst.	330,000	46,000	376,000		
312.10	Primary Heat Exchangers, Insulation & Supports	6	377,000	24,000	401,000		
312.11	Boiler Feed System (Pumps, Heaters, Condensers, etc.)	1 Syst.	87,000	27,000	114,000		
312.12	Scram Poison System	1 Syst.	24,000	7,500	31,500		
312.13	Shim Poison System	1 Syst.	38,100	12,000	50,100		
312.14	Cation Removal System	1 Syst.	57,500	16,350	73,850		
312.15	Overflow Tank & Auxiliaries	1 Syst.	43,000	13,000	56,000		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
312.16	Feed Water System (Primary	1 Syst.	142,140	31,500	173,640		
312.17	Instrumentation	1 Syst.	246,300	81,000	327,300		
312.18	Cranes & Hoists	2	25,000	12,500	37,500		
312.19	Materials Handling Equipment	1 Syst.	5,000	—	5,000		
312.20	Fuel Rod Coffins	6	75,000	5,000	80,000		
312.21	Power Wiring	1 Syst.	20,000	30,000	50,000		
312.22	Ventilating Equipment	1 Syst.	10,000	8,000	18,000		
312.23	Equipment Painting	1 Syst.	3,000	7,000	10,000		
312.24	Viewing Equipment	1 Syst.	15,000	3,000	18,000		
	SUBTOTAL		2,213,140	394,850		2,607,990	
312.25	Design Cost (15%)				408,000		
312.26	Contractors Overhead & Fees (13%)				350,000		
	SUBTOTAL					758,000	3,365,990

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
314.0	TURBO GENERATOR UNITS						
314.1	Turbo Generators & Auxiliary Supports	1	1,495,000	125,000	1,620,000		
314.2	Condenser & Auxiliaries, Supports & Insulation	1 Syst.	200,000	90,000	290,000		
314.3	Main Steam & Auxiliary Piping Systems, Valves, Supports & Insulation	1 Syst.	212,000	148,000	360,000		
314.4	Cranes & Hoists	1	37,500	12,500	50,900		
314.5	Lubricating System	1 Syst.	6,000	4,000	10,000		
314.6	Instrumentation	1 Syst.	15,000	25,000	40,000		
314.7	Plant Electrical Cost	1 Syst.	101,000	221,000	322,000		
314.8	Equipment Painting	1 Syst.	2,500	15,000	17,500		
	SUBTOTAL		2,069,000	640,500		2,709,500	
314.9	Design Cost (5%)				131,600		
314.10	Constractors Overhead & Fee (13%)				356,000		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
	SUBTOTAL					487,600	3,197,100
315.0	ACCESSORY ELECTRICAL EQUIPMENT						
315.1	Auxiliary Generator & Foundations	1 Unit	715,000	141,000	856,000		
315.2	Switch Gear & Transformers, Power Wiring & Busses	1 Syst.	116,000	50,000	166,000		
	SUBTOTAL					1,022,000	
315.3	Design Cost (3%)				31,400		
315.4	Contractors Overhead & Fee (13%)				136,000		
	SUBTOTAL					167,400	1,189,400
316.0	MISCELLANEOUS POWER PLANT EQUIPMENT						
316.1	Compressor & Piping	1 Syst.	12,000	6,000	18,000		
316.2	Station Maintenance Equipment	1 Syst.	5,000	2,000	7,000		
	SUBTOTAL					25,000	

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
316.3	Design Cost (10%)				2,500		
316.4	Contractors Overhead & Fees				3,250		
	SUBTOTAL					5,750	30,750
372.0	OFFICE FURNITURE & EQUIPMENT		23,000	2,000	25,000		
373.0	TRANSPORTATION EQUIPMENT		24,000	1,000	25,000		
374.0	MAINTENANCE EQUIPMENT & SUPPLIES		18,000	7,000	25,000		
376.0	LABORATORY EQUIPMENT		6,000	4,000	10,000		
378.0	PLANT COMMUNICATIONS		3,000	2,000	5,000		
379.0	HEALTH PHYSICS EQUIPMENT		10,000	2,000	12,000		
	SUBTOTAL					102,000	102,000
390.0	OUTSIDE FACILITIES						
390.1	Wells & Pumping Equipment	1 Syst.	14,000	10,000	24,000		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
390.2	Raw Water Storage System	1 Syst.	40,000	38,000	78,000		
390.3	Cooling Tower, Foundations, Pumps & Piping	1 Syst.	332,717	190,000	522,717		
390.4	Effluent Pond	1 Unit	10,000	15,000	25,000		
390.5	Fire Protection System	1 Syst.	10,000	20,000	30,000		
390.6	Sanitary Water System	1 Syst.	30,000	11,000	41,000		
390.7	Waste Treatment System	1 Syst.	223,500	100,000	323,500		
390.8	Sewerage & Drainage System	1 Syst.	8,000	12,000	20,000		
390.9	Roads & Railroads	1 Syst.	14,250	39,000	53,250		
390.10	Yard & Fence Lighting	1 Syst.	9,000	10,000	19,000		
390.11	Landscaping	1 Syst.	2,470	5,500	7,970		

Table 5.4 (Cont.)

Construction Cost Estimate
37,500 KW Nuclear Power Plant

Code	Description	Units	Equipment Cost	Installation Cost	Total	Subtotal	Grand Total
390.12	Parking Area	1 Syst.	1,280	1,500	2,780		
390.13	Fencing	1 Syst.	22,300	---	22,300		
390.14	Auxiliary Buildings (pump houses, security office, etc.)		57,000	38,700	95,700		
390.15	Outside Steam Distribution	1 Syst.	16,000	9,000	25,000		
390.16	Off Gas Stack & Fan Equipment	1 Syst.	18,000	9,000	27,000		
390.17	Instrumentation	1 Syst.	4,000	8,000	12,000		
390.18	Power Wiring	1 Syst.	30,000	55,000	85,000		
	SUBTOTAL					1,414,217	
390.19	Design Cost (10%)				134,000		
390.20	Contractors Overhead & Fee (13%)				175,000		
	SUBTOTAL					309,000	1,723,217
	GRAND TOTAL						10,663,109

Chapter VI

COST OF POWER

The selling price for power at the generator bus bar is estimated at about 10 mills per KWH, based on a load factor of 80 per cent and a maximum capability of 37,500 KW. The breakdown is as follows:

Table 6.1

Cost of Nuclear Power - Mills/KWH

80 Per Cent Service Factor

Case	First 7.5 Years	After 7.5 Years
Capital Charges at 14%	5.70	5.70
Fuel Rental at 4%	0.80 (2.2 Charges)	0.60 (1.65 Charges)
Operating Costs	1.60	1.30
Fuel Reprocessing and Transportation		
(1000 MWD/ton Fuel Life)	2.00	
(2000 MWD/ton Fuel Life)		1.00
Fuel Make-Up Cost	----	1.00
TOTAL, NUCLEAR PLANT	10.10	9.60

This price is for a fully equipped power plant in a region not already industrialized.

Capital Charges

Capital charges are based on an installed plant cost of $10,663,109 as developed in the preceding chapter. The rate is taken as 14 per cent, which is typical of capital charges for modern coal steam plants. The breakdown varies from place to place but is roughly as follows.

Average Return on Money	5.5%
Taxes and Insurance	5.6
Depreciation	2.9
	14.0%

Fuel Rental

The value of the initial fuel inventory is estimated at $5,230,000 based on a cost of $15 per lb. of U_3O_8 and separative work cost of $50 per Kg U. The cost for finished uranium slugs containing 1.46 per cent U-235 is $72.70/lb.

The fuel inventory will gradually change its character, approaching a composition which will permit better utilization of U-235. Initially, the reactor will burn U-235 almost exclusively. After the initial reactivity period, it will burn about equal parts of U-235 and U-238 and will eventually approach a condition in which six parts of U-238 will be consumed for each part of U-235. Thus, the inventory will appreciate somewhat in value over the long term.

In view of the uncertain value of the inventory, the possibility of other uses (such as fuel for fast reactors), and its long-term tendency to improve in quality, we treat it as a non-depreciating property of the AEC which we propose to rent. At a total rental charge of 4 per cent, the inventory charge amounts to 0.80 mills/KWH for 2.2 reactor charges. If a number of power reactors of this type are in operation, the inventory per reactor can probably be reduced to something like 1.65 charges, so that the rental charge would be reduced to 0.60 mills/KWH.

Plant Operating Expense

The operating cost of a 37,500 KW nuclear power plant operating with an 80 per cent on-stream efficiency has been estimated at 1.598 mills/KWH. The various contributions to this cost are shown in Table 6.2.

Table 6.2

Operating Costs of Nuclear Power Plant

Production Capacity 37,500 KW
On-Stream Efficiency 80 Per Cent

Item	Annual Cost, $	Contribution to Power Cost
Direct Payroll	319,841	1.220 mils/KWH
Fringe Benefits	35,800	0.136 "
Maintenance Supplies	59,135	0.225 "
Operating Chemicals	4,400	0.017 "
	419,176	1.598 mils/KWH

Personnel Requirements

Figure 6.1 shows a proposed organization chart with personnel requirements for the nuclear power complex. A total of 88 people are required, of whom 41 normally work the day shift only while 47 work a rotating shift. It is expected that this plant will be a "grass roots" plant, and therefore no dependence on a government agency or a parent company for services such as accounting, security, personnel, etc., has been assumed.

The total manpower required at the plant site is shown in Table 6.3, with comparable figures for a 30,000 KW separately operated coal-steam power plant.* The personnel requirements for the nuclear plant are similar to those for a normal coal plant except for additional technical people required in the early operating stages, and special security and uranium accounting. The cost of the security department alone amounts to 0.302 mills/KWH.

Table 6.3

Personnel Required

	Nuclear Plant	Coal Plant
General Administrative		
Operating Supervision	5	6
Security	2	-
Accounting	1	1
Clerical	6	4
Technical	4	-
	18	11
Operating Labor		
Operators (Including Foremen)	30	29
Maintenance	11	13
Utilities	6	8
Security	23	-
	70	50

* Information for Radford Arsenal power plant taken from report by Appalachian Electric Power Company.

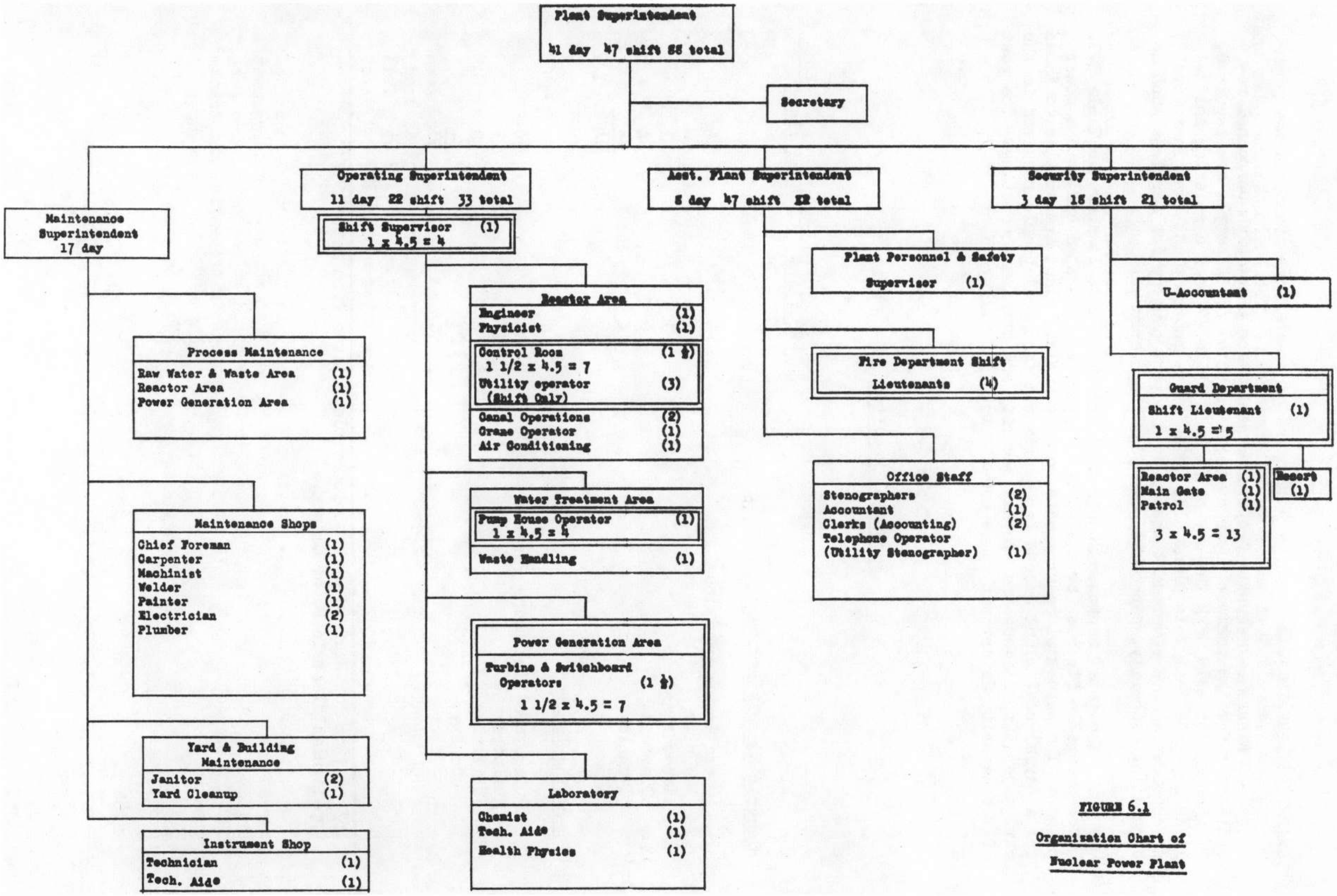


FIGURE 6.1

Organization Chart of Nuclear Power Plant

Maintenance supplies are based on general experience in the power field and are related to the maintenance labor. Total maintenance labor and materials amount to 1.58 per cent per year on the capital investment.

Operating Chemicals

During each reactor cycle, various chemicals are consumed and are therefore considered as operating chemicals. The principal chemicals required are boric acid for shim control, sulfuric acid for cooling tower scale control and for regenerating the cation exchange resin, and make-up resins for the several ion-exchange beds. Lesser quantities of other chemicals are also required. There is listed in Table 6.4 an estimate of the chemicals required per reactor cycle, together with the current cost of these chemicals.

Table 6.4

Operating Chemicals

Item	Purpose	Quantity	Cost, $
Boric Acid	Shim Control	3.25 Tons	487
Potassium Tetraborate	Scram Shutdown	485 lbs.*	63
Hydrogen	Hydrogen Blanket	3 Cylinders	15
Sodium Hydroxide	Neutralizations	125 lbs.	6
Sulfuric Acid	Scale Control & Regeneration	41,500 Gal. 66° Be	415
Resins	Make-Up Requirements	17 cu. ft.	192
Chlorine	Alge Control	550 lbs.	54
		Total/Cycle	1,232

*Based on one scram.

Fuel Reprocessing and Transportation

The cost of fuel reprocessing is computed at $5/lb. of metal processed. The fuel will be shipped to and from the processing plant in lead coffins each weighing about 35 tons. Each coffin holds about 1/3 of a full reactor charge. The processing plant is assumed to be within 1000 miles of the power plant and the assumed shipping charge of 10 cents per ton mile covers a considerable amount of special handling of the fuel coffins.

During the initial operating period of the plant, the processing rate is taken as one metric ton per 1000 MWD of heat output. In subsequent periods, it is assumed that this rate can be reduced to one metric ton per 2000 MWD of heat output, with proportional savings in processing and transportation.

<u>Fuel Make-Up Cost</u>

During the initial reactivity period, no extra fuel need be added, so that the make-up fuel cost will be zero. After this, fuel must be added at a rate of about 2.12 lbs. per day and concentration of 4.5 per cent U-235. The cost is based on the same assumptions as before, namely, $15/lb. for U_3O_8 and $50/Kg U for separative work, leading to a charge of 1.00 mill/KWH.

This cost will gradually decrease to a limiting value of about 0.4 mill/KWH when the inventory has been through an irradiation of the order of 200,000 MWD/ton.