GA–A27039

DATA AND MODELS FOR COST ANALYSES FOR FABRICATION OF DIRECT DRIVE IFE TARGETS

by
W.S. RICKMAN and D.T. GOODIN

Prepared under
General Atomics IR&D Funding

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ABSTRACT

Chemical engineering analyses are underway for a commercial-scale [1000 MW(e)] divinyl benzene foam-based Inertial Fusion Energy (IFE) Target Fabrication Facility (TFF). This facility is designed to supply 500,000 4 mm o.d. targets per day – coated via interfacial polycondensation, dried with supercritical CO_2, sputter coated with Au and/or Pd, filled with deuterium-tritium (DT), layered at cryogenic temperatures and injected into the fusion chamber. Such targets would be used in a direct-drive IFE power plant.

The work uses manufacturing processes being developed in the laboratory, chemical engineering scale-up principles and established cost estimating methods. The plant conceptual design includes a process flow diagram, mass & energy balances, equipment sizing and sketches, storage tanks and facility views.

The cost estimate includes both capital and operating costs. Initial results for a TFF dedicated to one 1000 MW(e) plant indicate that the costs per target are well within the commercially viable range. Larger TFF plants [3000 MW(e)] are projected to lead to significantly reduced costs per injected target. Additional cost reductions are possible by producing dried, sputter-coated empty shells at a central facility that services multiple power plants.

The results indicate that the installed capital cost is about $100M and the annual operating costs will be about $20M, for a cost per target of about $0.17 each. These design and cost projections assume that a significant process development and scale-up program is successfully completed for all of the basic unit operations included in the facility.

I. INTRODUCTION AND BACKGROUND

The target for an Inertial Fusion Energy (IFE) power plant introduces the fusion fuel into the chamber, where it is compressed and heated to fusion conditions by the driver beams. The "Target Fabrication Facility" (TFF) of a 1000 MW(e) IFE power plant must supply about 500,000 targets per day. The targets are injected into the target chamber at a rate of 6–10 Hz and tracked precisely so the driver beams can be directed to the target. The feasibility of developing successful fabrication and injection methodologies at the low cost required for energy production (about \$0.25–0.30/target, about 10^4 less than current costs) [1] is a critical issue for inertial fusion.

To help identify major cost factors and technology development needs, we have utilized a classical chemical engineering approach to the TFF. We have identified potential manufacturing and handling processes for each step of production, and have evaluated the raw materials, labor force, cost of capital investment, and waste handling costs for providing 500,000 direct-drive radiation preheat targets [2,3] per day. We have prepared preliminary equipment layouts, and determined floor space and facility requirements. The purpose of this is not to provide a final plant design, rather to show that production of targets at the required throughput rates and at low cost is feasible. The analyses assume an "nth-of-a-kind" TFF and utilize standard industrial engineering cost factors.

These cost analyses assume that the process development is accomplished to allow scaling of current laboratory methods to larger sizes, while still meeting target specifications. A development program is underway at various laboratories to support this scale-up [4]. The program includes development of methods to produce foam shells by microencapsulation, measurements and analyses of permeation filling of the shell with DT fusion fuel, studies of cryogenic fluidized beds for layering of the fuel, and construction of a precision injection and tracking system to demonstrate that proper placement of the final cryogenic target can be accomplished. This paper summarizes the modeling work underway to show the feasibility of a cost-effective direct-drive target supply for IFE.

This modeling methodology is intended to provide a first cut at the facility design concepts and cost, a framework to compare and contrast future design decisions, and a tool to help guide future research directions, as well as enough information to allow full peer review of the calculational approach and all of the assumptions that have been used in estimating the capital and operating costs.

II. PROCESS DESCRIPTION

Following are descriptions of each of the 13 major process steps leading to a filled, layered target (as shown in Fig. 1) that is ready for injection [5]:

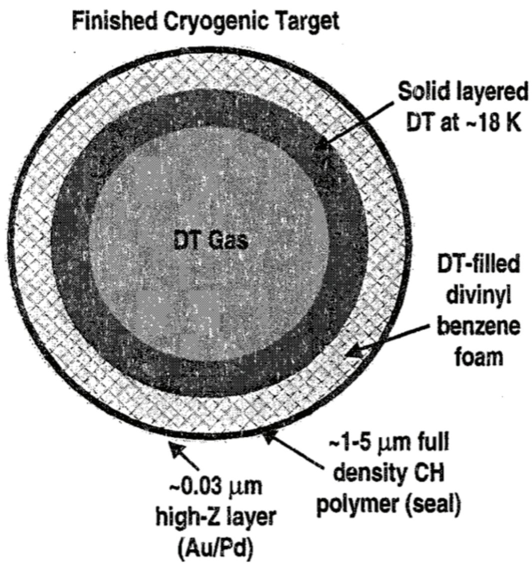

Fig. 1. Finished NRL radiation preheat target..

Process Step #1 — Divinylbenzene (DVB) foam shells are made with a dibutyl phthalate foam solvent and a 2,2′azo-bis-iso-butyronitrile (AIBN) initiator (for subsequent DVB cross-linking). Water is inside of the hollow targets and water/PVA (polyvinyl alcohol) is on the outside. These targets flow with the outer water into rotary contactors where the targets comprise ~8% of the contactor total volume (a lower solids ratio may be used for the initial process stage where the targets are not yet fully cured and are thus more fragile) [see Fig. 2].

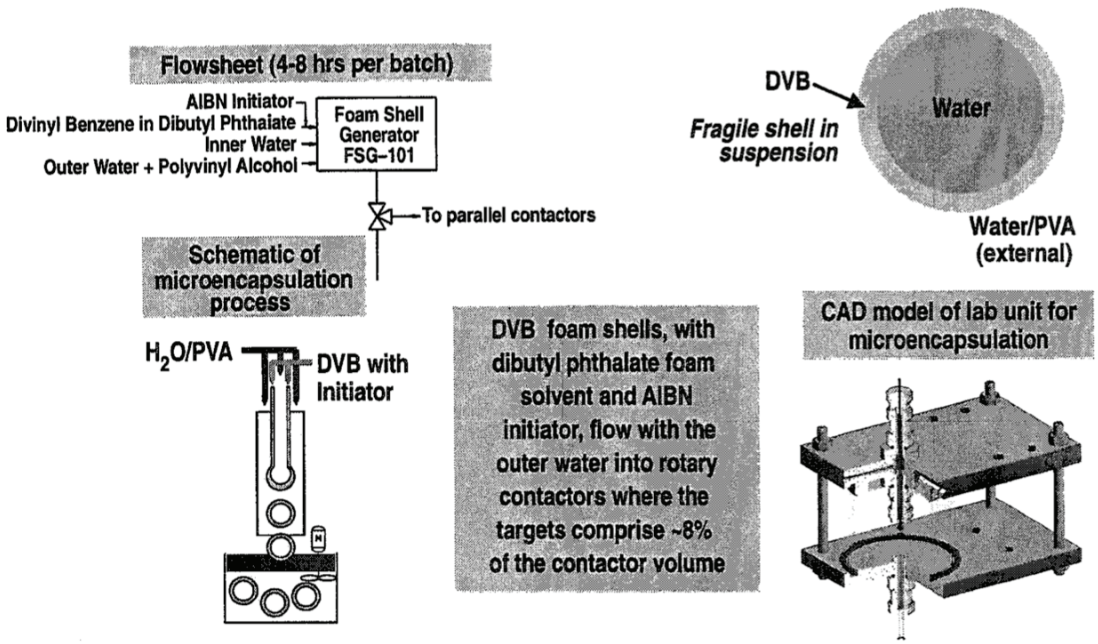

Fig. 2. Process step #1 — generation of DVB foam shells.

Process Step #2 — The freshly formed DVB targets are gently stirred by the rotation of the contactor as the foam partially cross-links at ambient temperatures (see Fig. 3).

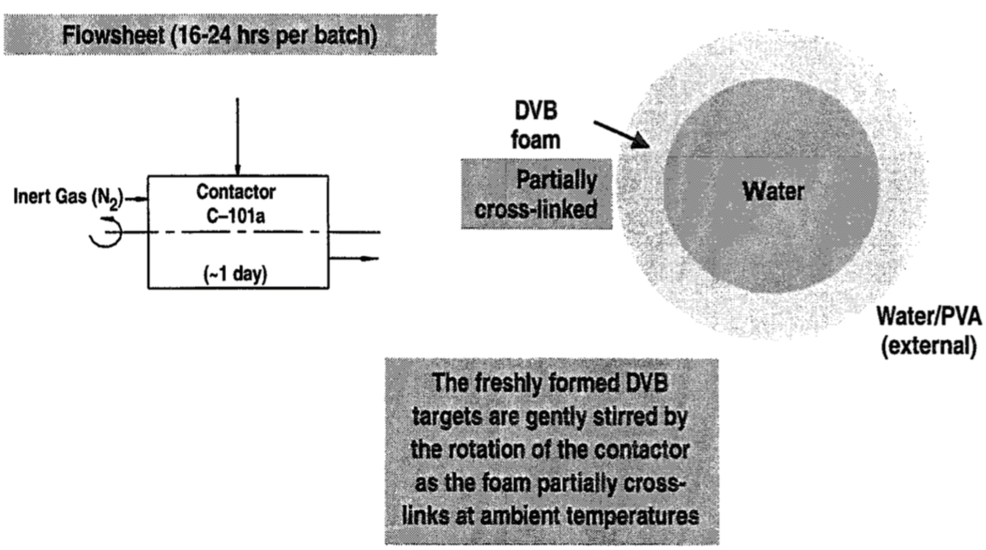

Fig. 3. Process step #2 — ambient temperature curing and spheroidizing.

Process Step #3 — The partially cross-linked targets are heated to 60°C to more fully polymerize & cross-link the DVB foam (see Fig. 4).

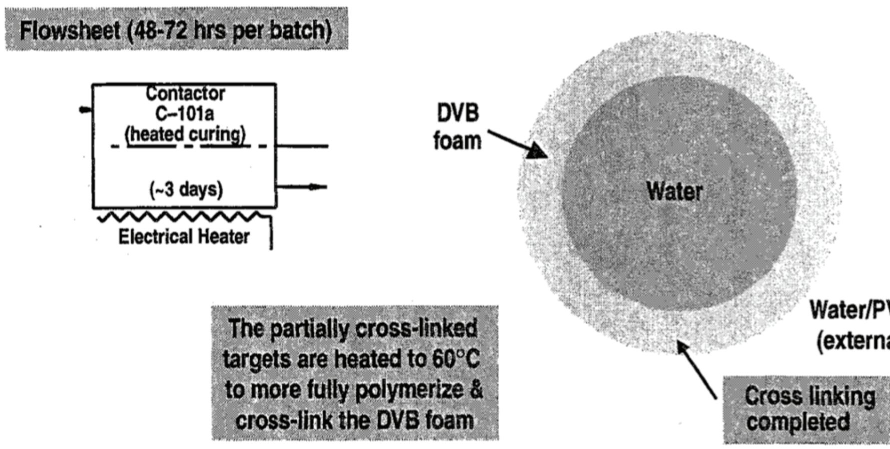

Fig. 4. Process step #3 — heated curing (~60°C).

Process Step #4 — Isopropanol is sufficiently miscible in both water and oil (parachlorotoluene) to facilitate the transition from inner water (step #1–3) to inner oil (step #5) [see Fig. 5].

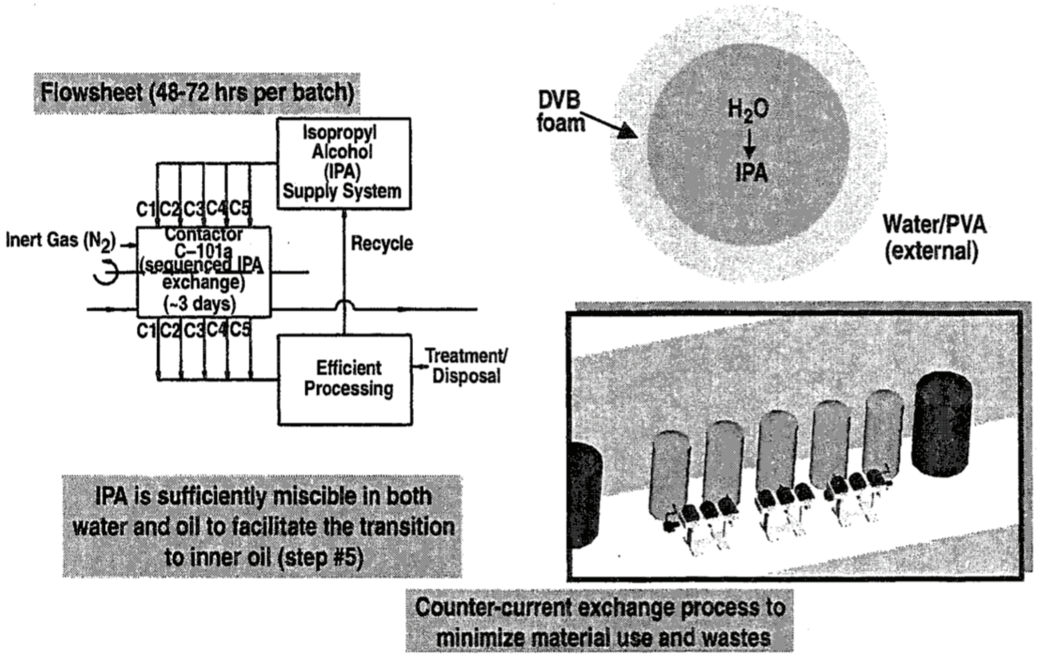

Fig. 5. Process step #4 — isopropanol exchange.

Process Step #5 — Oil (parachlorotoluene) is transferred into the targets to provide a medium for Monomer A (isophthaloyl dichloride) to subsequently be dissolved into (in Step # 6) [see Fig. 6].

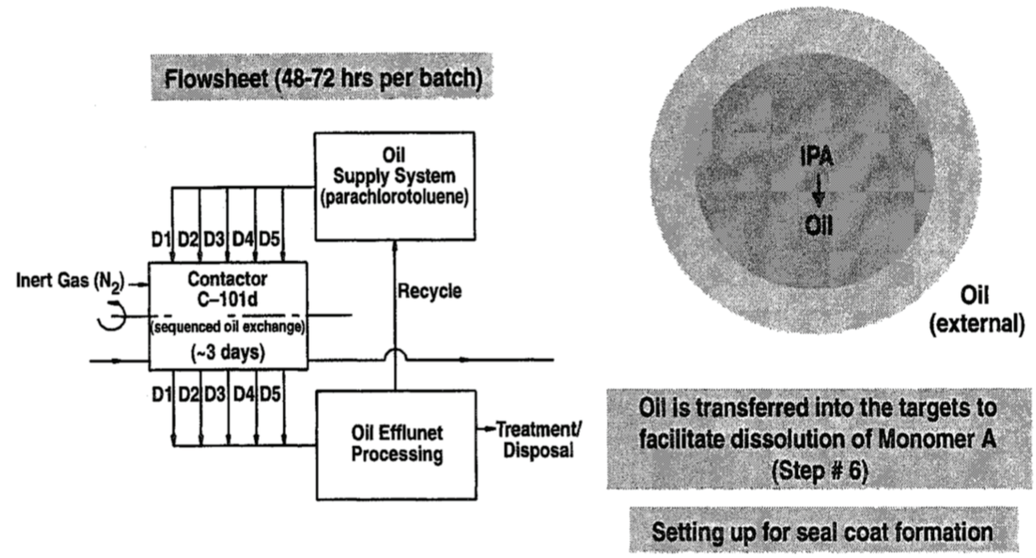

Fig. 6. Process step #5 — oil exchange.

Process Step #6 — Monomer A is dissolved into the oil inside of the targets (see Fig. 7).

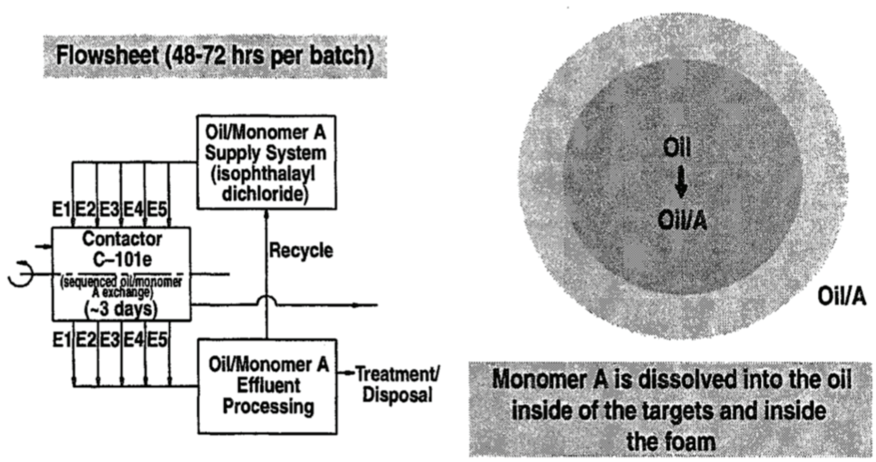

Fig. 7. Process step #6 — loading of Monomer A.

Process Step #7 — Water/surfactant replaces the oil outside of the targets, keeps them from sticking together, and provides an aqueous medium for Monomer B (poly 4-vinyl phenol) to be dissolved in Step #8 (see Fig. 8).

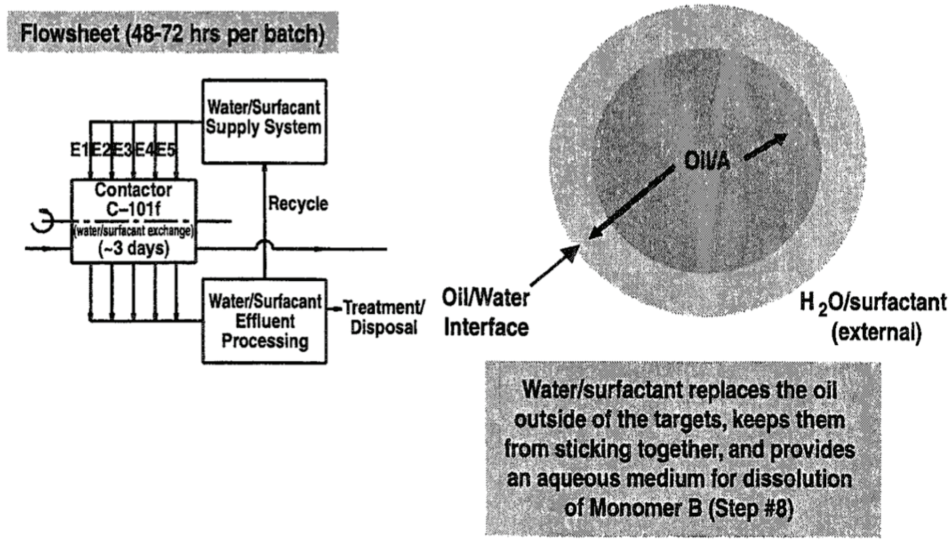

Fig. 8. Process step #7 — water/surfactant exchange.

Process Step #8 — Monomer B is added to the water/surfactant to initiate the formation of the 1–5 μm thick seal coat via polymerization of Monomers A and B at the oil/water interface on the target surface (see Fig. 9).

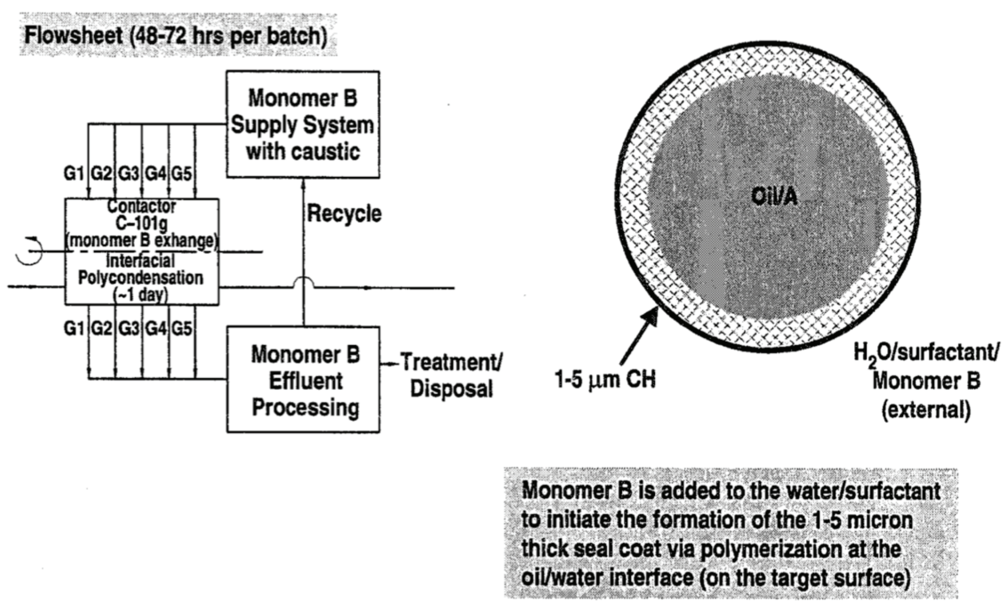

Fig. 9. Process step #8 — Monomer B (interfacisal polycondensation).

Process Step #9 — Isopropanol is sufficiently miscible in both oil (parachlorotoluene) and CO_2 to facilitate the transition from inner oil/outer water (step #8) to inner/outer CO_2 (step #10) [see Fig. 10].

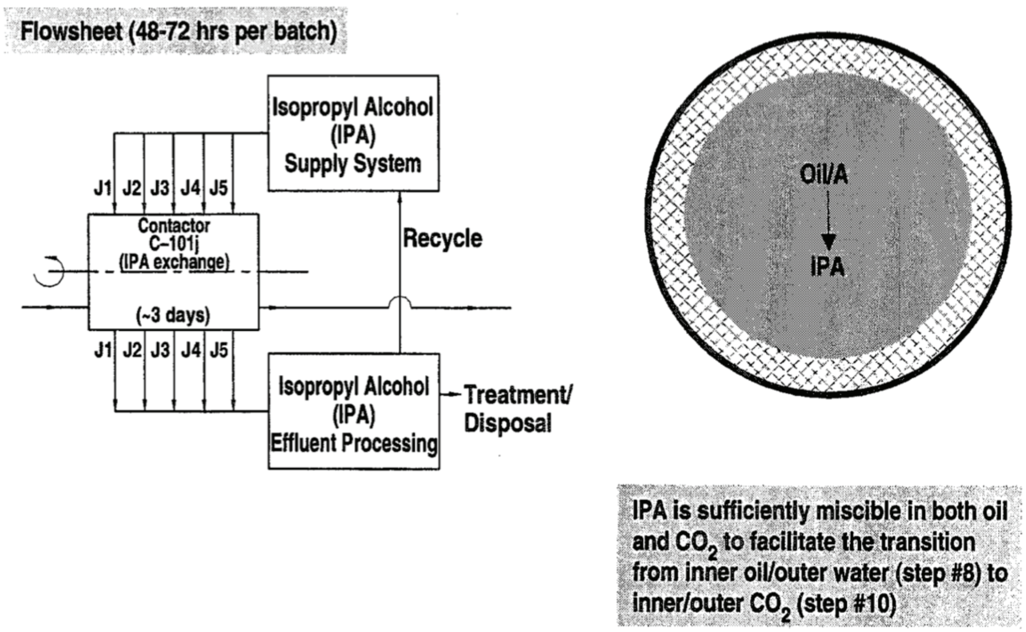

Fig. 10. Process step #9 — isopropanol exchange.

Process Step #10 — Liquid subcritical CO_2 (20°C–800 psig) replaces the inner IPA by countercurrent stagewise dilution contacting. The resulting liquid-CO_2 filled targets are heated beyond the CO_2 critical point (31°C–1070 psig) to reduce surface tension to zero and thus prevent target stress fracturing from depressurization forces during subsequent venting of the supercritical CO_2. This results in dry targets with only ambient pressure gaseous CO_2 inside/outside, ready for the high-Z coating in step #11 (see Fig. 11).

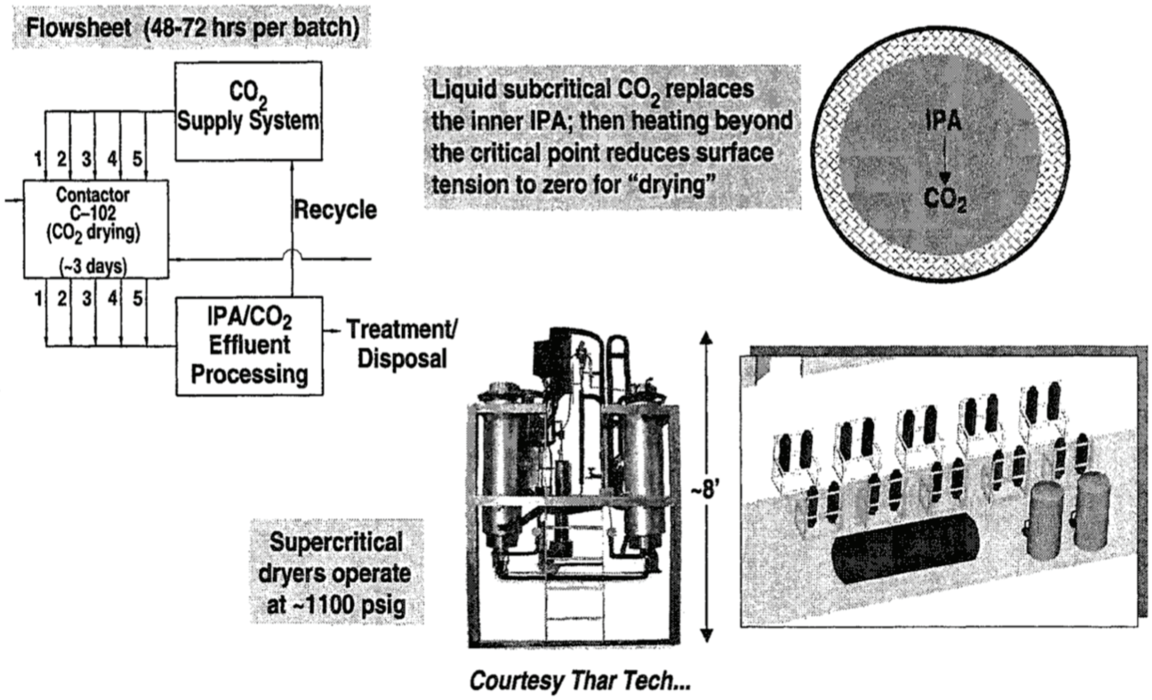

Fig. 11. Process step #10 — CO_2 rinsing and critical point drying.

The actual process sequence for critical point drying is as follows:

1. Targets (filled with IPA) are loaded into the pressure vessel.
2. Pressure vessel is filled with liquid CO_2 (@ 20°C–800 psig) from a refrigerated liquid CO_2 tank (example @ 15°C–300 psig).
3. System is allowed time to equilibrate miscible fluids (liquid CO_2 and liquid IPA) inside and outside of target.
4. External CO_2/IPA mixture is drained into waste tank, where CO_2 is vented (could also be recycled with commerically available systems if desired).
5. Rinsing is repeated several times to yield targets that essentially are filled with liquid CO_2 only.
6. System temperature is raised to above the critical point (@ 31°C–1070 psig) and vented, with supercritical CO_2 more easily vented due to its greatly reduced (essentially zero) surface tension and thus high diffusivity.
7. Dry targets are removed and transferred to the sputtering stage of target fabrication.

This process is practiced commercially on a wide variety of materials, with carbon dioxide being the most common solvent due to its superior physical properties (vapor pressures, miscibility, etc.). A small pilot-scale commerical system will be the correct size for the TFF processing line (see example in Figs. 12 and 13 and specifications in Attachment 1).

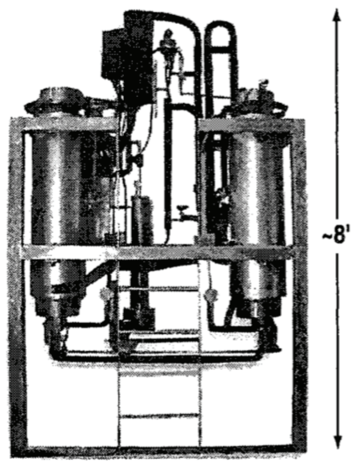

Fig. 12. Production-scale batch CO_2 critical point dryer.

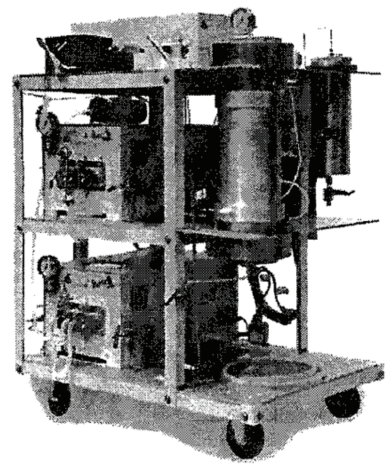

Fig. 13. Pilot scale batch CO_2 point dryer.

Process Step #11 — A thin (~ 0.03 μm) gold and/or palladium coating is added to the outer surface of the dried targets by a batch sputtering process (i.e. physical vapor deposition) performed in a vacuum (which removes the gaseous CO_2 remaining in the target from Step #10) [see Fig. 14].

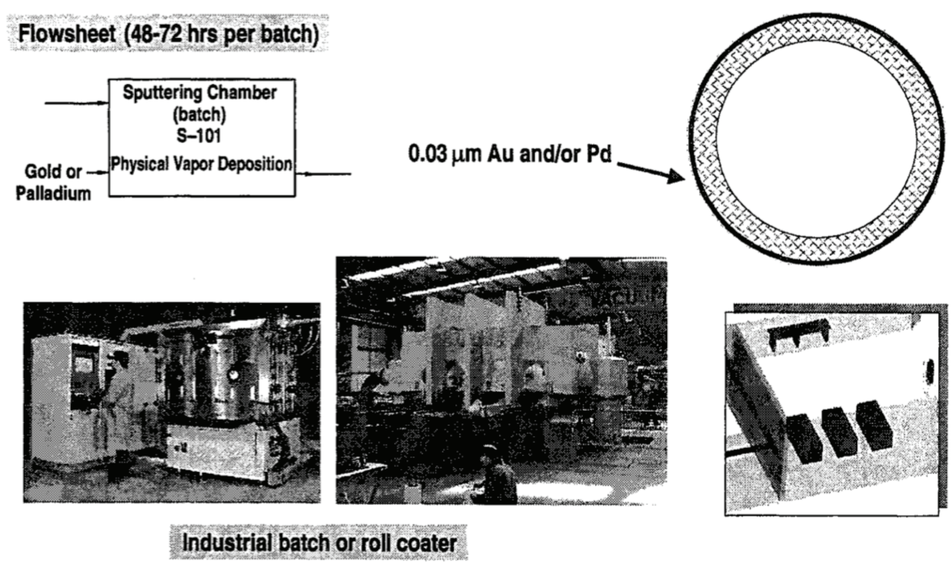

Fig. 14. Process step #11 — high-Z sputter coating.

Process Step #12 — DT is loaded into the targets by diffusion at high pressures (at room temperature or above) followed by condensation at cryogenic temperatures (≤ 20 K) to lower the internal pressure in the targets to prevent target rupturing as the external pressure is reduced (see Fig. 15).

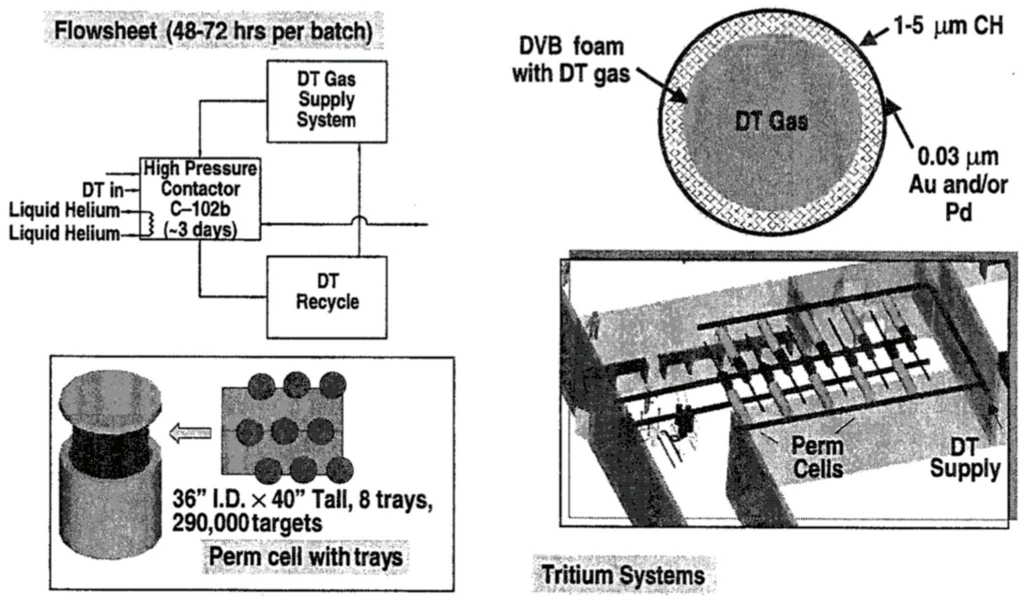

Fig. 15. Process step #12 — DT filling in a permeation cell.

Process Step #13 — DT-filled targets are maintained at a temperature slightly below the triple point while they are gently fluidized with gaseous helium (to maintain a time-averaged highly isothermal temperature profile on the entire surface of the sphere) and exposed to a heating beam that will result in preferential sublimination at thicker areas and eventually yield a uniform DT layer (see Fig. 16).

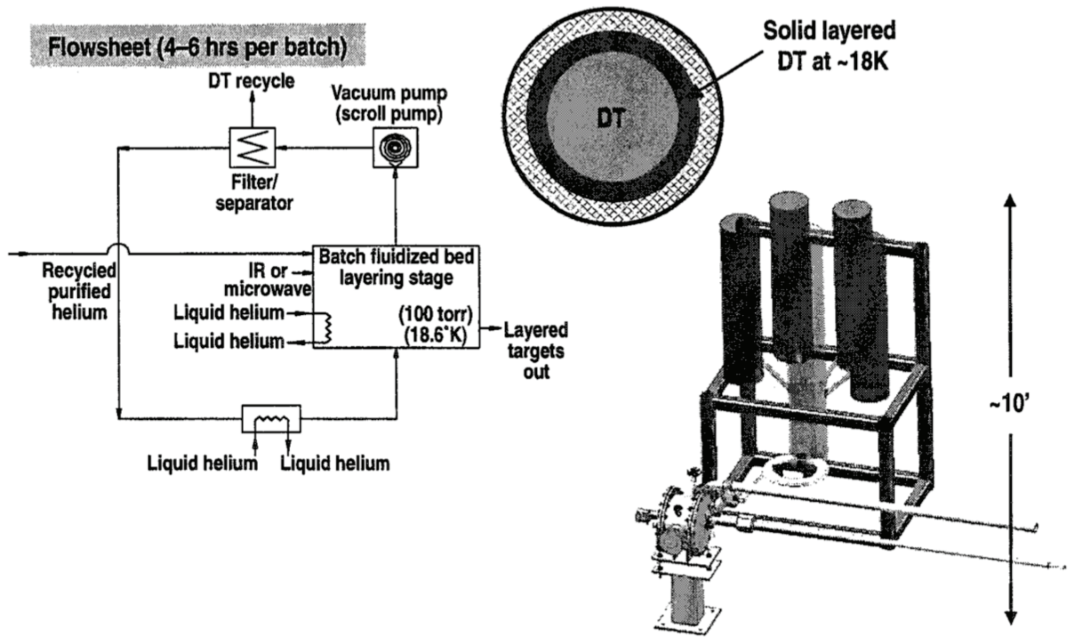

Fig. 16. Process step #13 — cryogenic fluidized bed layering and transfer to target injection.

III. MODELING ASSUMPTIONS

A number of process assumptions have been made, based on:

- Preliminary requirements for the IFE radiation preheat direct drive targets (see Attachment 2).
- Discussions with researchers in each of the enumerated process steps to reflect their latest findings.
- Interactions with vendors of process equipment that is adaptable to this service (such as critical point driers).

IV. PROCESS FLOW AND FACILITY LAYOUT

The plant conceptual design includes a process flow diagram, mass & energy balances, equipment sizing and sketches, storage tanks and facility views (plan, elevation & perspective).

The preliminary plant layout is illustrated in Fig. 17. The TFF will operate on a batch-continuous mode wherein batches of targets are placed in rotary contactors (see Fig. 18) for a series of chemical processes to yield resultant wet, overcoated shells (through step 9). Each process step requires a discrete period of time prior to the entire contactor (and contents) moving on to the next step – analogous to an automobile assembly plant. This will minimize the transfer of targets from one piece of equipment to another until they are overcoated (and thus more durable) to minimize damage and improve yields.

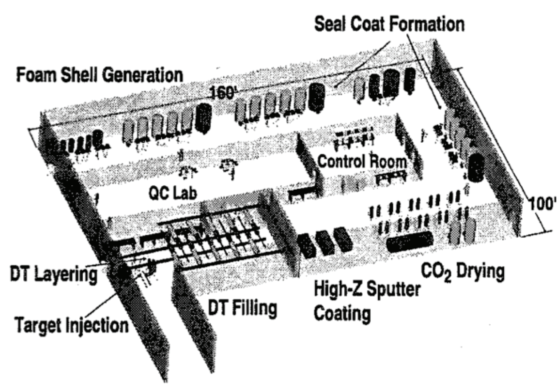

Fig. 17 IFE farget fabrication facility isometric view.

After the wet targets are removed from the rotary contactor, they are then dried, sputter coated and DT-filled in batches prior to being layered in a continuous delivery to the target injection system.

Production scale contactor
- **Rotary contactor does first 9 process steps**
- **Contactor ~50 cm ID × ~50 cm long and holds a ~8 h target supply**
- **Stagewise backmix concept eliminates shell transfers and potential attrition to improve yields**

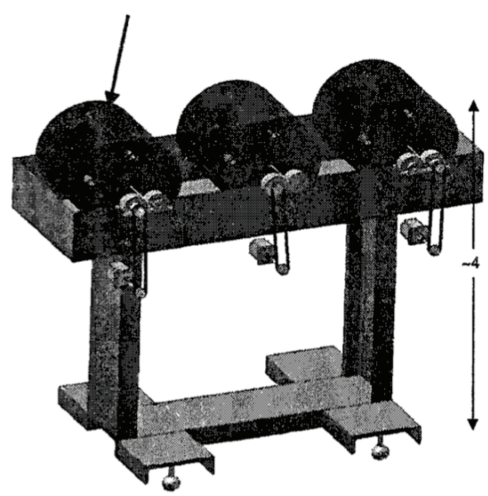

Fig. 18. Rotary contactor - a basic functional unit of the TFF.

V. CALCULATIONAL APPROACH AND EQUATIONS

The work uses basic manufacturing methods being developed in the laboratory, chemical engineering scale-up principles and practices, including counter-current, stagewise contacting and established cost estimating methods and factors. Recycle and beneficial reuse of process effluents are being designed into the facility.

The chemical engineering modeling techniques are intended to provide guidance on process development needs (and subsequent research directions) and to serve as a standardized method of comparing process costs for future evaluations of foam and various other target types.

A detailed material and energy balance (M&EB) was prepared to provide information on the flow rates and quantities of raw materials, finished products and by-products for the entire TFF. All of the cost calculations for chemicals, utilities and waste disposal use mass quantities calculated in the M&EB.

Statistical sampling of target batches will be performed at every process step to avoid unnecessary further processing of off-spec targets. Finished dried shells with high-Z coatings will be sampled (100% QA in a final "flow-through" step) and stockpiled (potentially at a central facility serving multiple power plants) to assure a reliable supply backlog of several days of on-spec empty targets. The empty targets need only then be DT-filled and cryo-layered prior to injection. Overall target QA rejection rates are arbitrarily assumed in this work to be 25%,* with sensitivity studies covering a wider range of 5%–75% reject rates.

*Conservatively high reject rates were used in these analyses (25% nominal and a range of 5%–75%) to illustrate the robust nature of the calculational assumptions - it is expected that process development will lead to lower reject rates, but this analysis shows that is not an absolute requirement.

VI. CAPITAL COST ESTIMATION

The cost estimate includes both capital and operating costs. Capital costs are broken down into purchased equipment, engineering/contingency, buildings/auxiliaries and piping/electrical/ instrumentation. Operating costs are broken down into operating staff, chemicals, maintenance, utilities and waste disposal. Sampling and inspection equipment and staffing costs are included at all stages of target preparation. Where appropriate, initial discussions are underway with vendors of commercial equipment that may be used in the facility. In other cases, the costs of new or novel equipment have been estimated using engineering judgement followed by peer feedback from researchers skilled in these areas of expertise.

VII. FINANCING CALCULATIONS

Target Fabrication Facility capital costs are treated as an annual expense. Design and construction costs are typically paid for by a combination of sources, including debt (bonds), preferred dividend stock, and common equity stock.

Standard financial treatments [6] result in a levelized "fixed charge rate" of expressing the annualized expense of repaying the design and construction costs to these three sources.

The fixed charge rate is calculated using inputs ranging from interest rates, stock returns, tax rates, depreciation schedules, etc. Details are included in excerpts found in Attachment 3.

For a 30-year facility with typical financial assumptions, the fixed charge rate is calculated to be 12.5% per year as shown in Attachment 4.

VIII. OPERATING COSTS

A generous operating staff has been allocated to the operations. There are 12 staff working a normal 5 days per week, 8 hours per day shift and an additional 28 production personnel present per shift to operate the facility. The model assumes 5-shift operation to cover 24/7 operations along with vacations, holidays, etc. Job categories include operators, technicians, health physicists, QA/QC specialists, supervisors, engineers and clerks.

Maintenance expenses are calculated using a factored percentage (6% per year) of installed capital costs. Utilities, waste disposal and chemical costs were calculated using vendor-supplied prices coupled with M&EB mass flow requirements.

IX. MODEL SENSITIVITY RESULTS

Results of the base-case model are shown in Fig. 19, including itemized summaries of capital and operating costs on a per injected target basis. For the baseline design assumptions, the cost per target is 16.6¢. We also looked at the sensitivity of this result to changes in one or more of the assumptions. The results are given in Table 1. These single and multiple variable responses illustrate that the costs per injected target are within a 25¢ cost goal even with significant increases in assumptions.

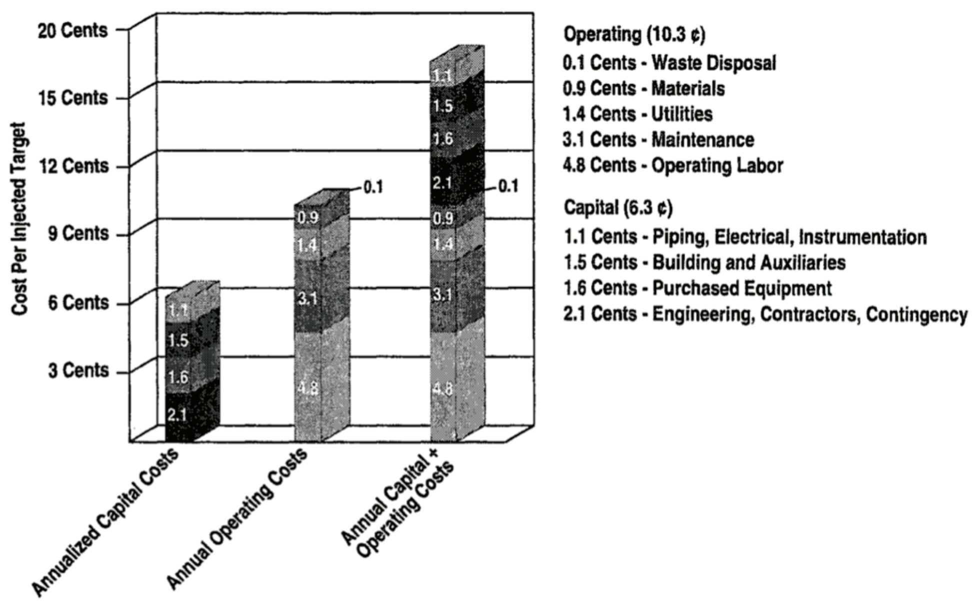

Fig. 19. Projected capital and operating costs per injected target at a 1000 MW(e) power plant.

Table 1. Results of Model Sensitivity Studies*

Case	Description	Cost per Injected Target (¢)
	Single variable responses [1000 MW(e) plant]:	
1	Baseline (@25% reject rate)	16.6
2	Doubled staffing costs	21.3
3	Doubled capital costs	26.0
4	Doubled maintenance costs	19.6
5	Doubled utilities costs	18.0
6	Baseline (@5% reject rate)	15.6
7	Baseline (@50% reject rate)	18.7
8	Baseline (@75% reject rate)	24.5
	Multiple variable responses [1000 MW(e) plant]:	
9	All costs 25% higher and 50% reject rate	24.3
	Larger plant case:	
10	3000 MW(e)	10.3

Hybrid plant cases (empty targets made at a 10,000 MW(e) equivalent central facility):

Case 11 – 1000 MW(e)	empty capsules (made off-site)	2.9¢ per injected target
	fill/layer/inject (on-site)	11.7¢ per injected target
	Total:	14.6¢ per injected target
Case 12 – 3000 MW(e)	empty capsules (made off-site)	2.9¢ per injected target
	fill/layer/inject (on-site)	6.5¢ per injected target
	Total:	9.4¢ per injected target

*See Attachment 5 for Cases 1–12.

The cost of injected targets is estimated to be <17¢ each for a 1000 MW(e) power plant.

Significantly lower costs on the order of <10¢ per injected target are calculated for a 3000 MW(e) plant. Additional cost savings of 10%–15% are possible by fabricating the empty dry targets at a central facility and then filling/layering/injecting them at the power plant site. The empty, dry shells are estimated to cost only 2.9¢ per target when made in this large quantity (10,000 MW(e) equivalent). This economy of scale results in a savings of 0.9¢ per injected target (or 9% cost reduction) at a 3000 MW(e) plant and a savings of 2.0¢ per injected target (or 12% cost reduction) at a 1000 MW(e) plant.

As a measure of the robustness of the cost estimates, we calculate that doubling of significant individual cost assumptions leads to projected costs of <25¢ per injected target for a 1000 MW(e) plant, which is well within previously published goals.

X. PROCESS DEVELOPMENT PLAN

To achieve the cost projections discussed above, a significant technology and process development program will be required. A three-phase program is envisioned to develop process unit operations for the production of layered, D_2-filled targets – starting at lab-scale and ending at a commercial prototype. The objective of Phase 1 is to develop laboratory-scale methods and apparatus for the production of layered, D_2-filled targets. The objective of the second phase is to develop an integrated set of full-scale process unit operations. The objective of the third phase is to parametrically test equipment in sequential campaigns to produce finished DT-filled targets, and to modify equipment to attain product specifications and throughput/reliability goals. The resultant facility is ready for use as a commercial prototype (see Attachment 6).

XI. CONCLUSIONS

A facility flowsheet, plant layout and cost model have been formulated using classical chemical engineering principles to scale-up current laboratory fabrication methods.

For the baseline assumptions, the annualized capital costs represent roughly 40% of the cost per target while annual operating costs are ~60% (for large power plants in the 1000–3000 MW(e) range). Economies of scale (in terms of capital equipment, staffing and overhead) favor larger plants. Capital and operating costs both increase less rapidly than production rate increases, which leads to lower unit costs (from 16.6¢ per injected target at 1000 MW(e) to 10.0¢ per injected target at 3000 MW(e).

These projections assume that a significant process R&D program (summarized herein) is successfully completed.

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ATTACHMENT 1

SFE-1000

Supercritical Fluid Extraction System

The SFE-1000 is an automated Supercritical Fluid Extraction System from Thar Tech's line of Pilot Scale Systems. Features of the components in the integrated system and factory installed options are listed below.

System Rating

- Operating Pressure: 50 - 600 bar
- Operating Temperature: Ambient - 150°C @ 600 bar
- Carbon Dioxide Flow Rate: 200 grams/min Max.
- Co-solvent: See options
- Fluid/Solvent compatibility: Carbon Dioxide and most hydrocarbon solvents

High Pressure Pump *P-series*

Thar Designs Smart High Pressure Pumps are ideal pumps for high pressure, supercritical fluids and pulseless flow applications. These high performance pumps feature: dual stainless steel heads with a cam driven sapphire piston assembly, self priming check valves, pressure sensor, pressure gauge, brushless motor and a rupture disc assembly. A unique grooved path is machined inside each pump head assembly for coolant circulation, which increases compression efficiency per piston stroke by removing the generated heat. The pumps are capable of control based on feedback from the pressure sensor or flow meter. The ability to control pressure or flow is enhanced by rear- mounted, brushless, high- torque motor. The pump can be controlled using a programmable display or RS232C interface via PC. The Smart High Pressure Pump can be used in conjunction with additional Thar Designs pump models to deliver heterogeneous fluids into a system at variable flow rates.

- Wetted Material: High Strength SS, UHMW, PEEK, Teflon
- Flow Rate: up to 200 grams/minute
- Operating Pressure: up to 600 bar (8700 psia) allowance for pressure relief device
- Temperature: Ambient
- Fluid: Carbon dioxide
- Head Cooling: Inlet and outlet tube connection for circulating coolant for each head
- Pressure Sensor for max. pressure setting and Pressure Gauge
- No Helium headspace carbon dioxide supply required
- No air required for operation
- Liquid CO_2 @ 850 psia is required – dip tube cylinder required
- Control: Pressure and equation flow control capability; Normal operating mode is flow control mode based on feedback from flow meter or in equation mode
- Option: Flow meter for flow control. Must be purchased with the system for calibration at factory.

Cooling Heat Exchanger

A heat exchanger is used to cool and liquefy CO2 before it enters the pump for maximum efficiency. A cooling bath is required to circulate coolant through the pump heads and cooling heat exchanger.

- Wetted Material: 304 or 306 SS

Electrical Heating Heat Exchanger

A high wattage electrical heat exchanger is a vital and integral part of the system for achieving a desired fluid temperature prior to entering the extraction vessel. As the flow rates and extraction vessel sizes increase in a system, ovens for vessel heating or heating the vessel alone are no longer a viable option. Fluid's residence time in the extraction vessel is short and the mass of the vessel is large; heating the vessel alone will not suffice. This heat exchanger upstream from the vessel ensures that the fluid is heated prior to entering the vessel.

- Wetted Material: SS tubing 304 or 306
- Process connection: Tubing: 1/8" SS high pressure
- Temperature: up to 250_C
- Connected to Temperature control module

High Pressure Vessel

"Finger Tight" high pressure vessels are designed for simple opening and closing. The seal is Polyimide "C" cup type with an energized spring. The spring under pressure is energized and forces the inner lip to contact the surface of the threaded cap. The outer lip contacts the inner vessel wall forming a pressure seal. Caps at each end of the vessel, along with a seal, have a frit assembly to provide even distribution of fluid during introduction. The vessel body is made of 17-4PH stainless steel, which is 60% stronger than 300 series. Stainless steel reduces vessel weight and dimensions. Thar's cap design with spring-loaded seal, not only enhances safety, but also lends to automation for efficient loading and unloading of large vessels. Importantly, Thar Designs' smaller vessels can be heated using ovens and the larger vessels can be heated with heating jackets.

- Wetted Material: 17-4PH and Polyimide
- Material of construction: 17-4-PH stainless, Nitronic 60
- Volume: 1L
- I.D: 3.00"
- O.D: 4.50"
- Pressure: up to 689 bar (10,000 psia)
- Temperature: up to 150_C
- Fluid: Carbon dioxide and most hydro-carbon solvents
- Thermocouple for fluid temperature measurement – J Type; monitor only connected to Temperature Control Module
- Heating Jacket with power connection and surface thermocouple to maintain extraction temperature, connected to temperature control module

- Mounted on the skid for easy access

High Pressure Valve

High pressure On/Off valve provides the user with the capability to maintain static pressure on the vessel.

- Wetted Material: 17-4-PH and Teflon

Back Pressure Regulator

Thar Designs' Smart Back Pressure Regulator is state of the art in pressure control for supercritical fluids. The unit's valve assembly is motor driven and temperature controlled to compensate for cooling during depressurization. A built-in pressure sensor provides closed loop feedback for control and pressure alarm monitoring.

- Wetted Material: SS and PEEK
- Low Dead Volume for reduced contamination
- Material: SS 316 or 17-4PH
- Flow Rate: up to 350 grams/min
- Pressure: up to 689 bar (10,000 psi)
- Fluid Temperature: up to 150_C
- Fluid: Carbon Dioxide and hydro carbon solvents
- Heating: to make sure the carbon dioxide will not freeze

Cyclone Separator

Thar Designs' High Pressure Collection System is an efficient way of collecting particles or liquids. The fluid is introduced tangentially at a high velocity into the cyclone separator chamber. Centrifugal forces act on the heavier particles forcing them to the inner wall of the separator and allowing the light gases to exit through a center tube. The bottom is tapered to provide efficient collection of separated material. Self-sealing "finger tight" cap is easy to open and close.

- Wetted Material: 17-4, Nitronic 60 and Polyimide
- Volume: 500 mL
- Design Pressure: 100 bar (1450 psi)
- Operating Pressure: Max. 17 bar
- Temperature: Ambient
- Fluid: Carbon Dioxide and hydrocarbon solvents
- Needle Valve at the bottom to facilitate collection
- Heating to prevent freezing

Temperature Control Module – Six Zone

This temperature controller with RS232 port is connected to the PC. It is capable of monitoring and controlling up to six temperature zones independently. The

thermocouple inputs are J-Type and outputs are control signal lines connected to relays for heater control.

- Inputs and outputs: 6
- Alarm setting for each zone
- Numeric display cycles through zone conditions
- Monitoring and control via ICM software

Manual Back Pressure Regulator

This manual back pressure regulator is used to maintain pressure on the cyclone separator for efficient collection and prevent freezing that occurs at depressurization.

- Material: High Strength SS
- Pressure: Up to 17 bar (250 psi)

Safety

- Mechanical - Rupture Disc on the pump. The pressure rating of the system is adjusted for operation at various pressure and temperature conditions. Normally, the rated operating pressure of tubing and rupture disc is at 23 deg. C (72 deg F).
- Threaded Vessel Enclosures are safer than ring or flange closures
- User-settable and factory set software pressure and temperature alarms. Alarms are monitored on individual components and signaling to interconnected system components via software on PC

Skid, Tubing, Fittings, Assembly and Testing

The system is designed to offer the customer maximum flexibility for experimentation or production on a smaller scale. The skid-mounted system is assembled in the factory and tested to operating conditions. All fittings and interconnect tubing is pressure-tested prior to the unit shipping from the factory.

PC with Thar Designs ICM Software Package

Custom developed Graphical Instrument Control Module software package on Windows operating system is used for system operation and monitoring. Data from all instruments and connected sensors in the system, is made available to the user in real-time on individual graphical and numeric display panels. The data can be logged at user selectable intervals to create batch records and view conditions that existed in the system during the run. It can also be imported into Excel for analysis. The user can manipulate each instrument in the system individually or use recipes/scripts for automated operation. Simple yet powerful scripting language allows the user to create and save scripts for automated setup of operating conditions and alarm settings. Text messages in the status window give the user detailed system status.

- Includes PC with keyboard, mouse and multi-port RS232 card
- Monitor
- Pre-loaded and configured ICM software package

Warranty

Thar Designs warranties its systems and equipment for a period of one Year on parts and labor. Items not covered under the warranty are consumable items such as: seals, check valves, tubing, nuts, ferrules, damage caused by improper maintenance, negligent use or damage resulting from modifications made by the user without approval of Thar Designs. The system is shipped for use with carbon dioxide and most hydrocarbon solvents. Use of fluids or materials incompatible with system and without consultation with Thar Designs nullifies the warranty. Please check with Thar Designs for additional details.

Installation and Training

Included in the system price is operation and installation training at Thar Designs factory in Pittsburgh, all expenses for travel are customer responsibility. If the system is purchased from an appointed Thar Designs distributor, the customer can make arrangements for onsite training and installation by the distributor's service personnel. Thar Designs service engineers are available for onsite training at additional charge. All expenses, including airfare, are billed to the customer. Retraining of personnel or customer support beyond initial start-up and training is subject to additional charges. Thar Designs does not provide consultation on process development or experimentation under the system sales agreement. These services are available from Thar Designs.

Thar designs

AVAILABLE OPTIONS

High Pressure Co-solvent Pump

There are two options available to the customer in selecting a co-solvent pump. The co-solvent pump is integrated into the system and will pump a co-solvent as a percentage of the carbon dioxide flow rate up to its maximum flow rate and pressure rating.

Option:

- Operating Pressure: 600 bar
- Flow rate: up to 50g/min

Option:

- Operating Pressure: 380 bar
- Flow rate: up to 10 mL/min

Note: With Option SFE-1000-OC1 and 2 for co-solvent pump, the system can be used up to 600 bar without using the co-solvent pump and the valve in off position. The valve to isolate the co-solvent pump is included with SFE-1000-OC1 and 2.

High Pressure Static Mixer

Thar Designs High Pressure Mixer is capable of blending different liquids into one uniform concentration. The mixer does not have any moving parts and has low dead volume. The mixer is designed for pressure of up to 680 bar and temperature of up to 150_C. This mixer has been successfully used with carbon dioxide and a variety of hydrocarbon solvents.

- Material: SS 316 or other High Strength SS
- Flow Rate: up to 200 mL/min
- Operating Pressure: up to 600 bar
- Temperature: up to 100 _C
- Fluid: CO2 and most hydrocarbon solvents

Note: High Pressure Static Mixer is required with any Co-solvent pump option. It is included in the assembly when a part number for co-solvent pump is selected.

Mass Flow Meter

This mass flow meter is located on the input side of carbon dioxide pump. Liquefied carbon dioxide mass passing through the flow meter provides feedback to the pump for flow control.

- Operating Pressure: up to 100 bar
- Flow rate range: 5 – 200 grams/min of carbon dioxide
- Integrated and calibrated with carbon dioxide pump

Thar designs

Circulating Cooling Bath

A circulating cooling bath is required to circulate coolant through pump heads and cooling heat exchanger.

- Cooling capacity: 480 watts at 0_C
- Reservoir capacity: 13 liters
- Pumping capacity: 9 or 15 liters/min

Note: If the customer chooses to supply the circulating cooling bath, it should meet the specifications stated above to ensure adequate cooling for pump and heat exchanger.

Ordering Information

Part#	Description
SFE-1000-1-Base	SFE 1000 base configuration – 110V
SFE-1000-2-Base	SFE 1000 base configuration – 220V
02212	Cooling bath – 110V
02032	Cooling bath – 220V
05230	Flow meter 100 bar – 110V
05231	Flow meter 100 bar – 220V
SFE-1000-OB1	Co-solvent Pump with static mixer 50 g/min, 600 bar – 110V
SFE-1000-OB2	Co-solvent Pump with static mixer 50 g/min, 600 bar – 220V
SFE-1000-OC1	Co-solvent Pump with static mixer 10mL/min, 380 bar – 110V
SFE-1000-OC2	Co-solvent Pump with static mixer 10mL/min, 380 bar – 220V

Example of 110V system order with factory configured options:
List each part number as separate line item on quote or PO

1. SFE-1000-1-Base SFE 1000 Base system
2. 02212 Cooling Bath
3. 05230 Flow meter
4. SFE-1000-OC1 Modifier Pump 10mL/min

For site preparation requirements or details, please request document F103 System Site Requirements from Thar Designs or its representative.

Thar designs

SFE-2000

Supercritical Fluid Extraction System

The SFE-2000 is an automated Supercritical Fluid Extraction System from Thar Tech's line of Pilot Scale Systems. Features of the components in the integrated system and factory installed options are listed below.

System Rating

- Operating Pressure: 50 - 600 bar
- Operating Temperature: Ambient - 150°C @ 600 bar
- Carbon Dioxide Flow Rate: 200 grams/min Max.
- Co-solvent: See options
- Fluid/Solvent compatibility: Carbon Dioxide and most hydrocarbon solvents

High Pressure Pump *P-series*

Thar Designs Smart High Pressure Pumps are ideal pumps for high pressure, supercritical fluids and pulseless flow applications. These high performance pumps feature: dual stainless steel heads with a cam driven sapphire piston assembly, self priming check valves, pressure sensor, pressure gauge, brushless motor and a rupture disc assembly. A unique grooved path is machined inside each pump head assembly for coolant circulation, which increases compression efficiency per piston stroke by removing the generated heat. The pumps are capable of control based on feedback from the pressure sensor or flow meter. The ability to control pressure or flow is enhanced by rear- mounted, brushless, high- torque motor. The pump can be controlled using a programmable display or RS232C interface via PC. The Smart High Pressure Pump can be used in conjunction with additional Thar Designs pump models to deliver heterogeneous fluids into a system at variable flow rates.

- Wetted Material: High Strength SS, UHMW, PEEK, Teflon
- Flow Rate: up to 200 grams/minute
- Operating Pressure: up to 600 bar (8700 psia) allowance for pressure relief device
- Temperature: Ambient
- Fluid: Carbon dioxide
- Head Cooling: Inlet and outlet tube connection for circulating coolant for each head
- Pressure Sensor for max. pressure setting and Pressure Gauge
- No Helium headspace carbon dioxide supply required
- No air required for operation
- Liquid CO2 @ 850 psia is required – dip tube cylinder required
- Control: Pressure and equation flow control capability; Normal operating mode is flow control mode based on feedback from flow meter or in equation mode
- Option: Flow meter for flow control. Must be purchased with the system for calibration at factory.

Cooling Heat Exchanger

A heat exchanger is used to cool and liquefy CO_2 before it enters the pump for maximum efficiency. A cooling bath is required to circulate coolant through the pump heads and cooling heat exchanger.

- Wetted Material: 304 or 306 SS

Electrical Heating Heat Exchanger

A high wattage electrical heat exchanger is a vital and integral part of the system for achieving a desired fluid temperature prior to entering the extraction vessel. As the flow rates and extraction vessel sizes increase in a system, ovens for vessel heating or heating the vessel alone are no longer a viable option. Fluid's residence time in the extraction vessel is short and the mass of the vessel is large; heating the vessel alone will not suffice. This heat exchanger upstream from the vessel ensures that the fluid is heated prior to entering the vessel.

- Wetted Material: SS tubing 304 or 306
- Process connection: Tubing: 1/8" SS high pressure
- Temperature: up to 250_C
- Connected to Temperature control module

High Pressure Vessel

"Finger Tight" high pressure vessels are designed for simple opening and closing. The seal is Polyimide "C" cup type with an energized spring. The spring under pressure is energized and forces the inner lip to contact the surface of the threaded cap. The outer lip contacts the inner vessel wall forming a pressure seal. Caps at each end of the vessel, along with a seal, have a frit assembly to provide even distribution of fluid during introduction. The vessel body is made of 17-4PH stainless steel, which is 60% stronger than 300 series. Stainless steel reduces vessel weight and dimensions. Thar's cap design with spring-loaded seal, not only enhances safety, but also lends to automation for efficient loading and unloading of large vessels. Importantly, Thar Designs' smaller vessels can be heated using ovens and the larger vessels can be heated with heating jackets.

- Wetted Material: 17-4PH and Polyimide
- Material of construction: 17-4-PH stainless, Nitronic 60
- Volume: 2L
- I.D: 3.00"
- O.D: 4.50"
- Pressure: up to 689 bar (10,000 psia)
- Temperature: up to 150_C
- Fluid: Carbon dioxide and most hydro-carbon solvents
- Thermocouple for fluid temperature measurement – J Type; monitor only connected to Temperature Control Module
- Heating Jacket with power connection and surface thermocouple to maintain extraction temperature, connected to temperature control module

- Mounted on the skid for easy access

High Pressure Valve

High pressure On/Off valve provides the user with the capability to maintain static pressure on the vessel.

- Wetted Material: 17-4-PH and Teflon

Back Pressure Regulator

Thar Designs' Smart Back Pressure Regulator is state of the art in pressure control for supercritical fluids. The unit's valve assembly is motor driven and temperature controlled to compensate for cooling during depressurization. A built-in pressure sensor provides closed loop feedback for control and pressure alarm monitoring.

- Wetted Material: SS and PEEK
- Low Dead Volume for reduced contamination
- Material: SS 316 or 17-4PH
- Flow Rate: up to 350 grams/min
- Pressure: up to 689 bar (10,000 psi)
- Fluid Temperature: up to 150_C
- Fluid: Carbon Dioxide and hydro carbon solvents
- Heating: to make sure the carbon dioxide will not freeze

Cyclone Separator

Thar Designs' High Pressure Collection System is an efficient way of collecting particles or liquids. The fluid is introduced tangentially at a high velocity into the cyclone separator chamber. Centrifugal forces act on the heavier particles forcing them to the inner wall of the separator and allowing the light gases to exit through a center tube. The bottom is tapered to provide efficient collection of separated material. Self-sealing "finger tight" cap is easy to open and close.

- Wetted Material: 17-4, Nitronic 60 and Polyimide
- Volume: 500 mL
- Design Pressure: 100 bar (1450 psi)
- Operating Pressure: Max. 17 bar
- Temperature: Ambient
- Fluid: Carbon Dioxide and hydrocarbon solvents
- Needle Valve at the bottom to facilitate collection
- Heating to prevent freezing

Temperature Control Module – Six Zone

This temperature controller with RS232 port is connected to the PC. It is capable of monitoring and controlling up to six temperature zones independently. The

thermocouple inputs are J-Type and outputs are control signal lines connected to relays for heater control.

- Inputs and outputs: 6
- Alarm setting for each zone
- Numeric display cycles through zone conditions
- Monitoring and control via ICM software

Manual Back Pressure Regulator

This manual back pressure regulator is used to maintain pressure on the cyclone separator for efficient collection and prevent freezing that occurs at depressurization.

- Material: High Strength SS
- Pressure: Up to 17 bar (250 psi)

Safety

- Mechanical - Rupture Disc on the pump. The pressure rating of the system is adjusted for operation at various pressure and temperature conditions. Normally, the rated operating pressure of tubing and rupture disc is at 23 deg. C (72 deg F).
- Threaded Vessel Enclosures are safer than ring or flange closures
- User-settable and factory set software pressure and temperature alarms. Alarms are monitored on individual components and signaling to interconnected system components via software on PC

Skid, Tubing, Fittings, Assembly and Testing

The system is designed to offer the customer maximum flexibility for experimentation or production on a smaller scale. The skid-mounted system is assembled in the factory and tested to operating conditions. All fittings and interconnect tubing is pressure-tested prior to the unit shipping from the factory.

PC with Thar Designs ICM Software Package

Custom developed Graphical Instrument Control Module software package on Windows operating system is used for system operation and monitoring. Data from all instruments and connected sensors in the system, is made available to the user in real-time on individual graphical and numeric display panels. The data can be logged at user selectable intervals to create batch records and view conditions that existed in the system during the run. It can also be imported into Excel for analysis. The user can manipulate each instrument in the system individually or use recipes/scripts for automated operation. Simple yet powerful scripting language allows the user to create and save scripts for automated setup of operating conditions and alarm settings. Text messages in the status window give the user detailed system status.

- Includes PC with keyboard, mouse and multi-port RS232 card
- Monitor
- Pre-loaded and configured ICM software package

Warranty

Thar Designs warranties its systems and equipment for a period of one Year on parts and labor. Items not covered under the warranty are consumable items such as: seals, check valves, tubing, nuts, ferrules, damage caused by improper maintenance, negligent use or damage resulting from modifications made by the user without approval of Thar Designs. The system is shipped for use with carbon dioxide and most hydrocarbon solvents. Use of fluids or materials incompatible with system and without consultation with Thar Designs nullifies the warranty. Please check with Thar Designs for additional details.

Installation and Training

Included in the system price is operation and installation training at Thar Designs factory in Pittsburgh, all expenses for travel are customer responsibility. If the system is purchased from an appointed Thar Designs distributor, the customer can make arrangements for onsite training and installation by the distributor's service personnel. Thar Designs service engineers are available for onsite training at additional charge. All expenses, including airfare, are billed to the customer. Retraining of personnel or customer support beyond initial start-up and training is subject to additional charges. Thar Designs does not provide consultation on process development or experimentation under the system sales agreement. These services are available from Thar Designs.

AVAILABLE OPTIONS

High Pressure Co-solvent Pump

There are two options available to the customer in selecting a co-solvent pump. The co-solvent pump is integrated into the system and will pump a co-solvent as a percentage of the carbon dioxide flow rate up to its maximum flow rate and pressure rating.

Option:

- Operating Pressure: 600 bar
- Flow rate: up to 50g/min

Option:

- Operating Pressure: 380 bar
- Flow rate: up to 10 mL/min

Note: With Option SFE-2000-OC1 and 2 for co-solvent pump, the system can be used up to 600 bar without using the co-solvent pump and the valve in off position. The valve to isolate the co-solvent pump is included with SFE-2000-OC1 and 2.

High Pressure Static Mixer

Thar Designs High Pressure Mixer is capable of blending different liquids into one uniform concentration. The mixer does not have any moving parts and has low dead volume. The mixer is designed for pressure of up to 680 bar and temperature of up to 150_C. This mixer has been successfully used with carbon dioxide and a variety of hydrocarbon solvents.

- Material: SS 316 or other High Strength SS
- Flow Rate: up to 200 mL/min
- Operating Pressure: up to 600 bar
- Temperature: up to 100 _C
- Fluid: CO2 and most hydrocarbon solvents

Note: High Pressure Static Mixer is required with any Co-solvent pump option. It is included in the assembly when a part number for co-solvent pump is selected.

Mass Flow Meter

This mass flow meter is located on the input side of carbon dioxide pump. Liquefied carbon dioxide mass passing through the flow meter provides feedback to the pump for flow control.

- Operating Pressure: up to 100 bar
- Flow rate range: 5 – 200 grams/min of carbon dioxide
- Integrated and calibrated with carbon dioxide pump

Circulating Cooling Bath

A circulating cooling bath is required to circulate coolant through pump heads and cooling heat exchanger.

- Cooling capacity: 480 watts at 0_C
- Reservoir capacity: 13 liters
- Pumping capacity: 9 or 15 liters/min

Note: If the customer chooses to supply the circulating cooling bath, it should meet the specifications stated above to ensure adequate cooling for pump and heat exchanger.

Ordering Information

Part#	Description
SFE-2000-1-Base	SFE 2000 base configuration – 110V
SFE-2000-2-Base	SFE 2000 base configuration – 220V
02212	Cooling bath – 110V
02032	Cooling bath – 220V
05230	Flow meter 100 bar – 110V
05231	Flow meter 100 bar – 220V
SFE-2000-OB1	Co-solvent Pump with static mixer 50 g/min, 600 bar – 110V
SFE-2000-OB2	Co-solvent Pump with static mixer 50 g/min, 600 bar – 220V
SFE-2000-OC1	Co-solvent Pump with static mixer 10mL/min, 380 bar – 110V
SFE-2000-OC2	Co-solvent Pump with static mixer 10mL/min, 380 bar – 220V

Example of 110V system order with factory configured options:
List each part number as separate line item on quote or PO

1. SFE-2000-1-Base SFE 2000 Base system
2. 02212 Cooling Bath
3. 05230 Flow meter
4. SFE-2000-OC1 Modifier Pump 10mL/min

For site preparation requirements or details, please request document F103 System Site Requirements from Thar Designs or its representative.

Thar designs

SFE-5000

Supercritical Fluid Extraction System

The SFE-5000 is an automated Supercritical Fluid Extraction System from Thar Tech's line of Pilot Scale Systems. Features of the components in the integrated system and factory installed options are listed below.

System Rating

- Operating Pressure: 50 - 600 bar
- Operating Temperature: Ambient - 150°C @ 600 bar
- Carbon Dioxide Flow Rate: 200 grams/min Max.
- Co-solvent: See options
- Fluid/Solvent compatibility: Carbon Dioxide and most hydrocarbon solvents

High Pressure Pump *P-series*

Thar Designs Smart High Pressure Pumps are ideal pumps for high pressure, supercritical fluids and pulseless flow applications. These high performance pumps feature: dual stainless steel heads with a cam driven sapphire piston assembly, self priming check valves, pressure sensor, pressure gauge, brushless motor and a rupture disc assembly. A unique grooved path is machined inside each pump head assembly for coolant circulation, which increases compression efficiency per piston stroke by removing the generated heat. The pumps are capable of control based on feedback from the pressure sensor or flow meter. The ability to control pressure or flow is enhanced by rear- mounted, brushless, high- torque motor. The pump can be controlled using a programmable display or RS232C interface via PC. The Smart High Pressure Pump can be used in conjunction with additional Thar Designs pump models to deliver heterogeneous fluids into a system at variable flow rates.

- Wetted Material: High Strength SS, UHMW, PEEK, Teflon
- Flow Rate: up to 200 grams/minute
- Operating Pressure: up to 600 bar (8700 psia) allowance for pressure relief device
- Temperature: Ambient
- Fluid: Carbon dioxide
- Head Cooling: Inlet and outlet tube connection for circulating coolant for each head
- Pressure Sensor for max. pressure setting and Pressure Gauge
- No Helium headspace carbon dioxide supply required
- No air required for operation
- Liquid CO2 @ 850 psia is required – dip tube cylinder required
- Control: Pressure and equation flow control capability; Normal operating mode is flow control mode based on feedback from flow meter or in equation mode
- Option: Flow meter for flow control. Must be purchased with the system for calibration at factory.

Cooling Heat Exchanger

A heat exchanger is used to cool and liquefy CO2 before it enters the pump for maximum efficiency. A cooling bath is required to circulate coolant through the pump heads and cooling heat exchanger.

- Wetted Material: 304 or 306 SS

Electrical Heating Heat Exchanger

A high wattage electrical heat exchanger is a vital and integral part of the system for achieving a desired fluid temperature prior to entering the extraction vessel. As the flow rates and extraction vessel sizes increase in a system, ovens for vessel heating or heating the vessel alone are no longer a viable option. Fluid's residence time in the extraction vessel is short and the mass of the vessel is large; heating the vessel alone will not suffice. This heat exchanger upstream from the vessel ensures that the fluid is heated prior to entering the vessel.

- Wetted Material: SS tubing 304 or 306
- Process connection: Tubing: 1/8" SS high pressure
- Temperature: up to 250_C
- Connected to Temperature control module

High Pressure Vessel

"Finger Tight" high pressure vessels are designed for simple opening and closing. The seal is Polyimide "C" cup type with an energized spring. The spring under pressure is energized and forces the inner lip to contact the surface of the threaded cap. The outer lip contacts the inner vessel wall forming a pressure seal. Caps at each end of the vessel, along with a seal, have a frit assembly to provide even distribution of fluid during introduction. The vessel body is made of 17-4PH stainless steel, which is 60% stronger than 300 series. Stainless steel reduces vessel weight and dimensions. Thar's cap design with spring-loaded seal, not only enhances safety, but also lends to automation for efficient loading and unloading of large vessels. Importantly, Thar Designs' smaller vessels can be heated using ovens and the larger vessels can be heated with heating jackets.

- Wetted Material: 17-4PH and Polyimide
- Material of construction: 17-4-PH stainless
- Volume: 5L
- I.D: 4.00"
- O.D: 6.00"
- Pressure: up to 689 bar (10,000 psia)
- Temperature: up to 150_C
- Fluid: Carbon dioxide and most hydro-carbon solvents
- Thermocouple for fluid temperature measurement – J Type; monitor only connected to Temperature Control Module
- Heating Jacket with power connection and surface thermocouple to maintain extraction temperature, connected to temperature control module

- Mounted on the vessel stand

High Pressure Valve

High pressure On/Off valve provides the user with the capability to maintain static pressure on the vessel.

- Wetted Material: 17-4-PH and Teflon

Back Pressure Regulator

Thar Designs' Smart Back Pressure Regulator is state of the art in pressure control for supercritical fluids. The unit's valve assembly is motor driven and temperature controlled to compensate for cooling during depressurization. A built-in pressure sensor provides closed loop feedback for control and pressure alarm monitoring.

- Wetted Material: SS and PEEK
- Low Dead Volume for reduced contamination
- Material: SS 316 or 17-4PH
- Flow Rate: up to 350 grams/min
- Pressure: up to 689 bar (10,000 psi)
- Fluid Temperature: up to 150_C
- Fluid: Carbon Dioxide and hydro carbon solvents
- Heating: to make sure the carbon dioxide will not freeze

Cyclone Separator

Thar Designs' High Pressure Collection System is an efficient way of collecting particles or liquids. The fluid is introduced tangentially at a high velocity into the cyclone separator chamber. Centrifugal forces act on the heavier particles forcing them to the inner wall of the separator and allowing the light gases to exit through a center tube. The bottom is tapered to provide efficient collection of separated material. Self-sealing "finger tight" cap is easy to open and close.

- Wetted Material: 17-4, Nitronic 60 and Polyimide
- Volume: 1000 mL
- Design Pressure: 100 bar (1450 psi)
- Operating Pressure: Max. 17 bar
- Temperature: Ambient
- Fluid: Carbon Dioxide and hydrocarbon solvents
- Needle Valve at the bottom to facilitate collection
- Heating to prevent freezing

Temperature Control Module - Six Zone

This temperature controller with RS232 port is connected to the PC. It is capable of monitoring and controlling up to six temperature zones independently. The

thermocouple inputs are J-Type and outputs are control signal lines connected to relays for heater control.

- Inputs and outputs: 6
- Alarm setting for each zone
- Numeric display cycles through zone conditions
- Monitoring and control via ICM software

Manual Back Pressure Regulator

This manual back pressure regulator is used to maintain pressure on the cyclone separator for efficient collection and prevent freezing that occurs at depressurization.

- Material: High Strength SS
- Pressure: Up to 17 bar (250 psi)

Safety

- Mechanical - Rupture Disc on the pump. The pressure rating of the system is adjusted for operation at various pressure and temperature conditions. Normally, the rated operating pressure of tubing and rupture disc is at 23 deg. C (72 deg F).
- Threaded Vessel Enclosures are safer than ring or flange closures
- User-settable and factory set software pressure and temperature alarms. Alarms are monitored on individual components and signaling to interconnected system components via software on PC

Skid, Tubing, Fittings, Assembly and Testing

The system is designed to offer the customer maximum flexibility for experimentation or production on a smaller scale. The skid-mounted system is assembled in the factory and tested to operating conditions. All fittings and interconnect tubing is pressure-tested prior to the unit shipping from the factory.

PC with Thar Designs ICM Software Package

Custom developed Graphical Instrument Control Module software package on Windows operating system is used for system operation and monitoring. Data from all instruments and connected sensors in the system, is made available to the user in real-time on individual graphical and numeric display panels. The data can be logged at user selectable intervals to create batch records and view conditions that existed in the system during the run. It can also be imported into Excel for analysis. The user can manipulate each instrument in the system individually or use recipes/scripts for automated operation. Simple yet powerful scripting language allows the user to create and save scripts for automated setup of operating conditions and alarm settings. Text messages in the status window give the user detailed system status.

- Includes PC with keyboard, mouse and multi-port RS232 card
- Monitor
- Pre-loaded and configured ICM software package

Warranty

Thar Designs warranties its systems and equipment for a period of one Year on parts and labor. Items not covered under the warranty are consumable items such as: seals, check valves, tubing, nuts, ferrules, damage caused by improper maintenance, negligent use or damage resulting from modifications made by the user without approval of Thar Designs. The system is shipped for use with carbon dioxide and most hydrocarbon solvents. Use of fluids or materials incompatible with system and without consultation with Thar Designs nullifies the warranty. Please check with Thar Designs for additional details.

Installation and Training

Included in the system price is operation and installation training at Thar Designs factory in Pittsburgh, all expenses for travel are customer responsibility. If the system is purchased from an appointed Thar Designs distributor, the customer can make arrangements for onsite training and installation by the distributor's service personnel. Thar Designs service engineers are available for onsite training at additional charge. All expenses, including airfare, are billed to the customer. Retraining of personnel or customer support beyond initial start-up and training is subject to additional charges. Thar Designs does not provide consultation on process development or experimentation under the system sales agreement. These services are available from Thar Designs.

AVAILABLE OPTIONS

High Pressure Co-solvent Pump

There are two options available to the customer in selecting a co-solvent pump. The co-solvent pump is integrated into the system and will pump a co-solvent as a percentage of the carbon dioxide flow rate up to its maximum flow rate and pressure rating.

Option:
- Operating Pressure: 600 bar
- Flow rate: up to 50g/min

Option:
- Operating Pressure: 380 bar
- Flow rate: up to 10 mL/min

Note: With Option SFE-5000-OC1 and 2 for co-solvent pump, the system can be used up to 600 bar without using the co-solvent pump and the valve in off position. The valve to isolate the co-solvent pump is included with SFE-5000-OC1 and 2.

High Pressure Static Mixer

Thar Designs High Pressure Mixer is capable of blending different liquids into one uniform concentration. The mixer does not have any moving parts and has low dead volume. The mixer is designed for pressure of up to 680 bar and temperature of up to 150_C. This mixer has been successfully used with carbon dioxide and a variety of hydrocarbon solvents.

- Material: SS 316 or other High Strength SS
- Flow Rate: up to 200 mL/min
- Operating Pressure: up to 600 bar
- Temperature: up to 100 _C
- Fluid: CO2 and most hydrocarbon solvents

Note: High Pressure Static Mixer is required with any Co-solvent pump option. It is included in the assembly when a part number for co-solvent pump is selected.

Mass Flow Meter

This mass flow meter is located on the input side of carbon dioxide pump. Liquefied carbon dioxide mass passing through the flow meter provides feedback to the pump for flow control.

- Operating Pressure: up to 100 bar
- Flow rate range: 5 – 200 grams/min of carbon dioxide
- Integrated and calibrated with carbon dioxide pump

Circulating Cooling Bath

A circulating cooling bath is required to circulate coolant through pump heads and cooling heat exchanger.

- Cooling capacity: 480 watts at 0_C
- Reservoir capacity: 13 liters
- Pumping capacity: 9 or 15 liters/min

Note: If the customer chooses to supply the circulating cooling bath, it should meet the specifications stated above to ensure adequate cooling for pump and heat exchanger.

Ordering Information

Part#	Description
SFE-5000-1-Base	SFE 5000 base configuration – 110V
SFE-5000-2-Base	SFE 5000 base configuration – 220V
02212	Cooling bath – 110V
02032	Cooling bath – 220V
05230	Flow meter 100 bar – 110V
05231	Flow meter 100 bar – 220V
SFE-5000-OB1	Co-solvent Pump with static mixer 50 g/min, 600 bar – 110V
SFE-5000-OB2	Co-solvent Pump with static mixer 50 g/min, 600 bar – 220V
SFE-5000-OC1	Co-solvent Pump with static mixer 10mL/min, 380 bar – 110V
SFE-5000-OC2	Co-solvent Pump with static mixer 10mL/min, 380 bar – 220V

Example of 110V system order with factory configured options:
List each part number as separate line item on quote or PO

1. SFE-5000-1-Base SFE 5000 Base system
2. 02212 Cooling Bath
3. 05230 Flow meter
4. SFE-5000-OC1 Modifier Pump 10mL/min

For site preparation requirements or details, please request document F103 System Site Requirements from Thar Designs or its representative.

ATTACHMENT 2

From: D. Goodin/F. Elsner
To: Distribution
Re: Meeting on NRL Radiation Preheat Target Design Specifications

A meeting to discuss requirements and specifications for the NRL Radiation Preheat Target for IFE was held at NRL on June 1, 2001. Attending were:

A. Schmitt	NRL
D. Colombant	NRL
J. Gardner	NRL
D. Goodin	GA
F. Elsner	GA
G. Besenbruch	GA
A. Nobile	LANL

Based on the discussions at this meeting , the "Preliminary Specifications and Requirements for IFE Radiation Preheat Direct Drive Target" which was drafted on October 30, 2000 was updated (Attachment 1). The major conclusions/updates are summarized below.

1. Changed the density of the foam shell from 20±5 mg/cc to 20-120 mg/cc and ±25%.
2. Changed seal coat density from 1.4 g/cc to 1.0-1.4 g/cc
3. Changed the size of perturbations of most sensitivity from 20-100μm to 50-100μm.
4. Added a specification for holes in the gold layer.
5. Added a specification on inner ice surface finish of 2μm RMS.
6. Added a specification on overall target mass uniformity (within a single target) of <2%.
7. Added a specification on shell-to-shell total diameter variation of <10%.

It was also noted that an actual power spectrum of a foam shell would be a very useful input for the NRL target designers. GA is working to develop a capability to supply such an input for target design codes.

<u>Distribution</u>
Attendees
Ron Petzoldt
Neil Alexander
Abbas Nikroo
John Sethian

Preliminary Specifications and Requirements for IFE Radiation Preheat Direct Drive Target

Continuing discussions with NRL target design specialists have led to a set of preliminary requirements for the radiation preheat target (Table 1). It must be recognized that these are preliminary specifications that represent best estimates at this point in time, and that an iterative cycle between target designers and target fabricators must continue to take place to finalize these requirements.

Fabrication of a low-density foam shell with sufficiently high sphericity and wall uniformity is important because the final symmetry of the DT/foam layer (the ablator) in the cryogenic target is determined by the initial geometry of the foam layer. The foam shells ideally will have a composition of carbon and hydrogen.

The reference foam wall thickness is 289 μm with an acceptable range of ± 20 μm. The shell outer diameter is 4.0 ± 0.2 mm. The target foam density range is 20 - 120 mg/cc with a tolerance of ±25%. The ideal foam pore size from target design considerations is on the order of several tenths of microns. Best current estimates are that the foam pore size must definitely be less than 3 μm, and 1 μm may be acceptable. It has been agreed with NRL to set the requirement at <1 μm for the moment. The shell out-of-round specification is set at 1% of the shell radius (20 μm). Out-of-round is the difference in the largest and smallest measured diameters of the shell. Non-concentricity is defined as the offset of the centers of the ID and the OD of the shell, as a fraction of the average wall thickness. This specification is also set at 1%. The foam areal density should be constant to ± 0.3%, over lengths of 50 to 100 μm[1].

The functions of the seal coat on the foam are to prevent evaporation of the DT fill and to provide a smooth outer surface over which the high-Z layer is applied. Since the quantity of material in the seal coat is less than the ~ 1/4 that of foam, it is thought that percent level concentrations of oxygen and nitrogen are acceptable (see Table 1). The seal coat thickness is specified as 1 ± 1 μm (it must be thick enough to accomplish its functions, as stated below) and the density is assumed to be 1.4 ± 0.2 g/cc. The surface finish must be consistent with a final target surface finish of <50 nm RMS over lengths of 50 to 100 μm. There must be no gap between the foam and the seal layer (i.e., it must be conformal).

[1] Modes from ~100 to 500.

The high-Z layer is typically assumed to be gold. Its thickness is known to be a fairly sensitive parameter. The specification value is set at 325 ± 5 nm. The final target surface finish is required to be <50 nm RMS over lengths of 50 to 100 μm. The deviation from uniformity for the high-Z layer must be less than 10% of its thickness. Holes or penetrations in the gold are limited in size. Hole diameters of ~1μm are thought to be certainly acceptable, ~5μm may be acceptable, and ~10 μm are almost certainly unacceptable. The requirement is listed as <1-5 μm pending further information. The high-Z layer should be reflective enough to IR radiation.

The completed target must be capable of being permeation filled with DT at room temperature (i.e., sufficient DT permeability to allow filling in a practical time frame), it must prevent evaporation of the DT at cryogenic temperature (i.e., have sufficiently low permeability to allow handling of the filled target in a low-pressure, cryogenic environment without significantly altering the DT fill), and it must "wick" DT into the foam at cryogenic temperatures (i.e., fully wet the foam without bubbles or voids). The completed and filled target must have sufficient strength for handling for experiments. The inner ice surface finish is assumed to be 2 μm (RMS). An overall mass uniformity variation in a single target must be less than 2%. The greatest sensitivity is to perturbations with sizes between 50 and 100 μm.

These requirements are expected to be updated and modified as design calculations continue and experimental work progresses.

Table 1
Summary of Preliminary Specifications for NRL Radiation Preheat Target for IFE

IFE RADIATION PREHEAT DIRECT DRIVE TARGET SPECIFICATIONS - Rev 1				
Foam Shell	Value	Units	Tolerance (±)	Comments
_	_	_	_	
Composition	C,H,O,N			
Oxygen - max a/o	TBD			
Nitrogen - max a/o	TBD			
Thickness	289	microns	20	Equivalent to ~3 μm of full density plastic
Outer Diameter	4	mm	0.2	
Density	20-120	mg/cc	25%	Pending 2D calculations
Pore Size	1	microns	must be <3	
Impurity Levels	TBD			
Out-Of-Round	1	% of radius		
Non-Concentricity (Wmax-Wmin)	1	% of average wall thickness		
Areal density uniformity	<0.3	% density variation		Equivalent to 500 Angstroms of material at the average density of the mixed DT/foam.
Seal Coat				
Composition	C,H,O,N			
Oxygen - max a/o	35	a/o		
Nitrogen - max a/o	20	a/o		
Thickness	1	micron	1	must provide smooth surface & prevent DT evaporation
Density	1-1.4	g/cc		
Surface Finish	<500	Angstroms		Sensitive to power spectra (more at low modes, less at high modes, worst at modes 50-100)
Permeability	TBD			

Gold Overcoat						
Thickness	325	Angstroms	50			
Density	20	g/cc	5			
Impurities	TBD					
Surface Finish	<500	Angstroms		Most sensitive to lengths of 50 to 100 microns (modes 250 to 500)		
Uniformity	10	% of gold thickness				
Pores through gold	<1-5	micron (diameter)				
Filled Target						
Wicking	Capability to fill with DT at room temperature and retain DT at cryo. Must "wick" DT into foam at cryotemperatures and fully wet the foam (no bubbles)					
DT Thickness	190	microns	20			
Inner ice surface finish	<2	microns (RMS)				
Overall mass uniformity (within a single target)	<2	%				
Shell-to-shell total diameter variation	<10	%				
Target Injection						
Placement	+/-5	mm				
Alignment of drivers on target	+/- 20	microns				
Heatup of DT ice	1.8	Kelvin				

ATTACHMENT 3

DOE/NE-0095
Dist. Category UC-80

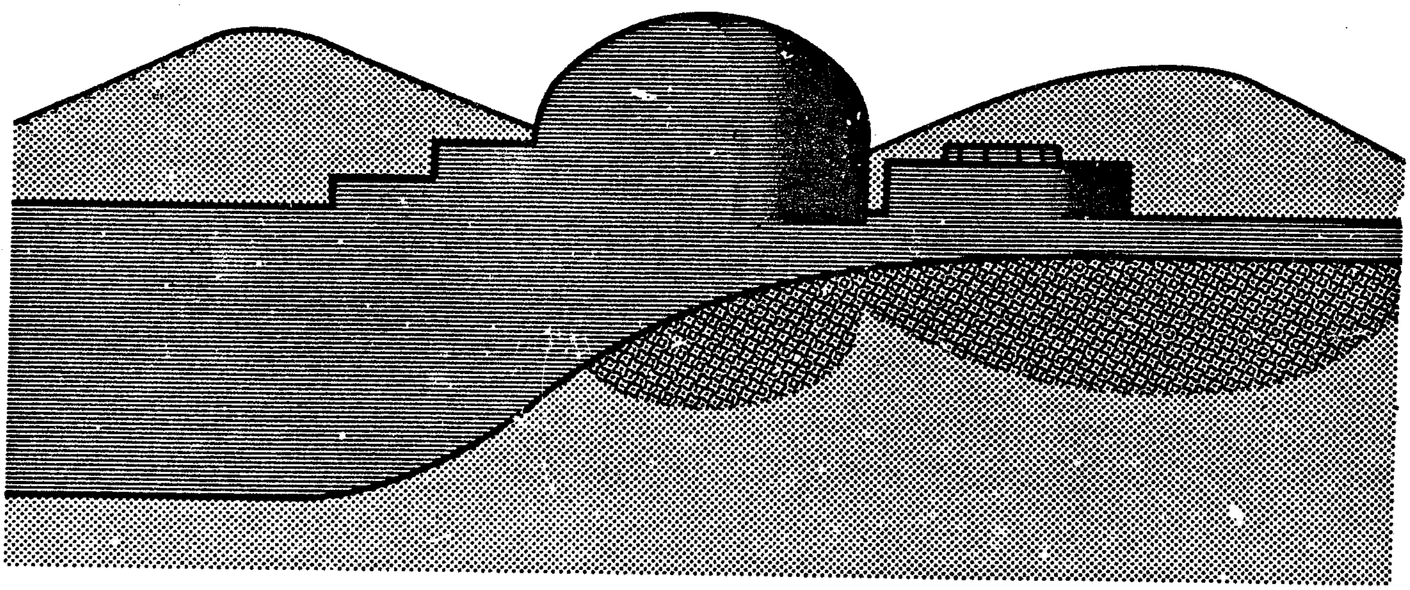
DOE/NE--0095

DE89 000407

Nuclear Energy Cost Data Base

A Reference Data Base for Nuclear and Coal-fired Powerplant Power Generation Cost Analysis

Published: September 1988



U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Program Support
Washington, D.C. 20545

MASTER

PREFACE

The purpose of this Data Base is to periodically provide the Office of Nuclear Energy with a consistent set of baseline data and assumptions for performing comparative power cost analyses for nuclear and fossil-fired generating plants. It is intended for the use of offices within Nuclear Energy and their contractors who have a continuing need to prepare independent economic analyses directed at specific aspects of power cost. Although many of these analyses are prepared for different reasons, there are baseline cost estimates and financial and engineering assumptions that are common to many of these analyses.

This is the fourth update of this Data Base since the first version was published in October of 1982. As anticipated, users of these Data Bases have provided a number of constructive recommendations. Since the purpose of this Data Base is to provide a basis for the economic modeling of future systems, the reference capital investment costs reflect an attempt to show the effects of nuclear licensing and regulatory reform and shorter lead times that will be characteristic of new commercially competitive plants that would begin operation around the turn of the century. These capital investment costs were obtained from the Energy Economic Data Base Phase IX (EEDB-9) published by the DOE, Office of Nuclear Energy (DOE/NE-0091).

Office of Nuclear Energy staff and contractors are encouraged to use the Data Base to the extent possible, in particular, the financial assumptions, such as cost of money, fixed charge rate, and light-water reactor (LWR) front-end fuel cycle unit costs. Some elements of the Data Base, such as liquid metal reactor reprocessing and refabrication costs and uranium price, are highly uncertain, and deviation from the Data Base may be appropriate. Further, if users are aware of alternative sources of data that they feel are more appropriate, they are encouraged to contact us. Comments and suggestions to improve the quality of the Data Base are encouraged. Please direct these to:

U.S. Department of Energy
Office of Nuclear Energy
Mail Stop E-477, NE-44 (Germantown)
Washington, DC 20545

Telephone inquiries may be directed to the above office at (301) 353-3773. This report was prepared by J. G. Delene and K. A. Williams of the Engineering Technology Division at the Oak Ridge National Laboratory under the sponsorship of B. H. Shapiro of the DOE Office of Nuclear Energy, Plans and Evaluations Division.

It is our intent to update the Data Base periodically, but this will be possible only through feedback from you, the user. Hence, your comments will be appreciated. Also, we would like to know of additional persons who should receive copies.

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NUCLEAR ENERGY COST DATA BASE

J. G. Delene[a]
K. A. Williams[a]
B. H. Shapiro[b]

ABSTRACT

A reference data base and standard methodology are needed for performing comparative nuclear and fossil power generation cost analyses for the Department of Energy, Office of Nuclear Energy. This report contains such a methodology together with reference assumptions and data to be used with the methodology. It is intended to provide basic guidelines or a starting point for analyses and to serve as a focal point in establishing parameters and methods to be used in economic comparisons of nuclear systems with alternatives.

The data base is applicable for economic comparisons of new base load light-water reactors on a once-through cycle, and high- and low-sulfur coal-fired plants, and oil- and natural gas-fired electric generating plants coming on line around the turn of the century. In addition to current generation light-water reactors and fossil fuel-fired plants, preliminary cost information is also presented on improved and advanced light-water reactors, liquid metal reactor plants and fuel cycle facilities.

This report includes an updated data base containing proposed technical and economic assumptions to be used in analyses, discussions of a recommended methodology to be used in calculating power generation costs, a sample calculation for illustrative and benchmark purposes and projected power generation costs for fission and coal-fired alternatives. Effects of the 1986 Tax Reform Act are included.

1. INTRODUCTION

There is a continuing need in the Department of Energy (DOE),[c] Office of Nuclear Energy, to conduct economic analyses of alternative

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[a]Oak Ridge National Laboratory.
[b]U.S. Department of Energy.
[c]A listing of acronyms is given in Appendix A.

nuclear systems and competing sources of electric power. It is desirable that these analyses use consistent engineering economic approaches and valid baseline financial, cost, and other data. In response to this need the Nuclear Energy Cost Data Base (NECDB) was developed.[1-4] It contains proposals for standard methodologies and for reference assumptions and data to be used with these methodologies for performing comparative nuclear and fossil power generation cost analyses. In preparing this version of the data base, all procedures, assumptions, and cost levels were reviewed and updated.

The following list highlights the changes from the December 1986 NECDB:[4]

1. Cost data are escalated to January 1987 price levels.
2. Effects of the Tax Reform Act of 1986 are included.
3. Updated capital investment costs have been obtained from the Energy Economic Data Base, Phase IX (EEDB-9),[5] and medium size (550 MWe) nuclear plant information is included.
4. Preliminary capital investment cost information is included on a 550 MW(e) and an 1100 MW(e) Improved Pressurized Water Reactors and a 550 MW(e) Advanced Pressurized Water Reactor.
5. The reference capacity factor is increased to 75%.
6. Nuclear plant Operation and Maintenance (O&M) costs are based on a recent revision to the costing procedure, and comparisons of the model predictions and recent plant data are provided. In addition to median current experience O&M costs, better of current experience costs are provided for nuclear plants for the first time.
7. Fuel cost methodology and an example calculation are included for LMR plants with on-site recycle facilities.
8. Power generation cost results using NECDB methodology and cost parameters are included for the alternative light water reactors and coal-fired plants in the midwest region.

As was the case with the 1986 version of the NECDB, presentation of the methodology emphasizes constant dollar analyses, and most of the mathematical formulations appear in the appendices. The use of the phrase "current dollars" for costs including inflation has caused some confusion in the past since current also means now. Therefore, as in the previous NECDB, costs including inflation are referred to as nominal dollars.

The philosophy used in the preparation of this report is one of optimism. The present state of the nuclear industry is characterized by extended plant lead times, regulatory backfitting, and greatly increased engineering costs. This is not true of all nuclear plant construction. There are better experience nuclear plants which are constructed on time and at a reasonable cost. The adoption of the regulatory reform package proposed by DOE is also expected to reduce the costs of nuclear plant construction. It is clear that without improvements in the construction and regulation of nuclear plants, it will be difficult to assure the commercial viability of nuclear power. [The economic viability problem and its associated uncertainties are discussed in a recent

Oak Ridge National Laboratory (ORNL) study.][6] Thus, the reference cost information in the present data base reflects improved construction practices and the implementation of reforms with the concomitant improvements in costs and operating performance. These capital investment costs were obtained from the Energy Economic Data Base, Phase IX (EEDB-9).[5]

In the future there may be changes in the optimum size, type, and design of marketable reactors. There is new interest in small and medium size reactors and in more advanced reactor concepts other than those marketed today. Such advanced concepts include Modular High-Temperature Gas-Cooled Reactors and Modular Liquid Metal Reactors. Technical and cost information on these advanced concepts are presently being developed and will be included in future data bases when the costs for these concepts become better defined. There is also interest in alternative fossil-fired plants including fluidized bed combustion and oil/gas combined cycle plants. These will be included in the NECDB when cost models are available. Since future LWRs may be smaller than the current reference size of 1100 MW(e), data for a small [550 MW(e)] PWR better experience plant based on current technology is included in this report. In addition, preliminary capital investment cost information is included for Improved and Advanced Pressurized Water Reactors. A summary of the capital investment costs for the alternative power plants is given in Table 1.1. The Improved Pressurized Water Reactor (IPWR) incorporates the effects of plant standardization and modularization of plant systems and equipment as well as the improved construction practices and regulatory reform assumed for the better experience (BE) cost model. The Advanced Pressurized Water Reactor (APWR) in addition includes the application of passive safety features including related innovative design and construction features. The basic methodologies and economic assumptions given in this data base can be used to evaluate these concepts as well. A summary of the levelized power generation cost estimates for each of the alternative power plants is given in Table 1.2 for a site in the midwest region of the United States. The results project that the present median experience nuclear plant (PWRME) will not be competitive with coal, while the current better experience plants (PWRBE) will have power generation costs approximately equal to those of the coal-fired alternative depending on plant size and number of units. The results also indicate that the improved (IPWR) and advanced (APWR) nuclear plants are expected to be very competitive.

There are, of course, large uncertainties in the results shown in Table 1.2. The competitiveness of coal-fired plants depends to a large extent on the price of coal. Coal cost varies regionally and is expected to increase in the future. Refinements to nuclear plant capital investment cost models are continuing. The O&M costs for the improved and advanced plants were assumed to be the same as for today's better experience nuclear plants. The O&M costs for these advanced plants are expected to be lower than for today's plants, and work is underway to better define these costs.

Table 1.1. Capital investment costs for alternative power plants[a] [$/kW(e)]

Plant	Plant size MW(e)	With inflation[b]	1987 $
PWR/ME	1 × 1100	7200	3820
PWR/BE	1 × 1100	3645	1935
IPWR	1 × 1100	2855	1515
PWR/BE	2 × 550	3930	2085
IPWR	2 × 550	3145	1670
APWR	2 × 550	2875	1525
Coal	2 × 550	2625	1390
PWR/BE	1 × 550	4695	2490
IPWR	1 × 550	3685	1955
APWR	1 × 550	3365	1785
Coal	1 × 550	2980	1580

[a]Midwestern plant site, year 2000 startup.

[b]Includes inflation at 5%/year.

Table 1.2. Levelized power generation costs for alternative power plants[a] (1987 dollar)

Plant	Plant size [MW(e)]	Levelized cost [mills/kWh(e)]
PWR/ME	1 × 1100	77
PWR/BE	1 × 1100	44
IPWR	1 × 1100	38
PWR/BE	2 × 550	48
IPWR	2 × 550	42
APWR	2 × 550	40
Coal	2 × 550	48
PWR/BE	1 × 550	57
IPWR	1 × 550	49
APWR	1 × 550	47
Coal	1 × 550	52

[a]Year 2000 startup at midwestern site.

It is recognized that individual data parameters (such as uranium price projections and construction lead times) may not be applicable to specific future reactor types and scenarios and that improvements can be made. The NECDB provides basic guidelines or a starting point for analyses and also serves as a focal point in establishing parameters and methods to be used in economic comparisons of nuclear systems with alternatives. It is intended that the NECDB be updated periodically to reflect any improvements in methodology and changes in the expected values of parameters in the data base. This report then is a vehicle through which, by review and comment, improvements can be made.

The methodology in this data base deals only with comparison of plant "bus-bar" costs, either on a year-by-year or a levelized cost basis. Bus-bar costs are one but not the only consideration entering into the decision making process for adding new capacity. Other considerations include the utility projected financial health, the regulatory and financial climates, utility system effects, and projected load growth.

The NECDB presently is limited to current and future LWRs, liquid metal reactors (LMRs) of the LSPB (large-scale prototype breeder) type, conventional coal-fired plants burning either high- or low-sulfur coal, and base load oil- and natural gas-fired plants.

In summary, the NECDB includes proposed technical and economic assumptions to be used in analyses, discussions of recommended methodologies to be used in calculating power generation costs, sample calculations for illustrative and benchmark purposes, and a summary of the projected power generation costs from the alternative plants. A new Appendix included in this version deals with levelized cost for on-site fuel recycle for an LMR.

2. DATA BASE

The reference data base is composed of the basic economic information needed to evaluate the economic competitiveness of nuclear and fossil fuel-fired options for base load electric power generation. This data base includes technical and financial parameters, capital investment costs, nonfuel operation and maintenance costs, fuel cost information, and fuel cycle charge and discharge "mass balance" information.

2.1 Technical and Financial Parameters

Recommended reference technical parameters for use in comparative analyses are given in Table 2.1. Financial parameters are given in Table 2.2. A discussion of each parameter follows.

Plant size. The reference LWR plant size chosen is typical of recently completed plants and plants now under construction. The reference coal-fired plant size is larger than the typical coal-fired plant

Table 2.1. Reference technical parameters

Plant size, MW(e)	
Nuclear	1 × 1100 (1 × 550)[a]
Coal	2 × 550 (1 × 550)[a]
Gas/oil	2 × 550
Locations	See Fig. 2.1
Capacity factor, %	75 (55-85)[a]
Heat rate, average annual Btu/kWh	
LWR	10,200
LMR	9,050
Eastern bituminous coal	9,900
Western sub-bituminous coal	10,200
Gas	9,600
Oil	9,400
Licensing and construction lead times, years	
Nuclear	8 (6-14)[a]
Coal	6 (5-8)[a]
Gas and oil	5 (4-6)[a]
Enrichment plant tails assay, %	0.20
Startup year	2000 (2005)[a]

[a]Range of variation or alternate parameters in parentheses.

Table 2.2. Reference financial parameters

Plant life, years	40
Analysis period, years	30
Reference year	1987
Inflation rate, %/year	5
Escalation rate in excess of inflation rate for power plant construction, %/year	0
Capitalization, %	
Debt	50
Preferred stock	10
Common equity	40
Return on capitalization, %/year	
Debt interest	9.7 (4.5)[a]
Preferred dividend	9 (3.8)[a]
Common equity return	14 (8.6)[a]
Average cost of money (AFUDC rate), %/year	11.35 (6.05)[a]
Federal income tax rate, %/year	34
State income tax rate, %/year	4
Effective (tax-adjusted) cost of money (discount rate), %/year	9.57 (4.35)[a]
Local property tax rate,[b] %/year	2
Tax depreciation method	TRA-86[c]
Tax depreciation life, years	
Nuclear	15
Fossil	20
Interim replacement rate,[d] %/year	0.5
Decommissioning cost, millions of 1986 dollars	
Fossil	25
Nuclear	145
Nominal interest rate on decommissioning fund,[e] %/year	7.0 (1.9)[a]
Fixed charge rates,[f] %/year	
Fossil	16.5 (9.74)[a]
Nuclear	16.3 (9.62)[a]

[a]Real (inflation adjusted) parameters in parentheses.

[b]Rate is applied to initial investment with no escalation due to inflation or decrease due to depreciation.

[c]Tax Reform Act of 1986 (see Table 2.6).

[d]Percent of initial investment in constant dollars, escalating at general rate of inflation.

[e]Interest rate on tax exempt highest grade state and local bonds.

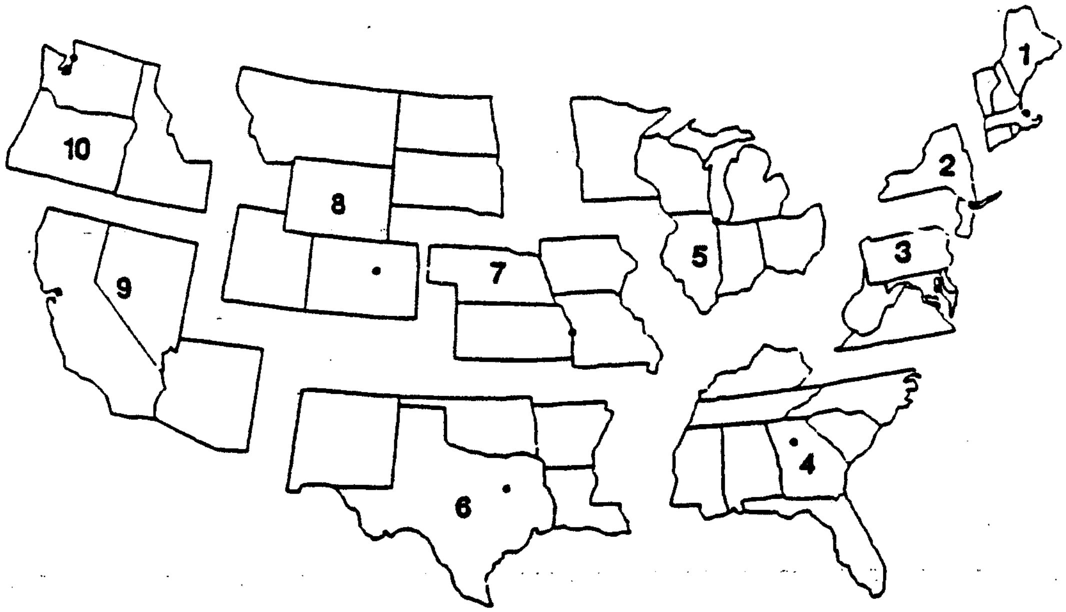
[f]Based on normalized tax accounting.

presently planned or under construction[7] (300-450 MWe) but is consistent with higher future power demands and larger utility systems. The reference site is assumed to contain either one 1100-MW(e) pressurized-water reactor (PWR) nuclear unit or two 550-MW(e) conventional coal-fired units operating with subcritical steam conditions. Since they serve the same capacity need, it is appropriate to compare a 2 × 550-MW(e) fossil plant with a 1 × 1100-MW(e) nuclear unit. Costs are also developed for a 1 × 550-MW(e) coal-fired fossil plant and 1 × 550 MW(e) nuclear plants. The interest in smaller nuclear units stems not only from financial considerations but also maintainability and operability considerations.

Locations. One reference plant location was selected for each of the ten DOE/EIA regions as shown in Fig. 2.1. For comparison, a map of the North American Electric Reliability Council regions is shown in Fig. 2.2. These reference cities were used to estimate regional capital investment cost differences. They were chosen because of their central location in the region and because of the availability of labor and commodity data needed to estimate cost differences. It should be noted that there can be large variations in costs within a region. The reference city costs are simply a means of expressing regional differences in the absence of more site specific data.

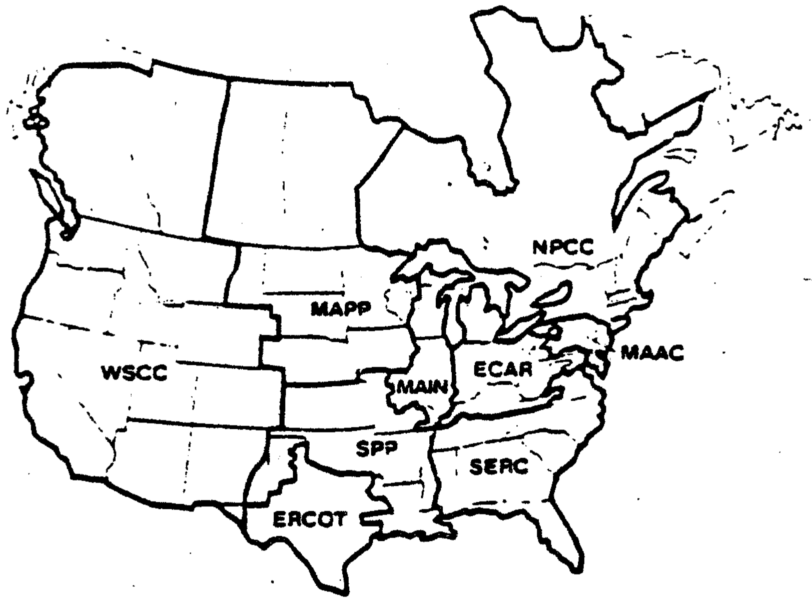
Capacity factor. An average net capacity factor of 75% is recommended as an attainable goal for base load generation plants coming on line around the turn of the century. It is an attainable goal and assumes that operating and regulatory factors causing past low capacity factors are resolved. A 75% capacity factor is consistent with better experience plants of today and therefore should be used with the reference BE cost models. A 65% capacity factor is recommended for use with the median experience (ME) cost models.

The lengthening of the period between refueling with the use of high burnup fuels and increased reliability with improved operation and maintenance and reduction of regulatory shutdowns should increase plant availability and capacity factors. Under such circumstances there is no fundamental reason why capacity factors of 75% or greater cannot be attained routinely by United States nuclear plants. Such a capacity factor is currently attained by many United States nuclear plants and routinely in Europe and the Far East. Seventeen U.S. nuclear plants achieved a 75% or better net capacity factor in 1985 (see Appendix D). In 1986 (Ref. 8) there were 19 such plants. Six out of 22 nations reporting 1985 and 1986 performance in the Nucleonics Week 1986 annual survey[9] achieved a 75% or better capacity factor for their nuclear plants in both those years. The average U.S. gross nuclear capacity factor was reported[9] as 58.91% in 1985 and 58.56% in 1986. These averages include units which were shut down for an entire year due to administrative and regulatory problems, i.e., Tennessee Valley Authority (TVA) nuclear plants, Rancho Seco, and Davis-Besse. As these units return to service, the U.S. average should rise.



Region		City
1.	New England	Boston
2.	New York/New Jersey	New York
3.	Mid Atlantic	Baltimore
4.	South Atlantic	Atlanta
5.	Midwest	Chicago
6.	Southwest	Dallas
7.	Central	Kansas City
8.	North Central	Denver
9.	West	San Francisco
10.	Northwest	Seattle

Fig. 2.1. The United States as subdivided into ten DOE/EIA regions.



ECAR
East Central Area Reliability Coordination Agreement

ERCOT
Electric Reliability Council of Texas

MAAC
Mid-Atlantic Area Council

MAIN
Mid-America Interpool Network

MAPP
Mid-continent Area Power Pool

NPCC
Northeast Power Coordinating Council

SERC
Southeastern Electric Reliability Council

SPP
Southwest Power Pool

WSCC
Western Systems Coordinating Council

Fig. 2.2. North American Electric Reliability Council regions.

It should be noted that most of the reported capacity factors, such as in Refs. 9 and 10 are gross capacity factors. Net capacity factors are somewhat larger than the gross factors since the plant rating is based on capacity available for sale and does not include internal usage. Plant capacity as used in this report is continuous net capacity, so a net capacity factor is applied.

The 75% figure is higher than recent industry averages (57% in 1985)[9] for nuclear and coal-fired plants. A North American Electric Reliability Council report[10] shows an average capacity factor from 1982 through 1985 of approximately 58% for nuclear units and 55% for coal-fired units. The average annual capacity factor for nuclear units during this period ranged from about 55% to 61% and for coal-fired units ranged from about 53% to 57%. Prior to the Three Mile Island accident, industry average nuclear unit capacity factors were approximately 65% and 68% in 1977 and 1978, respectively. This information is in basic agreement with other studies and surveys.[11,12]

Both the nuclear and coal-fired plants considered here are expected to supply base load power to the utility system. The capacity factors for these plants, therefore, are expected to approach their equivalent availability factors. Historically (1982–1985) the equivalent availability factors of coal-fired and nuclear units have been similar, averaging 65% for nuclear units and 72% for 400-MW(e) and larger coal-fired units from 1976 through 1985 (Ref. 10). Both nuclear and coal-fired plants should be subject to some of the same availability improvements. For this reason the nuclear and coal-fired plant capacity factors are assumed to be equal.

Heat rates. The term *heat rate* as used in the electric utility industry is the amount of heat input in British thermal units (Btu) required to produce a net output of 1 kWh of electricity. The heat rates shown are estimated annual average heat rates for recent and future units. Plant heat rates will vary with plant size,[13,14] fuel quality,[15] and operating characteristics.[14] In their 1986 Technical Assessment Guide,[16] the Electric Power Research Institute (EPRI) recommends a full load heat rate of 9850 Btu/kWh for a subcritical high-sulfur bituminous coal-fired plant with wet limestone flue gas desulfurization. In another EPRI report[17] the heat rate for a 500-MW(e) high-sulfur bituminous coal-fired plant operating at 70% capacity factor is 9986 Btu/kWh, while that for a similar low-sulfur sub-bituminous coal-fired plant is 10293 Btu/kWh or 3% higher than the bituminous coal-fired plant. Also, Gilbert/Commonwealth[13] estimates the heat rate for a 600-MW(e) coal-fired plant to be 9850 Btu/kWh. The recommended reference value in Table 2.1 of 9900 Btu/kWh is consistent with these studies. The western low-sulfur sub-bituminous coal-fired heat rate of 10,200 Btu/kWh is about 3% higher than the high-sulfur bituminous coal heat rate.

The Gilbert/Commonwealth paper[13] quotes a 600-MW(e) oil-fired plant heat rate of 9200 Btu/kWh. The Draft Northeast Regional Environmental Impact Statement[18] estimates the average heat rate for existing base load oil-fired plants in the Northeast to be 9340 Btu/kWh. The most recent EPRI Technical Assessment Guide[16] recommends 9680 Btu/kWh for oil-fired steam plant plants. The 9400 Btu/kWh recommended in Table 2.1 is approximately an average of these figures. Gas-fired boilers have a higher heat rate than oil-fired systems because of the greater moisture losses in the stack gas. These losses are estimated to increase the heat rate by about 2%, which translates to a heat rate of about 9600 Btu/kWh for gas-fired units. The LWR nuclear plant heat rate of 10,200 Btu/kWh is consistent with the mass balances developed by Combustion Engineering (see Sect. 2.8) and is attainable in new LWR plants. The LMR average annual heat rate of 9050 Btu/kWh is that for the Large Scale Prototype Breeder (LSPB) design and is consistent with the mass balances provided by the Electric Power Research Institute Consolidated Management Office (see Sect. 2.8).

Licensing and construction lead times. As used in this report, plant lead time includes the total elapsed time for design, engineering, licensing, construction, and startup. Trends in nuclear power plant lead times are shown in Table 2.3 (Refs. 19 and 20). Total lead time has been increasing. Lead times shown in Table 2.3 were divided into the time between NSSS order and issuance of the construction permit, and the time between the issuance of the construction permit and the operating license.

The lead time for nuclear units has increased significantly over the years from about 5 years before 1970 to 14 or more years currently. Some of this lengthening of nuclear plant lead times is caused by nonconstruction problems such as slowdowns due to decreased load growth, utility financial problems, and problems in obtaining final approval for plant startup. After construction completion, startup has been delayed due to slow resolution of regulatory issues such as emergency evacuation, which have increased substantially in the last few years. Estimated lead times for current and future coal-fired and nuclear plants are shown in Table 2.4. The values in the "typical current" category are consistent with projects today and reflect changing regulatory requirements and project deferrals due to reduced demand growth and utility financial constraints.

The intermediate term goal represents what could be done if regulatory reforms are enacted and construction practices improved. This latter category is recommended as the reference lead time for planning purposes. The 8-year total lead time for nuclear plants however represents an intermediate term goal and not an ultimate goal as there is still room for improvement as demonstrated in Japan and France. Increased modularization and factory fabrication, standardization of design, and improved construction practices can reduce lead time and costs further.[21,22] The IPWRs and APWR cost models include these features. For this reason a 6 year design and construction period is recommended for use with these models. Gas- and oil-fired base load plants are expected to have somewhat shorter lead times than coal-fired plants (See Table 2.1) because the fuel handling, combustion, and pollution control systems are simpler.

Table 2.3. Trends in average design and licensing lead times and construction duration for nuclear power plants[a]

Year of completion	Number of units	NSSS order to construction permit (months)	Construction duration[b] (months)	Total (months)
1969 and earlier	12	14	42	56
1970	4	13	43	56
1971	5	15	51	66
1972	6	19	53	72
1973	12	18	63	81
1974	14	19	66	85
1975	3	30	63	93
1976	7	25	84	109
1977	4	32	80	112
1978	3	33	77	110
1979	0			
1980	4	19	116	135
1981	2	32	114	146
1982	5	42	104	146
1983	4	39	111	150
1984	8	53	116	169
1985	9	32	135	167
1986	9	50	126	176
1987[c]	3	32	149	181

[a]Sources: "U.S. Central Station Nuclear Electric Generating Units: Significant Milestones (Status as of January 1, 1985);" DOE/NE-0030/12, U.S. Department of Energy, May 1985; and AIF Info Data Sheet: "Historical Profile of U.S. Nuclear Power Development" (1985-1987).

[b]From construction permit to operating license issuance.

[c]Projected.

Table 2.4. Estimated lead times for nuclear and coal-fired power plants

	Typical current	Intermediate term goal
Nuclear		
PSAR and ER preparation, review and engineering[a]	48	24
Construction and startup	120	72
Total, months	168	96
Coal		
ER preparation, review and engineering[a]	30	21
Construction and startup	54	51
Total, months	84	72

[a]Time from NSSS or boiler order to start of construction = PSAR and/or ER preparation + review and engineering time.

Enrichment plant tails. A standard transaction tails assay of 0.2% was originally set under the utility services enrichment contract. A variable tails option, however, is now available (formerly, deviations from the 0.20% standard tails assay increased the enrichment price). This surcharge for tails enrichments other than 0.20% was removed starting in FY 1987 for utilities obtaining 100% of their enrichment needs under the utility services contract. The optimum tails enrichment is a complicated function of uranium and enrichment (SWU) price and ultimately affects the total cost of front-end fuel cycle services. The optimum tails assay is about 0.30% based on the reference uranium and enrichment prices. However, with the projected decline in enrichment price and the projected increase in ore price over the period 1987 to 2030, the optimum should decrease to less than 0.25% by the year 2000 and to 0.14% by around 2030. The recommended 0.20% tails assay is therefore a good midpoint figure for plant startups in the year 2000 and later.

Startup year. It is not expected that there will be new orders for nuclear power plants until regulatory reform is enacted, societal concerns are resolved, load growth resumes, and utilities regain financial health. The earliest date for the startup of such a new plant will probably not be until the late 1990s or early in the next century. The reference startup date is January 2000 with an alternative date of 2005 indicated. The reference date is consistent with a 1992 nuclear steam supply system order date and an 8-year lead time.

Plant life. The recommended plant book life to be used in economic calculations is 40 years. The 40-year life is consistent with Nuclear Regulatory Commission (NRC) operating licenses, which are issued for a period of 40 years. Advanced reactors, however, may be designed for lives of 60 years or longer and the life of some current reactors may be extended for an additional 20 years or more.

Analysis life. An analysis life or levelization period of 30 years is recommended for use in the economic calculations. Therefore only the revenue requirements during the first 30 years of plant life are considered. Utilities often use even shorter periods, in the order of 15–20 years, for economic comparison purposes. These shorter amortization periods are often a compensation for financial risk and neglect the long-term benefits of a technology.

Reference year. Prices and costs are referenced to January 1987 dollars.

Inflation rate. Recent experience has demonstrated that the rate of inflation cannot be predicted with any certainty, especially over the course of the next 40-45 years. The inflation rate since 1970, as measured by the Gross National Product (GNP) Implicit Price Deflator, is shown in Table 2.5 (Ref. 23). The average rate in the decade from 1977 to 1987 was about 5.7%/year. This was a period punctuated by fluctuating oil and other energy prices. Since 1981 the inflation rate has slowed significantly, caused in part by declining oil prices in the period 1982–1986. The rate of change in the GNP Implicit Price Deflator declined to less than 4%/year between 1983 and 1987. The Energy Information Administration (EIA) estimates an average inflation rate between 1987 and 2000 of about 5.0%/year for their reference base case forecast.[24] There is wide disagreement on the future rate of inflation with projections typically ranging from about 3 to 7%. The last three years have been marked by a persistently low inflation rate which only recently has shown indications of turning upward into the 4 to 5%/year range on an annualized basis. The 5% rate recommended in this data base assumes that the price of oil will remain relatively stable after its steep 1986 decline and subsequent partial recovery, and that the problems with the U.S. deficit and trade imbalance will be solved. A range of uncertainty in the long term average inflation rate of 3 to 7%/year is recommended.

Escalation rate for power plant construction. The rate of change, or escalation rate, in power plant construction costs can be divided into three components: the contribution due to the general inflation rate as measured by the GNP Implicit Price Deflator; the contribution due to real changes in the costs of labor, equipment, and materials; and the contribution due to changes in scope resulting from regulatory requirements and design changes. The inflation assumptions were discussed

Table 2.5. Historical inflation rates

Year	Gross national product implicit price deflator[a,b]	Annual rate of inflation, %
1970	42.0	5.5
1971	44.4	5.7
1972	46.5	4.7
1973	49.6	6.7
1974	54.0	8.9
1975	59.3	9.8
1976	63.0	6.2
1977	67.3	6.8
1978	72.2	7.3
1979	78.6	8.9
1980	85.7	9.0
1981	94.0	9.7
1982	100.0	6.4
1983	103.9	3.9
1984	107.8	3.8
1985	111.2	3.2
1986	114.1	2.6
1987	117.5	3.0

[a]Source: "Annual U.S. Economic Data, 1977-1987," The Federal Reserve Bank of St. Louis, November 1988 and previous issues.

[b]1982 = 100.

in the previous paragraph. Regulatory reform is expected to reduce changes in scope to a minimum. Cost increases to new plants caused by future regulatory changes are therefore not included. Figure 2.3 shows a plot of the annual rate of change in the inflation rate and in the Handy-Whitman[23] (H-W) index for the H-W North Central region (which includes the EIA Midwest and Central regions plus North and South Dakota) for the "market basket" or mix of commodities used for coal-fired and nuclear plant construction. What is striking about the plot is the large increase in the Handy-Whitman indices relative to inflation following the oil price increases in 1973. During the last 10 years (1977–1986), however, there has been no average real increase in either coal or nuclear costs. In six of the seven years since 1980, the average rate of change in the Handy-Whitman index for both nuclear and fossil plant construction has averaged less than the GNP Implicit Price Deflator with a range of 0–1% less depending on region and fuel type.

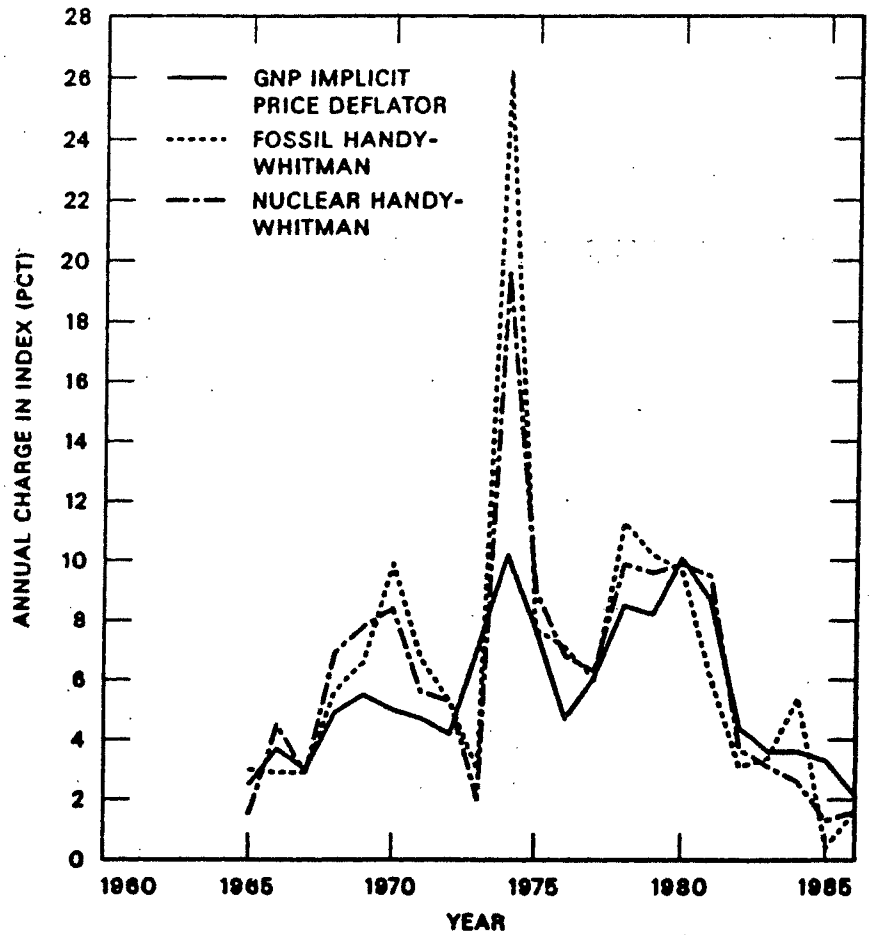


Fig. 2.3. Historical annual change in cost indices.

In this data base, it is assumed that oil prices will remain stable after their recent fluctuation with no large price discontinuities as occurred in 1973 and that current trends will continue. The real escalation rate for both nuclear and fossil-fired plants is assumed to be equal to the rate of inflation. The range of uncertainty is from an optimistic -1%/year to a pessimistic 5%/year, which assumes significant change in scope due to regulatory ratchetting.

Utility capitalization. The utility capitalization, the return on this capitalization, and the effective income tax rate are needed to calculate the average cost of money and the effective cost of money for the utility [see Eqs. (24) and (25) in Sect. 3]. The equity fraction of utility capitalization has been increasing in the last few years reflecting utility and regulatory commission effort to strengthen utility finances. The average utility equity/preferred/debt capitalization ratio for 1985 was 40.2/9.7/50.1 (Ref. 26). The 40/10/50 equity/preferred/debt capitalization recommended is the same as in the previous (NECDB-86) data base and is generally consistent with the 1985 data.

Return on capitalization. The returns shown are the estimated long run costs of debt, preferred stock, and common stock equity capitalizations. These returns are based on stable conditions and a 5%/year average inflation rate. The real returns (with inflation removed) are about 3.3%/year on long term treasury bonds, 4.5%/year for utility debt, 3.8%/year for utility preferred stock, and 8.6%/year for utility common equity. The real rate on tax exempt Aaa state and local bonds used for the decommissioning sinking fund is 1.9%/year.

There is disagreement on what the long run real returns should be. Different conclusions are often reached by two studies analyzing different time periods or the same time period but using somewhat different assumptions. The real, risk free, return on long term government bonds has been estimated to range from 2 to 4% with a mean of about 3% (Ref. 27). The reference 3.3% rate is about the middle of the range. The real returns are the same as recommended in the previous version of this data base and are about the same as what is currently being experienced in the market. During early to mid 1987 (Ref. 28), the yields on long term utility bonds averaged about 1.0–1.3% above the government bond yield. The recommended returns on U.S. Treasury and Aa utility bonds of 8.5% and 9.7%, respectively, assume a 1.2% differential and a stabilization of interest rates after the downward movement during 1986 and the upward adjustment during the second and third quarters of 1987. The real return on utility debt recommended in this report after adjusting for inflation is about 4.5%/year. The rate differential between the highest grade state and local bonds and long term U.S. Treasury bonds varies considerably depending on market conditions and anticipation of tax law changes. This rate differential is typically in the range of 1–3%. For the purpose of the decommissioning sinking fund, a 1.5% differential is assumed in nominal dollars. The recommended interest rate on the decommissioning funds is therefore 7.0%/year nominal or 1.9%/year real. This is an increase from the 6.5%/year nominal or 1.4% real rate used in NECDB-86.[4] This perceived increase may be due in part to the lower marginal tax rates under the Tax Reform Act making state or municipal bonds a less attractive investment than under the previous tax law; thus such issues must pay a slightly higher interest rate.

The average return on common equity authorized for electric utilities in 1986 was 13.5%, down significantly from 1985 (Ref. 29). Recognizing the effect of lower interest rates in 1986, Public Service Commissions have been decreasing the allowable return on equity. This equity return should increase if interest rates move upward. The Federal Energy Regulatory Commission's (FERC's) recommended generic rate of return on common equity announced in January 1987 was 11.20% (Ref. 30). Actual rates of return granted in 1987 are likely to be larger than this value especially if other interest rates rise. The 14%/year return on common equity shown in Table 2.2 is approximately 5.1 percentage points greater than the long term risk free rate (long term government bond rate). This is at the high end of the range calculated historically. The electric utility industry, however, is not considered by the investment community to be the low risk industry it once was.[31] If these perceptions continue in the future, utility common equity returns will remain historically high. If stability and predictability return to the electric utility industry, then required returns on equity may be less than recommended here.

"Historically, a given firm's preferred stock generally carried higher rates than its bonds because of the preferred's greater risk."[32] However, in recent years, preferred stock has been selling at lower rates than corporate bonds of the same quality. Preferred stock is an attractive corporate investment since 80% of these dividends are tax exempt to the corporation (85% were tax exempt under the previous law). In the 1980s the yields on utility preferred have been about 0.5 to 1.5 percentage points lower than similar grade utility bonds.[26] The recommended 9%/year yield on utility preferred stock is 0.7% less than the 9.7%/year yield on debt.

Average cost of money. The 11.35%/year nominal dollar average cost of money is computed using the capitalization fractions and the returns on capitalization. The real (adjusted for inflation) rate is 6.05%. Under the 1986 Tax Reform Act interest payments during construction can no longer be deducted as an expense for income tax purposes as incurred. Therefore the effective cost of money for construction purposes includes the full interest rate, and the average cost of money is used as the capitalization rate during construction.

Income tax rates. The incremental federal income tax rate on corporate income over $100,000 is 34% under the recently passed 1986 Tax Reform Act. This is a reduction from the 46% rate under the old tax law. State income taxes vary from state to state. The recommended 4% value is typical.

Effective cost of money. The tax-adjusted or effective cost of money of 9.57%/year is calculated using Eq. (26) from Sect. 3 of this report. This is an increase from the 9.01% used in the 1986 NECDB and is directly attributable to the lower tax rate under the new tax law. The tax adjusted cost of money is recommended for use as the discount rate for present value and levelization purposes (see Sect. 3). The real (adjusted for inflation) tax adjusted discount rate is 4.35%.

Local property tax rate. Local property and *ad valorem* taxes will vary from locality to locality. The recommended 2%/year rate is typical. Although local procedures vary, the value of the property to which the rate is applied will vary over time, both increasing as inflation increases cost levels and decreasing as the asset depreciates. For simplicity it is recommended that the tax rate be applied to the initial capitalized investment with no escalation due to inflation or decrease due to depreciation.

Tax life and tax depreciation schedule. The tax depreciation method and tax life reflect the 1986 change in the tax laws. The 1986 Tax Reform Act provides for a number of changes to the Accelerated Cost Recovery System (ACRS) used under the old law. The new, Modified Accelerated Cost Recovery System (MACRS)[33] lengthens tax depreciation schedules for both nuclear and coal-fired power plants. A 150% declining balance (DB) method with a 15-year tax life is now required for nuclear plants vs a 10-year tax life previously. Coal-fired plants require a 150% DB method with a 20-year tax life vs 15 years previously. The nuclear fuel tax depreciation schedule is improved, calling for a 200% DB over 5 years vs 150% DB over 5 years previously. The units-of-production depreciation method can still be used if desired for nuclear fuel. All DB methods provide for the switch to the straight line method when the straight line method produces a higher tax depreciation. The Act provides for only using half of the tax depreciation calculated by the depreciation method in the year the property is placed in service (half-year convention), however, the depreciation schedule is extended into the year following the tax life, this year also having half the annual tax depreciation. Therefore nuclear plant depreciation, for example, extends 16 years with half the nominal rate in the first and eleventh year. A year-by-year depreciation schedule was not provided in the 1986 Tax Reform Act. An estimate of the year-by-year percentages is shown in Table 2.6.

Interim replacement allowance. The reference interim replacement allowance is 0.5%/year of the initial capital investment. Interim replacement allowance is defined in the 1968 Hydroelectric Power Evaluation,[34] as the portion of the total investment required annually to provide for those units of property included in the plant with life spans less than the adopted overall facility service life, and a value of 0.35%/year was recommended based on "continuing studies." The 1979 Hydroelectric Power Evaluation[35] states "...it is assumed that each economic life selected properly reflects the weighted service life of each component and therefore an interim replacement allowance is not required." The 1979 EPRI Technical Assessment Guide[36] did not include an interim replacement allowance in the fixed charge rate, but did include a retirement dispersion allowance that is defined similarly to interim replacement allowance and has an approximate value of 0.5%/year. The 1986 EPRI Technical Assessment Guide[16] does not include either an interim replacement allowance or a retirement dispersion allowance. Backfitting costs are defined as those capitalized costs incurred after the plant is placed in commercial operation to comply with new nuclear safety and environmental regulations. None of the above studies discuss backfitting costs. Based on analyses of past experience, studies[37,38] have used interim replacement rates generally from 1-2%/year which includes some provision for backfitting costs. Historical experience on interim replacements is not an appropriate indication of what can be expected in the future, especially for nuclear. The reference interim replacement allowance of 0.5%/year for both coal-fired and nuclear plants does not include provision for backfitting costs. This is consistent with nuclear licensing reform. The estimates of nonfuel operation and maintenance (O&M) costs (Sect. 2.3) do not include capitalized

Table 2.6. Recovery percentages[a]

Year	Applicable percentage for class of property		
	5-year property (nuclear fuel)	15-year property (nuclear plant)	20-year property (fossil plant)
1	20.00	5.00	3.75
2	32.00	9.50	7.22
3	19.20	8.55	6.68
4	11.52	7.70	6.18
5	11.52	6.93	5.71
6	5.76	6.23	5.28
7		5.91	4.89
8		5.91	4.52
9		5.91	4.47
10		5.91	4.47
11		5.90	4.46
12		5.90	4.46
13		5.90	4.46
14		5.90	4.46
15		5.90	4.46
16		2.95	4.46
17			4.46
18			4.46
19			4.46
20			4.46
21			2.23

[a]Based on Tax Reform Act of 1986.

interim replacements. The interim replacement rate is applied to the initial capitalized investment. The cost in nominal dollars is expected to increase at the general rate of inflation.

Decommissioning cost. There are basically three methods which may be used for nuclear reactor decommissioning. These three techniques are deferred decontamination [mothballing for 30–50 years (plan 1)], entombment (plan 2), and immediate dismantlement and removal (plan 3). Immediate decontamination and removal is preferred, but deferred decontamination or entombment may be acceptable for occupational health or safety reasons. Deferred decontamination reduces the radioactive exposure during eventual dismantling; however, it also increases the total cost of decommissioning because surveillance is required during the mothballing period. However, the present worth of these costs may be less than for immediate dismantlement.[39] Entombment will probably not be acceptable.[40] Utilities are required to provide a decommissioning funding plan to the NRC. This plan includes an initial decommissioning cost estimate for the reactor, and a description of the method to be used to assure funds, including the means of adjusting cost estimates and funding level over the life of the facility. The cost estimate for decommissioning is either prescribed by the public utility commission or based on estimates made by the applicant. The utility may use a figure for plan 3 decommissioning prescribed by the NRC of $100 million (1984$) adjusted by twice the inflation rate in the absence of detailed estimates of its own.[40] Since a large commercial reactor has never been dismantled, these cost estimates are approximate. Generic decommissioning cost estimates for nuclear reactors were performed by Battelle in 1978 (Ref. 41). The NRC estimate of $100 million is based on these Battelle studies and their observation that past escalation has been at about twice the inflation rate. An update of the 1978 cost estimates, performed by Battelle for EPRI,[42] shows a total cost for immediate dismantlement of $79–94 million (1984$) for PWRs and a range of $97–120 million (1984$) for Boiling Water Reactors (BWRs) depending upon whether utility or constructor staffing was used for the operation.

A review of decommissioning cost studies[43] indicates an average estimated decommissioning cost of about $123 million in 1983 dollars. Some specific estimates include $80.1 million (January 1983$) for Florida Power Corporation's 90% of Crystal River;[44] $80 million in FY 1986 dollars for the decommissioning of the 72-MW(e) Shippingport Reactor;[45] and $55 million in 1985 dollars for the decommissioning of a 63-MW(e) BWR.[46] A recent Nuclear Energy Agency report[47] gives an estimate for a plan 3 decommissioning of 97 million in 1984 dollars for a 1300 MW PWR built in the United States. There are also estimates which indicate that the NRC $100 million groundrule may be too low or too high. The Energy Systems Research Group[48] of Boston, Mass., estimates an average decommissioning cost of $200 million for PWRs (1987 $). An estimate made of the decommissioning cost of the Nine Mile Point plant[49] indicates an overall cost range for decommissioning of $164 to $241 million in 1985 dollars. Others[50] have suggested that $100 million and the NRC suggested escalation are too high. Clearly decommissioning costs should be based on site specific studies where possible.

The $145 million recommendation for this data base was obtained by escalating the $100 million 1984$ estimate to a 1987 price assuming an escalation of twice the actual inflation over the 3 years, and then adding a 20% contingency to allow for future cost escalation in excess of inflation. The range of uncertainty in reported cost estimates is approximately $90 to $270 million.

The decommissioning cost for coal-fired plants is based on a study by Arkansas Power and Light.[51] Here a net decommissioning cost for two 800-MW(e) coal units was estimated to be about $24 million in 1983 dollars. The $25 million figure recommended for this data base was obtained by double escalating the Arkansas Power and Light figure to 1987 dollars and then scaling to a 2 × 550-MW(e) plant size using a six-tenths power scaling with plant size.

Appendix B. FIXED CHARGE RATE

Characteristic fixed charge rates for coal-fired and nuclear power plants may be estimated using a PWRR calculated from the detailed year-by-year revenue requirements described in Sect. 3.1,

$$FCR = \frac{(PWRR_c)\ CRF(X,N)}{I} . \tag{B.1}$$

A listing of a computer code which may be used to calculate year-by-year costs and the levelized fixed charge rate is given later in this Appendix.

B.1 Fixed Charge Rate Derivation

The fixed charge rate may also be derived from the revenue requirements equations and stated explicitly as a single equation. These equations are useful if year-by-year costs are not needed. The derivation given here is the same as in the previous NECDB except that the investment tax credit is not included so as to conform to the 1986 tax law revision.

Flow-through accounting

Starting with Eqs. (2) and (3) from Sect. 3.1,

$$R_n = eEV_n + pFV_n + bBV_n + D_n^B + O_n + T_n \quad , \tag{B.2}$$

and

$$T_n = t\ (R_n - D_n^T - bBV_n - O_n) . \tag{B.3}$$

Substituting Eq. (B.3) into (B.2) and rearranging,

$$R_n = \frac{XV_n}{(1-t)} + \frac{D_n^B}{(1-t)} - \frac{t}{(1-t)} D_n^T + O_n . \tag{B.4}$$

The present worth of these revenue requirements over M periods is

$$PWRR = \frac{1}{(1-t)} \sum_{n=1}^{M} \frac{XV_n}{(1+X)^n} + \frac{D_n^B}{(1+X)^n} - \frac{t}{1-t} \sum_{n=1}^{M} \frac{D_n^T}{(1+X)^n} + \sum_{n=1}^{M} \frac{O_n}{(1+X)^n} \tag{B.5}$$

M is any number of periods equal to or less than the plant life N. Frequently economic studies are made for periods shorter than the design life of the plant.

Now dealing only with the first summation in Eq. B.5 and noting that

$$D_n^B = \frac{I}{N}$$

and

$$V_n = I - \sum_{j=1}^{n-1} D_j^B \quad ,$$

so

$$V_n = I \left(1 - \frac{n-1}{N}\right).$$

Thus

$$\sum_{n=1}^{M} \left[\frac{XV_n}{(1+X)^n} + \frac{D_n^B}{(1+X)^n}\right] = \sum_{n=1}^{M} \frac{X\left(I - \frac{n-1}{N} I\right) + \frac{I}{N}}{(1+X)^n}$$

$$= I \left[\left(X + \frac{X}{N} + \frac{1}{N}\right) \sum_{n=1}^{M} \frac{1}{(1+X)^n} - \frac{X}{N} \sum_{n=1}^{M} \frac{n}{(1+X)^n}\right].$$

Since

$$\sum_{n=1}^{M} \frac{1}{(1+X)^n} = \frac{1}{CRF(X,M)}$$

and

$$\sum_{n=1}^{M} \frac{n}{(1+X)^n} = \frac{1+X}{XCRF\ (X,M)} - \frac{M}{X(1+X)^M}\,, \tag{B.6}$$

the first summation becomes

$$\sum_{n=1}^{M} \left[\frac{XV_n}{(1+X)^n} + \frac{D_n^B}{(1+X)^n}\right] = I\left[\frac{X}{CRF(X,M)} + \frac{M}{N\,(1+X)^M}\right]$$
$$= \left[1 - \left(1 - \frac{M}{N}\right)\frac{1}{(1+X)^M}\right] I\ . \tag{B.7}$$

If M=N, or the study life equals the plant book depreciation life, then Eq. (B.7) reduces to the initial investment. This is to be expected since the present worth of the return on and return of investment should equal the initial investment if the engineering economics were done correctly. The $\left(1 - \frac{M}{N}\right)/(1 + X)^M$ term is the present worth of the fraction of the plant which has not been depreciated for book purposes.

Substituting Eqs. (B.7) and (B.5) into Eq. (B.1) gives an expression for the fixed charge rate with flow-through accounting,

$$FCR = \frac{CRF(X,M)}{I}\left\{\frac{I}{1-t}\left[1 - \left(1 - \frac{M}{N}\right)\frac{1}{(1+X)^M}\right]\right.$$
$$\left. - \frac{t}{1-t}\sum_{n=1}^{M}\frac{D_n^T}{(1+X)^n} + \sum_{n=1}^{M}\frac{O_n}{(1+X)^n}\right\}. \tag{B.8}$$

The operating costs in Eq. (B.8) are the property taxes and the interim replacements. These costs may escalate with time,

$$O_n = \sum_k \pi_k\,(1 + r_k)^n\, I$$

and

$$\sum_{n=1}^{n} \frac{O_n}{(1 + X)^n} = I \sum_k \left[\pi_k \sum_{n=1}^{n} \frac{(1 + r_k)^n}{(1 + X)^n} \right]$$

$$= I \sum_k \frac{\pi_k}{CRF\left(\frac{X - r_k}{1 + r_k}, N\right)} .$$

A levelized tax depreciation, $\bar{d}$, as a fraction of initial investment, may be defined. To levelize a quantity, take the present worth of the year-by-year values and sum. Then apply a capital recovery factor to the sum to convert the present worth to a series of equal annual values,

$$\bar{d} = \frac{\sum_{n=1}^{M} \frac{D_n^T}{(1 + X)^n} \quad CRF(X,M)}{I} .$$

The total depreciable base for tax purposes is equal to the total capitalized investment, I, less the equity portion (both common and preferred) of the allowance for funds used during construction,

$$D_n^T = d_n^T f\ I ,$$

where f is the fraction of the initial capitalized investment which is depreciable for tax purposes. The "f" factor accounts for the fact that the equity portion of the AFUDC is not depreciable for tax purposes.[121]

$$\bar{d} = f\ CRF(X,M) \sum_{n=1}^{M} \frac{d_n^T}{(1 + X)^n} .$$

The fixed charge rate therefore becomes

$$FCR = \frac{CRF(X,M)}{1 - t} \left[1 - \frac{\left(1 - \frac{M}{N}\right)}{(1 + X)^M} \right]$$

$$- \frac{t}{1 - t} \bar{d} + \sum_k \pi_k \frac{CRF\ (X,M)}{CRF\left(\frac{X - r_K}{1 + r_K}, M\right)} . \qquad \text{(B.9)}$$

Normalized accounting

Starting from Eq. (2) and combining Eqs. (9) and (10) from Sect. 3.1 gives

$$R_n = eEV_n + pFV_n + bBV_n - D_n^B + O_n + T_n \tag{B.2}$$

and

$$T_n = t(R_n - bBV_n - O_n - D_n^T) + T_{d,n} \ . \tag{B.10}$$

Substituting Eq. (B.10) into Eq (B.2) and rearranging gives

$$R_n = \frac{XV_n}{(1-t)} + \frac{D_n^B}{(1-t)} + O_n - \frac{t}{1-t} D_n^T + \frac{T_{d,n}}{(1-t)} \ . \tag{B.11}$$

The rate base term, V_n, is

$$V_n = I - \sum_{j=1}^{n-1} (D_j^B + T_{d,j}) \quad ;$$

rearranging,

$$V_n = I - \sum_{j=1}^{n-1} D_j^B - \sum_{j=1}^{n-1} T_{d,j} \ . \tag{B.12}$$

Thus Eqs. (B.11) and (B.12) are exactly the same as the equivalent equations for flow-through accounting except for the deferred tax terms. Separating this term out from Eqs. (B.11) and (B.12) and rearranging, gives for each period n

$$\frac{T_{d,n}}{(1-t)} - \frac{X}{1-t} \sum_{j=1}^{n-1} T_{d,j}$$

The deferred taxes are

$$\begin{aligned} T_{d,n} &= t(D_n^T - D_n^{SL}) \\ &= t[fI(TDR)_n - \frac{fI}{N}] \\ &= tfI(TDR_n - \frac{1}{N}) \ . \end{aligned}$$

so,

$$\frac{1}{1-t}\left(T_{d,n} - X \sum_{j=1}^{n-1} T_{d,j}\right)$$

$$= \frac{fIt}{1-t}\left\{(TDR)_n - \frac{1}{N} - X \sum_{j=1}^{n-1} [(TDR)_j - \frac{1}{N}]\right\}.$$

The sum of the present worth of the revenue requirements of this component is a complicated function. It must be expanded term by term and then simplified. The final result for the deferred tax terms is

$$\frac{fIt}{(1-t)} \sum_{n=1}^{M} \frac{(TDR)_n - \frac{1}{N} - X \sum_{j=1}^{n-1} [(TDR)_j - \frac{1}{N}]}{(1+X)^n}$$

$$= \frac{fIt}{(1-t)} \; \frac{1}{(1+X)^M} \left[\sum_{n=1}^{M} (TDR)_n - \frac{M}{N}\right] \quad . \qquad \text{(B.13)}$$

If the analysis life is greater than the tax depreciation life (15 years for nuclear, 20 years for coal), then

$$\sum_{n=1}^{M} (TDR)_n = 1 \;,$$

and if the study life and book life are equal, then the entire term reduces to zero. The equation for the FCR with normalized accounting becomes

$$FCR = \frac{CRF(X,M)}{(1-t)} \left\{1 - \frac{\left(1 - \frac{M}{N}\right)}{(1+X)^M} + \frac{ft}{(1+X)^M}\left[\sum_{n=1}^{M} (TDR)_n - \frac{M}{N}\right]\right\}$$

$$- \frac{t}{1-t}\,\bar{d} + \sum_k \pi_k \frac{CRF(X,M)}{CRF\left(\frac{X - r_k}{1 + r_k}\,,\, M\right)} \;. \qquad \text{(B.15)}$$

B.2- Fixed Charge Rate Computer Code

The IBM-PC BASIC computer code used to calculate the fixed charge rates (FCR) using year-by-year revenue requirements' methodology is given in Fig. B.1. This is equivalent to the FORTRAN code shown in previous NECDBs. The output from a calculation using this code is shown in Fig. B.2. The first page of output prints the input data used in the calculation and the second page gives the annual revenue requirements for capital and the fixed charge rate. This is the calculation of the reference nuclear plant fixed charge rate.

The code calculates both constant and nominal dollar FCRs using the methodology described in Sect. 3.1. The relationship between the constant and nominal dollar FCRs (same relationship as for levelized price) was given in Eq. (24) where L equals zero since the constant dollar FCR is computed using the year of plant startup as the reference year. The code output in Fig. B.2 also shows the sum of the present worth of the revenue requirements (PWRR) over the study period.

The annual power cost generated by the capital investment alone is also calculated. Both the constant and nominal dollar values are shown for each year. These must be added to the O&M, fuel, and decommissioning annual costs to obtain the total power generation cost.

The fixed charge rate may be calculated over the entire plant life or over a shorter analysis period. The example in Fig. B.2 is for a 40 year plant life and 30 year analysis period.

Breakdowns of the reference FCRs are given in Table B.1. This breakdown was computed by first calculating component costs with the tax rate set equal to zero (t=o). The non-tax adjusted cost of money, X_1 [Eq. (25)], was used for these calculations. Thus,

$$\text{effective interest rate} = X_1 \ (0.1135) \ ,$$

$$\text{sinking fund depreciation} = \frac{X_1}{(1 + X_1)^N - 1} \ , \text{ and}$$

$$\text{other costs} = \pi_k \frac{\text{CRF}(X_1,\ N)}{\text{CRF}\left(\frac{X_1 - r_k}{1 + r_k}\ ,\ N\right)}$$

k=1 for property tax ($\pi_k = 0.02$ and $r_k = 0.0$)

k=2 for interim replacement ($\pi_k = 0.005$ and $r_k = 0.05$) .

```
10 REM  FCRATE.BAS
20 REM  FIXED CHARGE RATE FOR ELECTRIC POWER PLANT
30 REM  08/01/88
40 COLOR 14,9,11
50  'Select output destination
60 PRINT "      select output destination as follows"
70 PRINT "           1 - printer"
80 PRINT "           2 - screen"
90 PRINT "           3 - A:FCR.DAT"
100 PRINT "           4 - C:FCR.DAT"
110 INPUT DEVICE
120 IF DEVICE<1 OR DEVICE>4 THEN PRINT "BAD ENTRY -- TRY AGAIN":GOTO 60
130 ON DEVICE GOTO 140,170,190,210
140 WIDTH "LPT1:",120
150 OPEN "LPT1:" FOR OUTPUT AS #1
160 GOTO 220
170 OPEN "SCRN:" FOR OUTPUT AS #1
180 GOTO 220
190 OPEN "A:FCR.DAT" FOR OUTPUT AS #1
200 GOTO 220
210 OPEN "C:FCR.DAT" FOR OUTPUT AS #1
220 CLS
230 DIM B$(4),CREV(50),FR(3),PROP(50),PCND(50),PCCD(50),REVC(50),RT(3),
    REPL(50)
240 DIM RBASE(50),TAXD(50,4),IY(50),TD(50),TC(50),ROC(50),TXCAP(50)
250 DIM U$(50)
260 PRINT #1,  CHR$(18)
270 PRINT TAB(20) "FIXED CHARGE RATE"
280 PRINT
290 GOSUB 3650            '****** SETS UP FORMAT STATEMENTS *******
300 REM ***********************************************************
310 REM ************* DEFAULT DATA *********************************
320 REM ***********************************************************
330 NLF=40
340 NYR=30
350 INF=.05
360 INR=.05
370 TAXR=.3664
380 RINV=4011.5
390 FFAC=.7997
400 RITC=0!
410 CM$ = "N"
420 FOR I=1 TO 3
430 READ RT(I)
440 NEXT I
450 DATA .097,.09,.14
460 FOR I=1 TO 3
470 READ FR(I)
480 NEXT I
490 DATA .5,.10,.40
500 PTR=.02
```

Fig. B.1. Fixed charge rate code listing.

```
510 RIR=.005
520 NM$="N"
530 NDP=2
540 YROP=2000
550 TREF=1987
560 POWR=1100
570 CAPF=.75
580 OT$="Y"
590 IF DEVICE=2 THEN OT$="N"
600 REM
610 TAXD(1,1)=.2
620 TAXD(2,1)=.32
630 TAXD(3,1)=.192
640 TAXD(4,1)=.1152
650 TAXD(5,1)=.1152
660 TAXD(6,1)=.0576
670 FOR I=7 TO 36
680 TAXD(I,1)=0
690 NEXT I
700 REM
710 TAXD(1,2)=.05
720 TAXD(2,2)=.095
730 TAXD(3,2)=.0855
740 TAXD(4,2)=.077
750 TAXD(5,2)=6.930001E-02
755 TAXD(6,2)=6.233001E-02
760 TAXD(16,2)=.02945
770 FOR I=7 TO 15
780 TAXD(I,2)=.05905
790 NEXT I
800 FOR I=17 TO 36
810 TAXD(I,2)=0
820 NEXT I
830 REM
840 TAXD(1,3)=.0375
850 TAXD(2,3)=.0722
860 TAXD(3,3)=.0668
870 TAXD(4,3)=.0618
880 TAXD(5,3)=.0571
890 TAXD(6,3)=.0528
900 TAXD(7,3)=.0489
910 TAXD(8,3)=.0452
920 FOR I=9 TO 20
930 TAXD(I,3)=.0446
940 NEXT I
950 TAXD(21,3)=.0225
960 FOR I=22 TO 36
970 TAXD(I,3)=0
980 NEXT I
990 REM ************************************************************
1000 REM *************** OPTIONS AND DATA MENU **********************
```

Fig. B.1. (continued)

```
1010 REM *************************************************************
1020 REM
1030 NUM=999
1040 CLS
1050 PRINT "     THE AVAILABLE MENU OPTIONS AND THEIR VALUES AT THIS TIME ARE:"
1060 PRINT
1070 PRINT "     0 - RUN CASE, DATA ENTRY COMPLETE"
1080 PRINT "     1 - PROJECT LIFE YEARS";NLF
1090 PRINT "         LEVELIZING PERIOD YEARS";NYR
1100 PRINT "     2 - INFLATION RATE (FRACTION)   ";INF
1110 PRINT "     3 - INTERIM REPLACEMENT ESCALATION RATE ";INR
1120 PRINT "     4 - EFFECTIVE INCOME TAX RATE";TAXR
1130 PRINT "     5 - INITIAL CAPITAL INVESTMENTAT STARTUP, MILLION $";RINV
1140 PRINT "     6 - TAX DEDUCTABLE FRACTION OF TOTAL CAPITAL INVESTMENT";FFAC
1150 REM:PRINT "     7 - INVESTMENT TAX CREDIT RATE";RITC
1160 PRINT "     8 - INTEREST RATE ON DEBT";RT(1)
1170 PRINT "         RETURN ON PREFERRED STOCK";RT(2)
1180 PRINT "         RETURN ON COMMON STOCK";RT(3)
1190 PRINT "     9 - DEBT FRACTION";FR(1)
1200 PRINT "         PREFERRED STOCK FRACTION";FR(2)
1210 PRINT "         COMMON STOCK FRACTION";FR(3)
1220 PRINT:INPUT"ENTER OPTION NUMBER OR A 'RETURN' TO SEE REST OF MENU";QA$
1230 IF QA$="" THEN GOTO 1250
1240 NUM=VAL(QA$):GOTO 1420
1250 PRINT "     10 - PROPERTY TAX RATE";PTR
1260 PRINT "     11 - INTERIM REPLACEMENT RATE";RIR
1270 PRINT "     12 - NORMALIZED/FLOW-THROUGH ACCOUNTING ";NM$
1280 PRINT "     13 - TAX DEPRECIATION SCHEDULE";NDP
1290 PRINT "     ";B$(NDP)
1300 PRINT "     14 - YEAR OF STARTUP";YROP
1310 PRINT "     15 - REFERENCE YEAR";TREF
1320 PRINT "     16 - POWER LEVEL,MWe";POWR
1330 PRINT "     17 - CAPACITY FACTOR";CAPF
1340 IF DEVICE = 2 GOTO 1380      ' ANNUAL REV. REQ. NOT AVAIL FOR SCREEN
1350 PRINT "     18 - PRINTOUT ANNUAL REVENUE REQUIREMENTS ";OT$
1360 IF OT$="N" OR OT$="n" THEN GOTO 1380
1370 PRINT "     19 - COMPRESSED PRINTOUT FOR REVENUE REQUIREMENTS ";CM$
1380 PRINT "     99 - EXIT PROGRAM"
1390 PRINT V$
1400 PRINT "     ENTER A NUMBER FROM THE MENU"
1410 INPUT NUM
1420 IF NUM=0 GOTO 2150
1430 IF NUM = 99 GOTO 4290
1440 IF DEVICE=2 AND NUM=18 THEN CLS:PRINT N18$:PRINT V$:GOTO 1050
1450 IF NUM<1 OR NUM>19 THEN CLS:PRINT D$ :GOTO 1040
1460 IF NUM>9 THEN GOTO 1480
1470 ON NUM GOTO 1500,1550,1580,1610,1640,1670,1700,1740,1810
1480 ON (NUM-9) GOTO 1870,1900,1930,1970,2020,2040,2060,2080,2100,2120
1490 GOTO 1040
1500 PRINT "     INPUT PROJECT LIFE (years)"
```

Fig. B.1. (continued)

```
1510 INPUT NLF
1520 PRINT "     INPUT LEVELIZING PERIOD (years)"
1530 INPUT NYR
1540 GOTO 1040
1550 PRINT "     INPUT INFLATION FACTOR        "
1560 INPUT INF
1570 GOTO 1040
1580 PRINT "     INPUT INTERIM REPLACEMENT ESCALATION FACTOR "
1590 INPUT INR
1600 GOTO 1040
1610 PRINT "     INPUT EFFECTIVE INCOME TAX RATE"
1620 INPUT TAXR
1630 GOTO 1040
1640 PRINT "     INPUT TOTAL CAPITAL INVESTMENT"
1650 INPUT RINV
1660 GOTO 1040
1670 PRINT "     INPUT DEDUCTABLE FRACTION OF TOTAL CAPITAL INVESTMENT"
1680 INPUT FFAC
1690 GOTO 1040
1700 PRINT "     INPUT INVESTMENT TAX CkEDIT RATE AS A DECIMAL FRACTION"
1710 PRINT "         INV. TAX CREDITS NOT APPLICABLE AFTER 1986"
1720 INPUT RITC
1730 GOTO 1040
1740 PRINT "     INPUT INTEREST RATE ON DEBT AS A DECIMAL FRACTION"
1750 INPUT RT(1)
1760 PRINT "     INPUT RETURN ON PREFERRED STOCK AS A DECIMAL FRACTION"
1770 INPUT RT(2)
1780 PRINT "     INPUT RETURN ON COMMON STOCK AS A DECIMAL FRACTION"
1790 INPUT RT(3)
1800 GOTO 1040
1810 PRINT "     INPUT DEBT FRACTION (decimal)"
1820 INPUT FR(1)
1830 PRINT "     INPUT PREFERRED STOCK FRACTION (decimal)"
1840 INPUT FR(2)
1850 FR(3)=1-FR(1)-FR(2)
1860 GOTO 1040
1870 PRINT "     INPUT PROPERTY TAX RATE AS A DECIMAL FRACTION"
1880 INPUT PTR
1890 GOTO 1040
1900 PRINT "     INPUT INTERIM REPLACEMENT RATE AS A DECIMAL FRACTION"
1910 INPUT RIR
1920 GOTO 1040
1930 PRINT "     INPUT N FOR NORMALIZED ACCOUNTING"
1940 PRINT "        OR F FOR FLOW-THROUGH ACCOUNTING"
1950 INPUT NM$
1960 GOTO 1040
1970 PRINT "           1 FOR 5-YEAR PROPERTY"
1980 PRINT "           2 FOR 15-YEAR PROPERTY"
1990 PRINT "           3 FOR 20-YEAR PROPERTY"
2000 INPUT NDP
```

Fig. B.1. (continued)

```
2010 GOTO 1040
2020 PRINT"INPUT YEAR OF STARTUP":INPUT YROP
2030 GOTO 1040
2040 PRINT"INPUT REFERENCE YEAR FOR COSTS":INPUT TREF
2050 GOTO 1040
2060 PRINT"PLANT POWER LEVEL, MWe":INPUT POWR
2070 GOTO 1040
2080 PRINT"PLANT CAPACITY FACTOR": INPUT CAPF
2090 GOTO 1040
2100 PRINT"PRINTOUT ANNUAL REVENUE REQUIREMENTS (Y=YES,N=NO)":INPUT OT$
2110 GOTO 1040
2120 PRINT"COMPRESSED PRINTOUT FOR REVENUE REQUIREMENTS (Y=YES,N=NO)"
2130 INPUT CM$
2140 GOTO 1040
2150 PRINT
2160 PRINT "     ENTER RUN IDENTIFICATION (OR NULL LINE)"
2170 INPUT R$
2180 REM ************************************************************
2190 REM ********* CALCULATION OF ANNUAL REVENUE REQUIREMENTS *******
2200 REM ************************************************************
2210 PRINT "Please wait about 10 seconds for output"
2220 F=1+INF
2230 FIR=1+INR
2240 PRINT #1, V$
2250 EQINT=FR(2)*RT(2)+FR(3)*RT(3)
2260 ACOM=FR(1)*RT(1)+EQINT
2270 PWF=1+(ACOM-TAXR*FR(1)*RT(1))
2280 DCAP=FFAC*RINV
2290 AL=YROP-TREF
2300 FINF=F^(-AL)
2310 POWF=1000!/(8.76*POWR*CAPF)
2320 POWC=POWF*FINF
2330 ECOM=(PWF-1)*100
2340 PWC=1+(PWF-F)/F
2350 ECON=(PWC-1)*100
2360 BLF=NLF
2370 BYR=NYR
2380 XITC=DCAP*RITC
2390 DSL=DCAP/BLF
2400 DB=RINV/BLF
2410 PX=0
2420 PC=0
2430 IF NM$ = "F" GOTO 2450
2440 AITC=XITC/BLF
2450 XREPL=RIR*RINV
2460 XPROP=PTR*RINV
2470 FOR I=1 TO NYR
2480 TXCAP(I)=DCAP*TAXD(I,NDP)
2490 IF I=1 GOTO 2510
2500 GOTO 2640
```

Fig. B.1. (continued)

```
2510 REM  YEAR1
2520 IY(1)=YROP
2530 IF NM$="N" GOTO 2590
2540 REM  FLOW-THROUGH
2550 RBASE(I)=RINV
2560 TD(I)=0!
2570 TC(I)=TAXR*(DB-TXCAP(I)+EQINT*RBASE(I))/(1-TAXR)-XITC/(1-TAXR)
2580 GOTO 2630
2590 REM  NORMALIZED
2600 TD(I)=TAXR*(TXCAP(I)-DSL)
2610 RBASE(I)=RINV-XITC
2620 TC(I)=TAXR*(DB-TXCAP(I)+EQINT*RBASE(I)+TD(I))/(1-TAXR)
2630 GOTO 2750
2640 REM  FOR POST STARTUP YEARS
2650 IY(I)=IY(I-1)+1
2660 IF NM$="N" GOTO 2710
2670 REM FLOWTHROUGH
2680 RBASE(I)=RBASE(I-1)-DB
2690 TC(I)=TAXR*(DB-TXCAP(I)+EQINT*RBASE(I))/(1-TAXR)
2700 GOTO 2750
2710 REM NORMALIZED
2720 RBASE(I)=RBASE(I-1)-(DB+TD(I-1))+AITC
2730 TD(I)=TAXR*(TXCAP(I)-DSL)
2740 TC(I)=TAXR*(DB-TXCAP(I)+EQINT*RBASE(I)+TD(I))/(1-TAXR)
2750 ROC(I)=ACOM*RBASE(I)
2760 REPL(I)=XREPL*FIR^I
2770 PROP(I)=XPROP
2780 CREV(I)=ROC(I)+DB+TD(I)+TC(I)+REPL(I)+PROP(I)
2790 REVC(I)=CREV(I)*F^(-I)
2800 DISC=PWF^(-I)
2810 PX=CREV(I)*PWF^(-I)+PX
2820 DICC=PWC^(-I)
2830 PC=PC+REVC(I)*DICC
2840 PCND(I) = .1*POWF*CREV(I)
2850 PCCD(I) = .1*POWC*REVC(I)
2860 REVC(I)=REVC(I)*FINF
2870 NEXT I
2880 CRF=(PWF-1)/(1-DISC)
2890 FCR=PX*CRF/RINV
2900 CRC= (PWC-1)/(1-DICC)
2910 CCRR=PC*CRC/RINV
2920 PCNDL=.1*FCR*RINV*POWF
2930 PCCDL=.1*CCRR*RINV*POWC
2940 REM ************************************************************
2950 REM **************** PRINT CASE OUTPUT *************************
2960 REM ************************************************************
2970 CLS
2980 PRINT #1,V$
2990 PRINT #1, "      F I X E D   C H A R G E   R A T E"
3000 PRINT #1, V$
```

Fig. B.1. (continued)

```
3010 PRINT #1, "                VERSION  08-01-1988"
3020 PRINT #1, USING U$(1);DATE$
3030 PRINT #1, V$
3040 PRINT #1, V$; R$
3050 PRINT #1, V$
3060 PRINT #1, V$;"INPUT DATA"
3070 PRINT #1, V$;"__________"
3080 PRINT #1, V$
3090 PRINT #1, USING U$(2); NLF
3100 PRINT #1, USING U$(3); NYR
3110 PRINT #1, USING U$(4);INF
3120 PRINT #1, USING U$(5);INR
3130 PRINT #1, USING U$(6); TAXR
3140 PRINT #1, USING U$(7); RINV
3150 PRINT #1, USING U$(8); FFAC
3160 REM PRINT #1, USING U$(18); RITC       INV. CREDIT NOT AVAILABLE
3170 IF DEVICE = 2 THEN GOSUB 4200
3180 PRINT #1, USING U$(19); RT(1)
3190 PRINT #1, USING U$(20); RT(2)
3200 PRINT #1, USING U$(21); RT(3)
3210 PRINT #1, USING U$(22); FR(1)
3220 PRINT #1, USING U$(23); FR(2)
3230 PRINT #1, USING U$(24); FR(3)
3240 PRINT #1, USING U$(25); PTR
3250 PRINT #1, USING U$(26); RIR
3260 PRINT #1, USING U$(30); YROP
3270 PRINT #1, USING U$(31); TREF
3280 PRINT #1, USING U$(32); POWR
3290 PRINT #1, USING U$(33); CAPF
3300 IF NM$="N" OR NM$="n" GOTO 3320
3310 IF NM$="F" OR NM$="f" GOTO 3340
3320 PRINT #1, V$;"NORMALIZED ACCOUNTING"
3330 GOTO 3350
3340 PRINT #1, V$;"FLOW-THROUGH ACCOUNTING"
3350 PRINT #1, V$
3360 PRINT #1, V$;"ACRS CLASS: ";B$(NDP)
3370 IF DEVICE = 2 THEN GOSUB 4200
3380 IF OT$ = "N" OR OT$="n" GOTO 3520
3390 IF CM$ = "Y" OR CM$="y" THEN PRINT #1,  CHR$(15)
3400 PRINT #1,  CHR$(12)
3410 PRINT #1, V$;T$
3420 PRINT #1, V$
3430 PRINT #1, TAB(70);M$
3440 PRINT #1, E$;S$;J$;
3450 PRINT #1, F$;S$;USING H$;TREF;TREF;
3460 PRINT #1, L$;S$;K$
3470 IF OT$="Y" OR OT$="y" GOTO 3490
3480 GOTO 3520
3490 FOR I=1 TO NYR
3500 PRINT #1, USING C$;V$;IY(I);RBASE(I);ROC(I);DB;TXCAP(I);TC(I);TD(I);
     PROP(I);REPL(I);CREV(I);REVC(I);PCND(I);PCCD(I)
```

Fig. B.1. (continued)

```
3510 NEXT I
3520 PRINT #1, V$
3530 PRINT #1, USING U$(27); PX
3540 IF OT$="Y" OR OT$="y" THEN PRINT #1,  CHR$(18)
3550 PRINT #1, V$
3560 PRINT #1, V$
3570 PRINT #1, V$;"                           FIXED CHARGE RATE      LEVELIZED POWER
COST"
3580 PRINT #1, V$;"                           (FRACTION)             (Cents/KWHe)
3590 PRINT #1, V$
3600 PRINT #1, USING U$(28);FCR;PCNDL
3610 PRINT #1, USING U$(29);TREF;CCRR;PCCDL
3620 IF DEVICE = 2 THEN GOSUB 4200
3630 PRINT #1,  CHR$(12)
3640 GOTO 1040
3650 REM ************************************************************
3660 REM ************* FORMAT STATEMENTS ****************************
3670 REM ************************************************************
3680 V$="    "
3690 S$="  "
3700 E$="            RATE   RETURN  BOOK   TAX    I TAX   I TAX  PROP   INTRM "
3710 F$="     YEAR   BASE   ON CAP  DEPR   DEPR   CURR    DEFER  TAX    REPL "
3720 L$="     ----  ------  ------  -----  -----  ------  -----  -----  -----"
3730 C$="&####.  ####.#  ####.#  ###.#  ###.#  ###.#  ####.#  ###.# ###.#  ####.#
  ###.#   ##.##   ##.##"
3740 G$= "REVENUE REQUIR.  (Cents/KWHe)"
3750 J$= "(MILLION $)      (Cents/KWHe)"
3760 H$= "NOMNL $  ####. $  NOMNL $  ####. $"
3770 D$ = " BAD INPUT -- TRY AGAIN "
3780 K$= "-------  ------  -------  ------"
3790 W$= "###.#     ###.#      ##.##     ##.##"
3800 T$= "    ANNUAL REVENUE REQUIREMENTS (MILLION DOLLARS)"
3810 M$= " REVENUE REQUIR.    POWER COST"
3820 N18$= " Year-by-year output is not available for screen display"
3830 B$(1)="     5-YEAR PROPERTY"
3840 B$(2)="     15-YEAR PROPERTY"
3850 B$(3)="     20-YEAR PUBLIC UTILITY PROPERTY"
3860 U$(1)="              RUN DATE &"
3870 U$(2)="     PROJECT LIFE (years)                                    ##."
3880 U$(3)="     LEVELIZING PERIOD (years)                               ##."
3890 U$(4)="     INFLATION RATE                                         #.##"
3900 U$(5)="     INTERIM REPLACEMENT ESCALATION RATE                    #.##"
3910 U$(6)="     EFFECTIVE INCOME TAX RATE                             .####"
3920 U$(7)="     INITIAL CAPITAL INVESTMENT AT STARTUP, MILLION $  #####."
3930 U$(8)="     TAX DEDUCTABLE FRACTION OF TOTAL CAPITAL INVEST.  .####"
3940 U$(9)="     INVESTMENT TAX CREDIT RATE                              .##"
3950 U$(10)="     INTEREST RATE ON DEBT                                .####"
3960 U$(11)="     RETURN ON PREFERRED STOCK                            .####"
3970 U$(12)="     RETURN ON COMMON STOCK                               .####"
3980 U$(13)="     DEBT FRACTION                                        .####"
3990 U$(14)="     PREFERRED STOCK FRACTION                             .####"
4000 U$(15)="     COMMON STOCK FRACTION                                .####"
```

Fig. B.1. (continued)

```
4010 U$(16)="      PROPERTY TAX RATE                                                .##"
4020 U$(17)="      INTERIM REPLACEMENT RATE                                         .##"
4030 U$(18)="      INVESTMENT TAX CREDIT RATE                                      #.##"
4040 U$(19)="      INTEREST RATE ON DEBT                                          .####"
4050 U$(20)="      RETURN ON PREFERRED STOCK                                      .####"
4060 U$(21)="      RETURN ON COMMON STOCK                                         .####"
4070 U$(22)="      DEBT FRACTION                                                  .####"
4080 U$(23)="      PREFERRED STOCK FRACTION                                       .####"
4090 U$(24)="      COMMON STOCK FRACTION                                          .####"
4100 U$(25)="      PROPERTY TAX RATE                                               #.##"
4110 U$(26)="      INTERIM REPLACEMENT RATE                                       #.###"
4120 U$(27)="            SUM OF PRESENT WORTH OF REVENUE REQUIREMENTS AT STARTUP =
#####."
4130 U$(28)="           NOMINAL DOLLARS  =      .####                    ##.##"
4140 U$(29)="           #### DOLLARS     =      .####                    ##.## "
4150 U$(30)="      START OF OPERATION(YEAR)                              ####.##"
4160 U$(31)="      REFERENCE YEAR FOR COST DATA                          ####.##"
4170 U$(32)="      REACTOR POWER LEVEL, MWe                                 ####."
4180 U$(33)="      LIFETIME AVERAGE CAPACITY FACTOR                         #.##"
4190 RETURN
4200  ' pause for screen output
4210 PRINT, V$
4220 PRINT "press any key to continue"
4230 QQ$=INKEY$
4240 IF QQ$="" THEN 4230
4250 CLS
4260 PRINT,V$
4270 PRINT,V$
4280 RETURN
4290 END
```

Fig. B.1. (continued)

F I X E D   C H A R G E   R A T E

VERSION 08-01-1988
RUN DATE 08-02-1988

Fixed Charge Rate for PWR/BE Nuclear Plant

INPUT DATA

PROJECT LIFE (years)	40
LEVELIZING PERIOD (years)	30
INFLATION RATE	0.05
INTERIM REPLACEMENT ESCALATION RATE	0.05
EFFECTIVE INCOME TAX RATE	.3664
INITIAL CAPITAL INVESTMENT AT STARTUP, MILLION $	4012
TAX DEDUCTABLE FRACTION OF TOTAL CAPITAL INVEST.	.7997
INTEREST RATE ON DEBT	.0970
RETURN ON PREFERRED STOCK	.0900
RETURN ON COMMON STOCK	.1400
DEBT FRACTION	.5000
PREFERRED STOCK FRACTION	.1000
COMMON STOCK FRACTION	.4000
PROPERTY TAX RATE	0.02
INTERIM REPLACEMENT RATE	0.005
START OF OPERATION(YEAR)	2000.00
REFERENCE YEAR FOR COST DATA	1987.00
REACTOR POWER LEVEL, MWe	1100
LIFETIME AVERAGE CAPACITY FACTOR	0.75
NORMALIZED ACCOUNTING	

ACRS CLASS: 15-YEAR PROPERTY

Fig. B.2. Fixed charge rate code output.

ANNUAL REVENUE REQUIREMENTS (MILLION DOLLARS)

YEAR	RATE BASE	RETURN ON CAP	BOOK DEPR	TAX DEPR	I TAX CURR	I TAX DEFER	PROP TAX	INTRM REPL	REVENUE REQUIR. (MILLION $) NOMNL $	REVENUE REQUIR. (MILLION $) 1987 $	POWER COST (Cents/KWHe) NOMNL $	POWER COST (Cents/KWHe) 1987 $
2000	4011.5	455.3	100.3	160.4	133.0	29.4	80.2	21.1	819.3	413.8	11.34	5.73
2001	3881.8	440.6	100.3	304.8	75.2	82.3	80.2	22.1	800.7	385.2	11.08	5.33
2002	3699.3	419.9	100.3	274.3	79.6	71.1	80.2	23.2	774.3	354.7	10.71	4.91
2003	3527.9	400.4	100.3	247.0	83.1	61.1	80.2	24.4	749.5	327.0	10.37	4.52
2004	3366.5	382.1	100.3	222.3	86.1	52.1	80.2	25.6	726.4	301.8	10.05	4.18
2005	3214.1	364.8	100.3	200.0	88.6	43.9	80.2	26.9	704.6	278.8	9.75	3.86
2006	3069.9	348.4	100.3	189.4	87.0	40.0	80.2	28.2	684.2	257.9	9.47	3.57
2007	2929.6	332.5	100.3	189.4	81.7	40.0	80.2	29.6	664.4	238.5	9.19	3.30
2008	2789.3	316.6	100.3	189.4	76.4	40.0	80.2	31.1	644.7	220.4	8.92	3.05
2009	2649.0	300.7	100.3	189.4	71.2	40.0	80.2	32.7	625.0	203.5	8.65	2.82
2010	2508.7	284.7	100.3	189.4	65.9	40.0	80.2	34.3	605.5	187.7	8.38	2.60
2011	2368.4	268.8	100.3	189.4	60.6	40.0	80.2	36.0	586.0	173.0	8.11	2.39
2012	2228.1	252.9	100.3	189.4	55.3	40.0	80.2	37.8	566.6	159.3	7.84	2.20
2013	2087.8	237.0	100.3	189.4	50.1	40.0	80.2	39.7	547.3	146.6	7.57	2.03
2014	1947.4	221.0	100.3	189.4	44.8	40.0	80.2	41.7	528.1	134.7	7.31	1.86
2015	1807.1	205.1	100.3	94.5	74.3	5.2	80.2	43.8	509.0	123.6	7.04	1.71
2016	1701.6	193.1	100.3	0.0	105.0	-29.4	80.2	46.0	495.2	114.6	6.85	1.59
2017	1630.7	185.1	100.3	0.0	102.3	-29.4	80.2	48.3	486.8	107.3	6.74	1.48
2018	1559.8	177.0	100.3	0.0	99.6	-29.4	80.2	50.7	478.5	100.4	6.62	1.39
2019	1488.9	169.0	100.3	0.0	97.0	-29.4	80.2	53.2	470.3	94.0	6.51	1.30
2020	1418.0	160.9	100.3	0.0	94.3	-29.4	80.2	55.9	462.3	88.0	6.40	1.22
2021	1347.1	152.9	100.3	0.0	91.6	-29.4	80.2	58.7	454.3	82.4	6.29	1.14
2022	1276.2	144.8	100.3	0.0	89.0	-29.4	80.2	61.6	446.6	77.1	6.18	1.07
2023	1205.3	136.8	100.3	0.0	86.3	-29.4	80.2	64.7	438.9	72.2	6.07	1.00
2024	1134.4	128.8	100.3	0.0	83.6	-29.4	80.2	67.9	431.5	67.6	5.97	0.93
2025	1063.5	120.7	100.3	0.0	81.0	-29.4	80.2	71.3	424.1	63.3	5.87	0.88
2026	992.6	112.7	100.3	0.0	78.3	-29.4	80.2	74.9	417.0	59.2	5.77	0.82
2027	921.7	104.6	100.3	0.0	75.6	-29.4	80.2	78.6	410.0	55.5	5.67	0.77
2028	850.8	96.6	100.3	0.0	73.0	-29.4	80.2	82.6	403.2	52.0	5.58	0.72
2029	779.9	88.5	100.3	0.0	70.3	-29.4	80.2	86.7	396.7	48.7	5.49	0.67

SUM OF PRESENT WORTH OF REVENUE REQUIREMENTS AT STARTUP = 6393

	FIXED CHARGE RATE (FRACTION)	LEVELIZED POWER COST (Cents/KWHe)
NOMINAL DOLLARS =	.1631	9.05
1987 DOLLARS =	.0962	2.83

Fig. B.2. (continued)

Table B.1. Levelized fixed charge rate breakdown (%/year)

	Coal	Nuclear
Return[a] (average cost of money)	11.35	11.35
Sinking fund depreciation	0.35	0.35
Income tax[b]	1.98	1.77
Property tax	2.00	2.00
Interim replacement[c]	0.81	0.81
Total	16.5 (0.0974)[d]	16.3 (0.0962)[d]

[a]Capitalization 50% debt at 9.7%/year; 10% preferred at 9%/year; 40% equity at 14%/year.

[b]Computed using provisions of the Tax Reform Act of 1986 with 15-year tax life for nuclear plants and 20 years for coal-fired plants.

[c]Levelized; payments escalate at 5%/year.

[d]Constant dollar rate.

The income tax component was computed by taking the difference between the FCR calculated with taxes and the sum of the cost components calculated with a zero tax rate. For the reference capital investment costs shown on Table 2.9, the "f" factor is 0.7997 for nuclear and 0.8559 for coal-fired plants.

The nominal dollar FCRs for the coal-fired and nuclear plants were estimated to be ~16.5% and 16.3% using normalized tax accounting. The constant dollar FCRs were 9.74% for coal-fired plants and 9.62% for nuclear plants.

Appendix A

ACRONYMS, NOMENCLATURE, AND DEFINITION OF TERMS

Acronyms and Nomenclature

ACRS	accelerated capital recovery system
AE	architect-engineer
AFUDC	allowance for funds used during construction
APWR	Advanced pressurized water reactor
AVLIS	Atomic Vapor Laser Isotope Separation
A&G	Administrative and General
BE	better (or best) experience
BWR	Boiling Water Reactor
CP	construction permit
DB	declining balances
DEF	differential escalation factor
DOE	Department of Energy
EEDB	Energy Economic Data Base
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
FCF	Fuel Cycle Facility [as used in the NECDB, FCF means an on-site, integral (with reactor) fabrication and reprocessing facility]
FCR	fixed charge rate
FERC	Federal Energy Regulatory Commission
FGD	flue gas desulfurization
GDP	Gaseous Diffusion Plant
GNP	Gross National Product

HM	heavy metal
H-W	Handy-Whitman
IPWR	Improved pressurized water reactor
LEU	low-enriched uranium
LMR	liquid metal reactor
LSPB	Large Scale Prototype Breeder
LWR	light-water reactor
MACRS	modified accelerated capital recovery system
ME	median experience
MOX	mixed uranium and plutonium oxide
NASAP	Nonproliferation Alternative Systems Assessment Program
NECDB	Nuclear Energy Cost Data Base
NSSS	Nuclear Steam Supply System
ORNL	Oak Ridge National Laboratory
O&M	operation and maintenance
PNL	Pacific Northwest Laboratories
PWP	present worth of power production
PWR	pressurized-water reactor
PWRR	sum of the present worth of the revenue requirements
SAFAR	Safeguarded Fabrication and Reprocessing Plant
SWU	separative work unit
US	Utility Services (enrichment contract)
TVA	Tennessee Valley Authority

Definition of Terms

ACAP	annualized cost of capital
a	price escalation rate
B	fraction of capitalization from debt
B_m	interest paid on debt in year m
b	interest rate on debt
C_o	cost in a reference year or overnight capital investment cost
C_m	cost, m years after a reference year or common stock dividends paid in year m
CF	cash flow
CRF(d,N)	capital recovery factor for an interest rate d and N equal time periods
$(DC)_o$	decommissioning cost in reference year dollars
D_n^B	book depreciation for year n after startup
D_n^{SL}	Tax depreciation during year n computed using straight-line depreciation
D_n^T	tax deductible depreciation during year n after startup
$\overline{d}$	current dollar levelized tax depreciation factor
d_n^T	tax depreciation deduction in year n as a fraction of applicable investment
E	fraction of capital from equity
e	rate of return on equity investment
F	fraction of capital from preferred stock
f	fraction of capital investment which is depreciable for tax purposes
F_{cp}	fraction of overnight cost expended through construction permit date
F_o	fuel cost computed for a reference year

F_n	payments for fuel during period n
f_r	fraction of fuel cycle facility devoted to reprocessing
g	overall rate of price change, including inflation
h_j	fraction of overnight cost expended at time j
I	total capitalized investment cost at start of operation in nominal dollars
I_m	investment in year m
I_o	total capitalized investment at start of operation in constant dollars
$I_{B,j}$	total capitalized investment of type j in a nuclear fuel batch, B
i	general inflation rate, measured by GNP Implicit Price Deflator
L	period between reference cost year and year of commercial operation
Ld	lead or lag time for payment, years
M	economic study period, years
N	life of project, years
O	operating costs or other expensed items which may include O&M costs, fuel, interim replacement, property taxes, and decommissioning fund
O_m	operating costs which are expensed for tax purposes during year m
O_R	annual operating cost for reprocessing
OM	annual operation and maintenance cost
P_m	preferred stock dividends paid in year m
P_n	price in year n after startup in nominal dollars
$P_{o,n}$	price in year n after startup in constant dollars
P_{pu}	plutonium price
$\overline{P}$	nominal dollar levelized cost

$\overline{P}_o$	constant dollar levelized cost
p	interest rate on preferred stock
R_n	revenue or revenue requirements in year n
$R_{o,n}$	revenue or revenue requirements in constant dollars in year n
$RS_{B,j}$	revenue received from sale of excess fissile material
r	real cost escalation rate (differential rate over and above inflation)
S_B	total energy produced by a fuel batch
S_n	number of units (kWh) sold in year n
$S_{\ell,B}$	energy produced by a fuel batch in year ℓ following batch loading
S_A	equivalent constant annual number of units sold over life of facility
SFF(d,N)	sinking fund factor for d interest rate and N years
T	income taxes
T_c	current income taxes
T_d	deferred income taxes
T_m	taxes paid during year m
TDR	tax depreciation rate
t	effective tax rate
t_B	time, relative to reactor startup that fuel batch is loaded into core
t_c	reference time for cost data
t_j	time when construction money is spent
t_{op}	power plant operation date
V_n	rate base term in revenue requirements calculation
X	effective cost of money
X_o	effective constant dollar cost of money

X_1 direct weighted average cost of money

X_2 effective cost of money

X_{SF} interest rate for decommissioning sinking fund, assumed equal to rate on high grade state and local bonds

π an operating cost (such as property taxes) which can be related directly to initial capital investment, also Pi (3.1416)

Subscripts

B refers to a fuel batch

c refers to capital investment cost, or current as in current taxes

d refers to deferred as in deferred taxes, or to decommissioning costs

DC refers to decommissioning cost

F refers to fuel cost, or fabrication operation

f refers to federal income taxes

j index, signifying period of time or type of fuel purchase

k index for miscellaneous cost items included in fixed charge rate

ℓ index relative to fuel load

m index, equal to number of years since reference year

n index, year relative to year of commercial operation

o refers to initial or reference year or designates constant dollars

OM refers to operation and maintenance cost

R refers to reprocessing operation

s refers to state income taxes

SF refers to a sinking fund

T total, or tax

ATTACHMENT 4

NUCLEAR PLANT FCR FOR UTILITY PARAMETERS
FIXED CHARGE RATE COMPUTATION
PER NECDB PUBLISHED SEPTEMBER 1988
PROJECT AND FINANCIAL INPUT PARAMETERS

IDC YRS =	3.26
TOC =	780
IDC =	220
TCC =	1000

	BOOK LIFE, YRS	30
	LEVELIZATION PERIOD, YRS	30
	CONSTANT $ REF YEAR	2002
	COMM OPERATION YEAR	2040
TCC =	TOTAL CAPITAL COST, NOM M$	1000.00
IDC =	AFUDC, NOM M$	219.54
	TAX DEPRE PORTION, NOM M$	877.72
	TOTAL CAPITAL COST, CONST M$	225.29
	ANNUAL INFLATION RATE	4.00%
	FEDERAL INCOME TAX RATE	34.00%
	STATE INCOME TAX RATE	4.00%
	EFFECTIVE INCOME TAX RATE	36.64%
	ANNUAL PROPERTY TAX RATE	2.00%
	ANNUAL REPLACEMENT RATE	0.50%

CAPITALIZATION	
DEBT	50.0%
PREFERRED STOCK	10.0%
COMMON EQUITY	40.0%
RETURN ON CAPITALIZATION	
DEBT INTEREST	7.0%
PREFERRED DIVIDEND	8.0%
COMMON EQUITY RETURN	9.0%
AVG COST OF MONEY	7.90%
REAL AVG COST OF MONEY	3.75%
TAX-ADJUSTED COST OF MONEY	6.62%
REAL COST OF MONEY	2.52%

TAX DEPRECIATION SCH

OPER YR	DEPR %
1	5.000%
2	9.500%
3	8.550%
4	7.700%
5	6.930%
6	6.230%
7	5.905%
8	5.905%
9	5.905%
10	5.905%
11	5.905%
12	5.905%
13	5.905%
14	5.905%
15	5.905%
16	2.945%
	100.000%

YEARLY REVENUE STREAMS

YEAR	RATE BASE	RETURN ON CAP	BOOK DEPR	TAX DEPR	I TAX DEFER	I TAX CURR	PROP TAX	INTRM REPL	REVENUE REQ'MTS (MILLION $) NOM $	2002	CASHFLOW NOM M$	RETURN ON INVESTMT
											-1000	
2040	1000.0	79.0	33.3	43.9	5.4	22.4	20.0	5.2	165.3	35.8	117.7	#NUM!
2041	961.3	75.9	33.3	83.4	19.8	7.0	20.0	5.4	161.5	33.6	129.1	#NUM!
2042	908.1	71.7	33.3	75.0	16.8	8.7	20.0	5.6	156.2	31.3	121.9	#NUM!
2043	858.0	67.8	33.3	67.6	14.0	10.1	20.0	5.8	151.2	29.1	115.2	-23.97%
2044	810.7	64.0	33.3	60.8	11.6	11.4	20.0	6.1	146.4	27.1	108.9	-15.48%
2045	765.8	60.5	33.3	54.7	9.3	12.5	20.0	6.3	142.0	25.3	103.1	-9.72%
2046	723.1	57.1	33.3	51.8	8.3	12.5	20.0	6.6	137.8	23.6	98.7	-5.64%
2047	681.5	53.8	33.3	51.8	8.3	11.4	20.0	6.8	133.7	22.0	95.4	-2.64%
2048	639.9	50.6	33.3	51.8	8.3	10.4	20.0	7.1	129.6	20.5	92.2	-0.38%
2049	598.3	47.3	33.3	51.8	8.3	9.3	20.0	7.4	125.6	19.1	88.9	1.35%
2050	556.7	44.0	33.3	51.8	8.3	8.3	20.0	7.7	121.5	17.8	85.6	2.70%
2051	515.1	40.7	33.3	51.8	8.3	7.2	20.0	8.0	117.5	16.5	82.3	3.75%
2052	473.5	37.4	33.3	51.8	8.3	6.1	20.0	8.3	113.5	15.4	79.0	4.60%
2053	431.9	34.1	33.3	51.8	8.3	5.1	20.0	8.7	109.5	14.2	75.7	5.28%
2054	390.3	30.8	33.3	51.8	8.3	4.0	20.0	9.0	105.5	13.2	72.4	5.83%
2055	348.7	27.5	33.3	25.8	-1.2	12.5	20.0	9.4	101.5	12.2	59.6	6.22%
2056	316.6	25.0	33.3	0.0	-10.7	21.1	20.0	9.7	98.5	11.4	47.6	6.49%
2057	294.0	23.2	33.3	0.0	-10.7	20.6	20.0	10.1	96.5	10.7	45.8	6.73%
2058	271.4	21.4	33.3	0.0	-10.7	20.0	20.0	10.5	94.6	10.1	44.1	6.93%
2059	248.7	19.7	33.3	0.0	-10.7	19.4	20.0	11.0	92.6	9.5	42.3	7.10%
2060	226.1	17.9	33.3	0.0	-10.7	18.8	20.0	11.4	90.7	9.0	40.5	7.24%
2061	203.5	16.1	33.3	0.0	-10.7	18.3	20.0	11.8	88.8	8.4	38.7	7.37%
2062	180.9	14.3	33.3	0.0	-10.7	17.7	20.0	12.3	86.9	7.9	36.9	7.48%
2063	158.3	12.5	33.3	0.0	-10.7	17.1	20.0	12.8	85.0	7.5	35.1	7.57%
2064	135.7	10.7	33.3	0.0	-10.7	16.5	20.0	13.3	83.2	7.0	33.3	7.65%
2065	113.1	8.9	33.3	0.0	-10.7	16.0	20.0	13.9	81.4	6.6	31.5	7.72%
2066	90.5	7.1	33.3	0.0	-10.7	15.4	20.0	14.4	79.6	6.2	29.8	7.77%
2067	67.8	5.4	33.3	0.0	-10.7	14.8	20.0	15.0	77.8	5.8	28.0	7.82%
2068	45.2	3.6	33.3	0.0	-10.7	14.2	20.0	15.6	76.0	5.5	26.2	7.86%
2069	22.6	1.8	33.3	0.0	-10.7	13.7	20.0	16.2	74.3	5.2	24.4	7.90%
			1000.0	877.7	0.0	402.4						

	NOM $
PV SUM @ STARTUP, M$	1620.9
CAPITAL RECOVERY FACTOR	0.0775
FIXED CHARGE RATE	12.56%

ATTACHMENT 5

Case 1 — Baseline (@25% reject rate)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Calculated Parameters for Foam Target Production

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4 = the fill volume of each contactor (in liters)

975 = the total volume required for each tank (in liters)
1219.076 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.92 = height of tank, M
0.73 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

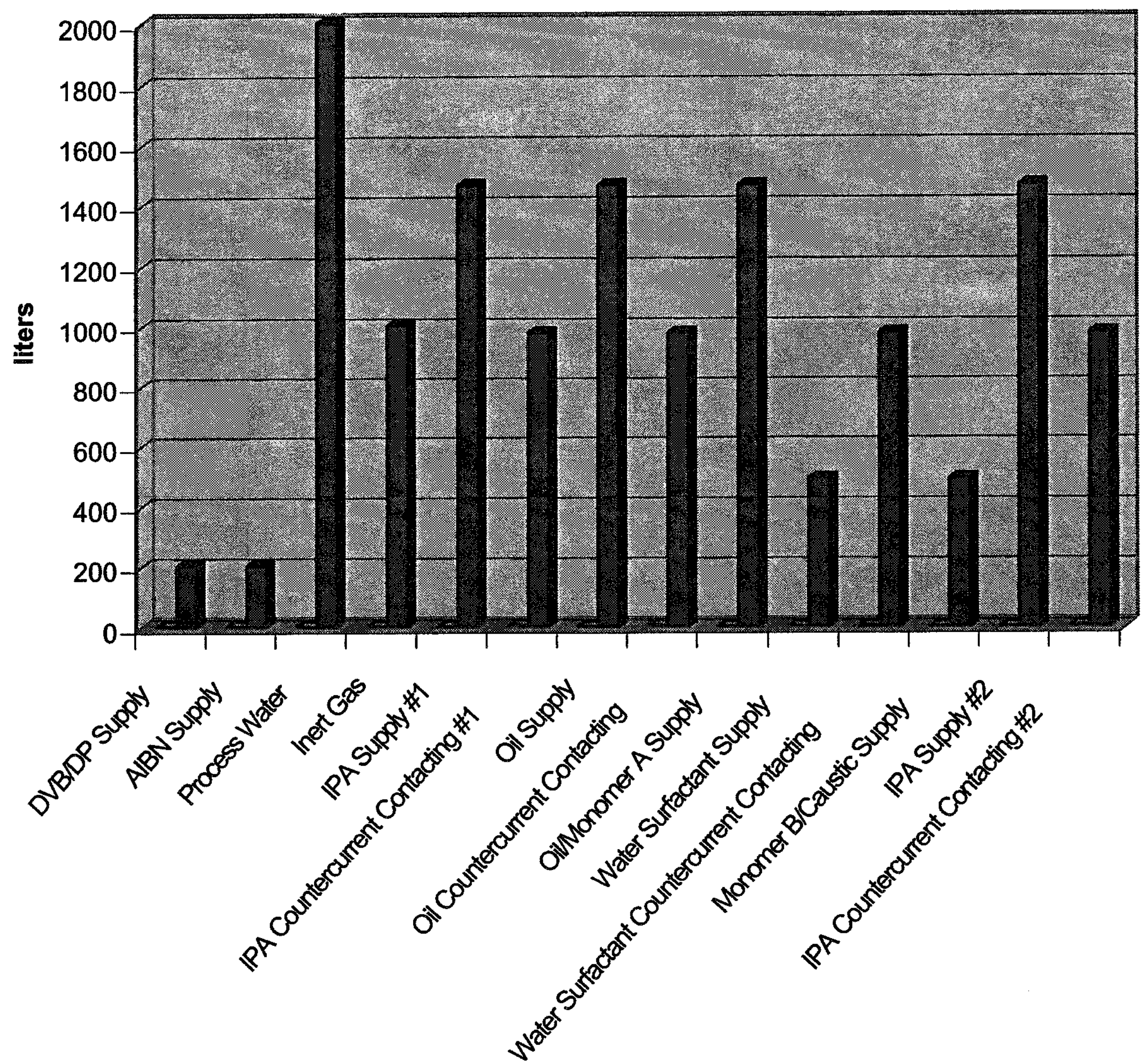
1.5 weeks storage in supply tank
1463 liters in storage tank

Tank Calculations for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1463	
IPA Countercurrent Contacting #1	5	975	
Oil Supply	1	1463	
Oil Countercurrent Contacting	5	975	
Oil/Monomer A Supply	1	1463	
Water Surfactant Supply	1	488	
Water Surfactant Countercurrent Contacting	2	975	
Monomer B/Caustic Supply	1	488	
IPA Supply #2	1	1463	
IPA Countercurrent Contacting #2	5	975	

Total Tanks 27

Tank Inventory for Foam Target Production



Tank Calculations for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1
Liquids	Divinyl Benzene	36.17											
	Dibutyl Phthalate	361.73				361.73		362	362				
	Water			605.79	4837.60	5443.39		5443	5443				
	AIBN		3.62										
	Polyvinyl Alcohol				48.38	48.38		48	48				
	Polymerized DVB					39.79		40	40				
	Isopropyl Alcohol (IPA)									5225			
	Parachlorotoluene											5225	
	Spent Solvent #1												
	Isophthaloyl dichloride												
	Poly 4-Vinyl Phenol												
	NaOH												
	Mixed liquid waste										5225		5225
	CO_2												
	Au or Pd												
Gases	N_2						93.80						
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6

	Stream Number:	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene									30		
	Dibutyl Phthalate											
	Water			5225		5216						
	AIBN											
	Polyvinyl Alcohol											
	Polymerized DVB											
	Isopropyl Alcohol (IPA)							5225		502		
	Parachlorotoluene	4389										
	Spent Solvent #1											
	Isophthaloyl dichloride	836										
	Poly 4-Vinyl Phenol					77						
	NaOH					3						
	Mixed liquid waste		5225		5225		5295		5225			
	CO_2										7028	
	Au or Pd											0.52
Gases	N_2											
Total, g/hr		5224.6	5224.6	5224.6	5224.6	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Tank Calculations for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)

	2006	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,381,691**				**$ 24,383,394**

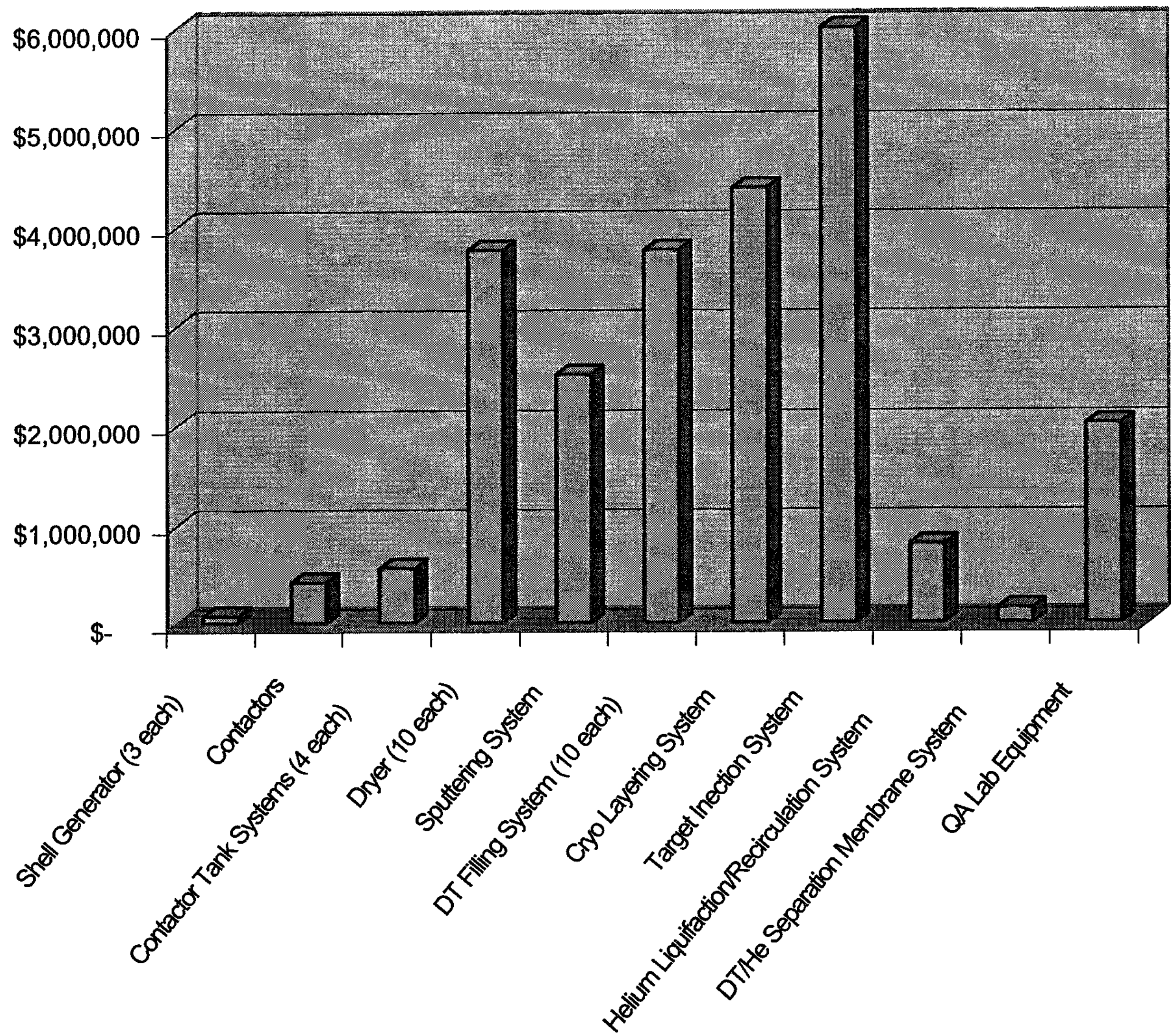
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,509,524
Electrical	$ 4,145,177
Instruments	$ 3,169,841
Building and services	$ 7,315,018
Site Preparation	$ 2,682,173
Auxiliaries	$ 13,410,867
Field Expenses	$ 10,484,859
Engineering	$ 8,290,354
Contractors fees	$ 4,145,177
Contingency	$ 9,509,524

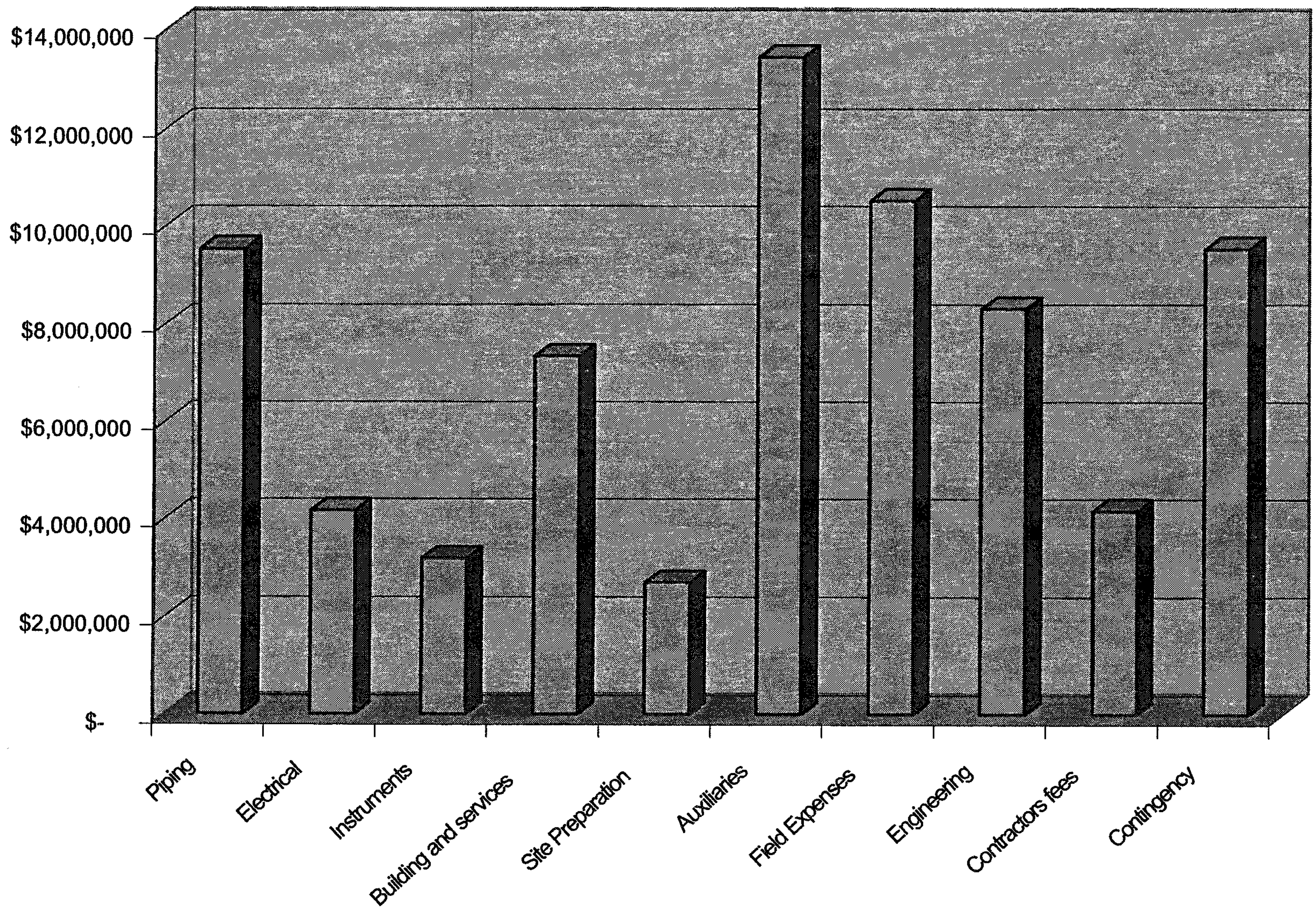
Total Installed Capital Cost **$ 97,044,204**

Annualized Cost of Capital Investment **$ 12,130,526**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



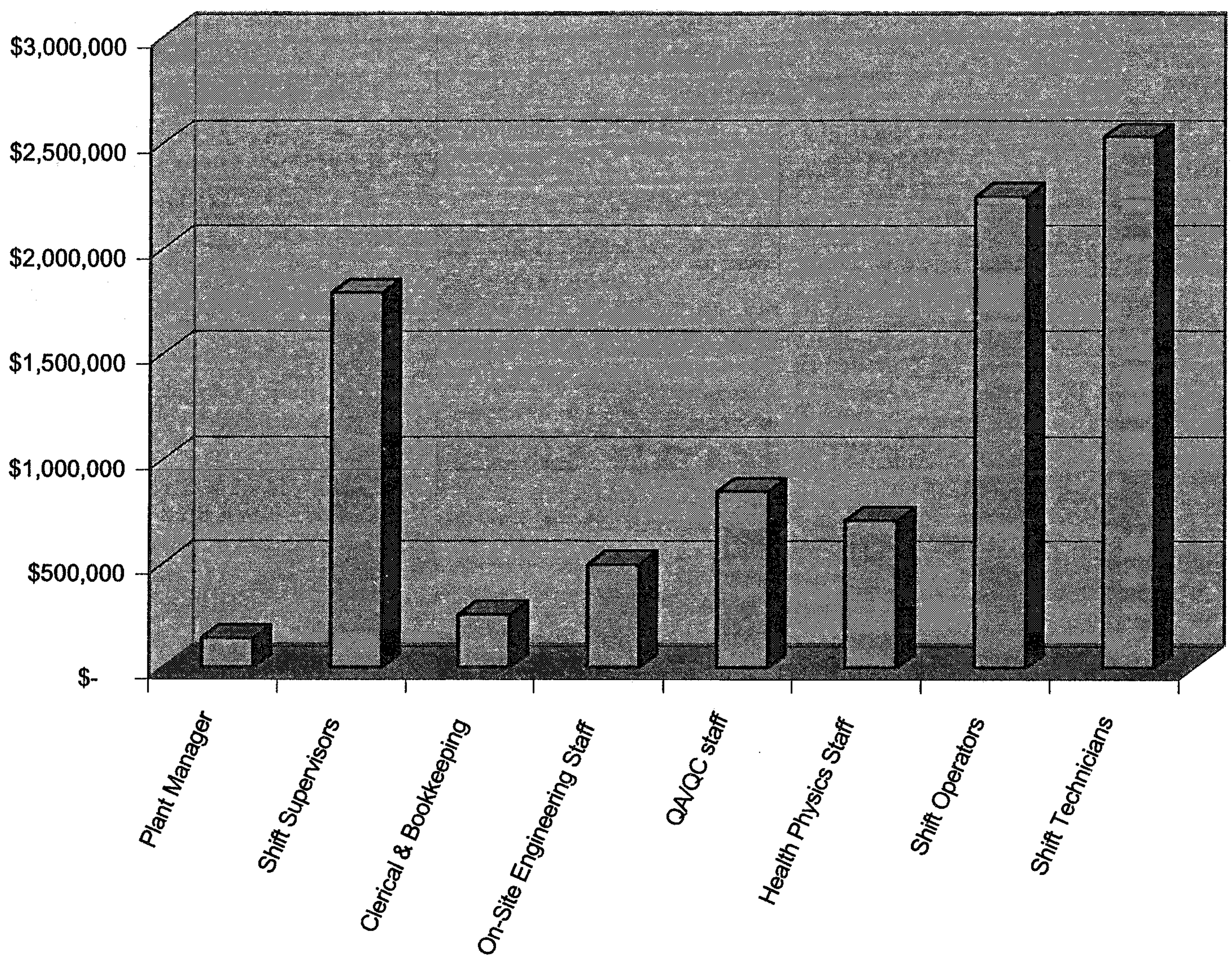
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041	1.34	1.34	1.00
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079	1.34	1.34	1.00
QA/QC staff	3	5	$ 40,000	$ 840,136	1.34	1.34	1.00
Health Physics Staff	2	5	$ 50,000	$ 700,113	1.34	1.34	1.00
Shift Operator - Contactor Area	2	5	$ 40,000	$ 560,090	1.34	1.34	1.00
Technician - Contactor Area	3	5	$ 30,000	$ 630,102	1.34	1.34	1.00
Shift Operator - Dryer Area	2	5	$ 40,000	$ 560,101	1.11	1.11	1.00
Technician - Dryer Area	3	5	$ 30,000	$ 630,114	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 560,134	1.02	1.02	1.00
Technician - Fill/Layer Area	3	5	$ 30,000	$ 630,151	1.02	1.02	1.00
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 8,968,372

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 840,136
Health Physics Staff	$ 700,113
Shift Operators	$ 2,240,326
Shift Technicians	$ 2,520,367

Operating Labor Costs for Foam Target Production

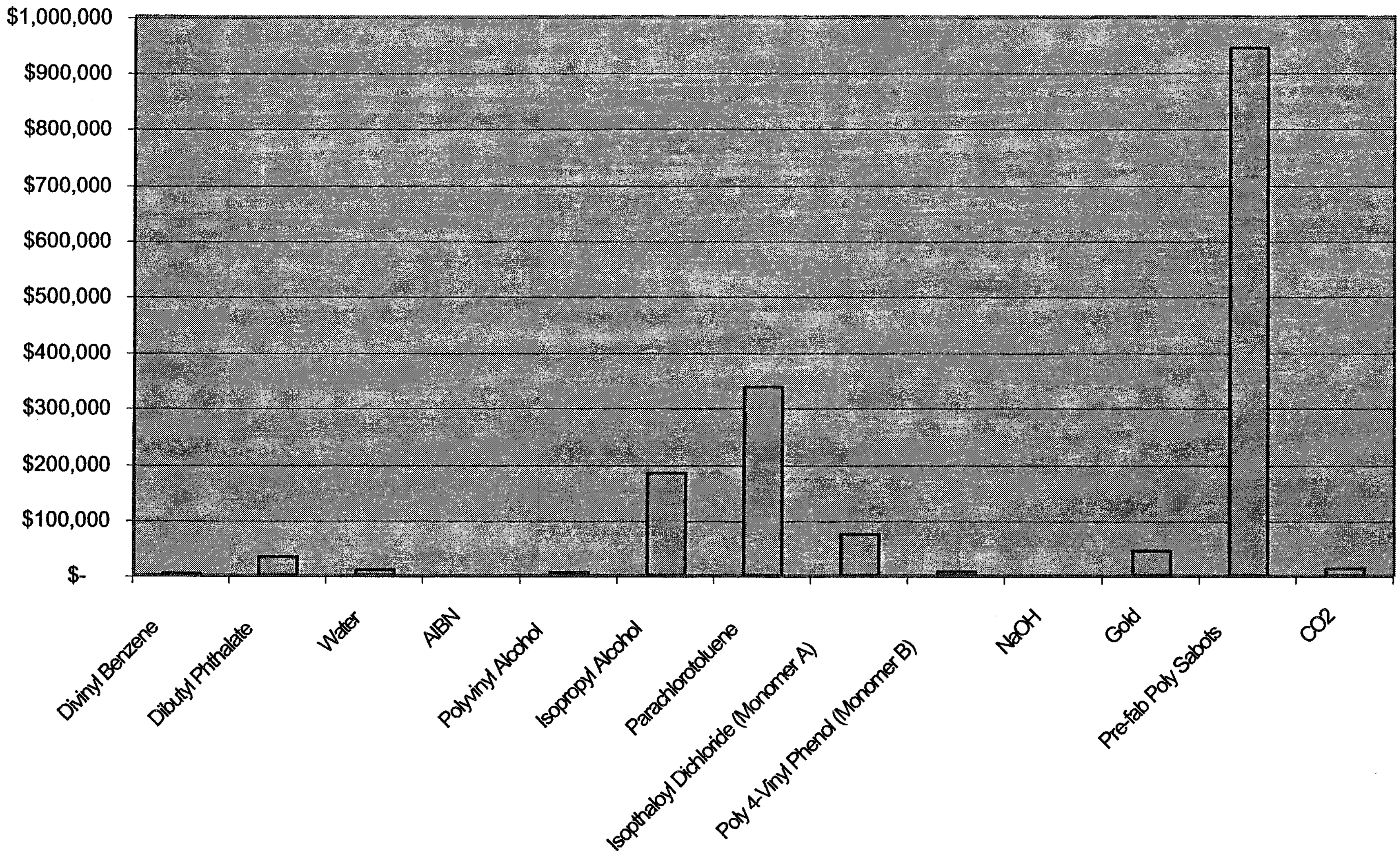


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	317	10.00	$ 3,169	
Dibutyl Phthalate	3169	10.00	$ 31,688	
Water	91457	0.10	$ 9,146	
AIBN	32	10.00	$ 317	
Polyvinyl Alcohol	424	10.00	$ 4,238	
Isopropyl Alcohol	91535	2.00	$ 183,070	
Parachlorotoluene	84212	4.00	$ 336,850	
Isopthaloyl Dichloride (Monomer A)	7323	10.00	$ 73,228	
Poly 4-Vinyl Phenol (Monomer B)	673	10.00	$ 6,731	
NaOH	25	2.00	$ 50	
Gold	4.6	9650.00	$ 43,950	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	61569	0.20	$ 12,314	

Annual materials costs = $ 1,648,274

Materials Costs (consumables) for Foam Target Production

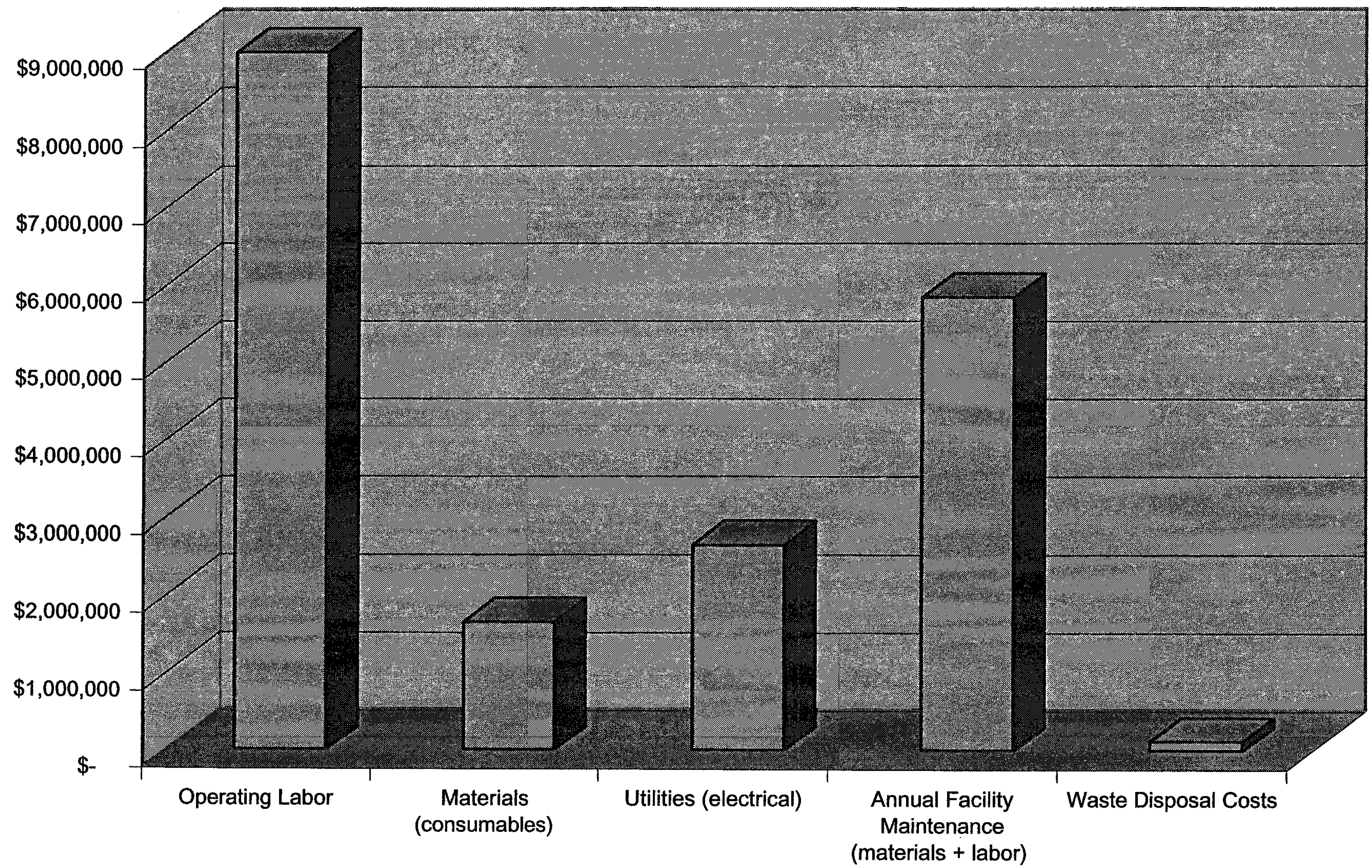


Operating Cost Summary for Foam Target Production

Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materials + labor)	$	5,822,652
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 19,197,281

Operating Costs for Foam Shell Production



Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (material	$	5,822,652
Waste Disposal Costs	$	122,047
Total Annual Operating Costs =	**$**	**19,197,281**

total cost per usable target =	0.166
cost for capital =	0.0641
cost for operating =	0.1015

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	561,691
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	24,383,394
	$	-
	$	-
Factored Balance of Plant Costs (from Mil	$	-
Piping	$	9,509,524
Electrical	$	4,145,177
Instruments	$	3,169,841
Building and services	$	7,315,018
Site Preparation	$	2,682,173
Auxiliaries	$	13,410,867
Field Expenses	$	10,484,859
Engineering	$	8,290,354
Contractors fees	$	4,145,177
Contingency	$	9,509,524
	$	-
Total Installed Capital Cost	$	97,044,204
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**12,130,526**

	cents per usable target	
waste disposal	0.065	
materials	0.871	
utilities	1.393	
maintenance	3.077	
operating labor	4.740	
	10.146	**total operating**
piping, electrical & instrumentation	1.111	
bldgs & auxiliaries	1.546	
purchased equipment	1.611	
engr, contractors, contingency	2.142	
	6.411	**total capital**
	16.557	**total capital + operating**

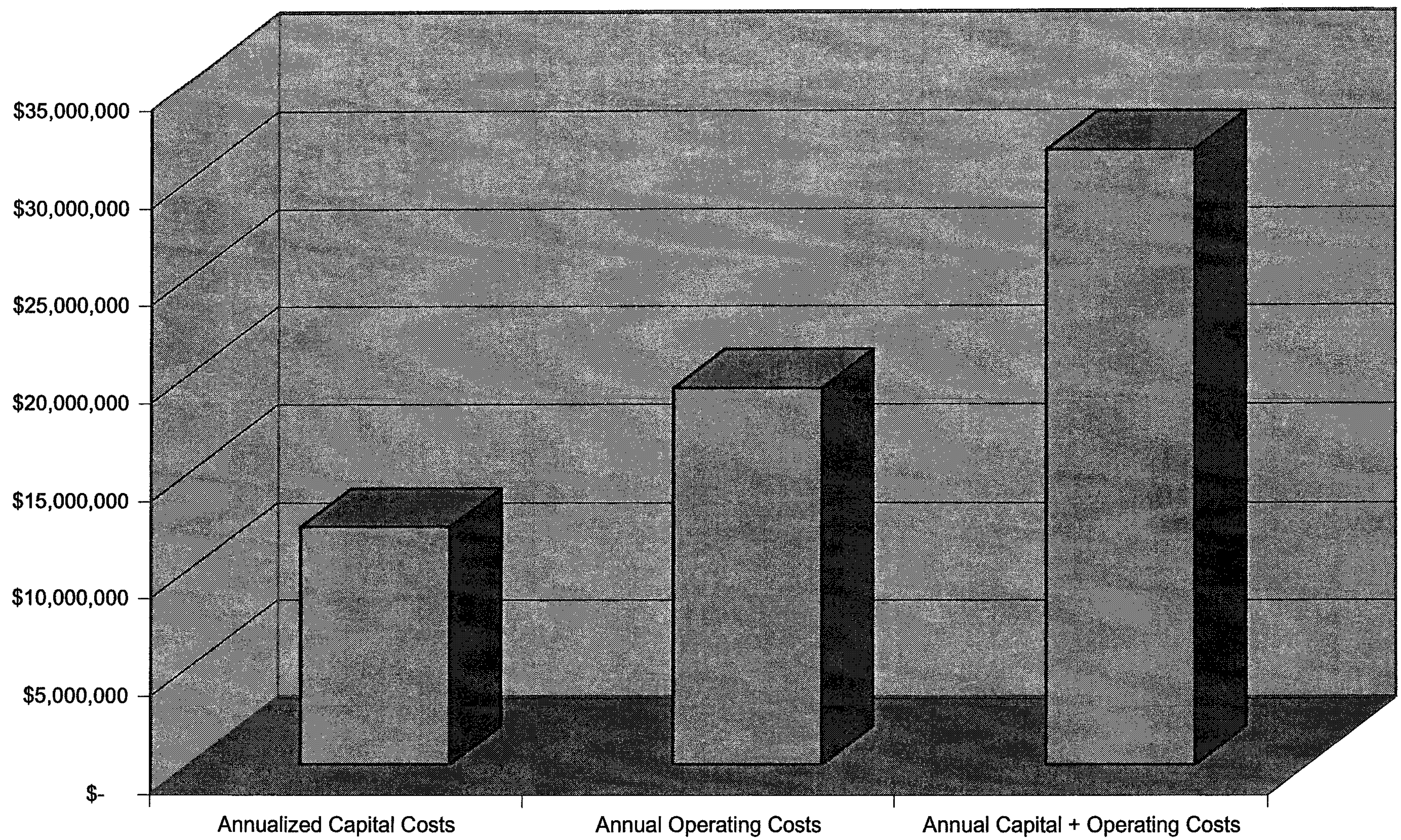
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 12,130,526
Annual Operating Costs	$ 19,197,281

Annual Capital + Operating Costs	**$ 31,327,807**

Cost per Injected Target = $ 0.166

Foam Target Production Costs



ATTACHMENT 5
Case 2 — Doubled staffing costs

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Specifications and Assumptions for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm

Specifications and Assumptions for Foam Target Production

1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate =	**25**

Tank Matrix for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4	= the fill volume of each contactor (in liters)
975	= the total volume required for each tank (in liters)
1219.076	= tank volume (with head-room allowance)
4	= L/D of vertical cylindrical
2.92	= height of tank, M
0.73	= diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

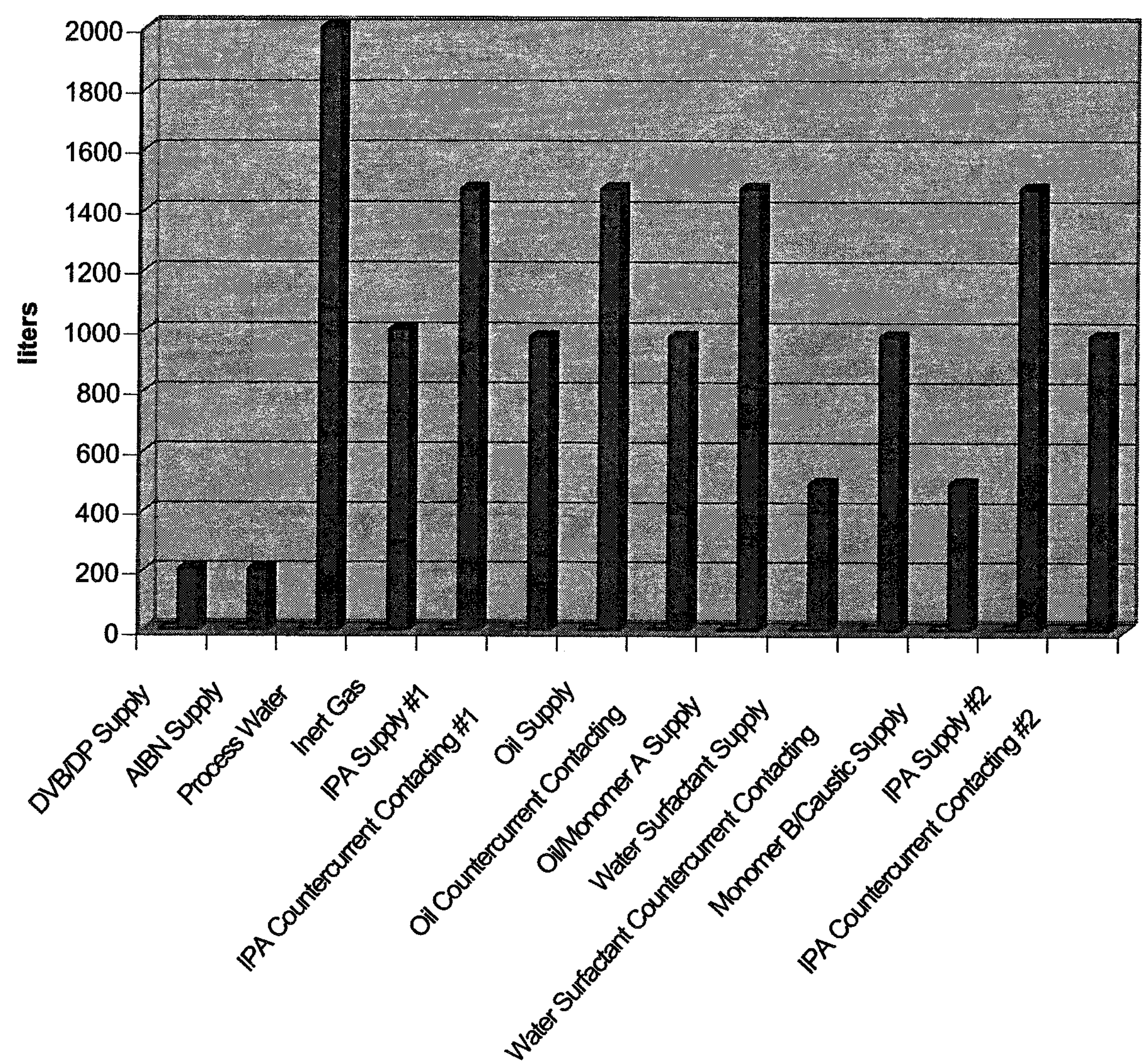
1.5 weeks storage in supply tank
1463 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1463	
IPA Countercurrent Contacting #1	5	975	
Oil Supply	1	1463	
Oil Countercurrent Contacting	5	975	
Oil/Monomer A Supply	1	1463	
Water Surfactant Supply	1	488	
Water Surfactant Countercurrent Contacting	2	975	
Monomer B/Caustic Supply	1	488	
IPA Supply #2	1	1463	
IPA Countercurrent Contacting #2	5	975	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	36.17																				30		
	Dibutyl Phthalate	361.73				361.73		362	362															
	Water			605.79	4837.60	5443.39		5443	5443							5225		5216						
	AIBN		3.62																					
	Polyvinyl Alcohol				48.38	48.38		48	48															
	Polymerized DVB					39.79		40	40															
	Isopropyl Alcohol (IPA)									5225										5225		502		
	Parachlorotoluene											5225		4389										
	Spent Solvent #1																							
	Isophthaloyl dichloride													836										
	Poly 4-Vinyl Phenol																	77						
	NaOH																	3						
	Mixed liquid waste										5225		5225		5225		5225		5295		5225			
	CO_2																						7028	
	Au or Pd																							0.52
Gases	N_2						93.80																	
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2006	KW usage
$	0.15	cost per KW-hr
	2	staff cost multiplier (for single variable sensitivity study)

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,381,691**				**$ 24,383,394**

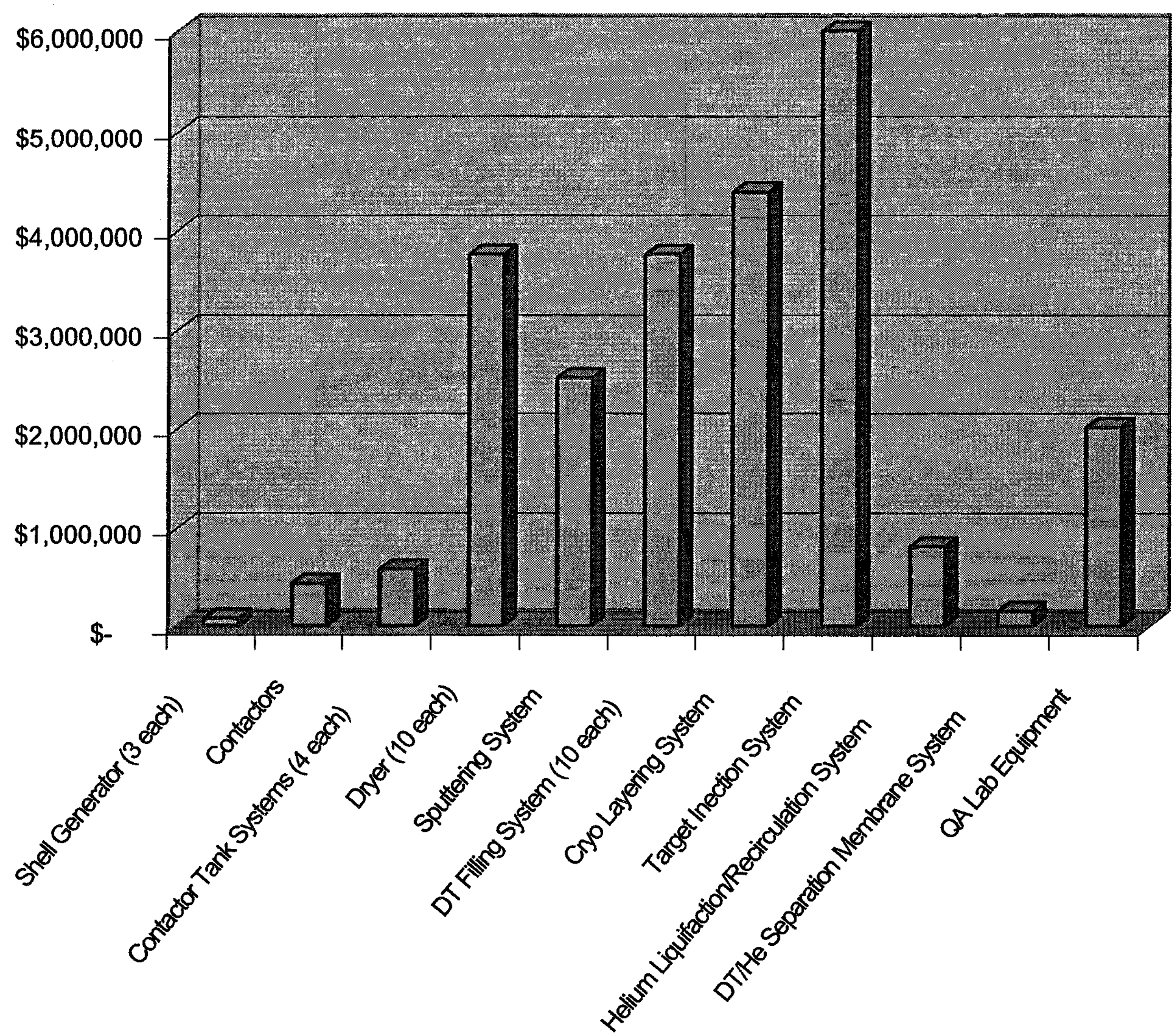
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,509,524
Electrical	$ 4,145,177
Instruments	$ 3,169,841
Building and services	$ 7,315,018
Site Preparation	$ 2,682,173
Auxiliaries	$ 13,410,867
Field Expenses	$ 10,484,859
Engineering	$ 8,290,354
Contractors fees	$ 4,145,177
Contingency	$ 9,509,524

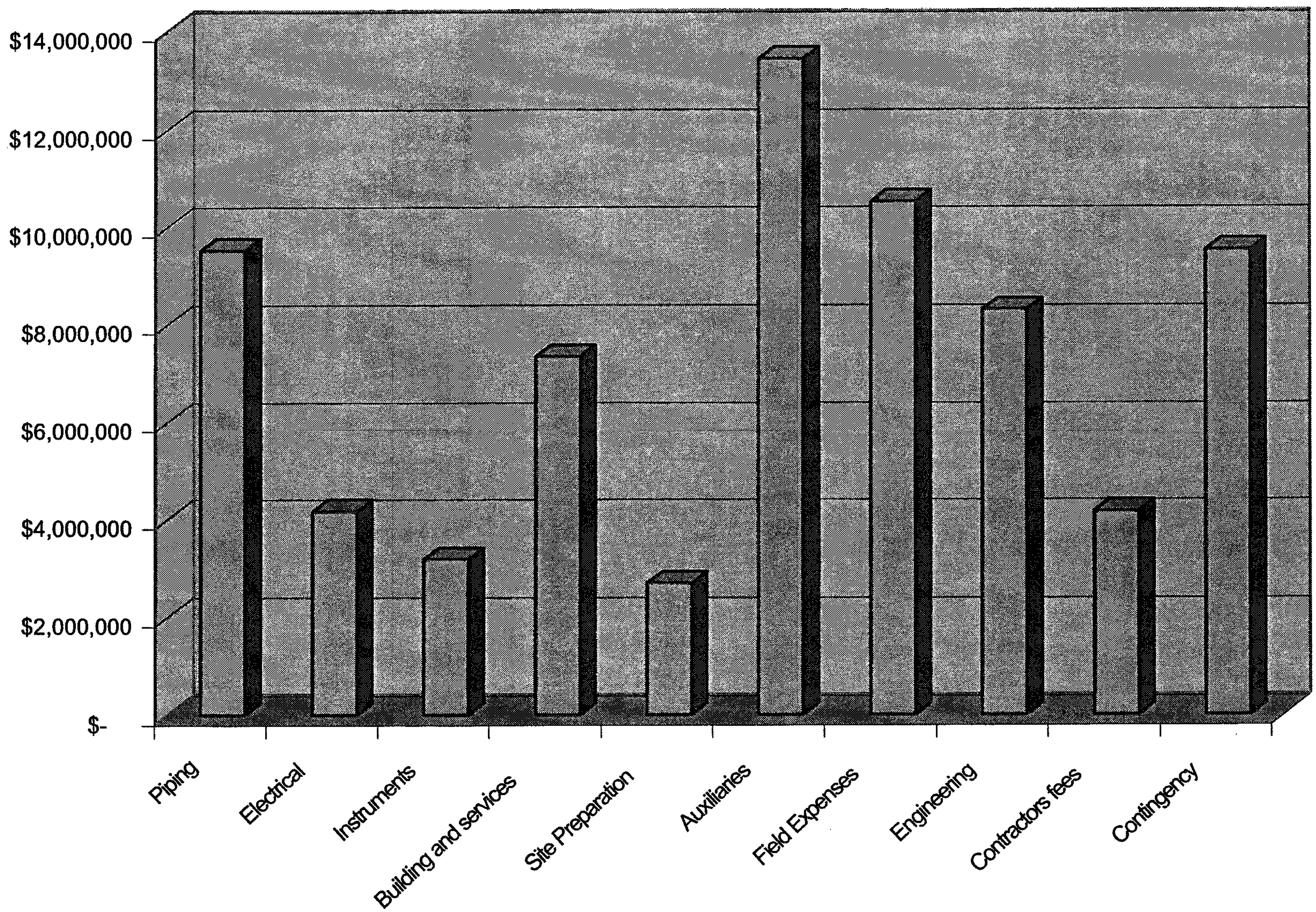
Total Installed Capital Cost **$ 97,044,204**

Annualized Cost of Capital Investment **$ 12,130,526**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

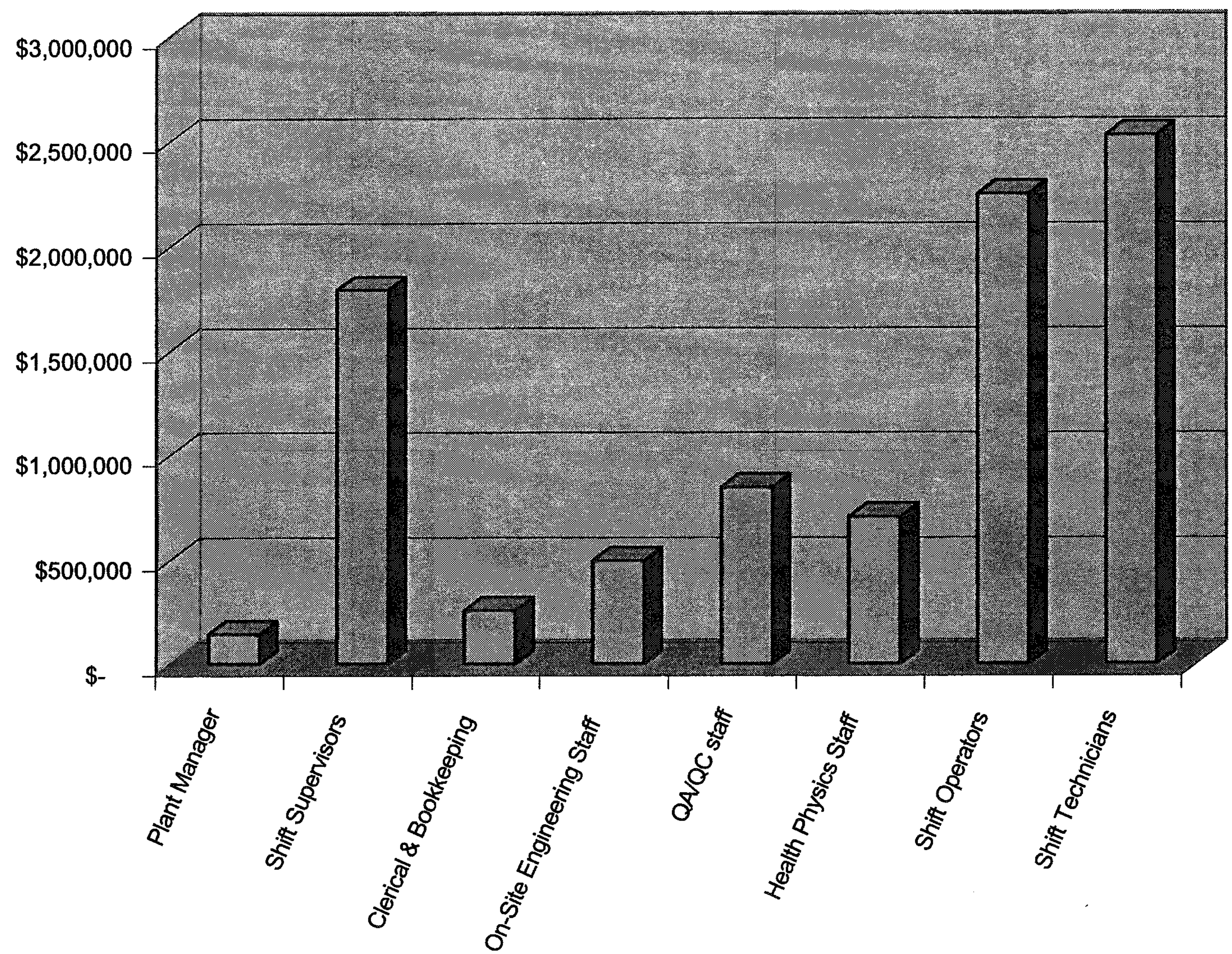
Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)
Plant Manager	1	1	$ 100,000	$ 140,023
Shift Supervisors	3	5	$ 85,000	$ 1,785,288
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079
QA/QC staff	3	5	$ 40,000	$ 840,136
Health Physics Staff	2	5	$ 50,000	$ 700,113
Shift Operator - Contactor Area	2	5	$ 40,000	$ 560,090
Technician - Contactor Area	3	5	$ 30,000	$ 630,102
Shift Operator - Dryer Area	2	5	$ 40,000	$ 560,101
Technician - Dryer Area	3	5	$ 30,000	$ 630,114
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 560,134
Technician - Fill/Layer Area	3	5	$ 30,000	$ 630,151
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000

Annual labor operating costs = $ 17,936,745

reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
1.34	1.337	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.11	1.11	1.00
1.11	1.11	1.00
1.02	1.02	1.00
1.02	1.02	1.00
n/a	n/a	n/a
n/a	n/a	n/a

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 840,136
Health Physics Staff	$ 700,113
Shift Operators	$ 2,240,326
Shift Technicians	$ 2,520,367

Operating Labor Costs for Foam Target Production

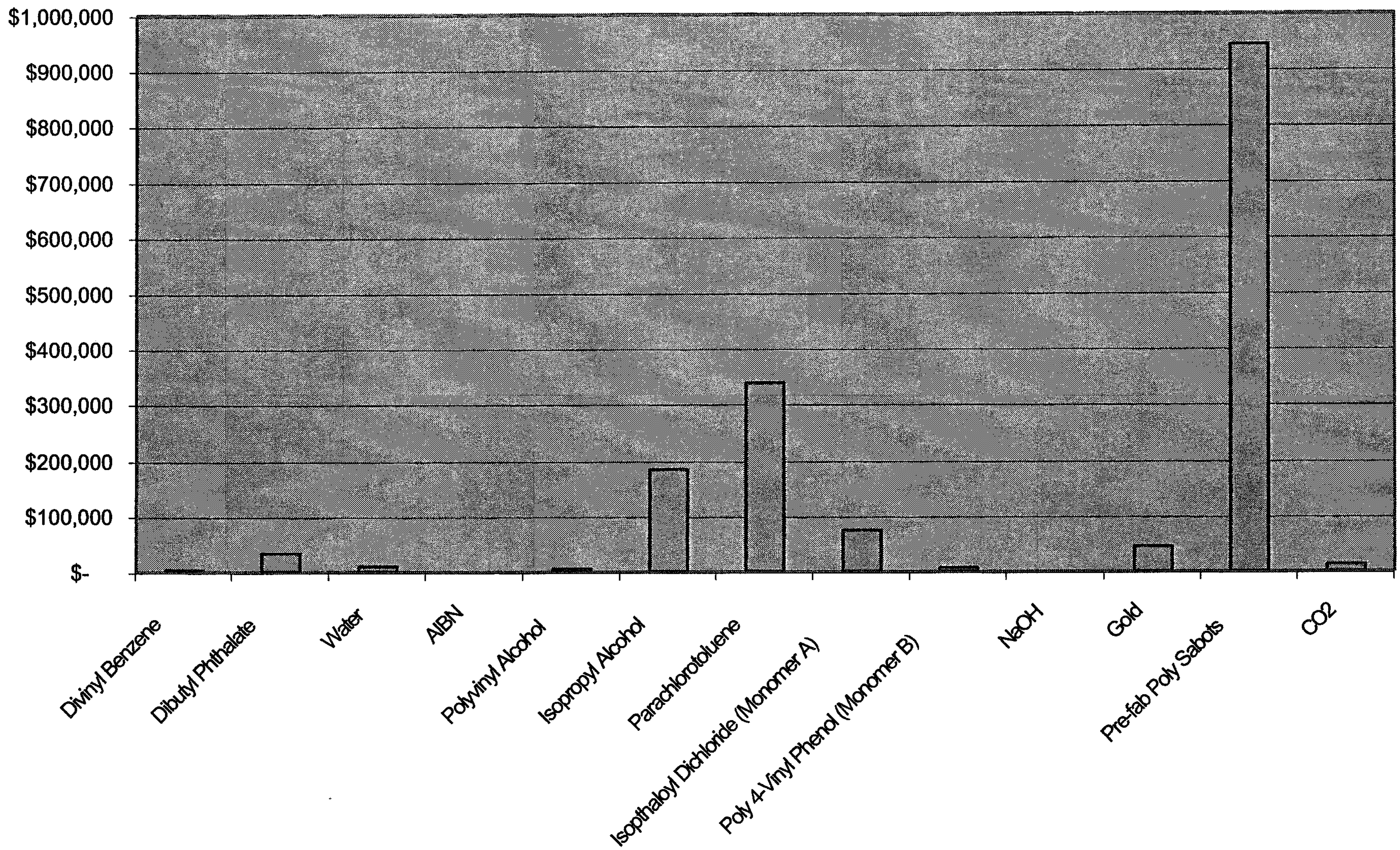


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr
Divinyl Benzene	317	10.00	$ 3,169
Dibutyl Phthalate	3169	10.00	$ 31,688
Water	91457	0.10	$ 9,146
AIBN	32	10.00	$ 317
Polyvinyl Alcohol	424	10.00	$ 4,238
Isopropyl Alcohol	91535	2.00	$ 183,070
Parachlorotoluene	84212	4.00	$ 336,850
Isopthaloyl Dichloride (Monomer A)	7323	10.00	$ 73,228
Poly 4-Vinyl Phenol (Monomer B)	673	10.00	$ 6,731
NaOH	25	2.00	$ 50
Gold	4.6	9650.00	$ 43,950
Pre-fab Poly Sabots	262090	3.60	$ 943,523 (= 0.5 cent per sabot)
CO2	61569	0.20	$ 12,314

Annual materials costs = $ 1,648,274

Materials Costs (consumables) for Foam Target Production

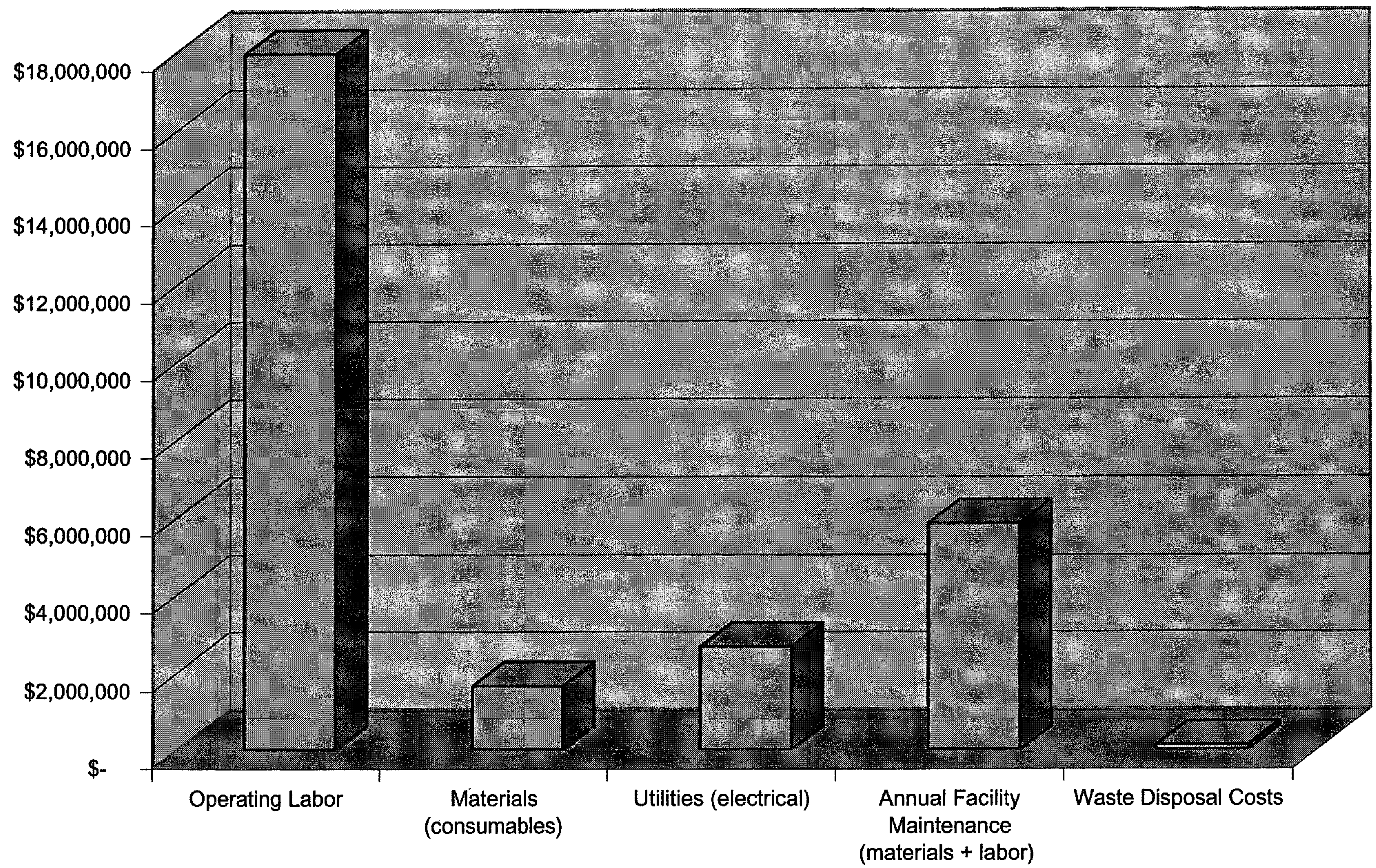


Operating Cost Summary for Foam Target Production

Operating Labor	$	17,936,745
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materials + labor)	$	5,822,652
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 28,165,654

Operating Costs for Foam Shell Production



Operating Labor	$	17,936,745
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materi	$	5,822,652
Waste Disposal Costs	$	122,047
Total Annual Operating Costs =	**$**	**28,165,654**

total cost per usable target =	0.213
cost for capital =	0.064
cost for operating =	0.149

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	561,691
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	24,383,394
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	9,509,524
Electrical	$	4,145,177
Instruments	$	3,169,841
Building and services	$	7,315,018
Site Preparation	$	2,682,173
Auxiliaries	$	13,410,867
Field Expenses	$	10,484,859
Engineering	$	8,290,354
Contractors fees	$	4,145,177
Contingency	$	9,509,524
	$	-
Total Installed Capital Cost	$	97,044,204
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**12,130,526**

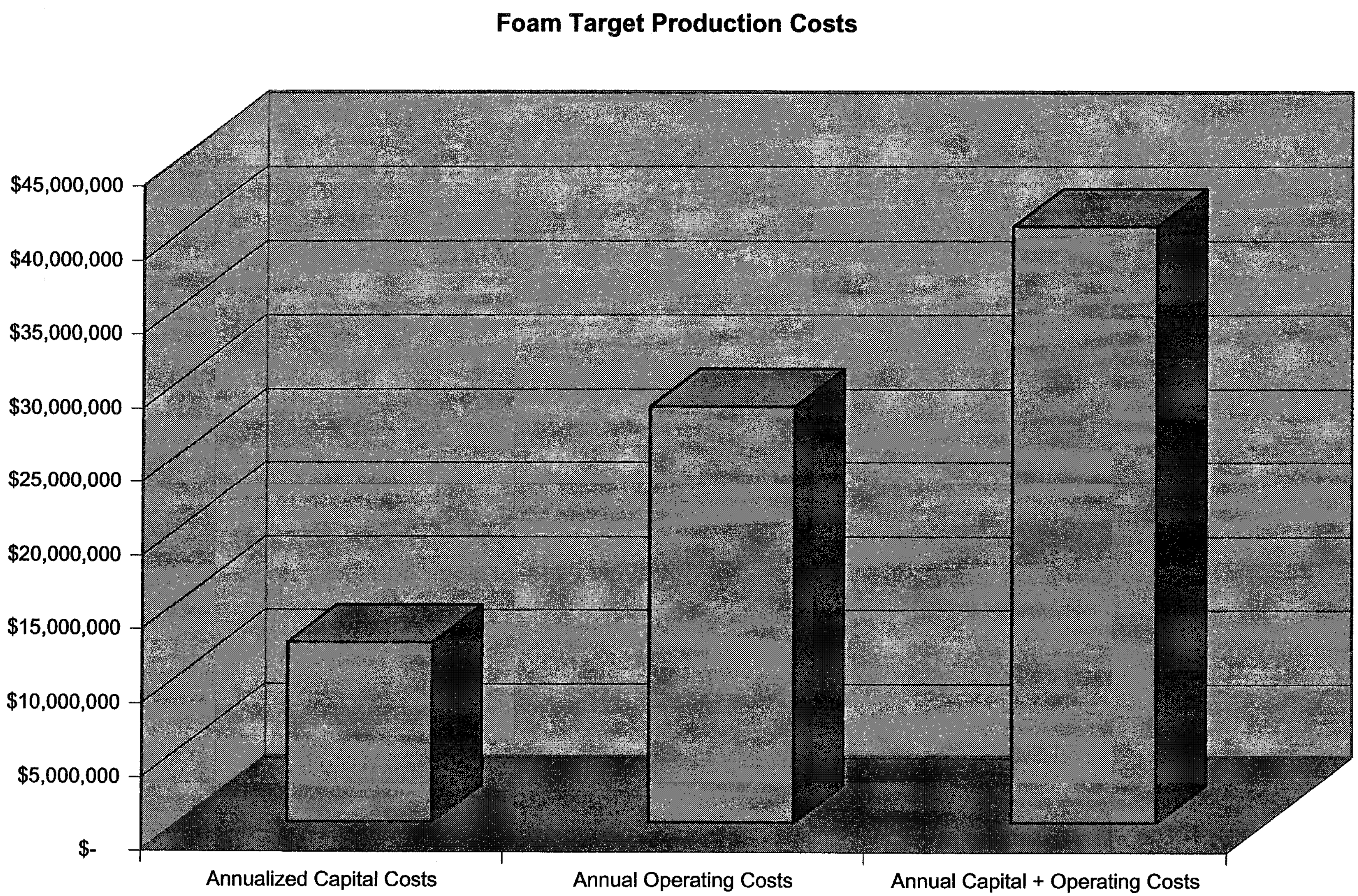
	cents per usable target	
waste disposal	0.065	
materials	0.871	
utilities	1.393	
maintenance	3.077	
operating labor	9.480	
	14.885	**total operating**
piping, electrical & instrumentation	1.111	
bldgs & auxiliaries	1.546	
purchased equipment	1.611	
engr, contractors, contingency	2.142	
	6.411	**total capital**
	21.297	**total capital + operating**

Cost Summary for Foam Target Production

Annualized Capital Costs	$ 12,130,526
Annual Operating Costs	$ 28,165,654

Annual Capital + Operating Costs	**$ 40,296,179**

Cost per Injected Target = $ 0.213


Foam Target Production Costs
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
Annualized Capital Costs
Annual Operating Costs
Annual Capital + Operating Costs

ATTACHMENT 5
Case 3 — Doubled capital costs

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4 = the fill volume of each contactor (in liters)

975 = the total volume required for each tank (in liters)
1219.076 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.92 = height of tank, M
0.73 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

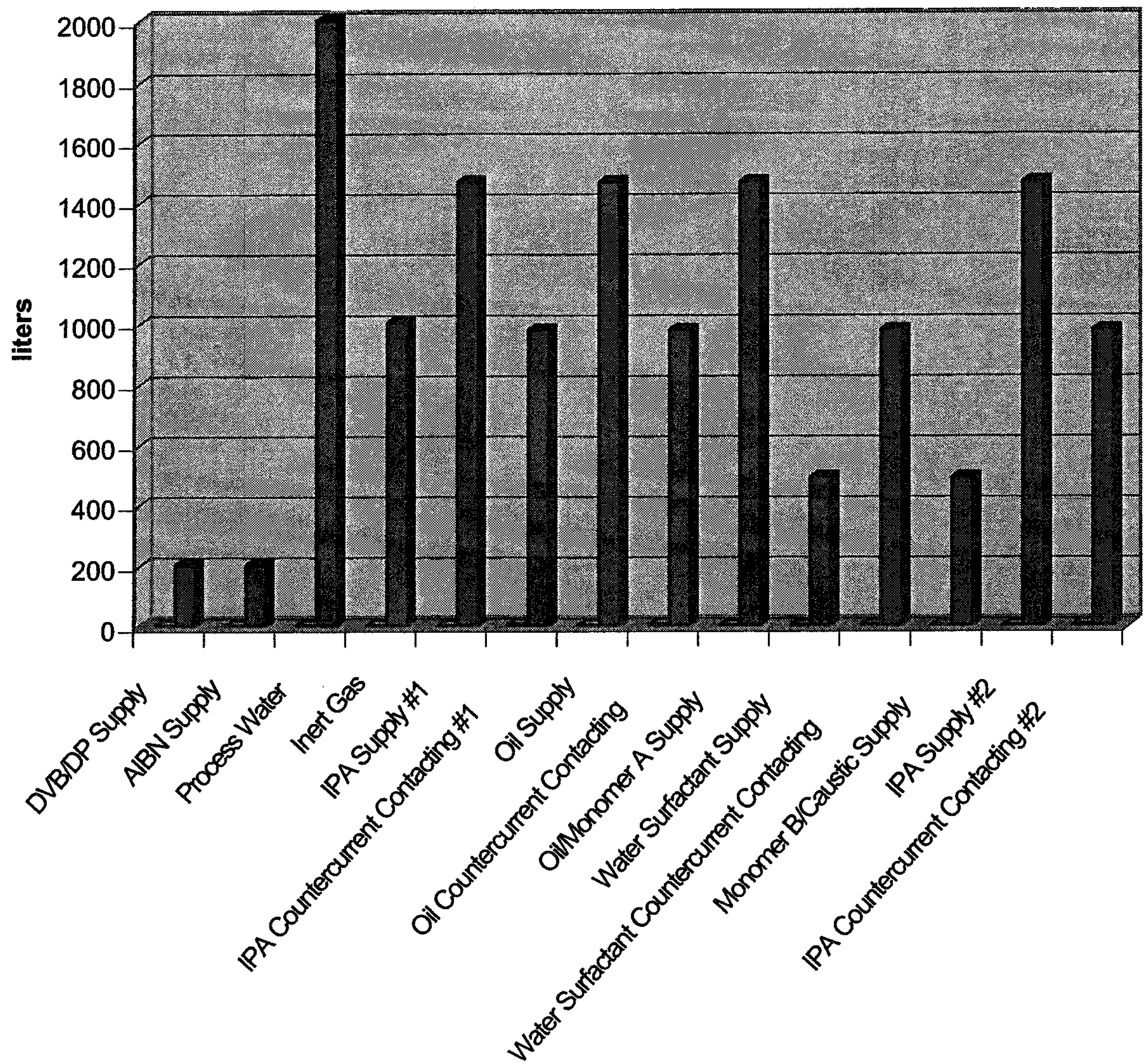
1.5 weeks storage in supply tank
1463 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1463	
IPA Countercurrent Contacting #1	5	975	
Oil Supply	1	1463	
Oil Countercurrent Contacting	5	975	
Oil/Monomer A Supply	1	1463	
Water Surfactant Supply	1	488	
Water Surfactant Countercurrent Contacting	2	975	
Monomer B/Caustic Supply	1	488	
IPA Supply #2	1	1463	
IPA Countercurrent Contacting #2	5	975	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	36.17																				30		
	Dibutyl Phthalate	361.73				361.73		362	362															
	Water			605.79	4837.60	5443.39		5443	5443							5225		5216						
	AIBN		3.62																					
	Polyvinyl Alcohol				48.38	48.38		48	48															
	Polymerized DVB					39.79		40	40															
	Isopropyl Alcohol (IPA)									5225										5225		502		
	Parachlorotoluene											5225		4389										
	Spent Solvent #1																							
	Isophthaloyl dichloride													836										
	Poly 4-Vinyl Phenol																	77						
	NaOH																	3						
	Mixed liquid waste										5225		5225		5225		5225		5295		5225			
	CO_2																						7028	
	Au or Pd																							0.52
Gases	N_2						93.80																	
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2006	KW usage
$	0.15	cost per KW-hr
	2	factor to multiply times costs (for single variable sensitivity calculations)

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,381,691**				**$ 48,766,787**

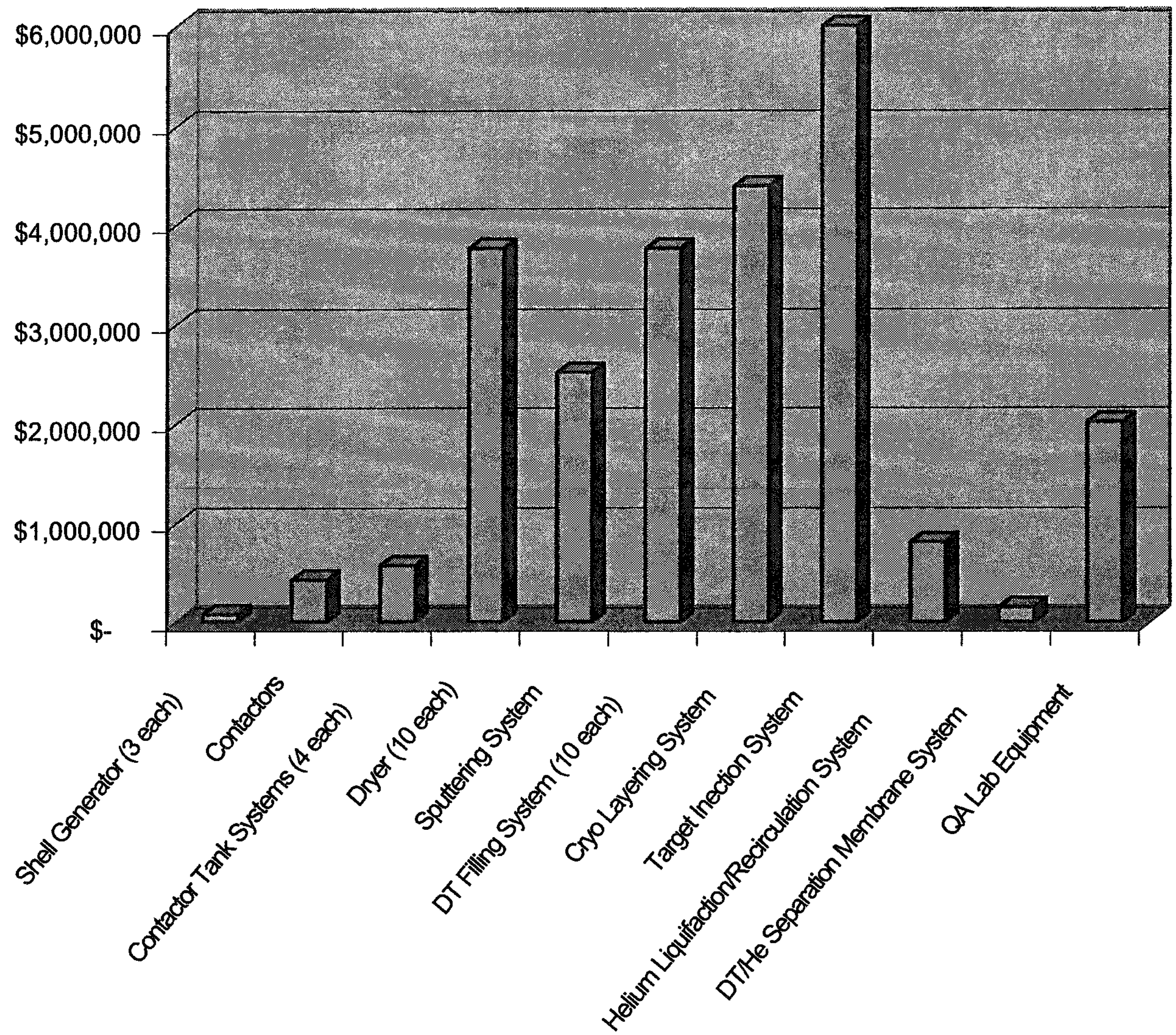
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 19,019,047
Electrical	$ 8,290,354
Instruments	$ 6,339,682
Building and services	$ 14,630,036
Site Preparation	$ 5,364,347
Auxiliaries	$ 26,821,733
Field Expenses	$ 20,969,719
Engineering	$ 16,580,708
Contractors fees	$ 8,290,354
Contingency	$ 19,019,047

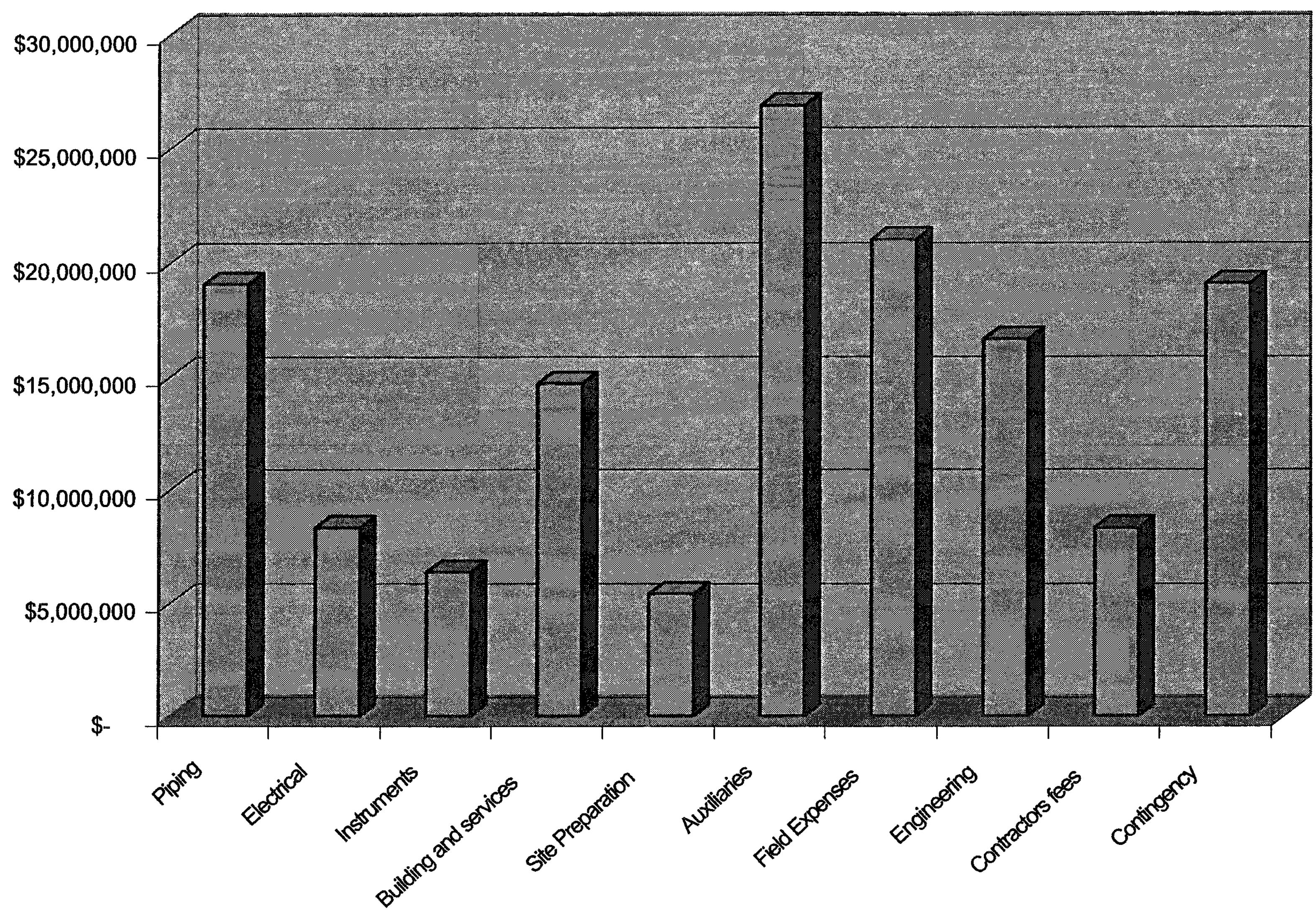
Total Installed Capital Cost **$ 194,091,814**

Annualized Cost of Capital Investment **$ 24,261,477**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



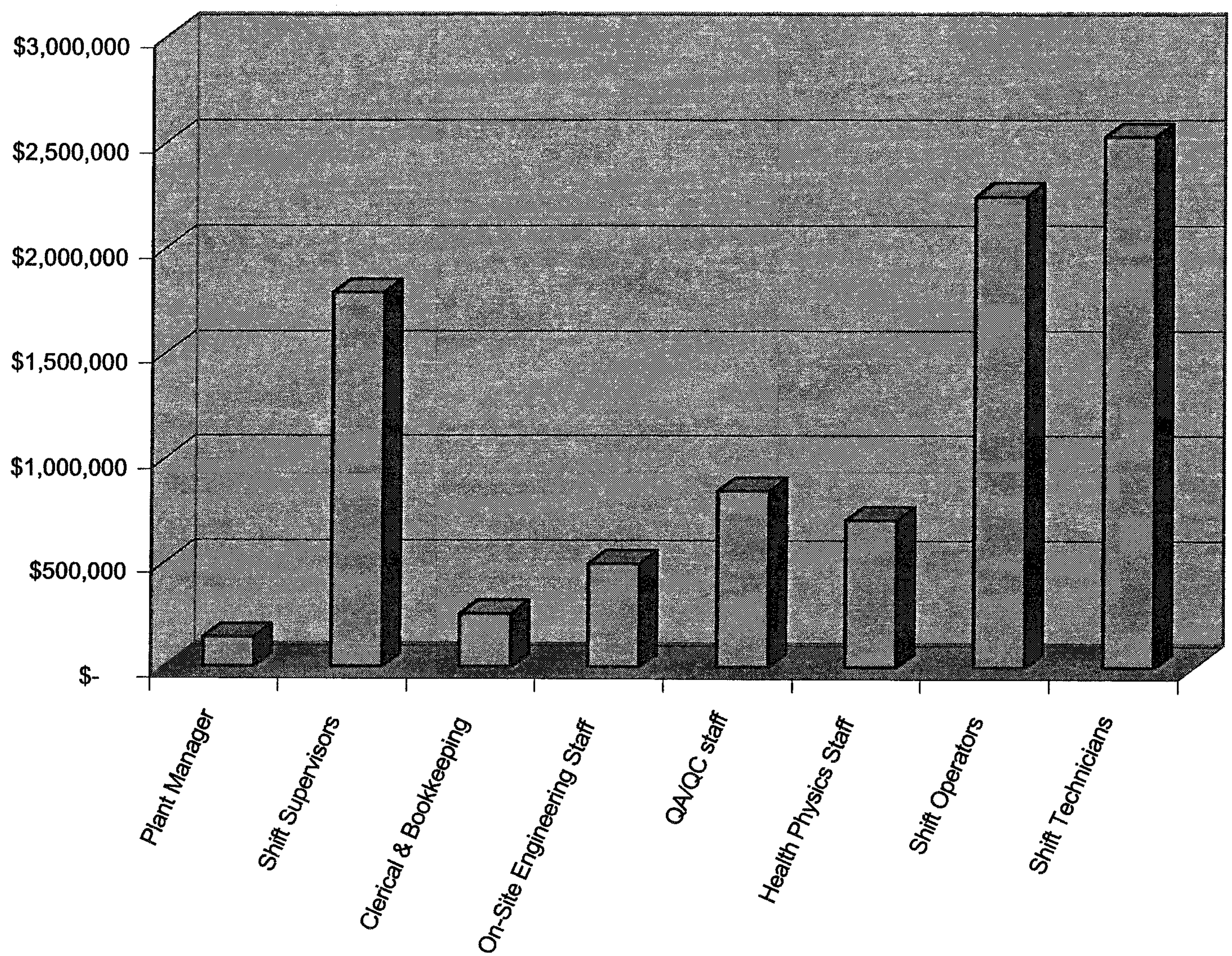
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041	1.34	1.34	1.00
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079	1.34	1.34	1.00
QA/QC staff	3	5	$ 40,000	$ 840,136	1.34	1.34	1.00
Health Physics Staff	2	5	$ 50,000	$ 700,113	1.34	1.34	1.00
Shift Operator - Contactor Area	2	5	$ 40,000	$ 560,090	1.34	1.34	1.00
Technician - Contactor Area	3	5	$ 30,000	$ 630,102	1.34	1.34	1.00
Shift Operator - Dryer Area	2	5	$ 40,000	$ 560,101	1.11	1.11	1.00
Technician - Dryer Area	3	5	$ 30,000	$ 630,114	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 560,134	1.02	1.02	1.00
Technician - Fill/Layer Area	3	5	$ 30,000	$ 630,151	1.02	1.02	1.00
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 8,968,372

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 840,136
Health Physics Staff	$ 700,113
Shift Operators	$ 2,240,326
Shift Technicians	$ 2,520,367

Operating Labor Costs for Foam Target Production



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AIBN	32	10.00	$ 317
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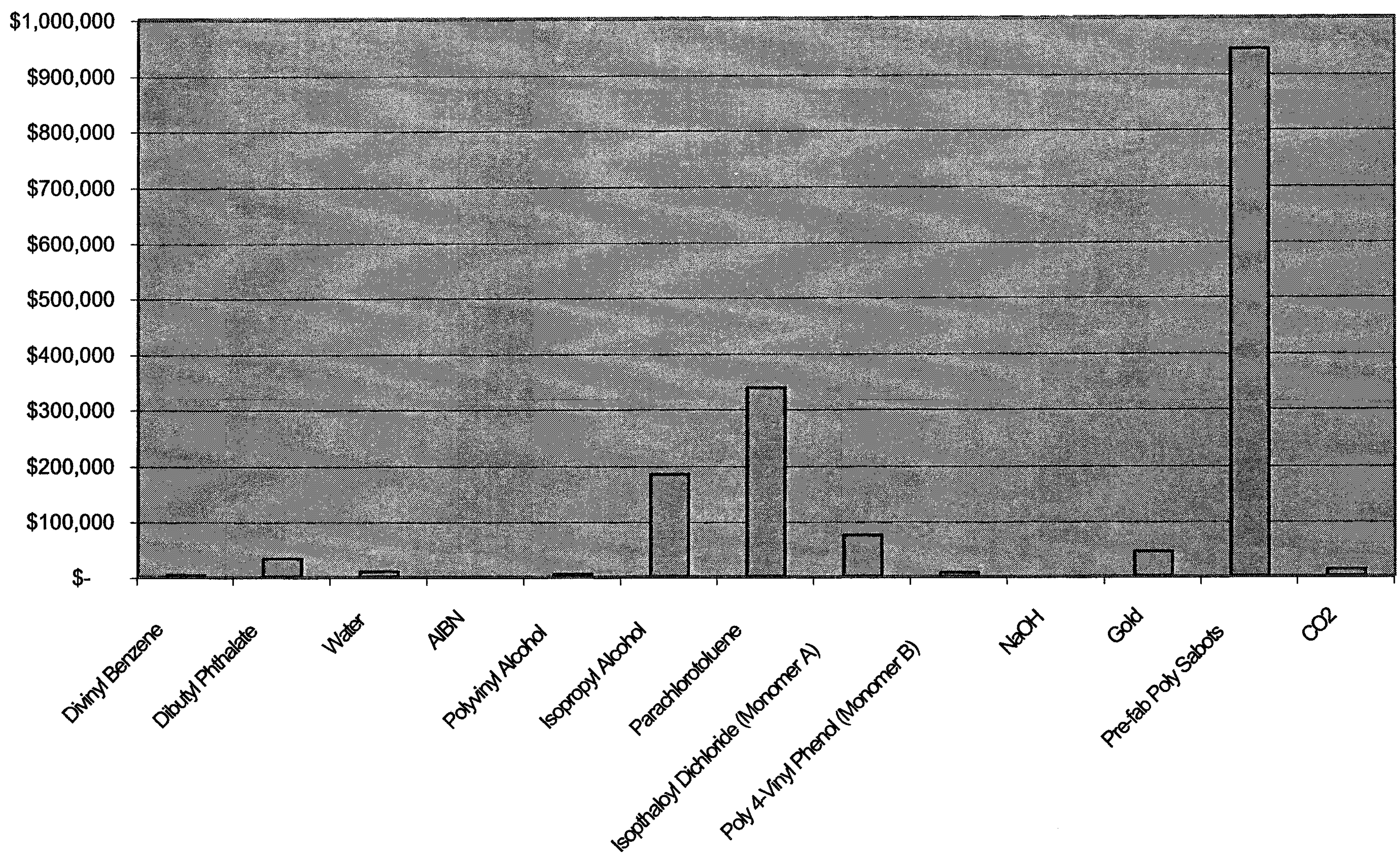
Parachlorotoluene	84212	4.00	$ 336,850
Isopthaloyl Dichloride (Monomer A)	7323	10.00	$ 73,228
Poly 4-Vinyl Phenol (Monomer B)	673	10.00	$ 6,731
NaOH	25	2.00	$ 50
Gold	4.6	9650.00	$ 43,950
Pre-fab Poly Sabots	262090	3.60	$ 943,523
CO2	61569	0.20	$ 12,314

Annual materials costs = $ 1,648,274

Materials Costs for Foam Target Production

(= 0.5 cent per sabot)

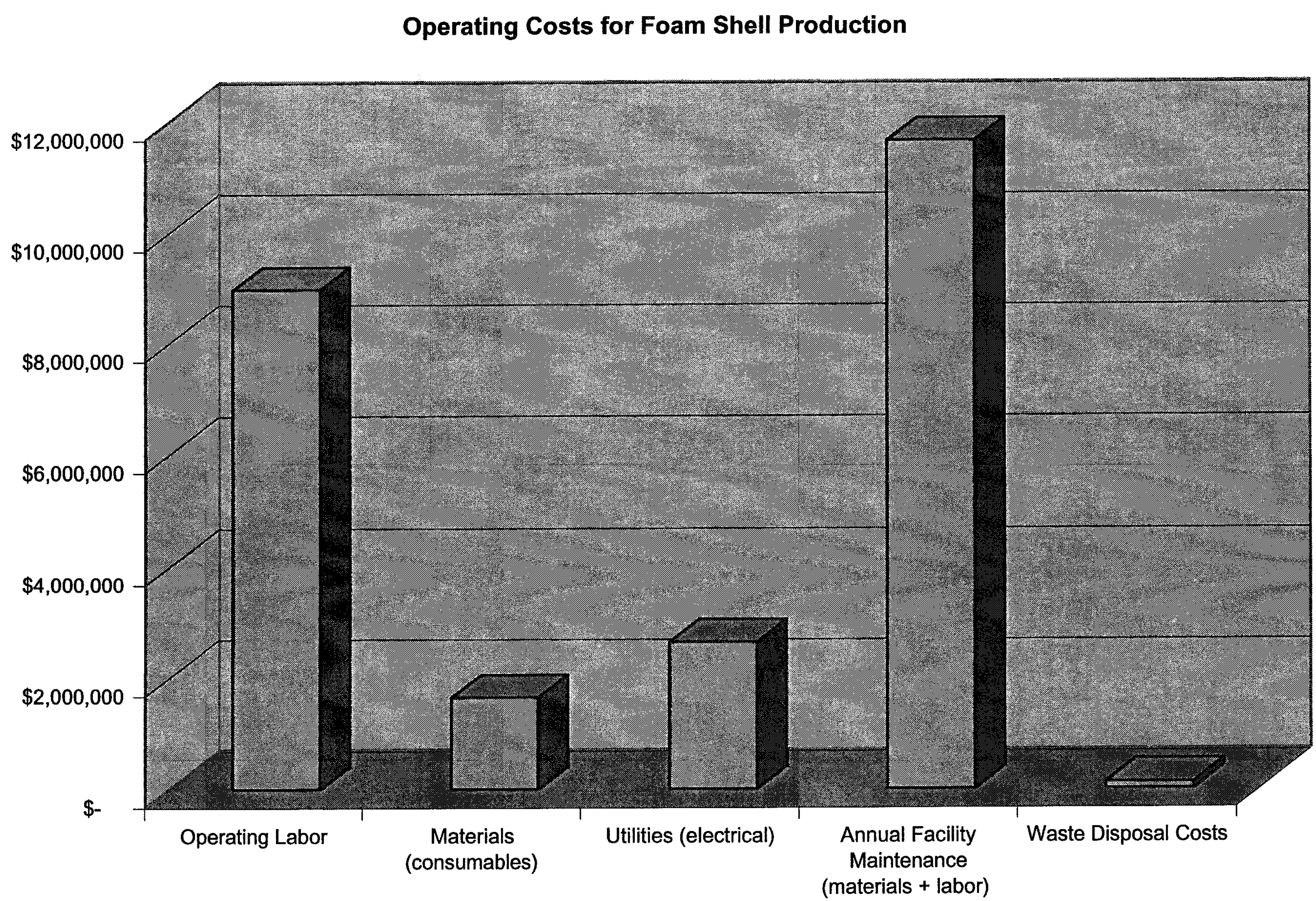
Materials Costs (consumables) for Foam Target Production



Operating Cost Summary for Foam Target Production

Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materials + labor)	$	11,645,509
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 25,020,138


Operating Costs for Foam Shell Production
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$-
Operating Labor
Materials (consumables)
Utilities (electrical)
Annual Facility Maintenance (materials + labor)
Waste Disposal Costs

Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materia	$	11,645,509
Waste Disposal Costs	$	122,047
Total Annual Operating Costs =	**$**	**25,020,138**

total cost per usable target =	0.260
cost for capital =	0.128
cost for operating =	0.132

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	561,691
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	48,766,787
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	19,019,047
Electrical	$	8,290,354
Instruments	$	6,339,682
Building and services	$	14,630,036
Site Preparation	$	5,364,347
Auxiliaries	$	26,821,733
Field Expenses	$	20,969,719
Engineering	$	16,580,708
Contractors fees	$	8,290,354
Contingency	$	19,019,047
	$	-
Total Installed Capital Cost	$	194,091,814
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**24,261,477**

	cents per usable target	
waste disposal	0.065	
materials	0.871	
utilities	1.393	
maintenance	6.155	
operating labor	4.740	
	13.223	**total operating**
piping, electrical & instrumentation	2.223	
bldgs & auxiliaries	3.093	
purchased equipment	3.222	
engr, contractors, contingency	4.285	
	12.822	**total capital**
	26.045	**total capital + operating**

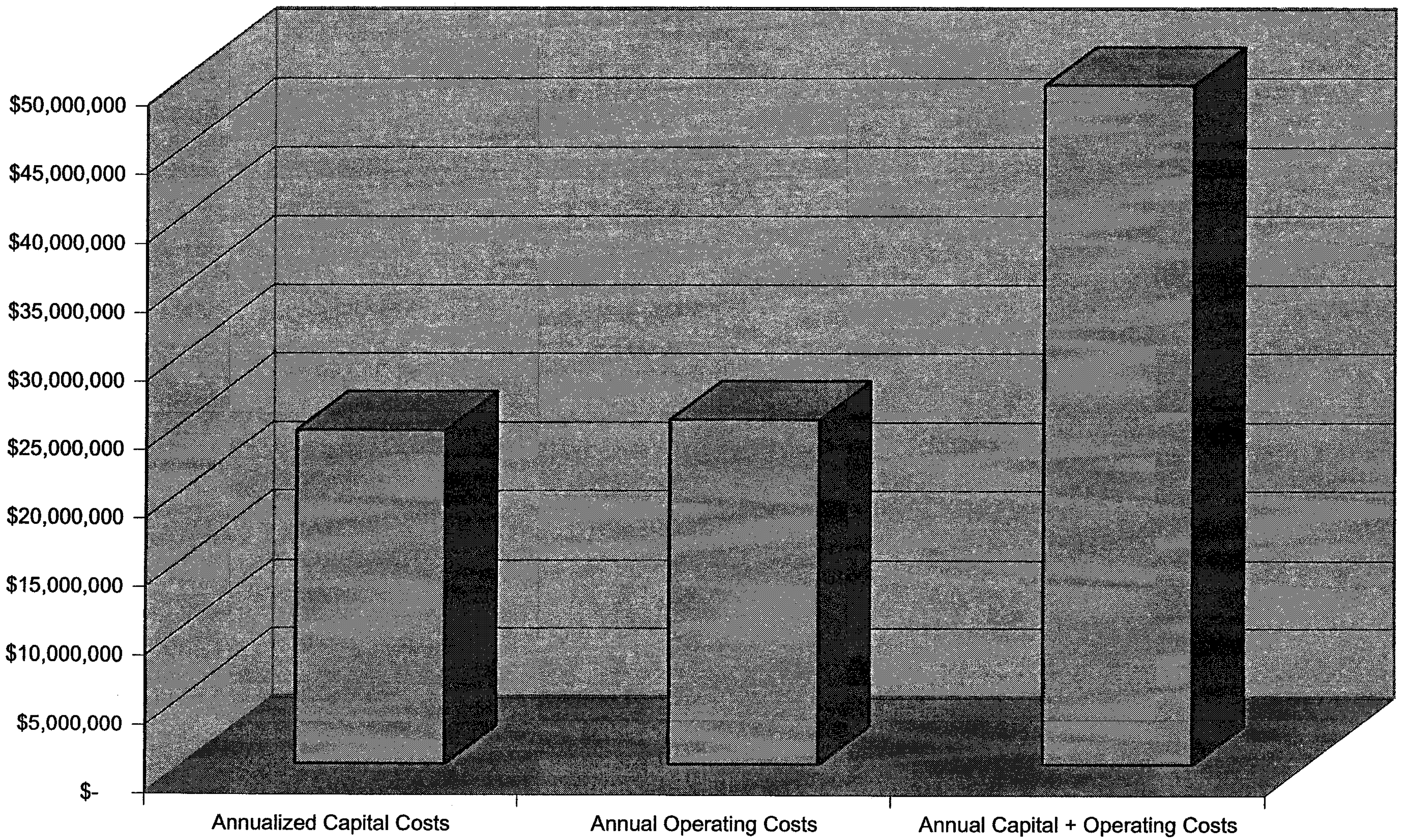
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 24,261,477
Annual Operating Costs	$ 25,020,138

Annual Capital + Operating Costs	**$ 49,281,615**

Cost per Injected Target = $ 0.260

Foam Target Production Costs



ATTACHMENT 5
Case 4 — Doubled maintenance costs

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4 = the fill volume of each contactor (in liters)

975 = the total volume required for each tank (in liters)
1219.076 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.92 = height of tank, M
0.73 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

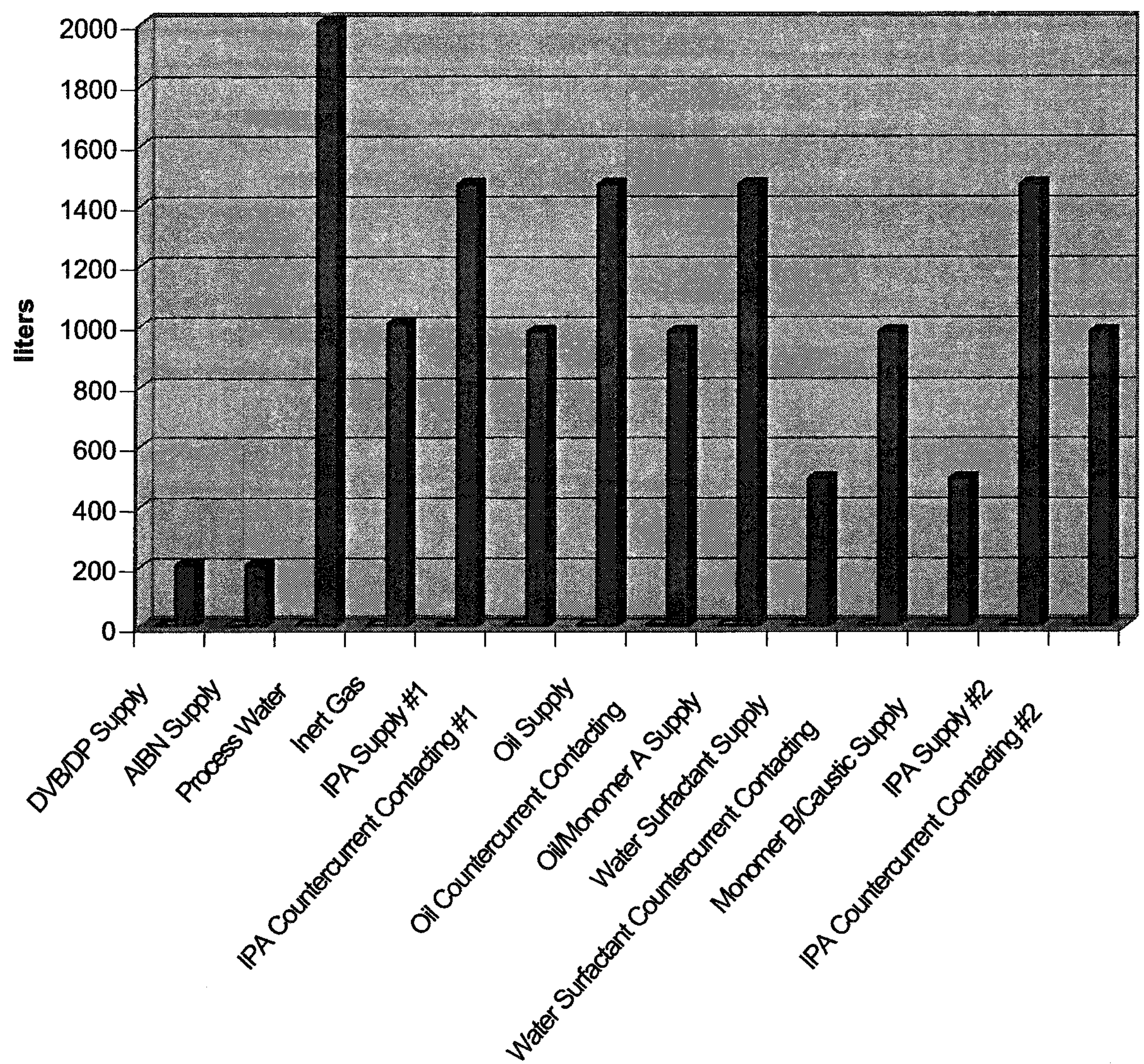
1.5 weeks storage in supply tank
1463 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1463	
IPA Countercurrent Contacting #1	5	975	
Oil Supply	1	1463	
Oil Countercurrent Contacting	5	975	
Oil/Monomer A Supply	1	1463	
Water Surfactant Supply	1	488	
Water Surfactant Countercurrent Contacting	2	975	
Monomer B/Caustic Supply	1	488	
IPA Supply #2	1	1463	
IPA Countercurrent Contacting #2	5	975	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	36.17																				30		
	Dibutyl Phthalate	361.73				361.73		362	362															
	Water			605.79	4837.60	5443.39		5443	5443							5225		5216						
	AIBN		3.62																					
	Polyvinyl Alcohol				48.38	48.38		48	48															
	Polymerized DVB					39.79		40	40															
	Isopropyl Alcohol (IPA)									5225										5225		502		
	Parachlorotoluene											5225		4389										
	Spent Solvent #1																							
	Isophthaloyl dichloride													836										
	Poly 4-Vinyl Phenol																	77						
	NaOH																	3						
	Mixed liquid waste										5225		5225		5225		5225		5295		5225			
	CO_2																						7028	
	Au or Pd																							0.52
Gases	N_2						93.80																	
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.8	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2006	KW usage
$	0.15	cost per KW-hr

2 factor to multiply maintenance costs by (for single variable response study)

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,381,691**				**$ 24,383,394**

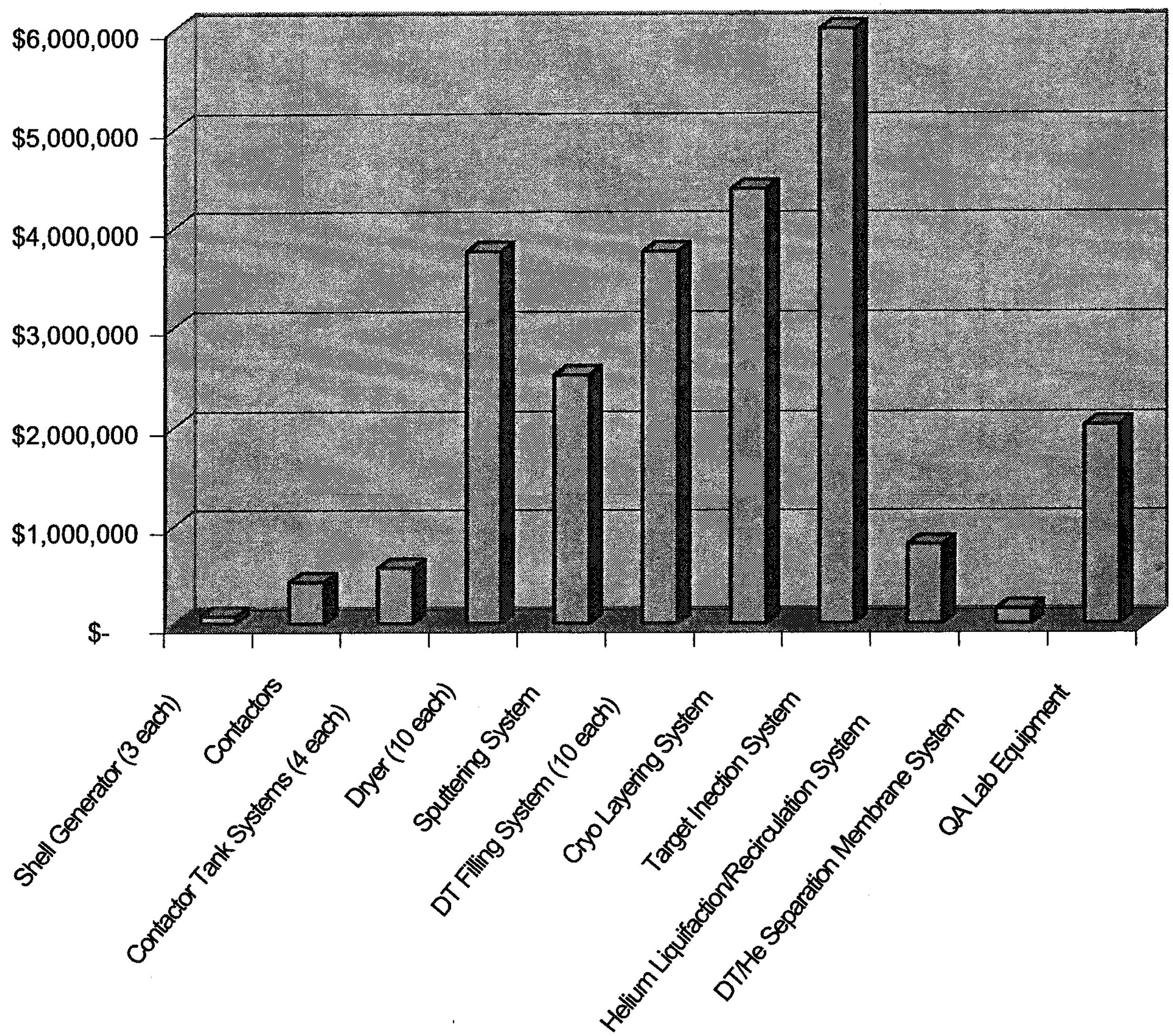
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,509,524
Electrical	$ 4,145,177
Instruments	$ 3,169,841
Building and services	$ 7,315,018
Site Preparation	$ 2,682,173
Auxiliaries	$ 13,410,867
Field Expenses	$ 10,484,859
Engineering	$ 8,290,354
Contractors fees	$ 4,145,177
Contingency	$ 9,509,524

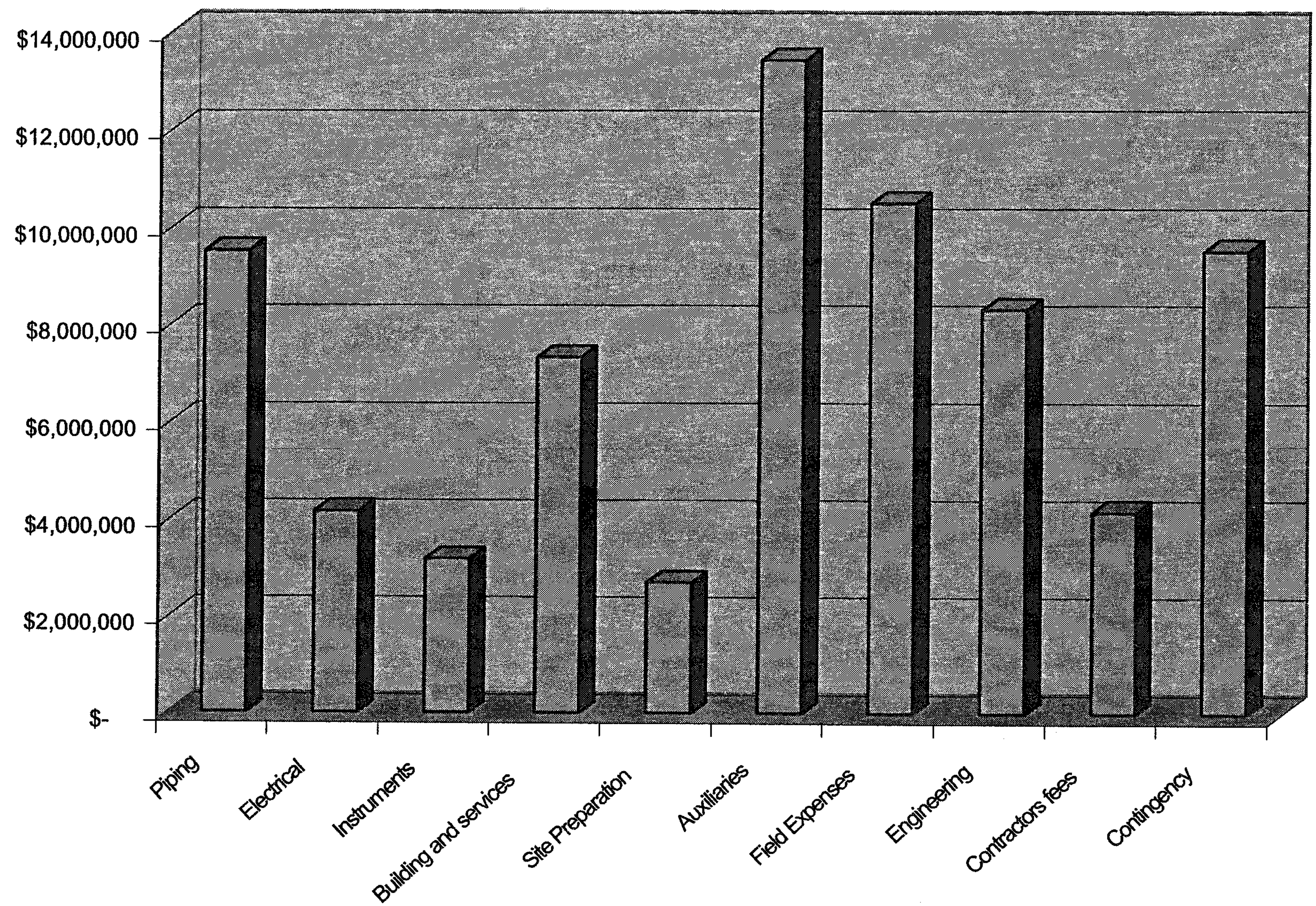
Total Installed Capital Cost **$ 97,045,907**

Annualized Cost of Capital Investment **$ 12,130,738**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



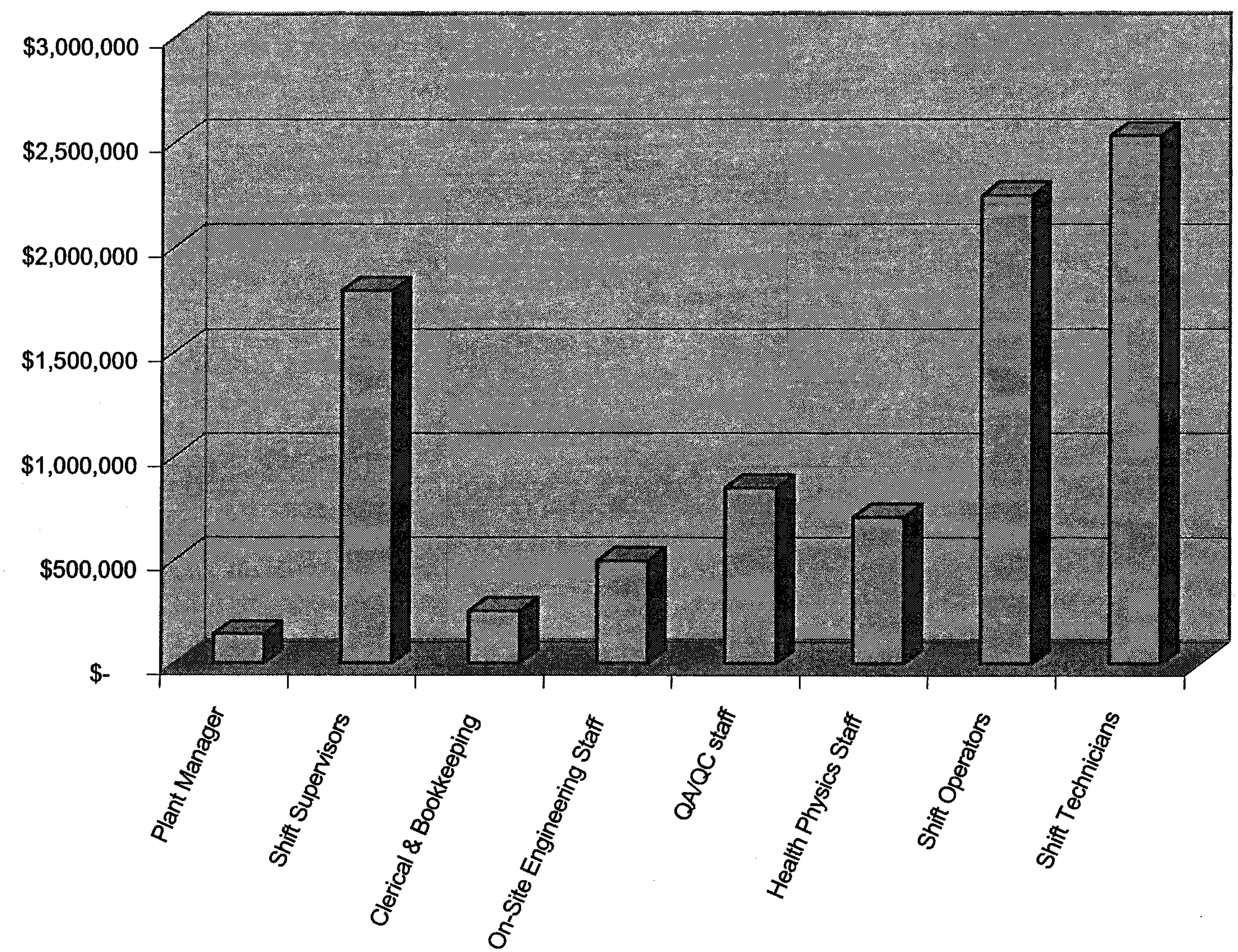
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041	1.34	1.34	1.00
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079	1.34	1.34	1.00
QA/QC staff	3	5	$ 40,000	$ 840,136	1.34	1.34	1.00
Health Physics Staff	2	5	$ 50,000	$ 700,113	1.34	1.34	1.00
Shift Operator - Contactor Area	2	5	$ 40,000	$ 560,090	1.34	1.34	1.00
Technician - Contactor Area	3	5	$ 30,000	$ 630,102	1.34	1.34	1.00
Shift Operator - Dryer Area	2	5	$ 40,000	$ 560,101	1.11	1.11	1.00
Technician - Dryer Area	3	5	$ 30,000	$ 630,114	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 560,134	1.02	1.02	1.00
Technician - Fill/Layer Area	3	5	$ 30,000	$ 630,151	1.02	1.02	1.00
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 8,968,372

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 840,136
Health Physics Staff	$ 700,113
Shift Operators	$ 2,240,326
Shift Technicians	$ 2,520,367

Operating Labor Costs for Foam Target Production

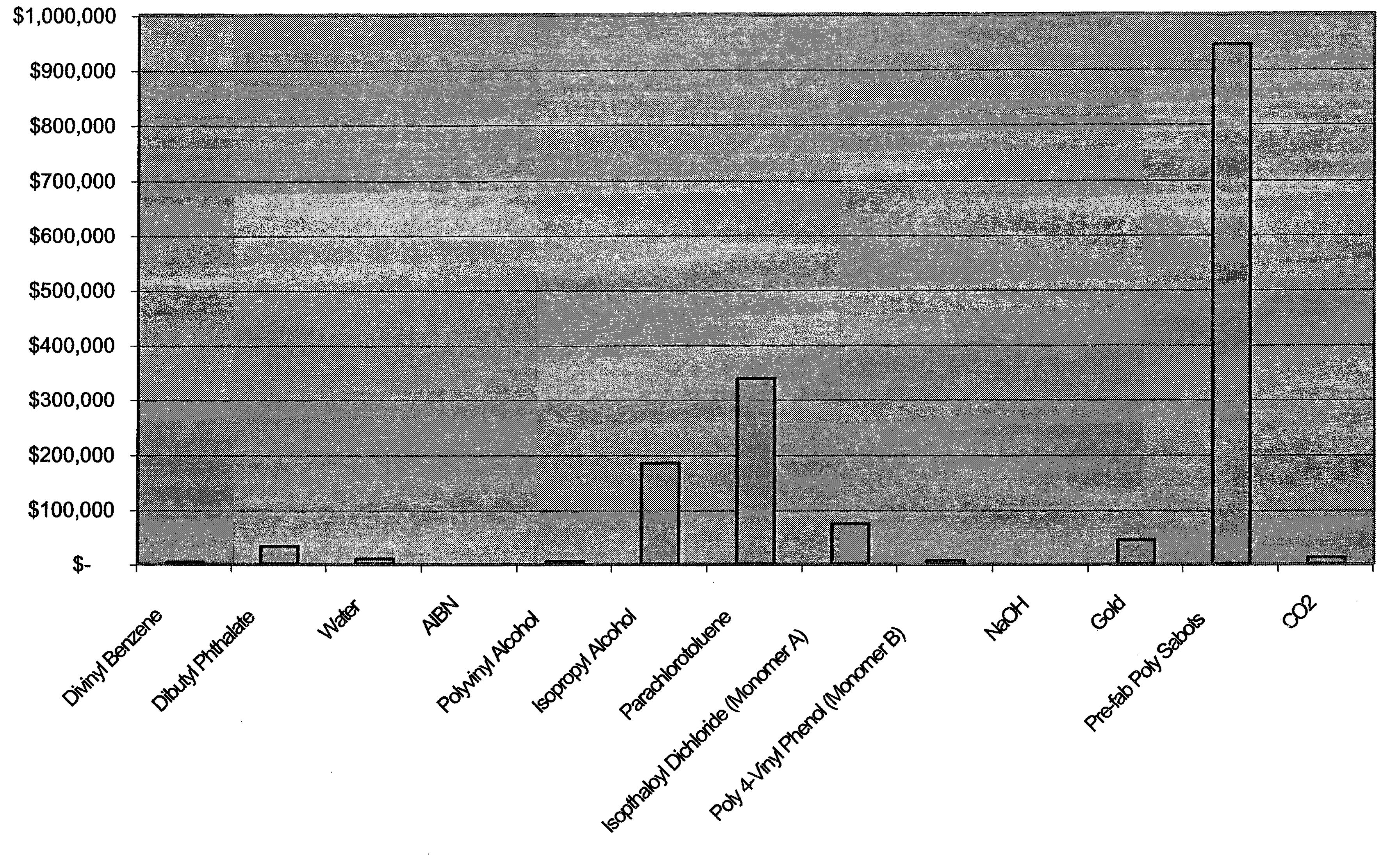


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	317	10.00	$ 3,169	
Dibutyl Phthalate	3169	10.00	$ 31,688	
Water	91457	0.10	$ 9,146	
AIBN	32	10.00	$ 317	
Polyvinyl Alcohol	424	10.00	$ 4,238	
Isopropyl Alcohol	91535	2.00	$ 183,070	
Parachlorotoluene	84212	4.00	$ 336,850	
Isopthaloyl Dichloride (Monomer A)	7323	10.00	$ 73,228	
Poly 4-Vinyl Phenol (Monomer B)	673	10.00	$ 6,731	
NaOH	25	2.00	$ 50	
Gold	4.6	9650.00	$ 43,950	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	61569	0.20	$ 12,314	

Annual materials costs = $ 1,648,274

Materials Costs (consumables) for Foam Target Production

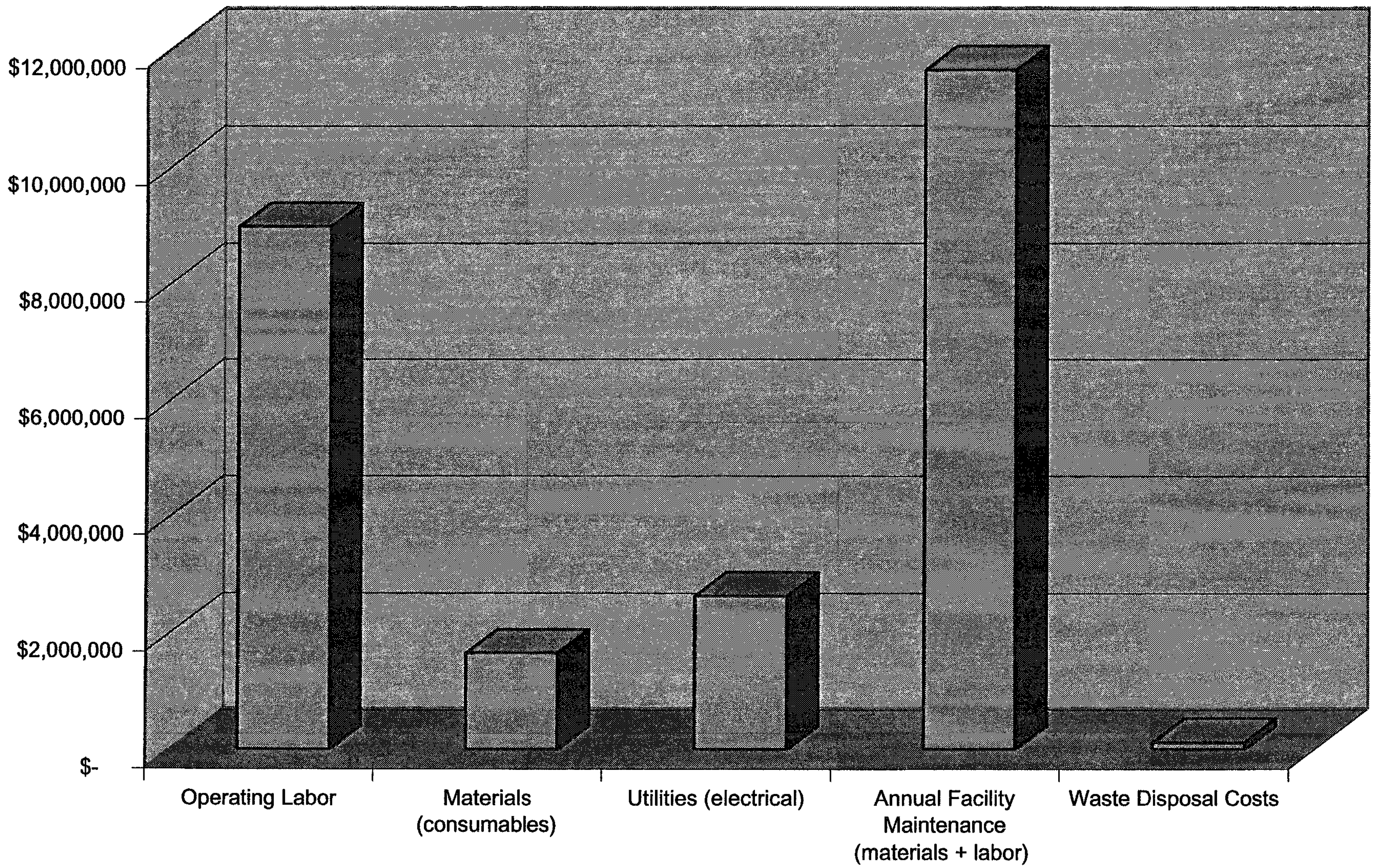


Operating Cost Summary for Foam Target Production

Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materials + labor)	$	11,645,509
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 25,020,138

Operating Costs for Foam Shell Production



Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materia	$	5,822,754
Waste Disposal Costs	$	122,047
Total Annual Operating Costs =	**$**	**19,197,383**

total cost per usable target =	0.196
cost for capital =	0.076
cost for operating =	0.120

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	561,691
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	24,383,394
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	9,509,524
Electrical	$	4,145,177
Instruments	$	3,169,841
Building and services	$	7,315,018
Site Preparation	$	2,682,173
Auxiliaries	$	13,410,867
Field Expenses	$	10,484,859
Engineering	$	8,290,354
Contractors fees	$	4,145,177
Contingency	$	9,509,524
	$	-
Total Installed Capital Cost	$	97,045,907
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**12,130,738**

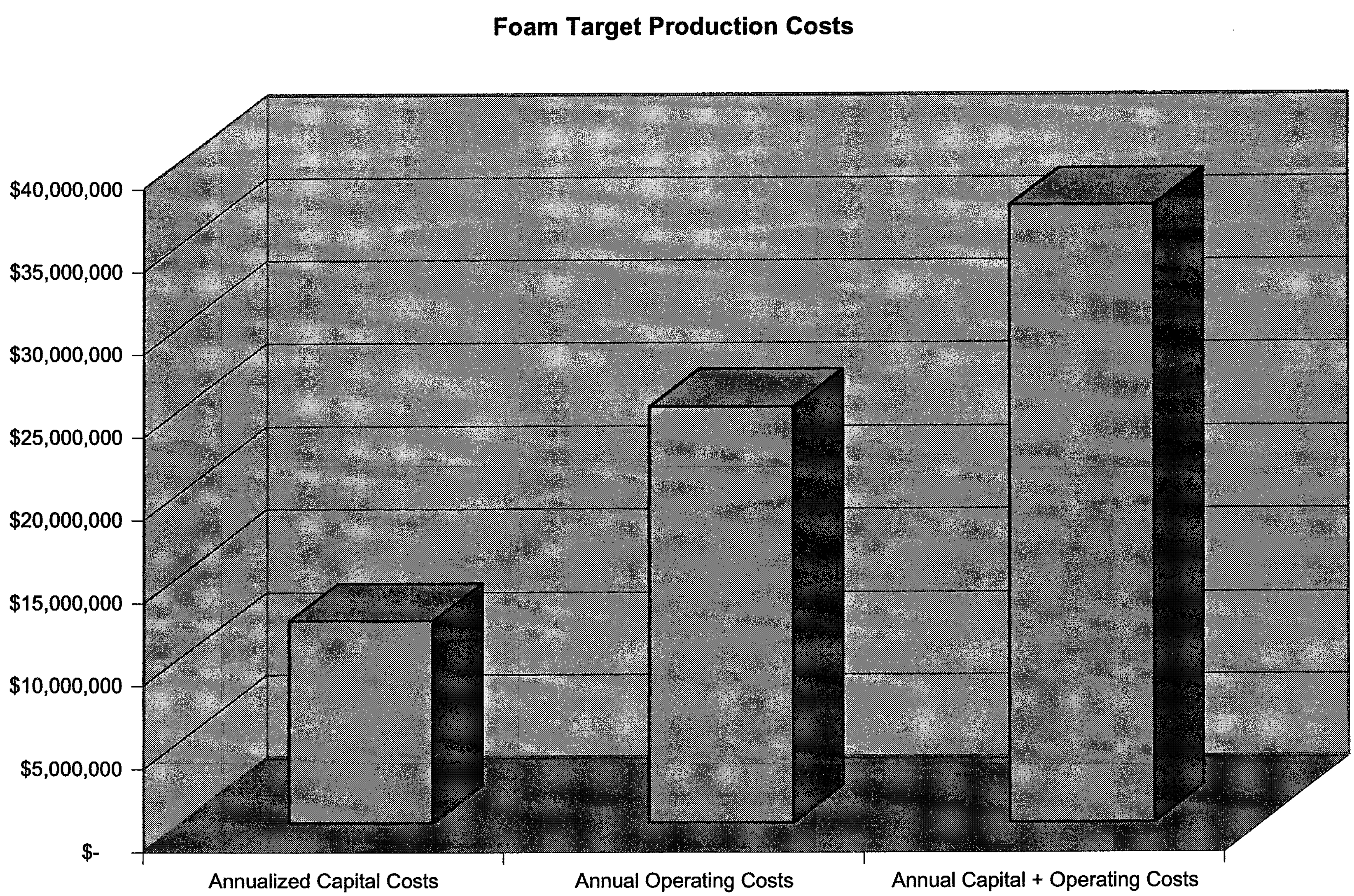
	cents per usable target	
waste disposal	0.076	
materials	1.033	
utilities	1.652	
maintenance	3.649	
operating labor	5.621	
	12.031	**total operating**
piping, electrical & instrumentation	1.318	
bldgs & auxiliaries	1.834	
purchased equipment	1.910	
engr, contractors, contingency	2.541	
	7.603	**total capital**
	19.634	**total capital + operating**

Cost Summary for Foam Target Production

Annualized Capital Costs	$ 12,130,738
Annual Operating Costs	$ 25,020,138

Annual Capital + Operating Costs	**$ 37,150,876**

Cost per Injected Target = $ 0.196


Foam Target Production Costs
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
Annualized Capital Costs
Annual Operating Costs
Annual Capital + Operating Costs

ATTACHMENT 5
Case 5 — Doubled utilities costs

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate = 25

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4 = the fill volume of each contactor (in liters)

975 = the total volume required for each tank (in liters)
1219.076 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.92 = height of tank, M
0.73 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

1.5 weeks storage in supply tank
1463 liters in storage tank

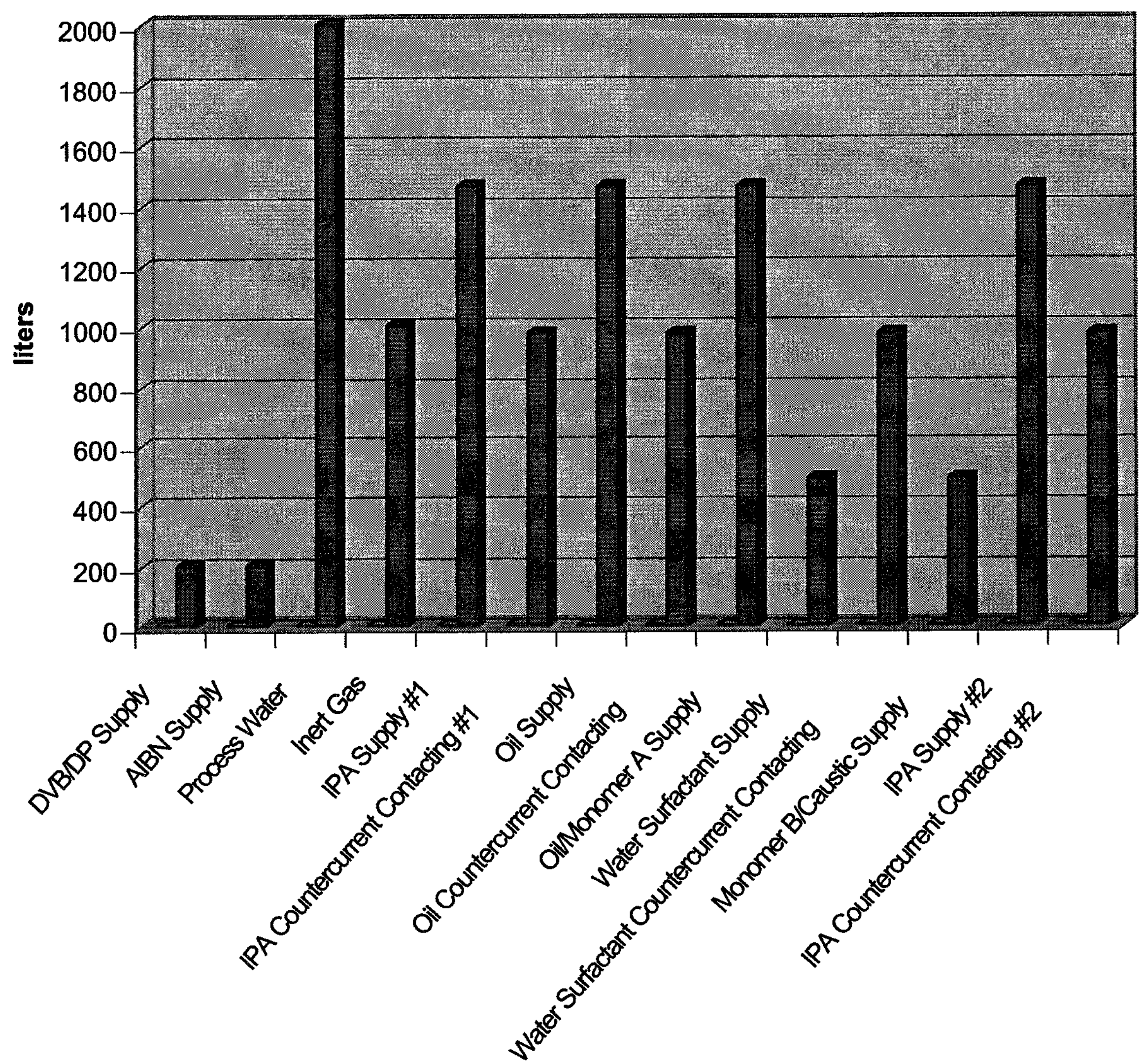
(a) Countercurrent contacting
(b) 25% reject rate through process

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1463	
IPA Countercurrent Contacting #1	5	975	
Oil Supply	1	1463	
Oil Countercurrent Contacting	5	975	
Oil/Monomer A Supply	1	1463	
Water Surfactant Supply	1	488	
Water Surfactant Countercurrent Contacting	2	975	
Monomer B/Caustic Supply	1	488	
IPA Supply #2	1	1463	
IPA Countercurrent Contacting #2	5	975	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	38.17																				30		
	Dibutyl Phthelate	361.73				361.73		362	362															
	Water			605.79	4837.60	5443.39		5443	5443							5225		5216						
	AIBN		3.62																					
	Polyvinyl Alcohol				48.38	48.38		48	48															
	Polymerized DVB					39.79		40	40															
	Isopropyl Alcohol (IPA)									5225										5225		502		
	Parachlorotoluene											5225		4389										
	Spent Solvent #1																							
	Isophthaloyl dichloride													836										
	Poly 4-Vinyl Phenol																	77					-	
	NaOH																	3						
	Mixed liquid waste										5225		5225		5225		5225		5295		5225			
	CO_2																						7028	
	Au or Pd																							0.52
Gases	N_2						93.80																	
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2006	KW usage
$	0.15	cost per KW-hr
	2	factor to multiply utilities by (for single variable response study)

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000

Total Process Equipment Cost	**$ 24,381,691**				**$ 24,383,394**

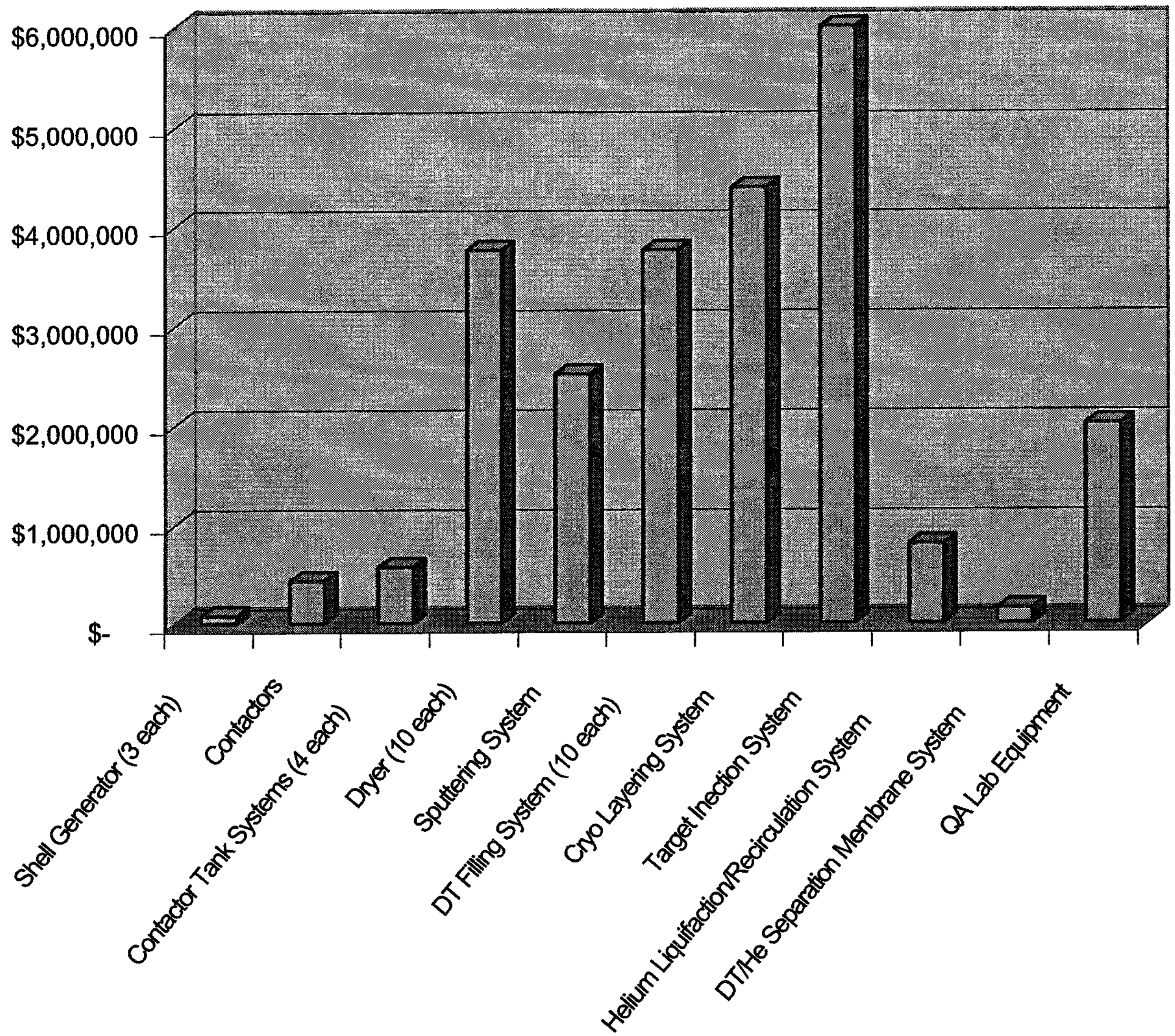
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,509,524
Electrical	$ 4,145,177
Instruments	$ 3,169,841
Building and services	$ 7,315,018
Site Preparation	$ 2,682,173
Auxiliaries	$ 13,410,867
Field Expenses	$ 10,484,859
Engineering	$ 8,290,354
Contractors fees	$ 4,145,177
Contingency	$ 9,509,524

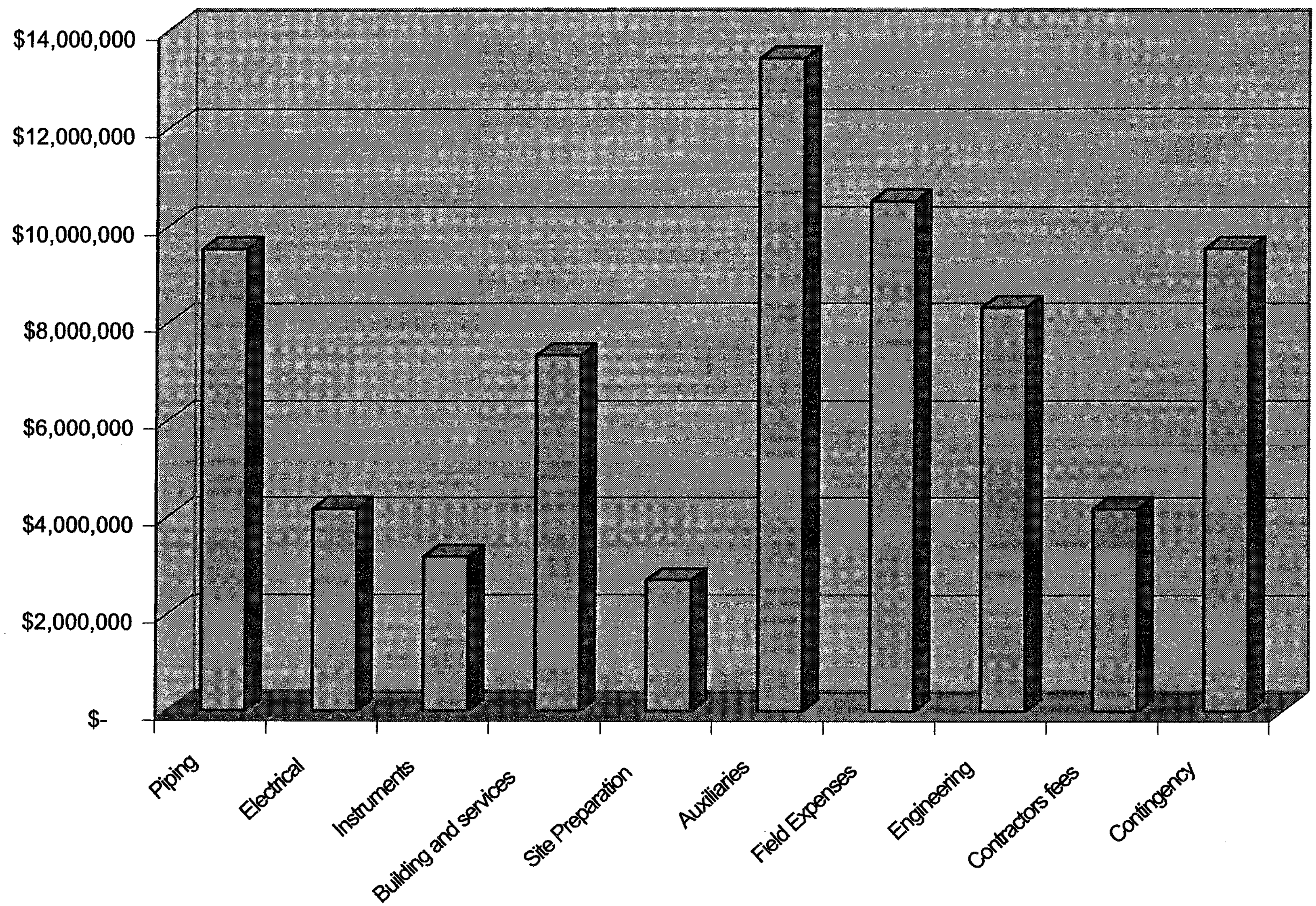
Total Installed Capital Cost **$ 97,045,907**

Annualized Cost of Capital Investment **$ 12,130,738**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



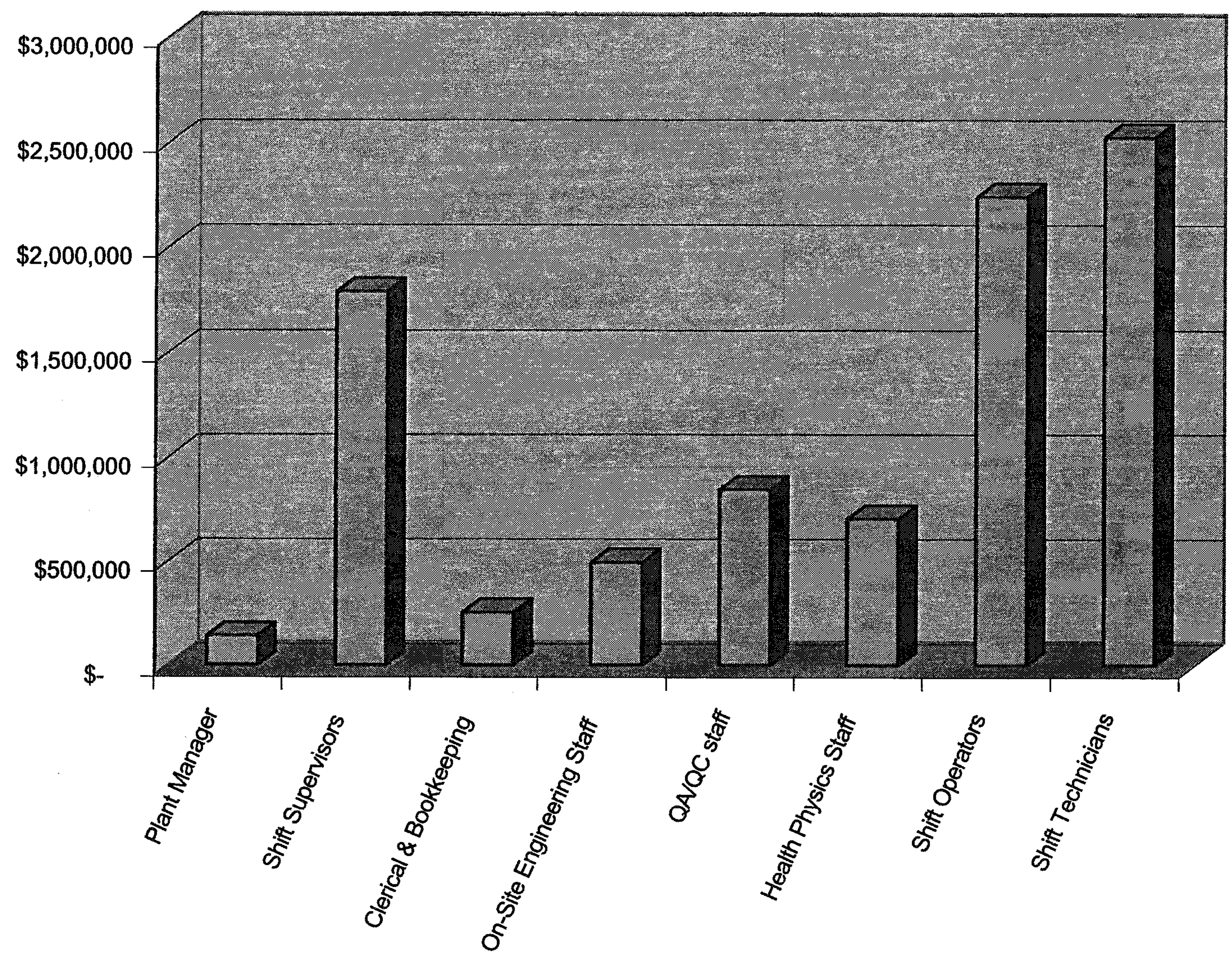
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041	1.34	1.34	1.00
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079	1.34	1.34	1.00
QA/QC staff	3	5	$ 40,000	$ 840,136	1.34	1.34	1.00
Health Physics Staff	2	5	$ 50,000	$ 700,113	1.34	1.34	1.00
Shift Operator - Contactor Area	2	5	$ 40,000	$ 560,090	1.34	1.34	1.00
Technician - Contactor Area	3	5	$ 30,000	$ 630,102	1.34	1.34	1.00
Shift Operator - Dryer Area	2	5	$ 40,000	$ 560,101	1.11	1.11	1.00
Technician - Dryer Area	3	5	$ 30,000	$ 630,114	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 560,134	1.02	1.02	1.00
Technician - Fill/Layer Area	3	5	$ 30,000	$ 630,151	1.02	1.02	1.00
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 8,968,372

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 840,136
Health Physics Staff	$ 700,113
Shift Operators	$ 2,240,326
Shift Technicians	$ 2,520,367

Operating Labor Costs for Foam Target Production

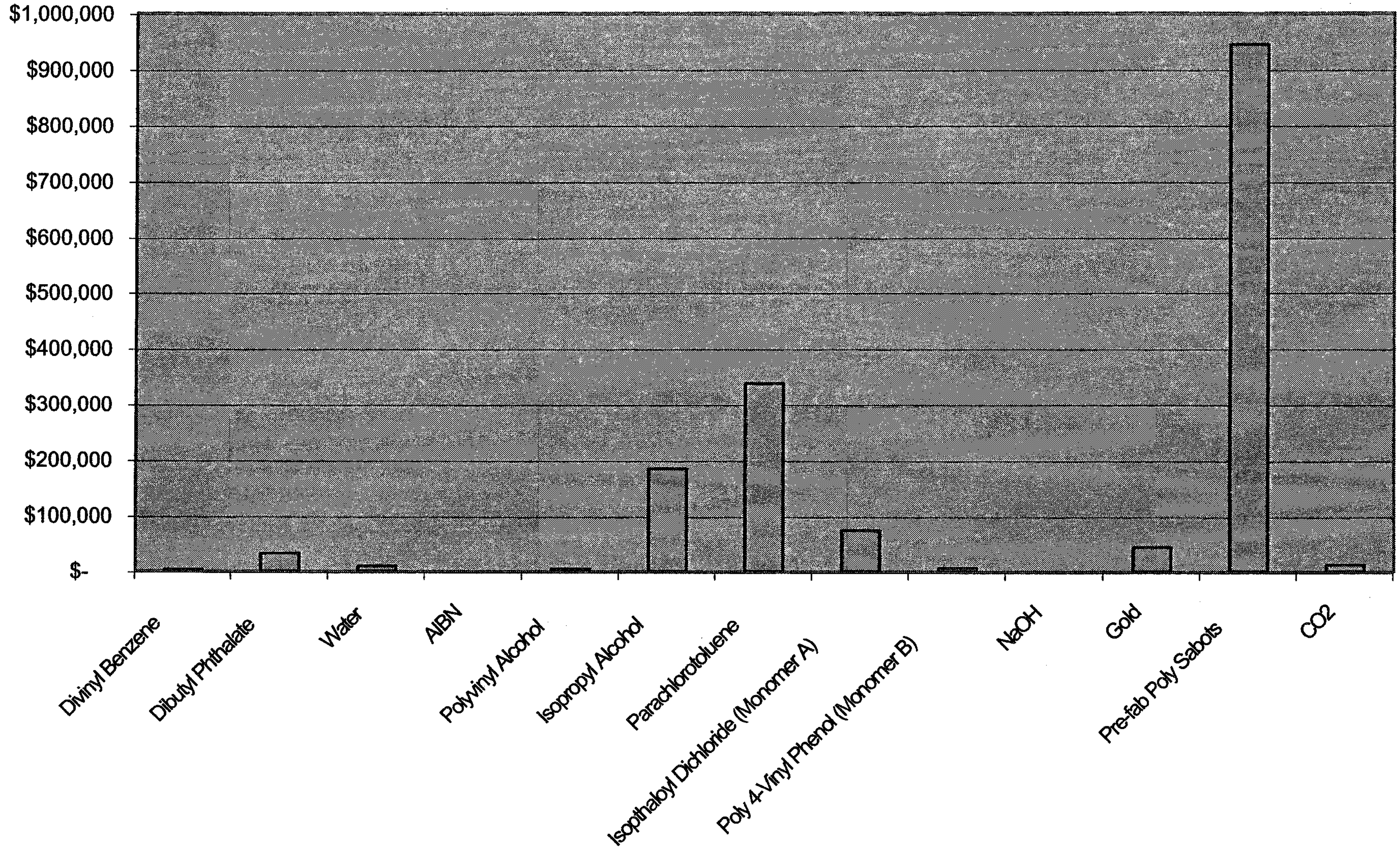


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	317	10.00	$ 3,169	
Dibutyl Phthalate	3169	10.00	$ 31,688	
Water	91457	0.10	$ 9,146	
AIBN	32	10.00	$ 317	
Polyvinyl Alcohol	424	10.00	$ 4,238	
Isopropyl Alcohol	91535	2.00	$ 183,070	
Parachlorotoluene	84212	4.00	$ 336,850	
Isopthaloyl Dichloride (Monomer A)	7323	10.00	$ 73,228	
Poly 4-Vinyl Phenol (Monomer B)	673	10.00	$ 6,731	
NaOH	25	2.00	$ 50	
Gold	4.6	9650.00	$ 43,950	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	61569	0.20	$ 12,314	

Annual materials costs = $ 1,648,274

Materials Costs (consumables) for Foam Target Production

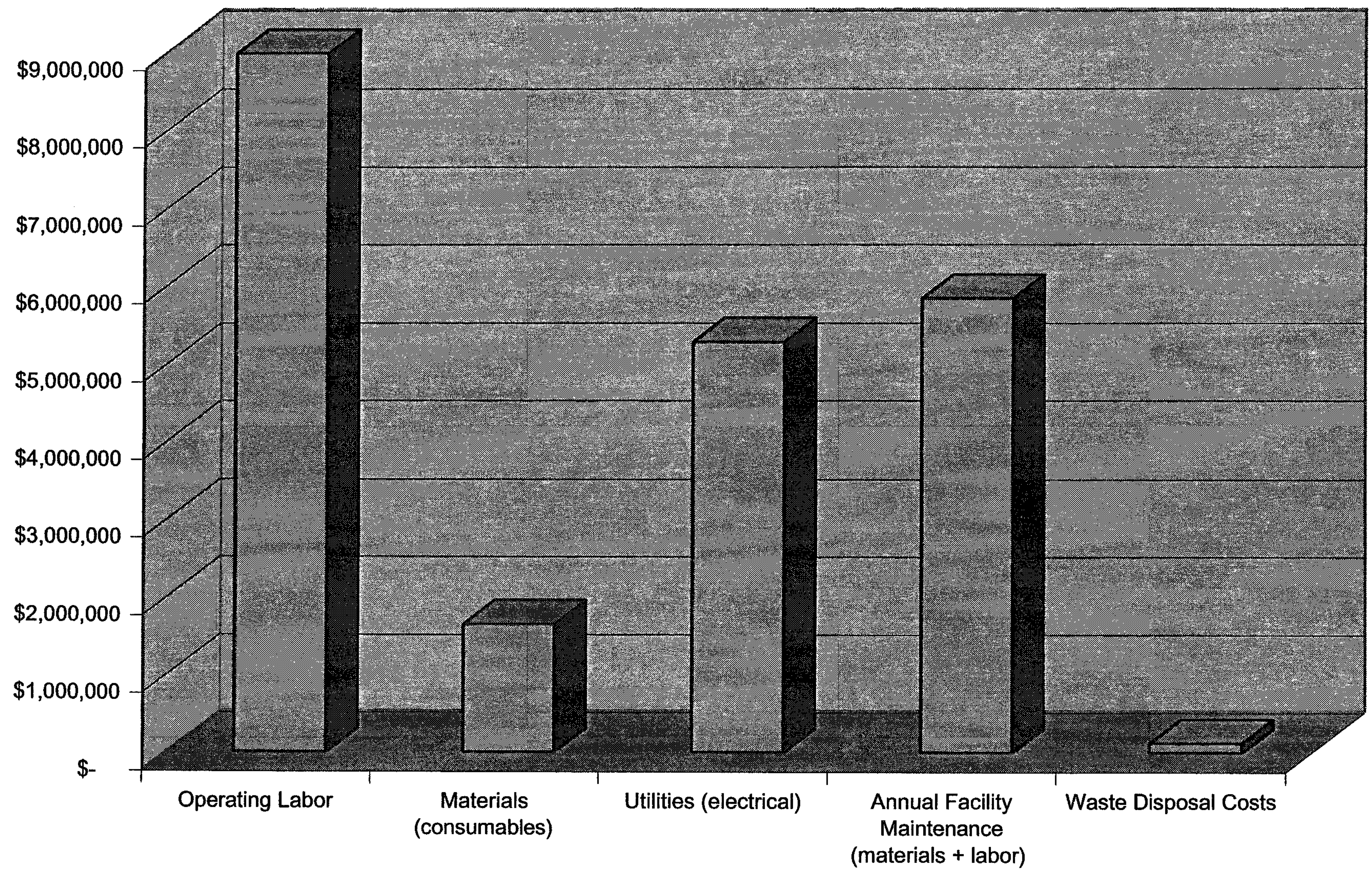


Operating Cost Summary for Foam Target Production

Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	5,271,872
Annual Facility Maintenance (materials + labor)	$	5,822,754
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 21,833,320

Operating Costs for Foam Shell Production



Operating Labor	$	8,968,372
Materials (consumables)	$	1,648,274
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materi	$	5,822,754
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 19,197,383

total cost per usable target =	0.179
cost for capital =	0.070
cost for operating =	0.110

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	561,691
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	24,383,394
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	9,509,524
Electrical	$	4,145,177
Instruments	$	3,169,841
Building and services	$	7,315,018
Site Preparation	$	2,682,173
Auxiliaries	$	13,410,867
Field Expenses	$	10,484,859
Engineering	$	8,290,354
Contractors fees	$	4,145,177
Contingency	$	9,509,524
	$	-
Total Installed Capital Cost	$	97,045,907
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**12,130,738**

	cents per usable target	
waste disposal	0.070	
materials	0.944	
utilities	1.510	
maintenance	3.336	
operating labor	5.139	
	10.999	**total operating**
piping, electrical & instrumentation	1.205	
bldgs & auxiliaries	1.676	
purchased equipment	1.746	
engr, contractors, contingency	2.323	
	6.950	**total capital**
	17.950	**total capital + operating**

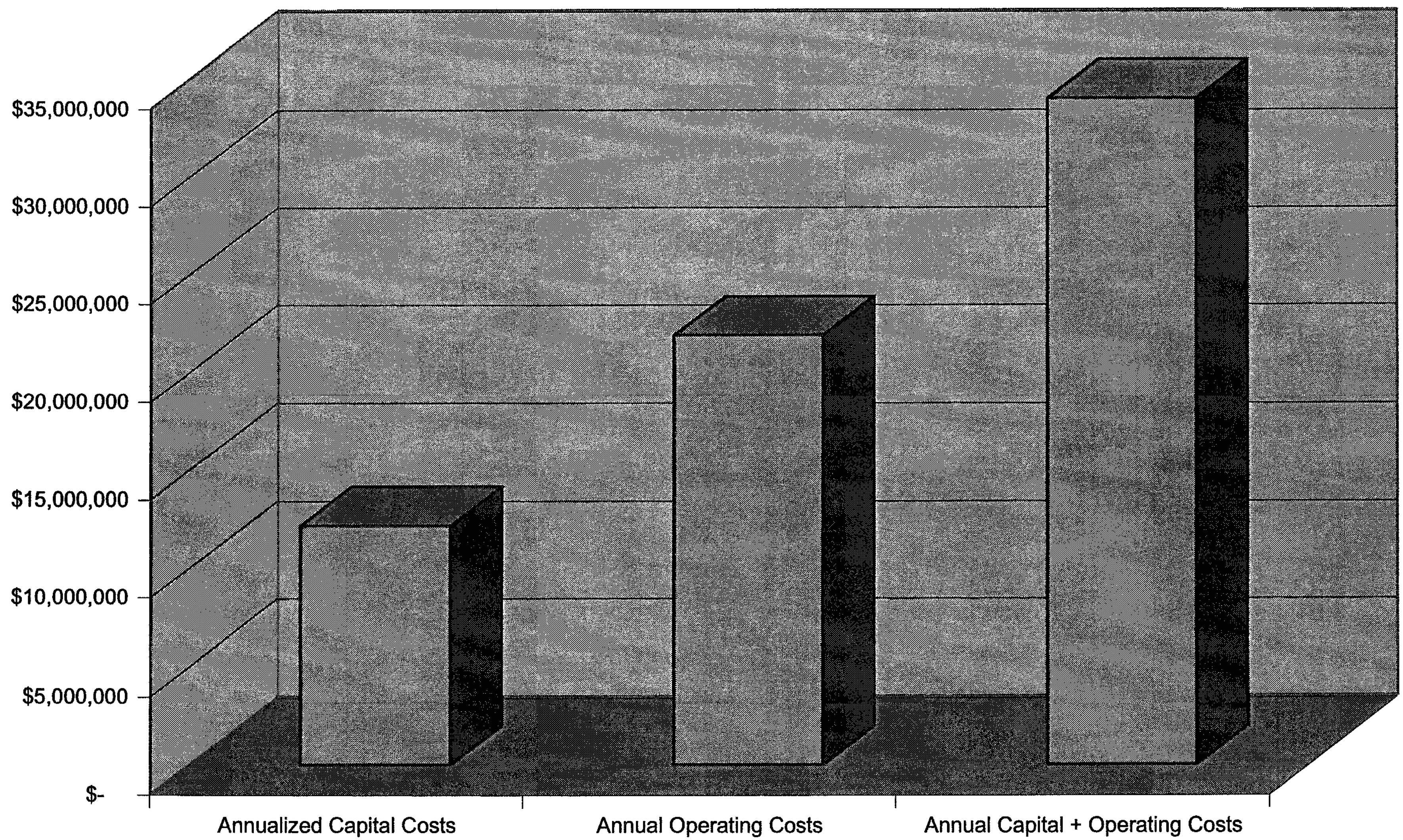
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 12,130,738
Annual Operating Costs	$ 21,833,320

Annual Capital + Operating Costs	**$ 33,964,058**

Cost per Injected Target = $ 0.179

Foam Target Production Costs



ATTACHMENT 5
Case 6 — Baseline (@5% reject rate)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
1.0	% reject rate at droplet forming stage
1.0	% reject rate at ICP stage
1.0	% reject rate at CO2 drying stage
1.0	% reject rate at high Z coating stage
1.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
545116	total shells produced per day
22713	total shells produced per hour
28.4	mass flow of shells (DVB only), g/hr
2.84	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
284.42	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
476.3	inner water flow, g/hr
476.3	inner water flow, cc/hr
0.033	volume of each shell, cc
760.7	volume of shells produced, cc/hr
3803.7	volume of outer water, cc/hr
3803.7	mass flow of outer water, g/hr
36515.5	contactor initial fill volume, cc
91288.8	contactor initial total volume, cc
48.8	contactor diameter, cm
48.8	contactor length, cm
38.0	PVA usage, g/hr
54773	vapor space in contactor, cc
54773	N_2 usage, cc/hr
73.8	N_2 usage, g/hr
198967381	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.64	mass flow usage of gold in high Z coating, g/hr
219	volume of waste per contactor, liters
657	volume of waste per day from contactors, liters
0.66	tons per day of waste liquids from contactors
240	tons per year of waste liquids from contactors
6086	volume of shells in dryer, cc
20286	volume of dryer, cc
23.5	contactor diameter, cm
46.9	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.05	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	1	1.052	22713	227	1.000
ICP layer	1	1.041	22486	225	0.990
CO_2 drying	1	1.031	22261	223	0.980
Sputter Coating	1	1.020	22039	220	0.970
DT Filling	1	1.010	21818	218	0.961
Layering and Injection	0	1	21600	0	0.951

overall % reject rate = 5

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

36.5 = the fill volume of each contactor (in liters)

767 = the total volume required for each tank (in liters)
958.5322 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.69 = height of tank, M
0.67 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

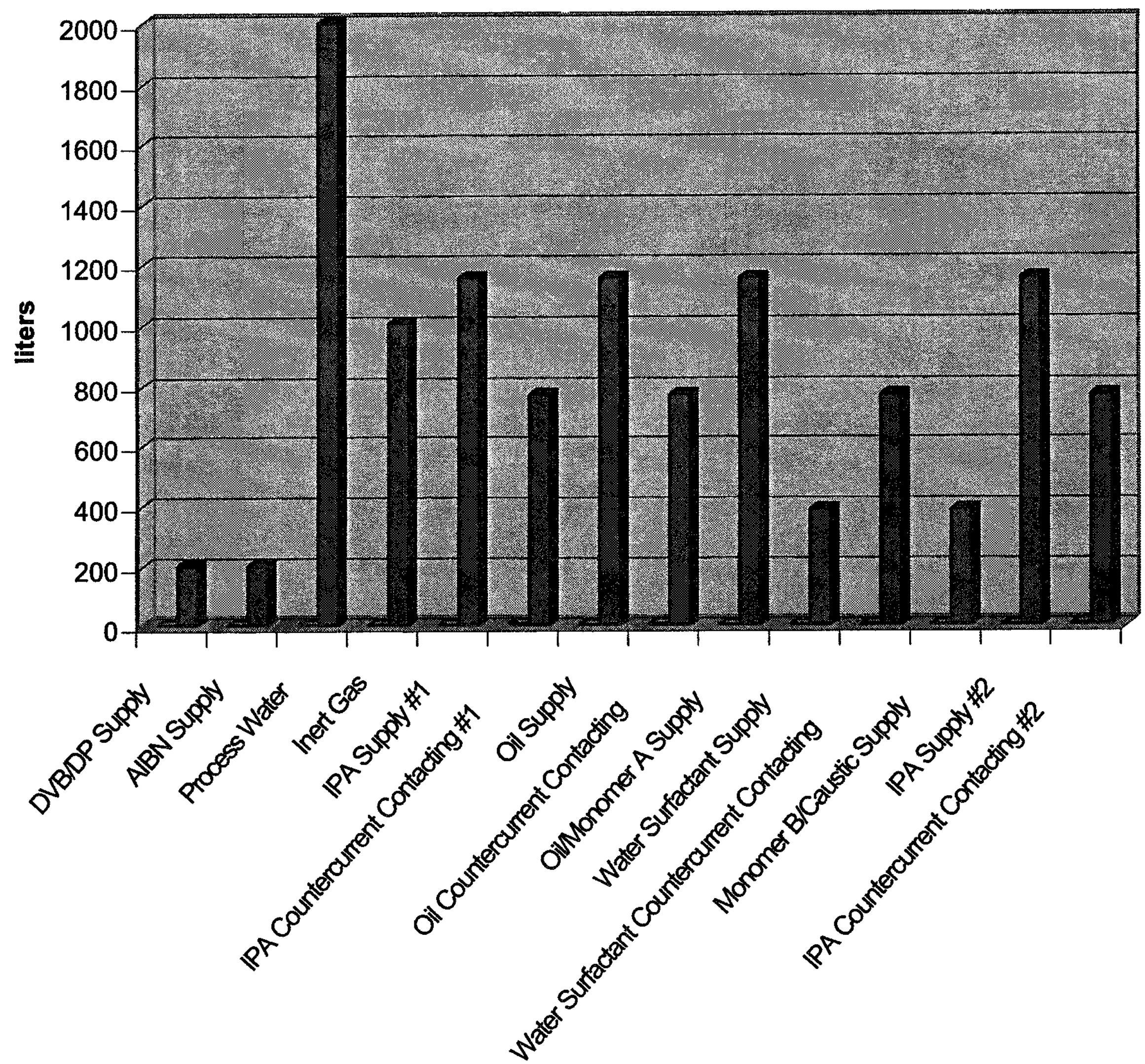
1.5 weeks storage in supply tank
1150 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	1150	
IPA Countercurrent Contacting #1	5	767	
Oil Supply	1	1150	
Oil Countercurrent Contacting	5	767	
Oil/Monomer A Supply	1	1150	
Water Surfactant Supply	1	383	
Water Surfactant Countercurrent Contacting	2	767	
Monomer B/Caustic Supply	1	383	
IPA Supply #2	1	1150	
IPA Countercurrent Contacting #2	5	767	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	28.44																				28		
	Dibutyl Phthalate	284.42				284.42		284	284															
	Water			476.32	3803.70	4280.02		4280	4280							4519		4510						
	AIBN		2.84																					
	Polyvinyl Alcohol				38.04	38.04		38	38															
	Polymerized DVB					31.29		31	31															
	Isopropyl Alcohol (IPA)									4519										4519		467		
	Parachlorotoluene											4519		3796										
	Spent Solvent #1																							
	Isophthaloyl dichloride													723										
	Poly 4-Vinyl Phenol																	66						
	NaOH																	3						
	Mixed liquid waste										4519		4519		4519		4519		4579		4519			
	CO_2																						6541	
	Au or Pd																							0.62
Gases	N_2						73.75																	
Total, g/hr		312.9	2.8	476.3	3841.7	4633.8	73.8	4633.8	4633.8	4518.8	4518.8	4518.8	4518.8	4518.8	4518.8	4518.8	4518.8	4579.4	4579.4	4518.8	4518.8	494.7	6541.4	0.6

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	73,607	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipme
	1577	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.05	1.34	0.866	$ 64,935
Contactors	$ 420,000	1.05	1.34	0.866	$ 363,634
Contactor Tank Systems (4 each)	$ 441,645	1.05	1.34	0.866	$ 382,374
Dryer (10 each)	$ 3,750,000	1.03	1.11	0.958	$ 3,592,521
Sputtering System	$ 2,500,000	1.02	1.05	0.982	$ 2,454,530
DT Filling System (10 each)	$ 3,750,000	1.01	1.02	0.994	$ 3,728,121
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,261,645**				**$ 23,911,116**

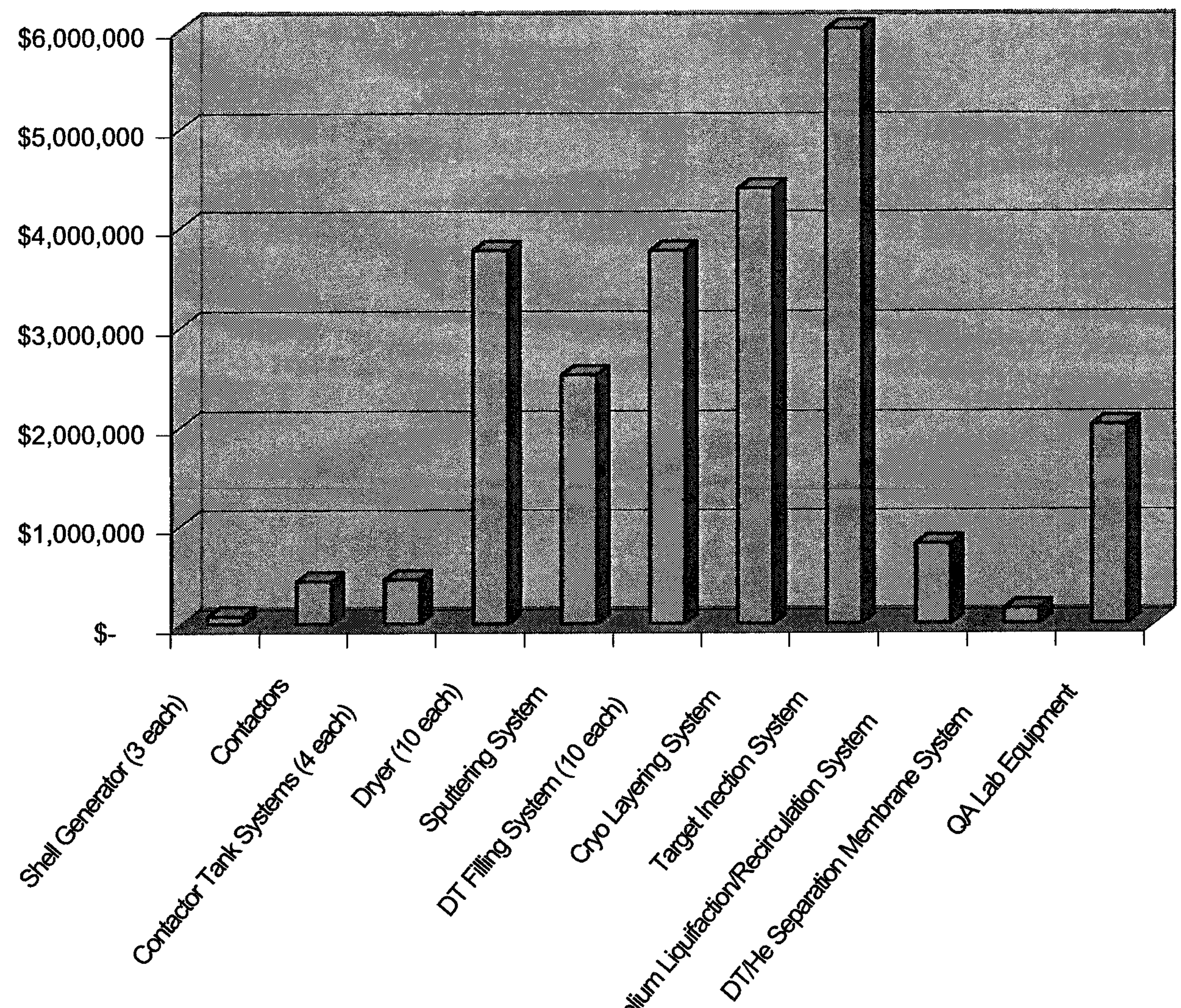
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,325,335
Electrical	$ 4,064,890
Instruments	$ 3,108,445
Building and services	$ 7,173,335
Site Preparation	$ 2,630,223
Auxiliaries	$ 13,151,114
Field Expenses	$ 10,281,780
Engineering	$ 8,129,779
Contractors fees	$ 4,064,890
Contingency	$ 9,325,335

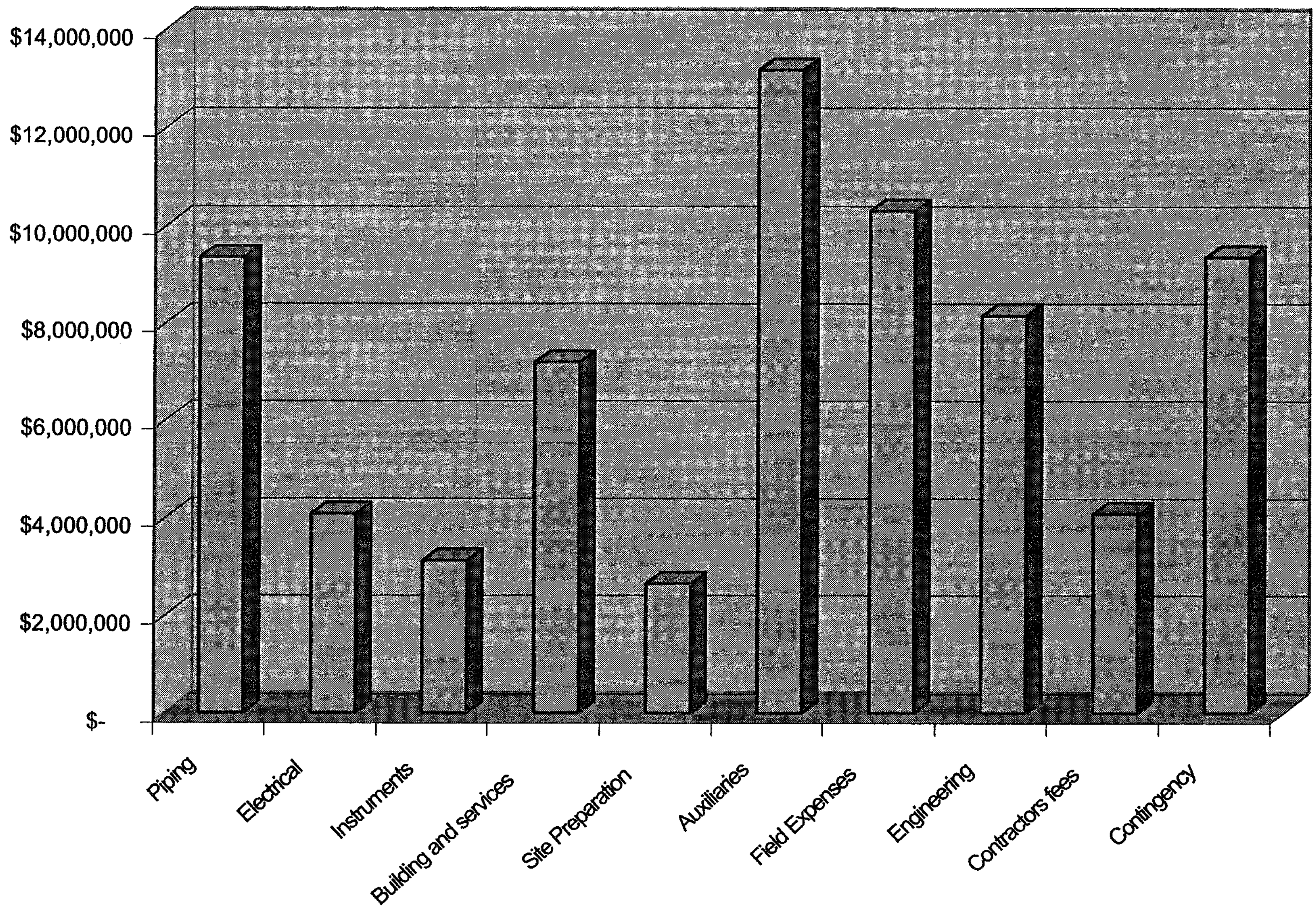
Total Installed Capital Cost **$ 95,166,242**

Annualized Cost of Capital Investment **$ 11,895,780**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



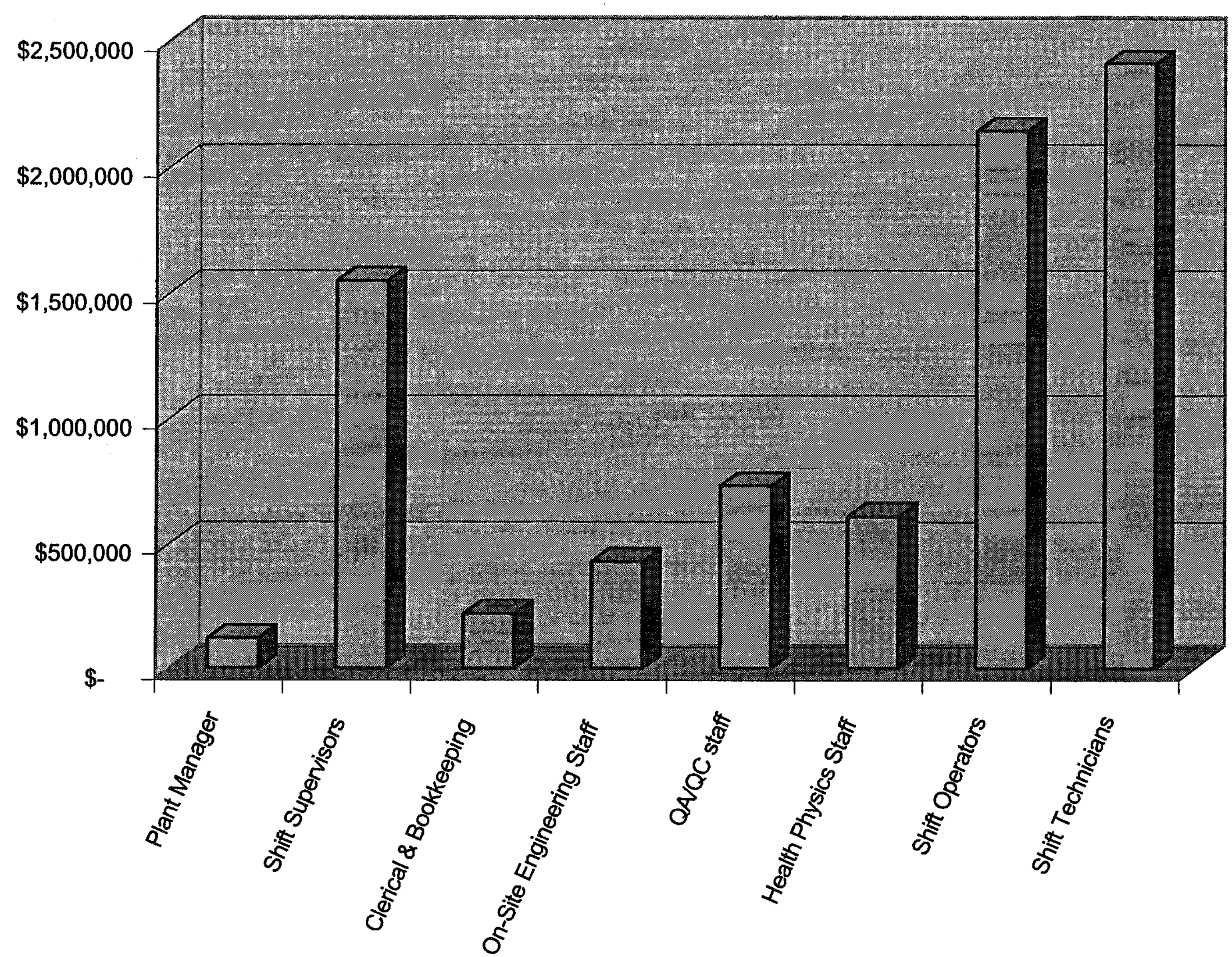
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 121,211	1.34	1.052	0.87
Shift Supervisors	3	5	$ 85,000	$ 1,545,446	1.34	1.05	0.87
Clerical & Bookkeeping	6	1	$ 30,000	$ 218,181	1.34	1.05	0.87
On-Site Engineering Staff	5	1	$ 70,000	$ 424,240	1.34	1.05	0.87
QA/QC staff	3	5	$ 40,000	$ 727,269	1.34	1.05	0.87
Health Physics Staff	2	5	$ 50,000	$ 606,057	1.34	1.05	0.87
Shift Operator - Contactor Area	2	5	$ 40,000	$ 484,846	1.34	1.05	0.87
Technician - Contactor Area	3	5	$ 30,000	$ 545,451	1.34	1.05	0.87
Shift Operator - Dryer Area	2	5	$ 40,000	$ 536,483	1.11	1.03	0.96
Technician - Dryer Area	3	5	$ 30,000	$ 603,544	1.11	1.03	0.96
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 556,733	1.02	1.01	0.99
Technician - Fill/Layer Area	3	5	$ 30,000	$ 626,324	1.02	1.01	0.99
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 8,185,785

Plant Manager	$ 121,211
Shift Supervisors	$ 1,545,446
Clerical & Bookkeeping	$ 218,181
On-Site Engineering Staff	$ 424,240
QA/QC staff	$ 727,269
Health Physics Staff	$ 606,057
Shift Operators	$ 2,138,062
Shift Technicians	$ 2,405,319

Operating Labor Costs for Foam Target Production

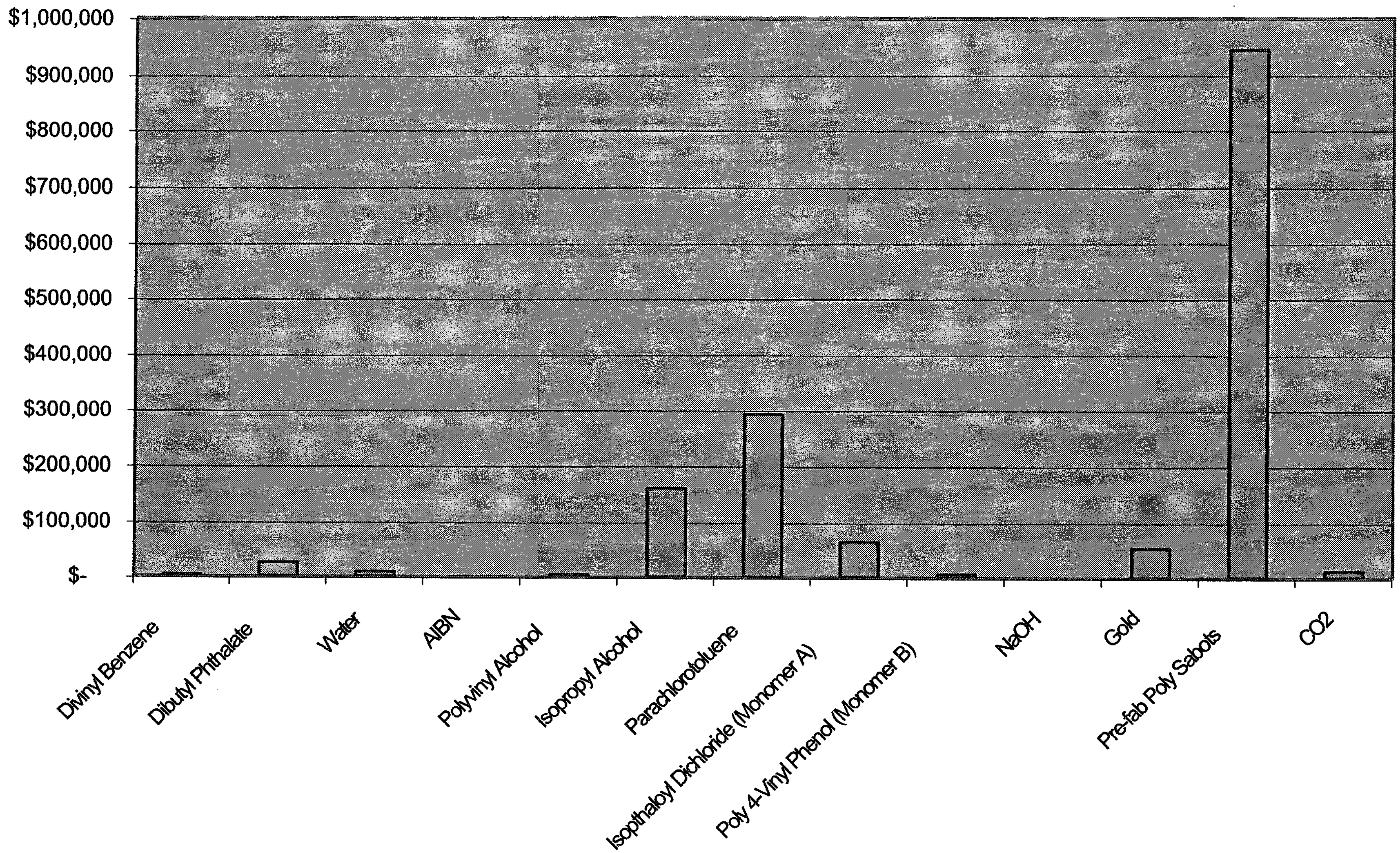


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	249	10.00	$ 2,492	
Dibutyl Phthalate	2492	10.00	$ 24,915	
Water	79094	0.10	$ 7,909	
AIBN	25	10.00	$ 249	
Polyvinyl Alcohol	333	10.00	$ 3,332	
Isopropyl Alcohol	79169	2.00	$ 158,339	
Parachlorotoluene	72836	4.00	$ 291,343	
Isopthaloyl Dichloride (Monomer A)	6334	10.00	$ 63,335	
Poly 4-Vinyl Phenol (Monomer B)	582	10.00	$ 5,821	
NaOH	24	2.00	$ 48	
Gold	5.4	9650.00	$ 52,583	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	57303	0.20	$ 11,461	

Annual materials costs = $ 1,565,350

Materials Costs (consumables) for Foam Target Production

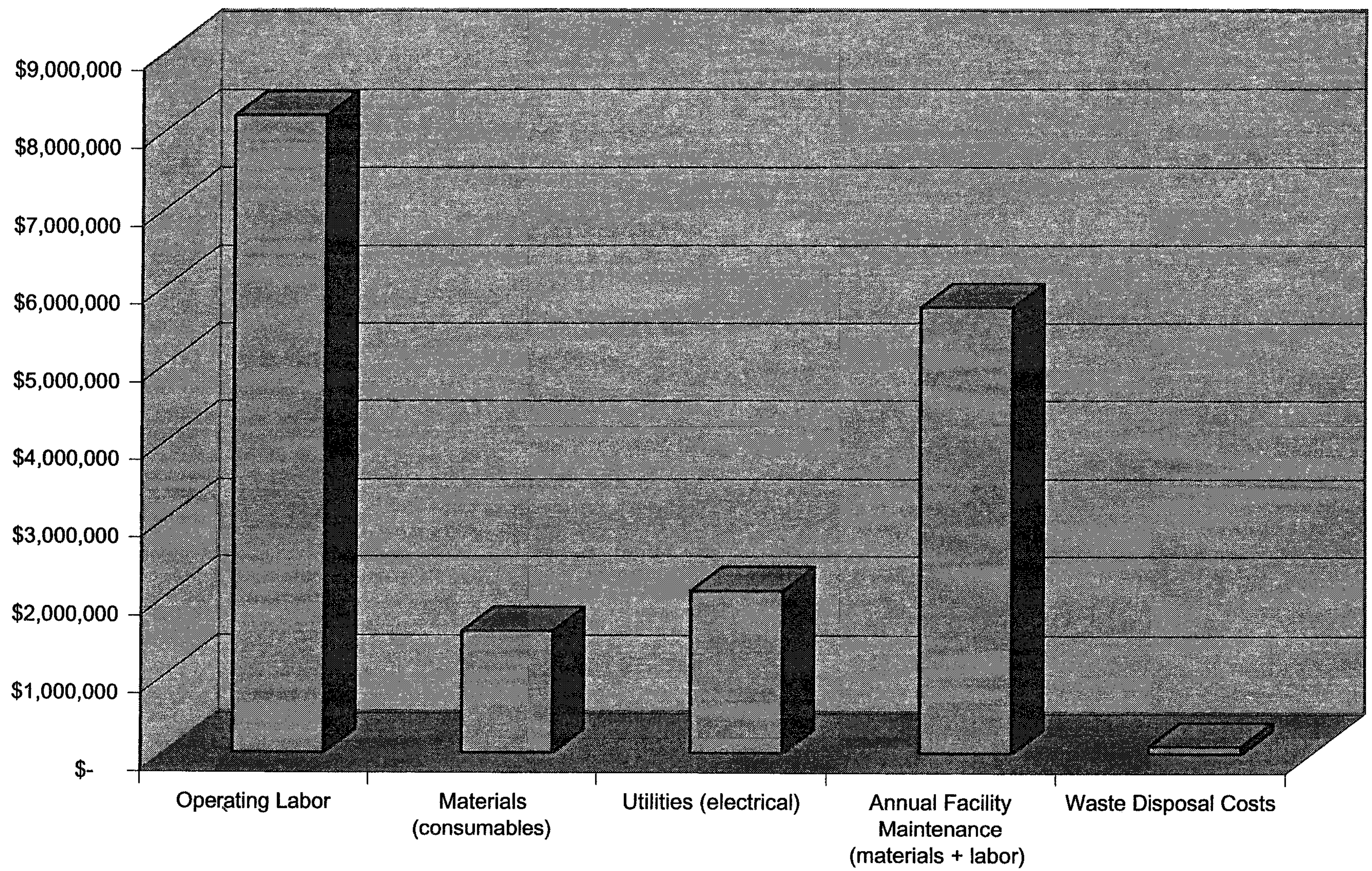


Operating Cost Summary for Foam Target Production

Operating Labor	$	8,185,785
Materials (consumables)	$	1,565,350
Utilities (electrical)	$	2,072,577
Annual Facility Maintenance (materials + labor)	$	5,709,975
Waste Disposal Costs	$	95,963

Total Annual Operating Costs = $ 17,629,649

Operating Costs for Foam Shell Production



Operating Labor	$	8,185,785
Materials (consumables)	$	1,565,350
Utilities (electrical)	$	2,072,577
Annual Facility Maintenance (materi	$	5,709,975
Waste Disposal Costs	$	95,963
Total Annual Operating Costs =	**$**	**17,629,649**

total cost per usable target =	0.156
cost for capital =	0.063
cost for operating =	0.093

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	441,645
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	23,911,116
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	9,325,335
Electrical	$	4,064,890
Instruments	$	3,108,445
Building and services	$	7,173,335
Site Preparation	$	2,630,223
Auxiliaries	$	13,151,114
Field Expenses	$	10,281,780
Engineering	$	8,129,779
Contractors fees	$	4,064,890
Contingency	$	9,325,335
	$	-
Total Installed Capital Cost	$	95,166,242
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**11,895,780**

	cents per usable target	
waste disposal	0.051	
materials	0.827	
utilities	1.095	
maintenance	3.018	
operating labor	4.326	
	9.317	**total operating**
piping, electrical & instrumentation	1.090	
bldgs & auxiliaries	1.516	
purchased equipment	1.580	
engr, contractors, contingency	2.101	
	6.287	**total capital**
	15.604	**total capital + operating**

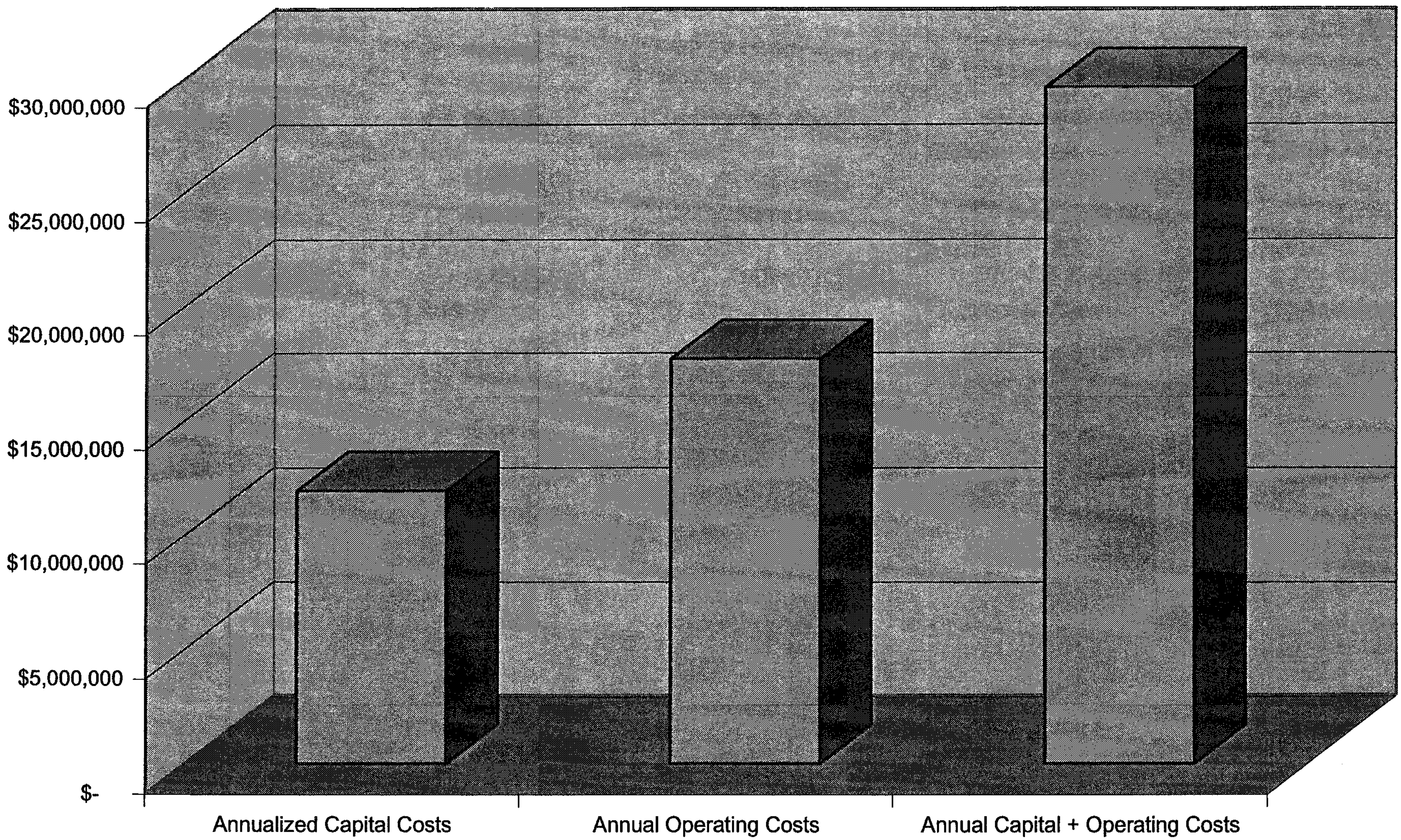
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 11,895,780
Annual Operating Costs	$ 17,629,649

Annual Capital + Operating Costs	**$ 29,525,430**

Cost per Injected Target = $ 0.156

Foam Target Production Costs



ATTACHMENT 5
Case 7 — Baseline (@50% reject rate)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
22.0	% reject rate at droplet forming stage
18.0	% reject rate at ICP stage
12.0	% reject rate at CO2 drying stage
7.0	% reject rate at high Z coating stage
5.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
1042479	total shells produced per day
43437	total shells produced per hour
54.4	mass flow of shells (DVB only), g/hr
5.44	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
543.93	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
910.9	inner water flow, g/hr
910.9	inner water flow, cc/hr
0.033	volume of each shell, cc
1454.8	volume of shells produced, cc/hr
7274.2	volume of outer water, cc/hr
7274.2	mass flow of outer water, g/hr
69832.2	contactor initial fill volume, cc
174580.5	contactor initial total volume, cc
60.6	contactor diameter, cm
60.6	contactor length, cm
72.7	PVA usage, g/hr
104748	vapor space in contactor, cc
104748	N_2 usage, cc/hr
141.0	N_2 usage, g/hr
380504832	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.71	mass flow usage of gold in high Z coating, g/hr
419	volume of waste per contactor, liters
1257	volume of waste per day from contactors, liters
1.26	tons per day of waste liquids from contactors
459	tons per year of waste liquids from contactors
11639	volume of shells in dryer, cc
38796	volume of dryer, cc
29.1	contactor diameter, cm
58.2	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
2.01	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	22	2.011	43437	9556	1.000
ICP layer	18	1.569	33881	6099	0.780
CO_2 drying	12	1.286	27782	3334	0.640
Sputter Coating	7	1.132	24448	1711	0.563
DT Filling	5	1.053	22737	1137	0.523
Layering and Injection	0	1	21600	0	0.497

overall % reject rate = 50

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

69.8 = the fill volume of each contactor (in liters)

1466 = the total volume required for each tank (in liters)
1833.095 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

3.34 = height of tank, M
0.84 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

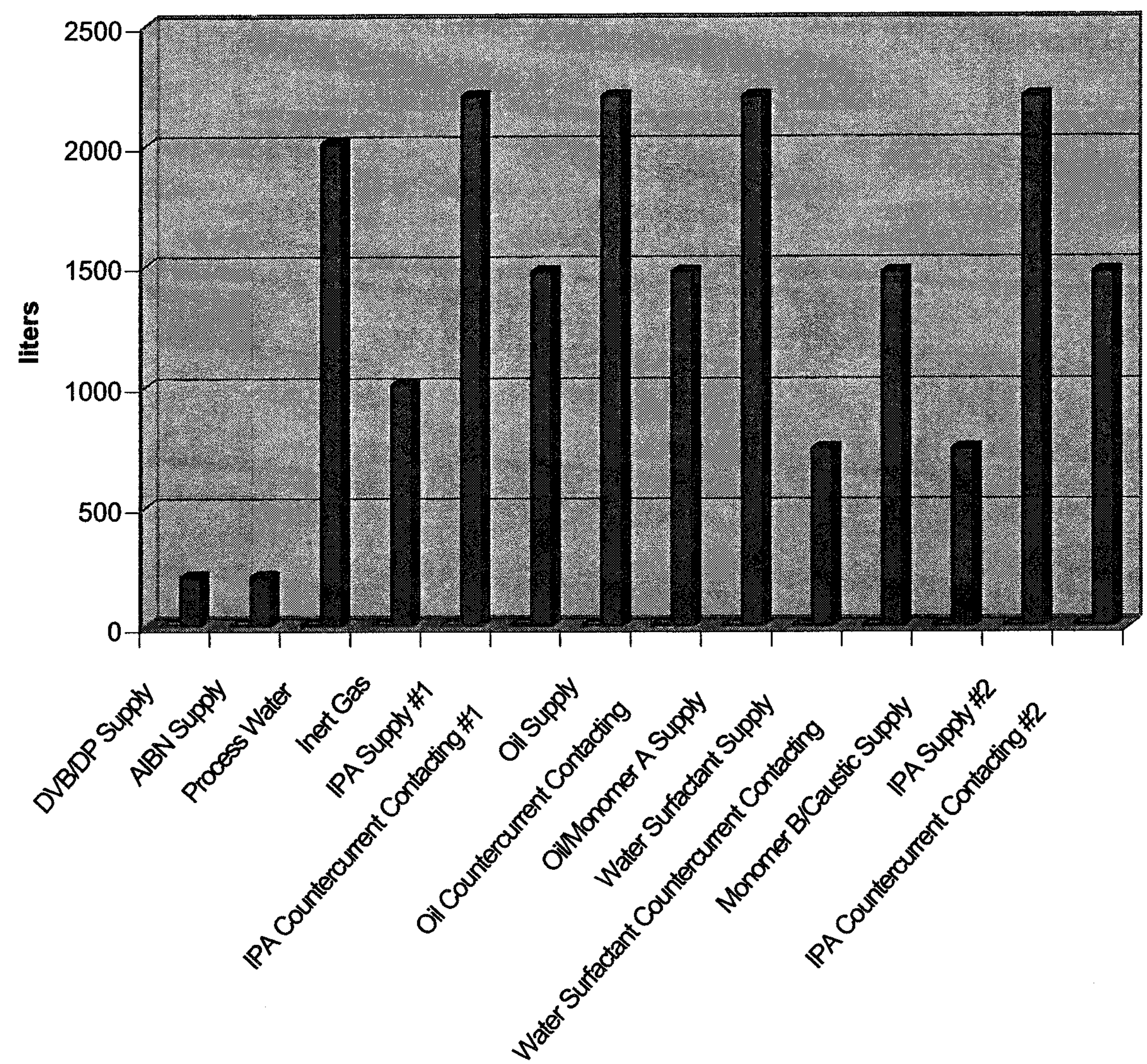
1.5 weeks storage in supply tank
2200 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	2200	
IPA Countercurrent Contacting #1	5	1466	
Oil Supply	1	2200	
Oil Countercurrent Contacting	5	1466	
Oil/Monomer A Supply	1	2200	
Water Surfactant Supply	1	733	
Water Surfactant Countercurrent Contacting	2	1466	
Monomer B/Caustic Supply	1	733	
IPA Supply #2	1	2200	
IPA Countercurrent Contacting #2	5	1466	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1
Liquids	Divinyl Benzene	54.39											
	Dibutyl Phthalate	543.93				543.93		544	544				
	Water			910.91	7274.19	8185.09		8185	8185				
	AIBN		5.44										
	Polyvinyl Alcohol				72.74	72.74		73	73				
	Polymerized DVB					59.83		60	60				
	Isopropyl Alcohol (IPA)									6809			
	Parachlorotoluene											6809	
	Spent Solvent #1												
	Isophthaloyl dichloride												
	Poly 4-Vinyl Phenol												
	NaOH												
	Mixed liquid waste										6809		6809
	CO_2												
	Au or Pd												
Gases	N_2						141.05						
Total, g/hr		598.3	5.4	910.9	7346.9	8861.6	141.0	8861.6	8861.6	6808.6	6808.6	6808.6	6808.6

	Stream Number:	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene									35		
	Dibutyl Phthalate											
	Water			6809		6799						
	AIBN											
	Polyvinyl Alcohol											
	Polymerized DVB											
	Isopropyl Alcohol (IPA)							6809		583		
	Parachlorotoluene	5719										
	Spent Solvent #1											
	Isophthaloyl dichloride	1089										
	Poly 4-Vinyl Phenol					100						
	NaOH					3						
	Mixed liquid waste		6809		6809		6902		6809			
	CO_2										8164	
	Au or Pd											0.40
Gases	N_2											
Total, g/hr		6808.6	6808.6	6808.6	6808.6	6901.9	6901.9	6808.6	6808.6	617.4	8163.7	0.4

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	140,767	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	3016	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	2.01	1.34	1.278	$ 95,813
Contactors	$ 420,000	2.01	1.34	1.278	$ 536,552
Contactor Tank Systems (4 each)	$ 844,601	2.01	1.34	1.278	$ 1,078,982
Dryer (10 each)	$ 3,750,000	1.29	1.11	1.094	$ 4,103,261
Sputtering System	$ 2,500,000	1.13	1.05	1.045	$ 2,612,201
DT Filling System (10 each)	$ 3,750,000	1.05	1.02	1.019	$ 3,821,528
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000

Total Process Equipment Cost **$ 24,664,601** **$ 25,573,337**

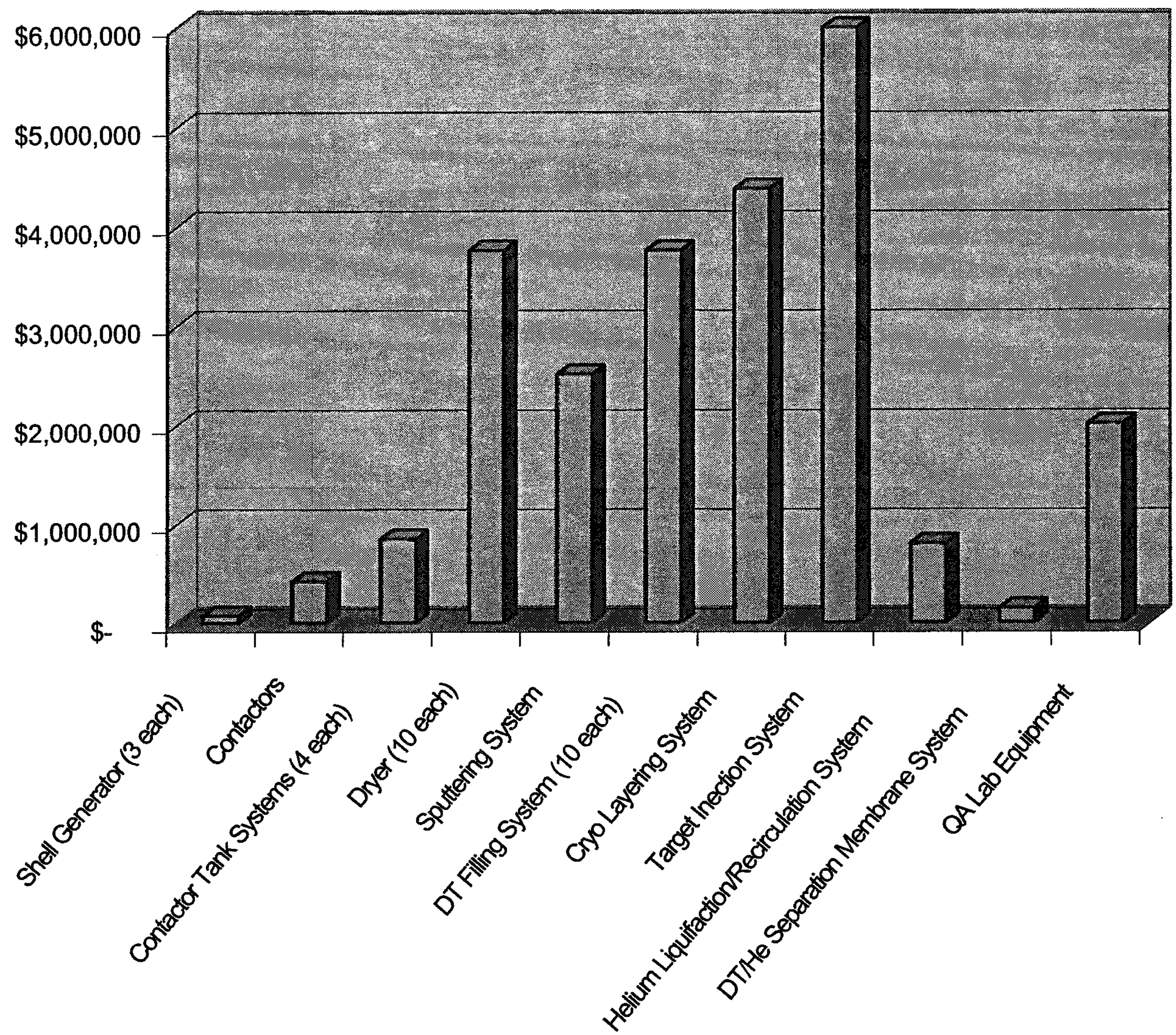
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 9,973,601
Electrical	$ 4,347,467
Instruments	$ 3,324,534
Building and services	$ 7,672,001
Site Preparation	$ 2,813,067
Auxiliaries	$ 14,065,335
Field Expenses	$ 10,996,535
Engineering	$ 8,694,935
Contractors fees	$ 4,347,467
Contingency	$ 9,973,601

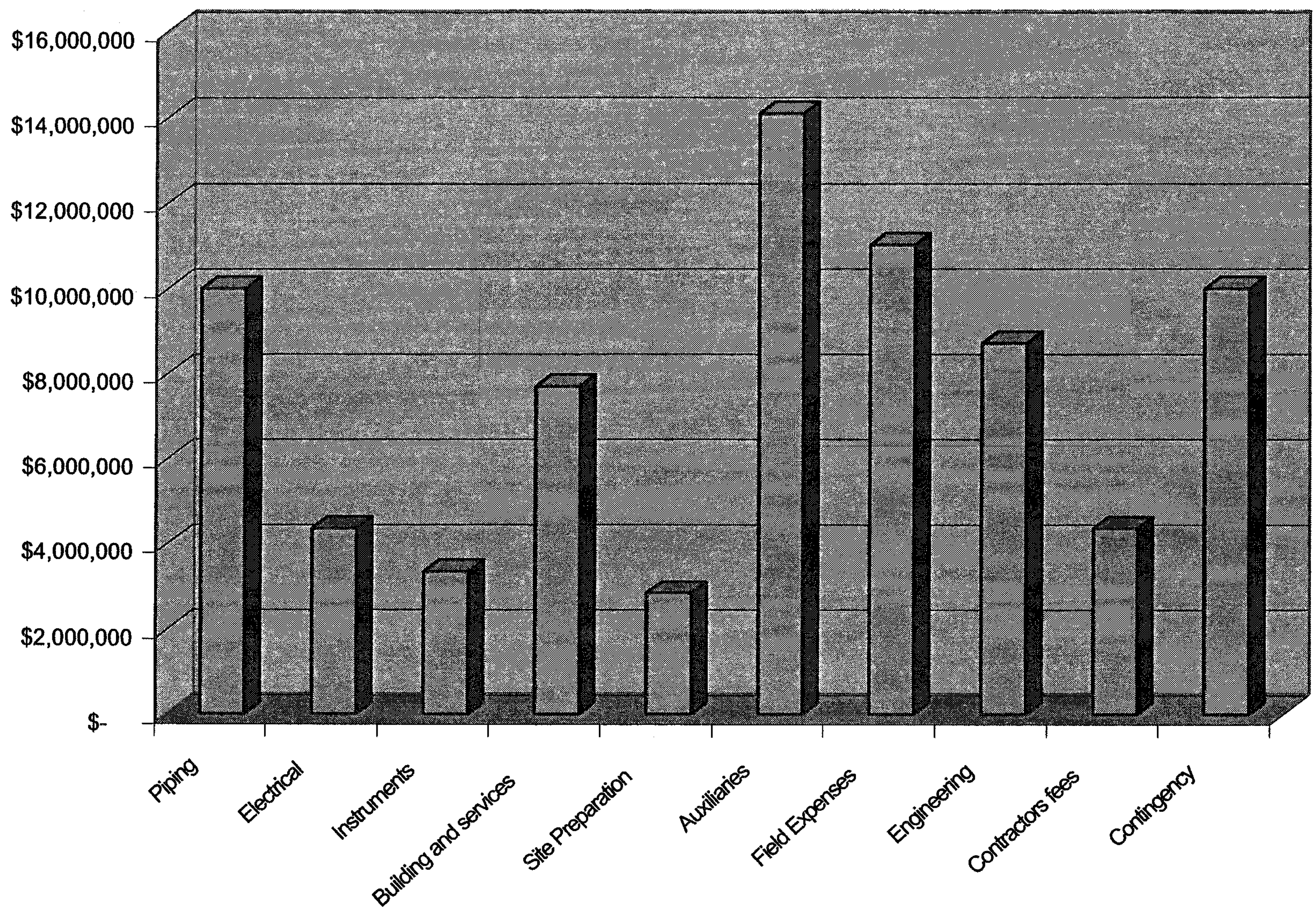
Total Installed Capital Cost **$ 101,781,880**

Annualized Cost of Capital Investment **$ 12,722,735**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

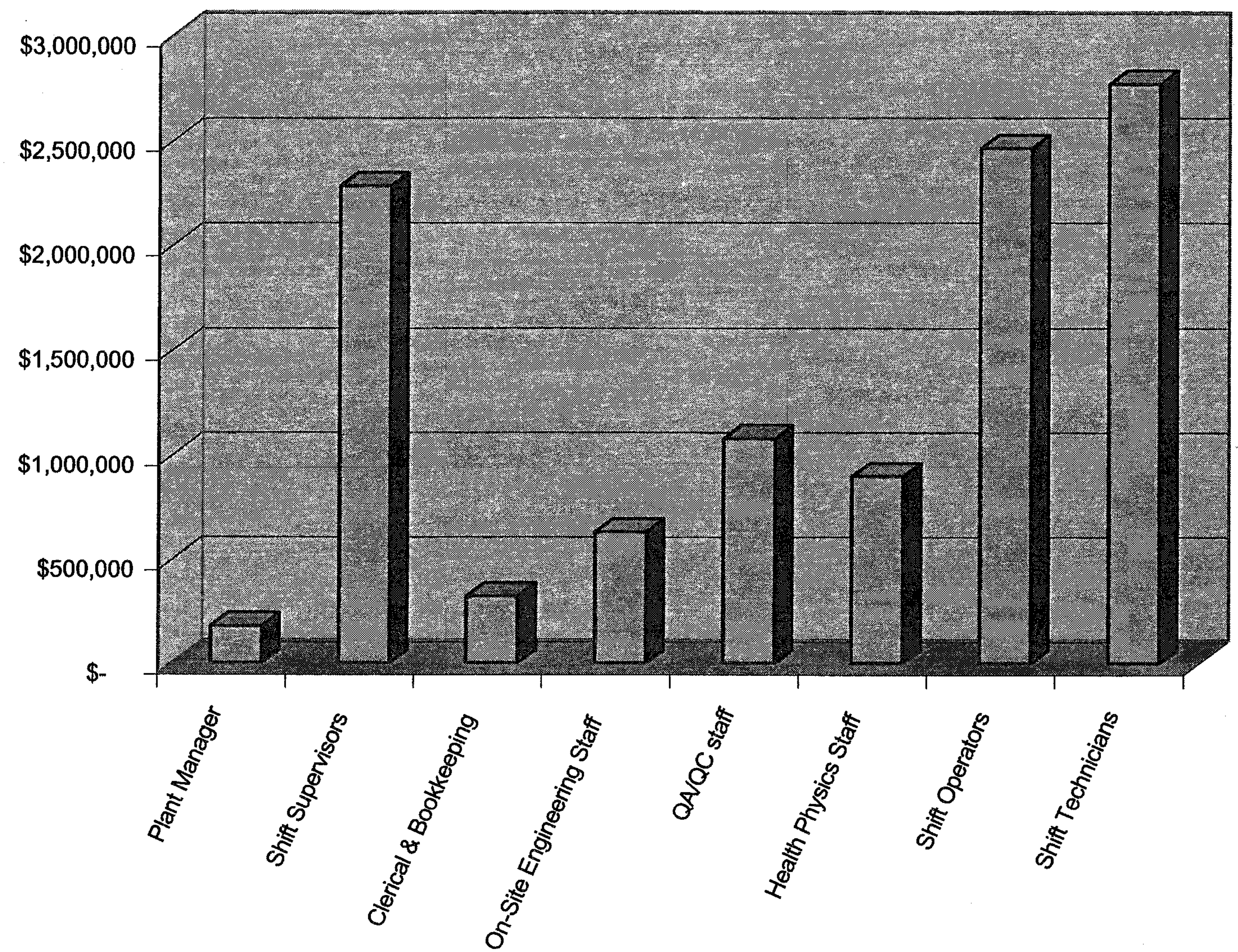
Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)
Plant Manager	1	1	$ 100,000	$ 178,851
Shift Supervisors	3	5	$ 85,000	$ 2,280,346
Clerical & Bookkeeping	6	1	$ 30,000	$ 321,931
On-Site Engineering Staff	5	1	$ 70,000	$ 625,977
QA/QC staff	3	5	$ 40,000	$ 1,073,104
Health Physics Staff	2	5	$ 50,000	$ 894,253
Shift Operator - Contactor Area	2	5	$ 40,000	$ 715,403
Technician - Contactor Area	3	5	$ 30,000	$ 804,828
Shift Operator - Dryer Area	2	5	$ 40,000	$ 612,754
Technician - Dryer Area	3	5	$ 30,000	$ 689,348
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 570,681
Technician - Fill/Layer Area	3	5	$ 30,000	$ 642,017
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000

Annual labor operating costs = $ 10,599,493

reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
1.34	2.011	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.34	2.01	1.28
1.11	1.29	1.09
1.11	1.29	1.09
1.02	1.05	1.02
1.02	1.05	1.02
n/a	n/a	n/a
n/a	n/a	n/a

Plant Manager	$ 178,851
Shift Supervisors	$ 2,280,346
Clerical & Bookkeeping	$ 321,931
On-Site Engineering Staff	$ 625,977
QA/QC staff	$ 1,073,104
Health Physics Staff	$ 894,253
Shift Operators	$ 2,458,838
Shift Technicians	$ 2,766,193

Operating Labor Costs for Foam Target Production

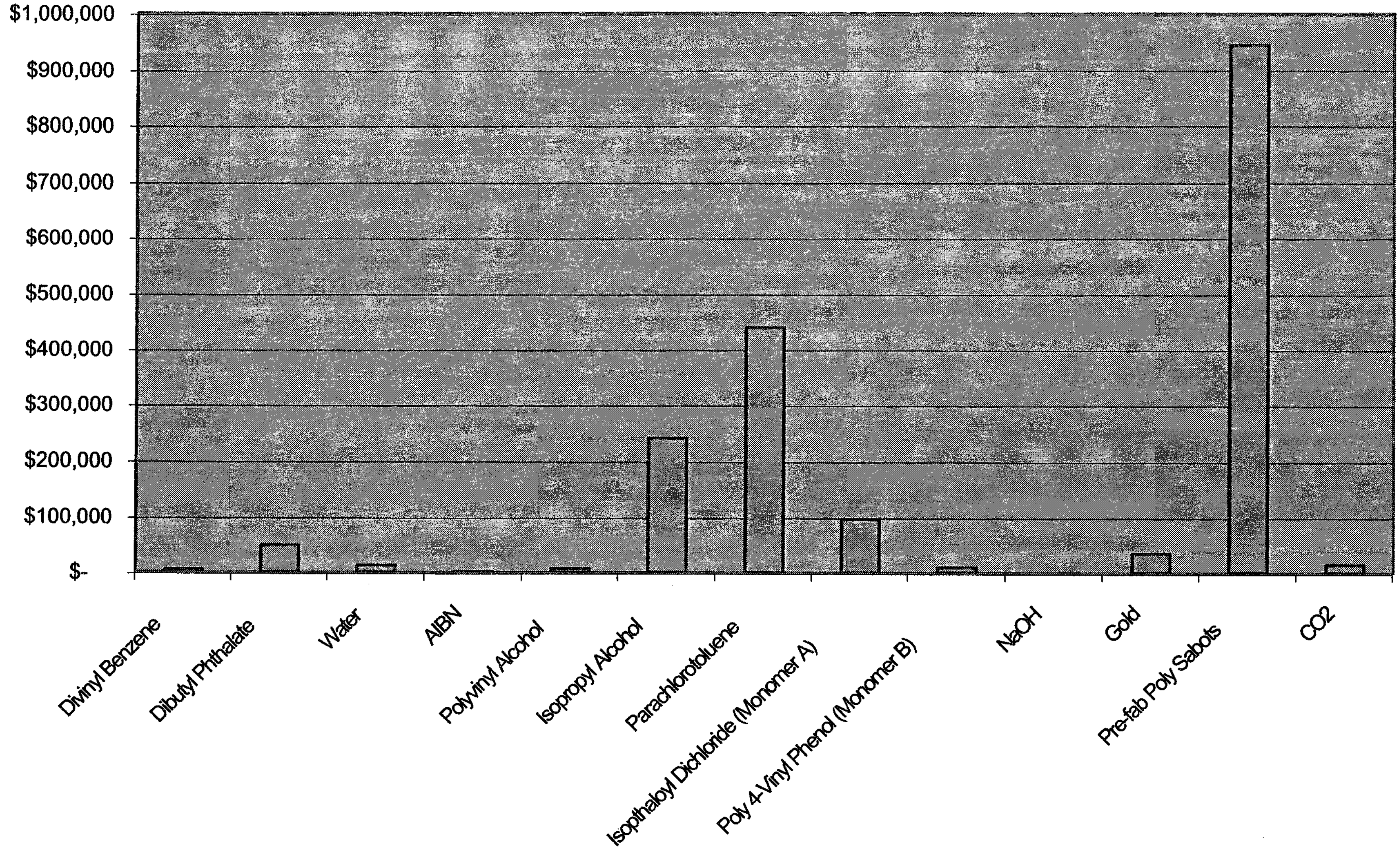


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	476	10.00	$ 4,765	
Dibutyl Phthalate	4765	10.00	$ 47,648	
Water	119199	0.10	$ 11,920	
AIBN	48	10.00	$ 476	
Polyvinyl Alcohol	637	10.00	$ 6,372	
Isopropyl Alcohol	119287	2.00	$ 238,575	
Parachlorotoluene	109744	4.00	$ 438,977	
Isopthaloyl Dichloride (Monomer A)	9543	10.00	$ 95,430	
Poly 4-Vinyl Phenol (Monomer B)	877	10.00	$ 8,771	
NaOH	29	2.00	$ 57	
Gold	3.5	9650.00	$ 33,837	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	71514	0.20	$ 14,303	

Annual materials costs = $ 1,844,655

Materials Costs (consumables) for Foam Target Production

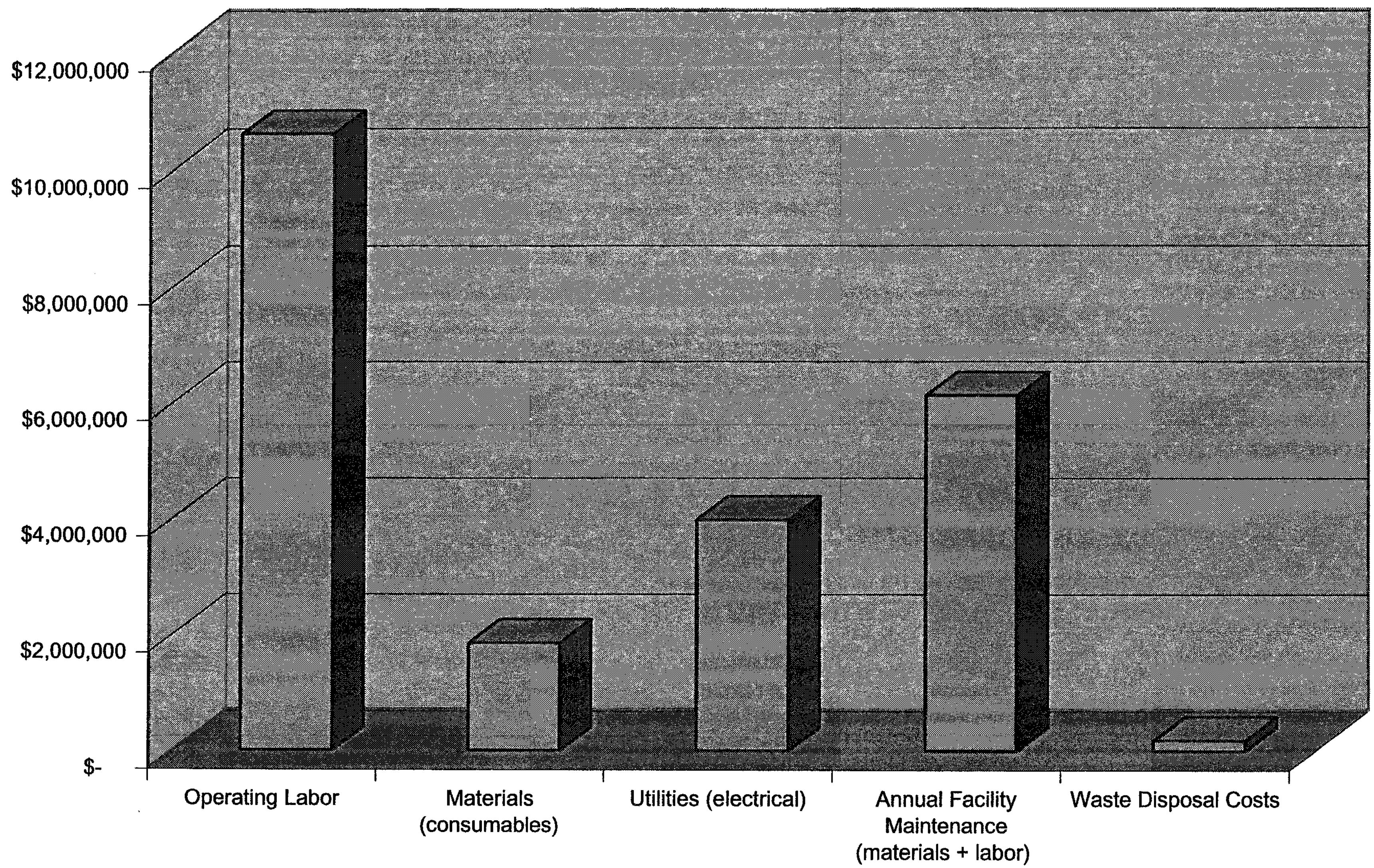


Operating Cost Summary for Foam Target Production

Operating Labor	$	10,599,493
Materials (consumables)	$	1,844,655
Utilities (electrical)	$	3,963,592
Annual Facility Maintenance (materials + labor)	$	6,106,913
Waste Disposal Costs	$	183,519

Total Annual Operating Costs = $ 22,698,172

Operating Costs for Foam Shell Production



Operating Labor	$	10,599,493
Materials (consumables)	$	1,844,655
Utilities (electrical)	$	3,963,592
Annual Facility Maintenance (materi	$	6,106,913
Waste Disposal Costs	$	183,519
Total Annual Operating Costs =	**$**	**22,698,172**

total cost per usable target =	0.187
cost for capital =	0.067
cost for operating =	0.120

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	844,601
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	25,573,337
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	9,973,601
Electrical	$	4,347,467
Instruments	$	3,324,534
Building and services	$	7,672,001
Site Preparation	$	2,813,067
Auxiliaries	$	14,065,335
Field Expenses	$	10,996,535
Engineering	$	8,694,935
Contractors fees	$	4,347,467
Contingency	$	9,973,601
	$	-
Total Installed Capital Cost	$	101,781,880
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**12,722,735**

	cents per usable target	
waste disposal	0.097	
materials	0.975	
utilities	2.095	
maintenance	3.227	
operating labor	5.602	
	11.996	**total operating**
piping, electrical & instrumentation	1.166	
bldgs & auxiliaries	1.622	
purchased equipment	1.689	
engr, contractors, contingency	2.247	
	6.724	**total capital**
	18.720	**total capital + operating**

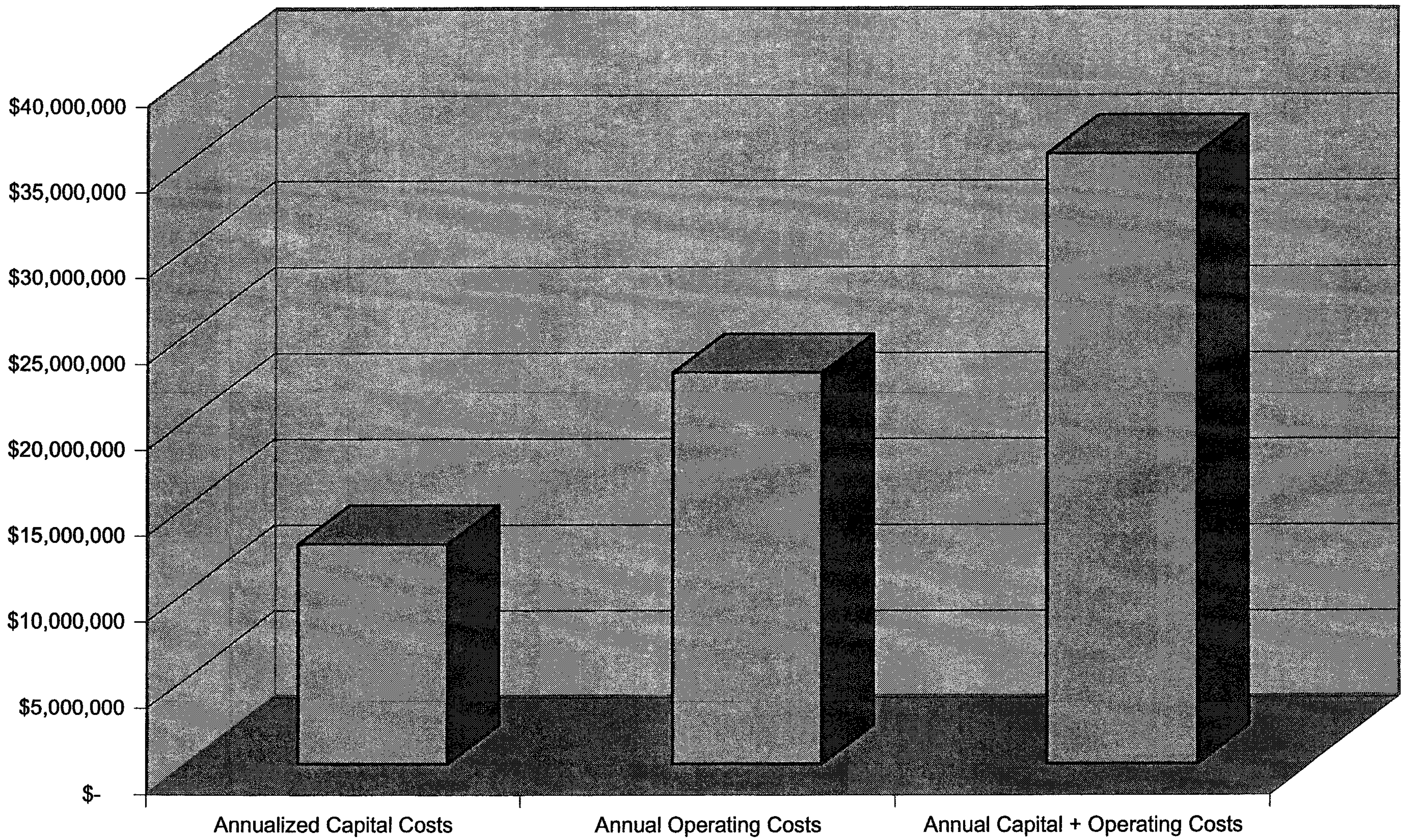
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 12,722,735
Annual Operating Costs	$ 22,698,172

Annual Capital + Operating Costs	**$ 35,420,907**

Cost per Injected Target = $ 0.187

Foam Target Production Costs



ATTACHMENT 5
Case 8 — Baseline (75% reject rate)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
40.0	% reject rate at droplet forming stage
30.0	% reject rate at ICP stage
20.0	% reject rate at CO2 drying stage
15.0	% reject rate at high Z coating stage
12.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
2062643	total shells produced per day
85943	total shells produced per hour
107.6	mass flow of shells (DVB only), g/hr
10.76	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
1076.22	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
1802.3	inner water flow, g/hr
1802.3	inner water flow, cc/hr
0.033	volume of each shell, cc
2878.5	volume of shells produced, cc/hr
14392.7	volume of outer water, cc/hr
14392.7	mass flow of outer water, g/hr
138169.6	contactor initial fill volume, cc
345424.0	contactor initial total volume, cc
76.0	contactor diameter, cm
76.0	contactor length, cm
143.9	PVA usage, g/hr
207254	vapor space in contactor, cc
207254	N_2 usage, cc/hr
279.1	N_2 usage, g/hr
752864782	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.84	mass flow usage of gold in high Z coating, g/hr
829	volume of waste per contactor, liters
2487	volume of waste per day from contactors, liters
2.49	tons per day of waste liquids from contactors
908	tons per year of waste liquids from contactors
23028	volume of shells in dryer, cc
76761	volume of dryer, cc
36.6	contactor diameter, cm
73.1	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
3.98	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	40	3.979	85943	34377	1.000
ICP layer	30	2.387	51566	15470	0.600
CO_2 drying	20	1.671	36096	7219	0.420
Sputter Coating	15	1.337	28877	4332	0.336
DT Filling	12	1.136	24545	2945	0.286
Layering and Injection	0	1	21600	0	0.251

overall % reject rate =	**75**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

138.2 = the fill volume of each contactor (in liters)

2902 = the total volume required for each tank (in liters)
3626.952 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

4.20 = height of tank, M
1.05 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

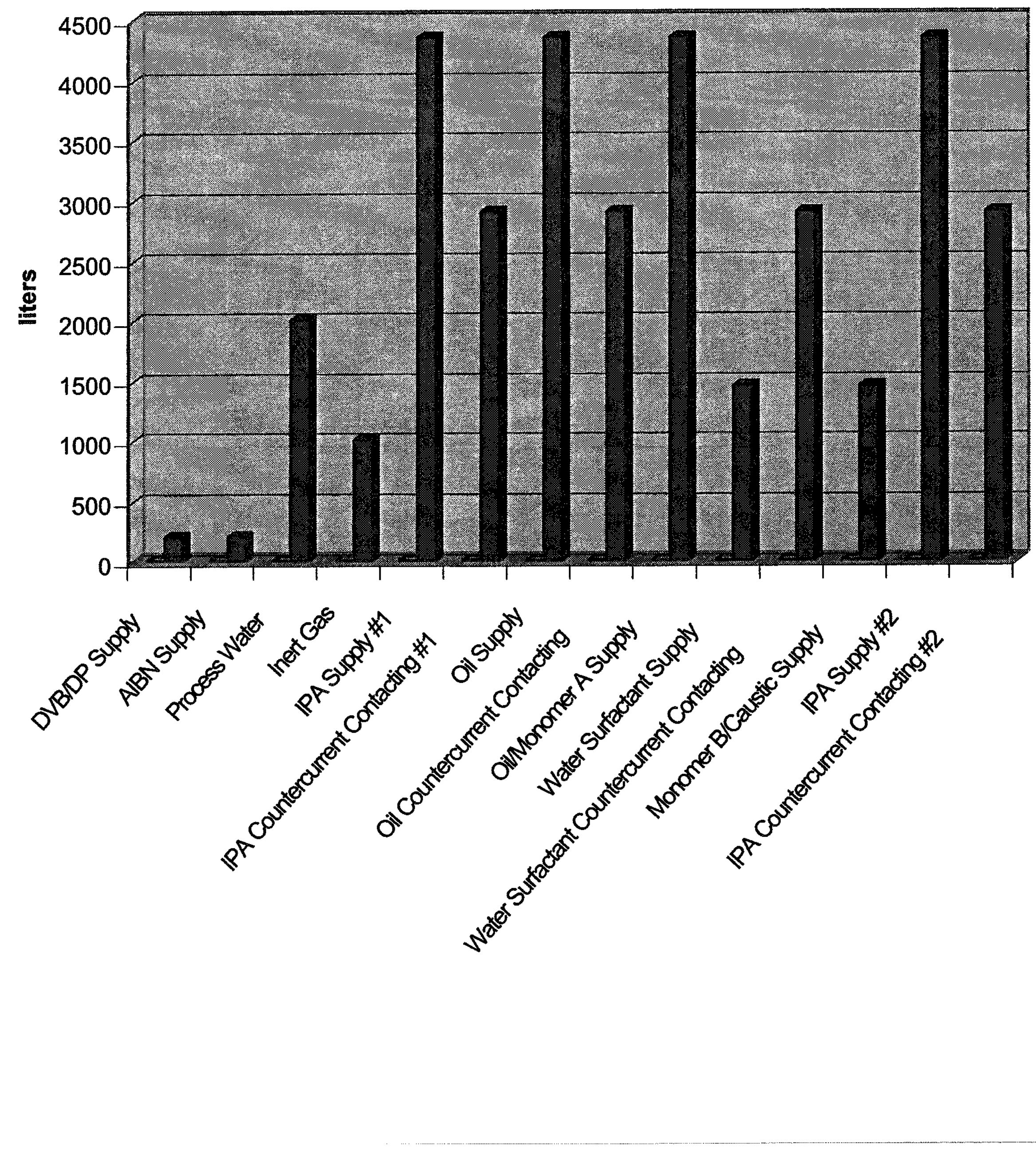
1.5 weeks storage in supply tank
4352 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	4352	
IPA Countercurrent Contacting #1	5	2902	
Oil Supply	1	4352	
Oil Countercurrent Contacting	5	2902	
Oil/Monomer A Supply	1	4352	
Water Surfactant Supply	1	1451	
Water Surfactant Countercurrent Contacting	2	2902	
Monomer B/Caustic Supply	1	1451	
IPA Supply #2	1	4352	
IPA Countercurrent Contacting #2	5	2902	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering			
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25			
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298			
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1			
Liquids	Divinyl Benzene	107.62																				45					
	Dibutyl Phthalate	1076.22				1076.22		1076	1076																		
	Water			1802.32	14392.67	16194.98		16195	16195							10363		10351									
	AIBN		10.76																								
	Polyvinyl Alcohol				143.93	143.93		144	144																		
	Polymerized DVB					118.38		118	118																		
	Isopropyl Alcohol (IPA)									10363										10363		757					
	Parachlorotoluene											10363		8705													
	Spent Solvent #1																										
	Isophthaloyl dichloride													1658													
	Poly 4-Vinyl Phenol																	152									
	NaOH																	4									
	Mixed liquid waste										10363		10363		10363		10363		10507		10363						
	CO_2																						10607				
	Au or Pd																							0.28			
Gases	N_2						279.08																				
Total, g/hr		1183.8	10.8	1802.3	14536.6	17533.5	279.1	17533.5	17533.5	10362.7	10362.7	10362.7	10362.7	10362.7	10362.7	10362.7	10362.7	10507.2	10507.2	10362.7	10362.7	802.2	10606.8	0.3			

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	278,520	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)

	5968	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	3.98	1.34	1.924	$ 144,291
Contactors	$ 420,000	3.98	1.34	1.924	$ 808,027
Contactor Tank Systems (4 each)	$ 1,671,123	3.98	1.34	1.924	$ 3,215,030
Dryer (10 each)	$ 3,750,000	1.67	1.11	1.280	$ 4,801,177
Sputtering System	$ 2,500,000	1.34	1.05	1.155	$ 2,886,620
DT Filling System (10 each)	$ 3,750,000	1.14	1.02	1.067	$ 4,001,120
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 25,491,123**				**$ 29,181,265**

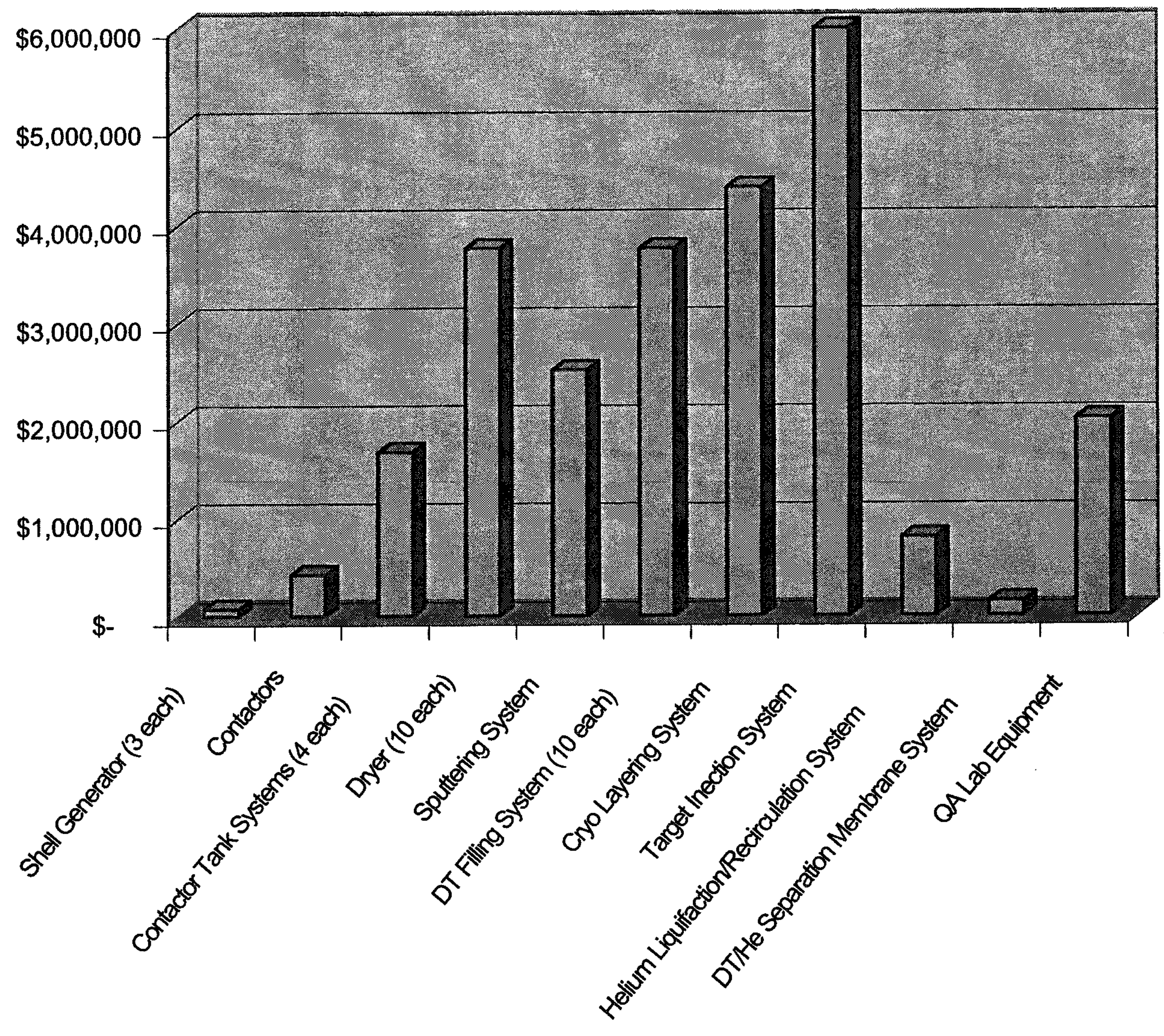
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 11,380,693
Electrical	$ 4,960,815
Instruments	$ 3,793,564
Building and services	$ 8,754,379
Site Preparation	$ 3,209,939
Auxiliaries	$ 16,049,696
Field Expenses	$ 12,547,944
Engineering	$ 9,921,630
Contractors fees	$ 4,960,815
Contingency	$ 11,380,693

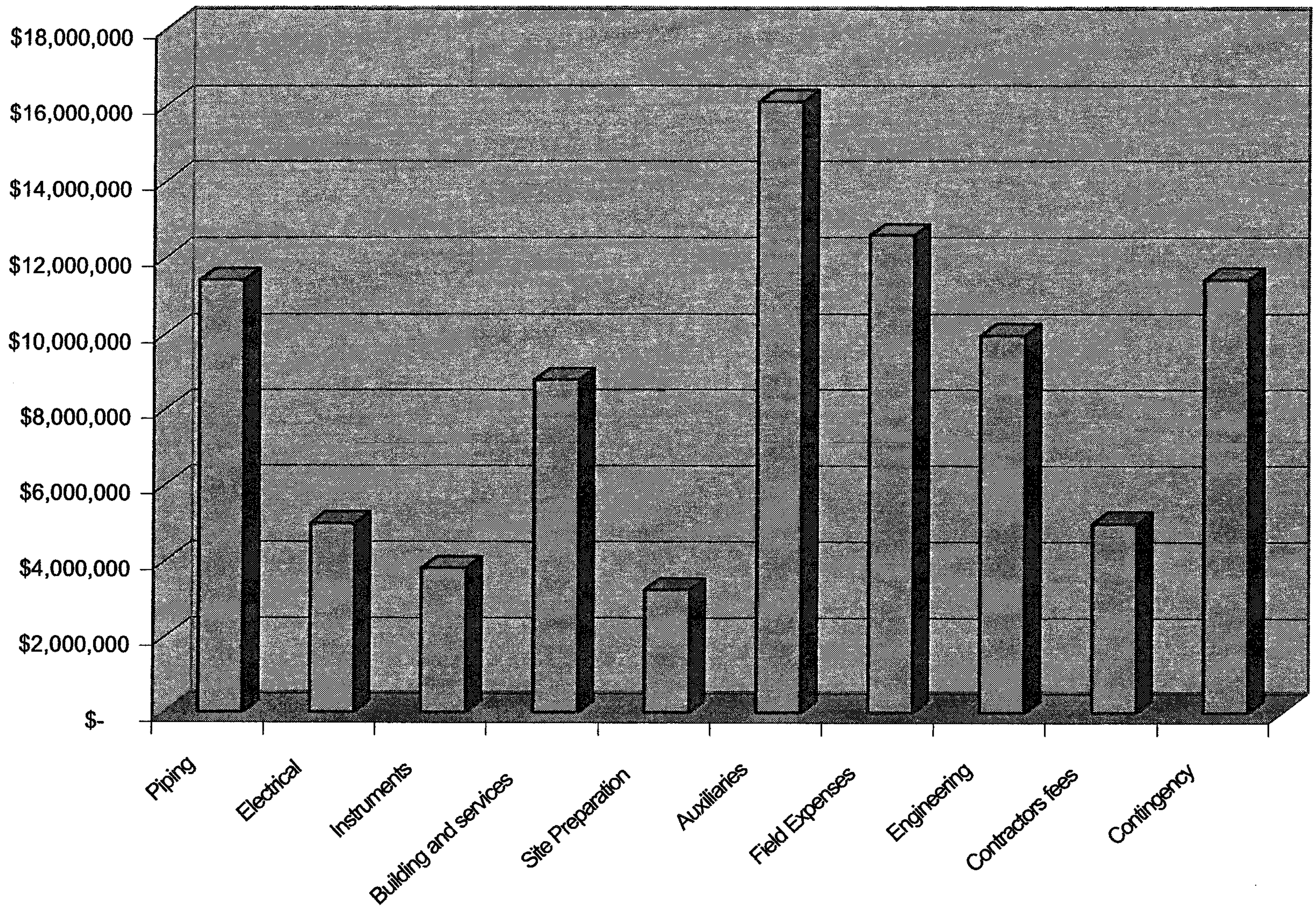
Total Installed Capital Cost **$ 116,141,434**

Annualized Cost of Capital Investment **$ 14,517,679**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



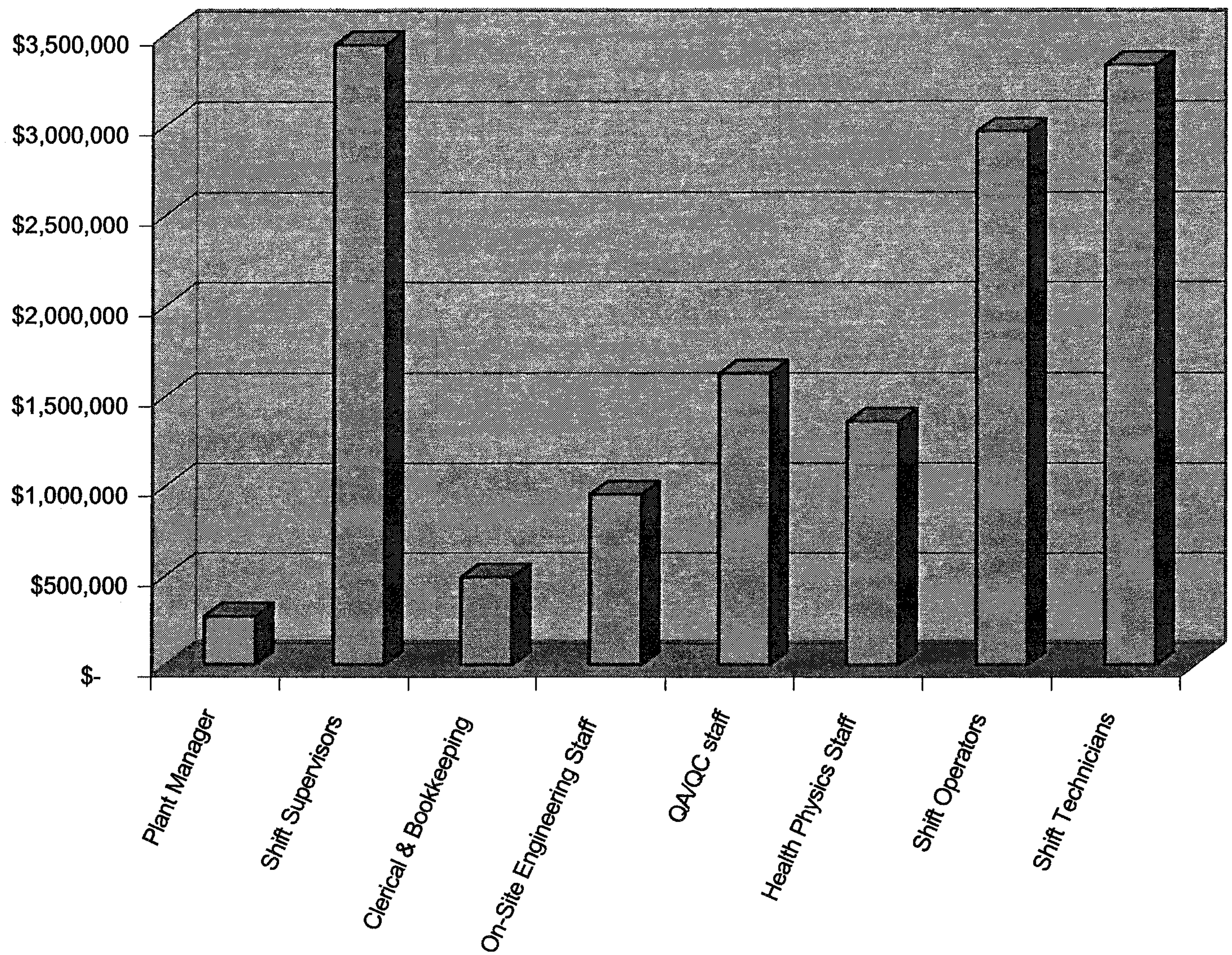
Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 269,342	1.34	3.979	1.92
Shift Supervisors	3	5	$ 85,000	$ 3,434,115	1.34	3.98	1.92
Clerical & Bookkeeping	6	1	$ 30,000	$ 484,816	1.34	3.98	1.92
On-Site Engineering Staff	5	1	$ 70,000	$ 942,698	1.34	3.98	1.92
QA/QC staff	3	5	$ 40,000	$ 1,616,054	1.34	3.98	1.92
Health Physics Staff	2	5	$ 50,000	$ 1,346,712	1.34	3.98	1.92
Shift Operator - Contactor Area	2	5	$ 40,000	$ 1,077,369	1.34	3.98	1.92
Technician - Contactor Area	3	5	$ 30,000	$ 1,212,041	1.34	3.98	1.92
Shift Operator - Dryer Area	2	5	$ 40,000	$ 716,976	1.11	1.67	1.28
Technician - Dryer Area	3	5	$ 30,000	$ 806,598	1.11	1.67	1.28
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 597,501	1.02	1.14	1.07
Technician - Fill/Layer Area	3	5	$ 30,000	$ 672,188	1.02	1.14	1.07
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 14,366,410

Plant Manager	$ 269,342
Shift Supervisors	$ 3,434,115
Clerical & Bookkeeping	$ 484,816
On-Site Engineering Staff	$ 942,698
QA/QC staff	$ 1,616,054
Health Physics Staff	$ 1,346,712
Shift Operators	$ 2,951,846
Shift Technicians	$ 3,320,827

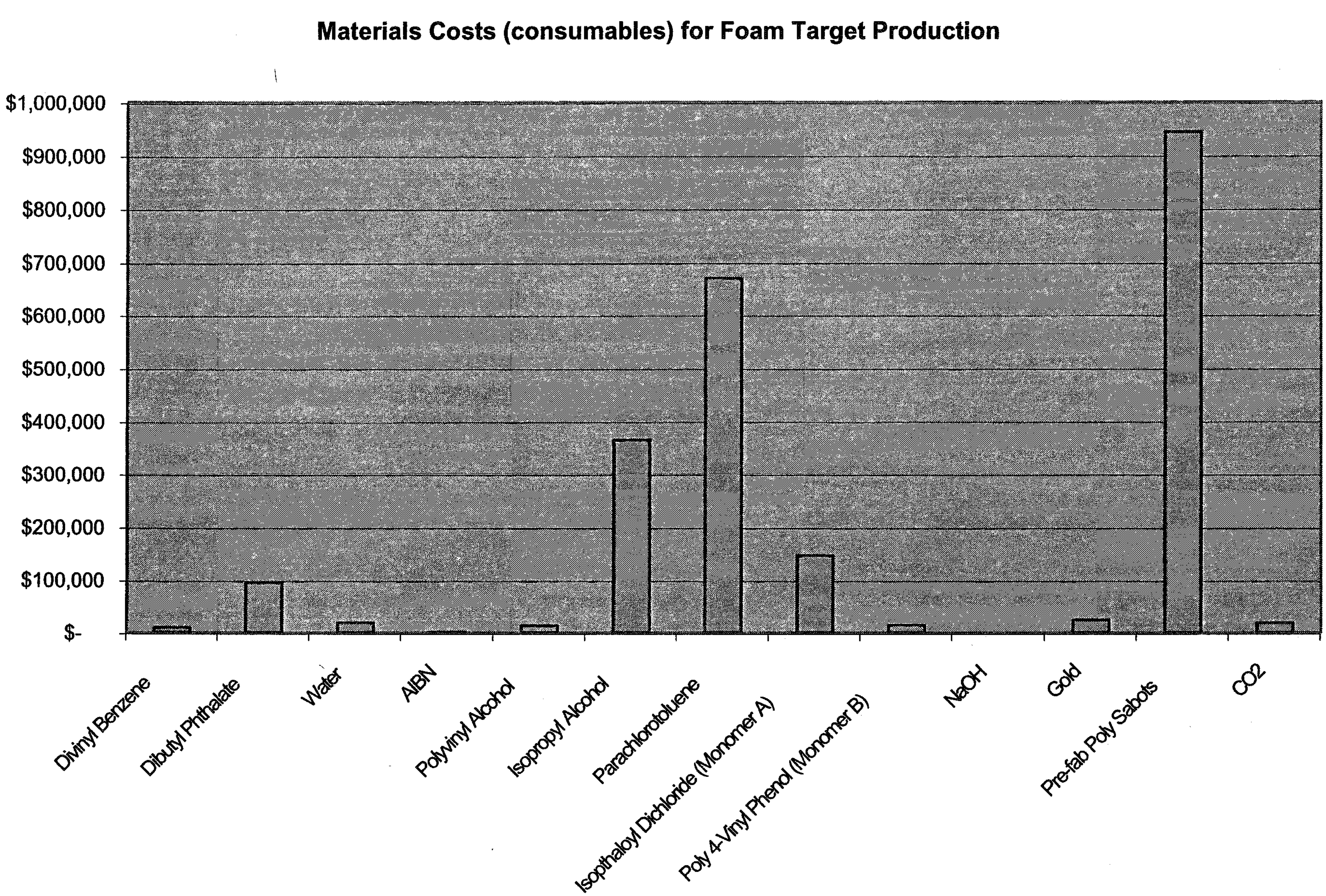
Operating Labor Costs for Foam Target Production



Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	943	10.00	$ 9,428	
Dibutyl Phthalate	9428	10.00	$ 94,277	
Water	181452	0.10	$ 18,145	
AIBN	94	10.00	$ 943	
Polyvinyl Alcohol	1261	10.00	$ 12,608	
Isopropyl Alcohol	181555	2.00	$ 363,110	
Parachlorotoluene	167030	4.00	$ 668,122	
Isopthaloyl Dichloride (Monomer A)	14524	10.00	$ 145,244	
Poly 4-Vinyl Phenol (Monomer B)	1335	10.00	$ 13,350	
NaOH	33	2.00	$ 67	
Gold	2.5	9650.00	$ 23,859	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	92916	0.20	$ 18,583	

Annual materials costs = $ 2,311,257

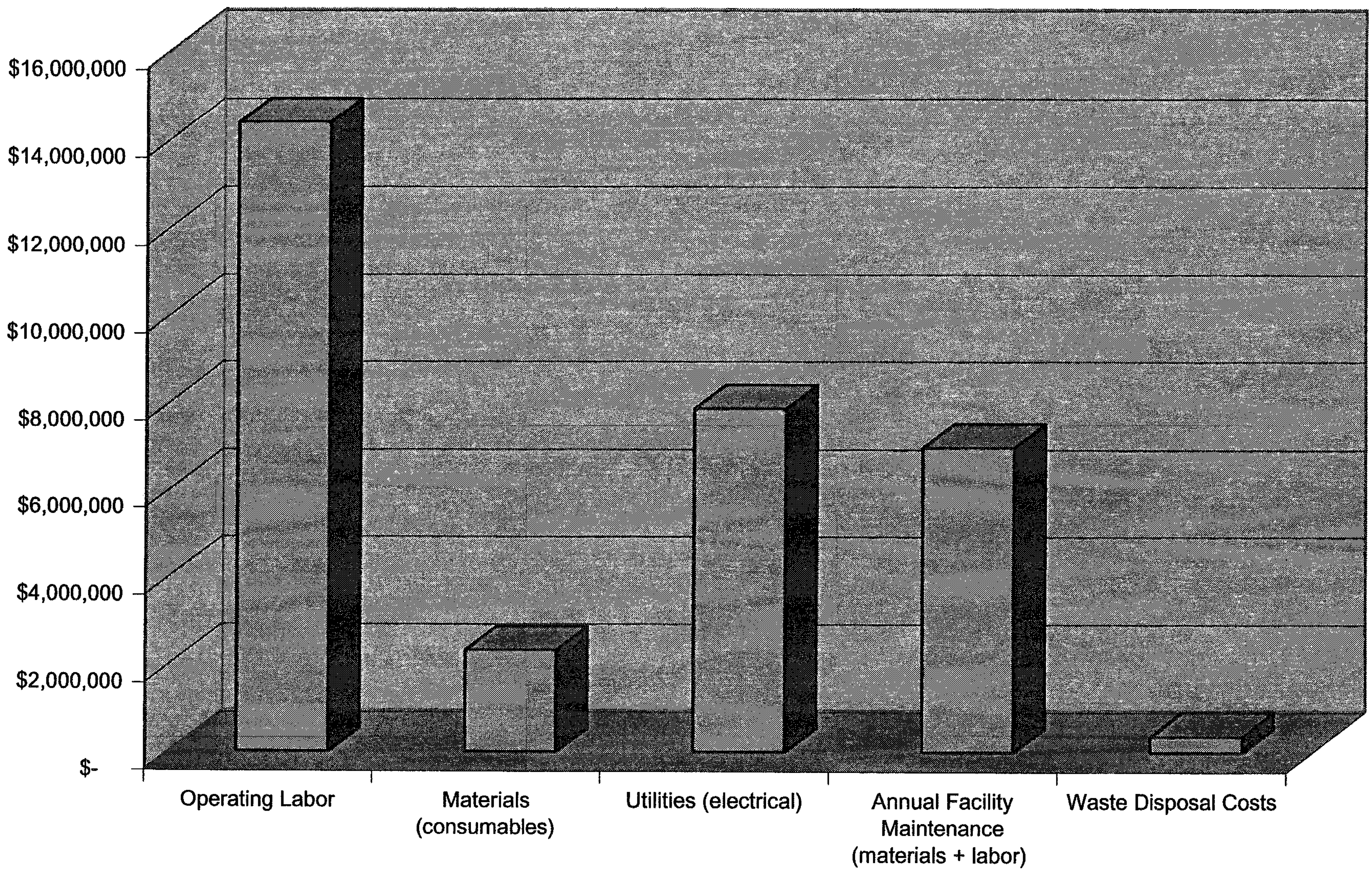

Materials Costs (consumables) for Foam Target Production
$1,000,000
$900,000
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$-
Divinyl Benzene
Dibutyl Phthalate
Water
AIBN
Polyvinyl Alcohol
Isopropyl Alcohol
Parachlorotoluene
Isopthaloyl Dichloride (Monomer A)
Poly 4-Vinyl Phenol (Monomer B)
NaOH
Gold
Pre-fab Poly Sabots
CO2

Operating Cost Summary for Foam Target Production

Operating Labor	$	14,366,410
Materials (consumables)	$	2,311,257
Utilities (electrical)	$	7,842,341
Annual Facility Maintenance (materials + labor)	$	6,968,486
Waste Disposal Costs	$	363,110

Total Annual Operating Costs = $ 31,851,605

Operating Costs for Foam Shell Production



Operating Labor	$	14,366,410
Materials (consumables)	$	2,311,257
Utilities (electrical)	$	7,842,341
Annual Facility Maintenance (materi	$	6,968,486
Waste Disposal Costs	$	363,110
Total Annual Operating Costs =	**$**	**31,851,605**

total cost per usable target =	0.245
cost for capital =	0.077
cost for operating =	0.168

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	1,671,123
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	29,181,265
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	11,380,693
Electrical	$	4,960,815
Instruments	$	3,793,564
Building and services	$	8,754,379
Site Preparation	$	3,209,939
Auxiliaries	$	16,049,696
Field Expenses	$	12,547,944
Engineering	$	9,921,630
Contractors fees	$	4,960,815
Contingency	$	11,380,693
	$	-
Total Installed Capital Cost	$	116,141,434
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**14,517,679**

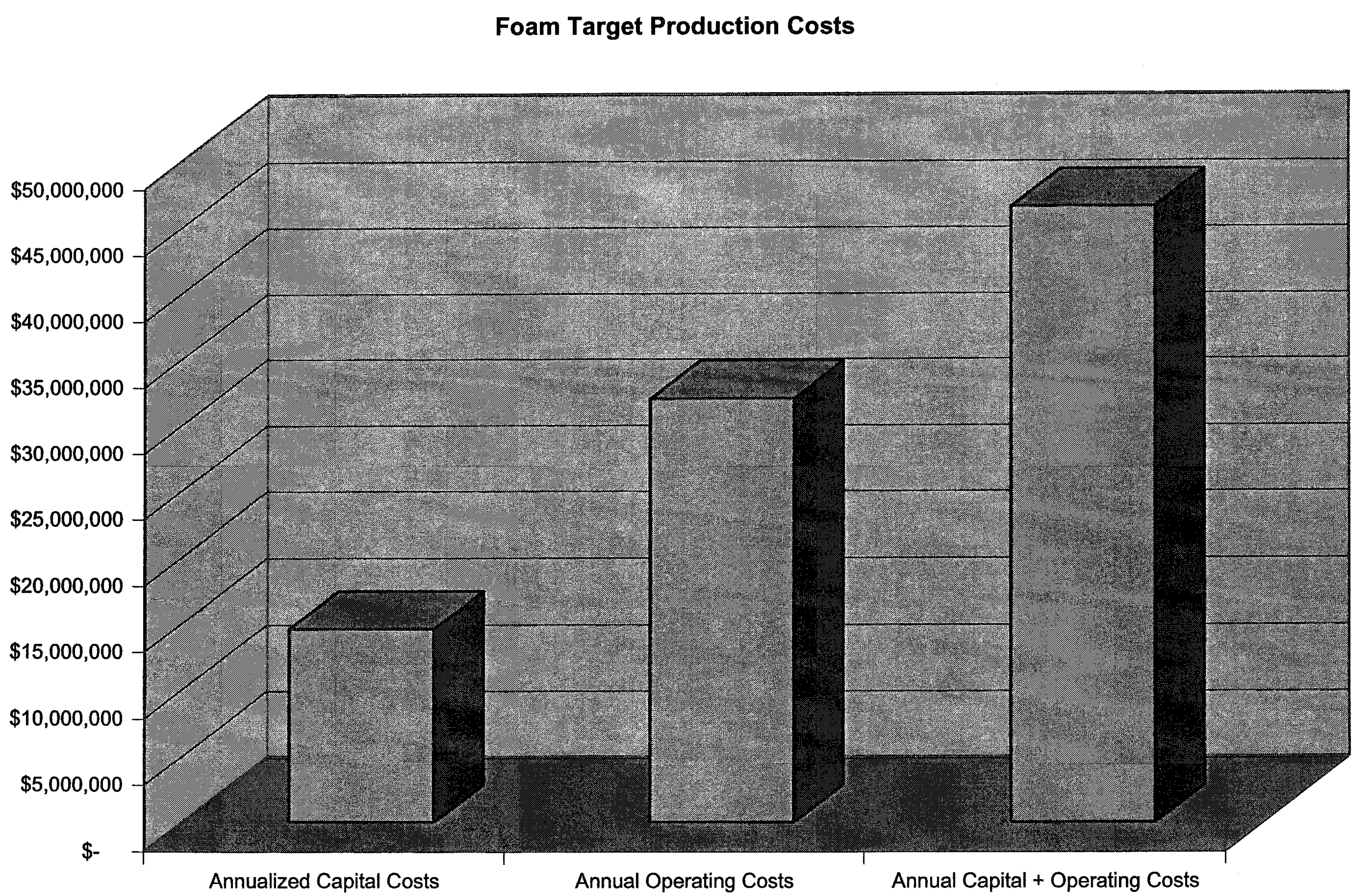
	cents per usable target	
waste disposal	0.192	
materials	1.221	
utilities	4.145	
maintenance	3.683	
operating labor	7.593	
	16.833	**total operating**
piping, electrical & instrumentation	1.330	
bldgs & auxiliaries	1.851	
purchased equipment	1.928	
engr, contractors, contingency	2.564	
	7.673	**total capital**
	24.506	**total capital + operating**

Cost Summary for Foam Target Production

Annualized Capital Costs	$ 14,517,679
Annual Operating Costs	$ 31,851,605

Annual Capital + Operating Costs	**$ 46,369,284**

Cost per Injected Target = $ 0.245


Foam Target Production Costs
$50,000,000
$45,000,000
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
Annualized Capital Costs
Annual Operating Costs
Annual Capital + Operating Costs

ATTACHMENT 5
Case 9 — All costs 25% higher and 50% reject rate

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
23.0	% reject rate at droplet forming stage
18.0	% reject rate at ICP stage
12.0	% reject rate at CO2 drying stage
6.0	% reject rate at high Z coating stage
4.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
1033900	total shells produced per day
43079	total shells produced per hour
53.9	mass flow of shells (DVB only), g/hr
5.39	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
539.45	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
903.4	inner water flow, g/hr
903.4	inner water flow, cc/hr
0.033	volume of each shell, cc
1442.9	volume of shells produced, cc/hr
7214.3	volume of outer water, cc/hr
7214.3	mass flow of outer water, g/hr
69257.5	contactor initial fill volume, cc
173143.8	contactor initial total volume, cc
60.4	contactor diameter, cm
60.4	contactor length, cm
72.1	PVA usage, g/hr
103886	vapor space in contactor, cc
103886	N_2 usage, cc/hr
139.9	N_2 usage, g/hr
377373605	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.70	mass flow usage of gold in high Z coating, g/hr
416	volume of waste per contactor, liters
1247	volume of waste per day from contactors, liters
1.25	tons per day of waste liquids from contactors
455	tons per year of waste liquids from contactors
11543	volume of shells in dryer, cc
38476	volume of dryer, cc
29.0	contactor diameter, cm
58.1	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.99	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	23	1.994	43079	9908	1.000
ICP layer	18	1.536	33171	5971	0.770
CO_2 drying	12	1.259	27200	3264	0.631
Sputter Coating	6	1.108	23936	1436	0.556
DT Filling	4	1.042	22500	900	0.522
Layering and Injection	0	1	21600	0	0.501

overall % reject rate =	**50**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

69.3	= the fill volume of each contactor (in liters)
1454	= the total volume required for each tank (in liters)
1818.01	= tank volume (with head-room allowance)
4	= L/D of vertical cylindrical
3.33	= height of tank, M
0.83	= diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

1.5 weeks storage in supply tank

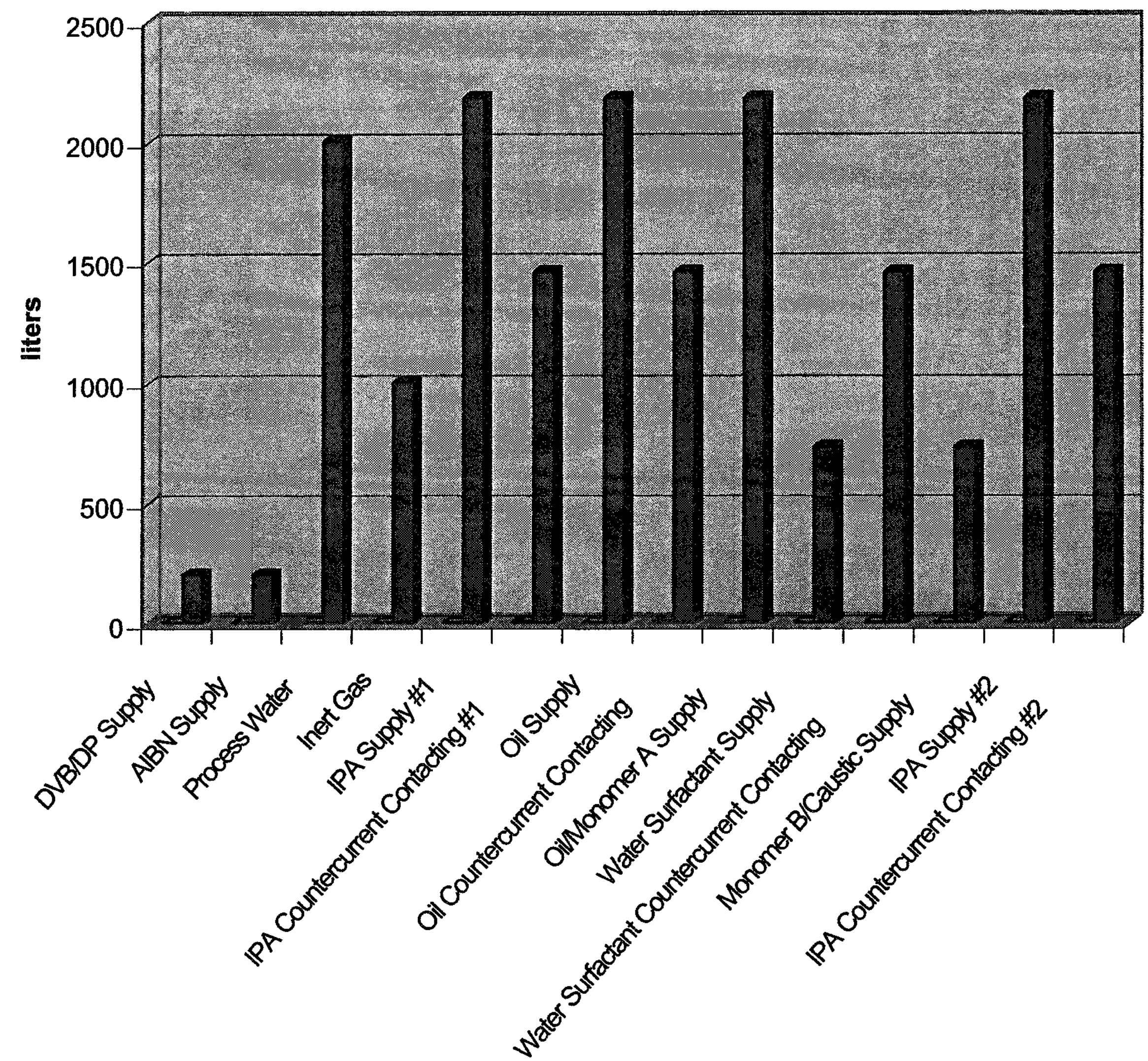
2182 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	2182	
IPA Countercurrent Contacting #1	5	1454	
Oil Supply	1	2182	
Oil Countercurrent Contacting	5	1454	
Oil/Monomer A Supply	1	2182	
Water Surfactant Supply	1	727	
Water Surfactant Countercurrent Contacting	2	1454	
Monomer B/Caustic Supply	1	727	
IPA Supply #2	1	2182	
IPA Countercurrent Contacting #2	5	1454	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	53.95																				34		
	Dibutyl Phthalate	539.45				539.45		539	539															
	Water			903.41	7214.33	8117.74		8118	8118							6666		6656						
	AIBN		5.39																					
	Polyvinyl Alcohol				72.14	72.14		72	72															
	Polymerized DVB					59.34		59	59															
	Isopropyl Alcohol (IPA)									6666										6666		570		
	Parachlorotoluene											6666		5599										
	Spent Solvent #1																							
	Isophthaloyl dichloride													1067										
	Poly 4-Vinyl Phenol																	98						
	NaOH																	3						
	Mixed liquid waste										6666		6666		6666		6666		6757		6666			
	CO_2																						7993	
	Au or Pd																							0.39
Gases	N_2						139.89																	
Total, g/hr		593.4	5.4	903.4	7286.5	8788.7	139.9	8788.7	8788.7	6666.0	6666.0	6666.0	6666.0	6666.0	6666.0	6666.0	6666.0	6757.5	6757.5	6666.0	6666.0	604.5	7992.7	0.4

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	139,608	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2992	KW usage
$	0.15	cost per KW-hr
	1.25	multiplier for all costs

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.99	1.34	1.271	$ 95,339
Contactors	$ 420,000	1.99	1.34	1.271	$ 533,898
Contactor Tank Systems (4 each)	$ 837,651	1.99	1.34	1.271	$ 1,064,810
Dryer (10 each)	$ 3,750,000	1.26	1.11	1.080	$ 4,051,479
Sputtering System	$ 2,500,000	1.11	1.05	1.032	$ 2,579,236
DT Filling System (10 each)	$ 3,750,000	1.04	1.02	1.013	$ 3,797,593
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,657,651**				**$ 31,809,196**

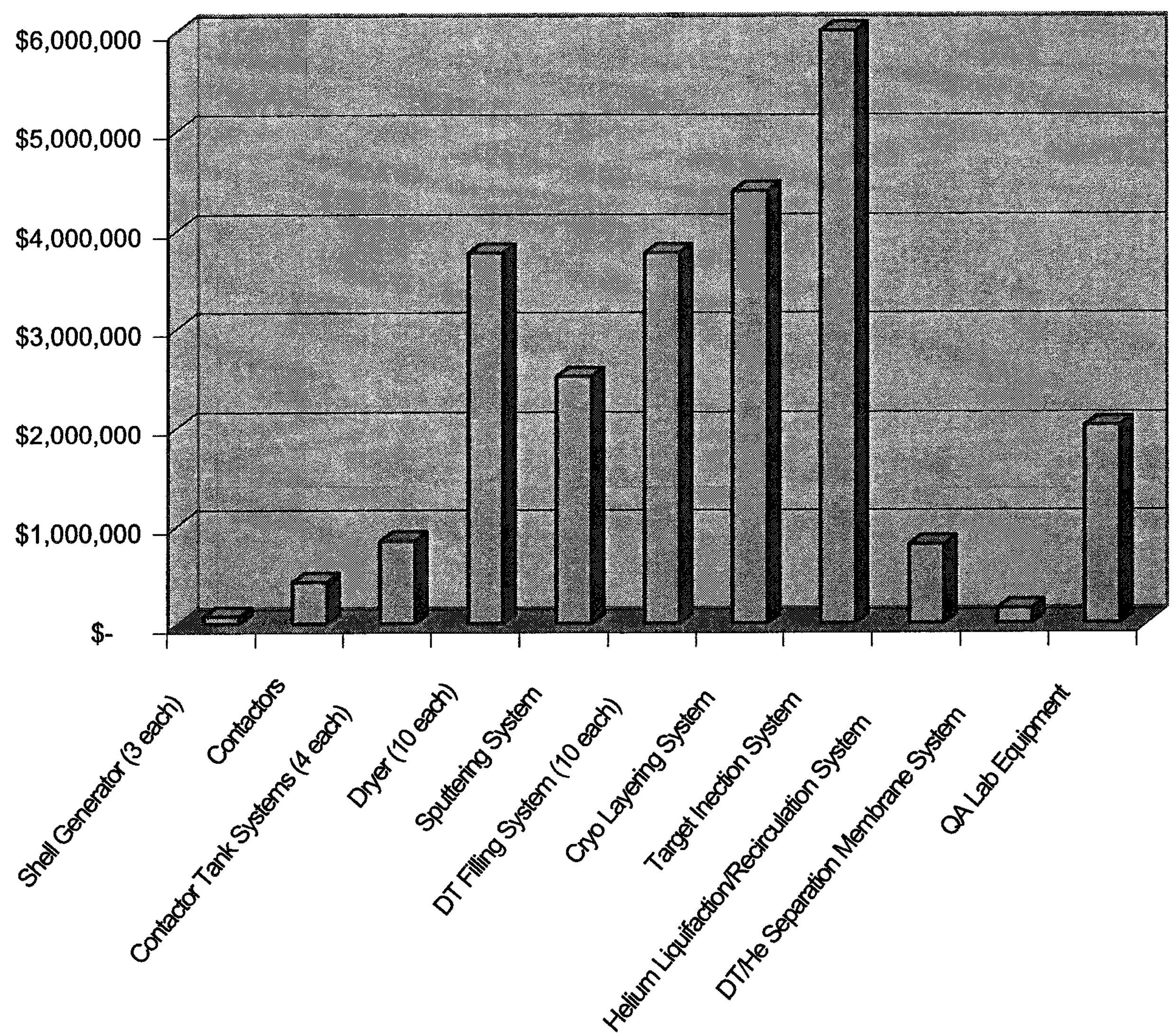
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 12,405,586
Electrical	$ 5,407,563
Instruments	$ 4,135,195
Building and services	$ 9,542,759
Site Preparation	$ 3,499,012
Auxiliaries	$ 17,495,058
Field Expenses	$ 13,677,954
Engineering	$ 10,815,127
Contractors fees	$ 5,407,563
Contingency	$ 12,405,586

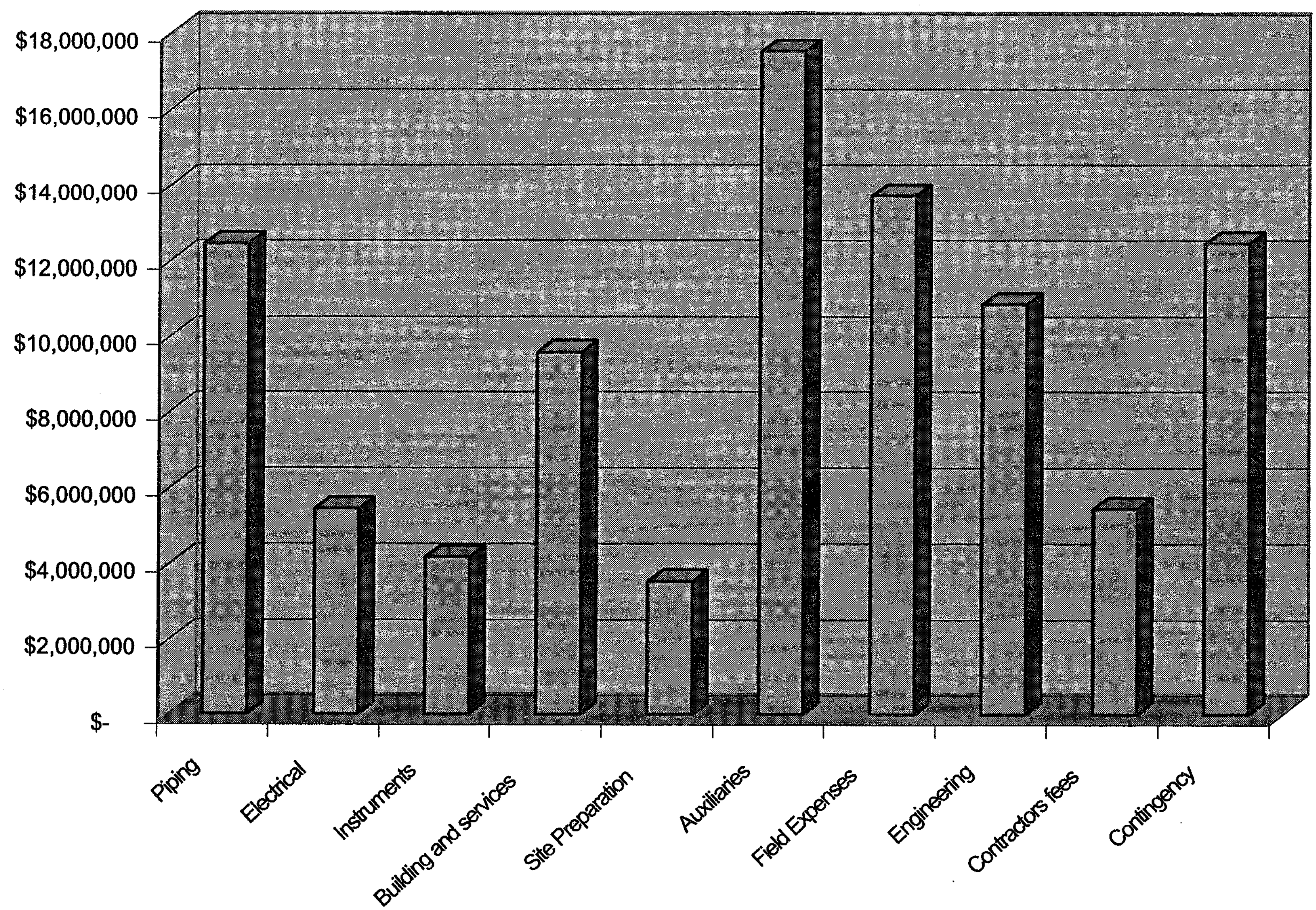
Total Installed Capital Cost **$ 126,600,599**

Annualized Cost of Capital Investment **$ 15,825,075**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production

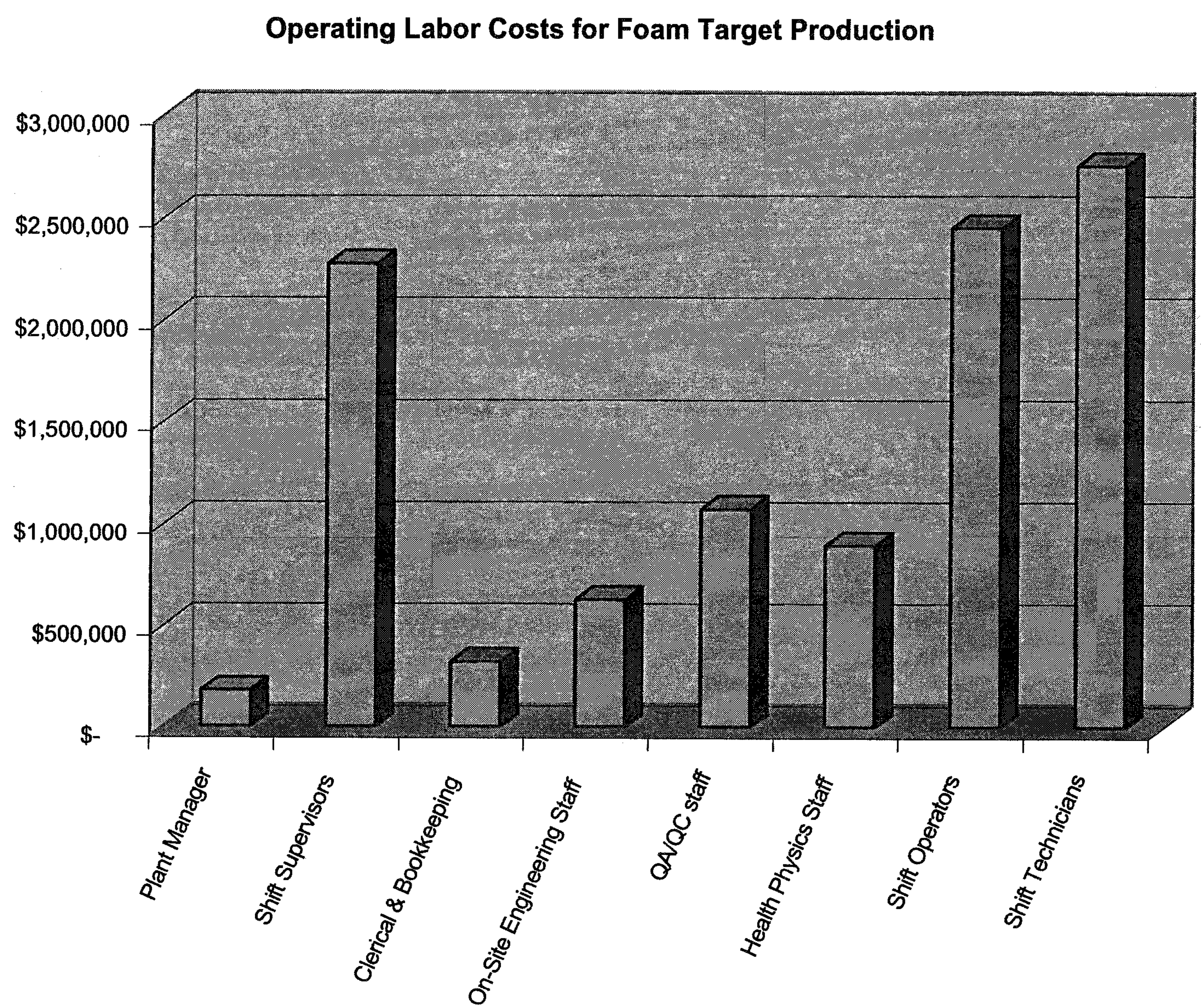


Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 177,966	1.34	1.994	1.27
Shift Supervisors	3	5	$ 85,000	$ 2,269,068	1.34	1.99	1.27
Clerical & Bookkeeping	6	1	$ 30,000	$ 320,339	1.34	1.99	1.27
On-Site Engineering Staff	5	1	$ 70,000	$ 622,882	1.34	1.99	1.27
QA/QC staff	3	5	$ 40,000	$ 1,067,797	1.34	1.99	1.27
Health Physics Staff	2	5	$ 50,000	$ 889,831	1.34	1.99	1.27
Shift Operator - Contactor Area	2	5	$ 40,000	$ 711,865	1.34	1.99	1.27
Technician - Contactor Area	3	5	$ 30,000	$ 800,848	1.34	1.99	1.27
Shift Operator - Dryer Area	2	5	$ 40,000	$ 605,021	1.11	1.26	1.08
Technician - Dryer Area	3	5	$ 30,000	$ 680,649	1.11	1.26	1.08
Shift Operator - Fill/Layer Area	2	5	$ 40,000	$ 567,107	1.02	1.04	1.01
Technician - Fill/Layer Area	3	5	$ 30,000	$ 637,996	1.02	1.04	1.01
Shift Operator - Target Injection Area	2	5	$ 40,000	$ 560,000	n/a	n/a	n/a
Technician - Target Injection Area	3	5	$ 30,000	$ 630,000	n/a	n/a	n/a

Annual labor operating costs = $ 10,541,367

Plant Manager	$ 177,966
Shift Supervisors	$ 2,269,068
Clerical & Bookkeeping	$ 320,339
On-Site Engineering Staff	$ 622,882
QA/QC staff	$ 1,067,797
Health Physics Staff	$ 889,831
Shift Operators	$ 2,443,993
Shift Technicians	$ 2,749,492

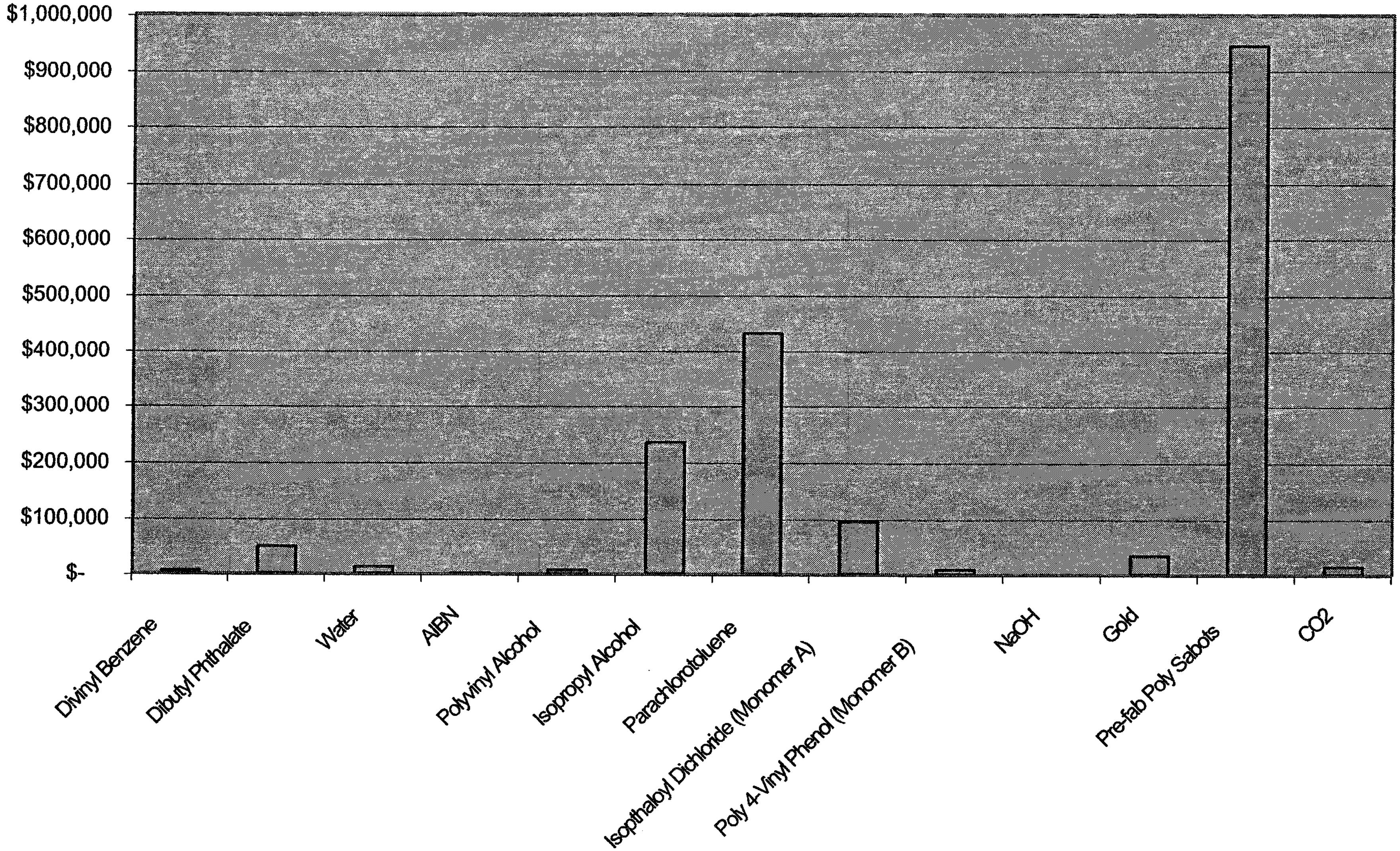

Operating Labor Costs for Foam Target Production
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$-
Plant Manager
Shift Supervisors
Clerical & Bookkeeping
On-Site Engineering Staff
QA/QC staff
Health Physics Staff
Shift Operators
Shift Technicians

Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	473	10.00	$ 4,726	
Dibutyl Phthalate	4726	10.00	$ 47,256	
Water	116704	0.10	$ 11,670	
AIBN	47	10.00	$ 473	
Polyvinyl Alcohol	632	10.00	$ 6,320	
Isopropyl Alcohol	116789	2.00	$ 233,578	
Parachlorotoluene	107446	4.00	$ 429,783	
Isopthaloyl Dichloride (Monomer A)	9343	10.00	$ 93,431	
Poly 4-Vinyl Phenol (Monomer B)	859	10.00	$ 8,587	
NaOH	28	2.00	$ 55	
Gold	3.4	9650.00	$ 32,704	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	70016	0.20	$ 14,003	

Annual materials costs = $ 1,826,110

Materials Costs (consumables) for Foam Target Production

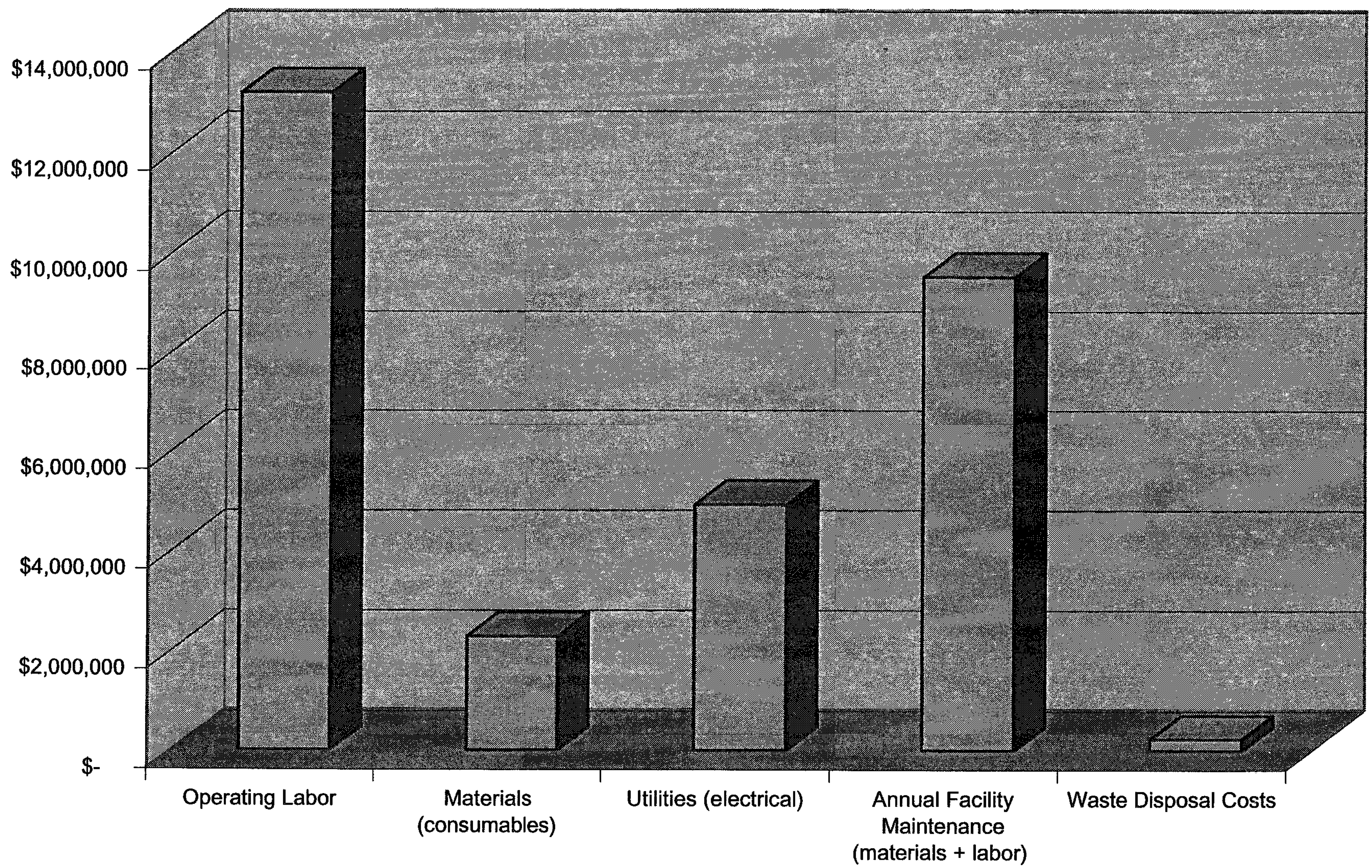


Operating Cost Summary for Foam Target Production

Operating Labor	$	13,176,709
Materials (consumables)	$	2,282,637
Utilities (electrical)	$	4,913,719
Annual Facility Maintenance (materials + labor)	$	9,495,045
Waste Disposal Costs	$	227,511

Total Annual Operating Costs = $ 30,095,621

Operating Costs for Foam Shell Production



Operating Labor	$	13,176,709
Materials (consumables)	$	2,282,637
Utilities (electrical)	$	4,913,719
Annual Facility Maintenance (materi	$	9,495,045
Waste Disposal Costs	$	227,511
Total Annual Operating Costs =	**$**	**30,095,621**

total cost per usable target =	0.243
cost for capital =	0.084
cost for operating =	0.159

Shell Generator (3 each)	$	75,000
Contactors	$	420,000
Contactor Tank Systems (6 each)	$	837,651
Dryer (10 each)	$	3,750,000
Sputtering System	$	2,500,000
DT Filling System (10 each)	$	3,750,000
Cryo Layering System	$	4,375,000
Helium Liquifaction/Recirculation System	$	800,000
DT/He Separation Membrane System	$	150,000
QA Lab Equipment	$	2,000,000
	$	-
	$	-
	$	-
Total Process Equipment Cost	$	31,809,196
	$	-
	$	-
Factored Balance of Plant Costs (from M	$	-
Piping	$	12,405,586
Electrical	$	5,407,563
Instruments	$	4,135,195
Building and services	$	9,542,759
Site Preparation	$	3,499,012
Auxiliaries	$	17,495,058
Field Expenses	$	13,677,954
Engineering	$	10,815,127
Contractors fees	$	5,407,563
Contingency	$	12,405,586
	$	-
Total Installed Capital Cost	$	126,600,599
	$	-
	$	-
Annualized Cost of Capital Investment	**$**	**15,825,075**

	cents per usable target	
waste disposal	0.120	
materials	1.206	
utilities	2.597	
maintenance	5.018	
operating labor	6.964	
	15.905	**total operating**
piping, electrical & instrumentation	1.450	
bldgs & auxiliaries	2.017	
purchased equipment	2.101	
engr, contractors, contingency	2.795	
	8.363	**total capital**
	24.269	**total capital + operating**

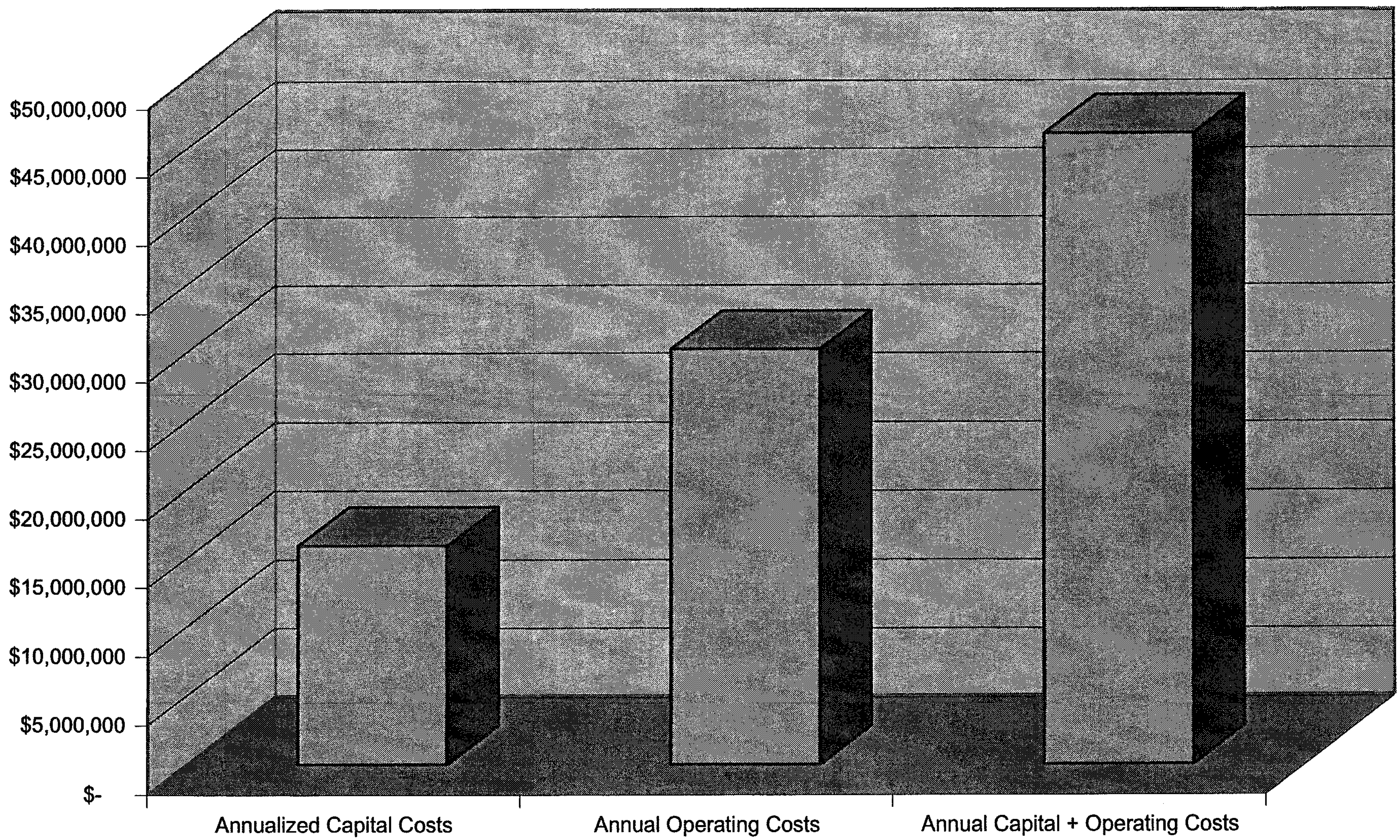
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 15,825,075
Annual Operating Costs	$ 30,095,621

Annual Capital + Operating Costs	**$ 45,920,696**

Cost per Injected Target = $ 0.243

Foam Target Production Costs



ATTACHMENT 5
Case 10 — 3000 MW(e)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
1555200	shells per day total production (on-spec) - @ 6 Hz per 100
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
2079862	total shells produced per day
86661	total shells produced per hour
108.5	mass flow of shells (DVB only), g/hr
10.85	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
1085.20	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
1817.4	inner water flow, g/hr
1817.4	inner water flow, cc/hr
0.033	volume of each shell, cc
2902.6	volume of shells produced, cc/hr
14512.8	volume of outer water, cc/hr
14512.8	mass flow of outer water, g/hr
139323.0	contactor initial fill volume, cc
348307.5	contactor initial total volume, cc
76.2	contactor diameter, cm
76.2	contactor length, cm
145.1	PVA usage, g/hr
208985	vapor space in contactor, cc
208985	N_2 usage, cc/hr
281.4	N_2 usage, g/hr
759149587	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
1.98	mass flow usage of gold in high Z coating, g/hr
836	volume of waste per contactor, liters
2508	volume of waste per day from contactors, liters
2.51	tons per day of waste liquids from contactors
915	tons per year of waste liquids from contactors
23221	volume of shells in dryer, cc
77402	volume of dryer, cc
36.7	contactor diameter, cm
73.3	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	86661	8666	1.000
ICP layer	8	1.204	77995	6240	0.900
CO_2 drying	5	1.107	71755	3588	0.828
Sputter Coating	3	1.052	68167	2045	0.787
DT Filling	2	1.020	66122	1322	0.763
Layering and Injection	0	1	64800	0	0.748

overall % reject rate = 25

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

139.3 = the fill volume of each contactor (in liters)

2926 = the total volume required for each tank (in liters)
3657.229 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

4.21 = height of tank, M
1.05 = diameter of tank, M

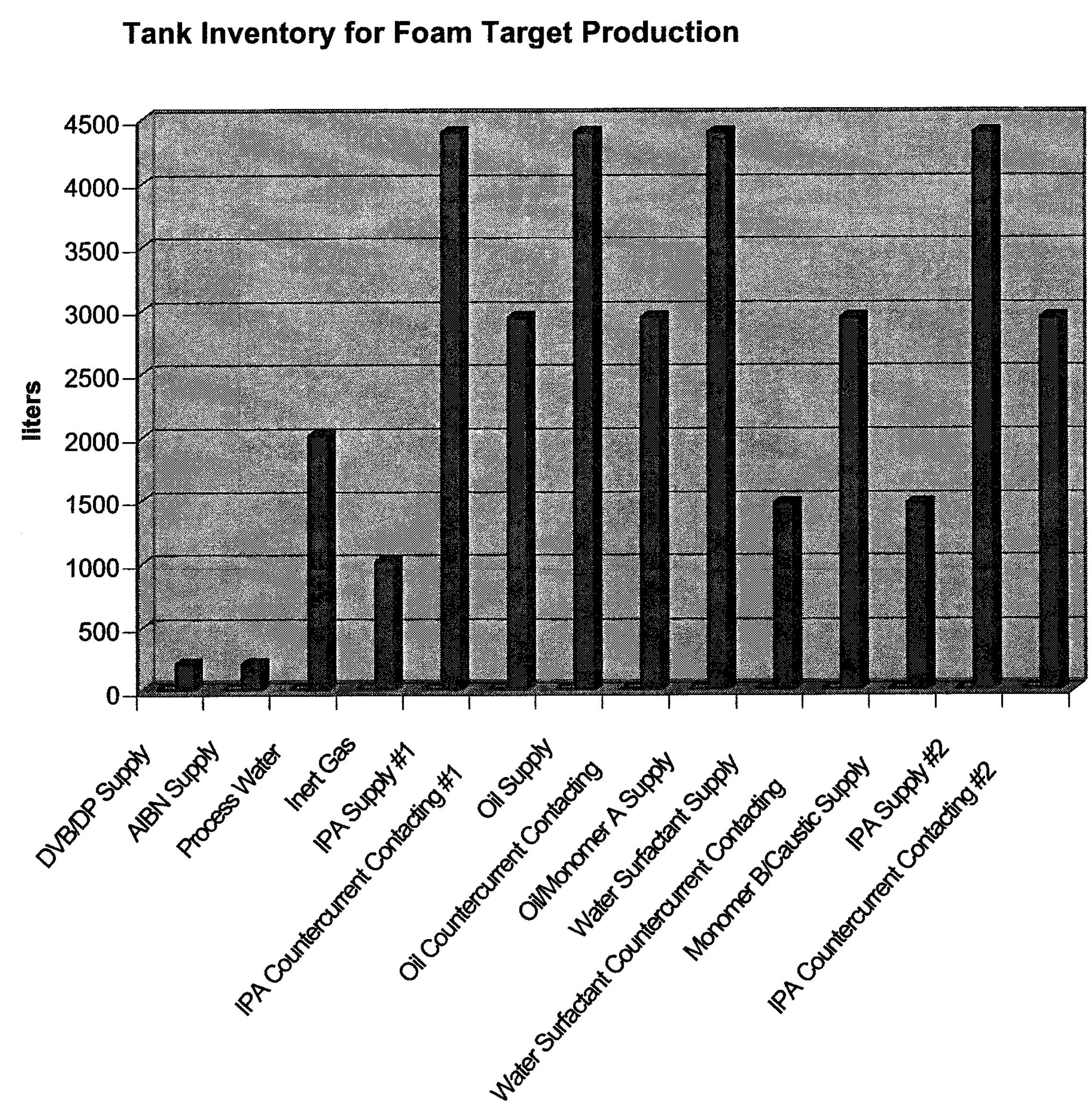
there are 5 of these tanks to provide a 5-step rinse

1.5 weeks storage in supply tank
4389 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	4389	
IPA Countercurrent Contacting #1	5	2926	
Oil Supply	1	4389	
Oil Countercurrent Contacting	5	2926	
Oil/Monomer A Supply	1	4389	
Water Surfactant Supply	1	1463	
Water Surfactant Countercurrent Contacting	2	2926	
Monomer B/Caustic Supply	1	1463	
IPA Supply #2	1	4389	
IPA Countercurrent Contacting #2	5	2926	

Total Tanks 27



Tank Inventory for Foam Target Production
liters
4500
4000
3500
3000
2500
2000
1500
1000
500
0
DVB/DP Supply
AIBN Supply
Process Water
Inert Gas
IPA Supply #1
IPA Countercurrent Contacting #1
Oil Supply
Oil Countercurrent Contacting
Oil/Monomer A Supply
Water Surfactant Supply
Water Surfactant Countercurrent Contacting
Monomer B/Caustic Supply
IPA Supply #2
IPA Countercurrent Contacting #2

Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	108.52																				90		
	Dibutyl Phthalate	1085.20				1085.20		1085	1085															
	Water			1817.36	14512.81	16330.18		16330	16330							15674		15647						
	AIBN		10.85																					
	Polyvinyl Alcohol				145.13	145.13		145	145															
	Polymerized DVB					119.37		119	119															
	Isopropyl Alcohol (IPA)									15674										15674		1505		
	Parachlorotoluene											15674		13166										
	Spent Solvent #1																							
	Isophthaloyl dichloride													2508										
	Poly 4-Vinyl Phenol																	230						
	NaOH																	9						
	Mixed liquid waste										15674		15674		15674		15674		15886		15674			
	CO_2																						21085	
	Au or Pd																							1.56
Gases	N_2						281.41																	
Total, g/hr		1193.7	10.9	1817.4	14657.9	17679.9	281.4	17679.9	17679.9	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15886.1	15886.1	15673.8	15673.8	1594.6	21085.1	1.6

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	3343	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 2,000,000	1	1	1.000	$ 2,000,000
Total Process Equipment Cost	**$ 24,381,691**				**$ 47,137,539**

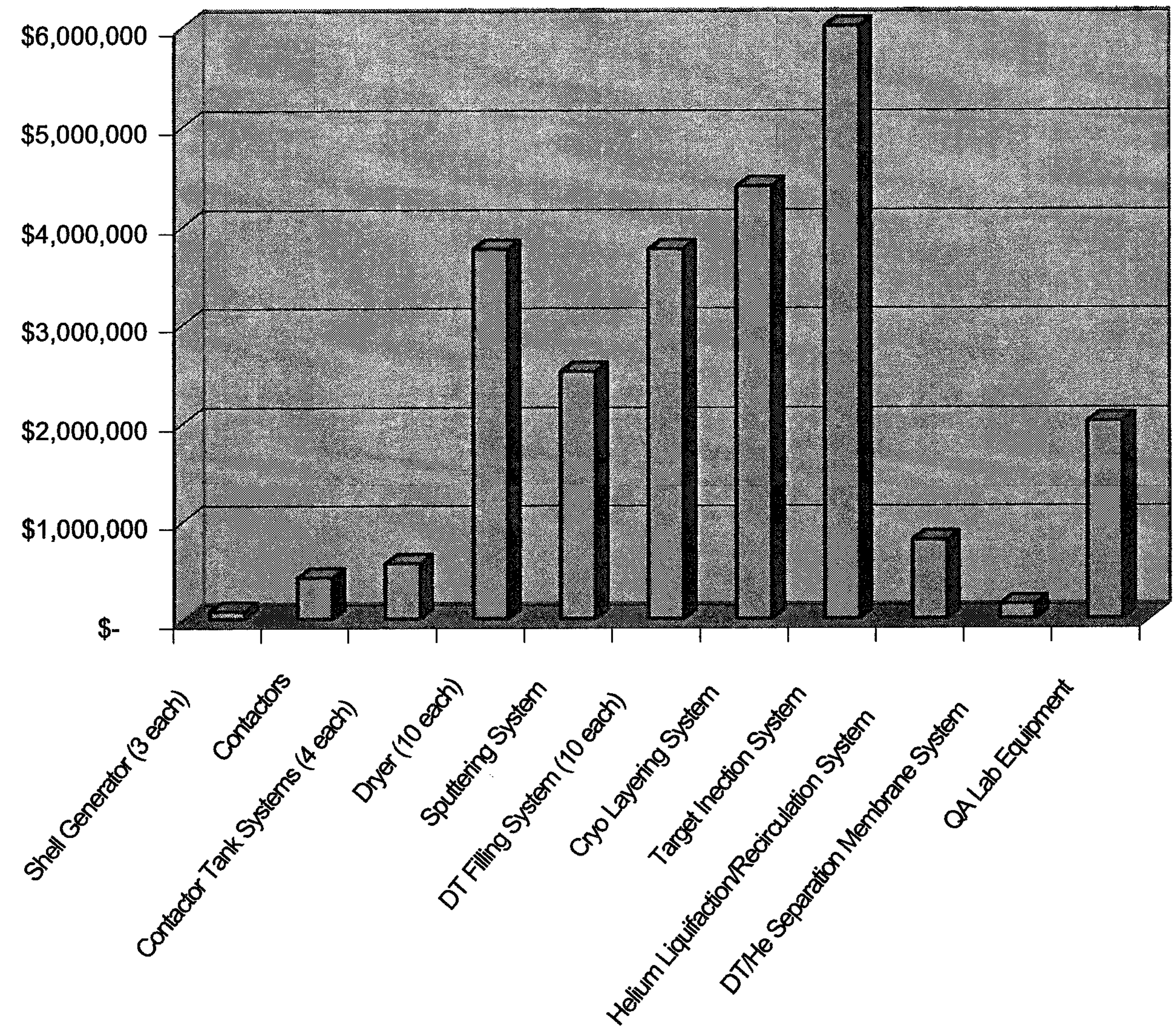
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 18,383,640
Electrical	$ 8,013,382
Instruments	$ 6,127,880
Building and services	$ 14,141,262
Site Preparation	$ 5,185,129
Auxiliaries	$ 25,925,646
Field Expenses	$ 20,269,142
Engineering	$ 16,026,763
Contractors fees	$ 8,013,382
Contingency	$ 18,383,640

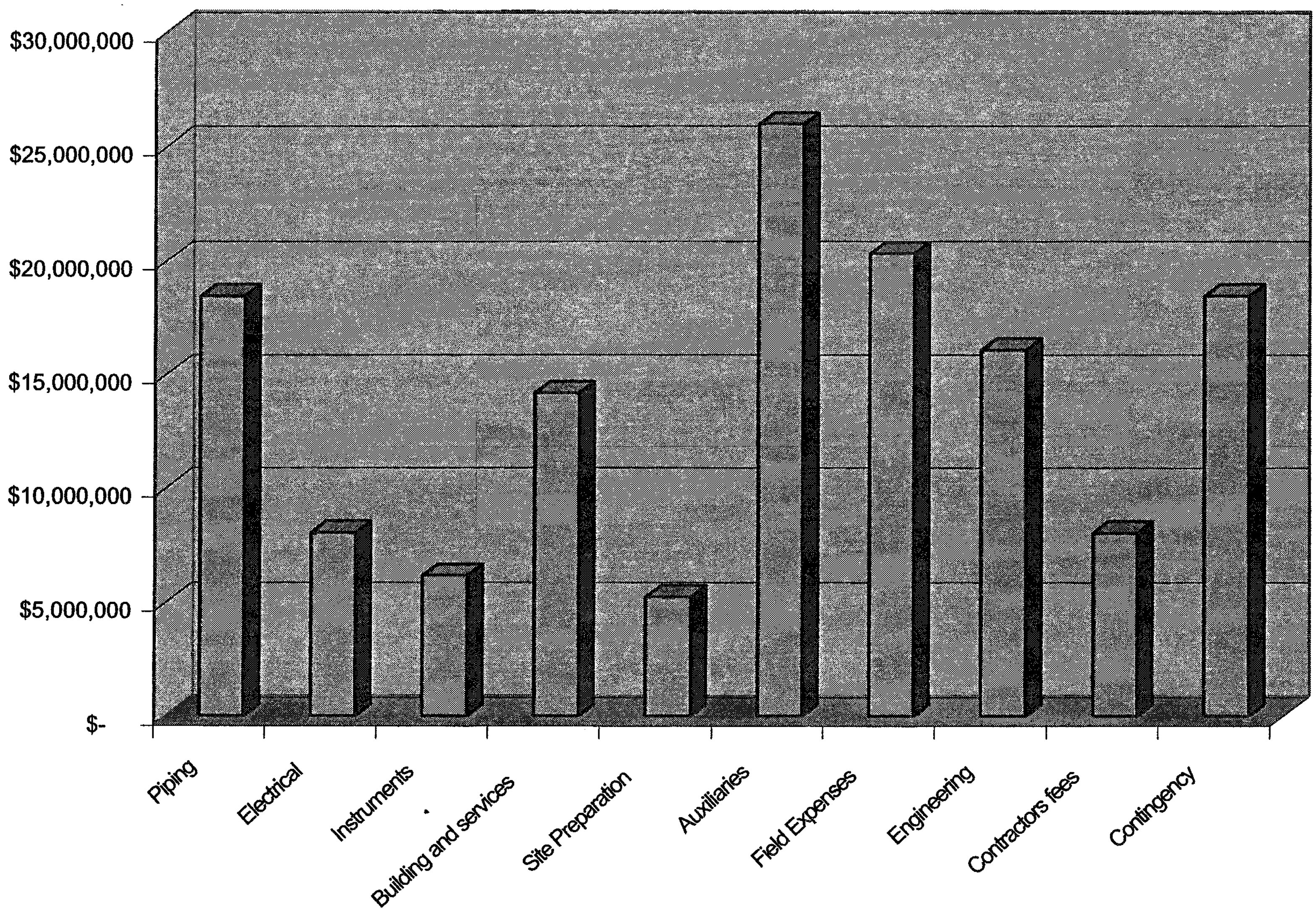
Total Installed Capital Cost **$ 187,607,405**

Annualized Cost of Capital Investment **$ 23,450,926**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

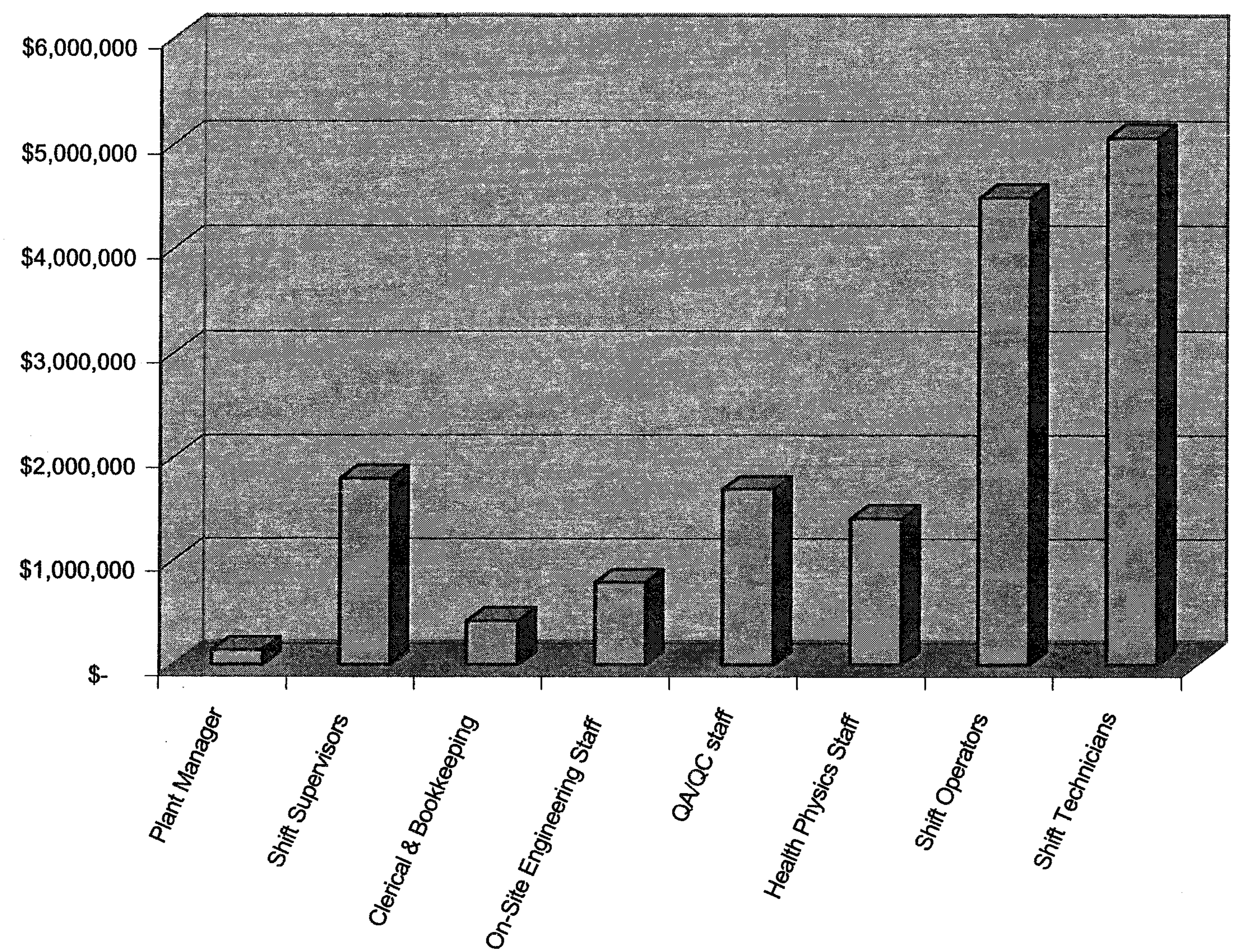
Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	10	1	$ 30,000	$ 420,068	1.34	1.34	1.00
On-Site Engineering Staff	8	1	$ 70,000	$ 784,127	1.34	1.34	1.00
QA/QC staff	6	5	$ 40,000	$ 1,680,271	1.34	1.34	1.00
Health Physics Staff	4	5	$ 50,000	$ 1,400,226	1.34	1.34	1.00
Shift Operator - Contactor Area	4	5	$ 40,000	$ 1,120,181	1.34	1.34	1.00
Technician - Contactor Area	6	5	$ 30,000	$ 1,260,203	1.34	1.34	1.00
Shift Operator - Dryer Area	4	5	$ 40,000	$ 1,120,203	1.11	1.11	1.00
Technician - Dryer Area	6	5	$ 30,000	$ 1,260,228	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	4	5	$ 40,000	$ 1,120,269	1.02	1.02	1.00
Technician - Fill/Layer Area	6	5	$ 30,000	$ 1,260,302	1.02	1.02	1.00
Shift Operator - Target Injection Area	4	5	$ 40,000	$ 1,120,000	n/a	n/a	n/a
Technician - Target Injection Area	6	5	$ 30,000	$ 1,260,000	n/a	n/a	n/a

Annual labor operating costs = $ 15,731,389

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 420,068
On-Site Engineering Staff	$ 784,127
QA/QC staff	$ 1,680,271
Health Physics Staff	$ 1,400,226
Shift Operators	$ 4,480,652
Shift Technicians	$ 5,040,734

plant size multiplier
3000
1.93

Operating Labor Costs for Foam Target Production

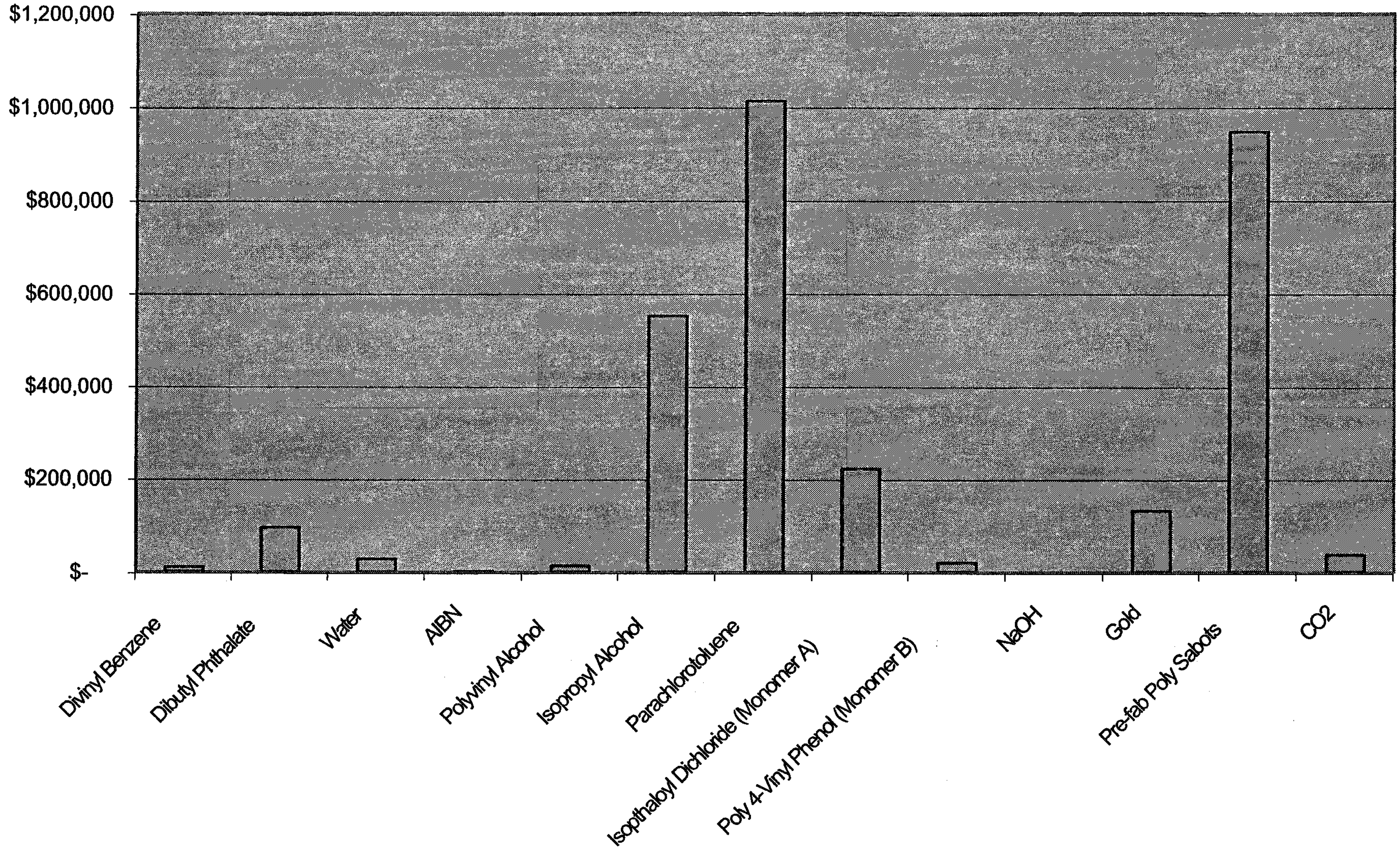


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	951	10.00	$ 9,506	
Dibutyl Phthalate	9506	10.00	$ 95,064	
Water	274370	0.10	$ 27,437	
AIBN	95	10.00	$ 951	
Polyvinyl Alcohol	1271	10.00	$ 12,713	
Isopropyl Alcohol	274606	2.00	$ 549,211	
Parachlorotoluene	252637	4.00	$ 1,010,549	
Isopthaloyl Dichloride (Monomer A)	21968	10.00	$ 219,685	
Poly 4-Vinyl Phenol (Monomer B)	2019	10.00	$ 20,192	
NaOH	76	2.00	$ 151	
Gold	13.7	9650.00	$ 131,851	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	184706	0.20	$ 36,941	

Annual materials costs = $ 3,057,774

Materials Costs (consumables) for Foam Target Production

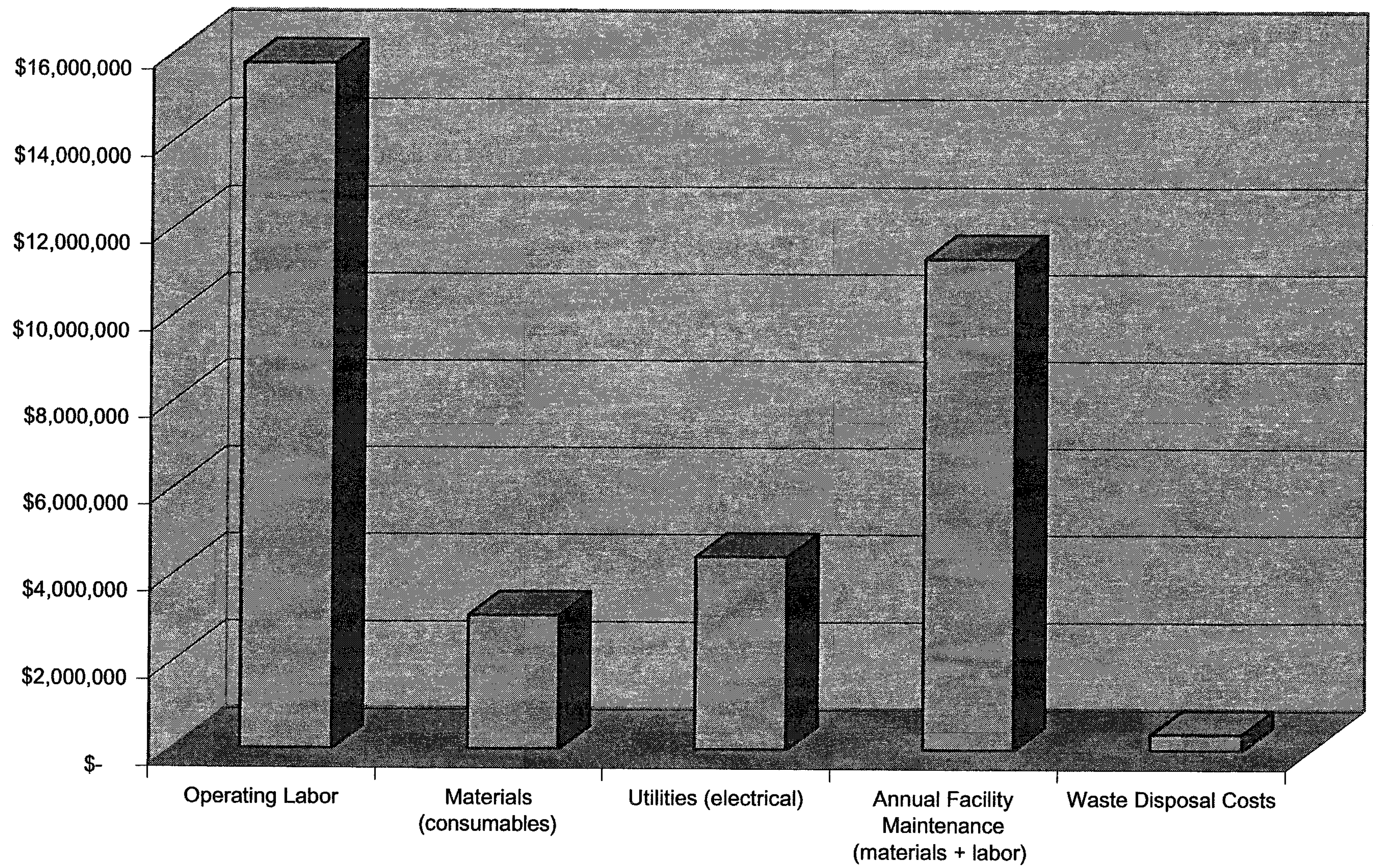


Operating Cost Summary for Foam Target Production

Operating Labor	$	15,731,389
Materials (consumables)	$	3,057,774
Utilities (electrical)	$	4,393,227
Annual Facility Maintenance (materials + labor)	$	11,256,444
Waste Disposal Costs	$	366,141

Total Annual Operating Costs = $ 34,804,975

Operating Costs for Foam Shell Production



waste disposal	0.065
materials	0.539
utilities	0.774
maintenance	1.983
operating labor	2.771
piping, electrical & instrumentation	0.716
bldgs & auxiliaries	0.996
purchased equipment	1.038

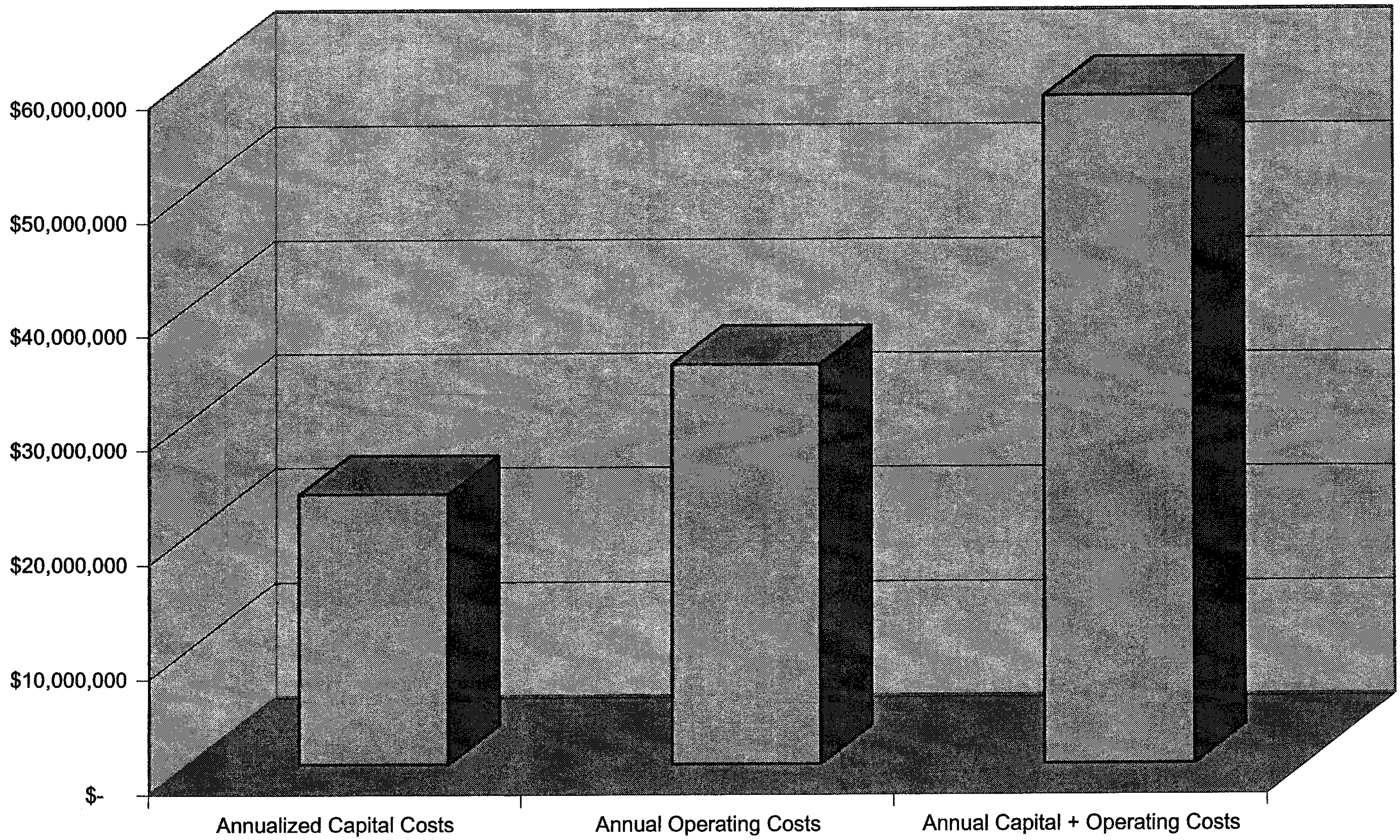
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 23,450,926
Annual Operating Costs	$ 34,804,975

Annual Capital + Operating Costs	**$ 58,255,900**

Cost per Injected Target = $ 0.103

Foam Target Production Costs



ATTACHMENT 5
Case 11 — Empty capsules (made off-site)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
5184000	shells per day total production (on-spec) - @ 6 Hz per 100
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
6932873	total shells produced per day
288870	total shells produced per hour
361.7	mass flow of shells (DVB only), g/hr
36.17	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
3617.33	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
6057.9	inner water flow, g/hr
6057.9	inner water flow, cc/hr
0.033	volume of each shell, cc
9675.2	volume of shells produced, cc/hr
48376.0	volume of outer water, cc/hr
48376.0	mass flow of outer water, g/hr
464410.0	contactor initial fill volume, cc
1161025.1	contactor initial total volume, cc
113.9	contactor diameter, cm
113.9	contactor length, cm
483.8	PVA usage, g/hr
696615	vapor space in contactor, cc
696615	N_2 usage, cc/hr
938.0	N_2 usage, g/hr
2530498623	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
6.61	mass flow usage of gold in high Z coating, g/hr
2786	volume of waste per contactor, liters
8359	volume of waste per day from contactors, liters
8.36	tons per day of waste liquids from contactors
3051	tons per year of waste liquids from contactors
77402	volume of shells in dryer, cc
258006	volume of dryer, cc
54.8	contactor diameter, cm
109.5	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	288870	28887	1.000
ICP layer	8	1.204	259983	20799	0.900
CO_2 drying	5	1.107	239184	11959	0.828
Sputter Coating	3	1.052	227225	6817	0.787
DT Filling	2	1.020	220408	4408	0.763
Layering and Injection	0	1	216000	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

464.4 = the fill volume of each contactor (in liters)

9753 = the total volume required for each tank (in liters)
12190.76 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

6.29 = height of tank, M
1.57 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

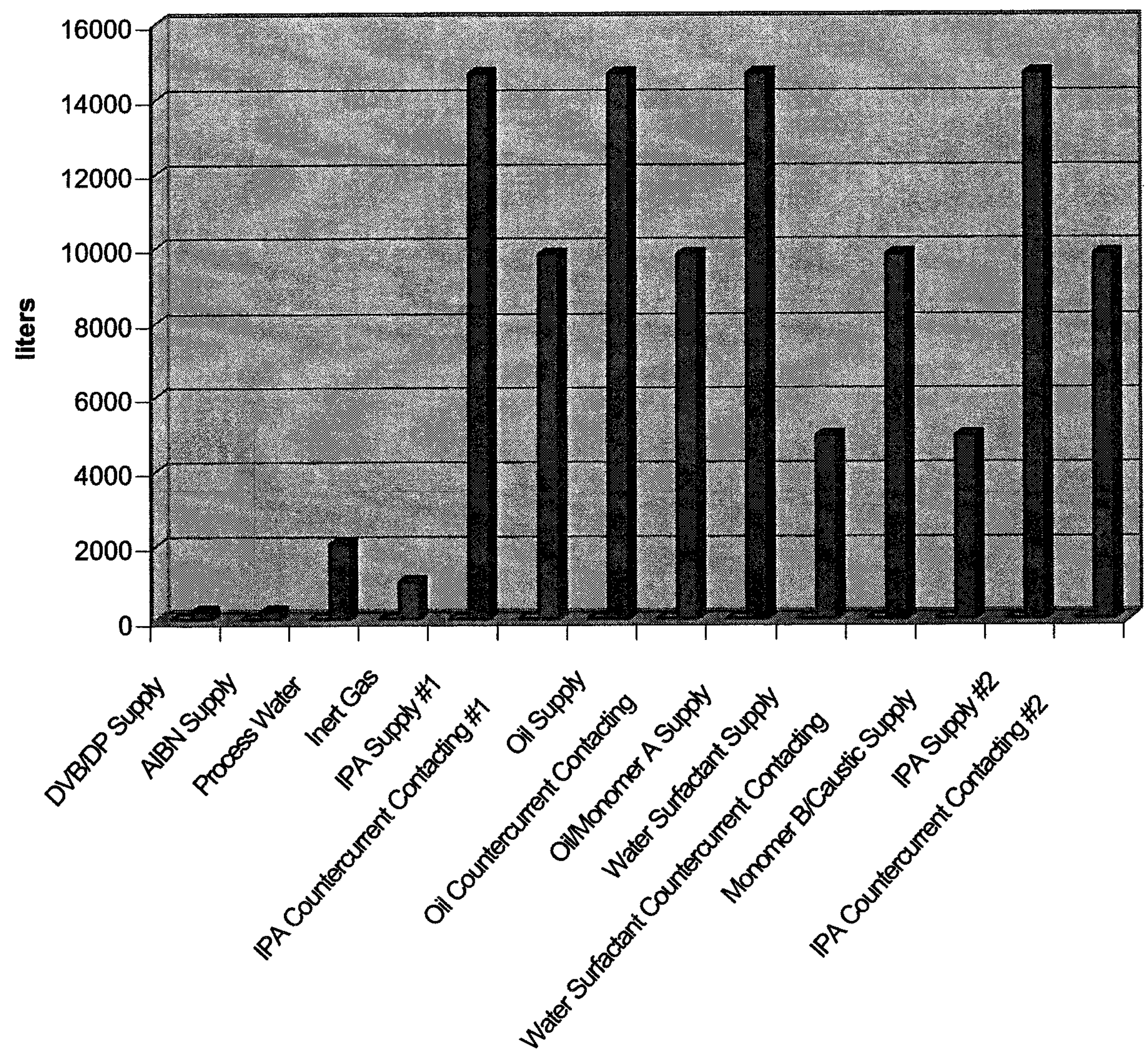
1.5 weeks storage in supply tank
14629 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	14629	
IPA Countercurrent Contacting #1	5	9753	
Oil Supply	1	14629	
Oil Countercurrent Contacting	5	9753	
Oil/Monomer A Supply	1	14629	
Water Surfactant Supply	1	4876	
Water Surfactant Countercurrent Contacting	2	9753	
Monomer B/Caustic Supply	1	4876	
IPA Supply #2	1	14629	
IPA Countercurrent Contacting #2	5	9753	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	361.73																				300		
	Dibutyl Phthalate	3617.33				3617.33		3617	3617															
	Water			6057.88	48376.05	54433.92		54434	54434							52246		52156						
	AIBN		36.17																					
	Polyvinyl Alcohol				483.76	483.76		484	484															
	Polymerized DVB					397.91		398	398															
	Isopropyl Alcohol (IPA)									52246										52246		5016		
	Parachlorotoluene											52246		43887										
	Spent Solvent #1																							
	Isophthaloyl dichloride													8359										
	Poly 4-Vinyl Phenol																	768						
	NaOH																	29						
	Mixed liquid waste										52246		52246		52246		52246		52954		52246			
	CO_2																						70284	
	Au or Pd																							5.20
Gases	N_2						938.02																	
Total, g/hr		3979.1	36.2	6057.9	48859.8	58932.9	938.0	58932.9	58932.9	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52953.6	52953.6	52246.1	52246.1	5315.4	70283.8	5.2

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	-	DT Filling System
$	-	Cryo Layering System
$	-	Target Injection System (4 times this for installed equipment)
	2675	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ -	1.02	1.02	1.000	$ -
Cryo Layering System	$ -	1	1	1.000	$ -
Target Inection System	$ -	1	1	1.000	$ -
Helium Liquifaction/Recirculation System	$ -	1	1	1.000	$ -
DT/He Separation Membrane System	$ -	1	1	1.000	$ -
QA Lab Equipment	$ 1,000,000	1	1	1.000	$ 1,000,000

Total Process Equipment Cost	**$ 8,306,691**				**$ 33,072,727**

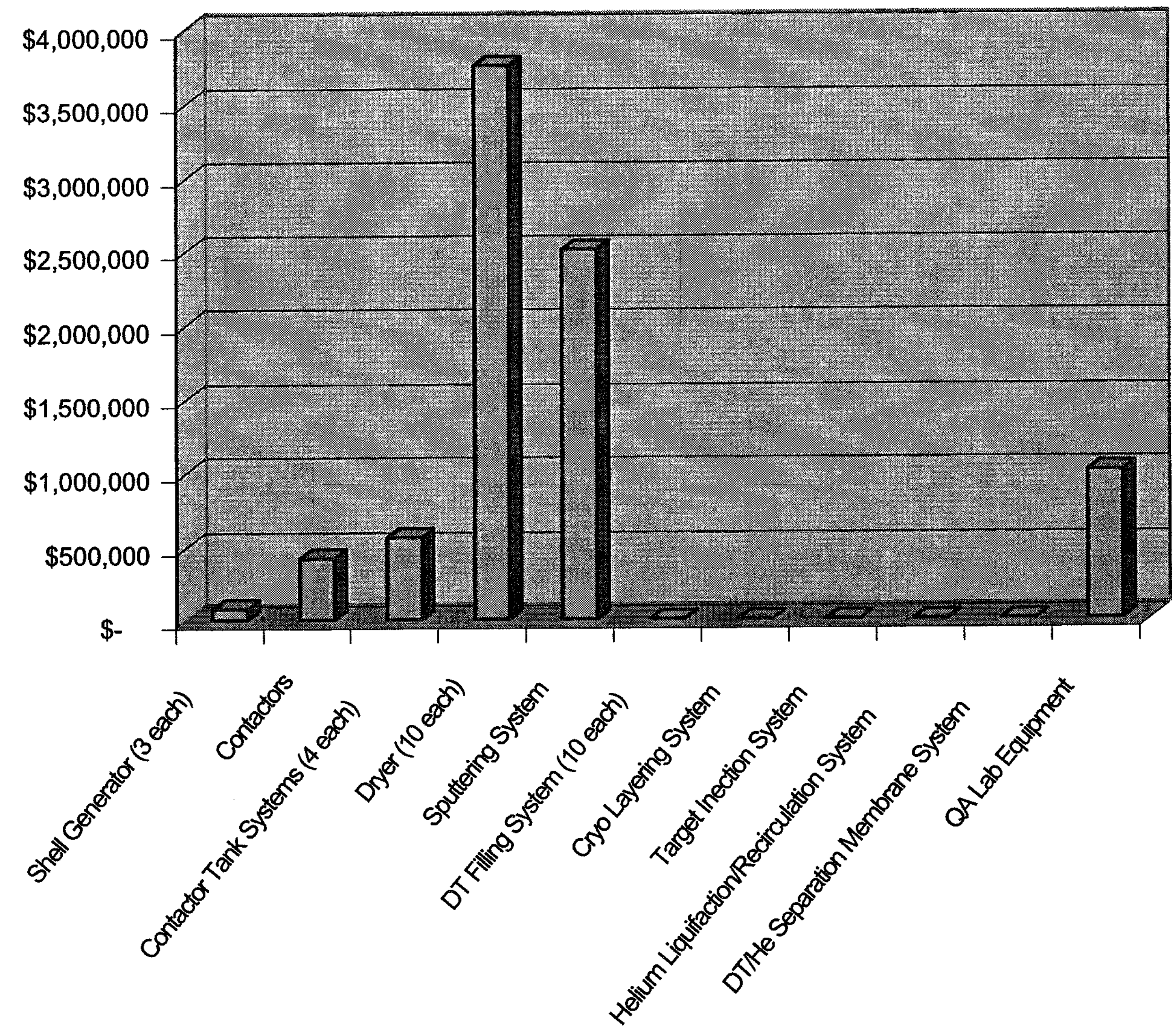
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 12,898,364
Electrical	$ 5,622,364
Instruments	$ 4,299,455
Building and services	$ 9,921,818
Site Preparation	$ 3,638,000
Auxiliaries	$ 18,190,000
Field Expenses	$ 14,221,273
Engineering	$ 11,244,727
Contractors fees	$ 5,622,364
Contingency	$ 12,898,364

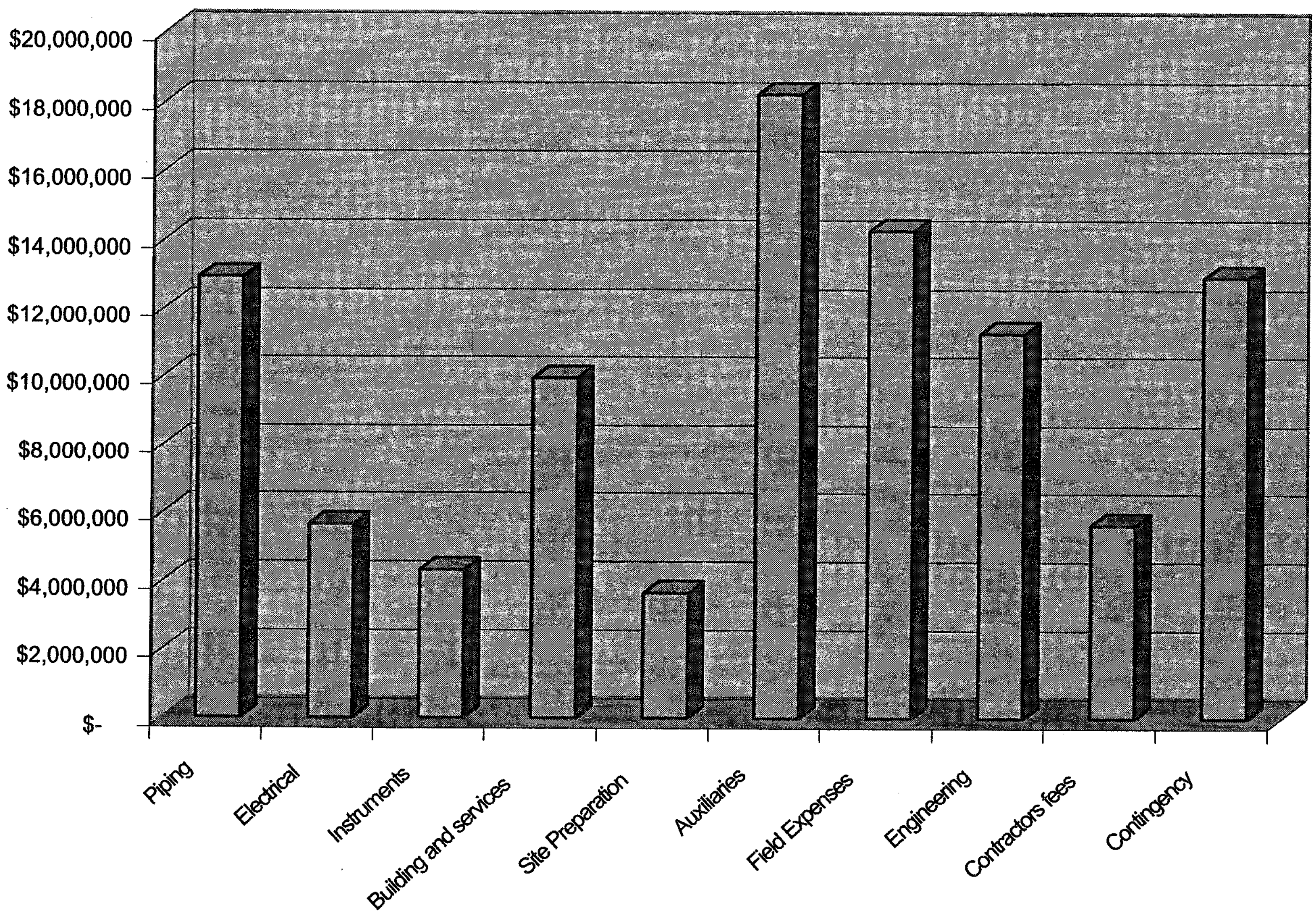
Total Installed Capital Cost **$ 131,629,454**

Annualized Cost of Capital Investment **$ 16,453,682**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

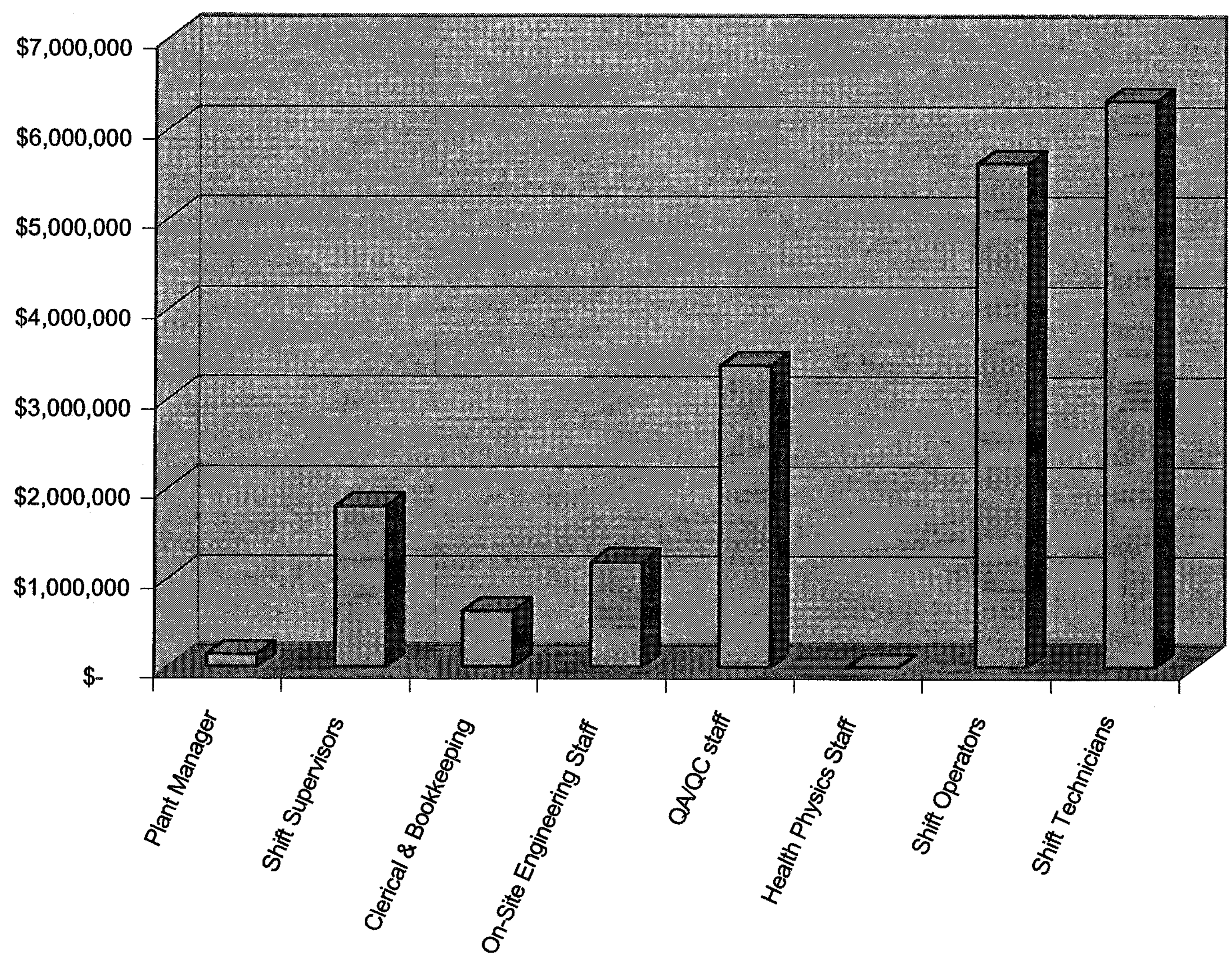
Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	15	1	$ 30,000	$ 630,102	1.34	1.34	1.00
On-Site Engineering Staff	12	1	$ 70,000	$ 1,176,190	1.34	1.34	1.00
QA/QC staff	12	5	$ 40,000	$ 3,360,542	1.34	1.34	1.00
Health Physics Staff	0	5	$ 50,000	$ -	1.34	1.34	1.00
Shift Operator - Contactor Area	10	5	$ 40,000	$ 2,800,452	1.34	1.34	1.00
Technician - Contactor Area	15	5	$ 30,000	$ 3,150,509	1.34	1.34	1.00
Shift Operator - Dryer Area	10	5	$ 40,000	$ 2,800,507	1.11	1.11	1.00
Technician - Dryer Area	15	5	$ 30,000	$ 3,150,570	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	0	5	$ 40,000	$ -	1.02	1.02	1.00
Technician - Fill/Layer Area	0	5	$ 30,000	$ -	1.02	1.02	1.00
Shift Operator - Target Injection Area	0	5	$ 40,000	$ -	n/a	n/a	n/a
Technician - Target Injection Area	0	5	$ 30,000	$ -	n/a	n/a	n/a

Annual labor operating costs = $ 18,994,182

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 630,102
On-Site Engineering Staff	$ 1,176,190
QA/QC staff	$ 3,360,542
Health Physics Staff	$ -
Shift Operators	$ 5,600,959
Shift Technicians	$ 6,301,079

plant size multiplier
3000
1.93

Operating Labor Costs for Foam Target Production

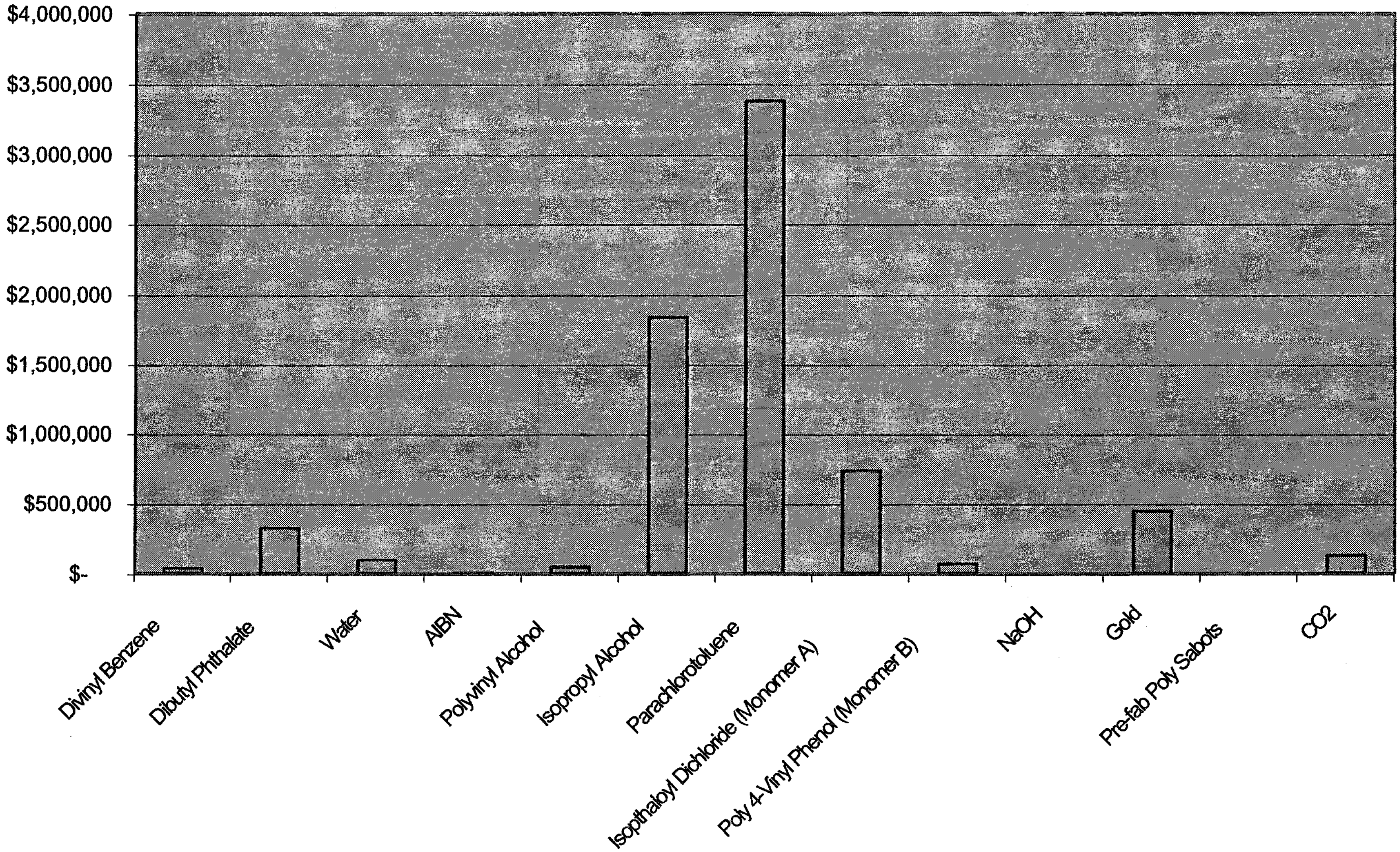


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	3169	10.00	$ 31,688	
Dibutyl Phthalate	31688	10.00	$ 316,878	
Water	914567	0.10	$ 91,457	
AIBN	317	10.00	$ 3,169	
Polyvinyl Alcohol	4238	10.00	$ 42,377	
Isopropyl Alcohol	915352	2.00	$ 1,830,704	
Parachlorotoluene	842124	4.00	$ 3,368,496	
Isopthaloyl Dichloride (Monomer A)	73228	10.00	$ 732,282	
Poly 4-Vinyl Phenol (Monomer B)	6731	10.00	$ 67,305	
NaOH	252	2.00	$ 505	
Gold	45.5	9650.00	$ 439,504	
Pre-fab Poly Sabots	0	3.60	$ -	(= 0.5 cent per sabot)
CO_2	615686	0.20	$ 123,137	

Annual materials costs = $ 7,047,503

Materials Costs (consumables) for Foam Target Production

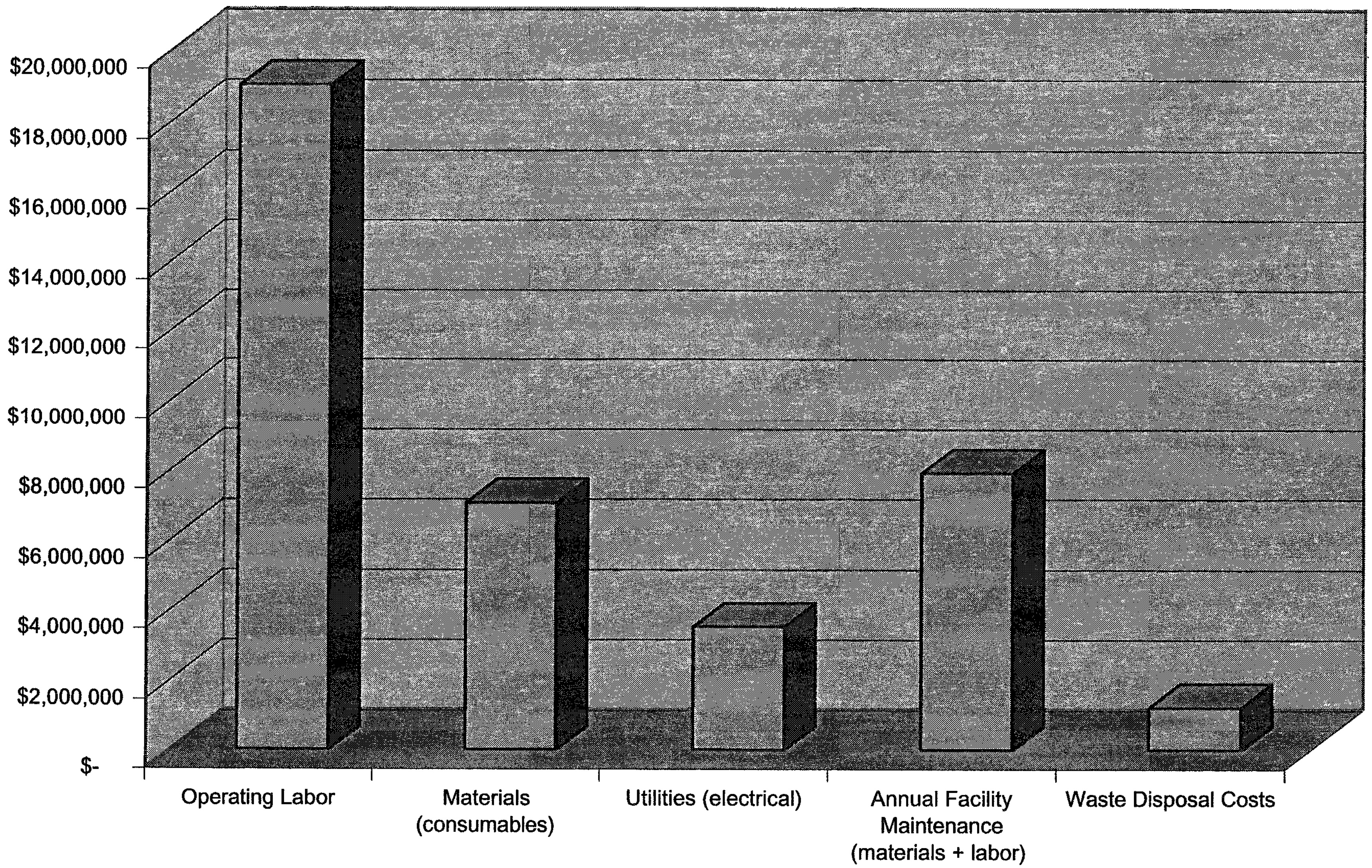


Operating Cost Summary for Foam Target Production

Operating Labor	$	18,994,182
Materials (consumables)	$	7,047,503
Utilities (electrical)	$	3,514,581
Annual Facility Maintenance (materials + labor)	$	7,897,767
Waste Disposal Costs	$	1,220,470

Total Annual Operating Costs = $ 38,674,503

Operating Costs for Foam Shell Production



waste disposal	0.065
materials	0.372
utilities	0.186
maintenance	0.417
operating labor	1.004

piping, electrical & instrumentation	0.151
bldgs & auxiliaries	0.210
purchased equipment	0.218

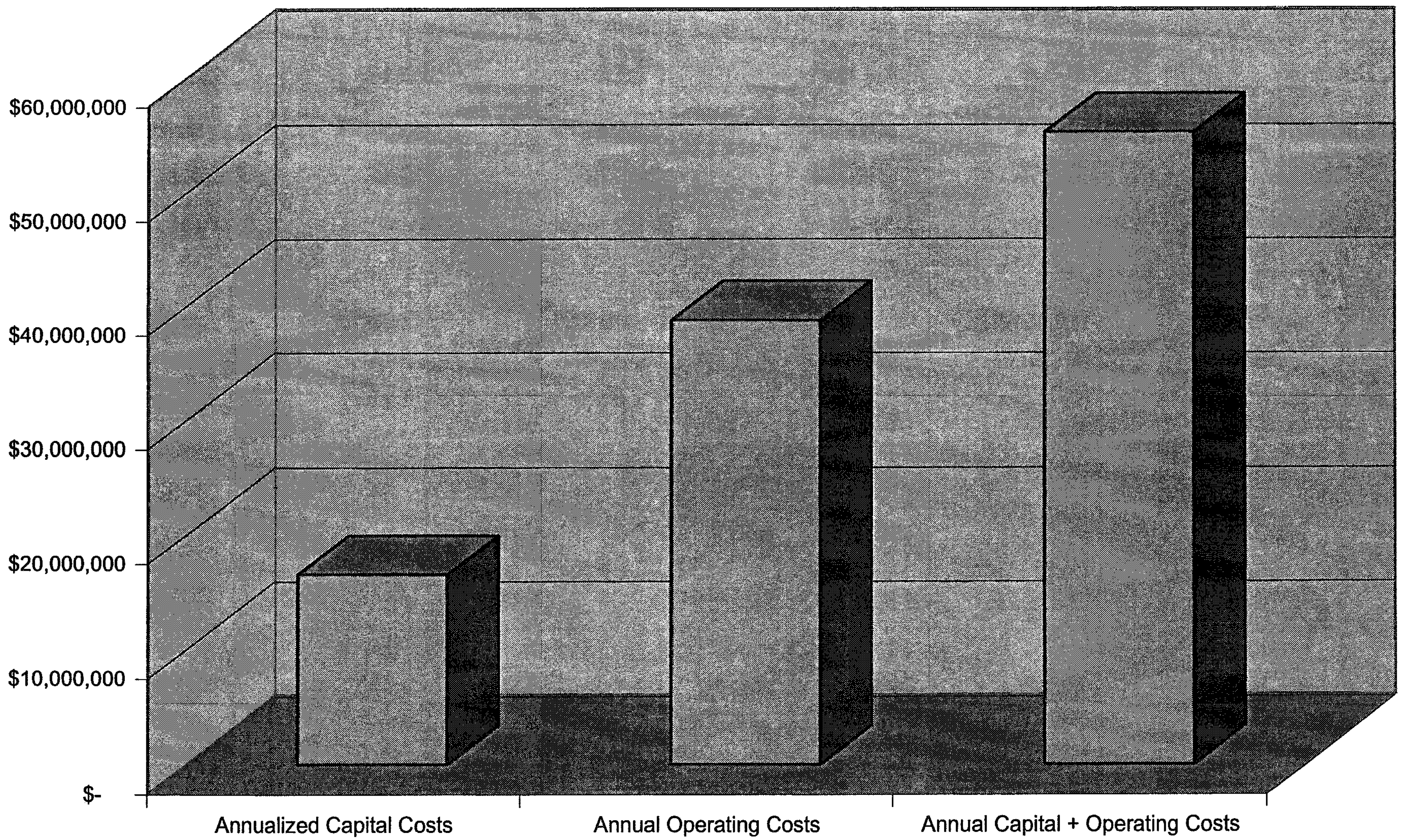
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 16,453,682
Annual Operating Costs	$ 38,674,503

Annual Capital + Operating Costs	**$ 55,128,185**

Cost per Injected Target = $ 0.0291

Foam Target Production Costs



ATTACHMENT 5
Case 11 — Fill/layer/inject (made on-site)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
518400	shells per day total production (on-spec) - @ 6 Hz per 100
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
693287	total shells produced per day
28887	total shells produced per hour
36.2	mass flow of shells (DVB only), g/hr
3.62	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
361.73	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
605.8	inner water flow, g/hr
605.8	inner water flow, cc/hr
0.033	volume of each shell, cc
967.5	volume of shells produced, cc/hr
4837.6	volume of outer water, cc/hr
4837.6	mass flow of outer water, g/hr
46441.0	contactor initial fill volume, cc
116102.5	contactor initial total volume, cc
52.9	contactor diameter, cm
52.9	contactor length, cm
48.4	PVA usage, g/hr
69662	vapor space in contactor, cc
69662	N_2 usage, cc/hr
93.8	N_2 usage, g/hr
253049862	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
0.66	mass flow usage of gold in high Z coating, g/hr
279	volume of waste per contactor, liters
836	volume of waste per day from contactors, liters
0.84	tons per day of waste liquids from contactors
305	tons per year of waste liquids from contactors
7740	volume of shells in dryer, cc
25801	volume of dryer, cc
25.4	contactor diameter, cm
50.8	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	28887	2889	1.000
ICP layer	8	1.204	25998	2080	0.900
CO_2 drying	5	1.107	23918	1196	0.828
Sputter Coating	3	1.052	22722	682	0.787
DT Filling	2	1.020	22041	441	0.763
Layering and Injection	0	1	21600	0	0.748

overall % reject rate = 25

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

46.4 = the fill volume of each contactor (in liters)

975 = the total volume required for each tank (in liters)
1219.076 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

2.92 = height of tank, M
0.73 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

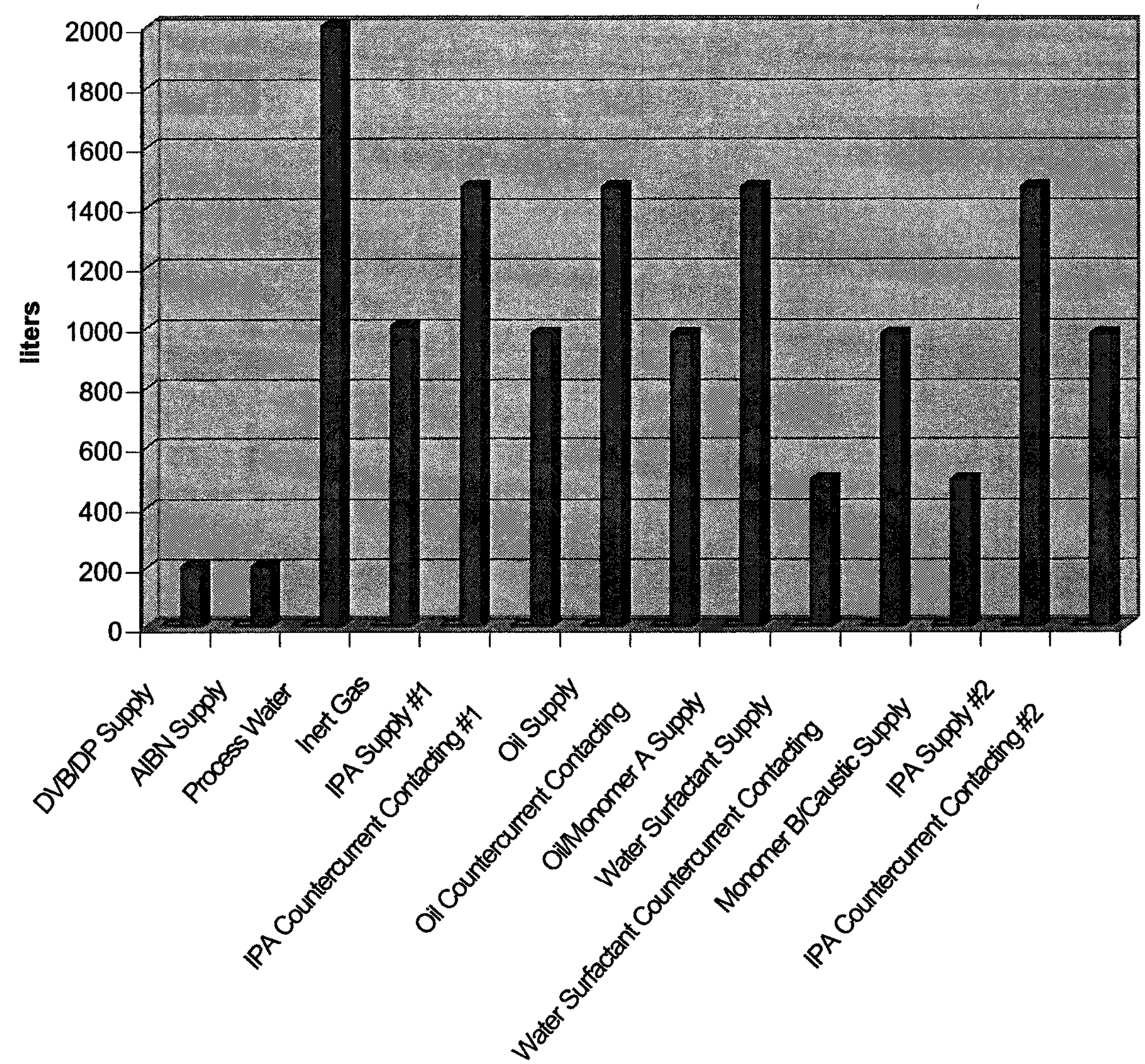
1.5 weeks storage in supply tank
1463 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	0	200	
AIBN Supply	0	200	
Process Water	0	2000	
Inert Gas	0	1000	nitrogen
IPA Supply #1	0	1463	
IPA Countercurrent Contacting #1	0	975	
Oil Supply	0	1463	
Oil Countercurrent Contacting	0	975	
Oil/Monomer A Supply	0	1463	
Water Surfactant Supply	0	488	
Water Surfactant Countercurrent Contacting	0	975	
Monomer B/Caustic Supply	0	488	
IPA Supply #2	0	1463	
IPA Countercurrent Contacting #2	0	975	

Total Tanks 0

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	36.17																				30		
	Dibutyl Phthalate	361.73				361.73		362	362															
	Water			605.79	4837.60	5443.39		5443	5443							5225		5216						
	AIBN		3.62																					
	Polyvinyl Alcohol				48.38	48.38		48	48															
	Polymerized DVB					39.79		40	40															
	Isopropyl Alcohol (IPA)									5225										5225		502		
	Parachlorotoluene											5225		4389										
	Spent Solvent #1																							
	Isophthaloyl dichloride													836										
	Poly 4-Vinyl Phenol																	77						
	NaOH																	3						
	Mixed liquid waste										5225		5225		5225		5225		5295		5225			
	CO_2																						7028	
	Au or Pd																							0.52
Gases	N_2						93.80																	
Total, g/hr		397.9	3.6	605.8	4886.0	5893.3	93.8	5893.3	5893.3	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5224.6	5295.4	5295.4	5224.6	5224.6	531.5	7028.4	0.5

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	-	cost per contactor
	42	calculated number of contactors
$	-	cost per shell generator
	3	shell generators needed
$	-	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	-	Dryer System - holds 8 hours of targets
$	-	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	1337	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ -	1.34	1.34	1.000	$ -
Contactors	$ -	1.34	1.34	1.000	$ -
Contactor Tank Systems (4 each)	$ -	1.34	1.34	1.000	$ -
Dryer (10 each)	$ -	1.11	1.11	1.000	$ -
Sputtering System	$ -	1.05	1.05	1.000	$ -
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 1,000,000	1	1	1.000	$ 1,000,000

Total Process Equipment Cost **$ 16,075,000** **$ 16,075,900**

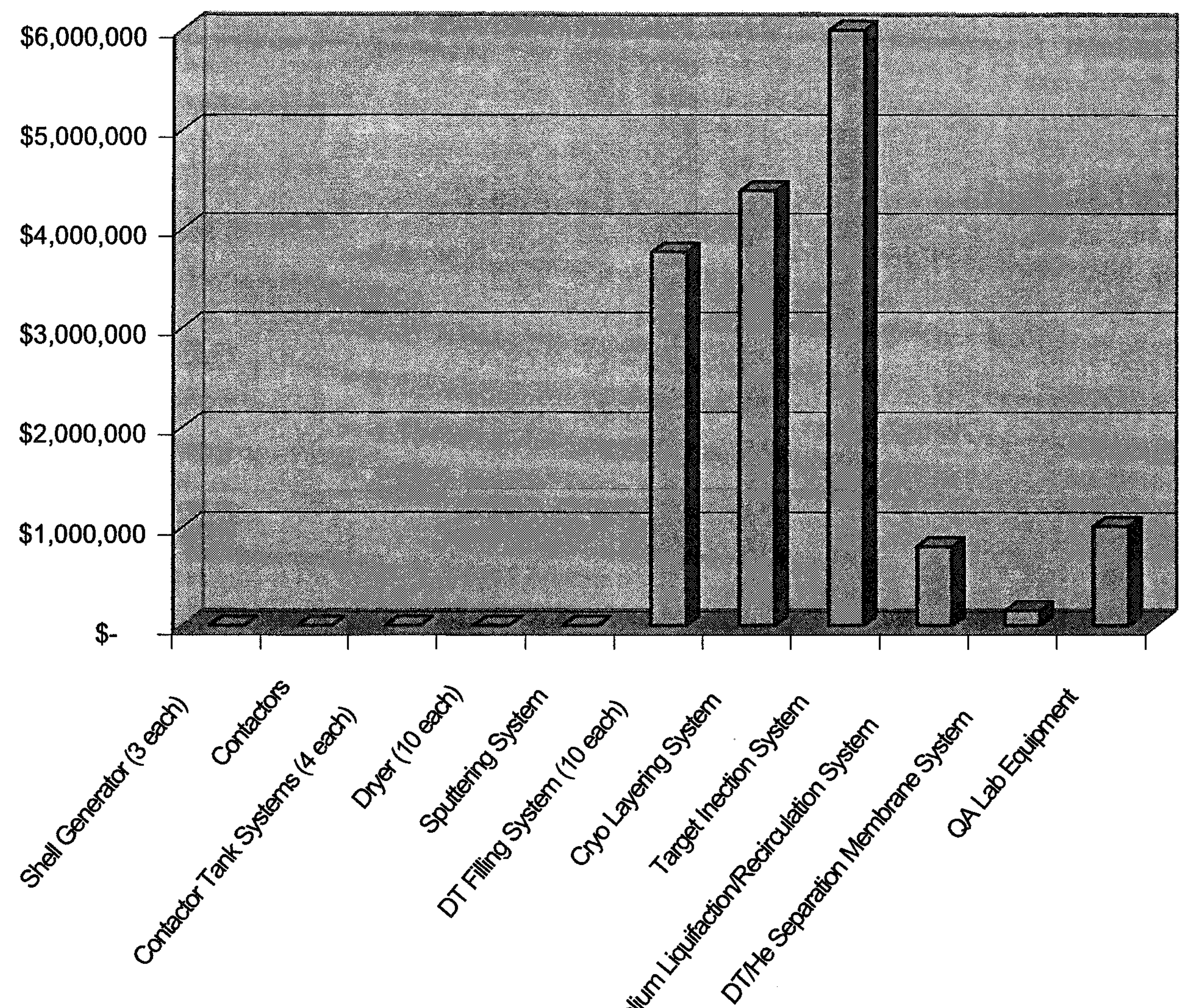
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 6,269,601
Electrical	$ 2,732,903
Instruments	$ 2,089,867
Building and services	$ 4,822,770
Site Preparation	$ 1,768,349
Auxiliaries	$ 8,841,745
Field Expenses	$ 6,912,637
Engineering	$ 5,465,806
Contractors fees	$ 2,732,903
Contingency	$ 6,269,601

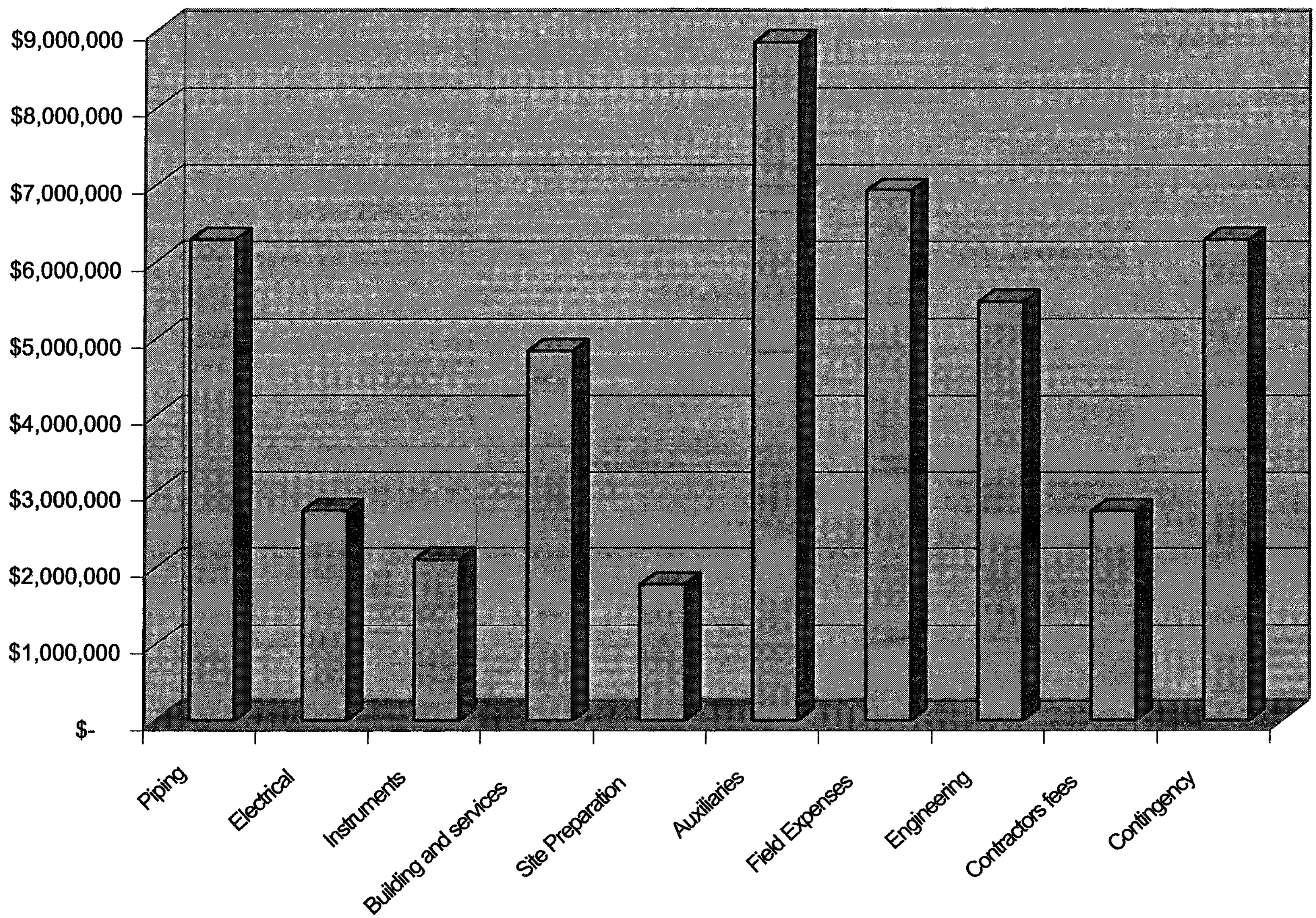
Total Installed Capital Cost **$ 63,981,183**

Annualized Cost of Capital Investment **$ 7,997,648**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)
Plant Manager	1	1	$ 100,000	$ 140,023
Shift Supervisors	3	5	$ 85,000	$ 1,785,288
Clerical & Bookkeeping	4	1	$ 30,000	$ 168,027
On-Site Engineering Staff	3	1	$ 70,000	$ 294,047
QA/QC staff	2	5	$ 40,000	$ 560,090
Health Physics Staff	2	5	$ 50,000	$ 700,113
Shift Operator - Contactor Area	0	5	$ 40,000	$ -
Technician - Contactor Area	0	5	$ 30,000	$ -
Shift Operator - Dryer Area	0	5	$ 40,000	$ -
Technician - Dryer Area	0	5	$ 30,000	$ -
Shift Operator - Fill/Layer Area	3	5	$ 40,000	$ 840,202
Technician - Fill/Layer Area	5	5	$ 30,000	$ 1,050,252
Shift Operator - Target Injection Area	3	5	$ 40,000	$ 840,000
Technician - Target Injection Area	5	5	$ 30,000	$ 1,050,000

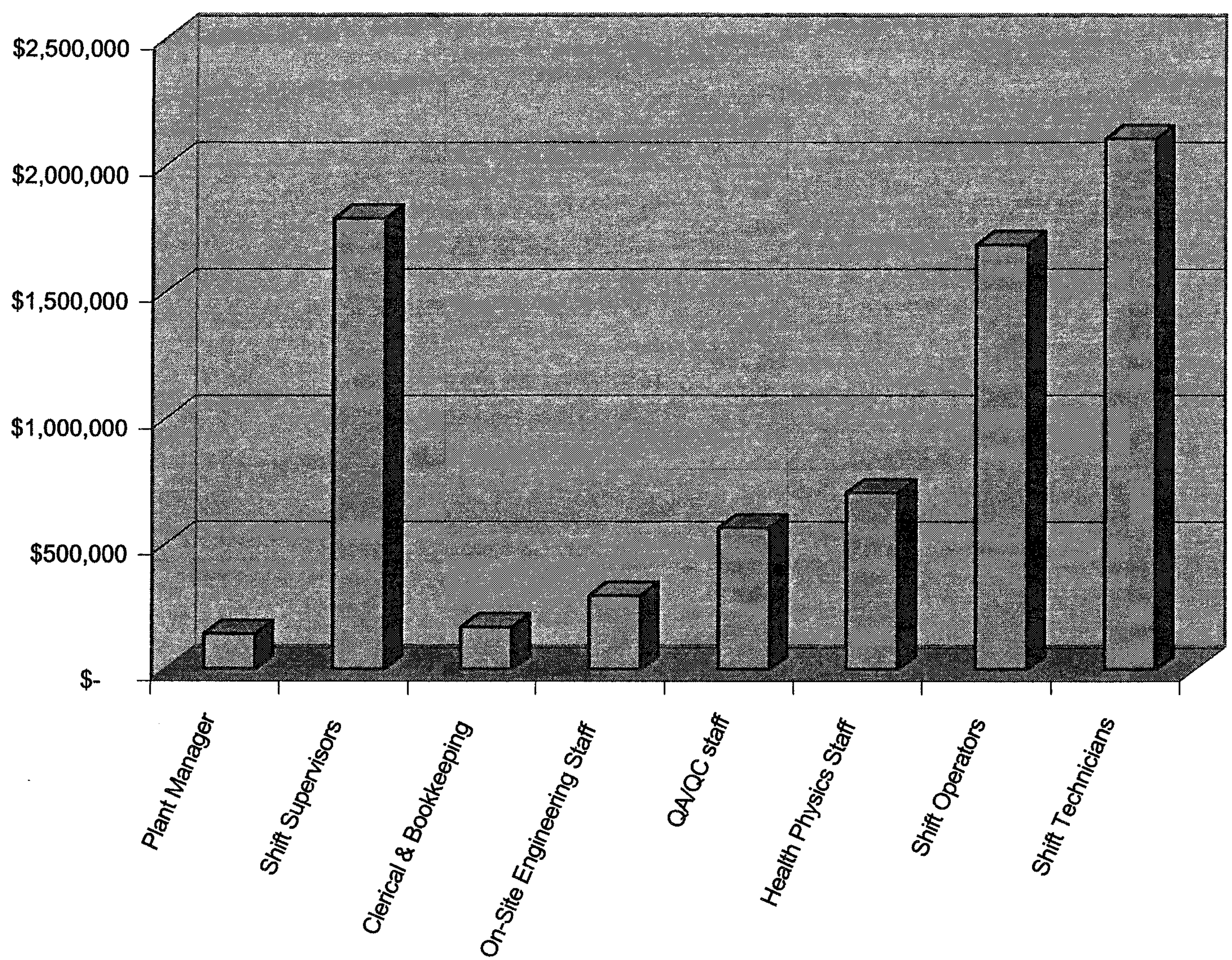
Annual labor operating costs = $ 7,428,042

reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
1.34	1.337	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.11	1.11	1.00
1.11	1.11	1.00
1.02	1.02	1.00
1.02	1.02	1.00
n/a	n/a	n/a
n/a	n/a	n/a

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 168,027
On-Site Engineering Staff	$ 294,047
QA/QC staff	$ 560,090
Health Physics Staff	$ 700,113
Shift Operators	$ 1,680,202
Shift Technicians	$ 2,100,252

plant size multiplier
1000
1.00

Operating Labor Costs for Foam Target Production



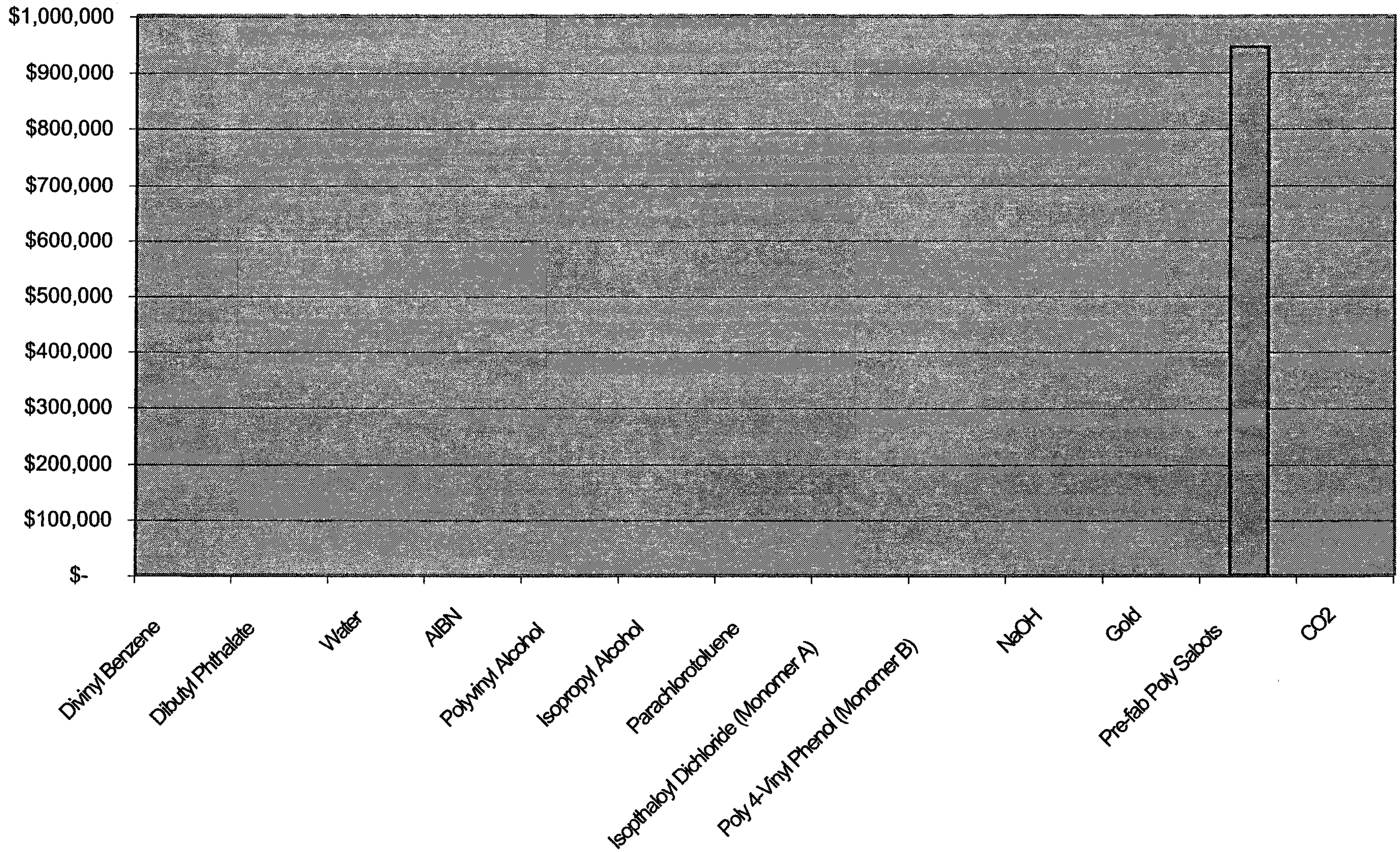
Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr
Divinyl Benzene	0	10.00	$ -
Dibutyl Phthalate	0	10.00	$ -
Water	0	0.10	$ -
AIBN	0	10.00	$ -
Polyvinyl Alcohol	0	10.00	$ -
Isopropyl Alcohol	0	2.00	$ -
Parachlorotoluene	0	4.00	$ -
Isopthaloyl Dichloride (Monomer A)	0	10.00	$ -
Poly 4-Vinyl Phenol (Monomer B)	0	10.00	$ -
NaOH	0	2.00	$ -
Gold	0.0	9650.00	$ -
Pre-fab Poly Sabots	262090	3.60	$ 943,523
CO2	0	0.20	$ -

(= 0.5 cent per sabot)

Annual materials costs = $ 943,523

Materials Costs (consumables) for Foam Target Production

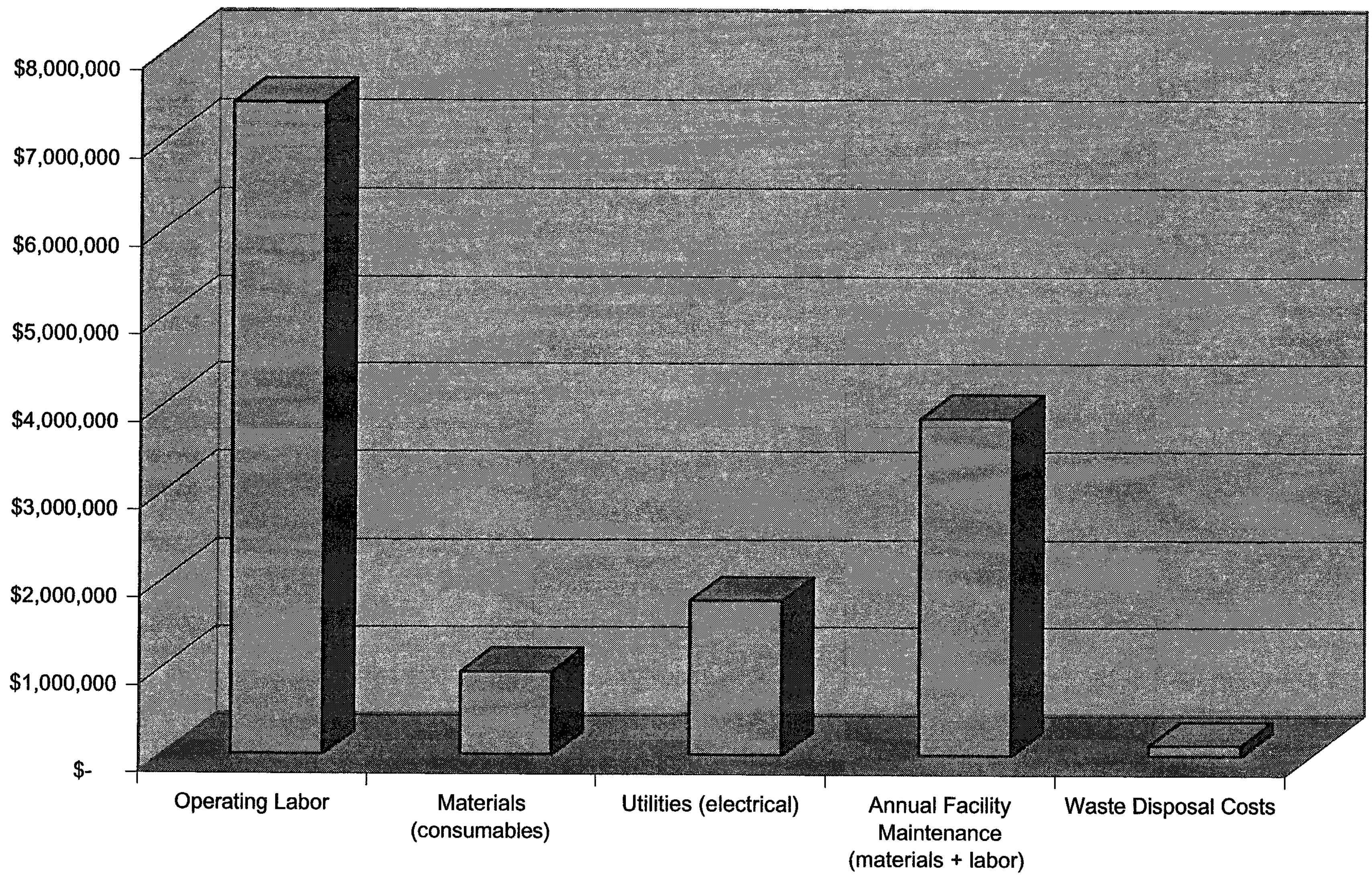


Operating Cost Summary for Foam Target Production

Operating Labor	$	7,428,042
Materials (consumables)	$	943,523
Utilities (electrical)	$	1,757,291
Annual Facility Maintenance (materials + labor)	$	3,838,871
Waste Disposal Costs	$	122,047

Total Annual Operating Costs = $ 14,089,775

Operating Costs for Foam Shell Production



waste disposal	0.065
materials	0.499
utilities	0.929
maintenance	2.029
operating labor	3.926
piping, electrical & instrumentation	0.733
bldgs & auxiliaries	1.020
purchased equipment	1.062

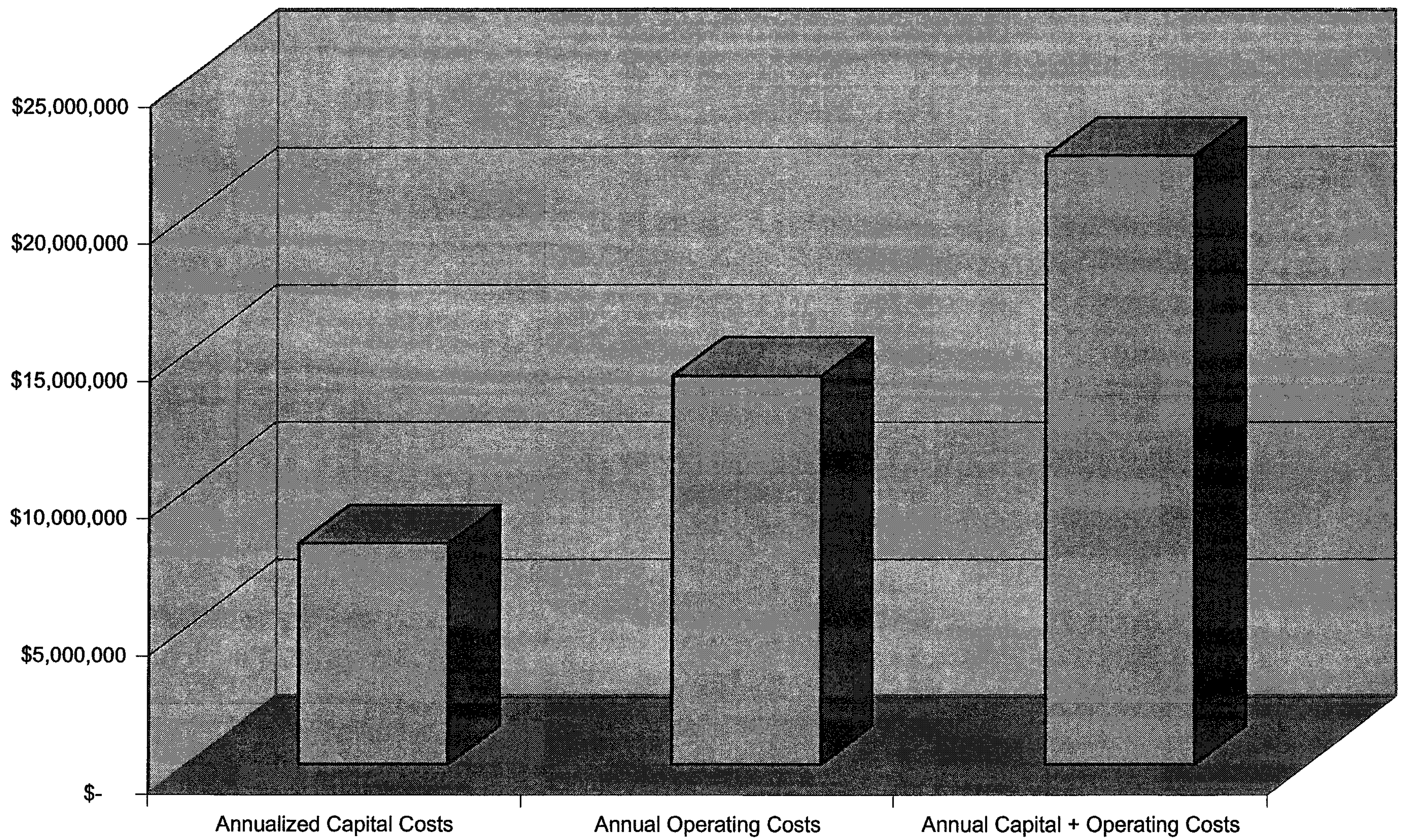
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 7,997,648
Annual Operating Costs	$ 14,089,775

Annual Capital + Operating Costs	**$ 22,087,422**

Cost per Injected Target = $ 0.117

Foam Target Production Costs



ATTACHMENT 5
Case 12— Empty capsules (made off-site)

Specifications and Assumptions for Foam Target Production

4000	micron foam shell outside diameter
289	micron thick foam wall
100	mg/cc foam density
1.0	micron thick seal coat
0.03	micron thick gold or palladium thickness
5184000	shells per day total production (on-spec) - @ 6 Hz per 100
25	overall rejection rate, percent
0.10	ratio of AIBN initiator to DVB
5	ratio of outer water to final shell volume
8	hrs of targets per contactor
40	per cent fill on contactor
1.0	ratio of contactor diameter to length
1.0	percent PVA in outer water
1.0	turn over per hour of contactor vapor space
0.0013	density of N2 at ambient conditions, g/cc
365	days per year operation
8760	hrs per year operation (24/7)
19.3	g/cc density of gold
5	shifts to cover 24/7 + vacations, etc
30	percent particle packing fraction in dryer
8	hrs of targets per dryer
0.47	density of liquid CO2, g/cc
0.50	ratio of CO2 dryer diameter to length
5	stages of contacting
5	stages contacted countercurrently
10.0	% reject rate at droplet forming stage
8.0	% reject rate at ICP stage
5.0	% reject rate at CO2 drying stage
3.0	% reject rate at high Z coating stage
2.0	% reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
6932873	total shells produced per day
288870	total shells produced per hour
361.7	mass flow of shells (DVB only), g/hr
36.17	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
3617.33	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
6057.9	inner water flow, g/hr
6057.9	inner water flow, cc/hr
0.033	volume of each shell, cc
9675.2	volume of shells produced, cc/hr
48376.0	volume of outer water, cc/hr
48376.0	mass flow of outer water, g/hr
464410.0	contactor initial fill volume, cc
1161025.1	contactor initial total volume, cc
113.9	contactor diameter, cm
113.9	contactor length, cm
483.8	PVA usage, g/hr
696615	vapor space in contactor, cc
696615	N_2 usage, cc/hr
938.0	N_2 usage, g/hr
2530498623	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
6.61	mass flow usage of gold in high Z coating, g/hr
2786	volume of waste per contactor, liters
8359	volume of waste per day from contactors, liters
8.36	tons per day of waste liquids from contactors
3051	tons per year of waste liquids from contactors
77402	volume of shells in dryer, cc
258006	volume of dryer, cc
54.8	contactor diameter, cm
109.5	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	288870	28887	1.000
ICP layer	8	1.204	259983	20799	0.900
CO_2 drying	5	1.107	239184	11959	0.828
Sputter Coating	3	1.052	227225	6817	0.787
DT Filling	2	1.020	220408	4408	0.763
Layering and Injection	0	1	216000	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

464.4 = the fill volume of each contactor (in liters)

9753 = the total volume required for each tank (in liters)
12190.76 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

6.29 = height of tank, M
1.57 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

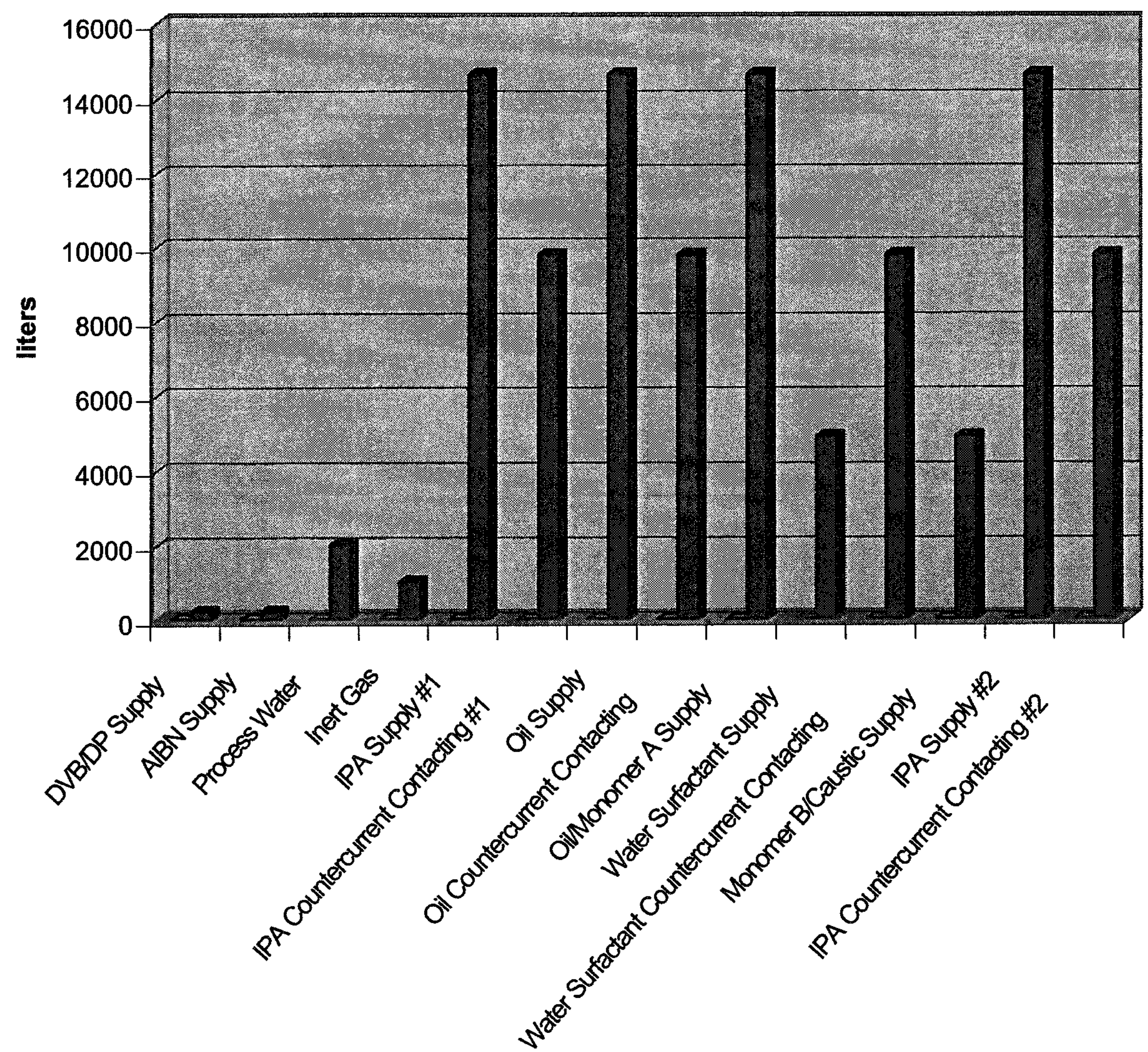
1.5 weeks storage in supply tank
14629 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	1	200	
AIBN Supply	1	200	
Process Water	1	2000	
Inert Gas	1	1000	nitrogen
IPA Supply #1	1	14629	
IPA Countercurrent Contacting #1	5	9753	
Oil Supply	1	14629	
Oil Countercurrent Contacting	5	9753	
Oil/Monomer A Supply	1	14629	
Water Surfactant Supply	1	4876	
Water Surfactant Countercurrent Contacting	2	9753	
Monomer B/Caustic Supply	1	4876	
IPA Supply #2	1	14629	
IPA Countercurrent Contacting #2	5	9753	

Total Tanks 27

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	361.73																				300		
	Dibutyl Phthalate	3617.33				3617.33		3617	3617															
	Water			6057.88	48376.05	54433.92		54434	54434							52246		52156						
	AIBN		36.17																					
	Polyvinyl Alcohol				483.76	483.76		484	484															
	Polymerized DVB					397.91		398	398															
	Isopropyl Alcohol (IPA)									52246										52246		5016		
	Parachlorotoluene											52246		43887										
	Spent Solvent #1																							
	Isophthaloyl dichloride													8359										
	Poly 4-Vinyl Phenol																	768						
	NaOH																	29						
	Mixed liquid waste										52246		52246		52246		52246		52954		52246			
	CO_2																						70284	
	Au or Pd																							5.20
Gases	N_2						938.02																	
Total, g/hr		3979.1	36.2	6057.9	48859.8	58932.9	938.0	58932.9	58932.9	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52246.1	52953.6	52953.6	52246.1	52246.1	5315.4	70283.8	5.2

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	10,000	cost per contactor
	42	calculated number of contactors
$	25,000	cost per shell generator
	3	shell generators needed
$	93,615	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	375,000	Dryer System - holds 8 hours of targets
$	2,500,000	Sputtering System
$	-	DT Filling System
$	-	Cryo Layering System
$	-	Target Injection System (4 times this for installed equipment)

	2675	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ 75,000	1.34	1.34	1.000	$ 75,012
Contactors	$ 420,000	1.34	1.34	1.000	$ 420,068
Contactor Tank Systems (4 each)	$ 561,691	1.34	1.34	1.000	$ 561,782
Dryer (10 each)	$ 3,750,000	1.11	1.11	1.000	$ 3,750,679
Sputtering System	$ 2,500,000	1.05	1.05	1.000	$ 2,499,953
DT Filling System (10 each)	$ -	1.02	1.02	1.000	$ -
Cryo Layering System	$ -	1	1	1.000	$ -
Target Inection System	$ -	1	1	1.000	$ -
Helium Liquifaction/Recirculation System	$ -	1	1	1.000	$ -
DT/He Separation Membrane System	$ -	1	1	1.000	$ -
QA Lab Equipment	$ 1,000,000	1	1	1.000	$ 1,000,000

Total Process Equipment Cost **$ 8,306,691** **$ 33,072,727**

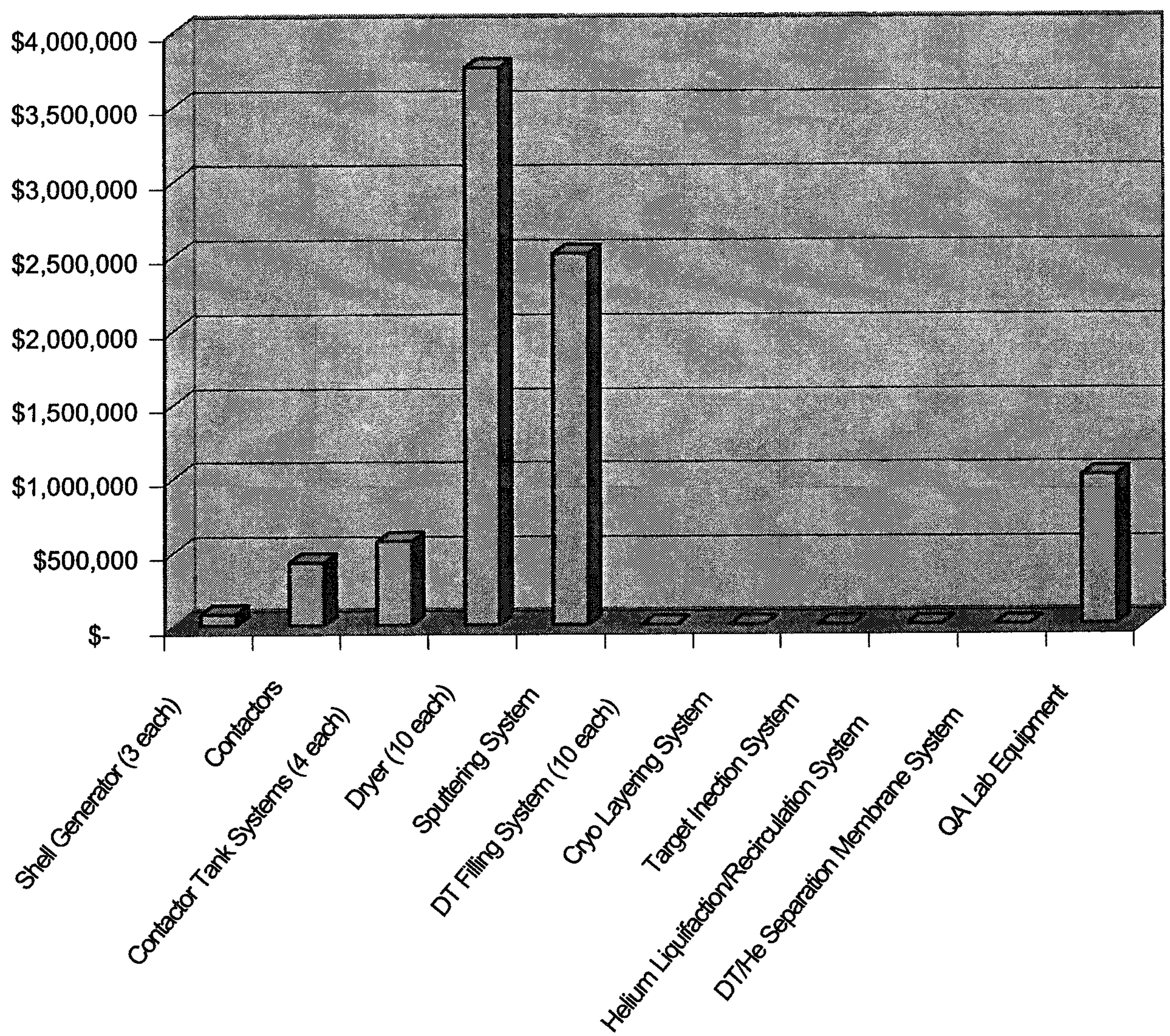
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 12,898,364
Electrical	$ 5,622,364
Instruments	$ 4,299,455
Building and services	$ 9,921,818
Site Preparation	$ 3,638,000
Auxiliaries	$ 18,190,000
Field Expenses	$ 14,221,273
Engineering	$ 11,244,727
Contractors fees	$ 5,622,364
Contingency	$ 12,898,364

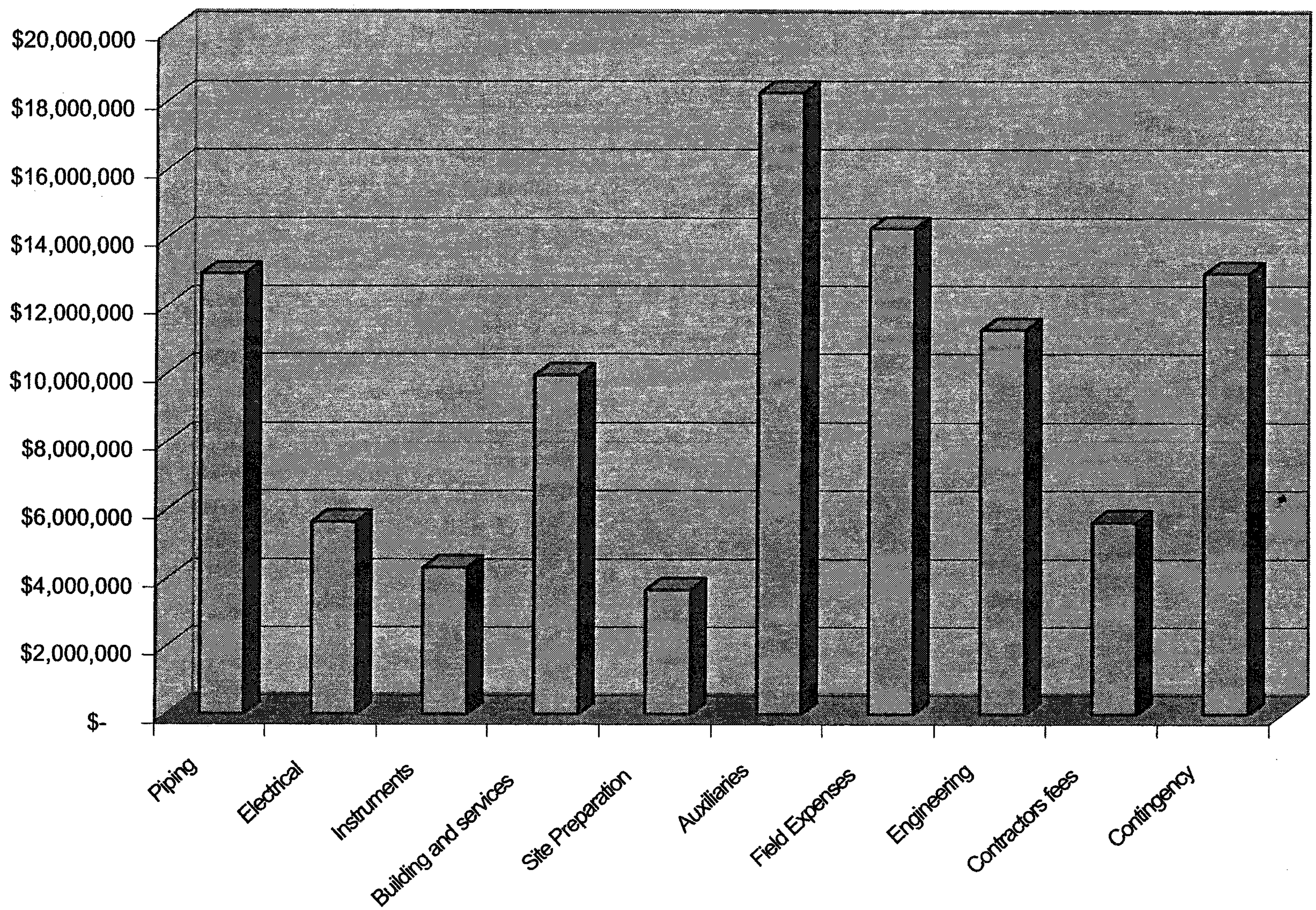
Total Installed Capital Cost **$ 131,629,454**

Annualized Cost of Capital Investment **$ 16,453,682**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

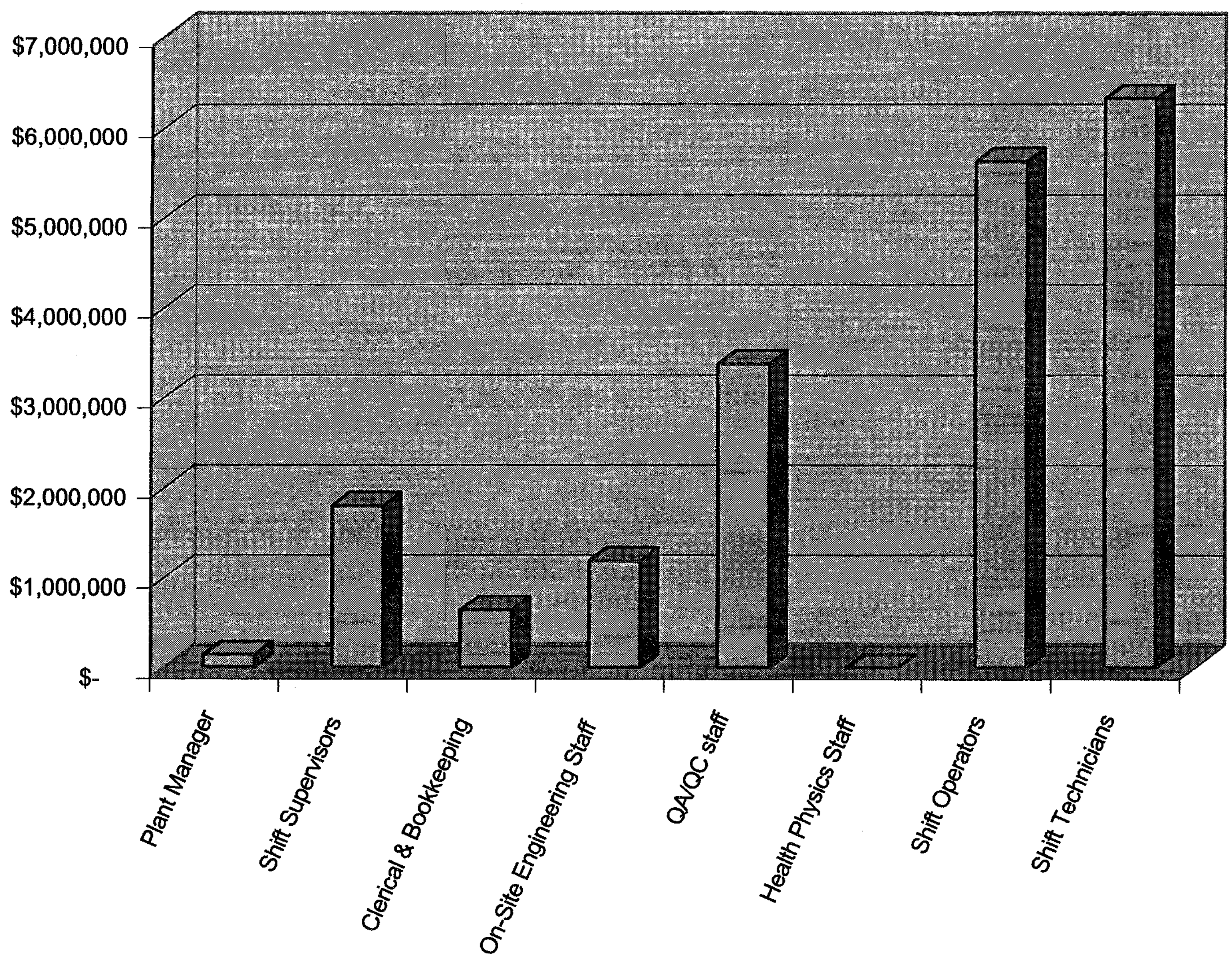
Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)	reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
Plant Manager	1	1	$ 100,000	$ 140,023	1.34	1.337	1.00
Shift Supervisors	3	5	$ 85,000	$ 1,785,288	1.34	1.34	1.00
Clerical & Bookkeeping	15	1	$ 30,000	$ 630,102	1.34	1.34	1.00
On-Site Engineering Staff	12	1	$ 70,000	$ 1,176,190	1.34	1.34	1.00
QA/QC staff	12	5	$ 40,000	$ 3,360,542	1.34	1.34	1.00
Health Physics Staff	0	5	$ 50,000	$ -	1.34	1.34	1.00
Shift Operator - Contactor Area	10	5	$ 40,000	$ 2,800,452	1.34	1.34	1.00
Technician - Contactor Area	15	5	$ 30,000	$ 3,150,509	1.34	1.34	1.00
Shift Operator - Dryer Area	10	5	$ 40,000	$ 2,800,507	1.11	1.11	1.00
Technician - Dryer Area	15	5	$ 30,000	$ 3,150,570	1.11	1.11	1.00
Shift Operator - Fill/Layer Area	0	5	$ 40,000	$ -	1.02	1.02	1.00
Technician - Fill/Layer Area	0	5	$ 30,000	$ -	1.02	1.02	1.00
Shift Operator - Target Injection Area	0	5	$ 40,000	$ -	n/a	n/a	n/a
Technician - Target Injection Area	0	5	$ 30,000	$ -	n/a	n/a	n/a

Annual labor operating costs = $ 18,994,182

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 630,102
On-Site Engineering Staff	$ 1,176,190
QA/QC staff	$ 3,360,542
Health Physics Staff	$ -
Shift Operators	$ 5,600,959
Shift Technicians	$ 6,301,079

plant size multiplier
3000
1.93

Operating Labor Costs for Foam Target Production



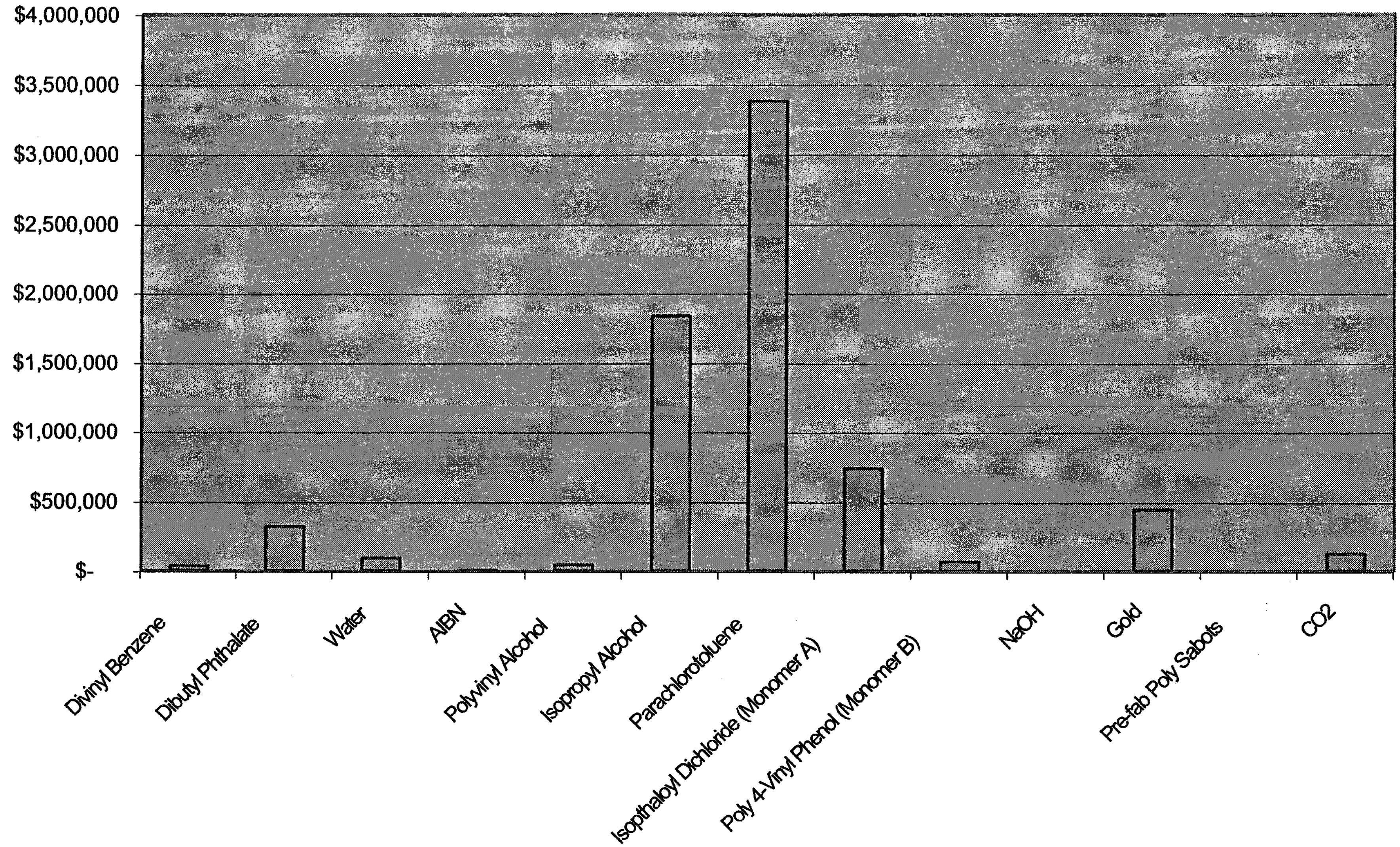
Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr
Divinyl Benzene	3169	10.00	$ 31,688
Dibutyl Phthalate	31688	10.00	$ 316,878
Water	914567	0.10	$ 91,457
AIBN	317	10.00	$ 3,169
Polyvinyl Alcohol	4238	10.00	$ 42,377
Isopropyl Alcohol	915352	2.00	$ 1,830,704
Parachlorotoluene	842124	4.00	$ 3,368,496
Isopthaloyl Dichloride (Monomer A)	73228	10.00	$ 732,282
Poly 4-Vinyl Phenol (Monomer B)	6731	10.00	$ 67,305
NaOH	252	2.00	$ 505
Gold	45.5	9650.00	$ 439,504
Pre-fab Poly Sabots	0	3.60	$ -
CO2	615686	0.20	$ 123,137

(= 0.5 cent per sabot)

Annual materials costs = $ 7,047,503

Materials Costs (consumables) for Foam Target Production

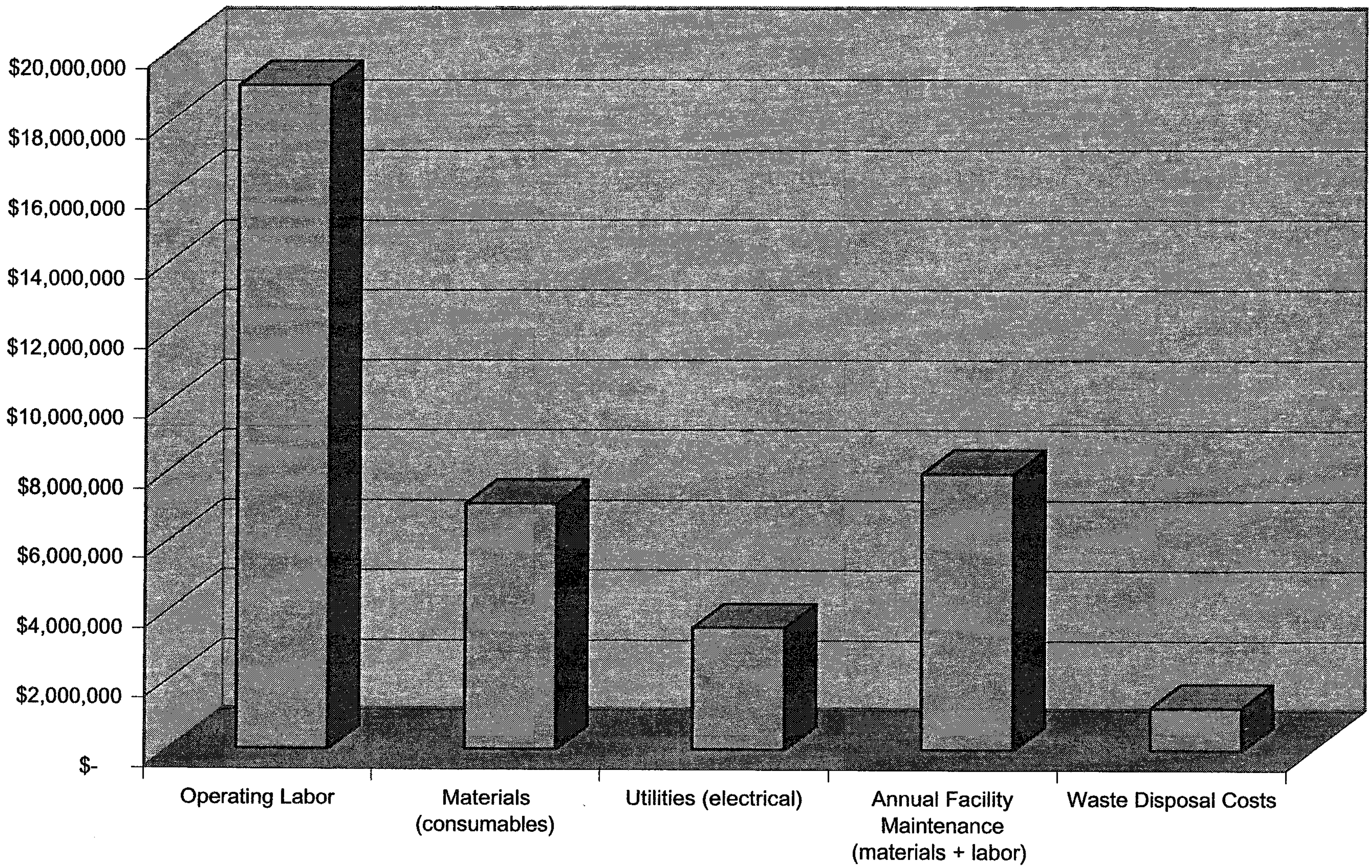


Operating Cost Summary for Foam Target Production

Operating Labor	$	18,994,182
Materials (consumables)	$	7,047,503
Utilities (electrical)	$	3,514,581
Annual Facility Maintenance (materials + labor)	$	7,897,767
Waste Disposal Costs	$	1,220,470

Total Annual Operating Costs = $ 38,674,503

Operating Costs for Foam Shell Production



waste disposal	0.065
materials	0.372
utilities	0.186
maintenance	0.417
operating labor	1.004
piping, electrical & instrumentation	0.151
bldgs & auxiliaries	0.210
purchased equipment	0.218

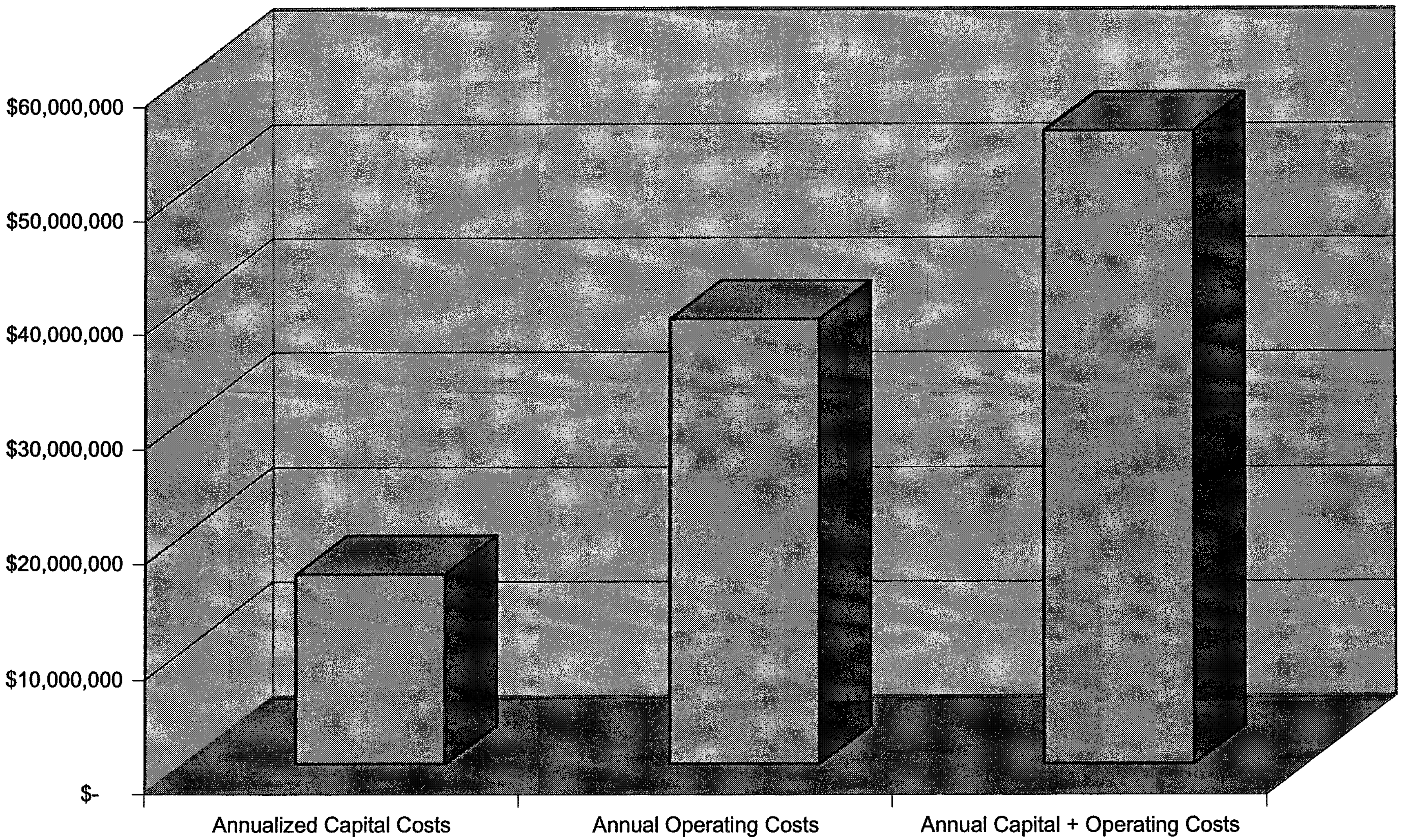
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 16,453,682
Annual Operating Costs	$ 38,674,503

Annual Capital + Operating Costs	**$ 55,128,185**

Cost per Injected Target = $ 0.0291

Foam Target Production Costs



ATTACHMENT 5
Case 12 — Fill/layer/inject (made on-site)

Specifications and Assumptions for Foam Target Production

4000 micron foam shell outside diameter
289 micron thick foam wall
100 mg/cc foam density
1.0 micron thick seal coat
0.03 micron thick gold or palladium thickness
1555200 shells per day total production (on-spec) - @ 6 Hz per 1000 MW times 3 = 18 Hz @ 3000 MW
25 overall rejection rate, percent
0.10 ratio of AIBN initiator to DVB
5 ratio of outer water to final shell volume

8 hrs of targets per contactor
40 per cent fill on contactor
1.0 ratio of contactor diameter to length

1.0 percent PVA in outer water

1.0 turn over per hour of contactor vapor space
0.0013 density of N2 at ambient conditions, g/cc

365 days per year operation
8760 hrs per year operation (24/7)

19.3 g/cc density of gold

5 shifts to cover 24/7 + vacations, etc

30 percent particle packing fraction in dryer
8 hrs of targets per dryer
0.47 density of liquid CO2, g/cc

0.50 ratio of CO2 dryer diameter to length

5 stages of contacting
5 stages contacted countercurrently

10.0 % reject rate at droplet forming stage
8.0 % reject rate at ICP stage
5.0 % reject rate at CO2 drying stage
3.0 % reject rate at high Z coating stage
2.0 % reject rate at DT filling stage

Calculated Parameters for Foam Target Production

0.013	volume of each shell wall, cc
0.00125	mass of each shell wall, g
2079862	total shells produced per day
86661	total shells produced per hour
108.5	mass flow of shells (DVB only), g/hr
10.85	mass flow of benzoyl peroxide, g/hr
0.10	ratio of foam to dibutyl phthalate
1085.20	mass flow of dibutyl phthalate, g/hr
0.021	inner water volume, cc/shell
1817.4	inner water flow, g/hr
1817.4	inner water flow, cc/hr
0.033	volume of each shell, cc
2902.6	volume of shells produced, cc/hr
14512.8	volume of outer water, cc/hr
14512.8	mass flow of outer water, g/hr
139323.0	contactor initial fill volume, cc
348307.5	contactor initial total volume, cc
76.2	contactor diameter, cm
76.2	contactor length, cm
145.1	PVA usage, g/hr
208985	vapor space in contactor, cc
208985	N_2 usage, cc/hr
281.4	N_2 usage, g/hr
759149587	total number of targets produced per year (usable and unusable)
0.00000151	volume of each high Z layer, cc
0.0000291	mass of each high Z layer, g
1.98	mass flow usage of gold in high Z coating, g/hr
836	volume of waste per contactor, liters
2508	volume of waste per day from contactors, liters
2.51	tons per day of waste liquids from contactors
915	tons per year of waste liquids from contactors
23221	volume of shells in dryer, cc
77402	volume of dryer, cc
36.7	contactor diameter, cm
73.3	contactor length, cm
1	number of fresh rinses (i.e. not recycled)
1.34	number of reject targets / usable targets

Production Rates at Major Process Steps as a Function of Reject Rates

Processing Step	Reject Rate (%) at this Process Step	Cumulative Production Multiplier (for this process step)	Shells Produced per Hour	Shells Rejected per Hour (integrated average over long time periods)	Fraction of Initially-Formed Shells Entering this Unit Operation
Shell form/cure	10	1.337	86661	8666	1.000
ICP layer	8	1.204	77995	6240	0.900
CO_2 drying	5	1.107	71755	3588	0.828
Sputter Coating	3	1.052	68167	2045	0.787
DT Filling	2	1.020	66122	1322	0.763
Layering and Injection	0	1	64800	0	0.748

overall % reject rate =	**25**

Tank Calculations for Foam Target Production

Each countercurrent contacting station will require 6 tanks as shown in the attached Process Flow Diagram

There are 6 stations required.

The tank volume is sufficient for 1 week of batch operations, which will reduce the coupling of unit operations and hereby increase system availability

139.3 = the fill volume of each contactor (in liters)

2926 = the total volume required for each tank (in liters)
3657.229 = tank volume (with head-room allowance)
4 = L/D of vertical cylindrical

4.21 = height of tank, M
1.05 = diameter of tank, M

there are 5 of these tanks to provide a 5-step rinse

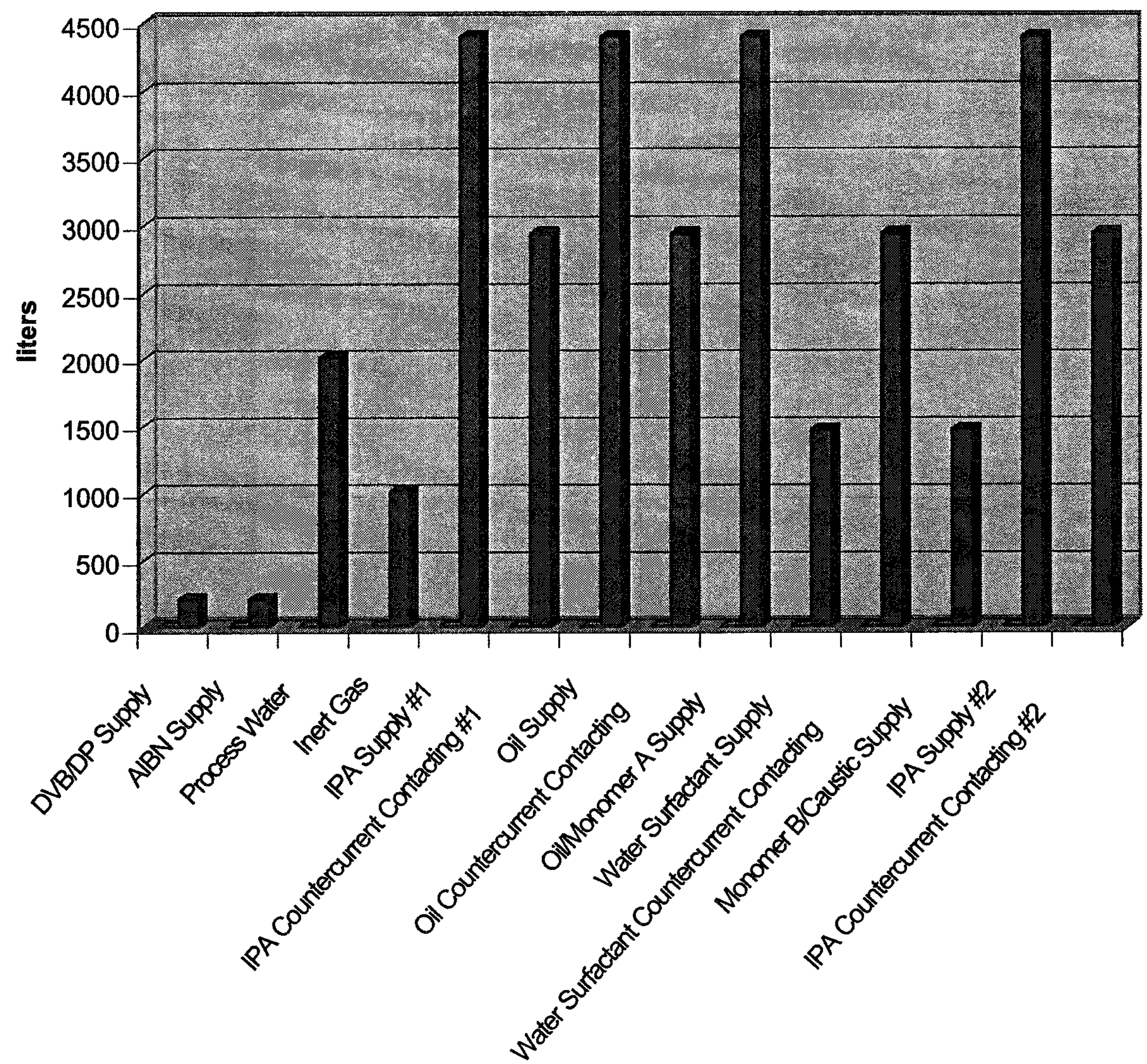
1.5 weeks storage in supply tank
4389 liters in storage tank

Tank Matrix for Foam Target Production

System	Number of Tanks	Tank Volume, liters	Notes
DVB/DP Supply	0	200	
AIBN Supply	0	200	
Process Water	0	2000	
Inert Gas	0	1000	nitrogen
IPA Supply #1	0	4389	
IPA Countercurrent Contacting #1	0	2926	
Oil Supply	0	4389	
Oil Countercurrent Contacting	0	2926	
Oil/Monomer A Supply	0	4389	
Water Surfactant Supply	0	1463	
Water Surfactant Countercurrent Contacting	0	2926	
Monomer B/Caustic Supply	0	1463	
IPA Supply #2	0	4389	
IPA Countercurrent Contacting #2	0	2926	

Total Tanks 0

Tank Inventory for Foam Target Production



Mass and Energy Balance for for Foam Target Production

	Stream Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Stream Name:	DVB Feed	Initiator Feed	Inner Water to Foam Shell Generator	Outer Water to Foam Shell Generator	Raw Shells to Contactor	Inert Gas to Contactor	Shells to Cure Contactor	Cured Shells	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	Oil to Contactor	Net Spent Liquid Discharge from Oil Cycle	Oil + Monomer A to Contactor	Net Spent Liquid Discharge from Monomer A Cycle	Water + Surfactant to Contactor	Net Spent Liquid Discharge from Water/Surfactant Cycle	Monomer B + Caustic to Contactor	Net Spent Liquid Discharge from Monomer B/Caustic Cycle	IPA to Contactor	Net Spent Liquid Discharge from IPA Cycle	IPA-filled targets to Drying	CO2 to Dryer	Gold or Palladium to Sputtering
	Temperature, °C	25	25	25	25	25	25	85	85	25	25	25	25	25	25	25	25	25	25	25	25	25	0	25
	Temperature, °K	298	298	298	298	298	298	358	358	298	298	298	298	298	298	298	298	298	298	298	298	298	273	298
	Pressure, atm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	1
Liquids	Divinyl Benzene	108.52																				90		
	Dibutyl Phthalate	1085.20				1085.20		1085	1085															
	Water			1817.36	14512.81	16330.18		16330	16330							15674		15647						
	AIBN		10.85																					
	Polyvinyl Alcohol				145.13	145.13		145	145															
	Polymerized DVB					119.37		119	119															
	Isopropyl Alcohol (IPA)									15674										15674		1505		
	Parachlorotoluene											15674		13166										
	Spent Solvent #1																							
	Isophthaloyl dichloride													2508										
	Poly 4-Vinyl Phenol																	230						
	NaOH																	9						
	Mixed liquid waste										15674		15674		15674		15674		15886		15674			
	CO_2																						21085	
	Au or Pd																							1.56
Gases	N_2						281.41																	
Total, g/hr		1193.7	10.9	1817.4	14657.9	17679.9	281.4	17679.9	17679.9	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15673.8	15886.1	15886.1	15673.8	15673.8	1594.6	21085.1	1.6

Cost Assumptions for Foam Target Production

	12.5	% capitalization rate
	6	% maintenance (as % of installed capital)
	14	total days of processing per batch
	8	hrs of targets per batch
$	-	cost per contactor
	42	calculated number of contactors
$	-	cost per shell generator
	3	shell generators needed
$	-	cost for each contactor counter-current tank sequence
	40	% benefits (added to salary for personnel costs)
$	400	per metric ton aqueous waste disposal cost
$	-	Dryer System - holds 8 hours of targets
$	-	Sputtering System
$	375,000	DT Filling System
$	4,375,000	Cryo Layering System
$	6,000,000	Target Injection System (4 times this for installed equipment)
	2006	KW usage
$	0.15	cost per KW-hr

Capital Costs for Foam Target Production

	Base Price for Processing on nominal (25% overall) reject rate	throughout multiplier based on actual reject rate	nominal reject rate at this stage (25% overall taken to be nominal)	cost multiplier based on 0.6 exponent scaling	projected costs for facility at stated reject rate
Shell Generator (3 each)	$ -	1.34	1.34	1.000	$ -
Contactors	$ -	1.34	1.34	1.000	$ -
Contactor Tank Systems (4 each)	$ -	1.34	1.34	1.000	$ -
Dryer (10 each)	$ -	1.11	1.11	1.000	$ -
Sputtering System	$ -	1.05	1.05	1.000	$ -
DT Filling System (10 each)	$ 3,750,000	1.02	1.02	1.000	$ 3,750,900
Cryo Layering System	$ 4,375,000	1	1	1.000	$ 4,375,000
Target Inection System	$ 6,000,000	1	1	1.000	$ 6,000,000
Helium Liquifaction/Recirculation System	$ 800,000	1	1	1.000	$ 800,000
DT/He Separation Membrane System	$ 150,000	1	1	1.000	$ 150,000
QA Lab Equipment	$ 1,000,000	1	1	1.000	$ 1,000,000

Total Process Equipment Cost **$ 16,075,000** **$ 31,077,642**

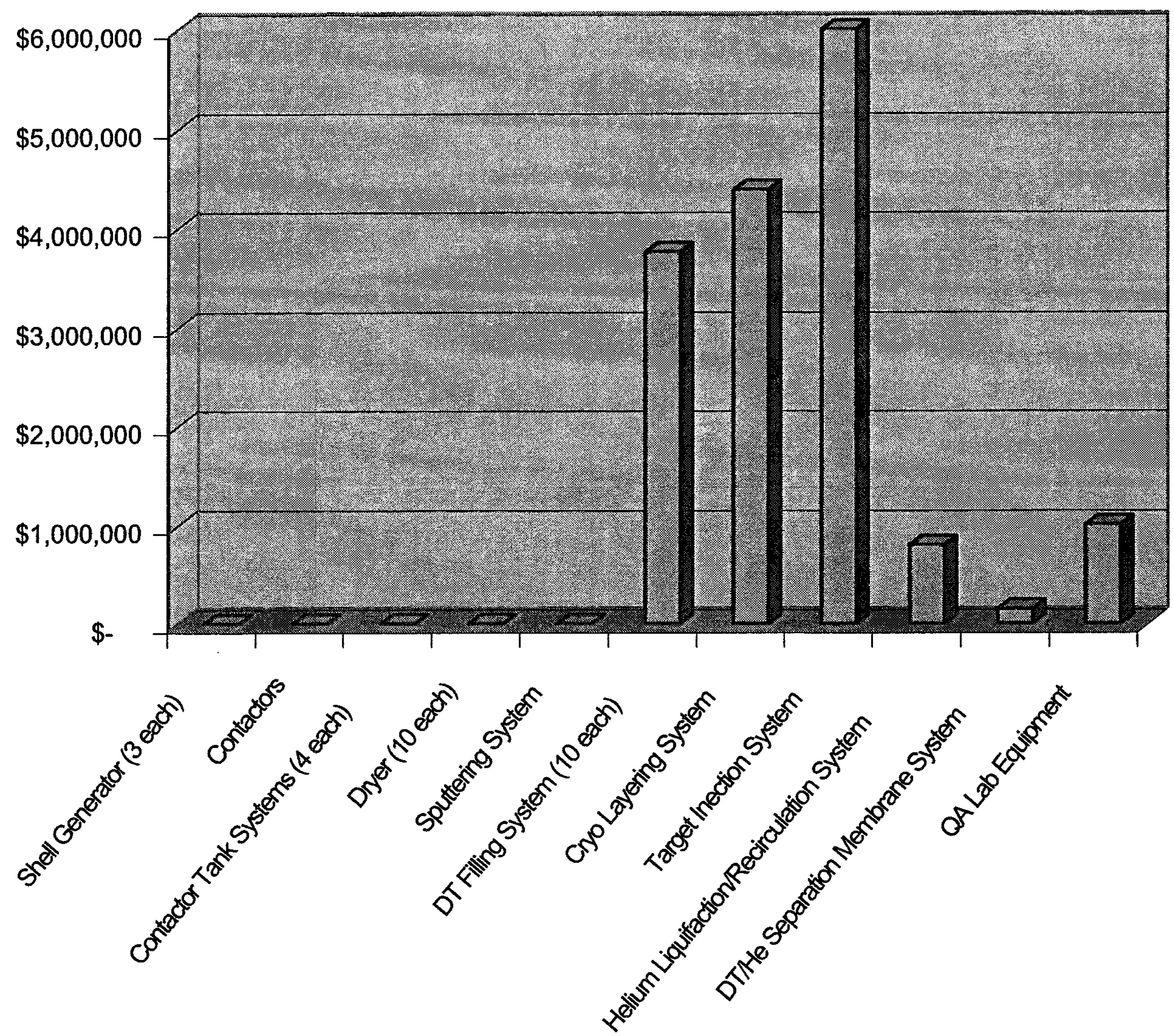
Factored Balance of Plant Costs (from Miller's Method)

Piping	$ 12,120,280
Electrical	$ 5,283,199
Instruments	$ 4,040,093
Building and services	$ 9,323,293
Site Preparation	$ 3,418,541
Auxiliaries	$ 17,092,703
Field Expenses	$ 13,363,386
Engineering	$ 10,566,398
Contractors fees	$ 5,283,199
Contingency	$ 12,120,280

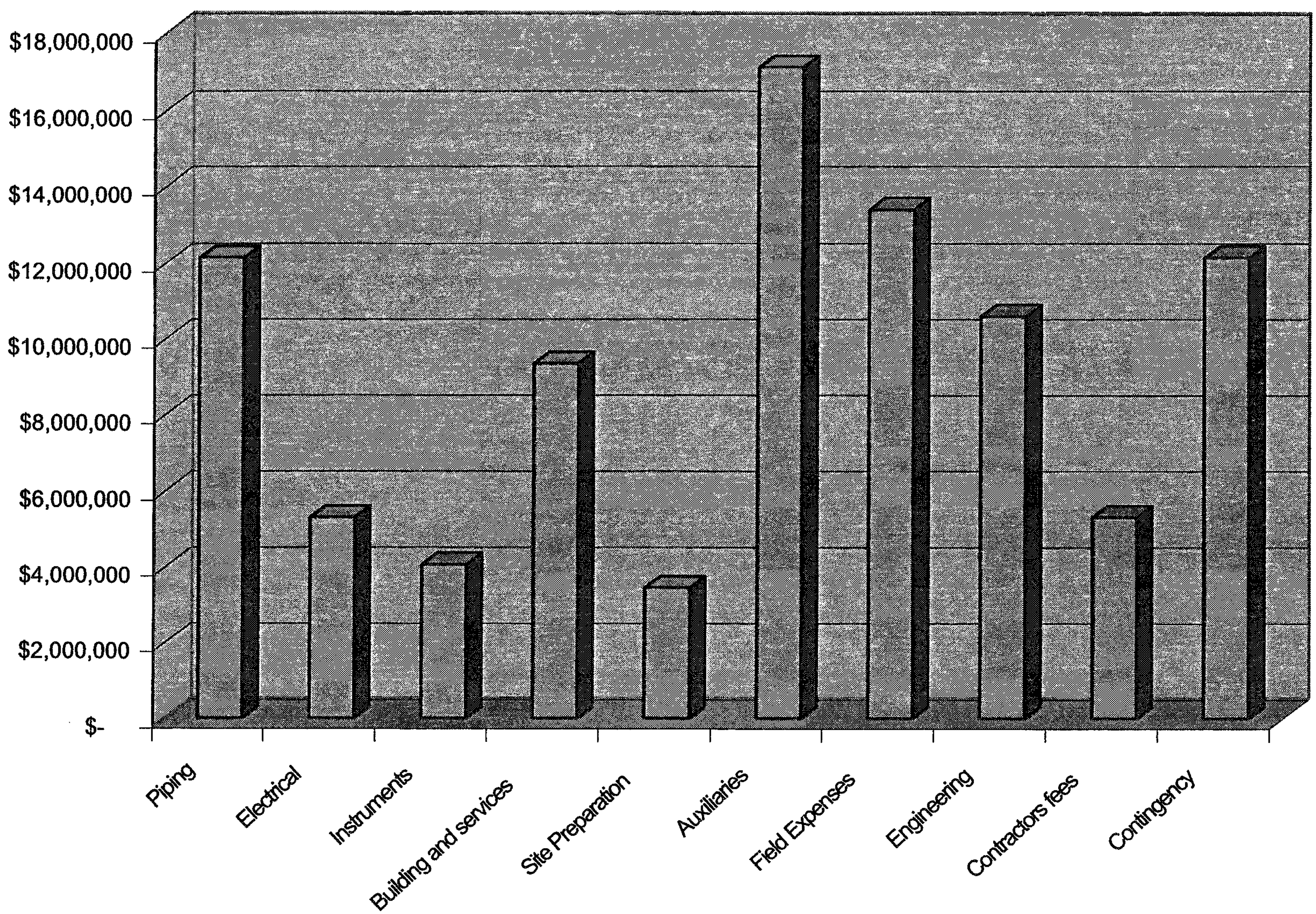
Total Installed Capital Cost **$ 123,689,014**

Annualized Cost of Capital Investment **$ 15,461,127**

Equipment Costs for Foam Target Production



Balance of Plant Costs for Foam Target Production



Operating Labor Costs for Foam Target Production

Position Title	Staff per Shift	Number of Shifts	$/yr salary	Total Cost (including factor for reject rates - see right)
Plant Manager	1	1	$ 100,000	$ 140,023
Shift Supervisors	3	5	$ 85,000	$ 1,785,288
Clerical & Bookkeeping	6	1	$ 30,000	$ 252,041
On-Site Engineering Staff	5	1	$ 70,000	$ 490,079
QA/QC staff	5	5	$ 40,000	$ 1,400,226
Health Physics Staff	4	5	$ 50,000	$ 1,400,226
Shift Operator - Contactor Area	0	5	$ 40,000	$ -
Technician - Contactor Area	0	5	$ 30,000	$ -
Shift Operator - Dryer Area	0	5	$ 40,000	$ -
Technician - Dryer Area	0	5	$ 30,000	$ -
Shift Operator - Fill/Layer Area	4	5	$ 40,000	$ 1,120,269
Technician - Fill/Layer Area	6	5	$ 30,000	$ 1,260,302
Shift Operator - Target Injection Area	4	5	$ 40,000	$ 1,120,000
Technician - Target Injection Area	6	5	$ 30,000	$ 1,260,000

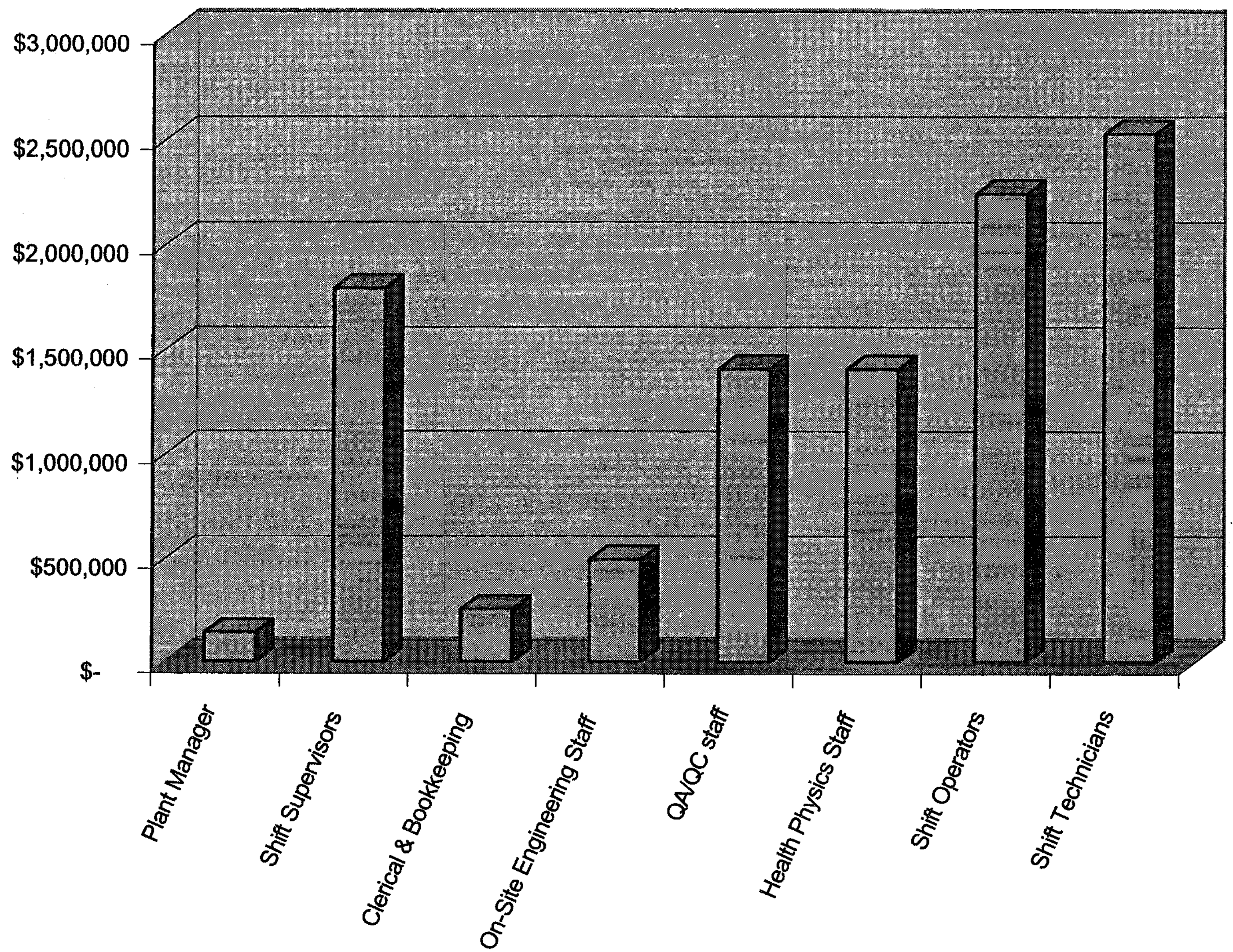
Annual labor operating costs = $ 10,228,454

reference reject rate (reference staffing costs are based on this)	Actual reject rate at this process stage for this case	multiplier using 0.6 exponent to account for adding staff to cope with higher than projected reject rates (25% overall is the expected level)
1.34	1.337	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.34	1.34	1.00
1.11	1.11	1.00
1.11	1.11	1.00
1.02	1.02	1.00
1.02	1.02	1.00
n/a	n/a	n/a
n/a	n/a	n/a

Plant Manager	$ 140,023
Shift Supervisors	$ 1,785,288
Clerical & Bookkeeping	$ 252,041
On-Site Engineering Staff	$ 490,079
QA/QC staff	$ 1,400,226
Health Physics Staff	$ 1,400,226
Shift Operators	$ 2,240,269
Shift Technicians	$ 2,520,302

plant size multiplier
3000
1.93

Operating Labor Costs for Foam Target Production

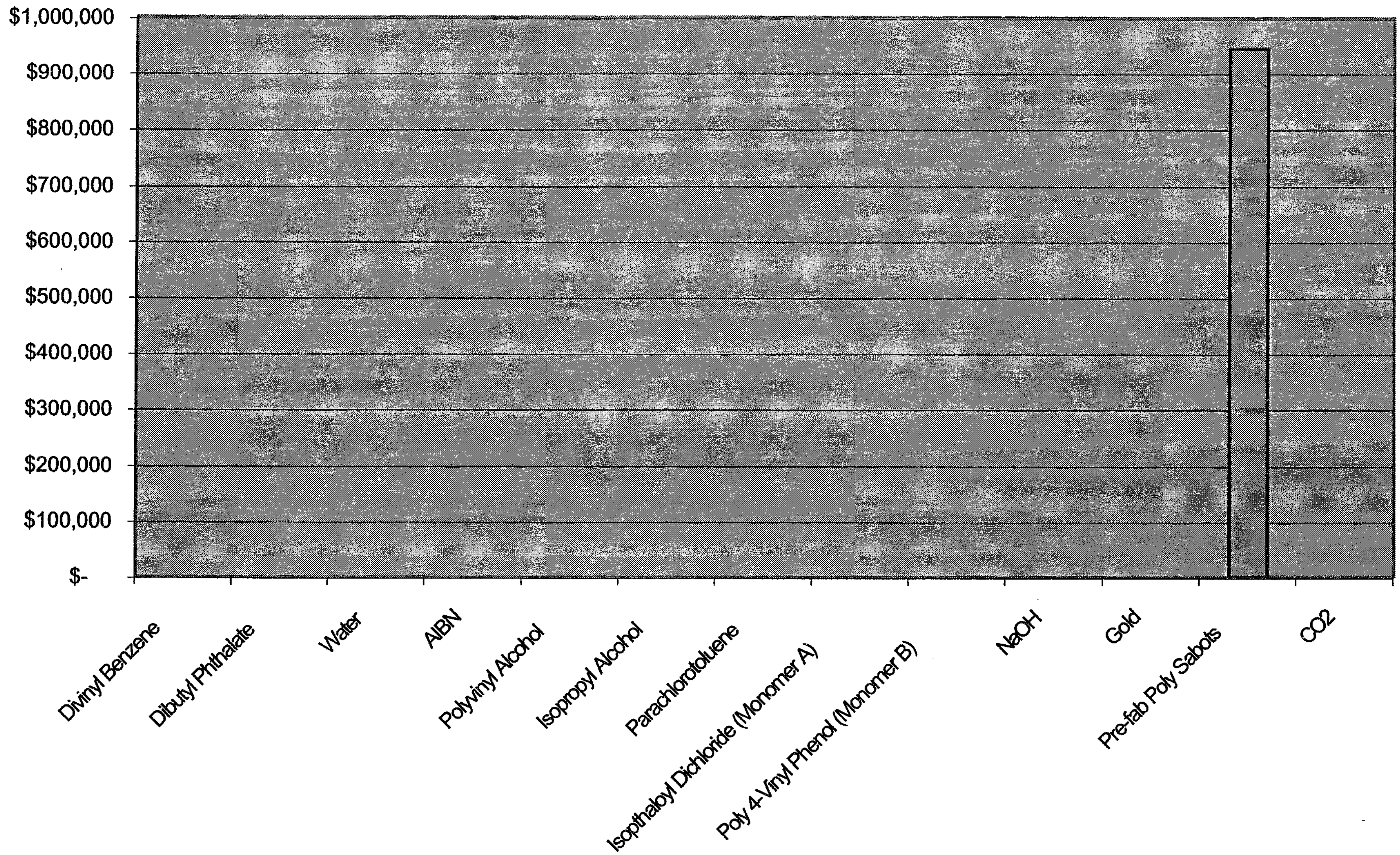


Materials Costs for Foam Target Production

Chemical	Kgs/yr	$/kg	$/yr	
Divinyl Benzene	0	10.00	$ -	
Dibutyl Phthalate	0	10.00	$ -	
Water	0	0.10	$ -	
AIBN	0	10.00	$ -	
Polyvinyl Alcohol	0	10.00	$ -	
Isopropyl Alcohol	0	2.00	$ -	
Parachlorotoluene	0	4.00	$ -	
Isopthaloyl Dichloride (Monomer A)	0	10.00	$ -	
Poly 4-Vinyl Phenol (Monomer B)	0	10.00	$ -	
NaOH	0	2.00	$ -	
Gold	0.0	9650.00	$ -	
Pre-fab Poly Sabots	262090	3.60	$ 943,523	(= 0.5 cent per sabot)
CO2	0	0.20	$ -	

Annual materials costs = $ 943,523

Materials Costs (consumables) for Foam Target Production

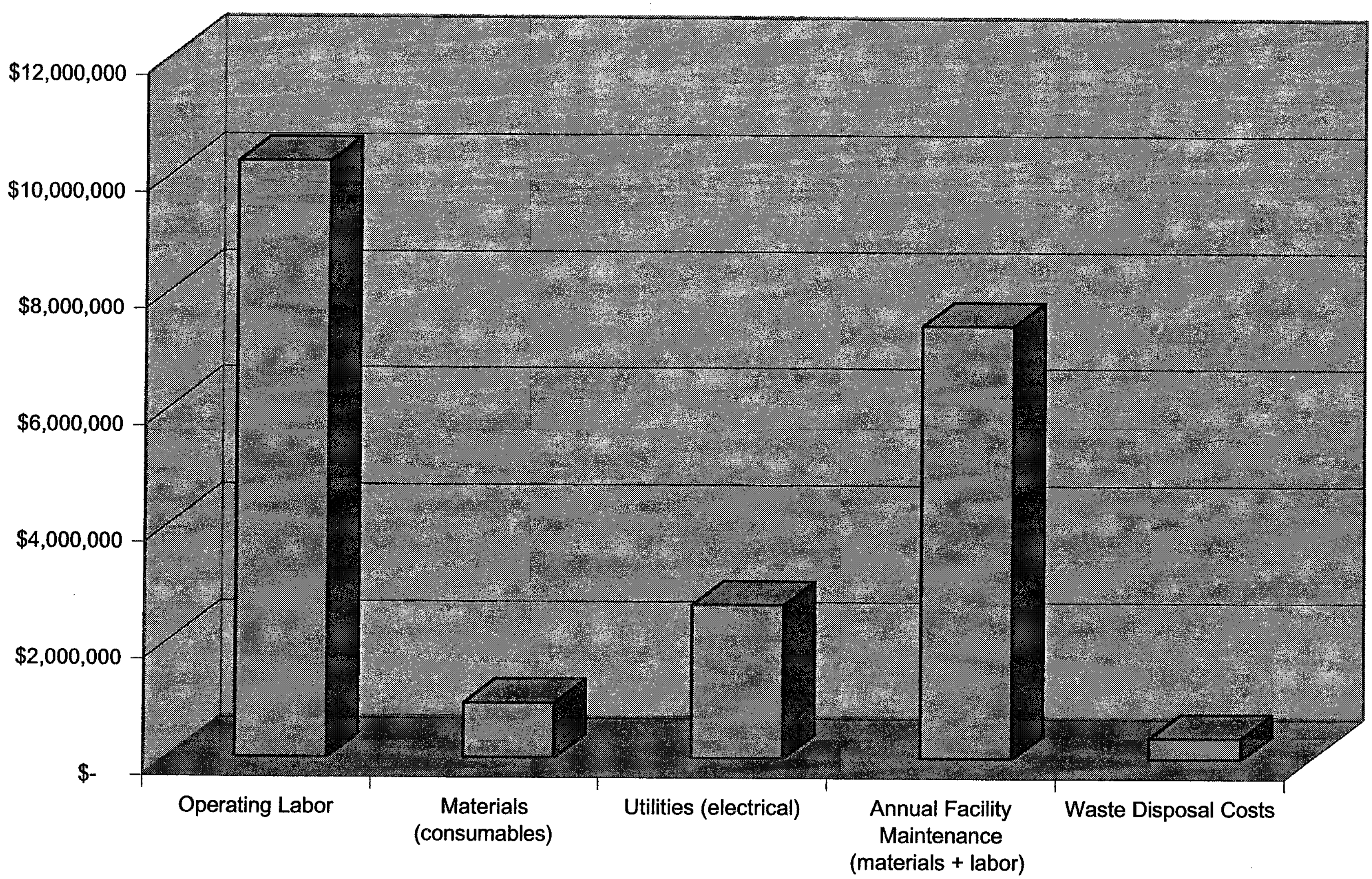


Operating Cost Summary for Foam Target Production

Operating Labor	$	10,228,454
Materials (consumables)	$	943,523
Utilities (electrical)	$	2,635,936
Annual Facility Maintenance (materials + labor)	$	7,421,341
Waste Disposal Costs	$	366,141

Total Annual Operating Costs = $ 21,595,395

Operating Costs for Foam Shell Production



waste disposal	0.065
materials	0.166
utilities	0.464
maintenance	1.307
operating labor	1.802
piping, electrical & instrumentation	0.472
bldgs & auxiliaries	0.657
purchased equipment	0.684

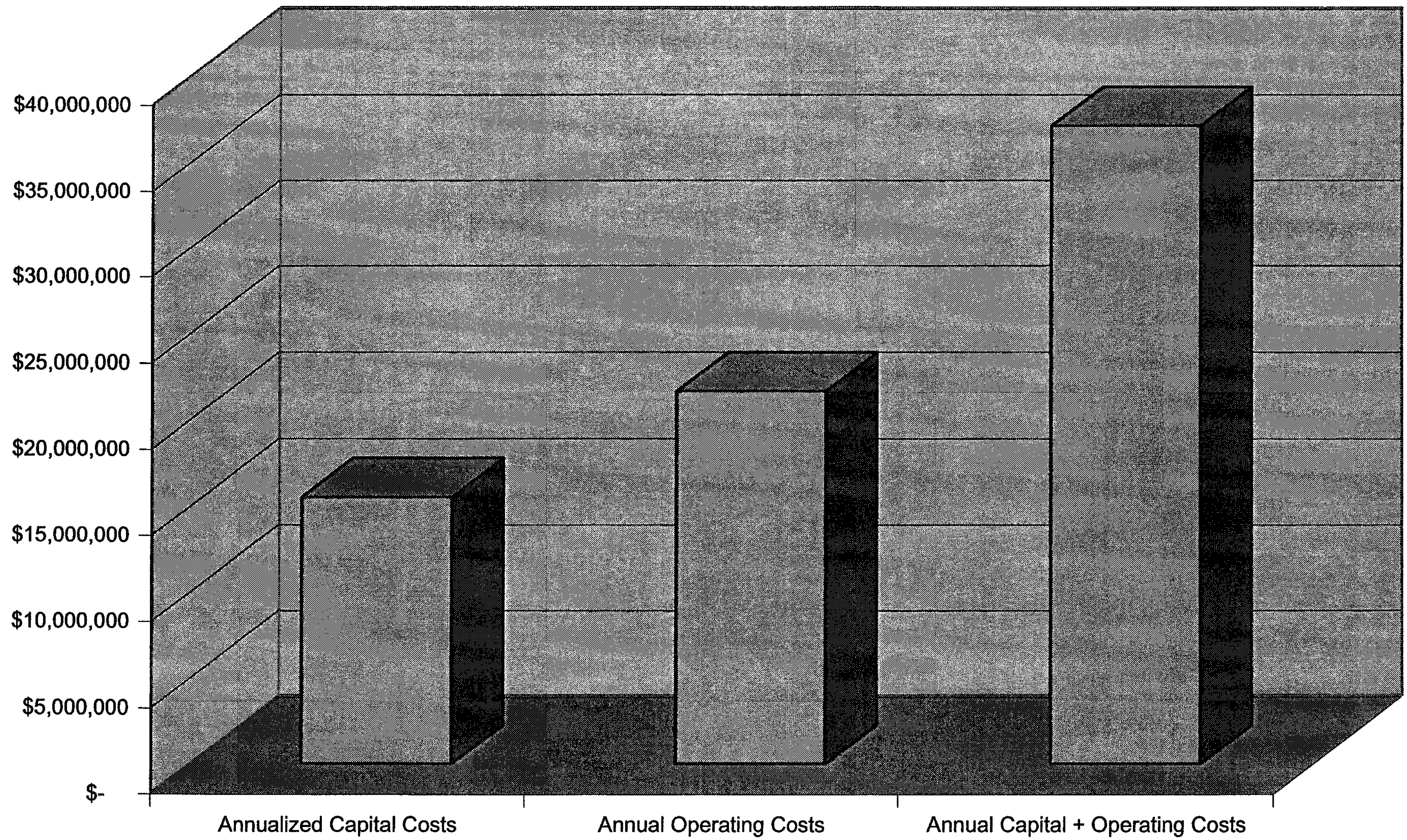
Cost Summary for Foam Target Production

Annualized Capital Costs	$ 15,461,127
Annual Operating Costs	$ 21,595,395

Annual Capital + Operating Costs	**$ 37,056,522**

Cost per Injected Target = $ 0.065

Foam Target Production Costs



ATTACHMENT 6

PROTOTYPE TARGET FABRICATION FACILITY

Process Development Plan

A three-phase program to develop process unit operations for the production of layered, D_2-filled targets – starting at lab-scale and ending at a commercial prototype

PHASE 1 – LABORATORY DEVELOPMENT

PHASE 1 OBJECTIVE:

Develop laboratory-scale methods and apparatus for the production of layered, D_2-filled targets.

HAPL HIGH GAIN DIRECT DRIVE TARGET PLAN FOR FY03-05

The top-level objectives of the high gain direct drive target fabrication and injection program for the FY03 to FY05 time frame are listed below. Completion of these objectives is intended to demonstrate the fundamental feasibility of target fabrication, injection, and tracking technology sufficient to proceed with the Integrated Research Experiment (IRE) phase of energy from inertial fusion.

OBJECTIVES

1. Develop methods to produce targets that meet the specifications from the target design codes; combine experimental data with mass-production process design studies to show that cost goals can be met.

2. Build an injection and tracking experimental system that accelerates room temperature targets under power plant conditions and demonstrate tracking of targets in flight to within ± 20 μm.

3. Measure the material properties and behavior of cryogenic DT under conditions relevant to IFE target injection; combine with analyses and modeling of the target/chamber interface to ensure target survival upon reaching chamber center.

The following tasks have been defined to meet these objectives in preparation for the IRE.

ID	TASK NAME	TASK OVERVIEW AND SCHEDULE	LEAD INSTITUTION	FISCAL YEAR
		Target Fabrication Tasks		
1 a	Foam shell production	Produce, using R&D scale equipment, target quality foam shells meeting requirements for the high gain direct drive target	Schafer	2003
1 b		Provide characterization of foam shells in support of development program	GA	2003
2 a	Foam shell overcoat	Provide polymer seal coat on foam shells meeting requirements for the high gain direct drive target.	Schafer	2003
		Adapt shell making and seal coat processes to mass production; interface with process design studies to show a feasible and economical mass-production pathway	Schafer	2004
2 b	Characterization support	Provide characterization support for polymer seal coat for high gain direct drive target	GA	2003
3	Application of high-Z layer:	Optimize high-Z over coat for high gain direct drive target target, accounting for target design, permeability, and reflectivity considerations; demonstrate techniques amenable to mass production	GA	2003
4	Cryo-Layering 1	Measure the surface finish of a DT layer formed in a torus with a foam underlay (to determine the smoothing effect of the foam)	LANL	2003 (Q1)
5	Cryo-Layering 2	Complete a detailed design and initiate procurement of a lab-scale system to demonstrate (with DD) layering of direct drive targets by mechanical motion with a method suitable for mass-production (e.g., fluidized bed, bounce pan, and/or spiral tube). The task will, by necessity, include filling and cooling targets to cryogenic temperatures. (If mechanical motion turns out to be unworkable, we will evaluate in-sabot layering methods.)	GA	2003
		Complete procurement and install equipment to demonstrate cryogenic layering of hydrogen isotopes on lab-scale.	GA	2004
		Conduct shakedown and operate lab-scale system to demonstrate mass-production layering method.	GA	2005

ID	TASK NAME	TASK OVERVIEW AND SCHEDULE	LEAD INSTITUTION	FISCAL YEAR
6 a	Process Development and Costing	Provide initial definition and layouts of pilot-plant sized equipment for fabrication of direct drive targets. Update TFF and pilot-plant equipment designs and preliminary layouts to reflect target program R&D results	GA	2003
6 b		Operate microencapsulation equipment to evaluate scaleup methods and provide shells for other experiments	GA	2003
6 a		Incorporate continuing target program R&D data for foam shells, sealcoats, and high-Z overcoatings into the Target Fabrication Facility (TFF) equipment lists and plant layouts. Provide definition of plant systems at a level commensurate with evolving process steps; define a feasible mass-production pathway to supply direct drive targets and update costing models	GA	2004
6 b		Operate microencapsulation equipment to parametrically evaluate methods for scale-up	GA	2004
6 a		Support the IRE decision process by providing a chemical engineering approach to the TFF and the IRE pilot-plant target factory that is integrated with results from experimental programs; include details of commercially available and custom-designed equipment for target mass production. Provide target production costing models at a level of detail sufficient (in a peer-review process) to demonstrate meeting cost goals. Coordinate and present information on target fabrication to support the IRE	GA	2005
6 b		Fabricate foam shells and seal coats using mass-production methods	GA	2005

ID	TASK NAME	TASK OVERVIEW AND SCHEDULE	LEAD INSTITUTION	FISCAL YEAR
		Target Injection and Tracking		
7	Target Injector	Complete shakedown and operate the target injection and tracking system (gas gun) in single-shot mode to determine tracking accuracy capability. Procure components and convert system to rep-rated operation (6 Hz for 12 shots). Construct R&D unit of several stages of an electromagnetic (EM) accelerator; use to evaluate accuracy of models	GA	2003
		Complete shakedown of injection and tracking system (gas-gun) in rep-rated mode; refine and optimize tracking system as needed. Operate EM accelerator to evaluate accuracy and precision.	GA	2004
		Complete injection and tracking (gas-gun) studies covering a variety of parametric conditions (velocity, acceleration, gas pressure, etc.) with room temperature targets to demonstrate design windows for meeting tracking accuracy requirements of ± 20 mm. Install a surrogate final optics/mirror unit on injection/tracking system and interface to tracking commands to provide an integrated demonstration of high-speed tracking and hitting the target on-the-fly with a low-power laser (with UCSD collaboration). Prepare preliminary design of multi-shot EM accelerator which will support Electra operations	GA	2005
8	DT Response During Injection	Deposit a layer of DT in a torus and observe effect of rapid heat pulse (with respect to the ability of the DT to survive as a high-gain IFE target). Prepare experimental device to allow conducting above experiment with foam underlay (as in high gain direct drive target) conduct experiment in FY04	LANL	2003
		Conduct experiments to determine the ability of DT with foam underlay to survive the rapid heat pulse characteristic of target injection into a high-temperature chamber. Measure elastic modulus and yield strength of DT under representative strain rates, repeat with foam-reinforced DT.	LANL	2004

ID	TASK NAME	TASK OVERVIEW AND SCHEDULE	LEAD INSTITUTION	FISCAL YEAR
8	DT Response During Injection	Measure DT response with rapid IR heating of filled spherical targets. This will by necessity require filling, cooling to cryogenic temperature, and layering (in layering sphere of the CPL).	LANL	2005
9	Target/Chamber Interface	[This task in the FY03-05 time frame will use data from target R&D and input from chamber R&D programs; assess the survival of the target based on modeling and analyses. Characterize the key issues and constraints by interaction with target physics, fabrication and experimental groups; help guide R&D on key material issues and develop solutions to ensure target survival.] Perform assessment of cryogenic materials properties necessary for target/chamber interface modeling. Develop modeling capabilities. Perform trajectory analysis in coordination with injection tasks.	GA/UCSD	2003
		Continue parametric analyses of target response during cryogenic handling and injection; provide feedback to guide R&D.	GA/UCSD	2004
		Bring together materials property data, models of target response during injection, and experimental program results to show a workable solution for direct drive target injection; demonstrate readiness to proceed with the IRE phase with respect to target survival during injection. Coordinate and present information on target injection and tracking to support the IRE.	GA/UCSD	2005

PHASE 2 – FULL-SCALE PILOT PLANT

PHASE 2 OBJECTIVE:

Develop an integrated set of full-scale process unit operations for the production of layered, D_2-filled targets.

PHASE 2 MAJOR TASKS:

TASK 2-1 — MARK I PROCESS REQUIREMENTS

A team of two engineers/scientists and one designer will spend twelve months detailing the process requirements for the unit operations as well as a comprehensive interface, QA/QC and controls system.

TASK 2-2 — MARK I EQUIPMENT DESIGN SPECIFICATIONS

A team of two engineers/scientists and one designer will spend eighteen months writing design specifications for the unit operations – each large enough to handle a 6 ℓ batch of finished product (sufficient for 8 hrs continuous production at 5 Hz injection rate).

TASK 2-3 — MARK I EQUIPMENT PROCUREMENT

A team of two engineers/scientists and one designer will spend twelve months procuring the process equipment.

TASK 2-4 — MARK I EQUIPMENT DELIVERY, INSTALLATION, CHECKOUT

A team of two engineers/scientists, one designer and two technicians will spend twenty-four months installing and checking out the entire Prototype Target Fabrication Facility.

TASK 2-5 — SHAKEDOWN TESTING OF EQUIPMENT

A team of two engineers/scientists, one designer and two technicians will spend eighteen months preparing the equipment for parametric testing.

TASK 2-6 — PARAMETRIC TESTING OF EQUIPMENT

A team of two engineers/scientists, one designer and two technicians will spend twelve months performing parametric testing aimed at producing an initial batch of D_2 filled, layered targets.

TASK 2-7 — PRODUCTION OF INITIAL BATCH OF D2 FILLED, LAYERED TARGETS

This is a milestone attained at the conclusion of parametric testing.

PHASE 2 EQUIPMENT SCOPE:

The following unit operations will be developed and integrated into the facility in three separate revisions:

Mark I — initial installation (Phase 2 in this overall Development Program);

Mark II — significant upgrade based on parametric testing of Mark I equipment;

Mark III — minor upgrade based on parametric testing of Mark II equipment):

(A) <u>Shell Generator</u>

3-fluid style continuous hollow shell generator to form DVB foam shells.

(B) Rotary Contactor

Rotary system to enhance contacting and promote shell sphericity while forming the thin CH outer coating.

(C) Rotary Contactor Tank System

Provides reagent supply and countercurrent intermediate fluid storage capacity for the rotary contactor.

(D) Critical Point Dryer

Commercial supercritical CO_2 system with materials handling features customized for this application.

(E) Sputtering System

Applies thin coating of high-Z material to the dried sphere.

(F) D2 Filling System

Diffuses D_2 into the shell at high pressures followed by cryogenic cooling and depressurization.

(G) Cryogenic Layering System

Uses a helium-fluidized bed at cryogenic temperatures along with a heat source to evenly distribute the D_2 in a layer on the inside surface of the foam shell.

(H) Helium Liquifaction/Recirculation Equipment

Services both the D_2 filling system and the cryogenic layering system.

(I) QA Lab Equipment

Provides vital feedback on batch acceptability in numerous pertinent parameters.

(J) Balance of Plant

Piping, electrical, instruments, auxiliaries and field expenses associated with all of these unit operations.

PHASE 2 CAPITAL COSTS FOR PROTOTYPE TARGET FABRICATION FACILITY:

	FY 2006	
	Mark 1 Equipment	
Shell Generator	$	25,000
Contactor	$	15,000
Contactor Tank System	$	90,000
Dryer	$	60,000
Sputtering System	$	450,000
DT Filling System	$	375,000
Cryo Layering System	$	550,000
Helium Liquifaction/Recirculation System	$	300,000
QA Lab Equipment	$	350,000

Total Process Equipment Cost	**$**	**2,215,000**

Factored Balance of Plant Costs (from Miller's Method)

Piping	$	863,850
Electrical	$	376,550
Instruments	$	287,950
Auxiliaries	$	1,218,250
Field Expenses	$	952,450

Total Installed Capital Cost	**$**	**5,914,050**

PHASE 2 SCHEDULE

	2005	2006	2007	2008	2009	2010	2011	2012
Task 2-1	******							
Task 2-2		******	***					
Task 2-3			****	***				
Task 2-4				****	******	***		
Task 2-5						****	******	
Task 2-6								******
Task 2-7								**X**

PHASE 3 – PILOT PLANT PARAMETRIC TESTING

PHASE 3 OBJECTIVE:

Parametrically test equipment in sequential campaigns to produce finished targets. Modify equipment to attain product specifications and throughput/reliability goals. Resultant facility is ready for use as a commercial prototype.

TASK 3-1 — Incorporate Mark II Equipment Upgrades to incorporate Lessons Learned

A team of eight engineers/scientists, two designers and eight technicians will spend nine months in the design, procurement, installation and shakedown of Mark II equipment upgrades.

TASK 3-2 — Parametric Testing of Mark II Equipment

A team of eight engineers/scientists, two designers and eight technicians will spend fifteen months performing parametric testing aimed at producing D_2 filled, layered targets to allow integrated operations with injection of 1 hr batches at 6 Hz.

TASK 3-3 — Integrated Operations with Injection of 1-hour Batches at 6 Hz

(21,600 targets @ bulk volume of ~ 0.7 ℓ/1 hr batch).
This is an intermediate milestone attained during parametric testing.

TASK 3-4 — Incorporate Mark III Equipment Upgrades to incorporate Lessons Learned

A team of eight engineers/scientists, two designers and eight technicians will spend nine months in the design, procurement, installation and shakedown of Mark III equipment upgrades.

TASK 3-5 — Parametric Testing of Mark III Equipment

A team of eight engineers/scientists, two designers and eight technicians will spend fifteen months performing parametric testing aimed at producing D_2 filled, layered targets to allow integrated operations with 5-day campaigns injection of 1 hr batches at 6 Hz.

TASK 3-6 — Fully Integrated Demonstration Testing

Four separate 5-day campaigns of 1 hr continuous injection per day – from raw materials to injected targets.

This is a final milestone attained at the end of parametric testing.

PHASE 3 EQUIPMENT SCOPE:

The initial pilot-plant installation (described in Phase 2) will be further developed and integrated into the facility in the Mark II and Mark III upgrades during Phase 3:

Mark I initial installation (Phase 2 in this overall Development Program);

Mark II significant upgrade based on parametric testing of Mark I equipment;

Mark III minor upgrade based on parametric testing of Mark II equipment):

PHASE 3 CAPITAL COSTS FOR PROTOTYPE TARGET FABRICATION FACILITY

	FY 2013 Mark II Upgrades	FY 2015 Mark III Upgrades
Shell Generator	8,750	5,000
Contactors (4 each)	14,000	8,000
Contactor Tank Systems (2 each)	61,250	35,000
Dryer	21,000	12,000
Sputtering System	157,500	90,000
DT Filling System	131,250	75,000
Cryo Layering System	192,500	110,000
Helium Liquifaction/Recirculation System	105,000	60,000
QA Lab Equipment	122,500	70,000
Total Process Equipment Cost	**$ 813,750**	**$ 465,000**
Piping	$ 317,363	$ 181,350
Electrical	$ 138,338	$ 79,050
Instruments	$ 105,788	$ 60,450
Auxiliaries	$ 447,563	$ 255,750
Field Expenses	$ 349,913	$ 199,950
Total Installed Capital Cost	**$ 2,172,713**	**$ 1,241,550**

PHASE 3 SCHEDULE:

	2013	2014	2015	2016
Task 3-1	*****			
Task 3-2	**	******		
Task 3-3		**X**		
Task 3-4			*****	
Task 3-5			**	******
Task 3-6				**X**