

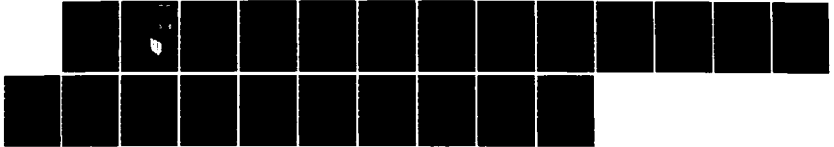
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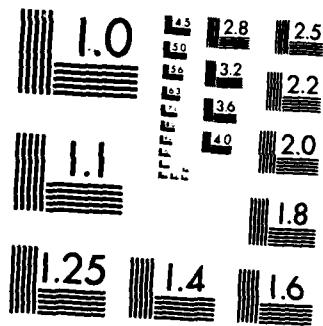
FIELD TEST OF LIFE-CYCLE COST ANALYSIS METHOD FOR
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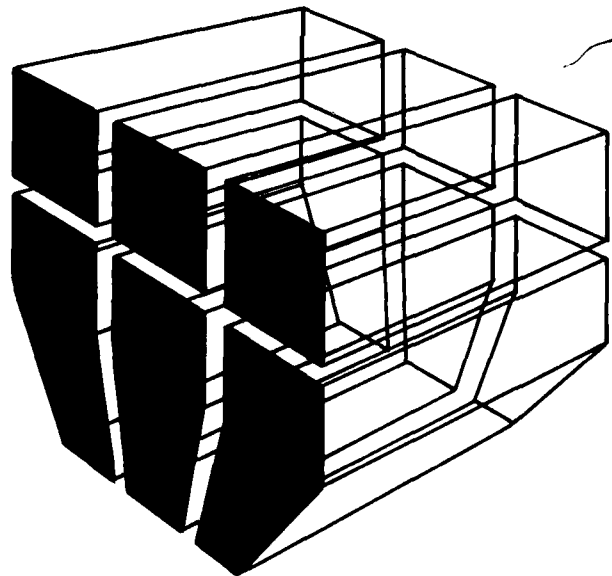
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September 1986
(Hazardous/Toxic Waste Control Technology)

Field Test of Life-Cycle Cost Analysis Method for Solvent Management

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by
B. A. Donahue
D. W. Sarver
E. M. Bellino

This report documents the field test of the U.S. Army Construction Engineering Research Laboratory's (USA-CERL) procedure for calculating the life-cycle cost (LCC) of solvent recycling. The test was conducted at the Rock Island Arsenal, which currently recycles its solvents off-post. The USA-CERL LCC analysis method was used to compare the off-post method with solvent recycling by distillation on-post. The LCC format was found to be useful in comparing the two methods and showed that the on-post method would provide the arsenal with significant savings over a 10-year project life.



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FOREWORD

This research was conducted for the Office of the Assistant Chief of Engineers (OACE) under Project 4A162720A896, "Environmental Quality Technology"; Task A, "Installation Environmental Management"; Work Unit 032, "Hazardous/Toxic Waste Control Technology." The work was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (USA-CERL). The OACE Technical Monitor was Ms. Marcia Read (DAEN-ZCE).

Dr. R. K. Jain is Chief of USA-CERL-EN. COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.



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FIELD TEST OF A LIFE-CYCLE COST ANALYSIS METHOD FOR SOLVENT MANAGEMENT

1 INTRODUCTION

Background

Recent national legislation and regulatory actions, such as the Resource Conservation and Recovery Act (RCRA), have emphasized that hazardous materials use and disposal is a nationwide problem. The Army uses large quantities of hazardous materials in many installation activities, and recognizing its responsibility to protect the environment, has published Army Regulation (AR) 200-1, which specifically addresses hazardous and toxic materials management.¹ Other military guidance pertaining to solvents is the *DOD Consolidated Guidance—Hazardous Material/Hazardous Waste/Disposal*² and AR 420-47.³ The Department of Defense (DOD) has also determined in its *Used Solvent Eliminations (USE) policy*⁴ that by 1 October 1986, all used solvents must be recycled, if economically and technically possible.

Solvents comprise a broad category of toxic organic chemicals. Organic solvents (those made of carbon, hydrogen, and oxygen) dissolve other substances and form a uniformly dispersed solution. They are a concern because they are toxic and sometimes ignitable.

Organic solvents have a wide variety of commercial and industrial uses which fall into three major areas: *cleaners, diluents, and test fluids*. Cleaning solvents include degreasing compounds for automotive and equipment parts, spot removers for fabrics, dry-cleaning solvents, and corrosion-removing compounds. Diluents are used as liquifiers or dissolvers, and include the alcohols, ketones, and esters, as well as thinners for paints and lacquers. Test fluids include heptanes and freon; an example of their use is for instrument calibration.

Solvent use is common on all installations throughout the continental United States and overseas. The large quantities (millions of gallons) of solvents used in maintenance and equipment refurbishing operations and disposed of Army-wide are of particular concern. Reducing solvent hazards such as this requires consistent managerial and technical guidance for use at all Army installations. Such guidance would include outlining procedures for solvent use minimization, substitution of less toxic solvents whenever applicable, and waste solvent minimization, handling, storage, reuse/recycling, and disposal.

To this end, the U.S. Army Construction Engineering Research Laboratory (USACERL) has been investigating the use of hazardous and toxic materials on Army install-

¹Army Regulation (AR) 200-1, *Environmental Protection and Enhancement* (Department of the Army [DA], November 1980).

²*DOD Consolidated Guidance—Hazardous Material/Hazardous Waste Disposal* (Department of Defense [DOD], April 1981).

³AR 420-47, *Solid and Hazardous Waste Management* (DA, January 1985).

⁴Memorandum for Secretaries of the Military Departments, Director, Defense Logistics Agency, Subject: *Used Solvent Elimination (USE) Program*, dated 10 January 1984.

ations and better methods for their management and ultimate disposal.⁵ USA-CERL had previously developed a life-cycle cost analysis method for determining the optimal solvent management alternative for an installation.⁶ This method considers several factors that are installation-specific: the amount of solvent used by the installation, whether solvents are segregated, and vapor pressure and losses, which depend on the types of solvents used. Options considered in the USA-CERL procedure include both on-post and off-post recycle methods. To test this procedure, USA-CERL chose the Rock Island Arsenal as a military facility which was representative of installations that use of large quantities of solvents in their daily operations.

Objective

The objective of this study was to field-test the procedure developed at USA-CERL for calculating the life-cycle cost (LCC) of (1) solvent recycling by distillation on-post and (2) solvent disposal using the current, off-post recycle methods at Rock Island Arsenal (RIA).

Approach

A demonstration of recycling, by distillation, PD-680 and 1,1,1-trichloroethane (TCE) generated at RIA was conducted; the quality of the distillate and residue were evaluated for ultimate disposal. Data were gathered on solvent generation rates and costs of present disposal methods, and an LCC for the present method of solvent management was developed for comparison to the LCC for recycling by distillation.

Mode of Technology Transfer

It is recommended that the information in this report be used to update AR 200-1, *Environmental Quality, Environmental Protection and Enhancement*, and AR 420-47, *Facilities Engineering Solid and Hazardous Waste Management*.

⁵B. Donahue and M. Carmer, *Solvent Cradle-to-Grave Management Guidelines for Use at Army Installations*, Technical Report N-168/A137063 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1983).

⁶B. Donahue and M. Carmer, Appendix B.

2 SOLVENT DISTILLATION TECHNOLOGY

USA-CERL demonstrated used solvent recovery technology at RIA with a 15 gal batch distillation unit. Three batches (two TCE and one PD-680) of dirty solvent were processed.

After the distillation unit was installed, but prior to operation, RIA Fire, Safety, and Health officers checked and approved the unit. During the TCE recovery, the RIA personnel monitored the air with a vapor detector. They determined that no significant level of TCE was emitted into the area immediately surrounding the unit. Only trace amounts of TCE vapor were noted at the clamps that lock the chamber lid in place. When the still bottoms from the TCE batch were removed and the chamber swabbed clean after TCE recovery in preparation for recycling PD-680, low levels of vapors were detected. However, this level of exposure would not occur for each batch processed. During normal operations, overall exposure would be less because the still bottoms would be removed only after a significant amount from several batches had been collected; also, the chamber would rarely need to be swabbed clean, because one still would be devoted solely to recycling one type of solvent.

Table 1 lists the recovery results and batch run times. Residue quantities for batches one and two differ because the TCE feeds contained dissimilar amounts of contaminant. There appears to have been a notable loss of PD-680 solvent from batch three. During vacuum operation, losses can occur when there is significant air leakage into the distillation system and when there is insufficient heat exchange (i.e., the product vapor is not completely condensed). Under normal conditions, there will be some air leakage into the system at the pipe joints and at the lids. It is essential that this leakage be minimized because solvent vapors are carried by the air and are lost when the air is vented out the discharge line.

Table 2 gives the chemical test results for batches one and two and also provides the standards for the TCE chemical tests identified as being most important. Appendix A provides a comprehensive list of standards for evaluating virgin materials. Both batches satisfied volatility standards (initial boiling point and dry point) and acid acceptance standards. The batch one product was slightly colored; however, after laboratory-scale distillation, the color was removed. The color was probably the result of stoddard solvent residue remaining in the system from the previous recovery cycle.

The critical test for TCE is the acid acceptance test. This test measures, in terms of weight percent of sodium hydroxide, the inhibitor level in the solvent. Inhibitors are added to the solvent to restrict corrosion. Two types of inhibitors are added to TCE: acid acceptors and metal stabilizers. Acid acceptors neutralize the hydrochloric acid formed during solvent use and application. Metal stabilizers promote passivation by combining with metal chlorides to form insoluble plugs that cover electron-deficient sites on the metal or oxide surface. The only inhibitor type that may have to be added to recycled TCE is the acid acceptor. The metal stabilizers will be recycled with the TCE.

The inhibitor level can be monitored with a simple acid acceptance test kit such as the one produced by Dow Chemical Corporation. Dow has also defined guidelines for interpreting the results of the acid acceptance test (see Appendix B).

The PD-680 solvent recycled at RIA was not typical. An initial boiling point of 284°F was recorded for the PD-680 solvent feed material during a laboratory-scale distillation. Evidently, some unknown contaminant with a low boiling point had been introduced into the solvent, hence the volatility characteristics would not satisfy virgin

Table 1
Solvent Yields and Operating Conditions

Batch	Batch Feed Material	Distillate (gal)	Residue (gal)	Run Time (gal)	(hr)	Vacuum
1	1,1,1-TCE	15	13½	1-2	5	0
2	1,1,1-TCE	15	14½	½	6	0
3	Stoddard	15	8½	3½	7½	-22.0 in.

Table 2
Chemical Test Data for 1,1,1,-Trichloroethane

	Acid Acceptance (as % NaOH by wt.), min.	Initial Boiling Point* (min. °C)	Dry Point** (max. °C)	Appearance	G.C. % wt, min.
1	0.16	72	77	Slight coloring	97.5%
2	0.12	73	77	Clear	93.1%
Standard (virgin 1,1,1-TCE)	0.10	70	88	Clear	93%

*Initial boiling point - thermometer temperature at the instant the first drop of condensate leaves the condenser.

**Dry point - thermometer temperature at the instant the last drop evaporates from the bottom of the distillation flask, disregarding any liquid on the flask walls.

material requirements. Generally, however, the recycled product has more high-boiling components, fewer low-boiling components, and a higher flash point than virgin stoddard solvent.

Another characteristic of stoddard solvent recycled from degreasing operations is the slight "rotten eggs" odor of hydrogen sulfide (H_2S) gas. The H_2S is derived from oil and lubrication additives. Indicator paper tests showed that the H_2S level in the recycled stoddard was about 1 part per million. This is the odor detection level for H_2S , but is well below permissible limits of exposure as defined by the National Institute for Occupational Safety and Health. It was also noted that the odor dissipates over time, since H_2S is a highly volatile, light gas.

3 LIFE CYCLE COST ANALYSIS FOR RECYCLE OFF-POST

Off-post recycling of solvents, the disposal method currently used by RIA, usually requires that the waste solvents be segregated and free of unusual contaminants. If contamination is a problem, the contractor will charge a higher price, and costly analysis will be required to determine the nature of the contaminants.

Storage and transportation costs are usually significant for this disposal option. Most contractors prefer to pick up a full truckload of solvent, so the installation must be able to store 4000 to 6000 gal of waste solvents. Containers, such as 55-gal drums, are commonly used to store waste solvent and to transport re-refined solvent from the contractor. Thus, when considering this option, one must also determine the cost of supplying and/or reconditioning storage containers. For example, one contractor used by RIA supplies reconditioned drums to customers at \$15 each. Contractors also charge a transportation fee to pick up a customer's waste solvent and deliver re-refined solvent; the fee is based on distance and ease of transferring the solvent from the customer's container to the truck.

It was determined that RIA must be able to store 6600 to 8000 gal of waste solvents, with 55-gal drum containers used for storage. In calculating the LCC analysis for this option, the costs of containers and transportation were taken into account. Table 3 shows the results of the LCC analysis for recycle off-post.

Table 3

LCC for Recycle by Contract Off-Post

Year	(A)* Cost of New Solvent	(B) Investment	(C) Recurring Cost	(D) Total Annual Cost	(E) 10% Present Value Factor	(F) Present Value
1	839,960	0	119,070	959,030	.954	914,914
2	839,960	0	119,070	959,030	.867	831,479
3	839,960	0	119,070	959,030	.788	755,715
4	839,960	0	119,070	959,030	.717	687,624
5	839,960	0	119,070	959,030	.652	625,287
6	839,960	0	119,070	959,030	.592	567,745
7	839,960	0	119,070	959,030	.538	515,958
8	839,960	0	119,070	959,030	.489	468,965
9	839,960	0	119,070	959,030	.445	426,768
10	839,960	0	119,070	959,030	.405	388,407

(G) LCC = total 6,182,862

*Letters in parentheses are keyed to sample calculations provided in Appendix C.

4 LIFE-CYCLE COST ANALYSIS FOR RECYCLE ON-POST

Recycling solvents on-post almost always requires purchasing distillation equipment. This equipment is readily available, and its size and configuration depend on the amounts and types of solvents to be processed. Most small-scale distillation equipment (less than 100 gal/day) operates in the batch mode. The smaller stills use electricity for energy, and the larger ones use steam.

An evaluation of RIA solvent use and waste solvent generation rates determined that two 55-gal distillation units would be needed for recycling waste solvent. A vacuum attachment for one of the units would be needed for PD-680 recovery because of its high boiling range. Both units would operate in the batch mode, using electricity for a power source.

The cost of new solvent required for make-up was determined by summing the values of the solvent lost during application and recovery. Typically, about 30 percent of PD-680 is lost during use. Another 5 to 10 percent is lost during distillation. Therefore, the total amount of PD-680 solvent that must be replaced usually amounts to about 35 to 40 percent of the total requirement. Loss rates for other solvents will vary, depending on vapor pressures and solvent uses.

For RIA, it was determined that PD-680 had a total loss of about 80 percent, while TCE had a total loss of about 82 percent. These rather high loss figures were calculated based on the difference between the total solvents purchased and the waste solvent turned in for disposal. Table 4 shows the results of LCC analysis for recycle on-post.

Table 4

LCC For Recycle by Distillation Method (On-Post)

Year	(A)* Cost of New Solvent	(B) Investment	(C) Recurring Cost	(D) Total Annual Cost	(E) 10% Present Value Factor	(F) Present Value
1	839,960	31,221	68,532	939,713	.954	896,486
2	839,960	0	68,532	908,492	.867	787,662
3	839,960	0	68,532	908,492	.788	715,891
4	839,960	0	68,532	908,492	.717	651,388
5	839,960	0	68,532	908,492	.652	592,336
6	839,960	0	68,532	908,492	.592	537,827
7	839,960	0	68,532	908,492	.538	488,768
8	839,960	0	68,532	908,492	.489	444,252
9	839,960	0	68,532	908,492	.445	404,278
10	839,960	0	68,532	908,492	.405	367,939

(G) LCC = total = 5,886,827

*Letters in parentheses are keyed to sample calculations in Appendix C.

5 ECONOMIC COMPARISON

The LCC format was useful in comparing two very different methods of waste solvent disposal and provides a logical choice for the item manager to follow. A comparison of the data in Tables 3 and 4 shows the direct benefits to operations of using distillation.

The following figures outline a 15-month return on investment:

Year	Current Method (Recycle Off-Post)	Distillation (On-Post)	Projected Annual Savings
1	\$914,914	\$896,946	\$17,968
2	\$831,479	\$787,663	\$43,816

These projected annual savings qualify the project for the Quick Return on Investment Program.⁷

The following figures summarize the bottom-line totals from Tables 3 and 4:

	Current Method (Recycle Off-Post)	Distillation (On-Post)	Projected Lifetime Savings
10-yr life	\$6,182,862	\$5,886,828	\$296,034

The indicated projected savings are over the 10-year life of the project.

The figures given above are based on some unusual reported data. RIA reports that it loses about 80 percent of its solvents, so only 20 percent is available for recycling. However, operations personnel at Safety Clean Co. indicate that their losses are normally around 30 to 40 percent.⁸ Thus, if RIA could decrease losses, recycling on-post would produce even greater savings and a faster payback.

⁷Engineer Technical Note No. 81, *CERL Portawasher Technology Transfer* (Office of the Chief of Engineers, 14 April 1981), Appendix B.

⁸Personal communication between Bernard Donahue (USA-CERL) and Bill Hoyn (Safety Clean Co.), 19 May 1983.

6 CONCLUSIONS

The LCC of solvent recycling at RIA by distillation on-post was compared with that of using current off-post methods. It was found that distillation on-post will provide significant savings--more than \$360,000 over the 10-year life of the project. If RIA can find a way to decrease its current solvent losses, so that more solvent is available for recycling, the savings gained by distillation will be increased accordingly.

APPENDIX A:

REFERENCES FOR SOLVENT SPECIFICATIONS

PD-680 - Dry-Cleaning Solvent

Federal Specification A-A-711, Dry Cleaning Solvent

ASTM - D156-82, Saybolt Color of Petroleum Products

ASTM - D484-71, Hydrocarbon Dry Cleaning Solvents

ASTM - D130-80, Detection of Copper Corrosion From Petroleum Products
by the Copper Strip Tarnish Test

ASTM - D86-82, Distillation of Petroleum Products

ASTM - D56-82, Flash Point by Tag Closed Tester

1,1,1 - Trichloroethane

Military Specification MIL-T-81533a, 1,1,1 - Trichloroethane (Methyl
Chloroform) Inhibited, Vapor Degreasing

ASTM - D1078-78, Distillation Range of Volatile Organic Liquids

ASTM - D2109-78, Nonvolatile Matter in Halogenated Organic Solvents and
Their Admixtures

ASTM - D2111-71, Specific Gravity of Halogenated Organic Solvents and
Their Admixtures

ASTM - D2108-71, Color of Halogenated Organic Solvents and Their Admixtures
(Platinum Colbalt Scale)

ASTM - D1364-78, Water in Volatile Solvents

APPENDIX B:

ACID ACCEPTANCE GUIDELINES*

1. Values of 0.08 percent and greater, as sodium hydroxide, are within the normal operating range.
2. Values of 0.08 percent to 0.04 percent indicate that the condition of the solvent is borderline and should be checked daily.
3. At values of less than 0.04 percent the solvent should be:
 - a. Discarded, or
 - b. Blended with virgin solvent at a minimum ratio of four parts virgin material to one part used material.
4. At a value of 0 percent acceptance, the solvent should be discarded.
5. Solvents that show a sudden decrease in acid acceptance should be tested frequently.

*From Gas Chromatograph and Acid Acceptance Procedures for the Analysis of Dow Chlorothene‡ VG‡ Solvent, Chlorothene‡ SM Solvent, and Neu-Tri‡ Solvent, (Dow Chemical Company, 1983), p 6. (‡ = Trademark of the Dow Chemical Company.)

APPENDIX C:

SAMPLE CALCULATIONS FOR DISTILLATION OFF-POST

(A) Cost of New Solvent

$$\begin{aligned} Y &= \text{Number of virgin PD-680 drums required per year} \\ &\times \text{cost of a drum of virgin PD-680} \\ &= 1660 \text{ drums/yr} \times \$130/\text{drum} \\ &= \$215,800/\text{yr} \end{aligned}$$

$$\begin{aligned} Z &= \text{Number of virgin 1,1,1-trichloroethane drums required per year} \\ &\times \text{cost of a drum of virgin 1,1,1-trichloroethane} \\ &= 3320 \text{ drums/yr} \times \$188/\text{drum} \\ &= \$624,160/\text{yr} \end{aligned}$$

Add all virgin solvent requirements to get the total new solvent requirement per year:

$$\begin{aligned} (A) &= Y + Z \\ &= \$839,960/\text{yr} \end{aligned}$$

(B) Investment Cost

The government will incur no investment cost for distillation equipment since the work will be done by contract.

(C) Recurring Costs

Cost of equipment used for storage and storage cost:

$$\begin{aligned} M &= \text{Storage cost} = \$1000/\text{yr} \\ N &= \text{On post transportation cost} = \$7120/\text{yr} \end{aligned}$$

Costs of labor, power, materials, maintenance, transportation, cost to buy back recycled solvent, and cost to dispose of used solvent off-post.

$$\begin{aligned} P &= \text{Labor costs} = \$21,200/\text{yr} \\ Q &= \text{Off post transportation costs} = \$3200/\text{yr} \\ R &= \text{Buy back costs} = \$52,200/\text{yr} \\ S &= \text{Cost to have used solvent disposed of off-post} = \$34,344/\text{yr} \end{aligned}$$

$$\begin{aligned} (C) &= P + Q + R + S + M + N \\ &= \$119,070/\text{yr} \end{aligned}$$

(D) Total Annual Cost

$$\begin{aligned} (D) &= (A) + (B) + (C) \\ &= \$959,030/\text{yr} \end{aligned}$$

(E) Standard present value factors

(See Table 1)

(F) Present value

$$\begin{aligned}(F_1) &= (D) \times (E) \\ &= \$914,914 \text{ for the first year}\end{aligned}$$

(G) Life-Cycle Cost

Sum of all present values:

$$\begin{aligned}(G) &= F_1 + F_2 + \dots + F_{10} \\ &= \$6,182,862\end{aligned}$$

Sample Calculations for Distillation On-Post

(A) Cost of New solvent

Y = Number of virgin PD-680 drums required per year
x cost of a drum of virgin PD-680 = cost of virgin PD-680 required per year

$$\begin{aligned}Y &= 1660 \text{ drums/yr} \times \$130/\text{drum} \\ &= \$215,800 \text{ per year}\end{aligned}$$

Z = Number of virgin TCE drums required per year x cost of a drum of virgin

TCE = cost of virgin TCE required per year

$$\begin{aligned}Z &= 3,320 \text{ drums/yr} \times \$188/\text{drum} \\ &= \$624,160 \text{ per year}\end{aligned}$$

Add all virgin solvent requirements to get the total new solvent requirement per year:

$$\begin{aligned}(A) &= Y + Z \\ &= \$839,960 \text{ per year}\end{aligned}$$

(B) Investment Cost

J = Cost of equipment to recycle solvent (first-year cost) = \$31,021

K = Installation cost of recycle equipment (first-year cost) = \$200

$$\begin{aligned}(B) &= J + K \\ &= \$31,221 \text{ for first year} \\ &= \$0 \text{ for the second through tenth years}\end{aligned}$$

(C) Recurring Costs

Recurring costs include labor, transportation, cost to buy back recycled solvent, cost to take used solvent off-post, materials, maintenance, disposal, transportation, and water costs.

- 1 = Labor costs = \$42,400/yr
- 2 = Power required to operate still = \$5430/yr
- 3 = Materials costs = \$200/yr
- 4 = Maintenance costs of recycle equipment = \$1000/yr
- 5 = Disposal cost of the residual sludge = \$1000/yr
- 6 = Transportation costs = \$10,320/yr
- 7 = Water costs = \$6880/yr
- 8 = Storage costs = \$1000/yr

$$(C) = 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 \\ = \$68,532/\text{yr}$$

(D) Total Annual Cost

$$(D) = (A) + (B) + (C) \\ = \$939,713 \text{ the first year} \\ = \$908,492 \text{ for the second through tenth years}$$

(E) Standard Present-Value Factors

(See Table 2)

(F) Present Value

$$(F) = (D) + (E) \\ (F_1) = 896,486 \text{ for first year}$$

(G) Life-Cycle Cost

Sum of all present values:

$$(G) = F_1 + F_2 + \dots + F_{10} \\ = \$5,886,827$$

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