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SUBJECT: THOREX, ANALYSIS OF MODIFICATION COSTS
TO: F. L. Culler
FROM: R. V. Foltz and W. R. Winsbro

ABSTRACT

Actual design and construction costs and schedules for a group of four short-cool processing modifications to the Thorex Pilot Plant are analyzed and summarized.

NOTICE

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APPROVED BY
PATENT DEPARTMENT

9-1-58 *[Signature]*
DATE SIGNATURE

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SUMMARY

The scope of this terminal report has been restricted to a description and an analysis of design and construction costs and schedules for the four Thorex short-cool processing modifications which were supervised by the Design Section. These modifications are: (1) Rework of the Isolation System, (2) the Third Uranium Cycle, (3) the IAWC Facility, and (4) the Expansion of the Thorium Storage Facility.

A total time interval of 16 months was required for the preliminary design, engineering design, procurement, and construction of these four modifications. A breakdown of the total cost required is summarized in the following table.

OVERALL SUMMARY OF DESIGN & CONSTRUCTION COSTS

<u>Title of Modification</u>	<u>Construction</u>	<u>Cost Breakdown</u>	
		<u>Design</u>	<u>Total</u>
Isolation Rework	\$28,900	\$10,900	\$39,800
Third Uranium Cycle	150,742	56,800	207,560
IAWC Facility	40,840	16,140	58,980
Thorium Storage Expansion	<u>16,608</u>	<u>6,255</u>	<u>22,863</u>
Total	<u>\$239,090</u>	<u>\$90,095</u>	<u>\$329,185</u>

The design costs include the cost of preliminary design, engineering design, and all procurement. Since it was not possible to isolate individual design costs for each modification, the above distribution reflects a breakdown of the total design cost according to construction costs. The design cost amounts to 27% of the total cost of the modifications, amounts to \$40,000 per man-year of Section engineering effort, and is equivalent to a unit cost of \$800 per finished construction drawing.

Procurement times for conventional stainless steel pumps, pipe, tubing, fittings, and conventional pneumatic instrumentation varied from two to four months. Special stainless pipe and tubing fittings, Chempumps, heat exchangers, glove boxes, and process vessels required from five to ten months.

For stainless steel construction, miscellaneous materials, such as helium, argon, welding rod, files, wire brushes, etc., were found to average about 12% of the total value of the worked material, and labor charges were found to average about 65% of the total worked material cost. Recommended procedures for estimating the cost of various types of construction are presented in Section 4.3. Some unit cost figures which were found to be reasonably reliable for estimating the cost of stainless steel piping materials are tabulated below.

Unit Costs for Stainless Piping Materials

<u>Item</u>	<u>Unit Cost</u>
Pipe, Schedule 40	\$3 per foot-inch of nominal diameter
Pipe, Schedule 10	\$2 per foot-inch of nominal diameter
Pipefittings (BW and Thr'd and including conventional manual valves)	50% of above piping cost
Tubing, 0.035" wall	\$1.50 per foot-inch of outside diameter
Swagelok fittings	
Tees, bulkhead, & BW	\$7 each
Thr'd connectors, unions, etc.	\$2.50 each
Special Belloseal Valves (manual) or Jets equipped with BW or Swagelok Connections	\$130 per inch of nominal diameter

Figure 1 of the appendix summarizes the actual design, procurement, and construction schedules for each of the modifications. For the larger modification projects where design drawings are required for all phases of construction, it appears that the man-months of craft effort required for ORNL construction is essentially equal to the number of design drawings required.

1.0 INTRODUCTION

The planning of modifications and additions required to accommodate the short-cool processing of irradiated thorium metal in the Thorex pilot plant facility was an important phase of the early planning for the Division's short-cool program proposal. By the time this proposal was accepted by the AEC late in FY'56, the following list of modifications had been definitely agreed upon.

- (1) Rework of the existing U^{233} ion exchange isolation system.
- (2) Addition of a third uranium solvent extraction system for the U^{233} product stream.
- (3) Addition of a 5000-gallon collection vessel (N-30) for the raffinate from the first cycle extraction column (IAW stream), hereafter referred to as the IAWC facility.
- (4) Expansion of the existing thorium storage facility by the addition of a new 5000-gallon vessel (P-25).
- (5) Addition of supplementary shielding about the existing process equipment.

At a later date, decisions were made (6) to expand the scope of the first two items to include the addition of a U^{233} storage system, (7) to add a dissolver and vessel off-gas scrubber, and (8) to add an interface purge system.

The design, procurement, and construction of the first four (4) of the above modifications was supervised by the Design Section, while that for the latter four (4) was supervised by the Pilot Plant and Unit Operations Sections.

The purposes of this report are two-fold: (1) to summarize the money and schedule requirements for the design, procurement, and construction phases of those four modifications which were supervised by the Design Section and (2) to extract and summarize basic information which would be of value in planning future modification and construction projects.

2.0 DESCRIPTION OF SHORT-COOL PROGRAM AND MODIFICATIONS

2.1 Short-Cool Program

The Thorex short-cool processing flowsheet was developed to alleviate the harmful effects of the uranium-232 isotope which is formed by the $(n, 2n)$ -reaction during the irradiation of thorium metal. U^{232} (70-year half-life) decays to Th^{228} (1.9-year half-life) which in turn decays through a lengthy chain of short-lived daughters, some of which are strong β - γ emitters, before ultimate decay to a stable form of lead. With a long-cooled processing flowsheet, wherein the irradiated metal is allowed to decay for some 6-9 months before processing, the growth of Th^{228} into the metal is such that its daughter activities become a major contributor to the activity of the thorium metal recovered from the process. By reducing the interval between irradiation and processing to 15-45 days, i.e., by short-cool processing, this source of contamination in the thorium product can be reduced to acceptable limits without significant adverse effects on the quality of the U^{233} product recovered. In other words, short-cool processing provides a means of restricting the adverse effects of U^{232} to only one of the two product streams recovered from the process. A second advantage to be gained from short-cool processing is that it provides a means for recovering some 15-20% of the potential "23" in the irradiated metal as a higher isotopic purity product. This results from the fact that in short-cool processing some 15-20% of the potential "23" in the thorium metal still exists as Pa^{233} (27.4 d half-life) which leaves the process along with the fission products via the first cycle extraction column raffinate stream (IAW stream). If the extraction of all of the thorium and uranium is complete during initial processing, this raffinate can be stored to allow time for the Pa^{233} to decay to U^{233} and then reprocessed for the recovery of a higher isotopic purity "23" product.

2.2 Isolation Rework

The ion exchange isolation system installed for the recovery of the "23" product stream during the original construction of the Thorex Pilot Plant was unsatisfactory for several reasons.

(1) Excessive pressure drops across the resin columns made it necessary to convert the system from a "gravity-flow" to a "force-flow" system following installation. This was accomplished by installing valves in all equipment off-gas lines which greatly complicated operation.

(2) The sampling procedure for the system, coupled with a poor hood exhaust system, presented a serious alpha contamination problem.

(3) Because fission product decontamination of the "23" product was not as high as expected, the shielding for the system was not adequate.

(4) The "downflow sorption and elution" chemical flowsheet utilized by the original system required lengthy elution, conditioning, and rinsing time cycles in contrast to a newly developed "upflow sorption-downflow elution" flowsheet.

The new isolation system contains two thorium and two uranium sorption columns, just as the original system. However, the cross-section for flow in the thorium columns was increased to that of the uranium columns, 5" Sch. 40 pipe, to reduce pressure drops and to increase the thorium loading capacity some threefold. Piping between the thorium and uranium columns is such that either thorium column could be placed on stream ahead of either uranium column. From criticality considerations, it was necessary to restrict the resin loading capacity of the uranium columns to 7 liters, equivalent to a maximum theoretical loading of 1900 grams of "23" or a normal operating loading of 1000-1200 grams. The thorium columns were sized for a 4-liter resin loading. The design sorption throughput capacity for the new system was 50 l/hr, or approximately 50% greater than the Thorex CU flow rate. The critically safe slab-type receivers were included in the system for the collection of the product and waste streams. Lapp pumps were added for the controlled metering of elution and decontamination reagents.

The newly developed "upflow sorption-downflow elution" flowsheet was adopted for all four of the columns. This made it necessary to install a close-fitting, heavy stainless steel, sliding plug in the top of each column to prevent fluidization during sorption and at the same time to provide relief for the normal volumetric changes which the resin undergoes throughout the operating cycle. The top of each column was machined on the i.d. to obtain the required fit between the teflon disc on the plug and the column.

Construction involved (1) the removal of all of the original equipment from within the hood area of the Thorex isolation area, (2) installation of all new process equipment in the hood behind two inches of lead shielding, and (3) the addition of two Lapp metering pumps and the rearrangement and relocation of the warm water recirculation system, required for the control of resin column temperatures, outside of the hood area.

2.3 Third Uranium Cycle

Three factors made it desirable to add a third uranium cycle to the Thorex Pilot Plant.

(1) Uranium product decontamination was not adequate for one cycle, long-cooled (6-9 months) processing, and it was expected that the two-cycle operation afforded by the co-decontamination flowsheet would not be adequate for short-cooled (15-45 days) processing.

(2) The activity level of the "23" product recovered in Thorex increases significantly during storage due to the growth of the U^{232} daughter activities. For this reason, it is essential to have a pre-shipment decontamination facility readily available.

(3) The citrate product recovered from the ion exchange isolation system is not chemically stable, i.e., tends to precipitate in an insoluble form on standing, which presents a serious storage problem. The third uranium cycle affords a means of converting the uranium product from a citrate to a much more stable nitrate form.

The Thorex third uranium cycle is designed for an instantaneous processing rate of 3 kg per day. The system employs a 15% TBP solvent and consists of a slab-type feed adjustment vessel, standard vertical extraction and strip columns equipped with the usual cold makeup and metering accessories, a $Ca(OH)_2$ solvent recovery system, an evaporator for concentrating the strip column product, a glove box product loading station, and two glove box sampling stations. All process equipment is located on the east wall of Cell 3 in Building 3019. The solvent recovery system and the cold makeup equipment are located north of Cell 4 in the operating gallery (old Purex Solvent Room). The instrument control panel, decontamination panel, and process metering station are located in the penthouse area immediately over Cell 3. The sampling glove boxes are located in the sampling gallery, and the product loading glove box is located outside of the process shielding in the Cell 3 access area. The majority of the valves installed in the process are Hoke bello seal valves, equipped with Swagelok ends, which are operated via extension handles from grated platforms located in front of the process equipment shielding.

Because of criticality considerations, all process collection and storage vessels, except for the slab-type feed adjustment vessel, are fabricated from 4"-pipe. The extraction and strip columns are fabricated from 1"-pipe in the pulse plate sections and 4"-pipe in the enlarged end sections. Lapp pumps are used for column pulsers and all radive metering operations. Eco centrifugal pumps are used for non-radive transfers and canned rotor Chempumps for radive transfers.

In addition to the installation of the above process equipment, construction for this project included a general rework of the Cell 3 process area. A faulty stainless steel floor and wall liner was removed, the floor slope and drainage system was improved, and a new stainless floor and wall liner was installed.

2.4 IAWC Facility

This facility was required to hold the first cycle extraction column raffinate stream from the Thorex pilot plant (IAW stream) during the start-cool processing program. Since the high protactinium content of the raffinate, (1/2 gram per gallon which is equivalent to a specific heat generation of 25 watts

per gallon or 88 Btu/hr per gallon) was expected to produce self-boiling in the collection vessel, it was agreed to concentrate the waste so that a 5000-gallon collection vessel (N-30) would be adequate. Because of the higher concentration of the raffinate in the storage vessel, as opposed to that of the IAW stream entering, it was identified as IAWC. Because of the heat generation problem, the vessel was equipped with an external water-cooling jacket and an overhead, downdraft, reflux condenser. Services were provided for maintaining a continuous flow of purge air through the vapor space of the vessel and its associated off-gas piping to prevent hydrogen and oxygen, formed from the radiolytic decomposition of water within the vessel, from accumulating to explosive concentration levels. A demineralized water purge was introduced to all submerged liquid level probes installed in the vessel to avoid the possibility of their plugging during extended storage. The vessel was located in Cell 4 of Building 3019 while the reflux condenser was located in the roof area immediately over this cell. No attempt was made to unit shield the vessel within the cell because of cost considerations. While the reflux condenser was not shielded, it was located so as to facilitate the installation of shielding at a later date, if required. The transmitters and recording instruments required for the system were mounted on existing transmitter racks and panel boards.

No provisions were made for sampling the contents of the decay vessel since there were no additional sampling points available for use at the Thorex remote sampling facility and since funds were not available for extending this facility. To alleviate this deficiency, the system was piped so that all wastes entering and leaving the decay vessel were routed through an intermediate 750-gallon collection vessel (N-22) which was serviced for remote sampling.

Following the collection of all of the protactinium-bearing wastes during the short-cool processing program, the wastes are to be stored for an additional 4-6 months to allow time for the decay of most of the protactinium to uranium and then reprocessed through the Thorex extraction system for the recovery of the uranium-233.

2.5 Thorium Storage Expansion

Around the middle of FY-56, the AEC requested ORNL to assume responsibility (1) for processing all of remaining irradiated thorium metal and (2) for providing permanent storage for all thorium metal recovered from the Thorex pilot plant. On this basis, a permanent thorium storage pit was constructed immediately south of Building 3019 and two 10,000-gallon storage tanks were installed therein.

Since the short-cool processing program involved the irradiation of an additional quantity of thorium metal, it became necessary to expand the capacity of this permanent storage facility. It was decided to purchase a 5000-gallon vessel in order to better utilize the remaining unoccupied space available within the pit.

3.0 DESIGN AND PROCUREMENT

For the 14-month period between June 1, 1956, and August 1, 1957, Design Section participation in the Thorex program was devoted almost totally to (1) the preliminary process design, (2) the procurement, and (3) the engineering detail design required for the four pilot plant modifications, which are described in this report.

3.1 Design Costs

By studying and analyzing each monthly Thorex Design Operating Report for this 14-month interval and making appropriate, and sometimes tedious, corrections for improper charges, it was possible to extract total costs applicable to the design of all four of the modifications. Since several different phases of the design for one or more of the modifications were frequently in progress at the same time, it was not possible to break the costs down according to the phase of design or the type of modification.

A breakdown of corrected total design costs, according to type of expense (labor, material, and overhead) and origin of expense, is presented in Table 9 of the appendix.

The total cost figure of \$90,095 represents the cost of the preliminary design, the process and instrument procurement, and the preparation of 106 engineering design drawings required to install the four modifications. Since the figure of 106 drawings is a conservative one, a unit design cost per finished drawing of \$800 is considered to be reasonably accurate. A percentage breakdown of this figure according to type of expense follows:

Direct Labor	51%
Indirect Labor	9%
Overhead	38%
Material	2%
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Total	100%

Since the design was being handled by two engineers, the total cost per man-year of section engineering effort was \$40,000, to be contrasted with the usual Design Section budget figure of \$25,000 per man-year.

3.2 Procurement Time Requirements

Figures 2, 3, and 4 of the appendix list all of the purchase requisitions issued for the four modifications and indicate in bar-graph form the total time interval required for the delivery of an acceptable product in each instance. The bars are broken down to show (1) the time interval separating the date of origin of the requisition and the vendor's "promised delivery", (2) the interval by which the vendor exceeded his "promised delivery" date, and (3) the interval required to negotiate a settlement following the delivery of an unacceptable product. As might be expected, the total time required for

delivery varies with the extent by which the material and fabrication specifications for the product depart from conventional practices. This fact is borne out in the table below which summarizes order of magnitude procurement periods, extracted from Figures 2, 3, and 4, required for various product specification groups.

APPROXIMATE PROCUREMENT TIMES

<u>Specification Groups</u>	<u>Delivery Period (Months)</u>
Conventional Electrical Items	1/2
Conventional Stainless Piping Materials	2-3
Piping & BW Fittings	
Tubing & Swagelok Tube Fittings	
Special Stainless Piping Materials	5-8
BW Swagelok Connectors	
1/4" BW Pipe Tees	
Pneumatic Instrumentation	2-4
Stainless Eco & Lapp Pumps	2-3
Stainless Chempumps & Heat Exchangers	4-6
Stainless Fabricated Vessels	7-10

4.0 CONSTRUCTION COSTS AND COST ESTIMATING

A total of nine work orders were written to cover the installation of the four modifications--two for Isolation Rework, four for Third Uranium Cycle, two for the IAWC Facility, and one for the Thorium Storage Expansion. The monthly charges to each of these work orders was reviewed in considerable detail in conjunction with (1) monthly reports for "special cost accumulation accounts" set up to cover material charges for certain phases of the construction and (2) monthly reports for the general Thorex operating account (3370-6). While there was no means available for cross-checking the integrity of the labor charges appearing on the work orders there were several ways of checking the material charges:

1. From a thorough knowledge of what each job involved and the material descriptions appearing on the reports, much could be learned from a thorough visual inspection of the reports. With the assistance of the Materials Control Group, the identity of mysterious "material charge corrections" and "purchase order numbers" could be determined.

2. By listing all expensive items of equipment purchased for each modification, the reports could be checked to assure that the appropriate debits were made.

3. Since a detailed bill of materials was issued with all drawing transmittals, it was possible to assemble composite bills of material for various phases of the construction, estimate their costs, and compare the resulting figures to actual material charges.

As a result of such an analysis, it was found that the Third Uranium Cycle work orders were the most reliable and that the Isolation Rework and IAWC Facility process work orders were noticeably less reliable and probably about comparable. The material charges to the Isolation Rework and IAWC Facility instrument work orders (A-11029 and A-11056) did not correlate well with the job descriptions for each. While the charges to the Thorium Storage Expansion work order are believed to be reliable, since actual charges agreed well with estimated charges, little data was available for a detailed analysis since this construction was performed on a CPFF basis by the H. K. Ferguson Co. In general, it appears that the reliability of individual work order reports decreases in proportion to the number of other project work orders currently in effect. There was a minimum of other Thorex modifications in progress during the period that the Third Uranium Cycle construction was in progress. Such was not the case for the Isolation Rework or the IAWC construction when modifications for the co-decontamination flowsheet and the installation of the interface purge system, respectively, were in progress.

4.1 Actual Construction Costs

Tables 1 through 6 of the appendix summarize material and labor charges for six of nine work orders involved, the two questionable work orders and the work order involving CPFF construction not being included. Material charges have been subdivided into two general classifications--worked material and purchased equipment. Principal contributors to the total cost under each are indicated. Where obvious errors and mischarges were detected during the review of the individual monthly reports, the appropriate corrections have been entered. The term miscellaneous material includes both direct material items, such as nuts, bolts, welding rod, etc., and indirect material, such as argon, helium, wire brushes, files, masking tape, etc. The principal crafts contributing to the total labor charge are indicated.

Table 10 of the appendix presents a breakdown of the construction charges for each of the nine work orders, grouped according to modification. The material, labor, and expense figures are the corrected material, labor, and expense allocation figures appearing in Tables 1 through 6. Actual work order charges have been included for the two questionable work orders (A-11029 and A-11056). Since the actual total charges to these two work orders agree well with the estimates prepared for each and since such charges represent only a small fraction of the total modification costs, the fact the material charges correlate poorly with the job description for each does not appreciably affect the overall cost picture. The "other overhead" figures is intended to allow for additional overhead items which were charged directly to the Thorex operating account, rather than to the work orders. This figure was taken as 30% of the expense allocation figure on the basis that the sum of such items and the expense allocation (65% of labor) normally run around 85% of the labor cost.

4.2 Estimating Piping Material Costs

A composite bill of materials for stainless steel piping was assembled for the Third Uranium Cycle and IAWC Facility from the individual bills of materials which were issued with each drawing transmittal. The total cost of the piping materials listed in these summary bills was then determined

for comparison with the actual piping material charges to the construction work orders. On analyzing the two detailed cost estimates prepared in this manner, it was possible to develop a simplified procedure for estimating the cost of stainless piping materials. Cost Estimates I and II, included in the appendix, illustrate the application of this simplified procedure, which involves the use of certain basic "unit cost" figures and "ratio" factors. The table below compares the results of these simplified cost estimates with (1) the results of the detailed estimates prepared from the composite bills of materials and (2) the actual piping material charges appearing on the construction work order for each project (see Tables 3 and 4).

COMPARISON OF STAINLESS PIPING MATERIAL COSTS

<u>Modification</u>	<u>Piping Material Cost From</u>		
	<u>Simplified Estimate</u>	<u>Detailed Estimate</u>	<u>Work Order</u>
Third Uranium Cycle	\$24,400	\$23,721	\$25,776
IAWC Facility	7,630	7,700	10,161

Agreement is observed to be good throughout except for the actual cost of the IAWC piping materials, which indicates that this work order probably bore the piping costs for some of the other Thorex modifications which were in progress at the same time.

4.3 Estimating Overall Construction Costs

By analyzing the work order cost breakdowns presented in Tables 1 through 6, some interesting correlations for cost estimation purposes can be extracted. For instance, four of the work orders summarized deal almost exclusively with stainless steel fabrication and construction. Table 7 of the appendix compares the ratio of direct labor to worked material charges for these four work orders. The correlation is remarkably good, the labor cost averaging around 66% of the worked material cost.

In Table 8, the ratio of miscellaneous worked material costs to total worked material costs are compared for the same four work orders, and it is observed that the correlation is even better. The miscellaneous material averaging around 12% of the total worked material cost.

Based on such analyses and a similar inspection of the Third Uranium Cycle instrument and electrical work orders (Tables 5 and 6), the following procedures are recommended for estimating ORNL construction costs for various types of construction.

RECOMMENDED COST ESTIMATION PROCEDURES FOR VARIOUS TYPES OF ORNL CONSTRUCTION

<u>Type of Construction</u>	<u>Recommended Procedure</u>
Stainless Steel Process	(a) Estimate purchased equipment cost by take-off. (b) Estimate worked material cost by take-off and the simplified procedures outlined in Cost Estimates I & II of the appendix. Add 12% to allow for miscellaneous worked material. (c) Estimate labor at 66% of (b).
Instrument	(a) Estimate purchased instrument cost by take-off. (b) Estimate total worked material at 40% of (a). (c) Estimate labor at 40% of (a).
Electrical	(a) Estimate purchased electrical equipment cost by take-off. (b) Estimate total worked material at 100% of (a). (c) Estimate labor at 200% of (a).

5.0 DESIGN, PROCUREMENT, AND CONSTRUCTION SCHEDULES

Figure 1 of the appendix shows in bar-graph form the actual periods of time required for the design, procurement, and construction phases of each modification and their time relation to each other. The numbers included in each bar indicate the number of drawings required for design, number of requisitions or purchase orders for procurement, and number of man-months of craft effort required for construction.

In general, it appears that about as much time was required for the engineering design, excluding preliminary design, of each modification as was required for construction. Procurement times were roughly comparable to design, or construction, times for Isolation Rework and Third Uranium Cycle, but were greater by a factor of three for the IAWC Facility and the Thorium Storage Expansion where the procurement of 5000-gallon stainless steel vessels to specifications tighter than the ASME Code was involved.

It is of particular interest to note the parallel between the number of man-months of craft effort and the number of finished design drawings required for each modification. The apparent extra manpower required for the smaller projects probably results from the fact that much of the construction for the smaller projects, such as electrical and instrumentation, is performed without formal design drawings.

COST ESTIMATE I

Third Uranium Cycle Piping Materials Cost (3370-6-1533)

(Simplified Estimate from Summary Bill of Material)

I. SS Piping Cost:

<u>Sch. 40 Pipe Sizes</u>	<u>B-M Quantity (Ft)</u>	<u>Foot-Inches</u>
10	10	100
5	20	100
4	160	640
3	80	240
2	180	360
1-1/2	280	420
1-1/4	100	125
1	580	580
3/4	120	90
1/2	600	300
3/8	500	190
1/4	520	130
1/8	20	3
		3,280 x \$3/ft-in. = \$9,800

II. SS Pipe Fitting Cost (BW and Threaded--including conventional manual valves)

50% of Piping Cost = \$4,900

III. SS Tubing Cost:

<u>Size (OD)</u>	<u>B-M Quantity (Ft)</u>	<u>Foot-Inches</u>
1/2"	1000	500
3/8"	3020	1130
1/4"	1120	280
		1,910 x \$1.50/ft-in. = \$2,900

COST ESTIMATE I (cont.)

IV. SS Swagelok Fittings:

<u>Type</u>	<u>Quantity</u>	<u>Cost</u>
BW connectors, tubing tees, and bulkhead fittings	200 ea x \$7.00 ea	= \$1,400
Threaded connectors, tube unions, caps, etc.	600 ea x \$2.50 ea	= <u>1,500</u>
	Total	\$2,900

V. Special SS Belloseal Valves (BW or Swagelok ends):

<u>Size</u>	<u>B-M Quantity</u>	<u>Size-Quantity Product</u>
1/4" OD	24 ea	6
1/2" OD	44 ea	22
1" P	2 ea	<u>2</u>
		30 x \$130 = \$3,900

VI. Summary of Piping Material Costs:

<u>Item</u>	<u>Cost</u>	<u>Percent of Total</u>
Pipe	\$9,800	40%
Pipe fittings	4,900	20%
Tubing	2,900	12%
Tube fittings	2,900	12%
Special Belloseal Valves	<u>3,900</u>	<u>16%</u>
Total	\$24,400	100%

COST ESTIMATE II

IAWC Facility Piping Material Cost (W.O. A-11057)

(Simplified Estimate from Summary Bill of Materials)

I. SS Piping Cost

<u>Sch. 40 Pipe Sizes</u>	<u>B-M Quantity (Ft)</u>	<u>Foot-Inches</u>
4"	60	240
2"	40	80
1-1/2"	40	60
1"	380	380
1/2"	360	180
3/8"	20	8
1/4"	200	50
1/8"	20	2
		<hr/>
		1,000 x \$3/ft-in. = \$3,000

<u>Sch. 10 Pipe Sizes</u>	<u>B-M Quantity (Ft)</u>	<u>Foot-Inches</u>
2"	20	40
1-1/2"	60	90
1"	80	80
1/2"	60	30
		<hr/>
		240 x \$2/ft-in. = 480
		<hr/>
		Total <u>\$3,480</u>

II. SS Pipe Fittings Cost (BW & Threaded and including conventional manual valves)

50% of Piping Cost = \$1,740

III. SS Tubing Cost

<u>Size (OD)</u>	<u>B-M Quantity (Ft)</u>	<u>Foot-Inches</u>
1/2"	220	110
3/8"	500	190
1/4"	200	50
		<hr/>
		350 x \$1.50/ft-in. = \$530

COST ESTIMATE II (cont.)

IV. SS Swagelok Fittings:

<u>Type</u>	<u>Quantity</u>	<u>Cost</u>
BW, tube tees, bulkhead fittings, etc.	25 ea x \$7.00 ea	= \$175
Threaded connectors, unions, caps, etc.	110 ea x \$2.50 ea	= <u>\$275</u>
	Total	\$450

V. Special SS Belloseal Valves (BW or Swagelok Ends) & Jets (BW Penberthy):

<u>Size</u>	<u>B-M Quantity</u>	<u>Size-Quantity Product</u>
1"P	11 ea	11 x \$130 ea = \$1,430

VI. Summary of Piping Material Costs:

<u>Item</u>	<u>Cost</u>	<u>Percent of Total</u>
Pipe	\$3480	46%
Pipe fittings	1740	22%
Tubing	530	7%
Tube fittings	450	6%
Special valves & jets	<u>1430</u>	<u>19%</u>
Total	\$7,630	100%

ISOLATION REWORK PROCESS CONSTRUCTION
(Work Order A-11027)

Table 1

Includes removal of original system and all fabrication, installation, piping, & shielding for new facility except Instrumentation (includes electrical & routing of instrument lines to transmitters)

MATERIAL COSTS

	<u>Material Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Corrections & Errors Noted</u>	<u>Corrected Charges</u>
Worked Material	SS Piping Material	\$ 6,912		\$ 6,912
	SS Structural Mat'l	1,692		1,692
	Lead	2,336		2,336
	Electrical Material	50		50
	Misc. Material	879		879
	TOTAL	\$11,869		\$11,869
Purchased Equipment	Two Lapp Pumps	--	\$1,242*	\$ 1,242
	GRAND TOTALS	\$11,869	\$1,242	\$13,111

* Charged directly to Thorex Operating Account

LABOR COSTS

<u>Craft Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Expense Allocation</u>	<u>Total Charge</u>
Supervision	\$1,090		
Pipefitters	2,633		
Welders	1,173		
Machinists	1,295		
Other	1,204		
TOTALS	\$7,395	\$4,151	\$11,546
Average Cost per Man-Day	\$ 21	\$ 12	\$ 33

Table 1

THIRD URANIUM CYCLE CELL PREPARATION
(Work Order A-11032)

Table 2

Includes removal of existing floor liner, re-surfacing floor for improved drainage, and re-lining.
Approximately 50% of existing wall liner was removed and replaced.

M A T E R I A L C O S T S

	<u>Material Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Corrections & Errors Noted</u>	<u>Corrected Charges</u>
Worked Material	SS Sheet Metal	\$2,873		\$2,873
	SS Angle & Plate	954		954
	SS Drain Piping	249		249
	Misc. Material	486		486
	TOTAL	\$4,562		\$4,562
Purchased Equipment	None			None
	GRAND TOTALS	\$4,562		\$4,562

L A B O R C O S T S

<u>Craft Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Expense Allocation</u>	<u>Total Charge</u>
Supervision	595		
Sheet Metal	1,143		
Pipefitters	574		
Welders	575		
Other	854		
TOTAL	\$3,741	\$2,142	\$5,883
<u>Average Cost per Man-Day</u>	\$ 21	\$ 12	\$ 33

Table 2

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880 018

THIRD URANIUM CYCLE PROCESS CONSTRUCTION
(Work Order A-111902 & Cost Accumulation Account -1533)

Table 3

Includes all fabrication, installation, piping, & shielding except
Instrumentation & Electrical (includes routing instrument lines to transmitter rack)

M A T E R I A L C O S T S				
	<u>Material Breakdown</u>	<u>Actual Charges to W. O. & Cost Accumulation Account</u>	<u>Correction & Errors Noted</u>	<u>Corrected Charges</u>
Worked Material	SS Piping Material	\$25,776		\$25,776
	SS Structural Mat'l	3,374		3,374
	Misc. Material	3,597		3,597
	Other	2,930	(\$2,930)*	--
	TOTAL	\$35,677		\$32,747
Purchased Equipment	10 Pumps	5,876	891**	6,767
	3 Glove Boxes	3,383		3,383
	TOTAL	\$ 9,259	\$891	\$10,150
	GRAND TOTALS	\$44,936	(\$2,039)	\$42,897

* \$2,700 lead, \$150 jet, & \$80 of Sq.-D electrical material charged to wrong work order.

** Lapp pump charged directly to Thorex operating account.

L A B O R C O S T S			
<u>Craft Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Expense Allocation</u>	<u>Total Charge</u>
Supervision	3,766		
Pipefitters	9,504		
Welders	3,668		
Machinists	1,416		
Riggers	1,273		
Other	2,251		
TOTAL	\$21,878	\$13,788	\$35,666
Average Cost Per Man-Day	\$ 21.50	\$ 13.50	\$ 35

Table 3

IADC FACILITY PROCESS CONSTRUCTION
(Work Order A-11057)

Table 4

Includes all installation & piping except for
Instrumentation (includes routing of instrument lines to transmitter rack).
No electrical required on job.

M A T E R I A L C O S T S				
	Material Breakdown	Actual Charges to Work Order	Corrections & Errors Noted	Corrected Charges
Worked Material	SS Piping Material	\$10,011	\$ 150*	\$10,161
	SS Structural Mat'l	361		361
	Misc. Material	1,225		1,225
	TOTAL	\$11,597		\$11,747
Purchased Equipment	5,000 Gal. Vessel	--	\$11,638**	11,638
	35 Sq. Ft. Condenser	1,065		1,065
	TOTAL	\$ 1,065	\$11,638	\$12,703
GRAND TOTALS		\$12,662	\$11,788	\$24,450

* \$150 jet improperly charged to third uranium cycle.

** Charged directly to Thorex operation account.

L A B O R C O S T S			
Craft Breakdown	Actual Charges to Work Order	Expense Allocation	Total Charge
Supervision	1,478		
Pipefitters	3,847		
Welders	1,326		
Other	680		
TOTAL	\$7,331	\$4,465	\$11,796
Average Cost Per Man-Day	\$ 21.20	\$ 12.80	\$ 34

Table 4

THIRD URANIUM CYCLE INSTRUMENT CONSTRUCTION
(Work Order A-111905 & Cost Accumulation Account -1535)

Table 5

Includes the procurement, fabrication, installation, piping, and calibration of all instrumentation.
(Does not include routing of instrument lines from transmitters to equipment)

M A T E R I A L C O S T S				
	<u>Material Breakdown</u>	<u>Actual Charges to W. O. & Cost Accumulation Account</u>	<u>Corrections & Errors Noted</u>	<u>Corrected Charges</u>
Worked Material	Piping Material	\$ 6,868	(\$143)*	\$ 6,725
	Structural Material	1,179	--	1,179
	Electrical Material	440	--	440
	Misc. Material	296	--	296
	TOTAL	\$ 8,783		\$ 8,640
Purchased Equipment	4 Rec.-Cont., 39 Trans., 22 Rec., 7 Control Valves, & 3 Annunciators	\$23,157	(\$855)* 592**	\$22,894
	GRAND TOTALS	\$31,940	(\$406)	\$31,534

* Excess material erroneously credited to -1435 cost accumulation account.

** Two control valves charged directly to Thorex operating account.

L A B O R C O S T S			
<u>Craft Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Expense Allocation</u>	<u>Total Charge</u>
Supervision	2,189		
Inst. Mech.	4,306		
Pipefitters	893		
Sheet Metal	618		
Other	895		
TOTAL	\$8,901	\$5,560	\$14,461
Average Cost Per Man-Day	\$ 22.80	\$ 14.20	\$ 37

Table 5

THIRD URANIUM CYCLE ELECTRICAL CONSTRUCTION
(Work Order A-111919)

Table 6

Includes all labor and material for electrical distribution to 10 pumps,
9 cell lights, 1 agitator, and 3 glove boxes (light and blower on each)
Magnetic starters included in pump circuits. Does not include electrical at instrument panelboard.

M A T E R I A L C O S T S				
	<u>Material Breakdown</u>	<u>Actual Charges to Work Order</u>	<u>Corrections & Errors Noted</u>	<u>Corrected Charges</u>
Worked Material	Conduit Material	\$ 857		\$ 857
	Sq.-D Duct	239		239
	Wire	247		247
	Misc. Material	<u>261</u>		<u>261</u>
	TOTAL	\$1,604		\$1,604
Purchased Equipment	Magnetic Starters	1,059		1,059
	Cell Lights	--	\$540*	540
	Motor & Light Switches	<u>289</u>		<u>289</u>
	TOTAL	\$1,348	\$540	\$1,888
	GRAND TOTALS	\$2,952	\$540	\$3,492

*Surplus from original construction; estimated value.

L A B O R C O S T S			
	<u>Actual Charges to Work Order</u>	<u>Expense Allocation</u>	<u>Total Charge</u>
Craft Breakdown	Supervision	548	
	Electricians	2,574	
	Others	<u>157</u>	
TOTALS	\$3,279	\$2,008	\$5,287
Average Cost Per Man-Day	\$22	\$13.50	\$35.50

Table 6

Table 7

RATIO OF LABOR COSTS TO WORKED MATERIAL COSTS FOR STAINLESS CONSTRUCTION

PROCESS WORK ORDER	MATERIAL COST BREAKDOWN			DIRECT LABOR (4)	RATIO OF (4)/(2) (PERCENT) (5)
	Purchased Equipment (1)	Worked Material (2)	Total (3)		
Isolation (A-11027)	1,242	11,869	13,111	7,395	62.5%
Cell 3 Lining (A-11032)	--	4,562	4,562	3,741	81.5%
3rd Cycle Process (A-111902)	10,150	32,747	42,897	21,878	67.0%
IAWC Process (A-11057)	12,703	11,747	24,450	7,331	62.5%
TOTALS	\$24,095	\$60,925	\$85,020	\$40,345	66.2%

Table 8

RATIO OF MISCELLANEOUS TO STAINLESS WORKED MATERIAL COSTS

<u>Process Work Order</u>	<u>Stainless Worked Mat'l Cost (1)</u>	<u>Misc. Worked Mat'l Cost (2)</u>	<u>Ratio (2)/(1) (Percent)</u>
Isolation (A-11027)	\$8,604	\$ 879	10.2
Cell 3 Lining (A-11032)	4,076	486	11.6
3rd Cycle (A-111902)	29,150	3,597	12.4
IAWC (A-11057)	<u>10,522</u>	<u>1,225</u>	<u>12.9</u>
TOTALS	\$52,352	\$6,187	11.8

SUMMARY OF THOREX DESIGN COSTS

Table 9

For Months of June, 1956, through August, 1957

DESIGN GROUP	BRIEF DESCRIPTION OF DESIGN CONTRIBUTION	L A B O R			
		Engrg.	Draft.	Other ¹	Total
Chem Tech Design Section	Preliminary process design, design supervision, and process procurement for all modifications. Engineering design included 79 process drawings.	\$20,765	\$15,397	\$7,654	\$43,816
Instrument Department (Work Order A-11021)	Procurement and engineering design for third uranium cycle instrumentation. Design in- cluded 15 new drawings and 14 transmitter module drawings.	\$ 3,393	\$ 1,859	--	\$ 5,252
Engineering Department (Work Order A-111904)	Engineering design assistance for third uranium cycle. Design included 4 cell structural, 3 cell piping, and 5 electrical drawings.	\$ 1,964	\$ 3,123	--	\$ 5,087
TOTALS		\$26,122	\$20,379	\$7,654	\$54,155
		OVERHEAD CHARGES ²			\$34,045 ³
		MISC. MATERIAL			1,895
		TOTAL DESIGN			\$90,095

¹ Includes other Design Section labor charges (Section Chief, Drafting Room Supervision, Secretaries, etc.)

² Includes all overhead charges (Expense Allocation, Health Physics, Utilities, Laboratory Director, Division Director, etc.)

³ Abnormally low percentage of total labor charges since approximately 60% of drafting charges were for Catalytic personnel.

Table 9

830 025

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SUMMARY OF THOREX MODIFICATION CONSTRUCTION COSTS

Table 10

MODIFICATION & PHASE OF CONSTRUCTION	BREAK-DOWN OF COSTS					Totals
	Material	Labor	Expense ¹	Work Order ²	Other Overhead ³	
Isolation Rework						
Process (A-11027)	13,111	7,395	4,151	24,657	1,243	25,900
Instrument (A-11029)*	1,983*	576*	338*	2,897*	103*	3,000*
						\$ 28,900
Third Uranium Cycle						
Cell Lining (A-11032)	4,562	3,741	2,142	10,445	637	11,082
Process (A-111902)	42,897	21,878	13,788	78,563	4,037	82,600
Instrument (A-111905)	31,534	8,901	5,560	45,995	1,665	47,660
Electrical (A-111919)	3,492	3,279	2,008	8,779	621	9,400
						\$150,742
IAWC Facility						
Process (A-11057)	24,450	7,331	4,465	36,246	1,334	37,580
Instrument (A-11056)*	4,095*	653*	394*	5,142*	118*	5,260*
						\$ 42,840
Thorium Storage Expansion (A-11089)						
ORNL Portion	11,250	442	267	--	80	12,039
CPFF Portion	4,569 ⁴	--	--	--	--	4,569
				16,528		\$ 16,608
TOTALS	\$141,943	\$54,196	\$33,113	\$229,252	\$9,838	\$239,090

* These figures are based on actual charges to indicated work order and are considered highly questionable since material charges bear little resemblance to job scope.

¹ Expense allocation only

² Total of material, labor, & expense allocation columns. Materials for work orders A-111902 and A-111905 were charged to cost accumulation accounts 3370-6-1533 & -1535, respectively, rather than to work orders.

³ Utility, Health Physics, Laboratory Director, Division Director, etc., charges

⁴ H. K. Ferguson fee for installation and piping. All materials were supplied by ORNL.

Table 10

FIGURE 1

OVERALL SUMMARY OF DESIGN, PROCUREMENT, & CONSTRUCTION SCHEDULES

Code

Preliminary Process Design

Drafting of engineering drawings

Drafting of new & transmittal of finished engineering drawings to field
(Number indicates the total number of engineering drawings issued)

Requisitioning & delivery of purchased equipment (number indicates number of requisitions)

Shop & field construction (number indicates total man-months of craft effort required)

DETAILED PROCUREMENT SCHEDULE

	1956						1957								
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
<u>Isolation Rework</u>															
Lapp Metering Pumps		D-53801													
<u>IAWC Facility</u>															
N-30 Vessel (5,000 gal.)				D-53803											
N-30 Condenser (35 ft ²)				D-53810											
<u>Thorium Storage Expansion</u>															
P-25 Vessel (5,000 gal.)				D-53802											
Liquid Level Float															
Spare Tape for Float															
<u>Third Uranium Cycle Process</u>															
Column Pulsers		D-53799													
Feed Metering Pump		D-53800													
4" P Caps, BW, 347				D-53804											
Chemiseal Gaskets				D-53805											
4" P, Sch 40, 347 SS				D-53806											
Product Evaporator Pump				D-53807											

Code

D-xxxxx

Interval between time requisition written & vendor's "promised" delivery.
Number indicates requisition number.

Interval by which "actual" delivery exceeded "promised" delivery.

Additional delay resulting from the receipt of an unacceptable product.

DETAILED PROCUREMENT SCHEDULE (CONT'D)

	1956						1957								
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Chempumps					D-53808				Chempump Corporation						
Eco Centrifugal Pumps				D-53809		Eco Engineering Co.									
1/4" P Tees, BW, 347 SS				D-53811					Stainless Piping Supply, Inc.						
Glove Boxes						D-53812			The John F. Deye Co.						
Stainless Quick-Disconnects						D-53813			Willis Supply Co.						
1/4" OD Tubing 304 SS						D-53814			Stainless Piping Supply, Inc.						
Ball Plug Valves, 316 SS						D-53815			The Greene-Wolf Co.						
Fog Nozzles, Teflon						D-53816			Bete Fog Nozzle, Inc.						
Reducing Tees, BW, 347 SS						D-53817			Stainless Piping Supply, Inc.						
Chemiseal Gaskets						D-53818			U. S. Gasket Co.						
Swagelok Tube Fittings						D-53819			James C. White Co.						
Swagelok BW Fittings					James C. White Co.	D-53820									
Spare Eco Centrifugal Pump						D-53821			Eco Engineering Co.						
Flexible Stainless Hoses						D-53822			Atlantic Metal Hose Co., Inc.						
8" I-beams & 6" Channels							D-53823		Siskin Steel & Supply Co., Inc.						
SS Swagelok Bulkhead Fittings									D-53824		James C. White Co.				
Solid Concrete Block									Southern Cast Stone Co., Inc.		D-53833				

Code

D-xxxxx

Interval between time requisition written & vendor's "promised" delivery.
Number indicates requisition number.

Interval by which "actual" delivery exceeded "promised" delivery.

Additional delay resulting from the receipt of an unacceptable product.

FIGURE 4

DETAILED PROCUREMENT SCHEDULE (CONT'D)

	1956						1957								
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
<u>Third Uranium Cycle Instruments</u>															
Pressure Switches						D-102061									
Hi-Range Transmitters						D-102065									
Recorder-Controllers						D-102063									
Recorders						D-102062									
Annunciators						D-102073									
Control Valve, 316 SS						D-102133									
Rotameters, M-U Metering						D-102074									
Orifice Flanges						D-102142									
Motor Starter Switches						D-102210									
Pneumatic Loading Stations						D-102214									
A C Ammeters											D-102555				
<u>Third Uranium Cycle Electrical</u>															
Magnetic Starters										D-53825					
SQ-D Electrical Duct										D-53826					
Sentinel Switches										D-53827					
Starters & Receptacles										D-53828					
Aluminum Condulets										D-53829					
Aluminum Conduit & Fittings										D-53830					

Code

D-XXXXX

Interval between time requisition written & vendor's "promised" delivery. Number indicates requisition number.

Interval by which "actual" delivery exceeded "promised" delivery.

Additional delay resulting from the receipt of an unacceptable product.

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- 35-36. W. R. Winsbro
- 37-38. Laboratory Records
39. Laboratory Records (RC)
- 40-41. Central Research Library
42. Document Reference Section

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