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A Standard Procedure for Cost Analysis of Pollution Control Operations; Volume II. Appendices

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A Standard Procedure for Cost Analysis of Pollution Control Operations; Volume II. Appendices

by

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ABSTRACT

A standard procedure has been devised for the engineering cost analysis of pollution abatement operations and processes. The procedure is applicable to projects in various economic sectors: private, regulated and public. The models are consistent with cost evaluation practice in engineering economy and financial analysis. The report presents a recommended format, termed the Specification, that should not exceed eight pages when executed. The guidelines facilitate the choice of procedures open to the estimator and the establishment of factors to be used in the evaluation. The Specification has three segments: descriptive, cost analysis, and reliability assessment. The bulk of the report consists of 11 appendices that provide detailed background material and two comprehensive examples. The appendix subjects are: Capital Investment Estimation; Annual Expense Estimate; The *Cash Flow* Concept; Discrete and Continuous Interest Factors; Measures of Merit; Cost Indices and Inflation Factors; Rates of Return and Interest Rates; Methods of Reliability Assessment; Sensitivity Analysis; Example I -- Cost Analysis of Flue Gas Desulfurization (FGD) Retrofit Facility; and Example II -- Cost Analysis of Chlorolysis Plant.

The Measures of Merit appendix considers: return on investment, internal rate of return, payout time, equivalent annual cost, and unit costs. A glossary is provided.

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APPENDIX A

CAPITAL INVESTMENT ESTIMATION

Fixed capital represents the funds invested in land, equipment, and buildings to manufacture or process materials. It is comprised of the funds required to design, build, and bring the facility to acceptable operation. In addition, working capital is needed to operate it. Several methods for the estimation of both types of capital will be presented.

FIXED CAPITAL REQUIREMENT

Fixed capital is comprised of outlays for:

- Land.
- Buildings and equipment (physical plant).

In addition, the following may contribute to the fixed capital:

- Spare parts and special tools.
- Interest during construction (allowance for funds during construction (AFDC)).
- Cost of modification of the facilities and start-up of the operation.

Note that the investment of all the fixed capital, except land, is depreciated.

ESTIMATION METHODS FOR BUILDINGS AND EQUIPMENT

The methods which are of special concern for our purposes are termed "Study" and "Preliminary" types (see Table 1, Section 2 in Volume I). However, the rapid but very approximate Order of Magnitude procedures are useful for a "ball park" figure early in the study; later they can provide a check on the result prepared by more detailed methods. The Definitive and Detailed types of estimates are undertaken for facilities to be or being built and sometimes for budget authorization; they call for detailed information from an engineering design and require both an experienced estimating organization and a substantial monetary outlay.

Order of Magnitude Estimates

Three methods used for making order of magnitude (back-of-the-envelope) capital investment estimates are delineated below.

1. Investment is estimated from average fixed capital per unit of annual capacity. Examples of annual capacity include kWhr of electricity, tons of a product chemical, tons of steel billets, and quantities of manufactured items. If such investment figures are available, an approximation of the capital cost is found from:

$$I_F = i_F \, r_a \qquad \text{(A-1)}$$

where:

I_F = total plant cost;

i_F = total plant cost per unit of annual production capacity; and

r_a = annual capacity (consistent units).

2. Investment is estimated by scaling a known investment for a plant of different size (A-1), according to the relation:

$$I_{Fb} = I_{Fa}(r_b/r_a)^n \qquad \text{(A-2)}$$

where:

I_{Fb} = fixed-capital investment of plant b;

I_{Fa} = fixed-capital investment of plant a;

r_b = capacity of plant b; and

r_a = capacity of plant a.

For a typical chemical process, the exponent, n, will be 0.7. For very small installations or for processes employing extreme conditions of temperature or pressure, the exponent is 0.3 to 0.5. And for plants achieving higher capacities by using several units rather than large equipment, the exponent is 0.8 to 0.9. Note that an exponent of 1 gives the relation of the first method.

3. Investment is calculated from turnover ratio (A-1, A-2), the annual revenue divided by the total plant investment. The fixed investment by this method is:

$$I_F = S \, r_a/T \qquad \text{(A-3)}$$

where:

S = market value per unit of production;

r_a = annual production rate; and

T = turnover ratio.

Values of turnover ratio for the manufacture of various chemicals range from 0.2 to 8 (A-1, A-3, A-4, A-5). Values of less than 1 are generally found in large volume, capital-intensive industries utilizing basic raw materials, such as steelmaking and power generation.

In all cases, investment data applying to one date can be corrected to another date by using an inflation index such as the Engineering New Record (ENR) indices or the Chemical Engineering magazine Plant Cost Index; see Appendix F.

Study and Preliminary Estimates

For guidance in research and development activities and engineering studies, the preliminary and study estimates (often called conceptual estimates) are appropriate. Both entail at least a preliminary process design with material balances, energy budget, and a list of sized equipment. In addition, the preliminary estimate includes, as distinct from the study type, surveys and some engineering of foundations, transportation facilities, buildings, structures, lighting, electrical equipment, and control instruments. The engineering requirements for these two types of estimates are outlined in Figure 2 in Section 2 of Volume I.

Ordinarily the study estimate is either a factored estimate or a unit-process estimate; the designation depends mainly on the kind of construction and the nature of the available correlations of cost data. A discussion of these two types of study estimates follows.

Factor Methods (First Form of Study Estimate) --

The factored approach is commonly used when the major plant items (MPIs) are shop fabricated. Examples are chemical plants, petroleum refineries, and facilities in power plants for flue gas desulfurization. This method calls for the costs of the MPIs, also termed the major equipment items.

The costs of the critical items of equipment should be secured from vendors and checked against experience, the quotations of other vendors, or literature sources. The cost of less important items can be approximated from literature sources. But checks should be secured for all figures as a regular procedure. Literature sources for equipment cost information are listed in Table A-1.

Methods are also required to adjust available cost data for one or several sizes to that required for the process. This is generally done

TABLE A-1. SOURCES OF EQUIPMENT COSTS WITH RELEVANT INFORMATION

Source	Reference	Basis[a]	Suggested Reference Time	Comment
Perry & Chilton	A-6	Various	Vary	To locate cost data, see under equipment type in index.
Chilton *et al.*	A-7	Varies with articles	Vary	--
Popper *et al.*	A-8	Varies with articles	Vary	--
Aries & Newton	A-1	Delivered	1954	--
Bauman	A-9	Purchased or erected as specified	1961	Installation costs provided separately. A good general reference.
Woods	A-2	Varies as stated	1970	Extensive tabulation.
Guthrie	A-10 A-11	Purchased	1968	These data are also well summarized in Baasel (A-13).
Kinkley & Neveril	A-12	Purchased	1975	For the following air pollution control devices and auxiliaries: electrostatic precipitators, venturi scrubbers, fabric filters, thermal and catalytic incinerators, absorbers, and ductwork.

[a]Purchased (same as FOB (free on board) vendor plant), delivered (same as FOB job site, or freight allowed), and erected (same as installed). Note that freight runs 1 to 5% of the purchase cost of equipment. For an average, use 3%.

by a relation of the form of equation A-2 except that whenever plant is mentioned, the term for equipment, E, is substituted, or

$$E_b = E_a(r_b/r_a)^n \qquad \text{(A-4)}$$

See reference A-6, p. 25-16, 17. The exponent n varies from 0.4 to 0.9, but a good average is 0.6; this is the reason that scaling costs this way is termed: use of "the six-tenths factor."

Of the many schemes which have been evolved for finding the total plant cost, I_F, three -- Lang, Chilton, and Guthrie -- will be singled out. Their salient features are listed in Table A-2. Variants of the Guthrie method are also discussed briefly.

1. Lang Method -- The Lang method should only be used for checking; it indicates roughly the magnitude of the lumped factor that generates the total plant cost from the sum of the delivered equipment costs.

2. Chilton Method -- This scheme was delineated with illustrative factors in Table 2 in Section 2 of Volume I. For the range of factors suggested by Chilton (A-15) for widely different conditions, Table A-4 should be consulted. Other sources, such as Peters and Timmerhaus (A-17), provide similar schedules. Judgment and experience are required to select the value of the Chilton factors from the ranges found in the literature. Data from definitive and detailed capital cost estimates can be used to develop factors for generic processes.

In Table A-5, the Lang factor is figured for a fluid process plant using typical Chilton factors. Since some off-battery-limits items (such as buildings, auxiliaries, and outside lines) are included, it is reasonable that the Lang factor will be higher than the 4.7 shown in Table A-3 for a battery-limits fluid process plant.

3. Guthrie Method -- The Guthrie scheme is the most complicated of the factor methods and should yield more reliable results because of a sounder basis for the installation charges. But the types of equipment for which the necessary cost data are correlated are limited.

The total module cost is comprised of the sum of the direct material cost, M (as purchased equipment items, E, and as material for field installation, m), and field labor costs, L, for each MPI, then compounded to the total module cost by factors which account for the indirects. To find the total fixed capital investment, the extra cost for adjuncts and auxiliaries is added to the sum of the total module costs. These costs and the procedures are delineated below.

TABLE A-2. EQUIPMENT COST MULTIPLIER SYSTEMS FOR CAPITAL COST ESTIMATION

Name	Nature	Comment	Reference
Lang	One multiplying factor for the sum, ΣE, of the costs of the MPIs.	See Table A-3 for values. Good for checking.	Lang (A-14) Woods (A-2, p. 181)
Chilton	One factor for each of the cost contributions applied to ΣE, the sum of the MPIs.	See Table A-4 for range of values. Excel. for checking.	Chilton (A-15) Aries & Newton (A-1, p. 5)
Guthrie	Factors for both (field) material and labor are applied separately to the cost for each item of equipment, to give the bare module cost. When factors are applied to the sum of bare module costs, to account for so-called indirects (e.g., insurance, sales tax), one gets the total module cost.	Use is restricted because of limited data.	Guthrie (A-10, A-11, A-16) Baasel (A-13, pp. 254, 460)

TABLE A-3. LANG SINGLE FACTORS (A-1, A-14)

(To Apply to the Sum of the Costs of Major Plant Items for Capital Cost Estimates - Battery Limits Plants)

Delivered Equipment Cost	X	3.1 for solid process plants 3.6 for solid/fluid plants 4.7 for fluid process plants	=	Total Estimated Plant Cost

NOTE: A more detailed schedule can be found in Woods (A-2, p. 181) for grass-roots, as distinct from battery limits, plants; also, the Woods schedule shows that from 1947 to 1963 the Lang factors increased because installation costs increased much more than the costs of major plant items.

TABLE A-4. CHILTON FACTORS FOR ESTIMATING TOTAL PLANT COSTS

Item No.	Item	Multiplying Factor	Operating on Item No.
1.	Delivered Equipment Cost	1.0	1
2.	Installed Equipment Cost	1.43[a]	1
3.	Process Piping		
	Type of Plant - Solid	0.07-0.10	2
	Solid/Fluid	0.10-0.30	2
	Fluid	0.30-0.60	2
4.	Instrumentation		
	Amount - None	0.03-0.05	2
	Some	0.05-0.12	2
	Extensive	0.12-0.20	2
5.	Buildings and Site Development		
	Type of Plant - Outdoor	0.10-0.30	2
	Outdoor/Indoor	0.20-0.60	2
	Indoor	0.60-1.00	2
6.	Auxiliaries (Electrical Item Power)		
	Extent - Minor Addition	0 -0.05	2
	Major Addition	0.05-0.75	2
	New Facilities	0.25-1.00	2
7.	Other	0 -0.50	2
8.	Total Physical Plant Costs (Σ Cost of items 2 through 7)		
9.	Engineering and Construction		
	Complexity - Simple	0.20-0.35	8
	Difficult	0.35-0.50	8
10.	Contingency & Contractor's Fee		
	Process - Firm	0.10-0.20	8
	Subject to Change	0.20-0.30	8
	Speculative	0.30-0.50	8
11.	Total Plant Cost (Σ Cost of items 8, 9, and 10)		

[a]Aries and Newton (A-1) give the average installed equipment cost as 1.43 times the equipment cost delivered; this was for the early 1950s. Now Woods (A-2) advises using a factor of 1.40 to 2.20.

TABLE A-5. EXAMPLE OF THE USE OF CHILTON FACTORS FOR CAPITAL COST ESTIMATION OF A FLUID-PROCESS PLANT

Item No.	Item	Multiplying Factor	Operating on Item No.	Cost of Item
1.	Equipment Costs, delivered	1.0	1	ΣE_D[a]
2.	Installed Equipment Cost, ΣE_I	1.60	1	1.60 ΣE_D
3.	Piping (Includes Insulation)	0.40	2	0.64 ΣE_D
4.	Instrumentation	0.10	2	0.16 ΣE_D
5.	Buildings and Site Development	0.30	2	0.48 ΣE_D
6.	Auxiliaries (Elec. & Stm. Power)	0.15	2	0.24 ΣE_D
7.	Outside Lines and Site Development	0.15	2	0.24 ΣE_D
8.	Total Physical Cost (items 2 through 7)			3.36 ΣE_D
9.	Engineering and Construction	0.35	8	1.18 ΣE_D
10.	Contingencies and Contractor's Fee	0.20	8	0.67 ΣE_D
11.	Size Factor	0	8	0
12.	Total Plant Cost (items 8 through 11)			5.21 ΣE_D[b]

[a]Sum of the delivered major plant items.

[b]For this plant, the Lang factor is 4.83.

The schedule for the Guthrie method is developed from these seven cost elements (some represent the sum of items above in the list):

• Equipment cost, FOB	(E)	M
• Direct (field) material	(m)	
• Direct (field) labor	(L)	
• Direct M and L costs	(E+m) + L or M + L = DC	
• Indirect costs	(IC)	
• Bare module costs	IC + DC = BMC	
• Total module costs	I_F	

The direct (field) material, m, consists of:

- Piping
- Concrete
- Steel
- Instrumentation
- Electrical
- Insulation
- Paint

[m ranges from 40% to 125% of E or a norm of 62%. Multiply E by 1.40 to 2.25 to get M, the total of all direct material costs (A-10, A-11).]

The direct (field) labor, L, applies to:

- Material erection
- Equipment setting

[L ranges from 50% to 70% of E or a norm of 58% (A-10, A-11).]

The sum of M + L comprises the total direct costs or total physical cost which is Item 8 in Table A-5. Then to the sum of the values of M + L for all the major plant items, indirect factors are applied to account for these three items:

- Freight, insurance, sales tax
- Construction overhead
- Engineering

[Indirect cost ranges from 25% to 45% of (M + L) (A-1, A-18); multiply (M + L) by 1.34 to get bare module cost (A-10, A-11).]

This yields the so-called "bare module cost." The "total module cost" is found by applying factors for these two items:

- Contingency [8 to 20% of bare module cost (A-17), or a norm of 15% (A-10, A-11)
- Contractor's fee [2 to 7% of bare module cost (A-17), or a norm of 3% (A-10, A-11)]

[Multiply bare module cost by 1.18 to give "total module cost" (A-10, A-11).]

If adjuncts or auxiliaries such as:

- Solids handling facilities
- Site development
- Industrial buildings
- Offsite facilities

apply, the extra investment for them needs to be added. In the calculation of these extra investments, one must allow for indirects: engineering, contractor's fee, etc.

The Guthrie references (A-10, A-11, A-16) provide values for FOB equipment costs, E, and the factors to compute material, M, and field labor cost, L. The equipment for which these data are available include process furnaces, heat exchangers, process vessels, pumps, and compressors. For equipment for which this information cannot be found in the literature, the factors can be back-calculated from detailed cost estimates or from the records of jobs actually constructed.

The contingency, for which 15 percent is allowed on the average by the Guthrie method, covers two shortcomings of the estimating procedure. One is ignorance: the failure to include items, generally minor but cumulatively significant, which escape accounting in a conceptual level estimate. These average about 10 percent of the fixed capital investment. The second shortcoming of the estimating procedure is the inability to predict many factors which affect the final cost; e.g., business conditions, weather, labor strife, and legislation.

This is a good place to illustrate the wide range of productivity, construction, labor wages, and (hence) field construction cost. Information from the experience of one contractor, Pullman Kellogg (formerly M. W. Kellogg), dated 1973, (A-19) shows that field construction labor costs vary as follows with those for a Gulf coast location:

Houston	1.00
Kansas City	1.37
Cincinnati	1.53
Detroit	1.73
St. Louis	2.01

4. <u>Guthrie Method Variants</u> -- Two variations of the Guthrie method are worthy of note because of their utility and as possible harbingers. One is the reduction of the number of major plant items to a few general classifications based on the variables which significantly affect the size of the equipment. Pullman Kellogg (A-19) did this for flue gas desulfurization by the wet limestone process. For this process, the factors to apply to major plant items were all related to one or the other of two basic process parameters; viz., the flue gas flow rate and the rate of sulfur removal from the fuel. The factors were:

Chemical process (size governed by the flue gas flow rate)	$M_C = 1.80\ E_C$ $L_C = 0.60\ E_C$

Solids handling (size governed by the rate of sulfur removal) $M_S = 1.40\ E_S$
$L_S = 0.40\ E_S$

where M, L, and E have their prior meaning and the subscripts C and S refer to chemical process and solids handling operations, respectively.

The other variant devised by the ICARUS Corporation is really a simplification of the Guthrie method. Correlations (A-20, A-21) are available for the contribution to the total module cost of a wide range of process equipment modules. Simply, the sum of these contributions gives the base plant cost (total bare module cost) to which only contingency and contractor's fees need to be added to get the total plant cost, I_F.

Unit Process Method (Second Form of Study Estimate) --

For this method, the unit processes to be carried out in the plant are identified and their capacity determined. Then the contribution to the total plant cost for each unit process is found from correlations. This procedure seems to be particularly suited to installations constructed in the field, such as municipal sewage plants. A substantial amount of information for both the identification, sizing, and costing of the unit process elements for liquid waste treatment facilities is available (A-22, A-23, A-24).

The unit process technique is similar to the ICARUS method (A-20, A-21) for which the elements are MPIs instead of unit processes. The unit process approach seems to be suited for other large facilities which are:

- To be field installed.
- Well established processes for which considerable reliable cost data are available.
- Essentially similar in the numbers and kinds of treatment steps.

This approach has been attempted for fluid process operations (A-25, A-26) but, because of the wide range of possible process modules, there are insufficient suitable data. At present this method seems applicable only to liquid waste treatment where the facilities are analogous to large sewage treatment works.

Retrofit Versus New Plant --

Often the process will constitute an add-on to a basic facility, such as a power plant. When the addition is made to an existing plant, it is termed a retrofit and the cost is more than for the addition to a new plant. Besides the knotty design problems, there is also the physical difficulty of interposing and tieing in the retrofit unit on the plant site. Some of the factors that contribute to the additional costs, as discussed by Kinkley and Neveril (A-12), are as follows:

Plant Age - May require structural modifications to plant and process alterations.

Available Space - May require extensive steel support construction and site preparation. Existing equipment may require removal and relocation. New equipment may require custom design to meet space allocations.

Utilities - Electrical, water supply, and waste removal and disposal facilities may require expansion.

Production Shut-down - Loss of production during retrofit must be included in overall costs.

Direct (field) Labor - If retrofitting is accomplished during normal plant operations, installation time and labor hours will be increased. If installation occurs during off-hours, overtime wages may be necessary.

Engineering - Increased engineering costs to integrate control system into existing process.

Most information for retrofit is from flue gas desulfurization (FGD) units added to coal-fired utility boilers. McGlamery et al. (A-27, p. 80) adjust the labor portion of the new investment for existing units by multiplying the projected labor requirements for a new unit by a retrofit difficulty factor of 1.25. This corresponds to an assumed labor efficiency of 80 percent for retrofit installations.

A detailed estimate of the extra cost for retrofits of the wet limestone scrubbing process by Pullman Kellogg (A-28) shows that the overall cost is about 25 percent more than for new plant installations. This study was for eight power plants in Ohio for which the capacity ranged from 250 MW to 2250 MW. Ponder et al. (A-29, p. 5-5) also provide information on the increase in capital costs with retrofit requirements.

Information developed by Ponder et al. is presented in Table A-6; it illustrates the wide range of costs possible for a retrofit installation.

As a rule of thumb, a retrofit cost should be increased from 25 to 40 percent over that for constructing a new facility.

Multiple Train Savings Factor --

When there are multiple units (as for scrubber trains for flue gas desulfurization), the fixed capital cost is less than a simple multiple of the cost for the installation of one train. There is information to suggest that the second and third trains would be 95 and 90 percent of the first train cost, respectively. (This corresponds to an exponent n of 0.90 in Equation (A-2).) This reduction in cost per unit results from the common series of engineering, purchasing, supervision, and administration of construction for the multiple train facility.

TABLE A-6. TYPICAL INCREASES IN CAPITAL COSTS WITH VARIOUS RETROFIT REQUIREMENTS (A-29)

Retrofit Requirements	Capital Cost Increase, %
Long duct runs	4 - 7
Tight space	1 - 18
Delayed construction (1 year delay)	5 - 15
Hilly terrain	0 - 10
New stack	6 - 20
Overall	16 - 70

INTEREST DURING CONSTRUCTION

For some pollution control facilities, the time from the beginning of the project until the start-up extends over several years. During this period, funds must be available to meet installments due the engineering/construction firms. This is generally long before the capital is available from bond or stock issues. Accordingly, loans are arranged on which interest is paid until the project is "capitalized." An allowance for this financial service is "interest during construction."

The proper estimation of the amount for this interest requires two kinds of information:

- The applicable interest rate.
- The loan schedule.

The interest rate, generally the prime rate, varies but has been 8 to 12 percent in recent years. It is generally less than the return that a business enterprise anticipates from its invested capital. See Appendix G.

For simplicity, the loan schedule is sometimes assumed to be linear with time; however, this is far from representative. Generally the required payments are larger during the latter part of the plant construction. Examples of schedules used in some estimates are given in Table A-7.

Note that the total interest charge can be significant. For the McGlamery et al. schedule, using 8 percent discrete interest with payments effective at the beginning of the year (the most severe case), the

TABLE A-7. TYPICAL PROJECT EXPENDITURE SCHEDULES

Years before Start-up	Adapted from Ponder *et al.* (A-29)	Adapted from McGlamery *et al.* (A-27, p. 26)	Unpublished Source
4	--	--	10
3	11	25	15
2	25	50	50
1	64	25	25
	100%	100%	100%

interest would accumulate to a 16 percent surcharge on the fixed capital investment. For projects of longer duration, such as a nuclear power plant over 7 years, this surcharge would increase the fixed capital by 30 to 40 percent.

MODIFICATION OF THE FACILITIES AND START-UP

For new processes, the possible increase in the capital investment because of equipment modifications needs to be recognized; the amount allowed for this purpose is related to the vague yardstick of "stage of development." For "first-of-a-kind" processes, and especially for plants built with insufficient or no piloting, these modification costs can represent a substantial portion of the total capital requirement. In any case, it is difficult to specify a figure or a range. For a well established operation, a few percent of the fixed capital is sufficient for modifications needed during start-up; sometimes no outlays are called for.

Some figures on start-up costs are given in Table A-8.

LAND

Generally land represents a minor portion of the investment; often it is neglected or covered by the contingency. For rough estimates it can be taken as 3 percent of the fixed capital.

The land area required to accommodate the facilities can be determined from the land needed for similar installations. In the absence of

TABLE A-8. START-UP COSTS

McGlamery *et al.* (A-27, p. 26) for flue gas desulfurization processes	Baasel (A-13, p. 363) for chemical processes	Peters and Timmerhaus (A-17, p. 116)
10% of I_F for regenerable processes	5-20% I_F	8-10% I_F
8% of I_F for throw-away processes		

other information, use 5 acres* per million dollars of fixed capital investment. However, the land area can be relatively large for certain pollution abatement operation; e.g., the land area acreage needed for ponding residues from "throw-away" flue gas desulfurization processes.

Cost figures found in the literature are:

Cost/Acre	Location	Time	Reference
$1000	U.S.	1976	A-24, p. H-6
$2000	Average for U.S.	Feb 1973	A-22, pp. 111-2
$3000	Midwest	mid-1972	A-27, p. 25
$150 to 20,000	U.S.	1961-1969	A-13, p. 41

For evaluating technical feasibility and preliminary cost comparison, a figure of $5000/acre ($1.235/m^2) is suggested. This includes the cost of the land and land rights, legal fees, and other special expenses incurred by its acquisition.

WORKING CAPITAL

Working capital may be defined as the funds necessary for the normal conduct of business. In general it is 10 to 15 percent of the fixed

*Although EPA policy involves use of metric units, acres are used here for simplicity. Readers more familiar with metric units should multiply the acreage figures by 4047 to convert to m^2.

capital investment or 15 to 35 percent of revenue. These funds cover the raw material stocks, in-process inventory, product inventory, extended credit to customers (accounts receivable), and current obligations for employees' wages and other services. Some schedules for making a more refined estimate are in Table A-9.

TABLE A-9. SCHEDULES FOR ESTIMATING WORKING CAPITAL

	General. Aries & Newton (A-1)	For Flue Gas Desulfurization. McGlamery *et al*. (A-27, p. 29)
Raw material stocks	30 days	21 days
In-process inventory	depends on process	--
Product inventory	30 days	--
Extended credit to customers	60 days	--
Operating expense	30 days	49 days

SUMMARY OF TOTAL CAPITAL INVESTMENT

Various schedules in Table 7 in Volume I were prepared to facilitate the organization of the total capital cost estimate. For the several procedures in use for plant cost estimation, Schedules A to G in Table 7 were developed. Schedule H in Table 7 takes the total plant cost from Schedule C, D, E, F, or G, and finds the total capital investment by adding the land value, working capital and, if applicable, interest during construction, and the cost of plant modification and start-up.

The total capital costs are generally reduced to some basis common to the technology to provide index values for ready comparison. Examples of such bases are $/kW, $/$10^6$ (Btu/yr),* $/100,000 bbl** of crude oil run/day.

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*Multiply $/($10^6$ Btu/yr)/ by 0.95 to convert values to $/(GJ/yr).

**Multiply $/100,000 bbl by 6.29×10^{-5} to convert values to $/$m^3$.

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APPENDIX B

ANNUAL EXPENSE ESTIMATE

CONTENTS

FIGURE

TABLES

APPENDIX B

ANNUAL EXPENSE ESTIMATE

The total of all the continuing costs incurred in and related to the manufacture of a product or the carrying out of a function is called "total annual expense." It includes operating costs (also termed manufacturing or production costs) and general expense (also termed home office overhead, and "downtown" costs). The items which comprise these costs are listed in Tables 3 and 4 in Section 2 of Volume I.

With one exception, all the components of operating costs are transferred (paid) to entities outside the operating organization. This exception is depreciation which is handled as a book transfer of funds.

For certain fields of technology (e.g., the treatment of sewage and industrial liquid wastes), the day-to-day costs of operation are designated as operating and maintenance costs (O&M). See references B-1, B-2, and B-3. Note that these O&M expenditures represent only a portion of the total operating costs, whereas, the total operating costs used in this work are just that and, of course, include "general expense."

It is essential that the estimator have several insights. He must realize that the schemes for estimating the components of operating costs are crude; unless there are actual costs from working plants to calibrate the technique, the results are suspect and may be greatly in error. However, in the absence of more definitive information, the procedure outlined in this section -- the factored expense estimate -- appears to be the best available.

The estimator should also perceive the various items as variables with values that depend on the level of capacity at which the plant is operating. Then one can envision a comprehensive model used widely in business for breakeven analysis and such. This model is particularly helpful in sensitivity analysis, which is treated in Appendix I.

THE OPERATING COST MODEL

A simple operating cost model is presented graphically in Figure B-1. Below are listed the three categories which describe how component costs can vary with the production rate. Each component is placed in the category that most closely represents its behavior.

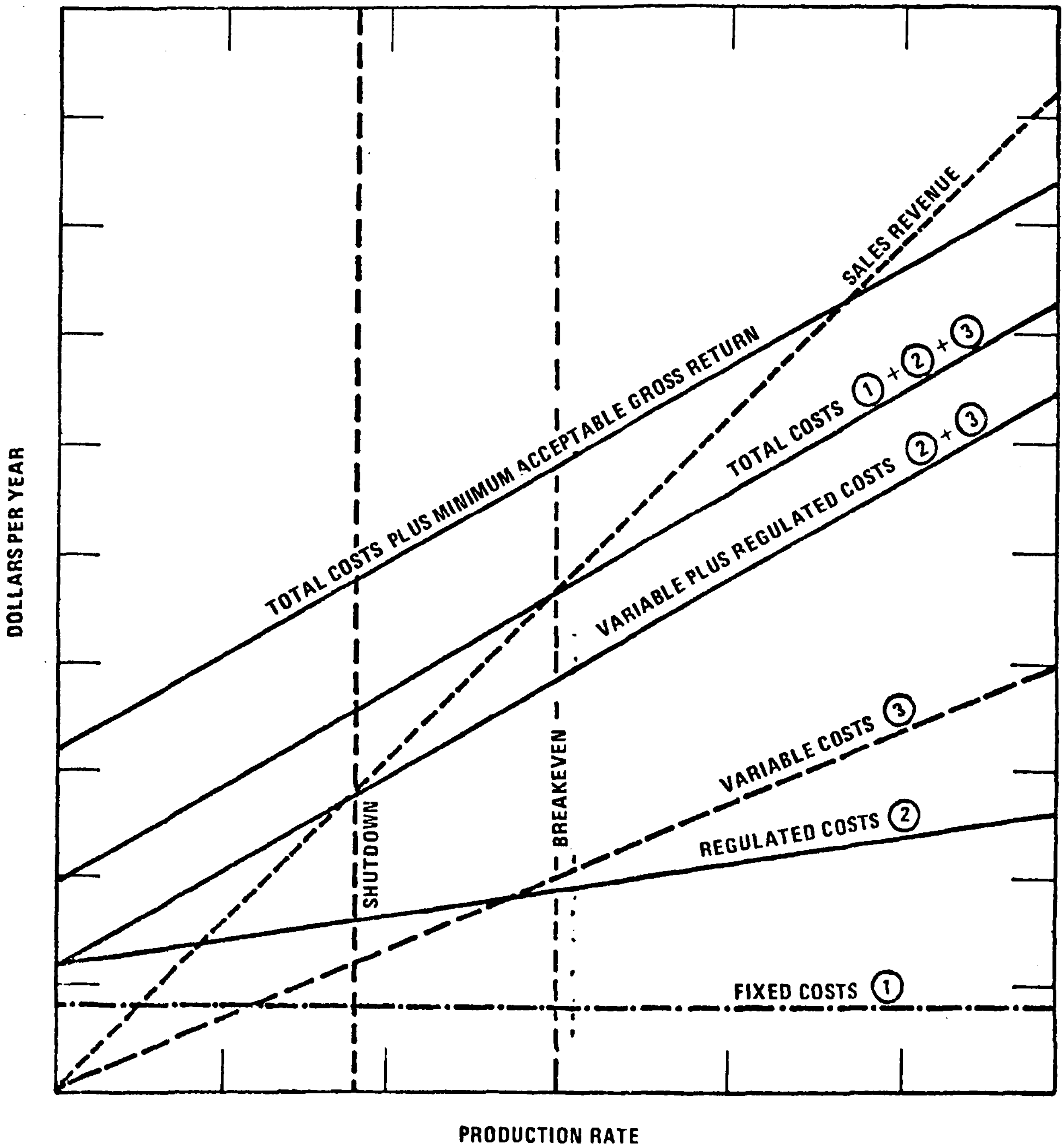

Figure B-1. Fixed, variable, and regulated costs plotted versus production rate.

Category	Component
1. Fixed costs (constant at all production levels)	Depreciation Property taxes Insurance
2. Variable costs (directly proportional to the production rate)	Raw materials Utilities Packaging Shipping
3. Regulated costs (never zero; generally taken to vary linearly with production rate)	Operating labor Plant overhead Supervision Maintenance General expenses

For other purposes it is useful to designate annual expenses as either direct or indirect. The classification of expense items under this scheme is described below.

1. Direct costs; i.e., those directly associated with the product or plant operation. Examples are raw materials, operating labor, maintenance.

2. Indirect costs; i.e., those not directly related to the operation. Examples are depreciation, taxes, administration. These are allocated costs; usually they persist whether the facility is operating or not.

COMPUTATION OF ANNUAL OPERATING EXPENSES

For an estimate of the operating costs, it is essential to have information from the mass and energy balance, an estimate of direct (operating) labor, and the estimated total plant cost. Below, there is a discussion of the procedures for arriving at an estimate for each element of the operating cost. For a survey of the items comprising operating costs, Table 3 in Section 2 of Volume I should be consulted.

The mass and energy balances are necessary to determine the quantities of raw materials and the utility duties. The total plant investment, I_F, provides a basis for the fixed charges. The fourth item needed is the direct (operating) labor. Although it is usually a rough estimate, several items are factored from this labor figure. Thus the operating costs are either the direct or the factored values of these four items: raw materials, utilities, direct operating labor, and plant investment.

Now it will be shown how each element of the operating costs (such as listed in Table 3 in Section 2 of Volume I) can be estimated.

Raw Materials

For large quantities, purchases of raw materials for the long term would be by negotiated contract. Accordingly, quotations from suppliers and advice from marketing people are desirable for the dominant items. However, published prices (e.g., from the Chemical Marketing Reporter (B-4)) serve as a check and also as a source of original price data for materials needed in small quantities.

Price quotations will be expressed as FOB the supplier's plant, or some other basing point. One should check that freight charges are included; otherwise it should be estimated (B-5) and added to prices that are FOB the supplier's plant.

Transferred raw materials are those diverted from another operating entity within the company. The "transfer price" is established by internal policy; it could be the current market price or the manufacturing cost plus transportation. If it is the latter, an allocated portion of the investment for the transferred material must be added to the investment of the plant being scrutinized.

"Raw materials" are credited with the value of any by-products. The prices of by-products can be estimated from the market price less the cost of further processing, packaging, selling, and transportation.

Operating Labor

Requirements for operating labor requirements (also termed just labor or direct labor) can be estimated by preparing a schedule of the jobs and functions to be carried out. Then with data from Haines (B-6), which gives likely time segments for most of the work items performed in the course of a day for a process plant operator, one can build up the total operating man-hour requirements.

Another approach is provided by the following equation from Wessel (B-7). Direct labor requirements can be approximated from the number of processing steps (very arbitrary), the production rate, and the nature of the operation from this relation:

$$\frac{\text{operating man-hours}}{\text{tons of product}} = f\left[\frac{\text{no. of process steps}}{(\text{capacity in tons/day})^{0.76}}\right] \qquad \text{(B-1)}$$

where f is determined by the kind of process and has values as follows:

23 for batch operations with a maximum of labor,
17 for operations with average labor requirements,
10 for well-instrumented, continuous process operations.

These sources only roughly indicate the operating labor needs; a knowledge of similar operations is more valuable.

Typical current labor rates are given in Table B-1. Note that they vary with location. Also wages for labor have escalated more than other costs. As a check, one can use an average from the annual earnings range of $12,000 - 15,000 per man-year; this includes shift differential and overtime.

TABLE B-1. AVERAGE HOURLY EARNINGS OF CHEMICAL WORKERS

	Avg Hrly Earnings Aug 1977	Avg Hrly Earnings 1976	% 1976 Earnings Increased Over 1971 Earnings
Louisiana	8.18	7.28	54.6
Texas	8.07	7.18	58.5
Oklahoma	7.95	7.21	68.1
Michigan	7.35	6.55	46.2
New Jersey	6.77	6.19	49.5
Indiana	6.62	6.28	46.7
Alabama	6.57	5.78	57.5
Illinois	6.39	6.06	46.7
Ohio	6.38	5.87	40.8
Massachusetts	6.21	5.61	39.2
Connecticut	6.17	5.61	39.9
New York	6.11	5.62	45.6
Pennsylvania	6.01	5.73	53.6

SOURCE: Chemical Week (B-5).

Although the actual wages for direct labor represent a small proportion of the manufacturing costs, many other items are estimated by multiplying the amount for direct labor by a factor. Accordingly the figure used should be as reliable as possible; more than one evaluation method is advisable.

Direct Supervision

This is taken as 10 to 25 percent of operating labor (B-8, p. 162); the percentage depends on the complexity of the operation and the quality of the personnel. For larger operations or situations where the actual number of positions can be identified, actual salaries might be used. Thus four shift foremen at $21,000/yr would be $84,000/yr.

Maintenance Labor and Materials

For a preliminary estimate, maintenance costs (labor and materials) are usually based on the total plant cost. Aries and Newton (B-8, p. 164) give factors from 4 to 10 percent; the actual value depends on the complexity of the process and the severity of the operating conditions. The factors are higher for rotating equipment. The material portion is of the order of 35 to 50 percent of the total. More detailed methods are in use. Supervision of maintenance is generally included in plant overhead.

Operating Supplies

Operating supplies are materials other than raw materials consumed in the operation. There are several ways of allowing for these run-of-the-mill items: one is to take 6 percent of operating labor (B-9, p.155); another is to take 15 percent of maintenance costs (B-8, p. 168). The cost of special supplies should be added to the figure for run-of-the-mill items. Catalysts are frequently listed separately.

Labor Additives

Amounts set aside for pensions, vacations, group insurance, disability pay, social security, unemployment taxes, etc., are termed fringes, labor additives, or payroll overhead. They can be estimated as 25-50 percent of the direct labor cost (B-10).

Utilities

The quantities required are generated by the mass and energy balances. As a check, one can use the tabulations of utility requirements which are available for many processes. Typical utility and related fuel costs are presented in Table B-2.

For a grass roots plant, the capital costs and operating costs of the utilities may be included with those of the facility. Similarly, for a battery limits unit, a portion of the utility capital cost may be allocated to an operation as well as the corresponding fraction of the operating expenses. However, for economic studies of pollution abatement processes it is more likely that direct utility charges (such as given in Table B-2) will be used.

Effluent Treatment and Disposal

Residues from many processes, including pollution control operations, must be disposed of by impounding (e.g., precipitates from "throw-away" FGD processes), by hauling to industrial dumps (e.g., residue from electroplating operations), and by dumping far at sea. The expense of disposal is handled either as another processing operation, in which case it is included in the operating expense, or as a service charge for hauling and further processing by another organization, if this is required.

TABLE B-2. TYPICAL UTILITY AND FUEL COSTS
(from various sources)

High Pressure Steam 400 psi	$1.00 - 1.50/10^3 lb	($2.20 - 3.30/Mg)
Low Pressure Steam 40 psi	$0.75 - 1.25/10^3 lb	($1.65 - 2.75/Mg)
Electricity	$0.015 - 0.05/kWhr	
Coal	$1.00 - 2.00/10^6 Btu	($0.95 - 1.90/GJ)
No. 6 Fuel Oil	$1.50 - 2.50/10^6 Btu	($1.42 - 2.40/GJ)
Distillate Fuel Oil	$1.80 - 2.80/10^6 Btu	($1.70 - 2.65/GJ)
Natural Gas	$1.00 - 2.50/10^6 Btu	($0.95 - 2.40/GJ)
Cooling Water	$0.03 - 0.10/10^3 gal.	(0.01 - 0.03/m^3)
Process Water	$0.15 - 0.50/10^3 gal.	(0.04 - 0.13/m^3)

Costs for landfilling or ponding of untreated sludge from FGD units were estimated in 1976 to range from $3.50* per dry ton for natural clay-lined ponds to $7.80* for Hypalon-lined ponds depending on the land costs and the ancillary equipment used (B-11). Treatment and disposal is more costly; estimates in 1976 dollars range from $7.50 to $11.40* per ton on a dry basis (B-12).

Preparation for Shipping

This item covers the work to transfer the product to the container in which it leaves the plant. Freight costs are not added here. If the product is sold on a delivered basis, freight costs should be subtracted from the gross sales price to get a net sales figure.

Plant Overhead

Plant overhead or general works expense is the cost of providing service functions required by the productive unit. It covers plant

*Multiply by 1.1 to convert from $ per (U.S. short) ton to $ per metric ton. Note that a metric ton corresponds to Mg.

management, general supervision of maintenance, personnel, plant protection, storerooms, accounting, purchasing, traffic, and other similar service items. It also includes the depreciation, operation, and maintenance costs of railroads, roads, sewers, parking lots, cafeterias, and other general facilities which serve the operating units.

This item may be estimated in several ways. It is often taken as 50-100 percent of operating and maintenance labor, or as a percentage of operating labor (e.g., 50 percent) plus a percentage of maintenance (e.g., 25 percent). Hackney (B-9, p. 157) proposes that overhead charges be calculated from proportions of both labor (45-50 percent) and investment (1-5 percent).

Control Laboratory

These costs depend on the nature of the process and the difficulty of maintaining quality control. The number of analysts or technicians can be estimated and multiplied by $40,000 to $50,000 per year per man. An alternate method for a complex process is to take 10 to 20 percent of the operating labor cost (B-9, p. 155).

Technical and Engineering

This should be handled in the same way as the Control Laboratory; i.e., $40,000 to $50,000 per year per man. This includes overhead and the salaries of supervisors, technicians, and secretaries.

Note that this also includes plant followup or technical service which can prove to be a substantial expense for a new pollution control process, particularly during the early years of operation.

Insurance and Taxes

These items are ordinarily taken as 1 and 2 percent of the fixed capital investment, respectively.

Royalties

Royalties may range from substantial to negligible, depending on the specific situation. Agreements generally provide a schedule of payment that is related to either the nominal plant capacity or the production per royalty period.

Depreciation

For profitability calculation and financial reporting, depreciation is customarily calculated by the straight line method. Accelerated methods, such as the sum of digits or double declining balance, are commonly used for income tax determination.

The straight line depreciation factor (or rate) is 1/n when n is the years of useful life as provided in the Internal Revenue Service (IRS) guidelines (B-13). Typical guideline lives are 11 years for a chemical plant, 16 years for a petroleum refinery, and 28 years for a steam electric utility. The annual depreciation is the total depreciable investment multiplied by the factor. Here the total depreciable investment is either the total plant cost or the plant cost less anticipated salvage. (It can also include interest during construction, modification of facilities, and start-up costs. See item 35, Schedule H, Table 7, Section 3 of Volume I.) Thus, for straight line depreciation, complete recovery of depreciable investment is provided in equal annual increments over the depreciation life of the plant.

Accelerated methods provide for a higher rate of recovery of capital during the early years of plant operation and therefore lead to lower income taxes during these early years; this is considered desirable. By far, the most widely used accelerated depreciation methods are the sum of the digits and the double declining balance.

In the double declining balance method, the depreciation factor for, say, an 11-year life is 2/11 (i.e., twice the straight line factor); but it is applied in a given year to the book value, which is the original depreciable investment less accumulated depreciation. No account is taken of salvage. However accounting techniques are available to make an end-of-depreciation-period adjustment.

For the sum of the digits method, the depreciation rate, d, for a given year, r, where n is the depreciation life in years, can be found from

$$d = \frac{n-r+1}{\sum_{1}^{n} n} = \frac{2(n-r+1)}{n(n+1)}$$

Then for the case where the depreciation life is 11 years, the depreciation rates are: for the first year --

$$d_1 = \frac{2(11-1+1)}{11(12)} = \frac{11}{66} \quad ;$$

for the second year --

$$d_2 = \frac{2(11-2+1)}{11(12)} = \frac{10}{66} \quad ; \text{ etc.}$$

As with the straight line method, these factors are applied to the total depreciable investment less any anticipated salvage.

Because the sum of digits method gives a linearly decreasing depreciation flow, for cost analyses it is generally preferred to the double declining balance method. On the other hand, accountants prefer the double declining balance; it requires fewer accounts!

Frequently special rules apply to pollution abatement equipment; for example, depreciation may be allowed over a shorter time (in some cases as little as 5 years). The rule is described in Appendix B of reference B-14 as follows.

> If the facility was placed in service before 1975, and is associated with a plant placed in operation before 1969 and the remaining life is 15 years or less, the pollution control project can be written off over a 5-year period. If the remaining life exceeds 15 years, the amount of the 5-year write-off is adjusted by the ratio of 15 to the remaining life in years. If the plant was installed after 1969, the life for tax depreciation is the same as the plant itself.

ESTIMATION OF GENERAL EXPENSES

For a preliminary estimate, the general expenses can be estimated as a percentage of either sales or the depreciable investment. Typical values are:

- Administration -- 2-3 percent of sales or investment.
- Sales expense -- 2-6 percent of sales (up to 30 percent for specialty items).
- Corporate research -- 2-5 percent of sales or investment.
- Finance (largely bond interest) -- this depends on the amount of debt.

For administration and research costs, investment is preferred as the basis by some. Sales expenses vary widely depending on the nature of the product or service. Finance costs generally include just the bond interest; the costs of administering the financial program are included under administration along with legal, accounting, and other services.

SUMMARY OF ANNUAL EXPENSES

The annual cost for each element is entered directly into Tables 9 and 10 in Section 3 of Volume I. Values for the annual charges for operating and general expenses are computed separately, and then added to find the total annual expense.

For pollution abatement activities the total annual expenses are customarily reduced to unit costs for either the output of the base plant or the recovered pollution material. Examples are $/kWhr for a power plant, $/ton* of sulfur for a unit cost for FGD unit, and $/$10^6$ Btu** for a coal cleaning plant. This practice reduces costs to a basis common for a given technology.

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B-10. Anon. Plant Sites 1977: It's North's Move. Chemical Week. p. 35. Nov. 10, 1976.

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*Multiply $/(U.S. short) ton by 1.1 to convert values to $/Mg.

**Multiply $/$10^6$ Btu by 0.95 to convert values to $/GJ.

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APPENDIX C

THE *CASH FLOW* CONCEPT

CONTENTS

FIGURES

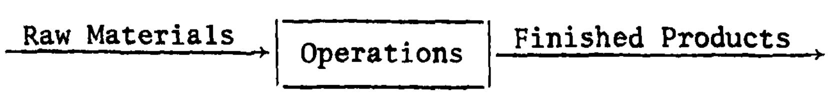
APPENDIX C

THE *CASH FLOW* CONCEPT

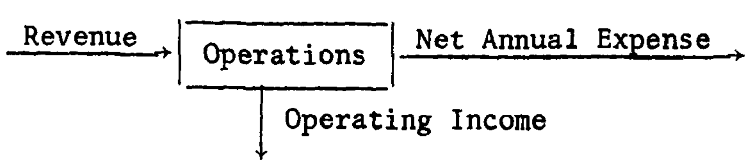
For an engineering cost analysis of a project or venture, it is necessary to identify the sources and represent the expected flow and disposition of the monies involved. To elucidate the money flow process for a going operation, a diagram will be used that is analogous to a process flow diagram showing the input of raw materials, the various processing steps and the flows, recycle and hold-up of intermediate material within the process, and finally the output of product. This way of looking at money transfers is readily grasped by technical people. A money stream particularly useful in the cost analysis of projects is *cash flow*, the sum of depreciation and net profit.

For such an analysis the flow of money is idealized. It can be considered one-time; i.e., a lump sum at an instant such as the purchase of land or of equipment and the allocation of working capital to a new project. The alternative situation is regular payments (as for wages, raw materials, and services) where the money flow is generally considered as continuous. Other regular schedules are sometimes employed, such as continuous but linearly decreasing or increasing costs. These idealized flows permit the use of simple models to describe the money flows for a project to be evaluated.

The various items of money flow will be looked at in more detail for the case of a going manufacturing business. The primary source of income necessary to maintain the health of the business is revenue from the sale of products. A large part of this income flows out of the company as expense. Using the proposed analogy, just as we have a flow diagram for materials in a process, viz.,

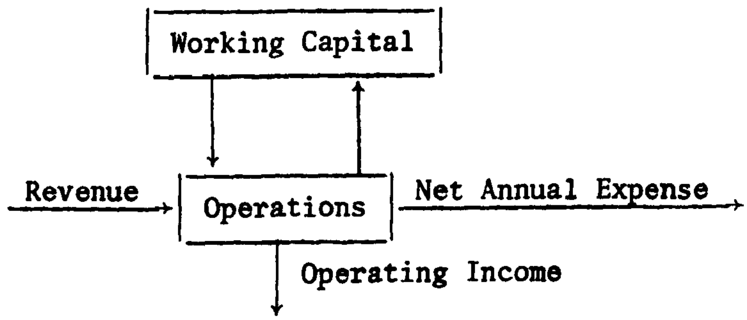


we can also have a similar chart for the flow of funds in a going operation:



Net Annual Expense includes all payments except capital investment, income taxes, stock dividends, depreciation, and repayment of borrowed funds. Note that interest on borrowed funds is an item of net annual expense.

It is necessary to have a supply of funds, called working capital, to meet demands for current expenses (e.g., raw materials, wages, salaries) while waiting for receipts from the sale of products or services. Obviously, it is desirable to keep the amount of capital tied up this way to as low a figure as is practical. Thus we have:



Over the long run the net flow of working capital into and out of the operations is zero, and none finds it way into net annual expense or operating income.

Now we will consider the complete money flow diagram, Figure C-1. The excess of revenue over net annual expense is termed operating income. From this stream, depreciation is diverted, leaving gross profit. The amount diverted is determined by depreciation accounting, the standard procedure used in business of charging for capital expenditures on a regular schedule over the period during which assets are in use. However, depreciation is handled as an item of annual expense and appears on operating expense sheets. Note, however, that it is an internal cost and is returned to the business. This is the reason depreciation is shown in the money flow diagram as separate from the net annual expense which represents dollars leaving the company. Depletion is handled in a similar way: it takes into account the consumption of assets which are exhaustible resources, such as the products of mines, forests, and oil and gas fields.

The gross profit remaining after the diversion of depreciation and depletion is subject to federal and state income taxes. After these taxes are deducted, the net profit remaining together with depreciation and depletion is shown in the money flow diagram, Figure C-1, as streaming into the firm's hypothetical bank. This combined stream is termed the *cash flow*.

Cash transfers to and from the company (other than the revenues, net annual expense, and income taxes, considered previously) are made

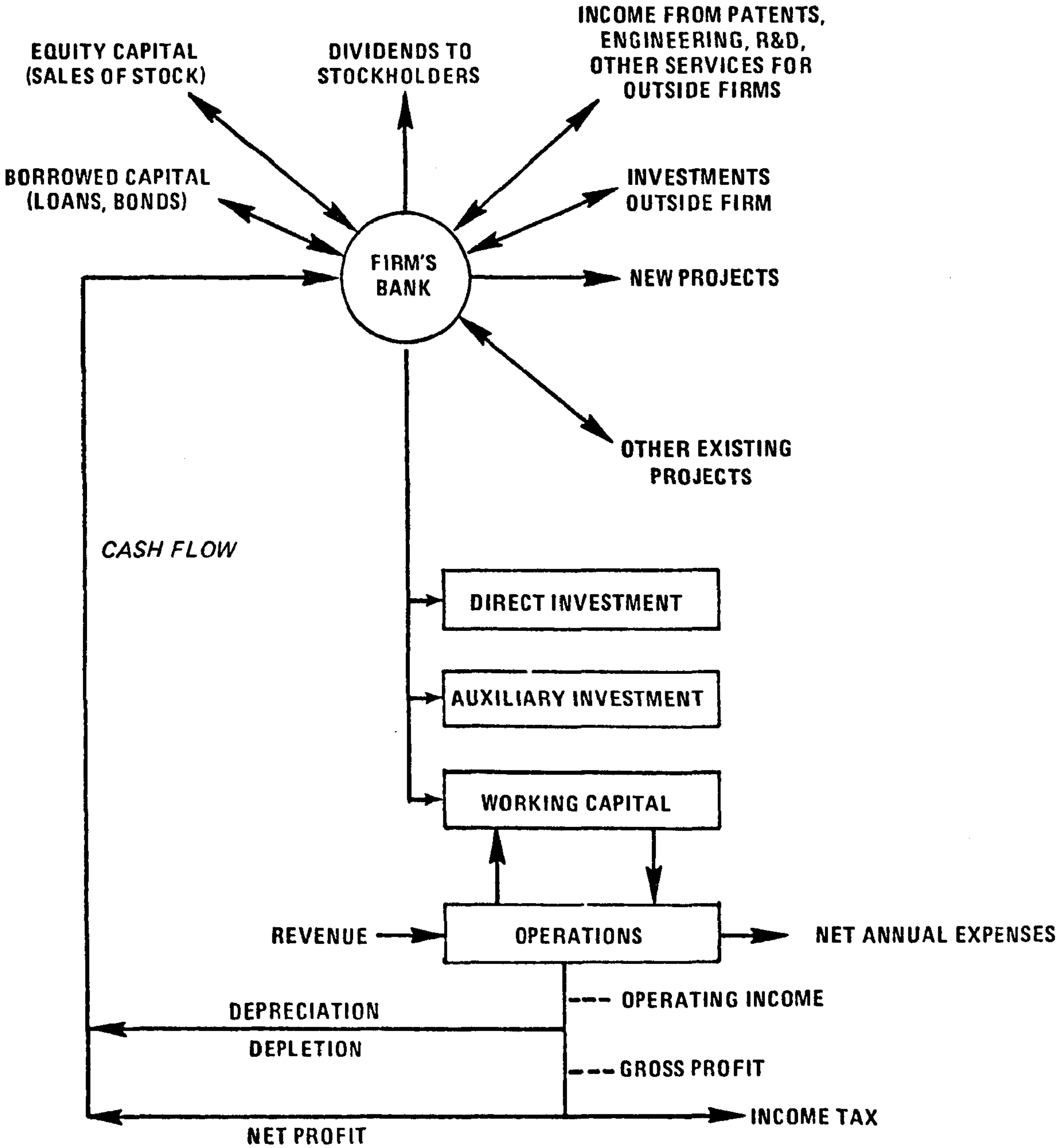


Figure C-1. Money flow diagram (this demonstrates the source of *cash flow*).

directly to and from the bank. Funds in the bank are used to repay borrowed capital, loans, and bonds, and to pay dividends on preferred and common stock. All of the net profit belongs to the owners (common stock shareholders) and, therefore, could be distributed as dividends. However, in most businesses roughly half of the net income is retained and (together with depreciation) helps to meet the continuing capital needs of the firm. This retained net profit (termed retained earnings) obviously increases the value of each owner's share of the enterprise (owner's equity).

In the previous discussion, we assumed a going operation for which the investment in plant facilities had already been made. Now we perceive that this investment and the necessary working capital were provided by the firm's bank, and that the depreciation and retained earnings from the project are now available for new projects and other capital requirements. The complete money flow diagram (Figure C-1) shows the recycle of funds, the flow of funds into new projects, and other flows associated with the various activities of the the firm's bank with outside entities. For example, the sale or leasing of patents and process know-how may be a very important source of funds.

We mentioned that the firm's bank disburses and receives funds other than those connected directly with operations. We can also look at the bank as the part of the firm that makes financial decisions concerning investments, expansions, and the like. This activity is similar to that of a commercial bank because it provides and allocates funds to competing projects. It decides what projects to approve and provides the necessary capitalization. All net profit and depreciation (i.e., *cash flow*) from the capitalized projects then return to the bank.

An examination of the lower portion of Figure C-1, now given with symbols in Figure C-2, shows that the *Cash Flow* for the year can be found from:

$$CF = D + (1-t)\ (S-C-D) \qquad \text{(C-1a)}$$

$$= tD + (1-t)S - (1-t)C \qquad \text{(C-1b)}$$

where

CF = *Cash Flow*
D = depreciation
S = revenue
C = net annual expenses
t = income tax rate.

Thus tD is the contribution to *cash flow* due to depreciation; (1-t)S, the contribution due to revenue; and -(1-t)C, the negative contribution due to expense.

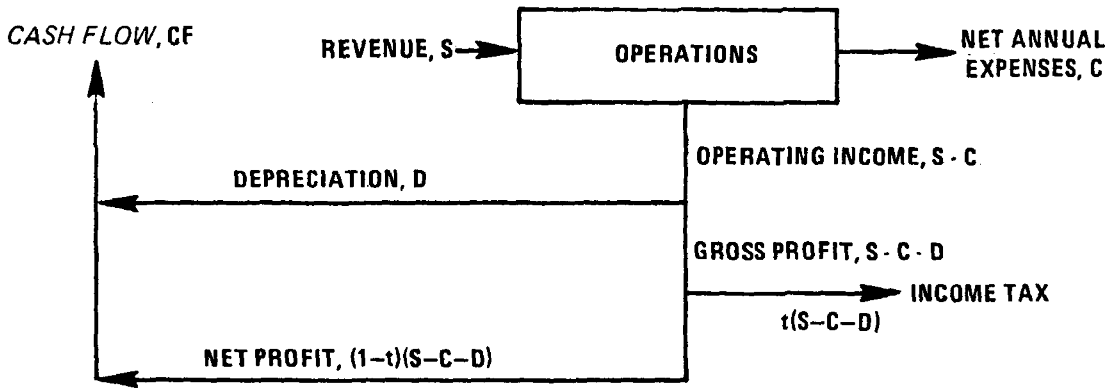


Figure C-2. Use of money flow diagram to define *cash flow*.

When a comparison is made between a candidate case and a base case, it is helpful to use the difference form of the foregoing equation:

$$\Delta CF = t\Delta D + (1-t)\Delta S - (1-t)\Delta C \qquad (C-2)$$

where $\Delta C = C_2 - C_1$, expense of the candidate case less expense of the base case. If the revenue is not affected by the process change then ΔS = zero, and would have no effect on the *cash flow*. The addition of an incremental investment (e.g., pollution abatement facilities) to an existing plant is an example of a situation where the foregoing difference equation would apply. In non-profit projects such as public works, over a period of time, revenues balance total annual expenses (which include depreciation) and there is no income tax since there is no profit. In this instance, depreciation is the only element of *cash flow*. Many of the activities of the bank do not apply; the borrowing and repayment of capital are essentially the only transactions. Depreciation is used to pay back the bondholders; it may be paid regularly or held in a sinking fund for later disbursement. Interest on the outstanding bonds is an item of annual expense.

Generally, attention is focused on a given project and not the entire enterprise. The flow of funds into and out of a project during its life may be shown in a "cumulative cash position chart," Figure C-3.

Zero time can be taken as the time when the plant first produces salable products or provides service. Prior to this, at a negative time, after the decision was made that the project should be undertak n, the firm's bank secures the necessary capital and makes it available to the project as needed for purchase of land, procurement and installation

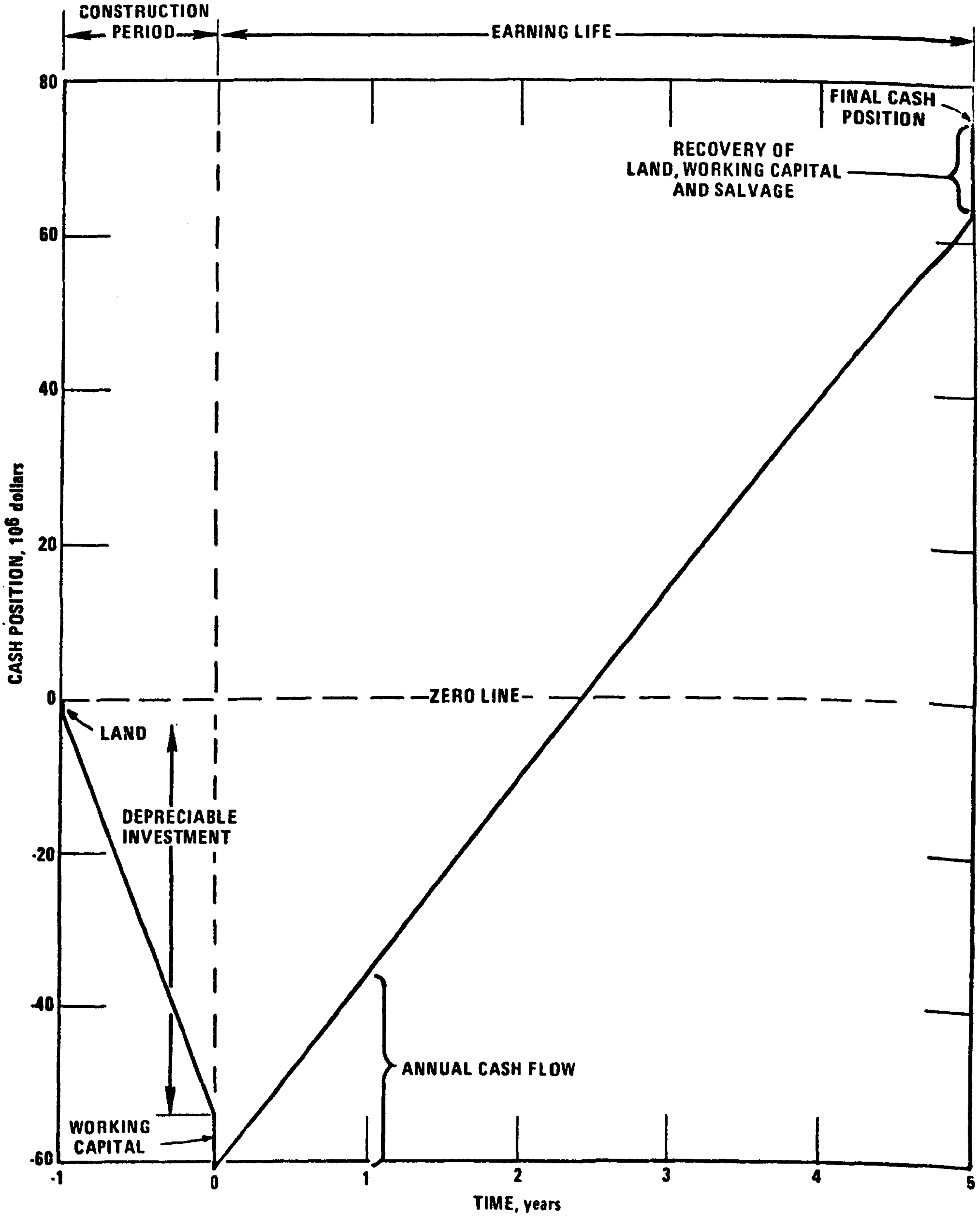


Figure C-3. Cumulative cash position chart (derived from (C-1)).

of equipment, investment in auxiliary facilities, and working capital. After time zero, the revenues should exceed the annual expenses and the project should begin to generate operating income. The cumulative *cash flow* is plotted throughout the life of the project and, at shutdown, adjustments are made for the recovery of land, working capital, and salvage value, if any. All the foregoing items, together with their timing, appear on the cumulative cash position chart. Fixed capital and other initial expenditures are shown below the horizontal base (zero) line in the negative region. Since *cash flow* is positive, it accumulates in the positive direction and after a period of time shows a positive cash position. Figure C-3 indicates that the cumulative *cash flow* first retires the investment. Profit appears only after the investment is completely paid off.

SELECTED REFERENCE

C-1. Perry, R. H., and C. H. Chilton, ed., "Chemical Engineers' Handbook," Fig. 25-9, McGraw-Hill (1973).

APPENDIX D

DISCRETE AND CONTINUOUS INTEREST FACTORS

CONTENTS

TABLE

APPENDIX D

DISCRETE AND CONTINUOUS INTEREST FACTORS

One should be conversant with both discrete and continuous interest to select and use discounting and compounding factors needed in the computation of several of the measures of merit (see Appendix E). Because discrete interest has been in common use and is explained consistently in a great number of texts both for business finance and engineering economy, this subject will not be developed here. For reference, Grant et al. (D-1) is particularly recommended. This work also contains complete discrete interest tables; however, these tables can be found in many other texts and reference works.

Continuous interest has not been as widely used; however, because it proves to be better suited to the evaluation of cash flow processes where some of the flows are more or less continuous, such as *cash flow* and construction costs, its use is growing: it is the standard in certain industries. However, because satisfactory instructions for the use of continuous interest tables can only be found in a few sources, sufficient background in this subject is provided here for the computation of measures of merit that use interest factors.

The explanation will be centered on the selection and modification of the table of continuous discounting factors from Hirschmann and Brauweiler (D-2) which are reproduced as Table D-1. Examples will be given to illustrate the use of this simple table for essential operations. Note the three panels that provide factors for some cash flows which occur at other than zero time:

Instantaneous Factors for cash flows that occur at a point in time after time zero;

Uniform Factors for cash flows that occur uniformly over a period of years, starting at time zero; and

Years-Digits Factors for cash flows declining to time zero at a constant rate over a period of years, starting at time zero.

Note that the interest factors are all for discounting, which means that they correct future flows against the calender to some earlier date such as a reference time zero. To identify the factor for a specific cash

TABLE D-1a. FACTORS FOR CONTINUOUS DISCOUNTING (D-2, p. 73)
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Instantaneous

Factors for Cash Effects That Occur at A Point in Time After the Reference Point.

R X T	0	1	2	3	4	5	6	7	8	9
0	1.0000	0.9901	0.9802	0.9704	0.9608	0.9512	0.9418	0.9324	0.9231	0.9139
10	0.9048	0.8958	0.8869	0.8781	0.8694	0.8607	0.8521	0.8437	0.8353	0.8270
20	0.8187	0.8106	0.8025	0.7945	0.7866	0.7788	0.7711	0.7634	0.7558	0.7483
30	0.7408	0.7334	0.7261	0.7189	0.7118	0.7047	0.6977	0.6907	0.6839	0.6771
40	0.6703	0.6637	0.6570	0.6505	0.6440	0.6376	0.6313	0.6250	0.6188	0.6126
50	0.6065	0.6005	0.5945	0.5886	0.5827	0.5770	0.5712	0.5655	0.5599	0.5543
60	0.5488	0.5434	0.5379	0.5326	0.5273	0.5220	0.5169	0.5117	0.5066	0.5016
70	0.4966	0.4916	0.4868	0.4819	0.4771	0.4724	0.4677	0.4630	0.4584	0.4538
80	0.4493	0.4449	0.4404	0.4360	0.4317	0.4274	0.4232	0.4190	0.4148	0.4107
90	0.4066	0.4025	0.3985	0.3946	0.3906	0.3867	0.3829	0.3791	0.3753	0.3716
100	0.3679	0.3642	0.3606	0.3570	0.3535	0.3499	0.3465	0.3430	0.3396	0.3362
110	0.3329	0.3296	0.3263	0.3230	0.3198	0.3166	0.3135	0.3104	0.3073	0.3042
120	0.3012	0.2982	0.2952	0.2923	0.2894	0.2865	0.2837	0.2808	0.2780	0.2753
130	0.2725	0.2698	0.2671	0.2645	0.2618	0.2592	0.2567	0.2541	0.2516	0.2491
140	0.2466	0.2441	0.2417	0.2393	0.2369	0.2346	0.2322	0.2299	0.2276	0.2254
150	0.2231	0.2209	0.2187	0.2165	0.2144	0.2122	0.2101	0.2080	0.2060	0.2039
160	0.2019	0.1999	0.1979	0.1959	0.1940	0.1921	0.1901	0.1882	0.1864	0.1845
170	0.1827	0.1809	0.1791	0.1773	0.1755	0.1738	0.1720	0.1703	0.1686	0.1670
180	0.1653	0.1637	0.1620	0.1604	0.1588	0.1572	0.1557	0.1541	0.1526	0.1511
190	0.1496	0.1481	0.1466	0.1451	0.1437	0.1423	0.1409	0.1395	0.1381	0.1367
200	0.1353	0.1340	0.1327	0.1313	0.1300	0.1287	0.1275	0.1262	0.1249	0.1237
210	0.1225	0.1212	0.1200	0.1188	0.1177	0.1165	0.1153	0.1142	0.1130	0.1119
220	0.1108	0.1097	0.1086	0.1075	0.1065	0.1054	0.1044	0.1033	0.1023	0.1013
230	0.1003	0.0993	0.0983	0.0973	0.0963	0.0954	0.0944	0.0935	0.0926	0.0916
240	0.0907	0.0898	0.0889	0.0880	0.0872	0.0863	0.0854	0.0846	0.0837	0.0829
250	0.0821	0.0813	0.0805	0.0797	0.0789	0.0781	0.0773	0.0765	0.0758	0.0750
260	0.0743	0.0735	0.0728	0.0721	0.0714	0.0707	0.0699	0.0693	0.0686	0.0679
270	0.0672	0.0665	0.0659	0.0652	0.0646	0.0639	0.0633	0.0627	0.0620	0.0614
280	0.0608	0.0602	0.0596	0.0590	0.0584	0.0578	0.0573	0.0567	0.0561	0.0556
290	0.0550	0.0545	0.0539	0.0534	0.0529	0.0523	0.0518	0.0513	0.0508	0.0503
300	0.0498	0.0493	0.0488	0.0483	0.0478	0.0474	0.0469	0.0464	0.0460	0.0455
310	0.0450	0.0446	0.0442	0.0437	0.0433	0.0429	0.0424	0.0420	0.0416	0.0412
320	0.0408	0.0404	0.0400	0.0396	0.0392	0.0388	0.0384	0.0380	0.0376	0.0373
330	0.0369	0.0365	0.0362	0.0358	0.0354	0.0351	0.0347	0.0344	0.0340	0.0337
340	0.0334	0.0330	0.0327	0.0324	0.0321	0.0317	0.0314	0.0311	0.0308	0.0305
350	0.0302	0.0299	0.0296	0.0293	0.0290	0.0287	0.0284	0.0282	0.0279	0.0276
360	0.0273	0.0271	0.0268	0.0265	0.0263	0.0260	0.0257	0.0255	0.0252	0.0250
370	0.0247	0.0245	0.0242	0.0240	0.0238	0.0235	0.0233	0.0231	0.0228	0.0226
380	0.0224	0.0221	0.0219	0.0217	0.0215	0.0213	0.0211	0.0209	0.0207	0.0204
390	0.0202	0.0200	0.0198	0.0196	0.0194	0.0193	0.0191	0.0189	0.0187	0.0185
400	0.0183	0.0181	0.0180	0.0178	0.0176	0.0174	0.0172	0.0171	0.0169	0.0167
410	0.0166	0.0164	0.0162	0.0161	0.0159	0.0158	0.0156	0.0155	0.0153	0.0151
420	0.0150	0.0148	0.0147	0.0146	0.0144	0.0143	0.0141	0.0140	0.0138	0.0137
430	0.0136	0.0134	0.0133	0.0132	0.0130	0.0129	0.0128	0.0127	0.0125	0.0124
440	0.0123	0.0122	0.0120	0.0119	0.0118	0.0117	0.0116	0.0114	0.0113	0.0112
450	0.0111	0.0110	0.0109	0.0108	0.0107	0.0106	0.0105	0.0104	0.0103	0.0102
460	0.0101	0.0100	0.0099	0.0098	0.0097	0.0096	0.0095	0.0094	0.0093	0.0092
470	0.0091	0.0090	0.0089	0.0088	0.0087	0.0087	0.0086	0.0085	0.0084	0.0083
480	0.0082	0.0081	0.0081	0.0080	0.0079	0.0078	0.0078	0.0077	0.0076	0.0075
490	0.0074	0.0074	0.0073	0.0072	0.0072	0.0071	0.0070	0.0069	0.0069	0.0068

R X T	0	10	20	30	40	50	60	70	80	90
500	0.0067	0.0061	0.0055	0.0050	0.0045	0.0041	0.0037	0.0033	0.0030	0.0027
600	0.0025	0.0022	0.0020	0.0018	0.0017	0.0015	0.0014	0.0012	0.0011	0.0010
700	0.0009	0.0008	0.0007	0.0007	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
800	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001
900	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
1000	0.0000									

R X T = ANNUAL INTEREST RATE X NUMBER OF YEARS IN TIME PERIOD INVOLVED

TABLE D-1b. FACTORS FOR CONTINUOUS DISCOUNTING (D-2, p. 73)
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Uniform

Factors for Cash Effects That Occur Uniformly Over a Period of Years Starting With the Reference Point.

R X T	0	1	2	3	4	5	6	7	8	9
0	1.0000	0.9950	0.9901	0.9851	0.9803	0.9754	0.9706	0.9658	0.9610	0.9563
10	0.9516	0.9470	0.9423	0.9377	0.9332	0.9286	0.9241	0.9196	0.9152	0.9107
20	0.9063	0.9020	0.8976	0.8933	0.8891	0.8848	0.8806	0.8764	0.8722	0.8681
30	0.8639	0.8598	0.8558	0.8517	0.8477	0.8438	0.8398	0.8359	0.8319	0.8281
40	0.8242	0.8204	0.8166	0.8128	0.8090	0.8053	0.8016	0.7979	0.7942	0.7906
50	0.7869	0.7833	0.7798	0.7762	0.7727	0.7692	0.7657	0.7622	0.7588	0.7554
60	0.7520	0.7486	0.7452	0.7419	0.7386	0.7353	0.7320	0.7288	0.7256	0.7224
70	0.7192	0.7160	0.7128	0.7097	0.7066	0.7035	0.7004	0.6974	0.6944	0.6913
80	0.6883	0.6854	0.6824	0.6795	0.6765	0.6736	0.6707	0.6679	0.6650	0.6622
90	0.6594	0.6566	0.6537	0.6510	0.6483	0.6455	0.6428	0.6401	0.6374	0.6348
100	0.6321	0.6295	0.6269	0.6243	0.6217	0.6191	0.6166	0.6140	0.6115	0.6090
110	0.6065	0.6040	0.6016	0.5991	0.5967	0.5942	0.5918	0.5894	0.5871	0.5847
120	0.5823	0.5800	0.5777	0.5754	0.5731	0.5708	0.5685	0.5663	0.5641	0.5618
130	0.5596	0.5574	0.5552	0.5530	0.5509	0.5487	0.5466	0.5444	0.5424	0.5402
140	0.5381	0.5361	0.5340	0.5320	0.5299	0.5279	0.5259	0.5239	0.5219	0.5199
150	0.5179	0.5160	0.5140	0.5121	0.5102	0.5082	0.5064	0.5044	0.5026	0.5007
160	0.4988	0.4970	0.4952	0.4933	0.4915	0.4897	0.4879	0.4861	0.4843	0.4825
170	0.4808	0.4790	0.4773	0.4756	0.4739	0.4721	0.4704	0.4687	0.4671	0.4654
180	0.4637	0.4621	0.4605	0.4588	0.4571	0.4555	0.4540	0.4523	0.4508	0.4491
190	0.4476	0.4460	0.4445	0.4429	0.4414	0.4399	0.4383	0.4368	0.4354	0.4338
200	0.4323	0.4308	0.4294	0.4279	0.4265	0.4250	0.4236	0.4221	0.4207	0.4193
210	0.4179	0.4165	0.4151	0.4137	0.4123	0.4109	0.4096	0.4082	0.4069	0.4055
220	0.4042	0.4029	0.4015	0.4002	0.3989	0.3976	0.3963	0.3950	0.3937	0.3925
230	0.3912	0.3899	0.3887	0.3874	0.3862	0.3849	0.3837	0.3825	0.3813	0.3801
240	0.3789	0.3777	0.3765	0.3753	0.3741	0.3729	0.3718	0.3706	0.3695	0.3683
250	0.3672	0.3660	0.3649	0.3638	0.3627	0.3615	0.3604	0.3593	0.3582	0.3571
260	0.3560	0.3550	0.3539	0.3528	0.3517	0.3507	0.3496	0.3486	0.3476	0.3465
270	0.3455	0.3445	0.3434	0.3424	0.3414	0.3404	0.3393	0.3384	0.3374	0.3364
280	0.3354	0.3344	0.3335	0.3325	0.3315	0.3306	0.3296	0.3287	0.3277	0.3268
290	0.3259	0.3249	0.3240	0.3231	0.3221	0.3212	0.3203	0.3194	0.3185	0.3176
300	0.3167	0.3158	0.3150	0.3141	0.3132	0.3123	0.3115	0.3106	0.3098	0.3089
310	0.3080	0.3072	0.3064	0.3055	0.3047	0.3039	0.3030	0.3022	0.3014	0.3006
320	0.2998	0.2990	0.2982	0.2974	0.2966	0.2958	0.2950	0.2942	0.2934	0.2926
330	0.2919	0.2911	0.2903	0.2896	0.2888	0.2880	0.2873	0.2865	0.2858	0.2850
340	0.2843	0.2836	0.2828	0.2821	0.2814	0.2807	0.2799	0.2792	0.2785	0.2778
350	0.2771	0.2764	0.2757	0.2750	0.2743	0.2736	0.2729	0.2722	0.2715	0.2709
360	0.2702	0.2695	0.2688	0.2682	0.2675	0.2669	0.2662	0.2655	0.2649	0.2642
370	0.2636	0.2629	0.2623	0.2617	0.2610	0.2604	0.2598	0.2591	0.2585	0.2579
380	0.2573	0.2567	0.2560	0.2554	0.2548	0.2542	0.2536	0.2530	0.2524	0.2518
390	0.2512	0.2506	0.2500	0.2495	0.2489	0.2483	0.2477	0.2471	0.2466	0.2460
400	0.2454	0.2449	0.2443	0.2437	0.2432	0.2426	0.2421	0.2415	0.2410	0.2404
410	0.2399	0.2393	0.2388	0.2382	0.2377	0.2372	0.2366	0.2361	0.2356	0.2350
420	0.2345	0.2340	0.2335	0.2330	0.2325	0.2319	0.2314	0.2309	0.2304	0.2299
430	0.2294	0.2289	0.2284	0.2279	0.2274	0.2269	0.2264	0.2259	0.2255	0.2250
440	0.2245	0.2240	0.2235	0.2230	0.2226	0.2221	0.2216	0.2212	0.2207	0.2202
450	0.2198	0.2193	0.2188	0.2184	0.2179	0.2175	0.2170	0.2166	0.2161	0.2157
460	0.2152	0.2148	0.2143	0.2139	0.2134	0.2130	0.2126	0.2121	0.2117	0.2113
470	0.2108	0.2104	0.2100	0.2096	0.2091	0.2087	0.2083	0.2079	0.2074	0.2070
480	0.2066	0.2062	0.2058	0.2054	0.2050	0.2046	0.2042	0.2038	0.2034	0.2030
490	0.2026	0.2022	0.2018	0.2014	0.2010	0.2006	0.2002	0.1998	0.1994	0.1990

R X T	0	10	20	30	40	50	60	70	80	90
500	0.1987	0.1949	0.1912	0.1877	0.1843	0.1811	0.1779	0.1749	0.1719	0.1690
600	0.1663	0.1636	0.1610	0.1584	0.1560	0.1536	0.1513	0.1491	0.1469	0.1448
700	0.1427	0.1407	0.1388	0.1369	0.1351	0.1333	0.1315	0.1298	0.1282	0.1265
800	0.1250	0.1234	0.1219	0.1206	0.1190	0.1176	0.1163	0.1149	0.1136	0.1123
900	0.1111	0.1099	0.1087	0.1075	0.1064	0.1053	0.1043	0.1031	0.1020	0.1010
1000	0.1000	0.0990	0.0980	0.0971	0.0962	0.0952	0.0943	0.0935	0.0926	0.0917
1100	0.0909	0.0901	0.0893	0.0885	0.0877	0.0869	0.0862	0.0855	0.0847	0.0840
1200	0.0833	0.0826	0.0820	0.0813	0.0806	0.0800	0.0794	0.0787	0.0781	0.0775
1300	0.0769	0.0763	0.0758	0.0752	0.0746	0.0741	0.0735	0.0730	0.0725	0.0719
1400	0.0714	0.0709	0.0704	0.0699	0.0694	0.0690	0.0685	0.0680	0.0676	0.0671
1500	0.0667	0.0662	0.0658	0.0654	0.0649	0.0645	0.0641	0.0637	0.0633	0.0629
1600	0.0625	0.0621	0.0617	0.0613	0.0610	0.0606	0.0602	0.0599	0.0595	0.0592
1700	0.0588	0.0585	0.0581	0.0578	0.0575	0.0571	0.0568	0.0565	0.0562	0.0559
1800	0.0556	0.0552	0.0549	0.0546	0.0543	0.0541	0.0538	0.0535	0.0532	0.0529
1900	0.0526	0.0524	0.0521	0.0518	0.0515	0.0513	0.0510	0.0508	0.0505	0.0502

R X T = ANNUAL INTEREST RATE X NUMBER OF YEARS IN TIME PERIOD INVOLVED

TABLE D-1c. FACTORS FOR CONTINUOUS DISCOUNTING (D-2, p. 73)

Excerpted by special permission from CHEMICAL ENGINEERING, July 19, 1965.

Years-Digits

Factors For Cash Effects Declining to Zero at a Constant Rate Over a Period of Years Starting With the Reference Point.

R X T	0	1	2	3	4	5	6	7	8	9
0	1.0000	0.9967	0.9934	0.9901	0.9868	0.9835	0.9803	0.9771	0.9739	0.9707
10	0.9675	0.9643	0.9612	0.9580	0.9549	0.9518	0.9487	0.9457	0.9426	0.9396
20	0.9365	0.9335	0.9305	0.9275	0.9246	0.9216	0.9187	0.9158	0.9129	0.9100
30	0.9071	0.9042	0.9013	0.8985	0.8957	0.8929	0.8901	0.8873	0.8845	0.8818
40	0.8790	0.8763	0.8736	0.8708	0.8682	0.8655	0.8628	0.8602	0.8575	0.8549
50	0.8523	0.8497	0.8471	0.8445	0.8419	0.8394	0.8368	0.8343	0.8317	0.8292
60	0.8267	0.8242	0.8218	0.3193	0.8169	0.8144	0.8120	0.8096	0.9072	[illegible]
70	0.8024	0.8000	0.7976	0.7953	0.7930	0.7906	0.7883	0.7860	0.7837	0.7814
80	0.7791	0.7769	0.7746	0.7724	0.7701	0.7679	0.7657	0.7635	0.7613	0.7591
90	0.7570	0.7548	0.7527	0.7505	0.7484	[illegible]	0.7441	0.7420	0.7399	0.7378
100	0.7358	0.7337	0.7316	0.7295	0.7275	0.7255	0.7235	0.7215	0.7195	0.7175
110	0.7155	0.7135	0.7115	0.7095	0.7076	0.7057	0.7037	0.7018	0.6999	0.6980
120	0.6961	0.6942	0.6923	0.6904	0.6885	0.6867	0.6848	0.6330	0.6812	0.6794
130	0.6776	0.6758	0.6740	0.6722	0.6704	0.6686	0.5568	0.6550	0.6532	0.6615
140	0.6598	0.6580	0.6563	0.6546	0.6529	0.6512	0.6495	0.6478	0.6461	0.6444
150	0.6428	0.6411	0.6394	0.6377	0.6361	0.6345	0.6329	0.6313	0.6297	0.6281
160	0.6265	0.6249	0.6233	0.6217	0.6201	0.6186	0.6170	0.6154	0.6139	0.6124
170	0.6109	0.6093	0.6078	0.6063	0.6048	0.6033	0.6018	0.6003	0.5988	0.5973
180	0.5959	0.5944	0.5929	0.5914	0.5900	0.5886	0.5871	0.5856	0.5842	0.5828
190	0.5814	0.5800	0.5786	0.5772	0.5758	0.5745	0.5731	0.5717	0.5703	0.5690
200	0.5677	0.5663	0.5649	0.5636	0.5623	0.5610	0.5596	0.5583	0.5570	0.5557
210	0.5544	0.5531	0.5518	0.5505	0.5492	0.5480	0.5467	0.5454	0.5441	0.5429
220	0.5417	0.5404	0.5391	0.5379	0.5367	0.5355	0.5342	0.5330	0.5318	0.5306
230	0.5294	0.5282	0.5270	0.5258	0.5246	0.5234	0.5222	0.5210	0.5198	0.5187
240	0.5176	0.5164	0.5152	0.5141	0.5130	0.5119	0.5107	0.5096	0.5085	0.5074
250	0.5063	0.5052	0.5041	0.5030	0.5019	0.5008	0.4997	0.4986	0.4975	0.4964
260	0.4953	0.4942	0.4931	0.4920	0.4910	0.4900	0.4889	0.4878	0.4868	0.4858
270	0.4848	0.4837	0.4827	0.4817	0.4807	0.4797	0.4787	0.4777	0.4767	0.4757
280	0.4747	0.4737	0.4727	0.4717	0.4707	0.4698	0.4688	0.4678	0.4668	0.4658
290	0.4649	0.4639	0.4629	0.4620	0.4611	0.4602	0.4592	0.4582	0.4573	0.4564
300	0.4555	0.4545	0.4536	0.4527	0.4518	0.4509	0.4500	0.4491	0.4482	0.4473
310	0.4464	0.4455	0.4446	0.4437	0.4428	0.4419	0.4410	0.4401	0.4392	0.4384
320	0.4376	0.4367	0.4358	0.4349	0.4340	0.4332	0.4324	0.4316	0.4308	0.4300
330	0.4292	0.4283	0.4274	0.4266	0.4258	0.4250	0.4242	0.4234	0.4226	0.4218
340	0.4210	0.4202	0.4194	0.4186	0.4178	0.4170	0.4162	0.4154	0.4146	0.4138
350	0.4131	0.4123	0.4115	0.4107	0.4099	0.4091	0.4083	0.4076	0.4069	0.4062
360	0.4055	0.4047	0.4039	0.4031	0.4023	0.4016	0.4009	0.4002	0.3995	0.3988
370	0.3981	0.3973	0.3965	0.3958	0.3951	0.3944	0.3937	0.3930	0.3923	0.3916
380	0.3909	0.3902	0.3895	0.3888	0.3881	0.3874	0.3867	0.3860	0.3853	0.3846
390	0.3840	0.3833	0.3826	0.3819	0.3812	0.3805	0.3798	0.3791	0.3785	0.3779
400	0.3773	0.3766	0.3759	0.3752	0.3745	0.3738	0.3732	0.3726	0.3720	0.3714
410	0.3708	0.3701	0.3694	0.3687	0.3681	0.3675	0.3669	0.3663	0.3657	0.3651
420	0.3645	0.3638	0.3632	0.3626	0.3620	0.3614	0.3608	0.3602	0.3596	0.3590
430	0.3584	0.3578	0.3572	0.3566	0.3560	0.3554	0.3548	0.3542	0.3536	0.3530
440	0.3525	0.3519	0.3513	0.3507	0.3501	0.3495	0.3489	0.3483	0.3478	0.3473
450	0.3468	0.3462	0.3456	0.3450	0.3444	0.3438	0.3432	0.3427	0.3422	0.3417
460	0.3412	0.3406	0.3400	0.3394	0.3388	0.3383	0.3378	0.3373	0.3368	0.3363
470	0.3358	0.3352	0.3346	0.3341	0.3336	0.3331	0.3326	0.3321	0.3316	0.3311
480	0.3306	0.3300	0.3294	0.3289	0.3284	0.3279	0.3274	0.3269	0.3264	0.3259
490	0.3254	0.3249	0.3244	0.3239	0.3234	0.3229	0.3224	0.3219	0.3214	0.3209

R X T	0	10	20	30	40	50	60	70	80	90
500	0.3205	0.3157	0.3111	0.3065	0.3020	0.2978	0.2936	0.2895	0.2856	0.2817
600	0.2779	0.2742	0.2707	0.2672	0.2637	0.2604	0.2572	0.2540	0.2509	0.2479
700	0.2449	0.2420	0.2392	0.2364	0.2337	0.2311	0.2285	0.2260	0.2235	0.2212
800	0.2188	0.2165	0.2143	0.2121	0.2098	0.2076	0.2056	0.2036	0.2016	0.1995
900	0.1975	0.1957	0.1939	0.1920	0.1902	0.1884	0.1867	0.1850	0.1834	0.1817
1000	0.1800	0.1784	0.1769	0.1753	0.1738	0.1723	0.1709	0.1694	0.1680	0.1667
1100	0.1653	0.1639	0.1624	0.1613	0.1601	0.1588	0.1576	0.1563	0.1551	0.1539
1200	0.1528	0.1516	0.1505	0.1494	0.1483	0.1472	0.1462	0.1451	0.1441	0.1430
1300	0.1420	0.1410	0.1401	0.1390	0.1382	0.1372	0.1363	0.1354	0.1345	0.1336
1400	0.1327	0.1318	0.1309	0.1301	0.1292	0.1284	0.1276	0.1268	0.1260	0.1252
1500	0.1244	0.1236	0.1229	0.1221	0.1214	0.1207	0.1200	0.1193	0.1186	0.1179
1600	0.1172	0.1165	0.1158	0.1151	0.1145	0.1139	0.1133	0.1126	0.1120	0.1113
1700	0.1107	0.1101	0.1095	0.1089	0.1084	0.1078	0.1072	0.1066	0.1060	0.1054
1800	0.1049	0.1044	0.1039	0.1033	0.1028	0.1023	0.1018	0.1012	0.1007	0.1002
1900	0.0997	0.0992	0.0987	0.0982	0.0978	0.0973	0.0968	0.0963	0.0959	0.0955

R X T = ANNUAL INTEREST RATE X NUMBER OF YEARS IN TIME PERIOD INVOLVED

flow, it is necessary to specify the annual interest rate*, R, in percent and the number of years in the time period involved, T. The value of the product RXT is used to find the appropriate discounting factor. Five examples of the use of this table follow.

1. To find the present worth at the start of a uniform *Cash Flow* of $150,000 per year over a 5 year period, at 15 percent interest, one first figures that RXT = 15 X 5 = 75. In Table D-1b, one goes down the left-hand RXT column to 70 and to the right to 5 for 75 and reads a discounting factor of 0.7035. For this case, the present worth is 150,000 X 5 X 0.7035 = $527,625.

2. Next the present worth will be found for a *Cash Flow* of $50,000 that occurs during the fifth year (4 to 5) of a project. The nominal discounting rate of interest is 12 percent. The discounting of this sum to time zero requires two discounting steps. First the sum which flows continuously from year 4 to year 5 is discounted to year 4 (this is the beginning of the 1-year period). For this operation R = 12, T = 1, or RXT = 12 X 1 = 12, for which the discounting factor from Table D-1b is 0.9423. Then this sum is discounted from year 4 to year zero using RXT = 12 X 4 = 48, using the factor 0.6188 from Table D-1a. The present worth calculation is: $50,000 X 0.9423 X 0.6188 = $29,155.

3. An extra operation is also needed to compound an amount of money. For an instantaneous cash effect, use the reciprocal of the discounting factor. An example would be the compounding of M$1,000 for land from 3 years before plant start-up (year -3) to start-up (year zero) using 16 percent interest. Hence, to compound, the reciprocal of the discounting factor for RXT = 16 X 3 = 48 or 0.6188 would be used. Using the reciprocal, the present worth is M$1,000 ÷ 0.6188 = M$1,616.

4. For a uniform cash flow (e.g., for capital construction costs) the calculation is more involved: first the cash flow must be discounted to the time it started; then this instantaneous value is compounded to a future value using the reciprocal of the instantaneous discounting factor as in Example 3. As an illustration, the present worth is sought for construction costs of M$10,000 occurring uniformly over 2 years before start-up (year -2) to start-up (year zero). Interest is 13 percent. The uniform discount factor for RXT = 13 X 2 = 26 is 0.8806; the instantaneous compounding factor, from the discounting factor for RXT = 13 X 2 = 26 of 0.7711, is 1/0.7711. Then the present worth is M$10,000 X 0.8806 ÷ 0.7711 = M$11,420.

5. Determine the present worth of maintenance charges that increase continuously from zero to M$100 per year over a 10-year period.

---

*This is nominal interest, as distinguished from the effective rate.

Interest is 15 percent. For this problem, the years-digits factors in Table D-1c, so-termed because they directly handle charges for sum-of-the-digits depreciation, facilitate the computation. The present worth is found by discounting M$100 per year for 10 years and subtracting from this the discounted value of M$100 per year at year zero declining at a constant rate over 10 years. RXT = 15 X 10 = 150; uniform factor = 0.5179; years-digits factor = 0.6428. Total maintenance costs = M$100 X 10 ÷ 2 = $500. Then, the present worth of M$100/year for 10 years is M$100 X 10 X 0.5179 = M$518 minus the present worth of $100/year declining to zero over 10 years M$500 X 0.6428 = M$321, giving a net present worth of M$197.

By operations similar to above, one can carry out most of the calculations needed to take continuous interest into account. For other situations, the appropriate factors can be calculated using formulas which can be found in a number of standard sources (D-1, D-2, D-3). Also Perry and Chilton (D-4) include a copy of the Gregory table which is very useful for directly carrying out certain operations such as those requiring two steps in Examples 2 and 4, above.

The two tables mentioned above (viz., Table D-1 and the Gregory table (D-4)) give nominal continuous interest factors; these were used first and continue to be used in many industries. However, it should be realized that there are also effective continuous interest tables in use (see Grant et al. (D-1)); these give present worth values equivalent to those calculated by discrete interest rates. The designation for a nominal rate is always slightly less than its effective interest equivalent; e.g., the effective interest equivalent is 10.52 percent for a nominal interest rate of 10 percent. A number of examples of the use of continuous interest factors are in Appendices E and K.

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APPENDIX E

MEASURES OF MERIT

CONTENTS

FIGURE

TABLES

APPENDIX E

MEASURES OF MERIT

The economic feasibility of a project is indicated by one or several relations involving both annual operating expense and investment cost. The application of these relations corresponds to life cycle cost analysis. These relations yield indices which have several general designations, such as measures of merit, figures of merit, and feasibility criteria. The commonly used criteria will be named and described. The applicability of the appropriate measures of merit to the three financial sectors, private, regulated, and public, will be delineated. Several examples of the computation of measures of merit are illustrated: three for privately financed facilities; one for a project in a regulated industry. Because of the simplicity of the method, it was not deemed necessary to illustrate by example the calculation of measures of merit for public sector projects.

CRITERIA FOR EVALUATION

The following will be considered:

1. Return on investment (ROI).
2. Internal rate of return (IROR).
3. Payout time.
4. Equivalent annual cost.
5. Unit costs.

Present value, or present worth, is also a common criteria but, since it can be computed as a step in the determination of IROR, equivalent annual cost, and certain unit costs, it is not specifically considered in this procedure.

Definitions

Return on Investment (ROI) --

Average annual net profit divided by total capital investment (including land and working capital) gives return on original investment (ROI). This is a widely used criterion for profitability.

Internal Rate of Return (IROR) --

Internal rate of return (IROR) -- also known as Interest Rate of Return, Discounted Cash Flow, and Profitability Index -- is another useful criterion. It is used when revenue is associated with the operation and profit is generated. It is the discount rate which gives a present value of zero for the sum of the cash flows occurring during the project lifetime: *cash flow*, capital outlays, and end-of-life recoveries. Inputs are positive (+) and outlays negative (-). The procedure takes into account the timing of the cash effects and whether they are continuous over a period of time or are discrete (instantaneous) transactions. The calculation of IROR is by trial and error; computer programs are available for this purpose.

Note that the IROR technique can be used to determine revenue requirements when the internal rate of return is specified.

Payout Time --

Payout time or just payout is the time in years required, after start of operations, for the accumulation of *Cash Flow* (net profit plus depreciation -- see Appendix C) to equal the depreciable investment. Although it is frequently mentioned, it is actually only of secondary importance.

Equivalent Annual Cost --

In this treatment "equivalent annual cost" will be used as a generic term to describe equivalent annual cash flows. Equivalent annual costs can be obtained by calculation, first of the present value of the cash flows of concern* by discounting at an assigned rate. As with the IROR procedure, the timing over the life of the project and the nature of cash flows (instantaneous or continuous) must be taken into account. This present value is then converted (at the same discount rate) to an equivalent annual cost over the life of the project. It can be calculated either as a uniform end-of-year value by using discrete interest factors, or a continuous flow throughout each year using continuous interest factors. The former corresponds to "equivalent uniform cash flow" as used by Grant et al. (E-1, p. 64) and UNACOST as defined by Jelen (E-2, p. 25). However, an "equivalent annual cost" for continuous flow throughout the year is often preferred.

A general expression for "equivalent annual cost or cash flow" is:

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*Note that the "cash flows of concern" depend on the nature of the equivalent annual cost to be calculated; e.g., revenue requirement, uniform annual cost, or equivalent annual value. These are developed immediately below.

$$\text{Equivalent Uniform Cash Flow} = \frac{\sum_{i=1}^{i=i} \sum_{n=1}^{n=n} C_{in} \frac{(1+s_i)^{n-1}}{(1+r)^n}}{\sum_{n=1}^{n=n} \frac{1}{(1+r)^n}} \quad . . . \qquad \text{(E-1)}$$

where:

C_{in} = cost component i at the end of n years evaluated at constant dollars when n = 1, where 1 designates the end of the first year of operation. Examples are operating expenses, interest on debt, equity dividends, income tax. For certain circumstances, investment items and capital recoveries at the project shutdown are included. Since investment charges mainly occur at times before startup (n = zero), the accommodation of these outlays requires extension of the n limits of Equation E-1 to minus n years.

s_i = escalation rate of cost component i (some costs such as bond interest and depreciation charges do not respond to inflation; these have values of s_i = zero).

r = discount rate reflecting expected return, or cost of capital.

n = year after start-up time (n = zero) during which or at the end of which the cash flow occurs.

Note that the discount rates used in Equation E-1 are discrete; continuous interest factors are more likely to be used for private sector analyses, particularly if some of the cash flows are continuous. Note that the term

$$\sum_{n=1}^{n=n} \frac{1}{(1+r)^n}$$

in the denominator corresponds to the "uniform annual series present worth factor" (E-1). The numerator in Equation E-1 is the "present value."

A number of "equivalent annual costs" in common use will now be described.

1. Annualized Cost -- This is a standard measure of merit for cost analysis of public utility (regulated industry) projects. All outlays that contribute to expected revenue are included: total operating expenses (including depreciation), interest on debt, income tax, and equity dividends. Capital outlays are reflected indirectly as depreciation charges, interest on debt, and equity dividends. Equation E-1 is

applied. An example of this computation is given in the example at the end of this appendix. A simplified procedure often-used is

Annual Cost = (Net Annual Expense) - (Debt Interest*)
+ (Capital Charge Factor) X (Capital Investment) ... (E-2)

The capital charge factor for electric utilities ranges from 0.15 to 0.20. It includes the depreciation charge, additional capital investment, average interest on debt, average equity dividends, and income tax. This procedure requires that output is constant and inflation is neglected. In Appendix J a comparison is made of the annualized cost calculated by both the detailed method that applies Equation E-1 and the simplified procedure based on Equation E-2.

2. Uniform Annual Cost (UAC) -- The computation of this value is described in texts on engineering economy (E-1, E-2). It is in common use in the private sector for determining the actual cost of a change in or addition to facilities. It also provides a basis for choice between alternatives. The candidate with the least negative UAC is preferred; this represents the minimum cost. Here *cash flow*, capital outlays, and end-of-life-recoveries are taken into account, an acceptable discount rate specified, and the procedures of depreciation accounting followed as elucidated by Equation C-2 and Figure C-2. The computation scheme is illustrated later in this appendix; see Third Private Financing Illustration. For some comparisons of alternatives, only the costs which vary from one alternative to the other need to be taken into account; this greatly reduces the computation effort and generates incremental UACs that highlight the difference in cost between the candidates.

3. Equivalent Annual Value -- This version of "equivalent annual cost" is used in evaluating public sector projects. It is found from

$$\text{Equivalent Annual Value} = \frac{\text{Total Capital Cost}}{\sum_{n=1}^{n=n} \frac{1}{(1+r)^n}} + \text{Annual O\&M Expenses} \quad \ldots \quad \text{(E-3)}$$

A particular use is in Cost-Effective Analysis for the selection of the preferred waste treatment system in connection with the EPA construction grants program (E-3). Details are provided under Publicly Financed Works Mode, below.

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*The Debt Interest is subtracted from the first term to obviate double counting; it is included in the last term.

Unit Costs --

Unit costs are costs per unit of product, service, or output. Four kinds in wide use are:

- Operating expense per unit of output.
- Capital investment per unit rate of output or capacity.
- Unit cost for cost-effectiveness analyses (total resource costs per unit of service).
- Revenue requirement per unit of output (when discounted costs and "discounted" outputs are used this is termed "levelized cost").

The first three unit costs listed are straightforward and readily computed. However, the revenue requirement per unit of output offers some difficulties: there are several variants, each of which needs to be carefully defined, and some are tedious to calculate.

1. Operating Expense Per Unit of Output -- This is simply the Average or Lifetime Operating Expense per Unit of Output. Here the Total Operating Expense or O&M may be used but the particular annual expense used should be identified. An example of units is mills/kWhr for a power plant.

2. Capital Investment Per Rate of Output -- This is merely the Capital Investment divided by the Capacity or Rate of Output. An example is $/kW for a power plant.

3. Unit Cost for Cost-Effectiveness Analysis -- This is the "equivalent annual value" divided by the annual output. It is used in the EPA construction grants program to identify the most cost-effective wastewater treatment management system (E-3, E-4). Results would be in $/1,000 gal.* of liquid waste treated. For details on this and "equivalent annual value," see Publicly Financed Works Mode, below.

4. Revenue Requirement Per Unit of Output -- This can be determined without discounting, in which case it is based on "lifetime average" costs. If both costs and output units are discounted, the revenue requirement per unit of output is called a "levelized cost." Two levelized cost procedures will be described: the Typical Utility Approach where only costs can be escalated; and the METREK Approach where the value of the output is also escalated. Illustrations of the calculation of all three of these unit costs are provided under Public Utility (Regulated) Financing Example, at the end of this Appendix.

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*Multiply $/1000 gal. by 0.264 to convert values to $/cubic meter.

The revenue requirement using lifetime average costs, or UC_{la}, is described by this expression:

$$UC_{la} = \frac{\sum_{i=1}^{i=i} \sum_{n=1}^{n=n} C_{in} (1+s_i)^{n-1}}{\sum_{n=1}^{n=n} P_n} \qquad \text{(E-4)}$$

where P_n = the output units during year n. Note that, as for annualized costs, $^nC_{in}$ consists of cost items that contribute to the total revenue. This method was used by McGlamery et al. (E-5, p. 83) to get lifetime average unit operating cost; it has also been both delineated and illustrated by the well-known National Gas Survey publication of the Federal Power Commission (E-6).

For levelized cost, the most common procedure, the so-called "typical utility approach" (E-7), gives a value, LC_u, as described by this equation:

$$LC_u = \frac{\sum_{i=1}^{i=i} \sum_{n=1}^{n=n} C_{in} \frac{(1+s_i)^{n-1}}{(1+r)^n}}{\sum_{n=1}^{n=n} P_n \frac{1}{(1+r)^n}} \qquad \text{(E-5)}$$

This was the approach used by McGlamery et al. (E-5, p. 83) to compute the levelized operating cost; for their study s_i equalled zero (inflation was not accounted for). In this approach, the revenue value placed on a unit of output is constant. This scheme serves to overstate the revenue requirement per unit of output in the early years and understate them in later years as shown in Figure E-1 and explained in detail in the last example in this appendix.

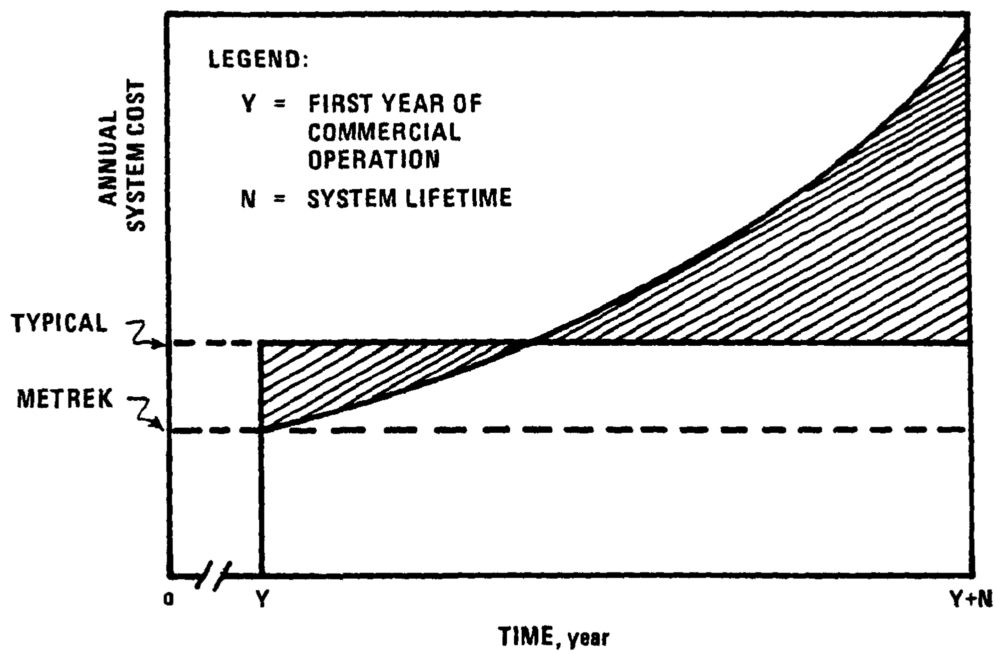
A modification of the "typical utility approach," which takes into account the anticipated growth in the value of the output, was suggested by Goudarzi et al. (E-7) and used in an ERDA report (E-8). This modification, called the "METREK approach," is represented by this relation where only the denominator term differs from that in Equation E-5:

$$LC_M = \frac{\sum_{i=1}^{i=i} \sum_{n=1}^{n=n} C_{in} \frac{(1+s_i)^{n-1}}{(1+r)^n}}{\sum_{n=1}^{n=n} P_n \frac{(1+s)^{n-1}}{(1+r)^n}} \qquad \text{(E-6)}$$

where s = the general inflation rate per year. Accordingly, in this METREK approach, the levelized cost is on a basis that approaches that of constant worth dollars. This results in revenue requirements in then-current dollars as shown in Figure E-1 that vary with predicted general inflation and are therefore more realistic. This matter is discussed further in the last example in this appendix.

Effect of Inflation on Measures of Merit

In the application of any measure of merit, the decision must be made between the use of then-current and constant worth dollars. For a general inflation rate applied across the board, each use will give the same value for present worth, but different values for a particular



THERE ARE SOME IMPORTANT ITEMS TO NOTE:

- BOTH METHODS ESTIMATE THE TOTAL REVENUE REQUIREMENTS IN A COMPARABLE FASHION AND THEREFORE RESULT IN THE SAME ESTIMATE FOR TOTAL REVENUE REQUIREMENTS.
- THE METREK APPROACH ATTEMPTS TO PROVIDE THE INDEX IN A MANNER WHICH CLOSELY RESEMBLES THE ANTICIPATED GROWTH IN COSTS.
- THE TYPICAL APPROACH SIGNIFICANTLY OVERSTATES THE COST IN THE EARLY YEARS AND UNDERSTATES COSTS IN LATER YEARS.

Figure E-1. Comparison of approaches to levelized cost (E-7).

measure of merit. This means that the evaluator must recognize acceptable values using then-current or constant worth dollars and the relationship between the two.

For the relationship between i', the minimum acceptable IROR using constant worth dollars, and i, the minimum acceptable IROR using then-current dollars, with a general inflation rate, s, Stermole (E-9) gives

$$i' = \frac{1 + i}{1 + s} - 1 \quad \ldots \qquad \text{(E-7)}$$

For example, if i = 20 percent, and s = 8 percent,

$$i' = \frac{1 + 0.20}{1 + 0.08} - 1 = 11.1 \text{ percent.}$$

This example also emphasizes that the values of i' for constant worth dollars are less, and by potentially substantial margins, than i for then-current dollars.

Note that the use of this relation assumes that all expenses and allocations escalate; actually charges for depreciation and debt interest do not respond to inflation.

CHOICES IN COMPUTATION OF MEASURES OF MERIT

Custom dictates that certain measures of merit be used to analyze projects for a given financial sector. Also, different modes of computation are followed for each financial sector. In addition there are several possible values or decisions for a number of computational features; the choice is generally influenced by practice. Necessary information about these modes and features are given below.

Computation Features

Selections must be made for these computation features: discounting, revenue requirement, recovering the investment, accounting for inflation, pertinent annual expenses, and types of interest factors.

Revenue Requirement -- Profit from revenue must be demonstrated for the evaluation of undertakings in regulated industries. It is certainly desirable for privately financed facilities; but if a loss is involved an evaluation can be executed if the tax relief is noted.

Pertinent Annual Expenses -- It is essential that all the net operating expenses be included for cases where revenue (private sector study) or revenue requirement (regulated sector study) is involved. O&M only is used for public sector projects and may be used for choice between alternatives where insufficient or no revenue is involved.

Discounting -- Discounted costs and revenues are always used for publicly financed works, but not always for privately financed and regulated industry projects.

Investment Recovery -- Undertakings in both the private and the regulated sectors return ("write off") the original investment as depreciation or end of project recoveries such as land and working capital.* For publicly financed projects, as for the EPA construction grants program, there is no investment recovery; the only return shown is defined by law and corresponds to Federal lending rates (see Appendix G).

Accounting for Inflation -- For public projects, inflation is not taken into account; the basis is the prices prevailing at the time of the analysis (E-3). The private and regulated sectors may or may not take inflation into account; both paths offer difficulties and benefits. In this connection, see Effect of Inflation on Measures of Merit, above.

Interest Factors -- Discrete interest factors are customarily used as discounting rates in regulated and public sector studies. Cost analyses of privately financed projects employ either discrete or continuous interest factors with a trend toward the latter.

Modes of Cost Analysis

The mode of analysis associated with each of the financial sectors is described below. As a part of the discussion, the likely computation features for each are also listed.

Privately Financed Project Mode -- This mode takes into account only *cash flow*, capital outlays, and end-of-project recoveries. It follows the conventions of depreciation accounting. The effects of income tax are registered either as decreased *cash flow* if revenue is taken into account, or as improved *cash flow* from reduced losses if it is not. The methods are expounded both in engineering economy texts (E-1, E-2) and books on financial analysis (E-10).

It has also been used for energy cost studies (DCF method in Reference E-6). The likely computation features, with an indication of those chosen for the private sector examples to follow, are:

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*Some procedures for engineering cost analysis recover the original investment by the sinking fund method. This is more likely for utilities; the method is given in texts in engineering economy (E-1). The current practice is to follow the business convention of recovering the nominal dollars invested.

Computation Feature	Likely Practice	Used in Examples for Private Inv. Financ.
Revenue Requirement	Needed for IROR, ROI, Payout.	Yes, for 1st example
	Not available when calculations for revenue required.	Yes, for 2nd example
	Not available when calculating "uniform annual cost."	Yes, for 3rd example
Pertinent Annual Expense	Need net annual expense for calculation of IROR, ROI, Payout, and also revenue required.	Used in 1st and 2nd examples
	Need only use O&M items and related overheads that vary from case to case for calculation of "uniform annual cost."	Applicable to 3rd example
Discounting	Yes	Yes
Investment Recovery	Recoup by depreciation charges and end-of-life recoveries.	Same
Accounting for Inflation	No preference	No
Interest Factors	Trend to continuous interest	Continuous interest

Public Utility (Regulated) Financed Mode -- This follows the levelized cost methodologies for determining the revenue requirement used in the electric utilities industry (E-7, E-8). In this procedure, the return to investors declines from year to year because it is computed on the book value of the depreciable investment. The likely computation features, with an indication of those chosen for the regulated sector example to follow, are:

Computation Feature	Likely Practice	Used in Example for Public Utility Fin.
Revenue Requirement	Calculated as annualized cost or levelized cost using appropriate discount factor (see Appendix G).	Same
Annual Expense	Use net annual expense	Same
Discounting	Yes	Yes
Investment Recovery	Recoup by depreciation charges and end-of-life recoveries.	Same
Accounting for Inflation	Likely	Yes
Interest Factors	Discrete interest	Same

Publicly Financed Works Mode -- The procedure is simple; it is delineated under Equivalent Annual Costs (Equation E-3) and Unit Costs, above. Accordingly, no example of a computation is provided. The various components of cost are calculated on the basis of prices prevailing at the time of the cost-effectiveness analysis. The other customary features are: discounting, no revenue requirement, no investment recovery, only O&M expenses, and the use of discrete interest for discounting. Therefore, Equation E-1 applies but with s_1 = zero. Van Note *et al*. (E-4) provides guidelines, cost data, and methodology. In this reference the cost data are based on the use of a 5-5/8 percent interest (discount) rate, but instructions are given for adjustment of the costs using the interest rate prevalent at the time of the analysis. For guidance in determining the interest (discount) rate to be applied, consult Appendix G.

EXAMPLES OF CALCULATION OF MEASURES OF MERIT

Calculation examples are provided for two modes of evaluation: the private (investor), also termed unregulated, and the public utility, also termed regulated.

Private (Investor) Financing Examples

Three kinds of computations are made for the private sector mode:

1. IROR, ROI, and Payout are found for the case where the expected revenue is furnished.

2. Revenue requirement is found where a discount factor is given (it generally corresponds to MARR, minimum acceptable rate of return).

3. "Uniform annual cost" where a choice is to be made between alternatives for a change or addition to a facility where the resulting revenue change is zero, cannot be identified, or is insufficient to show a profit.

The computation features selected for each are given in the subsection directly above.

First Private Financing Illustration - Revenue Known --

Since inflation is to be neglected, constant dollars, corresponding to then-current at the time of the analysis, will be used to calculate ROI, Payout, and IROR. A similar calculation is made for the Example in Appendix K.

Information follows for the project to be evaluated:

Items related to investment

Land (1 yr before start-up)	K$1,000
Fixed investment (uniform expenditure over 1 yr before start-up)	53,000
Working capital (at start-up)	7,000
Net salvage value (at shut-down)	3,000
Recovered nominal land value (at shut-down)	1,000
Recovered working capital (at shut-down)	7,000
Life of plant	5 years

Income statement items, on annual basis (assume uniform and continuous, year to year):

Revenue	K$100,000
Net operating expenses (excludes depreciation charges)	60,000
Depreciation (straight-line)	10,000
Income tax rate	50%
Net profit	K$15,000
Cash Flow (net profit plus depreciation)	25,000

Annual depreciation by the straight-line method can be determined two ways.

1. Allow for the net salvage value, then:

$$\text{Annual depreciation} = \frac{53,000 - 3,000}{5} = K\$10,000 \quad .$$

This method is used in this example; it is preferred.

2. When there is no basis for estimating a net salvage value or the accounting procedures completely "enter to costs" all investments, then:

$$\text{Annual depreciation} = \frac{53,000}{5} = K\$10,600 \ .$$

In the second instance, any net salvage which might arise represents extra gross profit and is therefore subject to the 50 percent income tax; if the estimated net salvage value is realized, the additional net profit would be K$1,500.

The cash flows over the life of the project can be effectively depicted in a cumulative cash position chart similar to Figure C-3.

Return on Investment--

$$\text{ROI} = \frac{15,000}{1,000 + 53,000 + 7,000} \text{ X } 100 = 24.6\%$$

Payout Time -- If the Annual Depreciation of K$10,000/year is used from the preferred first way, the *cash flow* is K$25,000. Then:

$$\text{Payout Time} = \frac{53,000 - 3,000}{25,000} = 2.0 \text{ years} \quad .$$

Interest Rate of Return -- The interest rate of return is calculated from the schedule on the next page. The net profit is (1 - income tax rate) (Revenue - Net Operating Expenses - Depreciation). For this case it is (1 - 0.5) (100,000 - 60,000 - 10,000) or (0.5)(30,000). Since the same discount factor applies to both the depreciation and the net profit, *cash flow*, which is their sum, could have been substituted in the tabulation on the next page. Also note that values of IROR (28.3 percent) always exceed ROI (24.6 percent) by up to 50 percent.

Second Private Financing Illustration - Revenue To Be Determined --

The purpose here is to compute the required revenue to cover the cost of the investment charge and annual operating expenses. This includes a return on investment which is handled by the discount rate; in this case it will correspond to a MARR of 15 percent. The same cash flows and financial factors will be used as in the first example, above, except for the revenue which now must be determined. The solution is

Time, Years	Item	Cash Flow, K$	First Trial		Second Trial	
			Factor at 25%	Present Worth	Factor at 30%	Present Worth
-1	Land Allocation	-1,000	1.2907	-1,290	1.3499	-1,350
-1 to 0	Fixed Investment	-53,000	1.1420[a]	-60,526	1.1662	-61,809
0(start-up)	Working Capital	-7,000	1.0000	-7,000	1.0000	-7,000
0 to 5	Depreciation	5(10,000)[b]	0.5708	28,540	0.5179	25,895
0 to 5	Net Profit	5(15,000)[b]	0.5708	42,810	0.5179	38,843
5	Net Salvage Value	3,000	0.2865	860	0.2231	669
5	Recovered Working Capital	7,000	0.2865	2,000	0.2231	1,562
5	Recovered Nominal Land Value	1,000	0.2865	286	0.2231	223
				K$5,680		-K$2,967

This gives IROR (by linear interpolation) of

$$25.0 + \left[\frac{5680}{5680-(-2967)}\right]5.0 = 28.3\%.$$

[a]Calculated from two factors in Table D-1: 0.8848 from the Uniform table for RXT = 25 X 1 = 25 (which discounts the uniform flow from -1 to zero to an instantaneous value at year -1); and 0.7748 from the Instantaneous table for RXT = 25 (the reciprocal of which compounds from an instant at year -1 to an instant at year zero). The desired combined factor is 0.8848 ÷ 0.7748 or 1.1420.

[b]Both the depreciation and annual profit for 1 year are multiplied by 5 to give these values for the life cycle.

analogous to that for IROR. Again, the *cash flow* will be broken into its components for convenience. Required revenue or revenue increment is ΔS to correspond with the symbol used in Equation C-2. The solution is organized below. If an interest rate of 28.3 percent (corresponding to the IROR calculation) had been used, the solved value of ΔS would have been K$100,000 to correspond to the annual revenue given in the IROR example.

Time, years	Item	Cash Flow, K$	Discount Factor at 15%	Present Worth, K$
-1	Land Purchase or Allocation	-1,000	1.162	-1,162
-1 to 0	Fixed Investment	-53,000	1.079	-57,187
0	Working Capital	-7,000	1.00	-7,000
0 to 5	Depreciation	(5)(10,000)	0.7035	35,176
0 to 5	Net Profit	0.5(5)(ΔS-70,000)	0.7035	-123,112+1.759ΔS
5	Recoveries	11,000	0.4702	5,192
		TOTALS		-148,093+1.759ΔS

Since Present Worth = 0,

$$-148{,}093 + 1.759\Delta S = 0$$

or, required revenue or revenue increment, ΔS = K$84,194.

Third Private Financing Illustration - Uniform Annual Cost --

Uniform annual cost is a technique for determining the actual cost of a change in or addition to facilities; it is widely used for making a choice between alternatives (E-1, E-2). For the solution, the same cash flows and financial factors will be used. It can be assumed that these apply to a plant addition for pollution abatement.

Now the "uniform annual cost," UAC, is found from the Total Present Worth by this relation:

$$\text{UAC} = \frac{\text{Total Present Worth}}{\text{(No. of yrs of operation)(Uniform continuous interest factor)}} \qquad \text{(E-8)}$$

which corresponds to Equation (E-1). Here, the number of years of operation is 5, and the Uniform continuous interest factor, used in the table below, is 0.7035; therefore,

$$\text{UAC} = \frac{-148{,}094}{5(0.7035)} = -\text{K\$}42{,}102 \quad .$$

Time, year	Item	Cash Flow, K$	Discount Factor at 15%	Present Worth K$
-1	Land	-1,000	1.162	-1,162
-1 to 0	Fixed Investment	-53,000	1.079	-57,187
0	Working Capital	-7,000	1.00	-7,000
0 to 5	Contribution to *Cash Flow* from Depreciation	0.5(5)(10,000)[a]	0.7035	17,588
0 to 5	Contribution to *Cash Flow* from Net Operating Expenses	-0.5(5)(60,000)[a]	0.7035	-105,525
5	Capital Recoveries	11,000	0.4702	5,192
	TOTAL			-148,094

[a]Consultation of Figure C-2 and Equation C-2 will elucidate the source of these two cash flows. Their sum constitutes the effect on total *cash flow*.

Summary Remarks --

The basic model has considerable flexibility; it can accommodate capital outlays at later dates, variable revenue, fluctuating operating expenses, price escalation, etc.

The effect of neglecting inflation corresponds to the use of then-current dollars at time zero for all outlays and revenues; this is tantamount to the application of constant dollars, which would be deflated from then-current dollars at later times. The significant result is that the measures of merit (e.g., ROI, IROR, Payout) appear less favorable than if then-current dollars had been used. The difference for IROR can be approximated for the above example from Equation (E-7) rearranged, or

$$i = (1+f)\ (1+i') - 1$$

where i' (or IROR with no inflation) = 28.7 percent; and f (general inflation) = 7 percent. Then,

$$i = (1+0.07)\ (1+0.287) - 1$$

$$= 0.377 \text{ or } 37.7\%.$$

Actually i would work out to be somewhat more because some cash flows (e.g., depreciation) do not respond to inflation.

Appendix K presents another example of cost analysis of a privately financed project which neglects inflation.

Public Utility (Regulated) Financing Example

This example, taken directly from Reference E-8, follows the levelized cost methodologies for determining the revenue requirement used in the electric utilities industry (E-5, E-6). In this procedure the return to investors declines from year to year because it is computed on the book value of the fixed investment.

For utility financing the measures of merit are:

- Equivalent annual cost -- specifically annualized cost.
- Unit costs for revenue requirement, which can be on different bases. The ones considered in this section are: lifetime average unit costs, levelized cost by the typical utility approach, and levelized cost by the METREK procedure.

The computation features have been given for this case in the subsection preceding the examples.

The example is concerned with a coal-fueled power plant and its flue gas desulfurization (FGD) unit. For the cost analysis, a unit capacity of 1 kW was used because it provides investment and costs independent of plant size. All calculations will have a basis of 1 kW and 1 year; therefore, investments will be in $/kW, costs in $/kW-yr, and net energy output in kWhr/kW-yr; i.e., the annual output of a 1 kW plant is in kWhr.

Cost Information --

The major input assumptions are presented in Tables E-1 and E-2. Construction takes place over 6 years (1975-1980) with start-up in 1981. The plant operates for 30 years.

Table E-3 contains details of the cost elements over the life of the plant. Sample calculations are given to show the development of the table based principally on the data in Tables E-1 and E-2.

Capital Cost of Plant -- The cost of the plant is given as $421/kW if built at 1975 prices; but, since it is built over a period of years, each year inflation increases expenditures by 5 percent. These yearly inflated expenditures are shown in Table E-3; it can be shown that the sum of the capital outlays is $497.08/kW. It is assumed that the outlay for construction during a given year is made available at the beginning of that year.

TABLE E-1. FINANCIAL FACTORS
FOR REVENUE REQUIREMENT ANALYSIS
(Public Utility Financing Example)

Capital Structure	
Debt	53%
Preferred Equity	12%
Common Equity	35%
	100%
Cost of Capital	
Interest on Debt	8.0%
Dividends on Preferred Equity	8.5%
Dividends on Common Equity	14.0%
Weighted Cost of Capital	10.16%[a]
Taxes	
State Income Tax	4.0%
Federal Income Tax	48.0
Combined Rate - Income Tax	50.0[b]
Gross Receipts and Sales Taxes	2.0
Investment Tax Credit (1st yr)	8.0
Property Tax	1.4
Depreciation	
Financial 30-yr life (straight-line)	3.3%
For income-tax purposes 20-yr life (sum of digits)	
Escalation	Nominal
GNP Deflator	5.0%
O&M	5.0

[a]Weighted cost of capital = (0.53) (0.08) + (0.12) (0.085)
bonds preferred stock
+ (0.35) (0.14) = 0.1016 or 10.16%.
common stock

[b]The combined rate of 50% (state 4%, Federal 48%) is obtained in this manner: combined tax rate = (1 - 0.04) (0.48) + 0.04 = 0.5008 or 50.0%. This is the result because Federal tax laws permit counting state income tax as a deductible expense.

TABLE E-2. INPUT DATA ASSUMPTION
FOR COMPUTATION OF REVENUE REQUIREMENTS
(Public Utility Financing Example)

• Start of Operation	1981
• Construction Period	6 years (1975-1980)
• Capital Cost (1975 Dollars)	$421/kW
• O&M Cost (1975 Dollars)	2.6 mills/kWhr
• Tax Life	20 years (sum of digits)
• Economic Life	30 years (straight-line)
• Average Capacity Factor[a]	60 percent

[a]The capacity factor varies from year to year; this is explained in the text.

TABLE E-3. LIFE CYCLE COSTS FOR NOMINAL 1 kW POWER PLANT (Basis: 1 kW and 1 year)

Year	Constr. Cash Flow	Tax Deprec.	Debt Inter.	Pref. Equity Dvdnds	Common Equity Dvdnds	Income Tax	Finan. Deprec.	Fuel Expen.	O&M	Gross Receipts Tax	Reven. Req'd	Net Energy Output, P_n	Capacity Factor
1975	8.42												
1976	30.94												
1977	51.06												
1978	141.33												
1979	173.99												
1980	91.34												
1981	0.00	61.06	27.18	6.54	31.42	-53.02	21.37	68.67	18.31	2.64	132.08	5255	0.600
1982	0.00	58.01	26.28	6.32	30.37	0.05	21.37	78.12	20.83	3.92	196.24	5694	0.650
1983	0.00	54.95	25.37	6.10	29.32	1.84	21.37	88.34	23.56	4.18	209.06	6132	0.700
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1999	0.00	6.11	10.87	2.62	12.57	30.45	21.37	161.47	43.06	5.95	297.32	5135	0.586
2000	0.00	3.05	9.97	2.40	11.52	32.23	21.37	165.21	44.05	6.04	301.76	5003	0.571
2001	0.00	0.00	9.06	2.18	10.47	34.02	21.37	169.43	44.91	6.11	305.54	4858	0.555
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2008	0.00	0.00	2.72	0.65	3.14	25.17	21.37	161.53	43.07	5.44	272.07	3311	0.378
2009	0.00	0.00	1.81	0.44	2.09	23.90	21.37	153.05	40.81	5.15	257.60	2988	0.341
2010	0.00	0.00	0.91	0.22	1.05	22.64	21.37	141.49	37.73	4.78	239.15	2631	0.300
TOTAL	497.08	641.13					641.13				7781.33	152664	
P.V.[a]	641.13	347.93	184.59	44.41	213.33	62.05	197.63	1044.61	278.53	43.06	2152.87	79941[b]	

NOTES: All costs are in then-current dollars. Net energy output per year for a 1 kW plant is in kWhr. A constant annual cost item not shown above is property tax (641.13) (0.014) = 8.98.

[a]The reference point for present value (P.V.) calculations is plant start-up (beginning of 1981).

[b]The P.V. for the Net Energy Output is obtained from the denominator of Equation (E-6). This discounts and corrects for general inflation.

Each year as funds become available they must carry an interest charge for the remaining construction years. The compounded values are:

First year outlays	$8.42 \times (1.1016)^6$	$= \$15.05$/kW	(1975)
Second year outlays	$30.94 \times (1.1016)^5$	= 50.20	(1976)
.	.	.	.
.	.	.	.
.	.	.	.
Sixth year outlays	$91.34 \times (1.1016)$	= 100.62	(1980)
		$\$641.13$/kW	

Hence $641.13/kW is the capital cost of the plant at start-up time in 1981, with allowance for interest and escalation during construction. The interest rate used is 10.16 percent, which is the same as the weighted cost of capital from Table E-1. Actually a different interest rate (reflecting the charges for a short-term loan) should be used. Note that the calculated value of the plant cost is also the present value shown in Table E-3.

Plant start-up costs were not specifically mentioned, although they might have been included in construction costs; plant start-up costs are customarily capitalized for a regulated industry. This ERDA example does not include working capital. Normally it would be required at plant start-up and would be added to construction costs to give total investment.

Net Energy Output -- The capacity factor schedule selected is representative of plant experience. The initial factor is 0.60 which increases to 0.70 over a 2-year period then declines exponentially to 0.3 by the end of the 30-year life.

Net energy output is based on the capacity factor. Accordingly, the annual net energy output of a 1 kW plant is:

$$1 \text{ kW} \times (24)\ (365) \times \text{capacity factor, kWhr} \quad .$$

For example:

in 1981, 1 kW X 8760 hrs/yr X 0.60 = 5255 kWhr; and

in 1982, 1 kW X 8760 hrs/yr X 0.65 = 5694 kWhr.

O&M (Operating and Maintenance) Cost -- The basic operating and maintenance expense is given as 2.6 mills/kWhr (1975 dollars). Total annual expenses are considered to vary with energy output and inflation. For example, in 1983 when the capacity is 6132 kWhr:

$$\text{Annual O \& M costs} = 0.0026 \times (1.05)^8 \times 6132 = \$23.56^*$$

---

*Then-current dollars.

Fuel Costs -- As with O&M costs, the price of fuel is subject to yearly inflation and the consumption is proportional to net energy output. Here, however, the basic information on price and heating value of fuel, efficiency of combustion, etc. is not available, so the cost for each succeeding year is calculated from the fuel cost for the first year, \$68.67, or:

1981 - first year fuel cost \$68.67 for 5255 kWhr net power output

1982 - second year fuel cost $68.67 \times \frac{5694}{5255} \times 1.05 = \$78.12$ for 5694 kWhr

1983 - third year fuel cost $68.67 \times \frac{6132}{5255} \times (1.05)^2 = \$88.34$ for 6132 kWhr; etc.

Tax Depreciation -- The depreciation for income tax is calculated by the sum-of-the-digits method for a 20-year period:

$$\Sigma\ 1+2+3+...+20 = \frac{n(n+1)}{2} = \frac{(20)(21)}{2} = 210$$

1981 - first year tax depreciation $= 641.13 \times \frac{20}{210} = \$61.06$

1982 - second year tax depreciation $= 641.13 \times \frac{19}{210} = \$58.01$, etc.

The use of sum-of-the-digits depreciation and for 20 years, the minimum allowed, serves to reduce the tax in earlier years as compared with the use of straight-line depreciation for this purpose.

Financial Depreciation -- Straight-line depreciation over the 30-year life is used for the depreciation charges involved in the computation of the revenue required. Hence,

$$\text{Financial depreciation} = \frac{641.13}{30} = \$21.37 \text{ per year.}$$

The use of straight-line depreciation is used to reduce the book value each year as shown.

Book value beginning of first year 1981 \$641.13
Book value beginning of second year 1982 \$641.13 - 21.37 = \$619.76
Book value beginning of third year 1983 \$641.13 - 2(21.37) = \$598.39, etc.

Return to Investors -- Each year the three classes of investors will receive interest and dividends as called for in the schedule in Table E-1, based on the book value. In addition, investors receive the straight-line depreciation each year, allocated as to type of holding.

The following table illustrates these points.

Debt (Bonds) 53% of total capital

Interest 1st yr (641.13) (0.53) (0.08) = 27.18 (1981)
2nd yr (619.76) (0.53) (0.08) = 26.28 (1982)
3rd yr (598.39) (0.53) (0.08) = 25.37, etc. (1983)

Return of Capital
(straight-line depreciation) (21.37) (0.53) = 11.33/yr

Preferred Equity 12% of total capital

Dividends 1st yr (641.13) (0.12) (0.085) = 6.54
2nd yr (619.76) (0.12) (0.085) = 6.32
3rd yr (598.39) (0.12) (0.085) = 6.10, etc.

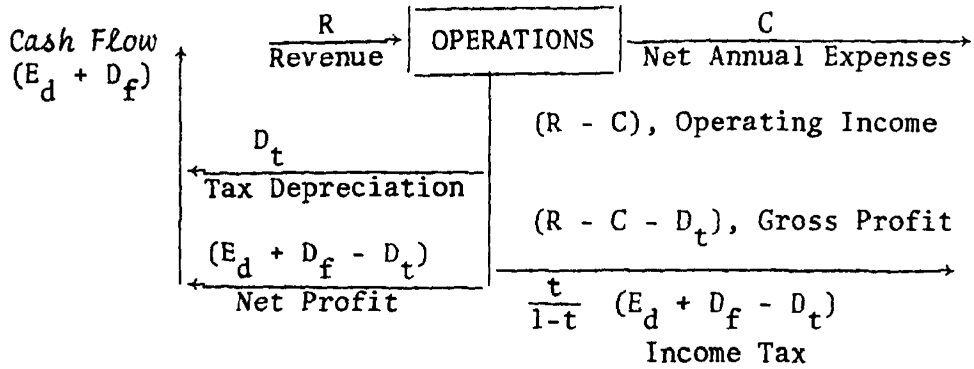
Return of Capital
(straight-line depreciation) (21.37) (0.12) = 2.56/yr

Common Equity 35% of total capital

Dividend 1st yr (641.13) (0.35) (0.14) = 31.42
2nd yr (619.76) (0.35) (0.14) = 30.37
3rd yr (598.39) (0.35) (0.14) = 29.32, etc.

Return of Capital
(straight-line depreciation) (21.37) (0.35) = 7.48/yr

Income Tax -- To determine the income tax, the Gross Profit is found by subtracting net annual expenses, C, plus tax depreciation, D_t, from revenue, R, as shown in the cash flow diagram (below), which is patterned after Figure C-2. This Gross Profit is subject to income tax rate, t. However, since revenues are not known, to calculate income tax and then revenue, it is necessary to start with the known values of *Cash Flow*, which are the sum of Equity Dividends, E_d, and Financial Depreciation, D_f, the capital return to investors. Note that debt interest is an annual expense.



From this diagram it is seen that

$$\text{Net Profit} = E_d + D_f - D_t \quad ,$$

from which it follows that

$$\text{Gross Profit} = \frac{1}{1-t}\,(E_d + D_f - D_t) \quad ,$$

and that income tax is t times the gross income or

$$\text{Income Tax} = \frac{t}{1-t}\,(E_d + D_f - D_t) \quad .$$

Since in this example $t = 0.5$ and $\frac{t}{1-t} = 1$, the income tax for each year can now be determined, or in

$$1982 \quad \text{income tax} = \underbrace{6.32 + 30.37}_{\text{Equity Dividends}} + \underbrace{21.37}_{D_f} - \underbrace{58.01}_{D_t} = 0.05 \quad .$$

The year 1981 is a special case because of an investment tax credit of 8 percent for the first year. First the income tax is computed as above, or

$$1981 \quad \text{income tax} = 6.54 + 31.42 + 21.37 - 61.06 = -1.73 \quad .$$

From this is deducted the tax credit of

$$641.13 \times 0.08 = 51.29 \quad ,$$

which results in a tax of

$$(-1.73) - (51.29) = -53.02 \quad .$$

Total Revenue, R -- By a balance of the input and output items of the cash flow diagram, it follows that:

$$R = C + \text{income tax} + E_d + D_f \quad .$$

All cost elements are now known except the gross receipts tax which is 2 percent of R. Then if one lets

$$C = C' + 0.02\ R \quad ,$$

where C' includes all costs except gross receipts tax (i.e., O&M, fuel, property tax* and debt interest),

$$0.98\ R = C' + \text{income tax} + E_d + D_f \quad ,$$

or

$$R = \frac{1}{0.98}\ [C' + \text{income tax} + E_d + D_f] \quad .$$

Property insurance which should be included as a cost item was neglected in this ERDA example. Therefore, for 1982:

$$R = \frac{1}{0.98}\ [\underset{\text{O\&M}}{20.83} + \underset{\text{Fuel}}{78.12} + \underset{\text{Debt int.}}{26.28} + \underset{\text{Prop. tax}}{8.98} + \underset{\text{Income tax}}{0.05}$$

$$+ \underset{\text{Equity}}{6.32} + \underset{\text{Dividends}}{30.37} + \underset{\text{Financ. Dep.}}{21.37}] = 196.24$$

The gross receipts tax = (0.02) (196.24) = 3.92.

Now that the values for the cash flows are developed (see Table E-3), the various values for annualized cost and other measures of merit can be computed.

Present Value Calculations --

To calculate the annualized and levelized costs, it is necessary to determine the total P.V. of the Revenue Required. Also, for inflation and to provide a check, the present value of each of the cash flow streams is shown at the bottom of each column in Table E-3. The values in Table E-3 are discrete year-end expenditures, except for construction expenditures which are at the beginning of each year. The reference point is plant start-up at the beginning of 1981. Recall that the discounting rate is the average cost of capital, 10.16 percent.

A sample present value calculation for O&M expenses follows:

$$\text{P.V.} = \frac{18.31}{1.1016} + \frac{20.83}{(1.1016)^2} + \frac{23.56}{(1.1016)^3} + \ldots + \frac{37.73}{(1.1016)^{30}} = \$278.53$$

Annualized Cost --

This is the same as the annual revenue requirement and is formed by the application of Equation (E-1). The value in the numerator is the present value of the revenue required, or $2,152.87 from Table E-3. The

*(641.13) (0.014) = $8.98/yr.

denominator for discrete interest is the "uniform series present worth factor,"

$$\frac{(1+r)^n - 1}{r(1+r)^n} \text{ which for 10.16\% interest } = \frac{(1.1016)^{30}}{0.1016(1.1016)^{30}} = 9.3025 \quad .$$

Therefore,

$$\text{Annualized Cost} = \frac{\$2152.87}{9.3025} = \$231.43 \quad .$$

Unit Costs --

For this example, which follows the utility financed mode, unit costs will only be calculated for the revenue requirement per unit of output which is $/kWhr, but is done on three bases: (1) lifetime average unit costs; (2) levelized cost by typical utility approach; and (3) levelized costs by METREK approach.

Lifetime Average Unit Cost -- This is found from Equation E-3, or

$$UC_{1a} = \frac{7781.33 \times 1000}{152,664} = 51.0 \text{ mills/kWhr} \quad .$$

The lifetime sums for the Revenue Required (the numerator) and the Net Energy Output (the denominator) are both found in the Total line in Table E-3.

Levelized Cost by Typical Utility Approach -- Utilities desire a constant levelized cost which will provide revenues over the years and give the same present value as that of the revenue requirements. Since the annual revenue for year n is $LC_u \times P_n$, for this example:

$$P.V. = 2152.87 = \frac{LC_u x5255}{1.1016} + \frac{LC_u x5694}{(1.1016)^2} + \ldots + \frac{LC_u x2631}{(1.1016)^{30}}$$

$$= LC_u \left[\frac{5255}{1.1016} + \frac{5694}{(1.1016)^2} + \ldots + \frac{2631}{(1.1016)^{30}}\right]$$

$$= LC_u \; [52,274]$$

$$\text{or} \quad LC_u = \frac{2152.87}{52,274} = \$0.04118/\text{kWhr} \quad \text{or} \quad 41.2 \text{ mills/kWhr.}$$

Note that, after LC_u is factored out of the above expression, there remains a sum of terms called, because of similarity of the series, the "present value of the energy output." The above relations correspond to Equation E-5!

The schedule below demonstrates how the revenues calculated from $LC_u x P_n$ also total the P.V. of the Revenue Requirement from Table E-3. This schedule also points out that by this levelized cost, the revenue received is more than required in the earlier years and less than in later years. The excess revenue in the early years is presumed to be invested at the discount rate, 10.16 percent, to yield needed funds in the later years.

Year	LC_u	x P_n	=	(P.V. of Level-ized Cost)		P.V. of Rev. Req. from Table E-3
1	(0.04118)	(5255)	=	216.40	vs.	132.08
2	(0.04118)	(5694)	=	234.48	vs.	196.24
.	.	.		.		.
.	.	.		.		.
.	.	.		.		.
30	(0.04118)	(2631)	=	108.34	vs.	239.15
	TOTAL			2152.87	equals	2152.87

<u>Levelized Cost by METREK Approach</u> -- For the comparison of technologies for generating electricity, Goudarzi et al. (E-7) have proposed a levelized cost, LC_M, as defined by Equation E-6. The values for energy output are substituted in this equation and rearranged in the same form used for the analysis above, or

$$P.V. = LC_M \left[5255 \frac{(1.05)^0}{1.1016} + 5694 \frac{(1.05)^1}{(1.1016)^2} + \ldots + 2631 \frac{(1.05)^{29}}{(1.1016)^{30}} \right]$$

where 1.05 is 1.0 plus the general inflation rate per year. Since the value of the terms within the brackets is 79,941,

$$LC_M = \frac{2152.87}{79,941} = \$0.0269/\text{kWhr} \quad \text{or} \quad 26.9 \text{ mills/kWhr.}$$

It will be noted that $LC_M x(1.05)^{n-1}$ equals the unit cost of power, \$/kWhr, for the nth year in then-current dollars. It will also be observed that the revenue received, $LC_M(1.05)^{n-1}P_n$, during the nth year closely corresponds to the required revenue as tabulated in Table E-3 because inflation is accounted for. In any case, the present value (as shown in the numerator in the expression immediately above) again equals \$2152.87.

Summary of Unit Costs -- A recapitulation of the preceding calculations and results with comments is presented here.

Levelized Cost	Equation Used	Numerical Calculation	Comment
Lifetime average unit cost, UC_{1a}	(E-4)	$\frac{7781.33X1000}{152,664}$ = 51.0 mills/kWhr	High; for rough indication
Typical utility approach, LC_u	(E-5)	$\frac{2152.87X1000}{52,274}$ = 41.2 mills/kWhr	In common use in electric utility industry
METREK approach, LC_M	(E-6)	$\frac{2152.87X1000}{79,941}$ = 26.9 mills/kWhr	Preferred method; most meaningful; revenue increased per $LC_M 1.05)^{n-1}$.

Summary Remarks --

The public utility method should be followed only when it is called for. Here, a capital structure must be specified that is the distribution of capital sources between equity sources and debt.

The preceding example included many details that can be disregarded in most cost analyses. These refinements with comments are:

1.	Price inflation	Include for long range projects.
2.	Variable output rate	Take into account if more than $\pm 20\%$ of the average.
3.	Variable operating expenses; e.g., for increased maintenance	Generally vary only if output rate changes considerably and inflation is accounted for.
4.	Discounting of cash flows	Always needed.
5.	Discounting of output units	Needed for levelized costs!

6.	Escalation of output value	Needed for METREK levelized cost which is preferable.
7.	Tax depreciation for income tax computation	Always needed.
8.	Financial depreciation to determine funds annually due investors	Generally keep the same as tax depreciation.

In addition, capital outlays at later dates and other features could have been accommodated. Because of the completeness of the model used in the example, it serves as a good basis for setting up procedures for particular studies.

For another, but simplified, example of the public utility approach, see Appendix J for the cost analysis of a retrofit flue gas desulfurization facility.

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APPENDIX F

COST INDICES AND INFLATION FACTORS

CONTENTS

FIGURE

TABLE

APPENDIX F

COST INDICES AND INFLATION FACTORS

In economic analyses, cost indices are used to correct historical cost data to a present or recent reference time. To adjust cash flows to future dates, these data need to be corrected by inflation factors. In some cases these factors are obtained by extrapolating recent cost indices; however, for the long term (e.g., 20 or 30 years), the estimated inflation rates attempt to take into account the various factors expected to affect prices.

Note that inflation as used in cost analysis refers to the rise in general prices corrected for an increase in productivity. Escalation corresponds in meaning to inflation; however, it pertains only to a specific commodity or service (F-1).

Several compilations of past representative costs for construction for different industries are published. These typical costs are reduced to indices with 100 as the base for a reference time. Examples of such indices are given in Table F-1. Note that the growth rates vary considerably from one index to another. These have been particularly marked since 1973 as can be seen from the plot of the Chemical Engineering magazine Plant Cost Index (solid line) given for illustrative purposes in Figure F-1. However, some engineering-construction firms feel that all the indices have not adequately reflected the marked escalation in plant costs since 1973. Brief descriptions of the first five indices listed are given in Peters and Timmerhaus (F-10). The Sewage Plant Index is described in reference (F-8).

Indices for other items have also been developed. Examples with growth rate data for 1967-72 (F-9) are:

Wholesale commodity prices	3.5%/year
Industrial chemicals prices	0.2
Plant maintenance	5.4
Chemical and allied products payroll	5.6
Fringe benefits	3.5

TABLE F-1. PLANT CONSTRUCTION COST INDICES

Index Title	Field of Application	Ref.	Yr for Base Value - 100	Growth rates, % yr. 67-72
Engineering News Record-Building	Industrial buildings	(F-2)	1967[a]	9.1 (F-9)
Engineering News Rec.-Construction	General construction	(F-2)	1967[a]	10.1 (F-9)
Chemical Engineering-Plant Cost	Process plants	(F-3, F-4)	1957-1959	4.7 (F-9) 9.0[b]
Nelson Refinery	Petroleum refineries and petrochemical plants	(F-5)	1946	9.3 (F-9)
Marshall and Swift[c]--Process Industry Equipm't	Process plants	(F-6)	1926	5.0 (F-9)
Sewage Treatment Plant Construction Cost	Sewage treatment plants	(F-7, F-8)	1957-1959	7.6 (F-8) 9.5[b]

[a]Engineering News Record Indices set base earlier at 100 in 1913, 1926, and 1949.

[b]For 1972-77.

[c]Formerly Marshall and Stevens.

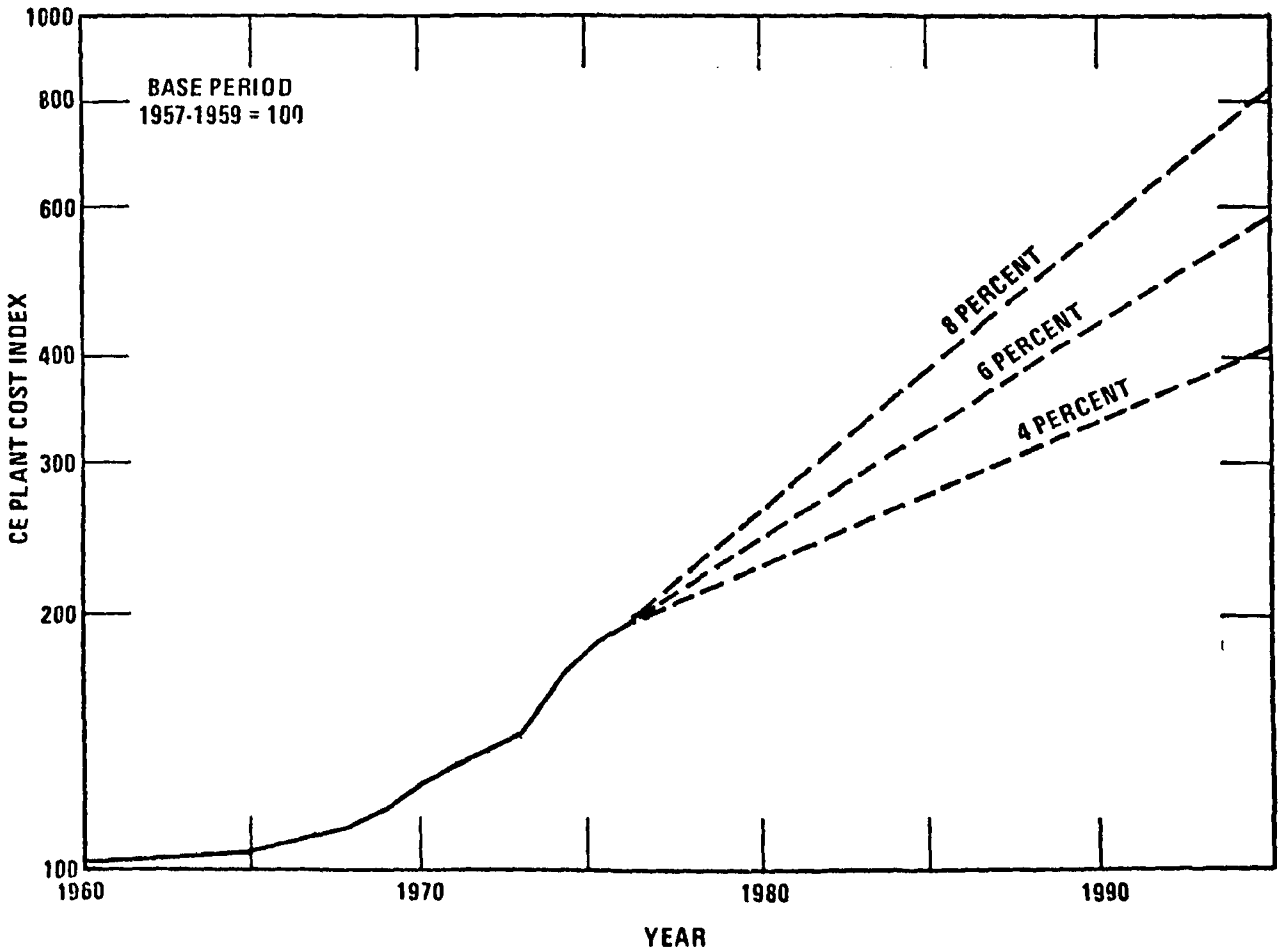

Figure F-1. CE Plant Cost Index to 1977 is indicated by the solid line. Extrapolations are shown by dotted lines for index escalated for escalation rates of 4, 6, and 8 percent/year.

INFLATION FACTORS

Sometimes the effect of inflation is ignored; this is common for projects up to a 10-year life. Some cost analyses require that the prices for future investments and expenses be reckoned. Where inflation rates are considered, a general rate or specific rates (escalation) must be selected. The rates specified can vary for different periods.

Two sets of rates used in 30-year projects are listed below:

from Doane *et al.* (F-11)

Rate of General Inflation	5%
Escalation Rate for Capital Costs	5%
Escalation Rate for Operating Costs	6%
Escalation Rate for Maintenance Costs	6%

from ERDA report (F-12)

O&M	5%
Gross National Product	5%

These rates are judged to be conservative, at least for fuel costs. Some fluctuation should be expected over a long-range period (such as 30 years) because of recessions, OPEC price increases, and similar factors. However, the indication from historical data (F-13, F-14) is that, without heretofore unimposed controls, inflation will continue for several decades. Some exacerbating factors are population growth, shrinking natural resources, public spending, and national budget deficits.

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APPENDIX G

RATES OF RETURN AND INTEREST RATES

CONTENTS

APPENDIX G

RATES OF RETURN AND INTEREST RATES

The nature of a specific rate of return must be defined. In Appendix E. Measures of Merit, both return on investment (ROI) and internal-rate-of-return (IROR) were described because of their utility for cost analysis; other rates of return are also in use. For some studies a minimum acceptable rate of return (MARR) must be specified either to provide a criterion, or to compute required revenue; such MARRs are discussed below. Note that it is not the same as the cost of capital; a MARR should be somewhat higher (G-1).

Interest specifically refers to charges for borrowed money; e.g., short term loans to underwrite construction, and long term debt such as bonds as a source of investment capital.

RATES OF RETURN

For the different sectors the rates of return (based on total capital investment) vary in character and magnitude. For private investments the expected return ranges from 5 to 25 percent after taxes; from corporate annual reports one can deduce that it averages much less, about 5 percent. For utilities, as an example of a regulated industry, the composite return to bondholders and stockholders at present is about 10 percent after taxes as shown in Table E-1. Of course on public projects the discount rate has generally corresponded to the cost of government borrowing; however, there is presently an inclination to raise this figure to 10 percent which is considered to be the current opportunity cost of capital (G-2).

Privately Financed Projects

A return figure for private sector facilities has several uses. Where revenue is generated, a minimum acceptable rate of return (MARR) will indicate if the project appears attractive. Conversely, for a required pollution abatement facility, it will indicate the true cost of meeting the regulations; such a true cost would include a reasonable return on investment.

The returns that companies expect depend both on the type of industry and (for the industry in question) the degree of risk -- operational or commercial. This table from Aries and Newton (G-3) is valid for illustrating these points.

Industry	Minimum acceptable ROI before taxes, %	
	Low Risk	High Risk
Industrial chemicals	11	44
Petroleum	16	39
Pulp and paper	18	40
Pharmaceuticals	24	56
Metals	8	24
Paints	21	44
Fermentation products	10	49

A TVA report (G-4) states that a rough consensus appears to be 7 percent for ROI and 12 to 15 percent for IROR.

It must also be realized that business firms will accept or allocate a lower return from essential or cost-reducing projects than from those for production expansion or new projects, a view Happel and Jordan (G-5) support with these figures:

Type of Project	Degree of Risk	Minimum Acceptable ROI after Taxes, %
Cost reducing; pollution abating	Low	10 to 15
Capacity expansion; upgrading production facilities	Moderate	15 to 25
New facilities for a new product	High	20 to 50 or more

Note that for a given situation the IROR ranges from about the same value to 50 percent higher than the ROI; the particular increase depends on both the life of the project and the ratio of depreciation to net profit.

Regulated Industries

Both an ERDA report (G-6) and Doane *et al.* (G-7) showed how a roughly 10 percent return was calculated for projects considered for regulated industry. The data and calculated weighted costs of capital follow. The basis here is an attractive return (viz., 14 and 12 percent) to holders of common stock.

Type of Facility	Electric Utility (G-6)	Solar Electric Systems (G-7)
Capital Structure, %		
Debt (bonds)	53	50
Preferred equity	12	10
Common equity	35	40
Cost of Capital, %		
Interest on debt	8.0	8
Dividends on preferred equity	8.5	8
Dividends on common equity	14.0	12
Weighted Cost of Capital, %	10.16[a]	9.6

[a]For the computation of this value, see footnote (a) to Table E-1.

From the manner of calculation for the public utility example in Appendix E, it is apparent that the return to the bondholders, an item of annual expense, is made each year before income taxes are paid. The dividend return to stockholders, preferred and common, constitutes profit to the "owners;" it is therefore after income taxes.

Public Projects

Two philosophies are current for fixing discount factors used in evaluating government-funded projects; e.g., Cost-Effectiveness Analysis. The first, which has prevailed at least since 1952, holds that the discount rate should correspond to the average rate of interest payable by the U.S. Treasury on marketable securities. Recently, a strong case was developed for the use of the opportunity cost of capital.

Discount Rate Corresponding to Interest Rate on Government Obligations --

The position, that the Government's investment decisions are related to the cost of Federal borrowing, has been represented by a series of laws and regulations that have promulgated discount factors to be used for Federally funded water and related land programs (G-8). These discount rates now designated by the Water Resources Council, under its "Principles and Standards," have increased from 2.50 percent in 1957 to 6-5/8 percent in April 1978. When it published its Cost-Effectiveness Guidelines in 1973 (G-9), EPA adopted these interest rates even though its Construction Grants Program is not covered by the Water Resources Council's "Principles and Standards."

Current WRC discount rates can be obtained from the Water Resources Council, 2120 L Street, NW, Washington, DC 20037.

Discount Rate Corresponding to Opportunity Cost of Capital --

This concept suggests that the proper discount rate to use for public investment projects should be based on the rate of return to private sector investment. The rationale advanced is that resources used for public investment have alternative uses in the production of private commodities which society foregoes for the sake of public investment (G-2).

For this rate of return to private sector investment, called opportunity cost of capital, 10 percent is being suggested. This rate was cited in the Office of Management and Budget's circular A-94 (G-10) for use in agency programs not covered by the WRC "Principles and Standards."

INTEREST RATES

For project evaluation the two common uses of interest rates are to estimate the cost of short-term loans and long-term debt. Short-term loans are invariably for allowance for funds during construction. For regulated industries these interest charges are customarily included in the capital investment; see the public utility examples in Appendices E and J. For privately financed projects, where construction loans are required, such interest charges are expensed, generally at the end of the first year of operation. These short-term loans call for commercial interest rates which are higher than the rates on bonds. The interest rates on construction loans vary from 8 to 12 percent; McGlamery *et al.* (G-11) used 8 percent.

Interest rates on bonds currently run 6 to 10 percent. Customarily they are introduced only in the evaluation of projects for either the regulated or public sector, despite the use of bonds to provide some capital for private enterprises.

For simplicity and convenience in some project evaluations, the same interest rate is used both for allowance for funds during construction and for debt. This was done in the examples for the public utility in Appendix E and the flue gas desulfurization retrofit in Appendix J.

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APPENDIX H

METHODS OF RELIABILITY ASSESSMENT

CONTENTS

FIGURE

APPENDIX H

METHODS OF RELIABILITY ASSESSMENT

Cost estimates are at best only approximately correct, and they vary widely in reliability. Both the estimator and those using the results should be aware of these limitations. Accordingly some indication of reliability is an essential aspect of any cost estimate; it certainly ensures that the measures of merit based on best-guess cost information do not become cast in concrete. Also, a reliability assessment, where alternatives are being judged, serves notice that the reliability of the comparison is no better than that of the candidate with the lowest reliability.

FACTORS AFFECTING ACCURACY

Although desirable, it is difficult to determine the accuracy of a cost estimate. Factors such as stage of development, extent of the engineering, definition of scope, quality of the cost data, and expertise of the estimator must be considered. In addition, uncertainties about future events (e.g., business conditions, weather, and the actual organization used to erect the plant) may greatly influence actual costs.

ACCURACY OF CAPITAL INVESTMENT FROM AVAILABLE CORRELATIONS

In Figure 1 in Section 1 and Table 1 in Section 2, both in Volume I, the accuracy for the capital cost of the plant is exhibited as a function of only one of the above factors, namely, the extent of the engineering. Also, the error range for the plant capital cost is illustrated by a so-called "envelope of variability" in Figure 2 in Section 2, also in Volume I.

A graphic support for this envelope of variability is presented in Figure H-1 taken from Bauman (H-1). It is based on a study of the results from 48 actual projects for each of which several types of estimates of increasing accuracy were prepared. A breakdown by type and cost is:

Type	No. of Plants	Range of Cost (10^6 $)
Fluid	16	0.5-38
Fluid/solid	6	0.1-26
Solid	8	1.0- 6
Auxiliary facilities	9	0.5- 5
Laboratories	9	0.5- 2.5

The plotted points of Figure H-1 represent the percent deviation of the estimated costs of specific projects from the actual cost. The various estimate types are represented; in fact, the data serve to indicate the improvement in the accuracy with increasing information. Almost all the order-of-magnitude estimates were lower than the costs of the final project for which they were prepared. Preliminary estimates, which were based on more information, were more equally distributed over and under their actual project costs. The definitive estimates show a narrower range of variation with a larger percentage exceeding their respective project costs. Of the 48 projects only 35 were approved by management on the basis of a definitive estimate. The authority to construct the remaining was based on estimates of lesser accuracy to save time in bringing a product to market.

These guidelines set forth by Bauman are supported by several substantial, but less complete, investigations by Tyler (H-2) and (in particular) Hirsch and Glazier (H-3). Tyler's comparison of many estimates with the actual construction costs shows that half the overruns were caused by circumstances such as inflation and delays beyond the influence of management while the other half were caused by factors within its control. Tyler also emphasizes the marked effect of the capabilities and ingenuity of the construction superintendents upon the cost of the actual plant installation.

PROCEDURES FOR ASSESSING THE RELIABILITY OF A MEASURE OF MERIT

Note that only the accuracy of one element of a cost estimate has been considered above; viz., the capital cost of the plant. However, an indication of the accuracy of a feasibility measure, such as ROI, must also take into account the error range of the other cash flows (e.g., revenue, total operating costs) and factors such as plant life, income tax rate, and rate of inflation. For an assessment of accuracy, generally only the dominant cash flows and the factors likely to change in value need to be taken into account.

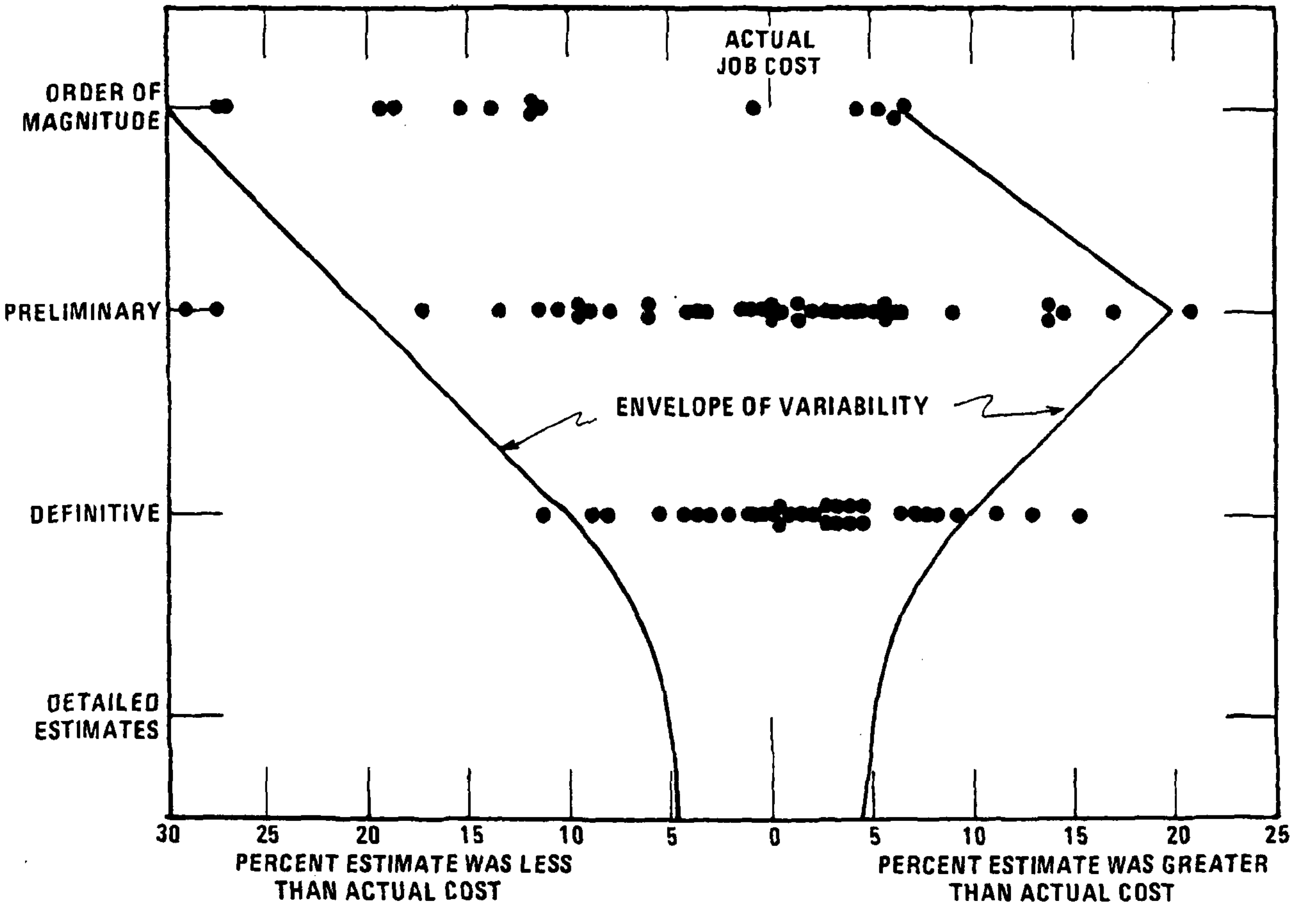

Figure H-1. Percent deviation from actual cost of various estimate types based on a study by Bauman (H-1). (Note that the percent deviation in this figure corresponds with the reliability figures in Table 1 in Volume I.)

For the purposes of this standard procedure, two modes will be reviewed:

- Opinion based on experience and correlations.
- Uncertainty analysis by statistical methods including the Monte Carlo technique.

Most cost estimates are presented using the mean or most likely values along with qualifying remarks. The first mode above requires that the estimator put his opinion on the line; an orderly basis for this, at least as it applies to the capital cost of the plant, is delineated below. The statistical approach requires a notion of the distribution of errors of the major cash flows and factors. A disadvantage of statistical methods is that they are presented in a form (cumulative frequency distribution) and use terms (standard deviation, variance) that are not familiar to many users. More information about these modes is given below.

Opinion-Based Mode

The opinion-based mode will be developed in some detail but only as it applies to the capital cost of facilities. Figure H-1 shows that the "envelope of variability" can be presented as a function of the degree of completeness of an engineering design. Other dominant aspects that affect the accuracy are reviewed below:

Stage of Development - If the process is new, and a preliminary design is based on a conceptual process, the error range will be broader than for an operation for which there are results from successful pilot plant operation.

Definition of Scope - By its nature this is vague and general for an order-of-magnitude estimate; but, for a preliminary estimate it can range from being indefinite to being fairly specific as illustrated in Table 6 in Section 3 of Volume I and the examples in Appendices J and K.

Quality of Cost Data - This varies widely. As stated in Appendix A, costs of the critical equipment items need to be secured from vendors and checked against experience, other vendors, or the literature. An equipment specification can be important here.

Expertise of the Estimator - The estimator should either be experienced or assemble his cost data with great care; in any case, he should possess good judgment. Care, experience, and discernment determine to a large extent the quality of a cost estimate.

Based on his assessment of these factors, the estimator should modify the error range found from Table 1 in Section 2 (also, see Figure 1 in Section 1 and Figure 2 in Section 2), all in Volume I.

An example of the use of the opinion mode for capital cost of facilities is given below for a conceptual process for which a preliminary* process design has been carried out by a contractor.

---

*A preliminary process design generally calls for a "study" estimate. A "preliminary" or "budget authorization" capital cost estimate requires more detailed engineering; Figure 2 in Section 2 (Volume I) clarifies this distinction.

a. The accuracy based on a preliminary process design can be found either from Figure 1 or Table 1 (Volume I) for a so-called "study" estimate to be . . . . ± 30%
(With further engineering study the estimate would have been termed "preliminary" or "budget authorization" and rated at ± 20% accuracy.)

b. The fact that the process is conceptual and that no pilot plant results are available affects the range of accuracy. It could be more, but use . . . . ± 50%
(Such estimates tend to be low, not high, because the complexity of a real process is usually not fully comprehended at this stage. See Figure H-1.)

c. The definition of scope is assumed to be consistent with the preliminary process design, so that there is no effect. At best, the range is still . . . . ± 50%

d. The quality of the cost data could be good if sufficient care were taken in delineating the equipment list and in defining the characteristics of the operation. Note that the excellent quality of cost data only serves to maintain the estimate within the previous range, not to constrict the range of accuracy. It remains, at best . . . . ± 50%

e. The lack of expertise of the estimator can now serve to broaden the range further. If it can be assumed that the person in charge of the cost estimate had experience with an engineering-construction firm in both process design and cost estimation, this can then at best maintain the range at . . . . ± 50%

This means that the error range for the capital cost estimate is judged to be ± 50 percent by the project officer.

If the capital cost estimate were a preliminary type, the degree of accuracy would first be judged to be ± 20 percent; but because the pilot plant data are inconclusive, the value might be increased to ± 30 percent.

Of course, in addition to the factors above, there is the effect of outside influences; e.g., business conditions, topography, climate, and availability of a competent organization for plant installation.

It must be realized that the error range of the other cash flows and factors must be taken into account in appraising the accuracy of the feasibility measures. It is virtually impossible to do this by the opinion mode. Accordingly, it may be advisable to invoke a statistical method.

Statistical Mode

This mode recognizes that each element of a cost estimate is a statistical concept characterized by a mean value and some measure of the probability distribution of the value. For example, if the distribution is normal, the standard deviation is sufficient to characterize the distribution. Such information, if available for the dominant cost elements (e.g., investment, operating costs, selling price), can be combined to calculate the distribution of various calculated results, such as return on investment.

For cases where the dominant cost elements can be assumed to have normal distributions, the method of calculation is outlined and illustrated by Ferencz (H-4). An example is also given by Hirsch and Glazier (H-3).

In other situations, some of the distributions are not normal. Also, there are software systems firms, such as McDonnell Douglas Automation Co., St. Louis, and Bonner and Moore Associates, Inc., Houston, that perform such calculations on a service basis.

In Appendix K, the reliability assessment segment includes an uncertainty analysis generated by the application of the Monte Carlo technique. Estimates of the expected range and the most likely values of the significant cost inputs are tabulated. The result is a cumulative frequency distribution plot for the ROI. One procedure for generating the probability distribution of the cost elements is crude but practical: a source with some knowledge about one element provides a most likely value, an optimistic value, and a pessimistic value. For example, a sales manager could furnish figures for the selling price and the market volume; a production manager could supply production costs; and the engineering department could work up the capital investment costs. This approach lends itself to establishing a probability distribution for each of the variables in question. The modified-beta probability is often used; however, other probability distributions can be and are used. For the applicable elements, the Monte Carlo technique can be used to obtain a probability distribution of the measure of merit; e.g., ROI. The information derived allows for better decisions than from the one-value best-estimate method. It is particularly helpful in deciding between alternatives; sometimes the choice is not the best-guess candidate, but the one with the most favorable probability situation. This entire subject, as it applies to facility feasibility, is briefly explained by Ross (H-5). There is extensive literature on this mode and programs can be purchased; e.g., from Decision Sciences Corp., St. Louis.

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APPENDIX I

SENSITIVITY ANALYSIS

CONTENTS

FIGURES

APPENDIX I

SENSITIVITY ANALYSIS

The modes for reliability assessment described in Appendix H yield an indication of the overall accuracy of the cost evaluation. However, these modes do not answer the question, "How sensitive are estimates to variations of a specific factor?" Or more to the point, they do not set at rest the issue, "Is there some probability that the original decision based on the best-guess estimate might be reversed because of the variation of a specific factor?" The answers are provided by a sensitivity analysis.

DEFINITION OF SENSITIVITY

Sensitivity relates to the extent of the change in a cost analysis resulting from a variation in one or more elements of the cost estimate. More particularly, a sensitivity analysis shows the influence of possible changes of the significant variables and identifies those that have a critical effect on the measures of merit. The analysis is especially concerned with factors that could bring about a change in the decision with only a small change in the value of the factors.

METHODS OF SENSITIVITY ANALYSES

The usual practice is to make a number of computations of measures of merit by varying each significant cost or financial factor over its likely range. Because of the many calculations that may be needed, a computer often proves helpful in executing a sensitivity study. In some situations mapping a space by changing one variable at a time requires a substantial effort; this may be markedly reduced by application of response surface techniques.

In response surface analysis each significant element is changed in accordance with an appropriate scheme; for example, a factorial design (I-1, I-2). The advantage of this method is that it determines the points (or other interfaces at which changes in decision may be required) with fewer calculations, and it provides information on the nature of the response in the vicinity of the critical areas.

SUGGESTED SENSITIVITY EVALUATIONS

Because of the rough nature of much of the information for a study or preliminary type estimate, a sophisticated sensitivity analysis (such as by response surface techniques) is generally not required. However, thought needs to be given to costs or other values that could vary considerably and thereby have a critical effect. Also, the sensitivity analyses need to be presented effectively.

A minimum procedure is to single out the dominant variables and demonstrate their effect on a measure of merit. In Figure I-1, the effect of relative maintenance charges is shown on the relatively uniform annual cost for the example of the FGD retrofit in Appendix J. This follows the relative profitability approach of Agarwal and Klumpar (I-3); it is well suited to this example.

Figure I-2 demonstrates the Strauss Chart (I-4). Usually a measure of merit is the ordinate. and the abscissa accounts for the over- or under-estimation of a significant parameter. The slope indicates the

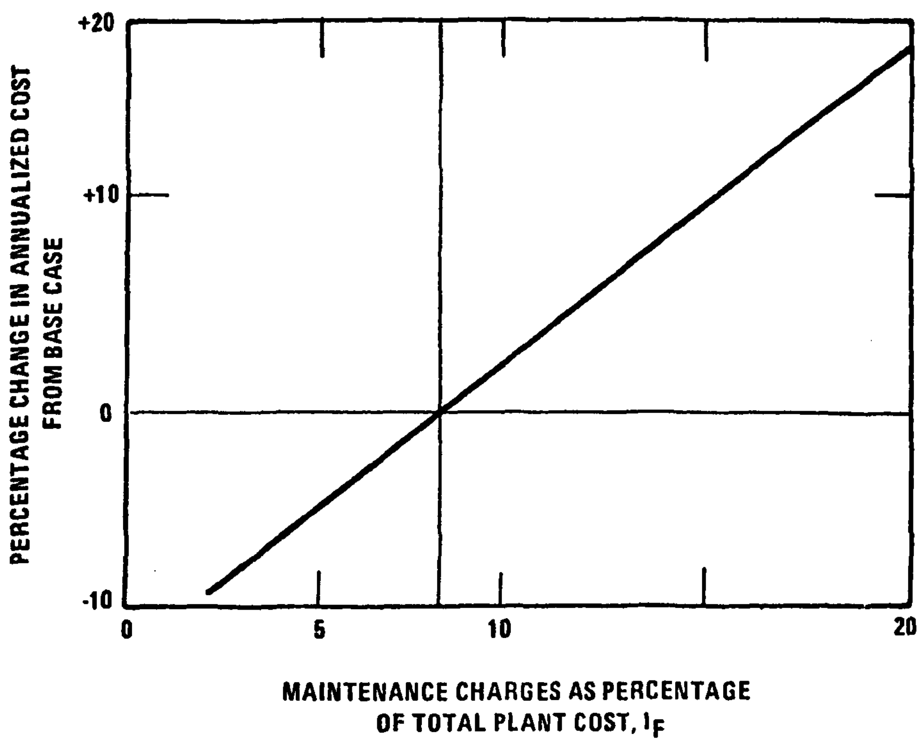

Figure I-1. Sensitivity analysis of maintenance charges for wet limestone process FGD unit for the example in Appendix J. (This corresponds to the relative profitability approach described by Agarwal and Klumpar (I-3)).

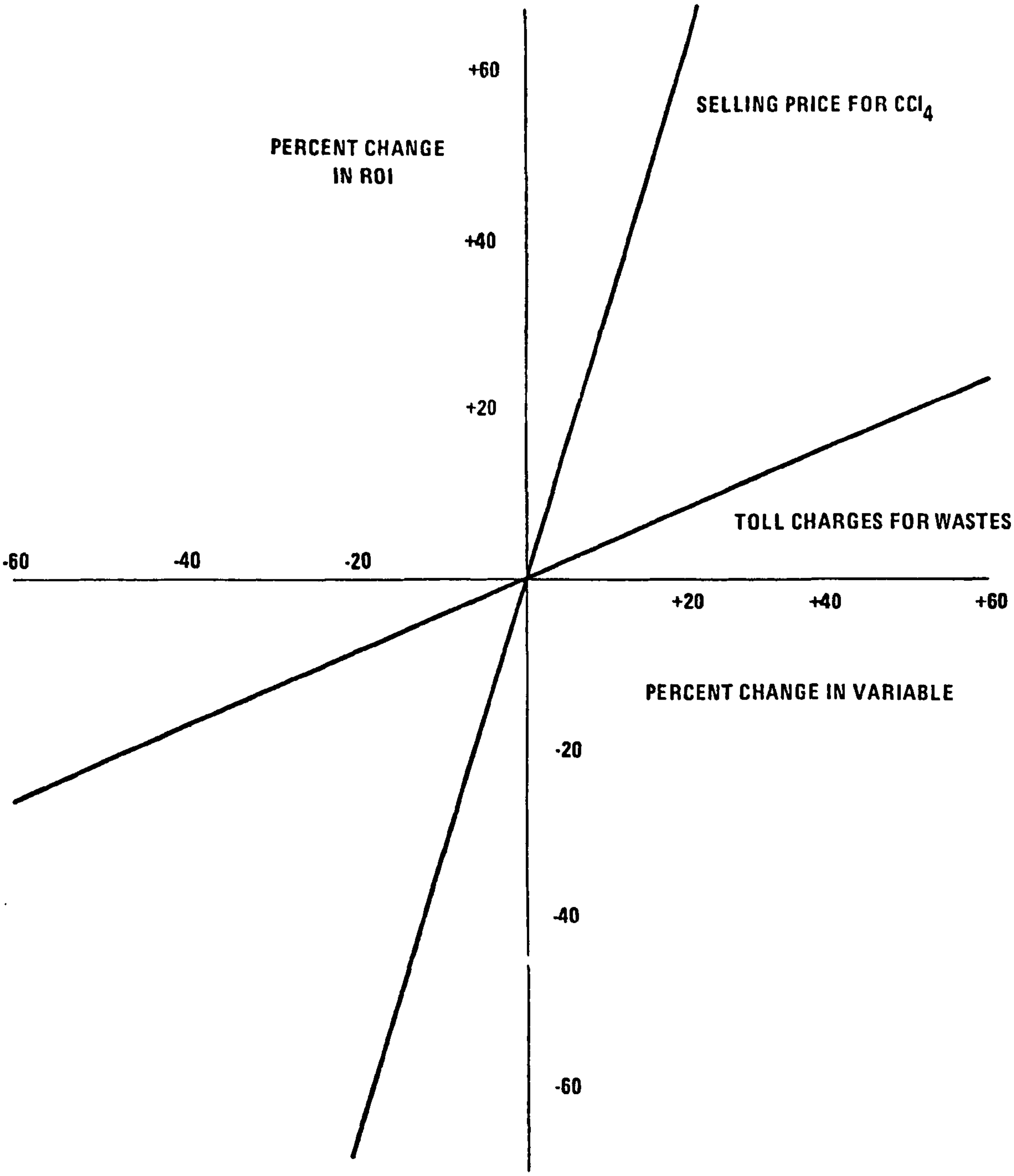

Figure I-2. Strauss Chart (I-4) for sensitivity analysis of CCl_4 price and handling tolls for residues on ROI for chlorolysis unit (for example in Appendix K).

degree of change in the measure of merit with an assumed percentage change in a parameter. The length of the line represents the range of sensitivity of the parameter. Arbitrarily, Strauss assigned positive slopes to revenue variables and negative slopes to operating expense variables. The illustrative chart (Figure I-2) depicts the effect of carbon tetrachloride (CCl_4) market price and handling tolls for residues on the return on investment (ROI) for the chlorolysis unit example in Appendix K. This chart demonstrates graphically that profitability is only moderately affected by changes in the residue handling tolls that can be exacted, but is very sensitive to the market price of CCl_4. In fact, the chart dramatically shows that a drop of over 20 to 30 percent in the expected price of CCl_4 would render the proposed process infeasible.

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APPENDIX J

EXAMPLE I -- COST ANALYSIS OF FLUE GAS DESULFURIZATION (FGD) RETROFIT FACILITY

CONTENTS

FIGURE

TABLES

APPENDIX J

EXAMPLE I -- COST ANALYSIS OF FLUE GAS DESULFURIZATION (FGD) RETROFIT FACILITY

The mode of cost analysis for public utilities will be demonstrated by this evaluation.

STATEMENT OF PROBLEM

An engineering cost analysis is required for a retrofit to a 500 MW coal-fired power station for the removal of SO_2 from the flue gases. The wet limestone process will be used.

SOURCE OF PROCESS AND COST DATA

The primary source of the process and cost data is an engineering study made by Catalytic, Inc. (J-1) for the limestone slurry scrubbing of flue gas. This complete cost study was further qualified as an example because of its later scrutiny by Pullman Kellogg (J-2). Except for the comprehensive study by TVA (J-3), few evaluations were found in EPA reports which proved satisfactory to demonstrate a cost evaluation.

GUIDELINE INFORMATION

The required guideline information, as outlined in Table 11 in Section 3 of Volume I, is developed in Table J-1.

SPECIFICATION

The data required as indicated by Tables 5 and 7 in Section 3 of Volume I are provided in Tables J-2 and J-3; these are supplemented by the information in Tables J-4 through J-7. Some pertinent comments are given below.

Descriptive Segment

See Table J-2. Note the process flowsheet, Figure J-1.

TABLE J-1. GUIDELINE INFORMATION FOR EXAMPLE I

DESCRIPTIVE SEGMENT	
Facility Description	
Plant Location	Midwest area.
Index for area construction labor costs	Stated as Cincinnati. Index not specifically declared in Catalytic report (J-1).
Capacity Rating	To reduce SO_2 content from flue gas from 500 MW coal-fired power station burning 3-1/2% S coal.
Abstract of Scope	Gas train - venturi and three-stage turbulent contact absorbers (TCA). To cover all equipment from boiler breeching to boiler stack. Processing areas to be included in the design are: 1. Limestone storage and processing. 2. Slurry scrubbing system with stack gas reheater and accessories. 3. Spent limestone slurry settling system and water recovery. The cost of the electrostatic precipitators associated with the boiler is not to be included in this estimate.
Performance Specifications	The boiler system with wet limestone scrubbing is to meet EPA standards for SO_2 emissions of 1.2 lb of SO_2 per million Btu (0.52 mg of SO_2/kJ) heat input.
Stage of Development	Detailed design of system is based on incomplete pilot plant work by TVA's Office of Agricultural and Chemical Development.

Table J-1 (Continued). Guideline Information for Example I

COST EVALUATION SEGMENT

Specified Parameters

Interest (Discount) Rate	Use 11%.
Facility Life and Depreciation Period	Use 15 years for both.
Construction Time	Three years.
Reference Year for Costs	1977.
Reference Units for Process Costs	For capital -- $/kW; for operating expense -- mills/kWhr.
Cost Index	Chemical Engineering (CE).
Inflation Rate	N.A. See under Feasibility Evaluation, below.

Cost Estimate - Capital Investment

Types of Capital Investment Estimates	Definitive, only because definitive estimate is available. Also, use Chilton and Lang methods as checks and to demonstrate these techniques.
Allowance for Funds During Construction	Capitalize. Schedule for funds: 25% 3 years before start-up, 50% 2 years before, and 25% 1 year before. Use 8% interest rate.
Modification of Facilities and Start-up	Capitalize. Use 8% of I_F.

Cost Estimate - Operating Expense

Total Operating Expenses vs. only O&M	Use total operating expenses.
Stream Time	7,000 hr/yr
Pre-production Expenses	N.A.
Direct (operating) Labor Rate	$7/hr
Depreciation	Use straight-line method.

Cost Estimate - Profit and *Cash Flow*

Revenue (if any)	Calculate revenue requirement.
Income Tax Rate	50%.

Table J-1 (Continued). Guideline Information for Example I

Feasibility Evaluation	
Mode of Cost Analysis	Utility financing.
Measures of Merit	Annualized cost, levelized cost, unit capital investment, and unit operating expense. The two unit costs are customary for economic analyses of FGD units.
Computation Features	Use discounting, calculate revenue requirement (inherent in annualized and levelized cost), recover investment (by depreciation), do not account for inflation, use total annual expenses, use discrete interest factors.
RELIABILITY ASSESSMENT SEGMENT	
Sensitivity Analysis	Investigate the sensitivity of the annualized cost for revenue requirement for annual maintenance charges from 2 to 20% of I_F. The process does not seem to be sensitive to other variables. Use "relative profitability" approach to depict sensitivity analysis.
Uncertainty Analysis	Use only opinion mode.

TABLE J-2. SUMMARY OF ECONOMIC EVALUATION FOR EXAMPLE I -- DESCRIPTIVE SEGMENT

FACILITY DESCRIPTION. Wet limestone process for flue gas desulfurization. 500 MW coal-fired power station retrofit. See flow diagram, Figure J-1. Location: midwest area. Cincinnati construction labor rates should apply.

CAPACITY RATING. For retrofit to 500 MW coal-fired power station. 1.54×10^6 acfm (43,600 m^3/min) of flue gas to venturi. Sulfur flow rate of 13,200 lb/hr (1.66 kg/s) (3-1/2% S coal).

ABSTRACT OF SCOPE. Fuel - coal with 3-1/2% S. Gas train - venturi and three-stage turbulent contact absorbers (TCA). Slurry flowrate: to venturi, 18 gpm/Macfm (2.41 m^3 slurry/10^3 m^3 inlet gas); to TCA, 40 gpm/Macfm (5.36 m^3 slurry/10^3 m^3 inlet gas). Total ΔP = 18 in. (0.46 m) w.c. Covers all equipment from boiler breeching to boiler stack. Processing areas included in the design are:

1. Limestone storage and processing.
2. Slurry scrubbing system with stack gas reheater and accessories.
3. Spent limestone slurry settling system and water recovery.

The cost of the electrostatic precipitators associated with the boiler is not included in this estimate.

PERFORMANCE SPECIFICATION. The boiler system with wet limestone scrubbing will meet EPA standards for SO_2 emissions of 1.2 lb of SO_2 per million Btu (0.52 mg/kJ) heat input.

STAGE OF DEVELOPMENT. Detailed design of system is based on incomplete pilot plant work by TVA's Office of Agricultural and Chemical Development (J-1).

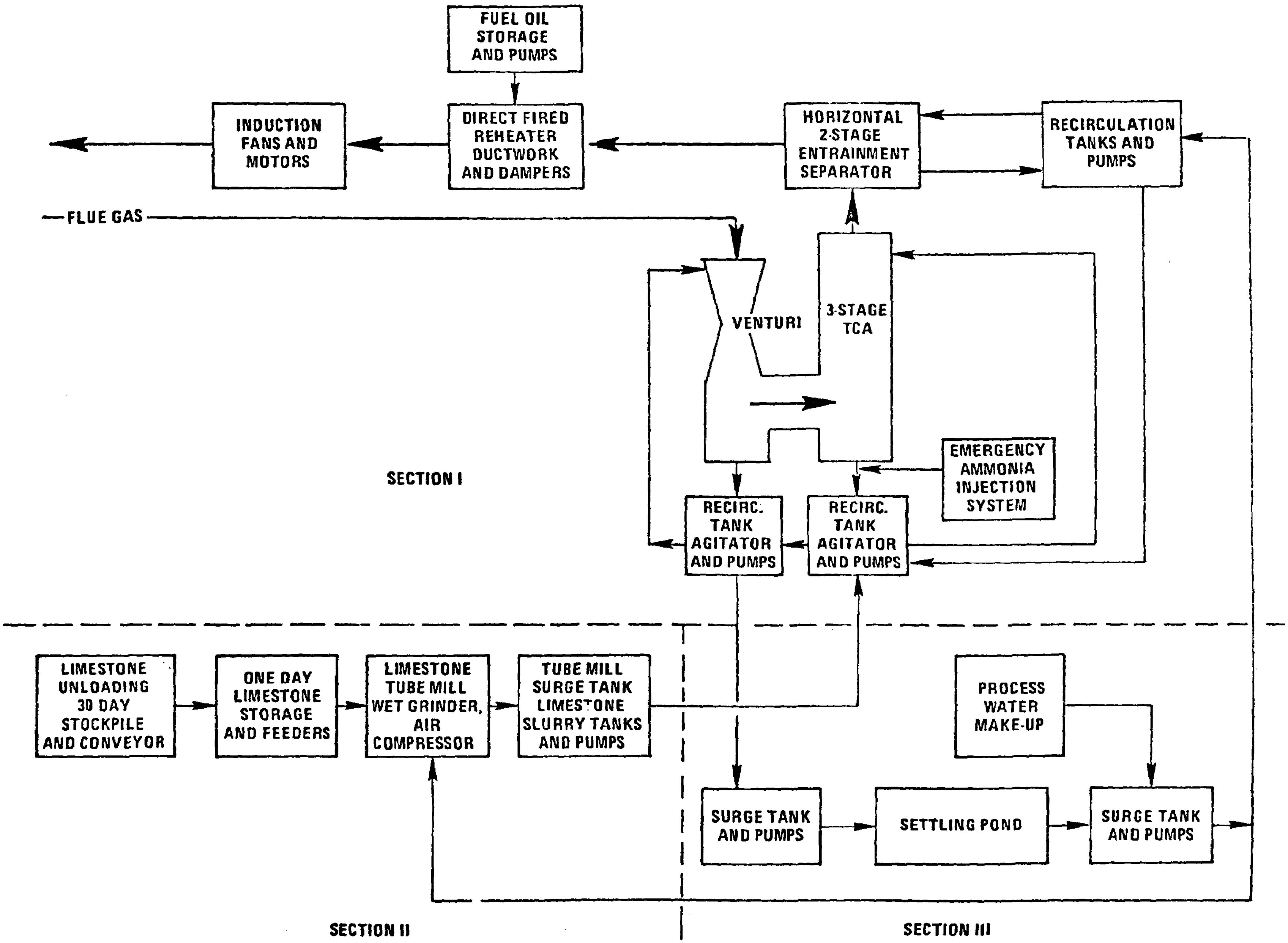


Figure J-1. Wet limestone FGD process flowsheet, adapted from Shore et al. (J-2).

TABLE J-3. SUMMARY OF ECONOMIC EVALUATION FOR EXAMPLE I -- COST ANALYSIS SEGMENT

FACILITY DESCRIPTION. Wet limestone process for flue gas desulfurization. 500 MW coal-fired power station - retrofit See flow diagram, Figure J-1. Plant Location -- Midwest area.	CAPACITY RATING. For retrofit to 500 MW coal-fired power station, 3-1/2% S Coal.

DISCOUNT RATE, 11%; FACILITY LIFE, 15 YRS; DEPRECIATION PERIOD, 15 YRS;

CONSTRUCTION TIME, 3 years; REFERENCE UNIT FOR PROCESS COST, kW, kWhr;

REFERENCE YEAR FOR COSTS, 1977; COST INDEX, CE; INFLATION RATE, N.A.

CAPITAL INVESTMENT ESTIMATION

Schedule A. Chilton method. Factored costs of sum of major plant items (MPIs).

	Item	Factor	Operating On Item No.	Cost of Item, K$
1.	Sum of major plant items (MPIs), ΣE, delivered	--	--	4,041
2.	Installed, erected equipment cost	1.43	1	5,779
3.	Piping (includes insulation)	0.30	2	1,734
4.	Instrumentation	0.10	2	578
5.	Buildings and site development	0.60	2	3,467
6.	Auxiliaries (electric, steam, etc.)	0.20	2	1,156
7.	Other			--
11.	Total physical cost (Direct cost), DC (sum of 2 to 7)			12,714

Use Schedule C to get the Total plant cost, item 31.

Table J-3 (Continued). Summary of Economic Evaluation for Example I Cost Analysis Segment

Schedule C. Calculation of total plant cost using direct cost from Schedule A

11. Total physical cost (Direct cost) DC	K$12,714
12. Indirect cost (34% of DC), IC	4,323
21. Total bare module cost, BMC	17,037
22. Contingency (15% of BMC)	2,555
23. Contractor's fee (3% of BMC)	511
Total new plant cost	K$20,103
27. Retrofit Increment (30% of new I_F)	6,031
31. Total retrofit plant cost (Total module cost), I_F	K$26,134

Schedule D. Lang method

Use $I_F = \Sigma E \times L \times (1 + RF)$

where ΣE = K$4,041 from item 1, Schedule A

L = 3.63 is the Lang factor for a solid/fluid plant from Table A-3.

RF = Retrofit Increment, 0.30 for this case.

Then I_F = K$4,041 (3.63) (1 + 0.30) = K$19,070.

Table J-3 (Continued). Summary of Economic Evaluation for Example I Cost Analysis Segment

Schedule G. Total plant cost from typical definitive estimates

Table J-4 is a source of Schedule G type information. However, these data are for a new facility; whereas, the desired installation is a retrofit.

Total new plant cost from Table J-4	K$20,153
27. Retrofit Increment, 30% of new I_F	6,046
31. Total retrofit plant cost (Total module cost), I_F	K$26,199

Because data from Schedule G are more detailed, they will be used. Note that they are 1972 costs.

Definitive Total Plant Cost Adjusted to 1977 Costs. Item 31, the Total Retrofit Plant Cost, will be corrected from 1972 to 1977 costs using the CE Plant Index (see Figure F-1), or

$$I_F = K\$26,199 \left(\frac{203}{137.5}\right) = K\$38,680 \quad .$$

Schedule H. Total capital investment

31. Total plant cost, I_F, from Schedule G and and adjusted to 1977	K$38,680
32. Interest during construction -- 0.1680 I_F	6,498
33. Modification of the facilities and start-up costs, 8% of I_F	3,094
35. Total depreciable investment, DI	48,272
36. Land, 600 acres (2.43×10^6 m^2) at \$2,000/acre (K\$494/10^6 m^2)	1,200
37. Working capital, 10% of DI	4,827
41. Total capital investment	K$54,299

Table J-3 (Continued). Summary of Economic Evaluation for Example I Cost Analysis Segment

ANNUAL OPERATING EXPENSE SUMMARY (from the subtotals in Table J-5, Operating Expense, and Table J-6, Average General Expense)

53. Raw materials	K$ 1,364
70. Processing	5,875
74. Plant overhead, control lab and technical	1,206
76, 77. Other fixed charges (insurance, property taxes, royalties)	1,160
78. Depreciation	3,218
87. Average general expense	2,224
90. Average total annual expense	K$15,047

PROFIT AND *CASH FLOW* (ANNUAL) SUMMARY

91. Revenue including value of byproducts	To be calculated
92. Gross profit (revenue - annual operating expense)	Varies each year; see Table J-7
93. Net profit (gross profit - income tax)	Varies each year; see Table J-7
94. *Cash flow* (depreciation + equity dividends)	Varies each year; see Table J-7

FEASIBILITY EVALUATION SUMMARY

104. Annualized cost for revenue requirement by simplified procedure, Equation E-2[a]	K$19,880
Annualized cost for revenue requirement by detailed method following Equation E-1[b] -- see Table J-7 for calculation	K$21,303
108. Levelized cost using typical utility approach	6.09 mills/kWhr
112. Total capital cost/kW = $\frac{K\$54,299}{500,000}$ =	\$108.60/kW
113. Operating expense/kWhr = $\frac{K\$15,047 \times 1000}{500,000 \times 7000}$ =	4.30 mills/kWhr

Descriptive appraisal of the financial merit of the venture: the costs are in line with those for operating installations.

[a]See p. J-16 for calculation.

[b]Includes average interest on debt of K$1,017. In this connection see footnote b on p. J-13.

TABLE J-4. ANALYSIS OF CAPITAL INVESTMENT DATA FOR LIMESTONE SLURRY FGD UNIT - 500 MW, 3.5% S Coal, NEW (J-1)

Unit	I Limestone Handling Unit	II Slurry Preparation Unit	III Scrubbing System	IV Flue Gas Discharge Unit	V Reheat System	VI Ammonia Unit	VII Waste Disposal	VIII Entrainment Separator	IX Major Elect. Equip.	Summary	Avg Case; See Guthrie (J-4, J-5)
Equip. Cost-FOB, E	57,050	617,400	1,796,000[a]	1,335,000[b]	156,770	10,000	37,990	30,900	--	4,041,310	
Field Mat'ls,[c] m	17,840	49,940	1,775,410	257,360	59,610	9,770	374,280	91,950	301,000	2,936,960	
Direct Mat'l, M	74,890	667,340	3,571,410[d]	1,592,360	216,380	19,770	412,270	122,850	301,000	6,978,270	
(M/E)	(1.31)	(1.08)	(1.97)	(1.19)	(1.38)	(1.97)	(10.85)	(3.98)	(-)	(1.73)	(1.62)
Direct Fld. Lab. L	66,550	145,570	1,114,460	395,000	72,650	16,730	453,870	80,310	29,200	2,374,340	
(L/E)	(1.17)	(0.24)	(0.62)	(0.30)	(0.46)	(1.67)	(11.95)	(2.60)	(-)	(0.59)	(0.59)
Direct Cost, M&L	141,440	812,910	4,685,870	1,987,360	289,030	26,500	866,140	203,160	330,200	9,352,610	
(M+L/E)	(2.48)	(1.32)	(2.61)	(1.49)	(1.84)	(2.65)	(22.80)	(6.57)	(-)	(2.31)	(2.20)
Indirect Cost										4,657,130	
(Indirect Factor)										(1.50)	(1.34)
							Total Bare Module Cost			14,009,740	
							Site Specific Items			4,311,300[e]	
							Base Plant Cost			18,321,040	
							Contingency 10%			1,832,100	
							Total New Plant Cost, I_F			20,153,140	4.99[f] (3.81)

[a] Includes 90% of Contract Cost for Scrubbers and Entrainment Separators.

[b] Mostly breeching.

[c] Piping, concrete, steel, instruments, electrical, insulation, paint.

[d] Includes Piping for Group IV.

[e] Site Specific Items

	I	II	III	IV	V	VI	VII	VIII	IX	Summary
Tankage	76,000	46,300	360,000		68,500			28,500		579,300
Site Dev.					33,000		3,694,000			3,727,000
Fire Prot.										5,000
							Site Specific Items			4,311,300

[f] Lang factors first including "site specific" costs $\frac{18,321,040(1 + 0.10)}{4,041,310} = 4.99$ (then excluding "site specific" costs $\frac{(14,009,740\ (1 + 0.10)}{4,041,310} = 3.81$).

TABLE J-5. ANNUAL OPERATING EXPENSE ESTIMATE FOR EXAMPLE I
WET LIMESTONE FGD PROCESS, 500 MW -- RETROFIT

Total Plant Cost, I_F: K$38,680; Depreciable Investment: K$48,272
Stream Hours: 7,000 hr/yr; Basic Unit of Capacity or Production: kWhr

	Unit	Units/ Year	Value $/Unit	UnitsX10^3 /kWhr	Total Costs mills/kWhr	Total Costs K$/yr
51. Raw materials						
Limestone	ton[a]	223.3X10^3	$6/ton	0.06381	0.383	1,340
Ammonia	ton[a]	200	$120/ton	0.00006	0.007	24
52. Byproduct credit; Ingredients					(none)	(none)
53. Subtotal					0.390	1,364
56. Operating labor, L, 4 men/shift	man-hour	33,600	$7/man-hr	0.0096	0.067[b]	235[b]
57. Direct supervision, 25% L					0.017	59
58, 59. Maintenance, 8%	I_F				0.882	3,094
60. Operating supplies	15% Main.				0.133	464
61. Labor additives, 35% L					0.023	82
62. Steam	10^3 lb[c]		--			--
63. Electricity	kWhr	79.1x10^6	0.01/kWh	22.6	0.226	791
64. Compressed air	10^3 cf[d]		--			--
65. Water	10^3 gal[e]	168,000	0.30/10^3 gal.	0.048	0.014	50
66. Fuel	10^6 Btu[f]	667,000	1.50/10^{6}Btu	0.19	0.286	1,000
67. Effluent trtmt and disposal					0.028	100

[a]Multiply ton by 908 to convert to kg.

[b]For 8400 hr/yr operation.

[c]Multiply 10^3 lb by 454 to convert values to kg.

[d]Multiply 10^3 cf by 28.32 to convert values to m^3.

[e]Multiply 10^3 gal by 3.785 to convert values to m^3.

[f]Multiply 10^6 Btu by 1.055 X 10^6 to convert values to kJ.

Table J-5 (Continued). Annual Operating Expense Estimate for Example I Wet Limestone FGD Process, 500 MW -- Retrofit

	Unit	Units/ Year	Value $/Unit	UnitsX10^3 /kWhr	Total Costs	
					mills/kWhr	K$/yr
68. Preparation for shipping					--	--
69. Other					--	--
70. Subtotal processing					1.676	5,875
71. Plant overhead, 50% operating labor + 25% maintenance					0.255	891
72. Control laboratory, 4 analysts					0.051	180
73. Technical and engineering, 3 engineers, plant follow-up					0.039	135
74. Subtotal overhead					0.345	1,206
76. Insurance and property taxes, 3% I_F					0.331	1,160
77. Royalty						--
78. Depreciation, straight-line					0.919	3,218
79. Subtotal fixed charges					1.250	4,378
80. TOTAL MANUFACTURING COST					3.681	12,823

TABLE J-6. AVERAGE GENERAL EXPENSE ESTIMATE FOR EXAMPLE I
WET LIMESTONE FGD PROCESS, 500 MW -- RETROFIT
Depreciable Investment: K$48,272
Total Capital Investment: K$54,299

81. Administration, 1/2% of depreciable investment - - - - -	K$ 241
83. Corporate research, 1% of depreciable investment - - - -	483
84. Average interest on debt, 8% of 40% of average book value[a] of total capital- - - - - - - - - - - - - - - - - - -	1,017
85. Other, 1% of investment - - - - - - - - - - - - - - - - -	483
87. Average general expense[b]- - - - - - - - - - - - - - -	K$2,224

[a]The calculation is 0.08 X 0.40 of the average book value of [(1 + 1/15) (48,272/2) + 54,299 - 48,272)]. Here K$48,272 is item 35, Total depreciable investment, and K$54,299 is item 41, Total capital investment in Table J-3. The above relation yields K$1,017 as shown. The (1 + 1/15) factor takes account of the shift of average book values from the beginning of each year to the end of each year when interest obligation is discharged. This can be seen clearly from the "Debt Interest" column in Table J-7.

[b]This is an Average general expense. For the utility financing mode, it decreases from the first year to the last because of diminishing values for debt interest. For this example the debt interest ranges from K$1,738 for the first year linearly to K$296 for the 15th year. See "Debt Interest" column in Table J-7.

TABLE J-7. LIFE CYCLE COSTS FOR EXAMPLE 1 -- PUBLIC UTILITY MODE OF EVALUATION

All values are in K$

Ref. Year	Capital Cost[a]		Total Ann. Exp. Less Debt Int.[b]	Deprec.	Book Value	Debt Interest at 8%[b,c]	Equity Dividends at 14%[b,d]	Income Tax[b]	Required Revenue	10% Present (Worth) Value Factor	P.V. of Required Revenue
	Item	Value									
-3	Land	1,200									
-3	25% construction	9,670									
-2	50% construction	19,340									
-1	25% construction	9,670									
0(1977)	Interest on const.	6,498									
0	Start-up cost	3,094									
0	Working capital	4,827									
1			14,030	3,218	54,299	1,738	4,561	6,758	24,890	0.9091	22,627
2			14,030	3,218	51,081	1,635	4,291	6,307	24,247	0.8264	20,038
3			14,030	3,218	47,863	1,532	4,020	5,857	23,602	0.7513	17,732
4			14,030	3,218	44,645	1,429	3,750	5,407	22,959	0.6830	15,681
5			14,030	3,218	41,426	1,326	3,480	4,956	22,316	0.6209	13,856
6			14,030	3,218	38,208	1,223	3,209	4,505	21,671	0.5645	12,233
7			14,030	3,218	34,990	1,120	2,939	4,055	21,028	0.5132	10,792
8			14,030	3,218	31,772	1,017	2,669	3,604	20,385	0.4665	9,510
9			14,030	3,218	28,554	914	2,399	3,154	19,742	0.4241	8,373
10			14,030	3,218	25,336	811	2,128	2,703	19,097	0.3855	7,362
11			14,030	3,218	22,118	708	1,858	2,253	18,454	0.3505	6,468
12			14,030	3,218	18,900	605	1,588	1,802	17,811	0.3186	5,675
13			14,030	3,218	15,681	502	1,317	1,352	17,166	0.2897	4,973
14			14,030	3,218	12,463	399	1,047	901	16,523	0.2633	4,351
15			14,030	3,218	9,245	296	777	450	15,880	0.2394	3,802
15	Recovery of land and working capital[a]	6,027	14,030	3,218	0				-6,027	0.2394	-1,443
							Total Present Value of Required Revenue				162,032

$$\text{Annualized Cost for Required Revenue}^{e} = \frac{\text{Present Value of Required Revenue}}{\text{Uniform Annual Series Present Worth Factor}} = \frac{162,032}{7.606} = \text{K\$21,303}$$

[a]The value of Land and Working capital, recovered at the end of the 15th year, is credited to the required revenue and, properly discounted, is credited to the Present Value of Required Revenue.

[b]The sum of these four items equals the required revenue for the year.

[c]Debt comprises 40% of the total capital investment.

[d]Equity (capital) comprises 60% of the total capital investment.

[e]Calculated from Equation E-1.

Cost Analysis Segment

Cost Estimate - Capital Investment --

Most of the cost data for the example are taken from Calvin (J-1), but other sources are also used as needed. Capital cost can be estimated in several ways because of the completeness of the data which are for a definitive estimate. In Table J-3, Schedules A, C, D, and G are completed to yield three values of the 1972 Total Plant Cost.

The factors used in the Chilton method (Schedule A) are arbitrary; their selection was guided by definitive cost data in Table J-4.

Note that the indirects are 50 percent of the total direct cost for Table J-4 items I to IX, but 34 percent of the sum of these plus the Site Specific Items. This 34 percent factor for indirects compares with the 35 percent average for engineering and construction in Table A-4 for typical Chilton factors. Also, the Guthrie scheme gives an average for this factor of 34 percent. Calvin showed only 10 percent for Contingency and no Contractor's Fee. The estimate herein contains a 15 percent Contingency and a 3 percent Contractor's Fee.

Generally retrofit increments increase the cost 25 to 40 percent over that for a new plant. The actual increment is very sensitive to site considerations. In this example, a 30 percent retrofit increment was used arbitrarily. The total retrofit plant cost from Schedule G, was escalated from 1972 to 1977 costs using the CE Plant Cost Index.

The interest charge for funds for construction using 8 percent interest, a 3-year construction period, and the schedule declared under the Guidelines is calculated as follows:

Years Before Start-up	Project Expenditure Schedule		Interest Factor at 8% Discrete Interest		Weighted Interest Factor
Third (-3 to -2)	25%	X	1.260	=	0.3150
Second (-2 to -1)	50%	X	1.166	=	0.5830
First (-1 to 0)	25%	X	1.080	=	0.2700
					1.1680

This means that 0.1680 times the construction cost is due for interest payments at start-up (time zero).

For Modification of Facilities and Start-up, the recommendation in Table A-8 taken from McGlamery et al. (J-3) will be followed. This charge is estimated at 8 percent of the Total Depreciable Investment. For Land, it is estimated that 600 acres (2.43×10^6 m^2) is required and that the cost per acre is $2,000 (K$494/10^6 m^2) from the table under

Land in Appendix A. The Working Capital will be taken as 10 percent of the Total Depreciable Investment.

An extra feature of Table J-4 is Guthrie factors which were calculated from the data for each of the process modules and for the summary; they are given in parentheses. The average values for the Guthrie factors are also given in the last column; these are taken from references J-4 and J-5. These compare well with the summary values. This is a good place to note that a definitive estimate is necessary to secure Guthrie factors for equipment not available in the literature.

Cost Estimate - Annual Expense --

For the conditions of the example, Tables J-5 and J-6 are completed Tables 9 and 10 in Volume I. Some changes made to the data taken from reference J-1 are:

- Four plant operators were used instead of two.
- 8 percent of I_F was shown for maintenance instead of 4 percent.
- Four analysts and three engineers were added for technical work related to the operation of the FGD facility.

Cost Estimate - Feasibility Evaluation --

The guidelines call for the determination of the annualized cost (for revenue requirement), levelized cost, unit capital investment, and unit operating expense. Recourse is made to the utility financing mode in determining annualized and levelized costs. The annualized cost is calculated first by the simplified procedure, Equation E-2, and then by the detailed method following Equation E-1. Because inflation is not to be accounted for, levelized cost by both the typical utility and the METREK approaches is the same.

Annualized Cost -- First the annualized cost is found by the simplified procedure; it can be used here because average net annual expense is constant from year to year. This approach applies to Equation E-2, which is rewritten for this exercise as follows:

Annualized Cost = (Average Net Annual Expense
- Average Debt Interest)
+ (Capital Charge) (Total Capital Investment)

Avg Net Ann. Exp. = Average Total Annual Expense - Depreciation

= K\$12,823 (Mfg Cost) + K\$2,224 (Avg Gen. Exp.) - K\$3,218 (Depreciation)

= K\$11,829

Capital Charge is a fraction which represents the depreciation, average debt interest, average equity dividends, average income tax, and later capital charges, if any. For this case:

$$\text{Capital Charge} = \underset{\text{Deprec.}}{\frac{1}{15}} + \underset{\text{Avg Debt Interest}}{\frac{0.08\text{x}0.4}{2}} + \underset{\text{Avg Equity Dividends}}{\frac{0.14\text{x}0.6}{2}} + \underset{\text{Avg Income Tax}}{\frac{0.14\text{x}0.6}{2}} + \underset{\text{Later Cap. Charges}}{0}$$

$$= 0.067 + 0.016 + 0.042 + 0.042 + 0$$

$$= 0.167.$$

Note that the three factors that operate on the "book value" are all divided by 2 to give an average because in the simplified procedure the "book value" is assumed to vary from the total depreciable capital to zero over the life of the operation. (Actually the book value varies from K$54,299 at the beginning of year 1 to zero at the end of year 15, after Land and Working Capital have been recovered. See Table J-7.) Accordingly,

$$\text{Annualized Cost} = \underset{\text{Avg Net Ann. Expense}}{\text{K\$11,829}} - \underset{\text{Avg Debt Interest}}{\text{K\$1,017}} + \underset{\text{Capital Charge}}{(0.167)}\ \underset{\text{Total Cap. Investment}}{(\text{K\$54,299})}$$

$$= \text{K\$19,880}.$$

Next the annualized cost is found by the detailed method. This solution is similar to the Public Utility Financing Example in Appendix E, except that many simplifications were introduced. The annualized cost for revenue requirement was computed by the use of Equation E-1 from the total of the present values of the yearly revenue requirements as displayed in Table J-7. For the actual calculation see the bottom of Table J-7.

It will be noted from Table J-7 that the revenue requirement for a given year is the sum of four items:

- Average Total Annual Expense (Item 90, Table J-3) less Average Debt Interest (Item 84, Table J-6);
- Debt Interest;
- Equity Dividends;
- Income Tax.

These are equivalent in value to the four cash flow streams leaving the Cash Flow Diagram. This will be demonstrated by considering the calculation of the Revenue, R, for the first year of operation. All figures are in K$. For this illustration, the Net Annual Expense for the first year is worked out below.

Net Annual Expense for the First Year

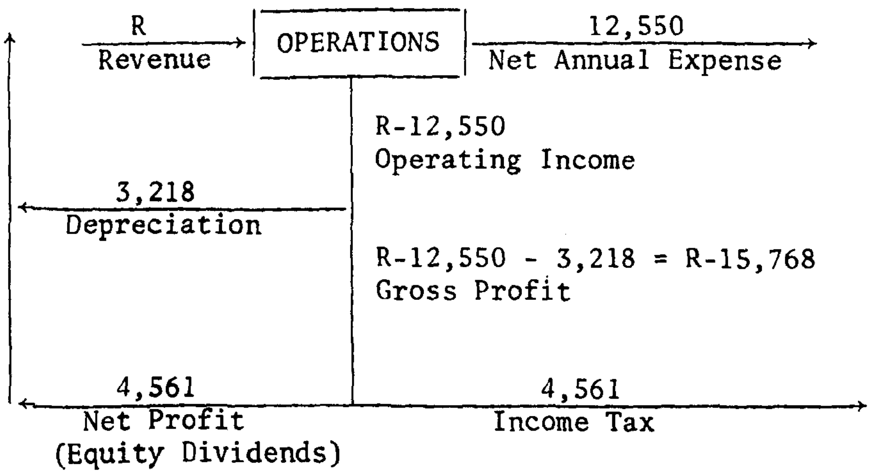
=	12,823	+	2,224	-	1,017	+	1,738	-	3,218
	Mfg Cost		Avg Gen. Expense		Avg Debt Interest		Debt Int. for 1st yr		Deprec.

= 12,550.

The Cash Flow Diagram for the first year is:

Cash Flow

Depreciation	3,218
Equity Div.	4,561
	7,779



The Revenue, R, for the first year can be found from the Cash Flow Diagram above by working down from the OPERATIONS box to the expression for Gross Profit, R-15,768, and then equating this to the sum of the Net Profit, 4,561 and the Income Tax, 4,561. Then solving

$$R - 15{,}768 = 4{,}561 + 4{,}561$$

$$R = 24{,}890.$$

The Revenue, R, for each year, can also be found by summing the four terms in the columns marked with footnote b in Table J-7. This is because an overall balance in the Cash Flow Diagram gives

R = Net Annual Expense + Income Tax + *Cash Flow* ,

which corresponds to

R = (Annual Expense less Debt Interest) + Debt Interest

+ Equity Dividends + Income Tax

where the terms on the right side of the equation correspond to the terms in the four columns marked with footnote b in Table J-7.

It is to be noted that the annualized cost by the simplified procedure (K$19,880) is about 7 percent lower than that by the detailed method (K$21,303).

Levelized Cost -- Because inflation is not taken into account in this example, Equation E-5 for the typical utility and Equation E-6 for the METREK approach both reduce to the same expression. Equation E-5 is now written in the form below to facilitate the calculation of levelized cost, LC_u:

$$LC_u = \frac{\text{Present Value of Required Revenue}}{\text{Production Units (Uniform Annual Series Present Worth Factor)}}$$

The "present value of the required revenue" is found on the bottom line of Table J-7; the "production units are energy output of 500 MW for 7000 hours per year; and the "uniform annual series present worth factor" is for a discount factor of 10 percent over 15 years. Therefore,

$$LC_u = \frac{\text{K\$162,030}}{(500 \times 7000)\ (7.606)}$$

$$= \$6.09/\text{MWhr or } 6.09 \text{ mills/kWhr} .$$

Unit Capital Investment -- This is readily calculated from available data. See item 112 in Feasibility Evaluation Summary, Table J-3.

Unit Operating Expense -- This is also simple to determine. Consult item 113 in Feasibility Evaluation Summary, Table J-3.

RELIABILITY ASSESSMENT SEGMENT

An open form is used for this segment. The information in Table J-8 is self explanatory.

OVERALL ASSESSMENT

The costs generated by this cost analysis are higher than those resulting from other studies and more in line with actual costs. This is particularly evident from these unit cost figures:

Capital Cost	$109/kW
Operating Expense	4.30 mills/kWhr

The reason for this is that the procedure takes into account capital costs and expenses that were neglected by other procedures and past studies.

TABLE J-8. SUMMARY OF ECONOMIC EVALUATION
FOR EXAMPLE I -- RELIABILITY ASSESSMENT SEGMENT

SENSITIVITY ANALYSIS

The percentage effect on the annualized cost of varying the maintenance charges from 2 percent to 20 percent of I_F is shown in Figure I-1. For the base case the maintenance charges are 8 percent of I_F. This serves to show that variation in maintenance charges can have a marked effect on annualized cost, from almost minus 10 percent to nearly plus 20 percent.

UNCERTAINTY ANALYSIS

Based on opinion-mode, the range of accuracy of the feasibility measures is ± 20 percent. This is essentially governed by the reliability of the capital cost estimate. The value of ± 20 percent for the capital cost estimate is developed as follows:

From available information, for a definitive estimate	± 10%
Stage of development - pilot plant data available, but inconclusive - broadens range	± 20%
Definition of scope - adequate	no change
Quality of cost data - judged to be good	no change
Expertise of the estimator - considered competent	no change

SELECTED REFERENCES

J-1. Calvin, E. L. Catalytic, Inc. A Process Cost Estimate for Limestone Slurry Scrubbing of Flue Gas. EPA-R2-73-148a; NTIS PB 219 016. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC. January 1973. 95 pp., Part I.

J-2. Shore, D., J. J. O'Donnell, and F. K. Chan. M. W. Kellogg. Evaluation of R&D Investment Alternatives for SO_x Air Pollution Control Processes. EPA-650/2-74-098; NTIS PB 238 263. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC. September 1974. 270 pp.

J-3. McGlamery, G. G., R. L. Torstrick, W. J. Broadfoot, J. P. Simpson, L. J. Henson, S. V. Tomlinson, and J. F. Young. Tennessee Valley Authority. Detailed Cost Estimates for Advanced Effluent Desulfurization Processes. EPA-600/2-75-006; NTIS PB 242 541. Prepared for EPA, Industrial Environmental Research Laboratory. Research Triangle Park, NC. January 1975. 417 pp.

J-4. Guthrie, K. M. Data and Techniques for Complete Capital Cost Estimating. Chem. Eng., 76(6):118 (1969).

J-5. Guthrie, K. M. Process Plant Estimating, Evaluation and Control. Craftsman Book Company of America, Solana Beach, CA. 1974. 606 pp.

APPENDIX K

EXAMPLE II -- COST ANALYSIS OF CHLOROLYSIS PLANT

CONTENTS

FIGURES

TABLES

APPENDIX K

EXAMPLE II -- COST ANALYSIS OF CHLOROLYSIS PLANT

This example illustrates the cost analysis of a plant for the manufacture of carbon tetrachloride (CCl_4) from waste chlorocarbon residues. The chlorolysis process not only has the merit of consuming toxic chlorocarbon residues, but compared to the current process for making CCl_4 it also conserves methane and chlorine supplies and electrical energy.

The well established mode of cost analysis for private sector projects will be employed. This mode conforms to depreciation accounting used in business; also, it is direct and relatively simple.

STATEMENT OF PROBLEM

The evaluation is for a "grass roots," regional plant which would process 25,000 mt*/yr or about 30 percent of the total chlorocarbon wastes now produced in the U.S. The expected production of 75,000 mt/yr (82,672 U.S. ton/yr) of CCl_4 from a plant of this capacity would be about 30 percent of a projected stabilized market.

The estimate is based on a selling price for CCl_4 of $300/mt, for by-product HCl of $27/mt, and a processing toll of $125/mt of chlorocarbon residues delivered. It is assumed that it would take 2 years to construct the plant.

SOURCE OF PROCESS AND COST DATA

Data for process engineering, capital cost, and operating expense are available from a report prepared by the Hoechst-Uhde Corporation (K-1), and one prepared for them by the Foster Wheeler Energy Corporation (K-2).

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*Note that metric ton corresponds to Mg.

GUIDELINE INFORMATION

The guideline information required as outlined in Table 11 of Volume I is developed in Table K-1.

SPECIFICATION

The data required as indicated by Tables 5 and 7 of Volume I are provided in Tables K-2 and K-3. Some pertinent comments are given below.

Descriptive Segment

See Table K-2. Note the process flowsheet, Figure K-1.

Cost Analysis Segment

Cost Estimate - Capital Investment --

Although cost data are available from a definitive cost estimate (K-2), the plant investment will also be found by two other procedures which are based on the sum of the costs of the major plant items (MPIs). These are the Chilton method (Schedules A and C) and the Lang method (Schedule D).

From Reference K-2, it is found that the sum of the cost of the MPIs, ΣE, is K$5,438. These are 1977 costs. Although it was not specifically stated, it is assumed that this figure includes freight (delivered basis).

Cost Estimate - Annual Expense --

For the conditions of Example II, Tables K-4 and K-5 were completed. Cost figures from the Hoechst-Uhde Corporation (K-1) were used as a basis for annual expenses.

Note that Start-up Costs will be expensed; this is common practice in the private sector.

Cost Estimate - Feasibility Evaluation --

Straight-forward calculations are made for ROI and Payout Time at the end of Table K-3, items 101 and 102. The IROR is readily calculated; see Table K-3, item 103.

RELIABILITY ASSESSMENT SEGMENT

An open form is used for this segment. The information in Table K-6 is self explanatory. Note that the sensitivity analysis chart was taken directly from an illustration for this example in Appendix I.

TABLE K-1. GUIDELINE INFORMATION FOR EXAMPLE II

DESCRIPTIVE SEGMENT	
Facility Description	
Plant Location	Gulf Coast.
Index for Area Construction Labor Costs	Index not specifically developed by Foster Wheeler in capital cost estimate prepared for Hoechst-Uhde (K-1).
Capacity Rating	A feed of 25,000 mt/yr of chlorocarbon residues to produce 75,000 mt (82,672 U.S. tons) per yr of CCl_4.
Abstract of Scope	Conventional "grass roots" chemical plant. Clear and level site. Foundations: conventional spread footings. No pumping station needed to provide cooling water. Require pretreatment of feed waste to remove particulates and moisture.
Performance Specifications	Feed residues must be chlorolyzed to CCl_4 in an environmentally acceptable manner.
Stage of Development	Research and development: (1) Bench-scale tests by Hoechst-Uhde (K-1); (2) Supporting bench-scale studies by Diamond Shamrock (K-3); (3) Commercial installations by Hoechst in West Germany. Design: Detailed process design (K-2).
COST EVALUATION SEGMENT	
Specified Parameters	
Interest (Discount) Rate	N.A.
Facility Life and Depreciation Period	For both, use 10 years.
Construction Time	2 years.
Reference Units for Process Costs	1 metric ton CCl_4 per year.
Reference Year for Costs	1977.
Cost Index	Chemical Engineering (CE); if required.
Inflation Rate	N.A. See under Feasibility Evaluation, below.

Table K-1 (Continued). Guideline Information for Example II

Cost Estimate - Capital Estimate	
Types of Capital Investment Estimates	Definitive, only because it is available. Also, use Chilton and Lang methods as checks and to demonstrate these techniques.
Allowance for Funds During Construction	See under Operating Expense, below.
Modification of Facilities and Start-up	See under Operating Expense, below.
Cost Estimate - Operating Expense	
Total Operating Expense vs. only O&M	Use total operating expenses.
Stream Time	8,000 hr/yr.
Pre-production Expenses	N.A.
Allowance for Funds During Construction	None. The construction is assumed to be internally financed.
Modifications of Facilities and Start-Up	Assumed to be 8% of I_F; 6% during the first year of operation (zero to 1), and 2% during the second year (1 to 2).
Direct (Operating) Labor Rate	\$8.65/hr.
Depreciation	Use straight-line method.
Cost Estimate - Profit and Cash Flow	
Revenue	From sales of CCl_4 and HCl and handling tolls for chlorocarbon residues used as a feed stream. Use \$300/mt for CCl_4, \$27/mt for HCl, and \$125/mt of chlorocarbon residues delivered.
Income Tax Rate	Use 50%.
Feasibility Evaluation	
Mode of Cost Analysis	Private sector.
Measures of Merit	IROR, ROI, and Payout Time.
Computation Features	Use discounting, revenue; recoup investment by depreciation charges and end-of-life recoveries for land and working capital; do not account for inflation; use total annual expense; employ continuous interest factors. Minimum acceptable ROI is 10%.

Table K-1 (Continued). Guideline Information for Example II

RELIABILITY ASSESSMENT SEGMENT	
Sensitivity Analysis	Investigate sensitivity of CCl_4 market price ($\pm$ 10%) and chloro-carbon residues handling toll ($50 to $200). Use Strauss chart.
Uncertainty Analysis	Investigate uncertainty of ROI using a statistical method, in particular, the Monte Carlo technique. Use judgment in ascertaining the dominant cost elements and their expected variability.

TABLE K-2. SUMMARY OF ECONOMIC EVALUATION FOR EXAMPLE II -- DESCRIPTIVE SEGMENT

FACILITY DESCRIPTION. Chlorolysis plant to convert 25,000 mt/yr of chlorocarbon residues to 75,000 mt/yr (82,672 U.S. ton/yr) of carbon tetrachloride (CCl_4). Block Flow Diagram - Figure K-1. Gulf Coast location.

CAPACITY RATING. A feed of 25,000 mt/yr of chlorocarbon residues, 60% VCM[a] waste, and 40% solvent waste would produce 75,000 mt (82,672 U.S. tons) CCl_4/yr. The stoichiometric balance that applies is:

$$1 \text{ kg residue} + 2.734 \text{ kg } Cl_2 \longrightarrow 3.010 \text{ kg } CCl_4$$

$$+ 0.723 \text{ kg HCl} + 0.001 \text{ kg } Br_2 \quad .$$

Note that this relation is for an average situation; the proportions will vary in practice with changes in the composition of the chlorocarbon residue.

ABSTRACT OF SCOPE. Conventional chemical plant. Identified waste pretreated to remove particulates and moisture. Includes conventional incineration unit.

PERFORMANCE SPECIFICATION. The chlorocarbon residues must be chlorolyzed to CCl_4 in an environmentally acceptable manner.

STAGE OF DEVELOPMENT. Research and development: (1) Successful bench scale tests on typical VCM[a] wastes and HO[b] by Hoechst-Uhde Corp. (K-1); (2) Independent supporting bench scale investigations by Diamond Shamrock (under EPA contract 68-01-0457) (K-3); (3) Commercial installations incorporating the chlorolysis process by Hoechst AG in West Germany (8,000 and 50,000 mt CCl_4/yr), and in USSR (38,000 mt CCl_4/yr). Design: Detailed process design (K-2).

[a]VCM is vinylchloride monomer.

[b]HO is Herbicide Orange.

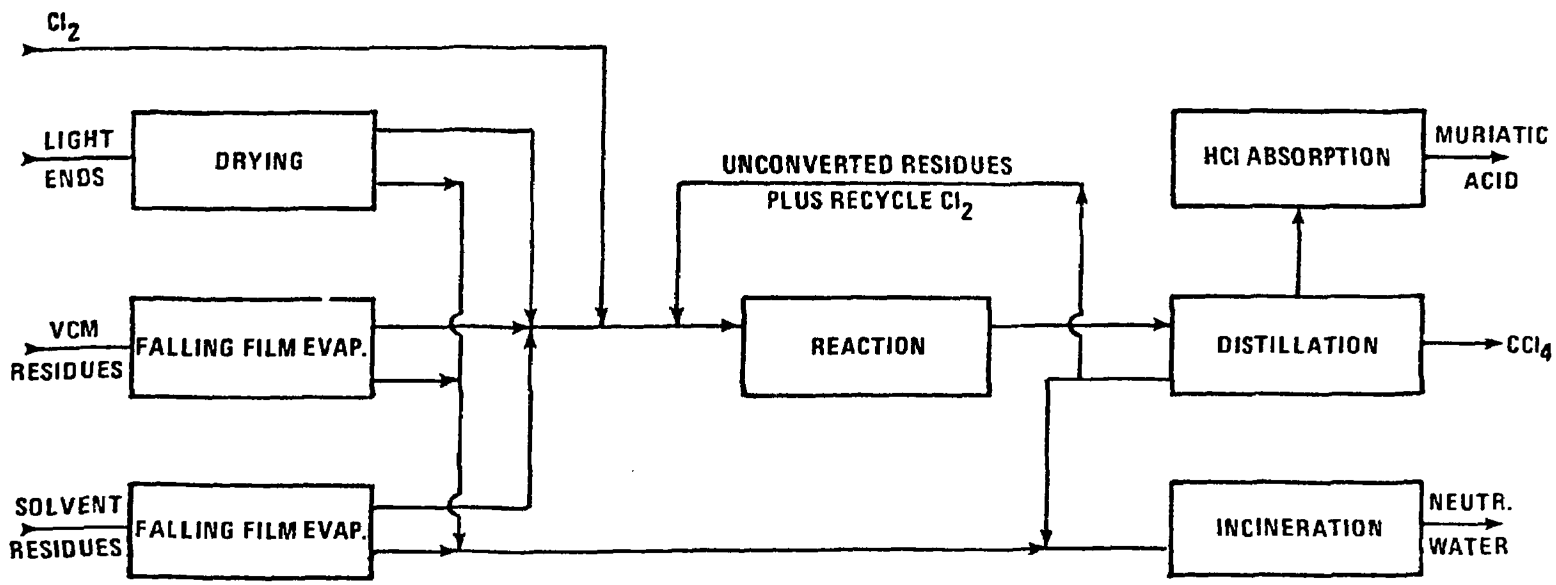

Figure K-1. Block flow diagram of chlorolysis plant, from (K-1)

TABLE K-3. SUMMARY OF ECONOMIC EVALUATION FOR EXAMPLE II -- COST ANALYSIS SEGMENT

FACILITY DESCRIPTION. Chlorolysis plant to convert 25,000 mt/yr of chlorocarbon residues to 75,000 mt (82,672 U.S. ton) of CCl_4. Block flow diagram - Figure K-1. Plant Location -- Gulf Coast	CAPACITY RATING. A feed of 25,000 mt/yr of chlorocarbon residues would produce 75,000 mt CCl_4/yr.

DISCOUNT RATE,[a] __ %; FACILITY LIFE, 10 YRS; DEPRECIATION PERIOD, 10 YRS;

CONSTRUCTION TIME, 2 YRS; REFERENCE UNIT FOR PROCESS COST, mt of CCl_4;

REFERENCE YEAR FOR COSTS, 1977; COST INDEX, CE; INFLATION RATE, N.A.

CAPITAL INVESTMENT ESTIMATION

Schedule A. Chilton method. Factored costs of sum of major plant items (MPIs).

	Item	Factor	Operating On Item No.	Cost of Item
1.	Sum of major plant items (MPIs), ΣE, delivered[b]	--	--	K$ 5,438
2.	Installed, erected equipment cost	1.43	1	7,776
3.	Piping (includes insulation)	0.60	2	4,666
4.	Instrumentation	0.15	2	1,166
5.	Buildings and site development	0.35	2	2,722
6.	Auxiliaries (electric, steam, etc.)	0.10	2	777
7.	Other	--	2	--
11.	Total Physical Cost (Direct Cost), DC (Sum of 2 to 7)			K$17,107

Use Schedule C to get the Total Plant Cost, Item 31.

[a]No discount rate is listed because IROR is computed.

[b]Same as FOB job site.

Table K-3 (Continued). Summary of Economic Evaluation for Example II -- Cost Analysis Segment

Schedule C. Calculation of Total Plant Cost Using Direct Cost from Schedule A.

11. Total Physical Cost (Direct Cost) DC	K$17,107
12. Indirect Cost (34% of DC), IC	5,816
21. Total Bare Module Cost, BMC	22,923
22. Contingency (15% of BMC)	3,428
23. Contractor's Fee (3% of BMC)	688
31. Total Plant Cost (Total Module Cost), I_F	K$27,039

Schedule D. Lang method

Use $I_F = \Sigma E \times L$

where ΣE = K$5,438 from Reference K-1.

L = 4.74 is the Lang factor for a fluid process plant from Table A-3.

Then I_F = K$5,438 X 4.74 = K$25,776.

Schedule G. Total Plant Cost from Typical Definitive Estimates.

Reference K-1 provides a definitive estimate of the Total Plant Cost; 1977 costs were used. Therefore,

31. Total Plant Cost from Reference K-1, I_F K$25,497

This figure will be used. Note that it is fairly close to the value of I_F by the Chilton and Lang factor methods. The reason for this is that the same figure for Item 1, Sum of major plant items (MPIs), ΣE, delivered, was used for all three estimates.

Table K-3 (Continued). Summary of Economic Evaluation for Example II -- Cost Analysis Segment

Schedule H. Total Capital Investment

31. Total Plant Cost, I_F, from Schedule C	K$25,497
32. Interest during Construction, if Applicable and Capitalized	NA[a]
33. Modification of Facilities and Start-up Costs, if Capitalized	NA[b]
35. Total Depreciable Investment	K$25,497
36. Land, 20 acres (80,900 m^2) at $5,000/acre ($1,240/10^6 m^2)	100
37. Working Capital[c]	5,990
41. Total Capital Investment	K$31,587

ANNUAL OPERATING EXPENSE SUMMARY (from the subtotals in Table K-4, Operating Expense, and Table K-5, General Expense)

53. Raw Materials	K$10,154
70. Processing	2,766
74. Plant Overhead, Control Lab, and Technical	1,145
76, 77. Fixed Charges Less Depreciation	382
78. Depreciation	2,500
87. General Expense	3,006
90. Total Operating Costs	K$19,953

[a]Common practice for the private sector is to charge interest on construction as an operating expense at the end of the first year of operation. However, since most of the project would be internally financed, interest is charged on only the fraction of the construction cost that corresponds to the debt fraction of the total capitalization for the company. This is generally 20 to 40%.

[b]For private sector companies, this item is generally expensed.

[c]Working capital is computed as follows:

Inventories; raw material for 1 month, 10,154/12 =	K$ 846
Finished product for 1 month, 19,953/12	1,663
Accounts receivable for 1 month, 27,326/12	2,277
Cash for 1 month expense less general expense and depreciation (19,953 - 3,006 - 2,500)/12	1,204
TOTAL Working Capital	K$ 5,990

Table K-3 (Continued). Summary of Economic Evaluation for Example II -- Cost Analysis Segment

PROFIT AND CASH FLOW SUMMARY

91. Revenue		
Toll for Handling wastes	25,000 mt @ $125/mt =	K$ 3,125
CCl_4	75,000 mt/yr @ $300/mt =	22,500
HCl (31% solution)	63,000 mt/yr @ $27/mt[a] =	1,701
		K$27,326
92. Gross Profit (Revenue - Annual Operating Expense)		7,373
93. Net Profit (Gross Profit - Income Tax[b])		3,687
94. Cash Flow (Net Profit + Depreciation)		6,187

[a]The market price would be about 50% higher, but a lower price might apply because of impurities.

[b]Use 50% income tax.

Table K-3 (Continued). Summary of Economic Evaluation for Example II -- Cost Analysis Segment

FEASIBILITY EVALUATION SUMMARY

101. $\underline{ROI} = \frac{3,687}{31,587} = 11.67\%$

102. $\underline{\text{Payout Time}} = \frac{25,497}{6,187} = 4.1$ years

103. Internal Rate of Return - Figures are in K$

Time, year	Item	Investment	Cash Flows	10% Factor	10% P.W.	15% Factor	15% P.W.
-2	Land	-100		1.2214	-122	1.3499	-135
-2 to 0	Depreciable Investment	-25,497		1.107	-28,225	1.166	-29,730
0	Working Capital	-5,990		1.0	-5,990	1.0	-5,990
0 to 1	Modification of Facilities and Start-up, 6% I_F		-0.5(1,530)[a]	0.9516	-728	0.9286	-710
1 to 2	Modification of Facilities and Start-up, 2% I_F		-0.5(510)[a]	0.8610	-220	0.7992	-204
0 to 10	*Cash Flow*		10(6,187)	0.6321	39,145	0.5179	32,042
10	Recover Working Capital	5,990	5,990	0.3679	2,204	0.2231	1,336
10	Write-off of Undepreciated Investment[b]	500	0.5(500)	0.3679	92	0.2231	56
10	Recover Land	100	100	0.3679	37	0.2231	22
					6,193		-3,313

103. IROR by linear interpolation $= 10 + 5 \left(\frac{6,193}{6,193 - (-3,313)} \right) = 13.26\%$

[a] As with any operating expense item, the contribution to *cash flow* is -(1 - tax rate) (expense). See Appendix C.

[b] K$1,000 capital investment for off-sites has a book value of K$500 at the end of 10 years because it is depreciated on a 20-year schedule.

Descriptive appraisal of the financial merit of the venture: Based on the "best estimate data" the profitability is considered marginal. This is confirmed by the uncertainty analysis which follows.

TABLE K-4. ANNUAL OPERATING EXPENSE ESTIMATE FOR EXAMPLE II
Chlorolysis Plant, 75,000 mt (82,672 U.S. ton)/yr of CCl_4
Stream Hours: 8,000 hr/yr
Basic Unit of Capacity or Production: metric ton of CCl_4

	Unit	Units /Year	Value $/Unit	Units/Basic Unit of Production	Total Costs $/mt of CCl_4	K$/yr
51. Raw Materials						
Chlorine	mt	68,123	140	0.9083	127.16	9,537
Caustic Soda(20%)	mt	14,500	24	0.1933	4.64	348
Methane	10^3 cf[a]	134,500	2	1.7933	3.59	269
53. Subtotal Ingredients					135.39	10,154
56. Operating Labor 10 men/shift	man-hour	88,000	8.65	1.1730	10.15	761
57. Direct Supervision 1 man/shift	man-hour	8,000	11.0	0.1176	1.29	97
58, 59. Maintenance, 4%, I_F					13.60	1,020
60. Operating Supplies						
61. Labor Additives 30% Labor + Supervision					3.44	258
62. Steam	10^3 lb[b]	115,000	1.81	1.53	2.77	208
63. Electricity	kWhr	$25.5X10^6$	0.015	340	5.11	383
64. Compressed Air	10^3 cf[a]		--		--	--
65. Water	10^3 gal.[c]	$3.9X10^6$	0.01	52	0.52	39
66. Fuel	10^6 Btu[d]				--	--
67. Effluent Trtmt and Disposal					--	--
68. Preparation for Shipping					--	--
69. Other					--	--
70. Subtotal Processing					36.88	2,766

[a]Multiply 10^3 lb by 454 to convert values to kg.

[b]Multiply 10^3 cf by 28.32 to convert values to m^3.

[c]Multiply 10^3 gal. by 3.785 to convert values to m^3.

[d]Multiply 10^6 Btu by 1.055 X 10^6 to convert values to kJ.

Table K-4 (Continued). Annual Operating Expense Estimate for Example II

71. Plant Overhead, 50% Operating Labor + 3% Total Plant Cost	15.27	1,145
72. Control Laboratory } included in plant Overhead	--	--
73. Technical and Engineering } included in plant Overhead	--	--
74. Subtotal Overhead	15.27	1,145
76. Insurance & Property Taxes, 1.5% I_F	5.10	382
77. Royalty	--	--
78. Depreciation, Straight-line: 10% Buildings and Equipment and 5% Off-sites[a]	33.33	2,500
79. Subtotal Fixed Charges	38.43	2,882
80. TOTAL MANUFACTURING COST	225.97	16,947

[a]Capital investment in off-sites is estimated at K$1,000 of the total depreciable investment.

TABLE K-5. GENERAL EXPENSE ESTIMATE FOR EXAMPLE II
Chlorolysis Plant - 75,000 mt/yr of CCl_4

81. Administration, 3% of Revenue[a]	K$ 820
82. Selling Expense, 5% of Revenue[a]	1,366
83. Corporate Research, 3% of Revenue[a]	820
84. Finance	
85. Other	
87. General Expense	K$3,006

[a]For revenue, see Item 91 in Table K-3 -- Profit and *Cash Flow* Summary.

SENSITIVITY ANALYSIS

The sensitivity of the ROI to both the CCl_4 sales price and the chlorocarbon residue handling toll is depicted graphically using a Strauss chart (see Appendix I). A variation of ± 10 percent from the most likely price of $300/mt is considered likely. At present, it is problematical what disposal practices will be eventually favored for cost or other reasons. This strong uncertainty is expressed by a range for the residue handling tolls from $50 to $200/mt.

UNCERTAINTY ANALYSIS

An uncertainty analysis was carried out using the Monte Carlo technique described in Appendix I. Ten dominant cost elements were considered to vary between limits on either side of the target value, e.g.,

	Most Likely	Minimum	Maximum	% Variation
Chlorine price, $/mt	140	126	154	± 10%
Maintenance, % of I_F	4	3	6	- 25%; + 50%

The calculations generated a table of the probability that the ROI would be less than the values shown.

The degree of uncertainty could be lessened by reducing the range of the cost elements in Table K-6, particularly those (such as CCl_4 price) that have such a marked effect on profitability.

OVERALL ASSESSMENT

The economic analysis calls for either a better market situation for CCl_4 or stringent environmental regulation which would support a handling toll in excess of $150/mt. If the figures used in the estimate obtained (viz., a handling toll of $125/mt of chlorocarbon residue delivered and a market price of $300/mt of CCl_4), private sector investment appears unlikely. However, with some government subsidy for capital investment, it is possible that some chemical companies could be interested in building and operating such a chlorolysis plant.

TABLE K-6. SUMMARY OF ECONOMIC EVALUATION FOR EXAMPLE II -- RELIABILITY ASSESSMENT SEGMENT

SENSITIVITY ANALYSIS

The percentage effect on ROI from varying the price of CCl_4 ± 10% (from $270 to $330/mt) and from varying the residue handling toll ± 60% (from $50 to $200/mt) is depicted in Figure I-2 in a Strauss chart. This analysis shows that a 5% drop in CCl_4 price to $285/mt or a 45% drop in the base handling toll of $125 to about $70/mt would reduce the ROI to 10%. The analysis also discloses that the economic feasibility is extremely sensitive to the CCl_4 market price, but only slightly sensitive to the figure for the residue handling toll.

UNCERTAINTY ANALYSIS

An uncertainty analysis, executed by the Monte Carlo technique, showed the probability that ROI would be less than stated values. In this analysis, 10 dominant cost elements were taken into account. They are listed with their considered variations below:

Cost Element	Unit	Most Likely	Minimum	Maximum	Percentage Variation
Chlorine price	$/mt	140	126	154	± 10
Operating labor force	men/shift	10	9	11	± 10
Maintenance, % I	--	4	3	6	- 25; + 50
I_F	K$	25,497	20,398	30,596	± 20
Residual waste	10^3 mt	25	18	30	- 28; + 20
Residual waste price	$/mt	125	50	200	± 60
CCl_4 production	mt/yr	75,000	63,750	86,250	± 15
CCl_4 price	$/mt	300	270	330	± 10
HCl production	mt/yr	63,000	53,550	72,450	± 15
HCl price	$/mt	27.00	22.50	31.50	± 17

The resulting analysis showed:

% ROI	-0.25	5	10	12	14	16	18	20	24
Prob. of obtaining less than the ROI shown	0.001	0.03	0.3	0.52	0.68	0.83	0.92	0.97	0.999

Table K-6 (Continued). Summary of Economic Evaluation for Example II -- Reliability Assessment Segment

These results are shown in Figure K-2 with a cumulative frequency distribution plot for ROI. The results indicate that the most likely ROI is 11.8% (the value of ROI at 50% probability). This value compares with the value of 11.67% shown in Table K-3. The difference is due to the fact that a few of the cost element distributions are not symmetrical. Figure K-2 also points out that there is a 70% probability of attaining the Minimum Acceptable Rate of Return (MARR) of 10% or higher.

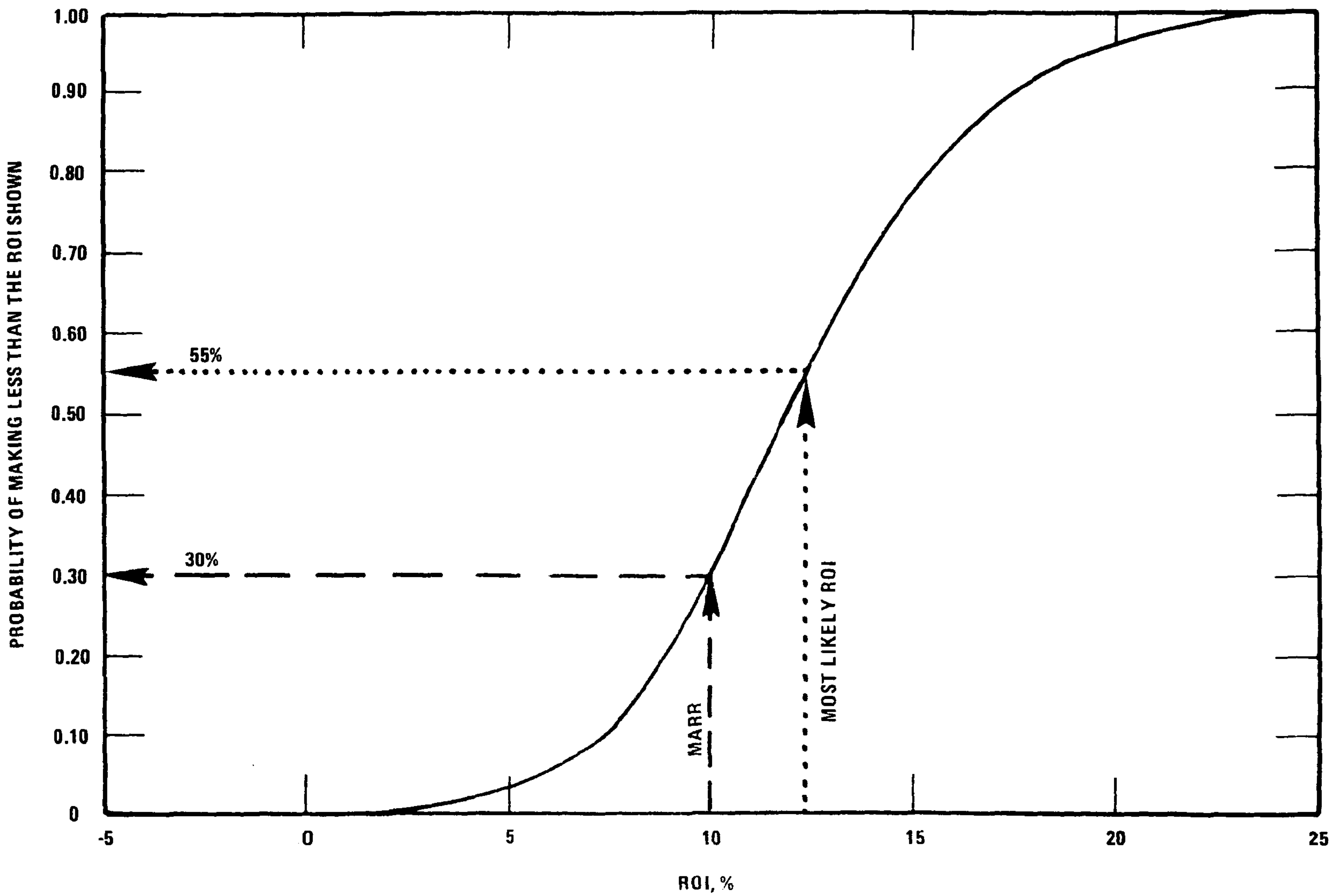

Figure K-2. Cumulative frequency distribution plot showing the probability that ROI would be less than stated value.

SELECTED REFERENCES

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K-3. Lavergne, E. A. Study of Feasibility of Herbicide Orange Chlorinolysis. EPA-600/2-74-006; NTIS PB 286-705. Prepared for EPA, Office of Research and Development, Washington, DC. July 1974. 67 pp.

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16. ABSTRACT Volume I is a user guide for a standard procedure for the engineering cost analysis of pollution abatement operations and processes. The procedure applies to projects in various economic sectors: private, regulated, and public. The models are consistent with cost evaluation practices in engineering economy and financial analysis. It presents a recommended format, termed the Specification, that should not exceed eight pages when executed. The guidelines facilitate the choice of procedures open to the estimator and the establishment of factors to be used in the evaluation. The Specification has three segments: descriptive, cost analysis, and reliability assessment. Volume II, the bulk of the document, contains 11 appendices (providing detailed background material) and 2 comprehensive examples. Appendix subjects are: Capital Investment Estimation, Annual Expense Estimate, The Cash Flow Concept, Discrete and Continuous Interest Factors, Measures of Merit, Cost Indices and Inflation Factors, Rates of Return and Interest Rates, Methods of Reliability Assessment, Sensitivity Analysis, Example I--Cost Analysis of Flue Gas Desulfurization (FGD) Retrofit Facility, and Example II--Cost Analysis of Chlorolysis Plant. The Measures of Merit appendix considers: return on investment, internal rate of return, payout time, equivalent annual cost, and unit costs. A glossary is provided.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Cash Flow	Pollution Control	13B
Cost Analysis	Interest	Stationary Sources	14A
Cost Estimates	Inflation	Measures of Merit	05A
Reliability		Rates of Return	14D
Fixed Investment		Sensitivity Analysis	05C
Operating Costs			

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