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CADMIUM AND CHROMIUM RECOVERY FROM ELECTROPLATING RINSEWATERS

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, Superfund-related activities, and pollution prevention. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Passage of the Pollution Prevention Act of 1990 marked a strong change in the U.S. policies concerning the generation of hazardous and nonhazardous wastes. This bill implements the national objective of pollution prevention by establishing a source reduction program at the EPA and by assisting States in providing information and technical assistance regarding source reduction. In support of the emphasis on pollution prevention, the "Waste Reduction Innovative Technology Evaluation (WRITE) Program" has been designed to identify, evaluate, and/or demonstrate new ideas and technologies that lead to waste reduction. The WRITE Program emphasizes source reduction and on-site recycling. These methods reduce or eliminate transportation, handling, treatment, and disposal of hazardous materials in the environment. The technology evaluation project discussed in this report emphasizes the study and development of methods to reduce waste.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

This evaluation addresses the product quality, pollution prevention, and economic issues involved in the use of ion exchange to recover cadmium and chromium from electroplating rinsewaters. Test results showed that the water returned to the rinse after ion exchange was of acceptable quality. On the cadmium line, the ion exchange resin was regenerated with sodium hydroxide solution and the regenerant was subjected to electrolytic metal recovery to recover cadmium for reuse in the plating bath. On the chromium line, the ion exchange resin was regenerated with sodium hydroxide solution and the regenerant was passed through a cation exchange resin in an effort to recover chromic acid. However, due to excess sodium hydroxide in the regenerant, chromic acid could not be recovered with the amount of resin used. The pollution prevention potential of ion exchange on the cadmium and chromium rinsewater is good, especially if further testing establishes good recovery of chromic acid. Payback periods of 1 year on the cadmium ion exchange and 8 years on the chromium system are projected.

This report was submitted in partial fulfillment of Contract Number 68-CO-0003, Work Assignment 3-36, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from May 1, 1991 to January 31, 1994, and work was completed as of January 31, 1994.

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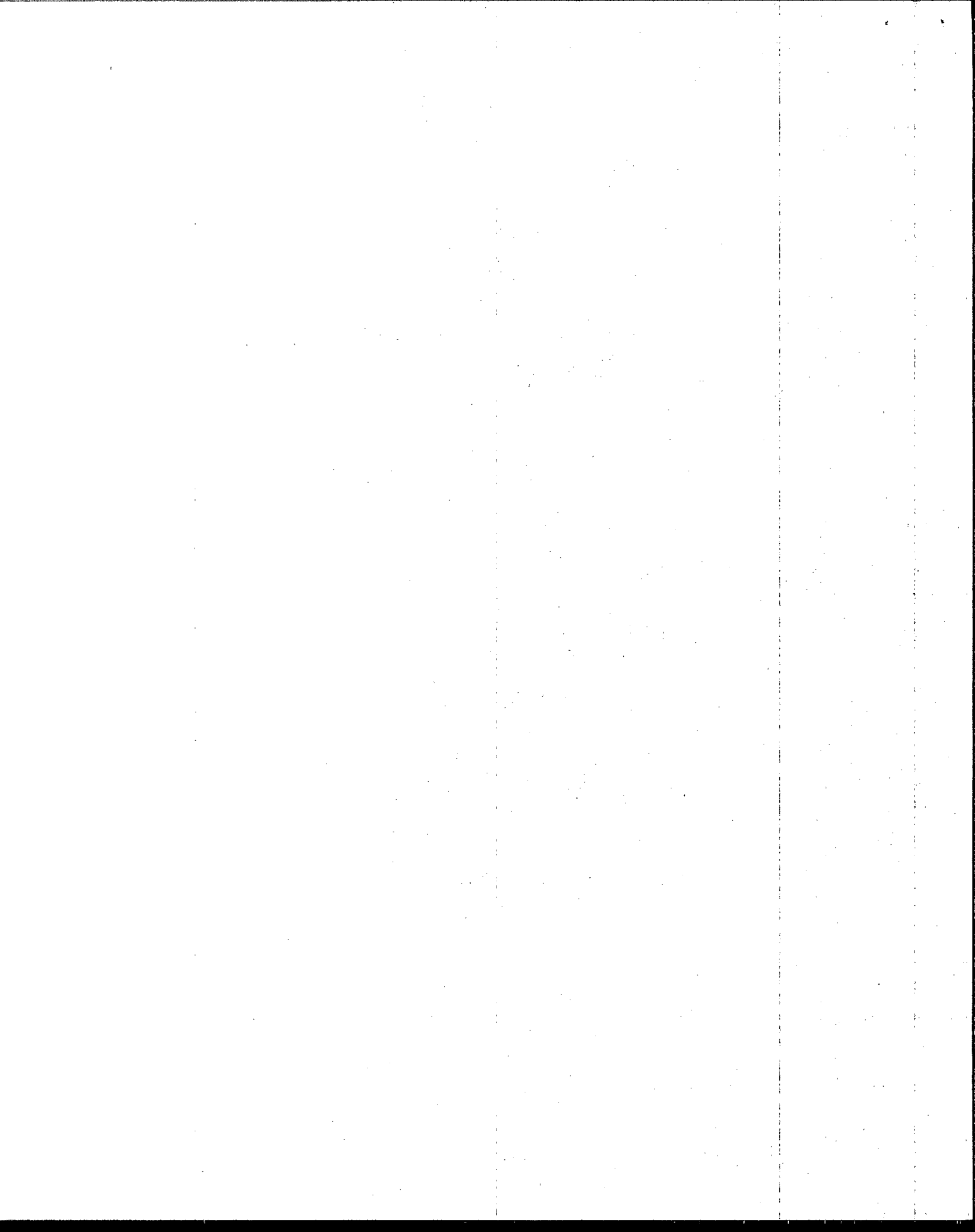
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SECTION 1

PROJECT DESCRIPTION

This study, performed under the U.S. Environmental Protection Agency's (EPA) Waste Reduction and Innovative Technology Evaluation (WRITE) Program, was a cooperative effort among EPA's Risk Reduction Engineering Laboratory (RREL), Connecticut Hazardous Waste Management Service (CHWMS), and Torrington Company. The objective of the WRITE Program is to evaluate, in a typical workplace environment, examples of prototype or innovative commercial technologies that have potential for reducing waste. In general, for each technology to be evaluated, three issues should be addressed.

First, it must be determined whether the technology is effective. Since waste reduction technologies usually involve recycling or reusing materials, or using substitute materials or techniques, it is important to verify that the quality of the recycled product is satisfactory for the intended purpose. Second, it must be demonstrated that using the technology has a measurable positive effect on reducing waste. Third, the economics of the new technology must be quantified and compared with the economics of the existing technology. It should be clear, however, that improved economics is not the only criterion for the use of the new technology. There may be justifications other than saving money that would encourage adoption of new operating approaches. Nonetheless, information about the economic implications of any such potential change is important.

This evaluation addresses the issues involved in using an ion exchange technology for recovering cadmium and chromium from electroplating rinsewater. The ion exchange system used in this study was manufactured by CTEO Tek, Inc.* and supplied by Plating Services, Inc.* Other ion exchange units and technologies (with varying capabilities) applicable to the same wastestream (electroplating rinsewaters) are also commercially available.

* Mention of trade names and products does not constitute endorsement for use.

PROJECT OBJECTIVES

The goal of this study was to evaluate a technology that could be used to recover cadmium and chromium from electroplating rinsewaters. This study had the following critical objectives:

- Evaluate the rinsewater quality to demonstrate the effectiveness of the ion exchange unit
- Evaluate the pollution prevention potential of this technology
- Evaluate the cost of ion exchange versus the cost of former practice (disposal).

DESCRIPTION OF THE SITE

The site for testing this new technology was The Torrington Company's Standard Plant located in Torrington, Connecticut. The Torrington Company is one of the world's leading broad-line bearing manufacturers. Production volume exceeds hundreds of thousands of assemblies per day. Many parts are highly precision crafted. The cadmium line processes 250,000 lbs of parts per year. The chromium line processes 350,000 lbs of parts per year. The Standard Plant has been cited in the past by the Connecticut Department of Environmental Protection (CDEP) for violating its municipal wastewater discharge permit. One reason for the violation was the presence of plating chemicals in the wastewater and sludge.

In order to alleviate the non-compliance problem and delist the sludge, Torrington first did an in-house assessment of the cadmium plating line and its corresponding discharge quantities. Next, various methods for recovering metals and cyanide from plating rinse water were investigated. A reverse osmosis unit was tested in-house on a trial basis, but the system performance was found to be unsatisfactory and the unit was removed. Since then, a combination of ion exchange and electrolytic metal recovery (EMR) are being evaluated on the cadmium line. The full-scale ion exchange unit was installed in May 1992 and is operating satisfactorily. A pilot ion exchange unit is being tested on the chromium line in preparation for full-scale installation. Although ion exchange is an established method for metal ions removal in the metal finishing industry, Torrington used a cautious approach to develop operating parameters specific to its plant.

DESCRIPTION OF THE TECHNOLOGY

Figure 1 shows the cadmium ion exchange system configuration. Counter flow rinsing and discharge of rinsewaters to waste treatment was the original practice. Eventually, a closed loop system which recirculates the rinsewater continuously through the ion exchange was established. Currently, rinse water from Rinse 1 tank is continuously drawn into the ion exchange column. The water is first passed through a filter to prevent suspended solids from contacting the resin. The anionic resin captures a cadmium-cyanide complex. The ion exchange column contains 2 cu ft (94 lbs) of anionic resin, the capacity of which is 2.5 lbs of cadmium per cu ft of resin. The water is then returned to Rinse 2 tank. An emergency bypass valve allows this water to be discharged to waste in the event that cadmium or cyanide levels are found to be too high. Some fresh make-up water is added daily to the tanks to compensate for water dragout on the workpiece.

The resin is periodically regenerated with a 15 to 20% NaOH solution. The resulting regenerant is taken to the EMR unit, where cadmium is recovered on the cathode and returned to the plating tank. Some cyanide is destroyed by decomposition in the EMR process. Both cadmium and cyanide are on EPA's 33/50 list of target chemicals.

Figure 2 shows the chromium system configuration. The primary ion exchange resin is anionic to remove hexavalent chrome. The full-scale unit is estimated to contain 3 cu ft (14 lbs) of anionic resin, with a capacity of 3 lbs of hexavalent chromium per cu.ft. of resin. In the future, a cationic resin component will be added to the primary resin to remove any trivalent chrome that may be present in the rinsewater. The anionic resin is periodically regenerated with a 15 to 20% NaOH solution and the resulting solution (sodium chromate) is run through a secondary (cationic) exchange unit, which should convert the regenerant back to chromic acid and return it to the plating tank. In the secondary resin, sodium ions in sodium chromate are substituted with hydrogen ions. Chromium is on EPA's 33/50 list of target chemicals.

SUMMARY OF APPROACH

Quality Assurance Project Plans (QAPPs) prepared at the beginning of this study (Battelle 1992a & b) describe the detailed approach and scientific rationale used to evaluate the ion exchange system. The evaluation covered product quality, pollution prevention, and economics of the process.



Figure 1. Ion exchange recovery of cadmium from plating rinsewater.

Product Quality Evaluation

The objective of this part of the evaluation was to show that the water that is processed through the ion exchange system is clean enough for use as rinsewater in the cadmium or chromium plating lines. Contaminant-free rinsewater ensures a good workpiece finish. The approach was to collect three samples each of the rinsewater before and after passing through the ion exchange system. These samples were analyzed in the laboratory to evaluate the removal of contaminants. Batches of rinsewater (one batch for cadmium and one for chromium) were also spiked with plating bath solution to elevate contaminant levels (cadmium or chromium). The spiked rinsewater was then run through the ion exchange in order to test the limits of the unit. Because rinsewater was continuously circulated through the ion exchange system throughout the day, three samples of the rinsewater — one each at the beginning, middle, and end of a shift — were taken to ensure that water quality remained relatively steady over time.

Pollution Prevention Evaluation

The pollution prevention potential of the technology was evaluated by estimating the amount of cadmium or chromium removed per year from the rinsewater that would otherwise have gone to waste. This was calculated based on (a) the cadmium and cyanide (or chromium) concentrations in time-averaged samples of the rinsewater collected during testing and (b) the annual water usage in the rinse tanks before ion exchange was installed.

The ability to recover the cadmium and chromium in forms that can be reused in the plating bath was also evaluated. The metals on the ion exchange resin were recovered during the regeneration of the resin. In the case of cadmium, the regenerant was passed through the resin and treated using electrolytic metal recovery (EMR) to recover the cadmium. Samples of the regenerant were collected immediately before and after the EMR operation in order to see how much cadmium was being recovered by EMR. During the on-site testing visit, the resin had not yet reached the point of exhaustion, and had not been regenerated. Torrington conducted the regeneration and EMR operations and collected the samples at a later date.

In the case of chromium, the regenerant was run through the secondary (cation) exchange resin to recover chromic acid, and pH of the regenerant was monitored.

Economic Evaluation

The economic evaluation took into account the capital and operating costs of the ion exchange technology. The cost of operating the ion exchange units was compared with the costs of wastewater treatment and disposal prior to installation of the new technology.

SECTION 2

PRODUCT QUALITY EVALUATION

The objective of the product quality evaluation was to show that ion exchange removes the contaminants present in rinsewater so that the water can be returned to the rinsing tanks and reused.

ON-SITE TESTING

Table 1 describes the on-site testing conducted on the cadmium line at Torrington. As each of three barrels of parts (workpiece) was dipped into Rinse 1 tank, a sample of rinsewater was collected from Rinse 1 tank to represent "before" conditions (samples CD-X1-B1 to CD-X1-B3). For the 1 min that the barrel is dipped in the tank, the concentration of contaminants washed off the parts is expected to reach maximum levels. Therefore, a continuous 1-min composite sample was drawn from Rinse 1 tank after a 5-sec delay for mixing following the immersion of each barrel. The rinse tank dimensions are not much larger than the dimensions of the barrel; thus, distribution of contaminants throughout the tank is quick.

Corresponding to each "before" sample, a 1-min continuous "after" sample (samples CD-X1-A1 to CD-X1-A3) was collected from a sampling port installed immediately after the ion exchange resin. The "after" sample was collected from this port instead of from Rinse 2 tank to get an estimate of the best water quality achievable by the ion exchange. The start of the "after" sample collection was delayed by 7 sec (from the start of the "before" sample) to allow the rinsewater drawn from Rinse 1 tank to circulate through the ion exchange to the sample port. This delay was previously determined based on the time it took water from the tank to start flowing out of the sample port after the ion exchange pump was first switched on.

In order to test the performance of the ion exchange system at higher-than-normal levels, a 5-gal batch of rinsewater from Rinse 1 was spiked with approximately 100 mL of liquid from the plating bath (representing higher dragout of contaminants). One spot sample each of the spiked rinsewater was collected both before (CD-XS-B1) and after (CD-XS-A1) passing it through the ion exchange.

TABLE 1. CADMIUM RINSEWATER TEST SAMPLES

Water Sample No.	Sample Description	Sample Location	Sample Type
CD-X1-B1	Before ion-x, Run 1	Rinse 1 Tank	1 min, continuous
CD-X1-B2	Before ion-x, Run 2	Rinse 1 Tank	1 min, continuous
CD-X1-B3	Before ion-x, Run 3	Rinse 1 Tank	1 min, continuous
CD-X1-A1	After ion-x, Run 1	Ion-x outlet	1 min, continuous
CD-X1-A2	After ion-x, Run 2	Ion-x outlet	1 min, continuous
CD-X1-A3	After ion-x, Run 3	Ion-x outlet	1 min, continuous
CD-XS-B1	Spike, before ion-x	Collection tank	spot
CD-XS-A1	Spike, after ion-x	Ion-x outlet	spot
CD-R1-B1	9:00am	Rinse 1 Tank	spot
CD-R1-B2	12:30pm	Rinse 1 Tank	spot
CD-R1-B3	4:00pm	Rinse 1 Tank	spot
CD-R2-B1	9:00am	Rinse 2 Tank	spot
CD-R2-B2	12:30pm	Rinse 2 Tank	spot
CD-R2-B3	4:00pm	Rinse 2 Tank	spot
CD-X30-B1	Before ion-x	Rinse 1 Tank	30 min continuous
CD-FB-1	Field blank	Tap water	spot

Three spot samples each were collected from Rinse 1 (CD-R1-B1 to CD-R1-B3) and Rinse 2 (CD-R2-B1 to CD-R2-B3) to represent the beginning, middle, and end of the first shift. The objective was to see how water quality in the rinse tanks varies throughout the day as the water is circulated continuously through the ion exchange unit.

In addition, a 30-minute continuous "before" composite sample was also collected from Rinse 1 tank to estimate the average loading on the ion exchange system. This additional sample was collected because the 1-min continuous composites described earlier were designed to capture maximum concentrations when the barrel is in the rinse, not average concentrations over a prolonged period of operation that includes the time periods in between successive barrels. Barrels are brought for rinsing intermittently. During the 30 min of this sample, 3 barrels were processed through the rinses (1 min in each tank for each barrel). A field blank consisting of a sample of the fresh city tap water used to supply the rinse tanks was collected to ensure that there were no contributions of contaminants from extraneous sources, as well as to provide a basis of comparison for evaluating cadmium and chromium removal from the rinsewater.

Table 2 describes similar testing conducted on the chromium system. This includes "before" and "after" 1-min samples, a spike sample, a 30-min continuous "before" composite (CR-X2-B1), and a field blank. Three spot samples (at the beginning, middle, and end of the shift)

TABLE 2. CHROMIUM RINSEWATER TEST SAMPLES

Water Sample No.	Sample Description	Sample Location	Sample Type
CR-X1-B1	Before ion-x	Rinse 1 Tank	1 min, continuous
CR-X1-B2	Before ion-x	Rinse 1 Tank	1 min, continuous
CR-X1-B3	Before ion-x	Rinse 1 Tank	1 min, continuous
CR-X1-A1	After ion-x	Ion-x outlet	1 min, continuous
CR-X1-A2	After ion-x	Ion-x outlet	1 min, continuous
CR-X1-A3	After ion-x	Ion-x outlet	1 min, continuous
CR-XS-B1	Spike, before ion-x	Collection tank	spot
CR-XS-A2	Spike, after ion-x	Ion-x outlet	spot
CR-X2-B1	Before ion-x	Rinse 1 Tank	30 min, continuous
CR-CX-A2	Regenerant	Collection tank	spot
CR-FB-1 ^(a)	Field blank	Tap water	spot

(a) Same source of water as on the cadmium line. Only one blank collected for both cadmium and chromium lines.

from each of the two rinse tanks were planned, just as in the cadmium rinsewater testing; but none were collected. This was because only a pilot system had been installed at Torrington at the time of testing. This system did not have enough resin to operate for the full shift. Therefore, the evolving water quality of the rinse tanks as the day progressed could not be monitored.

Samples collected for the cadmium and chromium systems were sent to an independent laboratory (Zande Environmental Services, Inc. in Columbus, Ohio) for analysis. The results of the laboratory analyses are described below.

ANALYTICAL TESTING RESULTS

Table 3 describes the results of the laboratory analysis of the cadmium rinsewater samples. Before ion exchange, the rinsewater showed maximum levels of 7.28 mg/L cadmium and 35.60 mg/L of cyanide (CD-X1-B1), but levels tended to vary with each run. Most of the cadmium and cyanide were removed after ion exchange — in some cases, below detection levels. The average loading on the ion exchange over a 30-min period was found to be 4.31 mg/L of cadmium and 17.6 mg/L of cyanide (CD-X30-B1). The pH of the rinsewater remained steady at alkaline levels throughout the testing. The field blank (tap water) showed very low levels of measured contaminants, indicating that there was no extraneous contribution to the results.

TABLE 3. CADMIUM RINSEWATER ANALYSIS

Sample No.	Sample Description	pH	Conductivity (umhos/cm)	Cadmium mg/L	Cyanide mg/L	Iron mg/L	Dissolved solids mg/L	Suspended solids mg/L
CD-X1-B1	Before ion-x, Run 1	11.26	783	7.28	35.60	0.57	226	1
CD-X1-B2	Before ion-x, Run 2	11.41	864	2.23	9.26	0.22	196	<1
CD-X1-B3	Before ion-x, Run 3	11.48	936	2.58	13.80	0.31	205	<1
CD-X1-A1	After ion-x, Run 1	11.45	867	0.015	0.037	0.06	147	<1
CD-X1-A2	After ion-x, Run 2	11.51	845	<0.01	0.047	0.06	161	2
CD-X1-A3	After ion-x, Run 3	11.51	885	0.01	0.041	0.02	163	<1
CD-XS-B1	Spike, before ion-x	NA ^(a)	NA	38.7	117	NA	NA	NA
CD-XS-A1	Spike, after ion-x	NA	NA	3.69	14.6	NA	NA	NA
CD-R1-B1	Rinse 1, 9:00 am	10.72	278	1.80	8.55	0.28	90	1
CD-R1-B2	Rinse 1, 12:30 pm	11.37	823	3.55	15.60	0.34	190	<1
CD-R1-B3	Rinse 1, 4:00 pm	11.40	985	4.71	24.70	0.41	225	10
CD-R2-B1	Rinse 2, 9:00 am	11.07	360	0.067	0.28	0.11	80	2
CD-R2-B2	Rinse 2, 12:30 pm	11.50	860	0.105	0.62	0.07	164	3
CD-R2-B3	Rinse 2, 4:00 pm	11.47	970	0.269	1.23	0.09	191	<1
CD-X30-B1	Rinse 1, 30-min	11.35	760	4.31	17.60	0.33	189	3
CD-FB-1	Field blank	7.50	65.3	<0.01	<0.01	0.21	50	1

(a) NA = Not analyzed.

When cadmium and cyanide levels in the rinsewater were artificially elevated to 38.7 and 117 mg/L, respectively (CD-XS-B1), the ion exchange reduced these to 3.69 and 14.6 mg/L, respectively (CD-XS-A1). This indicates that, at above-normal contaminant levels, the ion exchange system still removes most of the cadmium and cyanide, but is a little less effective. For these high initial levels, longer residence time in the resin or several passes through the resin would be required to regain the same degree of removal. However, such high levels are unlikely to be reached during normal operation.

The results of the spot samples taken at the beginning, middle, and end of a shift showed that contaminant levels rose steadily during the day. However, at the end of the shift, concentrations were still too low to be of any concern. This indicates that the continuous operation of the ion exchange system effectively controls the accumulation of contaminants to within acceptable levels.

Table 4 shows the averages calculated for the 1-min "before" and "after" samples (samples beginning with CD-X1-) collected during the three runs. A t-test was performed based on the averages and standard deviations of the data. Although, strictly speaking, a t-test may not be applicable because of the difference in variances between the "before" and "after" cases, it helps to highlight significant increases and decreases in the data. Differences between the "before" and "after" samples were examined at the 95% significance level. Suspended solids levels were very low in both "before" and "after" samples. Cadmium, cyanide, and iron in the rinsewater showed significant decreases in concentration after ion exchange. Overall dissolved solids levels also showed a significant decrease after ion exchange, indicating a decline in dissolved mass levels. Interestingly, conductivity did not show any significant change after ion exchange, indicating that the current-carrying capacity of the rinsewater did not change. During ion exchange, heavier ions (cadmium, iron, etc.) transfer to the resin and lighter sodium ions are transferred to the water. Thus, dissolved mass in the water decreases, whereas conductivity remains relatively constant. Small amounts of fresh make-up water are added to the rinsewater from time to time to compensate for water loss due to evaporation and dragout with the parts; this also helps control conductivity.

Table 5 describes the results of the laboratory analysis of the chromium rinsewater samples. Before ion exchange, the chromic acid contamination in the rinsewater lowered the pH to between 4.41 and 4.83. After ion exchange, the rinsewater pH was slightly alkaline (9.31 to 9.45) because chromate ions (and any other contaminant anions) had been substituted with hydroxide ions. The alkaline pH in the rinse tanks was neutralized by the chromic acid residue on the parts (workpiece). When chromium levels in the rinsewater were artificially elevated to 33.6 ppm (CR-XS-B1), the ion exchange reduced it to an acceptable level.

TABLE 4. STATISTICAL SIGNIFICANCE FOR CADMIUM EVALUATION

Item	Statistic	Cd mg/L	CN mg/L	Fe mg/L	pH S.U.	Cond. μmhos/cm	TSS mg/L	TDS mg/L
Before ion-x	Avg.	4.03	19.55	0.37	11.38	861	1.00	209.00
	Std. dev.	2.82	14.08	0.18	0.11	77	0.00	15.39
After ion-x	Avg.	0.006	0.042	0.047	11.49	866	1.33	157.00
	Std. dev.	0.008	0.005	0.023	0.03	20	0.58	8.72
Test statistic	t-value	2.47	2.40	3.03	-1.57	-0.10	-1.00	5.09
Effect of ion-x ^(a)	—	significant decrease	significant decrease	significant decrease	no significant change	no significant change	no significant change	significant decrease

(a) Based on level of significance of 0.05, t-values are compared to a t-critical of 2.132.

TABLE 5. CHROMIUM RINSEWATER ANALYSIS

Sample No.	Sample Description	pH	Conductivity μmhos/cm	Total chromium mg/L	Iron mg/L	Dissolved solids mg/L	Suspended solids mg/L
CR-X1-B1	Before ion-x, Run 1	4.83	103	20.0	0.90	93	9
CR-X1-B2	Before ion-x, Run 2	4.67	104	18.2	0.85	99	8
CR-X1-B3	Before ion-x, Run 3	4.41	106	21.3	0.87	106	6
CR-X1-A1	After ion-x, Run 1	9.38	198	0.048	0.15	96	<1
CR-X1-A2	After ion-x, Run 2	9.31	126	0.111	0.20	70	<1
CR-X1-A3	After ion-x, Run 3	9.45	115	0.271	0.26	71	<1
CR-XS-B1	Spike, before ion-x	NA ^(a)	NA	33.6	NA	NA	NA
CR-XS-A2	Spike, after ion-x	NA	NA	0.294	NA	NA	NA
CR-X2-B1	Rinse 1, 30-min	4.68	105	19.9	0.73	87	2
CR-FB-1	Field blank	7.50	65.3	0.04	0.21	50	1

(a) NA = Not analyzed.

Table 6 shows the averages calculated for the 1-min "before" and "after" samples (samples beginning with CR-X1-) collected during the three runs. A t-test was performed based on the averages and standard deviations of the data. Differences between the "before" and "after" samples were examined at the 95% significance level. Suspended solids levels in the "before" samples were relatively high, but were significantly reduced by the cartridge filter installed before the resin tank. Iron and total chromium levels decreased significantly after ion exchange. Iron removal may be due either to removal of ferrous suspended particles on the cartridge filter or to deposition of complexed iron on the resin. As in the cadmium tests, dissolved solids mass decreased significantly, whereas conductivity (current-carrying capacity) remained relatively constant after ion exchange. This is due to the heavier chromates in the rinsewater being replaced with lighter hydroxide ions.

PRODUCT QUALITY ASSESSMENT

On the cadmium line, the full scale ion exchange system effectively reduced contaminants in the ion exchange discharge to levels comparable to those in the fresh tap water blank. Dissolved solids and conductivity in the recycled rinsewater were slightly higher than in the field (tap water) blank, but typical of those found in the rinse tanks during continuous production. A conductivity sensor monitored the conductivity in Rinse 2 tank. Fresh water could have been introduced if conductivity became too high. Fresh water was also added periodically to make up for dragout losses. The flow rate of 5 gal/min through the ion exchange unit (containing 94 lbs of resin with a total capacity of 5 lbs of cadmium) appears sufficient to maintain contaminants at acceptable levels throughout the day under normal processing. A conductivity sensor in Rinse 2 tank monitored ion build-up in the rinsewater. The small volume of fresh make-up water was added periodically primarily to compensate for dragout losses, not to lower conductivity.

In the three months following this testing, Torrington has not noticed any decline in the quality of the parts processed through the cadmium rinse. For this testing, the rinsewater on the chromium line was processed through a pilot unit (< 1 gal/min). Contaminant levels were reduced significantly by ion exchange, to levels slightly above those found in the tap water blank. Torrington plans to further reduce total chromium concentrations in the rinsewater by adding a cation resin to remove any trivalent chrome in the rinsewater.

TABLE 6. STATISTICAL SIGNIFICANCE FOR CHROMIUM EVALUATION

Item	Statistic	Cr mg/L	Fe mg/L	pH S.U.	Cond. umhos/cm	TSS mg/L	TDS mg/L
Before	Avg.	19.83	0.87	4.64	104	7.67	99.33
	Std. dev.	1.56	0.03	0.21	2	1.53	6.51
After	Avg.	0.143	0.203	9.38	146	1.00	79.00
	Std. dev.	0.115	0.055	0.07	45	0.00	14.73
Test statistic	t-value	21.85	19.16	-36.80	-1.61	7.56	2.19
Effect of ion- χ^2 ^(a)	— ^(a)	significant decrease	significant decrease	significant increase	no significant change	significant decrease	significant decrease

(a) Based on level of significance of 0.05, t-values are compared to a t-critical of 2.132.

SECTION 3

POLLUTION PREVENTION POTENTIAL

The pollution prevention potential of the ion exchange technology was evaluated in terms of waste volume reduction and pollutant reduction. Waste volume reduction addressed the gross wastestream (e.g., lbs of wastewater treatment sludge) and environmental resources expended during disposal (e.g., landfill space). Pollutant reduction addressed the specific pollutants in the wastestream (e.g., chromium in the sludge).

WASTE VOLUME REDUCTION

Table 7, which is based on Torrington's plant records, shows the fresh water flow rates through the rinses before installing the ion exchange system (counter flow rinse only) and after installing the ion exchange system. On the cadmium line, without ion exchange, Torrington was maintaining 3 gal/min flow through Rinse 2, which overflowed into Rinse 1. An additional 5 gal/min of fresh water was also run through Rinse 1. On the chromium line, without a full-scale ion exchange system, Torrington ran a counter flow of 1 gal/min through Rinse 2, which overflowed into Rinse 1. Rinse 1 also had an independent supply of 1 gal/min. These continuous flows generated large amounts of wastewater that had to be treated on-site. With the ion exchange system on the cadmium line, Torrington required only 50 gal/day (for 2 shifts, or 16 hr of operation) to make up for dragout losses. A similar make-up amount is expected on the chromium line.

The wastewater generated each year by the rinsing operation is shown in Table 8. These annual numbers are based on the flow rates in Table 7 and an annual operating time of 16 hr/day (2 shifts), 5 days/week, and 50 weeks/yr. These numbers are typical of the influent volumes to Torrington's on-site treatment plant. By using ion exchange, wastewater as a wastestream requiring treatment is virtually eliminated.

The ion exchange operation generated small volumes of other wastestreams, namely, spent filters and the regenerant. On the cadmium line, Torrington changed the filter cartridge once in two months. On the chromium line, the cartridge change is expected to occur more frequently, possibly once a month.

TABLE 7. FRESH RINSEWATER FLOW RATES

Rinsewater	Flow Rate ^(a)	
	Without Ion Exchange ^(b)	With Ion Exchange ^(c)
<u>Cadmium System</u>		
Rinse 1	5 gal/min	0
Rinse 2	3 gal/min	50 gal/day
<u>Chromium System</u>		
Rinse 1	1 gal/min	0
Rinse 2	1 gal/min	50 gal/day

- (a) With or without ion exchange, water from Rinse 2 overflows into Rinse 1.
 (b) Continuous flow 16 hr per day as per Torrington's normal operating schedule.
 (c) Intermittent flow; make-up water daily average measured by Torrington.

On the cadmium line, the resin is scheduled to be regenerated about once a month when the line is operating at full capacity. Each regeneration consists of 8 gal of 50% NaOH in 12 gal of water, plus an additional 35 gal of water for rinsing the column (55 gal/regeneration, or 660 gal of regenerant/yr). The regenerant will be subjected to electrolytic metal recovery (EMR) to recover cadmium, and the rest will be sent to the on-site wastewater treatment plant.

TABLE 8. WASTE VOLUME REDUCTION

<u>Without Ion Exchange</u>		<u>With Ion Exchange</u>	
Waste Description	Amount Generated per year ^(a)	Waste Description	Amount Generated per year ^(b)
<u>Cadmium System</u>			
Wastewater	1,920,000 gal	Wastewater	0 gal
		Regenerant	660 gal
		Filter cartridges	6
<u>Chromium System</u>			
Wastewater	480,000 gal	Wastewater	0 gal
		Regenerant	840 gal
		Filter cartridges	12

(a) Based on Table 7 values at 16 hr/day, 5 days/week, 50 weeks/yr.

(b) Based on pilot tests conducted by Torrington and resin capacity.

The full-scale chromium ion exchange unit is expected to generate 70 gal of regenerant (20 gal of 50% NaOH in 50 gal of water) once a month, for a total of 840 gal of regenerant. The regenerant will be passed through a cation exchange resin to convert sodium chromate to chromic acid.

POLLUTANT REDUCTION

The pollutants of interest on the cadmium line are cadmium and cyanide. Without ion exchange, the cadmium in the rinsewater is lost to wastewater. This wastewater is sent to the on-site wastewater treatment plant. In a steel cyanide treatment tank, the wastewater is treated using chlorine gas, sodium hypochlorite, calcium hypochlorite, and sodium hydroxide to oxidize the cyanide. The wastewater then flows by gravity to another tank for neutralization. The cadmium and other metals form hydroxides that settle in the clarifier as sludge. This sludge is hauled off site for disposal. The treated water is discharged to the municipal sewer under a permit.

The average cadmium and cyanide concentrations in the wastewater when the cadmium line is operating at full capacity are 4.31 and 17.60 mg/L, respectively (see Table 3, sample CD-X30-B1). Without ion exchange, the annual generation of wastewater at full capacity is 1,920,000 gal (Table 8). Therefore, approximately 69 lbs of cadmium and 281 lbs of cyanide are lost annually. With ion exchange, most of the cadmium and cyanide are captured on the resin, which is regenerated with NaOH. The regenerant is then subjected to EMR. At the time of the on-site visit, the resin on the full-scale system was not yet exhausted (and had not been regenerated) due to reduced operation on the cadmium line at Torrington during that period. However, Torrington later regenerated the resin and demonstrated good recovery of cadmium by EMR on the cathode (see Appendix A). During the EMR operation, some of the cyanide also decomposed. The cathode (with the plated cadmium) in the EMR operation was then transferred to the cadmium plating tank, where it functions as a cadmium anode. The rest of the regenerant was then sent to the wastewater treatment plant.

On the chromium line, without ion exchange, the rinse wastewater is sent to a fiberglass tank, where it is mixed with sodium metabisulfite and sulfuric acid to reduce the hexavalent chrome to trivalent chrome. The wastewater is then sent to another tank for neutralization. Here the trivalent chrome forms a hydroxide that settles in the clarifier as sludge. The sludge is hauled offsite for disposal and the treated water is discharged to the municipal sewer under a permit.

The average chromium concentration in the rinse wastewater when the chromium line is operating at full capacity is 19.9 mg/L (Table 5, sample CR-X2-B1). Without ion exchange,

480,000 gal of wastewater is generated per year at full capacity (Table 8). Therefore, approximately 80 lbs of chromium is lost annually. With ion exchange, most of the chromium is captured on the resin, which is regenerated with NaOH. The regenerant is then passed through a cation exchange resin to convert sodium chromate to chromic acid. When this recovery was performed during the pilot unit testing, the final regenerant liquid still showed a pH of 13.08. Other parameters measured in the final regenerant were total chromium (14.6 mg/L), iron (0.28 mg/L), dissolved solids (14,111 mg/L), conductivity (68,800 μ mhos/cm), suspended solids (2 mg/L), and sodium (7,010 mg/L). This indicates that sodium chromate had not been converted to chromic acid, in which case the pH would have been much lower. This may be due to the fact that (a) an excess of NaOH was used to regenerate the resin and/or (b) there was insufficient resin to exchange all the sodium in the regenerant. Further testing is required to determine the feasibility of the chromic acid recovery process.

POLLUTION PREVENTION POTENTIAL ASSESSMENT

By using ion exchange, large volumes of water are prevented from going to waste. This water (an important resource) can be reused as a rinse on the cadmium and chromium lines. Virtually eliminating the wastewater stream also eliminates the hazardous sludge (containing cadmium or chromium) that must be handled, transported, and disposed. Cadmium and chromium are hazardous chemicals on EPA's Toxics Release Inventory. Both metals are also on the list of 17 priority pollutants targeted in the EPA Administrator's 33/50 Program for 50% reduction in releases by 1995.

With ion exchange, small volumes of regenerant and a few spent filter cartridges are generated that eventually have to be treated or disposed. The quantities of regenerant and filters are, however, much smaller than the volumes of wastewater and sludge generated when ion exchange is not used.

On the cadmium line, most of the cadmium that deposits on the resin can be recovered and reused in the plating bath. Some of the cyanide on the resin is destroyed during cadmium recovery (EMR) and the rest is destroyed in the on-site treatment plant. Therefore, cyanide is not a recoverable resource.

On the chromium line, further testing is necessary to determine the feasibility of recovering chromic acid for reuse in the plating bath.

SECTION 4

ECONOMIC EVALUATION

The economic evaluation involves a comparison of the costs of the ion exchange operation versus the former practice (counterflow rinse).

MAJOR OPERATING COSTS

Both cadmium and chromium lines are assumed to operate at full capacity for 16 hr/day, 5 days/week, and 50 weeks per year. Based on Torrington's plant records, Table 9 summarizes the major annual operating costs for the cadmium rinsewater line with and without ion exchange. Without ion exchange, the operating costs involved are for fresh water usage and wastewater treatment. Fresh water (city supply) at Torrington costs \$0.70 per 1000 gal. The annual usage of water is 1,920,000 gal (Table 8). Most of this water ends up as wastewater. Wastewater treatment costs for the cadmium line were based on an average cost of \$22 per 1000 gal of wastewater, which includes cost of treatment chemicals, sludge disposal, municipal sewer discharge fee, and treatment plant labor (see Appendix B).

With ion exchange, the operating costs in Table 9 were based on the following:

- Fresh water requirement of 50 gal/day (make up) at \$0.70/1000 gal.
- Energy costs were based on continuous operation of the ion exchange 0.5 hp circulation pump over a year and an EMR consumption of 6 kW hr for each regeneration (12 regenerations per year); electricity costs \$0.075/kW-hr at Torrington.
- Labor cost was based on 0.5 hr of operator involvement per day during normal operation, plus 4 hr operator time during each regeneration (12 regenerations per year). The average labor rate for the system operators is \$7/hr.
- Routine maintenance costs were based on replacement of the filter cartridge (\$5 each, six times per year), replacement of EMR anode plates (\$30 each, one per year) and EMR cathode plates (\$30 each, 12 per year), and maintenance labor of 24 hr/yr at \$7/hr).

TABLE 9. OPERATING COSTS COMPARISON FOR CADMIUM SYSTEM

Item	Amount used per year	Unit cost	Total Annual Cost
<u>Without Ion Exchange</u>			
Freshwater	1,920,000 gal	\$ 0.70/1000 gal	\$ 1,344
Wastewater treatment	1,920,000 gal	\$ 22/1000 gal	\$42,240
		Total	\$43,584
<u>With Ion Exchange</u>			
Freshwater	12,500 gal	\$0.70/1000 gal	\$9
Chemicals (50% NaOH)	96 gal	\$1.50/gal	\$144
Energy	1564 kW hr	\$0.075/kW hr	\$117
Labor	173 hr	\$7/hr	\$1,211
Routine maintenance			
- filter cartridges	6	\$5	\$30
- EMR anode plates	1	\$30	\$30
- EMR cathode plates	12	\$30	\$360
- labor	24 hr	\$7/hr	\$168
Waste Disposal			
- regenerant	660 gal	\$22/1000 gal	\$15
- filters	6	\$400/36 units	\$67
		Total	\$2,151

- Waste disposal costs due to ion exchange were based on regenerant disposal (660 gal/yr by on-site wastewater treatment at \$22/1000 gal) and disposal of spent filter cartridges (6 per year, off-site disposal at \$400 per 36 filters).

As Table 9 depicts, operating costs for ion exchange recovery are much lower than those for counter flow rinse alone. The main cost saving is the reduction in wastewater treatment costs. In addition to operating cost savings, the recovered cadmium has value because it is reused in the plating bath as a cadmium anode. The cost of cadmium anodes is approximately \$15/lb. For the 69 lbs/yr of cadmium that is deposited on the ion exchange resin, the resulting value recovered is approximately \$1,036/yr.

Based on Torrington's plant records, Table 10 summarizes the major operating costs for the chromium rinsewater line with and without ion exchange. Without ion exchange, the operating costs involved are for fresh water usage and wastewater treatment. Fresh water (city supply) at Torrington costs \$0.70 per 1000 gal. The annual water usage is 720,000 gal (Table 8). Most of this water ends up as wastewater. Wastewater treatment costs for the cadmium line were based

TABLE 10. OPERATING COSTS COMPARISON FOR CHROMIUM SYSTEM

Item	Amount used per year	Unit cost	Total Annual Cost
<u>Without Ion Exchange</u>			
Freshwater	480,000 gal	\$ 0.70/1000 gal	\$ 336
Wastewater treatment	480,000 gal	\$ 15/1000 gal	<u>\$7,200</u>
		Total	\$7,536
<u>With Ion Exchange</u>			
Freshwater	12,500 gal	\$0.70/1000 gal	\$9
Chemicals (50% NaOH)	240 gal	\$1.50/gal	\$360
Energy	1492 kW hr	0.075/kW hr	\$112
Labor	149 hr	\$7/hr	\$1,043
Routine maintenance			
- filters	12	\$5	\$60
- labor	24	\$7/hr	\$168
Waste Disposal			
- regenerant	840 gal	\$15/1000 gal	\$13
- filters	6	\$400/36 units	<u>\$67</u>
		Total	\$1,832

on an average cost of \$15 per 1000 gal of wastewater, which includes cost of treatment chemicals, sludge disposal, municipal sewer discharge fee, and treatment plant labor (see Appendix B).

With ion exchange, the operating costs in Table 9 were based on the following:

- Fresh water requirement of 50 gal/day (make up) at \$0.70/1000 gal.
- Energy costs were based on continuous operation of the ion exchange 0.5 hp circulation pump over a year; electricity costs \$0.075/kW hr at Torrington.
- Labor cost was based on 0.5 hr of operator involvement per day during normal operation, plus 2 hr operator time during each regeneration (12 regenerations per year). The average labor rate for the system operators is \$7/hr.
- Routine maintenance costs were based on replacement of the filter cartridge (\$5 each, six times per year) and maintenance labor of 24 hr/yr at \$7/hr).
- Waste disposal costs due to ion exchange were based on regenerant disposal (840 gal/yr by on-site wastewater treatment at \$15/1000 gal) and disposal of spent filter cartridges (6 per year, off-site disposal at \$400 per 36 filters).

As shown in Table 10, operating costs for ion exchange recovery are much lower than those for counter current rinse alone. The main cost saving is the reduction in wastewater treatment costs. In addition to operating cost savings, the chromium deposited on the ion exchange resin has value if it can be successfully recovered as chromic acid. The cost of chromic acid is approximately \$2.50/lb. Approximately 80 lbs/yr of chromium metal is deposited on the ion exchange resin. This corresponds to about 154 lbs of chromic acid (CrO_3). However, further testing is required to establish the feasibility of chromic acid recovery from the chromium in the regenerant.

CAPITAL COSTS

According to Torrington's plant records, the purchase price of the cadmium ion exchange system was \$8,100 (including ion exchange resin column, pumps, and collection tanks). The EMR equipment price was \$4,125 (including rectifier, pump, anodes, cathodes, and solution tank). Installation cost at Torrington, including materials (piping, etc.) and labor, was approximately \$3,500. To approximate the cost of in-house pilot testing used to determine specifications for the individual plant, \$5,000 was added to this figure.

The purchase price of the chromium ion exchange system (based on vendor information) is estimated to be \$8,200 (including ion exchange resin column, pumps, and tanks). Installation cost at Torrington is expected to be \$3,500, including materials (piping, etc.) and labor. The approximate cost of \$5,000 for in-house testing is also added for this unit.

RETURN ON INVESTMENT

A rough estimate of the payback period can be obtained by the following formula:

$$\text{Payback, yrs} = \frac{\text{capital cost}}{\text{operating cost savings} + \text{recovery value}}$$

For the cadmium ion exchange system, total capital costs are \$20,725 (purchase price, pilot testing, and installation), savings in annual operating costs are \$41,433 (difference in total operating costs between "with" and "without" ion exchange as per Table 9), and the recycled cadmium value is \$1,036. This gives a payback period of less than a year.

For the chromium system, the estimated total capital costs are \$16,700 (purchase price, pilot testing and installation) and savings in operating costs are \$5,704 (see Table 10). Because chromic acid recovery from the regenerant is yet to be established, no recycled chromium value is assumed. This results in a payback period of approximately 3 years.

The difference in payback periods between the ion exchange systems on the cadmium and chromium lines is primarily because, under former practice (without ion exchange), the water flow rate through the cadmium rinse tanks was much higher than in the chromium tanks. In addition, the unit cost of wastewater treatment for the cadmium rinsewater was also higher than that for chromium rinsewater. Because the operating costs for both cadmium and chromium ion exchange systems are similar, there is a greater annual operating cost savings for the cadmium line.

The above payback period estimation is a simple calculation that does not take into account such factors as cost of capital, inflation, etc. A more complete economic analysis is presented in Appendix C (cadmium line) and Appendix D (chromium line). The worksheets provided in the *Facility Pollution Prevention Guide* (U.S. EPA, 1992) were used for the calculations. Based on a detailed economic analysis, the cadmium ion exchange system still shows a payback period of less than 1 year. On the chromium line, a positive return on investment (ROI) occurs in year five (break-even point on the original capital investment). If a cost of capital of 15% is to be recovered, however, the payback period is 8 yrs ($ROI > 15\%$).

SECTION 5

QUALITY ASSURANCE

Quality Assurance Project Plans (QAPP) were prepared and approved by EPA before testing began (Battelle, 1992a and b). This QAPP contains a detailed design for conducting this study. The experimental design, field testing procedures, and laboratory analytical procedures are covered. The QA objectives outlined in this QAPP are discussed below.

ON-SITE TESTING

On-site testing for the cadmium ion exchange system was conducted as planned, except for the EMR test. Because the full scale system was installed a few days before on-site testing and because the workload on Torrington's cadmium line was somewhat reduced, the resin had not reached exhaustion and could not be regenerated during the on-site visit. However, Torrington subsequently performed the regeneration of the resin and EMR to demonstrate the recovery of cadmium in a reusable form. The resulting data are presented in Appendix A.

On-site testing for the chromium system was affected by the fact that a full-scale system was not installed in time for testing. A pilot system that had enough capacity to run for an hour was tested instead. Samples from the two rinse tanks that were planned to be collected in the morning, afternoon, and evening to monitor rinsewater quality over the entire day could not be collected. In the pilot unit, the regenerant could not be isolated between the primary ion (anion) exchange column and the auxiliary cation exchange column. Hence, a regenerant sample before cation exchange could not be obtained. Only the final regenerant sample after cation exchange was obtained. Figures 1 and 2 in Section 1 have been slightly modified (from those in the QAPP) to eliminate the collection tank from the loop. In both cases, the regenerant goes directly to the next step.

All other samples were collected as planned. The 2-hr continuous composite was changed to a 30-min composite because of the reduced scale of operation, and because the racks were being processed continuously rather than every 2 hr.

LABORATORY ANALYSIS

Appendix E lists the standard methods used for analyzing each parameter. Analysis was performed as planned on the cadmium and chromium samples collected. Holding time for pH, which had been set at 2 days, was exceeded by a day; however, this is not expected to have any significant effect on the results because the samples were on ice and pH of rinsewater is fairly stable.

The precision and accuracy of the analyses are listed in Tables 11 and 12, respectively. The regular sample and duplicate values listed in this table are based on pre-made dilutions of the original samples prepared by the analytical laboratory. Table 11 also gives the detection limits for each parameter. All laboratory blanks had very low or undetected values. Precision of the total dissolved solids analysis for the chromium system was slightly out of range (>25%). However, there was a wide enough difference (statistically) between the dissolved solids results for the "before" and "after" samples for this to be of any consequence. Sodium in the field blank (CR-FB-1) was measured at 2.63 mg/L. Sodium analysis was intended to be indicative of conversion of sodium chromate to chromic acid. However, because a regenerant sample could not be isolated before cation exchange, only the final regenerant was analyzed. The resulting sodium

TABLE 11. PRECISION DATA FOR RINSEWATER CHARACTERIZATION

Parameter	Sample No.	Regular Sample ^(a)	Duplicate ^(a)	Precision (% RPD)	Detection Limit	Laboratory Blanks ^(a)
<u>Cadmium Study</u>						
Cadmium	CD-R1-B2	941	982	4.3	10 ug/L	<10
Cyanide	CD-R1-B3	247	256	3.6	10 ug/L	<10
Iron	CD-R1-B3	410	408	-0.5	50 ug/L	<50
pH	CR-X1-B3	11.48	11.48	0.0	0.01 S.U.	5.35
Conductivity	CR-X1-B3	936	940	0.4	1.00 µmhos/cm	2.45
TDS	CR-X1-B3	205	202	-1.5	1 mg/L	<1
TSS	CR-X1-B3	<1	<1	0.0	0.1 mg/L	4
<u>Chromium Study</u>						
Chromium	CR-X1-B2	728	733	0.7	20 µg/L	<20
Sodium	CR-CX-A1	28.04	32.76	15.5	0.5 mg/L	<0.5
Iron	CR-X1-B2	855	852	-0.4	50 µg/L	<50
pH	CR-X1-B2	4.67	4.70	0.6	0.01 S.U.	5.35
Conductivity	CR-X1-B2	104	104	0.0	1.00 µmhos/cm	2.45
TDS	CR-X1-B2	99	98	-1.0	1 mg/L	<1
TSS	CR-X1-B2	8	6	-28.6	0.1 mg/L	4

(a) Units of measurement for each parameter are given in the "Detection Limit" column.

TABLE 12. ACCURACY DATA FOR RINSEWATER CHARACTERIZATION

Parameter	Sample No.	Regular Sample (ug/L)	Matrix Spike Level (ug/L)	Matrix Spike Measured (ug/L)	Accuracy % Recovery
<u>Cadmium Study</u>					
Cadmium	CD-R1-B2	941	1,000	1,953	101
Cyanide	CD-R1-B3	109.8	300	422.3	104
Iron	CD-R1-B3	410	1,000	1,317	91
<u>Chromium Study</u>					
Chromium	CR-X1-B2	728	1,000	1,693	97
Sodium	CX-CX-A1	28,040	5,000	32,760	94
Iron	CR-X1-B2	855	1,000	1,972	112

concentration is discussed in Section 3 under the heading "Pollutant Reduction." Based on the above discussion, completeness percentages are listed in Appendix F.

LIMITATIONS AND QUALIFICATIONS

Based on the above QA data, the results of the on-site and laboratory testing on the cadmium line can be considered a valid basis for drawing conclusions about product quality, pollution prevention potential, and economics. Economic and waste reduction information was obtained from Torrington's plant records over the past year.

On the chromium line, water quality in the rinse tanks could not be monitored over a period of one day of operation because of the small resin size. However, the contaminant removal in the chromium rinsewater samples actually collected follows the same pattern as in the cadmium samples. Given the chromium removal in the "after" samples exiting the ion exchange, it is expected that an appropriately sized ion exchange system would maintain good water quality in the rinse tanks. The unresolved issue in the pollution prevention evaluation on the chromium system is the feasibility of recovering chromic acid that can be returned to the plating bath. The on-site tests were unable to recover the chromium as chromic acid. More tests need to be performed to prevent chromium loss through the regenerant. Economically however, there is sufficient data to show that, even without the final recovery of chromium as chromic acid, the system results in cost savings for the user.

SECTION 6

CONCLUSIONS AND DISCUSSION

The evaluation showed that rinsewater on both the cadmium and chromium lines at Torrington Company can be reused after subjecting the water to filtration and ion exchange to remove impurities. Large volumes of water are thus prevented from going to waste. Disposal of large amounts of hazardous metals sludge in the environment is also prevented. The sidestreams from ion exchange are negligible compared to the wastewater and sludge wastestreams generated in the absence of ion exchange. The ion exchange resin can be regenerated with sodium hydroxide. On the cadmium line, the regenerant can be subjected to EMR and the cadmium recovered on the cathode. This electrode, with the deposited cadmium, is then inserted in the plating tank as a cadmium anode. In this way, a hazardous pollutant, cadmium, is reused. On the chromium line, further testing is necessary to establish the feasibility of recovering chromium as chromic acid for reuse in the bath.

Without ion exchange, the rinsewater is subjected to an expensive wastewater treatment process. The cost of operating the ion exchange unit is more than offset by the savings in wastewater treatment costs and by the value of the recovered product. On the cadmium line, this cost saving and recovery value result in a payback period of less than a year for the ion exchange system. On the chromium line, even without considering any recovered metal value, the wastewater treatment cost saving alone offsets the operating costs of the ion exchange, affording a payback period of eight years. The large difference in payback periods on the cadmium and chromium lines is due to rinsewater consumption (without ion exchange) of the cadmium line being much greater than that of the chromium line. With ion exchange, the resulting savings are greater for the cadmium line.

In addition to the direct economic benefits, the ion exchange system also reduces the potential liability of Torrington Company as a potentially responsible party (PRP) by virtually eliminating the risk involved during off-site transport and disposal of hazardous sludge. Torrington is also testing other means of pollution prevention (not part of this evaluation) on the cadmium and chromium electroplating lines. To remove carbonates from the plating tank and increase bath life, a chiller has been installed on the cadmium line. The EMR unit evaluated in this study is also being tested for removing cadmium from the dragout tank water. A scrubber is being installed on the

chromium line to capture chromium mists over the plating tank. The scrubber liquid is then passed through a separate ion exchange column to recover the chromium.

SECTION 7

REFERENCES

Battelle. *Quality Assurance Project Plan (QAPP) for Cadmium Recovery from Electroplating Rinsewater by Ion Exchange*. Columbus, Ohio, 1992a.

Battelle. *Quality Assurance Project Plan (QAPP) for Chromium Recovery from Electroplating Rinsewater by Ion Exchange*. Columbus, Ohio, 1992b.

U.S. Environmental Protection Agency (EPA). *Facility Pollution Prevention Guide*. EPA/600/R-92/088, May 1992.

APPENDIX A

EMR TEST RESULTS

Regenerant used was 8 gal of 50% NaOH in 12 gal of water. After regeneration, the column was rinsed with 35 gal of water, to give a total regenerant volume of 55 gal. This 55 gal was analyzed to contain 2.5 ppm cadmium and 400 ppm cyanide. Fifteen gal of water from the dragout (still rinse) tank was added to the regenerant. This dragout water contained 2000 ppm of cyanide and 250 ppm of cadmium, and was added to the regenerant before performing the EMR operation. The dragout water represents an additional wastestream that Torrington is trying to minimize.

The EMR used 4 volts, 40 amps in a 36-hr operation. The final regenerant solution (after EMR) contained only 13 ppm of cadmium, indicating that most of the cadmium had been recovered on the cathode. Some cyanide decomposed during the EMR operation, to a level of 1100 ppm. The exact mechanism of cyanide destruction by EMR is not known.

APPENDIX B

WASTEWATER TREATMENT COSTS

The wastewater treatment costs for the waste rinsewater on the cadmium line are based on the following plant information over the past year:

- Annual wastewater influent from the cadmium rinse is 1,920,000 gal/yr based on continuous production of 16hr/day, 5 days/week, and 50 weeks/yr
- Chemical usage based on
 - 172,000 lbs/yr of 25% NaOH at \$0.09/lb
 - 3,660 gal/yr of 50% NaOH at \$1.50/gal
 - 11 tons/yr of chlorine gas at \$550/ton cylinder
 - 5000 gal/yr of sodium hypochlorite at \$0.58/gal
 - 1500 lbs/yr of calcium hypochlorite at \$1.11/lb
- Labor cost of 2 hr/day of operating time at \$7/hr.
- Municipal sewer discharge fee of \$1.47/1000 gal of treated water
- Sludge disposal cost based on 21,000 lbs/yr of cadmium sludge hauled away at \$0.20/lb.

This gives an average cost of cadmium wastewater treatment of \$22/1000 gal.

Wastewater treatment costs for waste rinsewater on the chromium line were based on the following plant information over the last one year:

- Annual wastewater influent of 2,205,000 gal/yr. This influent consists not only of rinsewater from the chromium plating line, but also of rinsewater from the chromating line. However, all calculations are finally converted to a unit cost (\$/1,000 gal), which then applies to the 480,000 gal/yr from the chromium plating rinsewater line.
- Chemical costs are based on:
 - 7,200 gal/yr of 30% sulfuric acid at \$0.78/gal
 - 21,000 lbs/yr of sodium metabisulfite at \$0.25/lb
 - 1,000 gal/yr of 50% sodium hydroxide at \$1.50/gal
- Labor costs based on 2 hr/day of operating time at \$7/hr

- Municipal sewer discharge fee of \$1.47/1,000 gal of treated water
- 84,000 lbs/yr of chromium sludge hauled away at \$0.20/lb.

Therefore, the average wastewater treatment cost on the chromium rinsewater line is approximately \$15/1,000 gal.

APPENDIX C

ECONOMIC ANALYSIS OF CADMIUM RINSEWATER ION EXCHANGE

A more detailed economic analysis than the one presented in Section 4 of this report is described here. Worksheets provided in the *Facility Pollution Prevention Guide* (U.S. EPA 1992) were used for the calculations. In addition to the cadmium rinsewater data listed in Section 4, the following values were used:

- Capital Cost (Table C-1)
 - Total equipment cost of \$12,225 (including ion exchange and EMR) plus 10% tax
 - Total installation costs of \$3,500 in Section 4 were broken down into \$1,500 for materials and \$2,000 for installation (labor)
 - Plant engineering and contractor engineering costs were \$3,000 and \$2,000 based on the pilot ion exchange unit leasing and testing that was conducted prior to full-scale installation
 - Contingency costs of 5% of fixed capital (i.e., sum of all the above)
 - Working capital based on 1 month's cost of water, energy, and filters cost from Section 4
 - 100% equity (i.e., no loan taken)
 - Depreciation period of 10 yrs
 - Income tax rate of 34%
 - Escalation (inflation) rate of 5%
 - Cost of capital of 15%
- Table C-2 describes increased revenue, increased operating costs, reduced waste disposal costs of ion exchange (entered as positive numbers). Decreased revenue, decreased operating costs, and increased waste disposal costs due to ion exchange entered as negative values denoted by parentheses around the number).
 - Cadmium recovery value of \$1,036/yr
 - Increase in utilities costs based on electricity and water consumption from Section 4
 - Reduction in disposal costs based on wastewater (including sludge), regenerant, and filters treatment/disposal costs
 - Increase in operating labor based on Section 4 data
 - Increase in operating supplies based on NaOH required for regeneration
 - Increase in maintenance costs based on labor and materials as in Section 4
 - Supervision costs are 10 % of O&M labor
 - Overhead costs are a percentage of O&M labor and supervision

Table C-3 shows the revenues (recovered value) and operating savings resulting from use of ion exchange for the first three years. Table C-4 shows the return on investment (ROI). In the first year, the ROI exceeds 15%, which is the cost of capital (see Table C-1). Therefore, the payback period is less than 1 year.

TABLE C-1. CAPITAL COSTS FOR CADMIUM ION EXCHANGE

INPUT CAPITAL COST		OUTPUT CAPITAL REQUIREMENT	
		Construction Year	1
Capital Cost		Capital Expenditures	
Equipment	\$13,448	Equipment	\$13,448
Materials	\$1,500	Materials	\$1,500
Installation	\$2,000	Installation	\$2,000
Plant Engineering	\$3,000	Plant Engineering	\$3,000
Contractor/Engineering	\$2,000	Contractor/Engineering	\$2,000
Permitting Costs	\$0	Permitting Costs	\$0
Contingency	\$1,000	Contingency	\$1,000
Working Capital	\$45	Start-up Costs	\$2,000
Start-up Costs	\$2,000	Depreciable Capital	\$24,948
		Working Capital	\$45
% Equity	100%	Subtotal	\$24,993
% Debt	0%	Interest on Debt	\$0
Interest Rate on Debt, %	10.00%	Total Capital Requirement	\$24,993
Debt Repayment, years	0		
		Equity Investment	\$24,993
Depreciation period	10	Debt Principal	\$0
Income Tax Rate, %	34.00%	Interest on Debt	\$0
		Total Financing	\$24,993
Escalation Rates, %	5.0%		
Cost of Capital	15.00%		

TABLE C-2. OPERATING COSTS FOR CADMIUM ION EXCHANGE

Operating Cost/Revenue			
Marketable By-products		Operating Labor	
Cadmium	\$1,036	Operator hrs	173
Total \$/yr.	\$1,036	Wage rate, \$/hr.	\$7.00
		Total \$/yr.	\$1,211
Utilities			
Electric	\$117	Operating Supplies	
Water	(\$1,335)	Chemicals	\$144
Total \$/yr.	(\$1,218)		
		Maintenance Costs	
Raw Materials		Labor	\$168
Chemicals	\$0	Materials	\$420
Water	\$0		
Total	\$0		
		Supervision	
Decreased Waste Disposal		(% of O&M Labor)	10.0%
Water treatment	\$42,240		
Ion-X regenerant	(\$15)	Overhead Costs	
Ion-X filters	(\$67)	(% of O&M Labor + Supervision)	
Transportation, \$	\$0	Plant Overhead	25.0%
Storage Drums \$	\$0	Home Office	20.0%
Total Disposal \$	\$42,158	Labor Burden	28.0%

TABLE C-3. OPERATING SAVINGS USING CADMIUM ION EXCHANGE

REVENUE AND COST FACTORS-CADMIUM STUDY				
Operating Year Number		1	2	3
Escalation Factor	1.000	1.050	1.103	1.158
INCREASED REVENUES				
Increased Production		\$0	\$0	\$0
Marketable By-products		\$1,088	\$1,142	\$1,199
Annual Revenue		\$1,088	\$1,142	\$1,199
OPERATING SAVINGS (Numbers in parentheses indicate net expense)				
Raw Materials		\$0	\$0	\$0
Disposal Costs		\$44,266	\$46,479	\$48,803
Maintenance Labor		(\$176)	(\$185)	(\$194)
Maintenance Supplies		(\$441)	(\$463)	(\$486)
Operating Labor		(\$1,272)	(\$1,335)	(\$1,402)
Operating Supplies		(\$151)	(\$159)	(\$167)
Utilities		\$1,279	\$1,343	\$1,410
Supervision		(\$145)	(\$152)	(\$160)
Labor Burden		(\$446)	(\$468)	(\$492)
Plant Overhead		(\$398)	(\$418)	(\$439)
Home Office Overhead		(\$319)	(\$334)	(\$351)
Total Operating Savings		\$42,197	\$44,307	\$46,522

TABLE C-4. RETURN ON INVESTMENT FOR THE CADMIUM ION EXCHANGE SYSTEM

RETURN ON INVESTMENT—CADMIUM STUDY				
Construction Year	1			
Operating Year		1	2	3
Book Value	\$24,948	\$19,958	\$15,967	\$12,773
Depreciation (by straight-line)		\$2,495	\$2,495	\$2,495
Depreciation (by double DB)		\$4,990	\$3,992	\$3,193
Depreciation		\$4,990	\$3,992	\$3,193
Cash Flows				
Construction Year	1			
Operating Year		1	2	3
Revenues		\$1,088	\$1,142	\$1,199
+ Operating Savings		\$42,197	\$44,307	\$46,522
Net Revenues		\$43,285	\$45,449	\$47,722
– Depreciation		\$4,990	\$3,992	\$3,193
Taxable Income		\$38,295	\$41,458	\$44,528
– Income Tax		\$13,020	\$14,096	\$15,140
Profit after Tax		\$25,275	\$27,362	\$29,389
+ Depreciation		\$4,990	\$3,992	\$3,193
After-Tax Cash Flow		\$30,265	\$31,354	\$32,582
Cash Flow for ROI	(\$24,993)	\$30,265	\$31,354	\$32,582
Net Present Value	(\$24,993)	\$1,324	\$25,032	\$46,455
Return on Investment		21.09%	87.87%	110.25%

APPENDIX D

ECONOMIC ANALYSIS OF CHROMIUM RINSEWATER ION EXCHANGE

A more detailed economic analysis than the one presented in Section 4 of this report is described here. Worksheets provided in the *Facility Pollution Prevention Guide* (U.S. EPA 1992) were used for the calculations. In addition to the chromium rinsewater data listed in Section 4, the following values were used:

- Capital Cost (Table D-1)
 - Total equipment cost of \$8,200 plus 10% tax
 - Total installation costs of \$3,500 in Section 4 were broken down into \$1,500 for materials and \$2,000 for installation (labor)
 - Plant engineering and contractor engineering costs were \$3,000 and \$2,000 based on the pilot ion exchange unit leasing and testing that was conducted prior to full-scale installation
 - Contingency costs of 5% of fixed capital (i.e., sum of all the above)
 - Working capital based on 1 month's cost of water, energy, and filters cost from Section 4
 - 100% equity (i.e., no loan taken)
 - Depreciation period of 10 yrs
 - Income tax rate of 34%
 - Escalation (inflation) rate of 5%
 - Cost of capital of 15%
- Table D-2 describes increased revenue, increased operating costs, reduced waste disposal costs of ion exchange (entered as positive numbers). Decreased revenue, decreased operating costs, and increased waste disposal costs due to ion exchange entered as negative values denoted by parentheses around the number).
 - Cadmium recovery value of \$1,036/yr
 - Increase in utilities costs based on electricity and water consumption from Section 4
 - Reduction in disposal costs based on wastewater (including sludge), regenerant, and filters treatment/disposal costs
 - Increase in operating labor based on Section 4 data
 - Increase in operating supplies based on NaOH required for regeneration
 - Increase in maintenance costs based on labor and materials as in Section 4
 - Supervision costs are 10% of O&M labor
 - Overhead costs are a percentage of O&M labor and supervision

Table D-3 shows the revenues (recovered value) and operating savings resulting from use of ion exchange for the first three years. Table D-4 shows the return on investment (ROI). In the eighth year, the ROI exceeds 15%, which is the cost of capital (see Table D-1). Therefore, the payback period is approximately 8 years.

TABLE D-1. CAPITAL COSTS FOR CHROMIUM ION EXCHANGE

INPUT CAPITAL COST		OUTPUT CAPITAL REQUIREMENT	
		Construction Year	1
Capital Cost			
Equipment	\$9,000	Capital Expenditures	
Materials	\$1,500	Equipment	\$9,000
Installation	\$2,000	Materials	\$1,500
Plant Engineering	\$3,000	Installation	\$2,000
Contractor/Engineering	\$2,000	Plant Engineering	\$3,000
Permitting Costs	\$0	Contractor/Engineering	\$2,000
Contingency	\$875	Permitting Costs	\$0
Working Capital	\$15	Contingency	\$875
Start-up Costs	\$1,750	Start-up Costs	\$1,750
		Depreciable Capital	\$20,125
% Equity	100%	Working Capital	\$15
% Debt	0%	Subtotal	\$20,140
Interest Rate on Debt, %	10.00%	Interest on Debt	\$0
Debt Repayment, years	0	Total Capital Requirement	\$20,140
Depreciation period	10	Equity Investment	\$20,140
Income Tax Rate, %	34.00%	Debt Principal	\$0
		Interest on Debt	\$0
Escalation Rates, %	5.0%	Total Financing	\$20,140
Cost of Capital	15.00%		

TABLE D-2. OPERATING COSTS FOR CHROMIUM ION EXCHANGE

Operating Cost/Revenue			
Marketable By-products		Operating Labor	
Chromium	\$0	Operator hrs	149
Total \$/yr.	\$0	Wage rate, \$/hr.	\$7.00
		Total \$/yr.	\$1,043
Utilities			
Electric	\$112	Operating Supplies	
Water	(\$327)	Chemicals	\$360
Total \$/yr.	(\$215)		
		Maintenance Costs	
Raw Materials		Labor	\$168
Chemicals	\$0	Materials	\$60
Water	\$0		
Total	\$0		
		Supervision	
Decreased Waste Disposal		(% of O&M Labor)	10.0%
Water treatment	\$7,200		
Ion-X regenerant	(\$13)	Overhead Costs	
Ion-X filters	(\$67)	(% of O&M Labor + Supervision)	
Transportation, \$	\$0	Plant Overhead	25.0%
Storage Drums \$	\$0	Home Office	20.0%
Total Disposal \$	\$7,120	Labor Burden	28.0%

TABLE D-3. OPERATING SAVINGS USING CHROMIUM ION EXCHANGE

REVENUE AND COST FACTORS - CHROMIUM STUDY								
Operating Year Number	1	2	3	4	5	6	7	8
Escalation Factor	1.000	1.050	1.103	1.158	1.216	1.276	1.340	1.407
INCREASED REVENUES								
Increased Production	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Marketable By-products	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Annual Revenue	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
OPERATING SAVINGS (Numbers in parentheses indicate net expense)								
Raw Materials	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Disposal Costs	\$7,476	\$7,850	\$8,242	\$8,654	\$9,087	\$9,541	\$10,019	\$10,519
Maintenance Labor	(\$176)	(\$185)	(\$194)	(\$204)	(\$214)	(\$225)	(\$236)	(\$248)
Maintenance Supplies	(\$63)	(\$66)	(\$69)	(\$73)	(\$77)	(\$80)	(\$84)	(\$89)
Operating Labor	(\$1,095)	(\$1,150)	(\$1,207)	(\$1,268)	(\$1,331)	(\$1,398)	(\$1,468)	(\$1,541)
Operating Supplies	(\$378)	(\$397)	(\$417)	(\$438)	(\$459)	(\$482)	(\$507)	(\$532)
Utilities	\$226	\$237	\$249	\$261	\$274	\$288	\$303	\$318
Supervision	(\$127)	(\$134)	(\$140)	(\$147)	(\$155)	(\$162)	(\$170)	(\$179)
Labor Burden	(\$392)	(\$411)	(\$432)	(\$453)	(\$476)	(\$500)	(\$525)	(\$551)
Plant Overhead	(\$350)	(\$367)	(\$386)	(\$405)	(\$425)	(\$446)	(\$469)	(\$492)
Home Office Overhead	(\$280)	(\$294)	(\$308)	(\$324)	(\$340)	(\$357)	(\$375)	(\$394)
Total Operating Savings	\$4,841	\$5,083	\$5,337	\$5,604	\$5,884	\$6,178	\$6,487	\$6,812

TABLE D-4. RETURN ON INVESTMENT FOR CHROMIUM ION EXCHANGE

RETURN ON INVESTMENT - CHROMIUM STUDY									
Construction Year	1	1	2	3	4	5	6	7	8
Operating Year									
Book Value	\$20,125	\$16,100	\$12,880	\$10,304	\$8,243	\$6,231	\$4,218	\$2,206	\$193
Depreciation (by straight-line)		\$2,013	\$2,013	\$2,013	\$2,013	\$2,013	\$2,013	\$2,013	\$2,013
Depreciation (by double DB)		\$4,025	\$3,220	\$2,576	\$2,061	\$1,649	\$1,246	\$844	\$441
Depreciation		\$4,025	\$3,220	\$2,576	\$2,061	\$2,013	\$2,013	\$2,013	\$2,013
Cash Flows									
Construction Year	1								
Operating Year		1	2	3	4	5	6	7	8
Revenues		\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
+ Operating Savings		\$4,841	\$5,083	\$5,337	\$5,604	\$5,884	\$6,178	\$6,487	\$6,812
Net Revenues		\$4,841	\$5,083	\$5,337	\$5,604	\$5,884	\$6,178	\$6,487	\$6,812
- Depreciation		\$4,025	\$3,220	\$2,576	\$2,061	\$2,013	\$2,013	\$2,013	\$2,013
Taxable Income		\$816	\$1,863	\$2,761	\$3,543	\$3,872	\$4,166	\$4,475	\$4,799
- Income Tax		\$277	\$633	\$939	\$1,205	\$1,316	\$1,416	\$1,521	\$1,632
Profit after Tax		\$539	\$1,230	\$1,822	\$2,339	\$2,555	\$2,750	\$2,953	\$3,168
+ Depreciation		\$4,025	\$3,220	\$2,576	\$2,061	\$2,013	\$2,013	\$2,013	\$2,013
After - Tax Cash Flow		\$4,564	\$4,450	\$4,398	\$4,399	\$4,568	\$4,762	\$4,966	\$5,180
Cash Flow for ROI	(\$20,140)	\$4,564	\$4,450	\$4,398	\$4,399	\$4,568	\$4,762	\$4,966	\$5,180
Net Present Value	(\$20,140)	(\$16,172)	(\$12,807)	(\$9,915)	(\$7,400)	(\$5,129)	(\$3,070)	(\$1,203)	\$490
Return on Investment		-77.34%	-40.32%	-17.96%	-4.77%	3.62%	9.19%	13.01%	15.72%

APPENDIX E

STANDARD ANALYTICAL METHODS FOR RINSEWATER ANALYSIS

<u>Analyte</u>	<u>Standard</u>
Cadmium	EPA 3010, EPA 6010
Chromium	EPA 3010, EPA 6010
Iron	EPA 3010, EPA 6010
Cyanide	EPA 335.3
pH	EPA 150.1
Total dissolved solids	EPA 160.1
Total suspended solids	EPA 160.2
Sodium	EPA 3010, EPA 6010
Conductivity	EPA 120.1

APPENDIX F

COMPLETENESS

Sampling completeness is the percentage of samples actually collected out of those proposed in the QAPP. Analytical completeness is the percentage of valid results obtained from the collected samples. Tables F-1 and F-2 list the sampling and analytical completeness for the samples on the cadmium and chromium lines respectively. Wherever completeness was less than 100%, the impact is discussed in Section 5 of this report.

TABLE F-1. COMPLETENESS FOR CADMIUM ION EXCHANGE SAMPLES

Sample Category	Sampling Completeness (%) / Analytical Completeness (%)						
	Conductivity	TSS	TDS	Cadmium	Cyanide	pH	Iron
"Before" and "after" ion-x samples	100/100	100/100	100/100	100/100	100/100	100/0 ^(a)	100/100
Baseline (beginning, middle, and end of day)	100/100	100/100	100/100	100/100	100/100	100/0 ^(a)	100/100
Spikes "before" and "after" ion-x	NR ^(b)	NR	NR	100/100	100/100	NR	NR
Regenerant "before" and "after" EMR	NR	NR	NR	100/100	100/100	NR	NR
Field blank	100/100	100/100	100/100	100/100	100/100	100/0 ^(a)	100/100

(a) Holding time for pH exceeded by a day.

(b) NR = not required.

TABLE F-2. COMPLETENESS FOR CHROMIUM ION EXCHANGE SAMPLES

Sample Category	Sampling Completeness (%) / Analytical Completeness (%)						
	Chromium	pH	Conductivity	TSS	TDS ^(a)	Iron	Sodium
"Before" and "after" ion-x samples	100/100	100/100	100/100	100/100	100/0	100/100	NR
Baseline (beginning, middle, and end of day) ^(b)	0/0	0/0	0/0	0/0	0/0	0/0	NR
Spikes "before" and "after" ion-x	100/100	NR	NR	NR	NR	NR	NR
Regenerant ^(c) "before" and "after" EMR	50/100	50/100	NR	NR	50/0	50/100	50/100
Field blank	100/100	100/100	100/100	100/100	100/0	100/100	100/100

(a) Precision for TDS was slightly out of range.

(b) No baseline samples were collected because the capacity of the resin was too small.

(c) Regenerant "before" cation-x could not be isolated for collection.