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A DESIGN STUDY OF A LOW POWER
AQUEOUS HOMOGENEOUS BOILING REACTOR
POWER PLANT

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ABSTRACT

This design study describes a reactor and associated power plant that has been designed to produce 100 kw of net electric power and 400 kw of hot water space heating at a total thermal output of 1300 kw. The fuel consists of a solution of UO_2SO_4 in light water. Power is removed from the core by boiling the fuel solution and transferring the heat to the secondary steam system by condensing primary water on the external surface of a bayonet type boiler and boiling secondary water within the tubes. Saturated steam, produced in the boiler at 225 psia (Full Power) is used to drive a turbo generator. Extraction steam from the turbine is used, at a reduced pressure, for space heating.

The initial loading of the reactor is approximately 4.8 kg of U^{235} and operation based on an average load factor of 80 percent will require fuel addition at the rate of about 580 grams per year. It may be desirable to replace the fuel in the core after a period of 5 years operation due to the accumulation of corrosion products. The reactor control is affected automatically by power demand.

The major objective has been to design a reactor that is reliable and simple, requiring little if any operating personnel and routine maintenance only which can be performed by one man. The design should stress simplicity of the system, ease of erection at the site, initial transportability, reliability and ease of operation; these characteristics are then expected to result in greatly reduced effort and manpower support over a conventional system.

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INTRODUCTION

A boiling aqueous homogeneous reactor offers several attractive features for a small power station in remote localities. Most of the fundamental development work necessary to design such a reactor has been completed by the Homogeneous Reactor Project at Oak Ridge National Laboratory.

Since there are no structural materials in the core region and all of the fissionable material in the reactor system is in the core during normal operation, a low uranium inventory is possible. The removal of Xe-135 by the sparging action of the steam being generated in the boiling solution and the inherent stability of aqueous homogeneous reactors make it unnecessary to incorporate control rods in the design. No provision for xenon override is needed. The large negative temperature coefficient of the reactor makes it controllable by power demand and automatic operation is possible without servo-mechanism or other devices. A long fuel cycle is possible since fuel may be added to the reactor at any time to override fission product and higher isotope poisons. The expected lifetime of a batch of fuel is 3 to 5 years at 1.5 mw reactor power.

Since there are several possible solutions to the major problems of corrosion and recombination of radiolytic hydrogen and oxygen, several alternate reactor systems, incorporating these various solutions, are possible. The reactor system which appears most feasible in the light of present day technology without further developmental work, was chosen for a detailed design study. This system incorporates a low pressure recombination system and a loose fitting titanium liner in the reactor vessel.

Alternate systems, which have some very attractive features but whose feasibility is contingent upon the outcome of developmental work, are presented in the appendix. The advantages and disadvantages of each alternate are discussed in the appendices and summary.

The major consideration in the layout of the reactor equipment was reliability and ease of maintenance. Although this consideration is reflected as an increase in the gross weight and cost of the reactor shield, the expenditure is necessary for prolonged plant operation.

A. GENERAL DESCRIPTION OF REACTOR SYSTEM

A reactor power of 1500 kw is needed to supply a net electrical output of 125 kw and 400 kw of building heat. A small boiling homogeneous reactor utilizing a solution of 93 percent enriched uranium-235, as uranyl sulfate in ordinary water, has been designed to supply this power requirement.

The boiling reactor solution is contained in a 27 inch diameter titanium liner in a 30 inch I.D. cylindrical pressure vessel of type 347 stainless steel. The steam generated in the reactor solution is passed through a Zircaloy-2 entrainment separator and condensed on a bayonet tube type heat exchanger in the top section of the reactor vessel. Steam generated in the bayonet tubes is passed through a turbine to generate electricity. Low pressure steam is extracted from the turbine to furnish building heat.

Radiolytic hydrogen and oxygen formed in the reactor, along with diluent steam, is let down through a valve to a low pressure system. In the low pressure system the gases are recombined on a platinized alumina catalyst bed. The diluent steam is then condensed and returned to the reactor vessel from the condenser by a pulsafeeder feed pump. To protect the stainless steel vessel from corrosion, 100 ppm of oxygen is dissolved in the condensate by adding 0.01 scfm of O₂ gas to the pulsafeeder pump suction. The condensate is then pumped into the bottom of the reactor vessel between the titanium liner and the vessel wall. Condensate flows up between the vessel and liner and spills over the top of the liner into the core solution. This method should prevent uranyl sulfate from contacting the stainless steel wall.

A separate pulsafeeder pump is provided to transfer the uranyl sulfate fuel solution into the inner titanium vessel liners. Electric heaters on the fill line and pressure vessel are used to heat the fuel solution to 200 C before the reactor becomes critical, thereby preventing uranium peroxide from precipitating during start-up.

In order to economize reactor heat, most of the heat of recombination of the recombiner and the heat of vaporization of the diluent steam is transferred to the boiler feedwater in a heat exchanger following the recombiner. After passing through the recombiner and boiler feedwater heater the remaining steam and the 0.01 scfm of excess oxygen let down from the reactor passes through an aftercondenser where the steam is condensed. The remaining oxygen is passed through a refrigerated cold trap and an activated charcoal filter. The gaseous fission products carried with the oxygen are adsorbed on the charcoal and the oxygen vented up a stack.

A dump tank designed to contain the primary fuel inventory in an ever-safe geometry is provided. An electrically heated evaporator on the bottom of the dump tank is used to provide condensate at the recombiner condensers during start-up. The evaporator is used to keep the solution in the dump tank at 100 C to prevent peroxide precipitation after shutdown. The dump line is provided with a cooler, throttle valve, and a block valve. During a normal shutdown the flow is throttled to allow cooling of the fuel solution to 90 C and minimize dump valve corrosion.

The reactor and primary components are contained in a shielded steel tank which is covered with shielding plugs. The shielding for the tank con-

sists of a system of iron and water. The region immediately around the reactor vessel is filled with lead shot and water to provide both shielding and a region of high thermal flux where nuclear instruments can be located.

A vacuum of 2 to 3 inches of water is maintained inside the reactor compartments to prevent activated air from leaking out of the shield into the main building. The blower used for this purpose discharges 1000 scfm of air up a stack, diluting the oxygen and any fission gases that escape adsorption on the charcoal filter to a safe level of activity.

A flowsheet of the reactor system is shown in Fig. 1. Plant arrangement and reactor equipment arrangement are shown in Fig. 2 and Fig. 3.

All reactor system components exposed to primary reactor fluids are constructed of type 304 stainless steel with the exception of the titanium liners and Zircaloy-2 entrainment separator in the reactor vessel, Stellite ball check valves in the pulsafeeder feed pump, and Stellite trim on the valves.

Control of the reactor is mainly by power demand. The operating temperature can also be controlled by adjusting the water and uranium inventories.

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FIGURE 2

A

AA

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B. DESIGN DATA

TABLE I

1. Plant Performance

Maximum Generator Output	200 kw
Design Net Electrical Output (Est.)	100 kw
Maximum Net Electrical Output (Est.)	125 kw
Maximum Available Space Heat	400 kw
Salt Water Evaporator Heat Load	73.5 kw
Gross Cycle Efficiency	13.3%
Net Cycle Efficiency (Est.)	8.33%
Net Thermal Efficiency (Est.)	35.0%

2. Core Data

Fuel Solution	UO ₂ SO ₄ in H ₂ O
Diameter	27 inches
Critical Concentration	27 gm U-235/Liter
Critical Mass	4.788 kg U-235

	<u>1500 kw</u>	<u>Zero Power</u>
Temperature	250C	292C
Pressure	600 psia	1120 psia
Height of Solution	18.9 inches	18.7 inches
Volume	177.3 liters	175.5 liters
Average Void Fraction	9.75%	---
Hydrogen Gas Rate	.052 lb/min	---
Oxygen Gas Rate	.416 lb/min	---
Steam Rate	116.7 lb/min	---
Average Thermal Neutron Flux	7×10^{12} /cm ² -sec	

3. Reactor Steam Generator Data

Type	Vertical Bayonet Double Tube	
No. of Tubes	150	
Arrangement	1 - 3/4 inch triangular pitch	
Outer Tube Size	1 inch O.D.	
Inner Tube Size	1/2 inch O.D.	
Steam Flow Area	1.485 ft ²	
Heat Transfer Coefficient	300 - 400 Btu/hr - ft ² - °F	
Length	5.0 ft	
Material	Type 347 S.S.	
	<u>1500 kw</u>	<u>Zero Power</u>
Shell Side Pressure	600 psia	1120 psia
Shell Side Temperature	486F	558F
Tube Side Pressure	225 psia	1120 psia
Tube Side Temperature	392F	558F

4. Pressure Vessel Data

Overall Length	12 ft - 7 inches
Overall Diameter	4 ft - 5 1/2 inches
Fuel Container Shell Thickness	2 inches
Dome Thickness	2 - 9/32 inches
Design Pressure (A.S.M.E. Power Boiler Code)	1500 psia
Design Temperature	600F
Weight	24,500 lbs
Material	Type 347 S.S.
Loose Liner	3/16 inch titanium
Thermal Shield	1/2 inch titanium

C. SOLUTION CHEMISTRY

The chemistry of uranyl sulfate solutions under reactor conditions has been studied extensively at Oak Ridge National Laboratory. The Homogeneous Reactor Experiment utilizing this solution as fuel was operated satisfactorily at power densities up to 40 kw/l in the temperature range 200 to 260 C. Five chemical phenomena must be considered in designing a reactor system to handle this solution:

1. Uranium peroxide precipitation
2. Two-phase separation
3. Hydrolytic precipitation
4. Corrosion
5. Radiolytic decomposition of water

1. Uranium Peroxide Precipitation

Hydrogen peroxide is produced in the reactor fuel solution by radiation induced decomposition of water:

The hydrogen peroxide reacts quantitatively with the uranyl ion to produce uranium peroxide:

If the solubility of uranium peroxide (.0039M) is exceeded, solid UO_4 precipitates. This precipitation was observed in the Homogeneous Reactor Experiment when the reactor was operated at high power and low temperature.

The decomposition of peroxide in uranyl sulfate as a function of temperature and with several catalysts, has been studied and reported by M. D. Silverman, G. M. Watson and H. F. McDuffie⁽¹⁾. This report discusses the mechanisms by

which uranium peroxide is formed and decomposed and gives complete data and procedure for calculating the power density at which uranium peroxide will precipitate as a function of temperature. The presence of iron salts catalyzes the decomposition and allows a higher power density. If copper ions are also present a promoter reaction is set up which renders the iron catalyst at least four times as effective. The decomposition rate constant measured on a sample of fuel solution taken from the Homogeneous Reactor Experiment (1) is plotted in Fig. 4. The allowable power density as a function of temperature, Fig. 5, is calculated with the equation (1):

$$P.D. = k \left[\frac{(H_2O_2)_s}{.0052 G} \right]$$

where P.D. = Power density, kw/l

k = decomposition rate const, min⁻¹

(H₂O₂)_s = peroxide solubility, moles/liter

G = molecules H₂ produced/100 ev absorbed in solution.

To prevent peroxide precipitation in the reactor the fuel solution is heated to 200 C by electrical heaters on the fill line as it is pumped into the core from the dump tanks. The pressure vessel is also heated by strip heaters on the outside surface. This procedure insures that the fuel is above the temperature at which precipitation might occur before a critical level is attained in the reactor vessel.

2. Two-phase Separation

The phase diagram of the UO₂SO₄ - H₂O system (4) is shown in Fig. 6. In the range of concentrations from 20 to 40 gm U/kg H₂O, the possibility of separation

FIGURE: 4 20

REACTOR POWER DENSITY AT WHICH URANIUM PEROXIDE WILL PRECIPITATE IN $UO_2SO_4 \cdot H_2O$ SOLUTION. $[H_2O_2]$ SOLUBILITY = 0.039 M
 $G = 1.67$ MOLECULES H_2 / 100 EV

POWER DENSITY - (KW/L)

TWO PHASE SEPARATION DIAGRAM $\text{UO}_2\text{SO}_4 \cdot \text{H}_2\text{O}$

1 MOLE/1000g H_2O = 235.1 gm/Kg H_2O

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TEMPERATURE °C

FIGURE 6

of the uranyl sulfate solution into two phases sets an upper limit of approximately 300 C on the temperature at which the reactor can be operated. One of the high temperature phases is a heavy viscous liquid which is extremely corrosive. Consequently the reactor must be operated below the phase separation temperature.

3. Hydrolytic Precipitation

The hydrolytic precipitation of uranium as UO_2 from uranyl sulfate solutions is associated with the corrosive action of the solution against metal surfaces in the system. The uranyl ion is reduced to the $4+$ valence state by the metal and the uranium precipitate is UO_2 . The presence of sufficient dissolved oxygen in the solution will prevent the reduction of the uranyl ion and stabilize the solution. In type 347 stainless steel at temperatures above 200 C approximately 100 ppm of O_2 is required to prevent precipitation. Since a boiling solution can contain little dissolved oxygen, a stainless steel vessel cannot be used to contain it. As the corrosion rate of titanium in uranyl sulfate solution is very low up to 300 C a lower concentration of oxygen is needed to stabilize the solution than in a stainless system. In a boiling reactor, in which radiolytic hydrogen and oxygen are being generated, sufficient oxygen (6 ppm) remains in solution to prevent hydrolytic precipitation and allows the use of titanium as a containment vessel.

4. Corrosion

As discussed previously in the section on hydrolytic precipitation, uranyl sulfate solution cannot be contained in stainless steel at high temperatures unless dissolved oxygen is present in the solution to prevent reduction of the uranyl ion and stabilize the protective film on the steel. The following

exerpts from Homogeneous Reactor Project reports on corrosion experiments where oxygen was not present are included to verify this:

Reference 2 - "The weight loss of 347 SS in 250 C uranyl sulfate solution (40 g/l) without excess acid was 172.9 mdd or a rate of 29.7 mpy. With excess acid the weight loss was 543.5 mdd or a rate of 98.6 mpy. This test was only for 24 hour duration since the solution completely decomposed after that time."

Reference 3, Pg. 109. - "The ordinary use of stainless steel systems at elevated temperatures in uranyl sulfate solutions does not appear practical due to the reduction of the uranyl ions to oxides. Such reduction is accompanied by a heavy formation of uranium oxide film on the surface of the stainless steels. Exclusive of irradiation effects, this reduction of the solution may be attributed to corrosion reactions taking place on the metal surfaces at elevated temperature in the solution. An approach to solving this decomposition problem is to employ an oxidizing agent. The use of a partial pressure of oxygen will keep the solution oxidized."

Pg. 123. - "In a stainless steel autoclave, 40 g/l uranyl sulfate solution at 250 C was pressurized with 300 psi oxygen partial. After 336 hours, the solution showed no signs of decomposition and the corrosion rate of the 347 SS was 0.2 mpy after 270 hours."

Similar tests performed in titanium and zirconium bombs indicate that a partial pressure of oxygen is not necessary if titanium or zirconium are used. In the system presented in this design oxygenated condensate is pumped between the 347 SS pressure vessel and the titanium liner. Bayonet type heat exchanger

tubes of 347 SS are used in the vapor space above the solution. Since the liquid condensing on the tubes is in contact with a layer of radiolytic hydrogen and oxygen left around the tubes as the steam condenses, no reduction of entrained uranyl sulfate is expected. A Zircaloy-2 entrainment separator is provided to limit the uranyl sulfate concentration in the condensate on the tubes.

The use of 347 SS in the reactor low-pressure system is feasible since the solution temperature is only 100 C. The conditions in the low pressure system are almost identical to the conditions in the Homogeneous Reactor Experiment. No evidence of abnormal corrosion or hydrolytic precipitation in the low pressure system was found when the HRE was dismantled.

Stellite-6 and Stellite-12 are used as valve trim and for check valves in the pulsafeeder feed pump. Although the corrosion resistance of this material is satisfactory below 100 C in uranyl sulfate, the corrosion rate increases rapidly above 150 C. Care has been taken in the design to insure that Stellite is not exposed to uranyl sulfate solution above 90 C. The exceptions to this criterion are the dump valves during an emergency shutdown. The dump valve in the Homogeneous Reactor Experiment withstood several hot dumps before leakage was noted. Approximately 50 hot dumps occurred before a valve leak forced its replacement. The Stellite letdown valve is exposed only to steam.

5. Radiolytic Decomposition of Water

Water is decomposed into hydrogen and oxygen gas by the release of fission energy in the fuel solution. Approximately 1.67 molecules of water are dissociated per 100 ev of fission energy absorbed by the solution. At 1.5 mw reactor power 18.5 scfm of $H_2 + O_2$ gas are generated.

A homogeneous catalyst, such as copper sulfate, is ineffective in a boiling reactor. The catalytic reaction is first order in hydrogen concentration. Since no hydrogen partial pressure can exist in a boiling solution the recombination rate is negligible.

Since the hydrogen and oxygen cannot be recombined in solution, provision must be made to recombine the gas elsewhere.

The radiolytic gas will be let down through a valve into the low pressure dump tank along with 500 lbs/hr of diluent steam. The mixture of steam, hydrogen and oxygen will be passed through a bed of platinized alumina where the hydrogen and oxygen will be recombined. The heat of recombination will superheat the product steam to 1067°F. The explosive limit of a stoichiometric mixture of hydrogen and oxygen in steam is 26 mole percent (Fig. 7). The letdown mixture will be 10 mole percent hydrogen plus oxygen.

Several alternate methods for recombining the radiolytic gas have been studied and are incorporated in alternate proposals "A" and "B".

EXPLOSION LIMITS IN THE $H_2-O_2-H_2O$ SYSTEM (475 °F ISOTHERM)

- BATTELLE DATA
- U.S. BUREAU OF MINES DATA

FIGURE 7

D. PRESSURE VESSEL

The reactor pressure vessel, 8 ft. 4 in. long, is divided into two main sections by a bolted flange. The primary section, containing the core, is a cylinder 30 inches inside diameter with an elliptical head attached to one end and a flange for attachment to the steam generating section at the other end. This vessel is shown in Fig. 8.

The primary section of the pressure vessel consists of a titanium thermal shield containing the fuel solution followed by a loose titanium liner. The thermal shield reduces radiation heating and thermal stress in the stainless steel pressure vessel. A 1/2 in. tube, between the liner and thermal shield, terminates at the lowest point in the core and serves as a fill and drain line for the fuel solution.

The wall of the pressure vessel serves as a pressure container, neutron reflector and partial biological shield.

Increasing the thickness of the pressure vessel wall will reduce the pressure stress and increase the thermal stress due to radiation heating, both these effects must be taken into consideration. The neutron reflection of the vessel wall lowers the critical mass and flattens the neutron flux in the core. The steel in the vessel wall offers the most economical use of shielding since it is closest to the core. Taking all of the above effects into consideration resulted in the selection of 2 inches as the wall thickness.

The secondary or steam generating section of the pressure vessel consists of bayonet tubes, baffles and demister attached to a tube sheet and flange capped

by a steam dome. The tubes, baffles and demister extend into the primary vessel steam space above the fuel solution.

The primary and secondary sections of the pressure vessel are bolted together and sealed by a ring gasket which has been tapped to provide for leak detection. The gasket is plated with gold to prevent galling and to insure a tight seal. Further analysis of thermal shock conditions at the flanged connection, due to addition of cold feedwater to the steam dome, may require the use of a welded closure as shown in Fig. 9 to avoid leakage.

The choice of a loose titanium liner over a sealed liner was based upon an analysis of the operational stresses in the liner. The variation of pressure and temperature set up cycling stresses in the liner far exceeding the yield point. This problem could be solved by bonding titanium to carbon steel, however, this type of bonding has not been proven to date.

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E. CORE HEAT TRANSFER

The design of the reactor is such that heat is removed from solution by vaporization of water and subsequent escape of steam to the overhead condenser. The core void fraction is of interest because the nuclear calculations and operating pressures are highly dependent on this variable. No tried and proven method of void fraction prediction is yet in existence; however, Dr. P. C. Zmola of ORNL recently reported work correlates data from various experimenters (4). In essence, his conclusion is that the relative escape velocity, based on total area, is defined by:

$$U_s = U_0 \frac{f}{1-f}$$

where U_0 is a proportionality constant dependent upon pressure, and f is the local void fraction. An application of this postulate to a cylindrical core geometry is described in appendix IV and results in the equation:

$$\bar{f}_{CORE} = \frac{1}{1 + \frac{2 U_0 h_{fg}}{\bar{P}_{CORE} L U_g}}$$

The equation is plotted for this particular reactor in Figure 10, and describes average void fraction as a function of reactor power. This curve was used as the basis for nuclear and part load calculations. At 1500 kw the average core void fraction is 9.75 percent.

In the heat transfer calculations for the condensation of steam in the overhead condenser-boiler, the effect of the small fraction of non-condensable radiolytic H_2 and O_2 gas in the steam was taken into account.

CORE AVERAGE VOID FRACTION VERSUS REACTOR POWER...

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FIGURE 10

The method of Colburn and Hougen (5) was used to evaluate this situation (see appendix V). The results are that the clean overall heat transfer coefficient is about 400 BTU/hr-ft²-°F, decreasing to about 300 BTU/hr-ft²-°F if boiler side scaling occurs. The length of the tubes is picked to give the heat transfer area required in the fouled condition. The non-condensable gases have little effect on heat transfer characteristics as predicted by this method. There are two physical arguments which support this conclusion. The gas concentration leaving the condenser is specified at 10 mole percent maximum in order to stay well below the explosive limit. The average gas concentration over the length of the condenser is much less and consequently should have little effect. Gilliland of M.I.T. has published a paper (6) in which the molecular diffusivity is calculated for steam diffusing through gases. A very striking pressure effect is noted, such that the diffusivity mechanism is an order of magnitude better at elevated pressures than at atmospheric.

F. NUCLEAR CALCULATIONS

The reactor core is reasonably well optimized. Calculations have been made for critical mass versus height with void fraction as a parameter; the results are shown in Figures 11, 12, and 13. These curves are for three diameters in the region of interest and the minimum optimizes not only critical mass but insures that the reactor is stable against water removal or addition. Any change in water inventory will reduce the reactivity. It is noted that a radius to height ratio of about .70 describes the minimum in all cases. This ratio is used for optimization of the final core size. Core sizing is done by comparing two effects. As the size of the core is decreased, the average core void fraction is increased due to increased power densities. This has the effect of reducing moderator and increasing leakage, both of which result in higher critical mass. Similarly, as the reactor size is increased above the optimum, the leakage becomes less important and the critical concentration decreases very slowly. This also has the effect of increasing the total critical mass. The second effect for optimization is the reactor pressure rise during part load operation. For a constant fuel inventory reactor, the reactivity effects of a decrease in void fraction must be balanced by the reactivity effects of temperature. As a result, the temperature and pressure of the core increase continuously with power reduction from full power to zero power. The zero power pressure is the ultimate design pressure and the saturation temperature at that point cannot exceed the 300 C two phase separation limit. This phenomenon places an upper limit on the power density by limiting the void fraction to the reactivity change due to temperature between operating temperature and 300 C. This pressure rise phenomenon is a function of the full

CRITICAL MASS AS A FUNCTION OF SOLUTION HEIGHT 20 INCH I.D. CYLINDRICAL REACTOR

FIGURE: 11

CRITICAL MASS AS A FUNCTION OF SOLUTION HEIGHT 24 INCH ID CYLINDRICAL REACTOR

CRITICAL MASS AS A FUNCTION OF SOLUTION HEIGHT 28 INCH I.D. CYLINDRICAL REACTOR

power design conditions. A comparison of these two effects is shown in Figure 14 and the design point is indicated on that curve.

By selecting a core diameter of 27 inches, and a corresponding height of 18.9 inches for full load operation, the zero power pressure of the reactor is held to about 1120 psia. The corresponding zero power temperature is 292C. It should be noted that the critical mass at this design point is just about at a minimum with regard to reactor size. The power density at full power is 8.46 kilowatts per liter.

With these design parameters fixed it is possible to perform finalized, accurate nuclear calculations for the reactor core. A two group calculation using cylindrical geometry and a three inch stainless steel reflector is used to determine critical mass and flux. The constants used in this calculation are listed in Table II.

TABLE II

NUCLEAR CONSTANTS
(T = 250 C)

	σ_a	σ_f	σ_s	D_0	L_0^2
	barns	barns	barns	cm	cm ²
			<u>C O R E</u>		
Uranium	486.5	410.0	--	--	--
Water	.5153	--	71.5	--	--
Fast	--	--	--	2.478	52.42
Slow	--	--	--	$L/\Sigma a$	21.05
			<u>R E F L E C T O R</u>		
Fast	.00287	--	--	.889	310
Slow	.184	--	--	.641	3.48

f = Average Core Void Fraction

FIGURE 14

$$R = \frac{\sum_a^U}{\sum_a^{H_2O}}$$

$$\nu = 2.48$$

$$L_s^2 = \frac{L_o^2}{(1+R)(1-f)^2} \quad D_F = \frac{D_o}{(1-f)} \quad \tau = \frac{\tau_o}{(1-f)^2}$$

A critical concentration of 27 grams per liter was determined from these calculations. The flux distribution is shown in Figure 15. The integrated fission rate gives an average thermal flux of 7×10^{12} n/cm²-sec. and a peak to average thermal flux of 1.80:1.00. The effects of variable void fraction on flux distribution and critical concentration are calculated by dividing the core into two regions at the twenty centimeter radius point and treating the system as a two group, two-core-region reactor with estimated reflector savings. The flux distribution from the previous calculation is integrated to find average nuclear concentrations in each region. The result of this calculation is shown in Figure 16; although some perturbations are noted, it is quite similar to the previous calculation.

The following data were used to estimate the cumulative effects of fission products poisoning:

1. 1.5 percent samarium yield with a cross-section of 50,000 barns.
2. Cross-section of other non-volatile fission products - 20 barns per nucleus.
3. Cross-section of U-236 is 6 barns.

It is assumed that volatile fission products, particularly xenon-135, are completely sparged from the solution by steam.

The increase in concentration required to override these poisons is plotted as a function of core life in Fig. 17. It can be seen that there is no particular time at which the critical concentration drastically changes. At the end of 5 megawatt years (see Fig. 18) the critical concentration is increased by less than 10 percent. At the end of this period 2.4 kilograms of fuel will have been burned which is roughly 50 percent burnup, based on initial loading. The critical concentration at this time is about 29.7 grams per liter. Hence, there is no nuclear reason why continued burnup and extended core life is not feasible. The presence of fission products and crud in solution or vessel corrosion will probably determine the final core life. These effects are to be investigated fully during prototype operation.

The coefficient of reactivity due to temperature and voids has been calculated by use of the slope of reactivity versus pressure curves for various reactor powers, as shown in Fig. 19. The slope of these curves at zero reactivity is actually the reactivity coefficient and is plotted in Fig. 20, as a function of reactor power. This method of calculation necessarily includes the effect of void fraction, since the voids are dependent on reactor power and reactor power is a function of temperature. It should be noted that the void fraction effect is quite large near zero power, producing a combined temperature coefficient of $-1.6 \times 10^{-3}/^{\circ}\text{C}$ at zero power. At full power, the incremental effect of void fraction is lessened and the temperature coefficient is decreased to $4 \times 10^{-4}/^{\circ}\text{C}$.

INCREASE IN CRITICAL CONCENTRATION, ΔC , REQUIRED TO OVER RIDE POISON BUILDUP

ASSUMPTIONS:

- ① 100% Xe REMOVAL
- ② 70% OF FISSION PRODUCTS IN SOLUTION
- ③ SM YIELD = 1.5%, $\sigma_A = 50,000 \text{ A}$
- ④ FISSION PRODUCT $\sigma_A = 20 \text{ A}$
- ⑤ $\sigma_A(\text{U-236}) = 6 \text{ A}$

$\Delta C \text{ (GM 25/LITER)}$

FIGURE 17

TOTAL

SAMARIUM

LOW σ FISSION PRODUCTS

U-236

CORE LIFE - MEGAWATT YEARS

80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

RATIO OF CRITICAL FUEL CONCENTRATION TO INITIAL CONCENTRATION AS A FUNCTION OF OPERATING TIME

TEMPERATURE COEFFICIENT VERSUS REACTOR POWER

G. SHIELDING CALCULATIONS

Since it is necessary to transport all shielding material to the plant site at a cost of \$.20/lb, a shield design has been chosen that uses a minimum weight of shielding material other than water, which is available at the site. A shield composed of iron and water has been chosen as the configuration which requires the least transportation of material.

The thickness of iron is chosen to shield against delayed fission product gammas in case the shield tank should spring a leak and the water shielding drain out. A dose rate of 200 mr/hr at the outside of the shield 100 seconds after shutdown was chosen as the basis for this calculation. Two feet of iron is needed around the reactor and 1.75 feet around the low pressure equipment to meet this specification.

In addition to the two feet of iron, four feet of water around the reactor and two feet around the low pressure system is needed to reduce the gamma dose rate to 4 mr/hr at full power operation. The gamma spectrum escaping from the reactor vessel is shown in Fig. 21 and Table III.

The shielding required to attenuate the gamma flux was then checked for neutron attenuation. The data and method used for the neutron shielding calculations were taken from reference 7.

The fast neutron dose rate at the outside of the shield is 1.5 mrem/hr. Therefore the total dose rate at maximum power is 5.5 mr/hr.

FIGURE 21

ENERGY RANGE	VOLUME SOURCE INTENSITY					FLUX OUTSIDE VESSEL			
	NO. PHOTONS					NO. PHOTONS			
	SEC - CM ³ - WATT - MEV					SEC. - CM ² - WATT - MEV			
MEV	PROMPT FISSION X10 ⁵	U ²³⁵ CAPTURE X10 ⁵	FISSION PRODUCT X10 ⁵	IRON CAPTURE X10 ⁵	IRON INELASTIC X10 ⁵	CORE SOURCES PLUS SCAT- TERED COMP. X10 ⁴	FE CAPTURES & INELASTICS X10 ⁴	SCATTERED COMPONENT OF FE SOURCE X10 ⁴	TOTAL X10 ⁵
7.5-8.5	—	—	—	—	.0067	—	.0021	.0007	.0028
6.5-7.5	—	—	—	—	.0173	—	.005	.0035	.0085
5.5-6.5	—	.051	—	.178	.0446	.007	.059	.0438	.173
4.5-5.5	.218	.202	—	.702	.1170	.235	.192	.283	.710
3.5-4.5	.768	.110	—	.382	.2935	.787	.122	.731	1.65
2.5-3.5	1.865	.019	60	.064	.7480	4.22	.130	1.519	5.87
1.5-2.5	1.865	.154	1.93	.533	2.345	7.78	.288	5.567	13.64
.5-1.5	.812	.137	7.10	.476	9.800	15.94	.412	44.70	64.05

TABLE III

H. REACTOR SYSTEM COMPONENTS

Part 1 - Primary System Components - Design and Performance Features

In addition to the reactor vessel discussed in Section D, the following major items are included in the reactor system. All pressure parts of the components described are constructed of type 317 SS unless otherwise noted.

a. Reactor Dump Cooler (C-102) and Heater (N-104)

The dump cooler is of the two pipe counterflow type and is in operation only during normal draining of the reactor. The inner pipe is 3/4 in. Sch 40 and the outer pipe 1 1/4 in. Sch 40. The total cooler length is 21 ft, arranged in three 7 ft. lengths. When operating at a dump flow of 810 lb/hr and inlet temperature of 482 F, an outlet temperature of 194 F is anticipated with 2080 lb/hr of cooling water entering at 70 F. During actual dumping, the fuel flow will be controlled in order to keep the temperature at 194 F to prevent valve corrosion. In order to prevent peroxide precipitation in the cooler when the reactor is in operation, electric strip heaters (N-102) are located on the cooler.

b. Reactor Letdown Line Cooler (C-106)

In this heat exchanger, of the double pipe, counterflow type, heat is transferred from the mixture of letdown steam and gas to the returning fuel solution condensate. The unit is designed to remove enough heat from the letdown steam so that it enters the dump tank (F-104) as saturated vapor at 35 psia. The inner pipe of this cooler is 3/4 in. Sch

40 and the outer pipe $1\frac{1}{4}$ in. Sch 40. The cooler is mounted vertically in the letdown line and is approximately 3 ft. in length.

c. Dump Tank (F-104) and Heater (N-101)

The dump tank, shown in Figure 22, is constructed of 12 ft. of 12 in. Sch 40 pipe to which pipe caps have been welded at each end. Attached to the lower end of the tank is a 3 in. Sch 40 convection harp fitted with clam shell electric heaters on the riser section. This harp insures that the temperature in the dump tank remains above the peroxide precipitation limit at all times and also prevents excessive condensation of letdown steam. It is offset at an angle of 30 degrees from the dump tank in order to facilitate replacement of the heaters from above the shield compartment, if required. The volume of the dump tank and harp is approximately twice the fuel inventory of the reactor. A 3 in. vent nozzle to the recombination system and flanged nozzles for attachment of dump, fill and condensate return lines are welded to the top of the tank. A flanged connection to the circulating pump fuel handling head (J-107) is located at the bottom of the convection harp.

d. Mist Separator (G-102)

This unit is also shown in Figure 22 and is mounted directly to the dump tank (F-104) vent nozzle. The separator is 20 in. high, exclusive of heads and nozzles, and is fabricated of 12 in. Sch 40 pipe. The interior of the separator is filled with a basket assembly consisting of 3 - 6 in. layers of stainless steel wire mesh, separated by perforated plates to prevent matting.

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REV	DATE	DESCRIPTION	BY	CHK

FIGURE: 22

DESIGNED BY THE BARDOCK & WILSON CO. 1000 W. 10TH ST. ST. LOUIS, MO. 63101 TELEPHONE 381-1111 FAX 381-1111	
DUMP TANK & MIST SEPARATOR	
DATE 11/7/93	BY 256808

This mesh prevents entrained moisture from reaching the recombiner (G-103) where it would contaminate the catalyst. Moisture trapped by the separator drains back to the dump tank along the walls of the 3 in. inlet pipe. A 3 in. outlet nozzle at the top of the vessel is welded to a short section of flanged pipe that connects with the recombiner.

e. Recombiner (G-103) and Recombiner Heaters (N-102)

The recombiner is of the catalytic type and utilizes a bed of platinized alumina to recombine the hydrogen and oxygen in the letdown vapor. (8) This catalyst is contained in a hollow cylindrical container fabricated of perforated plate. The steam and gas mixture enters at the bottom of the vessel through a 3 in. flanged nozzle and passes upward into the center of the catalyst container, diffuses radially through the bed where the hydrogen and oxygen are recombined. The superheated vapor thus formed leaves the vessel through a 3 in. flanged outlet nozzle in the side of the vessel. The vessel shell is fabricated of 12 in. Sch 40 pipe. Three thermocouples are installed in wells located in the catalyst bed. Six electric heating elements (N-102) are provided to remove any moisture in the catalyst prior to startup. The unit is flanged into the system as noted above with flanges installed in the vertical position for easy removal if the catalyst requires replacement. A general arrangement view of the unit is shown in Figure 23.

f. Feed Water Heater (C-104)

During normal operation this heater serves to desuperheat and condense most of the steam leaving the recombiner. The unit is the vertical U-tube type

utilizing four water passes. The tubes are attached by expanding and seal welding to a $.7\frac{1}{4}$ in. tube sheet on top of which is mounted the upper head containing the inlet and outlet nozzles. The upper head is suitably baffled to direct water through the four passes. Superheated steam enters through a 3 in. flanged nozzle at the bottom of the unit and passes upward through 18 in. of wire mesh separated by perforated plates to prevent compacting. During passage through the mesh, the steam is desuperheated by direct contact with droplets of water draining from the condensing section above. After being desuperheated in this manner, the steam passes over the tube bank where it condenses on the relatively cool tubes. The tube bank is provided with suitable spacers to maintain tube alignment and baffles to prevent streaming of steam through the tube bank. The heating surface consists of twenty-four $1\frac{1}{2}$ in. x $.049$ in. thick U-shaped elements with an average length of 14.5 ft. The shell is fabricated of 8 in. Sch 40 pipe. Any uncondensed steam and non-condensable gases leave the vessel at the top through a 3 in. vent line located in the vicinity of the feed-water inlet. Condensate is drained back to the dump tank or circulating pump through loop seal connections at the lower head. This unit is shown on Fig. 24.

g. After Condenser (C-105)

This heat exchanger has been designed to take the entire recombiner heat load in case of shut-down of the feed-water heater (C-104). For this condition the unit is rated conservatively to insure that a minimum of water vapor enters the cold traps (G-105 and G-105A) thereby preventing them from becoming overloaded. Under these circumstances it is considered justifiable to use the same design proposed for the feed-water heater.

[illegible]

FEEDWATER HEATER CONDENSER

Diagram of a ring with dimensions and labels:

- Top arrow: 70% AREA, 50% RING
- Bottom arrow: 50% RING
- Left arrow: 50% RING
- Right arrow: 50% RING
- Center: 1/2
- Bottom label: RING A

RING 8

SECTION LINE INDICATES
ONE OF TWO 1" SQUARES
FOR TWO SQUARES

RING
1/2"

NOTE:
THESE RINGS A B & C MUST
BE SLIDING FIT TO ID OF
A 3CM 90 PIPE

FIGURE: 24

[illegible]

With a cooling water flow approximately equal to the maximum feed flow this unit will be operating more conservatively than the feed heater since the maximum inlet water temperature will be 70 F compared with a feed temperature of 127 F. The inlet steam connection to this heater is 3 in. and the vent connection to the cold traps is 3/4 in. This unit is shown on Figure 24.

h. Cold Traps (G-105 and G-105A)

The cold traps chosen are similar to those designed for the Homogeneous Reactor Test Project at ORNL. A drawing of these traps is reprinted from reference 9 and is shown in Figure 25. The cold traps are capable of removing heat from the gas, cooling it to a temperature of -20 C and freezing the vapor condensed. In addition the traps must remove fission product decay heat. The units consist of double pipe exchangers. The inner pipe, in which the letdown gages pass, is 4 in. Sch 40S pipe and the outer pipe, containing Freon-12 refrigerant, is 6 in. Sch 40S pipe. Cork insulation is located around the double pipe section to limit external heat absorption by the Freon. During the operating cycle one cold trap is used to cool the gas while the other is being defrosted by recirculating part of the warm refrigerant from the operating trap. When the defrosting has been completed, cool refrigerant is circulated to the unit. When it is down to operating temperature it is placed in service and the other unit is defrosted. The complete trapping and defrosting cycle is automatic. The vapor collected in the traps is drained into the after condenser during the defrosting operation thus maintaining a constant water inventory in the system.

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COLD TRAPS - G-105 & G-105A

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FIGURE: 25
PAGE 53

CUSTOMER	<i>AEC - ARMY REACTORS BRANCH</i>	JOB NO.	<i>ES-1136</i>
SUBJECT		BY	<i>RAD</i>
	<i>SOURCE: ORNL</i>	DATE	<i>5/17/55</i>

i. Refrigeration Unit (K-100)

A standard one ton Freon-12 refrigeration compressor is used to supply coolant to the cold traps (G-105 and G-105A). This compressor is furnished complete with receiver, condenser and controls for automatic operation. Provision is also made for connection to cooling coils for "freezing off" various lines in the reactor system during replacement of components such as reactor dump and letdown valves and circulating pump heads (J-107).

j. Charcoal Filter (G-104)

The charcoal filters consist of 120 ft. of pipe ranging in size from 3/4 in. diameter at the inlet end through 1 in, 1 1/2 in, 2 in, 2 1/2 in, 3 in, 4 in, to 6 in. at the outlet. Fifteen foot lengths of each size are used. During normal operation the filters operate at about 35 psig where their effectiveness is improved as compared with operation at atmospheric pressure. The charcoal filters are submerged in a tank which forms part of the reactor shield. This tank is located below the reactor vessel and water is circulated through it at approximately 10 gpm to remove decay heat. By limiting the temperature of the charcoal bed, high efficiency of operation is assured.

k. Stack Fan (J-109)

A stack exhaust fan is included in the system to insure dilution and dispersion of any radioactive gases that are not adsorbed in the charcoal filters. It also maintains a slight negative pressure on the shield compartment that draws any possible leakage from reactor system components up the stack where it is dispersed with the least possible danger to personnel.

The unit is designed for 1554 cfm of air at 4 inches H_2O static pressure when operating at 1695 rpm and 1.75 B.H.P.

1. Stack (L-100)

A 50 ft. high, 24 in. diameter steel stack, fabricated of 20 gage carbon steel plate is included to dissipate waste gases. This stack will be attached to the shielding structure with the upper 10 to 15 ft above the structure guyed for stability.

m. Pulsafeeder Pump Suction Line Coolers (C-107 & C-109)

These coolers are both of the double pipe counterflow type and are designed to cool the maximum letdown condensate flow of 540 lb /hr from 260 F to 150 F when supplied with 740 lb /hr of cooling water at 70 F, maximum. The inner pipe of these coolers is 3/4 in. Sch 40 and the outer pipe, 1-1/4 in. Sch 40. They are composed of two 9 ft. lengths in series, connected by a return bend and sloped for drainage. Cooler (C-107) is located on the line from the dump tank to the pulsafeeder head that is used to pump fuel solution to the reactor. Cooler (C-109) is located on the normal condensate return line from the recombiner condensing equipment to the second pulsafeeder head

n. Pulsafeeder Feed Pump (Circulating Pump J-107)

The pulsafeeder feed pump, Fig. 26, is a completely sealed positive displacement metal diaphragm pump. A Scott and Williams hydropulse unit is used to surge an intermediate column of water which in turn moves the diaphragm in the pulsafeeder head. The pulsafeeder head is equipped with two sets of check valves which enable the primary fluid to be pumped in batches.

A pump of this type was used in the Homogeneous Reactor Experiment. The two major problems encountered in this experiment are corrected in the present design. The pulsafeeder check valves are redesigned (10) to allow quiet, reliable performance up to 82 strokes per minute which is far in excess of the 40 to 50 stroke maximum for the HRE pumps. The use of a Scott and Williams hydropulse eliminates the problem of air leakage

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MATERIALS LIST						
ITEM NO	DWG. NO	QTY	NAME	SIZE	MATERIAL	
1	C 8224	2	Head	1 3/4 dia x 3" Hgt	SAE 4140	01 267
2	B-10224	2	Shell	13-9/16 ID x 3/4 Wall x 2 1/2 L	SAE 4140	01 267
3	A-10224	1	Diaphragm	13-9/16 dia x 0.015 In.	SAE 4140	01 267
4	C 8224	2	Center Ring (Half)	13 1/2 ID/13-9/16 ID x 1 1/2 L	SAE 4140	01 267
5	C 10674	2	Strainer Assembly	3/4 Sch 50 pipe x 2 1/2 L	SAE 4140	01 267
6	C 10674	1	Outlet Can	2 1/8 dia x 3" Hgt	SAE 4140	01 267
7	C 10674	2	Body (Quarter)	1 3/4 dia x 1 1/2 L	SAE 4140	01 267
8	C 10674	2	Lower Case	1 7/8 dia x 1 6/16 L	SAE 4140	01 267
9	C 10674	2	Upper Seat	1-7/8 dia x 3/8 L	SAE 4140	01 267
10	C 10674	2	Lower Seat	1-7/8 dia x 1-3/16 L	SAE 4140	01 267
11	C 10674	2	Upper Seat	1-7/8 dia x 3/8 L	SAE 4140	01 267
12	C 10674	4	Ball	1" dia x 1 1/2 L	SAE 4140	01 267
13	C 10674	2	Body (Inlet)	3 Dia x 6 3/4 L	SAE 4140	01 267

- Notes
- 1. Nipples (Item 7) To Be Welded To Bodes (Items 9 & 16)
Before Finish Machining Of Internal Bore
- 2. To Install Seats (Items 11 & 13) Bodes (Items 9 & 16)
To Be Heated To 700° - 800°F And Seats (Items 11 & 13)
To Be Heated To 1100° F
- 3. DESIGN PRESSURE & TEMPERATURE FLOODING @ 180°F
- 4. HYDROSTATIC TEST PRESSURE - 3300 PSI
- 5. DESIGN HEAD SHALL BE ASSEMBLED IN ACCORDANCE
WITH WELDING SEQUENCE AS GIVEN BY DWG TO B 4126
- 6. THE FINISHED HEAD SHALL MEET THE REQUIREMENTS
OF OEM SPECIFICATIONS B 1001
- 7. PATCH OF CONNECTIONS TO BE SUFFICIENT TO
SURE

FIGURE 26

WE. JING SEQUENCE & TEST PROCEDURE FOR DIAPHRAGM NOS	TD-B- 444
DIAPHRAGM HEAD CONTOUR DETAILS	C-18229
Check Valve Details	D-19374
Strainer & Pipe Line Strainer	D-18222
Diaphragm Head Details	D-18224
REFERENCE DRAWINGS	ENCL. NO.

A. RESEARCHERS OF CELL DET. & BLOOD NO. & ANAL.		2-20-55 (1058)		(184)	
NO.		REVISIONS		DATE	APPR.
DRAWING NO. D-19973					
DESIGN	DATE	DATE	APPROVED	DATE	
E. J. Davis	2-22-55	2-22-55	(184) E. J. Davis	2-22-55	
REVISION	DATE	REVISION	DATE	APPROVED	DATE
		C. Angel	3-1-55	S. C. Curran	3-1-55
HEALTH PROGRAM	RESEARCH		OPERATIONS		SAFETY
FILE PROGRAMS	RESEARCH STAFF		SUPERVISORS		

REVISED &
APPROVED
FOR
CONSTRUCTION
R.B. Briggs 3-2-76

MACHINE FINISH SPECIFICATIONS

1. Finish symbols are in accordance with ASA Standard B46.1 - 1947
2. Roughness height values are the maximum arithmetic average deviation from the mean surface, expressed in microinches.
2. For surfaces not otherwise indicated, roughness height shall not exceed

THIS DRAWING CLASSIFIED SECRET	HRT DIAPHRAGM PUMP	BLD# 7500
	DIAPHRAGM HEAD ASSEMBLY	
DATE: _____	OAK RIDGE NATIONAL LABORATORY (OFFICE USE)	
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED	CARBIDE AND CARBON CHEMICALS COMPANY A DIVISION OF UNION CARBIDE AND CARBON CORPORATION	
FINISHES: <u>16A</u>	DATE ORDER: _____	
DIMENSIONAL: <u>± .006</u>	QUANTITY: _____	REVISION: _____
ANALYSIS: <u>± .002</u>	DATE: <u>10/1/73</u>	BY: <u>W. J. ...</u>
SCALE: 1" = 1"		D-19973

✓ PAGE 57

D-19973

into the oil system. This unit has an adjustable capacity of 0 to 7 gallons per minute at 2000 psia and may be used to drive two pulsafeeder heads. The unit operates at 60 strokes per minute per head. At 600 psia a flow rate of one gpm per head is expected.

Experiments (11) performed at ORNL show that 200 to 300 ml/min at STP of O₂ can be added to the suction of the pulsafeeder head without seriously affecting pumping rate when 3 feet of suction head is available.

o. Fill Tank (F-105)

This vessel, shown in Fig. 27, is located above the reactor shield in the crane bay. It is formed of 6 in. Sch 40 pipe 12 in. long with a 6 in. Sch 40 pipe cap forming the lower head. A 6 in. - 150 lb. bolted lap joint flange with stub end forms the upper part of the shell and top closure. Fuel is placed in the vessel by removing the upper blind flange. After replacing the flange, air from the plant air system is supplied to the vessel at 80 psig through a check valve and forces the fuel through a remote operated valve to the dump tank. A line is provided on the tank to vent it to the stack after completion of the fill operation.

p. Sampler

A proposed system for removing fuel solution samples from the reactor is identical to the one being constructed for the Homogeneous Reactor Test. Details of construction and operation of this device may be obtained from the Homogeneous Reactor Project at Oak Ridge National Laboratory. A general assembly of this equipment is shown in Fig. 58.

Pg. 59

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MATERIALS LIST					
ITEM	QTY.	NAME	SIZE	MATERIAL

SECTION D-D
Scale: 1/2" SECTION B-B
Scale: 1/2" SECTION E-E
Scale: 1/2" SECTION C-C
Scale: 1/2" PLAN
(WITH CAPSULE REMOVED)
Scale: 1/2" SECTION A-A
Scale: 1/2" TUBE DISCONNECT DETAIL
Scale: 1/2" CATCH BASIN DETAIL
Scale: 1/2"

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- MACHINE FINISH SPECIFICATIONS:
1. Field symbols are in accordance with ASA Standard B46.1-1962.
 2. Surface finish values are the maximum authorized average deviation from the mean surface, expressed in microinches.
 3. For surfaces not otherwise specified, a maximum 32 microinches (16 microinches) is authorized.

FIGURE 58

NO.	REVISIONS	DATE	APPROV.	APPROV.
1	1	12/1/67		
2	2	12/1/67		
3	3	12/1/67		
4	4	12/1/67		
5	5	12/1/67		
6	6	12/1/67		
7	7	12/1/67		
8	8	12/1/67		
9	9	12/1/67		
10	10	12/1/67		

DATE	BY	CHKD	APPD
12/1/67	1	2	3
12/1/67	4	5	6
12/1/67	7	8	9
12/1/67	10	11	12

REFERENCE DRAWING	DWG. NO.
SAMPLERS FOR H.R.T. - BLOS. 7500	
GENERAL ASSEMBLY OF SAMPLING FACILITY	
ONE PRIME NATIONAL LABORATORY	
UNIVERSITY OF CARBIDE AND CARBON CHEMICALS COMPANY	
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION	
DATE: 12/1/67	APPD: 1
12/1/67	12/1/67
12/1/67	12/1/67
12/1/67	12/1/67
12/1/67	12/1/67

E-21579

The sampler consists of an isolation chamber and a remotely operated mechanism for removing a fuel sample from the isolation chamber and placing it in a shielded container. The isolation chamber is connected to both the reactor vessel and the low pressure dump tank by 1/4 in. lines. Double valves in these lines allow fuel solution to be circulated through the chamber and then isolated. The shielded carrier for transporting samples will weigh approximately 400 lbs.

q. Spent Fuel Removal Equipment

A line connected to the dump tank (F-104) for the removal of the fuel solution from the reactor is provided. During operation this line will be capped off with a blank flange. Two valves are provided in the line.

The fuel removal equipment consists of a 5 in. ever-safe container of 20 liter capacity with two valved connections. The horizontal ever-safe container is enclosed in a 7 in. thick lead coffin. The bottom line to the container is connected to the line from the reactor system with a union which is easily uncoupled. Another line is tee'd into the section between the valve on the system and the valve on the ever-safe container so the section of line at the union may be rinsed.

The fuel solution is first concentrated by pumping condensate from the condensor (C-105) to the reactor vessel and storing it there.

The ever-safe container is then evacuated with a vacuum pump through the upper line. The operator, working from behind a barricade with extension handles on the valve, closes the top valve and opens the valves in the line connecting the ever-safe containers with the reactor. The concentrated fuel is then drawn into the shielded container. The valves are then closed, the line backwashed, the union disconnected and capped off, and the door on the lead coffin lowered in place.

The fuel used in the Homogeneous Reactor Experiment was removed twice by this method after operation at 1 mw power (12).

r. Neutron Source

A one inch pipe is provided to guide a neutron source from the top of the reactor shield to a position just outside of the reactor vessel near the core region. A neutron source emitting 10^7 n/sec will be needed during initial startup. A Po-Be source of 1 curie strength will be adequate. Since Po-210 has a 138 day half-life, the effective life of the source is approximately one year.

To provide a neutron source after the first year of operation an inactive antimony - beryllium source clad in Zircaloy - 2 will be inserted in the bottom of the entrainment separator in the reactor vessel. A capsule consisting of 60 gm of antimony enclosed in 0.25 in. of beryllium will reach a source strength of 2×10^6 neutron/sec. after the reactor is operated for 6 months.

Part 2 - Secondary Plant Systems

The secondary plant consists of five interconnected subsystems designed to satisfy the electrical, heating and auxiliary needs of the plant. These subsystems are as follows:

- a. Main and auxiliary steam
- b. Feed condensate and makeup
- c. Salt water cooling
- d. Fresh water cooling
- e. Instrument and plant air

These systems are shown in Fig. 1. Standard power plant practice has been followed in the design and specification of all major components. The system is designed and instrumented to require a minimum of attention from the operator. All major plant pumps have been installed in duplicate, with provision for automatic switch-over in case of failure of the operating unit. This arrangement contributes significantly to plant reliability and does not greatly increase plant size or complexity since spares would normally be provided.

a. Main and Auxiliary Steam System

Secondary steam is generated in the tubes of the reactor heat exchanger (D-100) and collected in the steam dome. The steam pressure and temperature are a function of reactor load. The secondary boiler pressure varies from 225 psia at full load to 1120 psia at zero load. A constant speed turbine is operated with turbine steam pressures from

feed water heater (C-104). The boiler feed pumps (J-103 and J-103A) are of the triplex plunger type. One pump is normally in operation and supplies makeup water to the reactor steam drum through a flow control valve. Excess water is returned to the condenser hot well.

The plant distilled water makeup system consists of a salt water evaporator and vapor condenser (C-101) from which pure water is supplied to the storage tank (F-101). From this a distilled water pump (J-108 or J-108A) supplies makeup to the main condenser hot well, fresh water circulating system and hot water heating system. The discharge from these pumps is also used to maintain a positive pressure on the hot water heating tank (F-102).

c. Salt Water Cooling System

Salt water is pumped by a centrifugal circulating pump (J-104 or J-104A) from the source, assumed to be located about 500 feet from the plant. Inlet suction screens and an outlet duplex strainer (G-101) are provided to minimize fouling of heat exchanger equipment. Salt water serves as the cooling medium in the turbine oil cooler, evaporator vapor condenser, air compressor after cooler (C-103) and fresh water salt water heat exchanger (C-108) and supplies raw water feed to the salt water evaporator (C-101).

d. Fresh Water Cooling System

This system is incorporated in the plant to provide normal and emergency cooling for the reactor system. Due to the corrosive

action of salt water on stainless steel, its direct use for cooling in the primary reactor components is not practical. The fresh water system, consisting of a circulating pump (J-110 or J-110A), a cooling water make-up and expansion tank (F-106), and a fresh water-salt water heat exchanger (C-108), provides a source of cooling water for the primary equipment.

e. Instrument and Plant Air Systems

The air system is of conventional design and consists of air compressors (J-105 and J-105A), after cooler (C-103), air receiver (F-103), oil filter (G-100) and air dryers. These components supply air at required pressures for controls and other plant needs.

Part 3 - Secondary Plant Components, Design and Performance

a. Reactor Steam Generator (D-100)

The reactor vessel is designed in accordance with the ASME Power Boiler Code Section I, 1952 Edition (Revised July 1954).

The steam generating section of the reactor vessel as shown in Fig. 8 consists of a bayonet tube heat exchanger suspended in the steam space above the boiling solution. The steam generating section is composed of 150 vertical bayonet tubes spaced on 1.75 in. triangular pitch. Each bayonet element consists of a $67\frac{1}{2}$ in. long, 1 in. dia. x .135 in. outer tube wall, into which a $\frac{1}{2}$ in. x .049 in. wall tube $69\frac{1}{2}$ in. long is placed. The outer or riser tube is plugged and seal welded at the lower end and expanded and seal welded into a $7\frac{1}{4}$ in. thick tube sheet completely separating primary and secondary steam systems. The inner or downcomer tube is suspended from a $\frac{1}{2}$ in. combination tube sheet and water baffle. The lower end of the inner tube is approximately $2\frac{1}{4}$ in. from the bottom of the outer tube. This insures that no fouling will occur during the life of the unit.

A water level is maintained at 5 in. above the upper end of the downcomer tubes by controlling the feedwater flow. This water is distributed above the downcomers by a 1 in. perforated torus. Water flows down the inner tube to the bottom of the bayonet elements and up the annulus formed by the two tubes. Secondary steam is generated in the annulus by heat transferred from the primary steam.

Investigation of the characteristics of this boiler shows adequate natural

circulation. Since no steam is generated in the inner tube the density difference between the saturated water in this tube and the steam and water mixture in the annulus provides the required head for natural circulation. The steam water mixture leaving the annuli of the bayonet elements passes radially outward under the combination downcomer tube sheet and steam-water baffle and upward through a perforated plate, located between the steam-water baffle and the inner shell of the steam dome. The perforated plate distributes the mixture over the free surface above it. The steam bubbles escape at the surface and the remaining water is recirculated. Sufficient steam release area is provided by increasing the inside diameter of the steam dome to 36 in. The escape velocity of the steam from the surface will be low over the entire range of operating pressures and loads providing natural separation with low entrainment. Since even minute amounts of carryover are undesirable because of possible radioactive particles in the steam, an 18 in. x 18 in. corrugated scrubber element is placed in the steam dome to further insure dry steam. Sufficient water surge volume is provided in the steam dome for satisfactory operation during normal transients. Maximum load design conditions of the units are as follows:

Primary steam pressure - 600 psia
Secondary steam pressure - 225 psia
Feedwater temperature - 253F
Output steam rate - 5,215 lb/hr

When operating the unit at maximum rating with boiler water solids concentration of 400 ppm, and feedwater concentration of 3 ppm, blowdown requirements of the unit are estimated to be 45 lb/hr or approximately 2.2 gal/day.

The secondary section of the reactor vessel is constructed completely of type 347 SS and designed for a working pressure of 1500 psia. A $2\frac{1}{2}$ in. flanged steam outlet nozzle is provided at the top of the vessel. The $1\frac{1}{2}$ in. feedwater inlet line enters the vessel through a thermal sleeve slightly below the normal water level. A $\frac{1}{2}$ in. blowdown and sampling connection is provided just above the tube sheet. Two openings are located in the upper dome for x-raying the final circumferential weld. Plugs are inserted in these openings and seal welded after the x-ray operation is completed. Two thermocouple wells, for measuring primary steam temperatures, and the letdown line to the low pressure recombination system pass through the tube sheet between the outer row of tubes and the reactor shell. These lines pass through the steam-water space and leave the vessel through the upper steam dome.

b. Holdup Tank (F-100)

This vessel is located behind the shield and is constructed of 14 in. Sch 160 pipe with elliptical heads and designed for a maximum working pressure of 1500 psia. Two - $2\frac{1}{2}$ in. flanged inlet and outlet connections are provided near opposite ends of the tank. The overall length is 17 ft. Type 347 SS is used throughout. In addition to providing hold-up time for the decay of radioactive steam, the tank provides time to close the main steam valve in case of a boiler tube rupture and prevent contamination of the secondary plant. Further details of construction are shown in Fig. 28.

c. Blowdown Tank (F-107) and Heater (N-105)

The steam generator blowdown tank located in the shielded compartment and shown in Fig. 29 is designed for operation at atmospheric pressure. It is $36\frac{1}{4}$ in. I.D. x 7 ft. overall and is fabricated of $\frac{5}{8}$ in. type 347 SS plate. Boiler water is

discharged to the tank through a 1/2 in. I.P.S. connection. The tank is vented to the stack through a 3 in. I.P.S. line located at the opposite end of the tank. Submerged type electric heaters are located in the bottom of the vessel to evaporate the water. The vaporized water is vented to the stack leaving all radioactive particles in the bottom of the tank. Thermostatic control of heater element temperature is provided to insure long heater life.

d. Main Turbo-Generator Set (J-106 and N-100)

A 250 kw base mounted package turbo-generator, type "SHB" manufactured by the Worthington Corporation is provided complete with exciter generator, reduction gear, constant speed oil relax governor, automatically controlled steam inlet valves, oil operated trip and throttle valve, emergency overspeed governor, steam strainer, motor and hand operated synchronizing devices, vibrating tachometer, complete lubricating system including turbine-driven auxiliary oil pump and oil cooler, gauges and gauge board, hand operated generator and exciter field rheostats. The inlet steam opening is $2\frac{1}{2}$ in. and the exhaust opening, 16 in. A 3 in. non-controlled extraction opening is designed to supply 1800 lb/hr of steam at 15 psig during normal full load operation.

The 5000 rpm turbine drives the generator at 1200 rpm through a type D-4 double helical single reduction gear. The generator is designed for 312 kva at 80 percent power factor, 3 phase 60 cycle, 440 volts. A direct connected 125 volt d.c. exciter is employed. Flexible couplings are used to connect turbine, generator and reducing gear.

The unit is designed for a maximum pressure of 600 psig at the throttle. A general arrangement drawing of a similar unit, designed for 250 psig maximum, is shown in Fig. 30. Total shipping weight of the 600 psig unit is 22,000

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FORM "S" MULTISTAGE STEAM TURBINE
OIL RELAY GOVERNOR AUTOMATIC NOZZLE CONTROL
DRIVING
250 KW - 312 KVA - 3 PHASE - 60 CYCLE - 80% P.F.
220₃₀₀ VOLTS, GENERATOR
AND
3 KW - 125 V - DIRECT CONNECTED EXCITER
THRU
FORM "D" REDUCTION GEAR 45-1/2, 1200 R.P.M.

NOTES:

1. TURBINE MUST BE RELIEVED OF ALL RUNNING STRAINS BY USE OF PROPER SUPPORTS FOR PIPING.
2. STEAM INLET AND EXHAUST PIPING MUST BE ARRANGED TO AVOID IMPOSING ANY SUBSTANTIAL FORCES ON THE TURBINE CASING.
3. FOUNDATION BOLTS SHOULD NOT BE RISIDELY LOCATED UNTIL UNIT IS IN PLACE ON FOUNDATION, AS BOLT HOLES IN BASEPLATE MAY VARY SLIGHTLY.

APPROXIMATE WEIGHTS	
TURBINE	2230 LBS
GEAR	1750 LBS
GENERATOR	2300 LBS
BASEPLATE (EQUALLY DISTRIBUTED)	2400 LBS
ACCESSORIES	540 LBS
TOTAL APPROXIMATE WEIGHT	11,240 LBS

FIGURE: 30

pounds. Design turbine exhaust pressure is 28 in.Hg vacuum. Turbine performance under anticipated operating conditions is discussed further in Section "K".

e. Main Condenser (C-100)

A Ross Heater and Manufacturing Company surface condenser is designed for a steam flow of 3700 lb/hr with a 28 in.Hg vacuum. This flow corresponds to a maximum turbine load of 225 kw with 1800 lb/hr extraction at 15 psig which is equivalent to the maximum reactor design load of 1500 kw of heat. A reduction in size and cost could be realized by designing the unit for a mean operating load. However, this saving would be small and would affect overall plant costs but slightly.

Design particulars and performance characteristics of the unit as shown on Fig. 31 and Fig. 32 are as follows:

Condenser diameter	18 in.
Number of tubes	750
Tube size	3/4 in. x 18 BWG
Tube length	10 ft.
Heating surface	294 ft. ²
Water passes	3
Cooling water flow	300 gpm
Cooling water inlet temperature	60 F maximum
Cooling water outlet temperature	83.4 F maximum
Cooling water head loss	12 ft. H ₂ O
Cleanliness factor	73 percent
Overall length	12 ft. 8 in.
Overall height required including pumps	8 ft. 5 in.
Overall width including air ejectors	3 ft. 3 in.
Tube material	Admiralty metal
Shell material	carbon steel
Water box material	cast iron
Tube sheets	Muntz metal

UNCLASSIFIED ROSS TYPE "A" BALANCED FLOW SURFACE CONDENSER

ROSS HEATER & MFG. CO., INC.

Division of American Radiator & Standard Heating Corporation
1407 WEST AVE.
BUFFALO 13, N. Y.

UNCLASSIFIED
FIGURE: 31

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ROSS TYPE "A" BALANCED FLOW SURFACE CONDENSER

ROSS

UNCLASSIFIED

ROSS HEATER & MFG. CO., INC.

DIVISION OF AMERICAN RADIATOR & STANDARD SAFETY CORPORATION

1407 WEST AVE.
BUFFALO 13, N. Y.

FIGURE: 32

SHEET 8.1 A 1

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h. Boiler Feed Pumps (J-103 and J-103A)

The boiler feed pumps are motor driven, triplex plunger type. This pump has gained wide acceptance for high head-low capacity service. These units are designed to supply 12 gpm of 250 F feed at pressures up to 1200 psia, which is 80 psi above the anticipated secondary steam pressure. The pumps are driven by 15 hp 440 volt open drip-proof motors operating at 1750 rpm. Pump speed will be approximately 300 rpm. A special water lubricated plunger packing is supplied to prevent oil contamination. The units are furnished complete with base plate and flexible coupling. The pumps and piping are protected from excessive pressures by a pressure control valve and a variable speed drive may be used to control flow.

i. Salt Water Evaporator (C-101)

A standard marine type, single effect evaporator with distiller cooler condenser was chosen. This unit is manufactured by the Davis Engineering Corporation and has a rated capacity of 2.5 gph of distilled water when supplied with auxiliary steam at 15 psig. Brine concentration during operation is 4.7 percent. By continuous blowdown, a water purity below 2 ppm can be obtained. Since the water make-up requirements of the plant do not exceed 1 gph during normal operation, better performance is expected. The shell and tube distiller condenser and cooler employs salt water as the cooling medium. Leaving this exchanger, part of the water is used as evaporator feed, thereby increasing the efficiency of the unit. With a brine concentration of 4.7 percent the rated performance of the unit is as follows:

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SALT WATER EVAPORATOR & DISTILLER CONDENSER C-101
FIGURE - 22

Pump casings and impellers are bronze and pump shafts are fabricated of Monel. Two 40 hp, open, drip-proof motors turning at 3450 rpm are used to drive the units through flexible couplings. Inlet screens are provided to keep debris from entering the pumps. A duplex strainer is located in the discharge line of the pumps to reduce fouling of the condenser. A pressure signal on the main control panel indicates when to switch to the alternate duplex filter. An alarm circuit signals failure of either pump. As in the other main pumps, automatic emergency switchover is included in the motor control circuits.

n. Salt Water - Fresh Water Heat Exchanger (C-108)

A Ross Heater and Manufacturing Company, Number 806 BCF, heat exchanger of the single pass, counterflow type has been selected for this service. A view of this unit showing materials of construction is shown in Fig. 34. Pertinent performance information is tabulated below:

Design heat load	932,000 Btu/hr
Fresh water flow	8,320 lb/hr
Fresh water inlet temperature	182 F
Fresh water outlet temperature	70 F
Sea water flow	50,000 lb/hr
Sea water inlet temperature	60 F
Sea water outlet temperature	79 F
Fresh water pressure drop	1 psi
Sea water pressure drop	1 psi
Tube side design pressure	150 psig
Shell side design pressure	225 psig

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Single-pass Design Cut Away to Show Details

UNCLASSIFIED

6 SALT WATER-FRESH WATER HEAT EXCHANGER (C-108)

DECLASSIFIED

FIGURE :- 3471229.10

o. Fresh Water Circulating Pumps (J-110 and J-110A) and Makeup Tank (F-106)

The fresh water circulating pumps are the centrifugal, motor driven type with 30 gpm capacity at 92 feet discharge head and 48 NPSH. Provision is made for automatic switchover to the standby unit in case of failure of the operating unit. This insures cooling water to reactor system coolers at all times. A Worthington type DN-52 pump with cast iron casing and bronze fittings has been selected for this service. It is driven directly by a 3 hp, 3450 rpm motor. The cooling water makeup tank is 2 ft. 6 in. O.D., 4 ft. high and is made of carbon steel. Inlet, outlet, vent and fill connections are shown on Fig. 1.

p. Air Compressors (J-105 and J-105A)

Two Worthington, base-mounted, type 20XBR2, air compressors are included to supply instrument and plant air as shown in Fig. 35. They are V-belt driven by 20 hp, 440 volt, 3 phase motors. These compressors are of the 3 cylinder, 2 stage, air cooled type and are rated at 80 cfm at 80 psig discharge pressure. Provision is made for automatic stop-start or bypass control. For automatic start-stop control, the compressor operates between the limits of 80 to 100 psig discharge pressure. Using bypass control the compressor runs continuously, discharging at 80 psig. A pressure controlled switchover is provided to start the idle unit during peak demand periods or in case of failure of the operating compressor. Motor starters with overload control, air suction mufflers and filters are supplied with the units.

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HL-13742

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FIGURE: 35

3 CYL AIR COMPRESSOR
GENERAL ARRANGMENT
WORTHINGTON CORPORATION
100 TO 1000 PSI 100 HP TO 1000 HP
DATE 2-10-54 DRAWN R.E. CHAPMAN
SCALE 3/8" = 1" FOOT HL-13742

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q. Air Compressor After Cooler (C-103)

A Worthington pipe line after cooler, size "SP", with integral water separator and drain trap, is installed between the air compressors (J-105) and air receiver (F-103). A sight glass for cooling water outlet, a thermometer, separator water gage glass and an automatic solenoid cooling water valve connected to the air compressor starters are furnished as standard equipment. The cooler is designed to cool air to within 15 F of the inlet water temperature and withstand cooling water pressures of 150 psig. A general arrangement view of this equipment is shown in Fig. 36.

r. Air Receiver(F-103)

A vertical air receiver manufactured by the Worthington Corporation is incorporated in the air system. This vessel, No. TNK-66, shown in Fig. 37, is designed for a working pressure of 135 psig in accordance with ASME and National Board Code for Unfired Pressure Vessels. The vessel is furnished with safety valve, drain cock, discharge line valve, pressure gage and mounting feet.

s. Oil Filter (G-100)

A J. F. Pritchard type "R", size 3 Oilsorber filter is used to remove entrained oil and condensate from the compressed air supply. This filter is designed for 150 psig working pressure and is of the cartridge type, permitting easy replacement of the filter element. A drawing of this piece of equipment is shown in Fig. 38.

Supersedes Dwg. K-110365

UNCLASSIFIED WORTHINGTON PIPELINE AFTERCOOLERS GENERAL ARRANGEMENT

AFTERCOOLERS FOR PIPE LINES

SIZE	A	B	C	D	E	F	G	H	AIR CONNECTIONS								WATER		J DRAIN
									Inlet				Outlet				IN	OUT	
									SIZE	DI	BC	BOLT	SIZE	DO	BC	BOLT			
SP-2	11'-10"	21½"	5⅝"	1½"	4"	2½"	10'-4⅞"	1⅞"	1½"	Screwed		1½"	Screwed		½"	1"	½"		
SP-1	11'-11"	26½"	6½"	1½"	6"	3"	10'-4⅞"	2⅝"	2"	Screwed		2"	Screwed		½"	1"	½"		
OO-P	12'-1⅜	29½"	8"	2½"	6"	4½"	10'-1"	3"	3"	Screwed		3"	Screwed		½"	1½"	½"		
OO-PS	12'-1⅜	29½"	8"	2½"	6"	4½"	10'-1"	3"	3"	Screwed		3"	Screwed		½"	1½"	½"		
O-P	12'-2½"	34½"	10½"	4½"	8"	4½"	10'-1"	4"	4"	Screwed		4"	9"	7⅝"	8-⅝"	½"	1½"	½"	
O-PS	12'-4½"	34½"	12½"	5"	10"	4½"	10'-1"	5"	5"	Screwed		5"	10"	8½"	8-½"	½"	1½"	½"	
1-P	12'-4½"	34½"	12½"	5"	10"	4½"	10'-1"	5"	5"	Screwed		5"	10"	8½"	8-½"	½"	1½"	½"	
2-P	12'-4½"	34½"	12½"	5"	10"	4½"	10'-1"	5"	5"	Screwed		5"	10"	8½"	8-½"	½"	1½"	½"	
2-PS	12'-4½"	34½"	12½"	5"	10"	4½"	10'-1"	5"	5"	Screwed		5"	10"	8½"	8-½"	½"	1½"	½"	
3-P	12'-4½"	34½"	12½"	5"	10"	4½"	10'-1"	5½"	5"	Screwed		5"	10"	8½"	8-½"	1"	1½"	½"	
4-P	12'-6½"	36½"	14½"	5½"	12"	5½"	10'-1"	6"	6"	Screwed		6"	11"	9½"	8-½"	1"	1½"	½"	
5-P	12'-6½"	36½"	14½"	5½"	12"	5½"	10'-1"	7"	6"	Screwed		6"	11"	9½"	8-½"	1"	1½"	½"	
5-PS	13'-4½"	36½"	14½"	5½"	12"	11⅜	10'-1"	8⅝"	6"	11"	9½"	8-½"	6"	11"	9½"	8-½"	1½"	2"	½"
5A-PS	12'-10½"	36½"	14½"	5½"	12"	5½"	10'-1"	8⅝"	8"	Screwed		6"	11"	9½"	8-½"	1½"	2"	½"	
6-P	13'-4½"	36½"	14½"	5½"	12"	11⅜	10'-1"	8⅝"	6"	11"	9½"	8-½"	6"	11"	9½"	8-½"	1½"	2"	½"
6-AP	12'-10½"	36½"	14½"	5½"	12"	5½"	10'-1"	8⅝"	8"	Screwed		6"	11"	9½"	8-½"	1½"	2"	½"	
7-AP	12'-10½"	36½"	14½"	5½"	12"	5½"	10'-1"	9½"	8"	Screwed		6"	11"	9½"	8-½"	1½"	2"	½"	

EQUIPMENT: Moisture separator; cast-iron sight jacket-cone for cooling water outlet, plug for moisture drain, thermometer and water gauge glass for separator.

NOTE - For Preliminary use only unless certified.

SIZE _____

CUSTOMER _____ CUSTOMERS ORDER # _____

BRANCH OFFICE NO. _____ OUR SHOP ORDER _____

CERTIFIED BY **UNCLASSIFIED** DATE _____

WORTHINGTON CORPORATION
BUFFALO, NEW YORK

K-153200

Revised 3-3-47 Revised 5-25-50 Revised 12/1/50 Revised 1/30/51

PART NO.	NO. OF PARTS PER SET	NAME OF PART	QTY	PART NO.

ES-1156 AIR RECEIVER

PART NO.	SIZE	A	B	C	D	E	F	G	H	J	K
TNK-G5	24 X 72	72	24	14	42	10 1/2	1 1/2	18	21	23 1/2	27
TNK-G6	30 X 84	84	30	17	51	12 3/4	1 1/2	24	27	29 1/2	33
TNK-G3	36 X 96	96	36	19	57	14 1/4	2	30	33	35 1/2	38
TNK-96	42 X 120	120	42	24	72	18	2 1/2	36	39	41 1/2	44

ALL RECEIVERS TO BE BUILT IN STRICT ACCORDANCE WITH "ASME AND NATIONAL BOARD" CODE FOR UNFIRED PRESSURE VESSELS AND DESIGNED FOR 135 LBS WORKING PRESSURE, WHICH SHALL BE INSPECTED AND TESTED DURING CONSTRUCTION BY AUTHORIZED INSPECTOR.

FACTORY SETTING OF POP SAFETY VALVE WILL NOT EXCEED 135 LBS PER SQUARE INCH GAUGE PRESSURE IN ACCORDANCE WITH CODE.

RECEIVER SERIAL NUMBER, "ASME AND NATIONAL BOARD" INSPECTION STAMP SHOWING WORKING PRESSURE, ETC., TO BE STAMPED NEAR MANHOLE OR INSPECTION OPENINGS.

SAFETY VALVE AND PRESSURE GAUGE FURNISHED BY WORTHINGTON CORPORATION

FIGURE: 32

PLEASE NOTE
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DESIGNED BY: _____
CHECKED BY: _____
APPROVED BY: _____

DATE: _____

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.

ALL DIMENSIONS ARE TO CENTER UNLESS OTHERWISE SPECIFIED.

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ALL DIMENSIONS

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WORTHINGTON CORPORATION
HOLLYWOOD, FLORIDA
SALES, ENGINEERING, ESTIMATION, SERVICE
 

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"X" LBS. OF ADSORBENT
"Y" MINIMUM HEAD CLEARANCE
FOR REMOVAL OF CATRIDGE
"Z" WEIGHT

OLD DWG. NO. WAS DE6:5245

SIZE	PRESSURE	DIMENSIONS												
		A	B	C	D	E	F	C-1	N-1	N-2	N-3	X	Y	Z
2	150 [#]	2'-2"	3'-0"	3'-10"	8"	7"	5"	$\frac{3}{4}$ "	1 $\frac{1}{2}$ "	1 $\frac{1}{2}$ "	6"	2'-0"	2'-6"	200 [#]
	300 [#]	2'-2"	3'-0"	3'-10"	8"	7"	5"	$\frac{3}{4}$ "	1 $\frac{1}{2}$ "	1 $\frac{1}{2}$ "	6"	2'-0"	2'-6"	200 [#]
3	150 [#]	2'-2"	3'-6"	4'-4"	9 $\frac{3}{4}$ "	8"	7 $\frac{1}{4}$ "	1"	2"	2"	8"	4'-0"	3'-2"	300 [#]
	300 [#]	2'-2"	3'-6"	4'-4"	9 $\frac{3}{4}$ "	8"	7 $\frac{1}{4}$ "	1"	2"	2"	8"	4'-0"	3'-2"	300 [#]
4	150 [#]	2'-2"	3'-6"	4'-4"	11"	6 $\frac{1}{2}$ "	9 $\frac{1}{4}$ "	1"	2 $\frac{1}{2}$ "	2 $\frac{1}{2}$ "	10"	6'-0"	3'-0"	450 [#]
	300 [#]	2'-2"	3'-6"	4'-4"	11"	6 $\frac{1}{2}$ "	9 $\frac{1}{4}$ "	1"	2 $\frac{1}{2}$ "	2 $\frac{1}{2}$ "	10"	6'-0"	3'-0"	450 [#]
5	150 [#]	2'-2"	3'-8"	4'-8"	1'-0"	6 $\frac{1}{4}$ "	10 $\frac{1}{2}$ "	1"	3"	3"	12"	8'-0"	3'-0"	600 [#]
	300 [#]	2'-2"	3'-8"	4'-8"	1'-0"	6 $\frac{1}{4}$ "	10 $\frac{1}{2}$ "	1"	3"	3"	12"	8'-0"	3'-0"	600 [#]

ES-1156 OIL
 FILTER

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Designs shown herein are covered by the following patents:

- 1803036 2107496
- 1826912 2299920
- 1836503 2342421
- 2100667

and other patents pending.

DRN. *R.M.B.*
 CHK. *T.R.H.*
 SCALE *None*
 DATE *12-3-59*
 APPD. *R.M.H.*

EQUIPMENT DIVISION

J. F. PRITCHARD & CO.
 KANSAS CITY, MISSOURI

TYPE "R" OILSORBER OR
 TYPE "H" HYDRYER
 SERIES 150 & 300

SIZE	CLASS NO.	GROUP NO	SHEET NO
D			1436

NO.	REVISION	BY	DATE	APPD.

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FIGURE 38

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t. Air Dryers (L-101)

A J. F. Pritchard & Co. Hydrier assembly is provided to supply moisture free air to all instruments and control valves. The No. 10CBV150E model shown in Fig. 39 consists of two dryer units filled with Sovabad adsorbing agent and are arranged for alternate, semi-automatic, operation. Each unit will operate satisfactorily for 8 hours at rated capacity of 60 scfm dry air. When supplied with saturated air at 100 F and 100 psig, each unit will deliver saturated air at a dewpoint of -20 F. Maximum water removal during an 8 hour operating period is 11.3 pounds. Transfer of the flow from the operating unit to the reactivated unit periodically is accomplished by a simple manual operation. Six hours is required for reactivation of the adsorbent. Replacement should not be required during the life of the units. Reactivation is accomplished by electric heaters requiring 4.5 kw. Water vapor is removed by a small exhaust fan.

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PLAN

ELEVATION

SECTION A-A

SECTION B-B

FIGURE: 39

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EQUIPMENT DIVISION			
J F PRITCHARD & CO			
KANSAS CITY, MISSOURI			
HYDRYER		ASSEMBLY	
FOR			
MODEL 100BY150E HYDRYER			
DATE	BY	DATE	BY
60	60	60	28A

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I. INSTRUMENTATION AND CONTROLS

Instruments required to control the primary and secondary system are shown on Figure 1. Details of the instruments and their arrangements are shown on Figures 40, 41, 42, and 43. An instrumentation schedule is given in Table IV.

TABLE IV
INSTRUMENT & CONTROL SCHEDULE

1. INSTRUMENTS	<u>NUMBER</u>	<u>SERVICE</u>
a. <u>Temperature Indicators</u>		
	T1-1-8	Reactor pressure vessel (D-100)
	T1-9	Condensate return to reactor (D-100)
	T1-10	Letdown steam from reactor (D-100)
	T1-11	Condensate to letdown cooler (C-106)
	T1-12	Fuel solution to pulsafeeder suction (J-107)
	T1-13	Fuel solution in dump tank (F-104)
	T1-14	Cooling water from pulsafeeder (J-107) suction cooler (C-109)
	T1-15	Condensate from after condenser (C-105) and feedwater heater (C-104)
	T1-16	Steam to feedwater heater (C-104)
	T1-17-20	Steam in recombiner (G-103)
	T1-21-22	Charcoal filter (G-104)

Proposed Instrument & Control for Homogeneous Atomic Reactor
 The Babcock & Wilcox Company
 Contract E51156

FIGURE 40

BAILEY METER CO.
 CLEVELAND, OHIO 44115
 DWG. NO. D 50229

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PROPOSED
INSTRUMENTS & CONTROLS FOR HOMOGENEOUS ATOMIC REACTOR
FOR
THE BABCOCK & WILCOX CO
CONTRACT ES 1156

FIGURE 41

UNCLASSIFIED

137

30

N 1

V 2

N 6

LR JR

N 10

N 12

N 10

71 I 28

PR 30/TH 30
PH 10

LR 30, PR 28

TR 11

N-L

TR 10 TR 30
PH 8

N-L

N 7

PR 38

78"

79"

44"

SUGGESTED ARRANGEMENT
PANEL MOUNTING

THE BARCOCK COMPANY

CONT.

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FOR
THE BRISCOE & WILCOX CO
CONTRACT ES 1156

FIGURE. 42

BAILEY METER CO
CLEVELAND OHIO DATE 5/12/55 BY ZDA
DWG No C3017928-A

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PROPOSED LAYOUT OF INSTRUMENTS & CONTROL ON CONTROL CONSOLE

FOR
THE BABCOCK & WILCOX COMPANY
CONTRACT ES1156

FIGURE 43

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BAILEY METER CO.
CLEVELAND OHIO DATE 5 11 55 BY BMS
Dwg No C3017927-A

<u>NUMBER</u>	<u>SERVICE</u>
T1-23	Steam to mist separator (G-102)
T1-24	Cooling water from pulsafeeder suction cooler (C-107)
T1-25	Cooling water from after condenser (C-105)
T1-26	Cooling water from dump cooler (C-102)
T1-27	Feedwater from feedwater heater (C-104)
T1-28	Feedwater to feedwater heater (C-104)
T1-29	Cooling water from turbine oil cooler (J-106)
T1-30	Hot water heating tank (F-102)
T1-31	Evaporator vapor condenser C-101) coolant outlet
T1-32	Air receiver (F-103)
T1-33	Water from cooling water exchanger (C-108)

b. Temperature Recorders

TR-1	Reactor primary steam at internal demister discharge (D-100)
TR-2	Reactor primary steam at top of steam generating tubes
TR-3	Secondary steam in reactor steam dome
TR-4	Reactor dump line at outlet of cooler (C-102)
TR-5	Recombiner (G-103)

	<u>NUMBER</u>	<u>SERVICE</u>
c. <u>Level Indicators</u>		
	LI-1	Blowdown tank (F-107)
	LI-2	Chemical fill tank (F-105)
	LI-3	Main condenser hot well (C-100)
	LI-4	Evaporator shell (C-101)
	LI-5	Distilled water tank (F-101)
	LI-6	Cooling water makeup tank (F-106)
d. <u>Level Recorders</u>		
	LR-1	Dump tank (F-104)
	LR-2	Reactor steam dome (D-100)
e. <u>Pressure Indicators</u>		
	PI-1	Dump tank (F-104)
	PI-2	Before charcoal filters (G-104)
	PI-3	Secondary steam after PRV-10
	PI-4	Auxiliary steam
	PI-5	Boiler feed pump discharge
	PI-6	Boiler feed pump relief line
	PI-7	Condensate pump discharge
	PI-8	Vacuum in reactor cell
	PI-9	Main condenser (C-100) vacuum
	PI-10	Salt water to sea
	PI-11	Hot water booster pump discharge (J-102)

<u>NUMBER</u>	<u>SERVICE</u>
P1-12	Salt water circulating pump discharge (J-104) after strainer
P1-13	Salt water circulating pump discharge before strainer (J-104)
P1-14	Salt water circulating pump (J-104) discharge
P1-15	Air receiver (F-103)
P1-16	Air compressor (J-105) discharge
P1-17	Plant air
P1-18	Instrument air
P1-19	Oxygen receiver pressure
P1-20	After charcoal filters (G-104)
P1-21	Distilled water pump (J-111) discharge
P1-22	Cooling water pump (J-110) discharge

f. Monitrons

M-1	Reactor compartment
M-2	Letdown system compartment
M-3	Diluent air suction
M-4	Diluent air suction
M-5	Secondary steam outlet from reactor
M-6	Secondary steam outlet from reactor
M-7	Feedwater return to feed pumps
M-8	Cooling water return to exchanger (C-108)

	<u>NUMBER</u>	<u>SERVICE</u>
g. <u>Pressure Recorders</u>	PR-1	Reactor (D-100) primary side, scram signal
	PR-2	Holdup tank (F-100)

h. Flow Recorders

FR-1	Secondary steam to plant
FR-2	Secondary feedwater

2. CONTROLS

<u>NUMBER</u>	<u>SERVICE</u>
V-1	Temperature indicator and control valve reactor dump line, scram open
V-2	Automatic block valve reactor dump line scram open
V-3	Level indicator and control valve dump tank (F-104)
V-4	Level control valve operating in conjunction with V-3
V-5	Manual block valve cooling water to dump cooler (C-102) scram open
V-6	Automatic block valve outlet of cold traps (C-105) scram closed
V-7	Manual block valve fill line to dump tank, scram closed
V-8	Flow control valve letdown line
V-9	Automatic bulkhead block valve secondary steam, scram closed
V-10	Pressure reducing valve, secondary steam to turbine (N-100) and air ejectors (J-101)

<u>NUMBER</u>	<u>SERVICE</u>
V-11	Pressure control valve, feed pump (J-103) discharge
V-12	Level control valve reactor steam dome (D-100)
V-13	Temperature control valve, cooling water exchanger (C-108)
V-14	Pressure reducing valve main to auxiliary steam
V-15 A&B	Manual control valves turbine (N-100) bypass
V-16	Level control valve condenser (C-100) hot well
V-17	Temperature control valve turbine (N-100) oil cooler
V-18	Temperature control valve, hot water heater (F-104)
V-19	Pressure reducing valve, instrument air
V-20	Level control valve evaporator (C-101) brine level
V-21	Level control valve fresh water makeup tank (F-106)
V-22	Automatic switch over valves cold traps (G-105)
V-23	Automatic switch over valves cold traps (G-105A)
V-24	Steam generator blowdown control valve
V-25	Oxygen pressure control valve

NUMBER

SERVICE

V-27	Manual block valve fuel to waste storage
V-28	Manual block valve fuel sampler
V-29	Manual block valve fuel sampler
V-30	Pressure reducing valve, air ejecting steam

1. Primary System Instrumentation

The instruments and controls for the primary system have been selected using the operational experience of the Homogeneous Reactor Project at Oak Ridge as a guide.

The percentage of radiolytic gas in the steam space of the reactor vessel is controlled by temperature measurements. The temperature of the boiling solution and the temperature at the top of the steam space are compared and used to control a steam letdown valve (V-8). An orifice is also installed in the let-down line to reduce the pressure drop across the control valve. At full power operation, 500 lb/hr of steam is let down to the low pressure system to maintain a radiolytic gas concentration of 10 mole percent maximum in the reactor vessel.

Scram circuits are provided which are actuated by a signal from either reactor pressure or one of the monitrons. When the scram circuit is actuated the following action takes place:

- a. The automatic block valve on the steam line to the turbine closes.
- b. The manual block valve in the line between the fill tank and the dump tank closes.
- c. The temperature control valve and the automatic block valve in the reactor dump line opens.
- d. The pulsafeeder feed pump motor is shut off.
- e. The automatic block valve in the charcoal filter feed line closes.
- f. The automatic block valve in the cooling water line to the reactor dump line opens.

A pressure recorder is provided to monitor reactor pressure. The sensing element is a strain gage pressure cell. Excessive pressure in the reactor will actuate the scram circuit.

A temperature control valve and an automatic block valve are provided in the reactor dump line. Both valves will open on the scram signal. For normal shutdown the automatic block valve is manually opened and the rate of letdown is controlled by the temperature control valve.

A pressure regulating valve is installed downstream of the charcoal filter to regulate the pressure of the off-gas line from the condensers. An automatic block valve which closes on the scram signal is installed between the cold traps and the charcoal filter.

Automatic block valves downstream of the cold traps are opened and closed by a signal from an automatic timer. The timer is interlocked to the controls of the refrigeration unit and directs the flow of either hot or cold refrigerant to the cold traps.

Condensate from the after condenser and feedwater heater is returned by gravity to either the dump tank or the suction line of one of the pulsafeeder feed pump heads. Interlocked level control valves are provided to regulate flow to the pump heads. These valves are so arranged that under all operating conditions flow is insured through each valve. This feature is desirable since it maintains a flow of condensate on the outside of the reactor liner and also tends to prevent solid accumulation in the dump tank evaporator.

Manual control valves are provided to regulate the boiler blowdown flow, sampler flow and waste fuel flow.

All pumps except the pulsafeeder feed pump and the hot water booster pump have installed spares and are equipped with pressure alarm switches. A loss of discharge pressure causes the spare pump to start. The alarm will continue to sound until manually disengaged.

2. Nuclear Instrumentation

Two nuclear channels are provided for monitoring the reactor power by means of the neutron flux. A U-235 fission chamber is provided to measure the power level during startup and a gamma compensated, boron coated ion chamber for normal operation.

The chambers are located in thimbles inserted in a region of lead shot and water just outside of the reactor pressure vessel. The thermal neutron flux in this region of 10^{10} n/cm²/sec. is produced by the moderation of fast neutrons leaking out of the reactor. A lead-water instrument assembly similar to this is used in the Homogeneous Reactor Test (13).

A block diagram of the nuclear channels is shown in Fig. 44. A logarithmic count rate meter and recorder is connected to the fission chamber. A sealed fission chamber which does not require inert gas flow is used. The compensated ion chamber drives a 6 decade log N recorder and also a period amplifier and meter. A high neutron level contact in the log N circuit will initiate an emergency shutdown. This chamber is also of the sealed type.

3. Secondary System

The instruments and controls for the secondary system have been selected in accordance with accepted commercial practice. For descriptive purposes the secondary system may be subdivided into sections, as follows:

a. Steam System

Control of the steam system is based on the operational demands of the turbo-

UNCLASSIFIED

START UP CHANNEL

OPERATING CHANNELS

PROPOSED NUCLEAR INSTRUMENTATION

FOR

THE BABCOCK & WILCOX Co

FOR

CONTRACT ES1156

FIGURE: 44

BAILEY METER CO

CLEVELAND, OHIO DATE 5-11-55 BY CLK

DWG. No B3017926-A

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b. Evaporator Section

Steam for the salt water evaporator and the hot water space heating tank is supplied by uncontrolled extraction from the turbine at pressures ranging from 15 to 40 psig. This steam may also be supplied through a pressure regulating valve bypassing the turbine.

A level control valve is supplied to maintain the required feed to the evaporator. All other instruments necessary for proper operation of the evaporator are supplied with the unit.

c. Space Heating System

The temperature of the hot water tank is maintained constant by means of a temperature control valve in the steam feed line. Space heating controls are not provided.

J. PLANT ARRANGEMENT AND ERECTION

1. Plant Arrangement

The overall plant arrangement is shown in Fig. 2. The primary system components are contained within the shielded area and are described in Section 4 part 1. The secondary system components, with the exception of the cooling water pumps, are located on two levels immediately adjoining the shielded area.

No underground construction is planned. The building is mounted on a concrete pad using piling or a ventilated floating support construction. The type of foundation used depends on the terrain at the various locations. Foundation or building details, with the exception of the shielding structure, are not included in this report.

Components of the secondary system, which are located on the first floor of the building adjoining the shielding structure include the stack fan, refrigeration unit, hydropulse unit, oil-water heads for the circulating pump, hot water tank, booster pump, deaerating condenser and condensate pumps. The control room and a storeroom are also located on the first floor. The oil-water heads of the circulating pump are enclosed in one foot of concrete shielding to isolate the water section of the pump in the event of diaphragm failure.

Secondary system components located on the second floor include the air receiver, oil filter, water separator, air dryer of the instrument and plant air system, salt water evaporator, distilled water storage tank, distilled water pump, turbo-generator unit, cooling water heat exchanger, pumps, makeup tank, duplex salt water strainer and the boiler feed pumps.

The ventilation stack is located outside the building and may be supported directly from the building for about four-fifths of its length.

The cooling water pumps are located in a separate shed at the water source. For estimating purposes, it is assumed that the distance between the building and the cooling water pumps is approximately five hundred feet. Protection against freezing is provided for the water lines by wrapping the lines in a common conduit and providing either electrical or steam heat for the conduit. A convenient source of salt water is assumed. At locations where salt water, or fresh water is not available, the cooling system can be arranged in one of two alternate methods. The first of these is a closed cooling water system in which the cooling is done by an air cooler and the cooling duties arranged in a manner similar to that shown for the direct pumping arrangement. The second alternate method is an air cooled condenser and air coolers for the remaining cooling loads. The first alternate method is preferred since it is more compact and leads to more favorable plant control than the latter.

2. Shielding Arrangement

The arrangement of shielding for the primary system components is shown in Fig. 3. Components of the primary system located in this area are the reactor, steam holdup tank, steam block valve, dump tank, mist separator, low pressure recombiner, feedwater heater, aftercondenser cold traps, charcoal filter, pulsafeder pump, off gas cooler, dump cooler, two coolers on the pulsafeder pump suction lines, samples, and all valves which must be shielded.

The shield is composed of three tanks fabricated from one inch steel plate. The tank immediately around the reactor is filled with lead shot and water. The next tank section is filled with iron and water and provides an annulus around the reactor and the dry cell containing the majority of the primary system components. The outer tank of the shield is water filled and provides an annulus which completely encloses both inner tanks. The valves are located in a compartment of the dry cell at the opposite end from the reactor and is separated from the other components by a six inch lead wall. The steam holdup tank is located in the iron and water filled annulus.

The removable plugs covering the shielded area are fabricated from one-half inch steel plate and are filled for one-half their depth with iron and water and with water for the remainder of their depth. They are reinforced to permit easy removal by crane.

The charcoal filter is located directly beneath the reactor in a tank which is an extension of the tank surrounding the reactor. Since the filter requires separate cooling and less shielding than the reactor, it is isolated by a division plate which forms a floor for the reactor shield tank.

Steel structural members are provided to support the shield and reactor components. The six main columns will be extended to support the bridge crane which is located directly above the shielded area.

3. Plant Erection

Erection costs and procedures have been prepared considering only the equipment necessary to erect the plant components. With the exception of shielding, the cost of the building and its erection has not been included.

It has been assumed that the building will include:

- a. A concrete pad as shown on Figs. 2 and 3.
- b. A two story section for containment of the secondary system components.
- c. The main columns for the remainder of the building, the roof of this section, and the upper siding.

Coordination with the building contractor is expected. The following erection schedule is set up to allow erection in one season.

- a. Transport all material, 90 to 100 workmen, and three (3) B&W Supervisors to the job site.
- b. Begin the erection of shielding tanks and structurals and prepare foundations for large equipment.
- c. Continue welding of shielding tanks and proceed with installation of all equipment items.
- d. Proceed with erection of shielding tanks, install reactor, fit, place and weld pipe lines, valves and fittings.
- e. Fill shielding tanks with lead and steel shot, insulate pipe lines.
- f. Apply external insulation to shielding, install and connect all controls.
- g. Fill shielding tanks with water and conduct final tests.

Three shifts of thirty to thirty-five men each will be required. These shifts will work on a fifty-six hour work week.

Construction equipment which is to be transported to the job site includes four gas driven welding machines complete with fuel, and rigging equipment. Weight of this equipment is estimated at five tons.

4. Subassemblies

Complete subassemblies consistant with air transport restrictions have been considered. The turbo generator and pump-motor sets will be unit assemblies. The instrument panel will be delivered completely wired and tested. The evaporator is a complete unit and piping is prefabricated and limited in size to air transport restrictions. Control valve stations will be completely assembled and in many cases include adjoining equipment. A tabulation of overall dimensions, weights, and cost of the station components follows.

5. Component Size, Weight and Cost

NO.	DESCRIPTION	OVERALL SIZE			WEIGHT (lbs.)	COST
		WIDE	DEEP	LONG		
C-100	Deaerating Condenser	18"	18"	12'-8"	4,400	\$ 4,608
C-101	Evaporator				7,000	13,455
C-102	Dump Line Cooler	1 3/4"	6'-3"	7'-0"	80	647
C-103	Air Compressor After-cooler	3 1/2"	21 1/2"	11'-10"	150	Included with instrumentation
C-104	Feedwater Heater Condenser	12 1/2"	12 1/2"	10'-0"	750	4,221
C-105	After Condenser	12 1/2"	12 1/2"	10'-0"	750	4,221
C-106	Let Down Line Cooler	1 3/4"	1 3/4"	3'-0"	20	204
C-107	Pulsafeeder Suction Cooler	1 3/4"	3'-2"	9'-0"	70	555
C-108	Salt Water to Fresh Water Heat Exchanger	9 3/4"	9 3/4"	6'-7"	13,220 300	27,711 638
C-109	Pulsafeeder Suction Cooler	1 3/4"	3'-2"	9'-0"	70	5,549
D-100	Reactor	4'-5 1/2"	4'-5 1/2"	12'-7"	24,465	83,229
F-100	Holdup Tank	3'-1"	2'-9"	17'-0"	4,370	8,860
F-101	Distilled Water Storage Tank	4'-9"	4'-9"	7'-8"	770	1,062
F-102	Hot Water Tank	2'-6"	2'-6"	7'-0"	1,290	621
F-103	Air Receiver	2'-6"	2'-6"	8'-0"	1,070	Included with instrumentation
F-104	Dump Tank	21"	3'-2 1/2"	13'-0"	885	3,348
F-105	Fill Tank	11"	15"	2'-11"	260	1,805
F-106	Cooling Water Makeup Tank	2'-6"	2'-6"	4'-0"	2,080	626
F-107	Blowdown Tank	3'-1 1/2"	3'-1 1/2"	7'-0"	2,980	1,283
G-100	Air Compressor Oil Filter	9 3/4"	9 3/4"	4'-4"	300	134,932
G-101	Duplex Filter	3'-0"	22"	2'-0"	200	690
G-102	Mist Separator	12 3/4"	12 3/4"	3'-2"	570	1,850
G-103	Recombiner	12 3/4"	2'-4 1/2"	6'-6"	385	2,746
G-104	Charcoal Filter	6'-0"	8'-0"	5'-0"	1,065	7,163
G-105	Cold Trap	13"	6 5/8"	7'-0"	200	1,264
G-105A	Cold Trap	13"	6 5/8"	7'-0"	200	1,264
K-100	Refrigeration Unit	2'-6"	2'-8"	4'-10"	1,300	805
J-101	Air Ejector Condenser	2'-5"	4'-2"	3'-9"	Included with Condenser	Included with turbine
J-102	Hot Water Booster Pump	11"	10"	20"	120	167
J-103	Boiler Feed Pump	2'-2"	4'-6"	3'-6"	3,000	3,114
					59,100	153,995

NO.	DESCRIPTION	OVERALL SIZE			WEIGHT (lbs.)	COST
		WIDE	DEEP	LONG		
J-103A	Boiler Feed Pump	2'-2"	4'-6"	3'-6"	59,100 3,000	153,995 \$ 3,114
J-104	Cooling Water Pump	2'-0"	2'-0"	8'-0"	2,500	1,483
J-104A	Cooling Water Pump	2'-0"	2'-0"	8'-0"	2,500	1,483
J-105	Air Compressor	2'-6"	2'-8"	4'-10"	1,340	Included with instrumentation
					68,440	
J-105A	Air Compressor	2'-6"	2'-8"	4'-10"	1,340	160,075 "
J-106	Turbine				22,000	57,471
J-107	Circulating Pump				1,000	8,050
J-108	Condensate Pump	12"	12"	2'-3"	880	1,323
J-108A	Condensate Pump	12"	12"	2'-3"	880	1,323
J-109	Stack Fan	3'-0"	2'-8"	4'-6"	200	328
J-110	Cooling Water Pump	12"	12"	23"	150	253
J-110A	Cooling Water Pump	12"	12"	23"	150	253
J-111	Distilled Water Pump	12"	12"	17"	225	270
J-111A	Distilled Water Pump	12"	12"	17"	225	270
L-100	Stack	2'-6 1/4"	2'-6 1/4"	50'-0"	1,580	684
L-101	Air Dryer	3'-3"	5'-6"	6'-0"	2,600	Included with instrumentation
					99,670	
L-102	Crane	4'-0"	4'-0"	15'-0"	36,000	8,625
N-100	Electric Generator	Included	with	turbine		238,925
N-101	Dump Tank Evaporator Heater	Included	with	tank		
N-102	Recombiner Heater	Included	with	recombiner		575
N-103	Reactor Preheat	Included	with	reactor		
N-104	Dump Line Heaters	Included	with	cooler	100	
	Instrumentation Controls and Air System	See	Detail Drawings		15,600	150,750
					151,370	
	Shielding				2,369,090	217,612
						607,862
	Insulation for Plant and Shielding (85 percent Magnesia)				2,200	3,770
	Reactor System Component Insulation				1,200	920
	Valves				3,400	11,719
	Pipe and Fitting				32,405	26,121
	Sampler				3,500	11,000
					194,075	661,392
					2,369,090	
					2,563,165	

K. OPERATIONAL PERFORMANCE

1. Core Operation and Nuclear Performance

The boiling aqueous homogeneous reactor has several distinctive features which are especially suited for remote locations. The most striking advantage is the inherent stability of this type.

Stability against rapid reactivity additions has been demonstrated on the HRE⁽¹⁴⁾. Stability against boiling fluctuations has been investigated theoretically by J. M. Stein and P. R. Kasten⁽¹⁵⁾ and demonstrated experimentally in the Supe reactor by P. R. Kasten⁽¹⁶⁾.

The effects of temperature and void fraction on power level and operational characteristics are discussed in Section F.

Fig. 45 indicates steam pressure in the secondary system as a function of reactor power.

2. Startup

For the initial startup the fuel solution will be contained in the fuel dump tank (F-104). The heater on the recombiner (G-103) will be on and all cooling water flows adjusted to normal rates. The evaporator at the bottom of the dump tank is operating, evaporating steam at the rate of 500 lbs/hr which is condensed in the second condenser (C-105). Electric heaters on the reactor pressure vessel (D-100) are on and the vessel heated to 220 C. As soon as the reactor vessel is up to the desired temperature the condensate pulsafeeder feed pump (J-107) is started and condensate is pumped from the condenser hot well (C-105) to the reactor vessel. This condensate passes between the reactor vessel and titanium liner and is heated by the pressure vessel wall. As soon as the reactor vessel is filled with steam at 240 psia or higher, the valve blocking the flow of fuel from the dump tank to the fuel pulsafeeder feed pump is opened and fuel solution is pumped into the reactor vessel. Heaters on the fill line

STEAM PRESSURE VERSUS REACTOR POWER

AVERAGE SPECIFIC POWER = 8.45 KW/LITER
CORE DIAMETER = 27 INCHES

REACTOR PRESSURE = 1150 PSIA

STEAM PRESSURE PSIA

1000 PSIA

800 PSIA

600 PSIA

400 PSIA

200 PSIA

REACTOR POWER KILOWATTS

heat the solution to 200 C.

When critical level is reached in the reactor vessel the neutron flux rises from source level to a point where sufficient nuclear power is being generated to maintain the reactor just critical at progressively increasing temperature, as additional fuel is added. As nuclear power generation proceeds, the temperature control on the letdown valve starts letting steam, hydrogen and oxygen to the low pressure system. When the normal level in the dump tank is reached, the automatic level controller throttles the valves on the pulsafeder suctions to maintain a constant level.

Power withdrawal from the reactor can now begin. When the turbine is heated and the generator synchronizes with the standby diesel-electric generator, the turbine governor setting is increased and plant load transferred.

As reactor power is increased, the amount of steam letdown from the reactor vessel to the low pressure system will increase automatically. Control of this letdown is discussed in Section I. The uranium remaining in the dump tank (F-104) is gradually transferred to the core as the dump tank solution is diluted by condensate from the condensers (C-104 and C-105). A synchronous generator is used to maintain a constant electrical frequency and the speed controlling governor on the turbine controls the steam flow to the turbine to meet load requirements. Control of the reactor power will thus be completely automatic.

3. Shutdown

The plant electrical load will be transferred to the standby generator. The steam valve from the reactor is then closed and the reactor power allowed to decay to the normal heat loss from the reactor system.

The cooling water flow to the dump line cooler (C-102) is increased to maximum and an automatic-controlled dump initiated. A throttling valve in the dump line controls the dumping rate to maintain a temperature of 90 C at the dump valves.

The dump tank evaporator (N-101) is left on to maintain the fuel solution in the dump tank at 100 C for 24 hours. This will prevent uranium precipitation due to decay beta and gamma activity in the fuel solution.

4. Long Term Operation

Samples of fuel solution are to be removed at intervals of one month and shipped to a facility for chemical analysis. The overall corrosion rate of the stainless steel parts of the system is determined from the nickel concentration in the solution. The corrosion of the titanium liner is determined from the titanium concentration.

The pH of the solution is determined at regular intervals and additions of sulfuric acid are made to maintain a proper hydrogen ion concentration. Sulfuric acid is used up when uranyl sulfate corrodes metals. A determination of pH on the site with a pH paper will probably be adequate. Conventional glass electrode pH meters are not advisable since the electrode breaks down when exposed to the intensely radioactive fuel solution.

Periodic additions of fuel are needed to override fission product poisons as shown in Fig. 17, and to replace burnup. Approximately 1.32 gm U-235 are destroyed per megawatt per day⁽¹⁷⁾.

One fuel addition every two weeks will probably be sufficient. A fuel addition system is provided to inject fuel or sulfuric acid into the dump tank. The addition is placed in the fill tank (F-105) and 80 psig air pressure applied to the tank. The valves between the fill tank and dump tank are then opened and the fuel is forced into the system. A sight glass is provided on the fill tank to prevent excessive air from being blown into the reactor system. After the fuel addition, the valves to the dump tank are closed and the fill tank vented to the stack. The frequency at which fuel additions and adjustment of pH are required is to be determined in a prototype of the system.

5. Heat Balance

In calculating plant heat balances several assumptions were made regarding the nature and magnitude of the various loads. These assumptions are discussed further in the paragraphs which follow. Table 5 shows major heat balance items at the loads considered. Complete heat balance information for the "maximum" load condition is shown on the Engineering Flow Diagram, Figure 1.

Maximum Load

The maximum design reactor load was set at 1500 kw by a preliminary plant heat balance. In making the final analysis, the maximum specified loads to the station of 125 kw of electricity and 400 kw of heating were considered. A 73.5 kw heat load to the makeup evaporators was assumed. This load corresponds to 250 lb/hr of distilled water, which is considered more than ample for plant needs. Air ejector requirements of 130 lb/hr of throttle steam are included. The results of the heat balance indicate a maximum plant electrical output under the above conditions of 200 kw. After subtracting 125 kw for station requirements, 75 kw remain for possible use by plant auxiliary equipment. Since the installed capacity of all plant equipment, operable at any given time, is only about 90 kw, it is believed that the maximum station load requirements can be satisfied with ample margin of safety.

Normal Load

This load is considered representative of mean operating conditions. Station heating electrical demands were based on the load factors suggested in the specifications. The electrical load factor of 75 percent was assumed to apply to the 75 kw of electricity set aside for plant auxiliaries at "maximum" load. Evaporator and air ejector loads were considered to be the same as specified for maximum load.

3/4, 1/2 and 1/4 Normal Load

TABLE V
SYSTEM HEAT BALANCE

Load Condition	Maximum	Normal	$\frac{3}{4}$ Normal	$\frac{1}{2}$ Normal	$\frac{1}{4}$ Normal
Reactor Heat Load - kw	1500	1080	875	676	475
Total Electrical Load - kw	200	150	112.5	75	37.5
Heating Load - kw	400	200	150	100	50
Evaporator Load - kw	73.4	73.4	73.4	73.4	73.4
Total Secondary Steam - lb/hr	5215	3760	3055	2330	1055
Turbine Steam - lb/hr	5085	3630	2925	2200	1525
Air Ejector Steam - lb/hr	130	130	130	130	130
Secondary Steam Enthalpy - Btu/lb	1199.9	1204.5	1204.1	1203.0	1200.0
Secondary Pressure From Boiler - psia	225	405	500	615	730
Total Extraction Steam - lb/hr	1775	1026	840	649	454
Extraction Pressure - psia	30	30	30	30	30
Extraction Enthalpy - Btu/lb	1130	1130	1129	1136	1148
Extraction Steam to Heating - lb/hr	1499	750	564	373	184
Extraction Steam to Evaporator - lb/hr	276	276	276	273	270
Steam to Main Condenser - lb/hr	3312	2604	2085	1554	1071
Turbine Exhaust Enthalpy - Btu/lb	1022	1038	1041	1062	1092
Condenser Vacuum - in.Hg	28	28	28	28	28
Feed to Feed Heater - °F	127.3	138.0	146.6	160.6	188.8
Feed to Boiler - °F	253.1	256.4	257.7	258.7	259.1
Reactor Let-down Flow - lb/hr	540.3	389.5	315.0	243.0	171.0
Steam Enthalpy From Recombiner - Btu/hr	1567	1567	1567	1567	1567
Primary Steam to After-Cond.(C-105) - lb/hr	69.2	81.0	88.4	104.3	110.6
Pressure of Steam in After-Cooler - psia	35	35	35	35	35

L. MAINTENANCE

All components in the reactor system which are subject to failure are designed to make remote removal possible.

The system valves are located in a separate shielded compartment. The two flanges on each valve are secured by one set of thru bolts. The flanges are located in a horizontal plane to make the bolts accessible from the top.

The pulsafeeder heads may require replacement periodically. The connecting lines are flanged and located so that the bolts are accessible from the top. Jackets through which refrigerant can be circulated are installed next to the flanges, making it possible to freeze an ice plug in the line. The flanges can then be broken and the pump removed without removing the fuel inventory from the reactor system. The pulsafeeder pump used on the Homogeneous Reactor Experiment was replaced several times remotely.

The electric heaters on the dump tank are patterned after the HRT Pressurizer Heaters and may be replaced remotely. Thermocouples and the heaters in the recombiners are also remotely replaceable.

Flanges are provided on all major components to make removal possible even though it may be difficult. The reactor equipment is waterproofed to allow flooding of the reactor compartment. Difficult maintenance jobs can be done underwater. The use of water shielding will probably not be necessary to change valves and pumps.

The tube bundle in the reactor vessel can be removed by unbolting the large flange at the top of the vessel. Disposal of the radioactive reactor components will require the improvisation of shielded carriers or facilities for storing hot equipment.

The method used to remove the colandria of the Chalk River reactor would probably be applicable. The hot component was dropped into a canvas bag on a sled which was dragged to a burial ground by a shielded tractor and a long cable. The HRE was dismantled in a similar fashion using a shielded truck. An 18 ft. deep pool of water was constructed at the HRE site to store components for examination.

The maintenance experience on the Homogeneous Reactor Experiment⁽¹⁴⁾ was used as a guide in laying out the equipment. Additional experience will be gained when the Homogeneous Reactor Test is operated at Oak Ridge National Laboratory.

M. LOGISTIC SUPPORT OF OPERATIONS

As a result of the large power per pound ratio and the absence of combustion wastes the logistic support of operations for this type of plant will be considerably less than for a conventional power unit.

For purposes of estimating the fuel requirements, it is assumed that the entire charge of 4.8 kg of fuel will be replaced every five years. It has been calculated that fuel addition will be necessary at the rate of 0.58 kg per year. The total amount of fuel required for a twenty year period amounts to approximately 33 kg. It is suggested that a five year supply of fuel be stored at the station.

No provisions have been made for waste fuel recovery. It is planned that the waste fuel will be stored locally in a shielded container.

Periodic samples are to be analyzed to determine the rate of corrosion in the system. Since a chemical facility to perform this analysis has not been included in the design of the station it is planned to transport the sample to a site where the analysis can be performed. The weight of the package to be transported will be approximately three hundred pounds. The samples removed at regular intervals are accumulated at the site and shipped to the analytical laboratory when weather permits.

It is suggested that the following spares be provided at the station at the start of operations:

1. A spare for each primary system valve - excluding the valve operator.
2. Three metal diaphragm valve operators and six metal diaphragms.
3. Two pulsafeeder heads.
4. Six diaphragms for the secondary system valve operators.
5. Miscellaneous secondary system materials such as gaskets, packing, instrument tubing and piping.

Sulfuric acid will be added periodically to the fuel solution. It is predicted, however, that the amount will be small and, therefore, it is not considered a logistic problem. Two - 5 lb. bottles of 36N acid should be an adequate supply.

Oxygen is fed continually to the fuel solution. Between twenty-four and thirty standard oxygen cylinders will be required per year. Shipment of liquid instead of compressed oxygen, and the use of an on-site oxygen generator, are alternatives which merit consideration.

Miscellaneous operational replacement materials or parts will undoubtedly be required in addition to those already mentioned. It is not likely, however, that these requirements will exceed a few hundred pounds a year. Prototype operation will be used to help predict the logistic support of operations.

N. PROTOTYPE PLANT

The requirements of a prototype plant to be built in the United States vary depending on the location of the plant and the specific regulations of various authoritative groups. The prototype design is also dependent on the particular features being tested. For example, shielding can be tested either by actual duplicate construction or by simulated mock-ups. Sub-assembly and package planning can be checked by either a duplicate layout or by scale models. The essential differences between a remote location reactor and its prototype can be broken down into three categories:

1. Containment
2. Instrumentation
3. Testing

1. Containment

Three methods of containment are proposed, each of which has definite advantages. The ideal proposal is to build an exact duplicate of the remote location plant. Every important feature can be checked simultaneously at one site and the interdependence of components observed. A probable restriction to this proposal is that the site would, for safeguard reasons, have to be a remote area. The National Reactor Testing Station at Arco, Idaho is ideal for this purpose. Many test facilities, such as a hot laboratory, are available at that site.

The second proposal requires one large containment tank to house the entire primary system, dump tanks and shielding arrangement. Steam equipment can be constructed as per remote locate plan. The containment drum would have to be about thirty-six feet in diameter and about thirty-five feet long, designed for about 25 psia. The volume of the tank is sufficient to withstand system flashing, such as would occur in a major rupture of the system.

Another proposal is to eliminate the shield, as designed, and use two small containment tanks. The pressure vessel container would be ten feet in diameter and eighteen feet high with a design pressure of 140 psia. It should have a five foot diameter hemispherical closure, permitting easy removal of the pressure vessel dome and for normal operation is filled with helium to eliminate argon activation problems. The containment drum for the components would have to be about ten feet in diameter, twenty feet long. This system does not allow for testing of shield or equipment arrangement but should be less costly than unitized containment.

2. Instrumentation

The system is designed so that additional instrumentation is unnecessary for normal operation; however, for testing and check purposes it will probably be desirable to include additional compensated ion chambers and fission chambers. Additional flow meters and thermometers are required to obtain accurate heat balance data.

3. Testing

The major item in this category is a hot laboratory to analyze samples and investigate corrosion of the system. A staff of ten to twelve technical people are required for test operations and analysis.

O. COST ANALYSIS

1. Single Plant, Arctic Location

a. Components	\$ 661,332
b. Erection	536,000
c. Transportation (2,559,665 lbs)	511,933
d. Fuel (20 years)	5,280
e. Engineering	<u>75,000</u>
Total	\$1,789,545

2. State Side Prototype Plant, No Containment

a. Components	\$ 661,332
b. Erection	154,890
c. Fuel	5,280
d. Engineering	75,000
e. Operation and Testing	<u>300,000</u>
Total	\$1,196,502

No estimate has been made of containment cost, as this will depend on the selected plant location and the degree of containment desired.

3. Estimated Costs of Twelve Plants, Arctic Location

a. Components	\$ 575,300
b. Erection	536,000
c. Transportation	511,933
d. Fuel	5,280
e. Engineering	<u>6,250</u>
Total	\$1,644,763

APPENDIX I - Alternate System A

Boiling Reactor - Low Pressure Recombiner - Titanium Clad Reactor Vessel.

An alternate reactor system based on the assumption that a titanium clad reactor vessel can be designed has been investigated. If a mechanically sealed liner can be developed this could also be used. A flowsheet of this system is shown in Figure 46.

The system is basically the same as the primary design. The pulsafeeder feed pump to transfer condensate from the condenser hot well to the bottom of the reactor vessel is eliminated. The condensate is allowed to overflow into the dump tank and pumped directly into the bottom of the reactor vessel by the single pulsafeeder pump.

The main advantages of this system are ease of operation, greater reliability from a corrosion standpoint, and reduction of oxygen consumption by a factor of five.

APPENDIX II - Alternate System B

Boiling Reactor - High Pressure Recombiner

An alternate reactor design incorporating high pressure recombination of the radiolytic hydrogen and oxygen in the steam space of the reactor vessel has been investigated. This system also incorporates a high pressure surge tank which improves the nuclear behavior of the system and also acts as a fuel storage tank. The flowsheet of this system is shown in Figure 47.

By incorporating both a high pressure recombiner and storage tank the necessity for a letdown valve and dump valve is eliminated. The pulsafeeder feed pump will be operated only at startup and to make fuel additions. Thus maintenance problems should be greatly reduced.

The system will require the development of a suitable method for cladding or installing mechanically sealed titanium liners in the reactor vessel, surge tank and connecting piping. Development work of this nature is now in progress to provide titanium lined systems for handling thorium slurries at ORNL, The Babcock & Wilcox Company, and elsewhere.

The design of the recombiner system is based on experiments performed at ORNL (18). A calrod heater element is inserted in a 3/4" SS thimble in the center of the bayonet tube bundle. The steam containing radiolytic hydrogen and oxygen rising from the boiling fuel solution is baffled to flow alternately past the boiler tubes and the glowing calrod element. As steam is condensed the mixture of steam, hydrogen and oxygen becomes combustible. As it passes the calrod unit, it is ignited and burns until it is below the combustible

limit. The mixture then passes the boiler tubes again, more steam is condensed, etc. until all of the hydrogen and oxygen is recombined. The recombiner tested at ORNL was operated at pressures up to 70 psig and used spark plugs to ignite the gas mixture. Before a recombiner of this type can be used in a reactor, a prototype should be built and tested for operational reliability and safety.

The design and operation of the secondary system is identical to the reference design. Operation of the primary reactor system is considerably different.

At startup the fuel solution is located in the surge tank. Any liquid in the hot well of the low pressure recombiner-condenser is pumped into the surge tank with the pulsafeeder feed pump and the valve between the surge tank and condenser closed. The fuel solution in the surge tank is heated to 200C by electric heaters on the evaporator at the bottom of the surge tank. The surge tank temperature is maintained at 200C by an automatic controller throughout operation. Oxygen gas is now injected into the surge tank by the oxygen addition system. This forces the fuel solution out of the surge tank into the reactor vessel. As soon as a critical level is attained in the reactor vessel the nuclear chain reaction begins generating heat and the fuel solution temperature rises. Addition of oxygen is continued until the reactor pressure reaches 637 psi. The reactor temperature will be 256C and the surge tank will contain an oxygen partial pressure of 410 psia at zero power. Power removal from the boiler is now initiated. As more power is removed from the reactor the void fraction in the core in-

creases and the critical temperature is lowered. This lowers the steam pressure in the reactor vessel. The excess pressure in the surge tank then forces solution to flow from the surge tank to the reactor to compensate for the loss of reactivity due to the increased void fraction in the core. In order to obtain a reactor performance curve which would allow reactor control by power demand but reduce the pressure change in the reactor to 50 psi between zero and full power, a surge tank vapor volume of 8 ft.³ was chosen. The behavior of reactor pressure as a function of power level is shown in Figure 48.

The boiler steam pressure as a function of reactor power is shown in Figure 48. The variation of pressure is much less than in the system without a surge tank. This reduces the maximum steam pressure sufficiently to permit elimination of the reducing valve.

A parameter study to determine the effect of surge tank temperature on the system was made. A variation of 20C in the surge tank temperature causes only 12 psi change in the reactor operating pressure at zero power (Figure 49).

In order to shut the reactor down during either normal or emergency conditions, the valve connecting the vapor space of the surge tank with the low pressure condenser is opened. When the gas and steam pressure in the surge tank is reduced the fuel solution is forced out of the reactor into the surge tank and the fission chain reaction is stopped. The condenser is equipped with a calrod recombiner similar to the one in the reactor vessel to recombine radiolytic gas produced during and after shutdown. As soon as

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300 143

SURGE TANK PARAMETERS

the heat is removed from the reactor fluids and the temperature in the condenser is below 100C, the oxygen gas is bled out of the system through a charcoal filter bed. The water which has collected in the condenser hot well during the shutdown can then be pumped back into the surge tank for the next startup.

- Shielding and equipment arrangement would be similar to the primary design. Since there are fewer valves and components in this system a smaller shield would be required.

APPENDIX III - Alternate System C

Non-Boiling Homogeneous Reactor

As an alternate proposal, a study was made of a non-boiling reactor system with bayonet cooling tubes immersed in the pot of uranyl sulfate solution. The need for a titanium lined vessel can be eliminated since an oxygen concentration can be maintained in the non-boiling system. The core is pressurized to 1200 psia with oxygen gas. Recombination of radiolytic gas by a homogeneous catalyst in solution is used. The recombiner in the low pressure system is designed to handle only after-shutdown gas production. The pressure vessel is modified by reducing the height and lowering the tubes into the fuel solution. The system components, other than the recombiner and reactor vessel are essentially the same as those in the primary proposal.

Heat removal from this system is the major design problem. An analytical power removal study, based on heat transfer by natural convection, is presented in appendix VI. Subject to accurate determination of the variables, the immediate conclusion is that a power density of 6 to 8 kilowatts per liter of solution can be obtained with reactor pressure at 1200 psia. The final optimization should be a balance between the number of coolant tubes required for heat removal and their poisoning effect on the critical mass of the reactor. The optimization procedure was not performed for this proposal.

A three foot right cylinder, three feet high, with 250 one inch O.D. coolant tubes is assumed for calculations. Triangular pitch of the tubes is about 2 inches. The reactor can be operated at relatively constant pressure and constant temperature over the entire range of power and is brought

critical by pumping heated fuel solution into the core. This calculation with 250 tubes assumes a maximum to average radial neutron flux of about 1.71:1.00.

Nuclear calculations were performed to determine the critical mass and maximum to average neutron flux for a 26 inch diameter right cylinder, 3 feet high, containing 130 stainless steel coolant tubes, with a two inch stainless steel reflector. Critical mass, as calculated by a two group, two region method is about 9.4 kilograms. The calculated flux distribution is shown in Figure 50, and gives a ratio of 1.34:1.00 maximum to average thermal neutron flux in the radial direction. Based on this flux distribution, a right cylinder 30 inches in diameter, 3 feet high, containing 175 coolant tubes, should be sufficient to remove 1500 kilowatts of heat from the solution in the form of 200 psia steam. The critical mass is not expected to be appreciably altered by the increased vessel diameter. If Zircaloy tubes are used the critical mass is reduced to 5.6 kg for the 26 inch diameter cylinder.

The solution to the problems of uranium peroxide precipitation and two phase separation are the same as in the primary design.

Since a 600 psi overpressure of oxygen is present, the core solution will be saturated with dissolved oxygen. Oxygen will be dissolved in the fuel solution during startup by an oxygen addition system in the fill line to insure a proper concentration at startup. As previously discussed in the section on solution chemistry in the primary design, the presence of dissolved oxygen eliminates the hydrolytic precipitation of UO_2 by preventing the reduction of the uranyl ion. A corrosion rate of less than 10 mpy (19) is expected

RELATIVE THERMAL FLUX

FIGURE 50

on the 347 SS pressure vessel.

A concentration of 0.1 moles of copper sulfate per kilogram of solution is used to recombine the radiolytic hydrogen and oxygen formed in the reactor. Copper sulfate was used successfully in the Homogeneous Reactor Experiment (20) for this purpose. The copper sulfate concentration required has been calculated for various core temperatures as a function of overpressure (Figure 51) using the data of H. F. McDuffie et al of Oak Ridge National Laboratory. Necessary data and details for the calculations are presented in reference 8.

With a total reactor pressure of 1200 psia the overpressure on the system is 600 psi. A copper concentration of 0.1 M will allow full power operation at reactor temperatures above 220 C.

COPPER SULFATE CONCENTRATION REQUIRED TO RECOMBINE 100% OF RADIOLYTIC GAS

POWER DENSITY-10KW/L

40gm U/L $UO_2SO_4 \cdot H_2O$ SOLUTION

NO EXCESS H_2SO_4

FIGURE 51

APPENDIX NOMENCLATURE

A - area - ft^2

Sub: i - inside tube
o - outside tube
m - mean
l - region I
ll - region II

$aL^3 \Delta t$ - Grashof Modulus

Cp - specific heat - $\text{Btu/lb} - ^\circ\text{F}$

Do - tube diameter - ft

Dm - mean diameter - ft

Dv - molecular diffusivity - ft^2/hr

f - core void fraction

Gmax - maximum mass flow rate - lb/hr-ft^2

g - gravitational constant - ft^2/hr

h - conductance - $\text{Btu/hr-ft}^2-^\circ\text{F}$

Sub: i - inside tube film
cond - tube
crud - inside scale
m - condensate film
g - gas film
c - film

h_{fg} - specific heat of vaporization - Btu/lb

k - thermal conductivity - $\text{Btu/hr-ft-}^\circ\text{F}$

K_g - mass transfer coefficient for gas film - $\text{lb/hr-ft}^2\text{-atm}$

K_l - flow loss coefficient

L - axial dimension - ft

M - ordinary molecular weight of gas

p - pressure - atmospheres

Sub: i - between gas and condensate film
v - main stream
mn - ln mean partial pressure difference

APPENDIX NOMENCLATURE
(Cont'd)

P_o - maximum power density - Btu/sec - ft³
 $\bar{P}$ - average power density - Btu/sec - ft³
 Pr - Prantl Modulus
 Q - heat rate - Btu/hr
 r - distance in radial direction
 R - radial dimension - ft
 t, T - temperature
 Sub: i - between gas and condensate films
 l - condensate
 v - main stream
 U - overall conductance - Btu/hr - ft² - °F
 U_o - velocity proportionality constant
 U_s - relative steam velocity based on total area - ft/sec
 V - velocity - ft/sec
 V_o - molal volume at the normal boiling point
 vg - specific vapor volume - ft³/lb
 W - weight flow - lb/hr
 x, z - distance in the axial direction
 ρ - density - lb/ft³
 $\bar{\rho}$ - average density - lb/ft³
 Γ - condensate mass flow rate - lb/ft-hr
 μ - viscosity - lb/ft-hr

APPENDIX IV - Void Fraction Calculation

$$(\text{See ref. 4}) U_s = \frac{Q_s}{A_T} = U_0 \frac{f}{1-f} \quad \text{where } f \text{ is the local void fraction}$$

U_0 is a function of the pressure and is plotted on Fig. 52.

$$U_s(r, z) = \frac{\int_0^z P(r, z) u_g dz}{h_{fg}}$$

$$U_0 \frac{f(r, z)}{1-f(r, z)} = \frac{u_g}{h_{fg}} \int_0^z P(r, z) dz$$

$$f(r, z) = \frac{\frac{u_g}{h_{fg}} \int_0^z P(r, z) dz}{U_0 + \frac{u_g}{h_{fg}} \int_0^z P(r, z) dz}$$

Assuming cylindrical geometry:

$$P(r, z) = P_0 m(r) n(z) = P_0 J_0\left(\frac{2.405}{R} r\right) \sin \pi z/L$$

where P_0 = Maximum power density in the volume.

$$\begin{aligned} P_0 &= \frac{\int_0^z P(r, z) dz}{\int_0^z \sin \pi z/L dz} \\ &= \frac{P_0 L}{\pi} J_0\left(\frac{2.405}{R} r\right) (1 - \cos \pi z/L) \end{aligned}$$

RELATIVE VELOCITY CONSTANT VERSUS PRESSURE

$$f(r, z) = \frac{\frac{P_0 L v_g}{h_{fg} \pi} J_0\left(\frac{2.405}{R} r\right) (1 - \cos \pi z/L)}{U_0 + \frac{P_0 L v_g}{h_{fg} \pi} J_0\left(\frac{2.405}{R} r\right) (1 - \cos \pi z/L)}$$

Re-writing:

$$\frac{f(r, z)}{1 - f(r, z)} = \frac{P_0 L v_g}{U_0 h_{fg} \pi} J_0\left(\frac{2.405}{R} r\right) (1 - \cos \pi z/L)$$

Assume as an approximation:

$$\begin{aligned} \frac{\bar{f}_{\text{CORE}}}{1 - \bar{f}_{\text{CORE}}} &\approx \frac{C \int_0^R m(r) 2\pi r dr \int_0^L n(z) dz}{\text{VOLUME} = \pi R^2 L} \\ &\approx \frac{P_0 v_g}{U_0 h_{fg} \pi^2 R^2} \int_0^R J_0\left(\frac{2.405}{R} r\right) 2\pi r dr \int_0^L (1 - \cos \pi z/L) dz \\ \frac{\bar{f}_c}{1 - \bar{f}_c} &\approx \frac{2 P_0 L v_g J_1(2.405)}{2.405 \pi U_0 h_{fg}} \end{aligned}$$

But $P_0 = \frac{2.405 \pi \bar{P}_{\text{CORE}}}{4 J_1(2.405)}$

$$\frac{\bar{f}_c}{1 - \bar{f}_c} = \frac{\bar{P}_{\text{CORE}} L v_g}{2 U_0 h_{fg}}$$

$$\bar{f}_{\text{CORE}} = \frac{1}{1 + \frac{2 U_0 h_{fg}}{\bar{P}_{\text{CORE}} L v_g}}$$

APPENDIX V - Pressure Vessel Condenser Calculation

Flow Rates	.052	lb/min	H ₂
	.416	lb/min	O ₂
	116.7	lb/min	Steam @ 600 psia

Assume as design data -

- (a) Vessel diameter - 2 feet
- (b) One inch OD tubes
- (c) Triangular pitch = 1-3/4 inches
- (d) 1.485 ft² flow area
- (e) Minimum flow area (baffled) = .562 ft²
- (f) No. of tubes = 150
- (g) Coolant pressure = 225 psia
- (h) Core pressure = 600 psia
- (i) h_{crud} = 2000 Btu/hr - ft² - °F
- (j) h_{boiling} = 2000 Btu/hr - ft² - °F
- (k) h_{cond.} = $\frac{12}{.01125}$ = 1000 Btu/hr - ft² - °F

$$\frac{1}{U'} = \frac{1}{h_i \frac{A_i}{A_o}} + \frac{1}{h_{cond} \frac{A_m}{A_o}} + \frac{1}{h_{crud} \frac{A_m}{A_o}} + \frac{1}{h_m}$$

Where h_m is the conductance across the condensate film (see page 276, ref. 5 for a discussion on the occurrence of dropwise condensation). Equation 16, page 268, is recommended:

$$h_m \left(\frac{\mu_f^2}{k_f^3 \rho_f g} \right)^{1/3} = .0077 \left(\frac{4\Gamma}{\mu_f} \right)^{.4}$$

Condensate steam flow = 110.2 lbs/min

$$\Gamma = \frac{w}{N\pi D_o} = \frac{110.2 \times 60}{150 \times 3.14 \times .0833} = 168.9 \text{ lbs/hr-ft}$$

$$\left. \begin{aligned} \mu_f &= .272 \text{ lb/ft-hr} \\ k_f &= .363 \text{ Btu/hr-ft-}^\circ\text{F} \\ \rho_f &= 50.03 \text{ lb/ft}^3 \\ g &= 4.17 \times 10^8 \text{ ft/hr}^2 \end{aligned} \right\} \text{At } 480 \text{ F}$$

$$\frac{4\Gamma}{\mu_f} = 2482 \text{ - Turbulent flow}$$

$$h_m = 1543 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$$

$$\text{Then } U' = 305.8 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$$

$$\text{Similarly at } 400 \text{ F} \quad U' = 300.0$$

The method of Colburn & Høugen for condenser design with flow of non-condensable gas is as follows:

$$W dt_L = U'(t_i - t_L) = h_g(t_v - t_i) + h_{fg} [K_G(p_v - p_i)]$$

See reference 5, page 284

$$\left[\frac{K_G P_{mm} D_o}{\mu_v} \right] \left[\frac{\mu_v}{c_v D_v} \right]^{2/3} = f \left[\frac{D_o G_{max}}{\mu_v} \right]$$

$$\begin{aligned}
 D_o &= .0833 \text{ ft} \\
 \mu_v &= .070 \text{ lb/ft-hr} \\
 \rho_v &= 1.00 \text{ lb/ft}^3 \\
 G_{\text{MAX}} &= \frac{.468 \times 60}{.562} = 50 \text{ lb/ft}^2\text{-hr}
 \end{aligned}$$

The molecular diffusivity is found in reference 6.

$$D_v = \frac{.0166 T^{3/2} \sqrt{\frac{1}{M_A} + \frac{1}{M_B}}}{P (V_{OA}^{1/3} + V_{OB}^{1/3})^{2/3}} = .15 \text{ ft}^2/\text{hr}$$

$$\text{Then } K_G = \frac{8.1}{P_{mn}}$$

See reference 5, page 229.

$$h_G = \frac{.33 k_v}{D_o} (P_n)^{1/3} \left(\frac{D_o G_{\text{MAX}}}{\mu_v} \right)^{.6}$$

$$h_G = .00285 Q_{\text{REMAINING}}^{.6} \quad (\text{for 10 rows})$$

Curves of the other quantities are shown as Figures 53, 54, 55 and 56.

The result of numerically integrating the equations is that T_i is essentially the steam saturation temperature and the overall heat transfer coefficient is about constant at 303 Btu/hr/ft²-F. Then for a coolant pressure of 225 psia:

$$Q = UA\Delta T$$

$$(1500) (3415) = (303) (37.5)L (480 - 392)$$

$$L = 5.12 \text{ ft.}$$

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LOG MEAN GAS PARTIAL ΔP VERSUS FILM INTERFACE TEMPERATURE

GAS PARTIAL PRESSURE VERSUS HEAT REMOVED BY CONDENSATION

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APPENDIX VI

Heat Removal From A Non-Boiling Homogeneous Solution

Introduction

The system considered is a pot containing an aqueous homogeneous volume heat source. Cooling is to be accomplished by vertical coolant tubes extending through the solution to the bottom of the pot. A constant temperature will be maintained inside the tubes as a result of boiling at constant pressure and transferring heat by generation of steam within the tubes.

Calculations for this system are complicated by many factors. In the past it has been assumed that both conductive and convective heat transfer would play important parts. Second, it is known that the film coefficient varies quite drastically with specific power. Finally, the flow and temperature distributions are intimately associated and must be evaluated simultaneously.

While this analysis does not attempt to completely solve these problems, the basic approach has been to make pessimistic assumptions to calculate the system. Actual conditions are expected to be improved, although the degree of improvement should not be of orders of magnitude.

Two models were postulated; one has natural circulation taking place about each individual tube. The second model postulated was a total pot mass circulation with the central riser region and the periphery downcomer region each containing half the coolant tubes. A model combining these two effects, although desirable, is felt to be practically impossible to describe.

Individual Tube Circulation

It is assumed that the soup circulation will be about each individual coolant tube with a specific volume of soup assigned to each tube. Should any additional cross circulation develop between different tubes, as a result of varying specific power, the net result would be to flatten the radial temperature distribution throughout the pot. The volume about each tube is divided into a riser region and a downcomer region in the vicinity of the tube, called regions I and II respectively. Then for a heat balance in the riser:

$$WC_p \frac{dT_I(x)}{dx} = \frac{\bar{P} \pi A_I}{2} \sin \pi x/L - k \pi D_m \frac{dT(x)}{dr}$$

and in the downcomer region:

$$WC_p \frac{dT_{II}(x)}{dx} = \frac{\bar{P} \pi A_{II}}{2} \sin \pi x/L + k \pi D_m \frac{dT(x)}{dr} - 2h \pi R_o \{T_{II}(x) - T_s\}$$

These equations may be solved simultaneously by numerical integration and the results will show, that for most regions of interest, the temperature difference between the two regions is so slight that the conductivity contributions may be neglected. Then by applying the conditions that

$$T_I(0) = T_{II}(L) \quad T_I(L) = T_{II}(0)$$

the following equations were obtained:

$$T_I(x) = \frac{\bar{P} A_I L}{2WC_p} (1 - \cos \pi x/L) + \frac{\bar{P} L}{WC_p} \left\{ A_I + \frac{A_{II}}{R} \right\} \frac{e^{-Ax}}{1 - e^{-AL}} + \frac{\bar{P} A_{II} L}{2WC_p R} + T_s$$

$$T_{II}(x) = \frac{\bar{P} L}{WC_p} \left\{ A_I + \frac{A_{II}}{R} \right\} \frac{e^{-Ax}}{1 - e^{-AL}} + \frac{\bar{P} A_{II} L^2 A}{2WC_p \pi R} \sin \pi x/L - \frac{\bar{P} A_{II} L}{2WC_p R} \cos \pi x/L + T_s$$

where

$$A = \frac{2h\pi R_o}{WC_p} \quad R = 1 + \frac{A^2 L^2}{\pi^2}$$

Then integrating over the axial length of each leg and subtracting to find the average temperature difference gives the equation:

$$\Delta T = \bar{T}_I - \bar{T}_{II}$$

$$= \frac{\bar{P}L}{WC_p} \left[\frac{A_I}{2} + \left(A_I + \frac{A_{II}}{R} \right) \left\{ \frac{e^{-AL}}{1 - e^{-AL}} - \frac{1}{LA} \right\} + A_I \left\{ \frac{1}{2R} - \frac{AL}{\pi^2 R} \right\} \right]$$

The film coefficient can be found by use of the Grashof Modulus:

$$h_c = C \frac{k}{L} (a L^3 \Delta t)^d$$

where d depends on the value of the

modulus and C is some experimental constant, assumed to be .55 in this analysis and

$$h = \frac{1}{\frac{1}{h_c} + \frac{t}{k} + \frac{1}{h_i}}$$

The natural circulation can be computed by equating the average density differences to the flow losses:

$$L(\bar{\rho}_{II} - \bar{\rho}_I) = \frac{K_1 \bar{\rho} V^2}{2g}$$

$$(WC_p)^2 = f(\bar{T}_I - \bar{T}_{II}) = f(\Delta T)$$

K_1 is expected to be about 4.0 for most applications. By plotting the heat balance equations and the natural circulation equation on the same sheet

$(\Delta T \text{ vs } WC_p)$ for various power levels, the operational points may be determined. With known operational points, the average temperatures and temperature distributions are computed from the heat balance equations.

Total Core Circulation

In this model the circulation is assumed to be up the central portion of the

core and down the peripheral region, undergoing volume heating and tube cooled in both regions. The flow area and the number of coolant tubes in each region are assumed equal. Development of the equations is quite similar to the first method, resulting that:

$$\bar{T}_I - \bar{T}_{II} = \frac{.5035 P_{max} A_1 L^2 A}{W C_p \pi^2 R}$$

Results

The maximum temperature head for each model was calculated for the geometry discussed for model one.

$$T_{I(L)}^{MAX} - T_s = \frac{P_{max} A_1 L}{W C_p} \left[1 + \frac{1}{2R} + \frac{(1 + \frac{1}{R}) e^{-AL}}{1 - e^{-AL}} \right]$$

Total core circulation:

$$T_{I(L)}^{MAX} - T_s = \frac{P_{max} A_1 L}{2 W C_p R} \left[1 + \frac{.9245 (1 + e^{-AL}) e^{-AL}}{1 - e^{-2AL}} \right]$$

These two functions are plotted in Figure 57.

Discussion

The methods used in this calculation are believed to be quite reliable, however, some of the specific factors are still uncertain. It is thought that radiolytic gas bubbling appreciably improves the convection heat transfer as predicted by the Grashof Modulus. Since copper sulfate suppresses gas formation, this effect should not be present, however, there may be other effects still unknown. The system flow losses, while not as critical as the film coefficient, nevertheless do effect the resultant temperatures.

MAXIMUM TEMPERATURE HEAD VERSUS MAXIMUM SPECIFIC POWER

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NO. 340. M. DIETZGEN GRAPH PAI

MAXIMUM CORE TEMP. (°F)

MILLIMETER

500
400
300
200
100
0

TOTAL CORE CIRCULATION
INDIVIDUAL TUBE CIRCULATION

0

10

20

30

CORE MAXIMUM SPECIFIC POWER (WATTS/CM²)

FIGURE 57

1957

SUMMARY

The reference reactor system design is based entirely on present day technology. It is felt that no further development work is needed in order to justify building a full-scale prototype. A better understanding of the operational characteristics can be obtained only in an operating reactor.

Design factors which should be confirmed are nuclear stability and operating characteristics, maximum reactor power output, heat transfer coefficient in the steam radiolytic gas mixture and general system operability. The manpower requirements for operation and maintenance can also be confirmed by prototype operation. The prototype plant, exclusive of building, will cost approximately \$900,000 at Arco, Idaho. An additional \$300,000 will be required for six months operation and testing.

The alternate systems described in the appendices have some attractive features but will require additional development work. Alternate system "A" requires the use of a titanium clad reactor vessel or a mechanically sealed liner. A large scale development program has been undertaken by Oak Ridge National Laboratory to solve this problem. Development work is also being undertaken by Lukens Steel Company and The Babcock & Wilcox Company. The development of satisfactory cladding will require up to two years. Solution of this problem should not require financial assistance from the Army.

The development of both titanium clad vessels and a high pressure recombination system is required to make alternate system "B" feasible. The use of high pressure recombination eliminates the dump valves, letdown valves and the need

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