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THE POOR MAN'S PILE - FIRST APPROXIMATION

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THE POOR MAN'S PILE - FIRST APPROXIMATION

0. Abstract

A brief study shows that a modification of the high flux pile, designed to operate at 3000 kw and suitable for experimental use in a large university or other research institution, can be built for about $2,500,000, contractor's overhead not included. Of this, the pile and its associated operating equipment is about one-fourth. The main innovations, aside from reducing the power and thus eliminating much of the process water equipment, are the substitution of graphite pebbles for the beryllium reflector of the high flux pile, the elimination of a water head tank, and the simplification of the experimental facilities. Operation of the facility, experimenters' salaries not included, would cost about one-quarter million dollars per year if run continuously. The initial charge of U^{235} should last 1/2 to 2 years, and would be returned to the Atomic Energy Commission for chemical treatment.

1. Introduction

The work on the high flux pile having been considerably altered by the Atomic Energy Commission, the writer has taken time to look briefly into another interesting problem which has been suggested from time to time

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by several members of the Laboratory. The problem is that of designing a pile installation based upon the high flux pile as proposed but operating at a lower power and costing so little as to make its construction by universities or other non-governmental institutions a possibility. This has become known in the Laboratory as "The Poor Man's Pile."

This study has been made hurriedly and it should be clear that the Poor Man's Pile has not actually been designed. Rather, certain changes in the design of the high flux pile have been imagined and a very rough estimate of the cost based upon these imagined changes has been made. The scope of this estimate includes only the pile, the building in which it is housed, a minimum number of laboratories in this building, the necessary equipment for circulating the water, cooling it, and allowing it to decay after purging. No facilities are envisioned for chemical treatment of the spent uranium and no extensive hot laboratories are included in the estimate. No shops, administrative offices, or other facilities are included, since it is assumed that the owner institution will already have such facilities at hand.

2. Description

It is proposed that the Poor Man's Pile be operated at heat rate of about 3000 kw (1/10 of that of the high flux pile) and it seems likely that it will contain about 3 kg of U^{235}. Beryllium will be eliminated and graphite pebbles about 3/4" in diameter will be substituted for it. These

[redacted]

will be cooled with air and will be located outside the 3/4" thick rectangular tank which will enclose the active section of the pile. The flux of fast neutrons will be approximately 1/10 that of the high flux pile, whereas the flux of slow neutrons, particularly in the graphite reflector, will probably be of the order of 1/20 that of the high flux pile; that is, the thermal neutron flux will average about 2×10^{13} in the pile itself, with very little rise, if any, in the graphite reflector. In the following sections a more detailed description of the proposed pile is given. In Table I some of the specifications are summarized.

2.1 The Pile Proper

The active material in the pile will be highly enriched U^{235}. The degree of enrichment is not critical and it seems likely that any enrichment from about 50% to the highest available will be satisfactory. The active assemblies will closely resemble those planned for the high flux pile, except that the plates will be flat instead of curved and the end boxes will be replaced with a pair of prongs which will fit into holes in an aluminum base plate just under the active section of the pile and into other holes in an aluminum guide plate which will be lowered over the active assemblies when they are in position. This guide plate then will be secured to the tank walls. The active assemblies will be approximately 3" square in cross section and the aluminum tank will be approximately 15 x 18" inside. There will, therefore, be 30 spaces in which active assemblies could be put.

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Four of these (the second from either end in the second and fourth rows) will be used as shim-safety rod locations. A fifth hole located centrally at the end of the middle row will be used as a regulating rod location. The shim-safety rods will consist of active assemblies of slightly-less-than-normal external dimension to provide adequate clearance for their necessary vertical movement. Surmounting the active portion of these rods will be an absorbing portion similar to that planned for the high flux pile. The regulating rod will be a beryllium cylinder surmounted by an absorbing portion also similar to that planned for the high flux pile. Both the shim-safety and regulating rods will be moved by connecting rods extending through the bottom of the tank and emerging from the ceiling of a 20' wide tunnel underneath the pile. The drives for all five rods will be located in this tunnel. The general arrangement is illustrated on Drawing TD-458.

Operation of the control rods from beneath the pile will make it possible to have them in position and in operating condition during the loading of the pile, thus avoiding one of the more hazardous problems of the high flux pile. The shim-safety rods will make no contact with any of the active assemblies or with the upper or lower aluminum perforated plates previously mentioned. They will be guided in their travel by guide bearings mounted on the downward extensions of the rods which penetrate through the bottom of the tank and the shielding into the tunnel under the pile. The remaining 25 holes will hold a maximum of about 3.5 kg. of U^{235}. If not so filled, aluminum dummies will be inserted to prevent by-passing of the water.

Because of the low flux, only a small amount (approximately 4%) of reactivity can ever be taken up by the growth of $Xenon^{135}$. Moreover, continuous operation of the pile, although desirable, will not be as necessary as for the high flux pile. Both these factors tend to relieve the pressure for getting the pile started quickly after an accidental shutdown

and make it unnecessary to have an elaborate system of servo mechanism and interlocks for rapid starting of the pile. Provisions for complete shutdown of the pile if the power exceeds a certain value or if the period becomes too high will be all that is necessary.

The tank in which the active assemblies will be supported will be approximately 28' high and will measure 15" x 18" inside. Its wall thickness will be 1½" except at the active section where to permit a greater escape of neutrons it will be made 3/4" thick. Water will be introduced near the top of this tank through two feed pipes, each about 8" in diameter. Water will flow out of the tank at the bottom through two 8" aluminum pipe water outlets. The tank will be supported by hanging from the thick concrete shield overhead. Sideways motion of the tank at the bottom will be prevented by a guide which, however, will permit vertical come and go. Part of the weight of the tank will be transmitted to the bottom thermal shield by springs upon which the tank will rest. A small space for these springs is shown in the Drawing TD-459. The tank will not be connected to any of the experimental holes.

The water speed through the active section of the pile will be approximately 3' per second, since the circulation rate will be about 1500 g/min. Because of the lower rate of heat generation, the accumulation of scale on the heat transfer surfaces will not be serious and the water can be treated and its pH adjusted in a way such as to minimize aluminum corrosion without the complicating factor of also minimizing scale formation.

Because the pile will be operated at a low power, replacement of the fuel assemblies need be carried out only very infrequently. Even if operated continuously at full power, fuel assembly replacement would have to be carried out only twice yearly. Under actual operating conditions, replacement once in one or two years is more likely. During this period it may

TABLE I - GENERAL SPECIFICATIONS

Physics

Power	3000 kw
Fast neutron flux in pile	$\sim 10^{13}$ n/cm^2 sec.
Thermal neutron flux in pile	$\sim 2 \times 10^{13}$ n/cm^2 sec.
U^{235} in pile	~ 3 kg.
Time assemblies stay in pile	$\frac{1}{2}$ - 2 yrs.

Process Water

Circulation rate	1,500 gpm
Temperature at pile inlet	110° F
Temperature at pile outlet	125° F
Purge rate	15 gpm

Building

Main room, plan	99 x 131 ft.
Process cells, plan	47 x 60 ft.

become desirable to add additional assemblies to compensate for depletion. When replacement is necessary, the plug which closes the top of the aluminum tank will be removed and the active assemblies will be drawn up through the water and transported sideways until over the vertical discharge chute. They will then be lowered through this chute into a shielded cask on a truck which will have been driven into the tunnel underneath the pile for this purpose. During transportation of the assemblies across the top of the pile structure, shielding will, of course, be necessary. This can be supplied by a temporary enclosure of concrete blocks or by a specially built shielded cask running on rails. For facility in handling such a cask the building will be equipped with a five-ton crane.

Surrounding the rectangular aluminum tank will be, as previously noted, a bed of graphite pebbles which will completely fill a space 6' square and about 15' high (the full height of the graphite reflector). Outside of this 6' x 6' space, solid graphite will be stacked to an additional distance of $4\frac{1}{2}$'. Outside the solid graphite will be located 8" of steel plates and a similar 8" thick layer of steel will be located immediately underneath the graphite and above it as shown in TD-459. This steel constitutes the thermal shield. Heat will be removed from the graphite and from the shield by air which will enter through the ducts shown in TD-458 and TD-459 in a manner somewhat similar to that planned for the high flux pile.

The use of graphite pebbles next to the active section of the pile is necessary in order to remove the heat generated in the graphite and also makes it possible to remove the graphite and replace it with fresh graphite in the event that it should become damaged by fast neutron effects. Removal of the pebbles can be accomplished by a strong air suction, such as a vacuum cleaner. The solid graphite will also be provided with cooling holes.

The experimental facilities of the pile consist of 46 openings of which a few must be used for insertion of ionization chambers for control of the pile. The general arrangement of the various holes is clear from the attached drawings. It should be noted that the arrangements shown are illustrative only and that changes in them can be made without seriously increasing the cost of the pile. However, it is highly desirable from the point of view of cost that all experimental holes be either parallel or perpendicular to each other, since holes at other angles will increase the complexity of the construction job. The facilities of the pile are probably adequate to accommodate about 9 simultaneous experimental projects, not counting a large number of holes which could be simultaneously used for simple bombardments. The principal types of facilities planned are as follows:

a) Sixteen 4" square holes penetrating to regions of various intensity

b) One thermal column provided with a lead door but without a Bi window

c) One 18" square vertical hole proceeding to a region of moderate intensity in which large samples can be exposed

d) One 2' square hole proceeding to a region of relatively low intensity and fitted with lead gates and suitable for biological experiments

e) Twenty 2" square or round vertical holes proceeding to a region of high intensity and suitable for bombardment of materials

f) Four 1" round tubes for pneumatically operated sample capsules.

2.2 The Water System

The water system will be composed of vessels and piping of aluminum or stainless steel with the possible exception of the regulating rod, which will be beryllium. This rod, however, can be clad if necessary

to avoid a corrosion problem. The principal elements of the water system are similar to those of the high flux pile, except that it is planned to pump directly from the sump tank into the pile. No head tank is planned. The water then flows downward through the pile, emerging from beneath it and passing to a seal tank, the purpose of which, as in the case of the high flux pile, is to maintain at all times approximately 20' of water over the active portion of the pile. The water overflows from the seal tank into an overflow tank through a non-entraining type of overflow. From the overflow tank it is sucked into a flash-type cooler which is operated at a partial vacuum in which a portion of the water is evaporated, is condensed on cooling coils located within the formation tank itself and within which also any fixed gases, such as hydrogen, oxygen or nitrogen, are removed. From the flash tank the water falls through a barometric leg to the sump tank and then passes through the circuit again. All parts of the pile which are inaccessible and are wetted by water will be made of aluminum, but once the piping has extended beyond the limits of the pile shield, stainless steel or stainless clad mild steel will be used. The various tanks will be stainless clad mild steel and the condenser coils will be stainless also.

Water will be purged from the system at 1% of the circulation rate (that is, at 15 gallons per minute) and will be made up by demineralized water introduced into the system at the same rate. The purge will pass to one of two 120,000 gallon retention basins in which it will stay for a time ample to permit decay of Na^{24} to far below tolerance levels. No other serious activities are expected to be present and the water should be safe to discharge from the retention basin into any normal stream.

The second retention basin is supplied as a reserve in case of emergency need and will be completely empty under normal conditions.

The demineralized water system will be of small size (maximum capacity 20 gallons per minute) and will not require a separate building. A tank for demineralized water storage, having a capacity of 60,000 gallons (approximately the volume of the circulating system) will be provided and located just outside the pile building.

The cooling tower over which the cooling water is passed between passes through fresh condenser coils will be located on top of the rear portion of the pile building. All the process water equipment, with the exception of the retention basins will, therefore, be in or attached to the pile building itself.

The pumps will be made of corrosion-resistant alloy and three pumps will be installed, of which any two can circulate the water at the desired rate. The third pump is a standby for use when one of the others is out of commission. In order to permit operation of one pump during a possible power outage, a small gasoline-engine-driven electric generator will be installed which will come into action automatically in the event of a power failure. Actually, there is little danger to be feared if the water circulation should stop because of the relatively large heat capacity of the pile and the fact that it may be shut down promptly in the event of any disturbance of operations.

2.3 Air System

Air for cooling the graphite will be drawn in from outdoors through a filter and will pass through ducts underneath the pile floor, flowing upward around the outside of the thermal shield, across the top of the graphite and down through the graphite, then being collected into other ducts also under the floor of the pile building. The air will then pass to a pair of fans, each of which can handle 25,000 cubic feet per minute at a pressure

rise of approximately 40" of water. The air will be exhausted from the fans through a 200' high, 4' inside diameter stack. The radioactivity of this air which will be primarily 110 minute A^{41} will, of course, be considerably less than the radioactivity from the present Clinton graphite pile and its release in the vicinity of the pile building will, therefore, cause no hazard and will not interfere with most types of experiments. The fans will be enclosed in a concrete cell and will be provided with dampers by means of which either fan can be isolated. It is believed that this will be just as satisfactory and much less expensive than using water-filled seal pits as is the present Clinton practice.

2.4 Building and Facilities

A floor plan of the building is shown in Drawing TD-458. This plan is schematic and does not indicate the exact location of such necessary facilities as locker rooms, etc. The estimated cost of the building, however, includes such facilities. It is planned that the building have a structural steel frame and that its walls be of brick, tile or concrete block and that they be windowless. It is also planned that the building be air-conditioned in order to minimize difficulties with instruments and to make the building a comfortable place in which to work. The building will contain a five-ton space covering crane which will not, however, span the entire 99' width of the building. The crane span will probably be about 60'. Additional columns for the support of the crane and of the roof will probably be required in the building but are not shown in the floor plan.

Approximately 2,000 sq. ft. of laboratory space is specified as being necessary within the limits of the pile building itself. These will be on the first floor. On the second floor there will be offices, lockers, and the control room for the pile, which will look out into the main pile room.

At the rear (North on the drawing) end of the Pile Building, there will be several cells attached which will contain the process equipment, as previously noted, and will also contain the process equipment operating control room. The fans and the water system will be controlled from this room. The process equipment cells will probably be made of concrete with a thickness of about 2' in order to insure adequate shielding.

3. Estimated Costs

The estimated cost of the Poor Man's Pile is shown in the following table.

TABLE II
ESTIMATED CONSTRUCTION COSTS

Item	Description	Cost	Totals
1. Pile tank and contents	28' x 15" x 18" Al tank, 1½" wall thickness, with top plug, water inlets and outlets, control rod guides and assembly support grids (top and bottom). ~ 3500 lbs.	$ 5,000	
2. Control Rod drives	Drives (motors, gearing and electrical work) for 4 shim-safety rods and 1 regulating rod. Includes all parts control rods except portion actually inserted in pile.	10,000	
3. Graphite pebbles	About 35,000 lbs. 3/4" diam. graphite pebbles	10,000	
4. Graphite bars	4" x 4" x various lengths machined graphite, about 158 tons finished	117,000	
5. Steel thermal shield	8" thick on all 6 sides of graphite. About 250 tons, as 1" plate	60,000	
6. Lead gates and doors	Thermal column and biological hole doors and gates	2,500	
7. Concrete shield	9' thick shield as shown on TD-458, plus necessary hole liners, reinforcing steel and anchor bolts. About 1500 cu. yards concrete. Also includes estimate of about $40,000 for excavation, pilings, foundations and footings directly under pile	120,000	

8. Instrumentation	Air flow indicator-recorders (4), neutron ion chambers plus amplifiers and recorders (5), 12 point temperature recorder plus elements, 12 gamma ion chambers, amplifiers and recorders, 5 control rod position indicators, water flow recorders (2), 5 microphones, 2 friskers, 5 monitrons, all panel boards and equipment in both control rooms	$ 25,000	
Total Pile Proper	Sum items 1 through 8		$349,500
9. Flash cooler	Approx. 3300 kw. heat rate to cool water from 125° F. to 110°F. Vacuum type, internal condenser, steam jets to remove fixed gases. Stainless steel clad on mild steel, stainless tubes	30,000	
10. Seal tank	10' D x 25' H working cap'y. 12,000 gals., 80-20 stainless clad steel tank. 11,000 lbs.	12,000	
11. Overflow tank	Same size and specifications as seal tank	12,000	
12. Sump tank	25' D x 10' H working cap'y 30,000 gals. 80-20 stainless clad steel tank. 18,000 lbs.	20,000	
13. Demineralized Water Storage Tank	60,000 gal. 80-20 stainless clad steel tank, 23,000 lbs.	25,000	
14. Process water pumps and drives	I-R Ircamet chem. type Model SHC, 40 - 50' head at 800 gpm. 76% eff'c'y. Mechanical shaft seal, 15 HP motors, 3 pumps plus electric motor drives, plus 1 20 HP Hercules standby gasoline engine generator. Eqpt $6865	7,900	
15. Cooling tower	To cool 1520 gpm water from 100°F to 85°F with wet bulb of 80°F. Plan 22' x 37', overall height 27'. Std. redwood spray-filled tower, incl. all sumps and internal piping. Binks K-800 or equal. Price erected.	12,000	
16. Cooling water pumps and drives	I-R Type 4CRVL pumps, 60 ft. head. 3 required. Each 20 HP electric drives. One 30 HP Hercules standby gasoline engine generator. Equipment $1868	2,200	

17.	Retention basins	2 basins, each 120,000 gals., concrete with roof	$ 24,000	
18.	Demineralizer	20 gpm capacity	4,000	
	Total Process Water and Cooling Water Systems	Sum of items 10 through 18		$149,100
19.	Blowers and drives	2 - 25,000 cfm centrifugal blowers, pressure rise approx. 50" water, including motors, drives, switch gear and installation	25,000	
20.	Building	All building structure above ground level, including 5 ton crane, but excluding: tunnel under building, pile concrete and foundations, laboratories in building, duct work under building, and building air conditioning	1,250,000	
21.	Laboratories	5 laboratories, 2000 ft.^{2} total, complete with furniture but not with portable equipment, supplies or instruments.	64,000	
22.	Basement tunnel	See drawing	100,000	
23.	Duct work under building	Air and water ducts. See drawing.	20,000	
24.	Building air conditioning	Dehumidification, cooling and filtering.	40,000	
25.	Stack	200 ft. high, 4 ft. I.D., reinforced concrete stack	100,000	
	Total Building and Structures			1,574,000

Total Materials and Labor		2,097,600
Engineering and Design	10%	209,760
Contingencies	15%	314,640
Total, not including contractor's overhead		2,622,000

Inspection of the table shows that the pile, plus the necessary process equipment and instruments, accounts for only about one-quarter of the total cost of the installation. The building accounts for the rest. Thus it is evident that although some reductions in the cost of the pile itself are possible, as noted below, these will make little difference in the overall cost of the installation unless the size of the building is substantially decreased.

In general, the assumptions made for the purposes of this estimate are conservative as regards the design of the pile. Thus it has been assumed that the biological shield, the thermal shield, and the total amount of graphite required around this pile are the same as the amounts required around the high flux pile. This is an obviously conservative assumption, and some saving could be achieved by reducing the thickness of the shield. It is possible also that the tunnel underneath the pile building could be reduced considerably in size if a means of unloading assemblies from the pile and into a truck were used which does not involve driving a truck underneath the pile. Such a means can easily be devised. The height of the graphite around the pile is considerably greater than is really necessary and probably could be reduced by two or three feet, thus raising the level of the bottom thermal shield and that of the sub-pile tunnel. Substantial savings would result. The retention basins are sufficient to hold up water from the pile at the normal rate of discharge for $1\frac{1}{2}$ days more than the 4 days allowed in the case of the high flux pile, even though the amount of radioactivity which it is expected to discharge will be less by more than a factor of 10. Presumably, the discharge from this basin should, therefore, be normally less than 1/20 of tolerance for complete 24-hour per day immersion or for drinking.

Although there are thus a number of possibilities for further reducing the cost of the pile itself, an even greater opportunity exists in

the case of the pile building, the size of which has been picked fairly arbitrarily.

The foregoing two paragraphs indicate that there is some cushion in the estimated cost. There is also a considerable element of uncertainty in the cost of certain parts of the pile. The more prominent uncertainties exist in the cases of the pile instrumentation, the control rod drives and the pile tank and its contents. The estimates made are believed to be reasonable, but only a considerable amount of detailed further study could establish this accurately. Fortunately, these items represent a small fraction of the total cost and the uncertainty in them is therefore relatively unimportant.

The operating costs of the installation will not be large. In Table III a number of the major items of cost are listed. In addition to the items listed, there will of course be expenditures for lighting and heating the installation, for supplying water and gas to it, etc. The list includes what appears to be a reasonable allowance for a security and patrol force on the assumption that such an installation as this would have to be guarded in accordance with existing practices of the Atomic Energy Commission, even though the installation were not owned by the government.

4. Conclusions

The brief study reported here seems to indicate that a pile which would operate at neutron fluxes equal to or greater than those prevailing at Hanford, at Argonne, or in Canada could be constructed for a total cost of about $2,500,000, all buildings and other installations included. Although this does not put the installation within the reach of very many institutions, it is of interest to note that the University of Chicago is currently spending $1,700,000 on a large cyclotron. Other electro-nuclear machines will be similarly expensive. It thus seems likely that with a little further study a

pile can be designed having approximately the above characteristics and costing little if any more than a large cyclotron.

TABLE III
SOME IMPORTANT OPERATING COSTS

Item	Remarks	Cost/yr.*
Power for cooling water pumps	30 kw	
Power for process water pumps	22 kw	$100,000
Fans	500 kw	
Water and water treatment		30,000
Labor, attendance and supervision	15 employees	72,000
Guards	9 employees	36,000
		$238,000

*Assuming 24 hours daily, 7 day weekly operation

5. Acknowledgements

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