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A STANDARD DESCRIPTION AND COSTING METHODOLOGY FOR THE BALANCE-OF-PLANT ITEMS OF A SOLAR THERMAL ELECTRIC POWER PLANT

Report of a Multi-Institutional Working Group

January 1983

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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by
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ABSTRACT

This report establishes standard descriptions for solar thermal power plants and develops uniform costing methodologies for nondevelopmental balance-of-plant (BOP) items. The descriptions and methodologies developed are applicable to the major systems under development within the U.S. Department of Energy (DOE) Solar Thermal Program. These systems include the central receiver, parabolic dish, parabolic trough, hemispherical bowl, and solar pond. The standard plant is defined in terms of four categories comprising (1) solar energy collection, (2) power conversion, (3) energy storage, and (4) balance-of-plant (BOP). Each of these categories is described in terms of the type and function of components and/or subsystems within the category.

A detailed description is given for the BOP category. BOP contains a number of nondevelopmental items that are common to all solar thermal systems. A standard methodology for determining the costs of these nondevelopmental BOP items is given. The methodology is presented in the form of cost equations involving cost factors such as unit costs. A set of baseline values for the normalized cost factors is also given. These baseline values were selected for use in making comparative assessments of different solar options. For determining the BOP costs for a particular plant at a specified site, the various cost factors must be chosen to meet site-specific requirements. The basis for the derivation of the cost equations and the rationale used in selecting values for cost factors involved in these equations are discussed. An example using the derived BOP methodology is also presented.

Future evolution of the BOP methodology is suggested. The development of scaling techniques for use with certain BOP items, establishment of BOP cost differences among different technologies, and implementation of probabilistic costing methods for an entire power plant are some of the recommendations made for future work.

FOREWORD

This report presents balance-of-plant (BOP) information developed by a multi-institutional working group. This information is cast in the form of a standard description and costing methodology for the BOP items of solar power plants. Use of this standardized approach will enable BOP costs for different solar technologies to be evaluated in a uniform manner.

Responsibility for coordination of this effort and the organization and preparation of this report was assigned by the Department of Energy (DOE) to the Jet Propulsion Laboratory (JPL). Under the management of E. S. (Ab) Davis, the JPL team that undertook this assignment included W. Revere, T. Fujita, J. Bowyer, and K. Terasawa.

A committee consisting of members having knowledge of BOP costing practices in the utility industry was formed to guide the effort. Members of this committee are listed below:

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NOMENCLATURE

A_{bt}	Area to be Blacktopped
A_c	Area of Solar Collectors Contained Within Plant Boundaries
A_{cb}	Area of Control Building Floor
A_{gh}	Area of Gate House Floor
A_l	Area of Land Required for Entire Plant
A_{ls}	Area to be Landscaped
A_{mb}	Area of Maintenance Building Floor
A_{pl}	Area of Parking Lot
A_{sw}	Area of Sidewalk
A_{wl}	Area of Wall Required at Plant Entrance
A_{wr}	Area of Warehouse Building Floor
C	Cost of Installed Solar Collection, Power Conversion, and Storage Subsystems
C_{ae}	Cost of Architectural and Engineering (A&E) Fees and Services
C_{ar}	Cost of Access Roads
$\overline{C}_{ar}$	Cost of Access Roads Per Unit Length
C_{bs}	Cost of Base Station for Communication
C_{bt}	Cost of Blacktopping
$\overline{C}_{bt}$	Cost of Blacktopping Per Unit Area
C_c	Cost of Construction
$\overline{C}_c$	Cost of Curbing Per Unit Length
C_{cb}	Cost of Control Building
$\overline{C}_{cb}$	Cost of Control Building Per Unit Floor Area
C_{cc}	Cost of Control and Cabling
$\overline{C}_{cc}$	Cost of Control and Cabling Per Unit Collector Area
C_{cg}	Cost of Clearing and Grubbing

$\bar{C}_{cg}$	Cost of Clearing and Grubbing Per Unit Land Area
C_{ce}	Cost of Communication Equipment
C_{cm}	Cost of Construction Management
C_{cp}	Cost of Central Processor
C_{ct}	Cost of Concrete Trenches
$\bar{C}_{ct}$	Cost of Concrete Per Unit Volume
$\bar{C}_{ctf}$	Cost of Concrete Forming Per Unit Length of Concrete Trench
$\bar{C}_{ctl}$	Cost of Concrete Labor Per Unit Length of Concrete Trench
C_{cy}	Cost Allocated for Contingencies
C_{dm}	Cost of Demineralizer
$\bar{C}_{dm}$	Cost of Demineralizer Per Unit Flow Rate
C_{dp}	Cost of Uninstalled Equipment in Direct Plant Cost Category
C_{dr}	Cost of Drainage
C_{du}	Cost of Dumping
$\bar{C}_{du}$	Cost of Dumping Per Unit Land Area
C_{ec}	Cost of Electrical Cabling
$\bar{C}_{ec}$	Cost of Electrical Cabling Per Unit Collector Area
C_f	Cost of Fencing
$\bar{C}_f$	Cost of Fencing Per Unit Length
$\bar{C}_{fm}$	Cost of Field Microprocessor Per Unit Collector Area
C_{fp}	Cost of Fire Protection System
$\bar{C}_{fp}$	Cost of Fire Protection System Per Unit Area of Control Building Floor
$\bar{C}_g$	Cost of One Gate of Selected Size
C_{gg}	Cost of a Grounding Grid for the Solar Collector Field
$\bar{C}_{gg}$	Cost of the Grounding Grid Per Unit Area of Solar Collectors Contained Within Plant Boundaries

C_{gh} Cost of Prefabricated Gate House

$\overline{C}_{gh}$ Cost of Gate House Per Unit Floor Area

$\overline{C}_{gr}$ Cost of Grading Per Unit Land Area

$\overline{C}_{io}$ Cost of Input/Output Cards Per Unit Collector Area

C_{l} Cost of Land

$\overline{C}_{l}$ Cost of Land Per Unit Area

C_{lm} Cost of Labor and Material for Field Erection Work Associated with Installation of Solar Collection, Power Conversion, and Storage Subsystems

C_{ls} Cost of Landscaping

$\overline{C}_{ls}$ Cost of Landscaping Per Unit Land Area

C_{mb} Cost of Maintenance Building

$\overline{C}_{mb}$ Cost of Maintenance Building Per Unit Floor Area

$\overline{C}_{mt}$ Cost of One Maintenance Truck of Selected Size

$\overline{C}_{mu}$ Cost of One Mobile Communication Unit

C_{pe} Cost of Plant Equipment in the Balance-of-Plant Category

C_{pf} Cost of Plant Facilities

C_{pl} Cost of Parking Lot

C_{pr} Cost of Protection Equipment

$\overline{C}_{pr}$ Cost of Lightning and Surge Protection Equipment Per Unit Power Plant Rating

C_{ps} Cost of Permits and Studies

$\overline{C}_{ps}$ Cost of Permits and Studies Per Unit Land Area

C_{sd} Cost for Spill Ditches

$\overline{C}_{sd}$ Cost of Spill Ditches Per Unit Length

C_{se} Cost of Sewer System

$\overline{C}_{se}$ Cost of Washroom Facilities Per Person Per Unit Power Plant Rating

C_{sp} Cost of Site Preparation

C_{sr} Cost of Spare Parts

$\overline{C}_{ss}$ Cost of Substation Per Unit Power Rating

C_{stu} Cost Associated with Plant Start-Up

$\overline{C}_{st}$ Cost of One Supply Truck of Selected Size

C_{su} Cost of Surveying

$\overline{C}_{su}$ Cost of Surveying Per Unit Land Area

$\overline{C}_{sw}$ Cost of Sidewalks Per Unit Length

$\overline{C}_{tm}$ Cost of Concrete Material Per Unit Volume

C_{tf} Cost of Temporary Facilities

$\overline{C}_{tf}$ Cost of Temporary Facilities Per Unit Construction Time Per Unit Power Plant Rating

C_{v} Cost of Vehicles

C_{wa} Cost of Water Supply System

C_{wl} Cost of Block Walls

$\overline{C}_{wl}$ Cost of Block Wall Per Unit Verticle Wall Area

C_{wr} Cost of Warehouse

$\overline{C}_{wr}$ Cost of Warehouse Building Per Unit Floor Area Per Unit Power Plant Rating

$\overline{C}_{ws}$ Cost of Water Supply Tanks Per Unit Volume of Tank Capacity

$\overline{C}_{wt}$ Cost of One Wash Truck of Selected Size

F_{ae} Factor for A&E Fee

F_{cm} Factor for Construction Management

F_{cy} Factor for Contingencies

F_{sp} Factor for Spare Parts

F_{stu} Factor for Start-Up Cost

L_{c} Length of Curbing

L_{ct} Length of Concrete Trench

L_d	Length of Ditches Needed for Field Drainage
L_f	Length of Fence
L_r	Length of Service and Access Roads
L_{sd}	Length of Spill Ditches
L_{sw}	Length of Sidewalks
N_g	Number of Gates
$\overline{N}_m$	Number of People at Plant Per Unit Power Plant Rating
$\overline{N}_{mt}$	Number of Maintenance Trucks of Selected Size Per Unit Power Plant Rating
N_p	Number of People Expected to be at Plant Site
$\overline{N}_{st}$	Number of Supply Trucks of Selected Size Per Unit Power Plant Rating
$\overline{N}_{wt}$	Number of Wash Trucks of Selected Size Per Unit Power Plant Rating
P_r	Rated Power of the Plant
T	Construction Time
T_f	Time to Fill Demineralizer Water Tanks for One Washing of the Solar Collectors
$\overline{V}_{ct}$	Volume of Concrete Per Unit Length of Concrete-Lined Trench
$\overline{V}_{gr}$	Volume of Dirt Moved Per Unit Area Being Graded
$\overline{V}_w$	Volume of Collector Wash Water Stored in Tanks Per Unit Collector Field Area
$\overline{V}_{wp}$	Volume of Demineralized Water Stored in Tanks for Use in Power Conversion (e.g., Feedwater Makeup for Steam Rankine Systems) Per Unit Power Plant Rating

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SECTION I

INTRODUCTION

This report establishes standard descriptions for solar thermal power plants and develops uniform costing methodologies for nondevelopmental balance-of-plant (BOP) items. Preparation of this report has involved the participation of Government laboratories responsible for managing development of the various solar thermal technologies. To provide guidance, a committee was formed of members from industry who have experience with power plants and with the requirements for nondevelopmental balance-of-plant items.

The overall objective of this activity has been to assist the U.S. Department of Energy (DOE) in the planning and management of the solar thermal technology development process. In assessing the performance and costs of different solar thermal technologies, it is essential that a standard description of the elements comprising the power plants be established. This creates a framework within which the development progress and status of each technology can be assessed. The establishment of standard costing methodologies for nondevelopmental balance-of-plant items will aid in determining overall plant costs in a uniform manner for all technologies. Thus, it is anticipated that results of this effort will be useful to (1) government planners, (2) system analysts engaged in comparing different options, and (3) power plant designers who could employ the BOP data as a basic reference source.

Additionally, this report will be useful in implementing the general procedures given in the Electric Power Research Institute's Technology Assessment Guide (TAG) (Ref. 1) by providing a detailed costing methodology for solar thermal technologies.

This report first provides standard plant descriptions involving (1) the grouping of elements within the plant into four major categories and (2) a detailed description of items included in the nondevelopmental balance-of-plant category. Then, a methodology for costing the nondevelopmental balance-of-plant items is given. For each BOP item, a cost equation is provided. These cost equations involve factors such as power rating, land area, plant perimeter, and normalized cost factors. For use in comparative assessment studies, a set of baseline values for normalized cost factors is provided.

The cost of the BOP items required by a solar thermal electric power plant is appreciably influenced by the size and generic type of the plant. However, by defining the cost of size-sensitive BOP items in terms of cost per unit of plant rated power, cost per unit of land area, or other appropriate measure of plant size, the influence of plant size on BOP costs can be virtually eliminated. The effect of different technologies on the cost of BOP items is not so easily removed from the total cost for the BOP; however, this effect is secondary to that of size, and these costs can be corrected as the design of a particular type of plant evolves. Studies to date have indicated that BOP costs represent 35-50% of total plant cost, irrespective of plant size or type.

In Section V of this report, it is specifically recommended that the effects of plant size and type on the BOP costs of a solar thermal electric plant be better defined through further study.

The source for the bulk of the equations and the baseline values for cost factors is a standard cost estimating handbook (Ref. 2) used by architectural and engineering (A&E) firms. Costs in this handbook are updated on a regular basis. In the present effort, the most recent costs in 1982 dollars are used or the latest available costs are adjusted to 1982 dollars. Since this handbook employs the British system of units, this system has been adopted for the present report. Use of British units will allow this report to be easily updated to reflect periodic revisions of values in the handbook. Appendix A provides conversion factors which can be used to express numerical values in the international system of units.

As noted previously, the determination of BOP costs in a uniform manner is an essential part of assessing the progress of different solar thermal technologies toward achieving system goals. Unless BOP costs for different technologies are determined in a uniform manner, system or plant-level comparisons can be misleading. Once the relatively certain costs for BOP items are determined, the requirements for developing other components to meet system targets can be more clearly identified.

The method by which more certain nondevelopmental BOP costs can be combined with less certain costs for developmental items to determine plant cost is called probabilistic costing and is described in Appendix B. Additionally, if it is desirable to form different cost categories or subgroups containing both developmental and nondevelopmental items, it is shown in Appendix B that the probabilistic costing methodology can be applied first to determine probabilistic costs for each subgroup and then to combine the subgroups into a probabilistic cost for the total plant. For the construction of plants having high developmental uncertainties, the use of a probabilistic method has clear advantages. It provides greater insight into the selection of alternatives than the more conventional approach of adding larger contingencies to account for developmental uncertainties. When considering mature plants, the usual practice of adding standard design contingencies is deemed adequate.

For solar power plants, there is a need to assess the costs of early systems, where developmental uncertainties are high. Furthermore, in planning research and development (R&D) programs, it is usually necessary to compare the projected costs of mature plants with other alternatives. The uncertainty associated with these projections is an important element of decision-making, and the use of probabilistic methods would again have advantages. The use of probabilistic methods necessitates greater effort and engineering judgment in developing the data base in a probabilistic framework. However, this additional effort does provide information that more sharply focuses decision-making issues and will obviate erroneous selections that can arise from use of simpler methods (see Appendix B).

The balance-of-plant costing methodology presented in this report is not all-encompassing, and it is expected that future evolutions will incorporate enhancements such as the following:

(1) Determination of scaling relations to allow easy assessment of plant size effects. The present effort provides baseline values for individual power plant items. Within the limitations of the approximations inherent in the data, these values are generally applicable to a range of sizes. After the plant's power rating, area, and physical dimensions are determined, the present methodology entails a detailed step-by-step procedure to determine costs. This procedure would have to be repeated for each plant size unless simple scaling relations are derived. Further, as the data base improves with regard to the level of approximation, it will be useful to refine the level of discrimination in determining scale effects and thereby improve the scaling relations in an evolutionary manner.

(2) Derivation of simplified cost relations that group detailed cost items together and provide a basis for the rapid estimation of total BOP costs. Costs which are relatively standard for all plants can be totaled separately from those items that are highly dependent upon site-specific conditions. Generic plant designs of different sizes must be prepared and analyzed as the basis for developing simplified relations. Comparisons to existing facilities will provide a basis for calibrating and validating the relations within the limitations of data available from early pilot plant and experimental projects.

(3) Development and implementation of methods to allow the probablistic combining of costs and to allocate BOP costs among different categories for various purposes, e.g., the comparison of components such as heliostats and related BOP items of different central receiver power plant designs. Since it appears that no single algorithm for allocation can be uniformly applied to all types of solar thermal electric power plants, the methodology should allow the use of different allocation algorithms for different generic plants where the need is clearly indicated. The methodology should be evolved in a flexible manner to allow use of different allocation strategies.

The last condition that must be imposed when implementing BOP methodology is the following: All design premises for the plant, such as duty cycle, plant size, location, and climatic conditions (Ref. 1), must be defined. If a particular plant design is being studied, the appropriateness of the baseline values (cost factors) to the selected design premises must be checked. Results can be significantly affected by differences between the design premises and the baseline values. For example, when comparing solar power plants having significantly different land area requirements, the location and associated land costs (design premise) will affect the comparison.

The following sections show how the BOP costing methodology was developed. In Section II, descriptions of the four major plant cost categories, the four BOP sub-categories, and the individual components comprising each sub-category are presented. The method for calculating the cost of the individual components and their sub-categories are presented in Section III. Section IV presents the unit cost factors for each component listed as well as samples of how all BOP costing can be used to help determine the cost of a solar thermal power plant.

SECTION II

STANDARD DESCRIPTIONS

A standard description of a solar power plant and its major subsystems has been established. This description will allow users of different technologies (including non-solar technologies) to assess power plants in a similar fashion, thus providing a common base for costing and system analyses. A "solar power plant" is defined as encompassing the total physical site, including all the solar and non-solar equipment necessary to provide electrical energy in the proper form and voltage for the time periods required by a specified load. This definition does not include off-site requirements such as railroad spurs or electrical power lines to the plant site.

A. MAJOR COST CATEGORIES

The solar power plant can be divided into major groups which correspond to developmental items (solar), modified equipment (thermal transport and power conversion unit), developmental non-solar equipment (storage), and standard equipment (balance-of-plant). These major categories can be further defined as follows:

(1) Solar -- includes all concentrators, concentrator foundations, receivers, and receiver support structures. Also included in this group is any thermal transport subsystem that may be needed to carry the thermal energy from the receiver to the engine.

(2) Power Conversion Unit -- includes all engine(s), associated engine controls, generator(s), and auxiliary equipment.

(3) Storage -- includes electrical, mechanical, and/or thermal energy storage equipment, including tanks, pumps, interconnecting piping, storage elements (e.g., batteries and thermal storage media such as molten salts or oils), foundations, instrumentation for monitoring, and power conditioners.

(4) Balance-of-Plant -- consists of the indirect costs such as fees, taxes, spares, and contingencies, the direct cost of equipment not included in the above categories, and the costs of services during construction.

The costs associated with the first three categories include the costs of delivery to the site. Some of the costs of installation are also included in these first three categories while some installation costs at the interfaces between items in the first three categories and BOP items are included in BOP costs.

B. BALANCE-OF-PLANT ITEMS

Particular emphasis is placed on providing standard descriptions for nondevelopmental balance-of-plant items that are common to all solar thermal plants. Since these items are also common to photovoltaic and wind power systems, the descriptions will be useful in providing a basis for assessing the developmental progress of solar thermal technologies in relation to these other technologies.

The balance-of-plant items have been grouped into sub-categories comprising site preparation, construction costs, plant facilities, and plant equipment. Standard descriptions of the elements in each sub-category are presented in Tables 1 through 4. As indicated in Table 1, site preparation includes land and related items such as surveying and grading. Construction costs, given in Table 2, encompass indirect costs such as A&E fees and services, construction management fees, and contingency. The plant facilities category of Table 3 includes items such as buildings, parking lots, and landscaping. Items such as vehicles, controls, substations, and communication equipment are included in the plant equipment category of Table 4.

Table 1. Description of Balance-of-Plant Items, Site Preparation

1.0		Site Preparation
1.1	Land	The cost of land associated with a solar power plant is expressed in dollars per acre and includes only the land within the physical boundary of the plant.
1.2	Permits/Studies	Any costs incurred due to permits and studies in order to obtain the land or the authority to proceed with construction of the solar power plant are expressed in dollars per acre of land.
1.3	Access Roads	Access roads and highway improvements required by the plant are not reflected in the standard balance-of-plant costs at this time.
1.4	Surveying	Surveying cost involves the surveying required to establish the property boundary lines for the plant, the layout of major solar concentrators, and the location of major buildings. This cost is expressed in dollars per acre.
1.5	Clearing and Grubbing	Clearing and grubbing is the removal of brush, shrubs, rocks, and grasses and is a prerequisite to construction of the plant itself. The cost of this operation is expressed in dollars per acre.
1.6	Dumping	Dumping refers to the cost of removing refuse such as shrubs, trees, and rocks from the job site to a suitable dump site. The cost is expressed in dollars per acre of land.
1.7	Grading	Grading may be needed to eliminate surface irregularities, such as gulleys or small mounds which would inhibit the deployment of the solar collectors or the erection of plant buildings. The cost for this activity is expressed in dollars per cubic yard.
1.8	Water Supply System	This item covers the cost of water storage tanks which would supply water for the power conversion unit (if needed) and washing of the solar collector. The cost is expressed in dollars per unit volume of storage capacity.
1.9	Sewer	This cost covers the hookup either to existing sewer lines or on-site storage tanks and/or chemical toilets for the plant maintenance crew and operators, if any. The cost is a function of both the average number of people at the plant and the size of the plant.
1.10	Drainage	This item covers the cost of drainage ditches for the solar collector field. The cost is expressed in dollars per unit length of drainage ditch.

Table 2. Description of Balance-of-Plant Items, Construction Costs

2.0		Construction Costs
2.1	A&E Fees and Services	A&E firms charge fees for their services as system integrators; they oversee plant construction, prepare the necessary drawings, and purchase major equipment needed to fabricate the total plant. The cost of A&E fees and services is expressed as a percent of total costs for which the A&E firm has responsibility.
2.2	Construction Management Fee	The construction management fee is paid to those construction firms that provide services at the plant site. Generally, a construction firm specializes in a particular type of work such as electrical, foundations, piping, etc., and employs the skilled labor and equipment necessary to accomplish the work. The construction firm may or may not supply the material and equipment to be installed, depending on the work to be done and the philosophy of the system integrator. The construction management fee is determined as a fraction of the construction or installation cost for which the construction management firm has responsibility.
2.3	Start-Up	This is the cost associated with the commissioning and debugging of the plant during its first few months of operation and is expressed as a percent of the cost of uninstalled equipment in the direct plant cost category.
2.4	Contingency	This item, expressed as a percent of the project total cost, accounts for overruns due to strikes, price accelerations, costing errors, design errors, and construction mistakes.
2.5	Temporary Facilities	During the construction of the solar power plant, certain temporary facilities, services, and utilities will be required. The following items are examples: contractors' offices, architect/owner's office, electrical service, water service, rain protection, telephones, radios, temporary toilets, furniture and fixtures, janitorial service, signs, alarm systems, dust and noise control, security, tool and storage sheds, and fences. The cost of temporary facilities can be expressed in dollars per year per megawatt-electric for a specified number of years and is also a function plant size (rating).

Table 3. Description of Balance-of-Plant Items, Plant Facilities

3.0		Plant Facilities
3.1	Control Building	The plant control building houses the supervisory controls for the plant. Due to the automated nature of solar power plants, this building may be smaller than that provided for a conventional power plant. The unit cost of the building can be expressed in dollars per square foot of building area.
3.2	Maintenance Building	The maintenance building may be part of the plant control building or may be attached to it. In either case, the maintenance building houses equipment and supplies required for the periodic and annual maintenance of the plant. Due to the modular nature of the equipment used in a solar power plant and the fact that most of the maintenance equipment can be stored outside, the maintenance area associated with the solar power plant may not be significant. In any case, the cost of the maintenance building can be expressed in the same manner as the cost of the control building.
3.3	Warehouse	The warehouse facilities needed for a solar power plant house only weather-sensitive spare parts and consumables. Outside storage for non-weather-sensitive items will supplement the warehouse facility. Since this facility may not be significant, it can be part of or attached to the plant's central control building. The warehouse cost is expressed in dollars per square foot and is a function of the power plant's size.
3.4	Parking Lot	A parking lot is needed for maintenance personnel, operators, and visitors to the plant. The cost is expressed in dollars per square foot.
3.5	Landscaping	Since most solar power plants will be operated for the benefit of the public, landscaping of any side of the plant facing a major highway or access road is required. Landscaping includes bushes or trees required to hide the collector field from view. The unit cost is expressed in dollars per square foot.
3.6	Fencing	Fencing is required to prevent animals and people from wandering into the plant site and possibly disrupting operation or injuring themselves. Therefore, a No. 2 mesh chainlink fence eight feet high with a top rail will be constructed around the perimeter of the plant. The cost of the fence is in dollars per linear foot.
3.7	Walls	In most cases, a block wall at the entrance of the plant is required as part of the landscaping scheme. For costing purposes, it has been assumed that a nominal hundred-and-fifty-foot wall of block-type construction is required for the plant. The cost of this wall is expressed in dollars per square foot.
3.8	Blacktopping	Because of local requirements and/or the use of heat transfer fluids in the collector field, a part or all of the collector field may require blacktopping. The blacktop is assumed to be two inches thick on native soil and is expressed in dollars per acre.
3.9	Spill Ditches	Spill ditches may be required if oil, chemical fluids, or molten salt is being piped around the field. Oil and chemical leaks will not be tolerated in many communities due to the possibility of poisoning the soil or contaminating water supplies. It is assumed that spill ditches will be lined with air-blown mortar; the corresponding cost is expressed in dollars per linear foot.
3.10	Concrete Trenches	Some plant designs may require wiring and piping to be laid in concrete trenches in order to meet local building codes. The cost of these concrete trenches, if required, is expressed in dollars per linear foot.

Table 3. Description of Balance-of-Plant Items, Plant Facilities (Cont'd)

3.11	Gate House	Most plants require a building to house a part-time or full-time plant security officer. Because the acreage of a solar power plant is extensive, plant security is supplemented by non-labor-intensive means such as guard dogs, electronic sensors, and television cameras. The cost of a gate house is expressed in dollars and prorated over the size of the plant.
3.12	Fire Protection	The fire protection system for a mature commercial solar power plant is designed to protect the central operations building. Fires that might occur in the field can be handled by the solar concentrator wash trucks. The fire protection system for the operations/warehouse building includes (1) a halon protection system for the inside of the building and (2) a fire hydrant and sprinkler system for the ground area surrounding the building. There are other plant areas that may require fire protection but are not included as part of the baseline plant used in this study. Such areas include thermal energy storage tanks that use oil, the turbine/generator area, control substation, and electrical substations.

Table 4. Description of Balance-of-Plant Items, Plant Equipment

4.0		Plant Equipment
4.1	Vehicles	The equipment required for maintenance of the solar thermal power plant is dependent upon the owner's maintenance philosophy and the plant's design. Vehicles such as cranes, cherry pickers, and trucks (which are relatively low-cost items) or specialized equipment (which cannot readily be rerted from outside sources) may be bought and stored on the plant site. The cost of these vehicles is prorated over the size of the plant because a larger plant requires more vehicles. Because solar collectors are added to the perimeter of a field to enlarge it, a larger field implies that maintenance equipment must travel farther from any central maintenance facility to perform necessary tasks.
4.2	Protection Equipment	As previously stated in 3.11, most of the security for a solar power plant must be non-labor-intensive. Therefore, the costs of television cameras, remote-controlled access gates, etc., are major costs in this cost category. The total cost for this equipment is prorated over the plant size. Again, assuming that a larger plant will require more equipment, the normalized cost (expressed in dollars per megawatt-electric) should be relatively insensitive to plant size.
4.3	Substation	The substation ties the dead-end rack of the utility system to the plant. The function of the substation is three fold: (1) to provide switching capability, (2) to provide voltage transformation if required, and (3) to provide voltage control. The cost of the substation is expressed in dollars per megawatt-electric.
4.4	Controls and Cabling	This cost item encompasses the control and cabling subsystem for the entire plant and includes any field wiring, instrumentation, microprocessors, and/or central computer facilities required by the plant. The cost of these items is expressed in dollars per square meter based on the solar collector area.
4.5	Electrical Cables	Electric cables are required to supply power to the collectors and in some systems to take power generated by the collectors back to the substation. Covered in this cost item are the electric cables, field transformers (if required), and any contactors, fuses, drive motor controllers, and junction boxes required for the particular solar power plant layout. The cost for these items is prorated on the basis of collector area.
4.6	Spares	To ensure continued energy production, items requiring long lead times to replace or items subject to wear, damage, or failure will be stocked at the site. The total cost for spare parts is expressed as a percent of the cost of uninstalled equipment in the direct plant cost category.
4.7	Communication Equipment	Automatically acquired data can be stored by the control subsystem. However, operators and dispatchers may not be located at the site, and, therefore, a communication link may be required for controlling the plant and/or for interrogating the subsystem data bank to determine plant status. Also, maintenance crews may require radios and walkie-talkies to communicate within plant boundaries. The cost of these items is prorated on the basis of the plant's nominal rating and is expressed in dollars per megawatt-electric.
4.8	Demineralizer	In order to prevent streaking and residue film buildup on the solar concentrators during washing, a source of clean, clear water is required. (Clear water is defined as having no more than 400 parts/million of total dissolved solids.) To provide clear water, a demineralizer or other type of water filtration system should be installed at the plant site. Additional capacity may be required to provide makeup water if a steam Rankine-cycle engine(s) is used for the plant.

Table 4. Description of Balance-of-Plant Items, Plant Equipment (Cont'd)

4.9	Grounding Grid	For reasons of personnel safety and the protection and proper operation of the electrical power and control equipment, it is assumed that a grounding grid will be installed for each collector unit. The grounding grid comprises a grounding wire and rod, which are buried in the ground beneath the solar collector field.

SECTION III

METHODOLOGY

In the preceding section, BOP items were grouped in the four major categories of site preparation, construction costs, plant facilities, and plant equipment. The methodology is expressed in the form of cost equations that have been grouped in the same categories. These equations are presented in Tables 5 through 8.

A. SITE PREPARATION

Most of the items in this category are functions of land area (see Table 5). Costs which are proportional to land area include land, permits/studies, surveying, clearing and grubbing, and dumping. Grading is a function of both land area and terrain characteristics as measured by $\overline{V}_{gr}$, the volume of dirt moved per unit land area. Other costs include access roads where costs are a function of the length of the road, L_r. The width and type of road, which also affect cost, are introduced through the cost factor, $\overline{C}_{ps}$. Sewage costs are determined by the number of people at the plant while drainage costs are a function of the length of the drainage ditch, L_d.

B. CONSTRUCTION COSTS

Except for the cost of temporary facilities, which is a function of plant construction time, T, the items in this category (Table 6) are proportional to costs or groups of costs that depend to some extent on the specifics of the contractual arrangements made for plant construction. For purposes of establishing a baseline costing methodology, it is assumed that the A&E firm is responsible for the entire plant, including supervision of the construction management firm and all equipment purchased for the plant. The A&E fees and services are then taken as a fraction of the total cost for which the A&E firm is responsible, except for contingencies.

The construction management fee is based on the cost of labor and material for the field erection work that is performed under the direction of the construction management firm. The quantity of material that is purchased by the construction management firm depends on the specifics of the agreement. For the baseline methodology, it is assumed that the construction management firm is responsible for (1) all costs in the site preparation category except for purchase of land, (2) all costs in the plant facilities category, and (3) all costs in the plant equipment category except for spare parts.

The start-up cost is expressed as a fraction of the cost of uninstalled equipment in the direct cost category, C_{dp}, where this cost includes BOP items. It is noted that a major portion of the checkout procedure for much of the equipment is accomplished in the factory and as part of the installation procedure. The start-up cost covers the checkout of all the equipment after it has been linked together.

The contingency factor, F_{cy}, is based on the total plant cost, including the cost for A&E fees and services. For early plants encumbered with developmental uncertainties, relatively high contingency factors are often employed. For mature plants, a lower factor to cover only design aspects is employed. If probabilistic procedures are employed as recommended in this effort, the contingency factor would be selected to cover design aspects while developmental uncertainties would be treated through probabilistic analyses (see Appendix B).

It is recognized that there are a number of contractual agreements and associated fee structures that depart from the baseline employed above. However, it is believed that costs from these different arrangements can be aggregated into the baseline format by considering the basic functions of the A&E firm and the construction management firm as defined in this study.

C. PLANT FACILITIES

As shown in Table 7, the costs of items in this category are governed by a diversity of factors. Costs of control, maintenance, and warehouse buildings are functions of their respective floor area requirements. The cost of the parking lot depends on the area of the lot, A_{pl}, and includes sidewalks (of area A_{sw}) that connect the parking lot with the building complex. Landscaping is a function of the area, A_{ls}, to be landscaped. Fencing costs depend on the length of fencing, L_f, and the number of gates, N_g. Costs of walls and blacktopping are proportional to the wall area and the area to be blacktopped, respectively. Costs of spill ditches and concrete trenches are functions of their respective lengths and cross sections. The cost of the guard house is proportional to its floor area, A_{gh}.

D. PLANT EQUIPMENT

This category encompasses a wide range of items as shown in Table 8. Vehicle costs are a function of the number of wash trucks, N_{wt}, the number of maintenance trucks, N_{mt}, and the number of supply trucks, N_{st}. Protection equipment and substation costs are proportional to the power rating of the plant. The costs for controls and associated cabling depend on the area of the collector field, A_c, and include the cost of a control processor, C_{cp}. Cost of electrical cabling for power transmission is proportional to the area of the collector field. The effect of differences in the type and layout of collector fields is reflected in the cost factor, $\overline{C}_{ec}$. The cost of spares is the product of the factor F_{sp} and the uninstalled cost of equipment denoted by C_{dp}. Cost of communication equipment includes a base station, C_{bs}, and mobil units for vehicles (trucks).

Table 5. Cost Equations for Balance-of-Plant Items, Site Preparation

Item	Equations to Determine Costs in Dollars
1.0 Site Preparation	$C_{sp} = C_l + C_{ps} + C_{ar} + C_{su} + C_{cg} + C_{du} + C_{gr} + C_{wa} + C_{se} + C_{dr}$
1.1 Land	$C_l = \overline{C}_l A_l$
1.2 Permits/Studies	$C_{ps} = \overline{C}_{ps} A_l$
1.3 Access Roads	$C_{ar} = \overline{C}_{ar} L_r$
1.4 Surveying	$C_{su} = \overline{C}_{su} A_l$
1.5 Clearing & Grubbing	$C_{cg} = \overline{C}_{cg} A_l$
1.6 Dumping	$C_{du} = \overline{C}_{du} A_l$
1.7 Grading	$C_{gr} = \overline{C}_{gr} \overline{V}_{gr} A_l$
1.8 Water	$C_{wa} = \overline{C}_{ws} \overline{V}_w A_c + \overline{C}_{ws} \overline{V}_{wp} P_r$
1.9 Sewer	$C_{se} = \overline{C}_{se} \overline{N}_m P_r$
1.10 Drainage	$C_{dr} = \overline{C}_{sd} L_d$

Table 6. Cost Equations for Balance-of-Plant Items, Construction Costs

Item	Equations to Determine Costs in Dollars
2.0 Construction Costs	$C_c = C_{ae} + C_{cm} + C_{stu} + C_{cy} + C_{tf}$
2.1 A&E Fees and Services	$C_{ae} = F_{ae} (C + C_{sp} + C_{pf} + C_{pe} + C_{cm} + C_{stu} + C_{tf})$
2.2 Construction Management Fee	$C_{cm} = F_{cm} [C_{lm} + (C_{sp} - C_l) + C_{pf} + (C_{pe} - C_{sr})]$
2.3 Start-Up	$C_{stu} = F_{stu} C_{dp}$
2.4 Contingency	$C_{cy} = F_{cy} (C + C_{sp} + C_{pf} + C_{pe} + C_{cm} + C_{stu} + C_{tf} + C_{ae})$
2.5 Temporary Facilities	$C_{tf} = \overline{C}_{tf} P_r T$

Table 7. Cost Equations for Balance-of-Plant Items, Plant Facilities

Item	Equations to Determine Costs in Dollars
3.0 Plant Facilities	$C_{pf} = C_{cb} + C_{mb} + C_{wr} + C_{pl} + C_{ls} + C_{fe} + C_{wl} + C_{bt} + C_{sd} + C_{ct} + C_{gh} + C_{fp}$
3.1 Control Building	$C_{cb} = \bar{C}_{cb} A_{cb}$
3.2 Maintenance Building	$C_{mb} = \bar{C}_{mb} A_{mb}$
3.3 Warehouse	$C_{wr} = \bar{C}_{wr} A_{wr} P_r$
3.4 Parking Lot	$C_{pl} = \bar{C}_{bt} A_{pl} + \bar{C}_c L_c + \bar{C}_{sw} A_{sw}$
3.5 Landscaping	$C_{ls} = \bar{C}_{ls} A_{ls}$
3.6 Fencing	$C_{fe} = \bar{C}_f L_f + \bar{C}_g N_g$
3.7 Walls	$C_{wl} = \bar{C}_{wl} A_{wl}$
3.8 Blacktopping (other than parking lot)	$C_{bt} = \bar{C}_{bt} A_{bt}$
3.9 Spill Ditches	$C_{sd} = \bar{C}_{sd} L_{sd}$
3.10 Concrete Trenches	$C_{ct} = (\bar{C}_{ctl} + \bar{C}_{ctf} + \bar{C}_{ct} \bar{V}_{ct}) L_{ct}$
3.11 Gate House	$C_{gh} = \bar{C}_{gh} A_{gh}$
3.12 Fire Protection	$C_{fp} = \bar{C}_{fp} A_{cb}$

Table 8. Cost Equations for Balance-of-Plant Items, Plant Equipment

Item	Equations to Determine Costs in Dollars
4.0 Plant Equipment	$C_{pe} = C_v + C_{pr} + C_{ss} + C_{cc} + C_{ec} + C_{sr} + C_{ce} + C_{pm} + C_{gg}$
4.1 Vehicle	$C_v = (\overline{C}_{wt}\ \overline{N}_{wt} + \overline{C}_{mt}\ \overline{N}_{mt} + \overline{C}_{st}\ \overline{N}_{st})\ P_r$
4.2 Protection Equipment	$C_{pr} = \overline{C}_{pr}\ P_r$
4.3 Substation	$C_{ss} = \overline{C}_{ss}\ P_r$
4.4 Controls and Cabling	$C_{cc} = (\overline{C}_{fm} + \overline{C}_{io} + \overline{C}_{cc})\ A_c + C_{cp}$
4.5 Electrical Cable	$C_{ec} = \overline{C}_{ec}\ A_c$
4.6 Spares	$C_{sr} = F_{sp}\ C_{dp}$
4.7 Communication Equipment	$C_{ce} = C_{bs} + \overline{C}_{mu}\ (\overline{N}_{mt} + \overline{N}_{st} + \overline{N}_{wt})\ P_r$
4.8 Demineralizer	$C_{pm} = \overline{C}_{pm}\ \dfrac{\overline{V}_w\ A_c}{T_f}$
4.9 Grounding Grid	$C_{gg} = \overline{C}_{gg}\ A_c$

SECTION IV

NORMALIZED COST FACTORS

Referring to Tables 5 through 8, it is clear that the cost equations are generally a function of a basic plant characteristic such as the land area and a normalized cost factor. For example, the cost of land is simply the cost of land per unit area times the land area. The normalized or unit cost factors clearly depend on site-specific conditions and the characteristics of the different solar technologies.

A. SPECIFIC PLANT SITES

When assessing a plant that is to be constructed at a specified location, site-specific factors can be determined and reflected in the normalized cost factors. For example, the unit cost of grading, $\overline{C}_{gr}$, depends on the type of soil while the length of access roads depends on the proximity of the plant to existing roads. The cost estimating handbook (Ref. 2) provides a basis for determining costs as a function of different site-specific factors.

B. BASELINE VALUES

When performing comparative assessments involving different technologies, it is useful to select baseline values that either correspond to a nominal set of selected site-specific conditions or represent a value determined for a particular technology that can provide insight into determining a comparable value for other technologies. Such a set of baseline values is presented in Tables 9 through 12 where the assumptions employed in determining the values are given.

For baseline comparative analysis purposes, the data in Tables 9 through 12 are considered to be applicable to solar plant sizes over a wide range from small plants of about 1 MWe to large plants on the order of 100 MWe. A few small items are determined from available data on specific systems. If a different system is being considered, these items should, of course, be checked. Some items such as the substation and computer are the subject of development activities. Their unit costs will undoubtedly vary with plant size, but the estimated costs for these items contain uncertainties that are probably greater than the scale effects.

C. SAMPLE USAGE

The balance-of-plant costs for a 5-MWe parabolic dish power plant are used to demonstrate the application of the cost equations and normalized cost factors. This plant is assumed to have no storage and is composed of 294 dish modules, 11 meters in diameter, whose combined output is 5 MWe at a direct insolation level of 1 kW/m^2. In addition to describing the plant's electrical output, it is necessary to specify seven factors that are also dependent on the type of plant. These factors are (1) the land area,

A_1, required for the entire plant, (2) the cost, C, of installed solar collection, power conversion, and storage subsystems, (3) the cost, C_{dp}, of uninstalled equipment in the direct plant category, (4) the cost of labor and materials for field erection work, C_{lm}, that is associated with the installation of the solar collection, power conversion, and storage subsystems, (5) the length, L_d, of brow trenches installed for field drainage (estimated here to be the same length as the perimeter of the plant), (6) the length of fencing around the plant perimeter, L_f, and (7) the construction time, T. For this particular example, the following values are used:

$$A_1 = 22 \text{ acres}$$

$$C = \$5,558,000$$

$$C_{dp} = \$6,329,000$$

$$C_{lm} = \$1,112,000$$

$$L_d = 3600 \text{ ft}$$

$$L_f = 3600 \text{ ft}$$

$$T = 2 \text{ years}$$

The above values, together with the baseline values of Tables 9 through 12, permit the equations of Tables 5 through 8 to be evaluated. For example, given the land area of A_1 = 22 acres and the baseline value of $\overline{C}_1$ = \$8500/acre from Table 9, the equation for the cost of land as given Table 5, Item 1.1, can be evaluated, i.e.,

$$C_1 = \overline{C}_1 A_1 = 22 \text{ acres x } \$8500/\text{acre} = \$187,000.$$

The values for BOP items obtained in this manner are summarized in Table 13. When the total cost of \$5.72 x 10^6 for nondevelopmental BOP items is normalized to the plant rating of 5 MWe, the cost is \$1144/kWe. If this cost is prorated to the 294 dish modules, a cost of \$19,456 per module results. It should be noted that BOP costs as defined in this effort include indirect costs for the entire power plant as reflected in the construction cost category.

The construction cost category contains three items that are often referred to as "indirect costs." These items are the A&E fees and services, construction management fee, and contingency. From Table 13, the combined cost of these three items is \$2.17 x 10^6. If BOP costs are broken down to reflect direct and indirect costs, it is found that

Direct BOP costs	:	\$3.55 x 10^6	\$ 710/kWe	\$12,075/module
Indirect costs	:	\$2.17 x 10^6	\$ 434/kWe	\$ 7,381/module
Total BOP costs	:	\$5.72 x 10^6	\$1,144/kWe	\$19,456/module

Since direct BOP costs are sometimes used, the significance of the above breakdown is stressed. The indirect costs constitute approximately 38% of the total BOP costs for the sample case.

The total cost of the plant is found by adding the installed cost of the solar collection, power conversion, and storage subsystems to the total BOP cost, i.e., the total installed cost is $C + C_{sp} + C_c + C_{pf} + C_{pe}$ = $11.28 x 10^6 for the sample case. Total plant costs for this 5-MWe, 294-module plant can be expressed in normalized form as $2256/kWe or $38,367/module. The following breakdown shows the influence of indirect costs on the cost of the total plant:

Item	$10^6$$	$/kWe	$/Module
Subsystems (Solar collection, power conversion, and storage)	5.56	1112	18,911
BOP			
Direct	3.55	710	12,075
(Subtotal)	(9.11)	(1822)	(30,988)
Indirect	2.17	434	7,381
Total	11.28	2256	38,367

For the sample case, indirect costs constitute approximately 19% of the total cost. In some cost estimates, total costs are determined as a product of a factor and total direct costs. For the sample case, this factor is approximately 1.24, i.e., direct costs are increased by 24% to account for indirect costs.

Table 9. Baseline Values for Normalized Cost Factors, Site Preparation

Normalized Cost Factors			Comments
Symbol	Value	Units	
$\overline{C}_1$	8500	\$/acre	Unit cost of land per References 3 and 4. This site-specific cost can range from \$1000/acre to \$20,000/acre. The value selected corresponds to a relatively undeveloped area near a utility grid and within 30 miles of an adequate labor pool.
$\overline{C}_{ps}$	425	\$/acre	Unit cost of permits and studies taken to be 5% of the land cost pending detailed analysis of data from DOE's 10-MWe Solar One facility.
$\overline{C}_{ar}$	23.36	\$/ft	Unit cost of a private asphalt road 20 feet wide on native soil per Reference 2, account 2-43, page 11.
$\overline{C}_{su}$	7450	\$/acre	Unit cost of surveying to layout property lines and to determine where solar collectors are to be located. Surveying cost to draw property lines for a parcel of land (\$850/acre per Ref. 2, account 1-0, p. 24). Also the amount of surveying for locating the solar collectors is estimated to be double the work needed to subdivide a 1-acre parcel of land into 50 lots (3300 \$/acre x 2 per Ref. 2, account 1-0, p. 24).
$\overline{C}_{cg}$	571	\$/acre	Unit cost of clearing and grubbing based on Reference 2, account 2-1, page 3, assuming the approximate density of shrubs is 20 feet center-to-center, which results in a work rate of 10,417 ft^2/h.
$\overline{C}_{du}$	1523	\$/acre	Unit cost of hauling and dumping refuse from the job site. See Appendix C.
$\overline{C}_{gr}$	6.69	$\$/yd^3$	Unit grading cost assuming a class 2 (sandy topsoil) site material and a 200-foot one-way length of haul per Reference 2, account 2-4, page 3.
$\overline{V}_{gr}$	2963	$yd^3/acre$	Volume of material per unit area to be moved during grading is based on a 2-foot cut or fill per Reference 2, account 2-3, page 1.
$\overline{C}_{ws}$	0.43	\$/gal	Unit water storage tank cost based on the storage tank at the DOE's 10-MWe Solar One facility.
$\overline{V}_w$	0.32	gal/m^2	Volume of water stored per unit area of collector field based on the DOE's 10-MWe Solar One facility, which employs a 28,600-gallon water tank to service a 89,000-m^2 collector field (1818 heliostats).
$\overline{V}_{wp}$	11,440	gal/MWe	Volume of water stored per unit plant rating based on the requirements for the 10-MWe steam Rankine-cycle system at DOE's Solar One facility.
$\overline{C}_{se}$	272	$\frac{\$}{person}$	Unit cost of washroom facilities based on using pre-plumbed units. For up to 15 people, the cost of a portable pre-plumbed washroom per McMaster Carr Catalog 85, page 775, Model 1 is \$8640. For 55 to 150 people, a larger unit (Model 3) is required at a cost of \$16,875. In addition, costs include a portable storage tank and a holding tank per McMaster Carr Catalog 85, page 917 (2.62 \$/gal each, for a total of 5.24 \$/gal for both tanks). Assuming 22 gallons/week per full-time person and 1 week of storage capacity, it follows that 5.24 \$/gal x 22 gal/person = 115.28 \$/person.
$\overline{N}_m$	1	$\frac{people}{MWe}$	Average number of equivalent full-time people at the plant per unit plant rating based on estimate of 5 people for a 5-MWe parabolic dish plant. This number includes operations and maintenance personnel. For systems employing central steam power generating equipment, additional persons may be needed.
$\overline{C}_{sd}$	7.92	\$/ft	Unit cost of spill ditches based on air-blown mortar "brow" ditches per Reference 2, account 2-24, page 2 (7 \$/ft) with associated trenching costs per Reference 2, account 2-22, page 2 (15.88 $\$/yd^3$ or 0.92 \$/ft).

Table 10. Baseline Values for Normalized Cost Factors, Construction Costs

Normalized Cost Factors			Comments
Symbol	Value	Units	
F_{ae}	0.10		Factor for A&E or prime contractor fees and services per Reference 2, account 1-0, page 11. The range can vary between 0.06 to 0.15, depending on market conditions.
F_{cm}	0.10		Factor for construction management fees and services to cover the prime contractor's cost for administration per Reference 2, account 1-0, page 5. The factor for the central receiver Solar One plant is 9.5%.
F_{stu}	0.01		Factor for start-up costs based on those of a mature Solar One type of plant as estimated by General Electric for Sandia Laboratories (Ref. 6, account 4850).
F_{cy}	0.08		Factor for contingency costs based on estimates for a mature Solar One type of plant as estimated by General Electric for Sandia Laboratories (Ref. 6, account 4850).
$\overline{C}_{tf}$	24,000	\$/MWe/yr	Unit cost of temporary facilities based on costs estimated for such facilities during construction of the solar total energy plant in Shenandoah, Georgia.

Table 11. Baseline Values for Normalized Cost Factors, Plant Facilities

Normalized Cost Factors			Comments
Symbol	Value	Units	
$\overline{C}_{cb}$	44	$/ft^2	Unit cost of constructing an office building per Reference 2, account 1-0, page 29.
A_{cb}	400	ft^2	Area of control room floor based on the assumption that a room 20 ft by 20 ft is adequate to house a computer and its peripheral equipment.
$\overline{C}_{mb}$	32.50	$/ft^2	Unit cost of constructing an industrial type of building per Reference 2, account 1-0, page 29.
A_{mb}	400	ft^2	Area of maintenance shop floor based on the assumption that a room 20 ft by 20 ft is adequate to house maintenance equipment.
$\overline{C}_{wr}$	22	$/ft	Unit cost of constructing a warehouse per Reference 2, account 1-0, page 30.
A_{wr}	160	ft^2/MWe	Area of warehouse floor based on the assumption that an inside storage area of 20 ft by 40 ft is adequate to store equipment such as solar collector drive motors, electrical cables, and valves for a 5-MWe plant. The cost is then prorated over the plant rating to reflect increased area required by larger plants.
$\overline{C}_{bt}$	1.00	$/ft^2	Unit cost of blacktopping per Reference 2, account 2-43, page 2.
A_{pl}	5000	ft^2	Area of the blacktopped parking lot.
$\overline{C}_{c}$	7.38	$/ft	Unit cost of standard curbing to be installed per Reference 2, account 2-45, page 3.
L_{c}	300	ft	Length of curbing associated with a 5000 ft^2 parking lot.
$\overline{C}_{sw}$	1.89	$/ft^2	Unit cost of 5-ft-wide sidewalks to be installed per Reference 2, account 2-46, page 3.
A_{sw}	1000	ft^2	Area of sidewalk based on an estimate of 200 ft of 5-ft-wide sidewalks for a solar plant.
$\overline{C}_{ls}$	1.50	$/ft^2	Unit cost associated with landscaping an area with medium visual density per Reference 2, account 2-48, page 1.
A_{ls}	5000	ft^2	Area to be landscaped based on the assumption that landscaping would be required for a 10-ft-wide by 250-ft-long strip of land on each side of the main plant entrance.
$\overline{C}_{f}$	11.30	$/ft	Unit cost of fencing assuming 8-ft-high No. 11 wire with #2 mesh at 8.80 $/ft plus top rail at 1.25 $/ft and 3-strand barbed wire at 1.25 $/ft per Reference 2, account 2-47, page 1.
$\overline{C}_{g}$	605	$/gate	Unit cost of an 8-ft-high by 20-ft-wide gate that is constructed from No. 11 wire.
N_{g}	2	gates	Number of gates that should be required for a solar plant.
$\overline{C}_{wl}$	2.28	$/ft^2	Unit cost for a block wall per Reference 2, account 4-1, page 1, assuming that the wall is constructed from standard blocks 8 in. by 8 in. by 16 in.
A_{wl}	800	ft^2	Area of wall based on the assumption that an 8-ft-high wall would be required for a length of 50 ft on each side of the main plant entrance.
$\overline{C}_{sd}$	7.92	$/ft	Unit cost for field drainage ditches (see Table 5).
L_{sd}	0	ft	Length of brow ditches needed to contain oil or chemical spills for a solar plant is assumed to be zero for the baseline, which is based on the Solar One central receiver plant. However, systems such as the parabolic trough will require spill ditches when using chemical heat transfer fluids.

Table 11. Baseline Values for Normalized Cost Factors, Plant Facilities (Cont'd)

Normalized Cost Factors			Comments
Symbol	Value	Units	
$\overline{C}_{ctl}$	3.97	\$/ft	Unit labor cost for concrete trenches includes fabrication of forms at a rate of 100 ft in 20 hours and a cost of 16.15 \$/workhour (per Ref. 2, account 3-5, pp. 4, 20) plus concrete work at 29.92 \$/yd^3, assuming 0.02469 yd^3/ft (trench 12 in. by 24 in. by 4 in.).
$\overline{C}_{ctf}$	0.96	\$/ft	Unit cost of materials used in making forms for concrete trenches (per Ref. 2, account 3-5, pp. 4, 20) is 0.48 \$/ft for each 2-ft-high trench wall, where two walls are required for the trench.
$\overline{V}_{ct}$	0.02469	yd^3/ft	Unit volume of concrete trench having the following cross-sectional dimensions: 12 in. wide by 24 in. deep by 4 in. thick.
$\overline{C}_{tm}$	48.58	\$/yd^3	Unit cost of concrete material per Reference 2, account 3-5, pages 4 and 20.
$\overline{C}_{gh}$	85	\$/ft^2	Unit cost of a prefabricated guard house per McMaster Carr Catalog 85, page 623.
A_{gh}	25	ft^2	Area of a gate house floor that is estimated to be adequate for a plant.
$\overline{C}_{fp}$	17.81	\$/ft^2	Unit cost of fire protection system per unit control building floor area (see Appendix D). Fire protection system uses a model KPH-25-25 Halon fire protection system for the control building (\$2200 per Ref. 2, account 15-105), a sprinkler system for the area surrounding the building (\$1473 per Ref. 2, account 2-48), and a fire hydrant with 200 ft of 6-in. supply line and valves (\$3281 per Ref. 2, accounts 2-39 & 2-40).

Table 12. Baseline Values for Normalized Cost Factors, Plant Equipment

Normalized Cost Factors			Comments
Symbol	Value	Units	
$\overline{C}_{wt}$	54,000	\$/vehicle	Unit cost of a 4000-gallon water tank truck with forward and rear spray nozzles, a 50-psi, 700-gal/min pump, and cab controls.
$\overline{N}_{wt}$ [(a)]	0.133	vehicle/MWe	Number of wash trucks per unit plant rating, assuming that each truck can service a 95-m^2 concentrator in 4 minutes and that all concentrators are to be cleaned at least every 5 working days. This results in the cleaning of 165 concentrators or 15,600 m^2 per truck.
$\overline{C}_{mt}$	28,000	\$/vehicle	Unit cost of maintenance trucks needed to service dish modules are estimated by assuming that these trucks would be similar to telephone wire maintenance trucks with integrated cherry pickers. The baseline cost is based on a manufacturer's quote.
$\overline{N}_{mt}$ [(a)]	0.8	vehicle/MWe	Number of maintenance trucks per unit plant rating is based on a preliminary analysis for a particular parabolic dish plant design (Ref. 4) wherein it was estimated that 1 failure, requiring 2.96 hours to repair, would occur every 222 hours. Based on a 23,000-m^2 plant (242 dishes) operating for 9 hours/day, approximately 10 failures/day would occur. These failures would require 29.6 hours of repair time and require 4 trucks, assuming that each truck is used for 8 hours each day.
$\overline{C}_{st}$	8,000	\$/vehicle	Unit cost of supply truck, assuming pickup trucks are used for maintenance of grounds and miscellaneous duties.
$\overline{N}_{st}$ [(a)]	0.4	vehicle/MWe	Number of supply trucks per unit plant rating, assuming that one pickup truck is required for every two maintenance vehicles.
$\overline{C}_{pr}$	1.29	\$/kWe	Unit cost of protection system based upon a study conducted for DOE by General Electric (GE) (Ref. 6). The study was conducted for a mature central receiver plant. The protection equipment (account 4330) covers ground registers, fire alarm system, and building lightning protection.
$\overline{C}_{ss}$	44	\$/kWe	Unit cost of a plant substation based on References 4 and 5. The previously mentioned report conducted by GE for DOE (Ref. 6) determined that the cost of the substation (account 431) and station service equipment (account 4320) would be 31.23 \$/kWe (1978\$) for a 100-MWe plant. Cost estimates conducted for the photovoltaic program in Reference 5 yielded costs of 30 to 50 \$/kWe (1978\$) for smaller plants. The above costs do not include the cost of a dc-to-ac inverter. Reference 5 indicates that future costs of inverters could be as low as 15 \$/kWe; however, current costs range from 400 to 1000 \$/kWe in the 10- to 100-kWe range and can be as low as 100 to 150 \$/kWe in the 5-MWe and greater range. For plants requiring inverters, the appropriate cost should be added.
$\overline{C}_{fm}$	5.89	\$/m^2	Unit cost of a field microprocessor based on use of a Texas Instruments Model 510 micro-programmable controller per each 95 m^2 of dish area. The list price of \$560 for this unit is used in the baseline estimate. For quantity buys, price reductions are available. It is assumed that one-axis tracking systems such as parabolic troughs could use a time-slicing technique to allow control of four troughs (each 2 m by 61 m) by one controller. This would reduce the prorated cost to 1.14 \$/m^2. Also, it is assmued that such a controller could control 4 heliostats of 50 m^2 each at a cost of 2.8 \$/m^2 (two-axis tracking but no engine or thermal transport valve controls).

[(a)] Round number of vehicles calculated in this manner to an integer.

Table 12. Baseline Values for Normalized Cost Factors, Plant Equipment (Cont'd)

Normalized Cost Factors			Comments
Symbol	Value	Units	
$\overline{C}_{io}$	1.35 to 8.84	$\$/m^2$	Unit cost of input/output modules is based on estimates of signal conditioning requirements. Using equipment from Texas Instruments that is compatible with their Model 510 controller, it is guesstimated that a dish system with engines mounted at the focal point of the concentrator will require an expander board at \$400 and eight special input/output modules for signal conditioning, at \$55 each or \$440 per dish. This results in a prorated cost of \$400 plus \$440 divided by 95 m^2, which equals 8.84 $\$/m^2$. It is assumed that a single heliostat would not require the expander board and would require only three special input/output modules at a cost of \$55 each, which is equal to $\$3.30/m^2$. Although tracking requirements are reduced for the one-axis tracking parabolic trough system, it is estimated that 3 input/output modules at \$55 each, or $\$1.35/m^2$, would still be required due to the additional requirement for thermal transport valving.
C_{cp}	3000	\$	Installed cost for a central processor system is based on the use of parabolic dish systems that employ autonomous modules and require only a simple data logger to record plant status. Such a unit might consist of an Apple II computer, two disk drives, phone modem, and printer at a cost of about \$3000. Should a plant utilize a central Rankine engine, a larger and more powerful computer system may be required.
$\overline{C}_{cc}$	0.16 to 1.98	$\$/m^2$	Unit cost of control cabling is based on employing a 24-conductor, #14-size wire cable at 1.96 \$/ft from the ground-mounted microprocessor to the various drives, receiver, and engine. It is estimated that an 11-meter-diameter dish would require approximately 54 ft of cabling whereas a single microprocessor controlling 4 heliostats would require about 37 ft per heliostat. Parabolic troughs would require only about 10 ft per trough. It was also assumed that the shielded control cabling, running from the field microprocessor to the various heliostats, would be laid in the same trench with the electrical lines and be separated by 1 ft of dirt. In addition to its primary function, the electrical power line would serve as the communication link between the central processor unit and the field microprocessor units. Based on this data, the cost of control cabling per square meter of collector area is 1.11 $\$/m^2$ for dishes, 1.48 $\$/m^2$ for heliostats, and 0.16 $\$/m^2$ for troughs.
$\overline{C}_{ec}$	6 to 13.22	$\$/m^2$	Unit cost of electrical cabling subsystem is based on the single line diagram and costing as shown in Appendix E. The cost for a two-axis dish-mounted engine system is estimated to be 13.22 $\$/m^2$ of collector area. The cost for heliostats or troughs is roughly estimated to be about 6 $\$/m^2$ due to the fewer electrical components required.
F_{sp}	0.05		Spare parts factor is based on estimates of equipment procurement to cover items normally requiring long lead times to replace or items subject to damage and wear.
C_{bs}	403	\$	Cost of a communications base station is based on a 4-watt unit (\$200) plus a steel tower antenna (\$223) located at the plant for use by maintenance personnel.
$\overline{C}_{mu}$	50	\$/vehicle	Unit cost of mobile units for communication is based on use of a 2-watt, 3-channel receiver/transmitter where one unit is installed in each vehicle.
$\overline{C}_{dm}$	6.15	\$/gal/day	Unit cost of a demineralizer used for steam Rankine systems is based on telephone quotes for a 6500-gallon/day skid-mounted system that would produce feedwater-quality water, having on the order of 400 parts per million of dissolved solids. The cost of the unit can vary depending upon the quality of the inlet water and complexity of the system.
T_f	7	days	Time required to fill demineralizer tanks for one field washing was assumed to be 7 days even though the period between washings is normally much greater. This provides a margin of safety for events such as dust storms.
$\overline{C}_{gg}$	6.32	$\$/m^2$	Unit cost of the grounding grid is based on data and guidelines from Reference 2, account 16-75. The sample grounding grid that was analyzed for cost estimating purposes is presented in Appendix F.

Table 13. Sample Usage of Baseline Values for a 5-MWe Parabolic Dish Plant

Item	$\$ \times 10^3$	$\$ \times 10^6$
1.0 Site Preparation		0.929
1.1 Land	187.0	
1.2 Permits/Studies	9.4	
1.3 Access Roads	45.6	
1.4 Surveying	163.9	
1.5 Clearing and Grubbing	12.6	
1.6 Dumping	33.5	
1.7 Grading	436.1	
1.8 Water	3.8	
1.9 Sewer	6.8	
1.10 Drainage	30.9	
2.0 Construction Costs		2.475
2.1 A&E Fees and Services	950.0	
2.2 Construction Management Fee	386.0	
2.3 Start-Up	63.0	
2.4 Contingency	836.0	
2.5 Temporary Facilities	240.0	
3.0 Plant Facilities		0.121
3.1 Control Building	17.6	
3.2 Maintenance Building	13.0	
3.3 Warehouse	17.6	
3.4 Parking Lot	9.1	

Table 13. Sample Usage of Baseline Values for a 5-MWe Parabolic Dish Plant (Cont'd)

Item	$ x 10^3	$ x 10^6
3.0 Plant Facilities (Cont'd)		
3.5 Landscaping	7.5	
3.6 Fencing	45.3	
3.7 Walls	1.8	
3.8 Blacktopping	0	
3.9 Spill Ditches	0	
3.10 Concrete Trenches	0	
3.11 Gate House	2.1	
3.12 Fire Protection	7.15	
4.0 Plant Equipment		2.198
4.1 Vehicles	163.9	
4.2 Protection Equipment	6.5	
4.3 Substation	720.0	
4.4 Controls and Cabling	445.4	
4.5 Electrical Cables	369.2	
4.6 Spares	316.4	
4.7 Communication Equipment	0.8	
4.8 Demineralizer	0	
4.9 Grounding Grid	176.5	
Total		5.723

SECTION V

RECOMMENDATIONS

It is recommended that

(1) The standardized plant descriptions and costing methodology developed in this report be implemented in U.S. Department of Energy program planning activities and in studies that compare the characteristics of different solar thermal power plants.

(2) Evolutionary development of the methodology be undertaken to (1) derive easier ways of using the costing relations for balance-of-plant items that include scaling relations to accommodate a wide range of plant sizes, (2) establish the effect of different types of solar thermal electric power plants on BOP costs, and (3) implement probabilistic methods for determining total plant costs as the basis for assessing technology options associated with developmental solar power systems.

SECTION VI

REFERENCES

1. "Technical Assessment Guide," Special Report P-2410SR, Electric Power Research Institute, Palo Alto, California, May 1982.

2. General Construction Estimating Standards, Richardson Engineering Services, Inc., San Marcos, California, 1982.

3. Kiceniuk, T., Costs and Considerations in Site Preparation for Solar Thermal Power Plants: A Preliminary Study, JPL Internal Report No. 5103-59, Jet Propulsion Laboratory, Pasadena, California, April 1979.

4. Phase 1 of the First (Solar) Small Power System Experiment Final Report, Report No. U-6529, Appendix I-4, Ford Aerospace and Communications Corp., Newport Beach, California, May 1979.

5. Lifetime Cost and Performance Model Support Study, Report No. FR955161-78, Theodore Barry and Associates, Los Angeles, California, September 1978.

6. Conceptual Design of an Advanced Central Receiver Power System, SAN-20500-1, Volumes 1-5, Contract No. EM-78-C-1725, General Electric Co., Schenectady, New York, June 29, 1979.

APPENDIX A

CONVERSION FACTORS

To convert from British units to the international system of units, the following factors are to be used:

To Convert from	To	Multiply by
	Length	
foot	meter	0.3048
inch	meter	0.0254
mile	meter	1609
yard	meter	0.9144
	Area	
acre	$meter^2$	4047
$foot^2$	$meter^2$	0.0929
$inch^2$	$meter^2$	6.45×10^{-4}
$mile^2$	$meter^2$	2.54×10^{6}
$yard^2$	$meter^2$	0.8361
	Volume	
$foot^3$	$meter^3$	0.02831
gallon	$meter^3$	3.785×10^{-3}
$inch^3$	$meter^3$	1.639×10^{-5}
$yard^3$	$meter^3$	0.7645
	Mass	
pound	kilogram	0.4536
ton (short)	kilogram	907.2

APPENDIX B

METHODS FOR DETERMINING PROBABILISTIC COSTS

This appendix refers to the methods that have been developed to treat probabilistic costs (Refs. B-1 through B-5) and shows that such probabilistic analyses do ensure the valid comparison of alternatives when uncertainties in cost are capable of being expressed in terms of probabilities.

In general, the nondevelopmental balance-of-plant items in a solar power plant can be estimated with a much higher degree of certainty than developmental items such as solar collectors. For each BOP item, it is possible to estimate an uncertainty range and an associated probability distribution function for the corresponding cost of the item.

By assessing the technological status and the type and extent of remaining R&D activities, it is also possible to estimate the probability distribution functions for costs corresponding to the developmental items in a solar power plant. To determine total plant costs, these less certain costs must be combined with the more certain BOP costs. Generally, total plant costs for a particular technology are compared to the costs for other technologies or options as a basis for planning and decision-making. It may also be desirable to compare particular groups of cost items which could include both developmental and nondevelopmental items.

The probabilistic methods for combining and analyzing total plant costs and groups of costs have been developed and are available in a computer program.[1] The key questions associated with the use of these methods are

(1) What is the value of more complex probabilistic analyses over simple analyses where "best guesstimates" are treated as deterministic values in making comparisons?

(2) Can comparisons based on the simpler deterministic approach lead to invalid or misleading conclusions?

A clear answer to these questions is found by analyzing simple examples. There are two specific objectives in formulating and analyzing examples. One is to point out the difficulties in interpreting "the total system cost" when it is computed as the mere sum of individual cost components -- an approach commonly taken. (Needless to say, each cost component is mutually exclusive and exhaustive.) The second is to provide a solution that eliminates this difficulty by adding a probabilistic dimension to the "total system cost."

Total system cost is actually an estimate of a random variable. The main difficulties in interpretation arise because this random variable is often treated as deterministic when an attempt is made to compute it. To illustrate, consider the following examples:

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[1]Smith, J. H., "Solar Thermal Probabilistic Costing Simulation -- Phase I: Input Data and Computation Verification," Internal Communication 311.9-227, Jet Propulsion Laboratory, Pasadena, California, July 27, 1981.

A. ADDITION OF THE MOST PROBABLE COSTS

Suppose there is a project, call it A, composed of two subsystems, 1 and 2 (see Table B-1). The most probable cost of subsystem 1 is $5 million and subsystem 2 is $3 million. However, the most probable cost for the total system in project A is not necessarily $8 million. This can be seen from the following example: Suppose subsystem 1 costs either $5 million or $6 million with probabilities of 0.6 and 0.4, respectively, while subsystem 2 costs either $3 million or $4 million with probabilities of 0.6 and 0.4. Clearly, the most probable cost for subsystem 1 is $5 million (0.6 probability) and for subsystem 2 is $3 million (0.6 probability). Yet the most probable cost for the total system in project A is not $8 million (0.36 probability), but $9 million (0.48 probability). Note that the probability of 0.48 for $9 million arises from the sum of two combinations, each having a probability of 0.24 (Table B-1).

Table B-1. Total System Costs and Probabilities for Project A[a]

(Costs in $ x 10^6)

Subsystem 1 Costs and Probabilities / Subsystem 2 Costs and Probabilities	[5] (0.6)	6 (0.4)
[3] (0.6)	8 (0.36)	[9] (0.24)
4 (0.4)	[9] (0.24)	10 (0.16)

(a) Probabilities are shown in parentheses. Subsystem costs denoted by 1 and 2 are assumed to be independent. The enclosing squares identify the most probable cost figures.

B. COST COMPARISONS OF PROJECTS

Suppose there is an additional project, called B. The two projects A and B have the same final output but different cost probabilities. The costs for project A were identified in Table B-1 of the previous example. The cost probabilities for project B are given in Table B-2. Table B-2 shows that the most probable cost for subsystem 1 in project B is $7 million while that for subsystem 2 is $2 million. From Table B-2, $9 million is the most probable total system cost for project B. (Recall this is the same result obtained for project A.)

Table B-2. Total System Costs and Probabilities for Project B

(Costs in $ x 10^6)

Subsystem 1 Costs and Probabilities / Subsystem 2 Costs and Probabilities	6 (0.4)	[7] (0.6)
[2] (0.95)	8 (0.38)	[9] (0.57)
3 (0.05)	[9] (0.02)	10 (0.03)

In comparing the costs of two projects, a common approach is to add the cost of each component as if the costs were deterministic. The resulting totals are compared to determine the preferred project. If the most probable costs are added for 1 and 2 in projects A and B, respectively, costs of $8 million for project A and $9 million for project B are predicted.[2] Project A would be selected over project B. Alternatively, we might compare the most probable total system costs for the two projects. As indicated above, the most probable total system cost is $9 million for both project A and project B. Based on this comparison, we would have no basis for choosing between the two projects.

However, closer inspection clearly indicates that project B is to be preferred to project A. The probability that the total system cost in project B is less than or equal to any given cost always exceeds the probability that project A can meet this system cost total. For example, the probability that system costs in project B will equal $9 million or less is 0.97. For project A the same probability is 0.84. Note that both projects have the same probability, 1.0, of achieving a system cost of $10 million or less. Because project B dominates project A in the sense just described, project B should be selected over project A. This is obscured by the common comparison methodologies outlined above. Only by examining the cumulative probability distributions for the two projects will this dominance become evident. The cumulative probability distributions corresponding to Tables B-1 and B-2 are shown in Figure B-1.

The detailed breakdown and associated costing methodology for BOP items developed in the body of this report are considered to be valuable steps toward generating inputs that are required in conducting probabilistic cost analyses.

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[2] In general, the mode of a distribution will not be preserved under addition while the operation of expectation will be. However, a comparison of projects based upon the expected values alone is also quite meaningless since the utility functions in general are not risk-neutral.

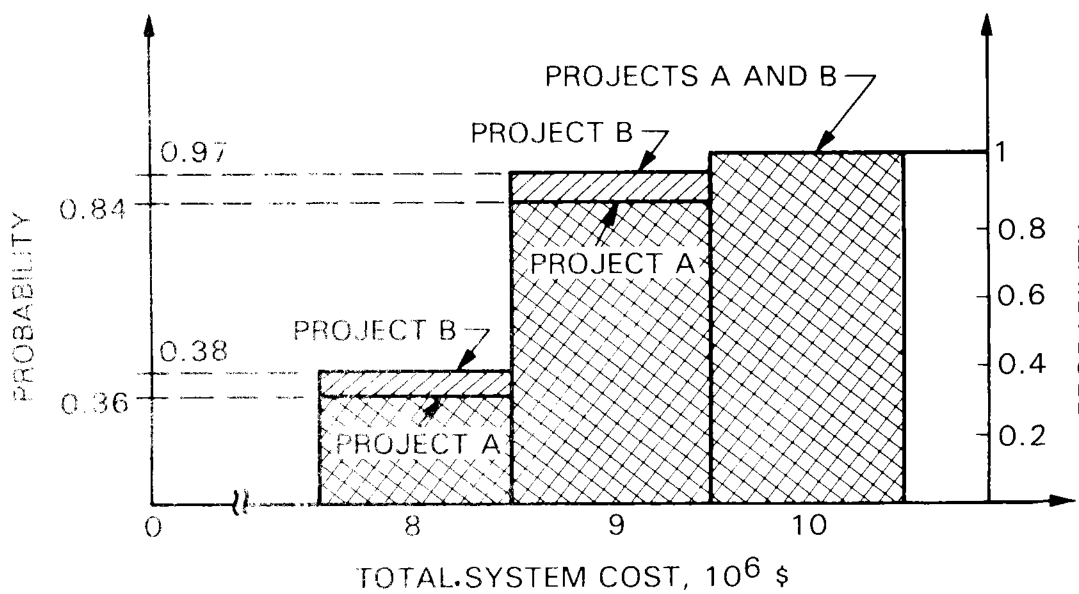

Figure B-1. Cumulative Probability Distribution for Projects A and B

REFERENCES FOR APPENDIX B

B-1. Terasawa, K., O'Toole, R., and Goldsmith, M., Methodology for the Estimation of Cost of Underground Nuclear Power Plants, JPL Internal Report 5030-89, Jet Propulsion Laboratory, Pasadena, California, May 1977.

B-2. Miles, R. F., Jr., Introduction to SIMRAND (Simulation of Research and Development Project), DOE/JPL 1012-68, Jet Propulsion Laboratory, Pasadena, California, March 1982.

B-3. Spetzler, C. S., and Stael Von Holstein, C. S., "Probability Encoding in Decision Analysis," Management Science, 22, No.3, November 1975.

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B-5. Saunder, W. E., "The Validity of Subjective Probability of Success Forecasts by R&D Project Managers," Transactions of Engineering Management, February 1969.

APPENDIX C

ESTIMATE FOR UNIT COST OF DUMPING

A. ASSUMPTIONS

(1) 3-Axle Dump Truck

(2) Class 4 Material (Brush and Shrub)

(3) 5 Miles to Dump Site on Dirt Road

(4) 988-B Loader

(5) Swell Allowance 45% (Ref. 2, account 2-23, p. 1)

B. CALCULATIONS

(1) Time (Ref. 2, account 2-23, p. 1):

(a) Spot Truck, 0.5 min

(b) Travel Time, 31.17 min

(c) Unload Time, 2.00 min

(d) Load Time

- Loader Rate, 4.08 yd^3/min (Ref. 2, account 2-18, p. 3)
- Capacity of Truck, 10 yd^3 (Ref. 2, account 2-23, p. 1)
- Time to Load Truck, 2.45 min

(e) Total Time Per Load, 36.12 min or 3.6 min/yd^3

(2) Cost of Truck is 54.24 \$/h (Ref. 2, account 2-23, p. 2)

(3) Gross Amount of Material to be Dumped = 269 yd^3/acre

(a) Swell Factor, 1.45

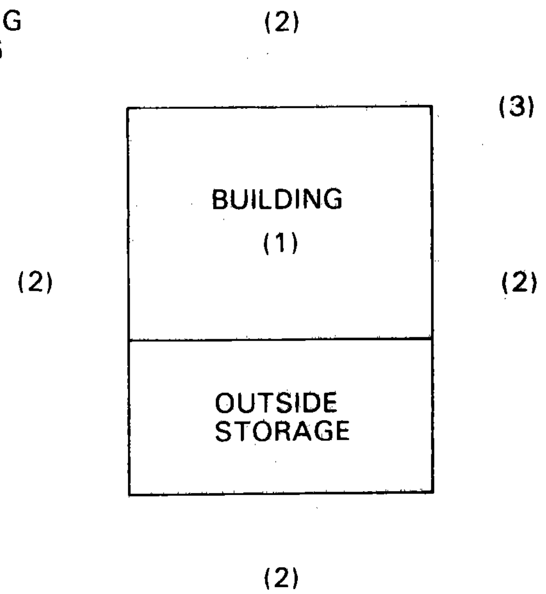
(b) Net Amount to be Dumped, 390 yd^3/acre

(4) Net Cost Per Acre:

$$\frac{390\ yd^3}{acre} \times \frac{3.6\ min}{yd^3} \times \frac{\$54.24}{(60-10^*)min} = 1523\ \$/acre$$

*Dead time of 10 minutes (Ref. 2, account 2-23, p. 2).

AREA SURROUNDING
CONTROL BUILDING
OF SAMPLE PLANT



		UNIT COST, $
(1)	HALON FIRE PROTECTION SYSTEM KPH 25-25, ACCOUNT 15-105[a]	2200
(2)	ROTARY HEAD SPRINKLERS 1 1/4 in., 40-ft RADIUS, QUANTITY 4, ACCOUNT 2-48, P. 5	88
	1-1/4-in. SUPPLY LINES, SCHEDULE 40, 280 ft, ACCOUNT 2-48, P. 4	605
	REMOTE CONTROL VALVES, QUANTITY 4, ACCOUNT 2-48, P. 6	780
(3)	FIRE HYDRANT 6 in., QUANTITY 1, ACCOUNT 2-40, P. 5	934
	ONE 6-in. 90° ELBOW, ACCOUNT 2-39, P. 2	170
	ONE 6-in. SHUTOFF VALVE, ACCOUNT 2-40, P. 1	417
	TOTAL COST	7124 OR 17.81 $/ft^2[b]

[a]COSTS FROM REFERENCE 2.
[b]COST NORMALIZED TO CONTROL BUILDING FLOOR AREA.

Figure D-1. Estimate for Unit Cost of Fire Protection Systems

APPENDIX E

ESTIMATE FOR UNIT COST OF ELECTRICAL CABLING SUBSYSTEM

There are two functions performed by the electrical cabling subsystem of a parabolic dish power plant. The first is to carry the energy produced by a dish module to the substation. The second is to carry power from the substation to the dishes for functions such as start-up, operation of auxiliaries, or for operation of the azimuth and elevation drives in the case of a thermal output plant.

This subsystem comprises the equipment between the field bus bar of the substation up to and including the junction box at the base of the dish. The electrical circuitry located on the concentrator for tracking and/or operation of electrical generation equipment and auxiliaries is specifically excluded from the cabling subsystem. This excluded electrical circuitry is treated as part of the concentrator and engine subsystems.

The installed price of the materials used in the electrical cabling subsystem is shown in Table E-1.

Table E-1. Electrical Cabling Subsystem Costs

Description	Quantity	Total Installed Price, $	Account & Page Nos. (Ref. 2)
Circuit Breaker, 15-60A 3P 480ac	1	143	16-43/3
Circuit Breaker, 125-225A 3P 600ac	1	446	"
Circuit Breaker, 15A 1P 240ac	4	160	"
Trenching for Power Cable, 6 in. x 4 ft	17.75 m	62	2-22/4
Direct Bury, Shielded #4, 3-Conductor Cable	11 m	54	16-20/5
Direct Bury, Shielded #4/0, 3-Conductor Cable	6.75 m	87	16-20/5
Cable Splice, 5000V Shielded #4/0 Cable	1	123	16-20/7
Junction Box, 24 x 24 x 6 in.	1	113	16-33/2
Cable Terminator	1	28	16-20/3
Total Installed Cost Per Dish		1216 or 13.22 $/m^2	

Notes:

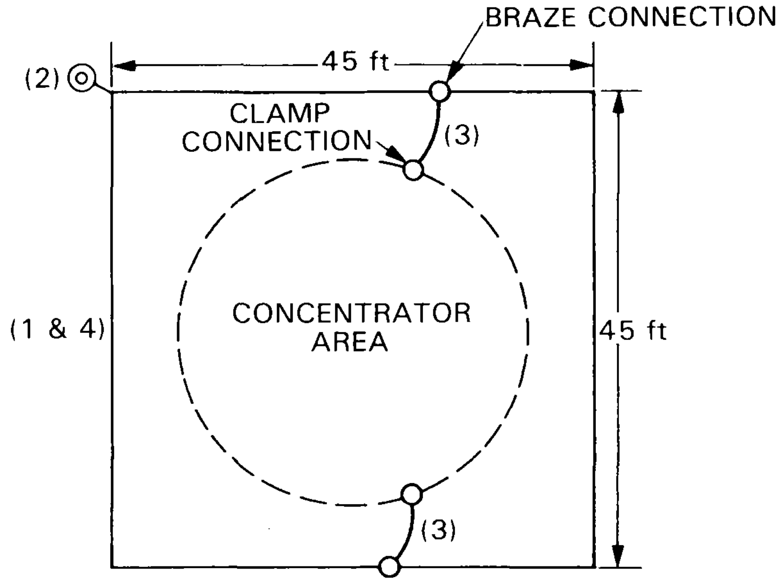
(a) Trenching applies to both the control and power cables.

(b) Service power for maintenance will be supplied by mobile units.

(c) Shielded cabling is required to eliminate radio interference of ac lines on control subsystem.

APPENDIX F

ESTIMATE FOR UNIT COST OF A GROUNDING GRID FOR A SOLAR COLLECTOR



		QUANTITY	UNIT COST, $
(1)	GROUNDING WIRE #2/0 AT 1.90 $/ft	180 ft	342.00
(2)	GROUNDING ROD	1	39.45
	GROUNDING COUPLING	1	10.01
	DRIVE STUDS	1	6.16
(3)	CLAMPS AT $6.96 EACH	2	13.92
	BRAZED CONNECTIONS AT $8.17 EACH	2	16.34
(4)	TRENCHING, 4-in. WIDE, 3-ft DEEP ($0.037\ yd^3/ft$) AT $20.92\ \$/yd^3$	$6.66\ yd^3$	139.32
	BACK FILL OF TRENCH AND COMPACT AT $\$5/yd^3$	$6.66\ yd^3$	33.30
	TOTAL COST		600.50
		OR	$6.32\ \$/m^2$ [a]

[a]NORMALIZED TO 95 m^2 CONCENTRATOR.

Figure F-1. Estimate for Unit Cost of Grounding Grid for a Solar Collector. (Richardson Estimating Guide, Account 16-75)

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