A Systematic Approach to the Design, Fabrication & Installation of an Electrochemical Processing Facility

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This paper describes an approach used to design, fabricate, and install an electrochemical processing facility. The formation and empowerment of a multidisciplinary team enabled us to meet our technical, cost, environmental and schedule requirements. Examples demonstrating the use of design tools, including process simulations, flowcharts, dimensionless groups, material balances, and teaming and planning tools are shown. The results of design verification tests that were performed on prototype tanks and chemical compatibility tests of floor and ceiling coatings are presented. In addition, lessons learned during this project are discussed.

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1.0 INTRODUCTION

Simulations and capacity analyses showed that Lockheed Martin's (LM) development metallization facility in Orlando, Florida was inadequate to meet future production requirements. This paper describes the approach that was utilized to design, fabricate, and install a facility for the metallization of plastics. Details about our processes for metallizing difficult-to-plate plastics appear in a separate paper [1]. Figure 1 shows a flowchart of the systematic approach we utilized to design, build, and install a production plating facility.

2.0 FORMATION OF A MULTIDISCIPLINARY TEAM

From the inception of the project, it was imperative to establish a team with representatives from all contributory disciplines to make decisions in all aspects of the project. Figure 2 shows some of the disciplines that we included in our team. We understood that incorrect assumptions at the beginning of the project could lead to costly changes downstream. It is much easier and cheaper to make changes on drawings than to make equipment or facility changes. Studies have shown that design typically consumes 5% of the project cost but impacts 60% of the total cost. It has been reported [2] that it is possible for maintenance costs of a poorly-designed finishing facility to be 300 percent higher than the minimum for a well-designed and adequately maintained facility. Thus, our goal was to utilize a multidisciplinary team to get all inputs in the design phase to achieve a cost-effective, well-designed facility. We made a point of reviewing the design with operators, engineers, and management in both team and one-on-one meetings. In addition, we reviewed the literature for examples from others [3-7] involved in chemical and electrochemical processes.

3.0 DEFINE PRODUCT FINISHES AND PRODUCTION RATE REQUIREMENTS

The finishes for existing and future product lines define specific processing requirements while production rates define tank and facility size requirements. It is important to review future growth plans to ensure that future requirements are covered. Figure 3 outlines rate requirements for our project. The finish requirements include an electroless copper base with no overcoat or an electrolytic copper, nickel, or tin-lead overcoat..

4.0 DEFINE PROCESSING AND PROCESS CONTROL REQUIREMENTS

We have identified and implemented stringent process chemistry control, agitation, and filtration requirements. Table 1 outlines some of the processing requirements for our project. It is important to include cleaning and stripping tanks in addition to chemical and electrochemical processing tanks. We have separate tanks for cleaning tools and parts to eliminate the possibility of contaminating our process tanks. The electroless copper tanks include in situ thickness monitors and automatic chemical analysis and replenishment.

Thorough rinsing and high quality deionized water are critical for electrochemical processing. Inadequate rinsing will defeat the object of every step in the plating cycle [8]. In order to minimize the amount of waste generated we utilized a recirculating rinsewater system for overflow and counterflow rinses. Each process tank is followed by a dragout rinse tank to minimize the loading on the recirculating deionized water system. The water in the dragout tank is used to make up evaporation losses from the process tank. Figure 4 shows our approach for rinsing and drying after application of electroless copper. Figure 5 summarizes the results of rinsing calculations that were used to identify our rinsewater flow requirements. The details of rinsing calculations [8] including on-line rinsing models [11] can be found elsewhere. It is important to understand dragout rates for all part types and to base rinsing calculations on the worst case scenario. Our recirculating rinsing system has dual banks of carbon, and anionic and cationic exchange resins in order to eliminate downtime for recharging the banks. The recirculating system includes ultraviolet flow-through reactors to inhibit algae growth. In addition, we have a fresh deionized water system with adequate capacity to backup the recirculating system in the event of failure. Both water systems have in-line conductivity meters that are monitored by our data acquisition system. In addition, the total organic carbon (TOC) for both water systems is monitored regularly.

5.0 VENDOR SELECTION

For design and construction, we decided to utilize commercial vendors as Lockheed Martin is not experienced in the design, fabrication, and installation of electrochemical processing facilities. Our team decided that we wanted a turn-key installation so that one vendor would be responsible for design, fabrication, and installation. We utilized shop guides, [9,10] on-line resources, [11,12] and technical consultants [13] to identify vendors that had experience with turn-key installations of electrochemical processing facilities. Their capabilities were evaluated to determine if our technical requirements could be met within our budget with little or no technical or schedule risk.

A bidders conference was held and vendors were briefed on our requirements, given a baseline design concept, and encouraged to reduce cost and space based on their previous design experiences. An evaluation team was assembled to review the technical and cost proposals from the vendors. As part of our technical assessment of the vendors, we asked the vendor to answer several technical questions for inclusion in the technical proposal. The financial rating [14] of potential vendors was checked to ensure they had the financial capacity to handle our project. The team evaluated each vendor's proposal using a detailed assessment matrix and selected the vendor that best met our technical, cost, and schedule requirements. In addition, we asked for references and visited the vendor's factory as well as facilities that were installed up to 10 years ago by the selected vendor. These visits helped to establish confidence in the vendor and allowed us to witness different plating line designs in operation.

6.0 DEFINE TANK SIZE AND EXHAUST REQUIREMENTS

The production rate, largest part size, bath loading requirements, and equipment (pumps, heaters, level controllers, ultrasonic transducers, mixing weirs, etc.) define the required tank size. In our case, a dome was the largest and most complicated part. The ultrasonic cleaning tanks were made 4 inches deeper than the other tanks to accommodate bottom-mounted ultrasonic transducers and maintain a constant working depth for all tanks. Separate compartments were added to the electroless copper tanks for holding bath-loading "dummy" panels to minimize damage to hardware caused by bumping hardware with the dummy panels. In addition, we allowed adequate space to accommodate manual insertion and removal of radomes from the tanks. Figure 6 shows details of our electroless copper tanks including the dummy compartments, mixing weir, and dispersion tube system. In addition to driving the tank size, the dome also created challenges for the spray rinses and air knives due to its geometry. Figure 7 shows the provisions for reproducibly positioning parts in each process tank as well as tooling for positioning radomes during immersion, spray rinsing and drying steps.

The exhaust system was designed as a down-draft system in order to minimize obstruction by hood trunks. We wanted access to both ends of the tanks for processing hardware, process control, changing filters, tank maintenance, and to accommodate future automation. The ventilation requirements are driven by the surface area and chemistry of the chemical process tanks [15]. We were able to reduce our exhaust volume by 20% by going utilizing a push-pull ventilation system instead of a pull only system. Thus, we reduced our makeup air requirements accordingly. An air abatement fume scrubber was provided for air compliance. The concentration of the circulating scrubber spray water is monitored and controlled by a conductivity meter. The scrubber's water is sent to waste treatment and replenished with fresh tap water when its conductivity setpoint is exceeded.

7.0 AUTOMATION

Our philosophy is that automation should pay for itself out of cost savings over the time period and production quantities of interest. The present line was designed to incorporate overhead or over-the-side automation in the future. Our production quantities for 1997 and 1998 were not large enough to justify the additional expense of an automatic plating line.

8.0 SIMULATIONS

Detailed flowcharts were established for our processes to metallize different parts utilizing a commercially available flowcharting package[16]. These flowcharts were then input to a simulation program[17] to ensure an efficient work flow for all parts and that rate requirements are met. An iterative approach was utilized to optimize the placement of support equipment and minimize congestion points. The rinses and all processing steps for the electroless copper process in the new facility were designed in series. Simulation methods proved to be cost effective for us to visualize work flows, understand and eliminate congestion points, and optimize lot sizes and facility layouts.

9.0 DEFINE FACILITY REQUIREMENTS

The facility requirements were established with inputs from steps 3 to 8 in Figure 1. These include heating, ventilation, air conditioning (HVAC), lighting, power, floor and ceiling coating, and waste treatment requirements as well as areas for pre-plating and post-plating operations. It is important to allow adequate space for efficient work flow and maintenance. We allowed space to access processing tanks from both ends.

Chemical fume exhaust requirements drove our HVAC requirements. In order to reduce the HVAC requirements we cover all chemical process tanks and run the exhaust system at a lower speed (50% reduction) during off hours. The exhaust and HVAC systems are interlocked to ensure that the air flow in the facility is balanced.

Lighting is important for inspecting parts before, during and after processing. We baselined the lighting conditions in our development facility and decided we wanted a light intensity of 100 to 135 footcandles in our new facility. We selected a metal halide lights since they met our requirements and provided a white light source.

Floors must be robust in order to support the finishing equipment. We chose to raise our tanks as shown in Figure 8 to accommodate the down-draft exhaust system and allow for gravity draining of tanks to our existing waste treatment facility. It is imperative to allow adequate time for concrete and any secondary coatings to properly cure. We performed chemical immersion tests to evaluate floor, grating, and ceiling coatings in 50% (v/v) nitric acid, 50 % (v/v) sulfuric acid, and 50% (v/v) hydrochloric acid for 12 to 120 hours. These tests were extremely useful in selecting coatings that will survive in the corrosive atmosphere of a plating shop. A two-layer polyurethane foam/polyester topcoat ceiling coating [18] and a vinyl ester floor coating performed well in our immersion tests. We selected a floor coating vendor who provided a limited 3-year warranty for the installed coating. To ensure longevity of the floor coating, our design incorporated a perimeter floor wash system to prevent chemicals from sitting for prolonged periods of time on the floor coating.

The plating facility was designed to use our existing waste treatment facility. The facility location was selected due to its proximity and because it was feasible to gravity feed waste streams to waste treatment. Waste minimization features incorporated in the design of the rinse water system and the conductivity control of the fume scrubber is expected to limit the waste water generated. The piping segregation of the concentrate waste streams will make it convenient in the future to intercept the waste for recycle and or treatment if and when new technology becomes cost effective.

10.0 OPTIMIZE FACILITY DESIGN TO MEET REQUIREMENTS

It is necessary to perform multiple iterations of the facility design in order to optimize operational factors such as:

1) non-recurring costs
2) recurring costs
3) schedule risk
4) technical risk
5) environmental concerns
6) future automation
7) future expansion/new business
8) space limitations

Keep good records in the form of flowcharts to understand what assumptions were made to reach the final approved design.

11.0 ESTABLISH DETAILED PLANS AND SCHEDULES

Overall and detailed plans should be established upon completion of the final facility design. The plans consist of detailed schedules with the critical path identified. Figure 9 shows our overall project schedule. It is important to hold frequent regular meetings and establish action items assigning responsibility for completing the action by the scheduled commitment date. These meetings must be attended by all key players to track progress, impacts, and ensure that nothing is overlooked. Communication between all parties is ensured in this manner.

12.0 FABRICATE PROTOTYPES AND PERFORM VALIDATION TESTS

Although three-dimensional CAD/CAM design tools are available, there is no substitute for actual prototypes. It is beneficial to fabricate prototype tanks, workbars, and tools to verify that nothing has been overlooked and that there are no space issues in any stations. We fabricated prototype electroless copper, process, and cleaning tanks as well as spray rinses and air knife stations to verify and/or refine agitation, position, spray rinsing, ultrasonic, and/or tooling issues. All team members moved the workbar with plating racks in and out of the prototype stations. We then collected inputs and comments from all to refine the tooling and tank designs.

We performed velocity measurements to ensure that hydrodynamic conditions were the same as the smaller development tanks and preserved dimensionless groups such as Reynold's number and aspect ratio. Ultrasonic tests were performed utilizing aluminum foil and an ultrasonic power monitor to verify uniform and consistent ultrasonic conditions.

13.0 FABRICATION AND FACTORY ACCEPTANCE

Figure 9 shows the schedule for the fabrication of our electroless processing lines. Plating lines were designed to be modular in order to minimize field installation time. The tanks were fabricated and assembled in lengths suitable for shipping and moving into the facility.

A factory acceptance plan was established to verify that all features were correct prior to shipping. If changes were necessary, they were made at the factory where it is more efficient to make changes.

14.0 INSTALLATION AND SITE ACCEPTANCE

The site must be ready to initiate the installation process and site preparation is shown in the critical path on our schedule. The floor, floor coatings, and ceiling coatings had to be complete and fully cured prior to initiating the installation process. The heavy equipment used to move the equipment and supports will damage the floor and its coating in the event either is not properly cured. We were aware of several projects that were delayed for months due to floor problems. A detailed site acceptance plan was prepared and executed to verify that all details such as valves, level and temperature controllers, pumps, timers, heaters, and rinses functioned properly. Items that were not correct were documented. Automatic startup and shutdown, as well as power failure simulations, were performed. An independent contractor was utilized to perform the testing and balancing of the HVAC systems.

Final documentation including as-built drawings of all details in the entire facility, operating and maintenance manuals, and recommended spares is one of the most important requirements of the acceptance plan. The site acceptance is complete after successful demonstration of all items in the acceptance plan and after the vendors holds a training session for LM's maintenance and engineering personnel.

15.0 CONCLUSIONS

The formation and empowerment of a multidisciplinary team enabled us to meet our technical, cost, environmental, and schedule requirements. It would have been impossible to meet our aggressive schedule without a team-based approach. The use of simulation methods proved to be cost effective for us to visualize work flows, understand and eliminate congestion points, and optimize lot sizes and facility layouts. Fabrication and evaluation of prototypes and performance testing of coatings were critical for verifying our design.

A number of lessons were learned during the course of this project that may be helpful to others:

1) Make sure drawing are accurate and contain all appropriate details as tanks and equipment are fabricated from drawings not the proposal;
2) Pay close attention to material selection and compatibility in all areas including o-rings, fasteners, fittings, hoists, and chains;

3) Provide vendors with detailed specifications to avoid ambiguity. It is probably impossible to provide too much information.

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Table I. **FACILTY PROCESS AND PROCESS CONTROL REQUIREMENTS**

Ite	Description
1	Ultrasonic Cleaning
2	Separate Area for Blast Equipment
3	Automatic Liquid Level Control
4	Easy Filter Change-out for In-tank Filter Pumps
5	Access to Tanks from Front and Back
6	Gravity Feed Drains
7	Separate Area for Plasma Equipment
8	Real Time In Situ Rate and Thickness Monitoring
9	Real Time Temperature Monitoring
10	High Quality Deionized Rinse Water
11	Real Time Rinse Water Conductivity Monitoring
12	Automated Chemical Analysis, Replenishment, and Monitoring for Electroless Copper Baths
13	Overflow Weir and Separate Dummy Compartments for Electroless Copper Baths
14	Tooling to Reproducibly Position Parts in Baths and Minimize Dragout
15	Real Time Statistical Process and Quality Control
16	Automated Data Collection for Weighing and Resistivity Measurements

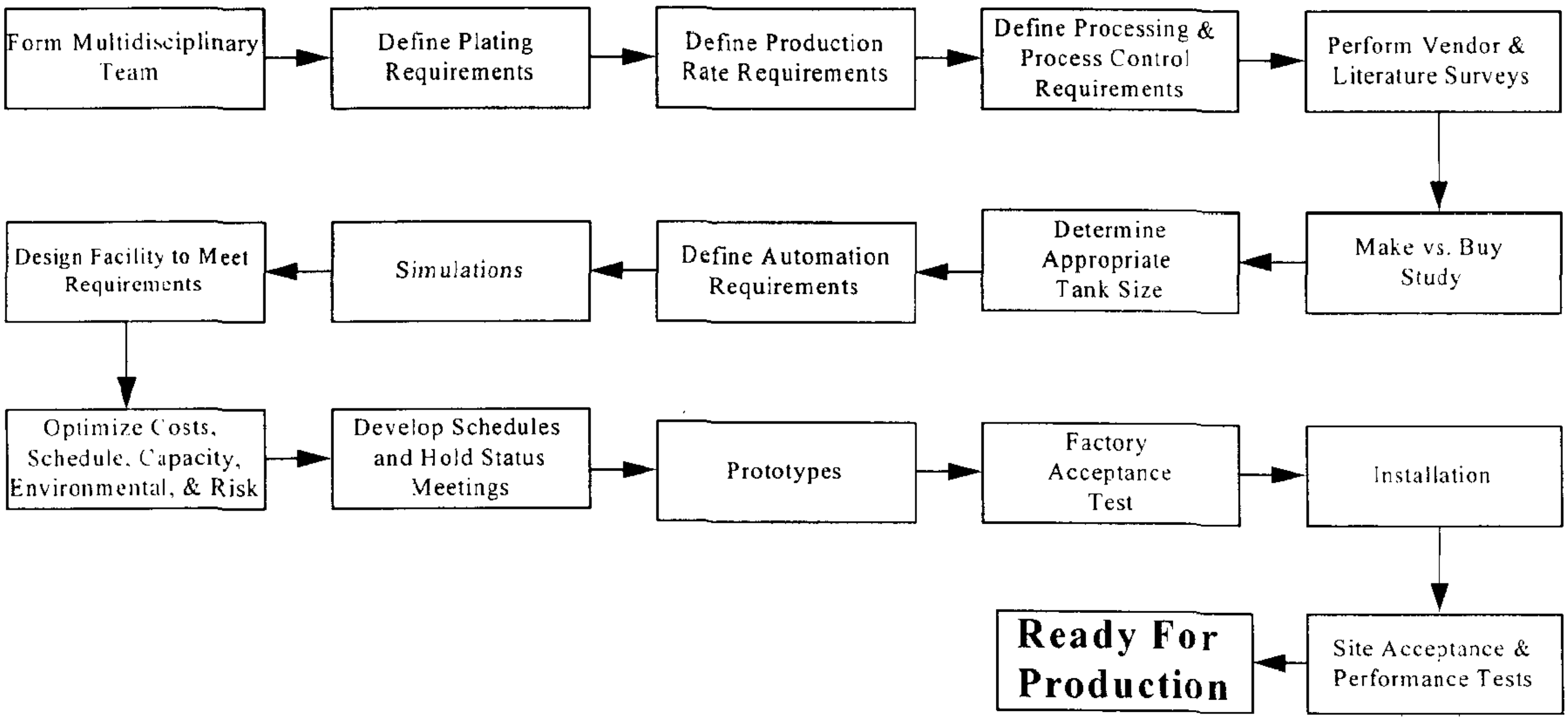


Figure 1. Overview of Systematic Approach for Establishing an Electrochemical Processing Facility

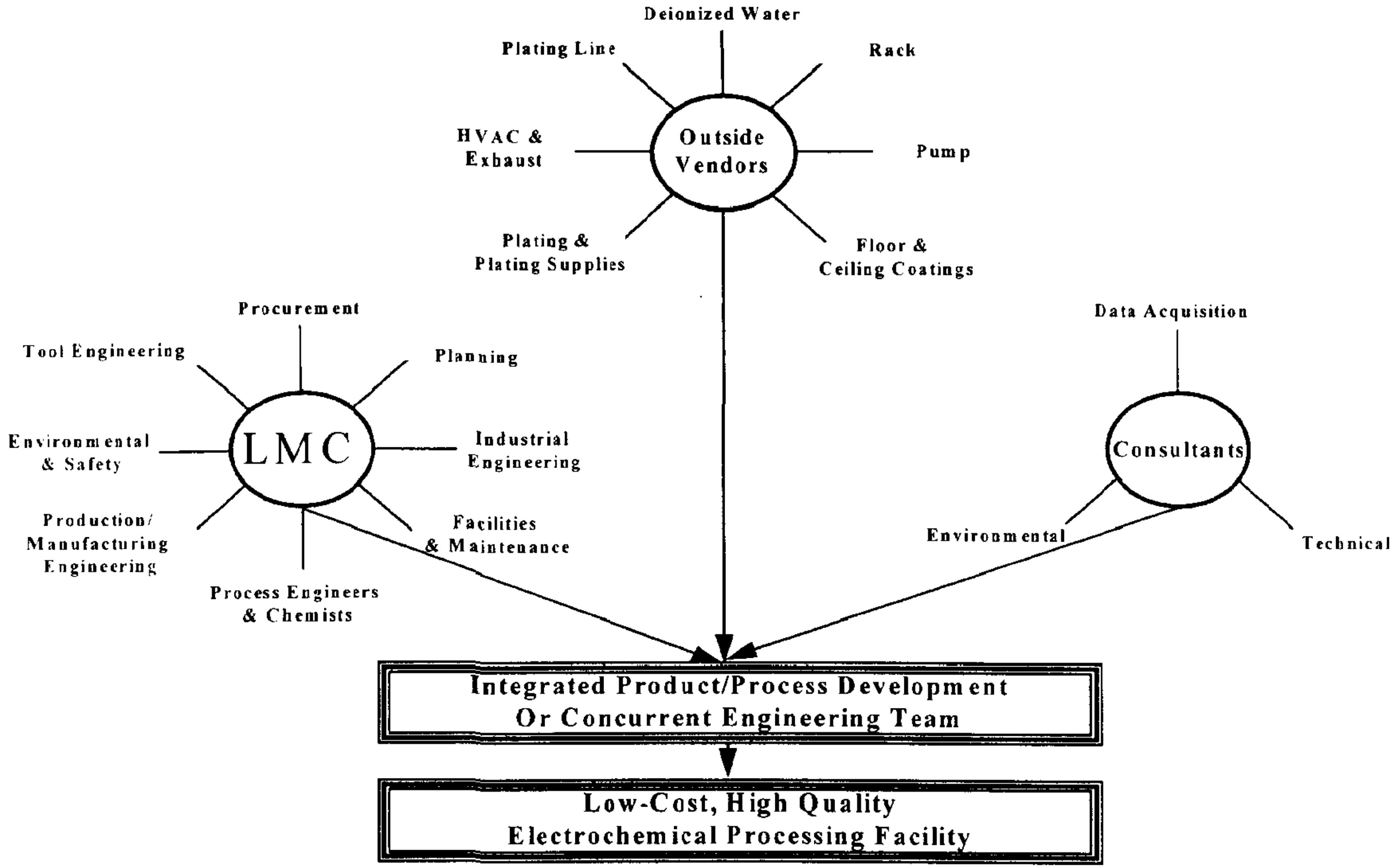


Figure 2. Multidisciplinary Team Approach

	1997						1998												1999			
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
PRODUCTION Requirements																						
LOT 1 QUANTITY (EACH)	5x	5x	5x	5x	5x	5x	5x	5x	5x													
LOT 2 QUANTITY (EACH)		x	2x	3x	3x	4x	6x	9x	12x	15x	17x	20x	22x	22x	22x	24x	24x	5x				
LOT 3 QUANTITY (EACH)																		9x	26x	26x	26x	26x
NEW PLATING LINE																						
30% Design	△																					
CER Approval	△																					
Final Design, Manufacture, Install	▭	▭	▭	▭	▭	▭																
Process Scale-up & Implementation							▭	▭	▭													
Line Ready for Production									△													

Figure 3. Production Rate Requirements and New Facility Schedule

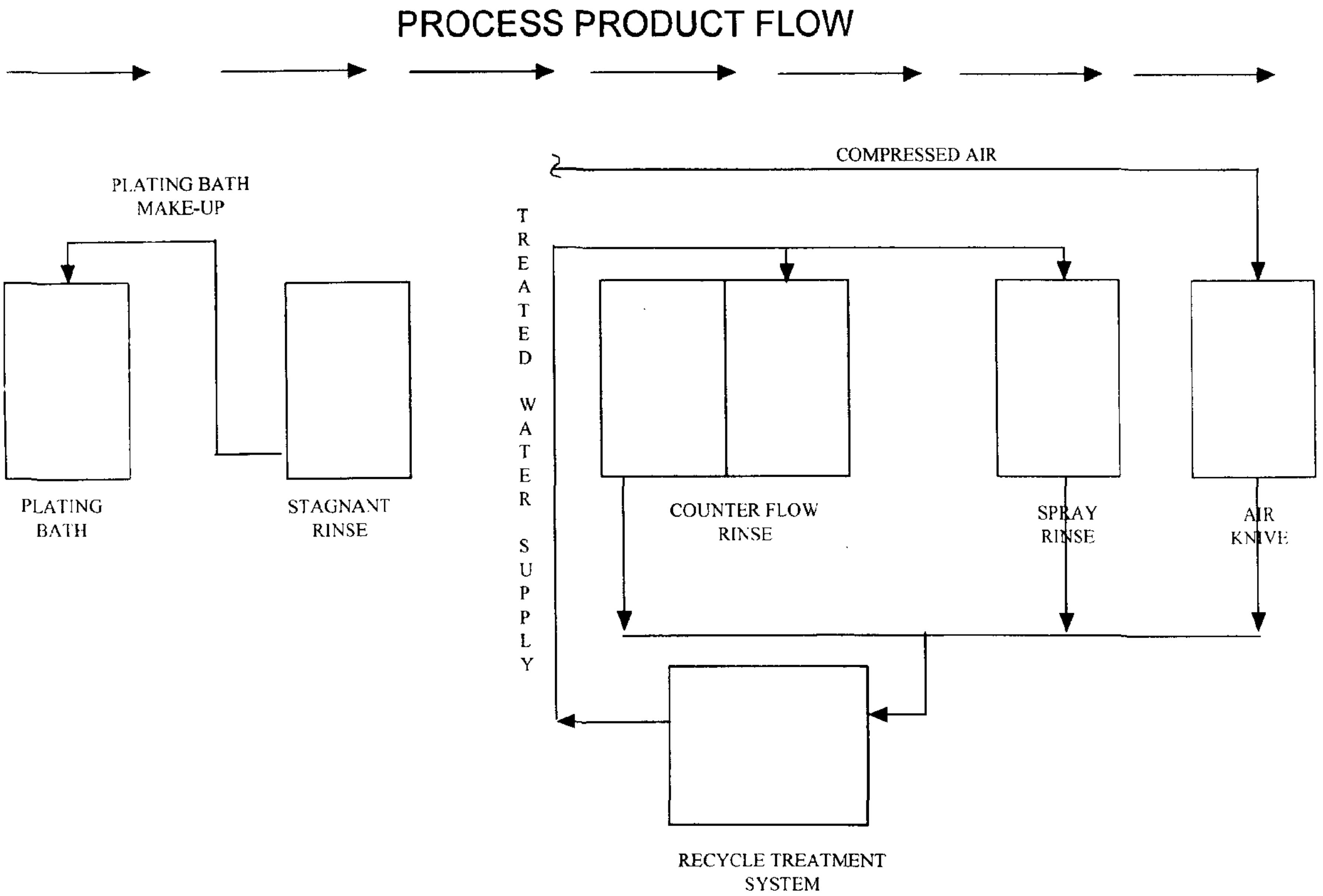


Figure 4. Recirculating Rinsewater System

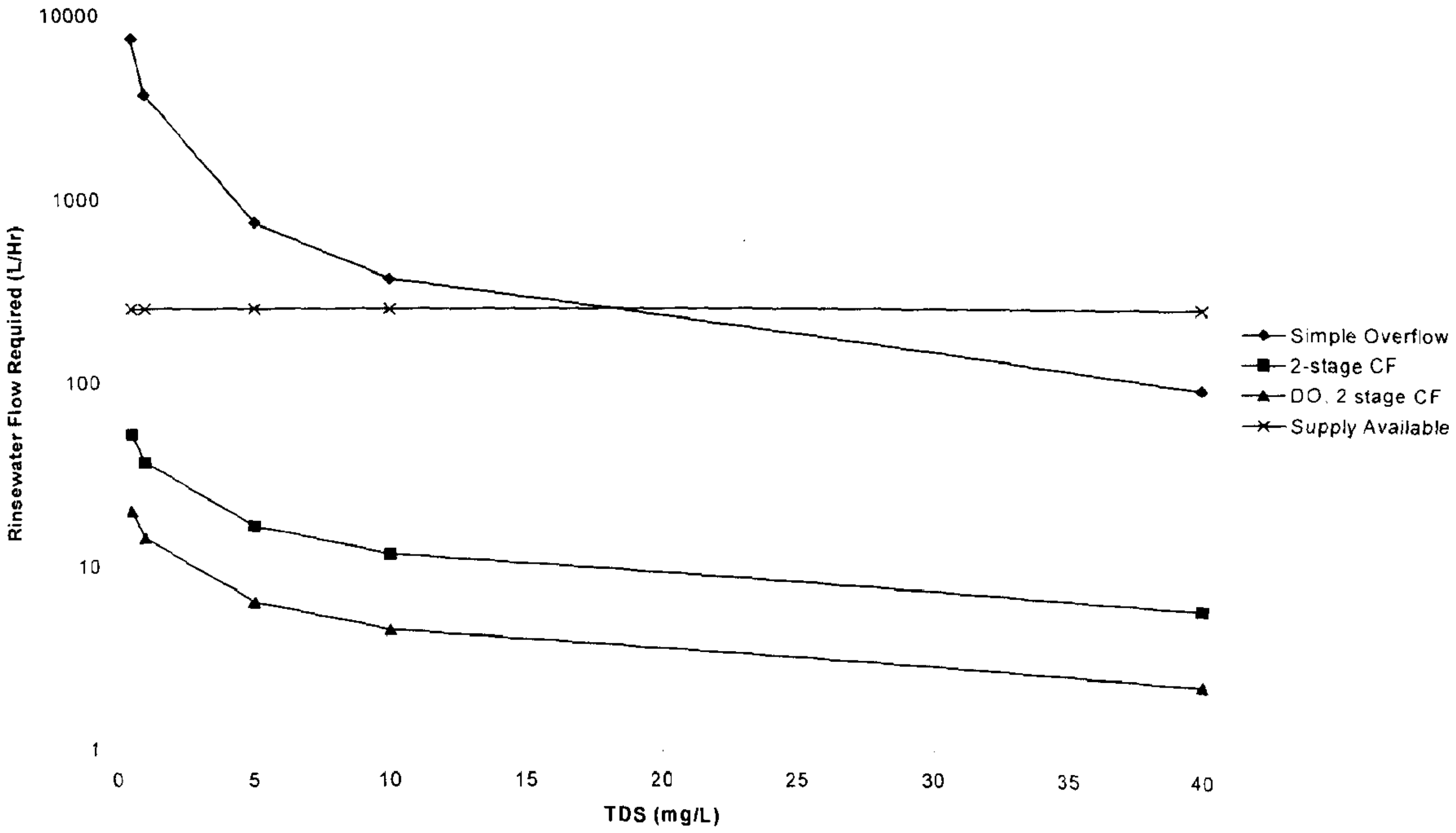


Figure 5. Effectiveness of Different Rinsing Approaches

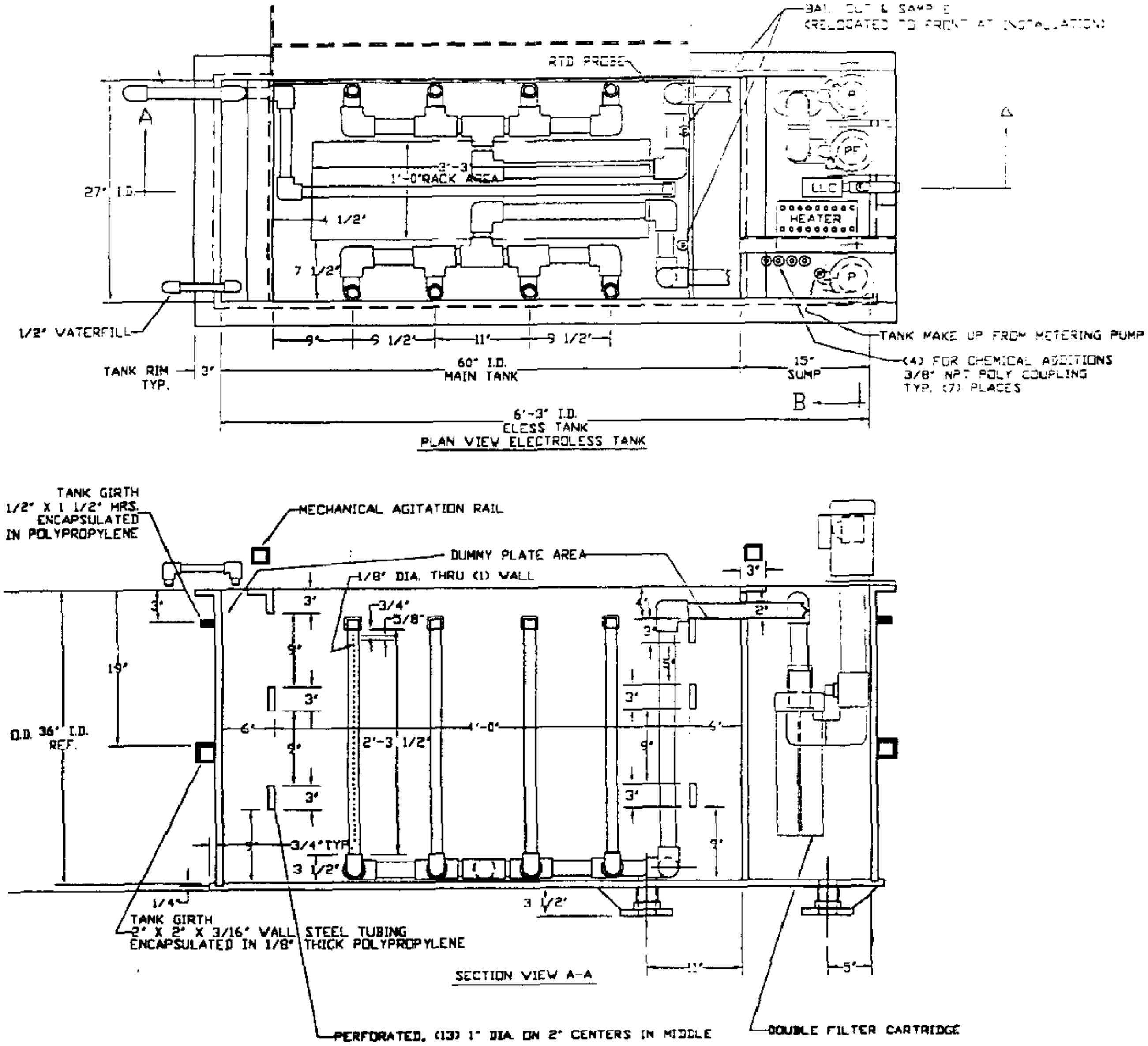
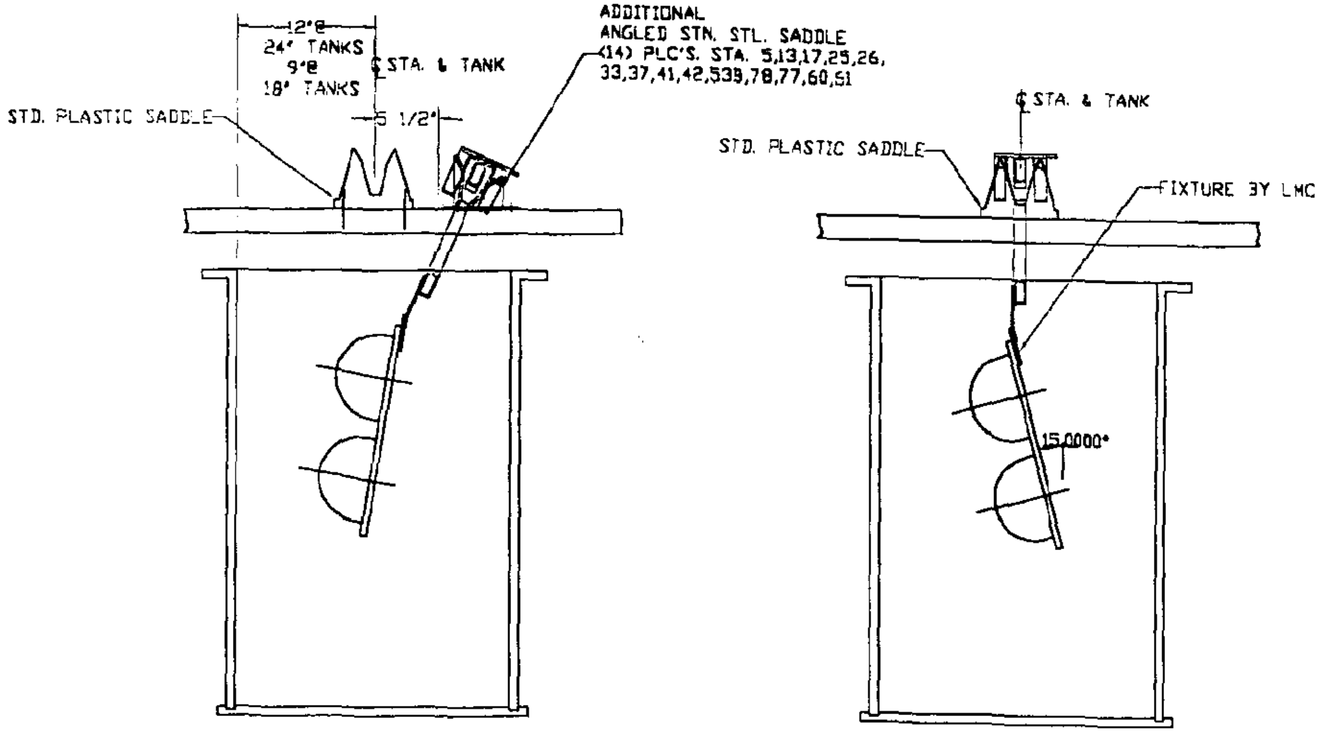


Figure 6. Electroless Copper Tank Drawing



FRONT VIEW OF TANK

OPTIONAL POSITION OF FIXTURE
IN D.I. SPRAY RINSE TANKS &
AIR KNIFE STATIONS

FRONT VIEW OF TANK

NORMAL POSITION OF FIXTURE
IN TANKS

Figure 7. Tooling for Positioning Domes in Processes Tanks

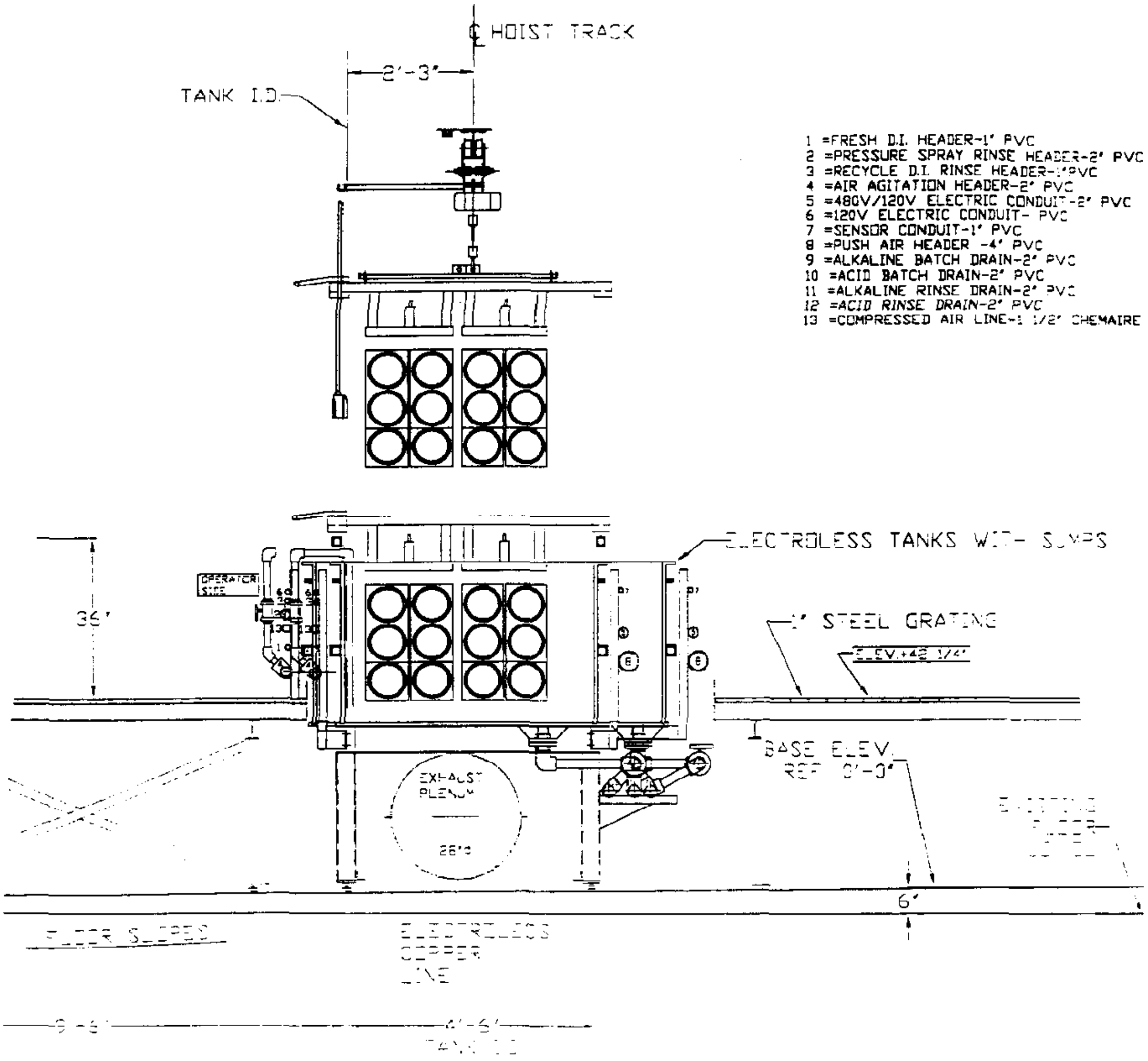
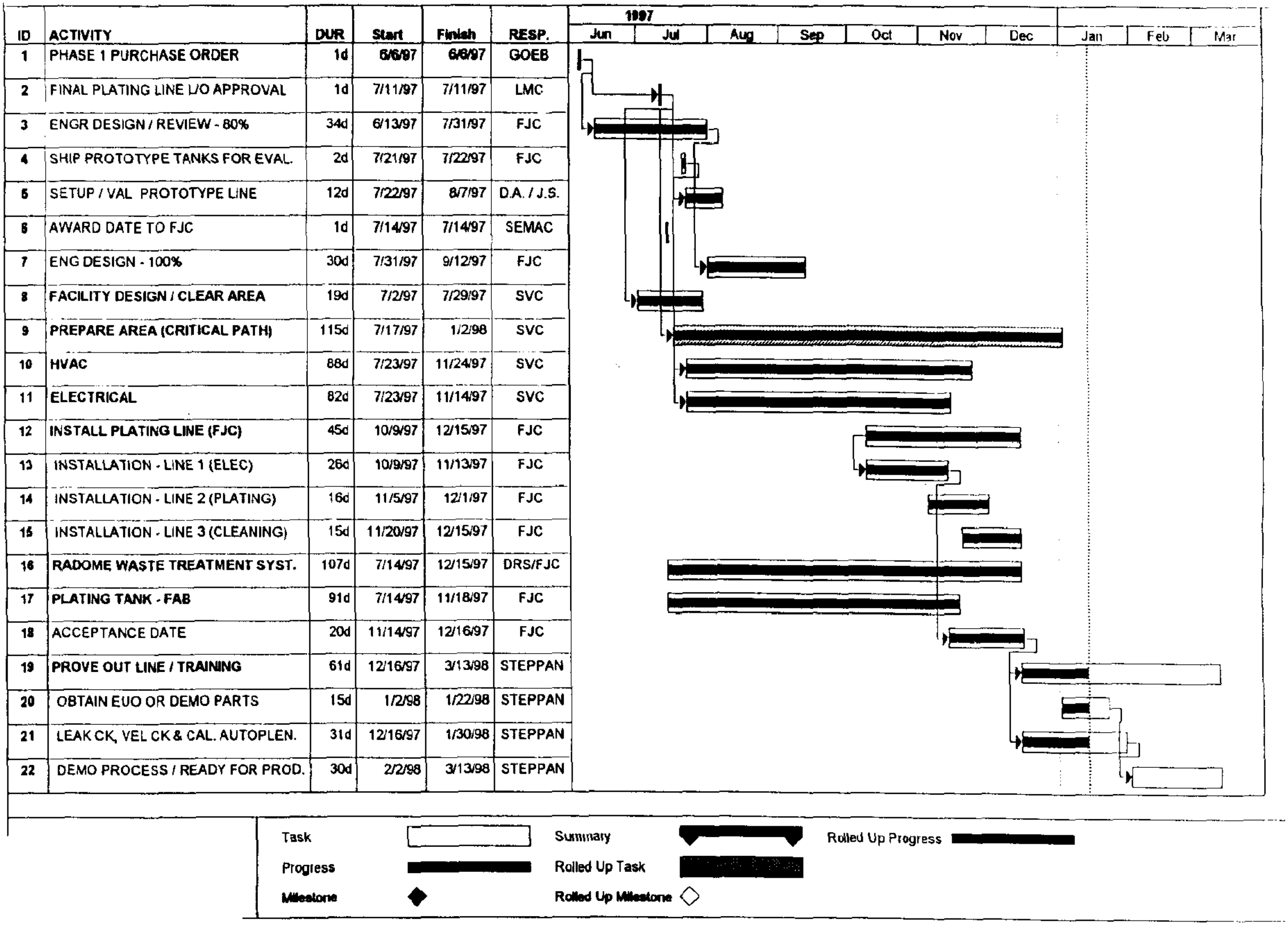


Figure 8. Cross Section of Electroless Copper Line



ID	ACTIVITY	DUR	Start	Finish	RESP.
1	**PHASE 1 PURCHASE ORDER**	1d	6/6/97	6/6/97	GOEB
2	FINAL PLATING LINE L/O APPROVAL	1d	7/11/97	7/11/97	LMC
3	ENGR DESIGN / REVIEW - 80%	34d	6/13/97	7/31/97	FJC
4	SHIP PROTOTYPE TANKS FOR EVAL.	2d	7/21/97	7/22/97	FJC
5	SETUP / VAL PROTOTYPE LINE	12d	7/22/97	8/7/97	D.A. / J.S.
6	AWARD DATE TO FJC	1d	7/14/97	7/14/97	SEMAC
7	ENG DESIGN - 100%	30d	7/31/97	9/12/97	FJC
8	**FACILITY DESIGN / CLEAR AREA**	19d	7/2/97	7/29/97	SVC
9	**PREPARE AREA (CRITICAL PATH)**	115d	7/17/97	1/2/98	SVC
10	**HVAC**	88d	7/23/97	11/24/97	SVC
11	**ELECTRICAL**	82d	7/23/97	11/14/97	SVC
12	**INSTALL PLATING LINE (FJC)**	45d	10/9/97	12/15/97	FJC
13	INSTALLATION - LINE 1 (ELEC)	26d	10/9/97	11/13/97	FJC
14	INSTALLATION - LINE 2 (PLATING)	16d	11/5/97	12/1/97	FJC
15	INSTALLATION - LINE 3 (CLEANING)	15d	11/20/97	12/15/97	FJC
16	**RADOME WASTE TREATMENT SYST.**	107d	7/14/97	12/15/97	DRS/FJC
17	**PLATING TANK - FAB**	91d	7/14/97	11/18/97	FJC
18	ACCEPTANCE DATE	20d	11/14/97	12/16/97	FJC
19	**PROVE OUT LINE / TRAINING**	61d	12/16/97	3/13/98	STEPPAN
20	OBTAIN EUO OR DEMO PARTS	15d	1/2/98	1/22/98	STEPPAN
21	LEAK CK, VEL CK & CAL. AUTOPLEN.	31d	12/16/97	1/30/98	STEPPAN
22	DEMO PROCESS / READY FOR PROD.	30d	2/2/98	3/13/98	STEPPAN

Figure 9. Master Schedule for Plating Facility