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Manpower and Cost Summary

TO: F. L. Culler

FROM: W. R. Winsbro and B. F. Bottenfield

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For The Atomic Energy Commission

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1.0 SUMMARY

A second thorium decontamination cycle, consisting of two solvent extraction pulse columns, a natural-convection evaporator-stripper and auxiliary mixing, storage and surge vessels, was installed as an adjunct to the existing Thorex Pilot Plant in Building 3019.

Specifications for welding, fabrication, and construction materials were relaxed somewhat from those used in the original pilot plant construction, because the corrosion service on the second cycle is not expected to be as rigorous as that encountered in many parts of the first cycle, particularly in the feed preparation areas. However, all process vessels and piping were constructed from types 304L and 347 stainless steel and were fabricated and joined by inspected welding techniques. The unit shielding philosophy, adhered to very strictly in the first cycle, was relaxed in construction of the second thorium cycle because of congestion within the process cell. New equipment developments used included an air lift as a feed metering pump, pulse pumping, and modifications to the concatenated pulse columns.

The installation of the second thorium cycle equipment was done on a crash program, which made advanced scheduling of design and construction phases impractical. Therefore, scheduling was done weekly by synchronizing operational and construction activities within the Thorex Pilot Plant with Design functions. The equivalent of approximately 66 drawings were prepared by the Design Section with a manpower expenditure of 5400 man-hours for design and procurement. The total construction manpower amounted to approximately 17,000 man-hours with a peak effort of 17 men. The critical item in completion of the construction program was the procurement of valves, process vessels, columns, and pumps.

The construction phase of the second thorium cycle was done on three work orders: one covering the electrical work, a second covering instrumentation, and the third covering equipment procurement costs and equipment placement and piping.

The total cost of the facility, including both design and construction was approximately \$185,000. The following table summarizes the cost of various phases of the total job.

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Phase	Description	Cost
Equipment*	Procurement and inspection	\$21,186
Installation	Installation, piping, shielding of equipment	64,235
Instrumentation	Procurement, installation and panel board piping	45,120
Electrical		12,700
Design	Engineering, drafting, overhead	42,935
Total		\$186,176

* Does not include approximately \$13,800 worth of salvage equipment acquired at no cost.

2.0 INTRODUCTION

Early production and development runs in the Thorex Pilot Plant gave a clear indication that the decontamination of highly-irradiated, short-cooled thorium from protactinium and fission products was inadequate in a single-cycle process. A second solvent extraction cycle flowsheet was developed on laboratory scale, and design of the equipment necessary to demonstrate such a flowsheet on pilot plant scale was begun.

The required equipment consisted of (1) a two-column solvent extraction system for the extraction of thorium from the first cycle partitioning column aqueous product and its subsequent stripping from the organic extractant into aqueous solution; (2) a natural convection evaporator-stripper for concentration of the aqueous thorium nitrate product; and (3) auxiliary mixing, storage, and surge vessels to provide the solvent extraction system with metered feed, extractant, scrub, and strip solutions.

The decision was made by the Pilot Plant Section to locate the radioactive processing equipment in Cell 7 of Building 3019 in close proximity to the uranium stripping and solvent recovery systems of

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the first cycle. Makeup equipment was located in the basement area immediately west of shielded Cell 7, inasmuch as space adjacent to the first cycle makeup equipment in the gallery was inadequate. The existing transmitter rack and instrument panel was extended to provide space for second cycle instrumentation.

This report, whose purpose it is to present in summary form the available cost and manpower information for the design and construction of the second thorium cycle processing equipment, includes the following data:

- (a) Design costs, manpower utilization and scheduling.
- (b) Procurement scheduling and equipment costs.
- (c) Construction costs, manpower utilization and scheduling.
- (d) Unit cost data for equipment groups and individual equipment pieces.

In addition, recommendations are made with regard to improvement in procurement, design and construction procedures and in the accumulation of equipment and construction cost data.

3.0 DESIGN AND PROCUREMENT PHILOSOPHIES

In general, the design, construction, and procurement philosophies adopted for second thorium cycle construction closely paralleled those adopted for first cycle Thorex construction. In addition, all supervisory personnel for the project (design, pilot plant, and construction) had actively participated in first cycle construction and, thus, were thoroughly familiar with these philosophies. These factors contributed significantly to the overall efficiency of the project.

The sections which follow briefly review the design and procurement philosophies for second cycle construction with heavier emphasis on the deviations from first cycle procedures.

3.1 Material-Assembly Philosophies

All major items of fabricated equipment (columns and vessels) were constructed of 304 ELC, heli-arc welded, and inspected by "dye-checking", radiographing, hydrostatic pressure and helium leak testing. This specification is superior to that used in comparable portions of first cycle construction where 347 stainless was the material of construction. This change was justified on the basis of first cycle Thorex corrosion

studies which indicated the resistance of 304 ELC superior to that of 347, while the cost is less. Rigid specifications for equipment in this category were desirable (1) to insure against the possibility of failure in the present application and (2) to broaden the re-use potentialities of the equipment for future projects.

All minor items of fabricated equipment (head pots, pressure pots, sample pots, and phase separators) were constructed of 347 stainless steel, heli-arc welded, and inspected by "dye-checking". Up-grading of material from 347 SS to 304 ELC was permissible if warranted from availability and/or delivery considerations. This specification represents a compromise between that for the major items of fabricated equipment, described above, and that for the process piping which follows:

All process piping was schedule 40, 304 ELC or 347 SS, metal-arc welded, with inspection limited to water and acid flushing. This specification is not as rigid as that for first cycle construction, where heli-arc welding of process piping was employed, since the streams to be processed contained little or no "23" and relatively low β - γ activities, thereby making it more difficult to justify the increased installation time and cost for heli-arc welding.

All cell service piping (water and steam) was schedule 40, 304 or 316 SS, metal-arc welded. Outside the cell, service lines were schedule 40 threaded brass pipe and/or copper tubing assembled with brass Swagelok fittings.

Instrument lines were 3/8" o.d. (0.035 wall), 304 SS tubing assembled with 316 SS Swageloks in the cell area and 3/8" o.d. copper, aluminum, or plastic tubing assembled with brass Swageloks outside the cell area. Short runs of 1/2" o.d. tubing were employed, however, at the transmitter rack and instrument panel board. Instrument probes inside of equipment were schedule 40, 304 ELC or 347 SS, 1/4" pipe, at the process vessel.

3.2 Instrumentation Philosophy

The instrumentation philosophy for second cycle was identical to that employed in first cycle construction. Pneumatic liquid level, density, and pressure recording, indicating, and control instruments were used throughout. A pressure transmitter was included in each installation to prevent the possibility of activity entering the process control area via instrument piping. Miniature two-pen recorders were used to conserve panel board space. Sharing of instrument purge lines were limited to pressure indicators only

(where an item of equipment was to be equipped both by an LR and a PI, for instance, the low pressure purge line for the PI transmitter was tied into the low pressure purge line of the LR transmitter at the transmitter rack).

3.3 Shielding Philosophy

The unit shielding philosophy adopted for first cycle construction was compromised considerably for the second thorium cycle. It was considered desirable to house the process equipment in Cell 7, as opposed to Cell 4, because of the closer proximity of the required sampling points (three spares and one sump sampler in adjoining Cell 6 and one sump sampler in Cell 7--first cycle operating experience had indicated that the cell floor sump samplers were of little value and could be re-assigned). Extra space was made available in Cell 7 by moving the clean solvent storage system from Cell 7 into a new shielded enclosure provided in the basement area immediately west of Cell 7. Even with this move, space limitations made it necessary to shield D-Column (P-50), E-Column (P-60), and the ET stripper (P-65) as a crowded group of equipment, rather than as individual units. This may not be too objectionable if activity carry-over from the first cycle equipment does not become excessive.

3.4 Equipment Changes and Improvements

The design philosophy for second cycle was altered (1) to reflect new equipment developments made since first cycle construction, and (2) to correct weak points experienced in the first cycle design. These developments and improvements are listed below.

New Developments

1. Use of a two-stage air-lift to meter the thorium stream into the second cycle extraction column, two-section concatenated D-Column.
2. Use of a pulse pump to pump overflow solvent from D-Column into the thorium strip column, single-section E-Column.
3. The concatenated check valve design was revised. A small weep hole (approximately 1/8" diameter) was drilled in the valve disc and the disc was spring loaded to minimize column hammer and vibration. In addition, the overall design of the valve was simplified and streamlined.
4. The organic transfer line between the two sections of D-Column was "necked down" in the horizontal run at the top of the column to obtain an average displacement velocity slightly in excess

of 2.5 feet per second in order to improve the removal of air from this section of the line. The line size was reduced from 1" IPS to 3/4" IPS in this particular case.

Improvements

1. Full length column jackets were included on all columns, as opposed to one two-foot jacket per column section, to improve column temperature control.

2. The pressure pot design was revised to include a thermowell so that the temperature of the aqueous stream leaving the bottom of the column could be obtained, as well as that of the organic leaving the top.

3. The column head pot design was revised by altering the length so that the bottom of the pot would extend below the normal equilibrium level required for the particular stream to enter the column, as dictated by stream density, to avoid "air-binding" within the outlet line below the pot.

4. The phase separator design was revised to include an air-lift drainage system. While these units are designed to separate immiscible organic phases from aqueous streams of higher density and thus are termed "phase separators", they operate on the basis of density difference and thus are really "density separators". For this reason, they will overflow aqueous via the organic outlet when the density of aqueous inlet stream is abruptly lowered by more than 0.15 specific gravity units, a situation commonly experienced during start-up operation following equipment decontamination. The addition of an air-lift drainage system to the separator does not prevent the occurrence of this difficulty, but does greatly facilitate the remedial procedure.

5. The design of the three-way valve control system for jet supply steam was modified slightly to overcome siphoning difficulties experienced with the first cycle installation. The vent port of each valve was vented directly to the atmosphere rather than to an atmospheric vented header. In the latter situation, the header becomes logged with steam which is not completely effective as a siphon breaker since it will condense on contact with the siphoning liquid.

6. Existing CPS-4 Lapp Pulsafeeders were modified for use as column pulsers. These units were procured as spares for the first cycle columns and are adjustable in both amplitude and frequency. While they are restricted to a sinusoidal pulse wave, they are devoid of the piston leakage and maintenance problems associated with the variable-wave first cycle hydraulic units.

7. Eco centrifugal pumps and rotameters were employed for the metering of non-radive make-up solutions, as opposed to the Milton Roy pumps and expensive remote-reading pump checkers employed as first cycle metering systems. The Eco pumps were installed over a chemical drainage trench to minimize floor erosion from shaft leakage. The Eco pump design is such that this leakage will drop directly into the trench without trickling over cast iron or steel base plates as in the case of the Milton Roy pumps.

3.5 Procurement Philosophies

As was the case for first cycle construction, all materials procured for second cycle construction were set aside and catalogued in a special second cycle stores administered by the Material Control Division. This arrangement again proved to be eminently satisfactory.

All procurement for second cycle was the responsibility of the Design Section. Responsibility for first cycle procurement was handled by a member of the Pilot Plant Section initially assigned to the Design Section, but ultimately shifted to the Pilot Plant because of manpower considerations. When subject pilot plant member was transferred from the Thorex project, this latter situation, as might be expected, proved to be both awkward and inefficient.

4.0 SCHEDULES

The installation of the second cycle equipment was a "crash" program, occasioned by the failure of the single-cycle process to provide adequate thorium decontamination. Therefore, pre-formulated scheduling was impossible. Each phase of the job--preliminary design, procurement, detail design, and construction--was undertaken as rapidly as information and materials could be made available and depended very heavily on the progress of the preceding phase. In an effort to work as efficiently as possible under these circumstances, weekly scheduling meetings were called between the Pilot Plant people, who were responsible for construction, and Design personnel, who were responsible for procurement and design. Scheduling of design, procurement and construction was outlined for four to five weeks in advance, with construction scheduling dependent upon design progress, equipment, and material deliveries, craft manpower availability, and synchronization with the operation of the existing pilot plant equipment.

A target construction completion date of December 1, 1955, was set at the outset of the design phase of the second cycle program. It was realized at that time, however, that even if design and construction manpower were available to meet such a completion date, delivery of purchased equipment would be almost certain to make such a target

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unattainable. Therefore, a completion date during the first quarter of calendar year 1956 was estimated, even though the December 1 date was retained as a target. Actual construction completion was realized about March 1, 1956.

4.1 Procurement Schedule

The schedule of procurement of critical equipment and materials is shown on Figure 1 of the appendix. The solid portion at the left of each bar indicates the time elapsed from the writing of the purchase requisition in the field to the date of the issuance of the purchase order. It should be noted that in nearly all cases the bids were reviewed by the requestor at the expense of perhaps as much as a week in some cases. Purchasing and requisitioning time, under these circumstances, averaged about 3-4 weeks for pipe, tubing and fittings and 5-6 weeks for valves, pumps, vessels, columns and heat exchangers. Instrumentation required about 3-4 weeks and electrical supplies less than two weeks.

The extensions of each bar compare "promised" and "actual" amounts of time required for fabrication and delivery. The extreme right end of the cross-hatched portion of the bar indicates the date on which delivery was promised, while the extreme end of the lower half of the bar represents the date on which the material or equipment was received at Oak Ridge. In some cases, there were wide discrepancies between promised and actual delivery dates. These are noticeable particularly among the small pipe items, some fittings, the vessels and columns, and process valves. These discrepancies were also reflected in the actual completion date of the construction. The delays in delivery of columns and, to a lesser extent, the head tank and evaporator could have delayed the overall construction by as much as two months, had it not been for the fact that the bellow-seal process valves were delayed even more. Poor delivery of these valves alone actually delayed the job completion by a full month, the rest of the construction having been completed by February 1.

Delay in deliveries of stainless steel piping was, percentage-wise, worse than the process equipment; but the construction schedule was not harmed, since the Hope-SCRUP bill of materials stores was used as a buffer supply. Had it not been for this material, the piping itself could have been a serious delay problem. Delivery of the canned rotor pumps was almost on schedule, although the delivery time was quite long. These pumps were not a delay problem only because it was possible to improvise, utilizing inferior, but available, equipment.

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4.2 Design and Construction Schedules

The schedule of effort expended in the design and construction of the second cycle system is presented graphically in Figure 2 of the appendix. The time spent in designing each phase of the project is indicated in the open bar opposite each type of design. The figures inside the bar indicate the number and size of drawings included in the "description". Construction time is indicated by a solid bar and represents the period of time over which the corresponding field construction was performed. Plotted below the design and construction schedule itself are manpower graphs which indicate the relative rate of manpower expenditure (in man-months per month) for both design and construction during the project period. Fabrication by outside vendors of process equipment has not been shown since it is included with the procurement schedule in Figure 1.

It will be noted that generally construction was carried on simultaneously with design or was begun immediately following design completion during the early months of the project, while during the latter months construction lagged completion of design by periods of as much as three weeks. This condition was the result of delivery delays on purchased equipment, which caused construction progress to decelerate with respect to design progress.

A total equivalent of 66 drawings were prepared for the second cycle modification. In many cases existing first cycle drawings were revised to include the second cycle equipment, and these are included in the total drawings at a value of one-half drawing each. The total design manpower expenditure required to produce these drawings was 5400 man-hours, including the allowance of an additional 20% (above actual engineering and drafting time) for design supervision and secretarial assistance. Therefore, the average manpower expenditure per drawing for design and procurement was approximately 82 man-hours. This figure is, of course, unusually low, since the project was merely an addition to existing equipment with pre-determined philosophies of design, fabrication, instrumentation, etc.

On Figure 3 is plotted the percentage of total craft effort as a function of time during the construction period. In addition to the heavy central curve for total craft effort, similar plots have been made for individual crafts and groups of crafts where they depart appreciably from the principal curve. It will be readily noted that craft manpower representing structural and concrete work peaks early in the construction period (curves 3, 9, 10) while the peak representing instrumentation and electrical work peaks late (curves 4, 8, 6). The pipefitter and welding effort and craft supervision (curves 2, 5, 7) follow the total manpower plot very closely, a fact that is not surprising since these two crafts plus the accompanying supervision represent almost half the total manpower and, therefore, actually determine the slope of the principal curve.

The total construction manpower expanded for the project was approximately 17,000 man-hours with the peak construction force at about 17 men. The breakdown of craft participation is shown in Table 1 of the appendix.

Weekly meetings were held each Monday during the construction phase of the job, at which Design and Pilot Plant personnel (problem leaders, design engineers, construction engineers) planned the design and construction schedules for a period of four to five weeks in advance. Then, on the following Wednesday, Pilot Plant and Mechanical Department personnel met to discuss the completion of the scheduled construction as planned. This close cooperation among the three interested groups did much to prevent inefficiency in coordinating the design, procurement and construction phases of the job.

4.3 Summary and Recommendations

Purchase time for critical process items was the principal factor in determining the completion date for construction of the second cycle. Many of the long delivery items were delivered 100% later than the date promised at the time the bid was accepted, while others of the critical items were not delayed at all. The large stainless steel equipment items (columns, evaporators, process tankage), when fabricated to a fairly rigid specification for use in corrosive service, required six to seven months for delivery (from date of requisition), as do special stainless steel valves. Special pumps required even more time--approximately eight months--but most of the stock items, such as stainless steel pipe, tubing and fittings, jets, heat exchangers, standard pumps and most instrumentation items required about three or four months.

5.0 DESIGN AND CONSTRUCTION COSTS

All engineering effort required for design and procurement, all drafting effort, and all inspection required for the SWEPCO fabricated equipment was charged to the Thorex design account (3370-23).

All construction costs incurred in the course of procurement, fabrication, installation, and piping of second cycle equipment were charged to one of three special work orders set up under the Thorex pilot plant operating account (3370-6). The identity and scope of each of these work orders are summarized below.

Work Order

Work Order Scope

A-5765

Instrumentation: Material, labor, and overhead to install and pipe transmitters and instruments and to install connecting instrument tubing between transmitter rack and instrument panel board.

A-5764

Electrical: Material, labor, and overhead required for all electrical wiring of motors, thermocouples, sparger solenoids, instrumentation, etc.

A-5763

Equipment, Placement, and Piping: Material, labor, and overhead not chargeable to either A-5765 or A-5764, consisting mainly of that required to procure or fabricate equipment, install probes or pulse plates, therein, place, pipe, and route instrument tubing to the transmitter rack. Also included is a small amount of structural work (installation of a panel board extension, a new transmitter rack, drainage trenches in the basement area, and shielding for the new solvent storage tank, T-5-M).

5.1 Design Costs

The estimated costs charged to the design account as a part of second cycle construction totaled \$47,800 as detailed below. These costs include the cost of inspection of purchased equipment, amounting to \$4,865, which should correctly appear as a part of the equipment cost.

<u>Expense Item</u>	<u>Cost</u>
Labor	\$24,000
Overhead	18,240
Material	695
Inspection	<u>4,865</u>
Total	\$47,800

These items were extracted from the monthly operating report cost summaries for the Thorex design account (3370-23). Labor and overhead figures thus obtained were scaled up by 20% to allow for Design Section overhead. The labor item thus includes the cost of engineering effort required for design and procurement, drafting effort, and a 20% allowance for section overhead. The inspection item includes material, labor, overhead, and travel expense incurred in testing weld and corrosion specimens and inspecting the five equipment units fabricated by SWEPCO (3 tanks and 2 pulse columns). This expense was incurred primarily by E. C. Miller's Inspection Engineering Division.

5.2 Equipment Costs

The cost of the equipment fabricated by SWEPCO totaled \$15,450 and is summarized in detail in Table 2 of the appendix. The most significant fact to be noted is that the inspection cost of \$4,865 represents better than 30% of the final equipment cost. The material, fabrication, and transportation portion of the total cost was found to be properly charged against the Equipment, Placement, and Piping work order A-5763. The inspection portion was charged to the Thorex design account as previously indicated (Section 5.1).

Purchased equipment expenditures for second cycle construction are summarized in Table 3 of the appendix. The delivered cost of this equipment is seen to total \$10,843. Spare and replacement parts served to increase this expenditure by approximately 25%. The delivered cost of all items, except for the two pulsers and the cast iron Chempump (P-50-P, P-60-P, and T-5-M-P), were found to be properly charged against the Equipment, Placement, and Piping work order A-5763. The pulsers were obtained as capitalized property items, and the Chempump as a spare part from first cycle Thorex construction. The delivered cost of these three items total \$5,107.

Five of the vessels used in second cycle construction were obtained as salvage vessels at zero cost. Table 4 of the appendix lists these vessels and assigns an estimated value to each. It is conservatively estimated that an expenditure of \$8,700 would have been required to purchase comparable vessels on the open market.

The cost of all major equipment required for second cycle construction is summarized below:

<u>Equipment Group</u>	<u>Actual Charges</u>	<u>Real Value</u>
Fabricated Equipment	\$10,585	\$15,450
Purchased Equipment	5,736	10,843
Rework Tanks	0	8,700
Total	<u>\$16,321</u>	<u>\$34,993</u>

The "actual charges" are those that were actually charged to the Equipment, Placement, and Piping work order A-5763, while the "real value" figures are those that would have been charged if all equipment had been fabricated or procured on the open market and properly charged to A-5763. The real value of the fabricated equipment is greater by the amount of the inspection costs, the purchased equipment by the value of the two pulsers and the cast iron Chempump, and the rework tanks by the estimated value of these vessels. The cost of spare and replacement parts is not included in purchased equipment costs since these are required for operation and maintenance and not for construction.

5.3 Placement and Piping Costs

Table 5 of the appendix presents a detailed summary of the Equipment, Placement, and Piping work order A-5763. Part I of the table presents a detailed description of the construction actually carried out under this work order; part II points out that the work actually done was equivalent to the installation of probes or pulse plates, placement, and piping of eight (8) functional groups of equipment; and part III presents a breakdown of actual charges made against the work order.

Certain corrections must be made to the charges presented in Table 5 before attempting to estimate material and labor expense incurred in placing and piping (includes installation of probes or pulse plates in equipment) a single functional group of equipment. (1) None of the three construction work orders include the labor and overhead charges for the pilot plant construction engineer that followed second cycle construction for eight months. This expense, estimated at \$9,000, will be prorated against each work order on the basis of total charge. (2) The material charge shown includes \$16,321 of equipment costs as discussed previously (Section 5.2). Making these corrections to the total shown gives a total placement and piping cost for eight (8) functional equipment groups as given below.

Total Charges to W. O. A-5763 - - - - -	\$75,310
Equipment Correction - - - - - deduct	16,321
Construction Engineering Correction - - - - - add	<u>5,246</u>

Corrected Total	\$64,235
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From this corrected total, an average placement and piping cost of \$8,000 is obtained for a functional equipment group. Of this expense, 20% is pipefitter and welder effort and 30% materials. It is of further interest to note that the piping of each functional unit involved routing some 500 feet of pipe (50% 1/2" IPS in this instance), 225 feet of stainless instrument tubing (3/8" o.d.), and 250 feet of copper instrument tubing (3/8" o.d.). These tubing quantities are required to route the instrument lines from the equipment to transmitter rack.

5.4 Instrumentation Costs

Table 6 of the appendix summarizes the Instrumentation work order A-5765 for second cycle construction. The total job is seen to be equivalent to that of installing, piping, and calibrating 25 panel mounted two-pen miniature recorders, controllers, or indicators. The total charge to the work order was \$41,881. The total material, labor, and overhead expense incurred in installing all instrumentation is this sum plus this work order's fair share of the pilot plant construction engineer's labor and overhead expense, namely \$3,239, which totals \$45,120.

The cost of a single panel mounted instrument (recorder, controller, or indicator) was thus in the order of \$1,800. For a recorder system, this would include the material, labor, and overhead required to install, pipe, and calibrate two transmitters and one two-pen recorder. For a control system, it would include the same for one transmitter, one recorder, and one controller. The average quantity of 1/4" and 3/8" copper or plastic tubing associated with each such panel unit was in the order 145 feet. Of this total unit cost, 50% was for materials, 8% for instrument mechanics, 8% for instrument engineers, and 4.5% for pipefitters.

The average cost of all panel mounted instruments not serviced by transmitters (toggles for remotely operated valves, conoflow units for Lapp Pulsafeeder control, rotameters for air-lift control, etc.) was estimated to be approximately one-quarter of the figure above, namely \$450 each.

The average cost of instrumenting a single functional group of equipment can be estimated by dividing the total instrumentation cost by the number of functional groups actually instrumented, namely seven. While eight units were placed and piped, only seven were instrumented, since relocation of the clean solvent storage system involved no instrumentation work. The average cost of instrumentation for a functional group of second cycle equipment was thus in the order of \$6,500.

5.5 Electrical Costs

The Electrical work order A-5764 for second cycle construction is summarized in Table 7 of the appendix. The entire job is shown to be equivalent to that of wiring 20 motors for power with both local and remote starter systems. The total cost of materials, labor, and overhead was the total for the work order plus \$515 (labor and overhead correction for the pilot plant construction engineer) or \$12,700. This yields an average wiring cost per motor of \$650. Of this total, 26% was for material and 35% for electricians.

The electrical material, labor, and overhead cost for wiring a single functional group of equipment was \$12,700/8, or approximately \$1,600.

5.6 Total Costs

The actual total "out-of-pocket" cost of the Thorex second thorium cycle construction is summarized below.

Summary of Actual Costs

<u>Item</u>	<u>Cost (\$)</u>
Major Equipment	\$ 21,186
Piping and Placement	64,235
Instrumentation	45,120
Electrical	12,700
Total	<u>\$143,241</u>

The cost figure for major equipment includes actual charges plus inspection costs, but does not include the value of capitalized and rework equipment utilized which is estimated to value \$13,807. The cost of spare and replacement parts and of surplus piping, fittings, instruments, etc., procured is not included in the figures presented.

The true cost of the facility is obtained by adding the estimated value of capitalized and rework equipment to the major equipment cost. The resultant costs present a more reliable picture of relative costs. Placement, piping, instrumentation, and electrical costs are seen to total 350% of the estimated equipment value.

Summary of True Costs

<u>Item</u>	<u>Cost (\$)</u>	<u>% Equipment Cost</u>
Major Equipment	\$ 34,993	100
Placement and Piping	64,235	185
Instrumentation	45,120	130
Electrical	12,700	35
Total	<u>\$157,048</u>	<u>450</u>

The costs of miscellaneous materials, labor, and overhead relative to the real value of the equipment installed are of interest and are compared below.

Summary of True Costs

<u>Item</u>	<u>Cost (\$)</u>	<u>% Equipment Cost</u>
Major Equipment	\$ 34,993	100
Miscellaneous Materials	47,628	135
Labor and Supervision	46,565	135
Overhead	27,862	80
Total	<u>\$157,048</u>	<u>450</u>

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Under the heading of miscellaneous materials are included all materials other than major equipment, such as piping, fittings, instruments, support materials, etc. Overhead is observed to average 60% of labor.

The design and procurement cost (equipment inspection cost excluded) for second thorium cycle construction totaled \$42,935. This is equivalent to 30% of the "out-of-pocket" cost or 27% of the true value of the construction. The design and procurement expense is primarily a labor and overhead expense, material costs amounting to only 1.6% of the total.

The average unit cost for placing, piping, instrumenting, and wiring a single functional group of second cycle equipment is summarized in the table which follows. The brief descriptions given opposite each construction phase have been condensed somewhat in the interest of simplicity and have been included to clarify and minimize misuse of the figures presented. The percentage contributions of material costs and of the principle crafts utilized for each phase have been included as a guide for making manpower estimates.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

While the second thorium cycle installation is not a typical example of radiochemical plant construction, it was of sufficient magnitude to provide information from which several conclusions and recommendations may be drawn. Some of these are applicable only to a program of limited scope and size, while others are of general applicability.

6.1 Conclusions

The following conclusions have been drawn from the second thorium cycle facility construction experience and additional experience gained both prior to and subsequent to that program:

1. The major factor in the scheduling of a construction program of this size is the procurement of the major process equipment--particularly expensive and complicated equipment. Vendors cannot be depended upon to meet promised delivery dates; therefore, schedules based upon such promises, even after receipt of initial bids, are not valid. Scheduling is much more realistic if based upon previous experience in procurement of similar equipment.
2. In the fabrication of large process equipment, it is generally true that the fabrication progresses in very nearly direct proportion with the emphasis placed upon delivery dates by the customer--and, more specifically, with the number of visits made by the customers' inspectors to the fabrication site. Utilization of the ORNL Inspection Engineering group under E. C. Miller was of considerable assistance in maintaining both speed and quality of fabrication. As this group is expanded and gains additional experience, it is felt that equipment procurement delays can and will be decreased in any construction program.
3. An obvious conclusion concerns the desirability of having design personnel responsible for procurement. It is important that the designer call upon the experience of the customer-operator in designing and purchasing equipment, but the mechanics of procurement are best handled by those persons most closely associated with the design and process data.
4. The selection by the Pilot Plant Section of work orders for the accumulation of construction cost information is thought to have been good. A fallacy noted during first cycle Thorex construction was that too many work orders were written and, as a consequence, assignment of time and materials costs to work order charges in the field was cumbersome. For a larger project than the second thorium cycle, where extensive building construction and structural work is required, the simple breakdown used here would be inadequate, but it served very well for accumulation of costs for the second cycle installation.

5. Another obvious conclusion is the desirability of close contact between design and construction representatives. In the case in question, a three-way coordination was required between design and pilot plant personnel and between pilot plant and construction personnel, inasmuch as design, construction and operation had to be done simultaneously. Subsequent experience has indicated that perhaps construction is better coordinated by direct contact between designer and constructor, with the operator kept informed as scheduling and design progress.

6.2 Recommendations

Based upon the conclusions drawn above and upon experience gathered in other construction projects, the following recommendations are made:

1. The responsibility for equipment procurement and construction schedule coordination with construction personnel should be placed upon the designer, as he is better aware of the design details which dictate specifications for procurement, fabrication, and installation.

2. Meetings between designer and constructor should be held at regular intervals to coordinate their functions, particularly in instances where design is preceding construction by a very narrow time margin.

3. Close cooperation should be maintained between the designer and the inspection engineer in order to keep equipment vendors and fabricators as well informed as possible and to bring as much pressure to bear as possible upon the vendor and fabricator to meet promised delivery dates.

4. A system of work orders for construction should be outlined which will give maximum useable material and labor cost information and maximum accuracy, while simultaneously requiring a minimum of difficulty for storekeeping personnel and construction supervision.

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7.0 APPENDIX

TABLE 1

MANPOWER BREAKDOWN

CONSTRUCTION

<u>Craft</u>	<u>Man-Hours</u>	
Pipefitter	4885	
Electricians	1819	
Supervision	1786	
Welders	1533	
Instrument Mechanics	1487	
Instrument Engineers	971	
Millwrights	869	
Machinists	503	
Sheet Metal	442	
Utility	355	
Laborers	329	
Carpenters	230	
Painters	163	
Transportation	133	
Riggers	127	
Miscellaneous	40	
Pilot Plant Construction Engineer	1350 (estimated)	
Total	17,022	
	<u>Man-Hours</u>	<u>%</u>
Equipment, installation, piping, structural and shielding	10,347	60.4
Instrumentation	4,413	26.2
Electrical	2,262	13.4
Total	17,022	100.0

DESIGN AND PROCUREMENT

Engineering	2,250
Drafting	2,250
Total	4,500

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TABLE 2

SWEPCO Fabricated Equipment Costs

Symbol	Title	Material and Fabrication	Transportation	Inspection	Total
P-50	D-Column (5" IPS x 40' Concatenated 2-Section)	\$4,088	\$ 64	\$1,910	\$6,072
P-60	E-Column (5" IPS x 20' Single Section)	2,194	16	1,020	3,220
P-51	DF Head Tank (100 Gal)	1,167	19	540	1,726
P-62	Vapor Separator (50 Gal)	915	11	425	1,351
P-65	ET Stripper (150 Gal)	<u>2,098</u>	<u>13</u>	<u>970</u>	<u>3,081</u>
	Totals	<u>\$10,462</u>	<u>\$123</u>	<u>\$4,865</u>	<u>\$15,450</u>

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TABLE 2

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TABLE 3
PURCHASED EQUIPMENT COSTS

Symbol	Title	Purchase	Transportation	Spare Parts
K-1-P	Eco Centrichem Pump	272	3	76
K-2-P	Eco Centrichem Pump	272	3	76
K-2-P-S	Eco Centrichem Pump	272	3	76
K-3-P	Eco Centrichem Pump	272	3	76
T-5-M-P	Cast Iron Chempump	348	4	352*
P-50-P	CPS-4 Lapp Pulser	2328	50	128
P-60-P	CPS-4 Lapp Pulser	2328	49	129
P-51-P	CPS-1 Lapp Metering Pump	1277	9	87
P-69-P	CPS-3 Lapp Metering Pump	1886	25	95
P-67	Evaporator Reboiler (25 Ft ²)	666	8	674*
P-68	Evaporator Condenser (35 Ft ²)	756	9	765*
Totals		<u>\$10,677</u>	<u>\$166</u>	<u>\$2,534</u>

Total Delivered Cost - \$10,843

Total Cost of Purchased Equipment - \$13,377

*Complete replacement units

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TABLE 3

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TABLE 4

Rework Tanks - Estimated Costs

Symbol	Title	Estimated Value
T-5-M	Clean Solvent Storage Tank (475 gal)	\$2,300
P-69	EW Surge Tank (225 gal)	1,600
K-1	DS Make-Up Tank (420 gal)	2,100
K-2	DS Metering Tank (120 gal)	1,100
K-3	EX Head Tank (225 gal)	1,600
Total		<u>\$8,700</u>

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TABLE 4

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SUMMARY OF W. O. A-5763 (EQUIPMENT, PLACEMENT, AND PIPING)

TABLE 5

PART I DETAILED JOB DESCRIPTION

1. Install pulse plates and place D-Column (P-50) and E-Column (P-60)
2. Install probes in rework tanks K-1, K-2, K-3, and P-69 and place
3. Install probes in fabricated (SWEPCO) Vessels P-51, P-62, and P-65 and place
4. Install 2 heat exchangers (P-67 and P-68), 2 Lapp Pulsers (P-50-P and P-60-P), 2 Lapp metering pumps (P-69-P and P-51-P), and 4 Eco centrifugal pumps (K-1-P, K-2-P, K-3-P, and K-2-P-S)
5. Fabricate and install following 13 pots, standpipes, etc.; 2 pressure pots (P-54 and P-61); 2 sample pots (P-55 and P-66); 2 phase separators (P-56 and P-63); 6 head pots (P-52, P-53, P-57, P-58, P-59, and P-64); 1 Flowchecker (P-69-FC).
6. Pipe all of above equipment. Includes 4000' of stainless steel piping (50% 1/2" IPS), 1800' of 3/8" o.d. tubing, and 2000' of 3/8" o.d. Cu tubing.
7. Remove T-5 and T-5-P from Cell 7 to make room for the above equipment and install new T-5-M and T-5-M-P in basement area.
8. Install shielding about T-5-M, install new support rack for 30 transmitters, fabricate 5-foot extension to main panel board, install drainage trenches in basement make-up area, and install steelwork for unit shielding.

PART II CONDENSED EQUIVALENT JOB DESCRIPTION

If the small amount of structural work is neglected, the job description given above can be reduced to the installation of pulse plates or probes and the placement and piping of 8 functional equipment groupings of comparable magnitude as listed below:

1. D-Column with its pulser, pressure pot, phase separator, and sample pot (P-50, P-50-P, P-54, P-55, P-56)
2. E-Column with its pulser, pressure pot, phase separator, and sample pot (P-60, P-60-P, P-61, P-63, P-66)
3. D-Column Make-up System (K-1, K-2, K-1-P, K-2-P, P-27, and P-58)
4. E-Column Make-up System (K-3, K-3-P, K-2-P-S, P-59, and P-57)
5. D-Column Feed System (P-51, P-52, P-53, and P-51-P)
6. Evaporator System (P-62, P-65, P-67, and P-68)
7. Solvent (EW) Metering System (P-69, P-69-FC, and P-69-P)
8. Removal of T-5 and T-5-P and installation of T-5-M and T-5-M-P

PART III BREAKDOWN OF W. O. CHARGES

	Effort		Cost Dollars	
	Man-Hours	% Total		
Supervision	1214	12.7	\$4,238	
Pipefitters	4027	42.3	9,713	
Welders	1420	14.9	3,419	
Others	2891	30.1	6,738	
	<u>9552</u>	<u>100.0</u>	<u>\$24,108</u>	\$24,108
Total Labor				14,493
Total Overhead				36,709
Total Materials				\$75,310
Grand Total				

TABLE 5

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SUMMARY OF W. O. A-5765

(INSTRUMENTATION)

TABLE 6

I DETAILED JOB DESCRIPTION

1. Installation of 33 Differential Pressure Transmitters
2. Installation of 10 two-point Taylor Recorders
3. Installation of 7 two-point Taylor Indicators
4. Installation of 4 Taylor Controllers
5. Installation of 2 Conoflow Units for Lapp Pulsafeeder Control
6. Installation of 12 Toggle Controls for remotely operated valves
7. Installation of 2 Rotameters for Air-lift Control
8. Installation of 3600' of 3/8" and 1/4" OD plastic and copper tubing between and at transmitter rack and panel board
9. Complete calibration and adjustment of 33 transmitters, 8-1/2 recorders, 7 indicators, 4 controllers, 8 toggle controls, 2 conoflow units and 2 rotameters

II CONDENSED EQUIVALENT JOB DESCRIPTION

The labor and material required to install, pipe, and calibrate indicating, recording, and controlling systems are essentially equal. The labor and material required for conoflow units, toggles, and rotameter is less by a factor of 10 (the absence of transmitter halves both labor and material requirements). On this basis, above instrumentation job is equivalent to installing, piping, and calibrating 25 panel mounted recorders, indicators, or controllers.

III BREAKDOWN OF W. O. CHARGES

	M-H	\$	
Instrument Engineer	971	3,650	
Instrument Mechanics	1,487	3,650	
Pipefitters	856	1,978	
Miscellaneous Crafts	663	2,000	
Total Labor	<u>3,977</u>	<u>\$11,278</u>	\$11,278
Total Overhead			6,681
Total Material			23,922
Grand Total			<u>\$41,881</u>

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TABLE 6

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SUMMARY OF W. O. A-5764

(ELECTRICAL)

TABLE 7

I DETAILED JOB DESCRIPTION

1. Power supply and local and remote starter switches for 10 electrical motors
2. Wiring for 11 pressure switches into panel alarm system
3. Wiring for 5 remotely located solenoids for panel board control
4. Wiring for 8 process thermowells
5. Wiring for 10 two-pen recorders and 4 controllers
6. Removal of one explosion proof cell light and the installation of two additional lights

II CONDENSED EQUIVALENT JOB DESCRIPTION

Labor and materials for items 4 and 6 above equivalent to wiring power supply to 10 additional motors.

Labor and materials for items 2, 3, and 5 comparable to installing local and remote starter switches on 10 such additional motors. Thus, total electrical job equivalent wiring 20 electrical motors (sum of motor, thermowells, and lights) for power and local and remote starter systems.

III BREAKDOWN OF W. O. CHARGES

	M-H	\$	
Supervision	321	1,134	
Electricians	<u>1819</u>	<u>4,435</u>	
Total Labor	<u>2140</u>	<u>\$5,569</u>	\$5,569
Total Overhead			3,298
Total Material			<u>3,318</u>
Grand Total			<u>\$12,185</u>

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