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COMPARATIVE LIFE-CYCLE COST ANALYSIS FOR LOW-LEVEL, MIXED WASTE REMEDIATION ALTERNATIVES

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Abstract

The purpose of this study is two-fold: 1) to develop a generic, life-cycle cost model for evaluating low-level, mixed waste remediation alternatives, and 2) to apply the model, specifically, to estimate remediation costs for a site similar to the Fernald Environmental Management Project near Cincinnati, OH.

Life-cycle costs for vitrification, cementation, and dry removal process technologies are estimated. Since vitrification is in a conceptual phase, computer simulation is used to help characterize the support infrastructure of a large scale vitrification plant. Cost estimating relationships obtained from the simulation data, previous cost estimates, available process data, engineering judgment, and expert opinion all provide input to an Excel based spreadsheet for generating cash flow streams. Crystal Ball, an Excel add-on, was used for discounting cash flows for net present value analysis.

The resulting LCC data was then analyzed using multi-attribute decision analysis techniques with cost and remediation time as criteria. The analytical framework presented allows alternatives to be evaluated in the context of budgetary, social, and political considerations. In general, the longer the remediation takes, the lower the net present value of the process. This is true because of the time value of money and large percentage of the costs attributed to storage or disposal.

Acknowledgments

This study would not have been possible without the efforts of a number of real world engineers who gave freely of their time and thoughts to enrich this product. Chief among these individuals is Mr. Terry Sams of Martin Marietta Corp. at Oak Ridge National Labs. His efforts to see that we understood both the cementation and dry removal processes were absolutely critical. Without his help we could not have accomplished this work. Mr. Rod Gimpel provided the same level of competence in terms of understanding the MAWS technology and the size of the problem at Fernald's OU-1 site.

Mr. Paul Krumrine provided expert review of this work and his timely and methodical review of this document have reduced the number of substantive errors and the possibility of miscommunications. Any errors left are the responsibilities of the authors themselves.

Finally, we would like to thank Ms. Grace Ordaz for her superior support of this project throughout. We are in debt to the entire Department of Energy for providing us such a worthwhile opportunity to address a real world problem with such far reaching potential.

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COMPARATIVE LIFE-CYCLE COST ANALYSIS FOR LOW-LEVEL MIXED WASTE REMEDIATION ALTERNATIVES

I. INTRODUCTION

Radioactive waste remediation is a high cost, high visibility issue for the U.S. Department of Energy (DOE). *Environmental Management 1994*, an annual report by the U.S. Department of Energy, describes their environmental restoration program:

> ...The Environmental Waste Management program is responsible for identifying and reducing risks and managing waste at 136 sites in 34 states and territories where nuclear energy or weapons research and production resulted in radioactive, hazardous , and mixed waste contamination. Portions of more than 3,300 square miles of land managed by the department contain contaminated surface or ground water, soil, and structures. The number of sites in the program continues to grow.... [DOE/EM-0119, 1994:1]

Historically, DOE waste remediation alternatives have included waste containment in barrels, concrete blocks, and geologic repositories. The fundamental issues in selecting among alternatives are cost, effectiveness, and timeliness. Reducing remediation cost and improving the long-term stability of the waste form hinges on exploiting technological innovations in waste remediation.

Of the available alternatives, DOE has deemed cementation as the best demonstrated available technology for heavy metal containment

[EPA/625/6-89/022, 1989:2-2]. A promising new development is radioactive waste vitrification using the Minimum Additive Waste Stabilization (MAWS) process. Demonstrations of this technology have indicated that MAWS may be a cost effective method for treating large volumes of mixed waste throughout the DOE complex. Initial cost estimates, however, are highly conceptual, use dated information, and are not complete [FERMCO, 1995:1]. Another process in which DOE has shown some interest for solving the same type of remediation problem extracts clean water from a contaminated slurry to produce a very stable and compact substance. This dry removal process was successfully used recently in Erwin Tennessee by Nuclear Fuel Services to remediate over 700,000 ft^3 of mixed waste [Sams, 1995]. A detailed cost estimate is necessary to compare vitrification to cementation and dry removal.

1.2 <u>Problem Statement</u>

DOE requires a life-cycle cost (LCC) model to compare radioactive waste remediation alternatives [CRDA, 1994]. As a specific application of the cost model, DOE has further requested a LCC comparison of vitrification, cementation, and dry removal for a site similar to the Fernald Environmental Management Project (FEMP) near Cincinnati, Ohio.

1.3 <u>Research Objective and Scope</u>

This research has two primary objectives. The first is to develop a generic, interactive, spreadsheet-based life-cycle cost model that uses net present value and risk analysis techniques for cost comparison. The second is to apply the model specifically to the vitrification, cementation, and dry removal methods of waste remediation. By using spreadsheet analysis and graphics capabilities, the model will provide direct and objective comparisons of remediation alternatives. Since vitrification is a new technology, the plant design and operations are conceptual. Therefore, computer simulation and engineering judgement are integral to the vitrification LCC estimate.

1.4 Approach

The cost model will rely heavily on historical data and previous estimates. For vitrification, a simulation model will provide an added dimension to conventional cost estimating techniques. Available cost data, combined with the simulation results, will be integrated with a spreadsheet-based LCC model for analysis and presentation. Based on our preliminary survey and DOE's recommendation, the following factors are considered the most significant cost drivers.

- **Support infrastructure:** Personnel, equipment, facilities, resources, etc. required to support a given system configuration.

- **Plant size/capacity:** The plant capacity determines the support infrastructure and total remediation time required.

- **Waste stream composition:** Waste stream composition affects both remediation cost and waste glass quality. Additives increase glass quality at the expense of operating and disposal costs. Decreased waste loading can also extend remediation completion time which may increase both cost and risk.

- **On-site versus off-site disposal costs**: The cost to transport and dispose of the final waste form varies with location and remediation method.

1.5 Overview

In Chapter 2, we review current process technology and product quality for cementation, vitrification, and dry removal. We also review cost estimating and analysis techniques that can be used in the development of a LCC model. Chapter 3 discusses the methodology for developing the life-cycle cost model. The cost breakdown structure and relevant cost elements are developed by adapting methods discussed in Chapter 2. Chapter 4 discusses the simulation and cost analysis results. In Chapter 5 we draw conclusions from the analysis results and recommend follow-on work. Detailed appendices are included to document the cost element database, the computer simulation, and the LCC model.

II. LITERATURE REVIEW

2.1 Introduction

Shrinking budgets and increasing public concern for environmental health are driving DOE's efforts to exploit technological developments in waste remediation. The purpose of this review is to establish the potential effectiveness of three waste remediation alternatives, to lay a foundation for cost estimation, and establish a framework for selecting the best alternative on the basis of LCC and processing time. To accomplish this purpose, we assess process technology and product quality for cementation and vitrification. We also review current procedures for cost estimation and analysis that can be used for life-cycle cost estimation. Finally, we review decision analysis tools that can aid decision makers in applying the results of our LCC model.

2.2 Alternative Technologies

2.2.1 Cementation. The cementation process involves mixing waste materials with portland cement, fly ash, and water to produce concrete. Cementation is attractive because it offers chemical stabilization within a mechanically stable waste form [Trussell, 1994: 507]. Cement is inexpensive and widely available, and processing methods are well understood. However, cementation increases the volume of the final waste form resulting in higher transportation, storage, and monitoring costs.

Additionally, there is some concern over the durability of concrete waste forms, particularly in climates where freeze and thaw occur [EPA/540/A5-89/004, 1990:2].

There are two methods for solidifying and stabilizing waste materials within concrete. The first method involves excavating the waste material and transporting it to a facility where it can be mixed with cement and water in a controlled environment. The resulting concrete waste forms are stored in underground vaults. This method, known as ex-situ cementation, produces a uniform and predictable waste form and allows for storage on- or off-site. Resulting waste forms have been subjected to both leach and compressive strength tests. Lin et al. performed product quality tests on samples from ex-situ cementation and discovered that under normal conditions the rate of leaching of hazardous materials from concrete waste forms was well within established tolerances [Lin, 1994:317]. However, when acidic leachates were used, the rate of leaching increased and the compressive strength of the concrete was greatly reduced. Based on their findings, storage of concrete waste forms should incorporate some form of acid resistance. Walton conducted leach tests using varied water flow rates to determine if perched water collecting on the top of underground concrete waste forms presented a hazard [Walton, 1994:1521]. His findings revealed levels of leachates well within the allowable limits. Based on the results of compressive strength tests, he predicted that the concrete waste forms would meet or exceed standards for structural strength for at least 100 years.

Another method for solidifying and stabilizing waste in concrete is called in-situ cementation. This method treats waste that has not been excavated. Additives are injected and mixed with the hazardous waste material in place. The additives bond chemically with contaminants, immobilizing them and containing them in a hardened, concrete-like mass. In-situ cementation avoids the cost of excavation, but can only be applied in cases where on-site storage is approved. Furthermore, the process is more difficult to control and leads to greater variation in the quality of the final waste form. A bench scale in-situ cementation process was demonstrated at Hialeah, Florida, in April, 1988 [EPA/540/A5-89/004, 1990:16]. Samples of the resulting waste form were tested for structural strength. Compressive strength of the resulting product was found to meet or exceed tolerances. Samples were also tested for containment of heavy metals, polychlorinated biphenyls (PCB), and organics. There was strong evidence of immobilization of heavy metals, but the results were inconclusive with regard to organic and PCB containment. In further testing, the Toxicity Characteristic Leaching Procedure (TCLP) showed higher concentrations of leachates from treated soils than from untreated soils, leaving uncertainty over the ability of the process to immobilize PCBs.

In summary, ex-situ cementation demonstrates more consistent waste form quality than in-situ cementation. Furthermore, ex-situ cementation allows storage on- or off-site. Based on current process technology and product quality, ex-situ cementation is a feasible alternative for remediation of low-level radioactive and mixed waste.

2.2.2 Vitrification. A promising technological development for radioactive waste remediation is vitrification using the Minimum Additive Waste Stabilization (MAWS) process. Vitrification involves melting a blend of glass forming agents and waste elements, and then rapidly cooling them to form a glass. Glass provides a stable medium for long term storage of radioactive waste. Vitrification of mixed wastes is an attractive remediation alternative because hazardous organic compounds are destroyed at the high process temperatures (typically 1050 - 1500°C) and toxic metals and radionuclides can be incorporated in the leach-resistant glass waste form [Peters, 1993:15]. Vitrification is unique in that the waste stream becomes part of the waste form as opposed to simply being contained within the waste form, as it is in the cementation process.

Ritter cites the benefits of radioactive and industrial waste vitrification:

- a stable waste form with low release rate
- no combustible properties
- low generation of respirable particles
- and flexibility to deal with a wide range of waste types [Ritter, 1992:269]

Stefanovskii et al. [Stefanovskii, 1991:386] add the fact that vitrification reduces the volume of material for final storage and monitoring to less than one-third of that produced by conventional waste remediation methods. To realize these benefits, however, careful consideration of the chemical composition of the glass components and the long range waste containment capabilities of the waste glass is required.

Vitrification involves three fundamentally interdependent aspects of waste form development:

- Chemical composition of the waste
- General process requirements (e.g., operating temperature, materials compatibility)
- Waste form performance requirements [Peters, 1993:15]

For example, the waste stream chemical composition defines its melting temperature, drives the operational requirements of the melter, and determines the performance of the waste glass (e.g. leachability). Since a typical waste stream is deficient in many of the required glass forming agents, vitrification relies heavily on the addition of costly additives.

The MAWS process is an optimized vitrification process that greatly reduces the need for purchased additives. MAWS blends various site waste streams to provide the glass formers and fluxes required to make a good glass, meet process constraints, and minimize additive costs. In addition, waste loading is increased and subsequent storage costs are reduced. Demonstrations of this technology have indicated that MAWS may be a cost effective method for treating large volumes of mixed wastes throughout the DOE complex. Initial cost estimates, unfortunately, are highly conceptual, use dated information, and are not complete [Ordaz, 1992:1].

Since glass formers occur naturally in soil, MAWS uses contaminated soils to supply glass forming additives. In the MAWS process, soil is mechanically separated by particle size. The small particles (less than 1/32 inch diameter), which contain the highest concentration of silicon, go directly into the melter. The larger particles are washed and the contaminated fraction is subjected to an ion exchange process that chemically binds the radionuclides with resins. The ion exchange output is only 20% of the input volume and the remaining 80% (considered clean) can be used for fill during site reclamation. The small particle soil is then sent to the melter. Via soil washing, the amount of purchased additives required for glass production is greatly reduced.

To be effective, vitrification must isolate the nuclear and chemical contaminants in a stable waste glass form. The most important waste glass quality metric is leachability [Paul, 1982:108]. Glass producers typically use two static leach tests: the MCC-1 leach test and the Product Consistency Test (PCT) [Bates, 1992:210]. Minimum glass quality standards can be correlated to waste stream composition. These standards will bound proportionate levels of glass formers, waste, and additives suitable for producing a good quality glass. Although input waste stream composition is the primary focus for quality control , the waste glass should be frequently tested for leach properties [Pegg, 1994].

2.2.2.1 Vitrification Process Technology. Emphasis on remediation of radioactive waste has led to substantial research in vitrification process technology. Several melter designs have been developed and tested. The leading proposals include a Joule heated ceramic melter, a plasma arc melter, and a stir melter. Additionally, in situ vitrification (ISV) is an experimental method for melting waste bearing soil in place rather than in a melter.

The first industrial scale application of vitrification to radioactive waste in a ceramic chamber was at the Pamela high-level vitrification facility in Mol, Belgium [Wiese, 1992:147]. Between October, 1985, and September, 1990, the Pamela facility successfully converted 603 cubic meters of high-level radioactive waste into glass. The Pamela facility used a Joule-heated ceramic melter with a capacity of eight cubic meters. After three years of operation, performance of the original melter began to degrade due to corrosion of the electrodes and refractory materials. This corrosion occurred as a result of the chemical aggressiveness of the glass melt. The original melter was replaced and the new melter functioned routinely through completion of the project. More recently, in October 1994, DOE completed the test phase at its Savannah River Defense Waste Processing Facility by successfully vitrifying simulated high-level radioactive waste. The joule-heated melter and auxiliary systems operated as designed, giving DOE a high level of confidence in this system to vitrify the 35 million gallons of waste stored at Savannah River [Rubin, 1994:14].

To determine if vitrification could be economically applied to low-level radioactive waste, Fernald Environmental Restoration Management Corporation (FERMCO) incorporated a joule-heated ceramic melter using the MAWS process at the Fernald Environmental Management Project [Ordaz, 1992:1-4]. Original tests were conducted using a 10kg/day melter, with follow-on testing using 100kg/day and 300kg/day melters. At melting temperatures between 1100 and 1600 degrees centigrade, up to 93% waste loading was achieved while producing quality glass. Greenman outlined an operations concept and order of magnitude cost for a melter capable of producing 100 tons of glass per day [Greenman, 1994].

Research was also conducted in Minsk in the former USSR using two variations of a plasma arc melter [Stefanovski, 1991:393]. The first version used a high-intensity arc running directly between an external electrode and the melt. Experiments showed that erosion of the external electrode prevented reliable operation when using this design. The second version used the jet of a plasma arc torch to indirectly heat the melt. Using this method, radioactive waste was successfully blended with glass forming additives to produce a glassy material with acceptable chemical stability.

Large-scale testing of a plasma arc system for radioactive waste vitrification was conducted in Butte, Montana, and in Muttenz, Switzerland [Hoffelner, 1992:14]. A scaled-up plasma arc plant was installed in 1990 at MGC-Plasma in Muttenz. Using a transferred arc plasma torch to heat a melt on a rotating hearth furnace, this plant can convert a wide range of contaminated materials, including metal barrels, to glass. Analysis had indicated that up to 99% of the total activity remains in the melt, and that the off-gases from the process contain only small amounts of fly ash (hazardous respirable solids). In recent developments, however, the plasma arc melter has seen stiff operational, regulatory, and economic scrutiny. In September 1994, an international symposium was held in France to discuss plasma arc technology. Experts in the field question the ability of a plasma arc system to neutralize heavy metals, meet regulatory requirements for the off-gas system, and economically remediate waste [Rubin, 1994:14].

A third melter technology under development is the stir melter [Wetmore, 1994:1]. The stir melter combines an electrically heated melting chamber with a device for stirring the melt to produce a homogeneous glass stream. DOE has ordered a stir melter for continued vitrification tests on simulated radioactive materials in Perrysburg, South Carolina. This system was scheduled to begin testing in August, 1994.

Finally, vitrification can be carried out without excavating contaminated soil using in-situ vitrification (ISV). ISV was developed by Pacific Northwest Laboratory [Buelt, 1991] and Battelle Memorial Laboratories [Shelley, 1990:47]. ISV places a square array of electrodes in the ground. A conductive starter path of flaked graphite and glass frit is placed along lines between the electrodes. As electricity flows between the electrodes, temperatures up to 2000 degrees centigrade produce a molten path that emanates outward. As the magma is allowed to cool, it forms a glassy substance that immobilizes heavy metals and radioactive isotopes. Escaping gases are trapped by a collection hood placed over the site. They are treated by quenching, scrubbing, dewatering, heating, particulate filtration, and activated-carbon adsorption. Having passed the US Environmental Protection Agency's most stringent leachability tests, the glass can simply be left in the ground and covered with clean backfill. There is, however, a fundamental problem with ISV not addressed in the literature - the extremely viscous magma begins to boil with explosive force and thus poses a serious safety hazard [Sams, 1995].

In summary, the feasibility of vitrification using plasma arc or stir melters is less certain than that of vitrification using a joule-heated melter. Furthermore, in contrast to in-situ vitrification, the output glass from a joule-heated melter may be stored on- or off-site. In short, in terms of process feasibility and stability of the final product, vitrification is a viable competitor to cementation or to dry removal for remediation of low-level mixed wastes. The preferred alternative will depend on a comparative LCC analysis.

2.2.3 Dry Removal. The dry removal process involves mixing a 50% water mixture of waste material with magnesium hydroxide which reacts with the toxic waste to make a insoluable compound. Then, a polymeric coagulant is added which turns the waste to a gel. Finally, the mixture is compressed in a filter press to evacuate much of the water. The final form of the waste material is a stable, dry (25% water content), and easily handled substance. The substance would either be stored onsite or transported to an offsite storage facility. The resulting waste form has been subjected to both leach and compressive strength tests [Sams, 1995].

Dry removal is attractive because it offers chemical stabilization within a mechanically stable waste form. The process utilizes well-understood technology and available equipment. Dry removal increases the volume of the final waste form resulting in higher transportation, storage, and monitoring costs than those in vitrification. Due to the success of the Erwin Tennessee operation where 700,000 ft^3 of mixed waste were remediated, there is little doubt that this waste form would pass the paint filter and TCLP tests. The 1994 technical report made by NFS about the entire remediation process was not releasable to the authors. Comments about the success of the process were made by Mr. Terry Sams, Martin Marietta Corporation, Oak Ridge National Laboratory, during an interview in March 1995.

Dry removal has been accomplished with other chemicals in the stabilization role such as sodium sulfide. Although this compound works extremely well, the human health hazard is great. Magnesium hydroxide has no similar health hazard associated with it [Sams, 1995].

In summary, the dry removal alternative to either cementation or vitrification is feasible for low-level mixed waste. It involves well-known technology, safe and inexpensive additives that have been successfully used elsewhere for this purpose, and a minimum amount of bulk up of the resultant waste.

2.3 Life-Cycle Cost Model

2.3.1 Cost Estimating. Recent economic trends predict shrinking budgets and a continued reduction in buying power. In addition to rising system acquisition costs, operations and maintenance costs are also increasing at alarming rates. It is important, therefore, to design, develop, acquire, operate, and maintain systems in the most cost effective manner. This awareness has driven an increased interest in total system, or life-cycle cost (LCC). LCC includes all costs associated with the full system acquisition cycle including research and development, production and construction, operations and maintenance, and retirement and disposal costs [Fabrycky, 1991: 122-126]. The LCC of a system can be represented as a net present value (NPV). The NPV is the amount of money needed to be set aside today to meet expected costs throughout the life of the system [Blank, 1989:342]. By considering the time value of money, LCC analysis will provide the DOE a fair comparison of alternatives with different remediation times.

A complete set of cost elements is key to meaningful LCC estimating. The cost breakdown structure (CBS) provides a functional breakdown of all project cost elements. The CBS described in Fabrycky and Blanchard [Fabrycky, 1991:122-126] is an excellent guide for cost element selection and classification. For technology demonstrations, the DOE has published a preferred format for reporting cost categories [Lankford, 1994]. A modified DOE format is used to organize available cost data for our method of LCC estimation.

Once cost elements have been selected and classified, they may be represented within a LCC model as trapezoidal cost elements (TCE), percentage cost elements (PCE), or recurring cost elements (RCE). A representative TCE, PCE, and RCE is illustrated in Figure 2.1 TCEs, PCEs, and RCEs are convenient tools for representing many complex cost profiles. Trapezoids can be used to approximate payment profiles for many complex systems and projects. TCEs consist of a phase-in period with linearly increasing cost, a constant-cost period with uniform cash flow, and a phase-out period with linearly decreasing cost [Habash, 1992:25]. Similar to TCEs, PCEs allocate percentages of the cost to a number of specified years. For example, a \$100,000 PCE might have 25% (\$25,000) of the cost incurred in year 1, with the remaining 75% (\$75,000) realized in year 4 of the project. Of the three cost elements, the recurring cost element is the most versatile. An RCE is a periodic payment made for a specified number of years. The total

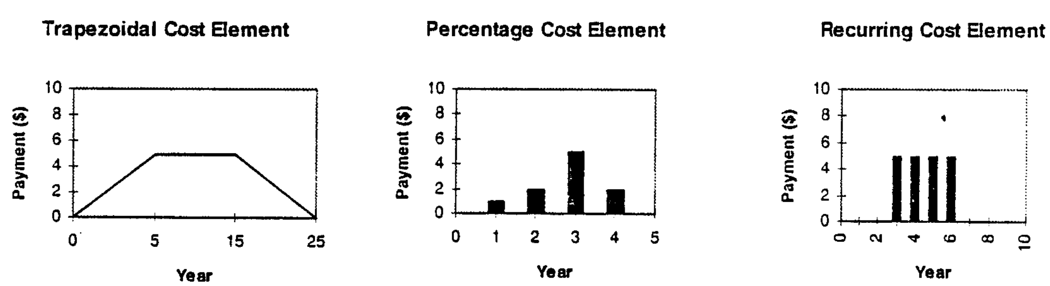

Figure 2.1

cost associated with an RCE is the sum of the annual payments made over the life of the project. RCE amounts may reference the annual cash flows of other cost elements in

Table 2.1

Year:	8	9	10	11	12	13	14	15	Total
Pmt:	$6.25M			$6.25M			$6.25M		$18.75M

addition to their total amounts and are time phased by specifying the number of payments, the start year, and a skip factor (number of years to skip between payments). For example, Table 2.1 represents a cash flow stream for re-bricking a melter. In this hypothetical example, the melter requires re-bricking every three years (skip factor of two) at a cost of $6.25M beginning in year eight.

Other tools for costing facilities, systems, capital equipment, etc., include cost capacity equations with industry standard exponents and the factor method as described by Blank and Tarquin [Blank, 1989:342]. The cost capacity equations are especially useful in determining scale-up costs for full-scale production. The cost prediction equation is

$$C_2 = C_1 \cdot \frac{Q2}{Q1}^n$$

where C_1 is the cost at capacity Q_1,
C_2 is the cost at the capacity Q_2,

x is a published, empirically derived exponent.

The factor method of cost estimation is

$$C_T = h \cdot C_E$$

where C_T is the total plant cost (including overhead),

h is the overall cost factor or summation of individual cost factors,

C_E is the cost sum of major equipment items.

Such tools, however, are useful only for processes that are well understood and for which actual cost data is available. Since the remediation alternatives considered are either conceptual or one of a kind, exponents and empirically derived factors are not available. In this case, heuristics supplied by professional estimators are often used for plant scale-up (or scale-down, as applicable) [Buckley, 1994] [Johnson, 1994].

2.3.2 Cost Risk Analysis. In a conceptual design, risk is inherent in point estimates for the various cost elements. Assessing cost uncertainty is therefore an integral part of LCC estimation. Uncertainties, in the present context, are statistically represented by cost risk distributions that describe the cost estimate range and likelihood of a given cost occurrence within that range. Risk factors, Monte Carlo simulation, network techniques, and cost estimating relationships (CER) are the most frequently used risk assessment techniques.

The risk factor approach, similar to the factor method mentioned previously, uses a multiplier derived from past data and experience. It is often a percentage applied to the total estimate or individual cost elements.

In Monte Carlo simulation, each cost element may be represented within a LCC model as a probability distribution around a mean value. These distributions are treated as theoretical populations from which random samples (cost estimates) are drawn [Dienemann, 1966:5,7]. Random sampling from the distributions of each cost element and multiple runs of the simulation provide statistical confidence in the results.

The network approach builds on the simulation approach. Networks represent interrelationships of major system activities and require multiple estimates of activities' durations. In this manner, costs associated with schedule deviations can be modeled.

Finally, CERs describe the cost of a project or system as a function of one or more independent variables. They can be obtained using least squares regression analysis on historical data. CERs, in conjunction with statistical bounds from the Monte Carlo simulation, can be used to forecast future observations using the following relationship [Neter, 1990:82]:

$$Y_{h(new)} = Y_{(hat)h} + t_{(n-p)} \cdot \sqrt{MSE \cdot (1 + X^t{}_h \cdot (X^t X)^{-1} \cdot X_h)}$$

where $t_{(n-p)}$ is a drawing from the students t-distribution with n-p degrees of freedom and X_h is a vector of h values for which predictions are desired. Except for the simple risk factor approach, all of these methods use cost distributions to model uncertainty.

Biery et al. recommend risk distributions that are unimodal, continuous, of a finite range, and capable of taking a variety of shapes or degrees of skewness [Biery, 1994:69-71]. The beta and triangular distributions are often used because they meet these criteria. Triangular distributions are favored, however, since they are easy to manipulate mathematically, do not require additional information such as shape parameters, and do not artificially narrow the range of the risk distribution by implying a nonexistent degree of precision. Once the appropriate cost distributions are selected, Monte Carlo simulation is used to generate the total cost risk profile through repeated random sampling from each distribution.

2.3.3 Survey of Cost Analysis Software. To facilitate LCC calculations, a computer software package may be helpful. Reviews of the capabilities of three commercial software packages follow. Microsoft Excel© 4.0 offers a multitude of built-in financial functions, extensive macro capabilities, and powerful graphics. @Risk 3.0© and Crystal Ball© 3.0.1 were reviewed as potential simulation add-ons to Excel©. Both packages offer a variety of graphical outputs including probability density distributions, cumulative density distributions, sensitivity diagrams, and trend graphs. Sensitivity diagrams are useful for highlighting the more significant cost distributions, and trend graphs illustrate how risk changes across time. Both @Risk© and Crystal Ball© offer a wide variety of distributions. Due to the anticipation of multiple runs with many configurations, Crystal Ball's© superior macro interface made it the preferred simulation complement to Excel©.

2.4 Decision Analysis Tools

Three decision analysis tools can be used to support the decision process: dominance graphs, proportional scoring, and strategy region graphs. Dominance graphs are used to rule out sub-optimal alternatives [Clemen, 991:437]. Figure 2.2 shows a dominance graph for a decision in which low life cycle cost and short remediation time are desired attributes. Alternative C1 may be ruled out because alternative M3 is both

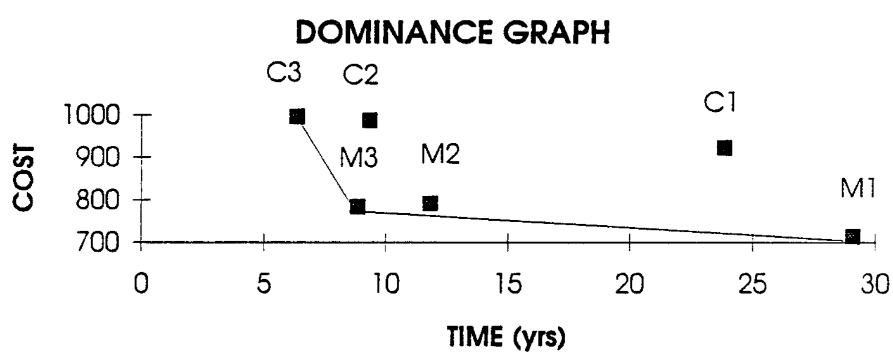

Figure 2.2

cheaper and faster. No matter what emphasis the decision maker places on cost, alternative M3 will always be preferred over alternative C1. Alternative M3 dominates

C1. The line connecting alternatives C3, M3, and M1 is called a frontier. Any alternative falling in the region to the right and above the frontier will be dominated.

Once dominated alternatives are ruled out, the decision maker compares the remaining alternatives using a common scale. This can be done using proportional scores [Clemen, 1991:439]. Each alternative is scored between zero and one depending on how its cost and time rank against competing alternatives. For example, the alternative with the lowest cost receives a cost score of one, while the alternative with the highest cost receives a cost score of zero. Alternatives with costs that fall between these extremes receive an interpolated cost score given by

$$cs_i = \frac{hc - c_i}{hc - lc}$$

where cs_i is the cost score for the i^{th} alternative,
c_i is the cost of the i^{th} alternative,
hc is the cost of the most expensive,
lc is the cost of the least expensive
alternative.

Once proportional scores have been calculated for each alternative, the decision maker determines the relative importance of cost and time in order to select from the competing alternatives. A strategy region graph can then be developed to help frame the decision [Clemen, 1991:125]. This graph identifies the preferred alternative for a given weight on cost versus time. The total score for each alternative is given by the weighted sum of cost score and time score. The break-even cost weight for the i^{th} and j^{th} alternatives is determined by solving the following equality:

$$cw \cdot cs_i + (1 - cw) \cdot ts_i = cw \cdot cs_j + (1 - cw) \cdot ts_j$$

where cw is the break-even cost weight,
cs_i is the cost score for the i^{th} alternative,
ts_i is the time score for the i^{th} alternative.

At the break-even cost weight, the decision maker is indifferent as to which alternative is preferred. The preferred alternative for cost weights above the break-even point can be determined by solving for total score using a higher cost weight to see which alternative achieves the highest score. By analyzing the break-even points between each pair of competing alternatives, a strategy region graph, as shown in Figure 2.5.2, can be developed that indicates the preferred alternative for a given cost weight.

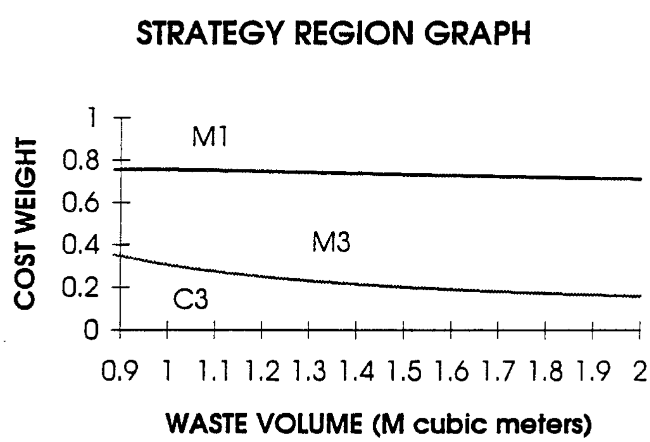

Figure 2.3

In this case, if the decision maker considers cost and time to be equally important, M3 is the preferred alternative. If cost is more important than time, M1 is preferred. Finally, if time is more important than cost, C3 is the preferred alternative.

2.5 Summary

The literature review indicates that cementation, vitrification, and dry removal are all feasible alternatives for low-level radioactive/mixed waste remediation. Product quality and process technology for these alternatives clearly demonstrate potential to support DOE's objectives for mixed waste remediation. Ex-situ remediation methods are applicable to a wider range of DOE sites than in-situ methods and provide better process and product quality control. Stir melters have not undergone bench scale testing and uncertainty currently surrounds the use of plasma arc melters. The feasibility of the joule-heated melter, on the other hand, has been established through successful bench-scale testing. The technologies involved in the cementation and dry removal processes are well-established and understood. Estimating the LCC of these new technologies involves cost estimation risk. Current techniques for cost risk and decision analysis can be incorporated within a LCC model for comparing waste remediation alternatives.

III. METHODOLOGY

3.1 Introduction

Our research resulted in a LCC model for NPV analysis of waste remediation alternatives. Specifically, we developed LCC cost estimates for remediating a site typified by operable unit 1 (OU-1) at the FEMP using three waste remediation alternatives - vitrification, cementation, and dry removal. Due to the disparate nature of the available cost information, different cost estimating strategies were required. Our cost estimating methodology is shown in Figure 3.1 and is described in Section 3.4. To estimate LCC for cementation and dry removal, we used previous cost estimates from prior waste remediation efforts, expert opinion, and vendor information. Cost data and process parameters from previous and ongoing projects were analyzed in order to develop heuristics for estimating future costs. Since vitrification is still in a conceptual development phase, these conventional estimating techniques are inadequate. Therefore, we added computer simulation as an extra dimension to our vitrification cost estimating methodology. Simulation enhanced our understanding of a large-scale vitrification process and helped define process parameters that drive cost.

Unlike conventional cost estimating methods, our analysis provides a statistical bound on the LCC. Given the cost model assumptions and range of each cost element, we determined an upper bound on LCC that will not be exceeded 95 times out of 100. In accordance with DOE's request, we developed a general model that can be used to estimate the cost to remediate a broad range of sites across the DOE complex.

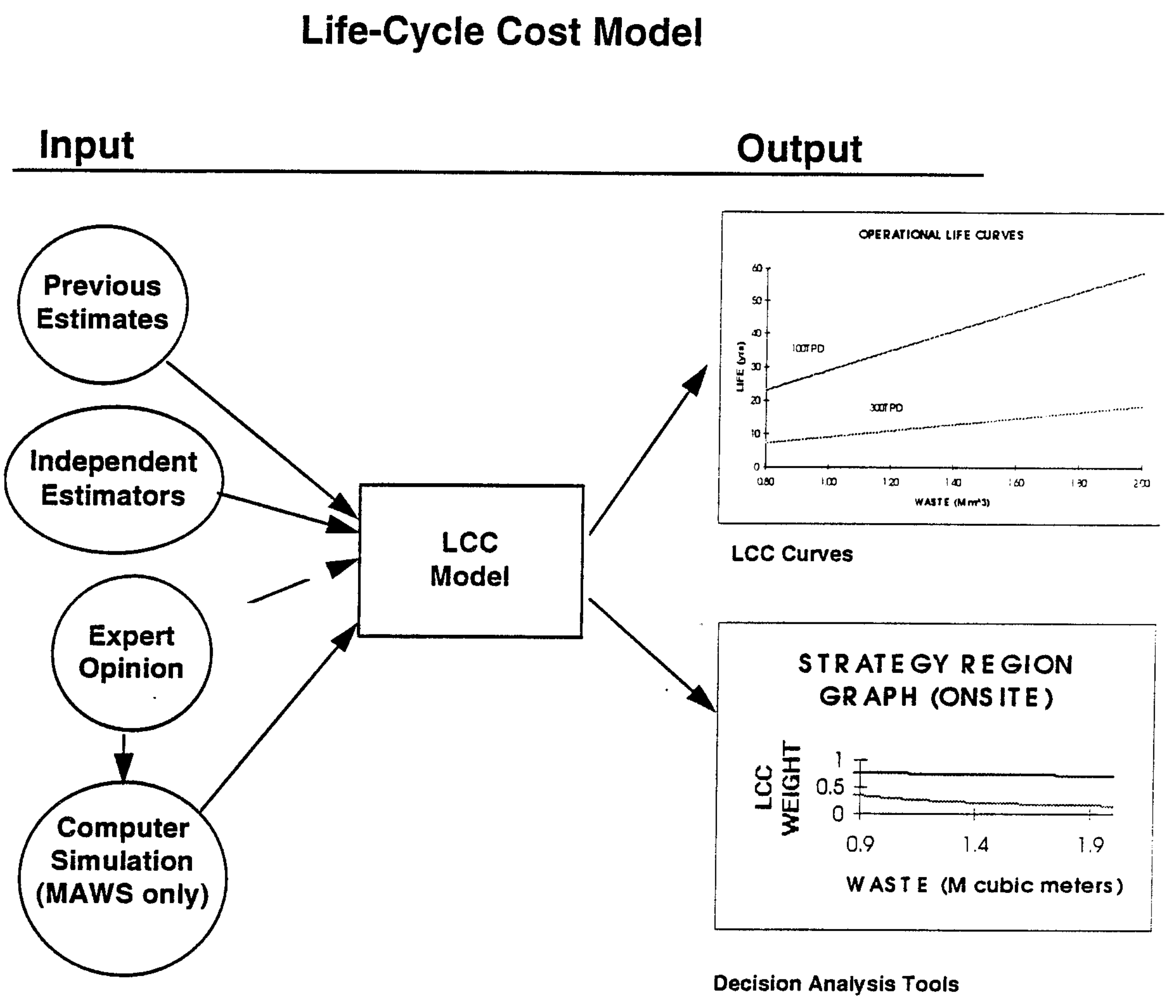

Figure 3.1 Life-Cycle Cost Model

Since each site has a different waste volume to remediate, the LCC model can be used to develop LCC estimates over a range of waste volumes. Because plant capacity has a significant impact on the time required to remediate a given volume of waste, the model allows for varying capacity and indicates its affect upon the LCC. Our goal was to characterize the inherent trade-offs between waste volume, plant capacity, project cost, and project duration.

3.2 MAWS Simulation

A large-scale process for vitrification of low-level radioactive waste has not been implemented. A bench scale MAWS (up to 300 kg/day output) process operated as part of the FEMP. To characterize the support infrastructure for a plant scale-up, we developed a computer simulation of a large-scale vitrification plant using FEMP lessons learned. In order to predict LCC for remediation of low-level radioactive waste using the MAWS concept, we designed the simulation using three main sources of input. First, we used design parameters and performance of the bench scale process at Fernald to gain understanding of how the MAWS concept is employed. Next, we combined lessons learned from the bench scale project using the judgment of project engineers to produce a conceptual design for large-scale implementation of MAWS. Finally, general contractors were approached within their respective areas of expertise to ascertain the nature of equipment or systems they would use to accomplish various aspects of the process. They were asked to describe performance parameters and costs associated with this equipment as though they were preparing a bid. Our design concept is mapped in Figure 3.2 and the simulation source code is included in Appendix I. Within the code for the initialization subroutine, parameters used for the simulation are defined and explained according to the three sources just described.

3.2.1 Why Simulation? There are three main benefits to LCC analysis that may be obtained through computer simulation of the MAWS process. First, the MAWS process for vitrification of low-level radioactive waste involves the interaction of parameters which vary randomly. For example, while a typical waste stream composition

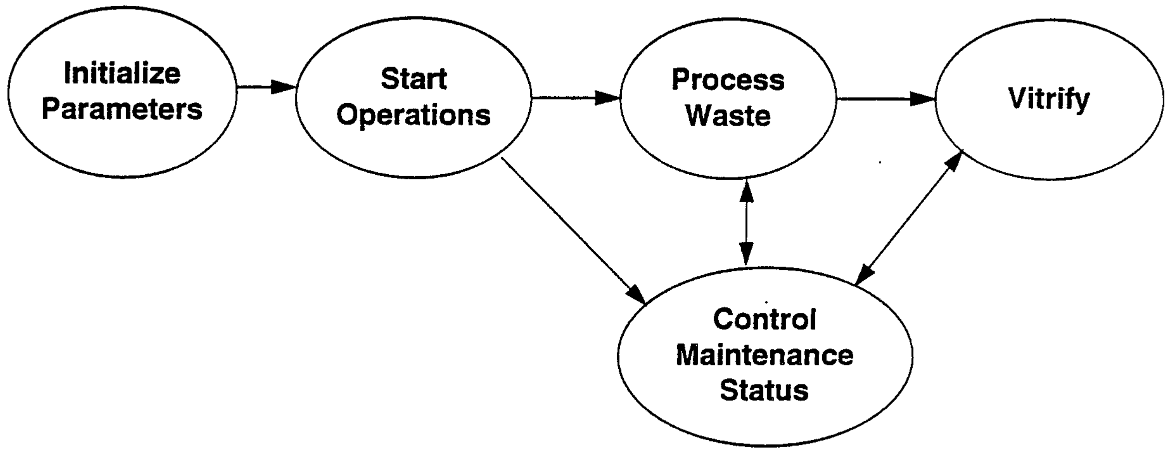

Figure 3.2 SLAM II Simulation Design Flow Diagram

is assumed for a given site, actual composition varies randomly from one batch of waste to another. Depending on the composition of a batch, various additives must be introduced in order to produce a suitable quality glass. These additives are expensive and add to the total mass of material which must be vitrified. Hence, the composition of the waste stream has a major influence on the time and cost involved in vitrification. In the computer simulation, the batch composition is varied randomly and the impact on throughput and cost is considered.

In a similar manner, the MAWS process ties together numerous activities having random durations. Some of these activities may be accomplished simultaneously, while others must be completed in a specific sequence. Each of these activities involves a piece of equipment or a system which is subject to failure. The reliability of each sub-system is random in nature, making the overall performance of the system highly stochastic. Computer simulation models this uncertainty and provides cost implications based on the resulting system performance.

Computer simulation provides a second benefit by enhancing the conceptual design of a large-scale MAWS system. Arrangement and throughput for the various components of the system can be varied as desired to find a workable and efficient design. Bottlenecks in the proposed system are identified and eliminated by altering the size and proportion of the various subsystems. Performance of alternative designs can be compared in search of an improved system. Using computer simulation does not guarantee an optimal system design, however, it helps ensure that the final cost estimate is based on a feasible system design that has been purged of major inconsistencies.

A third benefit of computer simulation is the potential for performing sensitivity analysis. Both the conceptual design of a large-scale MAWS and the cost implications drawn from this conceptual design are built upon several assumptions about uncertain events. It would be instrumental to know how LCC would be affected if one or more of these assumptions changed. If LCC varies significantly with small changes in one of the assumptions, more research to reduce uncertainty in this area would be merited. Computer simulation enables evaluation of the impact on LCC due to changes in our basic assumptions.

3.2.2 Choosing a Simulation Language. We chose SLAM II as our simulation language based on the following considerations:

- SLAM II is a familiar language and environment for all members of the project
- SLAM II is available on personal computers
- SLAM II uses FORTRAN subroutines which are familiar to all team members
- FORTRAN compilers are readily available as is a large volume of public domain source code

- FORTRAN is likely to be a familiar language to users and those conducting follow-on work

3.2.3 Developing the Simulation. In developing the simulation, several major assumptions were made regarding the MAWS process. First, we assumed a joule-heated ceramic melter would be used for a full scale implementation of MAWS. Three reasons for modeling a joule-heated melter are:

1) the bench scale employment of MAWS at Fernald used a joule-heated melter,

2) engineers at FERMCO advocated using a joule-heated melter [Gimpel, 1994],

3) the literature review indicated that joule-heated melters are among the most promising alternatives for vitrification, and that they present less risk than competing alternatives (see Section 2.3).

A further assumption is that the joule-heated melter would be operated continuously, with temporary shutdowns only for needed maintenance. The experience of process engineers with the bench-scale operation revealed a high cost in time and money stemming from shutting down and restarting the system. In order to support continuous operation of the melter, the soil washing process is also operated continuously. Other supporting subsystems, such as soil excavation and pit sludge removal, are carried out on weekdays with 8-hour shifts.

Based on the Fernald site, it is assumed that the MAWS process would blend waste from two separate streams. Contaminated sludge from the bottom of several waste pits would be blended with soil excavated from the berms surrounding the waste pits. We assume that total waste is divided among these two streams in a similar proportion to that observed at Fernald. These waste streams are blended in a proportion that allows complete remediation of pit sludge and soil simultaneously. This avoids restructuring the process and purchasing additional equipment to support melter operation when one of the waste streams is depleted. For example, once pit sludge is depleted, the melter must be fed entirely from berm soil. To keep up with the melter, the existing system would need to be augmented to increase the rate of excavation and preparation for the remaining waste stream. Such restructuring would be costly because it would lead to less than ideal utilization of capital equipment. The alternative solution of over-designing the system from the start is equally unattractive.

While no definitive standard has been established for the quality of glass produced by melting low-level radioactive waste, we assume that minimum quality standards will be applied and enforced by EPA. The only standard likely to be applied to low-level radioactive waste forms is the Toxic Characteristic Leach Procedure (TCLP) [Gimpel, 1994]. The TCLP tests the leach characteristics of heavy metals in the waste form. Because the ability to melt waste and produce a batch of glass is highly dependent on the chemical composition of the waste, the crew running the bench scale operation at Fernald designed and tested each batch of waste before feeding it into the melter. We assume that a large scale operation would proceed in the same manner. Catholic University has studied the vitrification process extensively. Based on their findings, Dr. Ian Pegg designed a series of compositional constraints which must be met in order to produce an acceptable glass. A major assumption of this simulation is that a batch of waste which meets these constraints will produce a glass capable of meeting EPA quality standards.

Based on studies conducted at Catholic University [Pegg,1994], each waste stream has been characterized in terms of the average weight percent of key elements in the form of oxides. These average percents are assumed to represent the true proportions of each element present in the population of waste to be treated. It must be noted, however, that we are sampling batches which represent only a very small portion of the total population. If we assume a degree of inhomogeneity in the population, sampling in this manner will introduce variation in the composition from one batch to the next. In order to account for this variation when characterizing each batch of waste, we divide the batch into 100 equal chunks. Each chunk is characterized independently of the others based on the draw of a uniform random variable. The range of the uniform random variable is divided into intervals, one interval for each of the key elements we need to track. The intervals are sized according to the average weight percent of each key element found in the population of waste to be treated. Each chunk is characterized according to the interval in which its random draw falls. The resulting weight percent of each key element is a binomially distributed random variable with parameters (n=100, p=weight percent). The variation of the resulting value is given by

$$\sigma_i^{\,2} = n \cdot p_i \cdot (1 - p_i)$$

where σ_i^2 is the variation of the weight percent of the i^{th} element,
n is the number of samples,
p_i=known percent composition of the i^{th} element.

By adjusting the number of samples, we ensure the resulting variation between batches matches that predicted by Dr. Pegg (see Section 3.2.4).

Once we characterize a batch of waste in terms of its composition, we must evaluate this composition against the constraints to determine if the batch may be fed into the melter. For constraints that are not satisfied, a combination of sodium carbonate (Na_2CO_3), silicon oxide (SiO_2), boric acid (H_3BO_3), and borax ($Na_2B_4O_7+5(H_2O)$) is added so that all constraints are met. Because these additives are expensive, the simulation incorporates a linear optimization subroutine that uses the dual simplex method to determine the quantity of each additive needed to meet all constraints at the lowest possible cost. When the batch passes all constraints, it enters the queue for the melter and the total amount of additives consumed is updated for costing purposes. Based on the judgment of Duratek process engineers, we modeled the duration of this blending and testing process as a uniform random variable ranging from 48 - 96 hours [Brown, 1994].

As mentioned previously, the MAWS process involves numerous activities having random durations. Within the simulation code, the reference for the duration of each activity modeled is documented. In order to model component reliability and maintenance costs, we asked manufacturers of each subsystem to provide mean time between failures; high, low and mean time to repair; related maintenance costs; and a window for expected availability of the system. Based on manufacturer recommendations, we assumed that time between failures is exponentially distributed about the mean, and that time to repair is uniformly distributed over the range from the low to the high estimate. Using the parameters given for each subsystem, we wrote subroutines to schedule failures and repairs and to alter the maintenance status of the respective subsystems appropriately. We adjusted throughput rates for each subsystem based on the subsystem maintenance status according to the following equation:

$$SWR = \frac{UR}{Units}$$

where SWR is the total soil wash rate in hours per cubic meter,
UR is the rate for one soil wash unit,
Units is the number of operating units.

There are a number of equations which characterize the process of vitrification of low-level radioactive waste using MAWS. Each of these equations is an assumption about how the process behaves. The first set of equations deals with the chemical process of converting a waste stream into a glass of suitable quality. Both Dr. Ian Pegg, at Catholic University, and Rod Gimpel, at FERMCO, have stated that no single equation captures glass chemistry in its entirety. Rather, Dr. Pegg has sought to establish proportionality constraints describing the interactions of key ingredients in the glass-making process. These constraints, based on experimental results, define a compositional region for forming a suitable quality glass. The following constraints, in weight percent, were developed by Dr. Pegg
:

$SiO_2 + Al_2O_3 + Fe_2O_3$	$\geq 40\%$
SiO_2	$\geq 25\%$
Al_2O_3	$\leq 20\%$
Fe_2O_3	$\leq 20\%$
B_2O_3	$\geq 5\%$
B_2O_3	$\leq 15\%$
$Na_2O + CaO + K_2O$	$\geq 10\%$
$Na_2O + CaO + K_2O$	$\leq 30\%$
MgO	$\leq 20\%$
CaO	$\leq 45\%$
P_2O_5	$\leq 2\%$
F	$\leq 15\%$

$$(SiO_2 + Al_2O_3 + Fe_2O_3)/(B_2O_3 + Na_2O + K_2O + CaO/2 + F) \leq 3\%$$

Another equation characterizing the MAWS process stems from the assumption that waste streams would be blended in order to complete remediation of pit sludge and berm soil simultaneously. The equations for determining the amount of pit sludge and berm soil to include in one batch are determined by simultaneously solving two equations. The first equation defines the known batch size in terms of the unknown quantities of pit sludge and berm soil to be included in each batch. The second equation defines the number of batches in terms of total waste divided by the quantity of waste per batch. The number of batches of pit sludge is then set equal to the number of batches of berm soil. The two resulting equations can be solved for the two unknowns, pit sludge per batch and berm soil per batch, in terms of the known values of total waste and batch size. The mathematics for this calculation are contained in Appendix K.

The time required to vitrify a batch of waste is a function of the melter size and a factor to convert solid waste input to glass output. Each batch is described in terms of its total mass of solids. When brought up to 1100 degrees centigrade, 40% of the mass, the organic portion, leaves the system as gas; the remaining 60% is converted to glass [Pegg,1994}. The vitrification time for one waste batch is

$$Time = 0.6 \cdot \frac{Solids}{Capacity}$$

where Time is the vitrification time (hours),
Solids is the mass of solids in the batch (tons),
Capacity is the melter output (tons/hour)

The volume of glass produced is

$$GlassVol = \frac{GlassMass}{GlassDen}$$

where GlassVol is the volume of glass (m^3),
GlassMass is the mass of glass produced (kg),
GlassDen is the waste glass density (kg/ m^3)

The glass is output in the form of glass gems which result in about 30% void space when packed [Pegg,1994]. Since disposal costs are a function of the waste volume, the output glass mass must be bulked up to account for void space:

$$GemVol = \frac{GlassVol}{0.7}$$

where GemVol is the glass gem volume (m^3),
GlassVol is the solid volume of glass (m^3)

Finally, power consumption is given by

$$Power = MW \cdot Waste$$

where Power is the power consumed (Mega-Watts-hours),
MW is the power consumption rate (Mega-Watts/ton),
Waste is the input waste (tons)

The nature of the vitrification process is well suited to modeling with discrete event simulation. At the level of detail desired for proportioning subsystems and monitoring costs and throughput, we chose to use a one hour time step. During excavation and transportation of raw waste, and mucking (pit sludge pumping), entities in the simulation represent truck loads of waste and cubic meters of waste, respectively. Later, during soil washing, blending, testing, and vitrification, entities represent batches of waste averaging 150,000 kg in weight.

Statistics from the simulation were broken into two categories. The first category, diagnostic statistics, provided system performance measures needed to make adjustments to the size and proportion of subsystems. Included in this category were availability and utilization of system components, wait times, and percent of time waiting for various components. The second category, cost drivers, tracked additives consumed, power consumption, and years of operation for a given configuration. These statistics provided input to the LCC model.

To generate LCC estimates over a range of sites, functional relationships between operating costs and waste volume are required. Cost Estimating Relationships (CER), obtained by regressing simulation output against waste volume, provide this relationship. CERs were created for operations life, additives consumed, power consumption, batches processed, and glass volume. The experimental design for each regression consisted of three levels of waste volume with five replications at each level (for a total of 15 runs). We selected the following three levels for waste volume: 1) 870,000 m^3, 2) 1,500,000 m^3, and 3) 2,000,000 m^3. These levels represent the waste volume range at typical DOE sites with the low end corresponding specifically to the FEMP OU-1 [Gimpel,1992:2] [Sams,1995]. This procedure was repeated for each of three plant capacities - 100, 300, and 500 tons of glass output per day. The mid-range capacity is roughly equivalent to Gimpel's cost model [Gimpel,1992:4]; the low and high plant capacities allow for cost versus time analyses for different plant capacities and waste volumes to remediate. Ultimately, the CERs allow us to interpolate costs between the three waste volumes modeled and to reflect the uncertainty associated with the simulation output.

3.2.4 <u>Simulation Verification and Validation</u>.

3.2.4.1 <u>Verification</u>. To verify that the simulation performs as designed, three diagnostic tools were incorporated. First, hand calculations determined the expected glass volume and process time from various sets of input to the simulation (see Appendix D). These calculations matched the corresponding output from the simulation.

Next, the characterization process for batches of waste was analyzed to determine if the mean and variation produced by the simulation matched the desired parameters. Simulation statistics for two elements, silica (SiO_2)and fluorine (F), were collected. Table 3.1 is a representative SLAM II simulation output used to track the mean and variance for one simulation run.

Table 3.1

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
SiO_2	.128E+00	.337E-01	.263E+00	.300E-01	.270E+00	4753
F	.988E-01	.298E-01	.302E+00	.100E-01	.230E+00	4753

The mean and variation of the weight percent for each of these elements closely approximated the desired mean (13% for SiO_2 and 10% for F) and variance (13% for SiO_2 and 10% for F) [Pegg, 1994]. Finally, the reliability of system components modeled by the simulation were compared to the expected availability provided by manufacturers and contractors. Simulation statistics for the number of operational resources were collected. Table 3.2 is a representative SLAM II simulation output used to track subsystem availability. In each case, the average number of operational resources matched the availability predicted by experts (e.g. 60-70% melter availability) [Greenman, 1994].

Table 3.2

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
MELTER IDLE	.006	.078	.00	1.00	0.00
AUGERS UP	.999	.036	.00	1.00	1.00
EXCAVS UP	.989	.103	.00	1.00	1.00
SWASH UP	1.930	.256	1.00	2.00	2.00
MELTERS UP	.665	.472	.00	1.00	1.00

3.2.4.2 Validation. To validate our results, we worked closely with process engineers throughout the development and maturation of the simulation. Various components of the simulation were demonstrated and discussed with Rod Gimpel at FERMCO, and all discrepancies were worked out. The performance of the soil washer as modeled by our simulation was comparable to a model constructed by Paul Hewen at Lockheed [Hewen,1995]. Process time, additives consumed, and glass volume produced were compared with previous calculations [Gimpel,1993:21]. Previous calculations for process time used four 90 ton per day melters, with three operating at any given time. The melter size was based on input waste dry weight. Our calculations used 65% availability for each melter, and melter size was based on glass output mass. Previous calculations for additives used sodium hydroxide (NaOH), SiO_2, and H_3BO_3, added to ensure a minimum of 10% flux. Our calculations added Na_2CO_3, SiO_2, H_3BO_3, and $Na_2B_4O_7+5(H_2O)$ in order to meet compositional constraints provided by Dr. Ian Pegg. Quantities of each additive were determined to meet the constraints at least cost. After accounting for these variations in underlying assumptions, the process time, additive quantity, and glass volume calculations in our simulation were comparable to previous calculations [Gimpel, 1995].

3.3 Basis of Estimate

Remediation activities require expensive equipment purchases and often take many operating years to complete. Fortunately, equipment selection and the concept of operations are areas that the design engineer can influence to minimize LCC. Therefore, the primary focus of this LCC analysis is operations and equipment costs. Other costs, including research and development, facilities, storage and disposal, and long term monitoring, rely heavily on previous estimates. In particular, facility costs are based on the Fernald Feasibility Study Report For Operable Unit 1 (FSR) [DOE, 1994]. Therefore, the cost breakdown structure (CBS) format (Figure 3.5) is not balanced in the level of detail presented in the various cost categories. Where applicable, previous estimates are cited and departures from those estimates are explained. This LCC analysis complements the best of what is available from preliminary cost estimates and adds a thorough operational cost analysis.

As previously described, the SLAM II simulation helps characterize the support infra-structure (i.e. personnel and support equipment) for three plant configurations. The three plant configurations differ in the number of 100 ton per day melters employed (either one, three, or five melters are used). To tune the simulation, the requisite number/size of soil washers, trucks, sludge pumps, hoppers, etc., are adjusted to levels that most efficiently support the given number of melters. Once the simulation is tuned, multiple simulation runs determine the remediation time, required additive amounts, energy consumption, and waste glass storage requirements for a given amount of waste input. As a result, the derived support infrastructure and simulation output provide input to the Monte Carlo cost estimating simulation.

3.3.1 Baseline System Description Enumeration and quantification of the various cost elements requires a baseline system description. Although the large-scale plant modeled for this cost estimate is conceptual, the following description, coupled with Figure 3.3, provides a sound basis for the estimate.

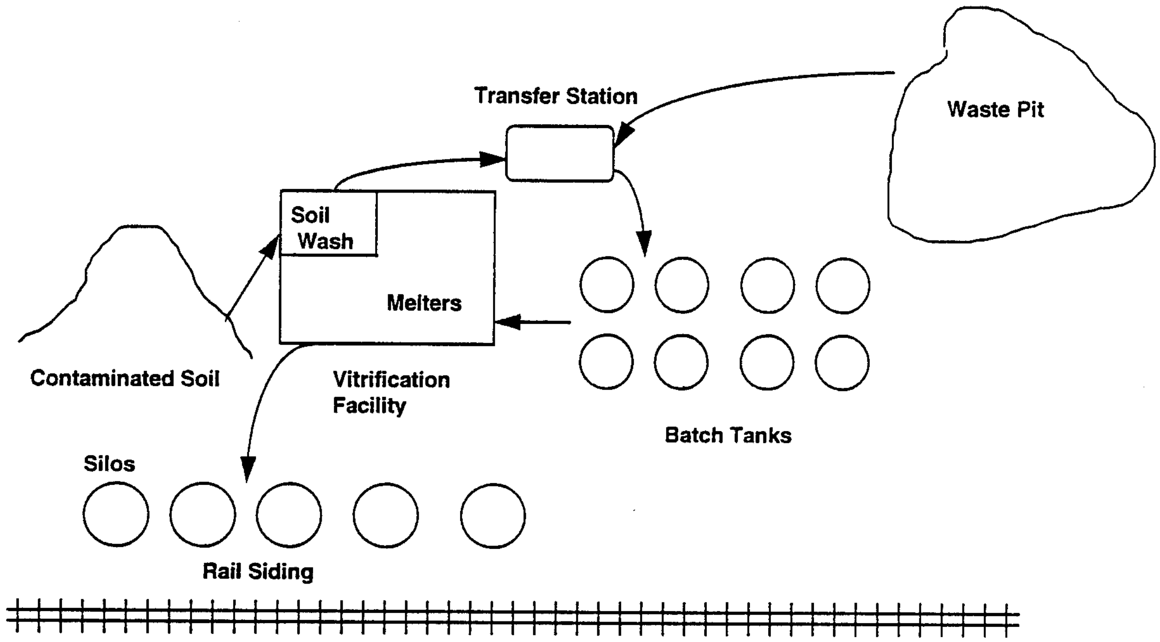

Figure 3.3. Vitrification Plant

3.3.1.1 Vitrification Plant

3.3.1.1.1 Vitrification Facility. The vitrification facility houses the melters, peripheral equipment, soil washers, and administrative offices. Several hoppers and/or enclosed storage areas are co-located within the vitrification facility to sustain operations when support equipment is down or supply shipments are interrupted - one each for excavated soil, small particle soil, ion-exchange resins, and additives.

3.3.1.1.2 Transfer Station. The transfer station is the hub for waste stream blending. Pit sludge is pumped to this station and then routed to the batch tanks. After blending, waste is routed back through the transfer station to the melters.

3.3.1.1.3 Ancillary Facilities. Ancillary facilities include an electrical power sub-station, fencing, and excavation for parking areas and required roadways.

3.3.1.1.4 Rail Siding and Silos (off-site disposal only). The rail siding and silos will facilitate transshipment to an off-site disposal facility.

3.3.1.1.5 Equipment.

- Melter waste glass output capacity is 100 tons per day per melter.
- Batch tanks hold 100,000 gallons each.
- Tanks are sized to feed one 100 ton per day melter for one day.
- Soil washer throughput is 4 m^3 per unit per hour. Single input and output feeds are used regardless of the number of soil washers.

3.3.1.1.6 Operations

3.3.1.1.6.1 Waste Stream Blending. There are three fundamental components to the input waste stream - pit sludge, berm soils, and barreled waste. The proportion of each waste stream in the batch tank is prescriptive; the goal is to have the pit sludge and contaminated soils depleted at about the same time. Pit sludge is pumped from the waste ponds directly to the transfer station and then routed to a batch tank. Berm soils are trucked to the pre-treatment facility for soil washing. Soil washing separates soil into clean aggregates and contaminated small particles. Soil wash products and additives are then fed to the batch tank along with the pit sludge. Laboratory crucible melt studies at Catholic University's Vitreous State Laboratory and Fernald's bench-scale vitrification plant have determined the optimal waste stream blend that satisfies processing parameter constraints and waste glass quality (i.e. melt viscosity, electrical conductivity, liquidus temperature, and leachability). The batch tank is filled two-thirds full to allow ample room for additives and then queued to await vitrification.

3.3.1.1.6.2 Batch Testing. A sample is taken from each batch tank to test waste input composition. If all component constraints are satisfied, the batch is ready for vitrification. If any constraints are not met, sufficient amounts of sodium carbonate, boric acid, borax, and sand are added to satisfy the deficiencies.

3.3.1.1.6.3 Vitrification. The blended waste is fed from a batch tank to a melter. Since the glass frit (glass making constituents) becomes electrically conductive at high temperatures, current passes between the electrodes and keeps the glass in its molten state. Water and organics are boiled off and toxins are collected by the off-gas system. The molten glass is tapped off and dropped onto a rotating steel plate. As the glass cools, it forms glass gems that are safely and easily handled, and provide a stable waste form for transport and storage.

3.3.1.1.6.4 Waste Glass Testing. A sample of waste glass output from each melter is tested weekly to ensure compliance with quality standards as defined by US and State Environmental Protection Agencies.

3.3.1.1.6.5 Maintenance. Routine maintenance is provided in-house as required. Specialized tasks such as melter rebricking and electrode replacement will be contracted to respective vendors.

3.3.1.1.2 <u>Waste Disposal</u>.

3.3.1.1.2.1 <u>On-site disposal</u>. Glass gems are buried in a tumulus (underground vault) using various clay and aggregate layers to isolate the waste. The tumulus leach field is monitored to ensure toxic leaching is in compliance with EPA guidelines.

3.3.1.1.2.2 <u>Off-site disposal</u>. Glass gems are rail transported to a commercial hazardous waste storage area in Utah that is operated by Envirocare. Long term monitoring is Envirocare's responsibility.

3.3.1.2 <u>Cementation</u>. The cementation plant layout is shown in Figure 3.4.

3.3.1.2.1 <u>Administrative Facility</u>. This facility includes locker rooms, showers, break room, temporary storage, and offices for plant administration.

3.3.1.2.2 <u>Waste Processing Structure</u>. The mixers and hoppers are mounted on structural steel beams. A batch tank is located next to this structure for

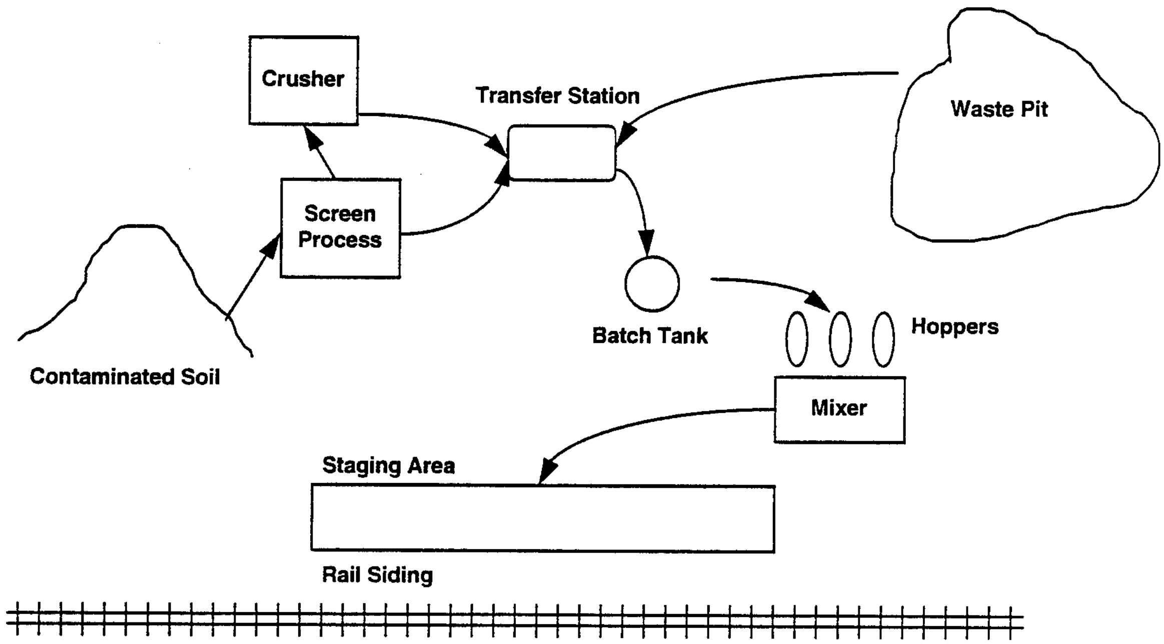

Figure 3.4. Cementation Plant

blending pit sludge and contaminated soil. There is one hopper each for cement, fly ash, and waste material.

3.3.1.2.3 Equipment List.

- Mixer output capacity is 200, 600, and 1,000 gallons per minute for configuration 1, 2, and 3, respectively.
- Batch tank holds 100,000 gallons. Tank will serve as a buffer for continuous waste feed to the mixers.

3.3.1.2.4 Transfer Station. The transfer station is used to meter inputs to achieve the desired blend of pit sludge, soil, and water. After blending, waste is routed to a hopper to await cementation.

3.3.1.2.5 Ancillary Facilities. Ancillary facilities include an electrical power sub-station, fencing, and excavation for parking areas and required roadways.

3.3.1.2.6 Rail Siding and Staging Area (off-site disposal only). The rail siding and staging area will facilitate transshipment to an off-site disposal facility.

3.3.1.2.7 Operations

3.3.1.2.7.1 Waste Stream Blending. There are three fundamental components to the input waste stream - pit sludge, berm soils, and barreled waste. The proportion of each waste stream in the batch tank is prescriptive; the goal is to have 50 - 60% solids in the tank. Pit sludge is pumped from the waste ponds directly to the transfer station and then routed to a batch tank. Berm soils are trucked to the pre-treatment area for screening and crushing. Soil is screened to pass aggregates less than 3/4 in. diameter. Larger aggregates, about 20% of the total input volume, must be crushed and then fed to the batch tank. Blended waste is fed to a hopper to await cementation.

3.3.1.2.7.2 Cementation. Three hoppers feed into the mixers - one each for cement, fly ash, and waste. The concrete blend consists of a mixture of 7 pounds of fly ash, 3 pounds of Portland cement, and one gallon of waste (at 50-60% solids). The mixed concrete is then poured into 110 gallon drums for curing. Cured waste forms provide a stable medium for transport and storage.

3.3.1.2.7.3 Concrete Waste Testing. Waste concrete samples are tested (one test per 1500 tons input) to ensure compliance with quality standards as defined by US and State Environmental Protection Agencies.

3.3.1.2.7.4 Maintenance. Routine maintenance is provided in-house as required. Specialized maintenance will be contracted to respective vendors.

3.3.1.2.7.5 Waste Disposal.

3.3.1.2.7.5.1 On-site Disposal. Concrete waste forms are buried in a tumulus using various clay and aggregate layers to isolate the waste. The tumulus leach field is monitored to ensure toxic leaching is in compliance with EPA guidelines.

3.3.1.2.7.5.2 Off-site Disposal. Concrete waste forms are rail transported to a commercial hazardous waste storage area in Utah operated by Envirocare. Long term monitoring is Envirocare's responsibility.

3.3.1.3 Dry Removal. The dry removal plant layout is shown in Figure 3.5.

3.3.1.3.1 Administrative Facility. This facility includes locker rooms, showers, break room, temporary storage, and offices for plant administration.

3.3.1.3.2 Waste Processing Structure. The filter presses and evaporators are mounted near the batch tanks which are used for blending pit sludge

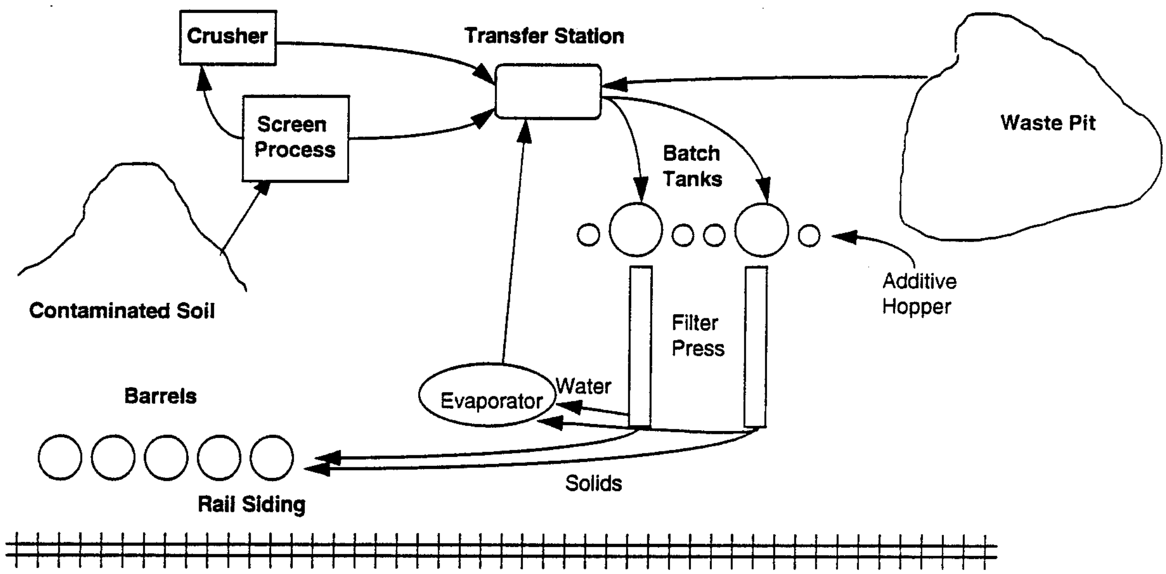

Figure 3.5. Dry Removal Plant

and contaminated soil. There is one hopper for each additive (magnesium hydroxide and a polymeric coagulant) located next to the batch tank.

3.3.1.3.3 Equipment List.

- Each filter press has the capacity to press 200 m^3 of a 50% water - 50% contaminated soil slurry in an eight-hour shift. There are two filter presses in Configuration 1, four filter presses in Configuration 2, and eight filter presses in Configuration 3 [Perry, 1976:19-69].
- Batch tank holds 100,000 gallons. Tank will serve as a buffer for smaller batch waste feed to the filter presses. There should be one batch tank for each filter press.
- Each evaporator has a 100 ft^2 heating surface [Perry, 1976:11-37].

3.3.1.3.4 Transfer Station. The transfer station is used to meter inputs to achieve the desired blend of pit sludge, soil, and water. Once the waste slurry is stabilized and the stabilized compounds are coagulated, the mixture is compressed.

3.3.1.3.5 Ancillary Facilities. Ancillary facilities include an electrical power sub-station, fencing, and excavation for parking areas and required roadways.

3.3.1.3.6 Rail Siding and Staging Area (off-site disposal only). The rail siding and staging area will facilitate transshipment of the barrels to an off-site disposal facility.

3.3.1.3.7 Operations

3.3.1.3.7.1 Waste Stream Blending. There are three fundamental components to the input waste stream - pit sludge, berm soils, and barreled waste. The proportion of each waste stream in the batch tank is prescriptive; the goal is to have 50 % solids in the tank. Pit sludge is pumped from the waste ponds directly to the transfer station and then routed to a batch tank. Berm soils are trucked to the pre-treatment area for screening and crushing. Soil is screened to pass aggregates less than 3/4 in. diameter. Larger aggregates, about 20% of the total input volume, must be crushed and then fed to the batch tank. Blended waste is stabilized, coagulated, and fed to the filter presses where the compression occurs.

3.3.1.3.7.2 Stabilization. Small amounts of magnesium hydroxide react with the heavy metals in the mixed waste slurry and cause them to be insoluble in water. The mixture is also quite safe for handling by humans. Other additives were considered such as sodium sulfide, but were not used. Sodium sulfide is itself a hazardous material in both the liquid and gaseous form and would require special handling and additional human health risks.

3.3.1.3.7.3 Coagulation. A polymeric coagulant, such as one produced by DOW Chemical Co., is added to the stabilized mixture to cause the suspended particles to gel together. The water can then be squeezed out without taking suspended, contaminated particles with it.

3.3.1.3.7.4 Filter Press. Each filter press is approximately 30 ft by 8 ft. by 5 ft. The press has nine banks or frames, each having its own filter and metal pressing plate. All nine banks are compressed simultaneously as the water is allowed to escape. The water is drained to the evaporator. When the waste has been compressed to 20% to 30% water content, the cakes are removed from the filter pads and placed into barrels for shipping.

3.3.1.3.7.5 Evaporator. The evaporator chosen for this process has 100 ft^2 of evaporation area. The capacity of this piece of equipment can easily perform the required evaporation from two filter presses. The water that is left after the evaporation is then recycled to the batch tanks.

3.3.1.3.8 Cementation. When the water becomes too concentrated from particles that did not coagulate or that passed through the filters, it is fed into a small cementation process. The amount of cementation that is required is so small (< 1% of the solids that need to be remediated), a cement truck can accomplish the task in a weekly mixing and pouring operation.

3.3.1.3.9 Dry Waste Testing. Waste concrete samples are tested (one test per batch tank per week) to ensure compliance with quality standards as defined by US and State Environmental Protection Agencies.

3.3.1.3.10 Maintenance. Routine maintenance is provided in-house as required. Specialized maintenance will be contracted to respective vendors.

3.3.1.3.11 Waste Disposal.

3.3.1.3.11.1 On-site Disposal. The dry waste is buried in a tumulus using various clay and aggregate layers to isolate the waste. Because it has already been compressed, the dry waste is easier to bury and meets the compaction requirements of EPA more easily than the concrete or glass beads waste forms. The tumulus leach field is monitored to ensure toxic leaching is in compliance with EPA guidelines.

3.3.1.3.11.2 Off-site Disposal. Dry waste are rail transported to a commercial hazardous waste storage area in Utah operated by Envirocare. Long term monitoring is Envirocare's responsibility.

3.3.2 Cost Breakdown Structure. The Fernald bench-scale project provided the framework for detailed MAWS operations and cost analysis. The cost estimates also incorporate the simulation data, FSR data, and the expert judgment of engineers, scientists, technicians, and management involved in the Fernald Environmental Management Project. In addition, private cost estimating consultants provided industry standard heuristics to apply to the FSR facilities costs [Buckley, 1994] [Johnson,1994].

The CBS in Figure 3.6 provides a top-level breakdown of all project cost elements including research and development, construction and capital equipment, operations and maintenance, and system phase-out and disposal costs. Detailed operations and equipment costs are described in the cost element dictionary, Appendix A (Cementation), Appendix B (MAWS), and Appendix L (Dry Removal).

Cost Breakdown Structure

I. Research and Development

II. Construction/Capital Equipment

A. Facilities
B. Capital equipment

III. Operations and Maintenance

A. Operations
B. Maintenance

IV. System Phase-out and Disposal

A. Waste storage
B. Waste transport
B. Equipment salvage
C. Facilities destruction
D. Site restoration
E. Long term monitoring

Figure 3.6

In accordance with DOE's recommendation [Murray,1994] and the advice of the estimating consultants [Buckley, 1994] [Johnson, 1994], several adjustments were made to the FSR facility cost estimates. The applied heuristics are summarized below:

- Direct supervision is charged at 6% of direct labor
- Tools and consumables are limited to 1.5% of total direct costs
- Equipment rental is limited to 3% of the total direct costs
- CERCLA costs are not included in our estimates and are subtracted from the FSR estimates. CERCLA costs are common to all alternatives and are small in comparison to total project cost
- Bond is 1% of the total contract
- FSR overhead and profit is 7% of the total contract. Changed this line item to 20% of direct labor + 9% of total contract + 6% of materials
- Reduced payroll burden and benefits which range from 50% to 77% over base labor rates to 30% of direct labor, the industry standard
- FERMCO project management is included as 6% of total project costs under a separate cost element; it is subtracted from the FSR estimates.
- Construction management is limited to the national standard of 4% of the total contract
- Engineering costs are reduced from 30% to 10% of direct costs
- Risk and contingency budgets, which ranged as high as 35%, were reduced; 10% risk should be more than sufficient for estimating construction costs, even for a conceptual design
- Operating costs are necessarily backed out of the FSR vitrification facility/operations estimate

The original and adjusted FSR facilities costs are provided in Appendix C.

3.4 LCC Model

Several aspects of radioactive waste remediation complicate LCC estimation. First of all, due to new technology and conceptual (or one of a kind) design, most cost elements are necessarily treated as random variables. Furthermore, duration of operations depends on the plant capacity and quantity of waste requiring remediation. A robust cost model should account for the cost uncertainties and varied project life. Therefore, to facilitate effective and rigorous cost analysis of competing waste remediation alternatives, a generic LCC model was developed that uses Monte Carlo simulation to model these uncertainties.

3.4.1 LCC Model Description.

The core of the model is a program written in Microsoft Excel © 4.0 macro language which serves as an interface to Crystal Ball © 3.0.3, a simulation add-on to Excel ©. The program is menu/prompt driven and requires minimal familiarity with the underlying spreadsheet and simulation environment. The program code is included in Appendix J . The LCC model features include

- unlimited number of variables/cost elements
- max project life of 200 years
- inflated/deflated cost discounting
- specification of simulation parameters
- automation of multiple simulations
- user-specified cost correlations
- user-defined names for variables and/or cost elements
- ability to handle any type of cost formula (constants, random variables, functions, or a combination)
- ability to define cost categories
- LCC probability/cumulative density functions
- LCC sensitivity to cost distributions
- bounds on annual cash flow over project life
- data for break-even analysis between alternatives

These capabilities allow the decision-maker to conduct what-if scenarios and analyses, as well as budget for projected costs.

3.4.2 Modeling Approach. Variables and cost elements are the fundamental building blocks of the LCC model. Variables are scalar values used in the model, such as power consumed, waste volume, and per unit disposal costs. They may be defined by engineering analysis, process simulation results, vendor information, or previous cost estimates. Cost elements, on the other hand, may be vectors or series of payments that are discounted over time at the given interest rate. They are expressed as functions of variables, distributions, or constant dollar amounts. We used three types of cost elements in our LCC model: trapezoidal cost elements (TCE), percentage cost elements (PCE), and recurring cost elements (RCE). Each cost element is described by type, name, amount, and time-phasing in the cost element dictionary found in Appendices A, B, and C.

Several cost elements used in the LCC model required unique applications of the RCE. For example, RCEs were used to time-phase costs associated with the CERs developed from simulation of the vitrification process. Average consumption/production rates were obtained by dividing the total usage by the operations life. Annual payments, expressed as the product of unit cost and annual consumption/production, were modeled using RCEs. In another example, RCEs were used to produce cost categories such as labor, additives, operations, maintenance, etc. The annual payments for cost categories are simply the sum of the corresponding payments of their component costs. Once categories were defined, overall inflation effects were readily modeled using RCEs together with a time index provided by the LCC model. Inflated project cash flows were modeled by multiplying the overall project cost by an inflation factor equal to

$$(1 + Inflation)^{Time}$$

where
Inflation is the inflation rate,
Time is the year the cost is incurred

The inflated payment streams were then discounted using the nominal discount rate.

To provide a fair and realistic comparison of alternatives, an infinite waste monitoring period was assumed in all cases. Monitoring costs were assumed to increase in proportion to total waste volume over the operating period. Monitoring costs extending beyond the end of operations were modeled as a lump payment incurred upon completion of operations. This single payment is the present value of a uniform payment incurred over an infinite number of years and can be expressed as:

$$Payment = \frac{Max\_Monitor\_Cost}{Rate}$$

where Payment is the present value of the cost incurred,
Max_Monitor_Cost is the cost for monitoring the final waste volume,
Rate is the nominal interest rate corrected for inflation.

This technique facilitates NPV calculations but the cash flow stream is actually a uniform annual payment incurred for an indefinite amount of time.

3.4.3 <u>Generating Cost Curves</u>. To predict LCC at intermediate waste volumes and to more readily identify potential break-even points between alternatives, we generated LCC observations at several levels of waste volume (Q). We used an experimental design resulting in 78 observations for each alternative. We varied waste volume from 0.8 to 2.0 million cubic meters in increments of 0.1 million cubic meters. To avoid the anomalies that could arise when the LCC model samples from a pseudo-random number stream, we ran trial runs to determine how many iterations were required before output stabilized. Based on trial runs, as illustrated in Figure 3.7, the Monte Carlo simulation reached steady state at about 250 iterations. A plot of LCC versus waste volume (Q) revealed some curvature (see Figure 4.2). We used a quadratic model to regress observations of LCC against Q to determine a functional form and generate smooth curves for LCC. Regression analysis results are contained in Appendix F.

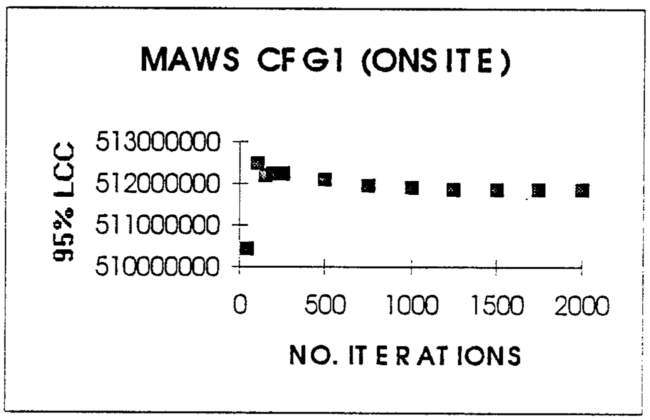

Figure 3.7 Justification for Using 250 Iterations

IV. ANALYSIS OF RESULTS

4.1 Introduction

LCC model results for cementation and vitrification are presented and analyzed in a format that directly supports the decision process. A total of six waste remediation alternatives are investigated - three plant capacity levels for both cementation and vitrification (see Table 4.1). Alternatives are first evaluated on the basis of LCC and

Table 4.1 Plant Capacities and Waste Processing Rates

Alternative	Plant Capacity	Waste Processing Rate
MAWS Vitrification	tons glass per day	m^3 per day
M1	100	138
M2	300	414
M3	500	690
Cementation	gallons concrete per minute	m^3 per day
C1	200	191
C2	600	573
C3	1000	955

processing time. For each alternative, LCC and remediation time are plotted over a range of waste volumes. Dominance graphs are then used to eliminate alternatives that demonstrate both higher cost and longer remediation time. Finally, strategy region graphs enable the decision maker to select from non-dominated alternatives based on the relative importance of cost versus remediation time.

4.2 Life Cycle Cost Curves

In Figure 4.1a-b, LCC is plotted against waste volume for all alternatives and for on- and off-site disposal. Each curve represents a 95% statistical upper bound on cost derived from the Monte Carlo simulation. In other words, 95 times out of 100, this LCC will not be exceeded. From Figure 4.1a-b, the smallest plant capacities exhibit the lowest cost and, from Figure 4.2, the longest remediation time. The LCC curves indicate that, based on cost alone, vitrification is always preferred. Also, the cost curves for larger capacity plants have steeper slopes. This is because operating costs are greater and incurred sooner than for alternatives with smaller plant capacities. Furthermore, the analysis indicates that the least expensive option, in terms of current dollars, is to extend the remediation process as long as possible by choosing the smallest plant capacity. In other words, the time value of money is a significant factor in choosing among alternatives.

4.3 Remediation Time Curves

Intuitively, short remediation times should be preferred. Therefore, using time as the only measure of effectiveness, large plant capacities are preferred. However, as seen in Figure 4.1a-b, larger plant capacities are more expensive. Figure 4.2 re-emphasizes the importance of considering time when selecting among alternatives. Techniques for multi-criteria decision analysis aid the decision process when more than one attribute is important and the various attributes cannot be easily converted to a common metric.

4.4 Multi-criteria Decision Analysis To analyze the trade-off between cost and remediation time, the dominance graphs in 4.4a-b were used to eliminate

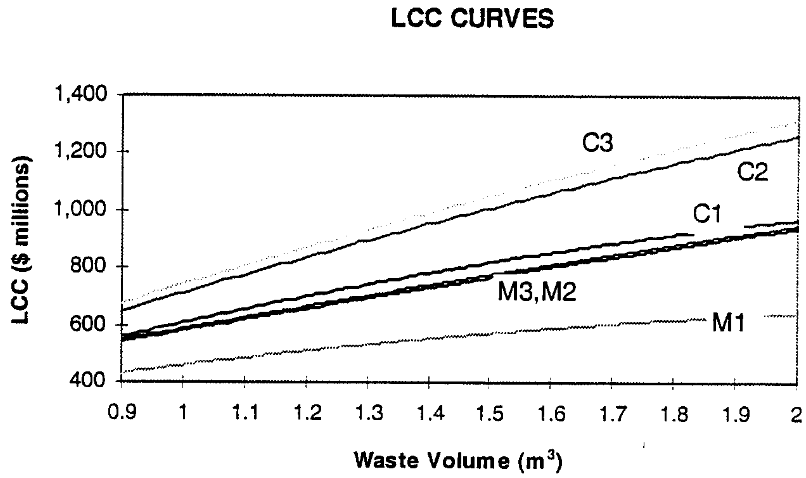

Figure 4.1a On-site Disposal

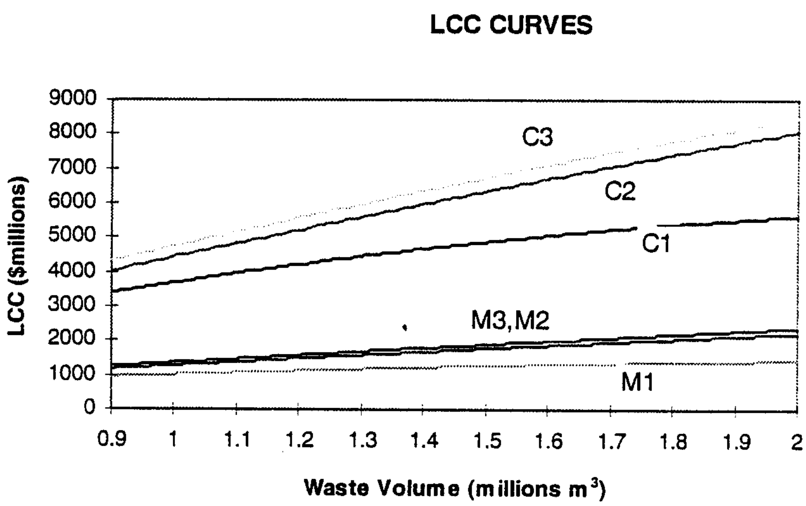

Figure 4.1b Off-site Disposal

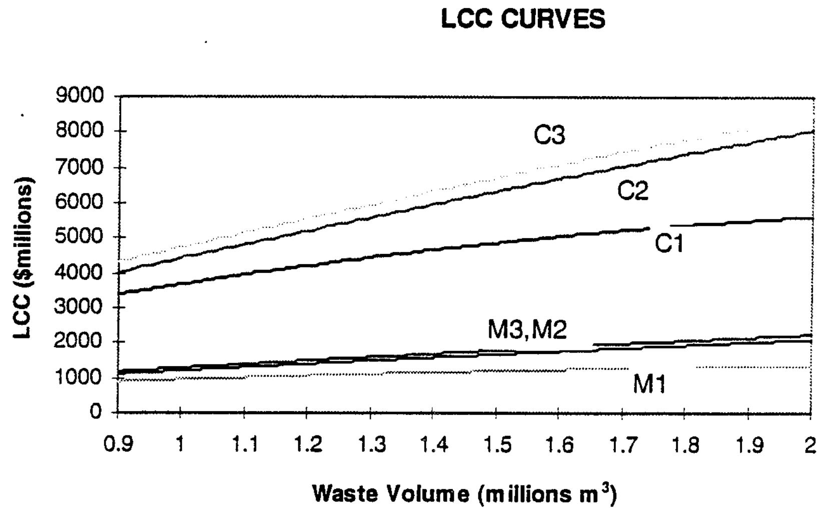

Figure 4.2 Remediation Time Curves

dominated alternatives. For the remaining alternatives, two strategy region graphs were created to incorporate both cost and remediation time in the decision process (Figure 4.4a-b). The first set of strategy region graphs represent the cost of extending remediation time by assigning a dollar cost penalty per cubic meter of waste for each year that remediation is delayed. This penalty quantifies DOE liability for public health risk and accounts for other costs associated with delayed remediation. Given the decision makers assessed penalty, one can identify the preferred alternative for a given waste volume (see Figure 4.4a).

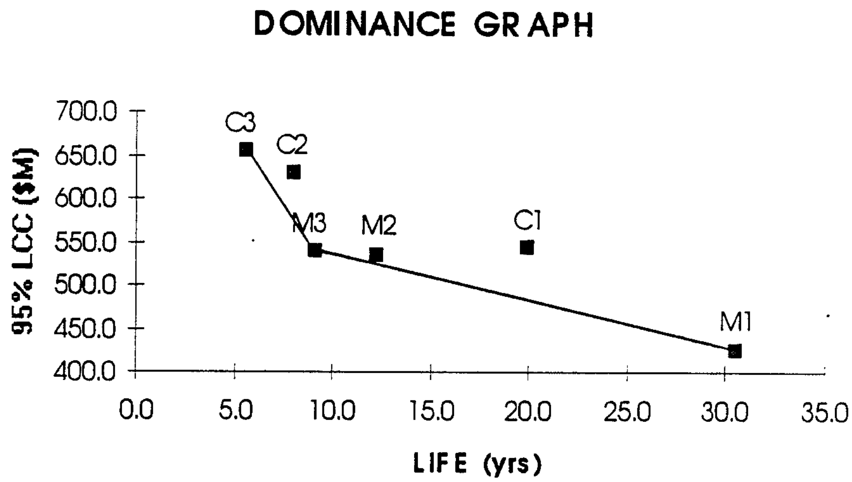

Figure 4.3a On-site Disposal

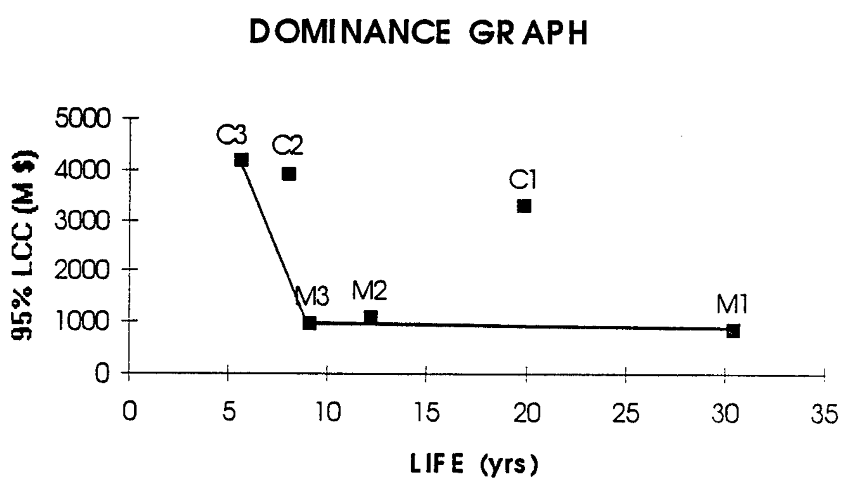

Figure 4.3b Off-site Disposal

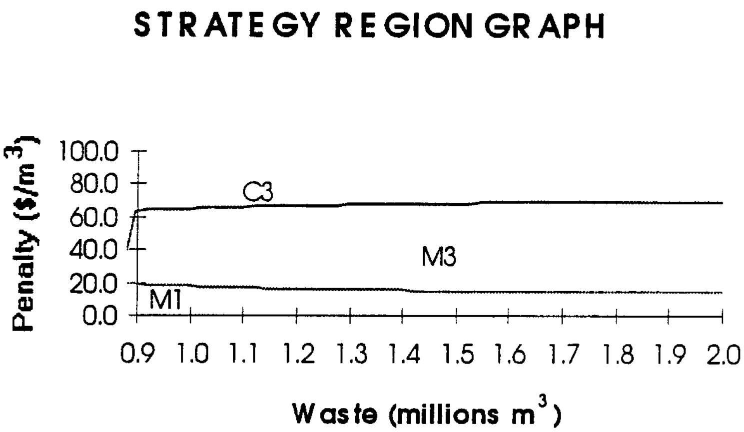

Figure 4.4a Remediation Delay Penalty, On-site Disposal

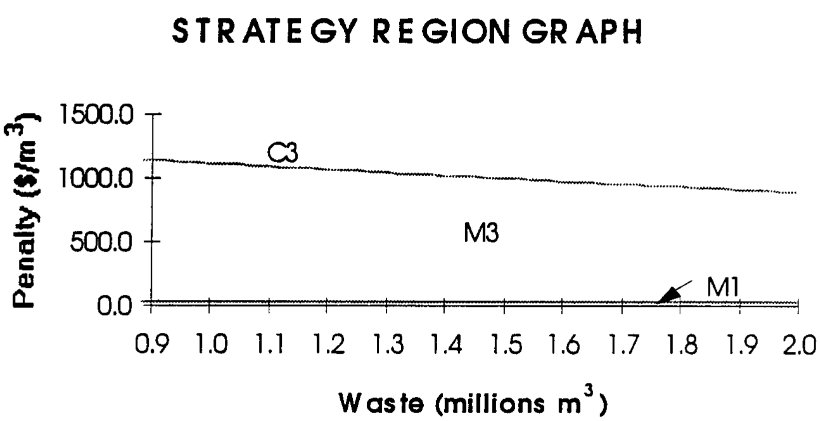

Figure 4.4b Remediation Delay Penalty, Off-site Disposal

For example, given a penalty of $500/m^3$, on-site disposal, and a site with 1 million cubic meters, the preferred alternative is C3. However, if the same penalty is imposed when off-site disposal is required, M3 is preferred.

The second set of strategy region graphs (Figure 4.5a-b) indicate a preferred alternative for a given cost weight. If the decision maker considers cost to be twice

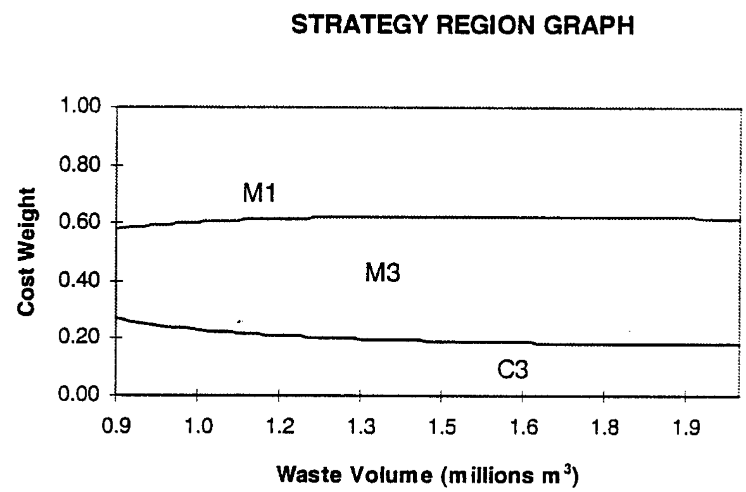

Figure 4.5a On-site Disposal

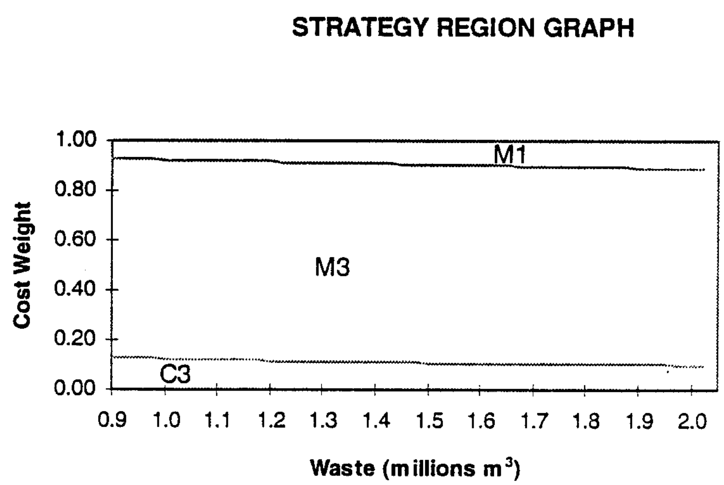

Figure 4.5b Off-site Disposal

as important as remediation time, his assigned cost weight is 0.66 (which makes the remediation time weight equal to 0.34). To combine the cost and time attributes requires a meaningful score related to each attribute [Clemen,1990:439]. Therefore, LCC and remediation time are normalized so that the worst (highest) LCC is scored at 0.0 and the best (lowest) LCC is scored at 1.0. Likewise, the longest and shortest remediation times are scored 0.0 and 1.0, respectively. Values between the extremes are scored proportionally. The total score is then a function of the individual scores for LCC and remediation time. The model for our hypothetical example is

$$Score_i = 0.66 \cdot LCC_i + 0.34 \cdot Time_i$$

where Score is the total score,
LCCi is the cost score,
Time is the remediation time score

From Figure 4.5b, with a 0.66 weight on cost, M3 is the preferred alternative for a site with 1 million cubic meters of waste requiring off-site disposal.

4.5 <u>Sensitivity Analysis</u>

The pie charts in Figure 4.6a-c indicate that disposal cost is the most significant cost driver. This fact is independent of the chosen alternative or the total waste volume to remediate. Therefore, assumptions affecting this cost category have the greatest potential to alter the decision strategy indicated by the model. Since disposal costs account for a disproportionately large percentage of LCC, factors influencing disposal costs deserve further analysis.

The factors driving disposal cost are waste volume, per unit disposal cost, and the real rate at which costs are discounted. The assumptions for volume reduction (or bulk-up) directly influence waste volume. Therefore, we examined LCC over the realizable range of values for vitrification volume reduction (0.8 to 0.5) and cementation bulk-up (1.4 to 2.4) [Gimpel,1994] [Sams,1994]. Also, it is possible that the treated waste can be reclassified (de-listed) into a category requiring lower per unit disposal costs for off-site disposal. Based on this possibility, we compared alternatives using the per unit disposal costs for de-listed wastes ($7.00 per cubic foot for de-listed waste versus $60.00 per cubic foot for listed waste). Finally, we ran the model using extreme real rate values to evaluate LCC sensitivity to real rate (1% - 5.5% versus the government directed 2.8%) [OMB, 1994:C-1].

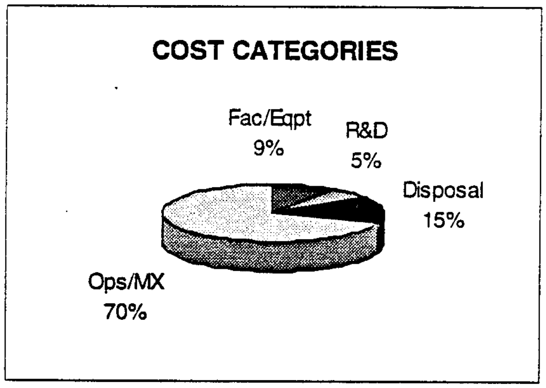

Figure 4.6a. Alternative M1 On-site

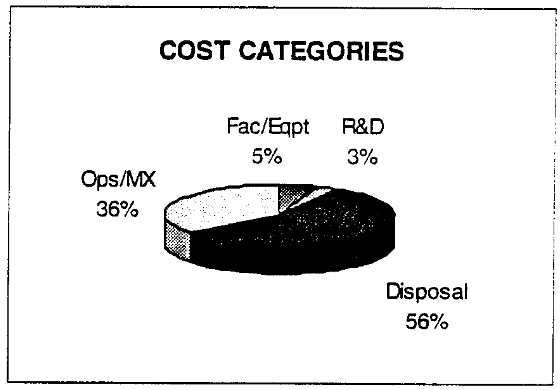

Figure 4.6b. Alternative M1, Off-site

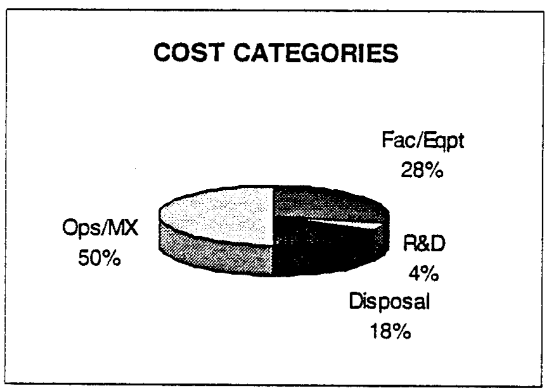

Figure 4.6c. Alternative M3 On-site

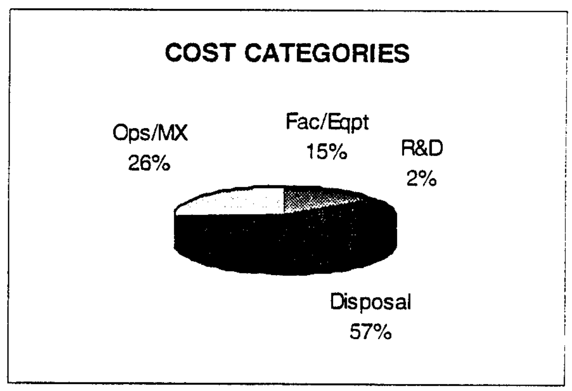

Figure 4.6d. Alternative M3, Off-site

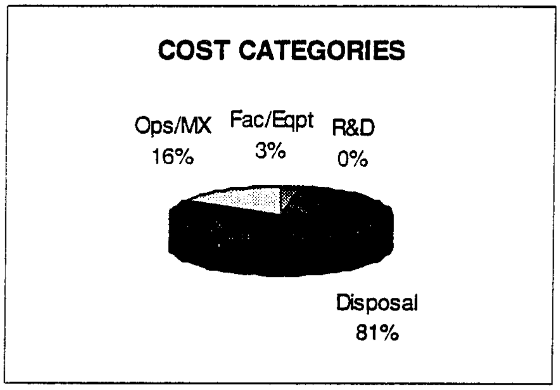

Figure 4.6e. Alternative C3 On-site

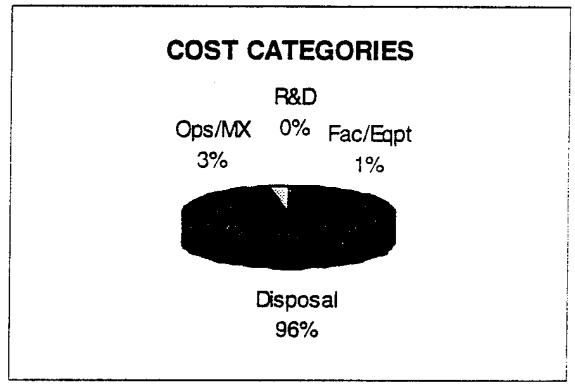

Figure 4.6f. Alternative C3, Off-site

4.5.1 Decision Analysis. Using DPL©, the influence diagram in Figure 4.7 was developed. Influence diagrams provide a graphical depiction of the decision

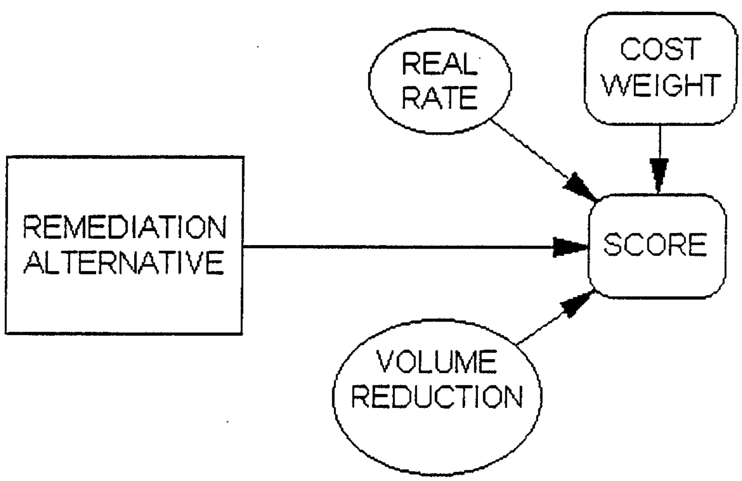

Figure 4.7 DPL© Influence Diagram

environment, highlighting key parameters that influence the performance of competing alternatives. To model the decision uncertainty, we varied volume reduction, real rate, and per unit disposal cost in the Monte Carlo simulation. The simulation designs and results are included as Appendix G. Using the Pearson-Tukey approximation to the normal distribution [Clemen, 1991:292], we represented the probability distributions for the outcomes of these uncertain events with three discrete values. We assumed that the extreme points for the range of realizable values constituted the 5th and 95th percentiles with discrete probabilities of 0.185. The base case value was considered to be the mean, with a discrete probability of 0.63. The resulting decision tree is depicted in Figure 4.8

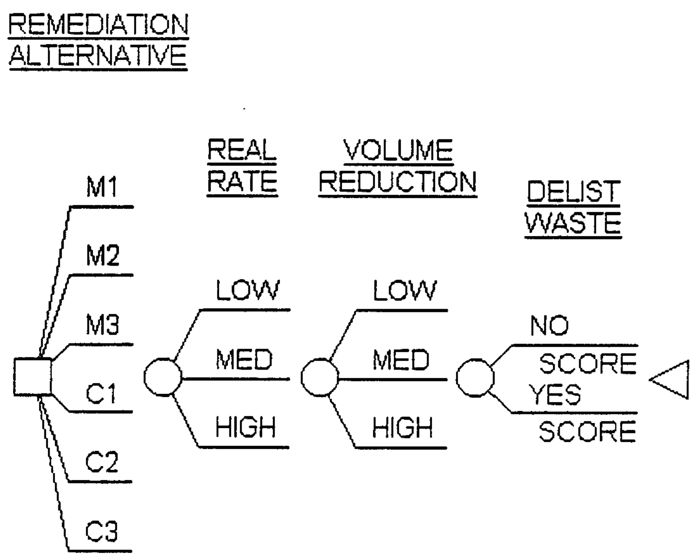

Figure 4.8 DPL© Decision Tree

and the expanded M1 branch is shown in Figure 4.9. Each branch of the decision tree represents a possible combination of outcomes for each of the uncertain parameters- volume reduction, real rate, and per unit disposal cost. Since these parameters affect alternatives differently, the value of each alternative must be calculated for each branch of the decision tree. Based on the relative performance of each alternative in both cost and remediation time, the values at the end of each branch of the decision tree were computed using proportional scoring as previously discussed. For each alternative, the score at the end of each branch is multiplied by the probability associated with that outcome. The scores for each scenario are included in Appendix H. The sum of these products is the alternative's total expected score. Since the total expected score depends on the emphasis that the decision maker places on cost and remediation time, cost weight was modeled as

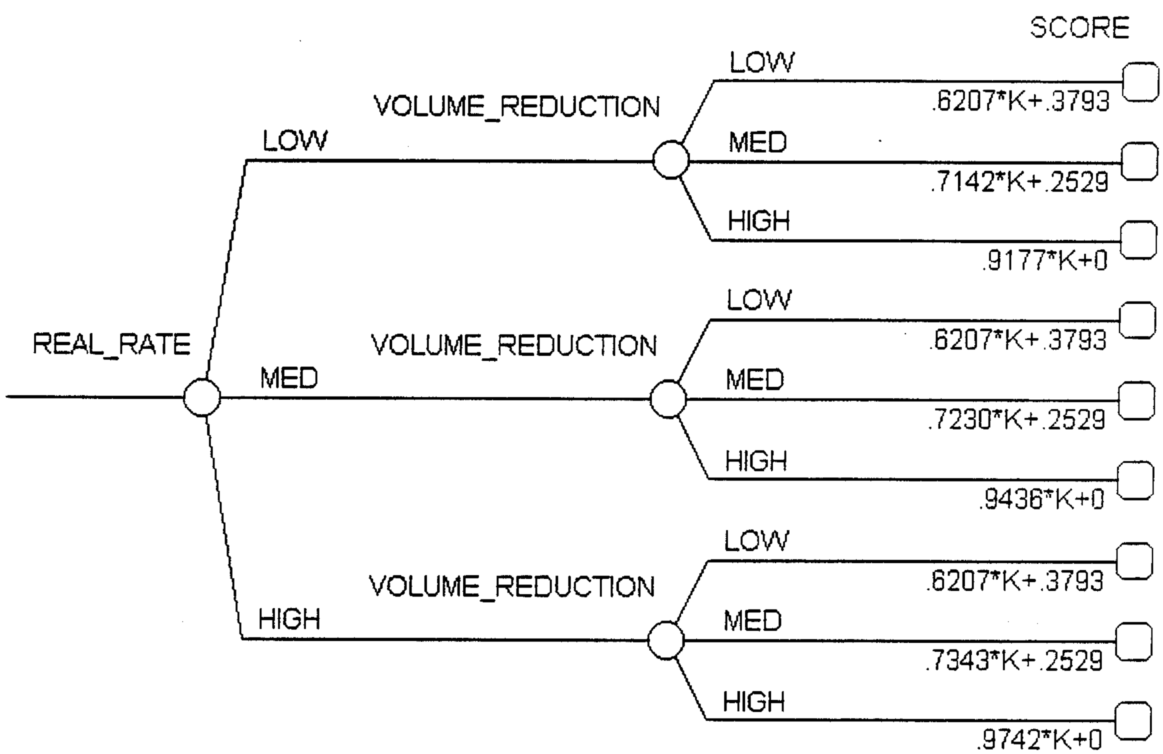

Figure 4.9 Expanded DPL© Decision Tree Branch for Alternative M1

a variable. By ranging cost weight from zero to one, the strategy region graphs in Figure 4.10 were developed. For a given cost weight, the preferred alternative, based on the expected total score, is indicated for each of six scenarios. In addition, the expected remediation time (years) and LCC ($million) for each alternative is shown in parenthesis. In general, if the emphasis on cost is high, M1 is the preferred alternative. On the other hand, if emphasis on cost is low, C3 is preferred. Finally, if cost and time are equally important, M3 is preferred.

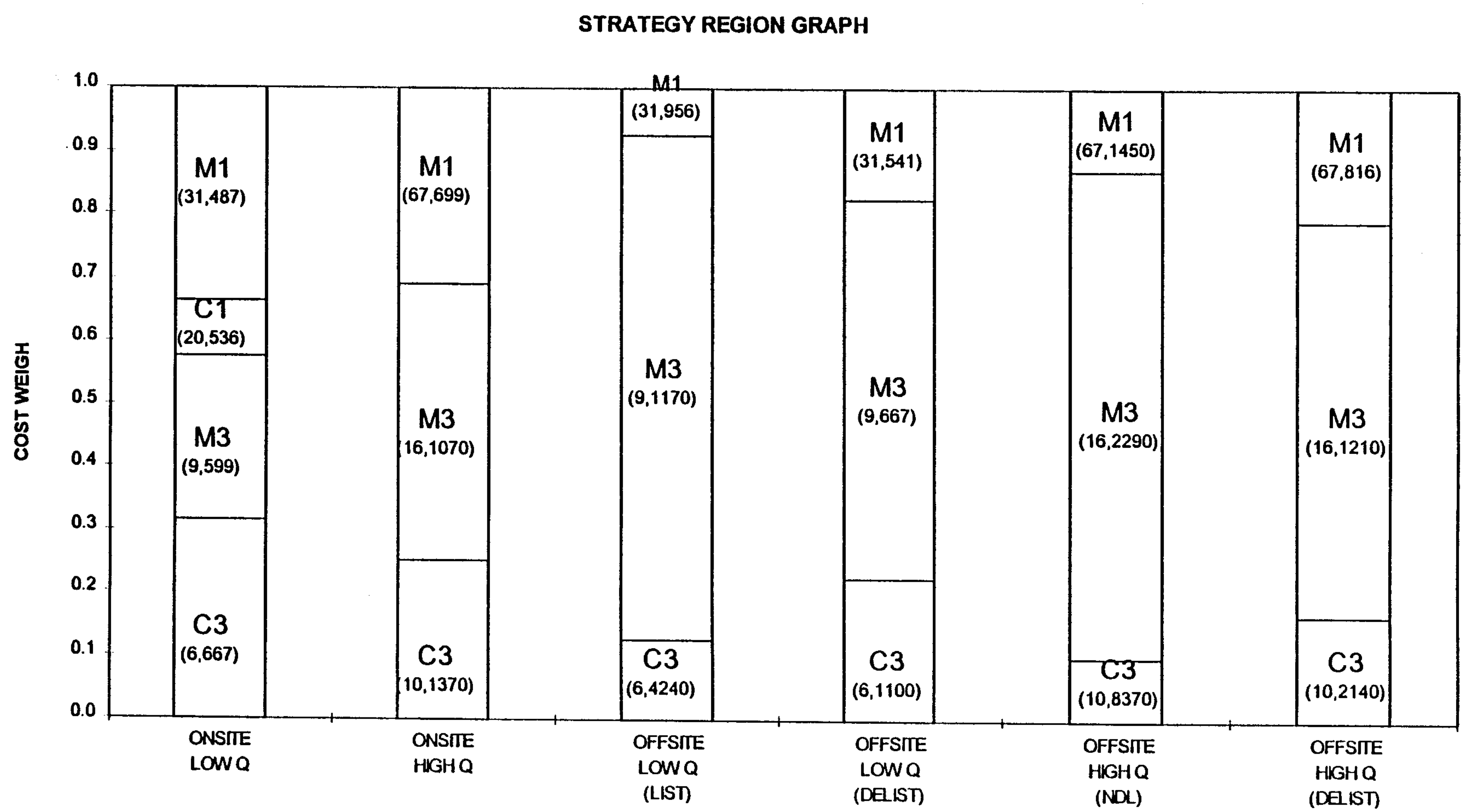

Figure 4.10. Master Strategy Region Graph

4.6 Cash Flow Diagrams

While LCC and remediation time are the primary criteria in comparing waste remediation alternatives, the decision maker must consider the cash flows associated with each alternative before making a final selection. An alternative may result in the lowest NPV and the shortest remediation time but requires initial cash outlays that cannot be supported within a constrained annual budget. Cash flow diagrams for non-dominated alternatives are depicted in Figure 4.11a-f.

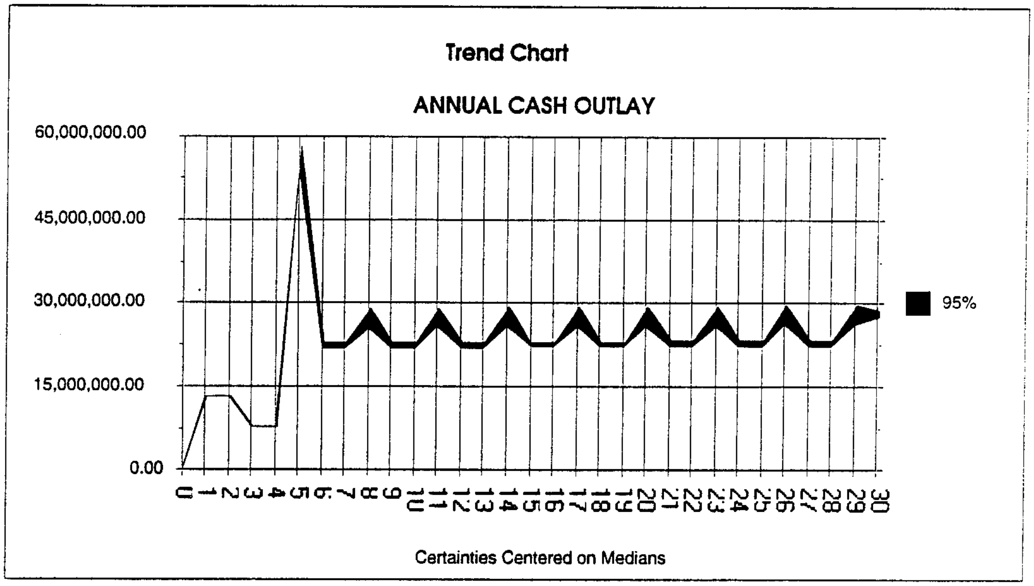

Figure 4.11a. M1 On-site Disposal

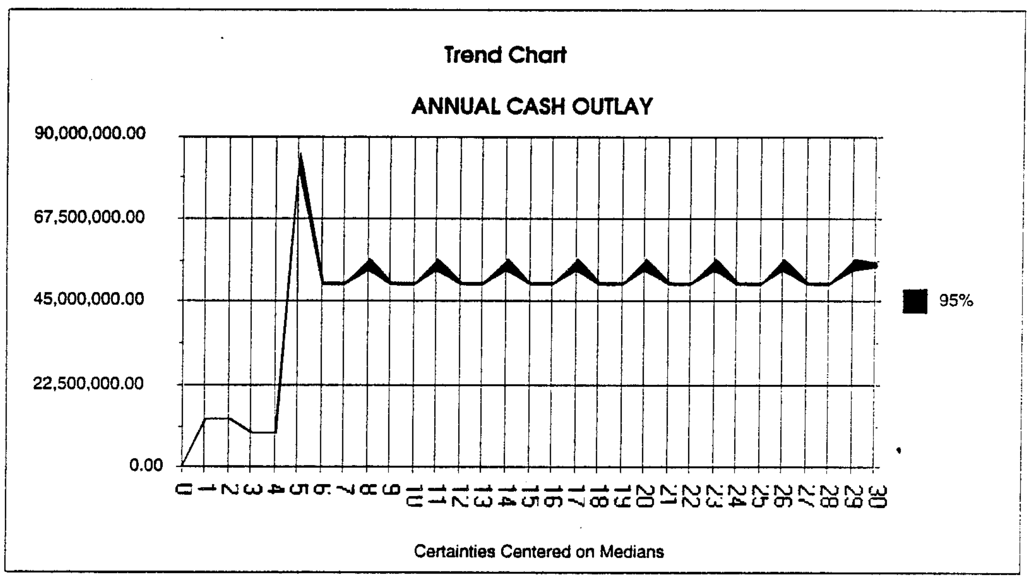

Figure 4.11b. M1Off-site Disposal

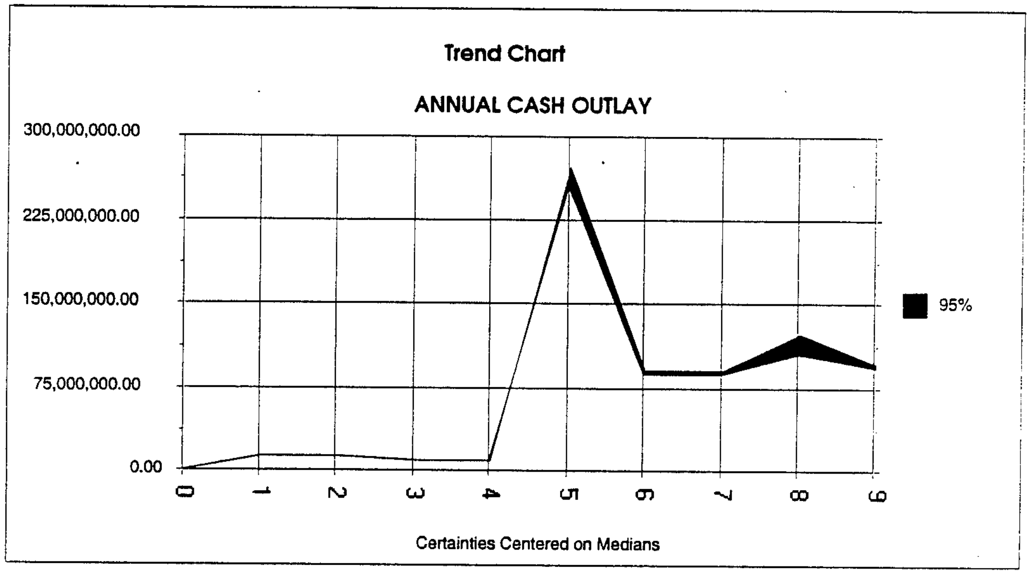

Figure 4.11c. M3 On-site Disposal

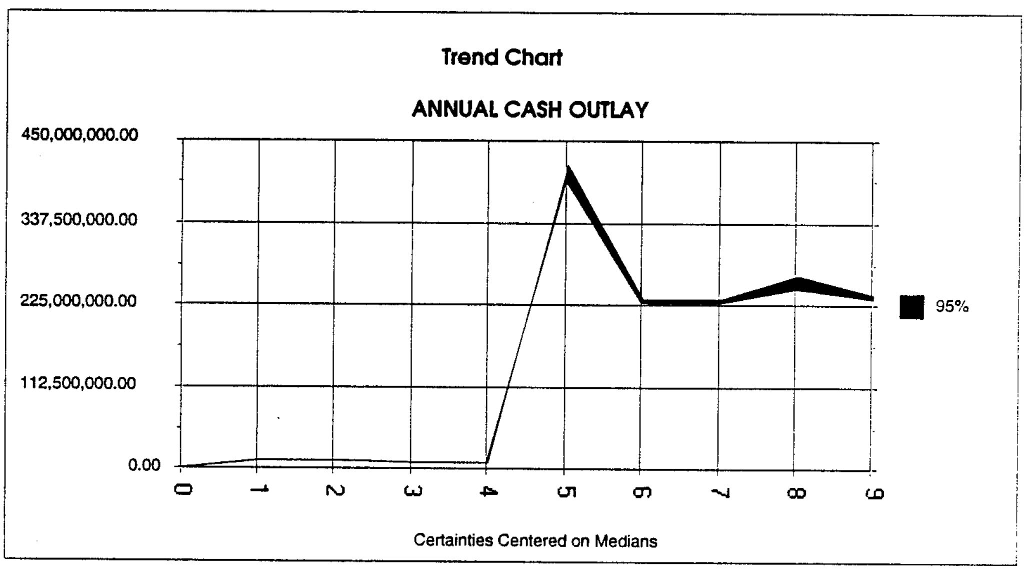

Figure 4.11d. M3 Off-site Disposal

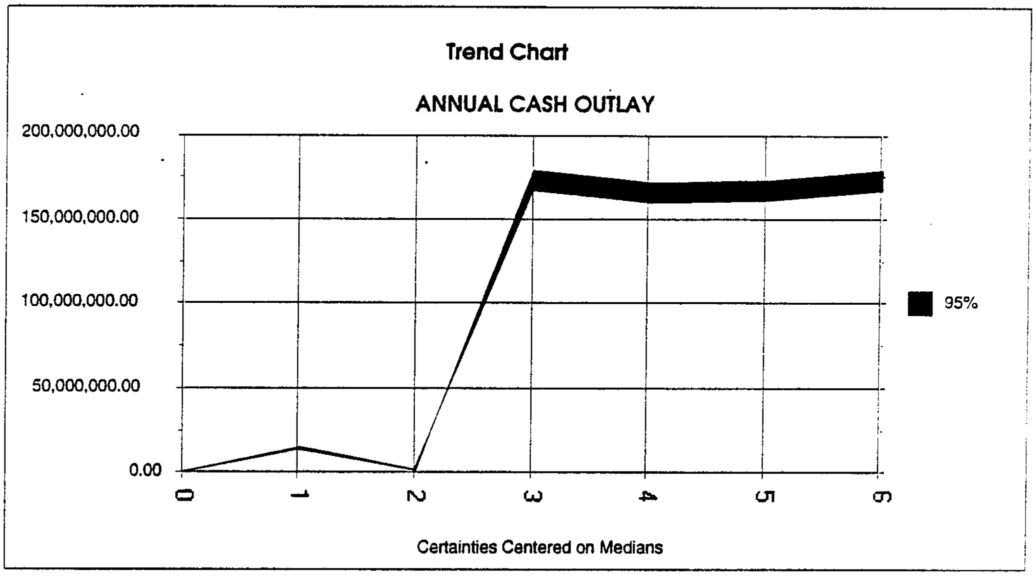

Figure 4.11e. C3 On-site Disposal

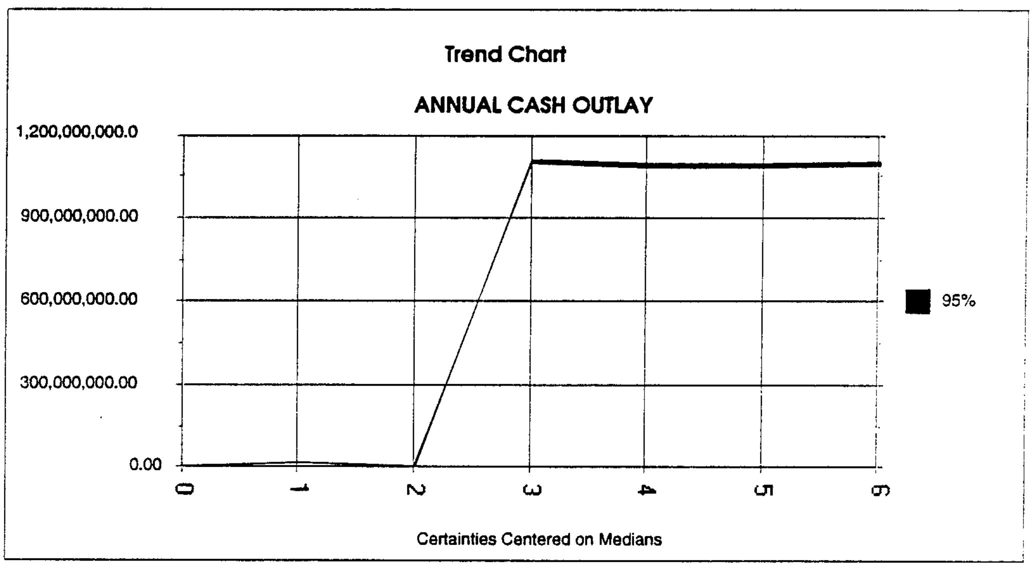

Figure 4.11f C3 Off-site Disposal

The periodicity in the vitrification cash flow streams in Figure 11a-b is due to the three year cycle for melter rebricking.

4.7 Summary

Evaluating waste remediation alternatives requires consideration of both LCC and remediation time. First, dominance graphs were used to eliminate alternatives that demonstrate both higher cost and longer remediation time. Second, strategy region graphs were developed to aid the decision maker in selecting the preferred alternative based on the relative importance of cost and time. Analysis indicated that disposal cost was a major cost driver, prompting closer scrutiny of the underlying assumptions affecting disposal cost. The key assumptions were values for volume reduction, per unit disposal cost, and the real rate at which costs are discounted. These assumptions were modeled as uncertain future events, and alternatives were evaluated based on expected total score for LCC and remediation time. Finally, strategy region graphs indicated the preferred alternative for a given cost weight based on the expected values of the decision for each parameter investigated.

Chapter 4: Addendum

In addition to cementation and vitrification, supplemental analysis included dry removal as a remediation alternative. The configurations and plant capacities for all three alternatives are provided in Table A4.1. Figures A4.1a-b illustrate on-site and off-site

Table A4.1. Plant Capacities and Waste Processing Rates

Alternative	Plant Capacity	Waste Processing Rate
MAWS Vitrification	tons glass per day	m^3 per day
M1	100	138
M2	300	414
M3	500	690
Dry Removal	m^3 filter press per day	m^3 per day
D1	227	170
D2	454	340
D3	908	680
Cementation	gallons concrete per minute	m^3 per day
C1	200	191
C2	600	573
C3	1000	955

LCC versus waste volume for all three alternative technologies and all configurations.

A4.1 Life-Cycle Cost Curves. Note that, based only on cost, D1 is the preferred alternative for on-site storage. This is due to low start-up costs and relatively low bulk-up factor and associated disposal costs for dry removal (about 13%) [Sams, 1994]. Note,

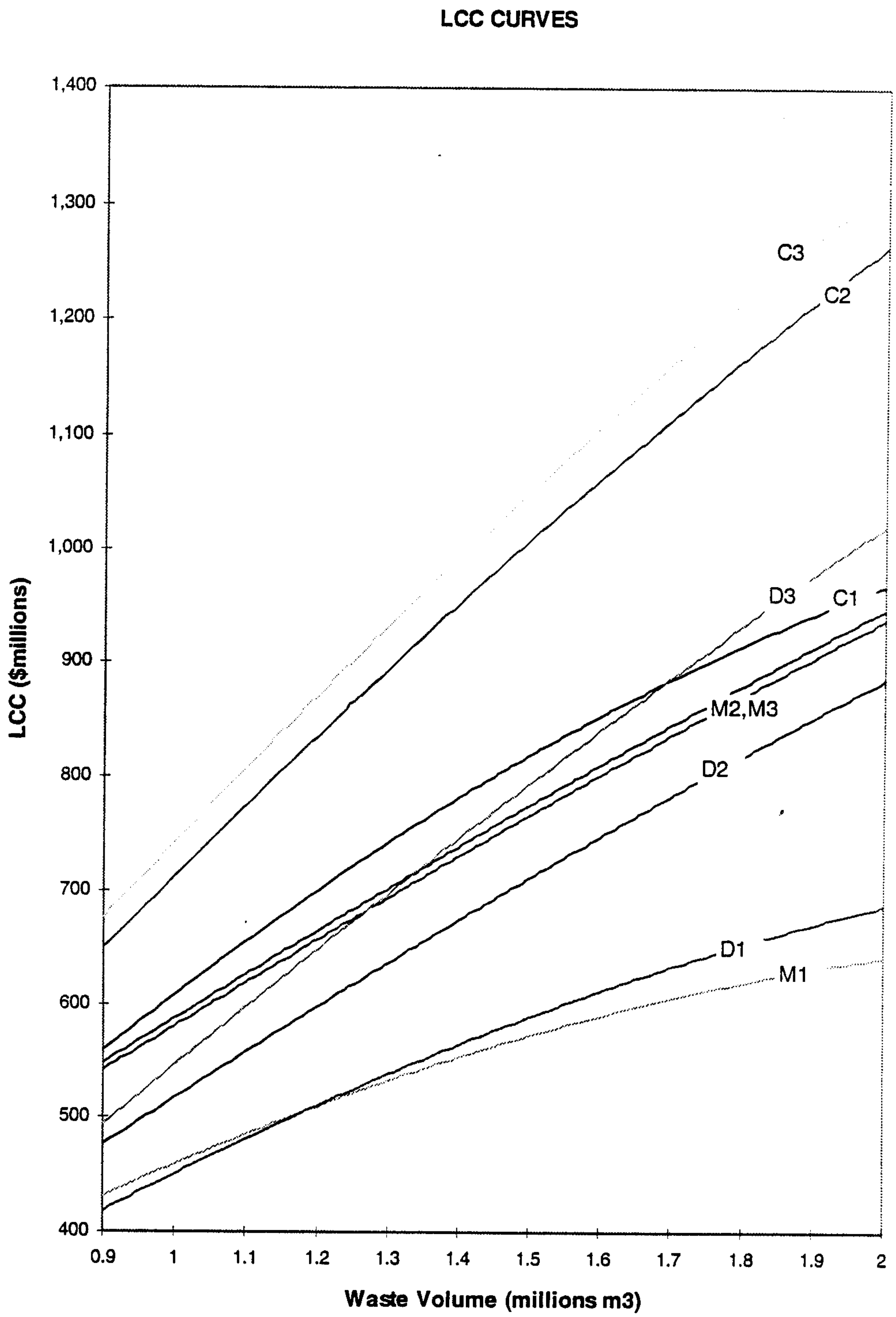

Figure A4.1a. On-site Disposal

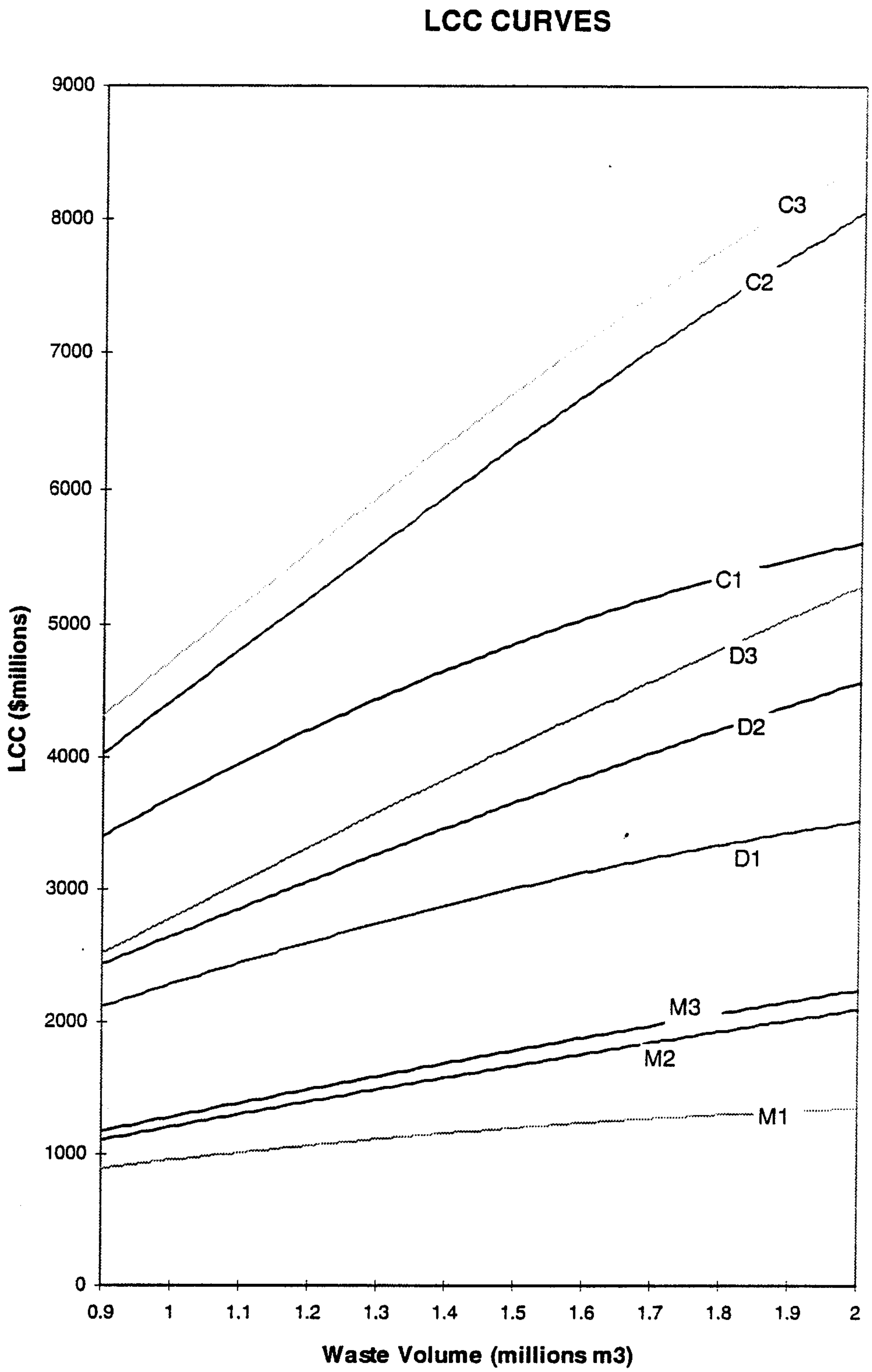

Figure A4.1b. Off-site Disposal

however, that the curves begin to come together for large waste volumes due to the MAWS volume reduction advantage. In addition, there is cross-over at 1.7 million cubic meters for the C1 and D3 alternatives; for low waste volumes, D3 is preferred over C1 and vice-versa. Even though dry removal has a bulk-up factor advantage, C1 is cheaper for high waste volumes because the disposal costs are deferred for many years. For off-site disposal, however, MAWS is always the preferred alternative due to lower waste volumes and associated disposal costs.

A4.2 Remediation Time Curves. Figure A4.2 illustrates the relative remediation time required for each alternative and a given waste volume. M2 and D2 cross-over at 1.2 million cubic meters because D2's three-year start-up advantage becomes insignificant beyond that point. Also, the M3 and C2 lines are close together because the remediation rates are very close. They cross-over because C2's two-year time advantage is insignificant beyond 1.8 million cubic meters. It is important to note that any perceived remediation time advantage is a function of the modeled plant size/capacity. While our models are based on a physically achievable, practically realizable range of plant capacities, remediation time advantages afforded a given configuration are highly sensitive to the analyst's discretion.

A4.3 Decision Analysis. Dominance graphs illustrate the importance of both LCC and remediation time. Figures A4.3a-d illustrate the trade-off between LCC and remediation time for on- and off-site disposal. Note that dry removal dominates the other alternatives for on-site storage but D3, M3, and M1 comprise the efficiency frontier for off-site disposal. D3, however, is probably not a good choice because it is much more expensive for a slight remediation time advantage ($3 billion to reduce remediation time by four years). Also, for on-site storage and high waste volumes, the difference in LCC for the three technologies investigated is relatively small. Finally, for off-site disposal, vitrification is clearly the preferred alternative.

Sensitivity analysis could be performed as described in section 4.5.1. The decision tree for this analysis would simply add the three dry removal alternatives as shown in Figure A4.4.

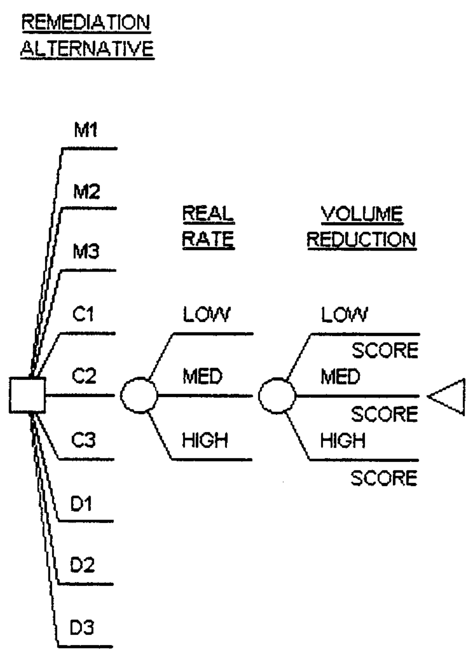

Figure A4.4. Decision Tree for Three Remediation Alternatives

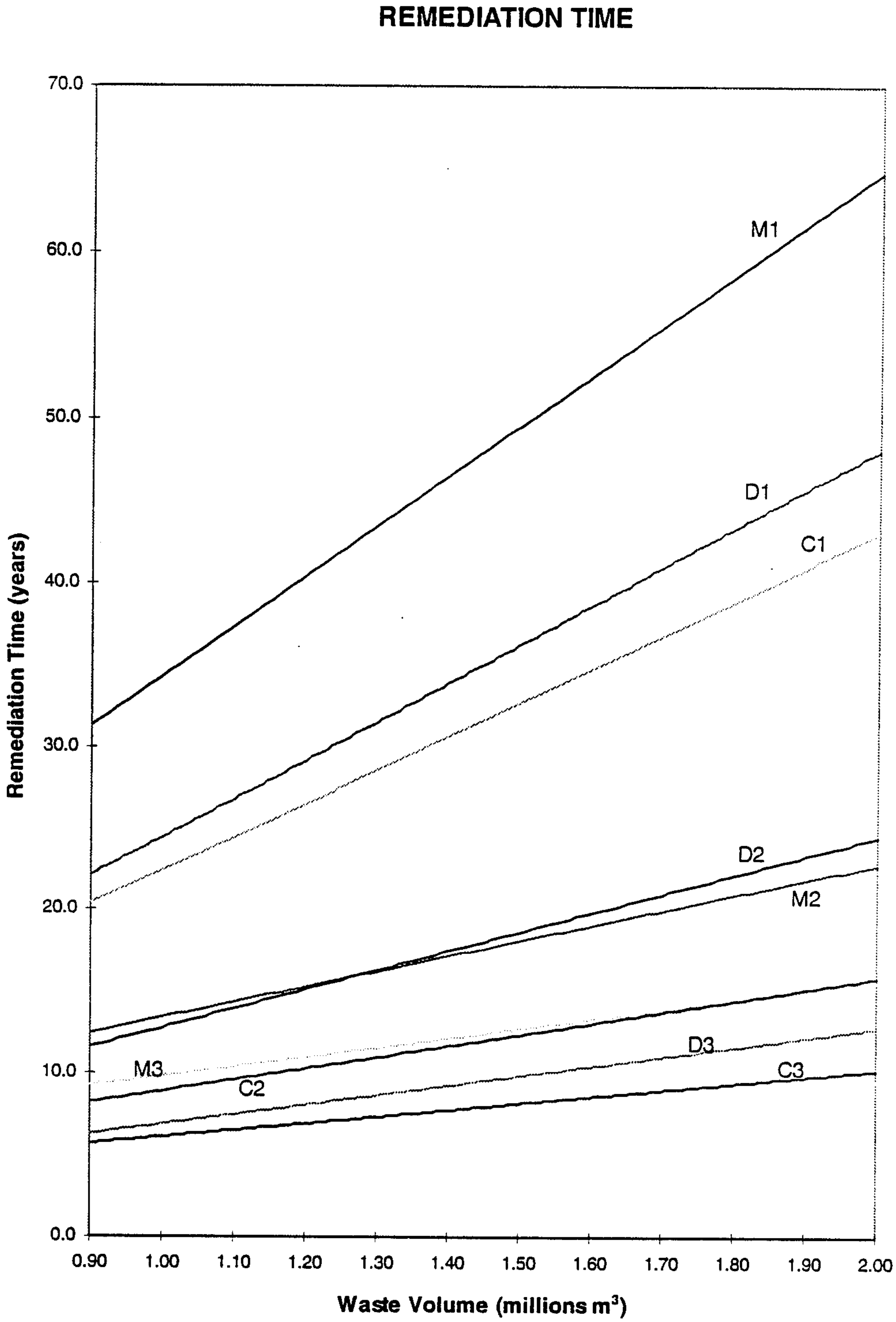

Figure A4.2. Remediation Time versus Waste Volume

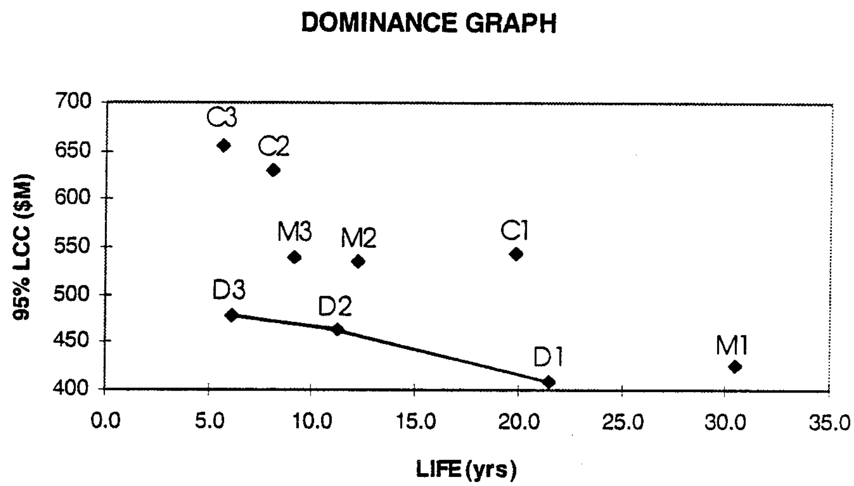

Figure A4.3a. On-site Storage, Low Waste Volume

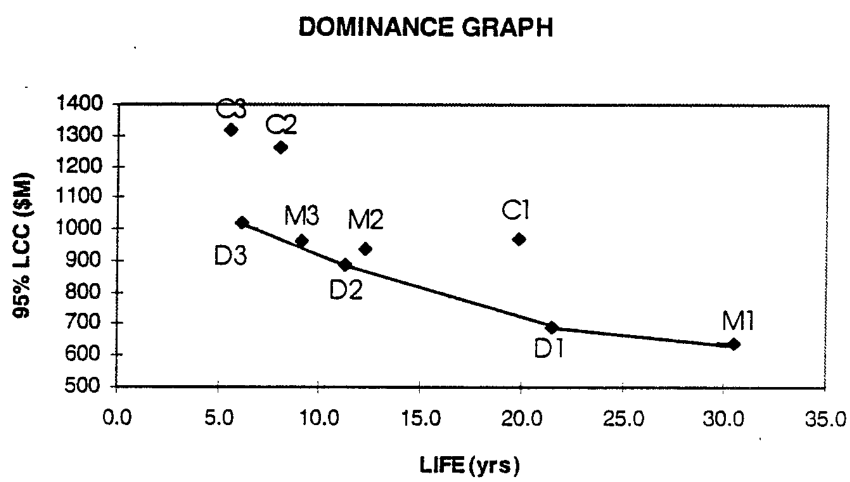

Figure A4.3b. On-site Storage, High Waste Volume

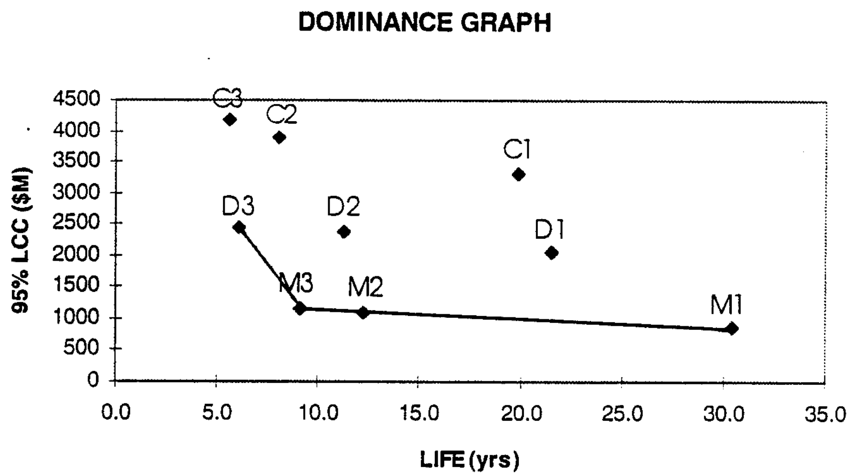

Figure A4.3c. Off-site Disposal, Low Waste Volume

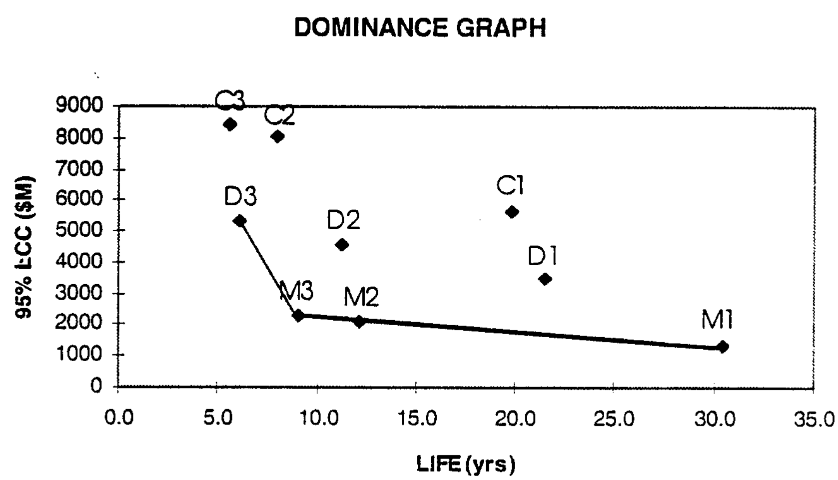

Figure A4.3d. Off-site Disposal, High Waste Volume

V. SUMMARY

LCC analysis is a comprehensive tool for economic comparison of alternatives. However, social and political considerations surrounding hazardous waste disposal force the decision maker to add a time dimension to the analysis. The multi-criteria decision analysis tools developed in this thesis provide a mechanism for ranking alternatives with varying cost and project life. Our analysis does not presuppose any preference for LCC versus remediation time, nor does it make tacit recommendations regarding alternatives. It does, however, provide a framework for making balanced decisions based on budgetary and political considerations.

5.1 Recommendations.

Three different, competing technologies have been analyzed for use in remediating low-level mixed waste sites, in particular, the Fernald OU-1 site. Models of three different levels or capacities of each technology were developed. Stochastic simulations were run under various scenarios to yield cost distributions. A 95% cost was identified for each level of technology and for each scenario, e.g., the costs plotted on all graphs have only a 5% chance of being exceeded.

Based upon the analysis in Chapters III and IV, we make the following recommendations:

- If the alternatives being considered for a given waste site are M1, M2, M3, C1, C2, and C3 (see Table 4.1), the Master Strategy Region Graph in Figure 4.10 should be used by the decision maker to determine the appropriate alternative and capacity.

- Because the costs associated with all of the alternatives are lower for on-site storage of the remediated waste, we recommend that the on-site storage option be exhaustively explored. The savings, regardless of whether M1, M3, or C3 is chosen as the alternative, are more than $500,000,000. For larger sites, the savings could be much more.
- Similar to the recommendation of storing wastes on-site, de-listing the mixed waste could have very large effects upon the cost. With savings of $400 million to $3.1 billion dollars at one site, it may be worth the high cost in time and money to fight to de-list the waste. Although no listed waste form has ever been de-listed, the leach characteristics of waste glass gems, concrete waste, and compacted filter cakes may be stable enough to make de-listing a possibility [Sams, 1995] [Gimpel,1994].
- If there are more than two competing alternative technologies for a waste site, we recommend that dominance graphs be constructed, as in Figure 4.3b, and used by decision makers. Specifically, for the case of a site the size of Fernald and with similar waste stream characteristics, we recommend dry removal as the remediation method if on-site storage is permitted (see Figures A4.2a and A4.2b). If the waste must be disposed of off-site, we recommend the MAWS process (see Figures A4.2c and A4.2d).
- Whenever the MAWS process is used, the cost of the additives is a significant factor. We strongly recommend that the optimization program be used to determine the appropriate (and most inexpensive) combination of additives. The use of this program alone could save hundreds of millions of dollars at each MAWS site.

- We recommend the decision maker use the decision analysis charts to assist him in making the sometimes difficult trade-off decision of time vs. cost.

The bottom line is that reducing LCC for low-level mixed waste remediation may be just as much a political decision as it is a fiscal or technical decision.

5.2 Contributions to Sponsor.

This LCC analysis is in accordance with the needs expressed by DOE in the interagency agreement [IA, 1994]. Specifically, DOE requested a generic, interactive LCC model for comparing waste remediation alternatives. DOE asked that each remediation alternative be reviewed to identify process-specific factors upon which to subsequently base sizing/design data and life-cycle cost information [IA, 1994:3]. For MAWS, DOE dictated that process-oriented modeling take information from the MAWS pilot plant at Fernald and from historical FEMP project costs. A Cost Breakdown Structure (CBS) was requested for allocation/collection of costs as they relate to the activities involved in each evaluated alternative. DOE suggested that the LCC model be implemented on a personal computer using a commercially available Monte Carlo simulation package. Finally, DOE required that the model be demonstrated by comparing MAWS and cementation for remediation of OU-1 waste at the FEMP [IA, 1994:4]. More recently, a third alternative technology was requested to be included in the analysis - dry removal [IA, 1995]. The following discussion briefly highlights how each of these requests were met through analysis and subsequent LCC model development.

Because cementation is a well characterized process for remediation of hazardous waste, we were able to use historical process and cost data as a basis for cementation cost factors and a CBS. Historical cost data was also used for analyzing dry removal costs. The cost factors for dry removal do not have the same reliability as those used in the two other analyses. However, the sensitivity analysis results indicate that the most uncertain factors (operating costs [Sams, 1995]), are not the major cost drivers. Therefore, variations in operating costs should not significantly affect the decision making process.

Since similar data was unavailable for vitrification, we developed a computer simulation of a conceptual vitrification process using lessons learned from the MAWS bench scale plant along with the ideas and experience of experts in the field. By incorporating diagnostic statistics, we used simulation to evolve the conceptual design into a working process model on which to base our estimates for equipment and facilities costs. At the heart of the MAWS process is the concept of blending waste streams and additives in a mixture that will make glass. Previous cost estimates used rough order of magnitude calculations to predict the cost of additives and the resulting waste loading for MAWS. These estimates included a caveat stating that project cost would vary greatly for varying glass formulas [Gimpel, 1992]. Using site characterization data from Catholic University [Pegg, 1994], we developed a method for simulating the multi-variate random distribution of waste stream composition in terms of the major ingredients critical to glass production. In this manner, we accounted for the affect of variation in waste stream composition on additive costs and waste loading.

Second, we modeled the glass production process as a linear program and used classical optimization techniques to minimize system cost. The objective was to minimize the cost incurred for additives, power, transportation, and storage costs associated with the additional glass volume produced by the additives. Using a dual simplex algorithm within the simulation, additives for each batch of waste were selected to meet compositional constraints for glass production while resulting in the lowest possible cost. If MAWS is the selected waste remediation alternative, we recommend that this algorithm be used to optimize waste stream blending. Using this algorithm, we show that borax, an additive not considered in previous cost estimates, can be used to reduce the cost of MAWS by nearly $200 million at FEMP (see Appendix L).

Third, statistical analysis of simulation results enabled us to estimate system performance and associated cost for a broad range of waste volumes. Waste volume is a common denominator among all sites. Using regression analysis, we developed cost estimating relationships for major cost drivers such as glass volume, power, and additives, in terms of waste volume. Since DOE must select waste remediation alternatives for numerous sites, the ability to estimate cost over a wide range of waste volume greatly enhanced the generic value of our LCC model.

Fourth, we used Monte Carlo simulation to statistically bound cost estimates. Previous cost estimates handled cost risk by adding a large risk percentage. Assigning probability distributions to the uncertain parameters influencing cost, we used Monte Carlo simulation to incorporate cost risk in the decision process. Comparing alternatives on the basis of the 95% confidence level for cost allows for a more equitable evaluation when competing alternatives involve different levels of subjective risk.

Finally, previous analysis considered cost as the only decision criteria. Social and political considerations suggest that timely waste remediation should also be included as a decision criteria. Therefore, we framed the decision using techniques for multi-criteria decision analysis. We modeled the selection of a waste remediation alternative as a decision being made under conditions of uncertainty regarding volume reduction, real rate, and per unit disposal cost. This modeling method enables the decision maker to easily conduct sensitivity analysis as requested by DOE [IA, 1994:4]. We show how to use strategy region graphs, dominance graphs, LCC curves, and sensitivity bar charts to give the decision maker the results of the analysis in the context of an intuitive and comprehensive decision support model.

5.3 Recommendations for follow-on work.

During the course of this study, we identified many opportunities for further research. Several ideas, along with a brief synopsis of each, are provided below:

5.3.1 Waste stream composition sensitivity analysis. Run a comparative LCC analysis based on a site similar to the FEMP but with different waste stream compositions and, therefore, a different glass formula. This study would reveal LCC and project duration sensitivity to waste stream composition.

5.3.2 Glass formula optimization. If a waste form database is available (for any remediation technology of interest, but specifically for MAWS), and it includes waste stream composition, waste loading, and leach properties, statistical methods could provide insight into optimal input waste form composition. The constraints used to define appropriate waste composition for making suitable glass were very conservative. A less conservative modeling of the waste composition could yield a great deal of additional savings. Neural nets combined with nonlinear optimization techniques may be the key to this type of analysis.

5.3.3 <u>Alternatives to soil washing</u>. Soil washing is an expensive part of the vitrification process modeled in this study. Capital equipment and resins for a site the size of the FEMP run $50M to $70M. As an alternative to soil washing, DOE has proposed thermal desorption which could be used as a stand alone process or as an adjunct to vitrification. Thermal desorption, however, is not appropriate for any waste containing radiation due to dusting and off-gas dangers [Sams 1995].

5.3.4 <u>Alternative vitrification technologies</u>. This study used a joule-heated melter for the vitrification process model. Further research could include alternative technologies including plasma arc and stir melters in addition to in-situ vitrification.

5.3.5 <u>Decision analysis tools</u>. This study employed several decision analysis tools and concepts. The decision programming language used, DPL, has many powerful capabilities that were not fully exploited in this LCC analysis. In particular, it has simulation capabilities that could generate sensitivity analyses on virtually every assumption in the model.

5.4 Final Cost Savings

One of the primary goals of this report was to compare estimated costs of remediation using different remediation technologies. The cost estimates are now available for MAWS, cementation,and dry removal alternatives. From the analysis in Chapter IV, it is apparent that cementation is dominated, in price and project life, by the other two alternative technologies. The chart below indicates the predicted cost savings by using either MAWS (M3) or dry removal (D3) over the cementation alternative (C3). The results are for on-site storage with low and high volume of waste, and then off-site disposal again with low and high volume waste, respectively.

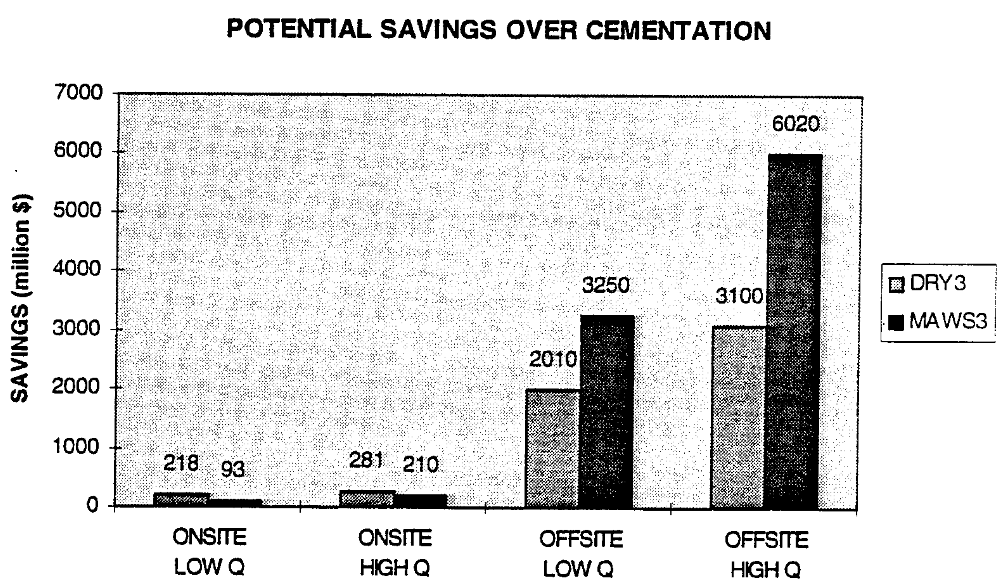

Figure 5.1 Estimated cost savings compared to cementation

Appendix A. Cementation Cost Element Database/Dictionary

Assumptions

Costs are reported in 1995 dollars.

All capital equipment purchases are made in the first year of operations.

Maintenance and replacement costs are 10% of equipment purchase cost per year (except for melters).

Long-term monitoring is required only for on-site storage.

Disclaimer: All product/equipment/service estimates are rough order of magnitude. They are provided as a courtesy of vendors and contractors and are subject to change pending clarification of requirements and contractrual agreement. The estimate provider is in no way bound by the information provided for this study.

VARIABLES:

NAME: LIFE
AMOUNT: 2+PROCESS_LIFE

DESCRIPTION: Time (years) from beginning of project to end of operations.
Monitoring costs beyond LIFE are discounted back to the end of operations life.

NAME: PROCESS_LIFE
AMOUNT: Cnfg:1 25.1*WASTE
Cnfg:2 8.4*WASTE
Cnfg:3 5*WASTE

DESCRIPTION: Predicted operations life (years).

NAME: RATE
AMOUNT: 0.058

DESCRIPTION: Nominal discount rate.

REFERENCE: Per OMB circular # A-94

NAME: REAL_RATE
AMOUNT: 0.028

DESCRIPTION: Real discount rate.

REFERENCE: Per OMB circular # A-94

NAME: INFLATION

AMOUNT: (RATE-REAL_RATE)/(1+REAL_RATE)

DESCRIPTION: Inflation rate.

REFERENCE: Calculated as a function of RATE and REAL_RATE

NAME: INFLATION_IND
AMOUNT: 0

DESCRIPTION: Inflation/deflation indicator: 0 = inflate costs, 1= deflate costs.

NAME: INF_DEF
AMOUNT: IF(INFLATION_IND=0,1+INFLATION,1/(1+INFLATION))

DESCRIPTION: Inflation/deflation factor: 0 = inflate costs, 1= deflate costs.

NAME: WASTE_INPUT
AMOUNT: 0.87 Mm^3 (i.e. Fernald OU-1)

DESCRIPTION: Total waste requiring remediation (Mm^3)

NAME: CAPACITY
AMOUNT: 200

DESCRIPTION: Cement mixer output capacity (gallons/minute).

REFERENCE: Engineering judgement based on average mixer size used in existing plants.

NAME: CONCRETE
AMOUNT: 2E6*WASTE_ INPUT/PROCESS_LIFE

DESCRIPTION: Predicted volume of concrete (m^3/year), bulk-up = 2.0, waste in million cubic meters

NAME: GEN_MX_PCT
AMOUNT: TRIANGULAR(.08,.10,.12)

DESCRIPTION: Assumes 10% of equipment purchase cost per year for maintenance and replacement.

REFERENCE: Engineering judgement.

NAME: LABOR1
AMOUNT: Configuration 1 = 40
Configuration 2 = 118
Configuration 3 = 189

DESCRIPTION: Number of general laborers. Labor1 and Labor2 breakout is per engineering judgement. 15% added for vacation, sick leave; additional 15% added for productivity factor for donning protective clothing, showers, etc. Rate adjustment = 1.15^2 = 1.32

REFERENCE: T. Sams and E. McDaniel/Martin Marietta Energy Systems:

CONFIG 1	Mixer Ops	= 25 for 200 gpm capacity 20 labor1 and 5 labor2	
	Other:		
	Eng. judgement:	Mat. handling	= 6
	Eng. judgement:	Sludge pumps	= 2
	Eng. judgement:	Excavation	= 1
	Eng. judgement:	Analytical	= 2
	Eng. judgement:	Health/Safety	= 1
		Total	= 12

10 Labor 1 + 2 Labor2
Add adjustment:
1.32 x Laborer 1 = 1.32*30 = 40
1.32 x Laborer 2 = 1.32*7 = 9

CONFIG 2	Mixer Ops = 75 for 600 gpm capacity 60 labor1 and 15 labor2		
Other:			
Eng. judgement:		Mat. handling	= 18
Eng. judgement:		Sludge pumps	= 4
Eng. judgement:		Excavation	= 6
Eng. judgement:		Analytical	= 2
Eng. judgement:		Health/Safety	= 1
		Total	= 31

29 Labor1 + 2 Labor2
Add adjustment:
1.32 x Laborer 1 = 1.32*89 = 118
1.32 x Laborer 2 = 1.32*17 = 22

CONFIG 3	Mixer Ops = 125 for 1000 gpm capacity 100 category 1 and 25 category 2 laborers		
Other:			
Eng. judgement:		Mat. handling	= 30
Eng. judgement:		Sludge pumps	= 4
Eng. judgement:		Excavation	= 8
Eng. judgement:		Analytical	= 2
Eng. judgement:		Health/Safety	= 1
		Total	= 45

43 Labor 1 + 2 Labor2
Add adjustment:
1.32 x Laborer 1 = 1.32*143 = 189
1.32 x Laborer 2 = 1.32*27 = 36

NAME: LABOR2
AMOUNT: Configuration 1 = 9
Configuration 2 = 22
Configuration 3 = 36

DESCRIPTION: Number of technicians.

REFERENCE: See Labor1 REFERENCE

NAME: STORAGE_IND
AMOUNT: 0 = on-site disposal; 1 = off-site disposal

DESCRIPTION:	Indicator for disposal alternative (on- or off-site).

NAME:	UNIT_MONITOR_COST
AMOUNT:	1.84
DESCRIPTION:	Annual waste monitoring cost in $/m3 of waste.
REFERENCE:	Rod Gimpel's March '92 estimate for delisted waste (inflated).

NAME:	UNIT_LABOR1_COST
AMOUNT:	TRIANGULAR (55.3E3,55.3E3, 58.1E3)
RISK:	(-0%,+5%)
DESCRIPTION:	This is the general labor rate per man-year.
REMARKS:	$19/hour burdened @40%; rate is per man-year, - 0%, +5%.
REFERENCE:	John Byrnes (FERMCO)

NAME:	UNIT_LABOR2_COST
AMOUNT:	TRIANGULAR (75.7E3,75.7E3, 83.3E3)
RISK:	(-0%,+5%)
DESCRIPTION:	This is the technician rate per man-year (i.e. melter operator).
REMARKS:	$26/hour burdened @40%; rate is per man-year, - 0%, +5%.
REFERENCE:	John Byrnes (FERMCO)

NAME:	UNIT_FLY ASH_COST
AMOUNT:	TRIANGULAR (15, 18, 20)
RISK:	(-16%,+11%)
DESCRIPTION:	Cost is $ per ton of fly ash.
REFERENCE:	T. Sams

NAME:	FLY ASH
AMOUNT:	1526000*WASTE_INPUT/PROCESS LIFE
DESCRIPTION:	Predicted tons per year of fly ash consumed. Based on concrete formula: Dry mix: 70% fly ash, 30% cement, and 10 lbs dry mix to to one gal of waste.
REFERENCE:	T. Sams

NAME:	UNIT_CEMENT_COST
AMOUNT:	TRIANGULAR (60, 70, 80)
RISK:	(-5%,+5%)
DESCRIPTION:	Cost per ton of cement.
REFERENCE:	T. Sams and Southwestern Portland Cement (Dayton,OH)
NAME:	CEMENT
AMOUNT:	654000*WASTE_INPUT/PROCESS LIFE
DESCRIPTION:	Predicted tons per year of cement consumed.
NAME:	UNIT_CONTAINER_COST
AMOUNT:	TRIANGULAR (110, 120, 130)
DESCRIPTION:	Cost for containers ($/container)
REMARKS:	Assume 110 gallon drums.
REFERENCE:	Terry Sams/Martin Marietta Energy Systems
NAME:	CONTAINERS
AMOUNT:	4800000*WASTE_INPUT/PROCESS LIFE
DESCRIPTION:	Containers per year for concrete disposal.
NAME:	UNIT_TRANS_COST
AMOUNT:	TRIANGULAR (260, 280, 300)
DESCRIPTION:	Cost for transportation to disposal site ($/m^3)
REMARKS:	Assume rail transport to Utah.
REFERENCE:	Terry Sams/Martin Marietta Energy Systems
NAME:	UNIT_ONSITE_COST
AMOUNT:	TRIANGULAR (270, 285, 300)
DESCRIPTION:	Cost for tumulus ($/m^3)
REFERENCE:	Rod Gimpel/FERMCO.
NAME:	UNIT_OFFSITE_COST
AMOUNT:	TRIANGULAR (1700, 2000, 2100)
DESCRIPTION:	$/m^3 for disposal at Envirocare
REFERENCE:	Terry Sams/ Martin Marietta Energy Systems

NAME: NUM_TESTOUT
AMOUNT: 52*CAPACITY/200

DESCRIPTION: Test output once per week per 200gal/min capacity.

REFERENCE: Approximately the same as for vitrification

NAME: UNIT_TESTOUT_COST
AMOUNT: 1000

DESCRIPTION: Cost forTCLP test.

REFERENCE: The same as for vitrification

NAME: DESTR_DISPOS
AMOUNT: TRIANGULAR (4.5E6,5.0E6,6.0E6)
RISK: (-10%,+20%)

DESCRIPTION: Destruction/demolition of processing equipment

REFERENCE: Same as for vitrification

NAME: PROTECTIVE_EQPT_PCT
AMOUNT: 0.08

DESCRIPTION: Special clothing, masks, safety glasses, etc.

REMARKS: Assume 8% of labor costs.

REFERENCE: FERMCO letter M:ENG: (TDD): 94-0034, 16 Sep 94.

NAME: OH_RATE
AMOUNT: 0.08

DESCRIPTION: Flat percentage of overall project cost minus additives, transportation, and storage costs.

REFERENCE: Industry standard

NAME: INIT_MONITOR_COST
AMOUNT: UNIT_MONITOR_COST*CONCRETE

DESCRIPTION: Cost for first year of monitoring

NAME: MAX_MONITOR_COST
AMOUNT: INIT_MONITOR_COST*PROCESS_LIFE

DESCRIPTION: Constant cost for long-term monitoring

NAME: MONITOR_IND
AMOUNT: 0
DESCRIPTION: 0 = Total monitor costs; 1 = Operations monitor costs.
NAME: CIVIL_ENG_ONSITE

AMOUNT: TRIANGULAR(11.38E6, 11.98E6, 12.58E6)
(-5%,+5%)

DESCRIPTION: Site preparation, 15,000 ft^2 facility, roads, etc.

REFERENCE: Adjusted FSR

NAME: CIVIL_ENG_OFFSITE
AMOUNT: TRIANGULAR(15.03E6, 15.82E6, 16.61E6)
(-5%,+5%)

DESCRIPTION: Site preparation, 15,000 ft^2 facility, roads, rail sidings, and staging area, etc.

REFERENCE: Adjusted FSR and engineering judgement

COST ELEMENTS:

TYPE: TCE
NAME: RESEARCH_DEV
AMOUNT: TRIANGULAR(2.1E6, 3.0E6, 3.45E6)
(-30%,+15%)

TIME PHASING:

START: 1
PHASE-IN: 0
CONSTANT: 2
PHASE-OUT: 0

DESCRIPTION: Research and development cost.

REFERENCE: T. Sams

TYPE: TCE
NAME: CIVIL_ENG
AMOUNT: IF(STORAGE_IND=0,CIVIL_ENG_ONSITE,CIVIL_ENG_OFFSITE)

TIME PHASING:

START: 1
PHASE-IN: 0
CONSTANT: 1
PHASE-OUT: 0

DESCRIPTION: Site preparation, facilities, roads, and rail sidings/staging for off-site disposal.

REFERENCE: Adjusted FSR

TYPE: PCE
NAME: EQPT_COST
AMOUNT:
Config. 1: TRIANGULAR(2.04, 2.26E6, 2.49E6)
Config. 2: TRIANGULAR(4.55E6, 5.05E6, 5.56E6)
Config. 3: TRIANGULAR(6.89E6, 7.66E6, 8.43E6)

RISK: (-10%,+10%)

TIME PHASING:

YEAR: 3 PERCENT: 100

DESCRIPTION:

	Config. 1	Config. 2	Config. 3
Mixer	80E3	190E3	330E3

Pre-processing equip.	21E3	51E3	81E3
Sludge pumps	30E3	30E3	30E3
Transfer station	250E3	250E3	250E3
Conveyors	120E3	120E3	120E3
Hopper for soil	50E3	75E3	100E3
Heavy equipment	350E3	750E3	950E3
Material handling	1.1E6	3.3E6	5.5E6
Motor pool	100E3	100E3	100E3
Cement/Fly ash hoppers	30E3	50E3	70E3
Batch tanks	130E3	130E3	130E3
* Total	2.261E6	5.051E6	7.661E6

REFERENCE:

Mixer: Feedco, Green Bay, WI
Pre-processing equipment: Rock crusher, mechanical sieve
Pumps: Capital Equipment Corp.
Transfer station: Williams Pipeline
Conveyors: FSR
Hopper: ACME construction estimators
Heavy equipment/ Motor pool: Various dealers
Material handling: Cranes, forklifts, flatbed trucks

TYPE: RCE
NAME: LABOR1_COST
AMOUNT: UNIT_LABOR1_COST*LABOR1

TIME PHASING:

START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: LABOR2_COST
AMOUNT: UNIT_LABOR2_COST*LABOR2

TIME PHASING:

START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: PROTECTIVE_EQPT
AMOUNT: PROTECTIVE_EQPT_PCT*LABOR1_COST

TIME PHASING:

START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: LABOR_COST
AMOUNT: SUM(LABOR1_COST, LABOR2_COST)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Total labor cost

TYPE: RCE
NAME: CEMENT_COST
AMOUNT: UNIT_CEMENT_COST*CEMENT
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: FLYASH_COST
AMOUNT: UNIT_FLYASH_COST*FLYASH
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: TRANS_COST
AMOUNT: UNIT_TRANS_COST*CONCRETE*STORAGE_IND
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: ONSITE_COST
AMOUNT: UNIT_ONSITE_COST*CONCRETE*(1- STORAGE_IND)
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Cost for tumulus.

TYPE: RCE
NAME: OFFSITE_COST
AMOUNT: UNIT_OFFSITE_COST*CONCRETE*STORAGE_IND, 0)
TIME PHASING:
START: 3
NO. PMTS: 6
SKIP FACTOR: 0

DESCRIPTION: Cost for disposal.
TYPE: RCE

NAME: GEN_MX_COST
AMOUNT: GEN_MX_PCT*EQPT_COST
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Assumes 10% of equipment purchase cost per year for maintenance and replacement (except for melters - melter maintenance is a separate cost element)

TYPE: RCE
NAME: TESTOUT_COST
AMOUNT: UNIT_TESTOUT_COST*NUM_TESTOUT
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: 1 TCLP test per week per 200 gpm capacity at 1000/test.

TYPE: RCE
NAME: OPS_MONITOR_COST
AMOUNT: INIT_MONITOR_COST*(TIME-2)*(1-STORAGE_IND)
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: \$1.84/m^3 output for long-term monitoring

TYPE: RCE
NAME: LUMP_MONITOR_COST
AMOUNT: IF(TIME=LIFE,(MAX_MONITOR_COST/REAL_RATE)*(1-STORAGE_IND),0)
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Lump all post-operations monitoring costs in the last year of operations. This is modeled as an infinite cash flow stream.

TYPE: RCE
NAME: MONITOR_COST
AMOUNT: IF(MONITOR_IND=0,(LUMP_MONITOR_COST+
OPS_MONITOR_COST)*(1-STORAGE_IND),
OPS_MONITOR_COST*(1-STORAGE_IND))
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Monitor cost is either the total of all monitoring costs out to infinity, or just the sum through the end of operations. This is used to get the operations and monitoring cost category without including the infinite cash flow stream for long-term monitoring.

TYPE: RCE
NAME: CE_DESTR_DISPOS
AMOUNT: IF(TIME=LIFE+1,DESTR_DISPOS,0)
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Destruction/demolition of processing equipment occurs at the end of operations

REFERENCE: Rod Gimpel/FERMCO.

TYPE: RCE
NAME: OH_RESEARCH_DEV
AMOUNT: OH_RATE*RESEARCH_DEV
TIME PHASING:
START: 0
NO. PMTS: 1
SKIP FACTOR: 0

DESCRIPTION: Overhead for research and development

TYPE: RCE
NAME: OH_OPSMX
AMOUNT: OH_RATE*OPSMX_BASE
TIME PHASING:
START: 3
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Overhead for operations and maintenance

TYPE: RCE
NAME: OH_FAC_EQPT
AMOUNT: OH_RATE*FAC_EQPT_BASE
TIME PHASING:
START: 0
NO. PMTS: 3
SKIP FACTOR: 0

DESCRIPTION: Overhead for facilities and equipment

REFERENCE: Rod Gimpel/FERMCO.

TYPE: RCE
NAME: OH_PHASEOUT_DISP
AMOUNT: OH_RATE* PHASEOUT_DISP_BASE
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead for destruction/demolition of processing equipment and transportation/storage of waste.

TYPE: RCE
NAME: OPSMX_BASE
AMOUNT: OPERATIONS+MAINTENANCE-ADDITIVES _COST
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead base for operations and maintenance phase - does not include cement and additive costs.

REFERENCE: Engineering judgement

TYPE: RCE
NAME: PHASEOUT_DISP_BASE
AMOUNT: SUM(TRANS_COST,ONSITE_COST,OFFSITE_COST, OPS_MONITOR_COST,CE_DESTR_DISPOS)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead base for transportation, storage, and destruction/demolition phase - does not include post-operations monitoring costs.

REFERENCE: Engineering judgement

TYPE:	RCE		
NAME:	FAC_EQPT_BASE		
AMOUNT:	SUM(CIVIL_ENG, CAP_EQPT)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0
DESCRIPTION:	Overhead base for facilities and equipment		
REFERENCE:	Engineering judgement		

TYPE:	RCE		
NAME:	CAP_EQPT		
AMOUNT:	EQPT_COST		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0
DESCRIPTION:	All capital equipment costs.		

TYPE:	RCE		
NAME:	OPERATIONS		
AMOUNT:	SUM(ADDITIVES_COST,LABOR_COST,PROTECTIVE_EQPT, TESTOUT_COST)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0
DESCRIPTION:	All capital equipment costs.		

TYPE:	RCE		
NAME:	FACILITIES_EQPT		
AMOUNT:	SUM(CIVIL_ENG, CAP_EQPT,OH_FAC_EQPT)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0
DESCRIPTION:	All facilities and equipment costs.		

TYPE:	RCE		
NAME:	FACILITIES_EQPT_INF		
AMOUNT:	FACILITIES_EQPT*(INF_DEF^TIME)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0
DESCRIPTION:	Inflated facilities and equipment costs.		

TYPE:	RCE		
NAME:	LABOR_COST		
AMOUNT:	SUM(LABOR1_COST, LABOR2_COST)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	ADDITIVES_COST		
AMOUNT:	SUM(CEMENT_COST,FLYASH_COST)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	MAINTENANCE		
AMOUNT:	GEN_MX_COST		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	OPS_MX		
AMOUNT:	SUM(OPERATIONS, MAINTENANCE,OH_OPSMX)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	RESEARCH_DEVELOP		
AMOUNT:	SUM(RESEARCH_DEV, OH_RESEARCH_DEV)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	OPS_MX_INF		
AMOUNT:	OPS_MX*(INF_DEF^TIME)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: Inflated operations and maintenance cost.

TYPE: RCE
NAME: PHASEOUT_DISPOSAL
AMOUNT: SUM(TRANS_COST, ONSITE_COST,OFFSITE_COST, MONITOR_COST, CE_DESTR_DISP0S,OH_PHASEOUT_DISP)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: All destruction/disposal, transportation, storage and monitoring costs.

TYPE: RCE
NAME: PHASEOUT_DISPOSAL_INF
AMOUNT: PHASEOUT_DISPOSAL*(INF_DEF^TIME)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Inflated destruction/disposal, transprtation, storage and monitoring costs.

TYPE: RCE
NAME: PROJECT
AMOUNT: SUM(RESEARCH_DEVELOP, FACILITIES_EQPT, OPS_MX, PHASEOUT_DISPOSAL)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overall project cost.

TYPE: RCE
NAME: PROJECT_INF
AMOUNT: PROJECT*(INF_DEF^TIME)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Inflated project cost.

TYPE: RCE
NAME: RESEARCH_DEVELOP_INF
AMOUNT: RESEARCH_DEV*(INF_DEF^TIME)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

Appendix B. Vitrification Cost Element Description/Database

Assumptions

Costs are reported in 1995 dollars.

All capital equipment purchases are made in the first year of operations.

Maintenance and replacement costs are 10% of equipment purchase cost per year (except for melters).

Long-term monitoring is required only for on-site storage.

Disclaimer: All product/equipment/service estimates are rough order of magnitude. They are provided as a courtesy of vendors and contractors and are subject to change pending clarification of requirements and contractrual agreement. The estimate provider is in no way bound by the information provided for this study.

VARIABLES:

NAME: LIFE
AMOUNT: 4+PROCESS_LIFE

DESCRIPTION: Time (years) from beginning of project to end of operations. Monitoring costs beyond LIFE are discounted back to the end of operations life.

NAME: PROCESS_LIFE
AMOUNT: PROCESS_LIFE_EST+PROCESS_LIFE_ERR*SQRT(PROCESS_LIFE_VAR)

DESCRIPTION: Predicted operations life (years) derived from regression of simulation output.

NAME: RATE
AMOUNT: 0.058

DESCRIPTION: Nominal discount rate.

REFERENCE: Per OMB circular # A-94

NAME:	REAL_RATE
AMOUNT:	0.028
DESCRIPTION:	Real discount rate.
REFERENCE:	Per OMB circular # A-94
NAME:	INFLATION
AMOUNT:	(RATE-REAL_RATE)/(1+REAL_RATE)
DESCRIPTION:	Inflation rate
REFERENCE:	Calculated as a function of RATE and REAL_RATE
NAME:	INFLATION_IND
AMOUNT:	0
DESCRIPTION:	Inflation/deflation indicator: 0 = inflate costs, 1= deflate costs.
NAME:	INF_DEF
AMOUNT:	IF(INFLATION_IND=0,1+INFLATION,1/(1+INFLATION))
DESCRIPTION:	Inflation/deflation factor: 0 = inflate costs, 1= deflate costs.
NAME:	WASTE_INPUT
AMOUNT:	0.870 (i.e. Fernald OU-1)
DESCRIPTION:	Total waste (Mm^3) requiring remediation-(millions of cubic meters)
NAME:	MELT_NUM
AMOUNT:	Configuration 1 = 1 Configuration 2 = 3 Configuration 3 = 5
DESCRIPTION:	Number of melters
REFERENCE:	Ranged to meet 5 - 25 year project life for amount of waste at Fernald OU-1.
NAME:	GLASS
AMOUNT:	(GLASS _EST + GLASS _ERR * SQRT(GLASS_VAR))/PROCESS_LIFE
DESCRIPTION:	Predicted volume of waste glass gems (m^3/year) derived from

	regression of simulation output.
NAME:	NUM_BATCHES
AMOUNT:	(NUM_BATCHES _EST + NUM_BATCHES _ERR * SQRT(NUM_BATCHES _VAR))/PROCESS_LIFE
DESCRIPTION:	Predicted number of batch tanks processed per year derived from regression of simulation output.
REFERENCE:	Simulation
NAME:	GEN_MX_PCT
AMOUNT:	TRIANGULAR(.08,.10,.12)
DESCRIPTION:	Assumes 10% of equipment purchase cost per year for maintenance and replacement.
REFERENCE:	Engineering judgement.
NAME:	LABOR1
AMOUNT:	Configuration 1 = 96 Configuration 2 = 122 Configuration 3 = 154
DESCRIPTION:	Number of general laborers. Labor1 and Labor2 breakout is per engineering judgement. 15% added for vacation, sick leave; additional 15% added for productivity factor for donning protective clothing, showers, etc. Rate adjustment = $1.15^2 = 1.32$
REFERENCE:	
CONFIG 1	Bill Greenman/Duratek: Melter = 30 per 5 ton/day + 5 for 2x capacity = 52 for 100 ton/day capacity = 44 Labor1 + 8 Labor 2 Add adjustment: = 1.32(44)Labor1 + 1.32(8)Labor2 = 58 Labor1 + 11 Labor2 Paul Hewen/Lockheed: Soil washer = (7 + # washers)*3 shifts = 8*3 = 24 add adjustment = 1.32(24) = 32 Labor1

Other:

Eng. judgement:	Sludge pumps = 2
Eng. judgement:	Excavation = 1
Eng. judgement:	Analytical = 2
Eng. judgement:	Health/Safety = 1

Total = 6
Add adjustment:
= 1.32(6)
= 8
= 6 Labor 1 + 2 Labor2

CONFIG 2 Bill Greenman/Duratek:
Melter = 30 per 5 ton/day + 5 for 2x capacity
= 60 for 300 ton/day capacity
= 51 Labor1 + 9 Labor 2
Add adjustment:
= 1.32(51)Labor1 + 1.32(9)Labor2
= 67 Labor1 + 12 Labor2

Paul Hewen/Lockheed:
Soil washer = (7 + # washers)*3 shifts
= 10*3 = 30
add adjustment
= 1.32(30) = 40 Labor1

Other:

Eng. judgement:	Sludge pumps = 4
Eng. judgement:	Excavation = 6
Eng. judgement:	Analytical = 2
Eng. judgement:	Health/Safety = 1

Total = 13
Add adjustment:
= 1.32(13)
= 17
= 15 Labor 1 + 2 Labor2

CONFIG 3 Bill Greenman/Duratek:
Melter = 30 per 5 ton/day + 5 for 2x capacity
= 63 for 300 ton/day capacity
= 62 Labor1 + 10 Labor 2
Add adjustment:
= 1.32(62)Labor1 + 1.32(10)Labor2
= 82 Labor1 + 13 Labor2
Paul Huen/Lockheed:

Soil washer = (7 + # washers)*3 shifts
= 14*3 = 42
add adjustment
= 1.32(42) = 55 Labor1

Other:

Eng. judgement:	Sludge pumps	= 4
Eng. judgement:	Excavation	= 8
Eng. judgement:	Analytical	= 2
Eng. judgement:	Health/Safety	= 1
	Total	= 15

Add adjustment:
= 1.32(15)
= 20
= 17 Labor 1 + 3 Labor2

NAME: LABOR2
AMOUNT: Configuration 1 = 13
Configuration 2 = 14
Configuration 3 = 16

DESCRIPTION: Number of technicians.

REFERENCE: See Labor1 REFERENCE

NAME: STORAGE_IND
AMOUNT: 0 = on-site disposal; 1 = off-site disposal

DESCRIPTION: Indicator for disposal alternative (on- or off-site).

NAME: UNIT_MONITOR_COST
AMOUNT: 1.84

DESCRIPTION: Annual waste monitoring cost in $\$/m^3$ of waste.

REFERENCE: Rod Gimpel's March '92 estimate (inflated).

NAME: UNIT_MELTER_COST
AMOUNT: TRIANGULAR (25E6,28E6,30E6)
RISK: (-10%,+7%)

DESCRIPTION: Unit cost for 1 melter.

REFERENCE: Bill Greenman (3 Nov 94 meeting in Gaithersburg, MD)

NAME: UNIT_FIX_COST
AMOUNT: TRIANGULAR(2.8E6, 4.2E6, 7.0E6)
RISK: (-30%,+67%)

DESCRIPTION: Melter maintenance.

REMARKS: Cost to rebrick and replace electrodes is 10%-25% of purchase and installation cost. Assume one fix per three years of operations.

REFERENCE: Bill Greenman/Duratek (3 Nov 94 meeting in Gaithersburg, MD) for low end and MTBF; Rod Gimpel/FERMCO for high end.

NAME: UNIT_LABOR1_COST
AMOUNT: TRIANGULAR (55.3E3,55.3E3, 58.1E3)
RISK: (-0%,+5%)

DESCRIPTION: This is the general labor rate per man-year.

REMARKS: $19/hour burdened @40%; rate is per man-year, - 0%, +5%.

REFERENCE: John Byrnes (FERMCO)

NAME: UNIT_LABOR2_COST
AMOUNT: TRIANGULAR (75.7E3,75.7E3, 83.3E3)
RISK: (-0%,+5%)

DESCRIPTION: This is the technician rate per man-year (i.e. melter operator).

REMARKS: $26/hour burdened @40%; rate is per man-year, - 0%, +5%.

REFERENCE: John Byrnes (FERMCO)

NAME: UNIT_POWER_COST
AMOUNT: TRIANGULAR (38, 43, 47)
RISK: (-9%,+8%)

DESCRIPTION: This is the transmission service rate ($ per MWH).

REMARKS: Low end is for 100% capacity; high end is for 65% capacity.

REFERENCE: Kathy Schellhammer/Dayton Power &Light Rates Analyst.

NAME:	POWER
AMOUNT:	(POWER _EST + POWER _ERR * SQRT(POWER_VAR))/ PROCESS_LIFE
DESCRIPTION:	Predicted MWH consumed per year derived from regression of simulation output.
NAME:	UNIT_SILICA_COST
AMOUNT:	TRIANGULAR (8, 9, 10)
RISK:	(-10%,+10%)
DESCRIPTION:	Cost is $ per ton of silica.
REFERENCE:	American Aggregates Corporation
NAME:	SILICA
AMOUNT:	(SILICA _EST + SILICA _ERR * SQRT(SILICA_VAR))/ PROCESS_LIFE
DESCRIPTION:	Predicted tons per year of silica consumed derived from regression of simulation output.
NAME:	UNIT_NA2CO3_COST
AMOUNT:	TRIANGULAR (90,98,108)
RISK:	(-5%,+5%)
DESCRIPTION:	Cost per ton of sodium carbonate.
REFERENCE:	Chemical Services Incorporated, Cincinatti, OH
NAME:	NA2CO3
AMOUNT:	(NA2CO3_EST + NA2CO3_ERR * SQRT(NA2CO3_VAR))/ PROCESS_LIFE
DESCRIPTION:	Predicted tons per year of sodium carbonate consumed predicted from regression of simulation output.
NAME:	UNIT_BORAX_COST
AMOUNT:	TRIANGULAR (316, 333, 350)
RISK:	(-5%,+5%)
DESCRIPTION:	Cost per ton of Borax.
REFERENCE:	Chemical Services Incorporated

NAME:	BORAX
AMOUNT:	(BORAX _EST + BORAX _ERR * SQRT(BORAX_VAR))/ PROCESS_LIFE
DESCRIPTION:	Predicted tons per year of borax consumed derived from regression of simulation output.
NAME:	UNIT_RESIN_COST
AMOUNT:	TRIANGULAR (40, 50, 60)
DESCRIPTION:	Resin cost per year (for soil washing). Soils assumed to be 60% of total waste volume; input waste dry density = 1.4 tons/m3.
REFERENCE:	Paul Hewen/Lockheed.
NAME:	SOIL
AMOUNT:	(SOIL_EST + SOIL _ERR * SQRT(SOIL _VAR))/ PROCESS_LIFE
DESCRIPTION:	Predicted tons per year of soil consumed predicted from regression of simulation output.
NAME:	UNIT_TRANS_COST
AMOUNT:	TRIANGULAR (260, 280, 300)
DESCRIPTION:	Cost for transportation to disposal site ($/m3).
REMARKS:	Assume rail transport to Utah.
REFERENCE:	Terry Sams/Martin Marietta Energy Systems
NAME:	UNIT_ONSITE_COST
AMOUNT:	TRIANGULAR (270, 285, 300)
DESCRIPTION:	Cost for tumulus ($/m^3)
REFERENCE:	Rod Gimpel/FERMCO.
NAME:	UNIT_OFFSITE_COST
AMOUNT:	TRIANGULAR (1700, 2000, 2100)
DESCRIPTION:	Cost for disposal at Envirocare
REFERENCE:	Terry Sams/ Martin Marietta Energy Systems

NAME:	UNIT_TESTIN_COST
AMOUNT:	1000
DESCRIPTION:	Test input composition for every batch. $1000/test.
REFERENCE:	Ian Pegg/Catholic University
NAME:	UNIT_TESTOUT_COST
AMOUNT:	1000
DESCRIPTION:	Cost for TCLP test.
REFERENCE:	Simulation; Ian Pegg/Catholic University.
NAME:	NUM_TESTOUT
AMOUNT:	52*MELT_NUM
DESCRIPTION:	TCLP test for every 500 metric tons output (approx. 1 week/500 tons with 1-100tpd melter) at $1000/test.
REFERENCE:	Simulation; Ian Pegg/Catholic University.
NAME:	DESTR_DISPOS
AMOUNT:	TRIANGULAR (4.5E6,5.0E6.6.0E6)
RISK:	(-10%,+20%)
DESCRIPTION:	Destruction/demolition of processing equipment.
REFERENCE:	Rod Gimpel/FERMCO.
NAME:	PROTECTIVE_EQPT_PCT
AMOUNT:	0.08
DESCRIPTION:	Special clothing, masks, safety glasses, etc.
REMARKS:	Assume 8% of labor costs.
REFERENCE:	FERMCO letter M:ENG: (TDD): 94-0034, 16 Sep 94.

NAME:	OH_RATE
AMOUNT:	0.08
DESCRIPTION:	Flat percentage of overall project cost minus additives, melters, transportation, and storage costs.
REFERENCE:	Industry standard

NAME:	PROCESS_LIFE_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for process life CER.

NAME:	GLASS_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for glass volume CER

NAME:	NUM_BATCHES_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for number of batches CER

NAME:	POWER_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for power CER

NAME:	SILICA_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for silica CER

NAME:	NA2CO3_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for sodium carbonate CER

NAME:	BORAX_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for borax CER

NAME:	SOIL_ERR
AMOUNT:	NORMAL(0,1)
DESCRIPTION:	Error term for soil CER
NAME:	PROCESS_LIFE_EST
AMOUNT:	Cfg1: 30.4*WASTE Cfg2: 9.4*WASTE Cfg3: 5.8*WASTE
DESCRIPTION:	Mean estimate for process life CER.
NAME:	GLASS_ EST
AMOUNT:	Cfg1: 387123.6*WASTE Cfg2: 387158.3*WASTE Cfg3: 386497.8*WASTE
DESCRIPTION:	Mean estimate for glass volume CER
NAME:	NUM_BATCHES_ EST
AMOUNT:	Cfg1: 5474.4*WASTE Cfg2: 5469.2*WASTE Cfg3: 5463.1*WASTE
DESCRIPTION:	Mean estimate for number of batches CER
NAME:	POWER_ EST
AMOUNT:	Cfg1: 2414749.5*WASTE Cfg2: 2415427.8*WASTE Cfg3: 2411669.2*WASTE
DESCRIPTION:	Mean estimate for power CER
NAME:	SILICA_EST
AMOUNT:	Cfg1: 154835.1*WASTE Cfg2: 155089.3*WASTE Cfg3: 155009.5*WASTE
DESCRIPTION:	Mean estimate for silica CER

NAME:	NA2CO3_EST
AMOUNT:	Cfg1: 133445.2*WASTE Cfg2: 133538.5*WASTE Cfg3: 133287.9*WASTE
DESCRIPTION:	Mean estimate for sodium carbonate CER
NAME:	BORAX_EST
AMOUNT:	Cfg1: 128255.7*WASTE Cfg2: 134138.6*WASTE Cfg3: 128277.8*WASTE
DESCRIPTION:	Mean estimate for borax CER
NAME:	SOIL_EST
AMOUNT:	Cfg1: 800970.5*WASTE Cfg2: 800803.7*WASTE Cfg3: 800880.4*WASTE
DESCRIPTION:	Mean estimate for borax CER
NAME:	VAR_CONST
AMOUNT:	1+.02854*WASTE^2
DESCRIPTION:	Variance estimate for process life CER.
NAME:	PROCESS_LIFE_VAR
AMOUNT:	Cfg1: .496816*VAR_CONST Cfg2: .108339* VAR_CONST Cfg3: .027639* VAR_CONST
DESCRIPTION:	Variance estimate for process life CER.
NAME:	GLASS_ VAR
AMOUNT:	Cfg1: 9195561*VAR_CONST Cfg2: 12762734* VAR_CONST Cfg3: 12890909*VAR_CONST
DESCRIPTION:	Variance estimate for glass volume CER

NAME: NUM_BATCHES_ VAR
AMOUNT: Cfg1: 88.86*VAR_CONST
Cfg2: 119.7* VAR_CONST
Cfg3: 24.49*VAR_CONST

DESCRIPTION: Variance estimate for number of batches CER

NAME: POWER_ VAR
AMOUNT: Cfg1: 353100929*VAR_CONST
Cfg2: 481417135* VAR_CONST
Cfg3: 481830596*VAR_CONST

DESCRIPTION: Variance estimate for power CER

NAME: SILICA_ VAR

AMOUNT: Cfg1: 17964155*VAR_CONST
Cfg2: 23160361* VAR_CONST
Cfg3: 24032286*VAR_CONST

DESCRIPTION: Variance estimate for silica CER

NAME: NA2CO3_ VAR
AMOUNT: Cfg1: 1852140*VAR_CONST
Cfg2: 2651460* VAR_CONST
Cfg3: 2330146*VAR_CONST

DESCRIPTION: Variance estimate for sodium carbonate CER

NAME: BORAX_ VAR
AMOUNT: Cfg1: 680569*VAR_CONST
Cfg2: 647768671* VAR_CONST
Cfg3: 928347*VAR_CONST

DESCRIPTION: Variance estimate for borax CER

NAME: INIT_MONITOR_COST
AMOUNT: UNIT_MONITOR_COST*GLASS

DESCRIPTION: Cost for first year of monitoring

NAME: MAX_MONITOR_COST
AMOUNT: INIT_MONITOR_COST*PROCESS_LIFE

DESCRIPTION: Constant cost for long-term monitoring

NAME:	MONITOR_IND		
AMOUNT:	0		
DESCRIPTION:	0 = Total monitor costs; 1 = Operations monitor costs.		

NAME:	CIVIL_ENG_ONSITE	
AMOUNT:		
	CFG1:	TRIANGULAR(13.61E6, 14.33E6, 15.05E6)
	CFG2:	TRIANGULAR(16.27E6, 17.13E6, 17.99E6)
	CFG3:	TRIANGULAR(17.81E6, 18.75E6, 19.69E6)
		(-5%,+5%)
DESCRIPTION:	Site preparation, facilities, roads, etc.	
REFERENCE:	Adjusted FSR	

NAME:	CIVIL_ENG_OFFSITE	
AMOUNT:		
	CFG1:	TRIANGULAR(17.26E6, 18.17E6, 19.08E6)
	CFG2:	TRIANGULAR(19.92E6, 20.97E6, 22.02E6)
	CFG3:	TRIANGULAR(21.46E6, 22.59E6, 23.72E6)
		(-5%,+5%)
DESCRIPTION:	Site preparation, facilities, roads, rail sidings, and silos, etc.	
REFERENCE:	Adjusted FSR and engineering judgement	

<u>COST ELEMENTS:</u>

TYPE:	TCE
NAME:	RESEARCH_DEV
AMOUNT:	TRIANGULAR(17.5E6, 25.0E6, 28.75E6)
	(-30%,+15%)

TIME PHASING:

START:	1
PHASE-IN:	0
CONSTANT:	2
PHASE-OUT:	0

DESCRIPTION:	Research and development cost.
REFERENCE:	Rod Gimpel/FERMCO

TYPE: TCE
NAME: CIVIL_ENG
AMOUNT: IF(STORAGE_IND=0,CIVIL_ENG_ONSITE,CIVIL_ENG_OFFSITE)
TIME PHASING:

START:	2
PHASE-IN:	0
CONSTANT:	2
PHASE-OUT:	0

DESCRIPTION: Site preparation, facilities, roads, and rail sidings/silos for off-site disposal.

REFERENCE: Adjusted FSR

TYPE: PCE
NAME: MELTER_COST
AMOUNT: UNIT_MELTER_COST*MELT_NUM
TIME PHASING:

YEAR:	5	PERCENT:	100

TYPE: RCE
NAME: MELTER_MX_COST
AMOUNT: UNIT_FIX_COST*MELT_NUM
TIME PHASING:

START:	8
NO. PMTS:	21
SKIP FACTOR:	2

DESCRIPTION: Melter maintenance

REMARKS: Cost to rebrick and replace electrodes is 10%-25% of purchase and installation cost

REFERENCE: Bill Greenman for low end; Rod Gimpel/FERMCO for high end

TYPE: PCE
NAME: EQPT_COST
AMOUNT: Config. 1: TRIANGULAR(5.94E6, 6.64E6, 7.26E6)
Config. 2: TRIANGULAR(16.04E6, 17.82E6, 19.6E6)
Config. 3: TRIANGULAR(34.43E6, 38.25E6, 42.08E6)
RISK: (-10%,+10%)
TIME PHASING:

YEAR:	5	PERCENT:	100

DESCRIPTION:

	Config. 1	Config. 2	Config. 3
Sludge pumps	30E3	30E3	30E3
Transfer station	250E3	500E3	750E3
Soil wash storage tank	100E3	100E3	100E3
Conveyors	120E3	120E3	120E3
Hopper for soil	50E3	75E3	100E3
Heavy equipment	350E3	750E3	950E3
Motor pool	100E3	100E3	100E3
Soil washer	4.6E6	13.8E6	32.2E6
Batch tanks	1.04E6	2.34E6	3.9E6
* Total	6.64E6	17.82E6	38.3E6

REFERENCE:

Pumps: Capital Equipment Corp.
Transfer station: Williams Pipeline
Soil wash/Batch storage tanks: Damon Construction, Dayton, Ohio
Conveyors: FSR
Hopper: ACME construction estimators.
Heavy equipment/ Motor pool: Various dealers
Soil washer: Duratek

TYPE: RCE
NAME: LABOR1_COST
AMOUNT: UNIT_LABOR1_COST*LABOR1

TIME PHASING:

START: 5
NO. PMTS: 66
SKIP FACTOR: 0

TYPE: RCE
NAME: LABOR2_COST
AMOUNT: UNIT_LABOR2_COST*LABOR2

TIME PHASING:

START: 5
NO. PMTS: 66
SKIP FACTOR: 0

TYPE:	RCE		
NAME:	PROTECTIVE_EQPT		
AMOUNT:	PROTECTIVE_EQPT_PCT*LABOR_COST		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

DESCRIPTION: Special clothing, masks, safety glasses, etc.

TYPE:	RCE		
NAME:	POWER_COST		
AMOUNT:	UNIT_POWER_COST*POWER		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	SILICA_COST		
AMOUNT:	UNIT_SILICA_COST*SILICA		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	NA2CO3_COST		
AMOUNT:	UNIT_NA2CO3_COST*NA2CO3		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	BORAX_COST		
AMOUNT:	UNIT_BORAX_COST*BORAX		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	RESIN_COST		
AMOUNT:	UNIT_RESIN_COST*SOIL		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	TRANS_COST		
AMOUNT:	UNIT_TRANS_COST*GLASS*STORAGE_IND		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	ONSITE_COST		
AMOUNT:	UNIT_ONSITE_COST*GLASS*(1- STORAGE_IND)		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

DESCRIPTION: Cost for tumulus.

TYPE:	RCE		
NAME:	OFFSITE_COST		
AMOUNT:	UNIT_OFFSITE_COST*GLASS*STORAGE_IND, 0)		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

DESCRIPTION: Cost for storage.

TYPE: RCE
NAME: GEN_MX_COST
AMOUNT: GEN_MX_PCT*EQPT_COST
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Assumes 10% of equipment purchase cost per year for maintenance and replacement (except for melters - melter maintenance is a separate cost element)

TYPE: RCE
NAME: TESTIN_COST
AMOUNT: UNIT_TESTIN_COST*NUM_BATCHES
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Test input composition for every batch.

TYPE: RCE
NAME: TESTOUT_COST
AMOUNT: UNIT_TESTOUT_COST*NUM_TESTOUT
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: TCLP test for every 500 metric tons output (approx. 1 week/500 tons with 1-100tpd melter) at $1000/test.

TYPE: RCE
NAME: OPS_MONITOR_COST
AMOUNT: INIT_MONITOR_COST*(TIME-4)*(1-STORAGE_IND)
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: $1.84/m^3 output for long-term monitoring

TYPE: RCE

NAME: LUMP_MONITOR_COST
AMOUNT: IF(TIME=LIFE,(MAX_MONITOR_COST/REAL_RATE)*(1-STORAGE_IND),0)
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Lump all post-operations monitoring costs in the last year of operations. Long-term monitoring is modeled as an infinite cash flow stream.

TYPE: RCE
NAME: MONITOR_COST
AMOUNT: IF(MONITOR_IND=0,(LUMP_MONITOR_COST+
OPS_MONITOR_COST)*(1-STORAGE_IND),
OPS_MONITOR_COST*(1-STORAGE_IND))
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Monitor cost is either the total of all monitoring costs out to infinity, or just the sum through the end of operations. This is used to get the operations and monitoring cost category without including the infinite cash flow stream for long-term monitoring.

TYPE: RCE
NAME: CE_DESTR_DISPOS
AMOUNT: IF(TIME=LIFE,DESTR_DISPOS/(1+REAL_RATE),0)
TIME PHASING:
START: 5
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Destruction/demolition of processing equipment occurs at the end of operations

REFERENCE: Rod Gimpel/FERMCO.

TYPE:	RCE		
NAME:	OH_RESEARCH_DEV		
AMOUNT:	OH_RATE*RESEARCH_DEV		
TIME PHASING:			
		START:	0
		NO. PMTS:	2
		SKIP FACTOR:	0

DESCRIPTION: Overhead associated with research and development.

REFERENCE: Rod Gimpel/FERMCO.

TYPE:	RCE		
NAME:	OH_OPSMX		
AMOUNT:	OH_RATE*OPSMX_BASE		
TIME PHASING:			
		START:	5
		NO. PMTS:	66
		SKIP FACTOR:	0

DESCRIPTION: Overhead associated with operations and maintenance

REFERENCE: Rod Gimpel/FERMCO.

TYPE:	RCE		
NAME:	OH_FAC_EQPT		
AMOUNT:	OH_RATE*FAC_EQPT_BASE		
TIME PHASING:			
		START:	0
		NO. PMTS:	5
		SKIP FACTOR:	0

DESCRIPTION: Overhead associated with facilities and equipment

REFERENCE: Rod Gimpel/FERMCO.

TYPE: RCE
NAME: OH_PHASEOUT_DISP
AMOUNT: OH_RATE* PHASEOUT_DISP_BASE
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead for destruction/demolition of processing equipment and transportation and storage of waste.

TYPE: RCE
NAME: OPSMX_BASE
AMOUNT: OPERATIONS+MAINTENANCE-ADDITIVES_COST
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead base for operations and maintenance phase - does not include additive costs.

REFERENCE: Engineering judgement

TYPE: RCE
NAME: PHASEOUT_DISP_BASE
AMOUNT: SUM(TRANS_COST,ONSITE_COST,OFFSITE_COST, OPS_MONITOR_COST,CE_DESTR_DISPOS)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overhead base for transportation, storage, and destruction/demolition phase - does not include post-operations monitoring costs.

REFERENCE: Engineering judgement

TYPE:	RCE		
NAME:	FAC_EQPT_BASE		
AMOUNT:	SUM(CIVIL_ENG, CAP_EQPT)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: Overhead base for facilities and equipment - does not include melter costs.

REFERENCE: Engineering judgement

TYPE:	RCE		
NAME:	CAP_EQPT		
AMOUNT:	SUM(MELTER_COST, EQPT_COST)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: All capital equipment costs.

TYPE:	RCE		
NAME:	FACILITIES_EQPT		
AMOUNT:	SUM(CIVIL_ENG, CAP_EQPT,OH_FAC_EQPT)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: All facilities and equipment costs.

TYPE:	RCE		
NAME:	FACILITIES_EQPT_INF		
AMOUNT:	FACILITIES_EQPT*(INF_DEF^TIME)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: Inflated facilities and equipment costs.

TYPE: RCE
NAME: OPERATIONS
AMOUNT: SUM(LABOR_COST, PROTECTIVE_EQPT,
POWER_COST,ADDITIVES_COST,
TESTIN_COST,TESTOUT_COST)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: All operations costs.

TYPE: RCE
NAME: LABOR_COST
AMOUNT: SUM(LABOR1_COST, LABOR2_COST)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

TYPE: RCE
NAME: ADDITIVES_COST
AMOUNT: SUM(SILICA_COST,NA2CO3_COST,BORAX_COST,RESIN_COST)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

TYPE: RCE
NAME: MAINTENANCE
AMOUNT: SUM(MELTER_MX_COST, GEN_MX_COST)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

TYPE: RCE
NAME: OPS_MX
AMOUNT: SUM(OPERATIONS, MAINTENANCE,OH_OPSMX)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

TYPE:	RCE		
NAME:	RESEARCH_DEVELOP		
AMOUNT:	SUM(RESEARCH_DEV, OH_RESEARCH_DEV)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

TYPE:	RCE		
NAME:	OPS_MX_INF		
AMOUNT:	OPS_MX*(INF_DEF^TIME)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: Inflated operations and maintenance cost.

`TYPE:	RCE		
NAME:	PHASEOUT_DISPOSAL		
AMOUNT:	SUM(TRANS_COST, ONSITE_COST,OFFSITE_COST, MONITOR_COST, CE_DESTR_DISPOS, OH_PHASEOUT_DISP)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: All destruction/disposal, transprtation, storage and monitoring costs.

TYPE:	RCE		
NAME:	PHASEOUT_DISPOSAL_INF		
AMOUNT:	PHASEOUT_DISPOSAL*(INF_DEF^TIME)		
TIME PHASING:			
		START:	0
		NO. PMTS:	71
		SKIP FACTOR:	0

DESCRIPTION: Inflated destruction/disposal, transportation, storage and monitoring costs.

TYPE: RCE
NAME: PROJECT
AMOUNT: SUM(RESEARCH_DEVELOP, FACILITIES_EQPT, OPS_MX, PHASEOUT_DISPOSAL)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Overall project cost.

TYPE: RCE
NAME: PROJECT_INF
AMOUNT: PROJECT*(INF_DEF^TIME)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

DESCRIPTION: Inflated project cost.

TYPE: RCE
NAME: RESEARCH_DEVELOP_INF
AMOUNT: RESEARCH_DEVELOP*(INF_DEF^TIME)
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0

Appendix C: Facilities Cost Estimation Worksheets

Vitrification Facility Cost

	FSR	Adjusted FSR 44,000 sf	33,000 sf	22,000 sf	15,000 sf
Excavation and civil	62,700	229,000 (same as for pre-treatment facility)			
Concrete	336,500	336,500			
Structural steel	2,273,100	2,273,100			
Machinery and eqpt	29,993,200	425,000 (overhead crane, feed conveyor, hopper)			
Piping	550,400	550,400			
Electrical	5,588,000	2,350,000			
Direct field costs	**38,803,900**	**6,164,000**			
Vitrification additives	22,500,000	0			
Supervision - contractor	2,498,617	369,840			
Tools/consumables	881,900	92,460			
Equipment rental	3,109,280	184,920			
Temp. facilities	881,900	98,900 (same as for pre-treatment facility)			
Temp. utl's hook-up	440,900	440,900			
Job clean-up	881,900	98,900 (same as for pre-treatment facility)			
Safety	440,900	49,500 (same as for pre-treatment facility)			
Health physics	3,624,500	406,700 (same as for pre-treatment facility)			
CERCLA	655,700	0			
Bond	388,000	93,600			
Overhead and profit	6,759,700	1,000,000 (approx. same as for pre-treatment facility)			
Payroll and benefits	7,371,100	494,775 (same as for pre-treatment facility)			
Indirect field costs	**50,434,397**	**3,330,495**			
Electrical power	46,200,000	0			
Soil/Water/Air	388,000	45,400 (same as for pre-treatment facility)			
Project mgmt	5,354,300	0			
Construction mgmt	6,246,700	379,780			
FERMCO field support	**58,189,000**	**425,180**			

Engineering	**15,170,500**	**616,400**				
Tax	5,649,600	211,900 (same as for pre-treatment facility)				
Risk	38,696,900	1,053,607				
Contingency	20,189,688	0				
Total	**$227,133,985**	**$11,801,582**	**$10,178,865**	**$7,375,989**	**$5,029,000**	

Rail Siding/Silos

	FSR	Adjusted FSR	
Excavation and Civil	1,231,700	1,231,700	
Concrete	0	0	
Structural Steel	0	0	
Machinery and Eqpmt	0	0	
Piping	0	0	
Electrical	0	0	
Direct field costs	**1,231,700**	**1,231,700**	
Supervision - contractor	53,200	73,902	
Tools/consumables	18,800	18,476	
Equipment rental	1,536,400	804,400	(subtracted locomotive lease & ops)
Temp. facilities	18,800	18,800	
Temp. utl's hook-up	9,400	9,400	
Job clean-up	18,800	18,800	
Safety	9,400	9,400	
Health physics	77,200	77,200	
CERCLA	13,700	0	
Bond	12,300	27,000	
Overhead and profit	270,000	334,200	
Payroll and benefits	240,800	93,865	
Indirect field costs	**2,278,800**	**1,485,442**	
Soil/Water/Air	12,300	12,300	
Project mgmt	210,600	0	
Construction mgmt	245,700	108,686	
FERMCO field support	**468,600**	**120,986**	

Engineering	**596,800**	**596,800**
Tax	58,900	58,900
Risk	1,019,656	343,493
Contingency	602,524	0
Total	**$6,256,980**	**$3,837,321**

Ancillary Facilities

	FSR	**Adjusted FSR**
Excavation and Civil	1,609,900	1,609,900
Buildings	605,500	605,500
Piping	550,400	550,400
Electrical	550,000	550,000
Direct field costs	**3,315,800**	**3,315,800**
Supervision - contractor	228,400	198,948
Tools/consumables	80,600	49,737
Equipment rental	272,200	99,474
Temp. facilities	80,600	80,600
Temp. utl's hook-up	40,300	40,300
Job clean-up	80,600	80,600
Safety	40,300	40,300
Health physics	331,300	331,300
CERCLA	58,500	0
Bond	33,200	56,400
Overhead and profit	410,600	792,500
Payroll and benefits	1,033,800	537,497
Indirect field costs	**2,690,400**	**2,307,656**
Soil/Water/Air	33,200	33,200
Project mgmt	499,000	0
Construction mgmt	420,500	224,938
FERMCO field support	**952,700**	**258,138**

Engineering	**1,021,200**	**331,580**
Tax	119,700	119,700
Risk	972,048	621,317
Contingency	567,028	0
Total	**$9,638,876**	**$6,954,192**

Appendix D. Verification/Validation of Simulation Results

Hand Calculations for Output Glass Volume:	
Berm Soil Volume (m3)	530000
% After Soil Wash	0.36
Volume of Soil to Melter	190800
Pit Sludge Volume (m3)	340000
Soil to Melter (m3)	190800
Total Waste to Melter (m3)	530800
Average Density (ton/m3)	1.4
Mass of Waste to Melter	743120
Bulk Up Due to Additives	1.47
Total Mass to Melter	1092386.4
Volume Reduction Factor	0.6
Mass to Glass	655431.84
Density of Glass (ton/m3)	2.7
Volume of Glass (m3)	242752.5333
Void Space Bulk Up Factor	0.7
Predicted Glass Gem Volume	**346789.3333**
Simulation Gem Volume	**331687**
Ratio of Actual to Predicted	**0.956450987**

Hand Calculations for life:

Melter O/P (tons/day)	100
Melter Availability	0.68
Adjusted Melter Output (tons/day)	68
0.6 Mass Reduction (organics)	0.6
Mass of waste/additives (tons/day)	113.3333333
Mass of waste (tons/day)	77.09750567
Total Waste to Remediate (tons)	743120
Predicted Days to Remediate	9638.703529
Predicted Years to Remediate	**26.40740693**
Simulation Results (years)	**26.4**
Ratio of Actual to Predicted	**0.999719513**

Appendix E. Regression Models for Cost Estimating Relationships

Regression models were used to obtain cost estimating relationships for each major cost driver in terms of waste volume. System configurations are:

Cementation:
A=On-site, B=Off-site
C1: 200 gallon/minute capacity
C2: 600 gallon/minute capacity
C3: 1000 gallon/minute capacity

Vitrification:
M1: 100 tons/day capacity
M2: 300 tons/day capacity
M3: 500 tons/day capacity

Q=Waste Volume
Life= the number of years it takes a particular configuration to process the given waste volume.
Glass=cubic meters of output glass for transport, storage, and disposal.
Power=megawatts of electricity consumed by the melters.
Soil=tons of soil washed by the soil washer. (used to compute resin cost)
Na2CO3=metric tons of soda ash added. (used to compute additive cost)
SiO2=metric tons of silicon dioxide added. (used to compute additive cost)
Borax=metric tons of borax added. (used to compute additive cost)
Batches=number of batches blended, tested, and vitrified. (used to compute cost for testing)

M1

Q	Life	Glass	Power	Soil	Na2CO3	SiO2	Borax	Batches
0.87	26.6	332801	2076087	709796	114480	128546	110490	4748
0.87	25.8	331665	2069022	709796	113668	127304	110149	4749
0.87	25.6	332099	2071758	709646	114240	127977	110210	4748
0.87	25.7	332537	2074311	709497	113837	129446	110746	4748
0.87	27.1	332001	2071265	709646	114299	128224	110263	4748
1.50	45.1	580079	3618384	1198928	199646	232608	192288	8212
1.50	45.9	581803	3629179	1198928	200797	232716	192683	8212
1.50	46	582947	3636326	1199074	201012	235752	193243	8213
1.50	45.6	582671	3634616	1198928	200958	234829	192790	8212
1.50	44.9	581302	3625589	1199074	201141	233309	192465	8212
2.00	60.4	773855	4826993	1598182	266423	310041	256342	10952
2.00	62.1	775115	4834867	1598328	267003	309669	256833	10956
2.00	61.2	776863	4845574	1598328	267789	313830	257346	10955
2.00	61.2	776096	4840982	1598182	267555	311562	256743	10955
2.00	59.5	775230	4835621	1598036	267980	311221	256764	10951

Life
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99885282
R Square	0.99770695
Adjusted R Square	0.92627838
Standard Error	0.70485184
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3026.308574	3026.309	6091.406	9.35353E-19
Residual	14	6.955425623	0.496816		
Total	15	3033.264			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	30.3656681	0.11908303	254.9958	4.49E-27	30.1102602	30.62108

Glass
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99986961
R Square	0.99973924
Adjusted R Square	0.92831067
Standard Error	3032.41842
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.93574E+11	4.94E+11	53675.24	6.80907E-25
Residual	14	128737860.6	9195561		
Total	15	4.93703E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	387123.567	512.3198276	755.6287	1.12E-33	386024.7493	388222.4

Power
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99987129
R Square	0.9997426
Adjusted R Square	0.92831403
Standard Error	18790.9822
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.92003E+13	1.92E+13	54376.1	6.25856E-25
Residual	14	4943414194	3.53E+08		
Total	15	1.92052E+13			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	2414749.47	3174.691435	760.6249	1.02E-33	2407940.431	2421559

Soil
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99976683
R Square	0.99953371
Adjusted R Square	0.92810514
Standard Error	8121.73974
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.97958E+12	1.98E+12	30010.55	2.97738E-23
Residual	14	923477189	65962656		
Total	15	1.9805E+12			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	800970.514	1372.148472	583.7346	4.14E-32	798027.5455	803913.5

Na2CO3
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9997804
R Square	0.99956085
Adjusted R Square	0.92813228
Standard Error	1360.93347
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	59020074728	5.9E+10	31865.88	2.01634E-23
Residual	14	25929958.82	1852140		
Total	15	59046004686			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	133445.229	229.9264499	580.3822	4.49E-32	132952.0855	133938.4

SiO2
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99850845
R Square	0.99701912
Adjusted R Square	0.92559055
Standard Error	4238.41416
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	84119070885	8.41E+10	4682.607	5.1497E-18
Residual	14	251498163.8	17964155		
Total	15	84370569049			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	154835.074	716.0699181	216.229	4.51E-26	153299.2551	156370.9

Borax
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99991159
R Square	0.99982318
Adjusted R Square	0.92839461
Standard Error	824.96607
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	53875394839	5.39E+10	79162.28	5.45073E-26
Residual	14	9527966.225	680569		
Total	15	53884922805			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	128255.747	139.3760412	920.2137	7.07E-35	127956.8146	128554.7

Batches
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99999364
R Square	0.99998728
Adjusted R Square	0.92855871
Standard Error	9.37514317
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	96725245.09	96725245	1100485	2.02735E-33
Residual	14	1230.506332	87.89331		
Total	15	96726475.6			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	5474.32302	1.58390798	3456.213	6.36E-43	5470.925877	5477.72

M2

Q	Life	Glass	Power	Soil	Na2CO3	SiO2	Borax	Batches
0.87	8.1	332462	2074937	709796	114404	129218	110297	4745
0.87	8.2	332108	2072251	709497	114435	127622	110332	4740
0.87	7.8	329199	2054413	709199	112600	126160	109610	4740
0.87	8.5	332259	2073609	709796	114906	128156	110288	4740
0.87	8	331856	2070879	709497	113576	127689	110544	4742
1.50	13.9	582666	3635550	1198199	201602	234638	193310	8204
1.50	14.5	580308	3620667	1198345	199852	232092	192514	8204
1.50	14.6	582766	3635079	1199074	201456	236980	193411	8204
1.50	14	579868	3617957	1198636	199817	232963	192240	8205
1.50	13.6	582488	3634288	1199074	201053	234114	193304	8210
2.00	18.6	776758	4845583	1598036	268573	312140	257532	10943
2.00	19.4	773972	4828591	1597890	266233	309202	256611	10946
2.00	19.2	777636	4851403	1597890	268496	315233	257834	10943
2.00	18.8	774966	4834322	1597744	267233	312024	256890	10944
2.00	18.7	776365	4843550	1598036	267942	312152	257572	10947

Life
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9974284
R Square	0.9948635
Adjusted R Square	0.9234349
Standard Error	0.3291496
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	293.772581	293.7726	2711.594	1.77294E-16
Residual	14	1.516752373	0.108339		
Total	15	295.2893333			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	9.4370406	0.055609035	169.7034	1.34E-24	9.317771006	9.55631

Glass
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99982
R Square	0.9996399
Adjusted R Square	0.9282114
Standard Error	3572.4968
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.96078E+11	4.96E+11	38869.25	5.54543E-24
Residual	14	178678270	12762734		
Total	15	4.96257E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	387158.29	603.5647806	641.4528	1.11E-32	385863.7703	388452.8

Power
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9998254
R Square	0.9996509
Adjusted R Square	0.9282223
Standard Error	21941.221
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.92975E+13	1.93E+13	40084.68	4.53986E-24
Residual	14	6739840654	4.81E+08		
Total	15	1.93042E+13			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	2415427.8	3706.916767	651.6002	8.88E-33	2407477.295	2423378

Soil
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9997656
R Square	0.9995313
Adjusted R Square	0.9281027
Standard Error	8140.936
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.97877E+12	1.98E+12	29857.03	3.07827E-23
Residual	14	927847735.4	66274838		
Total	15	1.9797E+12			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	800803.69	1375.391628	582.2369	4.29E-32	797853.7678	803753.6

Na2CO3
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9996875
R Square	0.9993751
Adjusted R Square	0.9279466
Standard Error	1628.3303
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	59368611203	5.94E+10	22390.92	1.99646E-22
Residual	14	37120433.83	2651460		
Total	15	59405731636			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	133538.52	275.1025031	485.4137	5.47E-31	132948.483	134128.6

SiO2
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9981065
R Square	0.9962165
Adjusted R Square	0.9247879
Standard Error	4812.5212
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	85375717550	8.54E+10	3686.286	2.42746E-17
Residual	14	324245048.4	23160361		
Total	15	85699962598			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	155089.34	813.0639332	190.7468	2.61E-25	153345.4945	156833.2

Borax
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9999209
R Square	0.9972538
Adjusted R Square	0.9264387
Standard Error	2541.302
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	53929271261	6.88E+10	68694.56	1.27481E-25
Residual	14	1106362.601	6.48E+08		
Total	15	53923037623			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	63175.659	429.942548	336.1948	8.33E-14	124904.137	963361

Batches
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9999913
R Square	0.9999827
Adjusted R Square	0.9285541
Standard Error	10.942867
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	96635387.95	96635388	807000.7	1.52242E-32
Residual	14	1676.448826	119.7463		
Total	15	96637064.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	5469.2258	1.848771216	2958.303	5.62E-42	5465.26054	5473.191

M3

Q	Life	Glass	Power	Soil	Na2CO3	SiO2	Borax	Batches
0.87	5.5	329307	2055169	709795	113199	126814	109808	4729
0.87	5.1	332054	2073412	709646	113969	127130	110546	4739
0.87	5	331222	2067714	709945	114216	128462	110335	4734
0.87	5.1	329860	2059068	709348	113277	126113	109613	4733
0.87	5.2	331895	2070779	709796	114051	128373	110693	4732
1.50	8.9	580165	3620108	1199074	200436	233090	192680	8199
1.50	8.6	580575	3623130	1199074	200022	233709	192718	8193
1.50	8.9	580254	3621393	1198636	200340	234358	192688	8193
1.50	8.8	581638	3629140	1198928	201160	235414	192972	8192
1.50	8.9	579640	3617552	1198782	199534	233123	192230	8192
2.00	11.8	773654	4827237	1597599	267450	310794	256832	10935
2.00	11.4	773996	4828187	1597890	266788	310577	256767	10932
2.00	11.6	775388	4837783	1598327	267105	313069	257023	10942
2.00	11.6	777082	4848087	1598182	268559	315162	257723	10932
2.00	11.7	773919	4829155	1597744	266427	311420	256582	10935

Life

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9981482
R Square	0.9962999
Adjusted R Square	0.9248713
Standard Error	0.1662487
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	104.189059	104.1891	3769.688	2.09991E-17
Residual	14	0.386941044	0.027639		
Total	15	104.576			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	5.8480355	0.028087328	208.209	7.66E-26	5.787794128	5.908277

Glass

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9998178
R Square	0.9996356
Adjusted R Square	0.928207
Standard Error	3590.3913
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.95086E+11	4.95E+11	38405.79	5.99496E-24
Residual	14	180472732.9	12890909		
Total	15	4.95266E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	386497.88	606.5880045	637.167	1.21E-32	385196.8793	387798.9

Power

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9998249
R Square	0.9996499
Adjusted R Square	0.9282213
Standard Error	21950.644
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.92597E+13	1.93E+13	39971.88	4.62376E-24
Residual	14	6745630927	4.82E+08		
Total	15	1.92664E+13			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	2411669.2	3708.508752	650.307	9.13E-33	2403715.274	2419623

Soil
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9997625
R Square	0.9995251
Adjusted R Square	0.9280965
Standard Error	8193.8013
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.97827E+12	1.98E+12	29465.54	3.3539E-23
Residual	14	939937305.7	67138379		
Total	15	1.97921E+12			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	800880.45	1384.323093	578.5358	4.69E-32	797911.3689	803849.5

Na2CO3
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9997247
R Square	0.9994494
Adjusted R Square	0.9280208
Standard Error	1526.4816
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	59215695377	5.92E+10	25412.87	8.77123E-23
Residual	14	32622046.87	2330146		
Total	15	59248317424			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	133287.91	257.8954167	516.8293	2.28E-31	132734.7833	133841

SiO2

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.998044
R Square	0.9960919
Adjusted R Square	0.9246634
Standard Error	4902.2735
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	85755020298	8.58E+10	3568.326	2.99679E-17
Residual	14	336452002.6	24032286		
Total	15	86091472300			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	155009.52	828.2273715	187.1582	3.4E-25	153233.1477	156785.9

Borax

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99988
R Square	0.9997599
Adjusted R Square	0.9283314
Standard Error	963.50752
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	54128504876	5.41E+10	58306.34	3.97664E-25
Residual	14	12996854.45	928346.7		
Total	15	54141501730			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	128277.89	162.7822878	788.0334	6.2E-34	127928.7539	128627

Batches

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9999872
R Square	0.9999745
Adjusted R Square	0.9285459
Standard Error	13.2666
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	96584299.7	96584300	548766.1	1.86714E-31
Residual	14	2464.037332	176.0027		
Total	15	96586763.73			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	5463.0661	2.241360231	2437.389	8.45E-41	5458.258877	5467.873

Appendix F. LCC Regressions

Quadratic regression models for plotting LCC versus waste volume. Variables are:

Q = input waste quantity in cubic meters
Q^2 = waste quantity squared
Ops Life = years required to remediate given volume of waste
LCC = life-cycle cost of the alternative for the given waste volume

Cementation:
C1: 200 gallon/minute capacity
C2: 600 gallon/minute capacity
C3: 1000 gallon/minute capacity
Q=Waste Volume

Vitrification:
M1: 100 tons/day capacity
M2: 300 tons/day capacity
M3: 500 tons/day capacity

		C1A		C2A		C3A	
Q	Q^2	Ops Life	LCC	Ops Life	LCC	Ops Life	LCC
0.9	0.8	17.9	547	6.0	711	3.6	699
0.9	0.8	17.9	548	6.0	714	3.6	698
0.9	0.8	17.9	548	6.0	713	3.6	701
0.9	0.8	18.5	547	6.2	616	3.7	697
0.9	0.8	18.5	549	6.2	617	3.7	698
0.9	0.8	18.5	547	6.2	616	3.7	697
1.0	1.0	20.5	617	6.9	710	4.1	699
1.0	1.0	20.5	619	6.9	708	4.1	697
1.0	1.0	20.5	616	6.9	707	4.1	698
1.1	1.2	22.6	661	7.6	799	4.6	858
1.1	1.2	22.6	662	7.6	800	4.6	855
1.1	1.2	22.6	661	7.6	796	4.6	856
1.2	1.4	24.6	702	8.3	798	5.0	857
1.2	1.4	24.6	704	8.3	798	5.0	858
1.2	1.4	24.6	704	8.3	797	5.0	857
1.3	1.7	26.7	740	9.0	885	5.4	856
1.3	1.7	26.7	741	9.0	883	5.4	858
1.3	1.7	26.7	743	9.0	883	5.4	858
1.4	2.0	28.7	775	9.7	971	5.8	1015
1.4	2.0	28.7	779	9.7	969	5.8	1014
1.4	2.0	28.7	780	9.7	970	5.8	1011
1.5	2.3	30.8	815	10.3	971	6.2	1012
1.5	2.3	30.8	814	10.3	971	6.2	1013
1.5	2.3	30.8	815	10.3	972	6.2	1013
1.6	2.6	32.8	851	11.0	1058	6.6	1169
1.6	2.6	32.8	854	11.0	1054	6.6	1167
1.6	2.6	32.8	851	11.0	1053	6.6	1164
1.7	2.9	34.9	882	11.7	1135	7.0	1165
1.7	2.9	34.9	881	11.7	1136	7.0	1165
1.7	2.9	34.9	885	11.7	1135	7.0	1164
1.8	3.2	37.0	914	12.4	1135	7.4	1169
1.8	3.2	37.0	914	12.4	1140	7.4	1165
1.8	3.2	37.0	912	12.4	1134	7.4	1163
1.9	3.6	39.0	942	13.1	1216	7.9	1313

1.9	3.6	39.0	946	13.1	1216	7.9	1312
1.9	3.6	39.0	947	13.1	1218	7.9	1312
2.0	4.0	41.1	972	13.8	1294	8.3	1315
2.0	4.0	41.1	972	13.8	1296	8.3	1313
2.0	4.0	41.1	972	13.8	1294	8.3	1313

C1A
SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adj. R Square	0.97
Standard Error	5.49
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Signif. F*
Regression	2	756447.24	378223.62	12551	6.42E-52
Residual	37	1115.03	30.14		
Total	39	757562.27			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	733.27	2.93	249.95	0.00	727.33	739.21
Q^2	-124.79	1.81	-68.92	0.00	-128.46	-121.12

C2A
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99
R Square	0.97
Adj. R Square	0.95
Standard Error	33.96
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Sign. F*
Regression	2	1599054.68	799527.34	693.23	1.81E-29
Residual	37	42673.75	1153.34		
Total	39	1641728.43			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
Q	794.55	18.15	43.78	0.00	757.77	831.32
Q^2	-81.38	11.20	-7.26	0.00	-104.08	-58.68

C3A
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.98
R Square	0.96
Adj. R Square	0.94
Standard Error	42.64
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Signif. F*
Regression	2	1764671.97	882335.98	485.19	9.20E-27
Residual	37	67285.49	1818.53		
Total	39	1831957.46			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
Q	826.92	22.79	36.29	0.00	780.75	873.10
Q^2	-83.97	14.07	-5.97	0.00	-112.47	-55.47

Cementation: Off-site

		C1B		C2B		C3B	
Q	Q^2	Ops Life	LCC	Ops Life	LCC	Ops Life	LCC
0.87	0.76	17.9	3382	6.0	3904	3.6	4464
0.87	0.76	17.9	3371	6.0	3899	3.6	4479
0.87	0.76	17.9	3361	6.0	3913	3.6	4451
0.90	0.81	18.5	3370	6.2	3896	3.7	4453
0.90	0.81	18.5	3345	6.2	3917	3.7	4461
0.90	0.81	18.5	3368	6.2	3894	3.7	4455
1.00	1.00	20.5	3789	6.9	4507	4.1	4451
1.00	1.00	20.5	3774	6.9	4502	4.1	4434
1.00	1.00	20.5	3784	6.9	4496	4.1	4441
1.10	1.21	22.6	4028	7.6	5044	4.6	5506
1.10	1.21	22.6	4040	7.6	5078	4.6	5457
1.10	1.21	22.6	4054	7.6	5041	4.6	5504
1.20	1.44	24.6	4280	8.3	5061	5.0	5480
1.20	1.44	24.6	4266	8.3	5087	5.0	5491
1.20	1.44	24.6	4278	8.3	5040	5.0	5450
1.30	1.69	26.7	4528	9.0	5610	5.4	5484
1.30	1.69	26.7	4529	9.0	5601	5.4	5464
1.30	1.69	26.7	4518	9.0	5583	5.4	5480
1.40	1.96	28.7	4708	9.7	6154	5.8	6501
1.40	1.96	28.7	4733	9.7	6146	5.8	6491
1.40	1.96	28.7	4731	9.7	6169	5.8	6518
1.50	2.25	30.8	4957	10.3	6120	6.2	6470
1.50	2.25	30.8	4945	10.3	6144	6.2	6481

1.50	2.25	30.8	4960	10.3	6147	6.2	6513
1.60	2.56	32.8	5102	11.0	6709	6.6	7485
1.60	2.56	32.8	5134	11.0	6693	6.6	7463
1.60	2.56	32.8	5113	11.0	6686	6.6	7469
1.70	2.89	34.9	5314	11.7	7175	7.0	7467
1.70	2.89	34.9	5321	11.7	7192	7.0	7484
1.70	2.89	34.9	5309	11.7	7195	7.0	7474
1.80	3.24	37.0	5491	12.4	7204	7.4	7455
1.80	3.24	37.0	5482	12.4	7197	7.4	7441
1.80	3.24	37.0	5486	12.4	7201	7.4	7463
1.90	3.61	39.0	5661	13.1	7699	7.9	8378
1.90	3.61	39.0	5645	13.1	7692	7.9	8463
1.90	3.61	39.0	5656	13.1	7704	7.9	8416
2.00	4.00	41.1	5811	13.8	8182	8.3	8428
2.00	4.00	41.1	5825	13.8	8192	8.3	8450
2.00	4.00	41.1	5818	13.8	8154	8.3	8440

C1B
SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adj. R Square	0.97
Standard Error	35.86
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	2	25174795.38	12587397.69	9786.01	5.62E-50
Residual	37	47591.77	1286.26		
Total	39	25222387.15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	4564.50	19.17	238.16	0.00	4525.66	4603.33
Q^2	-838.17	11.83	-70.85	0.00	-862.14	-814.20

C2B
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99
R Square	0.99
Adj. R Square	0.96
Standard Error	140.37
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	2	71048503.85	35524251.92	1802.88	8.13E-37
Residual	37	729055.29	19704.20		
Total	39	71777559.14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	4835.51	75.01	64.46	0.00	4683.52	4987.50
Q^2	-403.90	46.30	-8.72	0.00	-497.72	-310.09

C3B
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.98
R Square	0.96
Adj. R Square	0.93
Standard Error	280.82
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	2	73492259.89	36746129.94	465.98	1.85E-26
Residual	37	2917753.19	78858.19		
Total	39	76410013.08			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Q	5263.11	150.07	35.07	0.00	4959.05	5567.18
Q^2	-516.42	92.63	-5.58	0.00	-704.11	-328.74

Vitrification
ONSITE

Q	Q^2	M1 LCC($M)	M2 LCC($M)	M3 LCC($M)
0.87	0.76	425	535	540
0.90	0.81	432	540	540
1.00	1.00	458	573	597
1.10	1.21	484	626	597
1.20	1.44	506	655	675
1.30	1.69	535	689	734
1.40	1.96	555	733	730
1.50	2.25	575	766	789
1.60	2.56	589	798	782
1.70	2.89	603	845	860
1.80	3.24	620	873	860
1.90	3.61	630	896	910
2.00	4.00	641	940	962

M1

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99968481
R Square	0.99936972
Adjusted R Square	0.99924366
Standard Error	2.07943805
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	68561.889	34280.9445	7927.94827	9.94665E-17
Residual	10	43.24062586	4.32406259		
Total	12	68605.12962			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	101.369866	9.738388003	10.4093065	1.0992E-06	79.67138142	123.0684
Q	446.069959	14.40666782	30.9627434	2.8977E-11	413.9698971	478.17
Q^2	-88.065764	5.054458552	-17.4233824	8.2272E-09	-99.32780148	-76.8037

M2

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99928791
R Square	0.99857633
Adjusted R Square	0.9982916
Standard Error	5.70186138
Observations	13

ANOVA

	df	SS	MS	F	Significance F
Regression	2	228037.1052	114018.553	3507.05207	5.84851E-15
Residual	10	325.1122316	32.5112232		
Total	12	228362.2175			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	165.584797	26.7028578	6.20101406	0.00010132	106.0871113	225.0825
Q	443.850504	39.50337592	11.2357613	5.4108E-07	355.831482	531.8695
Q^2	-28.943156	13.85942806	-2.08833697	0.0633056	-59.82389143	1.93758

M3
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9912347
R Square	0.98254622
Adjusted R Square	0.97905546
Standard Error	20.3019891
Observations	13

ANOVA

	df	SS	MS	F	Significance F
Regression	2	232028.1543	116014.077	281.470906	1.61975E-09
Residual	10	4121.707599	412.17076		

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	164.722887	95.07792124	1.73250409	0.11385411	-47.12395968	376.5697
Q	454.090147	140.6553146	3.22838955	0.0090456	140.6905219	767.4898
Q^2	-31.450976	49.34773722	-0.6373337	0.53822485	-141.4046053	78.50265

OFFSITE

Q	Q^2	M1 LCC($M)	M2 LCC($M)	M3 LCC($M)
0.87	0.76	872	1097	1147
0.90	0.81	893	1099	1147
1.00	1.00	952	1192	1319
1.10	1.21	1005	1308	1320
1.20	1.44	1058	1397	1502
1.30	1.69	1120	1482	1671
1.40	1.96	1157	1590	1669
1.50	2.25	1200	1672	1826
1.60	2.56	1234	1758	1822
1.70	2.89	1267	1851	1998
1.80	3.24	1297	1928	1994
1.90	3.61	1322	2003	2143
2.00	4.00	1347	2094	2284

M1
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999805641
R Square	0.99961132
Adjusted R Square	0.999533584
Standard Error	3.541331087
Observations	13

ANOVA

	df	SS	MS	F	Significance F
Regression	2	322531.5293	161265.7646	12859.05685	8.87075E-18
Residual	10	125.4102587	12.54102587		
Total	12	322656.9395			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	161.4320497	16.58470001	9.733793773	2.03439E-06	124.4790289	198.38507
Q	989.5762556	24.53488851	40.33343193	2.10015E-12	934.9091078	1044.2434
Q^2	-198.927098	8.607859819	-23.10993703	5.20215E-10	-218.1066086	-179.74759

M2

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999668222
R Square	0.999336554
Adjusted R Square	0.999203864
Standard Error	9.672497621
Observations	13

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1409234.57	704617.2851	7531.405473	1.28537E-16
Residual	10	935.5721022	93.55721022		
Total	12	1410170.142			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	150.1785118	45.29807223	3.315340022	0.007808623	49.24809966	251.10892
Q	1142.149555	67.01255683	17.043814	1.01871E-08	992.8362473	1291.4629
Q^2	-85.6756092	23.51079342	-3.644096889	0.004506116	-138.0609305	-33.290288

M3

Regression Statistics	
Multiple R	0.992122024
R Square	0.98430611
Adjusted R Square	0.981167332
Standard Error	51.35796142
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1654303.236	827151.618	313.5953181	9.52035E-10
Residual	10	26376.40201	2637.640201		
Total	12	1680679.638			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	113.8491761	240.5187096	0.473348524	0.646128233	-422.059998	649.75835
Q	1272.34456	355.8158857	3.575850913	0.005046396	479.5372236	2065.1519
Q^2	-105.174908	124.8350187	-0.842511251	0.419195963	-383.3247112	172.9749

Appendix G. Experimental Designs

Experimental designs were used to collect cost data for each alternative at different settings of system parameters. The parameters varied were:

Unit Offsite Cost - the cost for disposing of one cubic meter of waste at Envirocare
Waste - the volume in cubic meters of waste at the site to remediate
Storage Ind - zero for on-site storage and one for off-site disposal
Real Rate - discount factor which considers both the nominal interest rate and inflation
Rate - the nominal interest rate
Life - number of years required for an alternative to complete remediation of the waste
Concrete - cubic meters of cemented waste produced per year
Glass - cubic meters of waste glass produced per year
Power - megawatts of electricity consumed by the melter
LCC - the life-cycle cost of the alternative at the given configuration

C1:

Unit Offsite Cost	Waste	Storage Ind	Real Rate	Rate	Process Life	Concrete	LCC
2000	0.87	0	0.028	0.058	17.86	97418.41	5.47E+08
2000	0.87	0	0.028	0.058	17.86	97418.41	5.48E+08
2000	0.87	0	0.028	0.058	17.86	97418.41	5.48E+08
2000	0.9	0	0.028	0.058	18.48	97418.41	5.47E+08
2000	0.9	0	0.028	0.058	18.48	97418.41	5.49E+08
2000	0.9	0	0.028	0.058	18.48	97418.41	5.47E+08
2000	1	0	0.028	0.058	20.53	97418.41	6.17E+08
2000	1	0	0.028	0.058	20.53	97418.41	6.19E+08
2000	1	0	0.028	0.058	20.53	97418.41	6.16E+08
2000	1.1	0	0.028	0.058	22.58	97418.41	6.61E+08
2000	1.1	0	0.028	0.058	22.58	97418.41	6.62E+08
2000	1.1	0	0.028	0.058	22.58	97418.41	6.61E+08
2000	1.2	0	0.028	0.058	24.64	97418.41	7.02E+08
2000	1.2	0	0.028	0.058	24.64	97418.41	7.04E+08
2000	1.2	0	0.028	0.058	24.64	97418.41	7.04E+08
2000	1.3	0	0.028	0.058	26.69	97418.41	7.4E+08
2000	1.3	0	0.028	0.058	26.69	97418.41	7.41E+08
2000	1.3	0	0.028	0.058	26.69	97418.41	7.43E+08
2000	1.4	0	0.028	0.058	28.74	97418.41	7.75E+08
2000	1.4	0	0.028	0.058	28.74	97418.41	7.79E+08
2000	1.4	0	0.028	0.058	28.74	97418.41	7.8E+08
2000	1.5	0	0.028	0.058	30.80	97418.41	8.15E+08
2000	1.5	0	0.028	0.058	30.80	97418.41	8.14E+08
2000	1.5	0	0.028	0.058	30.80	97418.41	8.15E+08
2000	1.6	0	0.028	0.058	32.85	97418.41	8.51E+08
2000	1.6	0	0.028	0.058	32.85	97418.41	8.54E+08
2000	1.6	0	0.028	0.058	32.85	97418.41	8.51E+08
2000	1.7	0	0.028	0.058	34.90	97418.41	8.82E+08

2000	1.7	0	0.028	0.058	34.90	97418.41	8.81E+08
2000	1.7	0	0.028	0.058	34.90	97418.41	8.85E+08
2000	1.8	0	0.028	0.058	36.95	97418.41	9.14E+08
2000	1.8	0	0.028	0.058	36.95	97418.41	9.14E+08
2000	1.8	0	0.028	0.058	36.95	97418.41	9.12E+08
2000	1.9	0	0.028	0.058	39.01	97418.41	9.42E+08
2000	1.9	0	0.028	0.058	39.01	97418.41	9.46E+08
2000	1.9	0	0.028	0.058	39.01	97418.41	9.47E+08
2000	2	0	0.028	0.058	41.06	97418.41	9.72E+08
2000	2	0	0.028	0.058	41.06	97418.41	9.72E+08
2000	2	0	0.028	0.058	41.06	97418.41	9.72E+08
2000	0.87	1	0.028	0.058	17.86	97418.41	3.38E+09
2000	0.87	1	0.028	0.058	17.86	97418.41	3.37E+09
2000	0.87	1	0.028	0.058	17.86	97418.41	3.36E+09
2000	0.9	1	0.028	0.058	18.48	97418.41	3.37E+09
2000	0.9	1	0.028	0.058	18.48	97418.41	3.34E+09
2000	0.9	1	0.028	0.058	18.48	97418.41	3.37E+09
2000	1	1	0.028	0.058	20.53	97418.41	3.79E+09
2000	1	1	0.028	0.058	20.53	97418.41	3.77E+09
2000	1	1	0.028	0.058	20.53	97418.41	3.78E+09
2000	1.1	1	0.028	0.058	22.58	97418.41	4.03E+09
2000	1.1	1	0.028	0.058	22.58	97418.41	4.04E+09
2000	1.1	1	0.028	0.058	22.58	97418.41	4.05E+09
2000	1.2	1	0.028	0.058	24.64	97418.41	4.28E+09
2000	1.2	1	0.028	0.058	24.64	97418.41	4.27E+09
2000	1.2	1	0.028	0.058	24.64	97418.41	4.28E+09
2000	1.3	1	0.028	0.058	26.69	97418.41	4.53E+09
2000	1.3	1	0.028	0.058	26.69	97418.41	4.53E+09
2000	1.3	1	0.028	0.058	26.69	97418.41	4.52E+09
2000	1.4	1	0.028	0.058	28.74	97418.41	4.71E+09
2000	1.4	1	0.028	0.058	28.74	97418.41	4.73E+09
2000	1.4	1	0.028	0.058	28.74	97418.41	4.73E+09
2000	1.5	1	0.028	0.058	30.80	97418.41	4.96E+09
2000	1.5	1	0.028	0.058	30.80	97418.41	4.95E+09
2000	1.5	1	0.028	0.058	30.80	97418.41	4.96E+09
2000	1.6	1	0.028	0.058	32.85	97418.41	5.1E+09
2000	1.6	1	0.028	0.058	32.85	97418.41	5.13E+09
2000	1.6	1	0.028	0.058	32.85	97418.41	5.11E+09
2000	1.7	1	0.028	0.058	34.90	97418.41	5.31E+09
2000	1.7	1	0.028	0.058	34.90	97418.41	5.32E+09
2000	1.7	1	0.028	0.058	34.90	97418.41	5.31E+09
2000	1.8	1	0.028	0.058	36.95	97418.41	5.49E+09
2000	1.8	1	0.028	0.058	36.95	97418.41	5.48E+09
2000	1.8	1	0.028	0.058	36.95	97418.41	5.49E+09
2000	1.9	1	0.028	0.058	39.01	97418.41	5.66E+09
2000	1.9	1	0.028	0.058	39.01	97418.41	5.64E+09
2000	1.9	1	0.028	0.058	39.01	97418.41	5.66E+09
2000	2	1	0.028	0.058	41.06	97418.41	5.81E+09
2000	2	1	0.028	0.058	41.06	97418.41	5.82E+09
2000	2	1	0.028	0.058	41.06	97418.41	5.82E+09
2000	0.87	1	0.01	0.07	12.50	97418.41	3.05E+09

2000	0.87	1	0.01	0.07	17.86	97418.41	4.09E+09
2000	0.87	1	0.01	0.07	21.40	97418.41	4.7E+09
2000	0.87	1	0.028	0.055	12.50	97418.41	2.61E+09
2000	0.87	1	0.028	0.055	17.86	97418.41	3.36E+09
2000	0.87	1	0.028	0.055	21.40	97418.41	3.79E+09
2000	0.87	1	0.055	0.085	12.50	97418.41	2.1E+09
2000	0.87	1	0.055	0.085	17.86	97418.41	2.57E+09
2000	0.87	1	0.055	0.085	21.40	97418.41	2.81E+09
245	0.87	1	0.01	0.07	12.50	97418.41	3.05E+09
245	0.87	1	0.01	0.07	17.86	97418.41	4.09E+09
245	0.87	1	0.01	0.07	21.40	97418.41	4.68E+09
245	0.87	1	0.028	0.055	12.50	97418.41	2.61E+09
245	0.87	1	0.028	0.055	17.86	97418.41	3.36E+09
245	0.87	1	0.028	0.055	21.40	97418.41	3.78E+09
245	0.87	1	0.055	0.085	12.50	97418.41	2.11E+09
245	0.87	1	0.055	0.085	17.86	97418.41	2.56E+09
245	0.87	1	0.055	0.085	21.40	97418.41	2.8E+09
2000	2	1	0.01	0.07	28.74	97418.41	6.29E+09
2000	2	1	0.01	0.07	41.06	97418.41	8.36E+09
2000	2	1	0.01	0.07	49.27	97418.41	9.56E+09
2000	2	1	0.028	0.055	28.74	97418.41	4.74E+09
2000	2	1	0.028	0.055	41.06	97418.41	5.81E+09
2000	2	1	0.028	0.055	49.27	97418.41	6.35E+09
2000	2	1	0.055	0.085	28.74	97418.41	3.3E+09
2000	2	1	0.055	0.085	41.06	97418.41	3.68E+09
2000	2	1	0.055	0.085	49.27	97418.41	3.85E+09
245	2	1	0.01	0.07	28.74	97418.41	6.29E+09
245	2	1	0.01	0.07	41.06	97418.41	8.26E+09
245	2	1	0.01	0.07	49.27	97418.41	9.59E+09
245	2	1	0.028	0.055	28.74	97418.41	4.78E+09
245	2	1	0.028	0.055	41.06	97418.41	5.82E+09
245	2	1	0.028	0.055	49.27	97418.41	6.35E+09
245	2	1	0.055	0.085	28.74	97418.41	3.3E+09
245	2	1	0.055	0.085	41.06	97418.41	3.69E+09
245	2	1	0.055	0.085	49.27	97418.41	3.84E+09
245	0.87	0	0.01	0.07	12.50	97418.41	5.09E+08
245	0.87	0	0.01	0.07	17.86	97418.41	6.64E+08
245	0.87	0	0.01	0.07	21.40	97418.41	7.54E+08
245	0.87	0	0.028	0.055	12.50	97418.41	4.37E+08
245	0.87	0	0.028	0.055	17.86	97418.41	5.47E+08
245	0.87	0	0.028	0.055	21.40	97418.41	6.08E+08
245	0.87	0	0.055	0.085	12.50	97418.41	3.53E+08
245	0.87	0	0.055	0.085	17.86	97418.41	4.2E+08
245	0.87	0	0.055	0.085	21.40	97418.41	4.53E+08
2000	2	0	0.01	0.07	28.74	97418.41	1.07E+09
2000	2	0	0.01	0.07	41.06	97418.41	1.4E+09
2000	2	0	0.01	0.07	49.27	97418.41	1.62E+09
2000	2	0	0.028	0.055	28.74	97418.41	8.08E+08
2000	2	0	0.028	0.055	41.06	97418.41	9.74E+08
2000	2	0	0.028	0.055	49.27	97418.41	1.06E+09
2000	2	0	0.055	0.085	28.74	97418.41	5.61E+08

2000	2	0	0.055	0.085	41.06	97418.41	6.14E+08
2000	2	0	0.055	0.085	49.27	97418.41	6.31E+08

C2:

Unit_Offsite_Cost	Waste	Storage_Ind	Real_Rate	Rate	Process_Life	Concrete	LCC
2000	0.87	0	0.028	0.058	6.00	290000.00	711402997
2000	0.87	0	0.028	0.058	6.00	290000.00	714152619
2000	0.87	0	0.028	0.058	6.00	290000.00	713404746
2000	0.9	0	0.028	0.058	6.21	290000.00	615902682
2000	0.9	0	0.028	0.058	6.21	290000.00	616611668
2000	0.9	0	0.028	0.058	6.21	290000.00	616229482
2000	1	0	0.028	0.058	6.90	290000.00	710044789
2000	1	0	0.028	0.058	6.90	290000.00	708479365
2000	1	0	0.028	0.058	6.90	290000.00	707244373
2000	1.1	0	0.028	0.058	7.59	290000.00	798719522
2000	1.1	0	0.028	0.058	7.59	290000.00	799724806
2000	1.1	0	0.028	0.058	7.59	290000.00	795522273
2000	1.2	0	0.028	0.058	8.28	290000.00	798264155
2000	1.2	0	0.028	0.058	8.28	290000.00	797879212
2000	1.2	0	0.028	0.058	8.28	290000.00	797302158
2000	1.3	0	0.028	0.058	8.97	290000.00	884938933
2000	1.3	0	0.028	0.058	8.97	290000.00	882610878
2000	1.3	0	0.028	0.058	8.97	290000.00	882992589
2000	1.4	0	0.028	0.058	9.66	290000.00	970547162
2000	1.4	0	0.028	0.058	9.66	290000.00	969465632
2000	1.4	0	0.028	0.058	9.66	290000.00	970473046
2000	1.5	0	0.028	0.058	10.34	290000.00	970653822
2000	1.5	0	0.028	0.058	10.34	290000.00	970805674
2000	1.5	0	0.028	0.058	10.34	290000.00	972298251
2000	1.6	0	0.028	0.058	11.03	290000.00	1057607465
2000	1.6	0	0.028	0.058	11.03	290000.00	1054483733
2000	1.6	0	0.028	0.058	11.03	290000.00	1052953903
2000	1.7	0	0.028	0.058	11.72	290000.00	1134536810
2000	1.7	0	0.028	0.058	11.72	290000.00	1136148364
2000	1.7	0	0.028	0.058	11.72	290000.00	1134909948
2000	1.8	0	0.028	0.058	12.41	290000.00	1135442248
2000	1.8	0	0.028	0.058	12.41	290000.00	1140119565
2000	1.8	0	0.028	0.058	12.41	290000.00	1133861727
2000	1.9	0	0.028	0.058	13.10	290000.00	1215506724
2000	1.9	0	0.028	0.058	13.10	290000.00	1215762645
2000	1.9	0	0.028	0.058	13.10	290000.00	1218430780
2000	2	0	0.028	0.058	13.79	290000.00	1293898665
2000	2	0	0.028	0.058	13.79	290000.00	1296072765
2000	2	0	0.028	0.058	13.79	290000.00	1294450783
2000	0.87	1	0.028	0.058	6.00	290000.00	3904289682
2000	0.87	1	0.028	0.058	6.00	290000.00	3898881014
2000	0.87	1	0.028	0.058	6.00	290000.00	3913046794
2000	0.9	1	0.028	0.058	6.21	290000.00	3895724847
2000	0.9	1	0.028	0.058	6.21	290000.00	3916953851
2000	0.9	1	0.028	0.058	6.21	290000.00	3894273577
2000	1	1	0.028	0.058	6.90	290000.00	4507413107
2000	1	1	0.028	0.058	6.90	290000.00	4501945637
2000	1	1	0.028	0.058	6.90	290000.00	4496006240

2000	1.1	1	0.028	0.058	7.59	290000.00	5044201332
2000	1.1	1	0.028	0.058	7.59	290000.00	5077645608
2000	1.1	1	0.028	0.058	7.59	290000.00	5040786172
2000	1.2	1	0.028	0.058	8.28	290000.00	5060672459
2000	1.2	1	0.028	0.058	8.28	290000.00	5087199893
2000	1.2	1	0.028	0.058	8.28	290000.00	5039731922
2000	1.3	1	0.028	0.058	8.97	290000.00	5609849686
2000	1.3	1	0.028	0.058	8.97	290000.00	5600987662
2000	1.3	1	0.028	0.058	8.97	290000.00	5583344569
2000	1.4	1	0.028	0.058	9.66	290000.00	6153691179
2000	1.4	1	0.028	0.058	9.66	290000.00	6146120168
2000	1.4	1	0.028	0.058	9.66	290000.00	6169102846
2000	1.5	1	0.028	0.058	10.34	290000.00	6119975435
2000	1.5	1	0.028	0.058	10.34	290000.00	6144205444
2000	1.5	1	0.028	0.058	10.34	290000.00	6147389314
2000	1.6	1	0.028	0.058	11.03	290000.00	6709060007
2000	1.6	1	0.028	0.058	11.03	290000.00	6693468122
2000	1.6	1	0.028	0.058	11.03	290000.00	6686427928
2000	1.7	1	0.028	0.058	11.72	290000.00	7175194952
2000	1.7	1	0.028	0.058	11.72	290000.00	7191635909
2000	1.7	1	0.028	0.058	11.72	290000.00	7194500034
2000	1.8	1	0.028	0.058	12.41	290000.00	7203795653
2000	1.8	1	0.028	0.058	12.41	290000.00	7196755293
2000	1.8	1	0.028	0.058	12.41	290000.00	7200898520
2000	1.9	1	0.028	0.058	13.10	290000.00	7698828224
2000	1.9	1	0.028	0.058	13.10	290000.00	7692061644
2000	1.9	1	0.028	0.058	13.10	290000.00	7703895382
2000	2	1	0.028	0.058	13.79	290000.00	8182046509
2000	2	1	0.028	0.058	13.79	290000.00	8191697103
2000	2	1	0.028	0.058	13.79	290000.00	8154141429
2000	0.87	1	0.01	0.07	4.20	290000.00	2914119674
2000	0.87	1	0.01	0.07	6.00	290000.00	4304512760
2000	0.87	1	0.01	0.07	7.20	290000.00	4952991380
2000	0.87	1	0.028	0.055	4.20	290000.00	2701942726
2000	0.87	1	0.028	0.055	6.00	290000.00	3930842603
2000	0.87	1	0.028	0.055	7.20	290000.00	4487175034
2000	0.87	1	0.055	0.085	4.20	290000.00	2408255191
2000	0.87	1	0.055	0.085	6.00	290000.00	3416409598
2000	0.87	1	0.055	0.085	7.20	290000.00	3855897649
245	0.87	1	0.01	0.07	4.20	290000.00	2921940174
245	0.87	1	0.01	0.07	6.00	290000.00	4290984818
245	0.87	1	0.01	0.07	7.20	290000.00	4965673865
245	0.87	1	0.028	0.055	4.20	290000.00	2704115364
245	0.87	1	0.028	0.055	6.00	290000.00	3899582680
245	0.87	1	0.028	0.055	7.20	290000.00	4471826008
245	0.87	1	0.055	0.085	4.20	290000.00	2406302088
245	0.87	1	0.055	0.085	6.00	290000.00	3406164010
245	0.87	1	0.055	0.085	7.20	290000.00	3871557137
2000	2	1	0.01	0.07	9.66	290000.00	7045001563
2000	2	1	0.01	0.07	13.80	290000.00	9603241966
2000	2	1	0.01	0.07	16.56	290000.00	1.1484E+10

2000	2	1	0.028	0.055	9.66	290000.00	6205433823
2000	2	1	0.028	0.055	13.80	290000.00	8175094545
2000	2	1	0.028	0.055	16.56	290000.00	9531038037
2000	2	1	0.055	0.085	9.66	290000.00	5146245738
2000	2	1	0.055	0.085	13.80	290000.00	6486079758
2000	2	1	0.055	0.085	16.56	290000.00	7345857128
245	2	1	0.01	0.07	9.66	290000.00	7059691257
245	2	1	0.01	0.07	13.80	290000.00	9608798038
245	2	1	0.01	0.07	16.56	290000.00	1.1467E+10
245	2	1	0.028	0.055	9.66	290000.00	6177070259
245	2	1	0.028	0.055	13.80	290000.00	8208059916
245	2	1	0.028	0.055	16.56	290000.00	9520281366
245	2	1	0.055	0.085	9.66	290000.00	5152285820
245	2	1	0.055	0.085	13.80	290000.00	6511385002
245	2	1	0.055	0.085	16.56	290000.00	7342825453
245	0.87	0	0.01	0.07	4.20	290000.00	477297148
245	0.87	0	0.01	0.07	6.00	290000.00	977338958
245	0.87	0	0.01	0.07	7.20	290000.00	774692264
245	0.87	0	0.028	0.055	4.20	290000.00	443269734
245	0.87	0	0.028	0.055	6.00	290000.00	712348881
245	0.87	0	0.028	0.055	7.20	290000.00	698576124
245	0.87	0	0.055	0.085	4.20	290000.00	394998673
245	0.87	0	0.055	0.085	6.00	290000.00	578968422
245	0.87	0	0.055	0.085	7.20	290000.00	601780468
2000	2	0	0.01	0.07	9.66	290000.00	1143433816
2000	2	0	0.01	0.07	13.80	290000.00	1522987607
2000	2	0	0.01	0.07	16.56	290000.00	1800885681
2000	2	0	0.028	0.055	9.66	290000.00	1006544188
2000	2	0	0.028	0.055	13.80	290000.00	1293142535
2000	2	0	0.028	0.055	16.56	290000.00	1495820900
2000	2	0	0.055	0.085	9.66	290000.00	838608916
2000	2	0	0.055	0.085	13.80	290000.00	1031400512
2000	2	0	0.055	0.085	16.56	290000.00	1156873400

C3:

Unit_Offsite_Cost	Waste	Storage_Ind	Real_Rate	Rate	Process_Life	LCC
2000	0.87	0	0.028	0.058	3.60	698531008.2
2000	0.87	0	0.028	0.058	3.60	697514086.9
2000	0.87	0	0.028	0.058	3.60	700564391.7
2000	0.9	0	0.028	0.058	3.72	696954898.4
2000	0.9	0	0.028	0.058	3.72	697675251.6
2000	0.9	0	0.028	0.058	3.72	696805913.3
2000	1	0	0.028	0.058	4.14	699434453.1
2000	1	0	0.028	0.058	4.14	697011814.6
2000	1	0	0.028	0.058	4.14	698382398.4
2000	1.1	0	0.028	0.058	4.55	858190147.1
2000	1.1	0	0.028	0.058	4.55	855330318.4
2000	1.1	0	0.028	0.058	4.55	855680290.1
2000	1.2	0	0.028	0.058	4.97	856691735.2
2000	1.2	0	0.028	0.058	4.97	858194299.5
2000	1.2	0	0.028	0.058	4.97	856807291.9
2000	1.3	0	0.028	0.058	5.38	856487840.1
2000	1.3	0	0.028	0.058	5.38	858197656.1
2000	1.3	0	0.028	0.058	5.38	857999278.1
2000	1.4	0	0.028	0.058	5.79	1014590861
2000	1.4	0	0.028	0.058	5.79	1014248206
2000	1.4	0	0.028	0.058	5.79	1010575812
2000	1.5	0	0.028	0.058	6.21	1012264330
2000	1.5	0	0.028	0.058	6.21	1012791552
2000	1.5	0	0.028	0.058	6.21	1013334293
2000	1.6	0	0.028	0.058	6.62	1169441522
2000	1.6	0	0.028	0.058	6.62	1166560123
2000	1.6	0	0.028	0.058	6.62	1164200458
2000	1.7	0	0.028	0.058	7.03	1164574026
2000	1.7	0	0.028	0.058	7.03	1164552478
2000	1.7	0	0.028	0.058	7.03	1163637599
2000	1.8	0	0.028	0.058	7.45	1169137282
2000	1.8	0	0.028	0.058	7.45	1164683645
2000	1.8	0	0.028	0.058	7.45	1163120359
2000	1.9	0	0.028	0.058	7.86	1312632507
2000	1.9	0	0.028	0.058	7.86	1311803343
2000	1.9	0	0.028	0.058	7.86	1312173167
2000	2	0	0.028	0.058	8.28	1315242904
2000	2	0	0.028	0.058	8.28	1312958813
2000	2	0	0.028	0.058	8.28	1313492527
2000	0.87	1	0.028	0.058	3.60	4464044163
2000	0.87	1	0.028	0.058	3.60	4479264375
2000	0.87	1	0.028	0.058	3.60	4451317132
2000	0.9	1	0.028	0.058	3.72	4452897575
2000	0.9	1	0.028	0.058	3.72	4460569646
2000	0.9	1	0.028	0.058	3.72	4455106456
2000	1	1	0.028	0.058	4.14	4451319825
2000	1	1	0.028	0.058	4.14	4434251992
2000	1	1	0.028	0.058	4.14	4440529788

2000	1.1	1	0.028	0.058	4.55	5505726338
2000	1.1	1	0.028	0.058	4.55	5457081251
2000	1.1	1	0.028	0.058	4.55	5503539060
2000	1.2	1	0.028	0.058	4.97	5480246909
2000	1.2	1	0.028	0.058	4.97	5490758759
2000	1.2	1	0.028	0.058	4.97	5450138361
2000	1.3	1	0.028	0.058	5.38	5483951817
2000	1.3	1	0.028	0.058	5.38	5463998183
2000	1.3	1	0.028	0.058	5.38	5479814465
2000	1.4	1	0.028	0.058	5.79	6501440192
2000	1.4	1	0.028	0.058	5.79	6491164558
2000	1.4	1	0.028	0.058	5.79	6517725249
2000	1.5	1	0.028	0.058	6.21	6470149301
2000	1.5	1	0.028	0.058	6.21	6480733021
2000	1.5	1	0.028	0.058	6.21	6513276757
2000	1.6	1	0.028	0.058	6.62	7485354163
2000	1.6	1	0.028	0.058	6.62	7463219141
2000	1.6	1	0.028	0.058	6.62	7469002062
2000	1.7	1	0.028	0.058	7.03	7467021531
2000	1.7	1	0.028	0.058	7.03	7483750891
2000	1.7	1	0.028	0.058	7.03	7474489116
2000	1.8	1	0.028	0.058	7.45	7455488534
2000	1.8	1	0.028	0.058	7.45	7441101183
2000	1.8	1	0.028	0.058	7.45	7463322831
2000	1.9	1	0.028	0.058	7.86	8378011994
2000	1.9	1	0.028	0.058	7.86	8463486103
2000	1.9	1	0.028	0.058	7.86	8416280903
2000	2	1	0.028	0.058	8.28	8427604047
2000	2	1	0.028	0.058	8.28	8449594116
2000	2	1	0.028	0.058	8.28	8440064680
2000	0.87	1	0.01	0.07	2.50	3670588882
2000	0.87	1	0.01	0.07	3.60	4808994686
2000	0.87	1	0.01	0.07	4.30	4803763154
2000	0.87	1	0.028	0.055	2.50	3402390375
2000	0.87	1	0.028	0.055	3.60	4441067123
2000	0.87	1	0.028	0.055	4.30	4459902948
2000	0.87	1	0.055	0.085	2.50	3090019930
2000	0.87	1	0.055	0.085	3.60	3982677032
2000	0.87	1	0.055	0.085	4.30	3973470228
245	0.87	1	0.01	0.07	2.50	3652136034
245	0.87	1	0.01	0.07	3.60	4822464614
245	0.87	1	0.01	0.07	4.30	4819006125
245	0.87	1	0.028	0.055	2.50	3419821238
245	0.87	1	0.028	0.055	3.60	4461560477
245	0.87	1	0.028	0.055	4.30	4429993125
245	0.87	1	0.055	0.085	2.50	3079987902
245	0.87	1	0.055	0.085	3.60	3984569170
245	0.87	1	0.055	0.085	4.30	3954580572
2000	2	1	0.01	0.07	5.81	7195535500
2000	2	1	0.01	0.07	8.30	9429378746
2000	2	1	0.01	0.07	10.00	11628521712

2000	2	1	0.028	0.055	5.81	6543933790
2000	2	1	0.028	0.055	8.30	8442795603
2000	2	1	0.028	0.055	10.00	10245029596
2000	2	1	0.055	0.085	5.81	5684725383
2000	2	1	0.055	0.085	8.30	7139480800
2000	2	1	0.055	0.085	10.00	8494005055
245	2	1	0.01	0.07	5.81	7208752910
245	2	1	0.01	0.07	8.30	9435839969
245	2	1	0.01	0.07	10.00	11613070067
245	2	1	0.028	0.055	5.81	6531895883
245	2	1	0.028	0.055	8.30	8417858689
245	2	1	0.028	0.055	10.00	10227914015
245	2	1	0.055	0.085	5.81	5677130463
245	2	1	0.055	0.085	8.30	7147260336
245	2	1	0.055	0.085	10.00	8463436002
245	0.87	0	0.01	0.07	2.50	594394608.8
245	0.87	0	0.01	0.07	3.60	754309292.7
245	0.87	0	0.01	0.07	4.30	742959572.3
245	0.87	0	0.028	0.055	2.50	555355985.3
245	0.87	0	0.028	0.055	3.60	698032597.2
245	0.87	0	0.028	0.055	4.30	690134112.4
245	0.87	0	0.055	0.085	2.50	504168182.2
245	0.87	0	0.055	0.085	3.60	623027523.3
245	0.87	0	0.055	0.085	4.30	614701304.8
2000	2	0	0.01	0.07	5.81	1160476265
2000	2	0	0.01	0.07	8.30	1469867464
2000	2	0	0.01	0.07	10.00	2591310315
2000	2	0	0.028	0.055	5.81	1053131190
2000	2	0	0.028	0.055	8.30	1317928644
2000	2	0	0.028	0.055	10.00	1809089230
2000	2	0	0.055	0.085	5.81	918662487.5
2000	2	0	0.055	0.085	8.30	1116308730
2000	2	0	0.055	0.085	10.00	1398372183

M1:

OFFSITE COST	WASTE	STORAGE IND	REAL RATE	RATE	LIFE	GLASS	POWER	LCC
2000	0.87	0	0.028	0.058	26.45	12734.3	79432.5	424608656
2000	0.9	0	0.028	0.058	27.36	12734.3	79432.5	431850291
2000	1	0	0.028	0.058	30.4	12734.3	79432.5	458068125
2000	1.1	0	0.028	0.058	33.44	12734.3	79432.5	483770705
2000	1.2	0	0.028	0.058	36.48	12734.3	79432.5	506416978
2000	1.3	0	0.028	0.058	39.52	12734.3	79432.5	534814685
2000	1.4	0	0.028	0.058	42.56	12734.3	79432.5	555147995
2000	1.5	0	0.028	0.058	45.6	12734.3	79432.5	574669497
2000	1.6	0	0.028	0.058	48.64	12734.3	79432.5	588846676
2000	1.7	0	0.028	0.058	51.68	12734.3	79432.5	602834053
2000	1.8	0	0.028	0.058	54.72	12734.3	79432.5	620343225
2000	1.9	0	0.028	0.058	57.76	12734.3	79432.5	630181476
2000	2	0	0.028	0.058	60.8	12734.3	79432.5	641463798
2000	0.87	1	0.028	0.058	26.45	12734.3	79432.5	872187724
2000	0.9	1	0.028	0.058	27.36	12734.3	79432.5	892618875
2000	1	1	0.028	0.058	30.4	12734.3	79432.5	951545745
2000	1.1	1	0.028	0.058	33.44	12734.3	79432.5	1005389479
2000	1.2	1	0.028	0.058	36.48	12734.3	79432.5	1057525473
2000	1.3	1	0.028	0.058	39.52	12734.3	79432.5	1119959931
2000	1.4	1	0.028	0.058	42.56	12734.3	79432.5	1157387421
2000	1.5	1	0.028	0.058	45.6	12734.3	79432.5	1199994124
2000	1.6	1	0.028	0.058	48.64	12734.3	79432.5	1234378563
2000	1.7	1	0.028	0.058	51.68	12734.3	79432.5	1267355081
2000	1.8	1	0.028	0.058	54.72	12734.3	79432.5	1296860426
2000	1.9	1	0.028	0.058	57.76	12734.3	79432.5	1322127186
2000	2	1	0.028	0.058	60.8	12734.3	79432.5	1346880444
2000	0.87	1	0.01	0.07	22.1	12734.3	79432.5	1015505417
2000	0.87	1	0.01	0.07	26.5	12734.3	79432.5	1182689109
2000	0.87	1	0.01	0.07	35.3	12734.3	79432.5	1435307450
2000	0.87	1	0.028	0.055	22.1	12734.3	79432.5	794492908
2000	0.87	1	0.028	0.055	26.5	12734.3	79432.5	890431399
2000	0.87	1	0.028	0.055	35.3	12734.3	79432.5	1022400278
2000	0.87	1	0.055	0.085	22.1	12734.3	79432.5	568387323
2000	0.87	1	0.055	0.085	26.5	12734.3	79432.5	615984152
2000	0.87	1	0.055	0.085	35.3	12734.3	79432.5	661650686
245	0.87	1	0.01	0.07	22.1	12734.3	79432.5	557600706
245	0.87	1	0.01	0.07	26.5	12734.3	79432.5	637636474
245	0.87	1	0.01	0.07	35.3	12734.3	79432.5	753275912
245	0.87	1	0.028	0.055	22.1	12734.3	79432.5	443271336
245	0.87	1	0.028	0.055	26.5	12734.3	79432.5	487920721
245	0.87	1	0.028	0.055	35.3	12734.3	79432.5	547498701
245	0.87	1	0.055	0.085	22.1	12734.3	79432.5	324164923
245	0.87	1	0.055	0.085	26.5	12734.3	79432.5	342916587
245	0.87	1	0.055	0.085	35.3	12734.3	79432.5	363002161
2000	2	1	0.01	0.07	50.7	12734.3	79432.5	1973369311
2000	2	1	0.01	0.07	60.8	12734.3	79432.5	2217702384
2000	2	1	0.01	0.07	81.1	12734.3	79432.5	2297866571
2000	2	1	0.028	0.055	50.7	12734.3	79432.5	1270729635
2000	2	1	0.028	0.055	60.8	12734.3	79432.5	1345480030

2000	2	1	0.028	0.055	81.1	12734.3	79432.5	135816057[illegible]
2000	2	1	0.055	0.085	50.7	12734.3	79432.5	7446662[illegible]
2000	2	1	0.055	0.085	60.8	12734.3	79432.5	756310069
2000	2	1	0.055	0.085	81.1	12734.3	79432.5	749266173
245	2	1	0.01	0.07	50.7	12734.3	79432.5	1047220205
245	2	1	0.01	0.07	60.8	12734.3	79432.5	1160641361
245	2	1	0.01	0.07	81.1	12734.3	79432.5	1180216559
245	2	1	0.028	0.055	50.7	12734.3	79432.5	689245226
245	2	1	0.028	0.055	60.8	12734.3	79432.5	719195560
245	2	1	0.028	0.055	81.1	12734.3	79432.5	711611451
245	2	1	0.055	0.085	50.7	12734.3	79432.5	413582505
245	2	1	0.055	0.085	60.8	12734.3	79432.5	414448586
245	2	1	0.055	0.085	81.1	12734.3	79432.5	405561865
245	0.87	0	0.01	0.07	22.1	12734.3	79432.5	496561758
245	0.87	0	0.01	0.07	26.5	12734.3	79432.5	564733318
245	0.87	0	0.01	0.07	35.3	12734.3	79432.5	667460965
245	0.87	0	0.028	0.055	22.1	12734.3	79432.5	397709321
245	0.87	0	0.028	0.055	26.5	12734.3	79432.5	432951915
245	0.87	0	0.028	0.055	35.3	12734.3	79432.5	486673806
245	0.87	0	0.055	0.085	22.1	12734.3	79432.5	290045202
245	0.87	0	0.055	0.085	26.5	12734.3	79432.5	305225854
245	0.87	0	0.055	0.085	35.3	12734.3	79432.5	321170806
2000	2	0	0.01	0.07	50.7	12734.3	79432.5	945604973
2000	2	0	0.01	0.07	60.8	12734.3	79432.5	1049435772
2000	2	0	0.01	0.07	81.1	12734.3	79432.5	1063791470
2000	2	0	0.028	0.055	50.7	12734.3	79432.5	6142216[illegible]
2000	2	0	0.028	0.055	60.8	12734.3	79432.5	64131782[illegible]
2000	2	0	0.028	0.055	81.1	12734.3	79432.5	639037054
2000	2	0	0.055	0.085	50.7	12734.3	79432.5	373387078
2000	2	0	0.055	0.085	60.8	12734.3	79432.5	372463277
2000	2	0	0.055	0.085	81.1	12734.3	79432.5	361929554

M2:

OFFSITE COST	WASTE	STORAGE IND	REAL RATE	RATE	LIFE	GLASS	POWER	LCC
2000	0.87	0	0.028	0.058	8.18	41187.05	256960	534650737
2000	0.9	0	0.028	0.058	8.46	41187.05	256960	539915280
2000	1	0	0.028	0.058	9.40	41187.05	256960	572757538
2000	1.1	0	0.028	0.058	10.34	41187.05	256960	625989554
2000	1.2	0	0.028	0.058	11.28	41187.05	256960	654684909
2000	1.3	0	0.028	0.058	12.22	41187.05	256960	689380946
2000	1.4	0	0.028	0.058	13.16	41187.05	256960	733029038
2000	1.5	0	0.028	0.058	14.10	41187.05	256960	765746707
2000	1.6	0	0.028	0.058	15.04	41187.05	256960	798179959
2000	1.7	0	0.028	0.058	15.98	41187.05	256960	844970091
2000	1.8	0	0.028	0.058	16.92	41187.05	256960	872618693
2000	1.9	0	0.028	0.058	17.86	41187.05	256960	896393952
2000	2	0	0.028	0.058	18.80	41187.05	256960	939902046
2000	0.87	1	0.028	0.058	8.18	41187.05	256960	1097265956
2000	0.9	1	0.028	0.058	8.46	41187.05	256960	1099010843
2000	1	1	0.028	0.058	9.40	41187.05	256960	1191953854
2000	1.1	1	0.028	0.058	10.34	41187.05	256960	1307533441
2000	1.2	1	0.028	0.058	11.28	41187.05	256960	1396521773
2000	1.3	1	0.028	0.058	12.22	41187.05	256960	1481518778
2000	1.4	1	0.028	0.058	13.16	41187.05	256960	1590418758
2000	1.5	1	0.028	0.058	14.10	41187.05	256960	1672334870
2000	1.6	1	0.028	0.058	15.04	41187.05	256960	1757750440
2000	1.7	1	0.028	0.058	15.98	41187.05	256960	1850782044
2000	1.8	1	0.028	0.058	16.92	41187.05	256960	1928351255
2000	1.9	1	0.028	0.058	17.86	41187.05	256960	2003209977
2000	2	1	0.028	0.058	18.80	41187.05	256960	2093781416
2000	0.87	1	0.01	0.07	6.80	41187.05	256960	1154454838
2000	0.87	1	0.01	0.07	8.20	41187.05	256960	1258664945
2000	0.87	1	0.01	0.07	10.90	41187.05	256960	1620580826
2000	0.87	1	0.028	0.055	6.80	41187.05	256960	1007312894
2000	0.87	1	0.028	0.055	8.20	41187.05	256960	1098197962
2000	0.87	1	0.028	0.055	10.90	41187.05	256960	1376613310
2000	0.87	1	0.055	0.085	6.80	41187.05	256960	837726109
2000	0.87	1	0.055	0.085	8.20	41187.05	256960	898539207
2000	0.87	1	0.055	0.085	10.90	41187.05	256960	1087530216
245	0.87	1	0.01	0.07	6.80	41187.05	256960	647701063
245	0.87	1	0.01	0.07	8.20	41187.05	256960	685681224
245	0.87	1	0.01	0.07	10.90	41187.05	256960	835860068
245	0.87	1	0.028	0.055	6.80	41187.05	256960	569614869
245	0.87	1	0.028	0.055	8.20	41187.05	256960	602366070
245	0.87	1	0.028	0.055	10.90	41187.05	256960	717658560
245	0.87	1	0.055	0.085	6.80	41187.05	256960	478654703
245	0.87	1	0.055	0.085	8.20	41187.05	256960	498619643
245	0.87	1	0.055	0.085	10.90	41187.05	256960	581713085
2000	2	1	0.01	0.07	15.60	41187.05	256960	2298552619
2000	2	1	0.01	0.07	18.90	41187.05	256960	2629360035
2000	2	1	0.01	0.07	25.10	41187.05	256960	3232948939
2000	2	1	0.028	0.055	15.60	41187.05	256960	1871760968

2000	2	1	0.028	0.055	18.90	41187.05	256960	20853281[illegible]
2000	2	1	0.028	0.055	25.10	41187.05	256960	24706182
2000	2	1	0.055	0.085	15.60	41187.05	256960	1413699608
2000	2	1	0.055	0.085	18.90	41187.05	256960	1526680179
2000	2	1	0.055	0.085	25.10	41187.05	256960	1716427463
245	2	1	0.01	0.07	15.60	41187.05	256960	1190610849
245	2	1	0.01	0.07	18.90	41187.05	256960	1329401200
245	2	1	0.01	0.07	25.10	41187.05	256960	1583628157
245	2	1	0.028	0.055	15.60	41187.05	256960	984846705
245	2	1	0.028	0.055	18.90	41187.05	256960	1070551971
245	2	1	0.028	0.055	25.10	41187.05	256960	1214707429
245	2	1	0.055	0.085	15.60	41187.05	256960	756878030
245	2	1	0.055	0.085	18.90	41187.05	256960	797165231
245	2	1	0.055	0.085	25.10	41187.05	256960	864497387
245	0.87	0	0.01	0.07	6.80	41187.05	256960	581438194
245	0.87	0	0.01	0.07	8.20	41187.05	256960	607704906
245	0.87	0	0.01	0.07	10.90	41187.05	256960	731910071
245	0.87	0	0.028	0.055	6.80	41187.05	256960	517158570
245	0.87	0	0.028	0.055	8.20	41187.05	256960	536961066
245	0.87	0	0.028	0.055	10.90	41187.05	256960	632713349
245	0.87	0	0.055	0.085	6.80	41187.05	256960	434650868
245	0.87	0	0.055	0.085	8.20	41187.05	256960	446586104
245	0.87	0	0.055	0.085	10.90	41187.05	256960	510702522
2000	2	0	0.01	0.07	15.60	41187.05	256960	1058716544
2000	2	0	0.01	0.07	18.90	41187.05	256960	1178642353
2000	2	0	0.01	0.07	25.10	41187.05	256960	13849341
2000	2	0	0.028	0.055	15.60	41187.05	256960	871473902
2000	2	0	0.028	0.055	18.90	41187.05	256960	947815400
2000	2	0	0.028	0.055	25.10	41187.05	256960	1065143424
2000	2	0	0.055	0.085	15.60	41187.05	256960	664259367
2000	2	0	0.055	0.085	18.90	41187.05	256960	706153592
2000	2	0	0.055	0.085	25.10	41187.05	256960	759690574

M3:

OFFSITE COST	WASTE	STORAGE IND	REAL RATE	RATE	LIFE	GLASS	POWER	LCC
2000	0.87	0	0.028	0.058	5.05	68645	428267	539533818
2000	0.9	0	0.028	0.058	5.22	68645	428267	539967055
2000	1	0	0.028	0.058	5.80	68645	428267	597311118
2000	1.1	0	0.028	0.058	6.38	68645	428267	597244302
2000	1.2	0	0.028	0.058	6.96	68645	428267	675037758
2000	1.3	0	0.028	0.058	7.54	68645	428267	733737064
2000	1.4	0	0.028	0.058	8.12	68645	428267	729686249
2000	1.5	0	0.028	0.058	8.70	68645	428267	789426412
2000	1.6	0	0.028	0.058	9.28	68645	428267	781862444
2000	1.7	0	0.028	0.058	9.86	68645	428267	860220594
2000	1.8	0	0.028	0.058	10.44	68645	428267	859678907
2000	1.9	0	0.028	0.058	11.02	68645	428267	909933461
2000	2	0	0.028	0.058	11.60	68645	428267	961697086
2000	0.87	1	0.028	0.058	5.05	68645	428267	1147359074
2000	0.9	1	0.028	0.058	5.22	68645	428267	1146627764
2000	1	1	0.028	0.058	5.8	68645	428267	1318559649
2000	1.1	1	0.028	0.058	6.38	68645	428267	1319805466
2000	1.2	1	0.028	0.058	6.96	68645	428267	1502328321
2000	1.3	1	0.028	0.058	7.54	68645	428267	1671401478
2000	1.4	1	0.028	0.058	8.12	68645	428267	1668817231
2000	1.5	1	0.028	0.058	8.7	68645	428267	1826458451
2000	1.6	1	0.028	0.058	9.28	68645	428267	1821910495
2000	1.7	1	0.028	0.058	9.86	68645	428267	1997613057
2000	1.8	1	0.028	0.058	10.44	68645	428267	1994309379
2000	1.9	1	0.028	0.058	11.02	68645	428267	2143415631
2000	2	1	0.028	0.058	11.6	68645	428267	2283598473
2000	0.87	1	0.01	0.07	4.2	68645	428267	1099909138
2000	0.87	1	0.01	0.07	5.05	68645	428267	1287853924
2000	0.87	1	0.01	0.07	6.73	68645	428267	1693268997
2000	0.87	1	0.028	0.055	4.2	68645	428267	985559693
2000	0.87	1	0.028	0.055	5.05	68645	428267	1147513153
2000	0.87	1	0.028	0.055	6.73	68645	428267	1481464374
2000	0.87	1	0.055	0.085	4.2	68645	428267	843204388
2000	0.87	1	0.055	0.085	5.05	68645	428267	971329455
2000	0.87	1	0.055	0.085	6.73	68645	428267	1220750928
245	0.87	1	0.01	0.07	4.2	68645	428267	612566234
245	0.87	1	0.01	0.07	5.05	68645	428267	681241096
245	0.87	1	0.01	0.07	6.73	68645	428267	851397514
245	0.87	1	0.028	0.055	4.2	68645	428267	552111491
245	0.87	1	0.028	0.055	5.05	68645	428267	610580439
245	0.87	1	0.028	0.055	6.73	68645	428267	748630514
245	0.87	1	0.055	0.085	4.2	68645	428267	476402088
245	0.87	1	0.055	0.085	5.05	68645	428267	522203723
245	0.87	1	0.055	0.085	6.73	68645	428267	625033295
2000	2	1	0.01	0.07	9.67	68645	428267	2370174927
2000	2	1	0.01	0.07	11.6	68645	428267	2720673799
2000	2	1	0.01	0.07	15.47	68645	428267	3246149604

2000	2	1	0.028	0.055	9.67	68645	428267	202760864[illegible]
2000	2	1	0.028	0.055	11.6	68645	428267	22835872[illegible]
2000	2	1	0.028	0.055	15.47	68645	428267	2670061339
2000	2	1	0.055	0.085	9.67	68645	428267	1617745042
2000	2	1	0.055	0.085	11.6	68645	428267	1790562363
2000	2	1	0.055	0.085	15.47	68645	428267	2017659707
245	2	1	0.01	0.07	9.67	68645	428267	1181293541
245	2	1	0.01	0.07	11.6	68645	428267	1309250167
245	2	1	0.01	0.07	15.47	68645	428267	1515061611
245	2	1	0.028	0.055	9.67	68645	428267	1026143823
245	2	1	0.028	0.055	11.6	68645	428267	1110565603
245	2	1	0.028	0.055	15.47	68645	428267	1254809732
245	2	1	0.055	0.085	9.67	68645	428267	825069047
245	2	1	0.055	0.085	11.6	68645	428267	884089506
245	2	1	0.055	0.085	15.47	68645	428267	965460913
245	0.87	0	0.01	0.07	4.2	68645	428267	544317059
245	0.87	0	0.01	0.07	5.05	68645	428267	599703863
245	0.87	0	0.01	0.07	6.73	68645	428267	735017179
245	0.87	0	0.028	0.055	4.2	68645	428267	494395115
245	0.87	0	0.028	0.055	5.05	68645	428267	539682166
245	0.87	0	0.028	0.055	6.73	68645	428267	649306526
245	0.87	0	0.055	0.085	4.2	68645	428267	425348743
245	0.87	0	0.055	0.085	5.05	68645	428267	463447923
245	0.87	0	0.055	0.085	6.73	68645	428267	543685144
2000	2	0	0.01	0.07	9.67	68645	428267	1031669278
2000	2	0	0.01	0.07	11.6	68645	428267	11211289[illegible]
2000	2	0	0.01	0.07	15.47	68645	428267	128999549[illegible]
2000	2	0	0.028	0.055	9.67	68645	428267	882951280
2000	2	0	0.028	0.055	11.6	68645	428267	962595281
2000	2	0	0.028	0.055	15.47	68645	428267	1074958401
2000	2	0	0.055	0.085	9.67	68645	428267	718786831
2000	2	0	0.055	0.085	11.6	68645	428267	760812188
2000	2	0	0.055	0.085	15.47	68645	428267	825407517

Appendix H. Score Sheets

For each of the following contingencies, alternatives were compared on the basis of LCC and process life. For on-site storage, the nine observations are the combinations resulting from three assumptions about volume reduction (or bulk up) and three assumptions about the real rate. For off-site storage, 18 observations arise because we consider both listed and delisted waste. Under each contingency, the best and worst performance in terms of LCC and process life provide the range over which the alternatives are proportionally scored. SL is the score for LCC and SN is the score for process life. The total score for an alternative in each contingency is the product of the decision maker's weight on LCC and the LCC score plus the product of his weight on process life and the process life score. Since the weight on process life is just one minus the weight on LCC, the total score is simply a function of weight on LCC. SLOPE and CONSTANT are the coefficient of cost weight and the constant term in the function for total score.

Low Waste Volume (870,000 m3), Onsite Storage:

LIFE	LCC	WORST_LIFE	BEST_LIFE	WORST_LCC	BEST_LCC	SN	SL	SLOPE	CONSTANT
M1									
26.1	5E+08	39.3	4.5	977338958	477297148	0.3793	0.9615	0.5822	0.3793103
30.5	6E+08	39.3	4.5	977338958	477297148	0.2529	0.8251	0.5723	0.2528736
39.3	7E+08	39.3	4.5	977338958	477297148	0	0.6197	0.6197	0
26.1	4E+08	39.3	4.5	712348881	397709321	0.3793	1	0.6207	0.3793103
30.5	4E+08	39.3	4.5	712348881	397709321	0.2529	0.888	0.6351	0.2528736
39.3	5E+08	39.3	4.5	712348881	397709321	0	0.7172	0.7172	0
26.1	3E+08	39.3	4.5	623027523	290045202	0.3793	1	0.6207	0.3793103
30.5	3E+08	39.3	4.5	623027523	290045202	0.2529	0.9544	0.7015	0.2528736
39.3	3E+08	39.3	4.5	623027523	290045202	0	0.9065	0.9065	0
M2									
10.8	6E+08	39.3	4.5	977338958	477297148	0.819	0.7917	-0.027	0.8189655
12.2	6E+08	39.3	4.5	977338958	477297148	0.7787	0.7392	-0.04	0.7787356
14.9	7E+08	39.3	4.5	977338958	477297148	0.7011	0.4908	-0.21	0.7011494

10.8	5E+08	39.3	4.5	712348881	397709321	0.819	0.6204	-0.199	0.8189655
12.2	5E+08	39.3	4.5	712348881	397709321	0.7787	0.5574	-0.221	0.7787356
14.9	6E+08	39.3	4.5	712348881	397709321	0.7011	0.2531	-0.448	0.7011494
10.8	4E+08	39.3	4.5	623027523	290045202	0.819	0.5657	-0.253	0.8189655
12.2	4E+08	39.3	4.5	623027523	290045202	0.7787	0.5299	-0.249	0.7787356
14.9	5E+08	39.3	4.5	623027523	290045202	0.7011	0.3373	-0.364	0.7011494
M3									
8.2	5E+08	39.3	4.5	977338958	477297148	0.8937	0.866	-0.028	0.8936782
9.05	6E+08	39.3	4.5	977338958	477297148	0.8693	0.7552	-0.114	0.8692529
10.73	7E+08	39.3	4.5	977338958	477297148	0.821	0.4846	-0.336	0.820977
8.2	5E+08	39.3	4.5	712348881	397709321	0.8937	0.6927	-0.201	0.8936782
9.05	5E+08	39.3	4.5	712348881	397709321	0.8693	0.5488	-0.32	0.8692529
10.73	6E+08	39.3	4.5	712348881	397709321	0.821	0.2004	-0.621	0.820977
8.2	4E+08	39.3	4.5	623027523	290045202	0.8937	0.5937	-0.3	0.8936782
9.05	5E+08	39.3	4.5	623027523	290045202	0.8693	0.4792	-0.39	0.8692529
10.73	5E+08	39.3	4.5	623027523	290045202	0.821	0.2383	-0.583	0.820977
C1									
14.5	5E+08	39.3	4.5	977338958	477297148	0.7126	0.936	0.2234	0.7126437
19.86	7E+08	39.3	4.5	977338958	477297148	0.5586	0.6269	0.0683	0.5586207
23.4	8E+08	39.3	4.5	977338958	477297148	0.4569	0.4458	-0.011	0.4568966
14.5	4E+08	39.3	4.5	712348881	397709321	0.7126	0.8767	0.1641	0.7126437
19.86	5E+08	39.3	4.5	712348881	397709321	0.5586	0.5247	-0.034	0.5586207
23.4	6E+08	39.3	4.5	712348881	397709321	0.4569	0.3309	-0.126	0.4568966
14.5	4E+08	39.3	4.5	623027523	290045202	0.7126	0.8122	0.0995	0.7126437
19.86	4E+08	39.3	4.5	623027523	290045202	0.5586	0.6086	0.0499	0.5586207
23.4	5E+08	39.3	4.5	623027523	290045202	0.4569	0.5103	0.0534	0.4568966
C2									
6.2	5E+08	39.3	4.5	977338958	477297148	0.9511	1	0.0489	0.9511494
8	1E+09	39.3	4.5	977338958	477297148	0.8994	0	-0.899	0.8994253
9.2	8E+08	39.3	4.5	977338958	477297148	0.8649	0.4053	-0.46	0.8649425

6.2	4E+08	39.3	4.5	712348881	397709321	0.9511	0.8552	-0.096	0.9511494
8	7E+08	39.3	4.5	712348881	397709321	0.8994	0	-0.899	0.8994253
9.2	7E+08	39.3	4.5	712348881	397709321	0.8649	0.0438	-0.821	0.8649425
6.2	4E+08	39.3	4.5	623027523	290045202	0.9511	0.6848	-0.266	0.9511494
8	6E+08	39.3	4.5	623027523	290045202	0.8994	0.1323	-0.767	0.8994253
9.2	6E+08	39.3	4.5	623027523	290045202	0.8649	0.0638	-0.801	0.8649425
C3									
4.5	6E+08	39.3	4.5	977338958	477297148	1	0.7658	-0.234	1
5.6	8E+08	39.3	4.5	977338958	477297148	0.9684	0.446	-0.522	0.9683908
6.3	7E+08	39.3	4.5	977338958	477297148	0.9483	0.4687	-0.48	0.9482759
4.5	6E+08	39.3	4.5	712348881	397709321	1	0.499	-0.501	1
5.6	7E+08	39.3	4.5	712348881	397709321	0.9684	0.0455	-0.923	0.9683908
6.3	7E+08	39.3	4.5	712348881	397709321	0.9483	0.0706	-0.878	0.9482759
4.5	5E+08	39.3	4.5	623027523	290045202	1	0.357	-0.643	1
5.6	6E+08	39.3	4.5	623027523	290045202	0.9684	0	-0.968	0.9683908
6.3	6E+08	39.3	4.5	623027523	290045202	0.9483	0.025	-0.923	0.9482759

Low Waste Volume, Offsite Disposal:

LIFE	LCC	WORST_LIFE	BEST_LIFE	WORST_LCC	BEST_LCC	SN	SL	SLOPE	CONSTANT
M1									
26.1	1E+09	39.3	4.5	4952991380	1.016E+09	0.252874	0.95754	0.704667	0.2528736
30.5	1E+09	39.3	4.5	4952991380	1.016E+09	0	0.893383	0.893383	0
39.3	1E+09	39.3	4.5	4952991380	1.016E+09	0.37931	1.05613	0.67682	0.3793103
26.1	8E+08	39.3	4.5	4487175034	794492908	0.252874	0.974019	0.721146	0.2528736
30.5	9E+08	39.3	4.5	4487175034	794492908	0	0.938281	0.938281	0
39.3	1E+09	39.3	4.5	4487175034	794492908	0.37931	1.061231	0.68192	0.3793103
26.1	6E+08	39.3	4.5	3982677032	568387323	0.252874	0.98606	0.733186	0.2528736
30.5	6E+08	39.3	4.5	3982677032	568387323	0	0.972684	0.972684	0
39.3	7E+08	39.3	4.5	3982677032	568387323	0.37931	1.003159	0.623849	0.3793103
26.1	6E+08	39.3	4.5	1725314408	557600706	0.252874	0.931459	0.678586	0.2528736
30.5	6E+08	39.3	4.5	1725314408	557600706	0	0.832429	0.832429	0
39.3	8E+08	39.3	4.5	1725314408	557600706	0.37931	1.097909	0.718598	0.3793103
26.1	4E+08	39.3	4.5	1552340704	443271336	0.252874	0.959742	0.706868	0.2528736
30.5	5E+08	39.3	4.5	1552340704	443271336	0	0.906023	0.906023	0
39.3	5E+08	39.3	4.5	1552340704	443271336	0.37931	1.107393	0.728083	0.3793103
26.1	3E+08	39.3	4.5	1339063311	324164923	0.252874	0.981524	0.72865	0.2528736
30.5	3E+08	39.3	4.5	1339063311	324164923	0	0.961733	0.961733	0
39.3	4E+08	39.3	4.5	1339063311	324164923	0.818966	0.181898	-0.63707	0.8189655
M2									
10.8	1E+09	39.3	4.5	4952991380	1.016E+09	0.778736	0.938245	0.159509	0.7787356
12.2	1E+09	39.3	4.5	4952991380	1.016E+09	0.701149	0.84633	0.14518	0.7011494
14.9	2E+09	39.3	4.5	4952991380	1.016E+09	0.818966	1.002081	0.183115	0.8189655
10.8	1E+09	39.3	4.5	4487175034	794492908	0.778736	0.917755	0.139019	0.7787356
12.2	1E+09	39.3	4.5	4487175034	794492908	0.701149	0.842358	0.141209	0.7011494
14.9	1E+09	39.3	4.5	4487175034	794492908	0.818966	0.988292	0.169327	0.8189655
10.8	8E+08	39.3	4.5	3982677032	568387323	0.778736	0.903303	0.124567	0.7787356

12.2	9E+08	39.3	4.5	3982677032	568387323	0.701149	0.84795	0.146801	0.7011494
14.9	1E+09	39.3	4.5	3982677032	568387323	0.818966	0.97677	0.157805	0.8189655
10.8	6E+08	39.3	4.5	1725314408	557600706	0.778736	0.890315	0.11158	0.7787356
12.2	7E+08	39.3	4.5	1725314408	557600706	0.701149	0.761706	0.060556	0.7011494
14.9	8E+08	39.3	4.5	1725314408	557600706	0.818966	0.989711	0.170746	0.8189655
10.8	6E+08	39.3	4.5	1552340704	443271336	0.778736	0.856551	0.077816	0.7787356
12.2	6E+08	39.3	4.5	1552340704	443271336	0.701149	0.752597	0.051447	0.7011494
14.9	7E+08	39.3	4.5	1552340704	443271336	0.818966	0.968096	0.149131	0.8189655
10.8	5E+08	39.3	4.5	1339063311	324164923	0.778736	0.828106	0.049371	0.7787356
12.2	5E+08	39.3	4.5	1339063311	324164923	0.701149	0.746233	0.045083	0.7011494
14.9	6E+08	39.3	4.5	1339063311	324164923	0.893678	0.235643	-0.65803	0.8936782
M3									
8.2	1E+09	39.3	4.5	4952991380	1.016E+09	0.869253	0.930832	0.061579	0.8692529
9.05	1E+09	39.3	4.5	4952991380	1.016E+09	0.820977	0.827869	0.006892	0.820977
10.73	2E+09	39.3	4.5	4952991380	1.016E+09	0.893678	1.007605	0.113927	0.8936782
8.2	1E+09	39.3	4.5	4487175034	794492908	0.869253	0.9044	0.035147	0.8692529
9.05	1E+09	39.3	4.5	4487175034	794492908	0.820977	0.813964	-0.00701	0.820977
10.73	1E+09	39.3	4.5	4487175034	794492908	0.893678	0.986809	0.09313	0.8936782
8.2	8E+08	39.3	4.5	3982677032	568387323	0.869253	0.881984	0.012731	0.8692529
9.05	1E+09	39.3	4.5	3982677032	568387323	0.820977	0.808931	-0.01205	0.820977
10.73	1E+09	39.3	4.5	3982677032	568387323	0.893678	0.987061	0.093382	0.8936782
8.2	6E+08	39.3	4.5	1725314408	557600706	0.869253	0.894118	0.024865	0.8692529
9.05	7E+08	39.3	4.5	1725314408	557600706	0.820977	0.7484	-0.07258	0.820977
10.73	9E+08	39.3	4.5	1725314408	557600706	0.893678	1.004701	0.111023	0.8936782
8.2	6E+08	39.3	4.5	1552340704	443271336	0.869253	0.849145	-0.02011	0.8692529
9.05	6E+08	39.3	4.5	1552340704	443271336	0.820977	0.724671	-0.09631	0.820977
10.73	7E+08	39.3	4.5	1552340704	443271336	0.893678	0.970127	0.076449	0.8936782
8.2	5E+08	39.3	4.5	1339063311	324164923	0.869253	0.804868	-0.06438	0.8692529
9.05	5E+08	39.3	4.5	1339063311	324164923	0.820977	0.703548	-0.11743	0.820977
10.73	6E+08	39.3	4.5	1339063311	324164923	0.712644	-1.69042	-2.40306	0.7126437

C1

14.5	3E+09	39.3	4.5	4952991380	1.016E+09	0.558621	0.219581	-0.33904	0.5586207
19.86	4E+09	39.3	4.5	4952991380	1.016E+09	0.456897	0.063929	-0.39297	0.4568966
23.4	5E+09	39.3	4.5	4952991380	1.016E+09	0.712644	0.594492	-0.11815	0.7126437
14.5	3E+09	39.3	4.5	4487175034	794492908	0.558621	0.303977	-0.25464	0.5586207
19.86	3E+09	39.3	4.5	4487175034	794492908	0.456897	0.190114	-0.26678	0.4568966
23.4	4E+09	39.3	4.5	4487175034	794492908	0.712644	0.64554	-0.0671	0.7126437
14.5	2E+09	39.3	4.5	3982677032	568387323	0.558621	0.412921	-0.1457	0.5586207
19.86	3E+09	39.3	4.5	3982677032	568387323	0.456897	0.344136	-0.11276	0.4568966
23.4	3E+09	39.3	4.5	3982677032	568387323	0.712644	0.863425	0.150781	0.7126437
14.5	1E+09	39.3	4.5	1725314408	557600706	0.558621	0.191464	-0.36716	0.5586207
19.86	2E+09	39.3	4.5	1725314408	557600706	0.456897	0	-0.4569	0.4568966
23.4	2E+09	39.3	4.5	1725314408	557600706	0.712644	0.659699	-0.05294	0.7126437
14.5	1E+09	39.3	4.5	1552340704	443271336	0.558621	0.164953	-0.39367	0.5586207
19.86	1E+09	39.3	4.5	1552340704	443271336	0.456897	0	-0.4569	0.4568966
23.4	2E+09	39.3	4.5	1552340704	443271336	0.712644	0.630358	-0.08229	0.7126437
14.5	9E+08	39.3	4.5	1339063311	324164923	0.558621	0.137292	-0.42133	0.5586207
19.86	1E+09	39.3	4.5	1339063311	324164923	0.456897	0	-0.4569	0.4568966
23.4	1E+09	39.3	4.5	1339063311	324164923	0.951149	-1.55194	-2.50308	0.9511494
C2									
6.2	3E+09	39.3	4.5	4952991380	1.016E+09	0.899425	0.164694	-0.73473	0.8994253
8	4E+09	39.3	4.5	4952991380	1.016E+09	0.864943	0	-0.86494	0.8649425
9.2	5E+09	39.3	4.5	4952991380	1.016E+09	0.951149	0.571697	-0.37945	0.9511494
6.2	3E+09	39.3	4.5	4487175034	794492908	0.899425	0.150658	-0.74877	0.8994253
8	4E+09	39.3	4.5	4487175034	794492908	0.864943	0	-0.86494	0.8649425
9.2	4E+09	39.3	4.5	4487175034	794492908	0.951149	0.562984	-0.38817	0.9511494
6.2	2E+09	39.3	4.5	3982677032	568387323	0.899425	0.165852	-0.73357	0.8994253
8	3E+09	39.3	4.5	3982677032	568387323	0.864943	0.037132	-0.82781	0.8649425
9.2	4E+09	39.3	4.5	3982677032	568387323	0.951149	0.941745	-0.0094	0.9511494
6.2	8E+08	39.3	4.5	1725314408	557600706	0.899425	0.527721	-0.3717	0.8994253
8	1E+09	39.3	4.5	1725314408	557600706	0.864943	0.397526	-0.46742	0.8649425
9.2	1E+09	39.3	4.5	1725314408	557600706	0.951149	0.867669	-0.08348	0.9511494
6.2	7E+08	39.3	4.5	1552340704	443271336	0.899425	0.491289	-0.40814	0.8994253

8	1E+09	39.3	4.5	1552340704	443271336	0.864943	0.370004	-0.49494	0.8649425
9.2	1E+09	39.3	4.5	1552340704	443271336	0.951149	0.826914	-0.12424	0.9511494
6.2	6E+08	39.3	4.5	1339063311	324164923	0.899425	0.454405	-0.44502	0.8994253
8	9E+08	39.3	4.5	1339063311	324164923	0.864943	0.351421	-0.51352	0.8649425
9.2	1E+09	39.3	4.5	1339063311	324164923	1	-2.2973	-3.2973	1
C3									
4.5	4E+09	39.3	4.5	4952991380	1.016E+09	0.968391	0.036571	-0.93182	0.9683908
5.6	5E+09	39.3	4.5	4952991380	1.016E+09	0.948276	0.037899	-0.91038	0.9482759
6.3	5E+09	39.3	4.5	4952991380	1.016E+09	1	0.393805	-0.6062	1
4.5	3E+09	39.3	4.5	4487175034	794492908	0.968391	0.012486	-0.9559	0.9683908
5.6	4E+09	39.3	4.5	4487175034	794492908	0.948276	0.007385	-0.94089	0.9482759
6.3	4E+09	39.3	4.5	4487175034	794492908	1	0.378358	-0.62164	1
4.5	3E+09	39.3	4.5	3982677032	568387323	0.968391	0	-0.96839	0.9683908
5.6	4E+09	39.3	4.5	3982677032	568387323	0.948276	0.002697	-0.94558	0.9482759
6.3	4E+09	39.3	4.5	3982677032	568387323	1	0.883156	-0.11684	1
4.5	1E+09	39.3	4.5	1725314408	557600706	0.968391	0.41498	-0.55341	0.9683908
5.6	1E+09	39.3	4.5	1725314408	557600706	0.948276	0.424191	-0.52408	0.9482759
6.3	1E+09	39.3	4.5	1725314408	557600706	1	0.708605	-0.2914	1
4.5	9E+08	39.3	4.5	1552340704	443271336	0.968391	0.363205	-0.60519	0.9683908
5.6	1E+09	39.3	4.5	1552340704	443271336	0.948276	0.371295	-0.57698	0.9482759
6.3	1E+09	39.3	4.5	1552340704	443271336	1	0.663342	-0.33666	1
4.5	8E+08	39.3	4.5	1339063311	324164923	0.968391	0.308434	-0.65996	0.9683908
5.6	1E+09	39.3	4.5	1339063311	324164923	0.948276	0.315963	-0.63231	0.9482759
6.3	1E+09	39.3	4.5	1339063311	324164923	1.12931	1.319406	0.190096	1.1293103

High Waste Volume (2,000,000 m3), Onsite Storage:

LIFE	LCC	WORST_LIFE	BEST_LIFE	WORST_LCC	BEST_LCC	SN	SL	SLOPE	CONSTANT
M1									
54.7	9.5E+08	85.1	7.81	2591310315	945604973	0.39332	1	0.60668	0.39332385
64.8	1E+09	85.1	7.81	2591310315	945604973	0.26265	0.93691	0.67426	0.26264717
85.1	1.1E+09	85.1	7.81	2591310315	945604973	0	0.92818	0.92818	0
54.7	6.1E+08	85.1	7.81	1809089230	614221671	0.39332	1	0.60668	0.39332385
64.8	6.4E+08	85.1	7.81	1809089230	614221671	0.26265	0.97732	0.71468	0.26264717
85.1	6.4E+08	85.1	7.81	1809089230	614221671	0	0.97923	0.97923	0
54.7	3.7E+08	85.1	7.81	1398372183	361929554	0.39332	0.98895	0.59562	0.39332385
64.8	3.7E+08	85.1	7.81	1398372183	361929554	0.26265	0.98984	0.72719	0.26264717
85.1	3.6E+08	85.1	7.81	1398372183	361929554	0	1	1	0
M2									
19.6	1.1E+09	85.1	7.81	2591310315	945604973	0.84746	0.93127	0.08381	0.84745763
22.9	1.2E+09	85.1	7.81	2591310315	945604973	0.80476	0.8584	0.05364	0.80476129
29.1	1.4E+09	85.1	7.81	2591310315	945604973	0.72454	0.73305	0.0085	0.72454393
19.6	8.7E+08	85.1	7.81	1809089230	614221671	0.84746	0.7847	-0.06276	0.84745763
22.9	9.5E+08	85.1	7.81	1809089230	614221671	0.80476	0.72081	-0.08395	0.80476129
29.1	1.1E+09	85.1	7.81	1809089230	614221671	0.72454	0.62262	-0.10193	0.72454393
19.6	6.6E+08	85.1	7.81	1398372183	361929554	0.84746	0.7083	-0.13916	0.84745763
22.9	7.1E+08	85.1	7.81	1398372183	361929554	0.80476	0.66788	-0.13688	0.80476129
29.1	7.6E+08	85.1	7.81	1398372183	361929554	0.72454	0.61622	-0.10832	0.72454393
M3									
13.7	1E+09	85.1	7.81	2591310315	945604973	0.92418	0.9477	0.02352	0.92418165
15.6	1.1E+09	85.1	7.81	2591310315	945604973	0.89921	0.89334	-0.00587	0.89921076
19.5	1.3E+09	85.1	7.81	2591310315	945604973	0.84914	0.79073	-0.05841	0.8491396
13.7	8.8E+08	85.1	7.81	1809089230	614221671	0.92418	0.7751	-0.14908	0.92418165
15.6	9.6E+08	85.1	7.81	1809089230	614221671	0.89921	0.70844	-0.19077	0.89921076
19.5	1.1E+09	85.1	7.81	1809089230	614221671	0.84914	0.6144	-0.23474	0.8491396

13.7	7.2E+08	85.1	7.81	1398372183	361929554	0.92418	0.65569	-0.26849	0.92418165
15.6	7.6E+08	85.1	7.81	1398372183	361929554	0.89921	0.61514	-0.28407	0.89921076
19.5	8.3E+08	85.1	7.81	1398372183	361929554	0.84914	0.55282	-0.29632	0.8491396
C1									
30.7	1.1E+09	85.1	7.81	2591310315	945604973	0.70333	0.92588	0.22256	0.70332514
43.1	1.4E+09	85.1	7.81	2591310315	945604973	0.54393	0.72361	0.17968	0.54392548
51.3	1.6E+09	85.1	7.81	2591310315	945604973	0.4377	0.59239	0.15469	0.43770216
30.7	8.1E+08	85.1	7.81	1809089230	614221671	0.70333	0.83772	0.1344	0.70332514
43.1	9.7E+08	85.1	7.81	1809089230	614221671	0.54393	0.6992	0.15528	0.54392548
51.3	1.1E+09	85.1	7.81	1809089230	614221671	0.4377	0.62882	0.19112	0.43770216
30.7	5.6E+08	85.1	7.81	1398372183	361929554	0.70333	0.8082	0.10487	0.70332514
43.1	6.1E+08	85.1	7.81	1398372183	361929554	0.54393	0.75691	0.21299	0.54392548
51.3	6.3E+08	85.1	7.81	1398372183	361929554	0.4377	0.74063	0.30292	0.43770216
C2									
11.7	1.1E+09	85.1	7.81	2591310315	945604973	0.95022	0.87979	-0.07043	0.95022457
15.8	1.5E+09	85.1	7.81	2591310315	945604973	0.89662	0.64916	-0.24747	0.89662311
18.6	1.8E+09	85.1	7.81	2591310315	945604973	0.86095	0.4803	-0.38066	0.86095041
11.7	1E+09	85.1	7.81	1809089230	614221671	0.95022	0.67166	-0.27856	0.95022457
15.8	1.3E+09	85.1	7.81	1809089230	614221671	0.89662	0.4318	-0.46482	0.89662311
18.6	1.5E+09	85.1	7.81	1809089230	614221671	0.86095	0.26218	-0.59877	0.86095041
11.7	8.4E+08	85.1	7.81	1398372183	361929554	0.95022	0.54008	-0.41014	0.95022457
15.8	1E+09	85.1	7.81	1398372183	361929554	0.89662	0.35407	-0.54255	0.89662311
18.6	1.2E+09	85.1	7.81	1398372183	361929554	0.86095	0.23301	-0.62794	0.86095041
C3									
7.81	1.2E+09	85.1	7.81	2591310315	945604973	1	0.86944	-0.13056	1
10.3	1.5E+09	85.1	7.81	2591310315	945604973	0.96778	0.68144	-0.28635	0.96778367
12	2.6E+09	85.1	7.81	2591310315	945604973	0.94579	0	-0.94579	0.94578859
7.81	1.1E+09	85.1	7.81	1809089230	614221671	1	0.63267	-0.36733	1
10.3	1.3E+09	85.1	7.81	1809089230	614221671	0.96778	0.41106	-0.55673	0.96778367
12	1.8E+09	85.1	7.81	1809089230	614221671	0.94579	0	-0.94579	0.94578859

7.81	9.2E+08	85.1	7.81	1398372183	361929554	1	0.46284	-0.53716	1
10.3	1.1E+09	85.1	7.81	1398372183	361929554	0.96778	0.27215	-0.69564	0.96778367
12	1.4E+09	85.1	7.81	1398372183	361929554	0.94579	0	-0.94579	0.94578859

High Waste Volume, Offsite Disposal:

LIFE	LCC	WORST_LIFE	BEST_LIFE	WORST_LCC	BEST_LCC	SN	SL	SLOPE	CONSTANT
M1									
54.7	2E+09	85.1	7.81	11628521712	1.973E+09	0	0.966	0.966	0
64.8	2E+09	85.1	7.81	11628521712	1.973E+09	0.393	1.073	0.679	0.3933238
85.1	2E+09	85.1	7.81	11628521712	1.973E+09	0.263	1.065	0.802	0.2626472
54.7	1E+09	85.1	7.81	10245029596	1.271E+09	0	0.99	0.99	0
64.8	1E+09	85.1	7.81	10245029596	1.271E+09	0.393	1.059	0.665	0.3933238
85.1	1E+09	85.1	7.81	10245029596	1.271E+09	0.263	1.057	0.795	0.2626472
54.7	7E+08	85.1	7.81	8494005055	744666241	0	0.999	0.999	0
64.8	8E+08	85.1	7.81	8494005055	744666241	0.393	0.961	0.568	0.3933238
85.1	7E+08	85.1	7.81	8494005055	744666241	0.263	0.946	0.684	0.2626472
54.7	1E+09	85.1	7.81	3945460982	1.047E+09	0	0.954	0.954	0
64.8	1E+09	85.1	7.81	3945460982	1.047E+09	0.393	1.124	0.73	0.3933238
85.1	1E+09	85.1	7.81	3945460982	1.047E+09	0.263	1.113	0.851	0.2626472
54.7	7E+08	85.1	7.81	3290593308	689245226	0	0.991	0.991	0
64.8	7E+08	85.1	7.81	3290593308	689245226	0.393	1.106	0.713	0.3933238
85.1	7E+08	85.1	7.81	3290593308	689245226	0.263	1.106	0.843	0.2626472
54.7	4E+08	85.1	7.81	2539953865	405561865	0	1	1	0
64.8	4E+08	85.1	7.81	2539953865	405561865	0.847	0.113	-0.734	0.8474576
85.1	4E+08	85.1	7.81	2539953865	405561865	0.805	-0.042	-0.847	0.8047613
M2									
19.6	2E+09	85.1	7.81	11628521712	1.973E+09	0.725	0.87	0.145	0.7245439
22.9	3E+09	85.1	7.81	11628521712	1.973E+09	0.847	1.011	0.163	0.8474576
29.1	3E+09	85.1	7.81	11628521712	1.973E+09	0.805	0.988	0.184	0.8047613
19.6	2E+09	85.1	7.81	10245029596	1.271E+09	0.725	0.866	0.142	0.7245439
22.9	2E+09	85.1	7.81	10245029596	1.271E+09	0.847	0.984	0.137	0.8474576
29.1	2E+09	85.1	7.81	10245029596	1.271E+09	0.805	0.971	0.167	0.8047613
19.6	1E+09	85.1	7.81	8494005055	744666241	0.725	0.875	0.15	0.7245439
22.9	2E+09	85.1	7.81	8494005055	744666241	0.847	0.942	0.095	0.8474576

29.1	2E+09	85.1	7.81	8494005055	744666241	0.805	0.925	0.12	0.8047613
19.6	1E+09	85.1	7.81	3945460982	1.047E+09	0.725	0.815	0.09	0.7245439
22.9	1E+09	85.1	7.81	3945460982	1.047E+09	0.847	1.022	0.174	0.8474576
29.1	2E+09	85.1	7.81	3945460982	1.047E+09	0.805	0.992	0.187	0.8047613
19.6	1E+09	85.1	7.81	3290593308	689245226	0.725	0.798	0.073	0.7245439
22.9	1E+09	85.1	7.81	3290593308	689245226	0.847	0.974	0.127	0.8474576
29.1	1E+09	85.1	7.81	3290593308	689245226	0.805	0.959	0.154	0.8047613
19.6	8E+08	85.1	7.81	2539953865	405561865	0.725	0.785	0.06	0.7245439
22.9	8E+08	85.1	7.81	2539953865	405561865	0.924	0.08	-0.845	0.9241817
29.1	9E+08	85.1	7.81	2539953865	405561865	0.899	-0.085	-0.984	0.8992108
M3									
13.67	2E+09	85.1	7.81	11628521712	1.973E+09	0.849	0.868	0.019	0.8491396
15.6	3E+09	85.1	7.81	11628521712	1.973E+09	0.924	0.994	0.07	0.9241817
19.47	3E+09	85.1	7.81	11628521712	1.973E+09	0.899	0.968	0.069	0.8992108
13.67	2E+09	85.1	7.81	10245029596	1.271E+09	0.849	0.844	-0.005	0.8491396
15.6	2E+09	85.1	7.81	10245029596	1.271E+09	0.924	0.961	0.037	0.9241817
19.47	3E+09	85.1	7.81	10245029596	1.271E+09	0.899	0.942	0.043	0.8992108
13.67	2E+09	85.1	7.81	8494005055	744666241	0.849	0.836	-0.013	0.8491396
15.6	2E+09	85.1	7.81	8494005055	744666241	0.924	0.944	0.019	0.9241817
19.47	2E+09	85.1	7.81	8494005055	744666241	0.899	0.927	0.028	0.8992108
13.67	1E+09	85.1	7.81	3945460982	1.047E+09	0.849	0.839	-0.011	0.8491396
15.6	1E+09	85.1	7.81	3945460982	1.047E+09	0.924	1.007	0.083	0.9241817
19.47	2E+09	85.1	7.81	3945460982	1.047E+09	0.899	0.978	0.079	0.8992108
13.67	1E+09	85.1	7.81	3290593308	689245226	0.849	0.783	-0.067	0.8491396
15.6	1E+09	85.1	7.81	3290593308	689245226	0.924	0.948	0.024	0.9241817
19.47	1E+09	85.1	7.81	3290593308	689245226	0.899	0.925	0.026	0.8992108
13.67	8E+08	85.1	7.81	2539953865	405561865	0.849	0.738	-0.111	0.8491396
15.6	9E+08	85.1	7.81	2539953865	405561865	0.703	-1.757	-2.46	0.7033251
19.47	1E+09	85.1	7.81	2539953865	405561865	0.544	-2.726	-3.27	0.5439255
C1									
30.74	6E+09	85.1	7.81	11628521712	1.973E+09	0.438	0.214	-0.224	0.4377022

43.06	8E+09	85.1	7.81	11628521712	1.973E+09	0.703	0.713	0.01	0.7033251
51.27	1E+10	85.1	7.81	11628521712	1.973E+09	0.544	0.602	0.058	0.5439255
30.74	5E+09	85.1	7.81	10245029596	1.271E+09	0.438	0.434	-0.004	0.4377022
43.06	6E+09	85.1	7.81	10245029596	1.271E+09	0.703	0.773	0.07	0.7033251
51.27	6E+09	85.1	7.81	10245029596	1.271E+09	0.544	0.731	0.187	0.5439255
30.74	3E+09	85.1	7.81	8494005055	744666241	0.438	0.599	0.161	0.4377022
43.06	4E+09	85.1	7.81	8494005055	744666241	0.703	0.776	0.073	0.7033251
51.27	4E+09	85.1	7.81	8494005055	744666241	0.544	0.668	0.124	0.5439255
30.74	2E+09	85.1	7.81	3945460982	1.047E+09	0.438	0	-0.438	0.4377022
43.06	3E+09	85.1	7.81	3945460982	1.047E+09	0.703	0.611	-0.092	0.7033251
51.27	4E+09	85.1	7.81	3945460982	1.047E+09	0.544	0.379	-0.165	0.5439255
30.74	2E+09	85.1	7.81	3290593308	689245226	0.438	0	-0.438	0.4377022
43.06	3E+09	85.1	7.81	3290593308	689245226	0.703	0.569	-0.134	0.7033251
51.27	3E+09	85.1	7.81	3290593308	689245226	0.544	0.395	-0.149	0.5439255
30.74	2E+09	85.1	7.81	2539953865	405561865	0.438	0	-0.438	0.4377022
43.06	2E+09	85.1	7.81	2539953865	405561865	0.95	-2.111	-3.061	0.9502246
51.27	3E+09	85.1	7.81	2539953865	405561865	0.897	-3.309	-4.206	0.8966231
C2									
11.66	7E+09	85.1	7.81	11628521712	1.973E+09	0.861	0.015	-0.846	0.8609504
15.8	1E+10	85.1	7.81	11628521712	1.973E+09	0.95	0.562	-0.389	0.9502246
18.56	1E+10	85.1	7.81	11628521712	1.973E+09	0.897	0.358	-0.539	0.8966231
11.66	6E+09	85.1	7.81	10245029596	1.271E+09	0.861	0.08	-0.781	0.8609504
15.8	8E+09	85.1	7.81	10245029596	1.271E+09	0.95	0.568	-0.382	0.9502246
18.56	1E+10	85.1	7.81	10245029596	1.271E+09	0.897	0.419	-0.478	0.8966231
11.66	5E+09	85.1	7.81	8494005055	744666241	0.861	0.148	-0.713	0.8609504
15.8	6E+09	85.1	7.81	8494005055	744666241	0.95	0.86	-0.091	0.9502246
18.56	7E+09	85.1	7.81	8494005055	744666241	0.897	0.781	-0.116	0.8966231
11.66	2E+09	85.1	7.81	3945460982	1.047E+09	0.861	0.364	-0.497	0.8609504
15.8	2E+09	85.1	7.81	3945460982	1.047E+09	0.95	0.806	-0.145	0.9502246
18.56	3E+09	85.1	7.81	3945460982	1.047E+09	0.897	0.642	-0.255	0.8966231
11.66	2E+09	85.1	7.81	3290593308	689245226	0.861	0.341	-0.519	0.8609504
15.8	2E+09	85.1	7.81	3290593308	689245226	0.95	0.751	-0.199	0.9502246

18.56	2E+09	85.1	7.81	3290593308	689245226	0.897	0.627	-0.27	0.8966231
11.66	1E+09	85.1	7.81	2539953865	405561865	0.861	0.319	-0.542	0.8609504
15.8	2E+09	85.1	7.81	2539953865	405561865	1	-2.181	-3.181	1
18.56	2E+09	85.1	7.81	2539953865	405561865	0.968	-3.228	-4.196	0.9677837
C3									
7.81	7E+09	85.1	7.81	11628521712	1.973E+09	0.946	0	-0.946	0.9457886
10.3	9E+09	85.1	7.81	11628521712	1.973E+09	1	0.527	-0.473	1
12	1E+10	85.1	7.81	11628521712	1.973E+09	0.968	0.33	-0.638	0.9677837
7.81	7E+09	85.1	7.81	10245029596	1.271E+09	0.946	0	-0.946	0.9457886
10.3	8E+09	85.1	7.81	10245029596	1.271E+09	1	0.508	-0.492	1
12	1E+10	85.1	7.81	10245029596	1.271E+09	0.968	0.346	-0.622	0.9677837
7.81	6E+09	85.1	7.81	8494005055	744666241	0.946	0	-0.946	0.9457886
10.3	7E+09	85.1	7.81	8494005055	744666241	1	0.854	-0.146	1
12	8E+09	85.1	7.81	8494005055	744666241	0.968	0.786	-0.182	0.9677837
7.81	2E+09	85.1	7.81	3945460982	1.047E+09	0.946	0.34	-0.606	0.9457886
10.3	2E+09	85.1	7.81	3945460982	1.047E+09	1	0.772	-0.228	1
12	3E+09	85.1	7.81	3945460982	1.047E+09	0.968	0.618	-0.35	0.9677837
7.81	2E+09	85.1	7.81	3290593308	689245226	0.946	0.268	-0.678	0.9457886
10.3	2E+09	85.1	7.81	3290593308	689245226	1	0.694	-0.306	1
12	3E+09	85.1	7.81	3290593308	689245226	0.968	0.56	-0.407	0.9677837
7.81	1E+09	85.1	7.81	2539953865	405561865	0.946	0.179	-0.767	0.9457886
10.3	2E+09	85.1	7.81	2539953865	405561865	1.101	1.19	0.089	1.101048
12	2E+09	85.1	7.81	2539953865	405561865	1.101	1.19	0.089	1.101048

APPENDIX I: VITRIFICATION PROCESS SIMULATION DESCRIPTION AND CODE

I.1 Introduction.

The vitrification process simulation is written in Simulation Language for Alternative Modeling (SLAM II) using FORTRAN subroutines. Figure I-1 displays the major subroutines and how they are inter-related. Section I.2 gives a brief description of the operations that take place within each subroutine. Section I.3 lists the limitations and suggested uses for the simulation. Finally, Section I.4 contains the source code for the simulation.

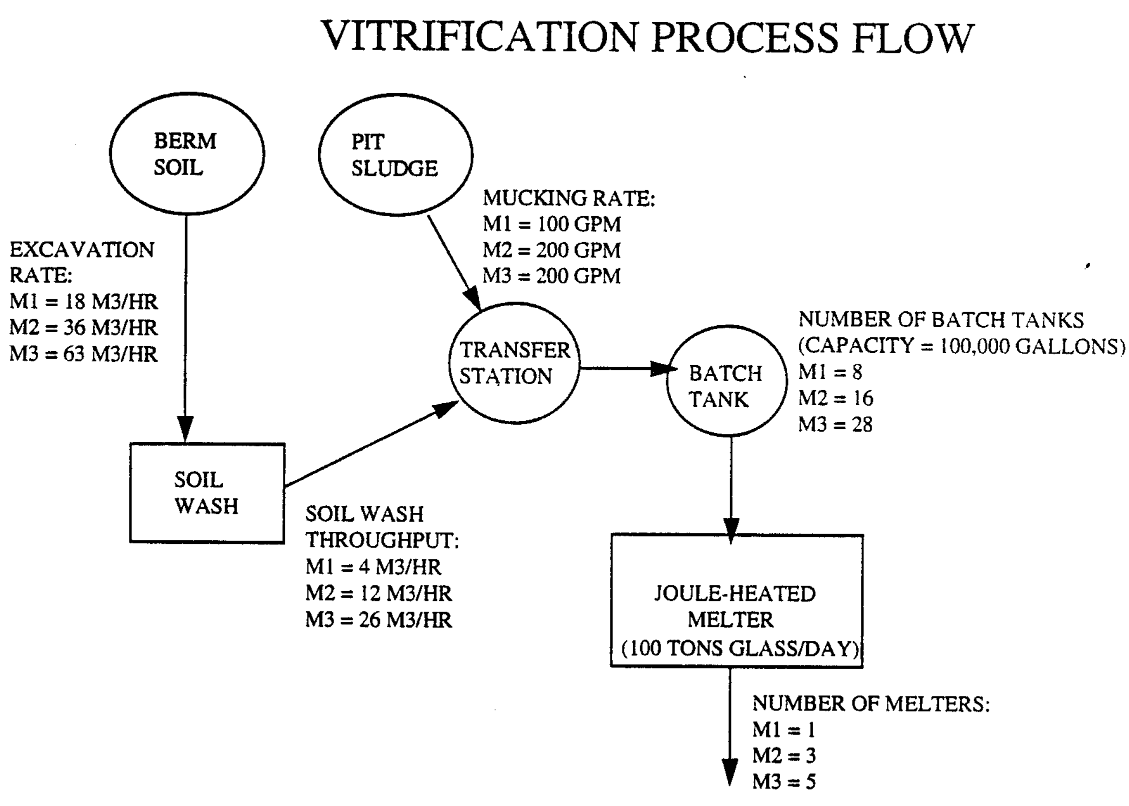

Figure I.1 Vitrification Simulation Flow Diagram

I.2 Subroutine Descriptions.

SUBROUTINE SUBINTLC

-called automatically by SLAM II EXECUTIVE

-used to set configuration, waste volume, and initialize simulation parameters

-schedules initial call to MUCK, EXCAV, BARRELS

-schedules first failure for each system component and calls DOWN

SUBROUTINE EVENT

-processes all subroutine calls

SUBROUTINE DOWN

-decreases number of operating units when a failure occurs

-sets repair time and schedules a call to UP

-sets next failure time and schedules a call to DOWN

SUBROUTINE UP

-increases number of operating units when a repair occurs

SUBROUTINE MUCK

-monitors shift status for mucking resources (shift is up 8 hrs/day, 5 days/week)

-adjusts mucking rate based on number of operating resources

-sets a batch tank busy when appropriate

-fills batch tanks with desired amount of pit sludge

-places filled batch tanks in queue 1 to await blending

-tracks remaining pit sludge

SUBROUTINE EXCAV

- monitors shift status for mucking resources (shift is up 8 hrs/day, 5 days/week)

-adjusts excavating rate based on number of operating resources

-delivers berm soil to a hopper where it awaits soil washing

-tracks remaining berm soil and quantity of soil in the hopper

SUBROUTINE BARRELS

- monitors shift status for mucking resources (shift is up 8 hrs/day, 5 days/week)

-adjusts barrel handling rate based on number of operating resources

-delivers barrels of waste to a processing rack where they await blending

SUBROUTINE SWASH

-adjusts soil washing rate based on number of operating modules

-removes a batch of soil from hopper

-calculates residence time in soil washer

-schedules call to SWOUT for end of residence time

SUBROUTINE SWOUT

-sends small particle soil to queue 2 to await blending

-sends contaminated resin to queue 3 to await blending

SUBROUTINE NEWBLEND

-characterizes the chemical composition of waste from each queue

-combines waste from each queue and characterizes the resulting blend

-calls DUALS to calculate optimal blend of additives to meet compositional constraints for vitrification

SUBROUTINE DUALS

-invokes a dual simplex linear solver to determine additive quantities need to meet compositional constraints at least cost.

-minimizes "Cx" subject to "Ax < B" where:

-- "x" is the vector of additive quantities (kg)

-- "C" is a vector of cost coefficients for the additives ($/kg)

-- "A" is a matrix built from the compositional constraints for vitrification

-- "B" is a vector of constants related to the composition of the input waste stream

-adds mass of additives to original mass of the batch of waste

-calls VITRIFY and passes the updated mass

SUBROUTINE VITRIFY

-sets a melter busy

-calculates melter residence time based on mass of solids in the batch

-schedules call to GLASSOUT for end of residence time

GLASSOUT

-frees a melter and a batch tank

-calculates volume of glass produced for each batch

-updates total glass volume

OTPUT

-called automatically by the SLAM II executive at end of each run

-calculates and displays diagnostic statistics

-writes cost related statistics to output file

I.3 Limitations.

- This simulation was designed to determine appropriate sizes for subsystems supporting a given number of 100 ton-per-day melters. It is not recommended for use as a blueprint for an actual vitrification facility.

- The optimization subroutine for waste blending is built on the compositional data and constraints supplied by Catholic University. The code in subroutine DUALs must be modified to accomodate alternative glass formulas.

• This simulation used excavation, mucking, and soil washing resources based on vendor information. Alternative resources may be modeled by updating the associated rates and numbers in subroutine SUBINTLC.

• This simulation models joule-heated melters with 100 ton-per-day glass throughput and 70% availability. To use a different melter, the user must update the melter residence time formula in subroutine VITRIFY.

• This simulation allows for three waste streams. The user must input the characteristics and amount of waste in each stream. Pit sludge and berm soil will automatically be blended in proportion to complete remediation of each waste stream at roughly the same time. This can be adjusted as desired by updating the formula for batch size of berm soil and amount of pit sludge in SUBINTLC.

I.4 Simulation Code.

```
SUBROUTINE INTLC
$include:'param.inc'
$include:'scom1.com'
    common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
   +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
   +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
   +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
   +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
   +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
   +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
   +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
   +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
   +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
   +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
   +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
   +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
   +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
   +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
   +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
    DIMENSION A(3)
C
```

```
C   INPUT THE RANDOM NUMBER STREAM FOR STOCHASTIC VARIABLES (USED
C   TO GET INDEPENDENT SIMULATION RUNS)
C
    ISTREAM=1
C
C   INITIALIZE THE SLAM XX() VARIABLES TO ZERO
C
    DO 1,I=1,99
    XX(I)=0.0
 1  CONTINUE
C
C   NOTE:  GLOBAL VARIABLES USED TO TRACK UTILIZATION AND STORE
C   CONFIGURATION
C
C   *** CONFIGURATION ***
C
C   NUMBER OF MELTERS
C
    QM=1.0
    XX(9)=QM
    XX(15)=QM
    XX(16)=QM
C
C   MELTER SIZE (METRIC TONS/DAY)
C
    MLTSIZ=100
C
C   BATCH TANK SIZE (CUBIC METERS)
C
    TNKSIZ=378.0
C
C   NUMBER OF BATCH TANKS
C
    BTANKS=8.0
    XX(1)=BTANKS
C
C   TOTAL PIT WASTE (CUBIC METERS)
    SLUDGE=342280
    XX(18)=SLUDGE
C
C   SOIL TO EXCAVATE (CUBIC METERS)
C
    SOIL=528250
    XX(17)=SOIL
C
C   *** VARIABLES CHARACTERIZING THE MUCKING OF PIT SLUDGE ***
C
C   AUGERS OPERATING
C
    QA=1.0
    XX(20)=QA
    XX(51)=QA
C
C   AUGER RATE (HOURS/CUBIC METER OF PIT SLUDGE DELIVERED)
C   RATE FOR ONE AUGER IS 0.044 HOURS/CUBIC METER
```

```
C
      TBDA=0.044/QA
C
C   TOTAL HOURS SPENT WAITING FOR A FREE BATCH TANK
C
      WBTANK=0.0
C
C
C   *** VARIABLES CHARACTERIZING THE EXCAVATION OF BERM SOIL ***
C
C   EXCAVATION RESOURCES
C
      QE=2.0
      XX(21)=QE
      XX(52)=QE
C
C   EXCAVATION RATE (HOURS/CUBIC METER OF SOIL EXCAVATED)
C   RATE FOR ONE EXCAVATOR IS 0.056 HOURS/CUBIC METER
C
      TBDE=0.056/QE
C
C   QUANTITY OF SOIL ACCUMULATED IN HOPPER THAT FEEDS THE SOIL WASHER
C   (CUBIC METERS)
C
      QHOP=0.0
C
C   HOPPER CAPACITY (CUBIC METERS)
C
      CAPHOP=650.0
C
C   TOTAL HOURS EXCAVATION RESOURCES SPEND WAITING FOR HOPPER SPACE
C
      WHOP=0.0
C
C   *** VARIABLES CHARACTERIZING HANDLING OF BARRELED WASTE ***
C
C   NOTE:  PROVISION IS MADE IN THIS SIMULATION FOR A THIRD WASTE
C        STREAM CALLED BARREL WASTE. BECAUSE NO CHARACTERIZATION
C        DATA WAS AVAILABLE FOR BARRELED WASTE AT FERNALD, AND
C        BECAUSE THE QUANTITY OF BARRELED WASTE THEIR IS INSIGNIFICANT
C        WHEN COMPARED TO PIT SLUDGE AND BERM SOIL, WE CHOSE TO
C        DISREGARD BARRELED WASTE.  THE FRAMEWORK IS PROVIDED TO
C        INCLUDE BARRELS IN FUTURE INVESTIGATIONS AT THE DISCRETION
C        OF THE USER.
C
C   NUMBER OF WASTE BARRELS
C
      BARELS=0.
      XX(19)=BARELS
C
C   NUMBER OF BARREL HANDLING RESOURCES
C
      QB=1.0
      XX(22)=QB
      XX(53)=QB
```

```
C
C   BARREL HANDLING RATE (HOURS/BARREL)
C   RATE FOR ONE RESOURCE IS 0.25 HOURS/BARREL
C
    TBDB=0.25/QB
C
C   NUMBER OF WASTE BARRELS BLENDED IN EACH BATCH TANK
C
    BPTANK=10.0
C
C   NUMBER OF BARRELS IN PROCESSING RACK, READY TO PUMP INTO BATCH TANK
C
    QRACK=0.0
C
C   PROCESSING RACK CAPACITY
C
    CAPRAC=50.0
C
C   TOTAL HOURS BARREL HANDLERS SPEND WAITING FOR RACK SPACE
C
    WRACK=0.0
C
C   *** VARIABLES CHARACTERIZING THE SOIL WASH PROCESS ***
C
C   SOIL WASH PROCESS ASSUMES A COMMON FEED AND OUTPUT SYSTEM SUPPORTING
C   A NUMBER OF SOIL WASH MODULES. EACH MODULE IS CAPABLE OF WASHING TWO
C   CUBIC METERS OF SOIL PER HOUR.
C
C   NUMBER OF SOIL WASH MODULES
C
    QS=2.0
    XX(54)=QS
    XX(28)=QS
C
C
C   *** VARIABLES CHARACTERIZING THE BLENDING PROCESS ***
C
C
C   SOLIDM/S/R/B IS THE PERCENT SOLIDS IN MUCKED PIT SLUDGE,
C   WASHED SOIL, RESINS FROM THE SOIL WASH, AND BARRELED WASTE.
C
    SOLIDM=.5
    SOLIDS=.35
    SOLIDR=.35
    SOLIDB=.35
C
C   DENSITY OF SOLIDS IN BATCH TANK (KILOGRAMS/CUBIC METER)
C
    DENSE=1400.0
C
C   EACH WASTE STREAM IS CHARACTERIZED IN TERMS OF WEIGHT PERCENT
C   OF KEY COMPONENTS. DR PEGG, FROM CATHOLIC UNIVERSITY, PROVIDED THE
C   FOLLOWING CHARACTERIZATION DATA FOR PIT SLUDGE, WASHED SOIL, AND
C   RESIN FROM THE SOIL WASHING PROCESS:
C
```

```
C    MEAN WEIGHT PERCENTS FOR EACH KEY COMPONENT(Pxxxx)
C
C    - 2nd CHARACTER REFERS TO
C     -- M: PIT SLUDGE (MUCK)
C     -- S: SMALL PARTICLE SOIL
C     -- R: RESINS FROM ION EXCHANGE
C     -- B: BARREL WASTE
C    - 3rd CHARACTER BEGINS COMPONENT ABBREVIATION
C     -- SIO: SILICON OXIDE
C     -- ALO: ALUMINUM OXIDE
C     -- ETC.
C
      PMALO=.04/1.017
      PMCAO=.45/1.017
      PMFEO=.05/1.017
      PMKO=.004/1.017
      PMMGO=.18/1.017
      PMNAO=.013/1.017
      PMPO=.015/1.017
      PMSIO=.13/1.017
      PMSO=.03/1.017
      PMF=.1/1.017
      PMBO=.002/1.017
      PMLIO=.003/1.017
C
      PSALO=.1
      PSCAO=.1
      PSFEO=.05
      PSKO=.02
      PSMGO=.03
      PSNAO=.01
      PSPO=.002
      PSSIO=.65
      PSSO=.003
      PSB=.002
      PSLIO=.001
      PSF=0.
C
      PRALO=.1
      PRCAO=.1
      PRFEO=.05
      PRKO=.02
      PRMGO=.03
      PRNAO=.01
      PRPO=.002
      PRSIO=.65
      PRSO=.003
      PRB=.002
      PRLIO=.001
      PRF=0.
C
      PBALO=.076
      PBCAO=.22
      PBFEO=.034
      PBKO=.02
```

```
      PBMGO=.053
      PBNAO=.01
      PBPO=0
      PBSIO=.57
      PBTIO=.005
C
C      BATCH TANK TEST TIME
C
      TLOTIM=60.0
      THITIM=108.0
C
C     *** VARIABLES CHARACTERIZING FAILURE AND REPAIR OF SUBSYSTEMS ***
C
C     MEAN TIME BETWEEN FAILURES (HOURS)
C
C     - TBFA: AUGER
C     - TBFE: EXCAVATOR
C     - TBFS: SOIL WASHER
C     - TBFB: BARREL MOVER
C     - TBFM: MELTER
C
      TBFA=15000.0
      TBFS=120.0
      TBFE=3000.0
      TBFB=1000.0
      TBFM=1000.0
C
C     MEAN TIME TO REPAIR (HOURS)
C
     AREPLO=12.0
     AREPHI=36.0
     SREPLO=4.0
     SREPHI=5.0
     EREPLO=24.0
     EREPHI=48.0
     BREPLO=5.0
     BREPHI=10.0
     REPLOM=480.0
     REPHIM=560.0
C

C     *** GENERAL SYSTEM VARIABLES ***
C
C     GLASS DENSITY (KG/M3) -- (THIS VALUE ASSUMES 0 VOID SPACE)
C
      GLSDEN=2700.
C
C     ASSUMPTIONS DRIVING CALCULATION OF PIT SLUDGE/SOIL PER BATCH TANK
C     - FILL BATCH TANK 2/3 FULL WITH PIT SLUDGE AND SOIL
C     - 35% SOLID CONTENT IN SLURRY EXITING SOIL WASH
C     - 35% SOLID CONTENT DESIRED IN BATCH TANK
C     - 64% OF SOIL BATCH LEAVES SOIL WASH AS CLEAN FILL
C     - 34% OF SOIL BATCH ENTERS BATCH TANK FOR VITRIFICATION
C     - AMOUNT OF SLUDGE PER BATCH CALCULATED TO COMPLETE
C       REMEDIATION OF SLUDGE AND SOIL AT ROUGHLY THE SAME TIME
```

```
C
      TEMP1=.66*SLUDGE*TNKSIZ
      TEMP2=SOLIDM*SOIL
      TEMP3=.97*SLUDGE
C
C      AMOUNT OF PIT SLUDGE PER BATCH TANK (CUBIC METERS)
C
      AMOUNT=(TEMP1/TEMP2)/(1+TEMP3/TEMP2)
C
C     SIZE OF SOIL BATCH TO PROCESS THROUGH WASHER (CUBIC METERS)
C     CALCULATED TO COMPLEMENT AMOUNT OF SLUDGE PER BATCH
C
      BATCH=.6485*TNKSIZ-.9722*AMOUNT
C
C     LOW AND HIGH TIMES FOR WASHING ONE BATCH OF BERM SOIL
C
      SWTIML=BATCH/(2.2*QS)
      SWTIMH=BATCH/(1.8*QS)
C
C
C     *** INITIAL SUBROUTINE CALLS ***
C
C     MUCK....
      CALL SCHDL(1,8.0,ATRIB)
C
C     EXCAV....
      CALL SCHDL(4,8.0,ATRIB)
C
C     BARREL....
      CALL SCHDL(5,8.0,ATRIB)
C
C     SWASH....
      CALL SCHDL(6,8.0,ATRIB)
C
C     NEWBLEND....
      CALL SCHDL(8,8.0,ATRIB)
C
C     SCHEDULE FIRST BREAKDOWN OF EACH RESOURCE:
C
C
      A(1)=1.0
      RATE=TBFA/QA
      TIME=EXPON(RATE,ISTREAM)
      CALL SCHDL(2,TIME,A)
C
      A(1)=2.0
      RATE=TBFS
      TIME=EXPON(RATE,ISTREAM)
      CALL SCHDL(2,TIME,A)
C
      A(1)=3.0
      RATE=TBFE/QE
      TIME=EXPON(RATE,ISTREAM)
      CALL SCHDL(2,TIME,A)
C
```

```
      A(1)=4.0
      RATE=TBFB/QB
      TIME=EXPON(RATE,ISTREAM)
      CALL SCHDL(2,TIME,A)
C
      A(1)=5.0
      RATE=TBFM/QM
      TIME=EXPON(RATE,ISTREAM)
      CALL SCHDL(2,TIME,A)
C
      RETURN
      END


SUBROUTINE DOWN
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
     common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
    +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
    +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
    +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
    +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
    +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
    +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
    +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
    +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
    +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
    +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
    +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
    +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
    +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
    +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
    +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C   ATRIB(1) MARKS RESOURCE TYPE
C
    IF(ATRIB(1) .EQ. 1.0) THEN
     IF(QA .LE. 0.0) THEN
       CALL SCHDL(2,.1,ATRIB)
       RETURN
     END IF
C
C    AN AUGER HAS FAILED
C     SCHEDULE REPAIR
      REPTIM=UNFRM(AREPLO,AREPHI,ISTREAM)
      CALL SCHDL(3,REPTIM,ATRIB)
C
C     AND SCHEDULE THE NEXT BREAK
      IF(XX(51) .LE. 0.0) THEN
      RATE=TBFA
      ELSE
      RATE=TBFA/XX(51)
      ENDIF
      TIME=EXPON(RATE,ISTREAM)
      TIME=TIME+REPTIM
```

```
      CALL SCHDL(2,TIME,ATRIB)
C
C     REDUCE OPERATING AUGERS BY ONE
C
     QA=QA-1.0
     XX(51)=XX(51)-1.0
C
C     MAKE SURE WE DON'T BREAK MORE RESOURCES THAN WE HAVE:
C
     IF(QA .LT. 0.0) QA=0.0
C
      RETURN
C
   ENDIF
C
   IF(ATRIB(1) .EQ. 2.0) THEN
    IF(QS .LE. 0.0) THEN
      CALL SCHDL(2,.1,ATRIB)
      RETURN
    END IF
C
C     A SOIL WASHER GOES DOWN
C
C     SCHEDULE REPAIR
    REPTIM=UNFRM(SREPLO,SREPHI,ISTREAM)
    CALL SCHDL(3,REPTIM,ATRIB)
C
C     AND SCHEDULE THE NEXT BREAK
    IF(XX(54) .LE. 0.0) THEN
    RATE=TBFS
    ELSE
    RATE=TBFS/XX(54)
    END IF
    TIME=EXPON(RATE,ISTREAM)
    TIME=TIME+REPTIM
    CALL SCHDL(2,TIME,ATRIB)
C
C     TAKE ONE SOIL WASH MODULE OFF LINE FOR MAINTENANCE
C
    QS=QS-1.0
    XX(54)=XX(54)-1.0
C     MAKE SURE WE DON'T BREAK MORE RESOURCES THAN WE HAVE:
C
    IF(QS .LT. 0.0) QS=0.0
C
    RETURN
C
   ENDIF
C
   IF(ATRIB(1) .EQ. 3.0) THEN
    IF(QE .LE. 0.0) THEN
      CALL SCHDL(2,.1,ATRIB)
      RETURN
    END IF
C
```

```
C     AN EXCAVATOR IS DOWN
C
C     SCHEDULE REPAIR
      REPTIM=UNFRM(EREPLO,EREPHI,ISTREAM)
      CALL SCHDL(3,REPTIM,ATRIB)
C
C     AND SCHEDULE THE NEXT BREAK
      IF(XX(52) .LE. 0.0) THEN
      RATE=TBFE
      ELSE
      RATE=TBFE/XX(52)
      ENDIF
      TIME=EXPON(RATE,ISTREAM)
      TIME=TIME+REPTIM
      CALL SCHDL(2,TIME,ATRIB)
C     REDUCE QE
      QE=QE-1.0
      XX(52)=XX(52)-1.0
C
    IF(QE .LT. 0.0) QE=0.0
C
      RETURN
C
    ENDIF
C
    IF(ATRIB(1) .EQ. 4.0) THEN
     IF(QB .LE. 0.0) THEN
       CALL SCHDL(2,.1,ATRIB)
       RETURN
     END IF
C
C     A BARREL MOVER IS DOWN
C
C     SCHEDULE REPAIR
      REPTIM=UNFRM(BREPLO,BREPHI,ISTREAM)
      CALL SCHDL(3,REPTIM,ATRIB)

C     SCHEDULE NEXT BREAK
      IF(XX(53) .LE. 0.0) THEN
      RATE=TBFB
      ELSE
      RATE=TBFB/XX(53)
      ENDIF
      TIME=EXPON(RATE,ISTREAM)
      TIME=TIME+REPTIM
      CALL SCHDL(2,TIME,ATRIB)
C
C     REDUCE QB
      QB=QB-1.0
      XX(53)=XX(53)-1.0
C
    IF(QB .LT. 0.0) QB=0.0
C
      RETURN
C
```

```
      ENDIF
C
      IF(ATRIB(1) .EQ. 5.0) THEN
       IF(QM .LE. 0.0) THEN
         CALL SCHDL(2,.1,ATRIB)
         RETURN
       END IF
C
C      A MELTER IS DOWN
C
C      SCHEDULE REPAIR
C
       REPTIM=UNFRM(REPLOM,REPHIM,ISTREAM)
       CALL SCHDL(3,REPTIM,ATRIB)
C
C      AND NEXT BREAK
C
          IF(XX(15) .LE. 1.0) THEN
           RATE=TBFM
           TIME=EXPON(RATE,ISTREAM)+REPTIM
           ELSE
            RATE=TBFM/XX(15)
            TIME=EXPON(RATE,ISTREAM)
          ENDIF
C
       CALL SCHDL(2,TIME,ATRIB)
C
C      REDUCE QM
       QM=QM-1.0
       XX(9)=XX(9)-1.0
       XX(15)=XX(15)-1.0
C
         IF(QM .LT. 0.0) QM=0.0
         IF(XX(9) .LT. 0.0) XX(9)=0.0
C
       RETURN
C
     END IF
     END


SUBROUTINE UP
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
     common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
    +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
    +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
    +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
    +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
    +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
    +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
    +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
    +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
    +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
```

```
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C     ATRIB(1) MARKS RESOURCE TYPE
C
      IF(ATRIB(1) .EQ. 1.0) THEN
C
C        AN AUGER HAS BEEN FIXED
C
C        INCREASE QA
         QA=QA+1.0
         XX(51)=XX(51)+1.0
         RETURN
C
      ELSE IF(ATRIB(1) .EQ. 2.0) THEN
C
C        SOIL WASHER HAS BEEN FIXED
C
C        RETURN SWASH MODULE TO OPERATION AFTER REPAIR
         QS=QS+1.0
         XX(54)=XX(54)+1.0
         RETURN
C
      ELSE IF(ATRIB(1) .EQ. 3.0) THEN
C
C        AN EXCAVATOR HAS BEEN FIXED
C
C        INCREASE QE
         QE=QE+1.0
         XX(52)=XX(52)+1.0
         RETURN
C
      ELSE IF(ATRIB(1) .EQ. 4.0) THEN
C
C        A BARREL MOVER HAS BEEN FIXED
C
C        INCREASE QB
         QB=QB+1.0
         XX(53)=XX(53)+1.0
         RETURN
C
      ELSE IF(ATRIB(1) .EQ. 5.0) THEN
C
C        A MELTER HAS BEEN FIXED
C
C        INCREASE QM
         QM=QM+1.0
         XX(9)=XX(9)+1.0
         XX(15)=XX(15)+1.0
         RETURN
C
```

```
      END IF
      END


      SUBROUTINE BARREL
$INCLUDE:'PARAM.INC'
$INCLUDE:'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C     IF NO MORE BARRELS,
C
      IF(BARELS .LE. 0.0) THEN
C
C       LOG XX(11), PERCENT OF TIME WAITING ON THE RACK
C
       XX(11)=WRACK*100/(TNOW*.333)
C
C       LOG XX(23), COMPLETION TIME FOR BARREL HANDLING (YRS)
C
       XX(23)=TNOW/8760.0
C
C       AND EXIT ROUTINE
C
       RETURN
C
      ENDIF
C
C     IF BARREL MOVER IS DOWN
C
      IF(QB .LT. 1.0) THEN
C
C       CHECK BACK IN 1 HOUR
C
       CALL SCHDL(5,1.0,ATRIB)
C
       RETURN
C
      END IF
C
```

```
C   CHECK THE TIME OF DAY TO SEE IF SHIFT IS UP
C
    CLOCK=MOD(TNOW,24.0)
C
    IF((CLOCK .LT. 8.0) .OR. (CLOCK .GE. 16.0)) THEN
C
C     SHIFT IS DOWN.  CALCULATE TIME UNTIL SHIFT IS UP.
C
      IF(CLOCK .GE. 16.0) THEN
C
        TIME=32.0-CLOCK
      ELSE
        TIME=8.0-CLOCK
      ENDIF
C
C     CALL BACK AFTER "TIME" HOURS
C
      CALL SCHDL(5,TIME,ATRIB)
      RETURN
C
    END IF
C
C   SHIFT IS DOWN ON WEEKENDS -- CHECK THE DAY TO SEE IF SHIFT IS UP
C
    CLOCK=MOD(TNOW,168.0)
C
    IF(CLOCK .GT. 120.0) THEN
C
C     IT'S THE WEEKEND.  CALCULATE TIME UNTIL SHIFT IS UP.
C
C     TIME=168.0-CLOCK
C
      CALL SCHDL(5,TIME,ATRIB)
      RETURN
C
    END IF
C
C
C   IF RACK NOT FULL
C
    IF(QRACK .LE. CAPRAC) THEN
C
C     MOVE A BARREL TO THE PROCESSING RACK
C
      QRACK=QRACK+1.0
      BARELS=BARELS-1.0
C
C     AND SCHEDULE THE NEXT ONE
C
      RATE=TBDB/QB
      CALL SCHDL(5,RATE,ATRIB)
      RETURN
C
    ELSE
C
```

```
C     OTHERWISE, LOG THE WAIT TIME
C
      WRACK=WRACK+1.0
      CALL SCHDL(5,1.0,ATRIB)
      RETURN
C
     END IF
     END




      SUBROUTINE EXCAV
$INCLUDE:'PARAM.INC'
$INCLUDE:'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C     IF THERE IS NO SOIL LEFT TO EXCAVATE
C
      IF(SOIL+QHOP-BATCH .LT. 9.0) THEN
C
C       EXIT ROUTINE
C
       RETURN
C
      ENDIF
C
C     IF THERE ARE NO EXCAVATION RESOURCES AVAILABLE OR THERE IS NO MORE
C     ROOM FOR SOIL WASH PRODUCT
C
      IF(QE .LT. 1.0 .OR. NNQ(2) .GT. 5) THEN
C
C       CALL BACK IN 4 HOURS
C
       CALL SCHDL(4,4.0,ATRIB)
       RETURN
C
      END IF
```

```
C
C   CHECK TIME TO SEE IF SHIFT IS UP
C
    CLOCK=MOD(TNOW,24.0)
C
    IF((CLOCK .LT. 8.0) .OR. (CLOCK .GE. 16.0)) THEN
C
C     SHIFT IS DOWN.  CALCULATE TIME UNTIL SHIFT IS UP.
C
     IF(CLOCK .GE. 16.0) THEN
C
      TIME=32.0-CLOCK
     ELSE
      TIME=8.0-CLOCK
     ENDIF
C
C     CALL BACK AFTER "TIME" HOURS
C
     CALL SCHDL(4,TIME,ATRIB)
     RETURN
C
    END IF
C
C     SHIFT IS DOWN ON WEEKENDS -- CHECK THE DAY TO SEE IF SHIFT IS UP
C
     CLOCK=MOD(TNOW,168.0)
C
     IF(CLOCK .GT. 120.0) THEN
C
C       IT'S THE WEEKEND.  CALCULATE TIME UNTIL SHIFT IS UP.
C
      TIME=168.0-CLOCK
C
      CALL SCHDL(4,TIME,ATRIB)
      RETURN
C
     END IF
C
C   IF HOPPER NOT FULL
C
    IF((QHOP .LT. CAPHOP) .AND. (SOIL .GE. 9.0)) THEN
C
C     CONTINUE TO FILL
C
     QHOP=QHOP+9.0
     SOIL=SOIL-9.0
C
     TBDE=1./(2.*QE)
     CALL SCHDL(4,TBDE,ATRIB)
     RETURN
C
     ELSE IF(SOIL .GE. 1.0) THEN
C
C     TRACK TIME SPENT WAITING FOR HOPPER
C
```

```
      WHOP=WHOP+1.0
C
C      AND LOOK AGAIN IN 1 HOUR
C
      CALL SCHDL(4,1.0,ATRIB)
      RETURN
C
    END IF
    END


 SUBROUTINE MUCK
 $INCLUDE:'PARAM.INC'
 $INCLUDE:'SCOM1.COM'
    common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
   +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
   +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
   +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
   +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
   +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
   +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
   +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
   +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
   +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
   +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
   +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
   +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
   +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
   +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
   +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
    DIMENSION A(3)
C
C    IF NO MORE SLUDGE
C
    IF(SLUDGE .LE. 0.0) THEN
C
C      WE ARE OUT OF SLUDGE.  SEND ACCUMULATED SLUDGE IN BTANK TO FILE
C      AND SCHEDULE TERMINATION OF THE SIMULATION.
C
     A(1)=ACCUM
     CALL FILEM(1,A)
C
C       CALCULATE PERCENT TIME WAITING FOR BTANK
C
      XX(10)=WBTANK*100.0/(TNOW*0.333)
C
C       CALCULATE PERCENT TIME WAITING FOR HOPPER
C
      XX(12)=WHOP*100.0/(TNOW*0.333)
C
C       LOG PERCENT TIME WAITING FOR SOIL
C
      XX(13)=WTSOIL*100/TNOW
```

```
C
      MSTOP=-1
      RETURN
C
     ENDIF
C
     IF(QA .LT. 1.0) THEN
C
C       ALL AUGERS ARE DOWN.  CALL BACK IN 4 HOURS
C
      CALL SCHDL(1,4.0,ATRIB)
      RETURN
C
     ENDIF
C
C    CHECK THE TIME OF DAY TO SEE IF SHIFT IS UP
C
     CLOCK=MOD(TNOW,24.0)
C
     IF((CLOCK .LT. 8.0) .OR. (CLOCK .GE. 16.0)) THEN
C
C       SHIFT IS DOWN.  CALCULATE TIME UNTIL SHIFT IS UP.
C
      IF(CLOCK .GE. 16.0) THEN
C
       TIME=32.0-CLOCK
      ELSE
       TIME=8.0-CLOCK
      ENDIF
C
      CALL SCHDL(1,TIME,ATRIB)
      RETURN
C
     END IF
C
C    SHIFT IS DOWN ON WEEKENDS -- CHECK THE DAY TO SEE IF SHIFT IS UP
C
     CLOCK=MOD(TNOW,168.0)
C
     IF(CLOCK .GT. 120.0) THEN
C
C       IT'S THE WEEKEND.  CALCULATE TIME UNTIL SHIFT IS UP.
C
C       TIME=168.0-CLOCK
C
      CALL SCHDL(1,TIME,ATRIB)
      RETURN
C
     END IF
C
C    IF A TANK IS NOT BEING FILLED AND NO TANK IS AVAILABLE
C
     IF((ACCUM .EQ. 0.0) .AND. (BTANKS .LT. 1.0)) THEN
C
C        LOG WAITING TIME AND CALL BACK 1 HOUR LATER
```

```
C
       WBTANK=WBTANK+1.0
C
      CALL SCHDL(1,1.0,ATRIB)
      RETURN
C
C   OTHERWISE, IF THERE IS NO SLUDGE ACCUMULATED
C
     ELSE IF(ACCUM .EQ. 0.0) THEN
C
C     START FILLING A NEW TANK
C
      BTANKS=BTANKS-1.0
      XX(1)=XX(1)-1.0
      ACCUM=ACCUM+1.0
      SLUDGE=SLUDGE-SOLIDM
C
     ELSE
C
C     IF A TANK IS BEING FILLED, CONTINUE
C
      ACCUM=ACCUM+1
      SLUDGE=SLUDGE-SOLIDM
C
     END IF
C
C   IF THERE IS ENOUGH FOR A BATCH
C
     IF(ACCUM .GE. AMOUNT) THEN
C
C     FILE AN ENTITY IN FILE 1 WITH ATRIB(1) = TOTAL VOLUME
C
      A(1)=AMOUNT
      CALL FILEM(1,A)
C
C     RESET ACCUMULATED SLUDGE
C
      ACCUM=0.0
C
     END IF
C
C   SCHEDULE NEXT M3 OF SLUDGE:  RATE/NUM_RESOURCES (HRS)
C
     TIME=TBDA/QA
     CALL SCHDL(1,TIME,ATRIB)
     RETURN
     END


SUBROUTINE SWASH
$INCLUDE:'PARAM.INC'
$INCLUDE:'SCOM1.COM'
     common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
    +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
```

```
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C   IF WE ARE OUT OF SOIL
C
      TEMP=SOIL+QHOP-BATCH
      IF((TEMP .LT. 9.0) .AND. (XX(35) .EQ. 994.)) THEN
C
C       EXIT SWASH ROUTINE
C
      RETURN
C
     ENDIF
C
C   IF SOIL WASHER IS DOWN OR SMALL PARTICLE STORAGE CAPACITY EXCEEDED
C
     IF(QS .EQ. 0.0 .OR. NNQ(2) .GT. 5) THEN
C
C     CALL BACK 4 HOURS LATER
C
      CALL SCHDL(6,4.0,ATRIB)
C
      RETURN
C
     END IF
C
C   IF A BATCH IS IN THE HOPPER
C
     IF(QHOP .GE. BATCH) THEN
C
C     SEND IT TO THE SOIL WASHER
      QHOP=QHOP-BATCH
C
C     AND SCHEDULE THE SOIL WASHING TIME (BOTH SIEVE AND ION EXCH)
C
       SWTIML=BATCH/(2.2*QS)
       SWTIMH=BATCH/(1.8*QS)
      TIME=UNFRM(SWTIML,SWTIMH,ISTREAM)
C
      CALL SCHDL(7,TIME+.1,ATRIB)
      CALL SCHDL(6,TIME,ATRIB)
      RETURN
C
```

```
      ELSE
C
C       LOG SOIL WAITING TIME
C
        WTSOIL=WTSOIL+1.0
C
C       AND CHECK AGAIN IN 1 HOUR
        CALL SCHDL(6,1.0,ATRIB)
C
        RETURN
C
      END IF
      END


      SUBROUTINE SWOUT
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
      DIMENSION A(3)
C
C     FILE SMALL PARTICLE SOIL BATCH
C     -ASSUME 20% OF BATCH IS SMALL PARTICLE SOIL
C
      A(1)=BATCH*RNORM(.2,.025,ISTREAM)
      CALL FILEM(2,A)
C
C     FILE RESINS FROM ION EXCHANGE PROCESS
C     - ASSUME RESIN VOL = 20% OF REMAINDER
C
      A(1)=BATCH-A(1)
      A(1)=A(1)*RNORM(.2,.025,ISTREAM)
C
      CALL FILEM(3,A)
      RETURN
      END
```

```
SUBROUTINE NEWBLEND
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
  common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
 +SIO,QNAO,ERATE,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
 +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
 +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
 +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
 +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
 +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
 +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
 +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
 +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
 +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
 +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
 +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
 +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
 +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
 +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
  DIMENSION A(17),B(17),C(17),D(17),E(17)
C
C   TEMP1 = 0 INDICATES AT LEAST ONE FILE IS EMPTY
C
  TEMP1=NNQ(1)*NNQ(2)*NNQ(3)
C
C   IF SOIL IS DEPLETED FIRST, AN ERROR HAS OCCURRED -- STOP SIMULATION
C
   IF((SOIL+QHOP-BATCH .LT. 9.0) .AND. (NNQ(2) .EQ. 0))THEN
C
     PRINT*,'IF WE ASSUME SLUDGE IS ALWAYS DEPLETED FIRST,'
     PRINT*,'THIS MESSAGE SHOULD NEVER APPEAR!!!!'
C
     PRINT*,'SLUDGE = ',SLUDGE
     PRINT*,'SOIL   = ',SOIL
     PRINT*,'BATCH  = ',BATCH
     PRINT*,'NNQ(2) = ',NNQ(2)
     PAUSE
C
     MSTOP=-1
C
   ENDIF
C
C   GIVEN THAT SOIL AND SLUDGE ARE LEFT, IF THERE IS NOT AT LEAST
C   ONE ENTITY IN FILES 1,2, AND 3
C
  IF(TEMP1 .EQ. 0.0)THEN
C
C   LOG TIME SPENT WAITING FOR SOIL WASH OUTPUT, XX(31), AND
C   SLUDGE, XX(32).
C
    IF(NNQ(2) .EQ. 0 .AND. NNQ(1) .GT. 0) XX(31)=XX(31)+1.
C
    IF(NNQ(1) .EQ. 0 .AND. NNQ(2) .GT. 0) XX(32)=XX(32)+1.
C
```

```
C     CALL BACK IN 1 HOUR
C
      CALL SCHDL(8,1.,ATRIB)
      RETURN
C
     ENDIF
C
C    REMOVE AN ENTITY FROM EACH WASTE STREAM AND CHARACTERIZE IT
C
C     PIT SLUDGE
C
      CALL RMOVE(1,1,A)
      A(2)=A(1)*RNORM(SOLIDM,.10,ISTREAM)
      A(3)=A(2)*DENSE
      DO 1, I=4,15
      A(I)=0.0
 1    CONTINUE
C
C     SET THE THRESHOLDS FOR IDENTIFYING EACH SAMPLE FROM THE WASTE
C     STREAM AS ONE OF THE LISTED KEY ELEMENTS.  START WITH THE
C     MOST COMMONLY OCCURING ELEMENT AND PROCEED TO THE LEAST COMMONLY
C     OCCURING ELEMENT.  USE THE POPULATION STATISTICS FOR MEAN
C     WEIGHT PERCENT OF EACH ELEMENT.
C
      A4=PMSIO
      A5=A4+PMCAO
      A6=A5+PMALO
      A7=A6+PMMGO
      A8=A7+PMFEO
      A9=A8+PMKO
      A10=A9+PMPO
      A11=A10+PMNAO
      A12=A11+PMSO
      A13=A12+PMBO
      A14=A13+PMLIO
      A15=A14+PMF
C
C     FOR EACH SAMPLE OF SIZE (A(3)/SAMPLES) KG, DRAW A UNIFORM
C     RANDOM NUMBER BETWEEN ZERO AND ONE AND COMPARE THIS NUMBER TO
C     PREDETERMINED THRESHOLD VALUES IN ORDER TO CHARACTERIZE THE
C     SAMPLE AS ONE OF THE KEY ELEMENTS.
C
C     THE DESIRED NUMBER OF SAMPLES IS ACCOMPLISHED BY SETTING THE
C     INCREMENT FOR THE COUNTER TO A(3)/N.
C
      SAMPLES=100.0
      X=A(3)/SAMPLES
      DO 10, COUNT=0.0,A(3),X
      DRAW=UNFRM(0.0,1.0,ISTREAM)
      IF(DRAW .LE. A4) THEN
      A(4)=A(4)+X
      ELSE IF(DRAW .LE. A5) THEN
      A(5)=A(5)+X
      ELSE IF(DRAW .LE. A6) THEN
      A(6)=A(6)+X
```

```
      ELSE IF(DRAW .LE. A7) THEN
      A(7)=A(7)+X
      ELSE IF(DRAW .LE. A8) THEN
      A(8)=A(8)+X
      ELSE IF(DRAW .LE. A9) THEN
      A(9)=A(9)+X
      ELSE IF(DRAW .LE. A10) THEN
      A(10)=A(10)+X
      ELSE IF(DRAW .LE. A11) THEN
      A(11)=A(11)+X
      ELSE IF(DRAW .LE. A12) THEN
      A(12)=A(12)+X
      ELSE IF(DRAW .LE. A13) THEN
      A(13)=A(13)+X
      ELSE IF(DRAW .LE. A14) THEN
      A(14)=A(14)+X
      ELSE IF(DRAW .LE. A15) THEN
      A(15)=A(15)+X
      END IF
 10   CONTINUE
C
      TEMP1=A(4)/A(3)
      TEMP2=A(15)/A(3)
      CALL COLCT(TEMP1,1)
      CALL COLCT(TEMP2,2)
C

C     SMALL PARTICLE SOIL
C
      CALL RMOVE(1,2,B)
      B(2)=B(1)*RNORM(SOLIDS,.10,ISTREAM)
      B(3)=B(2)*DENSE
      DO 12, I=4,15
      B(I)=0.0
 12   CONTINUE
C
C     SET THE THRESHOLDS FOR IDENTIFYING EACH SAMPLE FROM THE WASTE
C     STREAM AS ONE OF THE LISTED KEY ELEMENTS.  START WITH THE
C     MOST COMMONLY OCCURING ELEMENT AND PROCEED TO THE LEAST COMMONLY
C     OCCURING ELEMENT.  USE THE POPULATION STATISTICS FOR MEAN
C     WEIGHT PERCENT OF EACH ELEMENT.
C
      B4=PSSIO
      B5=B4+PSCAO
      B6=B5+PSALO
      B7=B6+PSMGO
      B8=B7+PSFEO
      B9=B8+PSKO
      B10=B9+PSPO
      B11=B10+PSNAO
      B12=B11+PSSO
      B13=B12+PSB
      B14=B13+PSLIO
      B15=B14+PSF
C
```

```
C     FOR EACH SAMPLE OF SIZE (B(3)/SAMPLES) KG, DRAW A UNIFORM
C     RANDOM NUMBER BETWEEN ZERO AND ONE AND COMPARE THIS NUMBER TO
C     PREDETERMINED THRESHOLD VALUES IN ORDER TO CHARACTERIZE THE
C     SAMPLE AS ONE OF THE KEY ELEMENTS.
C
C     THE DESIRED NUMBER OF SAMPLES IS ACCOMPLISHED BY SETTING THE
C     INCREMENT FOR THE COUNTER TO B(3)/SAMPLES.
C
      SAMPLES=100.0
      X=B(3)/SAMPLES
      DO 13, COUNT=0.0,B(3),X
      DRAW=UNFRM(0.0,1.0,ISTREAM)
      IF(DRAW .LE. B4) THEN
      B(4)=B(4)+X
      ELSE IF(DRAW .LE. B5) THEN
      B(5)=B(5)+X
      ELSE IF(DRAW .LE. B6) THEN
      B(6)=B(6)+X
      ELSE IF(DRAW .LE. B7) THEN
      B(7)=B(7)+X
      ELSE IF(DRAW .LE. B8) THEN
      B(8)=B(8)+X
      ELSE IF(DRAW .LE. B9) THEN
      B(9)=B(9)+X
      ELSE IF(DRAW .LE. B10) THEN
      B(10)=B(10)+X
      ELSE IF(DRAW .LE. B11) THEN
      B(11)=B(11)+X
      ELSE IF(DRAW .LE. B12) THEN
      B(12)=B(12)+X
      ELSE IF(DRAW .LE. B13) THEN
      B(13)=B(13)+X
      ELSE IF(DRAW .LE. B14) THEN
      B(14)=B(14)+X
      ELSE IF(DRAW .LE. B15) THEN
      B(15)=B(15)+X
      END IF
 13   CONTINUE
C
C     RESINS FROM ION EXCHANGE
C
      CALL RMOVE(1,3,C)
      C(2)=C(1)*RNORM(SOLIDR,.1,ISTREAM)
      C(3)=C(2)*DENSE
      DO 15, I=4,15
      C(I)=0.0
 15   CONTINUE
C
C     SET THE THRESHOLDS FOR IDENTIFYING EACH SAMPLE FROM THE WASTE
C     STREAM AS ONE OF THE LISTED KEY ELEMENTS.  START WITH THE
C     MOST COMMONLY OCCURING ELEMENT AND PROCEED TO THE LEAST COMMONLY
C     OCCURING ELEMENT.  USE THE POPULATION STATISTICS FOR MEAN
C     WEIGHT PERCENT OF EACH ELEMENT.
C
      C4=PRSIO
```

```
      C5=C4+PRCAO
      C6=C5+PRALO
      C7=C6+PRMGO
      C8=C7+PRFEO
      C9=C8+PRKO
      C10=C9+PRPO
      C11=C10+PRNAO
      C12=C11+PRSO
      C13=C12+PRB
      C14=C13+PRLIO
      C15=C14+PRF
C
C     FOR EACH SAMPLE OF SIZE (C(3)/SAMPLES) KG, DRAW A UNIFORM
C     RANDOM NUMBER BETWEEN ZERO AND ONE AND COMPARE THIS NUMBER TO
C     PREDETERMINED THRESHOLD VALUES IN ORDER TO CHARACTERIZE THE
C     SAMPLE AS ONE OF THE KEY ELEMENTS.
C
C     THE DESIRED NUMBER OF SAMPLES IS ACCOMPLISHED BY SETTING THE
C     INCREMENT FOR THE COUNTER TO C(3)/SAMPLES.
C
      SAMPLES=100.0
      X=C(3)/SAMPLES
      DO 16, COUNT=0.0,C(3),X
      DRAW=UNFRM(0.0,1.0,ISTREAM)
      IF(DRAW .LE. C4) THEN
      C(4)=C(4)+X
      ELSE IF(DRAW .LE. C5) THEN
      C(5)=C(5)+X
      ELSE IF(DRAW .LE. C6) THEN
      C(6)=C(6)+X
      ELSE IF(DRAW .LE. C7) THEN
      C(7)=C(7)+X
      ELSE IF(DRAW .LE. C8) THEN
      C(8)=C(8)+X
      ELSE IF(DRAW .LE. C9) THEN
      C(9)=C(9)+X
      ELSE IF(DRAW .LE. C10) THEN
      C(10)=C(10)+X
      ELSE IF(DRAW .LE. C11) THEN
      C(11)=C(11)+X
      ELSE IF(DRAW .LE. C12) THEN
      C(12)=C(12)+X
      ELSE IF(DRAW .LE. C13) THEN
      C(13)=C(13)+X
      ELSE IF(DRAW .LE. C14) THEN
      C(14)=C(14)+X
      ELSE IF(DRAW .LE. C15) THEN
      C(15)=C(15)+X
      END IF
 16   CONTINUE
CC      DO 17, I=3,15
CC      PRINT*,'B(',I,') = ',B(I),'  C(',I,') = ',C(I)
CC 17   CONTINUE
CC      PAUSE
C   IF THERE ARE ENOUGH BARRELS IN THE RACK FOR A BATCH
```

```
C
      IF(QRACK .GT. BPTANK) THEN
C
C     PULL THE BARRELS FOR THE BATCH AND CHARACTERIZE THE CONTENTS
C
       QRACK=QRACK-BPTANK
       D(1)=.2*BPTANK
       D(2)=D(1)*RNORM(SOLIDB,.025,ISTREAM)
       D(3)=D(2)*DENSE
       DO 18, I=4,12
       D(I)=0.0
 18    CONTINUE
C
C     SET THE THRESHOLDS FOR IDENTIFYING EACH SAMPLE FROM THE WASTE
C     STREAM AS ONE OF THE LISTED KEY ELEMENTS.  START WITH THE
C     MOST COMMONLY OCCURING ELEMENT AND PROCEED TO THE LEAST COMMONLY
C     OCCURING ELEMENT.  USE THE POPULATION STATISTICS FOR MEAN
C     WEIGHT PERCENT OF EACH ELEMENT.
C
       D4=PBSIO
       D5=D4+PBCAO
       D6=D5+PBALO
       D7=D6+PBMGO
       D8=D7+PBFEO
       D9=D8+PBKO
       D10=D9+PBPO
       D11=D10+PBNAO
       D12=D11+PBTIO
C
C     FOR EACH SAMPLE OF SIZE (D(3)/SAMPLES) KG, DRAW A UNIFORM
C     RANDOM NUMBER BETWEEN ZERO AND ONE AND COMPARE THIS NUMBER TO
C     PREDETERMINED THRESHOLD VALUES IN ORDER TO CHARACTERIZE THE
C     SAMPLE AS ONE OF THE KEY ELEMENTS.
C
C     THE DESIRED NUMBER OF SAMPLES IS ACCOMPLISHED BY SETTING THE
C     INCREMENT FOR THE COUNTER TO D(3)/SAMPLES.
C
       SAMPLES=100.0
       X=D(3)/SAMPLES
       DO 19, COUNT=0.0,D(3),X
       DRAW=UNFRM(0.0,1.0,ISTREAM)
       IF(DRAW .LE. D4) THEN
       D(4)=D(4)+X
       ELSE IF(DRAW .LE. D5) THEN
       D(5)=D(5)+X
       ELSE IF(DRAW .LE. D6) THEN
       D(6)=D(6)+X
       ELSE IF(DRAW .LE. D7) THEN
       D(7)=D(7)+X
       ELSE IF(DRAW .LE. D8) THEN
       D(8)=D(8)+X
       ELSE IF(DRAW .LE. D9) THEN
       D(9)=D(9)+X
       ELSE IF(DRAW .LE. D10) THEN
       D(10)=D(10)+X
```

```
      ELSE IF(DRAW .LE. D11) THEN
      D(11)=D(11)+X
      ELSE IF(DRAW .LE. D12) THEN
      D(12)=D(12)+X
      END IF
 19   CONTINUE
CC      DO 20, I=3,12
CC      PRINT*,'D(',I,') = ',D(I)
CC 20   CONTINUE
CC      PAUSE
C
      ELSE
C
C     OTHERWISE, ZERO-OUT THE D-VECTOR
C
      DO 65, I=1,12
       D(I)=0.
 65   CONTINUE
C
C      AND SKIP THE BARREL WASTE CHARACTERIZATION
C
      GOTO 85
C
      END IF
C
      SUM=0.0
      DO 70, I=4,12
       SUM=SUM+D(I)
 70    CONTINUE
      DO 80, I=4,12
       D(I)=D(3)*D(I)/SUM
 80    CONTINUE
C
C      BLEND THE 4 WASTE STREAMS
C
 85    DO 90, I=1,15
       E(I)=A(I)+B(I)+C(I)+D(I)
 90    CONTINUE
C
C     STORE THE BATCH CHARACTERISTICS IN XX(90) THRU XX(99).
C     THEN SEND THE BATCH TO THE DUAL SIMPLEX OPTIMIZER TO
C     DETERMINE ADDITIVES NEEDED:
C
      do 91, i=3,15
      XX(I+84)=E(I)
 91   continue
      call schdl(11,.1,atrib)
      call schdl(8,.1,atrib)
      return
C
C
      END
```

```
      SUBROUTINE DUALS
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
      DIMENSION da(14,13),db(13),A(14,18),B(14),C(18),XB(14),
     + BINV(14,14),SB(14),U(14),WORK(14),IB(14),E(3)
C
C     THERE ARE 14 COMPOSITIONAL CONSTRAINTS AND 18 VARIABLES
C     (4 POTENTIAL ADDITIVES AND 14 SLACK VARIABLES) IN THIS LP:
C
      m=14
      n=18
C
C     INITIALIZE THE "A" MATRIX TO ZERO:
C
      do 1000 i=1,m
      do 2000 j=1,n
      a(i,j)=0.d0
2000  continue
1000  continue
C
C     THE XX VECTOR CONTAINS THE FOLLOWING INFORMATION:
C
C     (87)=TOTAL MASS OF SOLIDS     (88)=MASS OF SIO2
C     (89)=MASS OF CAO              (90)=MASS OF AL2O3
C     (91)=MASS OF MGO              (92)=MASS OF FE2O3
C     (93)=MASS OF K20              (94)=MASS OF P2O5
C     (95)=MASS OF NA2O             (96)=MASS OF SO3
C     (97)=MASS OF B2O3             (98)=MASS OF LI2O
C     (99)=MASS OF F
C
C     ADDITIVES ARE:  XB(1)=NA2CO3  XB(2)=SIO2  XB(3)=H3BO3  XB(4)=BORAX
C
C     THESE ADDITIVES ARE BLENDED IN TO MEET THESE CONSTRAINTS:
C
C     SIO2+AL2O3+FE2O3>40 WT%
C     SIO2>25 WT%
C     AL2O3 <20 WT%
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C     FE2O3<20 WT%
C     B2O3<15 WT%
C     B2O3>5%
C     10<NA2O+LI2O+K20<30 WT%
C     MGO<20 WT%
C     CAO<45 WT%
C     P2O5<10 WT%
C     SO3<5 WT%
C     CL<2 WT%
C     F<15 WT%
C
C
C     SIO2+AL2O3+FE2O3/(B2O3+R+(CAO/2)+F)<3
C      WHERE R = .59 K2O +3.33 LI2O + NA2O
C
C     dB IS A VECTOR OF THE TOTAL MASS AND MASS OF KEY ELEMENTS.
C     IT IS USED TO CALCULATE THE RIGHT HAND SIDE FOR THE CONSTRAINTS
C     THAT DRIVE THE AMOUNT AND RESULTING COST OF ADDITIVES:
C
        dB(1)=XX(87)
        dB(2)=XX(88)
        dB(3)=XX(89)
        dB(4)=XX(90)
        dB(5)=XX(91)
        dB(6)=XX(92)
        dB(7)=XX(93)
        dB(8)=XX(94)
        dB(9)=XX(95)
        dB(10)=XX(96)
        dB(11)=XX(97)
        dB(12)=XX(98)
C
C        ASSUME 20% OF INPUT FLUORINE IS RECYCLED FROM EACH BATCH
C        TO THE NEXT VIA OFF-GAS SYSTEM.  THE LONG RUN AFFECT OF THIS
C        RECYCLING CAN BE REPRESENTED BY MULTIPLYING THE FLOURINE CONTENT
C        OF EACH BATCH BY 1.25:
C
        dB(13)=1.25*XX(99)
C
C     dA IS A MATRIX REPRESENTING THE COEFFICIENTS OF TOTAL MASS AND
C     MASS OF EACH KEY INGREDIENT IN THE CONSTRAINTS:
C
        dA(1,1)=.4
        dA(1,2)=-1.
        dA(1,3)=0.
        dA(1,4)=-1.
        dA(1,5)=0.
        dA(1,6)=-1.
        dA(1,7)=0.
        dA(1,8)=0.
        dA(1,9)=0.
        dA(1,10)=0.
        dA(1,11)=0.
        dA(1,12)=0.
        dA(1,13)=0.
```

dA(2,1)=.25
dA(2,2)=-1.
dA(2,3)=0.
dA(2,4)=0.
dA(2,5)=0.
dA(2,6)=0.
dA(2,7)=0.
dA(2,8)=0.
dA(2,9)=0.
dA(2,10)=0.
dA(2,11)=0.
dA(2,12)=0.
dA(2,13)=0.
dA(3,1)=-.2
dA(3,2)=0.
dA(3,3)=0.
dA(3,4)=1.
dA(3,5)=0.
dA(3,6)=0.
dA(3,7)=0.
dA(3,8)=0.
dA(3,9)=0.
dA(3,10)=0.
dA(3,11)=0.
dA(3,12)=0.
dA(3,13)=0.
dA(4,1)=-.2
dA(4,2)=0.
dA(4,3)=0.
dA(4,4)=0.
dA(4,5)=0.
dA(4,6)=1.
dA(4,7)=0.
dA(4,8)=0.
dA(4,9)=0.
dA(4,10)=0.
dA(4,11)=0.
dA(4,12)=0.
dA(4,13)=0.
dA(5,1)=-.15
dA(5,2)=0.
dA(5,3)=0.
dA(5,4)=0.
dA(5,5)=0.
dA(5,6)=0.
dA(5,7)=0.
dA(5,8)=0.
dA(5,9)=0.
dA(5,10)=0.
dA(5,11)=1.
dA(5,12)=0.
dA(5,13)=0.
dA(6,1)=.05
dA(6,2)=0.
dA(6,3)=0.

dA(6,4)=0.
dA(6,5)=0.
dA(6,6)=0.
dA(6,7)=0.
dA(6,8)=0.
dA(6,9)=0.
dA(6,10)=0.
dA(6,11)=-1.
dA(6,12)=0.
dA(6,13)=0.
dA(7,1)=.1
dA(7,2)=0.
dA(7,3)=0.
dA(7,4)=0.
dA(7,5)=0.
dA(7,6)=0.
dA(7,7)=-.59
dA(7,8)=0.
dA(7,9)=-1.
dA(7,10)=0.
dA(7,11)=0.
dA(7,12)=-3.31
dA(7,13)=0.
dA(8,1)=-.3
dA(8,2)=0.
dA(8,3)=0.
dA(8,4)=0.
dA(8,5)=0.
dA(8,6)=0.
dA(8,7)=.59
dA(8,8)=0.
dA(8,9)=1.
dA(8,10)=0.
dA(8,11)=0.
dA(8,12)=3.31
dA(8,13)=0.
dA(9,1)=-.2
dA(9,2)=0.
dA(9,3)=0.
dA(9,4)=0.
dA(9,5)=1.
dA(9,6)=0.
dA(9,7)=0.
dA(9,8)=0.
dA(9,9)=0.
dA(9,10)=0.
dA(9,11)=0.
dA(9,12)=0.
dA(9,13)=0.
dA(10,1)=-.45
dA(10,2)=0.
dA(10,3)=1.
dA(10,4)=0.
dA(10,5)=0.
dA(10,6)=0.

dA(10,7)=0.
dA(10,8)=0.
dA(10,9)=0.
dA(10,10)=0.
dA(10,11)=0.
dA(10,12)=0.
dA(10,13)=0.
dA(11,1)=-.1
dA(11,2)=0.
dA(11,3)=0.
dA(11,4)=0.
dA(11,5)=0.
dA(11,6)=0.
dA(11,7)=0.
dA(11,8)=1.
dA(11,9)=0.
dA(11,10)=0.
dA(11,11)=0.
dA(11,12)=0.
dA(11,13)=0.
dA(12,1)=-.05
dA(12,2)=0.
dA(12,3)=0.
dA(12,4)=0.
dA(12,5)=0.
dA(12,6)=0.
dA(12,7)=0.
dA(12,8)=0.
dA(12,9)=0.
dA(12,10)=1.
dA(12,11)=0.
dA(12,12)=0.
dA(12,13)=0.
dA(13,1)=-0.15
dA(13,2)=0.
dA(13,3)=0.
dA(13,4)=0.
dA(13,5)=0.
dA(13,6)=0.
dA(13,7)=0.
dA(13,8)=0.
dA(13,9)=0.
dA(13,10)=0.
dA(13,11)=0.0
dA(13,12)=0.
dA(13,13)=1.
dA(14,1)=0.
dA(14,2)=1.0
dA(14,3)=-1.5
dA(14,4)=1.0
dA(14,5)=0.
dA(14,6)=1.0
dA(14,7)=-1.77
dA(14,8)=0.
dA(14,9)=-3.0

```
      dA(14,10)=0.
      dA(14,11)=-3.0
      dA(14,12)=-9.93
      dA(14,13)=-3.0
C
C     COEFFICIENTS FOR NA2CO3, SIO2, H3BO3, AND BORAX IN EACH CONSTRAINT:
C
      A(1,1)=.4
      A(1,2)=-.6
      A(1,3)=.4
      A(1,4)=.4
      A(2,1)=.25
      A(2,2)=-.75
      A(2,3)=.25
      A(2,4)=.25
      A(3,1)=-.2
      A(3,2)=-.2
      A(3,3)=-.2
      A(3,4)=-.2
      A(4,1)=-.2
      A(4,2)=-.2
      A(4,3)=-.2
      A(4,4)=-.2
      A(5,1)=-.15
      A(5,2)=-.15
      A(5,3)=.41
      A(5,4)=.33
      A(6,1)=.05
      A(6,2)=.05
      A(6,3)=-.51
      A(6,4)=-.43
      A(7,1)=-.48
      A(7,2)=.1
      A(7,3)=.1
      A(7,4)=-.11
      A(8,1)=.28
      A(8,2)=-.3
      A(8,3)=-.3
      A(8,4)=-.09
      A(9,1)=-.2
      A(9,2)=-.2
      A(9,3)=-.2
      A(9,4)=-.2
      A(10,1)=-.45
      A(10,2)=-.45
      A(10,3)=-.45
      A(10,4)=-.45
      A(11,1)=-.1
      A(11,2)=-.1
      A(11,3)=-.1
      A(11,4)=-.1
      A(12,1)=-.05
      A(12,2)=-.05
      A(12,3)=-.05
      A(12,4)=-.05
```

```
      A(13,1)=-0.15
      A(13,2)=-0.15
      A(13,3)=-0.15
      A(13,4)=-0.15
      A(14,1)=-1.74
      A(14,2)=1.0
      A(14,3)=-1.68
      A(14,4)=-1.44
C
C    SET THE SLACK VARIABLES FOR EACH ROW TO ONE:
C
      A(1,5)=1.
      A(2,6)=1.
      A(3,7)=1.
      A(4,8)=1.
      A(5,9)=1.
      A(6,10)=1.
      A(7,11)=1.
      A(8,12)=1.
      A(9,13)=1.
      A(10,14)=1.
      A(11,15)=1.
      A(12,16)=1.
      A(13,17)=1.
      A(14,18)=1.
C
C    THE RIGHT HAND SIDE IS DETERMINED BY MATRIX MULTIPLICATION OF
C    dA TIMES dB:
    do 5000 i=1,M
      sum=0.0
        do 6000 j=1,13
6000      sum=sum+da(i,j)*db(j)
        b(i)=-sum
        xb(i)=-sum
5000  continue
C
C    COST COEFFICIENTS FOR NA2CO3,SIO2, H3BO3, AND BORAX IN $/KG ARE:
C
      C(1)=.792
      C(2)=.012
      C(3)=1.12
      C(4)=.314
C
C    COST COEFFICIENTS FOR THE SLACK VARIABLES ARE SET TO ZERO:
C
    DO 5001, I=5,N
    C(I)=0.0
5001 CONTINUE
C
C    IB IS A VECTOR DEFINING THE INITIAL BASIC VARIABLES.  SET ALL
C    SLACKS BASIC TO BEGIN:
      DO 1, I=1,m
      IB(I)=i+4
1     CONTINUE
C
```

```
C    THE INITIAL B-INVERSE MATRIX IS THE IDENTITY MATRIX:
C
     do 3000 i=1,m
     do 4000 j=1,m
     binv(i,j)=0.0
     binv(i,i)=1.0
 4000 continue
 3000 continue
C
C    BECAUSE WE HAVE BOTH GE AND LE CONSTRAINTS, WE GET A
C    NEGATIVE RHS. USE THE DUAL SIMPLEX METHOD:
C
     CALL DSMPLX(A,B,C,XB,BINV,SB,U,WORK,IB,OBJ,N,M,JOUT)
C
C    USE THE IB VECTOR TO DETERMINE WHICH, IF ANY, OF THE
C    ADDITIVES ARE BASIC OR NON-ZERO IN THE OPTIMAL SOLUTION:
C
     do 10 i=1,4
     do 20 j=1,n
     if(ib(j).eq.i) XX(i+70)=xb(j)
 20        continue
 10        continue
C
C    SET "E(1)" TO ORIGINAL TOTAL MASS PLUS ADDITIVES:
     e(1)=xx(74)+xx(73)+xx(72)+xx(71)+xx(87)
C
C    XX(75) THRU XX(78) TRACK TOTAL NA2CO3,SIO2, H3BO3, AND BORAX CONSUMED:
C
     xx(75)=xx(75)+xx(71)
     xx(76)=xx(76)+xx(72)
     xx(77)=xx(77)+xx(73)
     xx(78)=xx(78)+xx(74)
C
C    SEND THE BATCH TO VITRIFY WITH TOTAL MASS PASSED:
C
     TIME=UNFRM(TLOTIM,THITIM,ISTREAM)
     call schdl(9,TIME,E)
C
     return
     END
C
C
C
     SUBROUTINE PHIPRM(BINV,D,ELL,m)
C    IMPLICIT DOUBLE PRECISION(A-H,O-Z)
     DIMENSION BINV(14,14),D(14)
     INTEGER ELL
     TOL=1.D-6
     SUM=0.D0
     DO 100 I=1,m
 100 SUM=SUM+BINV(ELL,I)*D(I)
     IF (DABS(SUM).GE.TOL) GO TO 200
     STOP
 200 CONTINUE
     SUM=1.D0/SUM
```

```
      DO 300 I=1,m
 300  BINV(ELL,I)=SUM*BINV(ELL,I)
      DO 600 J=1,m
      IF (J.EQ.ELL) GO TO 600
      TEMP=0.D0
      DO 400 I=1,m
 400  TEMP=TEMP+BINV(J,I)*D(I)
      DO 500 I=1,m
 500  BINV(J,I)=BINV(J,I)-TEMP*BINV(ELL,I)
 600  CONTINUE
      RETURN
      END
C
C
      SUBROUTINE DSMPLX (A,B,C,XB,BINV,SB,U,WORK,IB,OBJ,N,M,JOUT)
C     IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION A(14,18),B(14),C(18),XB(14),BINV(14,14),
     +SB(14),U(14),WORK(14),IB(14)
      INTEGER ELL
C
C This program was taken from the book LINEAR PROGRAMMING
C  by M.J. Best and K. Ritter (Prentice Hall, 1985)
C
C     INITIALIZE
      ITER=0
      SUM=0.D0
      DO 100 I=1,m
 100  SUM= SUM+C(IB(I))*XB(I)
      OBJ=SUM
C
 200  CONTINUE
      CALL DRSTP1(XB,binv,SB,ELL,m,JOUT)
      IF (JOUT.EQ.1) return
C
      CALL DRSTP2(a,c,SB,U,IB,m,N,K,JOUT)
      IF (JOUT.EQ.3) THEN
      PRINT*,'AN INFEASIBLE BATCH WAS ENCOUNTERED.'
      PAUSE
      RETURN
      ELSE
      CONTINUE
      END IF
C
      CALL DRSTP3(binv,a,b,c,XB,WORK,U,IB,K,ELL,m,ITER,OBJ)
      GO TO 200
C
      END
C
      SUBROUTINE DRSTP1(XB,binv,SB,ELL,m,JOUT)
C     IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION XB(14),BINV(14,14),SB(14)
      INTEGER ELL
      TOL=1.D-6
      JOUT=0
      SMALL=1.D30
```

```
      ELL=0
      DO 100 I=1,m
      IF(XB(I).GE.SMALL) GO TO 100
      SMALL=XB(I)
      ELL=I
  100 CONTINUE
      IF (SMALL.GE.-TOL) JOUT=1
      IF (SMALL.GE.-TOL) RETURN
      DO 200 I=1,m
      SB(I) = - BINV(ELL,I)
  200 CONTINUE
      RETURN
      END
C
      SUBROUTINE DRSTP2(a,c,SB,U,IB,m,N,K,JOUT)
C       IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION A(14,18),C(18),SB(14),U(14),IB(14)
      TOL=1.D-6
      JOUT=0
      K=0
      SMALL=1.D30
      DO 300 I=1,N
      DO 100 J=1,m
      IF(IB(J).EQ.I) GOTO 300
  100 CONTINUE
      SUMU=0.D0
      SUMSB=0.D0
      DO 200 J=1,m
      SUMU = SUMU + a(J,I)*U(J)
      SUMSB = SUMSB + a(J,I)*SB(J)
  200 CONTINUE
       IF(SUMSB.LE.TOL) GOTO 300
      RATIO = (SUMU + C(I))/SUMSB
      IF(RATIO.GE.SMALL) GOTO 300
      SMALL = RATIO
      K = I
  300 CONTINUE
      IF(K.EQ.0) JOUT=3
      RETURN
      END
C
      SUBROUTINE DRSTP3(binv,a,b,c,XB,WORK,U,IB,K,ELL,m,ITER,OBJ)
C       IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION A(14,18),B(14),C(18),XB(14),BINV(14,14),
     +U(14),WORK(14),IB(14)
      integer ell
C
      DO 100 I=1,m
  100  WORK(I)=a(I,K)
      CALL PHIPRM(binv,WORK,ELL,m)
      IB(ELL)=K
C
C   UPDATE U
      DO 300 I=1,m
      SUM=0.D0
```

```
      DO 200 J=1,m
 200  SUM=SUM+BINV(J,I)*C(IB(J))
 300  U(I)=-SUM
C
C     UPDATE XB
      DO 500 I=1,m
      SUM=0.D0
      DO 400 J=1,m
 400  SUM=SUM+BINV(I,J)*b(J)
 500  XB(I)=SUM
C
C     UPDATE OBJECTIVE FUNCTION
      SUM=0.D0
      DO 600 I=1,m
 600  SUM=SUM+C(IB(I))*XB(I)
      OBJ=SUM
      ITER=ITER+1
      RETURN
C
      END


      SUBROUTINE VITRIFY
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C     IF THERE IS NOT ENOUGH SOIL TO MAKE A BATCH, WE ARE OUT OF PIT
C     SLUDGE AND BARELS, AND THERE ARE NO BATCH TANKS WAITING IN THE
C     QUEUES, WE ARE DONE.  EXIT THE ROUTINE.
C
      IF(((SOIL+QHOP-BATCH+SLUDGE+BARELS) .LT. 9.0) .AND.
     + ((NNQ(1) + NNQ(2)) .LE. 0)) THEN
C
        RETURN
C
      ENDIF
C
C     OTHERWISE, CHECK TO SEE IF A MELTER IS AVAILABLE
C
```

```
      IF(QM .GE. 1.0) THEN
C
C       A MELTER IS AVAILABLE, CALL IT UP
C
        QM=QM-1.0
        XX(9)=XX(9)-1.0
C
C       CHANGE ATRIB(1) TO OUTPUT GLASS MASS FROM BATCH
C       MASS REDUCTION IS ROUGHLY 40%
C
cc        ATRIB(1)=ATRIB(1)*0.6
C
C       CALCULATE THE TOTAL POWER REQUIRED TO VITRIFY ALL BATCHES (MW)
C
        XX(40)=XX(40)+0.0033*ATRIB(1)
C
C       SCHEDULE THE MELT TIME:
C       TIME TO MELT = (GLASS OUTPUT MASS)/MLTSIZ*41.67
C
        TMELT=ATRIB(1)/(MLTSIZ*41.67)
C
C       CALL GLASSOUT
        CALL SCHDL(10,TMELT,ATRIB)
C
        RETURN
C
      ELSE
C
C       NO MELTER IS AVAILABLE.  LOG WAITING TIME, CALL BACK LATER.
C
        WAITM=WAITM+1.0
C
C
        CALL SCHDL(9,1.0,ATRIB)
        RETURN
C
      END IF
      END

      SUBROUTINE GLASSOUT
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
```

```
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C
C     MELTER CYCLE IS COMPLETE
C
C     COUNT THE BATCHES
C
      XX(14)=XX(14)+1.0
C
      IF(MOD(XX(14),100.) .EQ. 0.0)THEN
C
       PRINT*,XX(14),' BATCHES PROCESSED IN ',TNOW/8760.,' YEARS'
C
      ENDIF
C
C     FREE UP MELTER AND BTANK
      BTANKS=BTANKS+1.0
      XX(1)=XX(1)+1.0
C
      QM=QM+1.0
      XX(9)=XX(9)+1.0
C
C     UPDATE VOLUME OF GLASS OUTPUT
C
C     BVOL=VOLUME OF GLASS FROM THIS BATCH
C
C     **** DIVIDING BY 0.7 ACCOUNTS FOR VOID SPACE IN GEMS *****
      BVOL=ATRIB(1)/(GLSDEN*0.7)
C
C     GLASSVOL = TOTAL GLASS PRODUCED
C
      GLSVOL=GLSVOL+BVOL
C
      RETURN
      END


      SUBROUTINE OTPUT
$INCLUDE: 'PARAM.INC'
$INCLUDE: 'SCOM1.COM'
      common/ucom1/SMX,BTANKS,BARELS,BSPACE,SOIL,QHOP,BATCH,QS,
     +SIO,QNAO,ERATIO,TLOTIM,THITIM,EXS,EXN,FIXTIM,MLTSIZ,
     +GLO,MID,HI,WAITM,GLSDEN,GLSVOL,SOLIDM,DENSE,PMALO,PMCAO,
     +PMFEO,PMKO,PMMGO,PMNAO,PMPO,PMSIO,PMTIO,VMALO,VMCAO,VMFEO,
     +VMKO,VMMGO,VMPO,VMSIO,VMTIO,PSALO,PSCAO,SOLIDS,SOLIDR,SOLIDB,
     +PSFEO,PSKO,PSMGO,PSNAO,PSPO,PSSIO,PSTIO,VSALO,VSCAO,VSFEO,
     +VSKO,VSMGO,VSPO,VSSIO,VSTIO,PRALO,PRCAO,SLUDGE,BPTANK,
     +PRFEO,PRKO,PRMGO,PRNAO,PRPO,PRSIO,PRSO,VRALO,VRCAO,VRFEO,
     +VRKO,VRMGO,VRPO,VRSIO,VRTIO,PBALO,PBCAO,BORON,TNKSIZ,
     +PBFEO,PBKO,PBMGO,PBNAO,PBPO,PBSIO,PBTIO,VBALO,VBCAO,VBFEO,
     +VBKO,VBMGO,VBPO,VBSIO,VBTIO,QA,ACCUM,QB,QRACK,CAPRAC,WRACK,
     +TBDB,TBDA,TBDE,QE,CAPHOP,WHOP,SWTIML,SWTIMH,WTSOIL,
     +TBFA,TBFS,TBFE,TBFB,TBFM,QM,AREPLO,AREPHI,SREPLO,SREPHI,
```

```
     +EREPLO,EREPHI,BREPLO,BREPHI,REPLOM,REPHIM,WBTANK,AMOUNT,
     +PMSO,PMF,PMBO,PMLIO,VMSO,VMF,VMBO,VMLIO,PSSO,PSB,PSLIO,PSF,
     +VSSO,VSB,VSLIO,PRB,PRLIO,PRF,ISTREAM
C
C   OTPUT PRINTS OUT KEY STATISTICS FOR TUNING THE SYSTEM AND FOR
C   FEEDING THE LIFE CYCLE COST MODEL.
C
      PRINT*,'--------------------------------------'
      PRINT*,'TOTAL TIME TO REMEDIATE SITE = ',TNOW/8760.
      PRINT*,' '
C
C    PACKING DENSITY OF GLASS GEMS IS 70% GEMS/30% VOID SPACE
C
C    GEMVOL = TOTAL STORAGE REQUIRED (M3)
C
      GEMVOL=GLSVOL/.7
C
      PRINT*,'GLASS GEM VOLUME = ',GEMVOL
      PRINT*,' '
      PAUSE
C
      PRINT*,'MELTER CONFIGURATION'
      PRINT*,' '
      PRINT*,'NUMBER OF MELTERS: ',XX(16)
      PRINT*,' '
      PRINT*,'MELTER SIZE (TPD): ',MLTSIZ
      PRINT*,'-----------------------------------------------------'
      PAUSE
C
      PRINT*,'              *** SUPPORT STATISTICS***'
      PRINT*,' '
      PRINT*,' '
      PRINT*,' '
      PRINT*,'SUPPORT CONFIGURATION:'
      PRINT*,' '
      PRINT*,'  SOIL WASHING CAPACITY (M3/HR): ',XX(28)*2.
      PRINT*,' '
      PRINT*,'  AUGERS/PUMPS:             ',XX(20)
      PRINT*,' '
      PRINT*,'  TRUCKS:                   ',XX(21)
      PRINT*,' '
      PRINT*,'  BARREL MOVERS:            ',XX(22)
      PRINT*,' '
      PAUSE
C
      PRINT*,'INITIAL QUANTITIES OF WASTE TO REMEDIATE:'
      PRINT*,' '
      PRINT*,'SOIL:   ',XX(17)
      PRINT*,' '
      PRINT*,'SLUDGE:  ',XX(18)
      PRINT*,' '
      PRINT*,'BARRELS: ',XX(19)
      PRINT*,' '
      PRINT*,' '
      PAUSE
```

```
C
      PRINT*,'ADDITIVES CONSUMED (METRIC TONS):'
      PRINT*,' '
      PRINT*,'NA2CO3 CUM = ',xx(75)/1000.
      PRINT*,' '
      PRINT*,'SIO2 CUM   = ',xx(76)/1000.
      PRINT*,' '
      PRINT*,'H3BO3      = ',xx(77)/1000.
      PRINT*,' '
      PRINT*,'BORAX      = ',xx(78)/1000.
      PRINT*,' '
      PAUSE
C
      PRINT*,'WASTE REMAINING (M3):'
      PRINT*,' '
C
      PRINT*,'SOIL    = ',SOIL
      PRINT*,'SLUDGE  = ',SLUDGE
      PRINT*,'BARRELS = ',BARELS
      PAUSE
C
      PRINT*,'***** PROCESS STATISTICS *****'
      PRINT*,' '
      PRINT*,'AVERAGE WAIT FOR MELTER: ',WAITM/XX(14),' HOURS'
      PRINT*,' '
      PRINT*,'PERCENT TIME WAITING FOR:'
      PRINT*,' '
      PRINT*,'BTANK          = ',XX(10)
      PRINT*,'RACK SPACE     = ',XX(11)
      PRINT*,'HOPPER SPACE   = ',XX(12)
      PRINT*,'SOIL           = ',XX(13)
      PRINT*,'SLUDGE         = ',XX(32)*100/TNOW
      PRINT*,'SOIL WASH OUT = ',XX(31)*100/TNOW
      PRINT*,' '
      PAUSE
C
      PRINT*,' '
      PRINT*,' '
      PRINT*,'# BATCHES PROCESSED:  ',XX(14)
      PRINT*,' '
C
      PRINT*,'FINAL FILE STATS'
      PRINT*,' '
      PRINT*,'NNQ(1)      = ',NNQ(1)
      PRINT*,'NNQ(2)      = ',NNQ(2)
      PRINT*,'NNQ(NCLNR) = ',NNQ(NCLNR)
      PAUSE
C
      OPEN(UNIT=10,FILE='C:\SLAMsys\SIMOUT\CNFG5kq3',STATUS='NEW')
C
C     WRITE OUTPUT TO FILE
C
      WRITE(10,90)
C
 90   FORMAT(/2X,'*** SIMULATION OUTPUT -- CONFIGURATION 3 ***')
```

```
C
      WRITE(10,*)'________________________________________'
C
      WRITE(10,91)ISTREAM
C
91    FORMAT(/2X,'Random Stream = ',T32,I2)
c
      WRITE(10,92)
C
92    FORMAT(/2X,'*** SYSTEM CONFIGURATION ***')
C
      WRITE(10,*)
C
      WRITE(10,100)XX(16),MLTSIZ
C
100   FORMAT(/2X,'# MELTERS:',T32,F2.0//2X,'O/P CAPACITY PER MELTER:',
     + T32,I3)
C
      WRITE(10,120)XX(17)+XX(18)
C
120   FORMAT(/2X,'Q = ',T32,F7.0)
C
      WRITE(10,*)'________________________________________'
C
      WRITE(10,125)
C
125   FORMAT(/2X,'*** SIMULATION OUTPUT ***')
C
      WRITE(10,*)
C
      WRITE(10,130)TNOW/8760.
C
130   FORMAT(/2X,'TOTAL TIME TO REMEDIATE SITE = ',T32,F4.1,1X,'YEARS')
C
      WRITE(10,135)GEMVOL
C
135   FORMAT(/2X,'GLASS GEM VOLUME = ',T32,F12.0,1X,'M3')
C
      WRITE(10,140)XX(40)
C
140   FORMAT(/2X,'POWER CONSUMPTION:',T32,F12.3,1X,'MW')
C
C
      WRITE(10,141)(XX(17)-SOIL-QHOP)*1.4
C
141   FORMAT(/2X,'TOTAL SOIL WASHED (TONS):',T32,F12.3,1X,'TONS')
C
      WRITE(10,143)
C
143   FORMAT(/2X,'ADDITIVES CONSUMED (METRIC TONS)')
C
      WRITE(10,147)XX(75)/1000.,XX(76)/1000.,XX(77)/1000.,XX(78)/1000.
C
147   FORMAT(/2X,'NA2CO3:',T10,F10.1/2X,'SIO2:',T10,F10.1/2X,
     + 'H3BO3:',T10,F10.1/2X,'BORAX:',T10,F10.1)
```

```
C
      WRITE(10,149)XX(14)
C
 149  FORMAT(/2X,'# BATCHES PROCESSED:',2X,F6.0)
C
      WRITE(10,*)'_________________________________________'
C
      WRITE(10,150)
C
 150  FORMAT(/2X,'*** SUPPORT CONFIGURATION ***')
C
      WRITE(10,*)
C
      WRITE(10,160)XX(28)*2.
C
 160  FORMAT(/2X,'SOIL WASHING CAPACITY (M3/HR):',T32,F4.0)
C
      WRITE(10,170)XX(20)
C
 170  FORMAT(/2X,'SLUDGE PUMPS:',T32,F4.0)
C
      WRITE(10,180)XX(21)
C
 180  FORMAT(/2X,'TRUCKS:',T32,F4.0)
C
      WRITE(10,*)'_________________________________________'
C
      WRITE(10,210)
C
 210  FORMAT(/2X,'*** STATISTICS ***')
C
      WRITE(10,*)
C
      WRITE(10,220)
C
 220  FORMAT(/2X,'PERCENT TIME SPENT WAITING FOR')
C
      WRITE(10,230)XX(10),XX(11),XX(12),XX(13),XX(32)*100/TNOW,
     +  XX(31)*100/TNOW
C
 230  FORMAT(/5X,'BATCH TANKS:',T22,F4.0/5X,'RACK SPACE:',T22,F4.0/5X,
     + 'HOPPER SPACE:',T22,F4.0/5X,'SOIL:',T22,F4.0/5X,'SLUDGE:',
     + T22,F4.0/5X,'SOIL WASH O\P:',T22,F4.0)
C
      WRITE(10,*)'_________________________________________'
C
      CLOSE(UNIT=10,STATUS='KEEP')
C
      RETURN
      END
```

CONTROL STATEMENT

```
GEN,TOLAND & WHITE,VITSIM1,11/14/1994,1,Y,Y,Y/Y,Y,Y/1,132;
LIMITS,3,3,300;
INITIALIZE,,2400000,Y;
TIMST,XX(1),BTANKS;
TIMST,XX(9),MELTER IDLE;
TIMST,XX(51),AUGERS UP;
TIMST,XX(52),EXCAVS UP;
TIMST,XX(54),SWASH UP;
TIMST,XX(53),BMOVERS UP;
TIMST,XX(15),MELTERS UP;
STAT,2,TIO;
STAT,1,SIO;
MONTR,INTERACT;
FIN;
```

Appendix J: EXCEL LIFE-CYCLE COST MACRO CODE

COMMAND MACRO (a)

****** CLOSE EXTRA FILES & OPEN MENUS ******

```
=OPEN("C:\EXCEL\LIBRARY\FILEFNS.XLA")
=SET.NAME("FILE_ID",0)
=HIDE()
=OPEN("C:\LCC\MENUS.XLS")
=HIDE()
=OPEN("C:\LCC\MENU.XLS")
=HIDE()
```

****** PRINT MAIN MENU ON TEMPLATE ******

```
=ACTIVATE("MENU.XLS")
=COPY("MENUS.XLS!C1")
=SELECT("C1")
=PASTE.SPECIAL(1)
=WINDOW.SIZE(175,210)
=SELECT("R1C1")
=UNHIDE("MENU.XLS")
=SET.NAME("MMENU",INPUT("Enter selection:",1,,5,200,50,))
=WINDOW.RESTORE()
=HIDE()
=IF(OR(INT(MMENU)<>MMENU,MMENU<1,MMENU>5))
=   ACTIVATE("MENU.XLS")
=   GOTO($A$20)
=END.IF()
=ACTIVATE("MENU.XLS")
=SELECT("C1")
=CLEAR(1)
```

****** LOAD DATA FILE ******

```
=IF(MMENU=1)
=   IF(FILE_ID=-1)
=      ACTIVATE(FILE_NAME)
=      CLOSE(FALSE)
=      ACTIVATE("MENU.XLS")
=   END.IF()
=   DEFINE.NAME("FILES",FILES("C:\LCC\DATA\*.DAT"))
=   SET.NAME("NFILES",COLUMNS(!FILES))
=   IF(TYPE(!FILES)=16)
=      ALERT("The data subdirectory is empty. Please create a data file first.",3)
=      GOTO($A$15)
=   END.IF()
```

****** PRINT FILE NAMES ON TEMPLATE ******

```
=   WINDOW.TITLE("LOAD.XLS")
=   SELECT("R1C1")
=   FORMULA("*** DATA FILES ***")
=   COLUMN.WIDTH(20)
=   FORMAT.FONT(,,TRUE,TRUE)
=   FORMULA.ARRAY("=TRANSPOSE(FILES)",OFFSET(!$A$3,0,0,NFILES,1))
=   COPY(OFFSET(!$A$3,0,0,NFILES,1))
=   SELECT("R3C1")
=   PASTE.SPECIAL(3)
=   SORT(1,!$A$3,1)
=   WINDOW.SIZE(148,210)
=   SELECT("R1C1")
=   UNHIDE("LOAD.XLS")
=   SET.NAME("FILE_NAME",INPUT("Enter the data file name:",2,,,180,50))
=   WINDOW.RESTORE()
=   HIDE()
```

****** CHECK FOR EXISTENCE OF FILE ******

```
=   SET.NAME("EXIST",'C:\EXCEL\LIBRARY\FILEFNS.XLA'!FILE.EXISTS("C:\LCC\DATA\"&FILE_NAME))
=   IF(EXIST=FALSE)
=      ACTIVATE("LOAD.XLS")
=      GOTO($A$59)
=   END.IF()
=   OPEN("C:\LCC\DATA\"&FILE_NAME)
```

****** CHECK FOR VALIDITY OF FILE ******

```
=   ACTIVATE(FILE_NAME)
=   GET.NAME("!SALSERO_BRAVO")
=   IF(TYPE($A$76)=16)
=      CLOSE(FALSE)
=      ALERT(""""&FILE_NAME&""" is not a compatible data file. Please select another file.",3)
=      ACTIVATE("LOAD.XLS")
=      GOTO($A$59)
=   END.IF()
=   SET.NAME("FILE_ID",-1)
=   ACTIVATE("LOAD.XLS")
=   WINDOW.TITLE("MENU.XLS")
=   GOTO($A$15)
=END.IF()
```

****** RUN SUBROUTINES ******

```
=IF(MMENU=2,RUN(DATA_CREATION_SUBROUTINE))
=IF(MMENU=3,RUN(DATA_EDITING_SUBROUTINE))
=IF(MMENU=4,RUN(SIMULATION_SUBROUTINE))
=IF(FILE_ID=-1)
=   ACTIVATE(FILE_NAME)
=   CLOSE(FALSE)

=END.IF()
```

```
=ACTIVATE("MENUS.XLS")
=CLOSE(FALSE)
=ACTIVATE("MENU.XLS")
=CLOSE(FALSE)
=ACTIVATE("LCC2.XLM")
=CLOSE(FALSE)

=RETURN()
```

DATA CREATION SUBROUTINE (b)

****** OPEN TEMPLATE ******

```
=OPEN("C:\LCC\TEMPLATE.XLS")
=HIDE()
=IF(FILE_ID=-1)
=    ACTIVATE(FILE_NAME)
=    CLOSE(FALSE)
=END.IF()
=SET.NAME("FILE_NAME","TEMPLATE.XLS")
=ACTIVATE(FILE_NAME)
```

****** OBTAIN NUMBER OF VARIABLES & COST ELEMENTS ******

```
=ALERT("Remember - data entry errors can be corrected by selecting View / Edit from the Main
 Menu.",2)
=SET.NAME("NVAR_M",INPUT("Enter the number of variables (VAR):",1))
=IF(OR(INT(NVAR_M)<>NVAR_M,NVAR_M<0),GOTO($A$121))
=SET.NAME("NTCE_M",INPUT("Enter the number of trapezoidal cost elements (TCE):",1))
=IF(OR(INT(NTCE_M)<>NTCE_M,NTCE_M<0),GOTO($A$123))
=SET.NAME("NPCE_M",INPUT("Enter the number of percentage cost elements (PCE):",1))
=IF(OR(INT(NPCE_M)<>NPCE_M,NPCE_M<0),GOTO($A$125))
=SET.NAME("NRCE_M",INPUT("Enter the number of recurring cost elements (RCE):",1))
=IF(OR(INT(NRCE_M)<>NRCE_M,NRCE_M<0),GOTO($A$127))
=SET.NAME("NCT_M",SUM(NVAR_M,NTCE_M,NPCE_M,NRCE_M))
=IF(NCT_M=0)
=    ALERT("The total number of variables/cost elements cannot be zero.
     Please enter correct data.",3)
=    GOTO($A$121)
=END.IF()
```

****** DEFINE COST DATA REFERENCES ******

```
=DEFINE.NAME("GEN_REF",!$A$1)
=DEFINE.NAME("VAR_REF",OFFSET(!GEN_REF,3,0,1,1))
=DEFINE.NAME("TCE_REF",OFFSET(!VAR_REF,NVAR_M+5,0,1,1))
=DEFINE.NAME("PCE_REF",OFFSET(!TCE_REF,NTCE_M+2,0,1,1))
=DEFINE.NAME("RCE_REF",OFFSET(!PCE_REF,NPCE_M+2,0,1,1))
=DEFINE.NAME("TIME_REF",OFFSET(!RCE_REF,NRCE_M+2,0,1,1))

=DEFINE.NAME("CF_REF",OFFSET(!TIME_REF,3,0,1,1))
```

```
=DEFINE.NAME("NAME_REF",OFFSET(!CF_REF,NTCE_M+NPCE_M+NRCE_M+2,0,1,1))

*** COPY GENERAL INPUTS TO TEMPLATE ***
=DEFINE.NAME("NCT",OFFSET(!GEN_REF,1,0,1,1))
=DEFINE.NAME("NVAR",OFFSET(!GEN_REF,1,1,1,1))
=DEFINE.NAME("NTCE",OFFSET(!GEN_REF,1,2,1,1))
=DEFINE.NAME("NPCE",OFFSET(!GEN_REF,1,3,1,1))
=DEFINE.NAME("NRCE",OFFSET(!GEN_REF,1,4,1,1))
=DEFINE.NAME("NCE",OFFSET(!GEN_REF,1,5,1,1))
=FORMULA("=SUM("&REFTEXT(!NVAR)&","&REFTEXT(!NCE)&")",!NCT)
=FORMULA(NVAR_M+3,!NVAR)
=FORMULA(NTCE_M,!NTCE)
=FORMULA(NPCE_M,!NPCE)
=FORMULA(NRCE_M,!NRCE)
=FORMULA("=SUM("&REFTEXT(!NTCE)&","&REFTEXT(!NPCE)&","&REFTEXT(!NRCE)&")",!NCE)

*** GENERATE TIME INDICES ***
=FORMULA(0,OFFSET(!TIME_REF,1,CO_8,1,1))
=FORMULA.FILL("=RC(-1)+1",OFFSET(!TIME_REF,1,CO_8+1,1,200))

*** OBTAIN NAMES OF VARIABLES, ELEMENTS, CATEGORIES ***
=SET.NAME("COUNT1",0)
=ALERT("Remember - names can only be used once and must contain letters, numbers,
 or underlines.",2)
=FOR("K_1",1,4)

*** DEFINE VAR-SPECIFIC DATA ***
=    IF(K_1=1)
=        SET.NAME("REF",!VAR_REF)
=        SET.NAME("NN",!NVAR)
=        SET.NAME("DES","VAR")
=        SET.NAME("CO_1",7)
=        GOTO($A$207)
=    END.IF()

*** DEFINE TCE-SPECIFIC DATA ***
=    IF(K_1=2)
=        SET.NAME("REF",!TCE_REF)
=        SET.NAME("NN",!NTCE)
=        SET.NAME("DES","TCE")
=        SET.NAME("CO_1",7)
=        SET.NAME("RO_1",0)
=        GOTO($A$207)
=    END.IF()

*** DEFINE PCE-SPECIFIC DATA ***
=    IF(K_1=3)

=        SET.NAME("REF",!PCE_REF)
```

```
=       SET.NAME("NN",!NPCE)
=       SET.NAME("DES","PCE")
=       SET.NAME("CO_1",7)
=       SET.NAME("RO_1",!NTCE)
=       GOTO($A$207)
=    END.IF()
```

****** DEFINE RCE-SPECIFIC DATA ******

```
=    IF(K_1=4)
=       SET.NAME("REF",!RCE_REF)
=       SET.NAME("NN",!NRCE)
=       SET.NAME("DES","RCE")
=       SET.NAME("CO_1",6)
=       SET.NAME("RO_1",!NTCE+!NPCE)
=       GOTO($A$207)
=    END.IF()
```

****** OBTAIN INPUTS ******

```
=    IF(MENU2=2,GOTO($A$217))
=    IF(NN=0, GOTO($A$240))
=    FOR("K_2",1,NN)
=       IF(AND(K_1=1,K_2<4))
=          IF(K_2=1,SET.NAME("NAME","TIME"))
=          IF(K_2=2,SET.NAME("NAME","LIFE"))
=          IF(K_2=3,SET.NAME("NAME","RATE"))
=          GOTO($A$219)
=       END.IF()
=       RUN($A$932)
```

****** COPY NAMES TO TEMPLATE ******

```
=       SET.NAME("COUNT1",COUNT1+1)
=       DEFINE.NAME(NAME,OFFSET(REF,K_2,CO_1,1,1))
=       FORMULA(NAME,OFFSET(REF,K_2,5,1,1))
=       FORMULA("="&REFTEXT(OFFSET(REF,K_2,5,1,1)),OFFSET(!NAME_REF,COUNT1,0,1,1))
=       FORMULA(DES,OFFSET(!NAME_REF,COUNT1,1,1,1))
=       IF(K_1=1,GOTO($A$238))
```

****** INITIALIZE CASH FLOW RANGES ******

```
=       SELECT(OFFSET(!CF_REF,RO_1+K_2,CO_8,1,1))
=       FORMULA(0)
=       FILL.AUTO(OFFSET(!CF_REF,RO_1+K_2,CO_8,1,201))
=       IF(AND(MENU2=1,MENU=3),RETURN())
```

****** DEFINE RELATED NAMES ******

```
=       DEFINE.NAME("TOTAL_"&NAME,OFFSET(!CF_REF,RO_1+K_2,0,1,1))
=       DEFINE.NAME("NPV_"&NAME,OFFSET(!CF_REF,RO_1+K_2,1,1,1))
=       DEFINE.NAME("AE_"&NAME,OFFSET(!CF_REF,RO_1+K_2,2,1,1))

=       DEFINE.NAME("FV_"&NAME,OFFSET(!CF_REF,RO_1+K_2,3,1,1))
```

```
=        IF(MENU2=2,GOTO($A$256))
=    NEXT()
=NEXT()
```

****** PRINT LABELS ON TEMPLATE ******

```
=FORMULA("GENERAL INPUTS:",!GEN_REF)
=FORMULA("VARIABLES:",!VAR_REF)
=FORMULA("TRAPEZOIDAL COST ELEMENTS:",!TCE_REF)
=FORMULA("PERCENTAGE COST ELEMENTS:",!PCE_REF)
=FORMULA("RECURRING COST ELEMENTS:",!RCE_REF)
=FORMULA("TIME INDICES:",!TIME_REF)
=FORMULA("CASH FLOWS:",!CF_REF)
=FORMULA("NAMES:",!NAME_REF)
```

****** OBTAIN VARIABLES, ELEMENTS, CATEGORIES ******

```
=SET.NAME("COUNT",0)
=FOR("K_1",1,4)
```

****** DEFINE VAR-SPECIFIC DATA ******

```
=    IF(K_1=1)
=        SET.NAME("REF1",!VAR_REF)
=        SET.NAME("NN",!NVAR)
=        SET.NAME("CO_3",8)
=        SET.NAME("CO_9",7)
=        SET.NAME("DES4","VAR")
=        SET.NAME("TYPE","")
=        GOTO($A$296)
=    END.IF()
```

****** DEFINE TCE-SPECIFIC DATA ******

```
=    IF(K_1=2)
=        SET.NAME("REF1",!TCE_REF)
=        SET.NAME("NN",!NTCE)
=        SET.NAME("CO_3",12)
=        SET.NAME("DES4","TCE")
=        SET.NAME("TYPE","")
=        GOTO($A$296)
=    END.IF()
```

****** DEFINE PCE-SPECIFIC DATA ******

```
=    IF(K_1=3)
=        SET.NAME("REF1",!PCE_REF)
=        SET.NAME("NN",!NPCE)
=        SET.NAME("CO_3",9)
=        SET.NAME("DES4","PCE")
=        SET.NAME("TYPE","")
=        GOTO($A$296)

=    END.IF()
```

**** DEFINE RCE-SPECIFIC DATA ****

```
=   IF(K_1=4)
=      SET.NAME("REF1",!RCE_REF)
=      SET.NAME("NN",!NRCE)
=      SET.NAME("CO_3",10)
=      SET.NAME("DES4","RCE")
=      GOTO($A$296)
=   END.IF()
```

**** OBTAIN REFERENCES TO VARIABLES &COST ELEMENTS ****

```
=   IF(MENU2=2,GOTO($A$303))
=   IF(AND(AND(MENU1>=2,MENU1<=5),MENU2=1,MENU=2),RETURN())
=   IF(NN=0, GOTO($A$669))
=   FOR("K_2",1,NN)
=      IF(AND(K_1=1,K_2=1),GOTO($A$668))
=      IF(K_1<>1,SET.NAME("COUNT",COUNT+1))
=      SET.NAME("NAME",DEREF(OFFSET(REF1,K_2,5,1,1)))
=      SET.NAME("REPEAT",0)
```

**** OBTAIN NUMBER OF REFERENCES ****

```
=      IF(DES4="RCE",SET.NAME("NREF_MAX",!NCT-1),SET.NAME("NREF_MAX",!NCT-2))
=      IF(NREF_MAX=0)
=         SET.NAME("NREF",0)
=         GOTO($A$320)
=      END.IF()
=      IF(AND(AND(MENU1>=2,MENU1<=5),MENU2=1,MENU=2),GOTO($A$314))
=      SET.NAME("NREF_DEF","")
=      SET.NAME("NREF",INPUT("Enter the number of cross references contained in
       "&DES4&" '"&NAME&"':",1,,NREF_DEF))
=      IF(OR(NREF=FALSE,NREF<0,INT(NREF)<>NREF),GOTO($A$314))
=      IF(NREF>NREF_MAX)
=         ALERT("The number of references exceeds the maximum possible.",3)
=         GOTO($A$314)
=      END.IF()
=      IF(AND(AND(MENU1>=2,MENU1<=5),MENU2=1,REPEAT=0),RETURN())
=      FORMULA(NREF,OFFSET(REF1,K_2,3,1,1))
```

**** MAKE ROOM FOR REFERENCES ****

```
=      IF(NREF=0,GOTO($A$476))
=      IF(OR(OFFSET(REF1,K_2,4,1,1)<>0,K_1=3))
=         SELECT(OFFSET(REF1,K_2,CO_3,1,3*NREF))
=         INSERT(1)
=      END.IF()
```

**** OBTAIN REFERENCES ****

```
=      SET.NAME("NAMES",!NCT)

=      SET.NAME("OFFSET",OFFSET(!NAME_REF,1,0,NAMES,2))
```

```
=      COPY(OFFSET)
=      ACTIVATE("MENU.XLS")
=      SELECT("R3C1")
=      PASTE.SPECIAL(3)
=      SET.NAME("POS",MATCH(NAME,OFFSET(!$A$3,0,0,NAMES,1),0))
=      SELECT("R"&ROW(OFFSET(!$A$3,POS-1,0,1,1)))
=      EDIT.DELETE(3)
=      SET.NAME("NAMES",NAMES-1)
=      IF(DES4<>"RCE")
=         SELECT("R"&ROW(OFFSET(!$A$3,0,0,1,1)))
=         EDIT.DELETE(3)
=         SET.NAME("NAMES",NAMES-1)
=      END.IF()
=      SET.NAME("NAME_COST",NAME)
=      FOR("K",1,NREF)
=         RUN($A$870)
=         SELECT("R"&ROW(OFFSET(!$A$3,POS-1,0,1,1)))
=         EDIT.DELETE(3)
```

****** OBTAIN TYPE OF REFERENCE ******

```
=         IF(DES4="RCE")
=            IF(NAME="TIME")
=               SET.NAME("TYPE"," (A)")
=            ELSE.IF(DES="VAR")
=               SET.NAME("TYPE","")
=            ELSE()
=               SET.NAME("TYPE_REF",INPUT("Refer to:  1) Amount     2) Annual CF",1,,1))
=               IF(AND(TYPE_REF<>1,TYPE_REF<>2),GOTO($A$359))
=               IF(TYPE_REF=1,SET.NAME("TYPE",""),SET.NAME("TYPE"," (A)"))
=            END.IF()
=         END.IF()
=         ACTIVATE("MENUS.XLS")
=         FORMULA(NAME,OFFSET(!$AC$1,K-1,0,1,1))
=         FORMULA(DES,OFFSET(!$AC$1,K-1,1,1,1))
=         FORMULA(TYPE,OFFSET(!$AC$1,K-1,2,1,1))
=         SET.NAME("NAMES",NAMES-1)
=         ACTIVATE("NAMES.XLS")
=      NEXT()
=      IF(NAMES<>0)
=         SELECT(OFFSET(!$A$3,0,0,NAMES,2))
=         CLEAR(1)
=      END.IF()
=      SET.NAME("NAME",NAME_COST)
```

****** CONFIRM REFERENCES ******

```
=      ACTIVATE("MENUS.XLS")
=      COPY(OFFSET(!$AC$1,0,0,NREF,2))

=      ACTIVATE("NAMES.XLS")
```

```
=       SELECT("R3C1")
=       PASTE.SPECIAL(3)
=       SELECT("C2")
=       ALIGNMENT(3)
=       WINDOW.SIZE(270,210)
=       SELECT("R3C1")
=       UNHIDE("NAMES.XLS")
=       SET.NAME("CONFIRM",INPUT("Are these cross references correct?",2,,"Y",245,50))
=       WINDOW.RESTORE()
=       HIDE()
=       IF(AND(LEFT(CONFIRM)<>"Y",LEFT(CONFIRM)<>"N"))
=          ACTIVATE("NAMES.XLS")
=          GOTO($A$385)
=       END.IF()
=       ACTIVATE("NAMES.XLS")
=       SELECT("C1:C2")
=       CLEAR(1)
=       IF(CONFIRM="N")
=          WINDOW.TITLE("MENU.XLS")
=          ACTIVATE("MENUS.XLS")
=          SELECT("C29:C31")
=          CLEAR(1)
=          ACTIVATE(FILE_NAME)
=          SET.NAME("REPEAT",-1)
=          GOTO($A$306)
=       END.IF()
=       WINDOW.TITLE("MENU.XLS")
=       ACTIVATE(FILE_NAME)
```

****** UPDATE DEPENDENCIES ******

```
=       IF(NREF=0,GOTO($A$476))
=       FOR("K_7",1,NREF)
=          SET.NAME("NAME_REF",DEREF(OFFSET('C:\LCC\[MENUS.XLS]MENUS'!$AC$1,K_7-1,0,1,1)))
=          SET.NAME("DES_REF",DEREF(OFFSET('C:\LCC\[MENUS.XLS]MENUS'!$AC$1,K_7-1,1,1,1)))
=          SET.NAME("TYPE_REF",DEREF(OFFSET('C:\LCC\[MENUS.XLS]MENUS'!$AC$1,K_7-1,2,1,1)))
=          IF(TYPE_REF=0,SET.NAME("TYPE_REF",""))
=          SET.NAME("LOC",TEXTREF(REPLACE(GET.NAME("!"&NAME_REF),1,1,"!")))
```

****** DEFINE VAR-SPECIFIC DATA ******

```
=          IF(DES_REF="VAR")
=             SET.NAME("CO_4",1)
=             SET.NAME("CO_5",-3)
=             SET.NAME("CO_6",-4)
=             SET.NAME("CO_7",-2)
=             GOTO($A$455)
=          END.IF()
```

****** DEFINE TCE-SPECIFIC DATA ******

```
=        IF(DES_REF="TCE")
=            SET.NAME("CO_4",5)
=            SET.NAME("CO_5",-3)
=            SET.NAME("CO_6",-4)
=            SET.NAME("CO_7",-2)
=            GOTO($A$455)
=        END.IF()
```

****** DEFINE PCE-SPECIFIC DATA ******

```
=        IF(DES_REF="PCE")
=            SET.NAME("CO_4",2)
=            SET.NAME("CO_5",-3)
=            SET.NAME("CO_6",-4)
=            SET.NAME("CO_7",-2)
=            GOTO($A$455)
=        END.IF()
```

****** DEFINE RCE-SPECIFIC DATA ******

```
=        IF(DES_REF="RCE")
=            SET.NAME("CO_4",4)
=            SET.NAME("CO_5",-2)
=            SET.NAME("CO_6",-3)
=            SET.NAME("CO_7",-1)
=            GOTO($A$455)
=        END.IF()
```

****** COPY INPUTS TO TEMPLATE ******

```
=        FORMULA(OFFSET(LOC,0,CO_5,1,1)+1,OFFSET(LOC,0,CO_5,1,1))
=        SET.NAME("OFFSET",CO_4+3*OFFSET(LOC,0,CO_6,1,1)+3*(OFFSET(LOC,0,CO_5,1,1)-1))
=        SET.NAME("REF_1",RELREF(OFFSET(REF1,K_2,5,1,1),OFFSET(LOC,0,OFFSET,1,1)))
=        SET.NAME("REF_2",RELREF(OFFSET(LOC,0,CO_7,1,1),OFFSET(REF1,K_2,CO_3+3*(K_7-1),1,1)))
=        IF(AND(DES_REF="PCE",OFFSET(LOC,0,1,1,1)<>0))
=            SELECT(OFFSET(LOC,0,OFFSET,1,3))
=            INSERT(1)
=        END.IF()
=        FORMULA("="&REF_1,OFFSET(LOC,0,OFFSET,1,1))
=        FORMULA(DES4,OFFSET(LOC,0,OFFSET+1,1,1))
=        FORMULA(TYPE_REF,OFFSET(LOC,0,OFFSET+2,1,1))
=        FORMULA("="&REF_2,OFFSET(REF1,K_2,CO_3+3*(K_7-1),1,1))
=        FORMULA(DES_REF,OFFSET(REF1,K_2,CO_3+3*(K_7-1)+1,1,1))
=        FORMULA(TYPE_REF,OFFSET(REF1,K_2,CO_3+3*(K_7-1)+2,1,1))
=    NEXT()
=    ACTIVATE("MENUS.XLS")
=    SELECT("C29:C31")
=    CLEAR(1)
=    ACTIVATE(FILE_NAME)
```

****** OBTAIN AMOUNTS FOR VARIABLES & ELEMENTS ******

```
=	SET.NAME("RVAR",INPUT("Does the amount for "&DES4&" '"&NAME&"' contain
	probability distributions?",2,,"N"))
=	IF(AND(LEFT(RVAR)<>"Y",LEFT(RVAR)<>"N"),GOTO($A$477))
=	IF(MENU=2,SET.NAME("AMOUNT_DEF","="&OFFSET(REF1,K_2,6,1,1)),
	SET.NAME("AMOUNT_DEF","="))
=	IF(OR(NREF<>0,RVAR="Y"),SET.NAME("AMT_TYPE",0),SET.NAME("AMT_TYPE",1))
=	SET.NAME("AMOUNT",INPUT("Enter the amount for "&DES4&" '"&NAME&"':"
	,AMT_TYPE,,AMOUNT_DEF))
=	IF(AMOUNT=FALSE,GOTO($A$481))
=	IF(MID(AMOUNT,2,1)="""")
=	   ALERT("The amount must begin with '='.",3)
=	   SET.NAME("AMOUNT_DEF",REPLACE(SUBSTITUTE(AMOUNT,"""",""),1,1,""))
=	   GOTO($A$481)
=	END.IF()
=	SET.NAME("AMOUNT",UPPER(AMOUNT))
=	IF(OR(NREF<>0,RVAR="Y"),SET.NAME("AMOUNT_TXT",REPLACE(AMOUNT,1,1,""))
	,SET.NAME("AMOUNT_TXT",AMOUNT))
=	IF(NREF=0,GOTO($A$517))
```

**** CONVERT NAMES TO R1C1 STYLE REFERENCES ****

```
=	FOR("K_7",1,NREF)
=	   SET.NAME("AMOUNT_TMP",AMOUNT)
=	   SET.NAME("OLD",DEREF(OFFSET(REF1,K_2,CO_3+3*(K_7-1),1,1)))
=	   SET.NAME("REF_DES",DEREF(OFFSET(REF1,K_2,CO_3+3*(K_7-1)+1,1,1)))
=	   SET.NAME("REF_TYPE",DEREF(OFFSET(REF1,K_2,CO_3+3*(K_7-1)+2,1,1)))
=	   IF(REF_TYPE=" (A)")
=	      SET.NAME("NEW",REPLACE(GET.NAME("!TOTAL_"&OLD),1,1,"!"))
=	      IF(OLD="TIME")
=	         SET.NAME("NEW",OFFSET(!TIME_REF,1,0,1,1))
=	         SET.NAME("NEW","!"&ADDRESS(ROW(NEW),COLUMN(NEW),,FALSE))
=	      END.IF()
=	      SET.NAME("REF10",REPLACE(GET.NAME("!TOTAL_"&NAME),1,1,"!"))
=	      SET.NAME("NEW",RELREF(TEXTREF(NEW),TEXTREF(REF10)))
=	      GOTO($A$510)
=	   END.IF()
=	   IF(REF_DES="VAR",SET.NAME("PREFIX",""),SET.NAME("PREFIX","TOTAL_"))
=	   SET.NAME("NEW",REPLACE(GET.NAME("!"&PREFIX&OLD),1,1,""))
=	   SET.NAME("AMOUNT",SUBSTITUTE(AMOUNT,OLD,NEW))
=	   IF(AMOUNT=AMOUNT_TMP)
=	      ALERT("'"&NAME&"' must contain a reference to '"&OLD&"'.",3)
=	      SET.NAME("AMOUNT_DEF","="&AMOUNT_TXT)
=	      GOTO($A$481)
=	   END.IF()
=	NEXT()
=	FORMULA(AMOUNT_TXT,OFFSET(REF1,K_2,6,1,1))
```

**** DEFINE COMMON REFERENCES ****

```
=	IF(K_1=1, GOTO($A$524))
=	SET.NAME("REF_REF",REPLACE(GET.NAME("!"&NAME),1,1,"!"))
```

```
=       SET.NAME("REF_FOR",REPLACE(REF_REF,1,1,""))
```

****** COPY VARIABLES TO TEMPLATE ******

```
=       IF(K_1=1)
=          FORMULA(AMOUNT,OFFSET(REF1,K_2,CO_9,1,1))
=          IF(AND(MENU2=1,MENU=2),RETURN())
=          GOTO($A$667)
=       END.IF()
```

****** OBTAIN TCE INPUTS ******

```
=       IF(K_1=2)
=          IF(AND(MENU2=1,MENU=3),GOTO($A$536))
=          FORMULA(AMOUNT,TEXTREF(REF_REF))
=          IF(AND(MENU2=1,MENU=2),RETURN())
=          SET.NAME("PHASE_IN",INPUT("Enter the phase-in period for "&DES4&" '"&NAME&"' :",1))
=          IF(OR(INT(PHASE_IN)<>PHASE_IN,PHASE_IN<0),GOTO($A$536))
=          SET.NAME("CONSTANT",INPUT("Enter the constant-cost period for
           "&DES4&" '"&NAME&"' :",1))
=          IF(OR(INT(CONSTANT)<>CONSTANT,CONSTANT<0),GOTO($A$538))
=          SET.NAME("PHASE_OUT",INPUT("Enter the phase-out period for
           "&DES4&" '"&NAME&"' :",1,,,,,))
=          IF(OR(INT(PHASE_OUT)<>PHASE_OUT,PHASE_OUT<0),GOTO($A$540))
=          IF(AND(PHASE_IN=0,CONSTANT=0,PHASE_OUT=0))
=             ALERT("At least one period must be non-zero. Please enter correct data.",3)
=             GOTO($A$536)
=          END.IF()
=          SET.NAME("START",INPUT("Enter the year payments start for "&DES4&" '"&NAME&"' :",1))
=          IF(OR(INT(START)<>START,START<0),GOTO($A$546))
```

****** COPY TCE INPUTS TO TEMPLATE ******

```
=          FORMULA(PHASE_IN,OFFSET(REF1,K_2,8,1,1))
=          FORMULA(CONSTANT,OFFSET(REF1,K_2,9,1,1))
=          FORMULA(PHASE_OUT,OFFSET(REF1,K_2,10,1,1))
=          FORMULA(START,OFFSET(REF1,K_2,11,1,1))
```

****** GENERATE TCE PHASE-IN CASH FLOWS ******

```
=          SET.NAME("HEIGHT",2/(PHASE_IN+2*CONSTANT+PHASE_OUT))
=          IF(PHASE_IN=0, GOTO(A$565))
=          FOR("PI",1,PHASE_IN)
=             SET.NAME("PERCENT",(2*PI-1)*HEIGHT/(2*PHASE_IN))
=             SET.NAME("CASH_FLOW","="&PERCENT&"*"&REF_FOR)
=             SET.NAME("PERIOD",OFFSET(!CF_REF,COUNT,CO_8+START+PI-1,1,1))
=             FORMULA(CASH_FLOW,PERIOD)
=          NEXT()
```

****** GENERATE TCE CONSTANT-COST CASH FLOWS ******

```
=          IF(CONSTANT=0, GOTO($A$572))

=          SET.NAME("PERCENT",HEIGHT)
```

```
=         SET.NAME("CASH_FLOW","="&PERCENT&"*"&REF_FOR)
=         SET.NAME("PERIOD",OFFSET(!CF_REF,COUNT,CO_8+START+PHASE_IN,1,CONSTANT))
=         FORMULA.FILL(CASH_FLOW,PERIOD)
```

****** GENERATE TCE PHASE-OUT CASH FLOWS ******

```
=         IF(PHASE_OUT=0, GOTO($A$580))
=         FOR("PO",1,PHASE_OUT)
=            SET.NAME("PERCENT",((2*PHASE_OUT+1)-2*PO)*HEIGHT/(2*PHASE_OUT))
=            SET.NAME("CASH_FLOW","="&PERCENT&"*"&REF_FOR)
=            SET.NAME("PERIOD",OFFSET(!CF_REF,COUNT,CO_8+START+PHASE_IN+CONSTANT+PO-1,
             1,1))
=            FORMULA(CASH_FLOW,PERIOD)
=         NEXT()
=         IF(AND(MENU2=1,MENU=3),RETURN())
=         GOTO($A$667)
=      END.IF()
```

****** OBTAIN PCE INPUTS ******

```
=      IF(K_1=3)
=         IF(AND(MENU2=1,MENU=3),GOTO($A$589))
=         FORMULA(AMOUNT,TEXTREF(REF_REF))
=         IF(AND(MENU2=1,MENU=2),RETURN())
=         SET.NAME("NO_PAYMENTS",INPUT("Enter the number of payments for "&DES4&" ""
          &NAME&"" :",1))
=         IF(OR(INT(NO_PAYMENTS)<>NO_PAYMENTS,NO_PAYMENTS<0),GOTO($A$589))
=         SET.NAME("DEF_PMT",INT(10000*100/NO_PAYMENTS)/10000)
=         SET.NAME("OFFSET2",CO_3+3*(OFFSET(REF1,K_2,3,1,1)+OFFSET(REF1,K_2,4,1,1)))
=         SET.NAME("TOTAL_PCT",0)
=         FOR("NPMT",1,NO_PAYMENTS)
=            SET.NAME("YEAR",INPUT("Enter the year payment "&NPMT&" is made for "&DES4&"
             ""&NAME&"" :",1))
=            IF(OR(INT(YEAR)<>YEAR,YEAR<0),GOTO($A$595))
=            IF(NO_PAYMENTS=1)
=               SET.NAME("PERCENT",100)
=               GOTO($A$609)
=            END.IF()
=            SET.NAME("CHECK",MATCH(YEAR,OFFSET(REF1,K_2,OFFSET2,1,2*NO_PAYMENTS),0))
=            IF(TYPE(CHECK)<>16)
=               ALERT("Year "&YEAR&" already contains a cash flow.",3)
=               GOTO($A$595)
=            END.IF()
=            SELECT(OFFSET(REF1,K_2,OFFSET,1,2*NO_PAYMENTS))
=            SET.NAME("PERCENT",INPUT("Enter the percentage of cost paid at the end
             of year "&YEAR&":",1,,DEF_PMT))
=            IF(OR(PERCENT<=0,PERCENT>100),GOTO($A$607))
=            SET.NAME("PERCENT",PERCENT/100)
=            IF(NPMT=1,SET.NAME("BOUND",YEAR),SET.NAME("BOUND",MAX(BOUND,YEAR)))

=            SET.NAME("TOTAL_PCT",TOTAL_PCT+PERCENT)
```

**** COPY PCE INPUTS TO TEMPLATE ****

```
=           SET.NAME("OFFSET",CO_3+3*(OFFSET(REF1,K_2,3,1,1)+OFFSET(REF1,K_2,4,1,1))
            +2*(NPMT-1))
=           FORMULA(NO_PAYMENTS,OFFSET(REF1,K_2,8,1,1))
=           FORMULA(YEAR,OFFSET(REF1,K_2,OFFSET,1,1))
=           FORMULA(PERCENT,OFFSET(REF1,K_2,OFFSET+1,1,1))
```

**** GENERATE PCE CASH FLOWS ****

```
=           SET.NAME("CASH_FLOW","="&PERCENT&"*"&REF_FOR)
=           SET.NAME("PERIOD",OFFSET(!CF_REF,COUNT,CO_8+YEAR,1,1))
=           FORMULA(CASH_FLOW,PERIOD)
=         NEXT()
```

**** CHECK FOR VALID TOTAL PAYMENT PERCENTAGE ****

```
=         IF(ABS(1-TOTAL_PCT)>0.01)
=           SELECT(OFFSET(REF1,K_2,OFFSET2,1,2*NO_PAYMENTS))
=           CLEAR(1)
=           SELECT(OFFSET(!CF_REF,COUNT,CO_8,1,1))
=           FORMULA(0)
=           FILL.AUTO(OFFSET(!CF_REF,COUNT,CO_8,1,BOUND+1))
=           ALERT("The sum of payment percentages is "&100*TOTAL_PCT&".
            Please enter correct data.",3)
=           GOTO($A$584)
=         END.IF()
=         IF(AND(MENU2=1,MENU=3),RETURN())
=         GOTO($A$667)
=       END.IF()
```

**** OBTAIN RCE INPUTS ****

```
=       IF(K_1=4)
=         IF(AND(MENU2=1,MENU=3),GOTO($A$643))
=         IF(AND(MENU2=1,MENU=2),GOTO($A$659))
=         SET.NAME("NO_PAYMENTS",INPUT("Enter the number of payments for "&DES4&"
          '"&NAME&"' :",1))
=         IF(OR(INT(NO_PAYMENTS)<>NO_PAYMENTS,NO_PAYMENTS<0),GOTO($A$643))
=         SET.NAME("START",INPUT("Enter the year payments start for "&DES4&" '"&NAME&"' :",1))
=         IF(OR(INT(START)<>START,START<0),GOTO($A$645))
=         IF(NO_PAYMENTS=1)
=           SET.NAME("SKIP",0)
=           GOTO($A$654)
=         END.IF()
=         SET.NAME("SKIP",INPUT("Enter the number of years between payments for "&DES4&"
          '"&NAME&"' :",1))
=         IF(OR(INT(SKIP)<>SKIP,SKIP<0),GOTO($A$651))
```

**** COPY RCE INPUTS TO TEMPLATE ****

```
=         FORMULA(NO_PAYMENTS,OFFSET(REF1,K_2,7,1,1))
=         FORMULA(START,OFFSET(REF1,K_2,8,1,1))
```

```
=         FORMULA(SKIP,OFFSET(REF1,K_2,9,1,1))
```

**** GENERATE RCE CASH FLOWS ****

```
=         SET.NAME("CASH_FLOW",AMOUNT)
=         FOR("NPMT",1,NO_PAYMENTS)
=            SET.NAME("PERIOD",OFFSET(!CF_REF,COUNT,CO_8+START+(SKIP+1)*(NPMT-1),1,1))
=            FORMULA(CASH_FLOW,PERIOD)
=         NEXT()
=         IF(AND(MENU2=1,OR(MENU=2,MENU=3)),RETURN())
=      END.IF()
=      IF(MENU2=2,GOTO($A$671))
=   NEXT()
=NEXT()
```

**** COMPUTE TOTAL, NPV, AE, & FV ****

```
=IF(!NCE=0,GOTO($A$683))
=SET.NAME("TOTAL","=SUM(OFFSET(RC,0,"&CO_8&",1,ROUND(LIFE,0)+1))")
=SET.NAME("NPV","=SUM(RC("&CO_8-1&"),NPV(RATE,OFFSET(RC,0,"&CO_8&",1,ROUND(LIFE,0))))")
=SET.NAME("AE","=ABS(PMT(RATE,ROUND(LIFE,0),RC(-1)))")
=SET.NAME("FV","=ABS(FV(RATE,ROUND(LIFE,0),,RC(-2)))")
=FORMULA.FILL(TOTAL,OFFSET(!CF_REF,1,0,!NCE,1))
=FORMULA.FILL(NPV,OFFSET(!CF_REF,1,1,!NCE,1))
=FORMULA.FILL(AE,OFFSET(!CF_REF,1,2,!NCE,1))
=FORMULA.FILL(FV,OFFSET(!CF_REF,1,3,!NCE,1))
=IF(MENU2=2,RETURN())
```

**** OBTAIN ASSUMPTIONS ****

```
=SET.NAME("NA",INPUT("Enter the number of assumptions (random variables):",1))
=IF(OR(INT(NA)<>NA,NA<0),GOTO($A$684))
=IF(NA>!NVAR+!NTCE+!NPCE-1)
=   ALERT("The number of assumptions exceeds the maximum possible.",3)
=   GOTO($A$684)
=END.IF()
=IF(NA=0,GOTO($A$700))
=SET.NAME("INDIC",0)
=SET.NAME("NAMES",!NVAR+!NTCE+!NPCE-1)
=SET.NAME("WORD","assumption ")
=SET.NAME("ROW",2)
=IF(MMENU=3,SET.NAME("NUMBER",1),SET.NAME("NUMBER",NA))
=RUN($A$748)
=SET.NAME("INDIC",-1)
=IF(MMENU=3,RETURN())
```

**** OBTAIN FORECASTS ****

```
=SET.NAME("NF",INPUT("Enter the number of forecasts (cost elements) to track:",1))
=IF(OR(INT(NF)<>NF,NF<1),GOTO($A$701))
=IF(NF>!NCE-1)

=   ALERT("The number of forecasts exceeds the maximum possible.",3)
```

```
=   GOTO($A$701)
=END.IF()
=SET.NAME("INDIC",1)
=SET.NAME("NAMES",!NVAR+!NCE-1)
=IF(MMENU=3,SET.NAME("NUMBER",1),SET.NAME("NUMBER",NF))
=SET.NAME("WORD","forecast ")
=SET.NAME("ROW",2)
=ACTIVATE("MENU.XLS")
=COPY("MENUS.XLS!C22")
=SELECT("C200")
=PASTE.SPECIAL(1)
=ACTIVATE(FILE_NAME)
=RUN($A$748)
=ACTIVATE("MENU.XLS")
=SELECT("C200")
=CLEAR(1)
=ACTIVATE(FILE_NAME)
=SET.NAME("INDIC",-1)
=IF(MMENU=3,RETURN())
```

****** OBTAIN DATA FILE NAME ******

```
=SET.NAME("FILE_DEF","")
=SET.NAME("FILE_NAME",INPUT("Enter a name for the new data file    (.DAT understood):",2,,FILE_DEF
=IF(OR(FILE_NAME=FALSE,FILE_NAME=""),GOTO($A$727))
=SET.NAME("FILE_NAME",UPPER(FILE_NAME))
=SET.NAME("IND",2)
=SET.NAME("NEW_NAME",FILE_NAME)
=RUN($A$942)
=IF(NAME_CHK=-1)
=   SET.NAME("FILE_DEF",FILE_NAME)
=   GOTO($A$727)
=END.IF()
=SAVE.AS("C:\LCC\DATA\"&FILE_NAME&".DAT")
=IF($A$737=FALSE)
=   SET.NAME("FILE_DEF",FILE_NAME)
=   GOTO($A$727)
=END.IF()
=SET.NAME("FILE_NAME",FILE_NAME&".DAT")
=SET.NAME("FILE_ID",-1)
=GOTO($A$15)

=RETURN()
```

****** ASSUMPTION/FORECAST SUBROUTINE ******

```
=SET.NAME("OFFSET",OFFSET(!NAME_REF,ROW,0,NAMES,2))
=COPY(OFFSET)
=ACTIVATE("MENU.XLS")

=SELECT("R3C1")
```

```
=PASTE.SPECIAL(3)
=FOR("K_2",1,NUMBER)
=    RUN($A$870)
=    SELECT(OFFSET(!$A$3,POS-1,0,1,2))
=    EDIT.DELETE(2)
=    SET.NAME("NAMES",NAMES-1)
=    ACTIVATE(FILE_NAME)
```

****** OBTAIN FORECAST TYPES ******

```
=    IF(INDIC=0)
=        SET.NAME("NAME1",NAME)
=        GOTO($A$815)
=    END.IF()
=    ACTIVATE("NAMES.XLS")
=    WINDOW.TITLE("MENU.XLS")
=    IF(DES="VAR")
=        SET.NAME("NAME1",NAME)
=        GOTO($A$815)
=    END.IF()
=    WINDOW.SIZE(165,210)
=    SELECT("R1C200")
=    UNHIDE("MENU.XLS")
=    SET.NAME("MENU5",INPUT("Enter selection:",1,,6,200,50,))
=    WINDOW.RESTORE()
=    HIDE()
=    IF(OR(INT(MENU5)<>MENU5,MENU5<1,MENU5>6))
=        ACTIVATE("MENU.XLS")
=        GOTO($A$772)
=    END.IF()
=    IF(MENU5=6)
=        ACTIVATE("MENU.XLS")
=        GOTO($A$823)
=    END.IF()
=    ACTIVATE(FILE_NAME)
```

****** OBTAIN INPUTS FOR CASH FLOWS ******

```
=    IF(MENU5=5)
=        SET.NAME("CF_TYPE",INPUT("1) All Yrs      2) Specific Yrs",1))
=        IF(AND(CF_TYPE<>1,CF_TYPE<>2),GOTO($A$790))
=        SET.NAME("LOC",ROW(TEXTREF(REPLACE(GET.NAME("!TOTAL_"&NAME),1,1,"!"))))
=        IF(CF_TYPE=1)
=            SET.NAME("REF",OFFSET(!$A$1,LOC-1,CO_8,1,ROUND(!LIFE,0)+1))
=            GOTO($A$816)
=        END.IF()
=        SET.NAME("NO_YEARS",INPUT("Enter the number of years:",1))
=        IF(OR(INT(NO_YEARS)<>NO_YEARS,NO_YEARS<1),GOTO($A$797))
=        FOR("K_3",1,NO_YEARS)

=            SET.NAME("YEAR",INPUT("Enter year "&K_3&":",1))
```

```
=          IF(OR(INT(YEAR)<>YEAR,YEAR<0),GOTO($A$800))
=          SET.NAME("REF",OFFSET(!$A$1,LOC-1,CO_8+YEAR,1,1))
=          SELECT(REF)
=          IF(MENU2=3,RUN('C:\CB\CBXL.XLA'!CB.ClearDataND),
           RUN('C:\CB\CBXL.XLA'!CB.DefineFore))
=       NEXT()
=       ACTIVATE("MENU.XLS")
=       GOTO($A$772)
=    END.IF()
```

****** DEFINE ASSUMPTIONS/FORECASTS ******

```
=    IF(MENU5=1,SET.NAME("NAME1","TOTAL_"&NAME))
=    IF(MENU5=2,SET.NAME("NAME1","NPV_"&NAME))
=    IF(MENU5=3,SET.NAME("NAME1","AE_"&NAME))
=    IF(MENU5=4,SET.NAME("NAME1","FV_"&NAME))
=    SET.NAME("REF",TEXTREF(REPLACE(GET.NAME("!"&NAME1),1,1,"!")))
=    SELECT(REF)
=    IF(MENU2=3,RUN('C:\CB\CBXL.XLA'!CB.ClearDataND),
     IF(INDIC=0,RUN('C:\CB\CBXL.XLA'!CB.DefineAssum),RUN('C:\CB\CBXL.XLA'!CB.DefineFore)))
=    IF(INDIC=1)
=       ACTIVATE("MENU.XLS")
=       GOTO($A$772)
=    END.IF()
=    IF(INDIC=0,ACTIVATE("NAMES.XLS"))
=NEXT()
=IF(INDIC=0,ACTIVATE("NAMES.XLS"),ACTIVATE("MENU.XLS"))
=IF(NAMES<>0)
=    SELECT(OFFSET(!$A$3,0,0,NAMES,2))
=    CLEAR(1)
=END.IF()
=WINDOW.TITLE("MENU.XLS")
=ACTIVATE(FILE_NAME)

=RETURN()
```

DATA EDITING SUBROUTINE (c)

****** CHECK FOR AVAILABILITY OF DATA ******

```
=IF(FILE_ID=0)
=    ALERT("No data is present. Please read or create data.",3)
=    GOTO($A$15)
=END.IF()
=SET.NAME("FLAG",0)
```

****** PRINT VIEW/EDIT MAIN MENU ON TEMPLATE ******

```
=ACTIVATE("MENU.XLS")

=COPY("MENUS.XLS!C4:C5")
```

```
=SELECT("C1")
=PASTE.SPECIAL(1)
=ACTIVATE(FILE_NAME)
=COPY(OFFSET(!GEN_REF,1,0,1,5))
=ACTIVATE("MENU.XLS")
=SELECT("R3C2")
=PASTE.SPECIAL(3,1,FALSE,TRUE)
=WINDOW.SIZE(210,210)
=SELECT("R13C1")
=UNHIDE("MENU.XLS")
=SET.NAME("MENU1",INPUT("Enter selection:",1,,8,225,50,))
=WINDOW.RESTORE()
=HIDE()
=IF(OR(INT(MENU1)<>MENU1,MENU1<1,MENU1>8))
=    ACTIVATE("MENU.XLS")
=    GOTO($A$854)
=END.IF()
=ACTIVATE("MENU.XLS")
=SELECT("C1:C2")
=CLEAR(1)
```

****** PRINT VIEW/EDIT NAMES MENU ON TEMPLATE ******

```
=IF(MENU1=1)
=    WINDOW.TITLE("NAMES.XLS")
=    SELECT("R1C1")
=    FORMULA("*** NAME ***")
=    COLUMN.WIDTH(30)
=    FORMAT.FONT(,,TRUE,TRUE)
=    SELECT("R1C2")
=    COLUMN.WIDTH(13)
=    FORMULA("*** TYPE ***")
=    FORMAT.FONT(,,TRUE,TRUE)
=    SELECT("C2")
=    ALIGNMENT(3)
=    IF(OR(MMENU=2,MMENU=4,MENU=2,MENU2=2,INDIC=0,INDIC=1),GOTO($A$907))
=    ACTIVATE(FILE_NAME)
=    SET.NAME("NAMES",!NCT-3)
=    COPY(OFFSET(!NAME_REF,4,0,NAMES,2))
=    ACTIVATE("NAMES.XLS")
=    SELECT("R3C1")
=    PASTE.SPECIAL(3)
```

****** VIEW OR EDIT NAMES? ******

```
=    WINDOW.SIZE(270,210)
=    SELECT("R3C1")
=    UNHIDE("NAMES.XLS")
=    SET.NAME("EDIT",INPUT("Edit a name?:",2,,"N",245,50))

=    HIDE()
```

```
=  IF(AND(LEFT(EDIT)<>"Y",LEFT(EDIT)<>"N"))
=     ACTIVATE("NAMES.XLS")
=     GOTO($A$889)
=  END.IF()
=  IF(LEFT(EDIT)="N")
=     ACTIVATE("NAMES.XLS")
=     WINDOW.TITLE("MENU.XLS")
=     GOTO($A$844)
=  END.IF()
```

****** DEFINE SUBROUTINE-SPECIFIC INPUTS ******

```
=  ACTIVATE("NAMES.XLS")
=  WINDOW.SIZE(270,210)
=  SELECT("R3C1")
=  UNHIDE("NAMES.XLS")
=  IF(OR(MMENU=4,INDIC=0,INDIC=1))
=     IF(OR(MMENU=4,MMENU=2),SET.NAME("PHRASE",WORD&K_2),
      SET.NAME("PHRASE","the "&WORD))
=     SET.NAME("NAME",INPUT("Enter the name of "&PHRASE&":",2,,,245,50))
=     GOTO($A$920)
=  END.IF()
=  IF(OR(MMENU=2,MENU=2,MENU2=2))
=     SET.NAME("NAME",INPUT("Enter the name of cost "&K&":",2,,,245,50))
=     GOTO($A$920)
=  END.IF()
=  SET.NAME("NAME",INPUT("Enter the name to edit:",2,,,245,50))
=  WINDOW.RESTORE()
=  HIDE()
```

****** CHECK VALIDITY OF NAME ******

```
=  ACTIVATE("NAMES.XLS")
=  SET.NAME("POS",MATCH(NAME,OFFSET(!$A$3,0,0,NAMES,1),0))
=  IF(TYPE(POS)=16,GOTO($A$907))
=  SET.NAME("DES",DEREF(OFFSET(!$B$3,POS-1,0,1,1)))
=  IF(OR(MMENU=2,MMENU=4,MENU=2,MENU2=2,INDIC=0,INDIC=1),RETURN())
```

****** OBTAIN NEW NAME ******

```
=  ALERT("Remember - names can only be used once and must contain letters, numbers,
   or underlines.",2)
=  IF(OR(MMENU=2,MENU2=2))
=     IF(AND(MMENU=2,K_1=1),SET.NAME("NUM",K_2-3),SET.NAME("NUM",K_2))
=     SET.NAME("NEW_NAME",INPUT("Enter a name for "&DES&" "&NUM&":",2))
=     GOTO($A$938)
=  END.IF()
=  SET.NAME("NEW_NAME",INPUT("Enter the new name:",2,,NAME))
=  IF(NEW_NAME=FALSE,GOTO($A$932))
=  SET.NAME("NEW_NAME",UPPER(NEW_NAME))

=  SET.NAME("IND",1)
```

****** CHECK SYNTAX OF NAME ******

```
=   SET.NAME("NAME_CHK",0)
=   SET.NAME("LENGTH",LEN(NEW_NAME))
=   IF(IND=1,SET.NAME("LEN_MAX",255),SET.NAME("LEN_MAX",8))
=   IF(LENGTH>LEN_MAX,GOTO($A$957))
=   IF(IND=1)
=      IF(ISREF(TEXTREF(NEW_NAME))=TRUE,GOTO($A$957))
=      IF(ISREF(TEXTREF(NEW_NAME,TRUE))=TRUE,GOTO($A$957))
=   END.IF()
=   FOR("K",1,LENGTH)
=      SET.NAME("VALUE",CODE(MID(NEW_NAME,K,1)))
=      IF(AND(K=1,VALUE>=48,VALUE<=57),GOTO($A$957))
=      IF(OR(VALUE<48,AND(VALUE>90,VALUE<>95),AND(VALUE>57,VALUE<65)),GOTO($A$957))
=   NEXT()
=   IF(IND=1,GOTO($A$961),RETURN())
=   SET.NAME("NAME_CHK",-1)
=   ALERT(""""&NEW_NAME&""" is not a valid name.",3)
=   IF(IND=1,GOTO($A$932),RETURN())
```

****** CHECK FOR DUPLICATE NAMES ******

```
=   IF(OR(MMENU=2,AND(MENU1<>1,MENU=3)),GOTO($A$965))
=   IF(NEW_NAME=NAME,IF(MENU1<>1,RETURN(),GOTO($A$889)))
=   ACTIVATE(FILE_NAME)
=   GET.NAME("!"&NEW_NAME)
=   IF(TYPE($A$965)<>16)
=      ALERT("The name """&NEW_NAME&""" already exists. Please use a different name.",3)
=      GOTO($A$932)
=   END.IF()
=   SET.NAME("FLAG",-1)
=   IF(OR(MMENU=2,MENU2=2))
=      SET.NAME("NAME",NEW_NAME)
=      RETURN()
=   END.IF()
```

****** REPLACE NAMES ON TEMPLATE ******

```
=   IF(DES="VAR",IF(MENU1=1,SET.NAME("LOC",POS+3),SET.NAME("LOC",POS)))
=   IF(DES="TCE",IF(MENU1=1,SET.NAME("LOC",POS-!NVAR+3),SET.NAME("LOC",POS)))
=   IF(DES="PCE",IF(MENU1=1,SET.NAME("LOC",POS-!NVAR-!NTCE+3),SET.NAME("LOC",POS)))
=   IF(DES="RCE",IF(MENU1=1,SET.NAME("LOC",POS-!NVAR-!NTCE-!NPCE+3),SET.NAME("LOC",POS)))
=   SET.NAME("NDEP",OFFSET(TEXTREF("!"&DES&"_REF"),LOC,4,1,1))
=   IF(NDEP=0,GOTO($A$985))
=   SELECT(OFFSET(!VAR_REF,1,6,!NCT+6,1))
=   FORMULA.REPLACE(NAME,NEW_NAME,2,2,FALSE)
=   SET.NAME("POS2",MATCH(NAME,OFFSET(!VAR_REF,1,5,!NCT+6,1),0))
=   FORMULA(NEW_NAME,OFFSET(!VAR_REF,POS2,5,1,1))
```

****** DEFINE NEW NAMES ******

```
=   DEFINE.NAME(NEW_NAME,TEXTREF(REPLACE(GET.NAME("!"&NAME),1,1,"!")))
=   IF(DES="VAR",GOTO($A$996))
=   DEFINE.NAME("TOTAL_"&NEW_NAME,TEXTREF(REPLACE(GET.NAME("!TOTAL_"&NAME),1,1,"!")))
=   DEFINE.NAME("NPV_"&NEW_NAME,TEXTREF(REPLACE(GET.NAME("!NPV_"&NAME),1,1,"!")))
=   DEFINE.NAME("AE_"&NEW_NAME,TEXTREF(REPLACE(GET.NAME("!AE_"&NAME),1,1,"!")))
=   DEFINE.NAME("FV_"&NEW_NAME,TEXTREF(REPLACE(GET.NAME("!FV_"&NAME),1,1,"!")))
```

****** DELETE OLD NAMES ******

```
=   DELETE.NAME(NAME)
=   IF(DES="VAR",GOTO($A$1003))
=   DELETE.NAME("TOTAL_"&NAME)
=   DELETE.NAME("NPV_"&NAME)
=   DELETE.NAME("AE_"&NAME)
=   DELETE.NAME("FV_"&NAME)
=   IF(MENU1<>1)
=       SET.NAME("NAME",NEW_NAME)
=       RETURN()
=   END.IF()
=   GOTO($A$884)
=END.IF()
```

****** PRINT VAR VIEW/EDIT MENU ON TEMPLATE ******

```
=IF(MENU1=2)
=   SET.NAME("DES","VAR")
=   RUN($A$1427)
```

****** VIEW/EDIT A VAR ******

```
=   IF(MENU2=1)
=       SET.NAME("DES","VAR")
=       SET.NAME("DES2","edit:")
=       RUN($A$1472)
=       SET.NAME("COL","C10")
=       RUN($A$1508)
=       SET.NAME("CO_1",8)
=       SET.NAME("REF1",TEXTREF("MENU.XLS!R9C1"))
=       SET.NAME("EXIT",3)
=       RUN($A$1520)
```

****** VIEW/EDIT VAR NAME ******

```
=       IF(MENU=1)
=           IF(OR(NAME="LIFE",NAME="RATE"))
=               ALERT("The name '"&NAME&"' cannot be changed.",3)
=               GOTO($A$1034)
=           END.IF()
=           RUN($A$930)
=           GOTO($A$1021)
=       END.IF()
```

****** VIEW/EDIT VAR AMOUNT ******

```
=       IF(MENU=2)
=           ACTIVATE(FILE_NAME)
=           SET.NAME("K_1",1)
=           RUN($A$1558)
=           SET.NAME("FLAG",-1)
=           GOTO($A$1021)
=       END.IF()
=       GOTO($A$1013)
=   END.IF()
```

****** ADD A VAR ******

```
=   IF(MENU2=2)
=       ACTIVATE(FILE_NAME)
=       SET.NAME("K_1",1)
=       SET.NAME("COUNT1",DEREF(!NVAR))
=       FORMULA(!NVAR+1,!NVAR)
=       SET.NAME("REF",!VAR_REF)
=       SET.NAME("K_2",!NVAR)
=       RUN($A$1598)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1013)
=   END.IF()
```

****** DELETE A VAR ******

```
=   IF(MENU2=3)
=       ALERT("Remember - a variable/cost element cannot be deleted if it is
        referenced by another cost.",2)
=       SET.NAME("DES","VAR")
=       SET.NAME("DES2","delete:")
=       RUN($A$1472)
=       ACTIVATE(FILE_NAME)
=       IF(OFFSET(!VAR_REF,POS1,4,1,1)<>0)
=           ALERT("VAR '"&NAME&"' cannot be deleted. Please remove all dependencies first.",3)
=           GOTO($A$1013)
=       END.IF()
=       SET.NAME("REF5",!NAME_REF)
=       SET.NAME("CO_3",8)
=       RUN($A$1612)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1013)
=   END.IF()
=   GOTO($A$844)
=END.IF()
```

****** PRINT TCE VIEW/EDIT MENU ON TEMPLATE ******

```
=IF(MENU1=3)

=   SET.NAME("DES","TCE")
```

```
=   RUN($A$1427)

*** VIEW/EDIT A TCE ***
=   IF(MENU2=1)
=       SET.NAME("DES","TCE")
=       SET.NAME("DES2","edit:")
=       RUN($A$1472)
=       SET.NAME("COL","C13")
=       RUN($A$1508)
=       FORMULA(OFFSET(!TCE_REF,POS1,11,1,1),"MENU.XLS!R8C2")
=       FORMULA(OFFSET(!TCE_REF,POS1,8,1,1),"MENU.XLS!R9C2")
=       FORMULA(OFFSET(!TCE_REF,POS1,9,1,1),"MENU.XLS!R10C2")
=       FORMULA(OFFSET(!TCE_REF,POS1,10,1,1),"MENU.XLS!R11C2")
=       SET.NAME("CO_1",12)
=       SET.NAME("REF1",TEXTREF("MENU.XLS!R16C1"))
=       SET.NAME("EXIT",4)
=       RUN($A$1520)

*** VIEW/EDIT TCE NAME ***
=       IF(MENU=1)
=           RUN($A$930)
=           GOTO($A$1092)
=       END.IF()

*** VIEW/EDIT TCE AMOUNT ***
=       IF(MENU=2)
=           ACTIVATE(FILE_NAME)
=           SET.NAME("COUNT",POS1)
=           SET.NAME("K_1",2)
=           RUN($A$1558)
=           SET.NAME("FLAG",-1)
=           GOTO($A$1092)
=       END.IF()

*** VIEW/EDIT TCE ALLOCATION ***
=       IF(MENU=3)
=           ACTIVATE(FILE_NAME)
=           SET.NAME("K_1",2)
=           SET.NAME("REF1",!TCE_REF)
=           SET.NAME("DES4","TCE")
=           SET.NAME("COUNT",POS1)
=           SET.NAME("RO_1",0)
=           SET.NAME("LOC",0)
=           RUN($A$1582)
=           SET.NAME("FLAG",-1)
=           GOTO($A$1092)
=       END.IF()

=       GOTO($A$1084)
```

```
=   END.IF()

*** ADD A TCE ***
=   IF(MENU2=2)
=       ACTIVATE(FILE_NAME)
=       SET.NAME("K_1",2)
=       SET.NAME("COUNT1",DEREF(!NVAR)+DEREF(!NTCE))
=       FORMULA(!NTCE+1,!NTCE)
=       SET.NAME("REF",!TCE_REF)
=       SET.NAME("K_2",!NTCE)
=       SET.NAME("COUNT",!NTCE)
=       RUN($A$1598)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1084)
=   END.IF()

*** DELETE A TCE ***
=   IF(MENU2=3)
=       ALERT("Remember - a variable/cost element cannot be deleted
        if it is referenced by another cost.",2)
=       SET.NAME("DES","TCE")
=       SET.NAME("DES2","delete:")
=       RUN($A$1472)
=       ACTIVATE(FILE_NAME)
=       IF(OFFSET(!TCE_REF,POS1,4,1,1)<>0)
=           ALERT("TCE '"&NAME&"' cannot be deleted. Please remove all dependencies first.",3)
=           GOTO($A$1084)
=       END.IF()
=       SET.NAME("REF5",OFFSET(!NAME_REF,!NVAR,0,1,1))
=       SET.NAME("REF3",OFFSET(!CF_REF,0,0,1,1))
=       SET.NAME("CO_3",12)
=       RUN($A$1612)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1084)
=   END.IF()
=   GOTO($A$844)
=END.IF()

*** PRINT PCE VIEW/EDIT MENU ON TEMPLATE ***
=IF(MENU1=4)
=   SET.NAME("DES","PCE")
=   RUN($A$1427)

*** VIEW/EDIT A PCE ***
=   IF(MENU2=1)
=       SET.NAME("DES","PCE")
=       SET.NAME("DES2","edit:")

=       RUN($A$1472)
```

```
=       SET.NAME("COL","C16:C18")
=       RUN($A$1508)
=       SET.NAME("CO_1",9)
=       SET.NAME("NPMT",OFFSET(REF,POS1,8,1,1))
=       SET.NAME("NREF",OFFSET(REF,POS1,3,1,1))
=       SET.NAME("NDEP",OFFSET(REF,POS1,4,1,1))
=       SET.NAME("OFFSET",CO_1+3*(NREF+NDEP))
=       FOR("K",1,NPMT)
=          SET.NAME("REFERENCE",TEXTREF("MENU.XLS!R8C1"))
=          FORMULA(K,OFFSET(REFERENCE,K,0,1,1))
=          FORMULA(OFFSET(REF,POS1,OFFSET+2*(K-1),1,1),OFFSET(REFERENCE,K,1,1,1))
=          FORMULA(100*OFFSET(REF,POS1,OFFSET+2*(K-1)+1,1,1),OFFSET(REFERENCE,K,2,1,1))
=       NEXT()
=       ACTIVATE("MENU.XLS")
=       SELECT(OFFSET(REFERENCE,NPMT+2,0,4+NREF+NDEP,3))
=       ALIGNMENT(1)
=       SELECT("R2C1")
=       FORMULA("4.   Exit",OFFSET(REFERENCE,NPMT+2,0,1,1))
=       SET.NAME("REF1",OFFSET(REFERENCE,NPMT+5,0,1,1))
=       SET.NAME("EXIT",4)
=       ACTIVATE(FILE_NAME)
=       RUN($A$1520)

*** VIEW/EDIT PCE NAME ***
=       IF(MENU=1)
=          RUN($A$930)
=          GOTO($A$1180)
=       END.IF()

*** VIEW/EDIT PCE AMOUNT ***
=       IF(MENU=2)
=          ACTIVATE(FILE_NAME)
=          SET.NAME("COUNT",!NTCE+POS1)
=          SET.NAME("K_1",3)
=          RUN($A$1558)
=          SET.NAME("FLAG",-1)
=          GOTO($A$1180)
=       END.IF()

*** VIEW/EDIT PCE ALLOCATION ***
=       IF(MENU=3)
=          ACTIVATE(FILE_NAME)
=          SET.NAME("K_1",3)
=          SET.NAME("CO_3",9)
=          SET.NAME("REF1",!PCE_REF)
=          SET.NAME("DES4","PCE")
=          SET.NAME("COUNT",!NTCE+POS1)

=          SET.NAME("RO_1",!NTCE)
```

```
=           SET.NAME("LOC",!NTCE)
=           SET.NAME("NREF",OFFSET(!PCE_REF,POS1,3,1,1))
=           SET.NAME("NDEP",OFFSET(!PCE_REF,POS1,4,1,1))
=           SET.NAME("NPAY",OFFSET(!PCE_REF,POS1,8,1,1))
=           SELECT(OFFSET(!PCE_REF,POS1,CO_3+3*(NREF+NDEP),1,2*NPAY))
=           CLEAR(1)
=           RUN($A$1582)
=           SET.NAME("FLAG",-1)
=           GOTO($A$1180)
=       END.IF()
=       GOTO($A$1172)
=   END.IF()
```

****** ADD A PCE ******

```
=   IF(MENU2=2)
=       ACTIVATE(FILE_NAME)
=       SET.NAME("K_1",3)
=       SET.NAME("COUNT1",DEREF(!NVAR)+DEREF(!NTCE)+DEREF(!NPCE))
=       FORMULA(!NPCE+1,!NPCE)
=       SET.NAME("REF",!PCE_REF)
=       SET.NAME("K_2",!NPCE)
=       SET.NAME("COUNT",!NTCE+!NPCE)
=       RUN($A$1598)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1172)
=   END.IF()
```

****** DELETE A PCE ******

```
=   IF(MENU2=3)
=       ALERT("Remember - a variable/cost element cannot be deleted
        if it is referenced by another cost.",2)
=       SET.NAME("DES","PCE")
=       SET.NAME("DES2","delete:")
=       RUN($A$1472)
=       ACTIVATE(FILE_NAME)
=       IF(OFFSET(!PCE_REF,POS1,4,1,1)<>0)
=           ALERT("PCE '"&NAME&"' cannot be deleted. Please remove all dependencies first.",3)
=           GOTO($A$1172)
=       END.IF()
=       SET.NAME("REF5",OFFSET(!NAME_REF,!NVAR+!NTCE,0,1,1))
=       SET.NAME("REF3",OFFSET(!CF_REF,!NTCE,0,1,1))
=       SET.NAME("CO_3",9)
=       RUN($A$1612)
=       SET.NAME("FLAG",-1)
=       GOTO($A$1172)
=   END.IF()
=   GOTO($A$844)

=END.IF()
```

```
*** PRINT RCE VIEW/EDIT MENU ON TEMPLATE ***
=IF(MENU1=5)
=    SET.NAME("DES","RCE")
=    RUN($A$1427)

*** VIEW/EDIT A RCE ***
=    IF(MENU2=1)
=        SET.NAME("DES","RCE")
=        SET.NAME("DES2","edit:")
=        RUN($A$1472)
=        SET.NAME("COL","C19")
=        RUN($A$1508)
=        FORMULA(OFFSET(!RCE_REF,POS1,8,1,1),TEXTREF("MENU.XLS!R8C2"))
=        FORMULA(OFFSET(!RCE_REF,POS1,7,1,1),TEXTREF("MENU.XLS!R9C2"))
=        FORMULA(OFFSET(!RCE_REF,POS1,9,1,1),TEXTREF("MENU.XLS!R10C2"))
=        SET.NAME("CO_1",10)
=        SET.NAME("REF1",TEXTREF("MENU.XLS!R15C1"))
=        SET.NAME("EXIT",4)
=        RUN($A$1520)

*** VIEW/EDIT RCE NAME ***
=        IF(MENU=1)
=            RUN($A$930)
=            GOTO($A$1286)
=        END.IF()

*** VIEW/EDIT RCE AMOUNT ***
=        IF(MENU=2)
=            ACTIVATE(FILE_NAME)
=            SET.NAME("COUNT",!NTCE+!NPCE+POS1)
=            SET.NAME("K_1",4)
=            RUN($A$1558)
=            SET.NAME("NO_PAYMENTS",OFFSET(REF1,K_2,7,1,1))
=            SET.NAME("START",OFFSET(REF1,K_2,8,1,1))
=            SET.NAME("SKIP",OFFSET(REF1,K_2,9,1,1))
=            RUN($A$1577)
=            SET.NAME("FLAG",-1)
=            GOTO($A$1286)
=        END.IF()

*** VIEW/EDIT RCE ALLOCATION ***
=        IF(MENU=3)
=            ACTIVATE(FILE_NAME)
=            SET.NAME("K_1",4)
=            SET.NAME("REF1",!RCE_REF)
=            SET.NAME("DES4","RCE")

=            SET.NAME("COUNT",!NTCE+!NPCE+POS1)
```

```
=           SET.NAME("RO_1",!NTCE+!NPCE)
=           SET.NAME("LOC",!NTCE+!NPCE)
=           SET.NAME("START",OFFSET(!RCE_REF,POS1,8,1,1))
=           SET.NAME("REF_AMT",OFFSET(!CF_REF,2+!NTCE+!NPCE+POS1,CO_8+START,1,1))
=           SET.NAME("AMOUNT",FORMULA.CONVERT(GET.CELL(6,REF_AMT),TRUE,FALSE,,REF))
=           RUN($A$1582)
=           SET.NAME("FLAG",-1)
=           GOTO($A$1286)
=        END.IF()
=        GOTO($A$1278)
=     END.IF()
```

**** ADD A RCE ****

```
=     IF(MENU2=2)
=        ACTIVATE(FILE_NAME)
=        SET.NAME("K_1",4)
=        SET.NAME("COUNT1",DEREF(!NVAR)+DEREF(!NCE))
=        FORMULA(!NRCE+1,!NRCE)
=        SET.NAME("REF",!RCE_REF)
=        SET.NAME("K_2",!NRCE)
=        SET.NAME("COUNT",!NTCE+!NPCE+!NRCE)
=        RUN($A$1598)
=        SET.NAME("FLAG",-1)
=        GOTO($A$1278)
=     END.IF()
```

**** DELETE A RCE ****

```
=     IF(MENU2=3)
=        ALERT("Remember - a variable/cost element cannot be deleted
         if it is referenced by another cost.",2)
=        SET.NAME("DES","RCE")
=        SET.NAME("DES2","delete:")
=        RUN($A$1472)
=        ACTIVATE(FILE_NAME)
=        IF(OFFSET(!RCE_REF,POS1,4,1,1)<>0)
=           ALERT("RCE '"&NAME&"' cannot be deleted. Please remove all dependencies first.",3)
=           GOTO($A$1278)
=        END.IF()
=        SET.NAME("REF5",OFFSET(!NAME_REF,!NVAR+!NTCE+!NPCE,0,1,1))
=        SET.NAME("REF3",OFFSET(!CF_REF,!NTCE+!NPCE,0,1,1))
=        SET.NAME("CO_3",10)
=        RUN($A$1612)
=        SET.NAME("FLAG",-1)
=        GOTO($A$1278)
=     END.IF()
=     GOTO($A$844)
=END.IF()
```

****** PRINT ASSUMPTION/FORECAST VIEW/EDIT MENU ON TEMPLATE ******

```
=IF(OR(MENU1=6,MENU1=7))
=   ACTIVATE("MENUS.XLS")
=   IF(MENU1=6,COPY("C8"),COPY("C9"))
=   SET.NAME("DES","VAR")
=   RUN($A$1434)
```

****** VIEW/EDIT AN ASSUMPTION/FORECAST ******

```
=   IF(MENU2=1)
=      ACTIVATE(FILE_NAME)
=      SELECT("R1C1")
=      IF(MENU1=6,RUN('C:\CB\CBXL.XLA'!CB.SelectAssum),RUN('C:\CB\CBXL.XLA'!CB.SelectFore)
=      IF(MENU1=6,RUN('C:\CB\CBXL.XLA'!CB.DefineAssum),RUN('C:\CB\CBXL.XLA'!CB.DefineFore
=      SET.NAME("FLAG",-1)
=      GOTO($A$1371)
=   END.IF()
```

****** ADD/DELETE AN ASSUMPTION/FORECAST ******

```
=   IF(OR(MENU2=2,MENU2=3))
=      ACTIVATE(FILE_NAME)
=      IF(MENU1=6,RUN($A$691),RUN($A$707))
=      SET.NAME("FLAG",-1)
=      GOTO($A$1371)
=   END.IF()
=   GOTO($A$844)
=END.IF()
```

****** SAVE CHANGES ******

```
=IF(FLAG=0,GOTO($A$1423))
=ACTIVATE(FILE_NAME)
=SET.NAME("SAVE",INPUT("Save changes?",2,,"Y"))
=IF(AND(LEFT(SAVE)<>"Y",LEFT(SAVE)<>"N"),GOTO($A$1399))
=IF(LEFT(SAVE)="N")
=   CLOSE(FALSE)
=   OPEN("C:\LCC\DATA\"&FILE_NAME)
=   GOTO($A$1423)
=END.IF()
=SET.NAME("FILE_DEF",REPLACE(FILE_NAME,LEN(FILE_NAME)-3,4,""))
=SET.NAME("FILE_NAME",INPUT("Enter the name of the file
 (.DAT understood):",2,,FILE_DEF))
=IF(OR(FILE_NAME=FALSE,FILE_NAME=""),GOTO($A$1407))
=SET.NAME("FILE_NAME",UPPER(FILE_NAME))
=SET.NAME("IND",2)
=SET.NAME("NEW_NAME",FILE_NAME)
=RUN($A$942)
=IF(NAME_CHK=-1)
=   SET.NAME("FILE_DEF",FILE_NAME)

=   GOTO($A$1407)
```

```
=END.IF()
=SAVE.AS("C:\LCC\DATA\"&FILE_NAME&".DAT")
=IF($A$1417=FALSE)
=    SET.NAME("FILE_DEF",FILE_NAME)
=    GOTO($A$1407)
=END.IF()
=SET.NAME("FILE_NAME",FILE_NAME&".DAT")
=GOTO($A$15)

=RETURN()
```

****** PRINT EDIT COST TYPE MENU ON TEMPLATE ******

```
=ACTIVATE("MENUS.XLS")
=IF(MID(!$G$1,5,3)<>DES)
=    SELECT("C7")
=    FORMULA.REPLACE(MID(!$G$1,5,3),DES,2,2,FALSE)
=END.IF()
=COPY("MENUS.XLS!C7")
=ACTIVATE("MENU.XLS")
=SELECT("C1")
=PASTE.SPECIAL(1)
=IF(MENU1=6,WINDOW.SIZE(260,210),IF(MENU1=7,WINDOW.SIZE(250,210),WINDOW.SIZE(210,210)))
=SELECT("R1C1")
=UNHIDE("MENU.XLS")
=SET.NAME("MENU2",INPUT("Enter selection:",1,,4,225,50,))
=WINDOW.RESTORE()
=HIDE()
=IF(OR(INT(MENU2)<>MENU2,MENU2<1,MENU2>4))
=    ACTIVATE("MENU.XLS")
=    GOTO($A$1437)
=END.IF()
```

****** CHECK FOR MINIMUM NUMBER OF VARIABLES/ELEMENTS ******

```
=IF(OR(MENU1=6,MENU1=7),GOTO($A$1466))
=ACTIVATE(FILE_NAME)
=IF(AND(MENU1<>2,OR(MENU2=1,MENU2=3),TEXTREF("!N"&DES)=0))
=    ALERT("No "&DES&"s are defined. Please select another option.",3)
=    ACTIVATE("MENU.XLS")
=    GOTO($A$1437)
=END.IF()
=IF(AND(MENU1=2,MENU2=3,TEXTREF("!N"&DES)=3))
=    ALERT("No further variables can be deleted. Please select another option.",3)
=    ACTIVATE("MENU.XLS")
=    GOTO($A$1437)
=END.IF()
=IF(AND(MENU2=3,!NCT=4))
=    ALERT("No further variables or cost elements can be deleted. Please select another option.",3)

=    ACTIVATE("MENU.XLS")
```

```
=   GOTO($A$1437)
=END.IF()
=ACTIVATE("MENU.XLS")
=SELECT("C1")
=CLEAR(1)

=RETURN()
```

****** OBTAIN NAME OF COST TYPE TO EDIT OR DELETE ******

```
=WINDOW.TITLE("NAMES.XLS")
=SELECT("R1C1")
=FORMULA("*** "&DES&"s ***")
=COLUMN.WIDTH(30)
=FORMAT.FONT(,,TRUE,TRUE)
=ACTIVATE(FILE_NAME)
=SET.NAME("REF",TEXTREF("!"&DES&"_REF"))
=SET.NAME("NN",TEXTREF("!N"&DES))
=SET.NAME("NAMES",NN)
=COPY(OFFSET(REF,1,5,NN,1))
=ACTIVATE("NAMES.XLS")
=SELECT("R3C1")
=PASTE.SPECIAL(1)
=IF(DES="VAR")
=   IF(MENU2=1,SET.NAME("NUM",1),SET.NAME("NUM",3))
=   SELECT(OFFSET(!$A$3,0,0,NUM,1))
=   EDIT.DELETE(2)
=END.IF()
=WINDOW.SIZE(200,210)
=SELECT("R1C1")
=UNHIDE("NAMES.XLS")
=SET.NAME("NAME",INPUT("Enter the "&DES&" to "&DES2,2,,,225,50))
=WINDOW.RESTORE()
=HIDE()
```

****** CHECK VALIDITY OF NAME ******

```
=ACTIVATE("NAMES.XLS")
=SET.NAME("POS1",MATCH(NAME,OFFSET(!$A$3,0,0,NAMES,1),0))
=IF(TYPE(POS1)=16,GOTO($A$1500))
=IF(DES="VAR",IF(MENU2=1,SET.NAME("POS1",POS1+1),SET.NAME("POS1",POS1+3)))
=SET.NAME("POS",POS1)
=WINDOW.TITLE("MENU.XLS")

=RETURN()
```

****** PRINT COST TYPE NAME & AMOUNT ON TEMPLATE ******

```
=ACTIVATE("MENU.XLS")
=COPY("MENUS.XLS!"&COL)

=SELECT("C1")
```

```
=PASTE.SPECIAL(1)
=SELECT("R2C1")
=ACTIVATE(FILE_NAME)
=FORMULA(""""&NAME&"""","MENU.XLS!R3C2")
=FORMULA(DEREF(OFFSET(REF,POS1,6,1,1)),"MENU.XLS!R4C2")

=RETURN()
```

**** PRINT COST TYPE REFERENCES ON TEMPLATE ****

```
=SET.NAME("NREF",OFFSET(REF,POS1,3,1,1))
=IF(NREF=0,GOTO($A$1531))
=FORMULA("Contains:",REF1)
=FOR("K",1,NREF)
=    SET.NAME("NAME_REF",DEREF(OFFSET(REF,POS1,CO_1+3*(K-1),1,1)))
=    SET.NAME("DES_REF",DEREF(OFFSET(REF,POS1,CO_1+3*(K-1)+1,1,1)))
=    SET.NAME("TYPE_REF",DEREF(OFFSET(REF,POS1,CO_1+3*(K-1)+2,1,1)))
=    IF(TYPE_REF=0,SET.NAME("TYPE_REF",""))
=    FORMULA(DES_REF&" '"&NAME_REF&"'"&TYPE_REF,OFFSET(REF1,K-1,1,1,1))
=NEXT()
=SET.NAME("NDEP",OFFSET(REF,POS1,4,1,1))
=IF(NDEP=0,GOTO($A$1543))
=IF(NREF=0,SET.NAME("REF2",REF1),SET.NAME("REF2",OFFSET(REF1,NREF+1,0,1,1)))
=FORMULA("Contained in:",REF2)
=FOR("K",1,NDEP)
=    SET.NAME("NAME_REF",DEREF(OFFSET(REF,POS1,CO_1+3*NREF+3*(K-1),1,1)))
=    SET.NAME("DES_REF",DEREF(OFFSET(REF,POS1,CO_1+3*NREF+3*(K-1)+1,1,1)))
=    SET.NAME("TYPE_REF",DEREF(OFFSET(REF,POS1,CO_1+3*NREF+3*(K-1)+2,1,1)))
=    IF(TYPE_REF=0,SET.NAME("TYPE_REF",""))
=    FORMULA(DES_REF&" '"&NAME_REF&"'"&TYPE_REF,OFFSET(REF2,K-1,1,1,1))
=NEXT()
```

**** PRINT COST TYPE MENU ****

```
=ACTIVATE("MENU.XLS")
=WINDOW.SIZE(260,210)
=SELECT("R2C1")
=UNHIDE("MENU.XLS")
=SET.NAME("MENU",INPUT("Enter selection:",1,,EXIT,245,50))
=WINDOW.RESTORE()
=HIDE()
=IF(OR(INT(MENU)<>MENU,MENU<1,MENU>EXIT),GOTO($A$1544))
=ACTIVATE("MENU.XLS")
=SELECT("C1:C3")
=CLEAR(1)

=RETURN()
```

**** EDIT COST TYPE AMOUNT ****

```
=SET.NAME("DES_TMP",DES)
```

```
=SET.NAME("K_2",POS1)
=RUN($A$256)
=SET.NAME("NREF_DEF",DEREF(OFFSET(REF1,K_2,3,1,1)))
=RUN($A$303)
=IF(NREF_DEF=0,GOTO($A$1576))
=FOR("K",1,NREF_DEF)
=    SET.NAME("NAME_REF",DEREF(OFFSET(REF1,K_2,CO_3+3*(K-1),1,1)))
=    SET.NAME("POS2",MATCH(NAME_REF,OFFSET(!VAR_REF,1,5,!NCT+6,1),0))
=    SET.NAME("POS3",MATCH(NAME,OFFSET(!VAR_REF,POS2,0,1,200),0))
=    SELECT(OFFSET(!VAR_REF,POS2,POS3-1,1,3))
=    EDIT.DELETE(1)
=    FORMULA(OFFSET(!VAR_REF,POS2,4,1,1)-1,OFFSET(!VAR_REF,POS2,4,1,1))
=NEXT()
=IF(MENU2=3,RETURN())
=SELECT(OFFSET(REF1,K_2,CO_3,1,3*NREF_DEF))
=EDIT.DELETE(1)
=IF(DES4="RCE",RETURN())
=RUN($A$321)
=SET.NAME("DES",DES_TMP)

=RETURN()
```

****** EDIT COST TYPE ALLOCATION ******

```
= SET.NAME("K_2",POS1)
=RUN($A$227)
=IF(DES4="RCE")
=    SET.NAME("CELL",MATCH(" (A*",OFFSET(REF1,K_2,CO_1,1,3*NREF),0))
=    IF(TYPE(CELL)=16,GOTO($A$1594))
=    SET.NAME("CO_3",CO_1)
=    SET.NAME("AMOUNT_TXT",DEREF(OFFSET(REF1,K_2,6,1,1)))
=    SET.NAME("AMOUNT","="&AMOUNT_TXT)
=    RUN($A$492)
=    RETURN()
=END.IF()
=RUN($A$519)

=RETURN()
```

****** ADD COST TYPE ******

```
=SET.NAME("DES_TMP",DES)
=SELECT("R"&ROW(OFFSET(!NAME_REF,COUNT1+1,0,1,1)))
=INSERT(3)
=SELECT("R"&ROW(OFFSET(REF,K_2,0,1,1)))
=INSERT(3)
=IF(K_1=1,GOTO($A$1607))
=SELECT("R"&ROW(OFFSET(!CF_REF,COUNT,0,1,1)))
=INSERT(3)

=RUN($A$168)
```

```
=SET.NAME("DES",DES_TMP)

=RETURN()
```

****** DELETE COST TYPE ******

```
=SET.NAME("K_2",POS1)
=SET.NAME("REF1",REF)
=SET.NAME("NREF",OFFSET(REF1,K_2,3,1,1))
=SET.NAME("NREF_DEF",NREF)
=IF(NREF_DEF=0,GOTO($A$1619))
=RUN($A$1565)
=RUN($A$996)
=FORMULA(NN-1,NN)
=SELECT("R"&ROW(OFFSET(REF,POS1,0,1,1)))
=EDIT.DELETE(3)
=SELECT("R"&ROW(OFFSET(REF5,POS1,0,1,1)))
=EDIT.DELETE(3)
=IF(DES<>"VAR")
=    SELECT("R"&ROW(OFFSET(REF3,POS1,0,1,1)))
=    EDIT.DELETE(3)
=END.IF()

=RETURN()
```

<u>SIMULATION SUBROUTINE (d)</u>

****** CHECK FOR AVAILABILITY OF DATA ******

```
=IF(FILE_ID=0)
=    ALERT("No data is present. Please read or create data.",3)
=    GOTO($A$15)
=END.IF()
=UNHIDE(FILE_NAME)
=WINDOW.MINIMIZE(FILE_NAME)
```

****** SELECT SIMULATION MODE ******

```
=SET.NAME("MODE",INPUT("1)  Single Sim     2)  Multiple Sims",1,,1))
=IF(AND(MODE<>1,MODE<>2), GOTO ($A$1644))
=IF(MODE=1,RUN($A$1652),RUN($A$1663))
=HIDE()
=GOTO($A$15)

=RETURN()
```

****** RUN SIMULATION & CREATE REPORTS SUBROUTINE ******

```
=RUN('C:\CB\CBXL.XLA'!CB.RunPrefs)
=ALERT("Remember - charts and reports may be generated, customized,
   printed and saved once the simulation terminates.",2)
=ALERT("When finished, click on the 'Resume Macro' icon to continue.",2)
```

```
=RUN('C:\CB\CBXL.XLA'!CB.Run)
=PAUSE()
=RUN('C:\CB\CBXL.XLA'!CB.ResetND)
=GOTO($A$1647)

=RETURN()

*** RUN MULTIPLE SIMULATIONS & CREATE REPORTS SUBROUTINE ***
=OPEN("C:\LCC\DATA\DATA.XLS")
=HIDE()

*** OBTAIN INPUT PARAMETERS ***
=SET.NAME("NUM_INP",INPUT("Enter the number of inputs in 'DATA.XLS' :",1))
=IF(OR(INT(NUM_INP)<>NUM_INP,NUM_INP<0),GOTO($A$1668))
=IF(NUM_INP>!NVAR+!NTCE+!NPCE-1)
=    ALERT("The number of inputs exceeds the maximum allowed.",3)
=    GOTO($A$1668)
=END.IF()
=IF(NUM_INP=0,GOTO($A$1684))
=SET.NAME("IND",0)
=SET.NAME("NAMES",!NVAR+!NTCE+!NPCE-1)
=SET.NAME("ROW",2)
=SET.NAME("WORD","input ")
=SET.NAME("NUMBER",NUM_INP)
=SET.NAME("PREFIX","X_")
=RUN($A$1771)

*** OBTAIN OUTPUT PARAMETERS ***
=SET.NAME("NUM_OUT",INPUT("Enter the number of outputs:",1))
=IF(OR(INT(NUM_OUT)<>NUM_OUT,NUM_OUT<1),GOTO($A$1684))
=SET.NAME("IND",1)
=SET.NAME("NAMES",!NVAR+!NCE-1)
=SET.NAME("ROW",2)
=SET.NAME("WORD","output ")
=SET.NAME("NUMBER",NUM_OUT)
=SET.NAME("PREFIX","Y_")
=RUN($A$1771)

*** OBTAIN SIMULATION SETTINGS ***
=SET.NAME("NUM_OBS",INPUT("Enter the number of simulations:",1))
=IF(OR(INT(NUM_OBS)<>NUM_OBS,NUM_OBS<1),GOTO($A$1695))
=SET.NAME("NUM_ITS",INPUT("Enter the number of iterations:",1))
=IF(OR(INT(NUM_ITS)<>NUM_ITS,NUM_ITS<1),GOTO($A$1697))
=SET.NAME("PERCENTILE",INPUT("Enter the desired percentile (deciles, quartiles, 5, 95, only):",1))
=IF(AND(INT(PERCENTILE/10)<>PERCENTILE/10,PERCENTILE<>5,PERCENTILE<>25,
 PERCENTILE<>75,PERCENTILE<>95),GOTO($A$1699))
=IF(INT(PERCENTILE/10)=PERCENTILE/10)

=    SET.NAME("FLAG",1)
```

```
=   SET.NAME("ROW",PERCENTILE/10+2)
=ELSE.IF(PERCENTILE=5)
=   SET.NAME("FLAG",2)
=   SET.NAME("ROW",3)
=ELSE.IF(PERCENTILE=25)
=   SET.NAME("FLAG",2)
=   SET.NAME("ROW",4)
=ELSE.IF(PERCENTILE=75)
=   SET.NAME("FLAG",2)
=   SET.NAME("ROW",6)
=ELSE.IF(PERCENTILE=95)
=   SET.NAME("FLAG",2)
=   SET.NAME("ROW",7)
=END.IF()
=RUN('C:\CB\CBXL.XLA'!CB.RunPrefs)
=ALERT("Remember - the data file may be customized, printed, and saved
 once the simulations are complete.",2)
=ALERT("When finished, click on the 'Resume Macro' icon to continue.",2)
```

****** READ INPUT ROWS ******

```
=SET.NAME("COUNTER",0)
=IF(NUM_INP=0,GOTO($A$1728))
=FOR("K_2",1,NUM_INP)
=   FORMULA(OFFSET(TEXTREF("DATA.XLS!R1C1"),COUNTER,K_2-1,1,1),TEXTREF("X_"&K_2))
=NEXT()
```

****** RUN SIMULATION & EXTRACT DATA ******

```
=RUN('C:\CB\CBXL.XLA'!CB.Simulation(NUM_ITS))
=IF(COUNTER=1,GOTO($A$1741))
=RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(2,3))
=IF(FLAG=1,RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(4,3)),
 RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(4,5)))
=RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(3,5))
=SET.NAME("COUNTER1",0)
=SELECT(REPLACE(REFTEXT(TEXTREF("Y_"&COUNTER1+1)),1,LEN(FILE_NAME)+1,""))
=RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(3,4))
=SET.NAME("COUNTER1",COUNTER1+1)
=IF(COUNTER1<NUM_OUT,GOTO($A$1736))
=RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(3,3))
=RUN('C:\CB\CBXL.XLA'!CB.ExtractDataND(1,FALSE))
```

****** WRITE OUTPUT ROWS ******

```
=FOR("K_2",1,NUM_OUT)
=   SET.NAME("OUTPUT",OFFSET(!$A$1,ROW,K_2,1,1))
=   FORMULA(OUTPUT,OFFSET(TEXTREF("DATA.XLS!R1C1"),COUNTER,NUM_INP+K_2,1,1))
=NEXT()
```

****** CHECK FOR TERMINATION & SAVE DATA FILE ******

```
=CLOSE(FALSE)
=SET.NAME("COUNTER",COUNTER+1)
=ACTIVATE("DATA.XLS")
=IF(INT(COUNTER/5)=COUNTER/5,SAVE())
=ACTIVATE(FILE_NAME)
=RUN('C:\CB\CBXL.XLA'!CB.ResetND)
=IF(COUNTER<NUM_OBS,GOTO($A$1723))
=ACTIVATE("DATA.XLS")
=UNHIDE("DATA.XLS")
=SAVE()
=WINDOW.MAXIMIZE()
=SELECT("R1C1")
=ALERT("The simulation runs are complete.",3)
=PAUSE()
=ACTIVATE(FILE_NAME)
=CLOSE(FALSE)
=OPEN("C:\LCC\DATA\"&FILE_NAME)
=GOTO($A$1648)

=RETURN()
```

****** INPUT/OUTPUT SUBROUTINE ******

```
=SET.NAME("OFFSET",OFFSET(!NAME_REF,ROW,0,NAMES,2))
=COPY(OFFSET)
=ACTIVATE("MENU.XLS")
=SELECT("R3C1")
=PASTE.SPECIAL(3)
=FOR("K_2",1,NUMBER)
=    RUN($A$870)
=    IF(AND(IND=1,DES<>"VAR"),GOTO($A$1783))
=    SELECT(OFFSET(!$A$3,POS-1,0,1,2))
=    EDIT.DELETE(2)
=    SET.NAME("NAMES",NAMES-1)
=    ACTIVATE(FILE_NAME)
```

****** OBTAIN FORECAST TYPES ******

```
=    IF(OR(IND=0,DES="VAR"))
=        SET.NAME("NAME1",NAME)
=        GOTO($A$1808)
=    END.IF()
=    SET.NAME("OUTPUT",INPUT("1) TOT   2) PV   3) AE   4) FV    5) CF",1))
=    IF(OR(INT(OUTPUT)<>OUTPUT,OUTPUT<1,OUTPUT>5),GOTO($A$1790))
```

****** OBTAIN INPUTS FOR CASH FLOWS ******

```
=    IF(OUTPUT=5)
=        SET.NAME("YEAR",INPUT("Enter the year:",1))
=        IF(OR(INT(YEAR)<>YEAR,YEAR<0),GOTO($A$1795))

=        SET.NAME("NAME1","TOTAL"&NAME)
```

```
=       SET.NAME("LOC",ROW(TEXTREF(REPLACE(GET.NAME("!"&NAME1),1,1,"!"))))
=       SET.NAME(PREFIX&K_2,OFFSET(!$A$1,LOC-1,CO_8+YEAR,1,1))
=       GOTO($A$1810)
=    END.IF()
```

****** READ INPUTS/OUTPUTS ******

```
=    IF(OUTPUT=1,SET.NAME("NAME1","TOTAL_"&NAME))
=    IF(OUTPUT=2,SET.NAME("NAME1","NPV_"&NAME))
=    IF(OUTPUT=3,SET.NAME("NAME1","AE_"&NAME))
=    IF(OUTPUT=4,SET.NAME("NAME1","FV_"&NAME))
=    SET.NAME(PREFIX&K_2,TEXTREF(REPLACE(GET.NAME("!"&NAME1),1,1,"!")))
=    ACTIVATE("NAMES.XLS")
=NEXT()
=IF(NAMES<>0)
=    SELECT(OFFSET(!$A$3,0,0,NAMES,2))
=    CLEAR(1)
=END.IF()
=WINDOW.TITLE("MENU.XLS")
=ACTIVATE(FILE_NAME)

=RETURN()
```

Appendix K: Calculations for Proportional Pit Sludge and Berm Soil Blending

As discussed in Section 3.2.3, the vitrification process simulation assumes that pit wastes and berm soils are proportionally blended to facilitate simultaneous completion of both waste streams. Two simultaneous equations are used to determine this proportion. The first equation comes from the assumption that a batch tank will be filled to 2/3 full with pit sludge and washed soil.

$$AP + .36 \cdot \frac{AS}{.35} = .667 \cdot CBT$$

where AP is the amount of pit sludge,
AS is the amount of soil fed to the soil washer,
0.36 is the portion of washed soil entering the melter,
0.35 is the percent of solids in the soil wash output,
CBT is the capacity of the batch tank.

The second equation comes from the desire to complete remediation of both waste streams simultaneously. The amount of pit sludge and berm soil to include in one batch is chosen so that an equal number of batches is produced from each waste stream.

$$\frac{TPS}{AP \cdot 0.5} = \frac{TBS}{AS}$$

where TPS is the total pit sludge to remediate,
TBS is the total berm soil,
.5 is the percent solids in the mucked pit sludge,
AP and AS are amounts of pit sludge/berm soil per batch.

Solving these two equations simultaneously yields:

$$AP = \frac{\left(\dfrac{.66 \cdot TPS \cdot CBT}{.5 \cdot TBS}\right)}{\left(\dfrac{.97 \cdot TPS}{.5 \cdot TBS}\right) + 1}$$

where AP is the amount of pit sludge per batch,
TPS is the total pit sludge to remediate,
TBS is the total berm soil to remediate,
CBT is the capacity of the batch tank.

$$AS = .65 \cdot CBT - .97 \cdot AP$$

where AS is the amount of berm soil fed to the soil washer,
CBT is the capacity of the batch tank,
AP is the amount of pit sludge per batch.

Appendix L. Dry Removal Cost Element Database/Dictionary

Assumptions:

Costs are reported in 1995 dollars.

All capital equipment purchases are made in the first year of operations.

Maintenance and replacement costs are 10% of equipment purchase cost per year (except for melters).

Long-term monitoring is required only for on-site storage.

Disclaimer: All product/equipment/service estimates are rough order of magnitude. They are provided as a courtesy of vendors and contractors and are subject to change pending clarification of requirements and contractual agreement. The estimate provider is in no way bound by the information provided for this study.

VARIABLES:

NAME:	LIFE
AMOUNT:	1+OPS_LIFE
DESCRIPTION:	Time (Years) from beginning of project to end of operations. Monitoring costs beyond LIFE are discounted back to the end of operations life.

NAME:	RATE
AMOUNT:	0.058
DESCRIPTION:	Normal discount rate.
REFERENCE:	Per OMB circular # A-94

NAME:	OPS_LIFE
AMOUNT:	23.53*WASTE*226.7/CAPACITY
DESCRIPTION:	Predicted operations life (years). It takes 23.53 years to remediate 1 million m3 of solid waste. A base of two filter presses can produce 226.7 m3 per day of remediated solid waste.

NAME:	REAL_RATE
AMOUNT:	0.028
DESCRIPTION:	Real discount rate.
REFERENCE:	Per OMB circular # A-94

NAME: INFLATION
DESCRIPTION: Inflation rate.
REFERENCE: Calculated as a function of RATE and REAL_RATE

NAME: WASTE
AMOUNT: 0.87
DESCRIPTION: Total waste requiring remediation (millions of m3). There are 0.87 million m3 of solid waste to remediate at the OU-l site of Fernald.

NAME: CAPACITY
AMOUNT: Config l: 226.7
Config 2: 453.4
Config 3: 906.8
DESCRIPTION: Number of m^3 of remediated waste per day for the particular size of plant that is being costed.
REFERENCE: Engineering judgment based on experience with a similar size operation in an existing plant.

NAME: CAKE
AMOUNT: 250 CAPACITY
DESCRIPTION: Annual amount of remediated waste produced in one year from this plant. Assume 250 work days per year and units in m^3/year.

NAME: GEN_MX_PCT
AMOUNT: TRIANGULAR(.08,. 10,.12)
DESCRIPTION: Assumes 10% of equipment purchase cost per year for maintenance and
replacement.
REFERENCE: T. Sams and E. McDaniel/Martin Marietta Energy Systems:

NAME: UNIT_OPS_COST
AMOUNT: TRIANGULAR(50,55,60)
DESCRIPTION: The overall cost of running the plant. The amount refers to dollars per m3 of remediated waste and covers many costs such as labor, electricity, and additives.
REFERENCE: This was an experiential cost factor that allowed cost estimation of a process without the rigor included in the other two alternatives' cost analyses. This cost value should be considered as

approximately correct. Terry Sams felt strongly that the cost was definitely within the bounds listed.

NAME:	STORAGE_IND
AMOUNT:	0 = on-site disposal; 1 = off-site disposal
DESCRIPTION:	Indicator for disposal alternative (on- or off-site).

NAME:	UNIT_MONITOR_COST
AMOUNT:	1.84
DESCRIPTION:	Annual waste monitoring cost in $/m3 of waste.
REFERENCE:	Rod Gimpel's March '92 estimate for delisted waste (inflated).

NAME:	UNIT_CONTAINER_COST
AMOUNT:	TRIANGULAR (110, 120, 130)
DESCRIPTION:	Cost (in dollars) for one 110 gallon container used for shipping the filter cake waste material.
REFERENCE:	Terry Sams' estimate during March 1995 meeting.

NAME:	CONTAINERS
AMOUNT:	2.4*CAKE
DESCRIPTION:	Predicted number of containers needed in one year for the waste removal. The conversion factor 2.4 is: 264 gals/m3 * container/l 10 gal.

NAME:	UNIT_TRANS_COST
AMOUNT:	TRIANGULAR (260, 280, 300)
DESCRIPTION:	Cost for transportation to disposal site ($/m3)
REMARKS:	Assume rail transport to Utah.
REFERENCE:	Terry Sams/Martin Marietta Energy Systems

NAME:	UNIT_ONSITE_COST
AMOUNT:	TRIANGULAR (270, 285, 300)
DESCRIPTION:	Cost for tumulus ($/m3)
REFERENCE:	Rod Gimpel FERMCO.

NAME:	UNIT_OFFSITE_COST
AMOUNT:	TRIANGULAR (1700, 2000, 2100)
DESCRIPTION:	\$/m3 for disposal at Envirocare
REFERENCE:	Terry Sams/ Martin Marietta Energy Systems

NAME:	NUM_TESTOUT
AMOUNT:	52*CAPACITY/226.7
DESCRIPTION:	Test output once per week per two filter press system (CAP=226.7)
REFERENCE:	Approximately the same as for vitrification, and cementation.

NAME:	UNIT_TESTOUT_COST
AMOUNT:	1000
DESCRIPTION:	Cost for TCLP test.
REFERENCE:	The same as for vitrification

NAME:	INIT_MONITOR_COST
AMOUNT:	UNIT_MONITOR*CAKE
DESCRIPTION:	Cost for first year of monitoring remediated onsite waste.

NAME:	MAX_ MONITOR_ COST
AMOUNT:	INIT_ MONITOR COST*OPS_LIFE
DESCRIPTION:	Constant cost for long-term monitoring

NAME:	MONITOR_IND
AMOUNT:	O
DESCRIPTION:	O = Total monitor costs; 1 = Operations monitor costs.

NAME:	CIVIL_ENG ONSITE
AMOUNT:	TRIANGULAR(11.38E6, 11.98E6, 12.58E6) (-5%,+5%)
DESCRIPTION:	Site preparation, 15,000 ft^2 facility, roads, etc. This is the same estimate as used for cementation.
REFERENCE:	Adjusted FSR

NAME: CIVIL_ENG_OFFSITE
AMOUNT: TRIANGULAR(15.03E6, 15.82E6, 16.61E6)
(-5%,+5%)
DESCRIPTION: Site preparation, 15,000 ft^2 facility, roads, rail sidings, and staging area, etc. Same estimate as used for cementation.
REFERENCE: Adjusted FSR and engineering judgment

NAME: OH_RATE
AMOUNT: 0.08
DESCRIPTION: Flat percentage of overall project cost minus additives, transportation, and storage costs.
REFERENCE: Industry standard

NAME: UNIT_ONSITE_COST
AMOUNT: 285
DESCRIPTION: The estimated cost per m3 of handling remediated waste onsite before the monitoring begins. This includes building the tumulus, preparing the property, and loading the tumulus with waste.
COST ELEMENTS:

TYPE: PCE
NAME: RESEARCH DEV
AMOUNT: 750000
RISK: (-10%,+10%)
TIME PHASING:
YEAR: 0 PERCENT: 100
DESCRIPTION: Site preparation, facilities, roads, and rail sidings/staging for off-site disposal.

TYPE: PCE
NAME: CIVIL_ENG
AMOUNT: IF(STORAGE_IND=0,CIVIL_ENG_ONSITE,CIVIL_ENG_OFFSITE)
RISK: (-10%,+10%)
TIME PHASING:
YEAR: 0 PERCENT 100

DESCRIPTION: Site preparation, facilities, roads, and rail sidings/staging for off-site disposal.
REFERENCE: Adjusted FSR

TYPE:	PCE
NAME:	EQPT_COST
AMOUNT:	Config. 1: TRIANGULAR(2.5E6,2.8E6, 3.lE6) Config. 2: TRIANGULAR(4.08E6, 4.535E6, 4.99E6) Config. 3: TRIANGULAR(7.65E6, 8.5E6, 9.35E6)
RISK:	(-10%,+10%)
TIME PHASING:	

YEAR: 1 PERCENT:100

DESCRIPTION:	Confg.1	Confg. 2	Confg.3
Filter Press(2*180,000)	360E3	720E3	1440E3
Evaporator	350E3	700E3	1400E3
Sieve	20E3	20E3	20E3
Crusher	25E3	25E3	25E3
Additive Hoppers	60E3	120E3	240E3
Transfer station	200E3	200E3	200E3
Conveyors	120E3	120E3	120E3
Hopper for soil	50E3	75E3	100E3
Heavy equipment	350E3	750E3	950E3
Material handling	1. lE6	1.47E6	2.93E6
Motor pool	100E3	100E3	100E3
Batch tanks	260E3	520E3	1040E3
Soil Hopper	50E3	50E3	50E3
Total′	2.8E6	4.535E6	8.5E6

REFERENCE: Perry and Chilton's Chemical Engineer's Handbook
Pre-processing equipment: Rock crusher, mechanical sieve,transfer station: Williams Pipeline
Conveyors: FSR
Hopper: Construction estimators
Heavy equipment Motor pool: Various dealers
Material handling: Cranes, forklifts, flatbed trucks

TYPE:	RCE
NAME:	TRANS_COST
AMOUNT:	UNIT OPS_COST*CAKE*STORAGE_IND
TIME PHASING:	
	START: 1
	NO. PMTS: 66
	SKIP FACTOR: 0
DESCRIPTION:	Annual predicted transportation cost.

TYPE: RCE
NAME: ONSITE_COST
AMOUNT: UNIT_ONSITE_ COST*CAKE*(l- STORAGE_IND)
TIME PHASING:

START: 1
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Annual cost for tumulus.

TYPE: RCE
NAME: OFFSITE_COST
AMOUNT: UNIT_OFFSITE_COST*CAKE*STORAGE_IND
TIME PHASING:

START: I
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Cost for disposal.

TYPE: RCE
NAME: GEN_MX_COST
AMOUNT: GEN_MX_PCT*EQPT_COST
TIME PHASING:

START: 1
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: Assumes 10% of equipment purchase cost per year for maintenance and replacement

TYPE: RCE
NAME: TESTOUT_COST
AMOUNT: UNIT_TESTOUT_COST*NUM_TESTOUT
TIME PHASING:

START: 1
NO. PMTS: 66
SKIP FACTOR: 0

DESCRIPTION: 1 TCLP test per week per 226.7m3/day capacity at 1000/test.

TYPE: RCE
NAME: OPS_MONITOR_COST
AMOUNT: INIT_MONITOR_COST*(TIME-l)*(l-STORAGE_IND)
TIME PHASING:
START: I
NO. PMTS: 66
SKIP FACTOR: 0
DESCRIPTION: $1.84/m3 output for long-term monitoring

TYPE: RCE
NAME: LUMP_MONITOR_COST
AMOUNT: IF(TIME=ROUND(LIFE,0),(MAX_MONITOR_COST/REAL_RATE)
(1-STORAGE_IND)*(1-MONITOR_IND),0)
TIME PHASING:
START: 1
NO. PMTS: 66
SKIP FACTOR: 0
DESCRIPTION: Lump all post-operations monitoring costs in the last year of operations. This is modeled as an infinite cash flow stream.

TYPE: RCE
NAME: OH_BASE
AMOUNT: SUM(CEMENT_ONSITE_COST,OPS_COST,OPS_MONITOR_COST,
ONSITE_COST, EQPT_COST, GEN_MX_COST, TESTOUT_COST,
CIVIL_ENG,RESEARCH_DEV)
DESCRIPTION: The total amount of costs upon which the overhead amount will be based.

TYPE: RCE
NAME: OVHD
AMOUNT: OH _RATE*OH_BASE
DESCRIPTION: The total amount of overhead ($) each year

TYPE: RCE
NAME: CEMENT_OFFSITE
AMOUNT: ABS(PMT(RATE,ROUND(OPS_LIFE,0),37931034.5*WASTE))
*STORAGE_IND
TIME PHASING:
START: 0
NO. PMTS: 21
SKIP FACTOR: 0

DESCRIPTION: Since cementation is a very small part of remediating mixed waste with dry removal (about 1% of remediated waste), 1% of the total cost of remediating the waste using cementation entirely and disposing of it OFFSITE was used as the base cost for this element. The NPV value is then spread throughout the life of the project to better indicate the expected cash flows.

TYPE: RCE
NAME: CEMENT_ONSITE
AMOUNT: ABS(PMT(RATE,ROUND(OPS_LIFE,0),5747126.4*WASTE))
*(l-STORAGE_IND)

TIME PHASING:
START: 0
NO. PMTS: 21
SKIP FACTOR: 0

DESCRIPTION :Since cementation is a very small part of remediating mixed waste with dry removal (about 1% of remediated waste), 1% of the total cost of remediating the waste using cementation entirely and disposing of it ONSITE as used as the base cost for this element. The NPV value is then spread throughout the life of the project to better indicate the expected cash flows.

TYPE: RCE
NAME: OPS_COST
AMOUNT: UNIT_OPS_COST*CAKE
TIME PHASING:
START: 0
NO. PMTS: 71
SKIP FACTOR: 0
DESCRIPTION: Annual cost of running the dry removal plant based upon the annual output of the plant and the previously discussed estimated cost per m^3.

TYPE: RCE
NAME: PROJECT
AMOUNT: SUM_CEMENT_OFFSITE_COST,OFFSITE_COST,
TRANS_COST,
LUMP_MONITOR_COST, OVHD,OH_BASE)

TIME PHASING:		
	START:	0
	NO. PMTS:	71
	SKIP FACTOR:	0
DESCRIPTION:	Overall project cost.	

TYPE:	RCE	
NAME:	PROJECT_INF	
AMOUNT:	PROJECT*((l+INFLATION*TIME)	
TIME PHASING:		
	START:	0
	NO. PMTS:	71
DESCRIPTION:	Inflated project cost.	

References

Bates, J.K., W.L. Ebert, X. Feng, and W.L. Bourcier. *Issues Affecting the Prediction of Glass Reactivity in an Unsaturated Environment,* Journal of Nuclear Materials, 190: 198-227 (August 1992).

Biery, Fred, David Hudak, and Shishu Gupta. *Improving Cost Risk Analyses*, Journal of Cost Analysis (Spring 1994).

Blank, Leland T. and Anthony J. Tarquin. Engineering Economy (Third edition). McGraw-Hill, 1989.

Bliss, G. *The Accuracy of Weapon Systems Cost Estimates*. Paper presented at the 59th Military Operations Research Symposium, U.S. Military Academy, West Point, N.Y. (June 1991).

Brown, Frank. Duratek process engineer at the FERMCO bench scale vitrification plant. Information exchanged in numerous meetings and telephone conversations throughout the project. July through November 1994.

Buckley, Garry. President, Mechanical Management, Lebanon, IN. Telephone interview. December 21, 1994.

Buelt, James L. and Richard K. Farnsworth. *In Situ Vitrification of Soils Containing Various Metals,* Nuclear Technology, 96: 178-184 (November 1991).

Cain, J.P., Nick Habash, and J.A. Gibson. *Analysis of Military Systems Using an Interactive Life Cycle Costing Model,* Air Force Institute of Technology.

Cheng-Fang Lin and Ten-Hung Huang. *Leaching Characteristics of a Model Solidification/Stabilization System : Tricalcium Silicate and Copper Oxide.* Journal of Hazardous Materials, 36-3: *305-319* (March 1994).

Clemen, Robert T. Making Hard Decisions. Belmont, California: Duxbury Press, 1990.

Defense Systems Management College. *Risk Management: Concepts and Guidance* (March 1989).

Department of Energy. Environmental Management 1994. DOE/EM-0119 P-1. (February 1994).

Dienemann, Paul F. *Estimating Cost Uncertainty Using Monte Carlo Techniques*. Memorandum RM-4854-PR. The Rand Corporation, Santa Monica, CA, January, 1966.

Environmental Protection Agency. International Waste Technologies/Geo-Con In Situ Stabilization/Solidification. EPA/540/A5-89/004. (August 1990).

Environmental Protection Agency. Stabilization/Solidification of CERCLA and RCRA Wastes. EPA/625/6-89/022. (May 1989).

Fabrycky, Wolter J. and Benjamin S. Blanchard. Life-Cycle Cost and Economic Analysis. Englewood Cliffs, New Jersey: Prentice Hall, 1991.

FERMCO. Technical Task Plan MA-5: Life Cycle Cost and System Scale-up Analysis for MAWS. (1995).

Fisher, G.H. *Cost Considerations in Systems Analysis*, The RAND Corporation, R-490-ASD, December, 1970, p.202.

Garvey, P. *A General Analytic Approach to System Cost Uncertainty Analysis*, Paper Presented at the 23rd Annual Department of Defense Cost Analysis Symposium (September 1989).

Gimpel, Rod. (FERMCO engineer). Engineering consultant assigned by DOE and FERMCO. Information exchanged in numerous meetings and telephone conversations throughout the project. July 1994 through March 1995.

Gimpel, Rod. *MAWS - A Development Program and Demonstration To Reduce Vitrification Remediation Treatment Costs*. Westinghouse Environmental Management Company of Ohio, Fernald Environmental Management Project, August 1992.

Gimpel, Rod and Rich Gibson. *Comments On PO-9 90% CDR*. Unpublished report for Westinghouse Environmental Management Company of Ohio, Fernald Environmental Management Project, January 1993.

Greenman, Bill (Vice-president for Technology Development, Duratek, Columbia, MD) Department of Energy Briefing, Waste Glass Chemistry. Address to Air Force Institute of Technology students and advisors. BDM, Gaithersburg, MD, 3 November 1994.

Habash, Nicolas M. An Interactive Life Cycle Forecasting Tool. MS thesis, AFIT/GOR 92D-01. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, December 1992.

Hewen, Paul. Lockheed engineer. Information exchanged in numerous telephone conversations throughout the project. October 1994 through January 1995.

Hoffelner, W., A.Chrubasik, R.C. Eschenbach, M.R. Funfshilling, and B. Pellaud. *Plasma Technology for Rapid Oxidation Melting and Vitrification of Low/Medium Radioactive Waste,* Nuclear Engineering International: 14-16 (October 1992).

IA DE-AI01-95EW55051. Interagency Agreement between the Department of Energy and the U.S. Air Force Institute of Technology for research funds. March 1995.

Johnson, Terry. Cost Estimator, Tecolote Engineering, Lompoc, CA. Telephone interview. January 10, 1994.

Lankford, EM-54. Memorandum of agreement with program managers and technical program officers for cost documentation of technology demonstrations. Department of Energy, Washington D.C., 21 October 1994.

McNichols, G. *On the Treatment of Uncertainty in Parametric Costing*. George Washington University (February 1976)

Murray, Alex. *Brief Review of Feasibility Study Report for Operable Unit 1*, Draft, U.S. DOE Fernald Field Office, March 1994.

Neter, John, William Wasserman, Michael H. Kutner. Applied Linear Statistical Models. Homewood, IL: Irwin, 1990.

Ordaz, Grace and Denise Freeman. *Minimum Additive Waste Stabilization,* Department of Energy News Bulletin (1992).

Paul, A. Chemistry of Glasses. New York: Chapman and Hall, 1982.

Pegg, Ian (Catholic University, Washington, D.C.) Department of Energy Briefing, Waste Glass Chemistry. Address to Air Force Institute of Technology students and advisors. BDM, Gaithersburg, MD 3 November 1994.

Perry, R. and Cecil Chilton. Chemical Engineers' Handbook. Fifth Edition, McGraw-Hill Book Company, New York, 1976.

Piepel, Grepory F. and John W. Shade. *In Situ Vitrification and the Effects of Soil Additives--A Mixture Experiment Case Study,* Journal of the American Ceramics Society, 75: 112-116 (January 1992).

Ritter, J.A., J.R. Zamecnik, N.D. Hutson, M.E. Smith, and J.T. Carter. *High-level Radioactive Waste Vitrification Technology and its Applicability to Industrial Waste Sludges*, Water science and technology: A Journal of the International Association on Water Pollution Research, 25, No. 3: 269-271 (1992).

Rubin, Debra K. *Plasma Heats Up for Waste*. Engineering News Record: 14 (September 1994).

Sams, Terry L.(Martin Marietta Energy Systems). Address to Air Force Institute of Technology students and advisors. Oak Ridge, TN, 9-10 February and 15-16 March 1995.

Shelley, Suzanne. *Turning Up the Heat on Hazardous Waste*, Chemical Engineering: 47-54, (October 1990).
Stefanovskii, S.V., I.A. Knyazev, and S.A. Dmitriev. *Vitrification of Radioactive Waste in a Plasma Reactor,* Physics and Chemistry of Materials Treatment, 25: 386-393 (July 1991).

Trussell, S. and R.D. Spence. *A Review of Stabilization/Solidification Interferences.* Waste Management, 14: 507-517 (November 6, 1994).

U.S. Department of Energy, Fernald Field Office. Feasibililty Study Report for Operable Unit 1, Volume 3, March 1994.

U.S. Department of Energy. MAWS Life Cycle Costs--Technical Task Plan. (March 1994).

U.S. Department of Energy. Peters, Richard, Joe Lucerna and M. John Plodinec. Vitrification Development Plan for U.S. Department of Energy Mixed Wastes. DOE/MWIP-11 (October 1993).

Walton, John C. *Leaching from Cementitious Waste Forms in Below Ground Vaults.* Journal of Environmental Engineering, 120-6: 1507-1522 (November/December 1994).

Wetmore, Kenneth H.. *Furnace Innovation for Nuclear Waste Vitrification...and much more,* Glass International: 19 (March 1994).

Wiese, Horst and Maurits Demonie. *Operation of the Pamela High-Level Waste Vitrification Facility,* Nuclear Engineering and Design, 137: 147-151 (1992).

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study is two-fold: 1) to develop a generic life-cycle cost model for evaluating low-level, mixed waste remediation alternatives, and 2) to apply the model specifically to estimate remediation costs for a site similar to the Fernald Environmental Management Project near Cincinnati, OH. LCC for vitrification, cementation, and dry removal process technologies are estimated. Since vitrification is in a conceptual phase, computer simulation is used to help characterize the support infra-structure of a large scale vitrification plant. Cost estimating relationships obtained from the simulation data, previous cost estimates, available process data, engineering judgement, and expert opinion all provide input to an Excel based spreadsheet for generating cash flow streams. Crystal Ball, an Excel add-on, was used for discounting cash flows for net present value analysis. The resulting LCC data was then analyzed using multi-attribute decision analysis techniques with LCC and remediation time as criteria. The analytical framework presented allows alternatives to be evaluated in the context of budgetary, social, and political considerations. In general, the longer the remediation takes, the lower the net present value of the process. This is true because of the time value of money and large percentage of the costs attributed to storage or disposal.

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