SAND 91-7005

CONCEPTUAL DESIGN OF A PHOTOCATALYTIC WASTEWATER TREATMENT PLANT

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Printed copy: A03
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Photo by Randy Montoya, Sandia National Laboratories.

Cover design by Gene Clardy, Sandia National Laboratories.

Distribution
Category UC-237

SAND91-7005
Unlimited Release
Printed July 1991

CONCEPTUAL DESIGN OF A PHOTOCATALYTIC WASTEWATER TREATMENT PLANT

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Sandia Contract: 66-8697

ABSTRACT

This report describes the conceptual design of a demonstration project in which solar energy is used to detoxify contaminated water. Parabolic trough collectors are used to concentrate direct ultraviolet insolation on a glass receiver tube containing a fixed catalyst. The study assesses the cost and schedule of the demonstration program and includes a plan for obtaining the necessary permits. The results of this study should be useful in determining the economic potential of future commercial facilities treating groundwater to bring it to the standards of drinking water. The site selected for the study is in Colorado where on a clear day at noon, the facility treats groundwater at a flow rate of 0.0063 m^3/sec (100 gpm). A complete design of the facility was developed, including the pre- and post-treatment necessary to maintain the required water chemistry.

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Section 1
EXECUTIVE SUMMARY

The Solar Energy Research Institute (SERI) and Sandia National Laboratories have demonstrated the decomposition of toxic organic compounds in water using sunlight. The contaminated water is mixed with oxygen or hydrogen peroxide, and then combined with a powdered titanium dioxide catalyst to form a slurry. Ultraviolet photons at the catalyst surface create electron-hole pairs. The oxygen or hydrogen peroxide molecules act as receptors for the holes, allowing water to react with the electrons and form hydroxyl radicals. The highly reactive radicals react with the toxic organic compounds, producing a non-toxic mixture of water, carbon dioxide, and dilute hydrochloric acid.

Small scale field tests at SERI and Sandia, using parabolic trough solar collectors, are examining annual system performance. Experimental and field tests are also underway to develop a fixed catalyst support that avoids the complexities of slurry preparation and catalyst retrieval.

Sandia has initiated this study for the conceptual design and permitting plan of a demonstration solar detoxification project. The objectives of the study are to assess the following:

- The cost and schedule of a demonstration program for DOE planning purposes
- The economic potential of future commercial facilities treating groundwater to drinking water standards.

The site selected for the study is the Rocky Flats Plant in Colorado, and parabolic trough collectors are used to concentrate direct ultraviolet insolation on a glass receiver tube with a fixed catalyst. On a clear day at noon, the facility treats a groundwater flow rate of 0.0063 m^3/sec (100 gpm). A simplified flow diagram is shown in Figure 1-1.

A pretreatment system modifies the groundwater chemistry in three areas to ensure complete decomposition of the toxic compounds. The first two requirements, as specified by SERI, include adjustment of the pH to a nominal value of 6 and addition of hydrogen peroxide (H_2O_2) and oxygen (O_2). The third requirement is the partial decomposition of calcium bicarbonate ($Ca(HCO_3)_2$) to prevent scale formation on the catalyst and reduce scavenging of hydroxyl radicals in the receiver.

As defined in the statement of work, 5 x 10^{22} ultraviolet photons per second must be delivered to the outside of the receiver tubes to treat the design flow rate of 0.0063 m^3/sec (100 gpm). This is accomplished with 1,145 m^2 (12,320 ft^2) of parabolic trough solar collectors using an aluminum reflector to provide a high reflectivity in the ultraviolet portion of the spectrum.

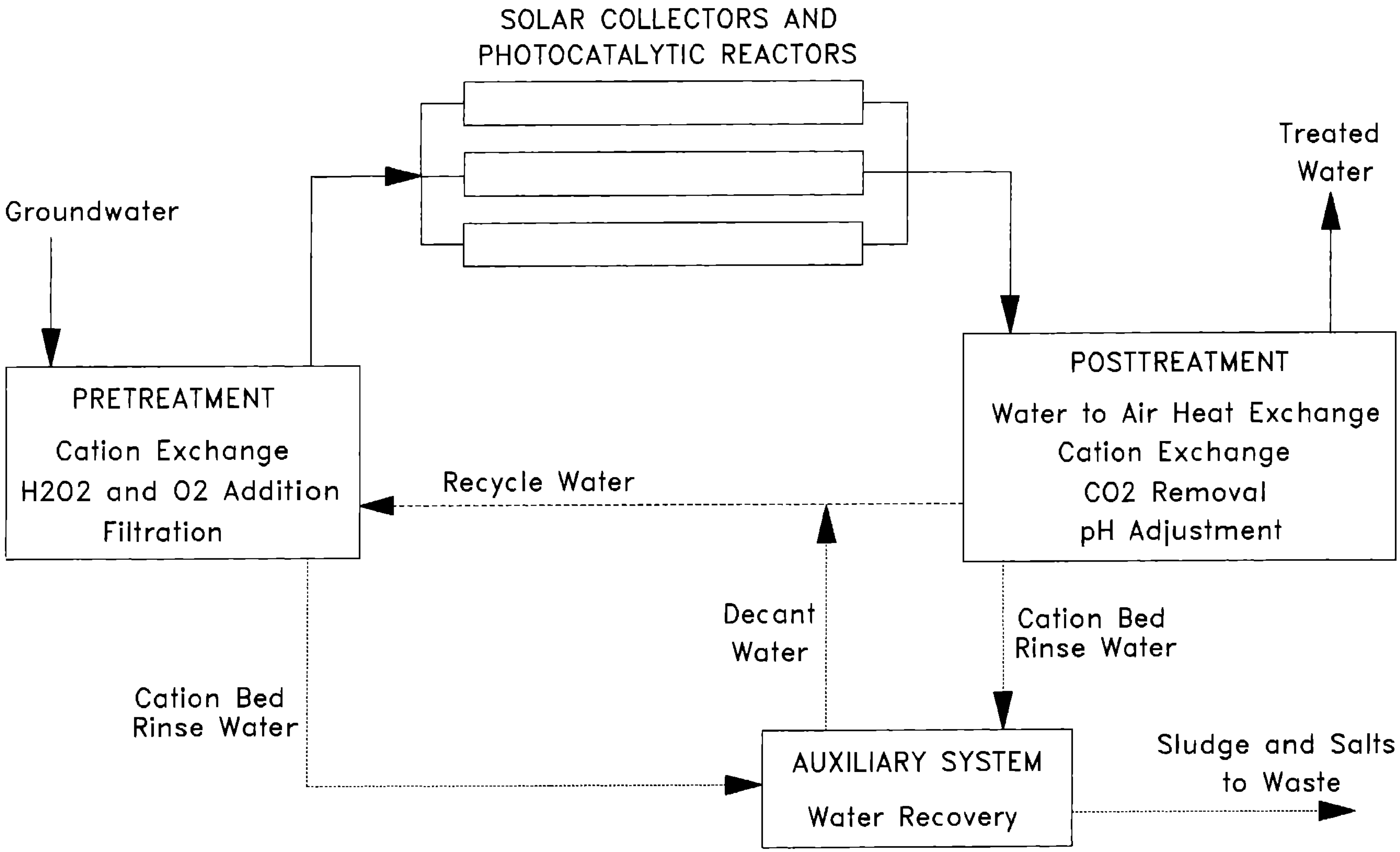

Figure 1–1 Simplified Flow Schematic

A posttreatment system modifies the treated water chemistry to meet Federal and Colorado regulatory requirements for drinking water. The modifications include:

- Reduction in the total dissolved solid concentrations to 400 ppm
- Increase in the pH to a nominal value of 6 to 9.

Assuming the facility operates for 7 days per week and 52 weeks per year, the annual volume of water treated by the facility is estimated to be 8,500,000 gallons.

To construct the facility, the following principal permits must be obtained:

- National Pollutant Discharge Elimination System (NPDES) (Federal)
- Resource Conservation and Recovery Act/Land Ban (RCRA) (Colorado)
- Hazardous Waste Transportation, Storage, and Disposal Site and Facility (TSD) (Colorado)
- Well Drilling and Building Permits (Colorado).

The permit requiring the most effort will likely be the NPDES permit for discharge of treated water into "a water of the state". A typical schedule for obtaining the necessary permits is approximately 9 months.

An economic summary of the facility is presented in Table 1-1. The basis for the estimates includes:

- Constant year (first quarter 1991) dollar analysis; escalation to future years is excluded
- Installed collector and receiver tube-with-catalyst costs of $215/m^2$ and $8.15/m ($20/ft^2$ and $26.70/ft), respectively
- An operator is at the facility each morning to monitor the startup of the mechanical equipment. Once startup is complete and the facility is operating normally, the operator leaves and the facility operates for the balance of the day unattended
- Private facility ownership, with a plant life of 20 years. 25 percent of the project is financed by equity, with a (real) return of 15.0 percent, and 75 percent is financed by debt, with a (real) interest rate of 4.6 percent. No Federal or state investment tax credit is assumed to be available.

The levelized cost of treated water is approximately $40 per 1000 gallons. Of this total, $25 is for capital recovery and $15 is for annual operating expenses. This cost is several times that from present water treatment facilities using air stripping or ultraviolet lamps, and is projected to be considerably more expensive than future ultraviolet lamp facilities that may require new posttreatment systems.

Table 1-1
SOLAR DETOXIFICATION FACILITY ECONOMIC SUMMARY

INSTALLED COST SUMMARY

	System Cost	Project Contingency	Total
0.0 LAND	$0	0%	$0
1.0 BUILDINGS AND SITE IMPROVEMENTS	$129,000	25%	$161,000
2.0 PRETREATMENT SYSTEM	$124,000	25%	$155,000
3.0 COLLECTOR SYSTEM	$291,000	15%	$335,000
4.0 RECEIVER TUBES AND CATALYST	$58,000	15%	$67,000
5.0 POSTTREATMENT SYSTEM	$263,000	25%	$329,000
6.0 AUXILIARY SYSTEMS	$84,000	25%	$105,000
7.0 CONTROL SYSTEM	$59,000	25%	$74,000
8.0 TOTAL FIELD COST			$1,226,000
9.0 CONSTRUCTION MANAGEMENT (5%)			$61,000
Subtotal			$1,287,000
10.0 ENGINEERING AND PROJECT MANAGEMENT (15%)			$193,000
Subtotal			$1,480,000
11.0 OWNER'S ENGINEERING AND PERMITS			$169,000
12.0 TOTAL FACILITY COST (First Quarter 1991 Dollars)			$1,649,000

ESCALATION AND ALLOWANCE FOR FUNDS DURING CONSTRUCTION

	Annual Distribution of Expenditures First Year (20%)	Second Year (80%)
TOTAL FACILITY COST (First Quarter 1991 Dollars)	$330,000	$1,319,000
ESCALATION (0%; First Quarter 1991 Dollars)	$0	$0
ALLOWANCE FOR FUNDS DURING CONSTRUCTION (7.2% Discount Rate; First Quarter 1991 Dollars)	$24,000	$0
	$354,000	$1,319,000

12.0 TOTAL FACILITY COST (First Quarter 1991 Dollars)	$1,649,000
13.0 ESCALATION (First Quarter 1991 Dollars)	$0
14.0 ALLOWANCE FOR FUNDS DURING CONSTRUCTION (First Quarter 1991 Dollars)	$24,000
15.0 PREPRODUCTION COSTS (2% Total Facility Cost plus 1 month operating cost)	$42,000
16.0 SPARE PARTS (0.5% of Total Facility Cost)	$8,000
17.0 TOTAL INSTALLED COST (First Quarter 1991 Dollars)	$1,723,000

Table 1-1 (Continued)
SOLAR DETOXIFICATION FACILITY ECONOMIC SUMMARY

AVERAGE ANNUAL PERFORMANCE	
OUTPUT, 1000 Gallons	8,500
CAPACITY FACTOR (Note 1)	0.162
LEVELIZED 1991 CONSTANT YEAR DOLLAR TREATED WATER COST	
1) ANNUAL CAPITAL EXPENSE	
LEVELIZED CAPITAL CARRYING CHARGE BASED ON PRIVATE OWNERSHIP, 20 YEAR PLANT LIFE, 15 YEAR DEPRECIATION SCHEDULE, AND 0 PERCENT INVESTMENT TAX CREDIT	0.127
LEVELIZED ANNUAL CAPITAL EXPENSE LEVELIZED CAPITAL CARRYING CHARGE x TOTAL INSTALLED COST	$219,000
2) ANNUAL OPERATING EXPENSE	
LEVELIZING FACTOR BASED ON CONSTANT DOLLAR ANALYSIS WITHOUT ESCALATION	1.000
LEVELIZED ANNUAL OPERATING EXPENSE LEVELIZING FACTOR x ANNUAL OPERATING EXPENSE	$124,000
3) TOTAL ANNUAL EXPENSES	
INSTALLED COST CONTRIBUTION	$219,000
OPERATING COST CONTRIBUTION	$124,000
TOTAL	$343,000
4) TREATED WATER UNIT COST, $/1000 Gallons	
INSTALLED COST CONTRIBUTION	$25.80
OPERATING COST CONTRIBUTION	$14.60
TOTAL, $/1000 Gallons	$40.40

Note
1) 100 percent capacity factor = (100 gal/min)(60 min/hr)(8,760 hrs/yr)

Much of the treated water cost is due to regulations that require the total dissolved solids concentration in the discharge water to meet drinking water standards. It can be concluded that a standalone solar facility to produce drinking quality water will not be economic in the near future, and this application should not be a near term target for solar detoxification. To improve the economics of the early solar facilities, sites or applications should be selected such that the treated water quality requirements can be held to a minimum. Potential examples include discharge to a publicly owned water treatment work or connection to an industrial facility that recycles process water. If an application can be found that does not require a posttreatment system, the cost of treated water can be decreased by approximately one third.

Other changes which will reduce the cost of treated water include:

- Selection of a collector field that is up to 50 percent larger than that required to meet the design point flow rate. Although this will increase the capital cost by approximately 15 percent, the capacity factor of the pretreatment and posttreatment equipment will increase by approximately 35 percent, and the overall facility economics will improve by approximately 15 percent

- Reinstitution of Federal or state solar investment tax credits, which will decrease the levelized capital carrying charge

- Research in catalysts which use a larger portion of the ultraviolet spectrum and the development of low cost collectors. Both activities are underway as part of the DOE Solar Thermal Industrial Program.

Section 2
INTRODUCTION AND BACKGROUND

The Solar Energy Research Institute (SERI) and Sandia National Laboratories have demonstrated the decomposition of toxic organic compounds in water using sunlight. The contaminated water is mixed with oxygen or hydrogen peroxide, and then combined with a powdered titanium dioxide catalyst to form a slurry. Ultraviolet photons at the catalyst surface create electron-hole pairs. The oxygen or hydrogen peroxide molecules act as receptors for the holes, allowing water to react with the electrons and form hydroxyl radicals. The highly reactive radicals react with the toxic organic compounds, producing a non-toxic mixture of water, carbon dioxide, and dilute hydrochloric acid.

2.1 LABORATORY EXPERIMENTS

Laboratory experiments at SERI have examined the decomposition of trichloroethylene (TCE), trinitrotoluene (TNT), and textile dye (Direct Red No. 79, $[C_{37}H_{32}N_6O_{17}S_4]\cdot 4Na$). Using a xenon lamp with filters to simulate concentrated ultraviolet radiation, and stoichiometric concentrations of dissolved oxygen, destruction of TCE was demonstrated from initial concentrations of 60 ppm to less than 50 ppb (Ref. 2-1). Additional results from the initial experiments, conducted through late 1989, include:

- TCE destruction rates vary with initial concentration; the highest pseudo first order rate constants were found with the lowest concentrations
- Destruction rates were found to vary linearly with ultraviolet flux
- Catalysts fixed on glass beads were found to be as effective as suspended catalysts.

2.2 FIELD TESTS

A small scale outdoor testing program is in progress at SERI to examine the following:

- Decomposition rates with solar radiation
- Effectiveness of receiver geometries and catalyst supports
- Recovery of catalyst from slurries
- Ultraviolet radiation data bases.

The facility uses a parabolic trough collector to reflect and concentrate sunlight, by a factor of 5, onto a glass receiver. Results to date with initial TCE concentrations of 30 ppm show reductions of a factor of 10 within 12 minutes using a batch process and a titanium dioxide slurry concentration of 0.1 percent.

An engineering scale test program is in progress at the Sandia National Laboratories Solar Thermal Test Facility in Albuquerque. The facility is conducting tests using parabolic trough collectors at a scale comparable to that for commercial systems to support performance assessments. Items under study include reflective film performance and toxic destruction rates as functions of titanium dioxide slurry concentration, hydrogen peroxide concentration, hour of the day, day of the year, and ultraviolet flux at the receiver. Initial results, through the spring of 1990, show the following (Ref. 2-2):

- Processing rates range from 10,000 gallons/(day-1000 m^2 reflector area) in January to 35,000 gallons/(day-1000 m^2 reflector area) in July

- Destruction rates per ultraviolet photon is not linear with increasing flux. For example, if the flux is doubled, the reaction rate is less than doubled. This is a somewhat different finding than had been seen in earlier laboratory experiments.

2.3 CURRENT PROJECTS

The Department of Energy (DOE) has initiated a program to design, install, and operate a solar detoxification facility at Lawrence Livermore National Laboratories in California. The facility, using parabolic trough collectors, will operate upstream of an existing ultraviolet-peroxidation facility. Laboratory test of groundwater sample show TCE concentration reductions from 400 ppb to 10 ppb within 10 minutes using a 0.1 percent by weight titanium dioxide slurry catalyst.

DOE, through Sandia National Laboratories, has also initiated this study with Bechtel Corporation for the conceptual design and permitting plan of a demonstration solar detoxification project. The objectives of the study are to assess the following:

- The cost and schedule of a demonstration program for DOE planning purposes

- The economic potential of future commercial facilities

The site selected for the study is the Rocky Flats Plant in Colorado, and the design groundwater flow rate is 0.0063 m^3/sec (100 gpm). The results of the study are the subject of this report.

2.4 DEMONSTRATION PROJECT CONCEPTUAL DESIGN AND PERMITTING PLAN

The conceptual design and permitting plan is divided into the 4 tasks below.

2.4.1 Task 1 - Conceptual Design of Solar Portion of Plant

The solar portion includes the parabolic trough collectors, foundations, drives, control system, and field piping. Candidate trough vendors were surveyed to determine the preferred design.

2.4.2 Task 2 - Conceptual Design of Balance of Plant

The balance of plant includes the following systems:

- Pretreatment system, to modify the chemistry of the groundwater to meet the requirements of the detoxification process
- Posttreatment system, to modify the chemistry of the treated water to meet the requirements of the Federal and state regulatory agencies
- Auxiliary systems, to treat the waste streams from the pretreatment and posttreatment systems
- Control system, to select the facility operating mode, align the collectors with the sun, and adjust the water flow rate in proportion to the ultraviolet flux.

Also included is an estimate of the annual volume of groundwater which is treated by the facility.

2.4.3 Task 3 - Permitting Plan

A summary of the permits and schedule required to license and operate the detoxification facility is provided. Permit requirements, such as total dissolved solid concentrations in the discharge water, are incorporated in the posttreatment system design.

2.4.4 Task 4 - Installed Cost and Operating Cost

Estimates are developed for the installed cost and annual operating cost. Combined with the estimate of the annual treated water volume, the unit cost of treated water, in $/1000 gallons, is provided.

2.4.5 Report Contents

The results of the conceptual design, permitting plan, and economic analysis are presented in Sections 3, 4, and 5 of this report, respectively. Four appendices contain the following information: Appendix A, Well Water Constituents and pH Data; Appendix B, Parabolic Trough Ultraviolet Performance Data; Appendix C, Collector Field Sizing and Design Point Performance; Appendix D, Hourly and Monthly Estimates of Treated Water Volume; and Appendix E, Total Field Cost Estimate Details.

Section 3
CONCEPTUAL DESIGN

Included in this section are descriptions of the facility design basis, water pretreatment system, collector system, posttreatment system, auxiliary systems, control system, and annual performance.

3.1 DESIGN BASIS

As discussed in Section 2, the purpose of the study is to assess the potential for commercial solar detoxification systems. As a result, the design basis was selected to be as representative as possible of conditions which could be encountered at potential commercial sites. In collaboration with Sandia and SERI, it was agreed to adopt Hillside 881 at the Rocky Flats Plant in Colorado as the site for the conceptual design. The design basis for the solar detoxification facility is described below. Details of the basis, such as groundwater chemistry, are presented in Appendix A.

It was further agreed that any unusual site characteristics that could significantly increase the cost estimate or extend the permitting plan schedule would be ignored. For the Rocky Flats Plant, this meant that the heavy metals and radionuclides found in the groundwater were assumed not to be present.

A simplified flow schematic, shown in Figure 3-1, illustrates the following systems:

- Pretreatment system to modify the chemistry of the water to conditions suitable for the catalytic decomposition process
- Collector system to reflect ultraviolet radiation on the catalyst surface
- Posttreatment system to modify the chemistry of the treated water to meet environmental regulations for discharge
- Auxiliary systems to treat the waste streams from the pretreatment and posttreatment systems.

The design bases for the pretreatment and posttreatment systems are summarized in Table 3-1. Well water constituents and pH data are presented in Appendix A. Additional information regarding the entries in the table is as follows:

- Well water temperature is assumed to remain below 21°C (70°F) throughout the year
- The catalyst in the receiver is fixed, and no catalyst slurry preparation or recovery equipment is required

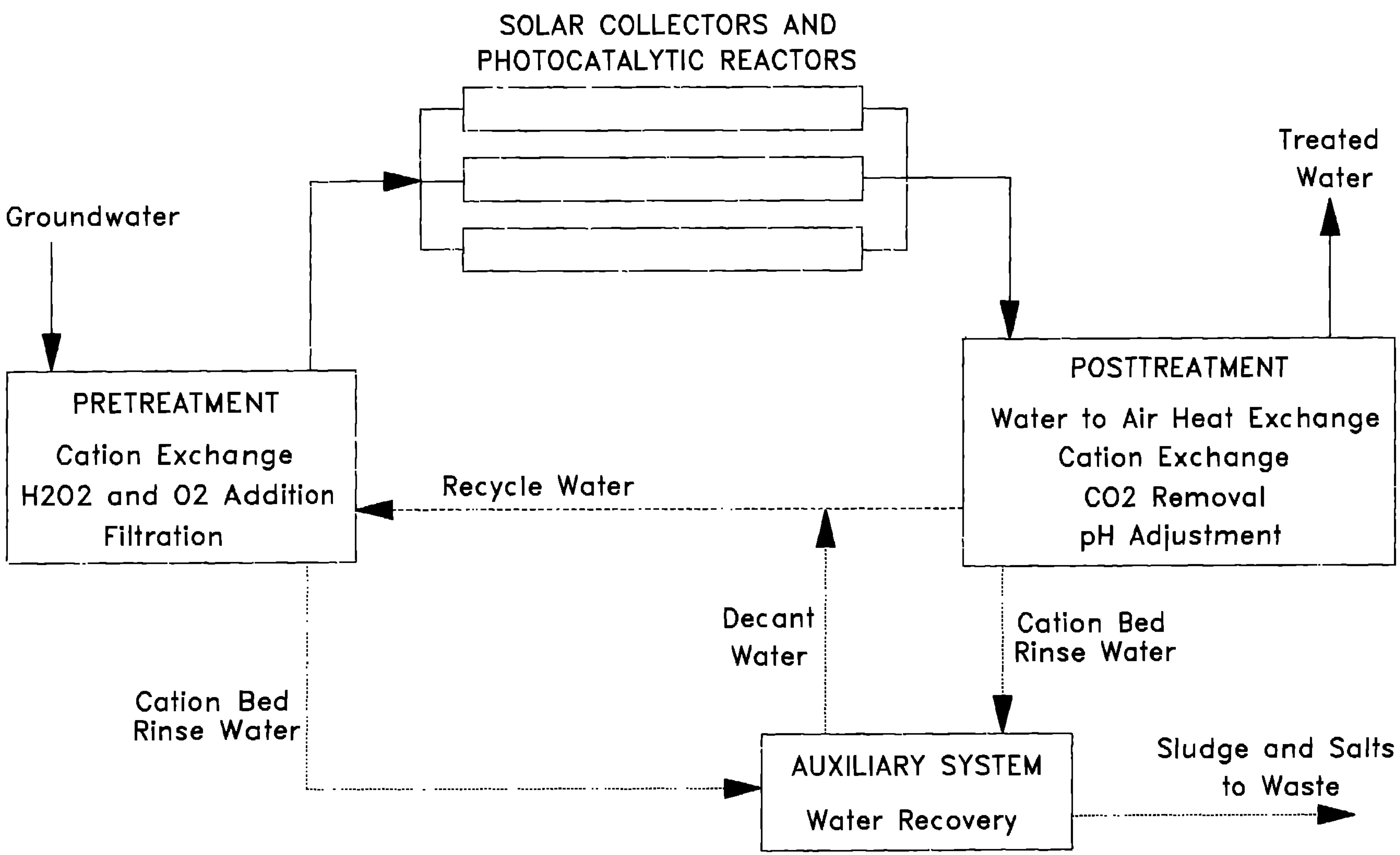

Figure 3–1 Simplified Flow Schematic

Table 3-1
DESIGN BASIS

	Well Water	Receiver Inlet	Receiver Outlet	Recharge Water
Temperature, °C	≤21	≤21	Calculated	Specified by permit
Pressure, kPa (psia)	100 (14.7)	275-415 (55-75)	Calculated	No Data
Water pH	7.6	6	NSR (1)	6-9
Total Dissolved Solids, ppm	718	NSR	NSR	400
Calcium (Ca), ppm	109.7	NSR (2)	NSR	NSR
Magnesium (M), ppm	26.1	NSR	NSR	NSR
Sodium (Na), ppm	87.4	NSR	NSR	NSR
Chloride (Cl), ppm	128	NSR	NSR	250
Sulfate (SO_4), ppm	122	NSR	NSR	250
Bicarbonate (as $CaCO_3$), ppm	274	NSR (3)	NSR	NSR
Potassium (K), ppm	2.7	NSR	NSR	NSR
Nitrite (_NO_2) and Nitrate (_NO_3), ppm	8.29	NSR	NSR	10
Suspended Solids	No Data	5 micron filter	NSR	NSR
Organics	Appendix A	NSR	NSR (4)	Appendix A
Metals	Appendix A	NSR	NSR	Ignored
Iron	0.041	NSR (5)	NSR	0.3
Radionuclides, pCi/l	Appendix A	NSR	NSR	Ignored

Notes:
1) NSR - No Specific Requirement
2) Provisions shall be made for scale removal in the receiver.
3) Bicarbonate concentration reduced by factor of 3 as a consequence of pH adjustment.
4) Volatile organic compound concentrations are assumed to be reduced in receiver to acceptable discharge levels. No alternate equipment will be provided for organics decomposition if the receiver malfunctions.
5) Iron precipitated as a consequence of hydrogen peroxide addition, and removed prior to delivery to solar collectors.

- To ensure an adequate supply of hydroxyl radicals ($OH^{\cdot}$) at the catalyst surface, hydrogen peroxide (H_2O_2) and oxygen (O_2) are added to the water entering the receivers. The design flow requirement for hydrogen peroxide is 0.64 liters/min (0.17 gal/min) of a 2 percent solution. Oxygen is to be added such that the saturation limit is reached

- Pretreatment requirements are as follows:

1) pH as close to 6 as practical

2) Prevent catalyst scale formation as a result of an increase in the temperature of the water in the reactor tubes

3) Iron will be converted to iron oxide by reaction with hydrogen peroxide. The oxide, and any suspended solids greater than 5 microns in size, will be removed by cartridge filters. A system to flush the receiver should scaling, iron oxide precipitation, or suspended solid contamination occur will be provided

4) The influence of bicarbonate on the organic decomposition reactions is not fully understood, and it is not clear how much of the bicarbonate must be removed to ensure complete decomposition. However, the reduction of the water pH to 6 is expected to lower the bicarbonate concentration of the original well water from 274 ppm (as $CaCO_3$) to a new value of 90 ppm (as $CaCO_3$)

   The decision not to completely remove bicarbonate was based on the treatment equipment complexities. For example, the bicarbonate concentration can be reduced to approximately 10 ppm by acid addition to a pH of 4-4.5, followed by caustic addition to return the pH to 6. However, carbon dioxide, created as a result of acid addition, must be removed prior to pH adjustment. The carbon dioxide can be removed in an air stripping column. However, volatile organic compounds will also be released in the column, and the treatment of the toxic compounds in the column significantly reduces the need for the solar detoxification equipment

   An alternate method for bicarbonate removal involves lime or caustic soda addition to a pH of 11-12, precipitation of the calcium carbonate, and acid addition to return the pH to 6. However, some of the non volatile organic compounds will precipitate with the calcium carbonate, and the treatment system must deal with the contaminated sludge. In addition, the system will be relatively complex, and its operating cost will be high due to the numerous consumable reagents (This method may be applicable for sites in which heavy metals are also present.)

   It is anticipated that the solar detoxification concept must be kept as simple and inexpensive as possible to maximize its commercial potential.

- Posttreatment requirements are as follows:

1) Only those species or water characteristics that are changed as a result of the pretreatment or photocatalytic process, and which exceed the limits for water discharge such as temperature and pH will be considered in the posttreatment system design. No consideration will be given to the concentrations of species which originally exceeded requirements for discharge or which would not be typical for other groundwater supplies. Examples include manganese, mercury, selenium, and radionuclides. These species are considered to be site specific and will not be treated for recharge

2) The one exception to this requirement involves total dissolved solid concentrations. Since many well waters have high dissolved solid concentrations, it may normally be required to reduce concentration levels to meet the permit requirements. Therefore, equipment is provided in the posttreatment design to reduce discharge water concentrations to 400 ppm

   Since it is believed that dissolved solids have no detrimental effect on receiver operation, and since removal of dissolved solids in the pretreatment system can remove a portion of the toxic organic compounds, dissolved solids are removed in the posttreatment system.

The design bases for the collector system are as follows:

- Parabolic trough collectors, redirecting sunlight onto a glass receiver tube, are used. The troughs are aligned on an East-West axis to minimize the seasonal variation in treated water output

- Organic destruction rates are linearly proportional to the flux at the receiver as indicated by laboratory tests

- As specified by Sandia, the design point ultraviolet flux delivered to the outside of a 50 mm (2 in.) diameter receiver tube is 5×10^{22} photons per second

- The design point is noon on the vernal equinox, with a direct normal insolation of 960 W/m^2

- The ultraviolet photon flux, in the 280 to 385 nanometer band with an air mass of 1.5, is calculated to be 1.82×10^{18} ultraviolet photons/(second-Watt direct normal insolation). The calculation is included in Appendix B

- The design treated water flow rate is 0.0063 m^3/sec (100 gpm) with a collector system inlet pressure not to exceed 520 kPa (75 psia)

- Inlet water temperature to the collector system is not to exceed 21°C (70°F), except during brief periods in which the water is recycled from the posttreatment system

3.2 PRETREATMENT SYSTEM

The pretreatment system receives groundwater from the well pumps and adjusts the water chemistry to conditions suitable for the detoxification process. Nomenclature for the process and control flow diagrams is shown in Figure 3-2. The pretreatment system flow diagram is presented in Figure 3-3 and an equipment list is shown in Table 3-2.

Groundwater enters the facility through two feed strainers to remove large suspended solids and flows to a raw water storage tank. At this point, the water pH is 7.6 and the total dissolved solid concentration is 818 ppm. The tank provides a constant supply for the raw water pump and a storage volume for recycled water from the posttreatment system. A 1 hour storage volume [23 m^3, (6,000 gal)] has been selected based on the following assumptions:

- The wells can provide a constant flow rate of 0.0063 m^3/sec (100 gpm)
- Flow from the wells can be reduced or stopped at any time
- Pressure from the well pumps is sufficient to fill the raw water tank

From the raw water tank, water flows to a raw water pump rated at 0.0063 m^3/sec (100 gpm) and 32 m (105 ft) total developed head. The pressure rise is equal to the friction losses in the pretreatment and collector systems. A recirculation line to the raw water tank ensures that a constant pressure is maintained in the pretreatment system and that the pump does not overheat under extended minimum flow conditions.

As noted above, the pH of the inlet water to the receivers should be as close to 6 as practical. Two methods were evaluated for adjusting the pH from 7.6 to 6.

3.2.1 Acid Addition

The first method simply adds hydrochloric acid to the water. However, the chloride from the acid will increase the dissolved solid concentration. Similar results are obtained if alternate acids are used. Since the groundwater dissolved solids concentration already exceeds the discharge requirement of 400 ppm, a pretreatment system that increases the concentration of the solids will add to the complexity of the posttreatment system that must decrease the concentration.

3.2.2 Cation Bed Exchanger

The second method uses a cation bed exchanger to remove calcium ions and decompose bicarbonate into water and carbon dioxide. Following the raw water pump, the flow splits into two streams. The first stream, which involves approximately 70 percent of the overall flow, passes through a cation bed exchanger. Here, hydrogen ions from the bed replace the calcium ions in the bicarbonate as follows:

GENERAL NOTES

NOMENCLATURE

AT - ANALYZER

DPI - DIFFERENTIAL PRESSURE INDICATOR

FT - FLOW RATE INDICATOR

LC - LEVEL CONTROL

LSHL - LEVEL SWITCH HIGH/LOW

ORP - OXIDATION REDUCTION POTENTIAL INDICATOR

PAL - PRESSURE ALARM LOW

PSL - PRESSURE SWITCH LOW

S/C - STROKE CONTROL (LENGTH AND/OR FREQUENCY)

TAH - TEMPERATURE ALARM HIGH

TC - TEMPERATURE CONTROL

TDS - TOTAL DISSOLVED SOLIDS

TI - TEMPERATURE INDICATOR

TOC - TOTAL ORGANIC CARBON

TSH - TEMPERATURE SWITCH HIGH

TSL - TEMPERATURE SWITCH LOW

UV - ULTRAVIOLET LIGHT

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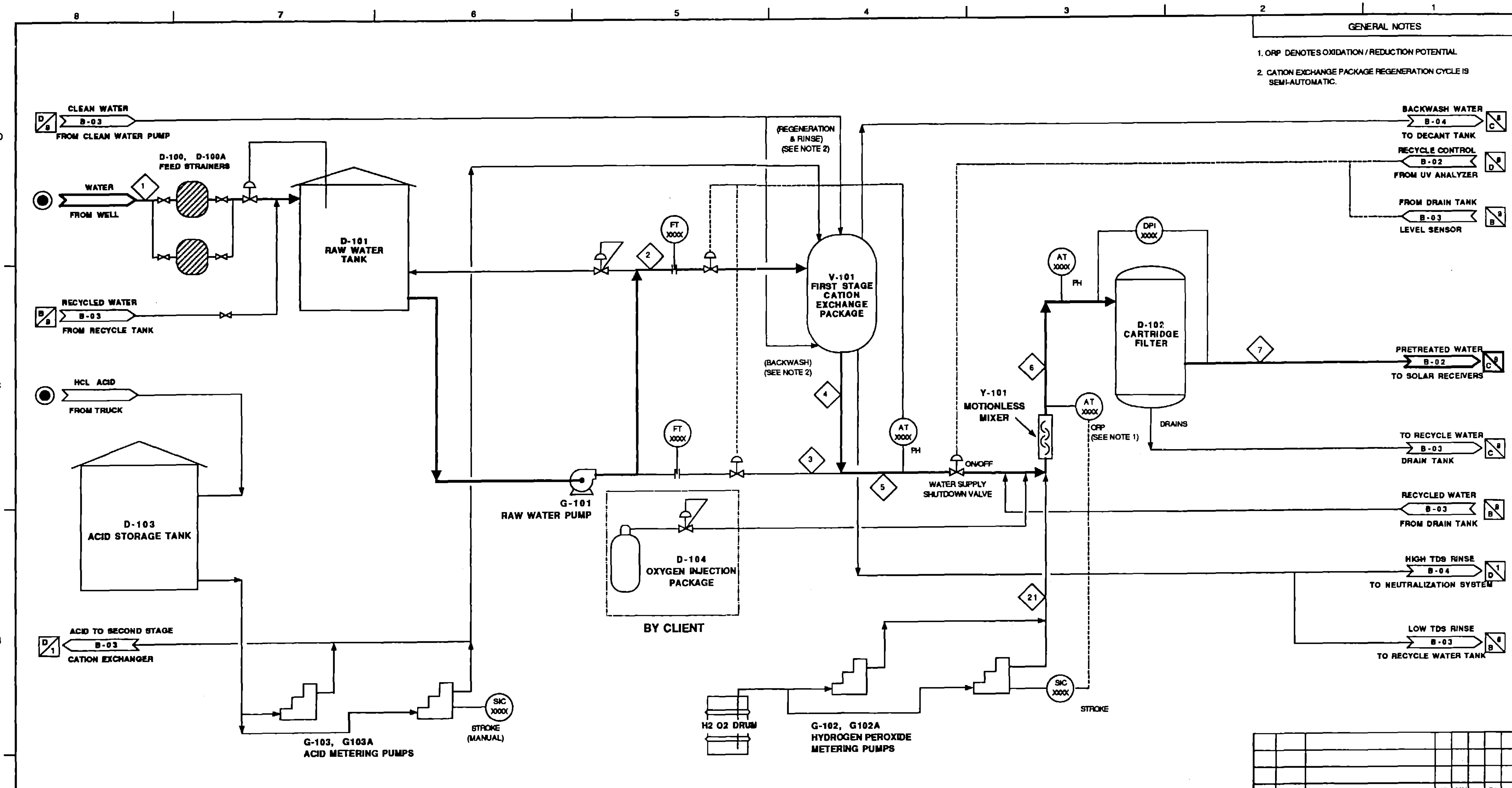
BECHTEL RESEARCH & DEVELOPMENT

SERI / SNLA SOLAR DETOXIFICATION PROJECT

PROCESS AND CONTROL FLOW DIAGRAM
NOMENCLATURE

JOB NO.	DRAWING NO.	REV
21030	B-00	A

Figure 3-2 Nomenclature for Process and Flow Diagrams



STREAM	1	2	3	4	5	6	7	8	9	10	11	12
FLOW (GPM)	100	70	30	70	100	100	100	100	100	100	100	0
PRESSURE (PSIG)	10	45	40	40	40	38	13	9	5	0	12	7
TEMPERATURE (DEG. C)	≤21	≤21	≤21	≤21	≤21	≤21	≤21	36	36	36	36	36
HCO_3^- (PPM)	334.3	334.3	334.3	0	100	100	100	100	100	100	100	100
PH	7.6	7.6	7.6	3.5-4	6	6	6	6	6	6	6	6
TDS	818	818	818	374	507	507	507	507	507	507	507	507
H_2O_2 (PPM)	0	0	0	0	0	35	35	35	35	≤1	1-3.5	≤1

STREAM	13	14	15	16	17	18	19	20	21	22	23
FLOW (GPM)	100	100	100	100	100	0	0	400 CFM	.007 (50%)	.00016 (42%)	.0035 (40%)
PRESSURE (PSIG)	12	7	7	0	10	0	40	0.1	40	5	10
TEMPERATURE (DEG. C)	36	36	36	≤21	≤21	36	36	≤21	≤21	≤21	≤21
HCO_3^- (PPM)	100	0	0	0	2-7	100	100	-	-	-	-
PH	6	3.5-4	3.5-4	5-7	6-7	6	6	-	-	2-3	14
TDS	507	374	374	374	390	507	507	-	-	-	-
H_2O_2 (PPM)	≤1	≤1	≤1	≤1	≤1	0-35	0-35	0	50% Concnt	0	0

Figure 3-3 Process and Control Flow Diagram: Pretreatment System

Table 3-2 (1 of 3)
EQUIPMENT LIST

NUMBER	EQUIPMENT NAME	SIZE	CAPACITY or DUTY	HP.	TYPE or OPERATION MODE	MATERIAL OF CONSTRUCTION
D-100/A	FEED STRAINERS	1'-0" dia x 1'-6" t-t			N/A	Polyethylene
D-101	RAW WATER TANK		6,000 gal.		N/A	Fiberglass
D-102	CARTRIDGE FILTER		100 gpm		8 hrs./day	304 SS, 5 microns nominal rating
D-103	ACID STORAGE TANK		2,000 gal.		N/A	Cross-linked polyethylene
D-104	OXYGEN INJECTION PACKAGE					
G-101	RAW WATER PUMP		100 gpm		8 hrs./day	304 SS
MG-101	RAW WATER PUMP MOTOR			4		
G-102/A	HYDROGEN PEROXIDE METERING PUMPS		1/2 gal/hr		8 hrs./day	316 SS
MG-102/A	HYDROGEN PEROXIDE METERING PUMP MOTORS			1/4		
G-103/A	ACID METERING PUMPS		1 gpm		Intermittent	Plastic
MG-103/A	ACID METERING PUMPMOTOR			1/4		
V-101	FIRST STAGE CATION EXCHANGE PACKAGE	4'-6" dia x 4'-6" t-t	70 gpm		16 hr. regeneration frequency	304 SS; 2-4 hrs. regeneration
Y-101	MOTIONLESS MIXER					
Y-201	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-202	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-203	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-204	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-205	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-206	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-207	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-208	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-209	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-210	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-211	SOLAR RECEIVERS STRING WITH SOLAR PANELS					
Y-201-1 TO Y-201-8	SOLAR RECEIVER/SOLAR PANEL MODULES (8 MODULES PER STRING TYPICAL OF 11 STRINGS)					
Y-202	ACTIVATED CARBON FILTER	55 gallon barrel				
AT-XXX	ULTRA VIOLET PYRHELIOMETER				Pyrheliometer with long wave filter	

Table 3-2 (2 of 3)
EQUIPMENT LIST

NUMBER	EQUIPMENT NAME	SIZE	CAPACITY or DUTY	HP.	TYPE or OPERATION MODE	MATERIAL OF CONSTRUCTION
D-301	CLEAN WATER TANK		10,000 gal.		N/A	Same as D-101
D-302	RECYCLE WATER TANK		6,000 gal.		N/A	Same as D-101
D-303	DEGASIFIER		100 gpm		8 hrs./day	Plastic or 304 SS
D-304	SURGE TANK		3,000 gal.		N/A	Same as D-101
E-301	WET-DRY WATER COOLER		100 gpm		Intermittent	304 SS
G-301	CLEAN WATER PUMP		100 gpm		8 hrs./day	304 SS
MG-301	CLEAN WATER PUMP MOTOR			2		
G-302	RECYCLING WATER PUMP		100 gpm		N/A	304 SS
MG-302	RECYCLING WATER PUMP MOTOR			4		
G-303	WATER COOLER SUMP PUMP		10 gpm			
MG-303	SUMP PUMP AIR MOTOR			1/4		
G-304	WATER COOLER PUMP		10 gpm			
MG-304	WATER COOLER PUMP MOTOR			1/4		
G-305	RECHARGE PUMP		100 gpm		8 hrs./day	304 SS
MG-305	RECHARGE PUMP MOTOR			1		
G-306/A	FERRIC CHLORIDE METERING PUMPS		1/2 gal/hr		8 hrs./day	316 SS
MG-306/A	FERRIC CHLORIDE METERING PUMP MOTORS			1/4		
G-307/A	PH CONTROL METERING PUMP		1/2 gal/hr		8 hrs./day	316 SS
MG-307/A	PH CONTROL METERING PUMP MOTORS			1/4		
K-301	DEGASIFIER BLOWER		400 cfm		8 hrs./day	Carbon steel
MK-301	DEGASIFIER BLOWER MOTOR			1/2		
V-300	ACTIVATED CARBON FILTER (WATER)	45" dia x 86.5" high	2 x 50 gpm		N/A	Epoxy lined carbon steel
V-301	SECOND STAGE CATION EXCHANGE PACKAGE	4'-0" dia x 5'-0" t-t	100 gpm		48 hr. regeneration frequency	304 SS; 2-4 hrs. regeneration
V-302	ACTIVATED CARBON FILTER (AIR)	55 gallon barrel			8 hr./day	Epoxy lined carbon steel
AT-XXX	TOTAL ORGANIC CARBON ANALYZER				Chromatograph with flame ionization detector	

Table 3-2 (3 of 3)
EQUIPMENT LIST

NUMBER	EQUIPMENT NAME	SIZE	CAPACITY or DUTY	HP.	TYPE or OPERATION MODE	MATERIAL OF CONSTRUCTION
D-401	DECANT TANK		2,000 gal.		N/A	Same as D-101
D-402	NEUTRALIZATION TANK		5,000 gal.		Intermittent	Same as D-101
G-401	DECANT WATER PUMP		30 gpm		Intermittent	304 SS
MG-401	DECANT WATER PUMP MOTOR			1		
G-402	DECANT TANK SLURRY PUMP		20 gpm		Intermittent	
MG-402	DECANT TANK SLURRY PUMP MOTOR			1		Air operated, Wilden type, plastic
G-403	NEUTRALIZATION WASTE PUMP		100 gpm			
MG-403	NEUTRALIZATION WASTE PUMP MOTOR			2		
G-404/A	NEUTRALIZATION METERING PUMPS		1/2 gal/hr		Intermittent	316 SS
MG-404/A	NEUTRALIZATION METERING PUMP MOTORS			1/4		
Y-401	SLUDGE FILTER PRESS		1 cu. ft.		Intermittent	Plastic
Y-402	NEUTRALIZATION TANK MIXER					
MY-402	NEUTRALIZATION TANK MIXER MOTOR					

$$2[R]H^{+}+Ca(HCO_3)_2 \rightarrow [R]Ca^{++}+2H_2CO_3 \qquad (1)$$

where [R] is the resin material. This reduces the pH to 3.5 to 4, causing a shift to the right in the following equilibrium reaction and the dissociation of bicarbonate into water and carbon dioxide:

$$H_2CO_3 \rightleftharpoons H_2O+CO_2 \qquad (2)$$

Calculations show that the carbon dioxide remains in solution, and the ion exchange reduces the dissolved solid concentration to 374 ppm.

The second stream bypasses the exchanger, maintaining a pH of 7.6 and a dissolved solid concentration of 818 ppm. The streams combine following the cation bed, producing a stream with the desired pH of 6 and a dissolved solid concentration of 507 ppm. The split between the two flows is adjusted based on the output of a pH meter.

Since the second method reduces the pH, bicarbonate, and the total dissolved solid concentrations, it was selected for the conceptual design.

Removal of the calcium ions also has a second benefit. Increasing water temperature in the solar receivers can thermally decompose calcium bicarbonate into calcium carbonate, water, and carbon dioxide as follows:

$$Ca(HCO_3)_2 \rightarrow CaCO_3+H_2O+CO_2 \qquad (3)$$

The solubility of calcium carbonate is very low, and the calcium carbonate will precipitate from the solution. The precipitate, in turn, will deposit on the reactor catalyst and tube walls, and decrease the decomposition efficiency. However, the removal of the calcium ions in the cation bed effectively precludes Reaction 3.

The cation bed is sized to operate continuously for 16 hours without regeneration. The exchanger vessel is constructed from carbon steel with a plastic lining, and contains 0.79 m^3 (28 ft^3) of weakly acidic resin (Room & Haas IRC-84, or similar).

Regeneration occurs every other evening, using a hydrochloric acid solution as follows:

$$[R]Ca^{++}+HCl \rightarrow [R]H^{+}+CaCl \qquad (4)$$

The volume of acid required for regeneration is approximately the same as that required for simple acid addition to reduce the pH to 6.

The calcium chloride is rinsed from the bed using treated water from the clean water tank in the posttreatment system. The rinse water with high concentrations of calcium chloride is sent to the neutralization tank in the auxiliary system for disposal. The rinse with low dissolved solid concentrations is sent to the recycle water tank in the posttreatment system for return through the collector system the following day.

Once a water pH of 6 is obtained, hydrogen peroxide and oxygen are added to provide a source of hydroxyl radicals in the receivers. The hydrogen peroxide injection rate is controlled by adjusting the pump stroke on the metering pumps in response to the oxidation reduction potential analyzer. The oxygen injection rate is adjusted in proportion to the raw water flow rate.

The dissolved iron ions and ferrous iron immediately react with the hydrogen peroxide to form a ferric iron oxide precipitate as follows:

$$2Fe^{++}+H_2O_2 \rightarrow Fe_2O_3\downarrow +H_2O \qquad (5)$$

The precipitate and any other fine suspended solids are removed in a 5 micron cartridge filter. The cartridges are replaced when the differential pressure across the filter exceeds 175 kPa (25 psi).

3.3 COLLECTOR SYSTEM

The collector system redirects direct insolation onto the receiver tubes, supports the receiver tubes, distributes contaminated water to the collectors, and collects treated water from the collectors. The system includes the parabolic trough collectors, foundations, drives, and field piping.

3.3.1 Survey of Ultraviolet Reflector Materials

Various reflector materials were surveyed, and their performance estimated, to determine the preferred approach for the conceptual design.

Materials Survey The only metal surface that offers high reflectivity values in the complete ultraviolet spectrum is aluminum (Ref. 3-1). Reflectivities range from 92.3 percent at 280 nanometers to 92.5 percent at 385 nanometers. In comparison, the comparable values for silver are 25.2 percent and 92.8 percent, respectively.

A new aluminum surface is fragile and needs protection from weathering and abrasion. Therefore, coatings such as aluminum oxide (anodized) and acrylic are normally applied. Two types of aluminum reflectors have been used with parabolic trough collectors. The first is based on an anodized reflector and the second uses a plastic film with an aluminum coating. Anodized aluminum sheets were used with poor results in the Coolidge (Ref. 3-2) and Willard (Ref. 3-3 and 3-4) parabolic trough installations. After one year of service at Coolidge, the reflectivity of the Coilzak^R surface had decreased from 70 percent to 58 percent, and the troughs at Coolidge and Willard were eventually resurfaced with the 3M plastic film reflector FEK-244. Anodized aluminum sheets currently available, such as Alanod, are claimed to be a much improved product with a new reflectivity of 88 percent and an extremely low degradation rate. Measurements of the reflectivity reported in 1982 indicated that the reduction in the ultraviolet spectrum may be no more than 5 percent (Ref. 3-5). Unfortunately, current measurements of ultraviolet reflectivity and degradation rates are not available, and there was judged to be insufficient information to select this reflector material for the conceptual design.

Several coated plastic film products have been used successfully in parabolic trough applications. The 3M film ECP-244, used by Solar Kinetics, consists of an aluminum surface 0.4 mil thick covered by an acrylic surface 3 mil thick. Solar Kinetics can provide collectors with this film from existing stock. However, ECP-244 is no longer being produced, and has been replaced by the 3M successor product SA-85. The new film uses a polyester back surface 2 mil thick, an aluminum surface 0.4 mil thick, and a very thin acrylic cover 0.1 mil thick. SA-85 is presently used in the Industrial Solar Technology parabolic troughs at the California Correctional Institution in Tahachapi, California. A second parabolic trough vendor, Sunsteam, Inc., uses a custom surface equivalent in construction and performance to SA-85. The back surface is a combination of aluminum foil 5 mil thick and a polyester sheet 1 mil thick. The reflector is an aluminum surface 0.4 mil thick and the cover is acrylic 0.1 mil thick.

Reflector Performance Ultraviolet reflectivities as a function of wavelength for ECP-244 and SA-85 were obtained from Sandia and 3M, respectively. Combining the reflectivities with the radiation intensities between 280 and 385 nanometers gives a weighted average reflectivity of 63 percent for new ECP-244 films and 87 percent for new SA-85 films. The superior reflectivity of SA-85 is due to the much thinner protective acrylic coating.

Once the films are mounted on a supporting substrate and exposed to the weather, it is expected that some degradation in reflectivity will occur. For the purposes of the conceptual design, it was estimated that two percentage points in specular reflectivity are lost due to bonding of the film to the substrate. This give new bonded film reflectivities of 61 percent for ECP-244 and 85 percent for SA-85. Further, it was assumed that the reflectivity of each film at its end of life would be 88 percent of the new bonded value. Thus, the end of life reflectivity for ECP-244 was 53 percent, and for SA-85, 75 percent.

3.3.2 Survey of Parabolic Trough Vendors

Five parabolic trough vendors were surveyed regarding potential collector designs for the detoxification facility. Information on performance, capital cost, operating cost, and field experience was requested. The results of the survey are summarized in Table 3-3. Shown in the table are the required collector areas to meet the design point ultraviolet flux on the receiver tubes. The required collector areas have been calculated from the following:

- Design point direct normal insolation of 960 W/m^2
- Air mass of 1.09 for a site with a latitude of 40° (Ref. 3-6)
- Fraction of ultraviolet photons in the total solar spectrum is 3.47 percent , or 33.33 W/m^2 (Appendix C).

Table 3-3
SUMMARY OF COLLECTOR VENDOR SURVEY

	SOLAR KINETICS			INDUSTRIAL SOLAR TECHNOLOGY	SUNSTEAM	BSAR SOLAR
LOCATION		DALLAS, TX		DENVER, CO	PALO ALTO, CA	SOLANA BEACH,CA
AVAILABILITY	5 Weeks	17 Weeks	17 Weeks	17 Weeks	18-20 Weeks	–
MODULE DIMENSIONS	7 Ft x 20 Ft	7 Ft x 20 Ft	7 Ft x 20 Ft	7.6 Ft x 20 Ft	2 x 3.33 x 22.66 Ft	2.5 Ft x 16 Ft
PERFORMANCE (End of Life UV Reflectivity)	53.38% 3M ECP-244	75.00% 3M SA-85	75.00% 3M SA-85	75.00% 3M SA-85	67.96% Including Glazing	75.00%
AREA REQUIRED, m2	1546	1100	1100	1100	1214	1100
MODULES REQUIRED	119	85	85	78	86	296
APERTURE WIDTH DIVIDED BY RECEIVER DIAMETER	42	42	42	46	20	15
INSTALLED COST	215 $/m2 $332,321	215 $/m2 $236,524	242 $/m2 (Replaceable Refl Sht) $266,227	231 $/m2 $254,125	209 $/m2 (Including 32 $/m2 Tooling) $253,741	873 $/m2 $960,396
(With Receiver Tube @ $26.70/ft)	$395,781	$281,691	$311,394	$295,820	$358,400 $319,550 (w/o tooling)	$1,086,864
O&M COST Labor Hr/Yr	104	104	104	160	135	–
Power kWh/Yr	2,600	2,600	2,600	4,000	3,500	–
Matls. $/m2-Yr	Not Stated	Not Stated	Not Stated	Not Stated	2 (Approx)	–
FIELD EXPERIENCE	46,500 m2 Since 1976	46,500 m2 Since 1976	46,500 m2 Since 1976	3,600 m2 Since 1985	1,500 m2 Since 1988	– –
FEATURES	Alum. Monocoq Structure	Alum. Monocoq Structure	Alum. Monocoq Structure	Aluminum Structure	Parabolic Film in Axial Tension	Alum. Acrylic Film on Laminated Wood
	3M ECP-244 On Hand		Replaceable Reflector Sheet Option	Light Weight	Clear Plastic Film Cover	3/4 Inch Cu in 1.4 Inch Glass Tube
	90 Deg Rim	90 Deg Rim	90 Deg Rim	70 Deg Rim	Rim Angle Over 90 Deg	95 Deg Rim
	3M Film/ Anodized Sheet Options	3M Film/ Anodized Sheet Options	3M Film/ Anodized Sheet Options	3M Film	Equiv 3M Film Dupont Cover	12 Sun Avg
MAJOR APPLICATION	Process Heat	Process Heat	Process Heat	Process Heat	Process Heat	Solar Still & Hot Water
WARRANTY	1 Year	1 Year	1 Year	1 Year	5 Years	–
SOLAR DETOX SERVICE	SATISFACTORY	SATISFACTORY	SATISFACTORY	SATISFACTORY	SATISFACTORY	NOT APPROPRIATE

Assuming a process requirement of 5×10^{22} ultraviolet photons/sec, as specified by Sandia, and an energy level of 1.82×10^{18} ultraviolet photons per Watt-second, the required ultraviolet power level is 27,500 Watts. With an ultraviolet insolation of 33.33 W/m^2 and the collector efficiencies noted above, the required collector areas can be determined. Given the required areas, and the unit costs provided by the vendors, estimates of the installed collector costs were made and are presented in Table 3-3.

The three most likely suppliers include Solar Kinetics, Industrial Solar Technology, and Sunsteam. Information from Luz International was not obtained in time to be included in the analysis, and the BSAR Solar offering, oriented largely to the home market, was judged to be inappropriate for this application.

The Solar Kinetics trough is 6.1 m (20 ft) long with an aperture width of 2.1 m (7 ft). With a receiver tube inside diameter of 51 mm (2 in.), the geometric concentration ratio is 42:1. Three design variations were considered, as follows:

1) Standard monocoque design, fabricated from aluminum and using the ECP-244 reflector film currently in stock. The total collector and receiver tube cost is $396,000

2) Standard monocoque design using the SA-85 reflector. The ultraviolet reflectivity of SA-85 is 1.4 times the reflectivity of the ECP-244. Therefore, the required collector area is reduced, and the collector and receiver tube cost decreases to $282,000

3) Modified monocoque design using the SA-85 reflector bonded to 20 mil aluminum sheets which can be removed and replaced. The total cost is $311,000.

The third option, available at a premium of $\$27/m^2$, permits quick and easy replacement of a reflector that is damaged or undergoes unexpected degradation. Solar Kinetics has installed more parabolic area than any of the remaining suppliers (except Luz International).

The Industrial Solar Technology design is very similar to the Solar Kinetics design, with a length of 6.1 m (20 ft), a width of 2.3 m (7.6 ft), and a concentration ratio of 45:1. It is the only candidate with the SA-85 reflector film currently operating in the field. The total collector and receiver tube cost is $296,000.

The Sunsteam collector uses a 2.5 mil thick ethylene-tetrafluoroethylene (Dupont Tefzel[R]) cover sheet over the trough aperture to minimize dirt accumulation on the reflector. Using an index of refraction of 1.358, the reflectivity and absorptivity losses of the cover sheet are estimated to be 2.3 percent and 9.4 percent, respectively. Assuming that the reflectivity of the Sunsteam reflector is comparable to that of SA-85, the overall reflectivity of a new, unbonded reflector is estimated to be 77 percent. Adjusting the reflectivity for bonding losses and degradation gives an end of life value of 68 percent.

The Sunsteam design uses parallel troughs on either side of a common torque tube. Each trough consists of a 5 mil aluminum membrane attached to parabolic shaped end forms. The end forms are spring loaded to tension the membrane into a parabolic trough. Each trough is considerably smaller than the Solar Kinetics design, with a length of 6.1 m (20 ft), a width of 1.0 m (3.3 ft), and a concentration ratio of 20:1. The total collector and receiver tube cost is $358,000, including a one time tooling charge of $35/m^2 to incorporate the latest design modifications. Without the tooling charge, the cost decreases to $320,000.

3.3.3 Parabolic Trough Selection

As shown in Table 3-3, the standard Solar Kinetics trough with the SA-85 reflector is the lowest cost option, and therefore was selected for the conceptual design. However, there is only a 5 percent difference between the Solar Kinetics and Industrial Solar Technology costs, and both are equally suitable.

Compared to the Sunsteam design, the Solar Kinetics trough offers a cost advantage because its requires a smaller total length of (relatively expensive) receiver tubes. The shorter length is due to a concentration ratio for the Solar Kinetics design that is approximately twice as high as that for the Sunsteam concept.

3.3.4 Collector Field Design

The required collector area of 1,100 m^2 (11,840 ft^2) is satisfied with an array of 88 Solar Kinetics modules, arranged in 11 rows of 8 modules each. A collector system flow diagram is shown in Figure 3-4, and a plan view of the collector field is shown in Figure 3-5. Details of the collector field sizing and design point performance are found in Appendix C. With a row spacing of 9.1 m (30 ft), the field East-West dimension is 56 m (184 ft), the North-South dimension is 90 m (295 ft), and the required area is 5,040 m^2 (1.25 acres). Including an allowance for the equipment building, perimeter road, laydown area, and fences the overall site area is 7,200 m^2 (1.8 acres).

The supply header from the raw water pump to the collectors is a 15 cm (6 in.) Schedule 80 polyvinyl chloride pipe. The pipe is buried below the frost line at a depth of 0.6 m (2 ft), and is sloped toward the equipment building with a 1 percent grade to ensure venting during startup and draining during shutdown.

The return header from the collectors to the water to air heat exchanger is also a 15 cm (6 in.) Schedule 80 polyvinyl chloride pipe. The pipe is elevated above the receiver tubes on support pedestals, and is sloped toward the equipment building with a 1 percent grade to ensure adequate venting and draining.

Flexible connections between the headers and receiver tubes are made by reinforced rubber hoses with an outer stainless steel braided jacket. The connections rise continuously between the supply header and the receiver tube, and between the receiver tube and the return header, to ensure that the receiver properly vents and drains.

Included in each connection to the return header are a manual gate valve and a venturi. During the facility startup and checkout, the flows in the 11 parallel collector rows will be simultaneously measured with the venturis. The gate valves will be adjusted, as necessary,

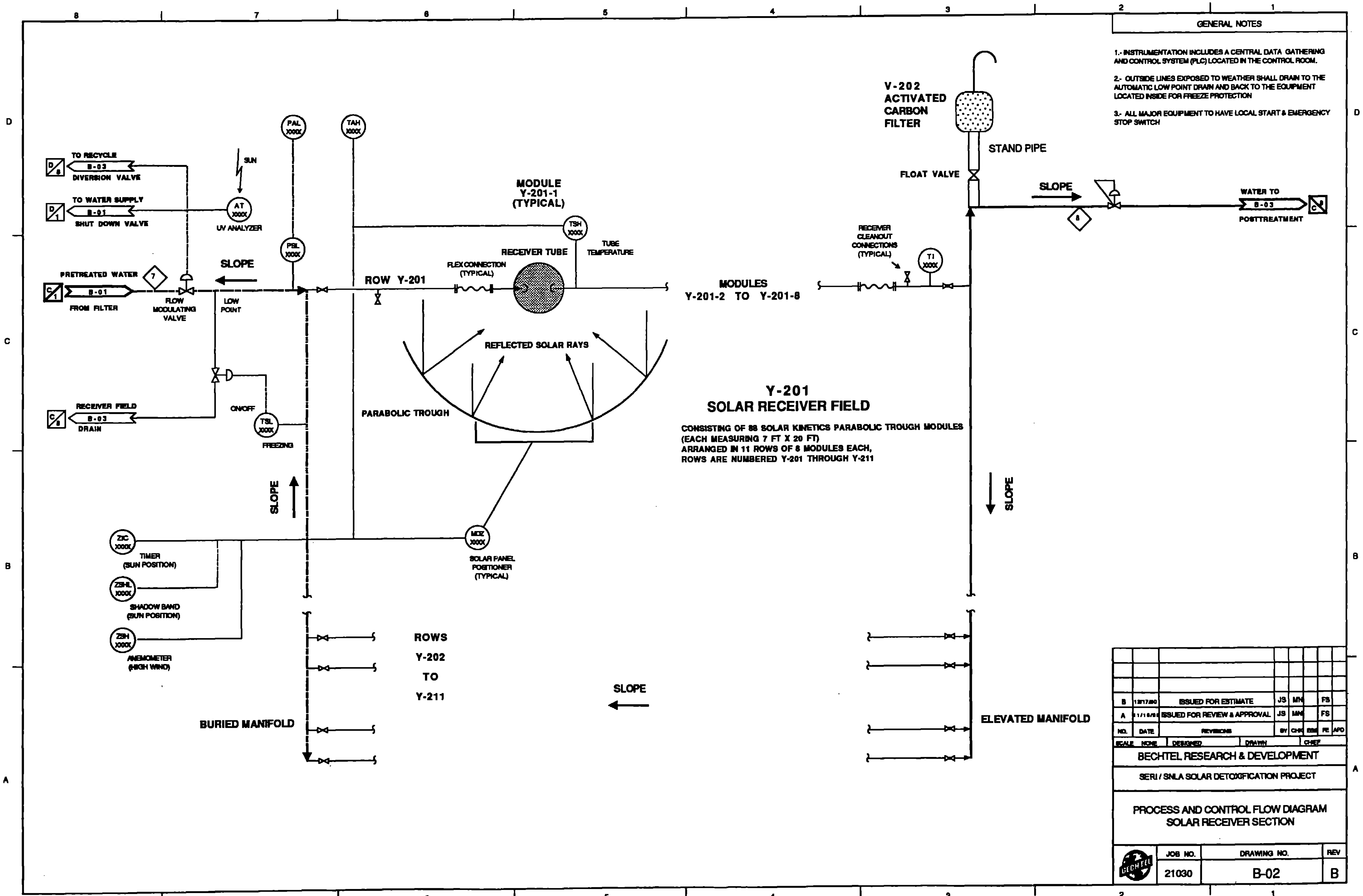


Figure 3-4 Process and Control Flow Diagram: Collector System

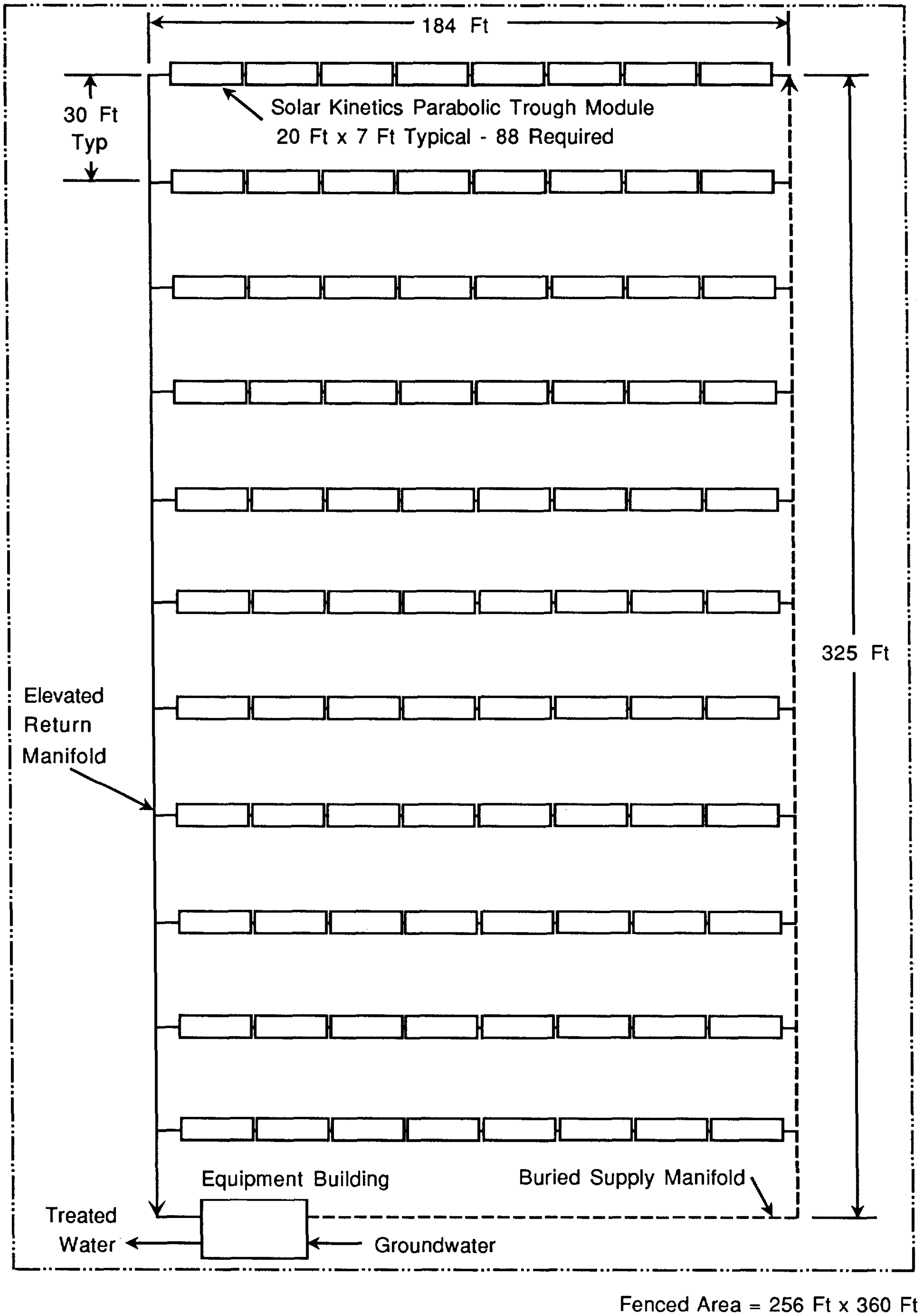


Figure 3-3 Collector Field Layout Diagram

to balance the flow among the rows. The flows can be checked periodically (perhaps annually) to ensure that the proper distribution is maintained. The design point pressure drop through the supply header, receiver, gate valve, and return header is 24 kPa (3.5 psi).

The collectors track the sun by means of shadow well sun sensor using three photovoltaic cells. One cell is at the center of the sensor, and measures the overall light intensity to ensure that the collectors are pointing toward the sun. The other two sensors are located on either side of an opaque screen. If the collectors are not aligned with the sun, one cell will be shaded and the cell currents will differ. The drive motor moves the collectors until the outputs from both cells are the same.

3.2 POSTTREATMENT SYSTEM

The posttreatment system receives treated water from the collector system, checks the water for residual organic compounds, adjusts the water chemistry to conditions suitable for discharge, and returns partially treated water to the pretreatment system during transient conditions. A process and control flow diagram is shown in Figure 3-6, and an equipment list is shown in Table 3-2.

The principal method for water flow rate control is a calculation of the ultraviolet flux incident on the receiver tubes. This is discussed below in Section 3.6. As an auxiliary control method, the treated water is monitored for residual organic compounds by a fast response, flame ionization gas chromatograph. If the principal calculation or the chromatograph indicate that decomposition is not complete, the water is directed to the recycle tank and returned to the pretreatment system.

Under design conditions, the temperature rise of the water through the collectors is estimated to be 15°C (27°F), giving an inlet temperature to the posttreatment system of 36°C (97°F). However, if recirculation of partially treated water is required following a cloud transient, the treated water temperature may exceed 40°C (104°F), which is the temperature limit for the cation exchanger in the posttreatment system (described below). To ensure that the temperature of treated water does not exceed the limits of the cation bed, a forced draft, water to air heat exchanger is provided at the inlet to the posttreatment system. To ensure adequate heat exchanger performance on hot summer days, a small quantity of treated water from the discharge tank is sprayed over the tubes.

Cooled treated water is sent to the clean water tank. Following the decomposition process, the constituents in the water are expected to be carbon dioxide, hydrochloric acid, and unreacted hydrogen peroxide. However, hydrogen peroxide will damage the granulated activated carbon filter (described below) and the cation bed in the posttreatment system. To remove the hydrogen peroxide, ferric chloride is mixed with the clean water, and the hydrogen peroxide decomposes in a catalytic process into water and oxygen. The efficiency of the decomposition reaction is monitored by the oxidation-reduction potential analyzer in the line from the clean water tank.

From the clean water tank, the treated water flows to a clean water pump rated at 0.0063 m^3/sec (100 gpm) and 11 m (35 ft) total developed head. The pressure increase is

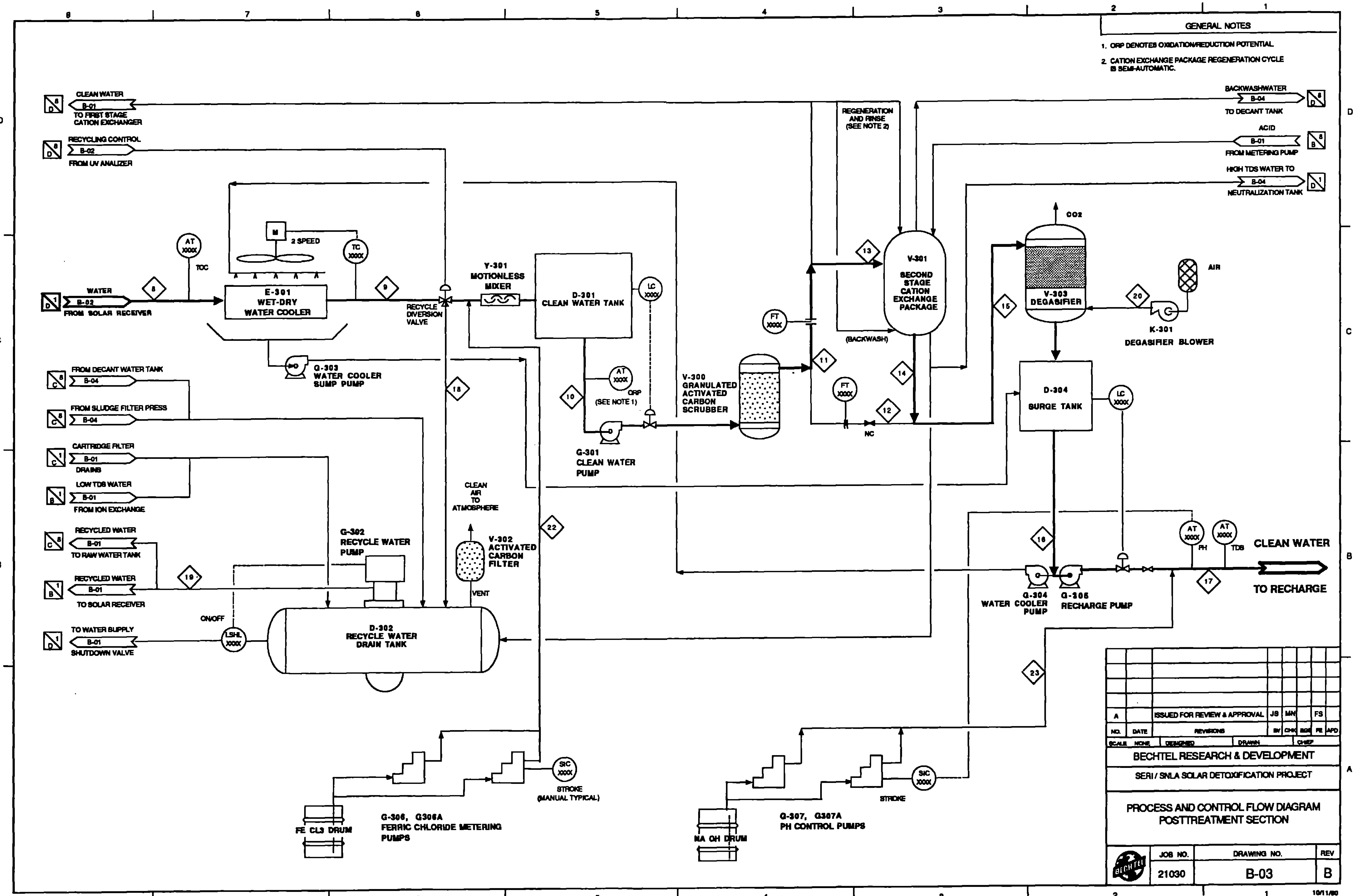


Figure 3-6 Process and Control Flow Diagram: Post-treatment System

necessary to overcome the friction losses in the balance of the posttreatment system. The entire flow passes through granulated activated carbon filters to remove trace quantities of organic materials and to ensure that partially treated water does not reach the discharge pump. Two 50 percent filters, with a combined carbon weight of 59 kg (130 lb), are provided. The carbon is replaced periodically as it accumulates organic materials.

The entire flow is directed to the posttreatment cation bed exchanger, where residual calcium bicarbonate is removed to reduce the total dissolved solid concentration to 374 ppm. The reaction chemistry is identical to that shown in Equations 1 and 2. However, the quantity of calcium ions removed in the posttreatment exchanger is less than that in the pretreatment exchanger, and the bed can operate continuously for 48 hours before regeneration is required.

The pH of the water leaving the cation bed is 3.5 to 4, and must be increased to 6 to 7 prior to discharge. The pH could be increased by adding sodium hydroxide; however, the hydroxide will react with the carbon dioxide from the decomposition process as follows:

$$NaOH + CO_2 \rightarrow NaHCO_3 \qquad (6)$$

The sodium bicarbonate increases the dissolved solid concentration above the 400 ppm discharge limit. To avoid this problem, the pH is increased in two steps. In the first step, the dissolved carbon dioxide concentration is reduced in an air blown degasifier. A reduction in concentration to 3-5 ppm causes an increase in the pH to nearly 6. In the second step, a small quantity of sodium hydroxide is added, bringing the pH to the required 6 to 7. The flow of sodium hydroxide is adjusted based on the reading of a pH analyzer in the discharge line. Since the quantity of sodium hydroxide is small, the total dissolved solid concentration increases only 16 ppm to a final value of 390 ppm.

Treated water flow from the degasifier passes through a surge tank and on to the discharge pump. The discharge pump is rated at 0.0063 m^3/sec (100 gpm), with a total developed head of 7 m (25 ft) to overcome the friction losses in the discharge piping.

3.5 AUXILIARY SYSTEMS

The auxiliary systems receive backwash and rinse water from the cation exchange beds, adjust the water chemistry to conditions suitable for disposal, and return filtered water to the posttreatment system. A process and control flow diagram is shown in Figure 3-7, and an equipment list is shown in Table 3-2.

During the regeneration process, the beds are backwashed with clean water to remove any small quantities of fractured resin material. This water is directed to a decant tank, where the resin is allowed to settle. Approximately once a month, the decanted water is returned to the recycle tank and the sludge is sent to a filter press. Filtered water from the press is returned to the recycle tank, and the partially dehydrated sludge, which is non hazardous, is sent off site to waste.

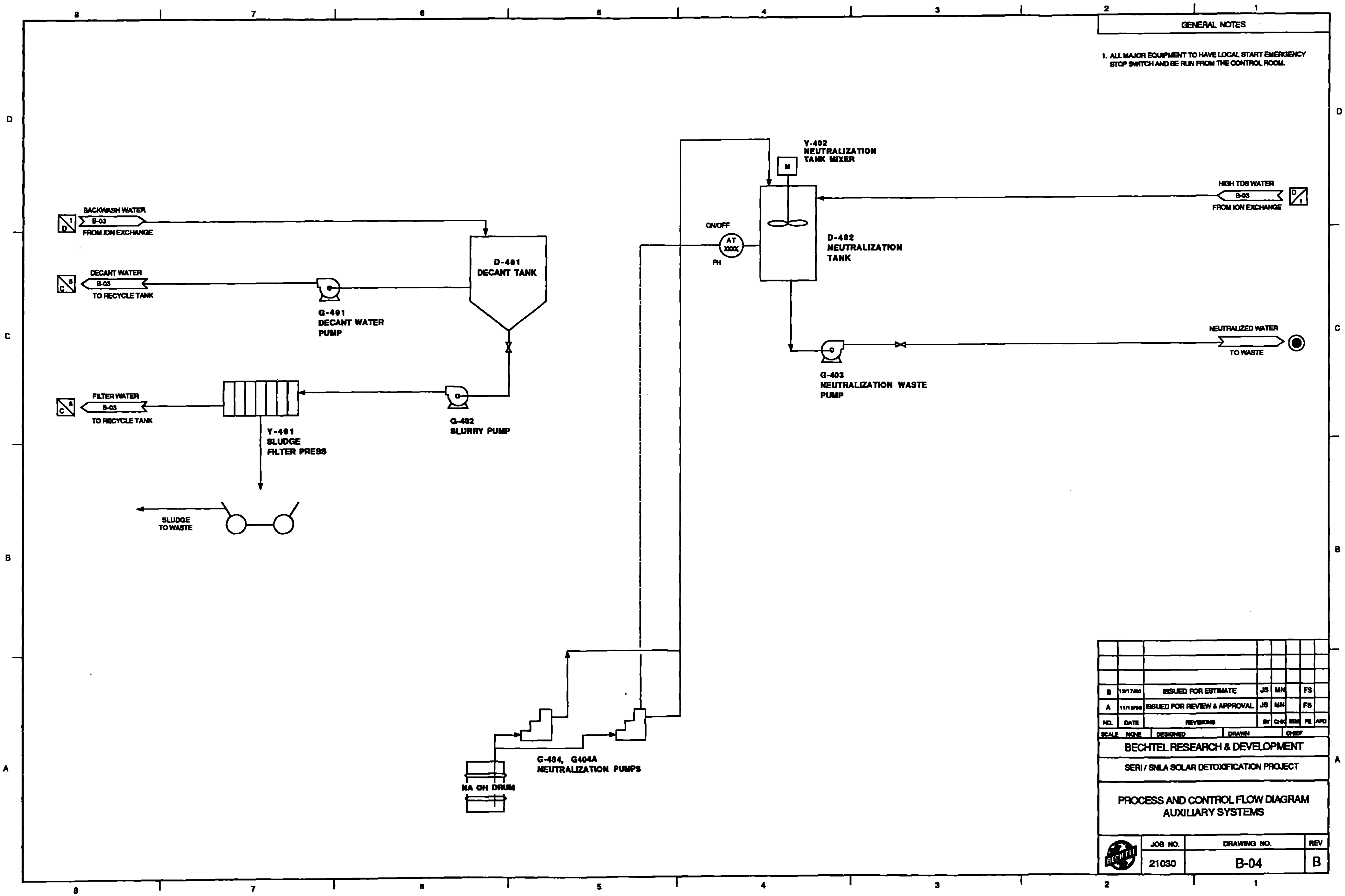


Figure 3-7 Process and Control Flow Diagram: Auxiliary Systems

After the cation bed exchangers are regenerated with hydrogen ions, the beds are rinsed to remove calcium chloride salts. Early in the rinse process, the water is highly acidic and has a high dissolved solid concentration. This water is directed to the neutralization tank. When the tank is full after several days, the sodium hydroxide metering pumps are started and inject sodium hydroxide into the tank until a pH of 6 to 7 is reached. The neutralized water, high in total dissolved solids, is sent to waste.

Also included in the auxiliary systems is an air compressor system, providing compressed air for the control valve actuators, decant slurry pump, and maintenance tools. The system includes a reciprocating compressor, rated at 7 liters/sec (15 scfm) and 860 kPa (110 psig), with a 2 kW (3 hp) motor, aftercooler, receiver, and dryer.

3.6 CONTROL SYSTEM

The control system performs the following functions:

- Establishes the facility operating modes to maximize the annual volume of treated water
- Switches between operating modes, either automatically or in response to operator commands
- Alarms the operator for conditions that are outside of normal, and initiates a facility shutdown for emergency conditions
- Logs anomalous equipment performance and collects operating data for performance analyses.

3.6.1 Operating Modes

The facility has 3 principal operating modes: off, normal operation, and regeneration. The facility also has 2 transition modes: startup, and shutdown. In the first operating mode (off), the collectors are stowed, the field piping is drained, all pumps are off, and the control system only monitors wind speed.

In the first transition mode (startup), the facility is brought from the off condition to the normal operation condition. The operator reviews the control system log to check for unusual equipment performance on the previous day, ensures that the regeneration of the cation exchangers has been completed, and checks the weather forecast for sub freezing temperatures that might cause ice to form in the receiver tubes. The raw water and recycle water pumps are started and checked for normal operation. Both pumps are run until the field piping and solar receivers are filled and vented. The collectors are aligned with the sun, and the flow rate through the raw water and recycle water pumps is adjusted to the ultraviolet insolation. When the treated water has completed at least one pass through the collectors, the recycle water pump is stopped, the clean water and discharge water pumps are started, and the treated water is directed to discharge.

In the second operating mode (normal operation), the collectors track the sun and the water flow rate is adjusted to maximize the annual volume of treated water. The principal parameter for setting the flow rate is a calculation by the control system of the ultraviolet flux on the receiver tubes. The calculation uses as its inputs the following:

- The direct normal ultraviolet insolation, as measured by a two axis tracking ultraviolet pyrheliometer
- Projected reflector area, as determined by the cosine of the azimuth angle of the sun. The control system determines the azimuth angle by a sun position algorithm
- Collector reflectivity, as measured daily by the operator.

The flow rate is set directly proportional to the ultraviolet flux on the receiver tubes if the flow rate is at least 20 percent of design conditions, or 0.0013 m^3/sec (20 gpm). Below this value, the flow through the cation beds tends to form channels and severely diminish the resin area for ion exchange. In addition, the friction losses in the parallel collector flow paths drop to extremely low values, and it is difficult to ensure a uniform flow distribution. To ensure that partially treated water does not reach the collectors or the clean water tank, the raw water pump is stopped and the collectors are defocused when the flow rate drops below 0.0013 m^3/sec (20 gpm). When insolation levels return to values that will support the minimum flow rate, the facility restarts automatically.

In the third operating mode (regeneration), the pretreatment cation beds are regenerated every other evening and the posttreatment beds every sixth evening. The process is automatic, and must only be monitored by the operator the following morning after it is complete.

In the second transition mode (shutdown), the facility is brought from the normal operation condition to the off condition. This occurs at the end of each day, and can also be initiated by low insolation due to clouds, a drop in air temperature to sub freezing levels, or high winds. The raw water, clean water, and discharge pumps are stopped, and the collectors and field piping automatically drain back to the recycle tank.

3.6.2 System Equipment

The control system equipment includes a process controller, operator station, communication bus, collector drive motor controller, data acquisition system, and weather station.

Process Controller The process controller is a microprocessor responsible for the following:

- Monitoring the weather station and time of day, and selecting the facility operating mode
- Calculating the ultraviolet flux on the receiver tubes and selecting the treated water flow rate

- Calculating the elevation angle of the sun and orienting the collectors with the sun
- Monitoring the facility instrumentation, such as tank levels and pump flow rates, and notifying the operator if abnormal conditions appear
- Initiating a facility shutdown under emergency conditions.

The process controller is a 12 MHz AT-compatible system, with 2 megabytes of random access memory (RAM) and a 60 megabyte hard disk. An operator station with a monitor, keyboard, external hard disc storage, and printer are also provided. From the station, the operator can monitor all plant functions and implement changes to the software.

Communication Bus A communication bus carries information between the process controller, facility instrumentation, and the collector drive motor controller. RS 232/422 serial input/output cards are used as the interface between the process controller, instrumentation, and drive motor controller.

Collector Drive Motor Controller The drive motor controller is responsible for receiving operating mode commands from the process controller and directing the drive motor to track, wait, or stow. As noted above, the actual position of the collector is governed by the shadow well sun sensor.

Data Acquisition System The data acquisition system processes and stores operating information for subsequent analysis of performance and trends. The system includes an AT-compatible computer, disc and tape storage, monitor, printer, and connection to the WWVB receiver (radio clock). Inputs to the data acquisition system are provided by the normal plant instrumentation.

Weather Station The facility weather station includes a two axis tracking ultraviolet pyrheliometer to measure the direct normal ultraviolet insolation, an anemometer to measure wind speed, and thermometers to measure air temperature. Other instrumentation, not directly related to control of the facility, include a two axis tracking pyrheliometer to measure total direct normal insolation, a pyranometer to measure total horizontal insolation, a sight glass to measure rainfall, and a hygrometer to measure dew point temperature.

3.7 ANNUAL FACILITY PERFORMANCE

The annual volume of groundwater that can be treated by the facility was estimated as follows:

- Clear sky values of direct normal insolation for each hour of the day on the 21st day of each month were taken from the ASHRAE tables for 40 degree north latitude site (Ref. 3-6)

- Sun elevation and azimuth angles for each hour of the day on the 21st day of each month were taken from the ASHRAE tables to determine the air mass at sea level (Ref. 3-6). The air mass at Rocky Flats was estimated to be 83 percent of the air mass at sea level

- The clear sky, direct normal ultraviolet radiation was calculated for each hour of the day on the 21st day of each month using the clear sky direct normal insolation, air mass, and the distribution of ultraviolet radiation to the total solar spectrum shown in Appendix C

- The average, direct normal ultraviolet radiation for each hour of the day on the 21st day of each month was calculated by multiplying the clear sky value by the ratio of Denver average daily direct normal insolation to ASHRAE clear sky daily direct normal insolation (Ref. 3-7)

- Collector efficiency values were reduced by the hourly values of the cosine of the angle between the normal to the collector and the sun azimuth

- Collector shadowing was calculated for early morning and late afternoon hours and reduced the collector efficiency during those hours in which shadowing occurred.

The facility also consumes electric energy for the pumps, collector drive motors, air compressor, control system, lights, and instrumentation. At the design point, the auxiliary power consumption was estimated as shown in Table 3-4.

At the design point, the auxiliary energy consumption is 1.5 kWh per 1000 gallons of treated water. The auxiliary consumption will change throughout the day and throughout the year in response to changing insolation and operating modes. The average annual consumption was estimated to be 20 percent greater than the design point consumption, or 1.8 kWh per 1000 gallons, to account for the following:

- Intermittent operation of the recycle water pump

- Evening regeneration of the cation bed exchangers

- Continuous operation of the control system.

Three parametric cases were studied to determine the probable range of annual treated water volumes. In Case 1, the lower flow limit for the cation bed exchangers was ignored and no limits were placed on winter operations. In particular, the facility is allowed to operate on days in which the air temperature is below freezing.

Table 3-4
DESIGN POINT AUXILIARY ELECTRIC POWER CONSUMPTION

Auxiliary Load	Power, kW
Raw water pump	3.2
Clean water pump	1.3
Discharge water pump	0.9
Metering pumps (3)	0.6
Water to air heat exchanger fan	0.0
Degasifier air blower	0.4
Collector drive motors	0.8
Air compressor (20 percent duty cycle)	0.4
Control system	1.5
Total	9.1

In Case 2, the minimum flow limit was imposed on the cation bed exchangers, but the facility operates throughout the year. In Case 3, the minimum flow limit was imposed, and the facility was assumed to be closed during November, December, and January. During these months, the daily temperatures are expected to remain below freezing, and there would be some risk in developing ice and cracking the receiver tubes.

The results of the analysis are summarized in Table 3-5. Detailed, hour by hour results for the Cases 2 and 3 are found in Appendix D.

Compared to conventional water treatment facilities, the capacity factors of the solar facility are low. At an alternate site, with higher annual insolation and warmer winter weather, the capacity factors can be expected to improve. However, low capacity factors are inherent in this technology, and an upper limit of perhaps 20 to 22 percent can be expected for a commercial plant at a site with above average insolation.

Table 3-5
ANNUAL FACILITY PERFORMANCE

Case	Minimum Flow, Percent of Design Flow	Operating Months	Annual Treated Water Volume	Auxiliary Energy Use, kWh	Capacity Factor (1)
1	0	12	33,700 m^3 (8,900,000 gal)	16,000	0.170
2	20	12	32,100 m^3 (8,500,000 gal)	15,000	0.161
3	20	9 (2)	27,800 m^3 (7,300,000 gal)	13,000	0.140

Notes:

1) Given by:

$$\frac{\textit{Treated Water Volume}}{\textit{Design Point Flow Rate} \times 60\frac{Min}{Hr} \times 8{,}760\frac{Hours}{Year}}$$

2) Excludes November, December, and January

Section 4
PERMITTING PLAN

This section addresses the Federal and state permit requirements and schedule for the solar detoxification facility.

4.1 FEDERAL REGULATORY PROGRAMS

The principal Federal regulatory programs include the National Pollutant Discharge Elimination System, the National Environmental Policy Act, the Endangered Species Act/Wildlife Coordination Act, and the National and Historic Preservation Act.

4.1.1 National Pollutant Discharge Elimination System (NPDES)

NPDES permits are required for any discharge to "surface waters of the US", including streams, marshes, rivers, and lakes. Permissible pollutant levels are specified such that the treated water will not degrade the quality of the surface water. Standards are provided for the following:

- Toxics and bacteria
- Total suspended solids
- Biological, chemical, and total oxygen demands
- Phosphates (PO_x), nitrates (NO_x), and other nutrients
- pH and hydrogen compounds
- Salinity, acidity, and alkalinity
- Chlorine, heavy metals, and other chemical constituents
- Taste, odor, color, turbidity, and temperature
- Trash, refuse, oil, and grease.

The most stringent requirements will be for discharge to a stream with cold water biota, and the standards may exceed those for drinking water. A NPDES surface water permit would likely be the most difficult a solar detoxification facility must obtain. The permitting effort would require approximately 6 months; however, it could be conducted in parallel with the Colorado Resource Conservation and Recovery Act permit (described below).

A stormwater permit for point source discharges from areas associated with industrial activity, including waste treatment or corrective action, is also required. The facility will require plans for sediment control during construction, and monitoring stormwater flows into state waters for possible contamination.

Colorado is authorized by the US Environmental Protection Agency to issue and enforce the NPDES permits in Colorado. The issuing agency is:

Water Quality Control Commission
4210 East 11th Avenue
Denver, Colorado 80220

Phone: (303) 331-4525

For the purposes of the study, the discharge basin is assumed to be a surface water and a NPDES permit will be required.

It should be noted that other discharge basins can be postulated that have less stringent water quality and permitting requirements. These include the following:

- Aquifer. If the aquifer has a beneficial use, a permit to discharge into the aquifer requires demonstration that the beneficial use will not be degraded. The highest beneficial use is human drinking water; however, the standards for temperature, pH, dissolved solids, and dissolved oxygen are not as strict as for surface waters. The treated water must comply with the Underground Injection Control (UIC) program requirements. The effort to secure a permit to discharge to an aquifer will not be significantly different than to discharge to a surface water

- Publicly owned water treatment works. Each water treatment work sets its own pretreatment requirements to avoid receiving industrial wastes which could upset its equipment or cause materials to pass through which violated surface water standards. However, these pretreatment requirements allow contaminant levels approximately 3 times greater than that for surface water discharge. In addition, permitting is less complex than discharge to an aquifer because potentially extensive studies of underground water flows are not required. The principal disadvantage to this approach is that the detoxification facility must be located nearby a sewer line feeding the water treatment works

- Recycle as process water in an industrial facility. If the detoxification facility is attached directly to the process generating the waste water, the treatment facility qualifies for a "closed pipe" exemption and does not need a permit. Industries in areas where the demand for water has exceeded the supply may be interested in treating and recycling the contaminated water which the industry had traditionally discarded.

4.1.2 National Environmental Policy Act (NEPA)

The NEPA requires an environmental impact statement for any Federal decision or project on Federally owned property which may affect the environment. In addition, if the entire project is located within the bounds of a Superfund site (such as Rocky Flats) and it treats water from the site, the project must conform to the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

At the start of the effort to develop a permitting plan, NEPA and CERCLA had separate regulatory requirements. Recently, the Department of Defense and the Department of Energy have agreed to integrate the CERCLA and NEPA requirements under a Federal Facilities Agreement and to develop an overall cleanup strategy. The process of approving the strategy will not start until the site is well characterized, environmental impacts have been evaluated, and the agencies are in agreement as to an appropriate strategy. The initial site characterization for CERCLA sites prior to adoption of a cleanup strategy may take several years.

Addition of a solar detoxification facility to the proposed cleanup strategy will require the Federal Facilities agreement to be modified. Also, an environmental assessment will need to be prepared and reviewed by the public and all signatories of the interagency agreements. Such agreements provide for regular meetings of all agencies with jurisdiction, and this can speed the review and comment process. Although a formal permit is not required at a Superfund site, the complexity of the environmental statement will be comparable to that required for a Resource Conservation and Recovery Act submittal (described below).

To further complicate the issue, if EPA Region 8 decides to have the detoxification technology reviewed by the EPA Superfund Innovative Technology Evaluation (SITE) group, delays of at least 18 months can be expected due to backlogs at the EPA.

In summary, construction of a demonstration facility at the Rocky Flats site is likely to be postponed for several years until a formal cleanup strategy has been adopted.

4.1.3 Other Federal Regulatory Programs

The facility must also comply with the following Federal regulatory programs:

- Endangered Species Act/Wildlife Coordination Act. These issues must be addressed in the NEPA environmental impact statement and be given substantial consideration in the permit application

- National and Historic Preservation Act. This act includes various Federal and state regulations which must be addressed in the environmental impact statement.

4.2 COLORADO REGULATORY PROGRAMS

The principal Colorado regulatory programs include the Resource Conservation and Recovery Act/Land Ban, Colorado air emission standards, Underground Storage Tank permit, Hazardous Materials Storage Permit, Alternative Technology program, and building permits.

4.2.1 Resource Conservation and Recovery Act (RCRA)/Land Ban

The activity initiating the requirement for a RCRA permit is the treatment of hazardous waste. Colorado is authorized to issue and enforce RCRA permits for the treatment, storage, and disposal of hazardous materials under the Colorado Hazardous Waste Regulations (6 Colorado Code of Regulations 1007-3). The hazardous waste treatment regulations in Colorado closely parallel the Federal regulations, even to the point of similar numbering. As with the Federal regulations, Colorado does not have a particular treatment, storage, disposal permit application. Each facility must develop its own application from the regulations, in consultation with the state permitting officer. Federal RCRA guidance documents are used as references by the state permitting officers and are recommended to facilities seeking guidance. There is a statutory requirement that the permit application be filed at least 180 days prior to start of facility construction.

The agency issuing the permit is:

Colorado Department of Health
4210 East 11th Avenue
Denver, Colorado 80220
Phone: (303) 320-8333

Contact: Carl Daily
Phone: (303) 331-4405

Four different permitting scenarios have been identified, as follows:

1) Installation at a CERCLA or a Federal Facilities Agreement site. As noted above, the permit schedule will be determined by the signatories to the interagency agreement and the involvement of the EPA SITE technology review group and may require several years.

2) Research and development permit at a location which is not at a CERCLA or Federal Facilities Agreement site. Colorado can be expected to review the application and issue the permit in 6 to 10 months, depending on the complexity of the facility and the application backlog.

3) Installation mandated as an interim corrective action ordered by a regulatory agency. In this situation, only Part A of the RCRA requirements would be required, and "there would be essentially no delay" (6 weeks) in receiving the approvals.

4) Detoxification facility attached to an industrial facility generating the waste water. The overall facility would qualify as a "Totally Enclosed Waste Treatment Facility" and would be exempt from the hazardous waste treatment permit requirements. Only drawings of the facility would need to be submitted to the state to substantiate the exclusion request.

For the purposes of the study, permitting scenario Number 2 has been adopted.

4.2.2 Other Colorado Regulatory Programs

The facility must also comply with the following Colorado regulatory programs:

- Air emission standards, including the New Source Performance Standards and Prevention of Significant Deterioration and the National Emission Standards for Hazardous Air Pollutants. These requirements are met by installing activated carbon filters on all equipment that vents to the atmosphere

- Underground Storage Tank Permits. Underground storage tank permits are required for underground tanks and buried piping containing hazardous materials. In the detoxification facility, this includes the recycle water drain tank and the supply manifold to the collector field

- Hazardous Materials Storage Permit. This permit, and associated emergency response plan, requires notification to emergency workers of the locations and amounts of hazardous materials in the facility. Included in this material category are the hydrogen peroxide, hydrochloric acid, and sodium hydroxide used in the pretreatment and posttreatment systems

- Alternative Technology. Colorado has an alternative technology encouragement program which may facilitate the permitting of a pilot plant; however, the program will not be applicable to future commercial facilities

- Normal building permits and land use ordinances.

4.2.3 Submittals

The following drawings will be required during the permitting process:

- Quadrangle map showing facility location, site vicinity map, block map, lot map, and plot plan

- Topographic study, geologic profile, and site boring location plan

- Wet land determination and vegetation plan
- Site grading and drainage plans, including yard civil and structural details and sanitary waste system plan
- Erosion and sediment control drawings, including diagram of proposed outfalls
- Process flow diagrams.

4.3 REGULATORY ISSUES AND PROGRAMS NOT COVERED

The following issues have been excluded from the permitting plan:

- Radioactive materials and heavy metals. As stated in the design basis, these materials are assumed not to be present in the groundwater. However, if heavy metals are encountered and must be treated or disposed on site, substantial additional RCRA permitting requirements can be expected
- Water rights. In Colorado, water rights are based on prior appropriation. This should not be an issue at the Rocky Flats Plant, but may be an issue at other sites in the western US (See Colorado Revised Statutes (CRS) § 37-90-138)
- Sewer extension permit, or permit to discharge to a publicly owned treatment facility
- Transportation of hazardous materials by motor vehicles
- Prohibitions on hazardous waste disposal or the burial of hazardous liquids (See CRS § 25-15-200.3(4)(a))
- Regulated substance release/public nuisance - corrective actions/hazardous substance incident reporting (See CRS § 43-91-113)
- OSHA requirements for worker training and right to know. OSHA rules are believed to be applicable, but are not considered a permitting issue.

Section 5
SCHEDULE, INSTALLED COST, AND OPERATING COST

Included in this section are discussions of the design and construction schedule, installed cost, operating cost, and treated water cost estimates. To simplify the analysis, all cost estimates are shown in constant year 1991 dollars, and the escalation rate for determining costs in future years is assumed to be zero.

5.1 DESIGN AND CONSTRUCTION SCHEDULE

A design and construction schedule for the facility is shown in Figure 5-1. The principal elements which determine the length of the schedule include:

- 9 month period to obtain the necessary permits. As outlined in Section 4, the schedule can be as short as 3 months if a waste treatment facility is mandated, and as long as 18 months for a first of a kind facility

- Vendor selection within 2 months from the start of final design

- 17 week procurement period for the solar collectors

- 2 month startup and checkout period.

The complete schedule for the demonstration facility requires slightly less than 2 years. If the facility design is replicated at another site by the same owner, much of the final design engineering can be reused and the schedule could be shortened by perhaps 2 to 3 months.

5.2 INSTALLED COST ESTIMATE

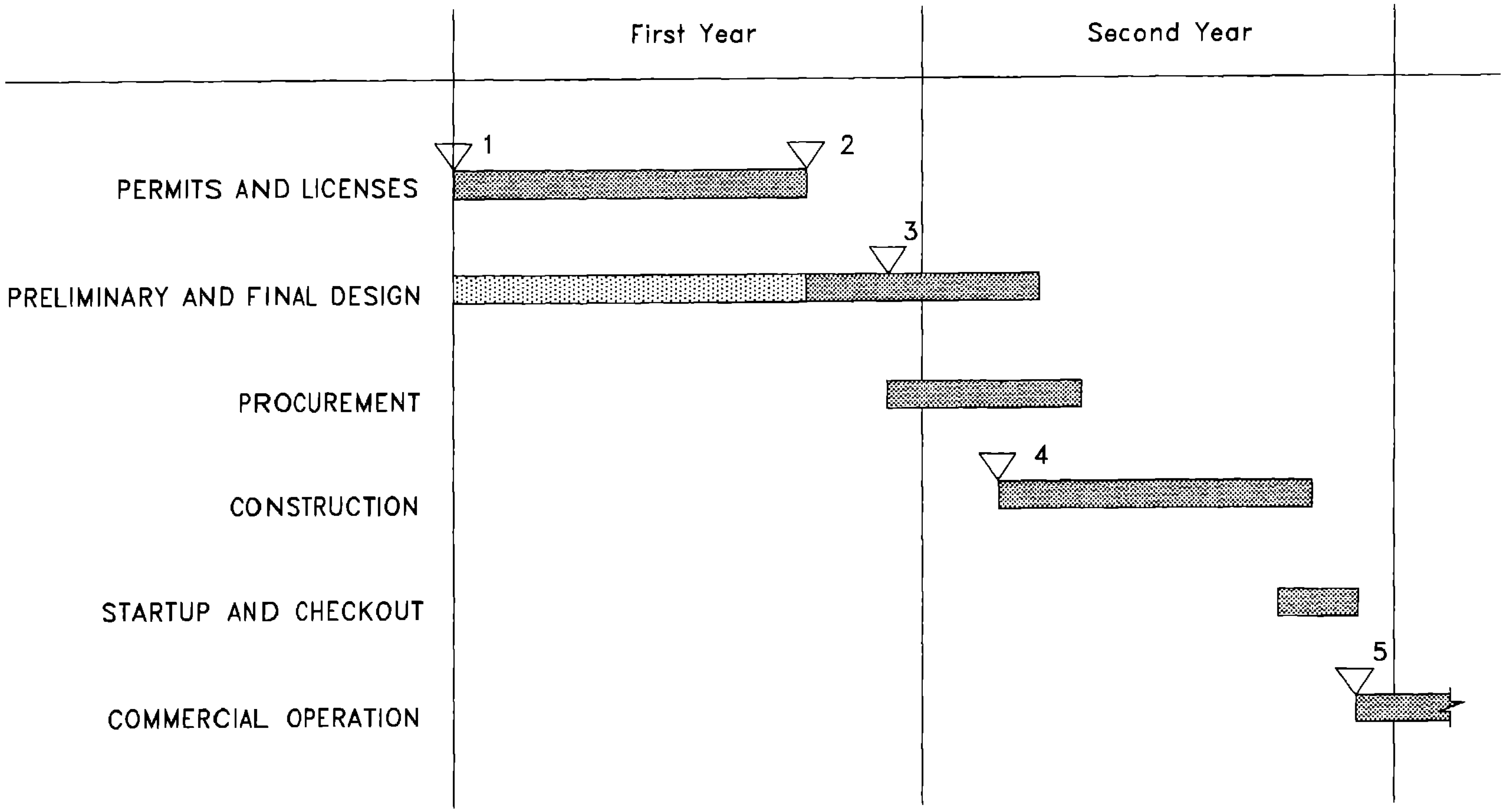
The installed cost estimate includes all of the costs associated with the design, construction, and startup of the facility. The estimate consists of the ten categories described below. A summary of the estimate is shown in Table 5-1, and the detailed development of the total field costs (direct field costs plus indirect field costs) is presented in Appendix E.

The principle qualifications to the estimate are as follows:

- Access to the Hillside 881 site is no more difficult or time consuming than access to a private commercial facility

- Electric power, potable water, and sewage facilities are assumed to be available at the site boundary

- Soil bearing capacities within 3 feet of grade are assumed to be at least 2,000 lb/ft^2



Milestones

1. Authorization to Proceed
2. Land Use Permit
3. Vendor Selection for Long Lead Procurement
4. Start of Civil/Construction Work
5. Start of Commercial Operation

Figure 5–1 Design and Construction Schedule

Table 5-1
TOTAL INSTALLED COST SUMMARY

		System Cost	Project Contingency	Total
0.0	LAND	$0	0%	$0
1.0	BUILDINGS AND SITE IMPROVEMENTS	$129,000	25%	$161,000
2.0	PRETREATMENT SYSTEM	$124,000	25%	$155,000
3.0	COLLECTOR SYSTEM	$291,000	15%	$335,000
4.0	RECEIVER TUBES	$58,000	15%	$67,000
5.0	POSTTREATMENT SYSTEM	$263,000	25%	$329,000
6.0	AUXILIARY SYSTEMS	$84,000	25%	$105,000
7.0	CONTROL SYSTEM	$59,000	25%	$74,000
8.0	TOTAL FIELD COST			$1,226,000
9.0	CONSTRUCTION MANAGEMENT (5%)			$61,000
	Subtotal			$1,287,000
10.0	ENGINEERING AND PROJECT MANAGEMENT (15%)			$193,000
	Subtotal			$1,480,000
11.0	OWNER'S ENGINEERING AND PERMITS			$169,000
12.0	TOTAL FACILITY COST (First Quarter 1991 Dollars)			$1,649,000

ESCALATION AND ALLOWANCE FOR FUNDS DURING CONSTRUCTION

	Annual Distribution of Expenditures	
	First Year (20%)	Second Year (80%)
TOTAL FACILITY COST (First Quarter 1991 Dollars)	$330,000	$1,319,000
ESCALATION (0%; First Quarter 1991 Dollars)	$0	$0
ALLOWANCE FOR FUNDS DURING CONSTRUCTION (7.2% Discount Rate; First Quarter 1991 Dollars)	$24,000	$0
	$354,000	$1,319,000

12.0	TOTAL FACILITY COST (First Quarter 1991 Dollars)	$1,649,000
13.0	ESCALATION (First Quarter 1991 Dollars)	$0
14.0	ALLOWANCE FOR FUNDS DURING CONSTRUCTION (First Quarter 1991 Dollars)	$24,000
15.0	PREPRODUCTION COSTS (2% Total Facility Cost plus 1 month operating cost)	$42,000
16.0	SPARE PARTS (0.5% of Total Facility Cost)	$8,000
17.0	TOTAL INSTALLED COST (First Quarter 1991 Dollars)	$1,723,000

- Land is assumed to be available at no cost to the project

- Future escalation costs are excluded.

5.2.1 Direct Field Cost

The total field cost includes the direct cost of equipment and bulk materials, plus the direct cost of installation labor. The estimate assumes that the facility design and construction is managed by an engineer-constructor, using a direct hire labor from union sources.

Direct Field Equipment Costs Budgetary estimates for the following major equipment were obtained from potential suppliers:

- Collectors and drives: Solar Kinetics, Inc.

- Receiver tubes with fixed catalyst: Solar Energy Research Institute

- Cation bed exchangers: IWT, Inc.

- Water to air heat exchanger: IMECO

- Filter press: West General Associates

- Cartridge filter: Filtrex, Inc.

- Air stripper: Chempro, Inc.

- Activated carbon filters: Weststate Carbon, Inc.

- Gas chromatograph: Rosemount Analytical

The balance of the equipment and bulk material estimates were obtained from informal vendor contacts and detailed Bechtel estimates of similar commercial and wastewater treatment facilities.

A Colorado state sales tax of 4.2 percent is applied to all material costs. The facility is located on Federal property, and the land is assumed to be available at no cost to the project.

Direct Labor Costs Construction labor rates were developed from craft wage rates in Colorado. The direct rates include all payroll additives for health, welfare, pension, vacation, FICA taxes, workmen's compensation, insurance, and 5 percent casual overtime. Sufficient labor is assumed to available in the greater Denver area, and as a result, no allowance is provided for travel or subsistence.

5.2.2 Indirect Field Costs

Indirect field costs are those material and labor costs that cannot be assigned to specific equipment items or systems. Included in indirect costs are the following:

- Temporary construction buildings, utility systems, and scaffolding
- Construction equipment, small tools, equipment maintenance, material handling, consumable supplies, and purchased utilities
- Crane, earth mover, and truck rentals
- Field staff, providing craft supervision, personnel activities, and warehousing
- Contractor overhead and profit.

Indirect costs are estimated to be $17.50 for each craft labor hour. The derivation of the indirect cost is included in the total field cost estimate details in Appendix E.

5.2.3 Project Contingency

The conceptual design presented in Section 3 does not include all of the detail which would be present in a final design. As a result, the total field costs shown in Appendix E are necessarily incomplete. To properly account for the unidentified costs, a contingency is added to each system cost, based on the level of definition in each system design. For this study, the following contingencies (in percent) have been used:

Collectors	15
Receiver tubes with catalyst	15
Mechanical and electrical equipment	25
Master control system	25

The sum of the direct field costs, indirect field costs, and project contingencies is the total field cost.

5.2.4 Construction Management

Construction management includes construction management, engineering support during construction, vendor and subcontractor administration, quality assurance, and scheduling. Construction management costs are estimated to be 5 percent of the total field costs.

5.2.5 Engineering and Project Management

Engineering and project management includes preliminary design, site investigations, engineering support during the permitting activities, final design engineering, specifications, procurement, vendor contract administration, scheduling, and cost estimating.

Engineering and project management costs are estimated to be 15 percent of the sum of the total field and construction management costs.

5.2.6 Owner's Engineering and Permits

Owner's engineering includes financial closing, owner's engineering and construction management, and property taxes and insurance during construction. Permits includes site studies, environmental studies, licenses, permits, and water rights.

Owner's engineering costs are estimated to be 6 percent of the sum of the total field costs, construction management costs, and engineering and project management costs. Permit costs include the following:

- During the preliminary design, one engineer full time for 3 months and half time for 6 months to prepare the environmental studies
- $5,000 for permit applications and filings with Colorado.

5.2.7 Escalation

The sum of the total field costs, construction management, engineering and project management costs, and owner's engineering and permits is the total facility cost (in first quarter 1991 dollars).

The permit, design, and construction period for the facility is approximately 2 years. During this time, the total facility cost can normally be expected to increase due to escalation. For this study, a constant year dollar analysis has been assumed, and the escalation in the total facility cost during the design and construction period is excluded.

5.2.8 Allowance for Funds During Construction

During the design and construction period, funds are being expended on the project, but the facility is not yet producing a useful product (treated water). The cost to the owner of committing these funds to the project rather than to a competing investment is a forfeiture of interest income. The cost, termed the allowance for funds during construction, is calculated as follows:

- Estimates are made of the percentage of funds spent during each year of the design and construction period. From the schedule in Figure 5-1, 20 percent of the project funds are estimated to be spent in the first year, and 80 percent in the second
- Interest on the annual expenditures is calculated from the end of the year to the start of commercial operations.

The interest rate is the weighted cost of capital, or discount rate. For this analysis, a discount rate of 7.2 percent was used, based on private ownership and a combination of debt and equity financing as follows (values in percent; debt and equity costs are real values that exclude escalation):

Source	Cost	Contribution	Return
Debt	4.6	75	3.5
Equity	15.0	25	3.7
			7.2

The discount rate is minimized by selecting as large a debt contribution as possible. However, the debt to equity ratio usually cannot exceed 3:1 due to bank requirements for equity participation.

5.2.9 Preproduction Costs

The preproduction costs include the following:

- One month of normal operation and maintenance costs to cover operator training
- 2 percent of the total facility cost to cover expected changes and modifications to equipment such that the facility meets its performance requirements.

5.2.10 Spare Parts

Included in the estimate is an allowance for spare parts equal to 0.5 percent of the total facility cost.

The sum of the total facility cost, escalation, allowance for funds during construction, preproduction costs, and spare parts is the total installed cost.

5.3 OPERATING COST ESTIMATE

The operating cost estimate includes all personnel and material costs required to operate and maintain the facility. A summary of the estimate is presented in Table 5-2. It is assumed that the facility owner contracts the operation to a private company, which operates and maintains the facility under an incentive contract. A private company is free to hire open shop (non union) personnel and to adjust the length of the work day to follow the seasons. In addition, the central office of the operating company can provide services such as supervision, procurement, maintenance, and payroll. For a small facility, this significantly reduces the number of personnel on the payroll. Private company operation of solar facilities has been successfully used (on a larger scale) by Luz International in its series of solar thermal power plants.

5.3.1 Personnel

A operation and maintenance staffing requirement has been developed based on the following:

Table 5–2
OPERATING COST ESTIMATE DETAIL

	BASE SALARY	ADDITIVES	G&A (1)	TOTAL
LABOR AND OVERHEAD				
- OPERATIONS: 0.4 (Notes 2,3)	$16,704	$5,178	$4,176	$26,100
- MAINTENANCE				
o MECHNICAL EQUIPMENT: 0.05 (Note 2)	$2,088	$647	$522	$3,300
o ELECTRICIAN: 0.05 (Note 2)	$1,670	$518	$418	$2,600
o INSTRUMENTATION AND COMPUTER TECHNICIAN: 0.1 (Note 2)	$3,341	$1,036	$835	$5,200

				$37,200
MAINTENANCE MATERIALS				
- COLLECTORS (10 year film life, $0.80/m^2-year levelized film replacement cost)				$900
- RECEIVER TUBES AND CATALYST (No replacement required)				$0
- MECHANICAL EQUIPMENT AND PIPING (2% material cost/year)				$6,000
- ELECTRICAL EQUIPMENT (2% material cost/year)				$300
- CONTROLS AND INSTRUMENTATION				
o CONTROL SYSTEM COMPUTERS (4% material cost/year)				$1,300
o INSTRUMENTATION (5% material cost/year)				$3,400
- SITE MAINTENANCE (Roads, fences, and weed control)				$500
- WASTE DISPOSAL				
o LIQUIDS: 70,000 gal/yr @ $0.04/gal ($0.02/gal hauling; $0.01/gal sampling; $0.01/gal disposal)				$2,800
o SOLIDS: 1,000 lbs/yr @ $0.10/lb				$100
- MISCELLANEOUS				
o SITE VEHICLE				$2,500
o EQUIPMENT RENTAL				$1,000
o MISCELLANEOUS				$2,000

				$20,800
CHEMICAL SUPPLIES				
- HYDROCHLORIC ACID (30% solution; 17,300 gallons @ $0.70/gallon)				$12,100
- FERRIC CHLORIDE (42% solution; 40 gallons @ $8.40/gallon)				$300
- SODIUM HYDROXIDE (40% solution; 1,150 gallons @ $3.50/gallon)				$4,000
- HYDROGEN PEROXIDE (50% solution; 3,575 gallons @ $7.40/gallon)				$26,500
- OXYGEN (7,040 lbs + 31% dewar leakage @ $0.33/lb)				$3,000
- ION EXCHANGE RESIN (7 ft3 @ $300/ft3)				$2,100
- DISTILLED WATER (2,000 gallons @ $0.05/gallon)				$100

				$48,100
AUXILIARY ELECTRIC ENERGY (15,000 kWh @ $0.10/kWh)				$1,500

SUBTOTAL				$108,000
OPERATING COMPANY FEE (15% of Subtotal)				$16,000

TOTAL OPERATING COST (First Quarter 1991 Dollars)				$124,000

1) General and administrative expenses
2) Equivalent full time personnel
3) Includes 0.05 man years for collector washing and inspection

- Facility operation is 7 days per week and 52 weeks per year

- According to Colorado regulations, the wastewater treatment facility can operate unattended if an operator can be sent to the plant on demand. Therefore, an operator is assumed to be the facility for 2 hours each morning to monitor the startup of the mechanical equipment. Once startup is complete and the facility is operating normally, the operator leaves and the facility operates for the balance of the day unattended

- Routine maintenance, such as collector cleaning and cartridge filter replacement, is conducted by the operator as needed. For maintenance that is of a special nature, such as computer repair, or if emergency maintenance is needed, the operating company provides the required personnel on a temporary basis.

The total annual operation requirement is estimated to be $^2/_5$ man years, and the total annual maintenance requirement is estimated to be $^1/_5$ man year. Base salaries for the personnel are based on experience with private operating companies in California. Added to the base salaries are the following personnel expenses:

- Additives for vacations, holidays, FICA taxes, health, and unemployment insurance equal to 31 percent of the base salary

- General and administrative expenses for the operating company equal to 25 of the base salaries. Included in the expenses are allowances for personnel travel, telephones, and office supplies.

5.3.2 Maintenance Materials

Annual maintenance material costs are estimated as follows:

- Collector reflective film replacement is required once every 10 years with a levelized cost of $0.80/m^2 (Ref. 5-1)

- Receiver tubes and catalyst are assumed to last for the life of the facility

- Mechanical and electrical equipment require 2 percent of the total field cost; computer equipment, 4 percent; and instrumentation, 5 percent

- Water from the neutralization tank is disposed off site; the disposal cost of $0.04/gal includes $0.02/gal for hauling, $0.01/gal for sampling, and $0.01/gal for disposal. Sludge from the filter press is disposed off site at a cost of $200/ton

- Allowances are provided for site maintenance, a site vehicle, and periodic equipment rental.

5.3.3 Chemical Supplies

The annual consumption of chemical supplies includes the following:

- 17,300 gallons of hydrochloric acid (HCl; 30% solution) for regeneration of the cation exchange beds
- 1,150 gallons of sodium hydroxide ($NaOH$; 40% solution) for pH adjustment of the recharge water and neutralization of the regeneration backwash water
- 3,575 gallons of hydrogen peroxide (H_2O_2; 50% solution) and 7,040 pounds of oxygen for water pretreatment. The lowest cost oxygen supply is liquid oxygen. Evaporation losses from the storage dewar add approximately 30 percent to the pretreatment requirement, giving a total annual consumption of 9,250 lbs.
- 40 gallons of ferric chloride ($FeCl_3$; 42% solution) for decomposition of hydrogen peroxide in the posttreatment system
- 7.0 cubic feet of cation exchange resin to replace the fractured bed material.

Bulk prices for the chemicals were obtained from commercial suppliers.

5.3.4 Auxiliary Electric Energy

The auxiliary electric energy use of the facility is approximately 0.5 kWh per m^3 (1.8 kWh per 1,000 gallons) of treated water. Using an annual treated water volume of 32,100 m^3 (8,500,000 gallons) and a purchased energy cost of $0.10/kWh, the annual expense for electric energy is $1,500.

5.3.5 Fee

If the facility meets its expected goal of annual treated water volume, the operating company is awarded a fee. For the purposes of the study, the fee is estimated to be 15 percent of the sum of the personnel, maintenance materials, chemical supplies, and auxiliary energy costs.

5.4 TREATED WATER COST ESTIMATE

The levelized cost of treated water, in constant year 1991 dollars per 1000 gallons, is the sum of the unit annual capital cost and the unit annual operating cost. The unit capital cost is calculated as follows:

$$\frac{\textit{Total Installed Cost x Levelized Capital Carrying Charge}}{\textit{Annual Treated Water Volume (1000 Gallons)}}$$

The unit operating cost is given by:

$$\frac{\textit{Annual Operating Cost x Levelizing Factor}}{\textit{Annual Treated Water Volume (1000 Gallons)}}$$

The levelized capital carrying charge is the annual revenue which must be generated to meet the carrying charges on each dollar of facility investment. The carrying charges are equal to the sum of the return on debt, return on equity, income taxes, book depreciation, property taxes, and insurance. For this study, a constant year, levelized capital carrying charge of 12.7 percent has been developed from the following:

- 75 percent of the plant is financed by debt with an interest rate of 4.6 percent
- 25 percent of the plant is financed by equity with a return on equity of 15.0 percent
- The combined Federal and state income tax rate is 41 percent
- The annual expenses for property taxes and insurance are 2 percent of the total installed cost
- The plant life is 20 years and the depreciation period is 15 years
- No investment tax credit is available.

The levelizing factor converts a series of payments, that is uniform over time except for a constant escalation rate, into an equivalent levelized cost. Normally, the operating costs can be assumed to increase over the life of the plant at a uniform rate as salaries and material prices increase. However, the escalation rate is taken to be zero, and the levelizing factor becomes 1.0.

The levelized unit cost of treated water is shown in Table 5-3. Also shown in the table are the costs of treated water if investment tax credits of 10 and 20 percent become available.

As a point of reference, levelized unit costs are also calculated for a plant life of 10 years and a depreciation schedule of 7 years. The results for investment tax credits of 0, 10, and 20 percent are shown in Table 5-4. The principal differences with the 20 year case are:

- The levelized capital carrying charge is greater because the capital investment must be recovered over a shorter period
- Operation and maintenance costs are lower because the collector film does not need to be replaced during the life of the plant.

Table 5-3
LEVELIZED COST ESTIMATE OF TREATED WATER
20 YEAR FACILITY LIFE
Constant Year 1991 $/1000 Gallons

	Investment Tax Credit		
	None	10 Percent	20 Percent
Levelized Capital Carrying Charge	0.127	0.112	0.097
Annual Capital Expense	$25.80	$22.70	$19.70
Annual Operating Expense	$14.60	$14.60	$14.60
Total, $/1000 Gallons	$40.40	$37.30	$34.30

Table 5-4
LEVELIZED COST ESTIMATE OF TREATED WATER
10 YEAR FACILITY LIFE
Constant Year 1991 $/1000 Gallons

	Investment Tax Credit		
	None	10 Percent	20 Percent
Levelized Capital Carrying Charge	0.170	0.147	0.124
Annual Capital Expense	$34.50	$29.80	$25.10
Annual Operating Expense	$14.50	$14.50	$14.50
Total, $/1000 Gallons	$49.00	$44.30	$39.60

Several items are apparent from an examination of the design and economic analysis, as follows:

- The cost of treated water is several times that from present water treatment facilities using air stripping or ultraviolet lamps, and is projected to be considerably more expensive than future ultraviolet lamp facilities that may require new posttreatment systems

- Approximately 30 percent of the capital and operating cost in the solar facility is due to regulations that require the total dissolved solid concentrations in the discharge water to meet drinking water standards. If a recharge basin can be identified that does not demand as strict a standard, the cost of water from the solar facility can be decreased to $25-$30/1000 gallons

- The cost of treated water can be reduced by selection of a collector field which is up to 50 percent larger than that required to meet the design point flow rate. Although this will increase the capital cost by approximately 15 percent, the capacity factor of the pretreatment and posttreatment equipment will increase by approximately 35 percent, and the overall facility economics should improve by approximately 15 percent

- A facility life of at least 20 years and the availability of investment tax credits are likely to be necessary conditions for the construction of commercial solar detoxification systems

- The operating costs are a significant portion of the treated water costs. Reductions are likely to be difficult due to the low capacity factor of the facility, and the costs of consumable supplies which are proportional to the treated water volume. One method for reducing operating costs might include the following:

    - Increase the capacity factor by increasing in the collector area

    - Develop detoxification systems that require a minimum of groundwater pretreatment

- Research in catalysts which can use a larger portion of the ultraviolet spectrum and development of low cost collectors will improve the facility economics. Both activities are underway as part of the DOE Solar Thermal Industrial Program.

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Appendix A

WELL WATER CONSTITUENTS AND pH DATA

Table A-1
GROUNDWATER CONSTITUENTS

ORGANICS	UNITS	INFLUENT [a] CONCENTRATION	TREATMENT REQUIREMENTS
Methylene Chloride	ug/l	<5[b]	5
Acetone	ug/l	<10[b]	50
Carbon Disulfide	ug/l	<5[b]	5
1,1 Dichloroethene	ug/l	622	7
1,1 Dichloroethane	ug/l	11	5
1,2 Dichloroethane	ug/l	2.0	5
1,1,1 Trichloroethane	ug/l	945	200
Carbon Tetrachloride	ug/l	65	5
Trichloroethene	ug/l	845	5
1,1,2 Trichloroethane	ug/l	<5[b]	5
Tetrachloroethene	ug/l	311	5
Toluene	ug/l	<5[b]	2000

METALS	UNITS	INFLUENT [a] CONCENTRATION	TREATMENT REQUIREMENTS
Aluminum	mg/l	0.0703	5
Antimony	mg/l	0.0264	.06
Arsenic	mg/l	0.0049	.05
Barium	mg/l	0.1076	1.0
Beryllium	mg/l	0.0022	0.1
Cadmium	mg/l	0.0021	0.01
Cesium	mg/l	0.1515	NS
Chromium	mg/l	0.0071	0.05
Copper	mg/l	0.0355	0.2
Iron	mg/l	0.0410	0.3
Lead	mg/l	0.0026	0.05
Lithium	mg/l	0.0450	2.5
Manganese	mg/l	0.0738	0.05
Mercury	mg/l	0.1290	0.002
Molybdenum	mg/l	0.0085	0.1
Nickel	mg/l	0.0683	0.2
Selenium	mg/l	0.1743	0.01
Silver	mg/l	0.0145	0.05
Strontium	mg/l	0.8287	NS
Thallium	mg/l	0.0072	0.01
Vanadium	mg/l	0.0391	0.1
Zinc	mg/l	0.1883	2.0

Table A-1 (Continued)
GROUNDWATER CONSTITUENTS

MAJOR IONS	UNITS	INFLUENT [a] CONCENTRATION	TREATMENT REQUIREMENTS
Calcium	mg/l	109.7	NS
Magnesium	mg/l	26.1	NS
Potassium	mg/l	2.7	NS
Sodium	mg/l	87.4	NS
Total Dissolved Solids	mg/l	718	400
Chloride	mg/l	128	250
Nitrite & Nitrate	mg/l	8.29	10
Sulfate	mg/l	122	250
Bicarbonate As ($CaCO_3$)	mg/l	274	NS

RADIONUCLIDES	UNITS	INFLUENT [a] CONCENTRATION	TREATMENT REQUIREMENTS
Gross Alpha	pCi/l	21.5	15
Gross Beta	pCi/l	17.8	50
Uranium (Total)	pCi/l	15.4	40
Strontium (89, 90)	pCi/l	<1.0[b]	8
Plutonium (239, 240)	pCi/l	<0.01	15
Americum (241)	pCi/l	<0.01	4
Tritium	pCi/l	<400[b]	20,000

a Based on a flow weighted average of the 881 Building footing drain flow (5 gpm) and alluvial groundwater at the 881 Hillside that would be collected in the french drain (2 gpm). Averages computed from the 1987 and 1988 data base, except organics. Organic compound concentrations determined from first and second quarter 1989 data.

b Detectable concentrations in some wells; however, blend should have non-detectable concentrations.

NS No standard.

Table A-2
GROUNDWATER pH DATA

LOCATION	CHEMICAL	RESULT	UNIT	QUAL.	D.LMT	GROUP	SMPL DATE
0187	pH	7.5	PHUNIT			RFIN	06-FEB-90
	pH	7.0	PHUNIT			RFIN	17-AUG-89
0387BR	pH	7.9	PHUNIT			RFIN	19-FEB-90
0487	pH	7.5	PHUNIT			RFIN	31-JAN-90
	pH	7.6	PHUNIT			RFIN	16-OCT-89
0587BR	pH	7.3	PHUNIT			RFIN	14-FEB-90
0687	pH	7.6	PHUNIT			RFIN	31-JAN-90
	pH	7.6	PHUNIT			RFIN	26-JUL-89
0887BR	pH	7.6	PHUNIT			RFIN	16-FEB-90
	pH	7.6	PHUNIT			RFIN	31-OCT-89
0974	pH	7.5	PHUNIT			RFIN	06-FEB-90
1074	pH	7.6	PHUNIT			RFIN	06-FEB-90
4387	pH	7.7	PHUNIT			RFIN	01-FEB-90
	pH	8.0	PHUNIT			RFIN	11-JUN-89
5287	pH	7.2	PHUNIT			RFIN	29-JAN-90
	pH	7.3	PHUNIT			RFIN	26-OCT-89
5387	pH	7.3	PHUNIT			RFIN	30-JAN-90
5986R6R	pH	7.6	PHUNIT			RFIN	20-MAR-90
6286	pH	8.5	PHUNIT			RFIN	16-FEB-90

19 records selected.

Table A-3
SERI REQUIREMENTS FOR WATER CHEMISTRY AT RECEIVER INLET

pH

Laboratory research has shown the photocatalytic process to be sensitive to pH. To date, experience has shown that maintaining a pH on the order of 6.0 produces the most effective destruction rates for chlorinated organics.

TEMPERATURE

Temperature has been demonstrated to be a minor factor in reaction rates for the photocatalytic process. However, the use of solar collectors has the inherent effect of increasing temperature of the process water as a function of flow rate. Boiling of the water through the reactors cannot be tolerated. Therefore receiving water for processing at or below ambient (preferably room temperature - say 21°C) is desirable.

PRESSURE

Working pressures of the glass tubing used for reactors in this process are on the range of 40 PSIG to 75 PSIG (pyrex glass). Pressure drops through the reactors have been estimated to run from less than 1 PSIG up to as much as 40 PSIG per control string, it is therefore necessary to receive the influent at pressures not less than 40 and not more than 60 PSIG to provide a safe operating range.

SUSPENDED SOLIDS

To avoid clogging and deposition of silt or other large scale contaminants in the system reactors or valves, the influent stream should be filtered to remove any suspended solids greater than 5 microns.

CATIONS

Iron is the only known cation to significantly affect photodestruction rates. Iron in the form of Fe^{+3} has been shown to decrease the photocatalytic reaction. These ions should be removed to the maximum degree economically feasible so that precipitation will not occur at pHs of 7.0 or below.

ANION

Bicarbonate is the only known anion to significantly affect photodestruction rates. Bicarbonate is a known competitor for hydroxyl radicals in a photocatalytic reaction. Experimental results show that concentrations in the range of 500 ppm of bicarbonate have a three fold negative impact on the reaction. Calculations indicate that such concentrations of bicarbonate can be offset by reducing the pH to 5.0. However pH reductions below 6.0 also negatively impact the reaction. Ground water samples from Lawrence Livermore Laboratory contain bicarbonate concentrations between 300 to 500 ppm. Our experience is incomplete in this area to know whether such concentrations are common or not. In this area, the contractors experience is needed. Some estimate on the design cost of a system to remove bicarbonate without adjusting pH below 6.0 is necessary. An order of magnitude of the cost and feasibility of reducing carbonate from concentrations of 2000 ppm, if such concentrations are ever likely to be encountered, down to 500 ppm or downwards to concentrations on the order of 10 ppm will help guide SERI designers in sizing the solar system.

UNKNOWNS

The photocatalytic process, as it is effected by common constituents of ground water, is poorly understood. Contractor guidance on what likely concentrations or ranges of concentrations for common cations and anions are to be encountered will help SERI researchers in conducting the proper experimental research to determine negative or positive effects of these constituents.

Appendix B

PARABOLIC TROUGH ULTRAVIOLET PERFORMANCE DATA

Table B-1
EFFECTIVE PHOTONS PER SECOND PER WATT IN THE 280 TO 385 nm UV BAND (AIR MASS = 1.5)

WAVELENGTH	IRRADIANCE*	PHOTONS/SEC-W**	PRODUCT
280	0		
290	0		
300	0		
310	18.1	1.58 (x 10^18)	28.59 (x 10^18)
320	80.6	1.63 (x 10^18)	131.41 (x 10^18)
330	166.2	1.68 (x 10^18)	279.44 (x 10^18)
340	212.4	1.73 (x 10^18)	367.94 (x 10^18)
350	251.3	1.78 (x 10^18)	448.13 (x 10^18)
360	278.2	1.83 (x 10^18)	510.27 (x 10^18)
370	340.6	1.89 (x 10^18)	642.08 (x 10^18)
380	352.8	1.94 (x 10^18)	683.06 (x 10^18)
SUM1 =	1700.2	SUM2 =	3090.92 (x 10^18)

UV PHOTONS PER SECOND PER UV WATT = SUM2/SUM1 = 1.82 (x 10^18)

* Taken from ASTM E891-82, "Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air Mass 1.5" , in units of W/(m2-micron)

** Photons/(Second-Watt) = .5095*10^16*Wavelength (in nanomenters)

Table B-2
REFLECTIVITY OF UNCOATED EVAPORATED METAL SURFACES

PERCENT NORMAL-INCIDENCE REFLECTANCE OF FRESHLY EVAPORATED MIRROR COATINGS OF ALUMINUM, SILVER, GOLD, COPPER, RHODIUM, AND PLATINUM, FROM THE ULTRAVIOLET TO THE INFRARED*†

λ, μm	Al	Ag	Au	Cu	Rh	Pt
0.220	91.5	28.0	27.5	40.4	57.8	40.5
0.240	91.9	29.5	31.6	39.0	63.2	46.9
0.260	92.2	29.2	35.6	35.5	67.7	51.5
0.280	92.3	25.2	37.8	33.0	70.7	54.9
0.300	92.3	17.6	37.7	33.6	73.4	57.6
0.315	92.4	5.5	37.3	35.5	75.0	59.4
0.320	92.4	8.9	37.1	36.3	75.5	60.0
0.340	92.5	72.9	36.1	38.5	76.9	62.0
0.360	92.5	88.2	36.3	41.5	78.0	63.4
0.380	92.5	92.8	37.8	44.5	78.1	64.9
0.400	92.4	95.6	38.7	47.5	77.4	66.3
0.450	92.2	97.1	38.7	55.2	76.0	69.1
0.500	91.8	97.9	47.7	60.0	76.6	71.4
0.550	91.5	98.3	81.7	66.9	78.2	73.4
0.600	91.1	98.6	91.9	93.3	79.7	75.2
0.650	90.5	98.8	95.5	96.6	81.1	76.4
0.700	89.7	98.9	97.0	97.5	82.0	77.2
0.750	88.6	99.1	97.4	97.9	82.6	77.9
0.800	86.7	99.2	98.0	98.1	83.1	78.5
0.850	86.7	99.2	98.2	98.3	83.4	79.5
0.900	89.1	99.3	98.4	98.4	83.6	80.5
0.950	92.4	99.3	98.5	98.4	83.9	80.6
1.0	94.0	99.4	98.6	98.5	84.2	80.7
1.5	97.4	99.4	99.0	98.5	87.7	81.8
2.0	97.8	99.4	99.1	98.6	91.4	81.8
3.0	98.0	99.4	99.3	98.6	95.0	90.6
4.0	98.2	99.4	99.4	98.7	95.8	93.7
5.0	98.4	99.5	99.4	98.7	96.4	94.9
6.0	98.5	99.5	99.4	98.7	96.8	95.6
7.0	98.6	99.5	99.4	98.7	97.0	95.9
8.0	98.7	99.5	99.4	98.8	97.2	96.0
9.0	98.7	99.5	99.4	98.8	97.4	96.1
10.0	98.7	99.5	99.4	98.9	97.6	96.2
15.0	98.9	99.6	99.4	99.0	98.1	96.5
20.0	99.0	99.6	99.4			
30.0	99.2	99.6	99.4			

* The reflectance of a good evaporated mirror coating is always higher than that of a polished or electroplated surface of the same material.

† G. Hass, in R. Kingslake, ed., "Applied Optics and Optical Engineering," vol. III, pp. 309–330, Academic Press, Inc., New York, 1965.

Source: American Institute of Physics Handbook, 3rd Ed., Mc Graw Hill, 1972

Table B-3
EFFECTIVE UV REFLECTANCE OF PLASTIC FILMS

3M ECP-244 EFFECTIVE REFLECTIVITY

WAVELENGTH	IRRADIANCE*	REFLECTIVITY	PRODUCT
280	0	0.37	0.00
290	0	0.20	0.00
300	0	0.16	0.00
310	18.1	0.17	3.08
320	80.6	0.29	23.37
330	166.2	0.44	73.13
340	212.4	0.47	99.83
350	251.3	0.52	130.68
360	278.2	0.62	172.48
370	340.6	0.77	260.56
380	352.8	0.86	301.64
390			
400			
SUM1 =	1700.2	SUM2 =	1064.77

EFFECTIVE REFLECTIVITY = SUM2/SUM1 = 62.63%

3M SA-85 EFFECTIVE REFLECTIVITY

WAVELENGTH	IRRADIANCE*	REFLECTIVITY	PRODUCT
280	0	0.63	0.00
290	0	0.80	0.00
300	0	0.86	0.00
310	18.1	0.87	15.75
320	80.6	0.87	70.12
330	166.2	0.87	144.93
340	212.4	0.87	185.21
350	251.3	0.87	219.38
360	278.2	0.87	242.87
370	340.6	0.87	297.00
380	352.8	0.87	306.94
390		0.00	0.00
400		0.00	0.00
SUM1=	1700.2	SUM2 =	1482.20

EFFECTIVE REFLECTIVITY = SUM2/SUM1= 87.18%

* Taken from ASTM E891-82, "Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air Mass 1.5", in units of w/(m2-micron)

Table B-4
SUNSTEAM COLLECTION EFFICIENCY (280-385 nm UV BAND)

3M SA-85 (EQUIVALENT) EFFECTIVE UV REFLECTIVITY

WAVELENGTH	IRRADIANCE*	REFLECTIVITY	PRODUCT
280	0	0.625	0.00
290	0	0.803	0.00
300	0	0.86	0.00
310	18.1	0.87	15.75
320	80.6	0.87	70.12
330	166.2	0.872	144.93
340	212.4	0.872	185.21
350	251.3	0.873	219.38
360	278.2	0.873	242.87
370	340.6	0.872	297.00
380	352.8	0.87	306.94
390		0	0.00
400		0	0.00
SUM1 =	1700.2	SUM2 =	1482.20

EFFECTIVE REFLECTIVITY (SUM2/SUM1)= 87.18%

END OF LIFE REFLECTIVITY = 76.76%

DUPONT TEFZEL 250 ZM FILM UV ABSORPTIVITY

WAVELENGTH	IRRADIANCE*	ABSORPTIVITY**	PRODUCT
280	0	0.081	0.00
290	0	0.0765	0.00
300	0	0.072	0.00
310	18.1	0.068	1.23
320	80.6	0.064	5.16
330	166.2	0.0615	10.22
340	212.4	0.059	12.53
350	251.3	0.058	14.58
360	278.2	0.057	15.86
370	340.6	0.0555	18.90
380	352.8	0.054	19.05
390	0	0	0.00
400	0	0	0.00
SUM =	1700.2	SUM =	97.53

EFFECTIVE ABSORPTANCE = 5.74% FOR 1.5 MIL FILM
= 9.38% FOR 2.5 MIL FILM

REFLECTANCE = 2.31%

EFFECTIVE TRANSMITTANCE = 88.53% FOR 2.5 MIL FILM

SUNSTEAM REFLECTANCE X TRANSMITTANCE = 77.18% NEW
= 67.96% END OF LIFE

* Taken from ASTM E891-82, "Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air Mass 1.5", in units of W/(m2-micron)

** Dupont values for 1.5 mil film

Table B-5
PROPERTIES OF CANDIDATE UV REFLECTIVE SURFACES

			SUNSTEAM PROPRIETARY SYSTEM		
SUPPLIER I.D.	**3M ECP-244** Discontinued	**3M SA-85**	REFLECTOR	COVER	**ALANOD** Anodized Aluminum Sheet
CONSTITUENT LAYERS	Back Side Adhesive 0.4 mil Al 3 mil Acrylic Front Side	Back Side Adhesive 2 mil Polyester 0.4 mil Al 0.1 mil Acrylic Front Side	Back Side 5 mil Al Foil Adhesive 1 mil Polyester 0.4 mil Al 0.1 mil Acrylic Front Side	2.5 mil Tefzel Film	Back Side Aluminum Sheet Bright Surface 0.1 mil Anodize Front Side
REFLECTANCE (280-385 nm band)	62.63% Per SNLA	87.18% Per 3M	87.18%		75.00% Approx.
TRANSMITTANCE	100.00%	100.00%		88.53%	100.00%
SYSTEM EFFICIENCY					
AS RECEIVED	62.63%	87.18%	77.18%		75.00% Approx.
AS BONDED	60.63%	85.18%			
ASSUMED END OF LIFE	53.38%	75.00%	67.96%		
COMMENTS	Displaced by 3M SA-85 Solar Kinetics Offering Based on Stock on Hand	Current 3M Film Indust Solar Tech Offering Solar Kinetics Option	Proprietary Sunsteam Offering		Distributed by Malco Metals Inc Palo Alto, CA Discarded for lack of Degradation Data

Appendix C

COLLECTOR FIELD SIZING AND DESIGN POINT PERFORMANCE

APPENDIX C
COLLECTOR FIELD SIZING AND DESIGN POINT PERFORMANCE

Collector Efficiency

75% for the Solar Kinetics SA-85 clad trough module at end of life per Table B-5

UV Photons/Second Per UV Watt

1.818 x 10^18 from Table B-1

Site Data

Location	Rocky Flats, Colorado
Latitude	40 degrees North
Elevation	5960 ft. above sea level
Air density	0.8351 x sea level density
Air mass	0.8351/(cos(zenith angle))

Design Point

Vernal equinox noon zenith angle	40 degrees (=latitude)
Air mass	1.0901 at vernal equinox noon

Ratio of UV Photons to Solar Band Photons

Curve fit of Figure C1 data for 280 to 385 nanometer UV wavelength band

(UV Watts/solar Watts) = 0.037 x EXP(-0.7072(air mass-1))
= 0.0347 @ design doint

Design Point Solar Radiation

960 Watts/m2

Design Point UV Radiation

33.33 UV Watts/m2 (=0.0347 x 960)

UV Watts Required

(5 X 10^{22} UV photons/second)/(1.818 X 10^{18} photons/second per watt)
= 27,500 UV Watts

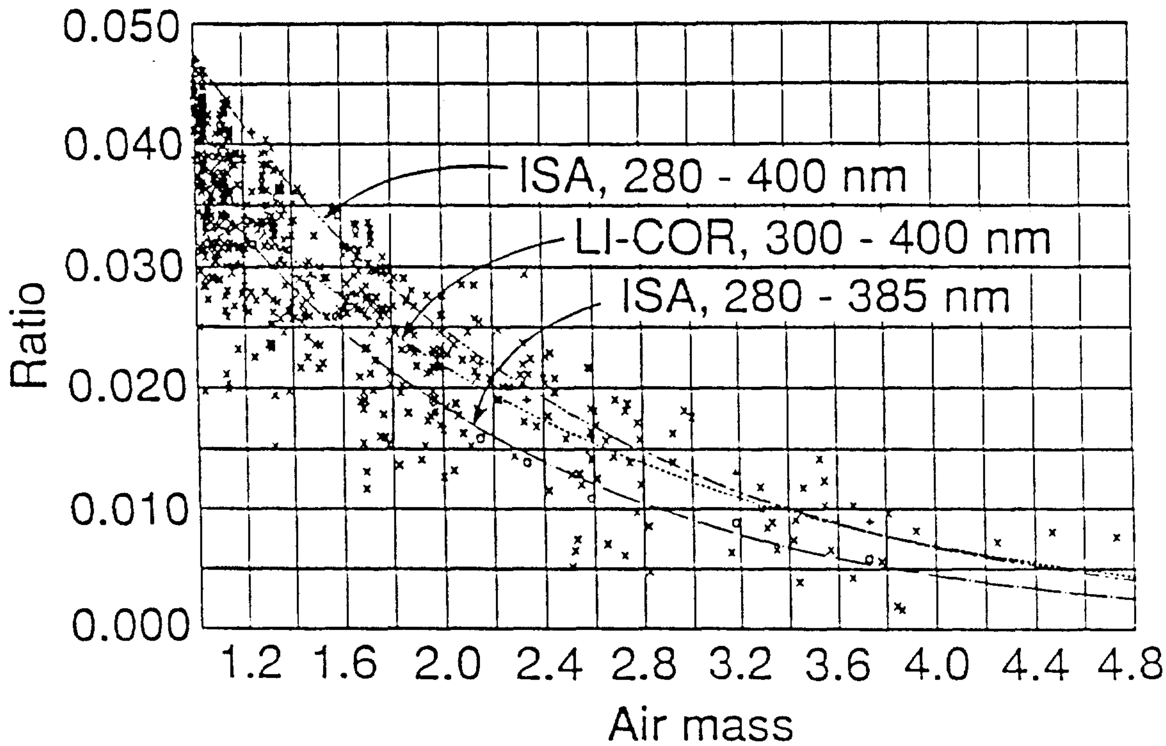

Figure C-1 Ratio of Ultraviolet Band to Total Direct Normal Insolation

Source: SERI/TP-215-3895, "Influence of Atmospheric Conditions on the Ratio of Ultraviolet to Total Solar Radiation"

Required Solar Kinetics Collector Area

= 27,500 UV Watts / (33.33 UV Watts/m2 X 0.75 EOL collector efficiency)
= 1,100 m2

Number of Modules

=1100 m2 / 13.006 m2 per module
= 84.6

Use 88 Solar Kinetics modules arranged in 11 rows of 8 modules each

The arrangement gives 11 parallel flow paths

Flow Rate Per Flow Path

100 gpm /11 = 9.09 gpm each

Pressure Loss

Single Receiver Tube Flow Path,

DP = $(f/891)*(L/d^5)*G^2$ in lb/in^2, where

G	=	Flow in gpm
f	=	Friction Factor from Figure C2
d	=	Receiver Tube or Pipe Inside Diameter, inches
L	=	Receiver Tube or Pipe Length, inches

Receiver Tube Pressure Loss

G	=	9.09 gpm
f	=	0.47
d	=	2 inches
L	=	240 x 8 = 1920 inches
DP	=	$(0.47/891)*(1920/ 2^5)*(9.09)^2$
	=	2.615 PSI

Associated Fittings	Equivalent Length, Ft
Open tube between modules, 12 x 2 Ft	24
End flex tubes, 2 x 10 Ft	20
Bends, entrance and exit	45
Valve	30
Total	120

Friction Factors for Nulite Mesh
Configuration 1: 1.5 in. and 2 in. Reactor

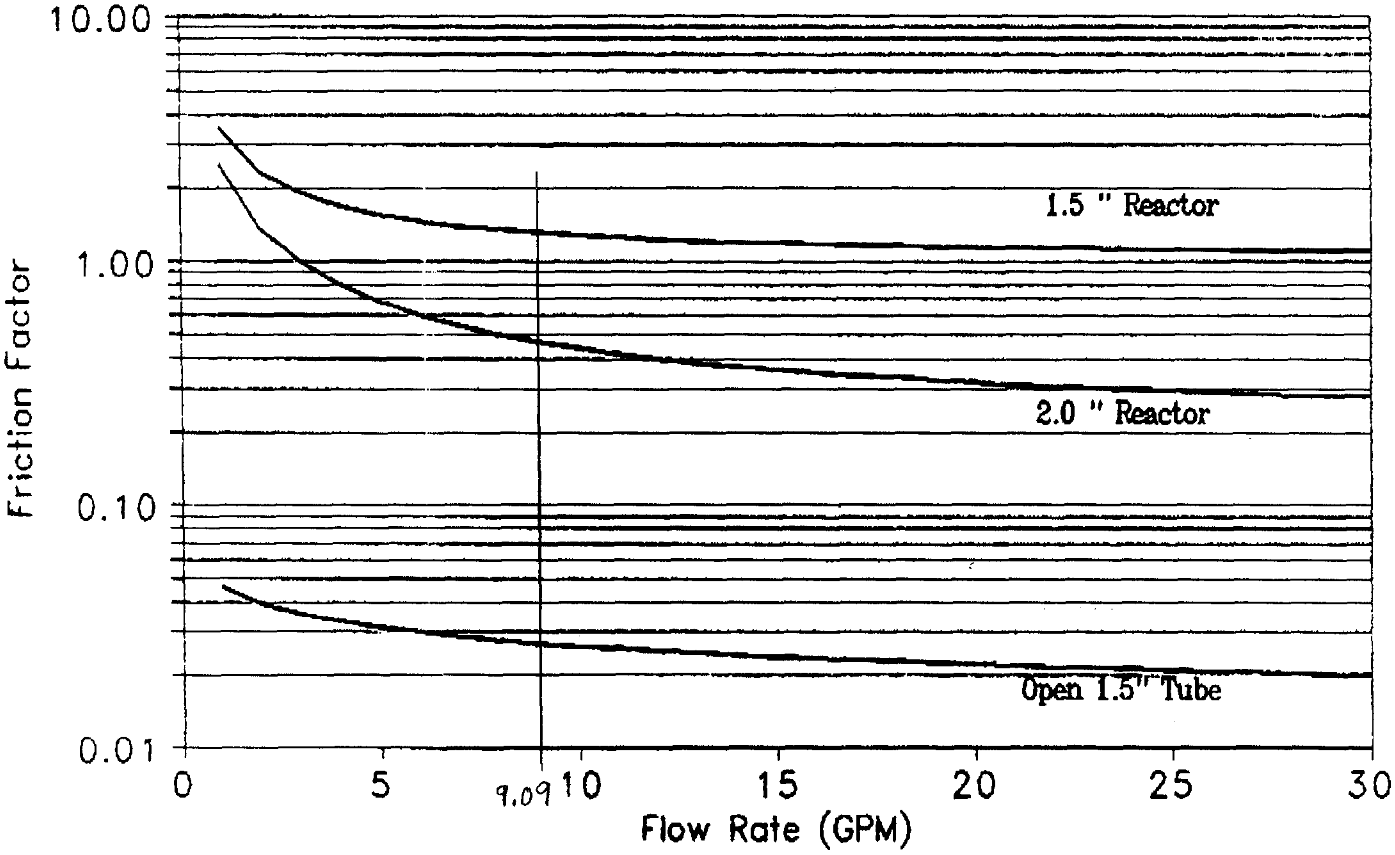

Figure C-2 Receiver Tube Friction Factors

Source: Solar Energy Research Institute

PSI/100 Ft = 0.0921 @ 9.09 gpm for 2 inch Sch 40
per Crane Technical Paper 410

DP = 1.2 x 0.0921 = 0.110 PSI

Total DP per receiver run = 2.725 PSI

Manifold Pressure Loss

6 inch Sch 40 DP PSI/100 Ft = 0.036 @ 100 gpm per Crane

Length = 660 Ft
Bends, valve = 150 Ft Equivalent Length

Total 810 Ft

DP = 8.1 x 0.036 = 0.292 PSI

Throttle Valve Flow Balancing Allowance

DP = 0.483 PSI (an arbitrary 16%)

Total Collector Field Pressure Drop = 3.50 PSI at EOL (2.725 + 0.292 + 0.483)

Temperature Rise

Interplolation from Table C1 for 9.09 gpm flow in an 8 ft wide aperture gives,

Temp. Rise/Ft = 0.108 Degrees C per Ft for an 8 Ft aperture.
= 0.094 Degrees C per Ft for a 7 Ft Solar Kinetics aperture.

Temperature Rise, DT, for each of the eleven 160 ft runs of receiver tube is,

DT = 160 x 0.094
= 15.0 C (27.1 F)

Table C-1
RECEIVER TEMPERATURE RISE

FLOW - gpm	TEMPERATURE RISE - Degrees C per Foot		
	2 Ft Aperture	4 Ft Aperture	8 Ft Aperture
1	0.24	0.48	0.96
2	0.12	0.24	0.48
4	0.06	0.12	0.24
5	0.05	0.10	0.19
7.5	0.03	0.06	0.13
10	0.02	0.05	0.10
15	0.02	0.03	0.06
20	0.01	0.02	0.05
25	0.01	0.02	0.04
30	0.01	0.02	0.03

Source: Solar Energy Research Institute

Appendix D

HOURLY AND MONTHLY ESTIMATES OF TREATED WATER VOLUME

Table D-1
12 MONTH OPERATION WITH 20 GPM MINIMUM FLOW

Table D-2
9 MONTH OPERATION (WINTER SHUTDOWN) WITH 20 GPM MINIMUM FLOW

TABLE D-1 (1 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

		PI	SPACING	APERTURE												
JANUARY	21	3.14	30.00	7.00												
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	0	0	142	239	274	289	295	289	274	239	142	0	0	0
	Clr Sky (W/m2)	0	0	0	448	754	864	912	931	912	864	754	448	0	0	0
	Clr Sky (kWh/m2)/Day	6.89														
	Denver (kWh/m2)/Day	5.56														
	Azimuth				55.3	44	30.9	16	0	16	30.9	44	55.3			
	Altitude				8.1	16.8	23.8	28.4	30	28.4	23.8	16.8	8.1			
	Zenith				81.9	73.2	66.2	61.6	60	61.6	66.2	73.2	81.9			
	Air Mass				5.93	2.89	2.07	1.76	1.67	1.76	2.07	2.89	5.93			
To Aperture	W/m2 (uv)				0.24	4.42	10.70	15.48	17.31	15.48	10.70	4.42	0.24			
To Receiver	W/m2 (uv)				0.19	3.54	8.56	12.39	13.85	12.39	8.56	3.54	0.19			
FLOW	Gallons/Minute				0.00	0.00	33.94	49.12	54.91	49.12	33.94	0.00	0.00			
	Gallons/Hour				0	0	2037	2947	3294	2947	2037	0	0			
	Gallons/Day	13262														
	Gallons/Month	411,120	4.85%													
COSINE FACTOR					0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58			
FRACTION NOT SHADED					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
COLLECTOR REFLECTIVITY					80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			

FEBRUARY	21															
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	0	69	224	274	295	305	308	305	295	274	224	69	0	0
	Clr Sky (W/m2)	0	0	218	707	864	931	962	972	962	931	864	707	218	0	0
	Clr Sky (kWh/m2)/Day	8.33														
	Denver (kWh/m2)/Day	5.93														
	Azimuth			72.7	62.2	50.2	35.9	18.9	0	18.9	35.9	50.2	62.2	72.7		
	Altitude			4.8	15.4	25	32.8	38.1	40	38.1	32.8	25	15.4	4.8		
	Zenith			85.2	74.6	65	57.2	51.9	50	51.9	57.2	65	74.6	85.2		
	Air Mass			9.98	3.14	1.98	1.54	1.35	1.30	1.35	1.54	1.98	3.14	9.98		
To Aperture	W/m2 (uv)			0.00	2.13	8.19	14.53	19.08	20.70	19.08	14.53	8.19	2.13	0.00		
To Receiver	W/m2 (uv)			0.00	1.71	6.55	11.63	15.26	16.56	15.26	11.63	6.55	1.71	0.00		
FLOW	Gallons/Minute			0.00	0.00	25.98	46.11	60.52	65.67	60.52	46.11	25.98	0.00	0.00		
	Gallons/Hour			0	0	1559	2767	3631	3940	3631	2767	1559	0	0		
	Gallons/Day	19854														
	Gallons/Month	555,913	6.55%													
COSINE FACTOR				0.31	0.52	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.52	0.31		
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

TABLE D-1 (2 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

MARCH 21

		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	0	171	250	282	297	305	307	305	297	282	250	171	0	0
	Clr Sky (W/m2)	0	0	539	789	890	937	962	968	962	937	890	789	539	0	0
	Clr Sky (kWh/m2)/Day	9.20														
	Denver (kWh/m2)/Day	6.28														
	Azimuth			80.2	69.6	57.3	41.9	22.6	0	22.6	41.9	57.3	69.6	80.2		
	Altitude			11.4	22.5	32.8	41.6	47.7	50	47.7	41.6	32.8	22.5	11.4		
	Zenith			78.6	67.5	57.2	48.4	42.3	40	42.3	48.4	57.2	67.5	78.6		
	Air Mass			4.22	2.18	1.54	1.26	1.13	1.09	1.13	1.26	1.54	2.18	4.22		
To Aperture	W/m2 (uv)			0.36	4.32	10.63	17.08	21.42	22.94	21.42	17.08	10.63	4.32	0.36		
To Receiver	W/m2 (uv)			0.29	3.45	8.66	13.66	17.14	18.36	17.14	13.66	8.66	3.45	0.29		
FLOW	Gallons/Minute			0.00	0.00	34.35	54.19	67.96	72.79	67.96	54.19	34.35	0.00	0.00		
	Gallons/Hour			0	0	2061	3251	4078	4368	4078	3251	2061	0	0		
	Gallons/Day	23147														
	Gallons/Month	717,564	8.46%													
COSINE FACTOR				0.26	0.50	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26		
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

APRIL 21

		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	89	206	252	274	286	292	293	292	286	274	252	206	89	0
	Clr Sky (W/m2)	0	281	650	795	864	902	921	924	921	902	864	795	650	281	0
	Clr Sky (kWh/m2)/Day	9.75														
	Denver (kWh/m2)/Day	6.53														
	Azimuth		98.9	89.5	79.3	67.2	51.4	29.2	0	29.2	51.4	67.2	79.3	89.5	98.9	
	Altitude		7.4	18.9	30.3	41.3	51.2	58.7	61.6	58.7	51.2	41.3	30.3	18.9	7.4	
	Zenith		82.6	71.1	59.7	48.7	38.8	31.3	28.4	31.3	38.8	48.7	59.7	71.1	82.6	
	Air Mass		6.48	2.58	1.66	1.27	1.07	0.98	0.95	0.98	1.07	1.27	1.66	2.58	6.48	
To Aperture	W/m2 (uv)		0.03	1.71	6.56	12.81	18.53	22.44	23.74	22.44	18.53	12.81	6.56	1.71	0.03	
To Receiver	W/m2 (uv)		0.02	1.37	5.25	10.25	14.82	17.95	18.99	17.95	14.82	10.25	5.25	1.37	0.02	
FLOW	Gallons/Minute		0.00	0.00	20.81	40.63	58.79	71.18	75.31	71.18	58.79	40.63	20.81	0.00	0.00	
	Gallons/Hour		0	0	1249	2438	3527	4271	4519	4271	3527	2438	1249	0	0	
	Gallons/Day	27488														
	Gallons/Month	824,637	9.72%													
COSINE FACTOR			0.20	0.32	0.53	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.53	0.32	0.20	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

TABLE D-1 (3 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

MAY 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	144	216	250	267	277	283	284	283	277	267	250	216	144	0
	Clr Sky (W/m2)	0	454	681	789	842	874	893	896	893	874	842	789	681	454	0
	Clr Sky (kWh/m2)/Day	9.96														
	Denver (kWh/m2)/Day	6.71														
	Azimuth		105.6	96.6	87.2	76	60.9	37.1	0	37.1	60.9	76	87.2	96.6	105.6	
	Altitude		12.7	24	35.4	46.8	57.5	66.2	70	66.2	57.5	46.8	35.4	24	12.7	
	Zenith		77.3	66	54.6	43.2	32.5	23.8	20	23.8	32.5	43.2	54.6	66	77.3	
	Air Mass		3.80	2.05	1.44	1.15	0.99	0.91	0.89	0.91	0.99	1.15	1.44	2.05	3.80	
	To Aperture W/m2 (uv)		0.54	3.39	8.35	14.16	19.36	22.95	24.16	22.95	19.36	14.16	8.35	3.39	0.54	
	To Receiver W/m2 (uv)		0.43	2.71	6.68	11.32	15.49	18.36	19.32	18.36	15.49	11.32	6.68	2.71	0.43	
FLOW	Gallons/Minute		0.00	0.00	26.49	44.91	61.43	72.82	76.64	72.82	61.43	44.91	26.49	0.00	0.00	
	Gallons/Hour		0	0	1590	2695	3686	4369	4598	4369	3686	2695	1590	0	0	
	Gallons/Day	29277														
	Gallons/Month	907,572	10.70%													
COSINE FACTOR			0.34	0.42	0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58	0.42	0.34	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

JUNE 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	22	155	216	246	263	272	277	279	277	272	263	246	216	155	22
	Clr Sky (W/m2)	69	489	681	776	830	858	874	880	874	858	830	776	681	489	69
	Clr Sky (kWh/m2)/Day	10.04														
	Denver (kWh/m2)/Day	7.36														
	Azimuth	117.3	108.4	99.7	90.7	80.2	65.8	41.9	0	41.9	65.8	80.2	90.7	99.7	108.4	117.2
	Altitude	4.2	14.8	26	37.4	48.8	59.8	69.2	73.5	69.2	59.8	48.8	37.4	26	14.8	4.2
	Zenith	85.8	75.2	64	52.6	41.2	30.2	20.8	16.5	20.8	30.2	41.2	52.6	64	75.2	85.8
	Air Mass	11.40	3.27	1.91	1.37	1.11	0.97	0.89	0.87	0.89	0.97	1.11	1.37	1.91	3.27	11.40
	To Aperture W/m2 (uv)	0.00	1.06	4.52	9.81	15.85	21.19	24.84	26.17	24.84	21.19	15.85	9.81	4.52	1.06	0.00
	To Receiver W/m2 (uv)	0.00	0.85	3.62	7.85	12.68	16.95	19.87	20.93	19.87	16.95	12.68	7.85	3.62	0.85	0.00
FLOW	Gallons/Minute	0.00	0.00	0.00	31.13	50.28	67.23	78.81	83.02	78.81	67.23	50.28	31.13	0.00	0.00	0.00
	Gallons/Hour	0	0	0	1868	3017	4034	4729	4981	4729	4034	3017	1868	0	0	0
	Gallons/Day	32275														
	Gallons/Month	968,249	11.42%													
COSINE FACTOR		0.46	0.40	0.46	0.61	0.76	0.89	0.97	1.00	0.97	0.89	0.76	0.61	0.46	0.40	0.46
FRACTION NOT SHADED		0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68
COLLECTOR REFLECTIVITY		80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%

TABLE D-1 (4 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

JULY 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	138	208	241	259	269	275	276	275	269	259	241	208	138	0
	Clr Sky (W/m2)	0	435	656	760	817	849	868	871	868	849	817	760	656	435	0
	Clr Sky (kWh/m2)/Day	9.64														
	Denver (kWh/m2)/Day	7.32														
	Azimuth		106.1	97.2	87.8	76.7	61.7	37.9	0	37.9	61.7	76.7	87.8	97.2	106.1	
	Altitude		13.1	24.3	35.8	47.2	57.9	66.7	70.6	66.7	57.9	47.2	35.8	24.3	13.1	
	Zenith		76.9	65.7	54.2	42.8	32.1	23.3	19.4	23.3	32.1	42.8	54.2	65.7	76.9	
	Air Mass		3.68	2.03	1.43	1.14	0.99	0.91	0.89	0.91	0.99	1.14	1.43	2.03	3.68	
	To Aperture W/m2 (uv)		0.65	3.80	9.25	15.62	21.28	25.21	26.53	25.21	21.28	15.62	9.25	3.80	0.65	
	To Receiver W/m2 (uv)		0.52	3.04	7.40	12.49	17.03	20.17	21.22	20.17	17.03	12.49	7.40	3.04	0.52	
FLOW	Gallons/Minute		0.00	0.00	29.34	49.55	67.52	79.98	84.16	79.98	67.52	49.55	29.34	0.00	0.00	
	Gallons/Hour		0	0	1760	2973	4051	4799	5049	4799	4051	2973	1760	0	0	
	Gallons/Day	32215														
	Gallons/Month	998,662	11.77%													
COSINE FACTOR			0.35	0.43	0.59	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.59	0.43	0.35	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

AUGUST 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	81	191	237	260	272	278	280	278	272	260	237	191	81	0
	Clr Sky (W/m2)	0	256	603	748	820	858	877	883	877	858	820	748	603	256	0
	Clr Sky (kWh/m2)/Day	9.21														
	Denver (kWh/m2)/Day	7.08														
	Azimuth		99.5	90	79.9	67.9	52.1	29.7	0	29.7	52.1	67.9	79.9	90	99.5	
	Altitude		7.9	19.3	30.7	41.8	51.7	59.3	62.3	59.3	51.7	41.8	30.7	19.3	7.9	
	Zenith		82.1	70.7	59.3	48.2	38.3	30.7	27.7	30.7	38.3	48.2	59.3	70.7	82.1	
	Air Mass		6.08	2.53	1.64	1.25	1.06	0.97	0.94	0.97	1.06	1.25	1.64	2.53	6.08	
	To Aperture W/m2 (uv)		0.04	1.93	7.23	14.11	20.35	24.64	26.17	24.64	20.35	14.11	7.23	1.93	0.04	
	To Receiver W/m2 (uv)		0.03	1.54	5.78	11.29	16.28	19.71	20.93	19.71	16.28	11.29	5.78	1.54	0.03	
FLOW	Gallons/Minute		0.00	0.00	22.92	44.78	64.58	78.18	83.02	78.18	64.58	44.78	22.92	0.00	0.00	
	Gallons/Hour		0	0	1375	2687	3875	4691	4981	4691	3875	2687	1375	0	0	
	Gallons/Day	30236														
	Gallons/Month	937,319	11.05%													
COSINE FACTOR			0.21	0.33	0.53	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.53	0.33	0.21	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

TABLE D-1 (5 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

SEPTEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	149	230	263	280	287	290	287	280	263	230	149	0	0
Clr Sky (W/m2)	0	0	470	726	830	883	905	915	905	883	830	726	470	0	0
Clr Sky (kWh/m2)/Day	8.54														
Denver (kWh/m2)/Day	6.81														
Azimuth			80.2	69.6	57.3	41.9	22.6	0	22.6	41.9	57.3	69.6	80.2		
Altitude			11.4	22.5	32.8	41.6	47.7	50	47.7	41.6	32.8	22.5	11.4		
Zenith			78.6	67.5	57.2	48.4	42.3	40	42.3	48.4	57.2	67.5	78.6		
Air Mass			4.22	2.18	1.54	1.26	1.13	1.09	1.13	1.26	1.54	2.18	4.22		
To Aperture W/m2 (uv)			0.37	4.64	11.79	18.81	23.55	25.32	23.55	18.81	11.79	4.64	0.37		
To Receiver W/m2 (uv)			0.29	3.71	9.43	15.05	18.84	20.25	18.84	15.05	9.43	3.71	0.29		
FLOW Gallons/Minute			0.00	0.00	37.42	59.67	74.70	80.32	74.70	59.67	37.42	0.00	0.00		
Gallons/Hour			0	0	2245	3580	4482	4819	4482	3580	2245	0	0		
Gallons/Day	25434														
Gallons/Month	763,024	9.00%													
COSINE FACTOR			0.26	0.50	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26		
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

OCTOBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	48	204	257	280	291	294	291	280	257	204	48	0	0
Clr Sky (W/m2)	0	0	151	644	811	883	918	927	918	883	811	644	151	0	0
Clr Sky (kWh/m2)/Day	7.74														
Denver (kWh/m2)/Day	6.35														
Azimuth			72.3	61.9	49.8	35.6	18.7	0	18.7	35.6	49.8	61.9	72.3		
Altitude			4.5	15	24.5	32.4	37.6	39.5	37.6	32.4	24.5	15	4.5		
Zenith			85.5	75	65.5	57.6	52.4	50.5	52.4	57.6	65.5	75	85.5		
Air Mass			10.64	3.23	2.01	1.56	1.37	1.31	1.37	1.56	2.01	3.23	10.64		
To Aperture W/m2 (uv)			0.00	2.12	8.64	15.73	20.76	22.56	20.76	15.73	8.64	2.12	0.00		
To Receiver W/m2 (uv)			0.00	1.69	6.91	12.58	16.61	18.05	16.61	12.58	6.91	1.69	0.00		
FLOW Gallons/Minute			0.00	0.00	27.40	49.90	65.87	71.58	65.87	49.90	27.40	0.00	0.00		
Gallons/Hour			0	0	1644	2994	3952	4295	3952	2994	1644	0	0		
Gallons/Day	21475														
Gallons/Month	665,729	7.85%													
COSINE FACTOR			0.31	0.52	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.52	0.31		
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

TABLE D-1 (6 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

YEAR ROUND PLANT OPERATION

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

NOVEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	0	136	232	268	283	288	283	268	232	136	0	0	0
Clr Sky (W/m2)	0	0	0	429	732	845	893	909	893	845	732	429	0	0	0
Clr Sky (kWh/m2)/Day	6.71														
Denver (kWh/m2)/Day	5.46														
Azimuth				55.4	44.1	31	16.1	0	16.1	31	44.1	55.4			
Altitude				8.2	17	24	28.6	30.2	28.5	24	17	8.2			
Zenith				81.8	73	66	61.4	59.8	61.5	66	73	81.8			
Air Mass				5.86	2.86	2.05	1.74	1.66	1.75	2.05	2.86	5.86			
To Aperture W/m2 (uv)				0.24	4.43	10.67	15.41	17.16	15.34	10.67	4.43	0.24			
To Receiver W/m2 (uv)				0.19	3.54	8.54	12.32	13.73	12.27	8.54	3.54	0.19			
FLOW Gallons/Minute				0.00	0.00	33.85	48.88	54.43	48.68	33.85	0.00	0.00			
Gallons/Hour				0	0	2031	2933	3266	2921	2031	0	0			
Gallons/Day	13182														
Gallons/Month	395,445	4.66%													
COSINE FACTOR				0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58			
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			

DECEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	0	89	217	261	280	285	280	261	217	89	0	0	0
Clr Sky (W/m2)	0	0	0	281	685	823	883	899	883	823	685	281	0	0	0
Clr Sky (kWh/m2)/Day	6.24														
Denver (kWh/m2)/Day	5.05														
Azimuth				53	41.9	29.4	15.2	0	15.2	29.4	41.9	53			
Altitude				5.5	14	20.7	25	26.6	25	20.7	14	5.5			
Zenith				84.5	76	69.3	65	63.4	65	69.3	76	84.5			
Air Mass				8.71	3.45	2.36	1.98	1.87	1.98	2.36	3.45	8.71			
To Aperture W/m2 (uv)				0.01	2.76	8.35	12.88	14.59	12.88	8.35	2.76	0.01			
To Receiver W/m2 (uv)				0.01	2.20	6.68	10.30	11.68	10.30	6.68	2.20	0.01			
FLOW Gallons/Minute				0.00	0.00	26.50	40.85	46.30	40.85	26.50	0.00	0.00			
Gallons/Hour				0	0	1590	2451	2778	2451	1590	0	0			
Gallons/Day	10860														
Gallons/Month	336,669	3.97%													
COSINE FACTOR				0.61	0.76	0.89	0.97	1.00	0.97	0.89	0.76	0.61			
FRACTION NOT SHADED				0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68			
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			
GALLONS PER YEAR	8,481,904														

TABLE D-2 (1 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

	PI	SPACING	APERTURE												
JANUARY 21	3.14	30.00	7.00												
HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	0	142	239	274	289	295	289	274	239	142	0	0	0
Clr Sky (W/m2)	0	0	0	448	754	864	912	931	912	864	754	448	0	0	0
Clr Sky (kWh/m2)/Day	6.89														
Denver (kWh/m2)/Day	5.56														
Azimuth				55.3	44	30.9	16	0	16	30.9	44	55.3			
Altitude				8.1	16.8	23.8	28.4	30	28.4	23.8	16.8	8.1			
Zenith				81.9	73.2	66.2	61.6	60	61.6	66.2	73.2	81.9			
Air Mass				5.93	2.89	2.07	1.76	1.67	1.76	2.07	2.89	5.93			
To Aperture W/m2 (uv)				0.24	4.42	10.70	15.48	17.31	15.48	10.70	4.42	0.24			
To Receiver W/m2 (uv)				0.19	3.54	8.56	12.39	13.85	12.39	8.56	3.54	0.19			
FLOW Gallons/Minute				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
Gallons/Hour				0	0	0	0	0	0	0	0	0			
Gallons/Day	0														
Gallons/Month	0	0.00%													
COSINE FACTOR				0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58			
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			

FEBRUARY 21															
HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	69	224	274	295	305	308	305	295	274	224	69	0	0
Clr Sky (W/m2)	0	0	218	707	864	931	962	972	962	931	864	707	218	0	0
Clr Sky (kWh/m2)/Day	8.33														
Denver (kWh/m2)/Day	5.93														
Azimuth			72.7	62.2	50.2	35.9	18.9	0	18.9	35.9	50.2	62.2	72.7		
Altitude			4.8	15.4	25	32.8	38.1	40	38.1	32.8	25	15.4	4.8		
Zenith			85.2	74.6	65	57.2	51.9	50	51.9	57.2	65	74.6	85.2		
Air Mass			9.98	3.14	1.98	1.54	1.35	1.30	1.35	1.54	1.98	3.14	9.98		
To Aperture W/m2 (uv)			0.00	2.13	8.19	14.53	19.08	20.70	19.08	14.53	8.19	2.13	0.00		
To Receiver W/m2 (uv)			0.00	1.71	6.55	11.63	15.26	16.56	15.26	11.63	6.55	1.71	0.00		
FLOW Gallons/Minute			0.00	0.00	25.98	46.11	60.52	65.67	60.52	46.11	25.98	0.00	0.00		
Gallons/Hour			0	0	1559	2767	3631	3940	3631	2767	1559	0	0		
Gallons/Day	19854														
Gallons/Month	555,913	7.58%													
COSINE FACTOR			0.31	0.52	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.52	0.31		
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

TABLE D-2 (2 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

MARCH 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	0	171	250	282	297	305	307	305	297	282	250	171	0	0
Clr Sky	(W/m2)	0	0	539	789	890	937	962	968	962	937	890	789	539	0	0
Clr Sky	(kWh/m2)/Day	9.20														
Denver	(kWh/m2)/Day	6.28														
	Azimuth			80.2	69.6	57.3	41.9	22.6	0	22.6	41.9	57.3	69.6	80.2		
	Altitude			11.4	22.5	32.8	41.6	47.7	50	47.7	41.6	32.8	22.5	11.4		
	Zenith			78.6	67.5	57.2	48.4	42.3	40	42.3	48.4	57.2	67.5	78.6		
	Air Mass			4.22	2.18	1.54	1.26	1.13	1.09	1.13	1.26	1.54	2.18	4.22		
To Aperture	W/m2 (uv)			0.36	4.32	10.83	17.08	21.42	22.94	21.42	17.08	10.83	4.32	0.36		
To Receiver	W/m2 (uv)			0.29	3.45	8.66	13.66	17.14	18.36	17.14	13.66	8.66	3.45	0.29		
FLOW	Gallons/Minute			0.00	0.00	34.35	54.19	67.96	72.79	67.96	54.19	34.35	0.00	0.00		
	Gallons/Hour			0	0	2061	3251	4078	4368	4078	3251	2061	0	0		
	Gallons/Day	23147														
	Gallons/Month	717,564	9.78%													
COSINE FACTOR				0.26	0.50	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26		
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

APRIL 21

HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	89	206	252	274	286	292	293	292	286	274	252	206	89	0
Clr Sky	(W/m2)	0	281	650	795	864	902	921	924	921	902	864	795	650	281	0
Clr Sky	(kWh/m2)/Day	9.75														
Denver	(kWh/m2)/Day	6.53														
	Azimuth		98.9	89.5	79.3	67.2	51.4	29.2	0	29.2	51.4	67.2	79.3	89.5	98.9	
	Altitude		7.4	18.9	30.3	41.3	51.2	58.7	61.6	58.7	51.2	41.3	30.3	18.9	7.4	
	Zenith		82.6	71.1	59.7	48.7	38.8	31.3	28.4	31.3	38.8	48.7	59.7	71.1	82.6	
	Air Mass		6.48	2.58	1.66	1.27	1.07	0.98	0.95	0.98	1.07	1.27	1.66	2.58	6.48	
To Aperture	W/m2 (uv)		0.03	1.71	6.56	12.81	18.53	22.44	23.74	22.44	18.53	12.81	6.56	1.71	0.03	
To Receiver	W/m2 (uv)		0.02	1.37	5.25	10.25	14.82	17.95	18.99	17.95	14.82	10.25	5.25	1.37	0.02	
FLOW	Gallons/Minute		0.00	0.00	20.81	40.63	58.79	71.18	75.31	71.18	58.79	40.63	20.81	0.00	0.00	
	Gallons/Hour		0	0	1249	2438	3527	4271	4519	4271	3527	2438	1249	0	0	
	Gallons/Day	27488														
	Gallons/Month	824,637	11.24%													
COSINE FACTOR			0.20	0.32	0.53	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.53	0.32	0.20	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

TABLE D-2 (3 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2 , 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

MAY	21															
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	0	144	216	250	267	277	283	284	283	277	267	250	216	144	0
Clr Sky	(W/m2)	0	454	681	789	842	874	893	896	893	874	842	789	681	454	0
Clr Sky	(kWh/m2)/Day	9.96														
Denver	(kWh/m2)/Day	6.71														
	Azimuth		105.6	96.6	87.2	76	60.9	37.1	0	37.1	60.9	76	87.2	96.6	105.6	
	Altitude		12.7	24	35.4	46.8	57.5	66.2	70	66.2	57.5	46.8	35.4	24	12.7	
	Zenith		77.3	66	54.6	43.2	32.5	23.8	20	23.8	32.5	43.2	54.6	66	77.3	
	Air Mass		3.80	2.05	1.44	1.15	0.99	0.91	0.89	0.91	0.99	1.15	1.44	2.05	3.80	
To Aperture	W/m2 (uv)		0.54	3.39	8.35	14.16	19.36	22.95	24.16	22.95	19.36	14.16	8.35	3.39	0.54	
To Receiver	W/m2 (uv)		0.43	2.71	6.68	11.32	15.49	18.36	19.32	18.36	15.49	11.32	6.68	2.71	0.43	
FLOW	Gallons/Minute		0.00	0.00	26.49	44.91	61.43	72.82	76.64	72.82	61.43	44.91	26.49	0.00	0.00	
	Gallons/Hour		0	0	1590	2695	3686	4369	4598	4369	3686	2695	1590	0	0	
	Gallons/Day	29277														
	Gallons/Month	907,572	12.37%													
COSINE FACTOR			0.34	0.42	0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58	0.42	0.34	
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

JUNE	21															
HOUR		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION	Btu/h ft2	22	155	216	246	263	272	277	279	277	272	263	246	216	155	22
Clr Sky	(W/m2)	69	489	681	776	830	858	874	880	874	858	830	776	681	489	69
Clr Sky	(kWh/m2)/Day	10.04														
Denver	(kWh/m2)/Day	7.36														
	Azimuth	117.3	108.4	99.7	90.7	80.2	65.8	41.9	0	41.9	65.8	80.2	90.7	99.7	108.4	117.2
	Altitude	4.2	14.8	26	37.4	48.8	59.8	69.2	73.5	69.2	59.8	48.8	37.4	26	14.8	4.2
	Zenith	85.8	75.2	64	52.6	41.2	30.2	20.8	16.5	20.8	30.2	41.2	52.6	64	75.2	85.8
	Air Mass	11.40	3.27	1.91	1.37	1.11	0.97	0.89	0.87	0.89	0.97	1.11	1.37	1.91	3.27	11.40
To Aperture	W/m2 (uv)	0.00	1.06	4.52	9.81	15.85	21.19	24.84	26.17	24.84	21.19	15.85	9.81	4.52	1.06	0.00
To Receiver	W/m2 (uv)	0.00	0.85	3.62	7.85	12.68	16.95	19.87	20.93	19.87	16.95	12.68	7.85	3.62	0.85	0.00
FLOW	Gallons/Minute	0.00	0.00	0.00	31.13	50.28	67.23	78.81	83.02	78.81	67.23	50.28	31.13	0.00	0.00	0.00
	Gallons/Hour	0	0	0	1868	3017	4034	4729	4981	4729	4034	3017	1868	0	0	0
	Gallons/Day	32275														
	Gallons/Month	968,249	13.19%													
COSINE FACTOR		0.46	0.40	0.46	0.61	0.76	0.89	0.97	1.00	0.97	0.89	0.76	0.61	0.46	0.40	0.46
FRACTION NOT SHADED		0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68
COLLECTOR REFLECTIVITY		80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%

TABLE D-2 (4 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

JULY 21															
HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	138	208	241	259	269	275	276	275	269	259	241	208	138	0
Clr Sky (W/m2)	0	435	656	760	817	849	868	871	868	849	817	760	656	435	0
Clr Sky (kWh/m2)/Day	9.64														
Denver (kWh/m2)/Day	7.32														
Azimuth		106.1	97.2	87.8	76.7	61.7	37.9	0	37.9	61.7	76.7	87.8	97.2	106.1	
Altitude		13.1	24.3	35.8	47.2	57.9	66.7	70.6	66.7	57.9	47.2	35.8	24.3	13.1	
Zenith		76.9	65.7	54.2	42.8	32.1	23.3	19.4	23.3	32.1	42.8	54.2	65.7	76.9	
Air Mass		3.68	2.03	1.43	1.14	0.99	0.91	0.89	0.91	0.99	1.14	1.43	2.03	3.68	
To Aperture W/m2 (uv)		0.65	3.80	9.25	15.62	21.28	25.21	26.53	25.21	21.28	15.62	9.25	3.80	0.65	
To Receiver W/m2 (uv)		0.52	3.04	7.40	12.49	17.03	20.17	21.22	20.17	17.03	12.49	7.40	3.04	0.52	
FLOW Gallons/Minute		0.00	0.00	29.34	49.55	67.52	79.98	84.16	79.98	67.52	49.55	29.34	0.00	0.00	
Gallons/Hour		0	0	1760	2973	4051	4799	5049	4799	4051	2973	1760	0	0	
Gallons/Day	32215														
Gallons/Month	998,662	13.61%													
COSINE FACTOR		0.35	0.43	0.59	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.59	0.43	0.35	
FRACTION NOT SHADED		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY		80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

AUGUST 21															
HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	81	191	237	260	272	278	280	278	272	260	237	191	81	0
Clr Sky (W/m2)	0	256	603	748	820	858	877	883	877	858	820	748	603	256	0
Clr Sky (kWh/m2)/Day	9.21														
Denver (kWh/m2)/Day	7.08														
Azimuth		99.5	90	79.9	67.9	52.1	29.7	0	29.7	52.1	67.9	79.9	90	99.5	
Altitude		7.9	19.3	30.7	41.8	51.7	59.3	62.3	59.3	51.7	41.8	30.7	19.3	7.9	
Zenith		82.1	70.7	59.3	48.2	38.3	30.7	27.7	30.7	38.3	48.2	59.3	70.7	82.1	
Air Mass		6.08	2.53	1.64	1.25	1.06	0.97	0.94	0.97	1.06	1.25	1.64	2.53	6.08	
To Aperture W/m2 (uv)		0.04	1.93	7.23	14.11	20.35	24.64	26.17	24.64	20.35	14.11	7.23	1.93	0.04	
To Receiver W/m2 (uv)		0.03	1.54	5.78	11.29	16.28	19.71	20.93	19.71	16.28	11.29	5.78	1.54	0.03	
FLOW Gallons/Minute		0.00	0.00	22.92	44.78	64.58	78.18	83.02	78.18	64.58	44.78	22.92	0.00	0.00	
Gallons/Hour		0	0	1375	2687	3875	4691	4981	4691	3875	2687	1375	0	0	
Gallons/Day	30236														
Gallons/Month	937,319	12.77%													
COSINE FACTOR		0.21	0.33	0.53	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.53	0.33	0.21	
FRACTION NOT SHADED		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
COLLECTOR REFLECTIVITY		80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	

TABLE D-2 (5 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

SEPTEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	149	230	263	280	287	290	287	280	263	230	149	0	0
Clr Sky (W/m2)	0	0	470	726	830	883	905	915	905	883	830	726	470	0	0
Clr Sky (kWh/m2)/Day	8.54														
Denver (kWh/m2)/Day	6.81														
Azimuth			80.2	69.6	57.3	41.9	22.6	0	22.6	41.9	57.3	69.6	80.2		
Altitude			11.4	22.5	32.8	41.6	47.7	50	47.7	41.6	32.8	22.5	11.4		
Zenith			78.6	67.5	57.2	48.4	42.3	40	42.3	48.4	57.2	67.5	78.6		
Air Mass			4.22	2.18	1.54	1.26	1.13	1.09	1.13	1.26	1.54	2.18	4.22		
To Aperture W/m2 (uv)			0.37	4.64	11.79	18.81	23.55	25.32	23.55	18.81	11.79	4.64	0.37		
To Receiver W/m2 (uv)			0.29	3.71	9.43	15.05	18.84	20.25	18.84	15.05	9.43	3.71	0.29		
FLOW Gallons/Minute			0.00	0.00	37.42	59.67	74.70	80.32	74.70	59.67	37.42	0.00	0.00		
Gallons/Hour			0	0	2245	3580	4482	4819	4482	3580	2245	0	0		
Gallons/Day	25434														
Gallons/Month	763,024	10.40%													
COSINE FACTOR			0.26	0.50	0.71	0.87	0.97	1.00	0.97	0.87	0.71	0.50	0.26		
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

OCTOBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	48	204	257	280	291	294	291	280	257	204	48	0	0
Clr Sky (W/m2)	0	0	151	644	811	883	918	927	918	883	811	644	151	0	0
Clr Sky (kWh/m2)/Day	7.74														
Denver (kWh/m2)/Day	6.35														
Azimuth			72.3	61.9	49.8	35.6	18.7	0	18.7	35.6	49.8	61.9	72.3		
Altitude			4.5	15	24.5	32.4	37.6	39.5	37.6	32.4	24.5	15	4.5		
Zenith			85.5	75	65.5	57.6	52.4	50.5	52.4	57.6	65.5	75	85.5		
Air Mass			10.64	3.23	2.01	1.56	1.37	1.31	1.37	1.56	2.01	3.23	10.64		
To Aperture W/m2 (uv)			0.00	2.12	8.64	15.73	20.76	22.56	20.76	15.73	8.64	2.12	0.00		
To Receiver W/m2 (uv)			0.00	1.69	6.91	12.58	16.61	18.05	16.61	12.58	6.91	1.69	0.00		
FLOW Gallons/Minute			0.00	0.00	27.40	49.90	65.87	71.58	65.87	49.90	27.40	0.00	0.00		
Gallons/Hour			0	0	1644	2994	3952	4295	3952	2994	1644	0	0		
Gallons/Day	21475														
Gallons/Month	665,729	9.07%													
COSINE FACTOR			0.31	0.52	0.72	0.87	0.97	1.00	0.97	0.87	0.72	0.52	0.31		
FRACTION NOT SHADED			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
COLLECTOR REFLECTIVITY			80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%		

TABLE D-2 (6 of 6) - ANNUAL PERFORMANCE OF ROCKY FLATS SOLAR DETOXIFICATION FACILITY

WINTER PLANT SHUTDOWN - NOVEMBER, DECEMBER AND JANUARY

40 DEGREES NORTH LATITUDE - ASHRAE CLEAR SKY INSOLATION MODEL - TABLE 2, 1987 HVAC HANDBOOK

5 TO 1 TURNDOWN - 20 GPM MINIMUM - MIDLIFE REFLECTIVITY = 80%

NOVEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	0	136	232	268	283	288	283	268	232	136	0	0	0
Clr Sky (W/m2)	0	0	0	429	732	845	893	909	893	845	732	429	0	0	0
Clr Sky (kWh/m2)/Day	6.71														
Denver (kWh/m2)/Day	5.46														
Azimuth				55.4	44.1	31	16.1	0	16.1	31	44.1	55.4			
Altitude				8.2	17	24	28.6	30.2	28.5	24	17	8.2			
Zenith				81.8	73	66	61.4	59.8	61.5	66	73	81.8			
Air Mass				5.86	2.86	2.05	1.74	1.66	1.75	2.05	2.86	5.86			
To Aperture W/m2 (uv)				0.24	4.43	10.67	15.41	17.16	15.34	10.67	4.43	0.24			
To Receiver W/m2 (uv)				0.19	3.54	8.54	12.32	13.73	12.27	8.54	3.54	0.19			
FLOW Gallons/Minute				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
Gallons/Hour				0	0	0	0	0	0	0	0	0			
Gallons/Day	0														
Gallons/Month	0	0.00%													
COSINE FACTOR				0.58	0.75	0.88	0.97	1.00	0.97	0.88	0.75	0.58			
FRACTION NOT SHADED				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			

DECEMBER 21

HOUR	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
INSOLATION Btu/h ft2	0	0	0	89	217	261	280	285	280	261	217	89	0	0	0
Clr Sky (W/m2)	0	0	0	281	685	823	883	899	883	823	685	281	0	0	0
Clr Sky (kWh/m2)/Day	6.24														
Denver (kWh/m2)/Day	5.05														
Azimuth				53	41.9	29.4	15.2	0	15.2	29.4	41.9	53			
Altitude				5.5	14	20.7	25	26.6	25	20.7	14	5.5			
Zenith				84.5	76	69.3	65	63.4	65	69.3	76	84.5			
Air Mass				8.71	3.45	2.36	1.98	1.87	1.98	2.36	3.45	8.71			
To Aperture W/m2 (uv)				0.01	2.76	8.35	12.88	14.59	12.88	8.35	2.76	0.01			
To Receiver W/m2 (uv)				0.01	2.20	6.68	10.30	11.68	10.30	6.68	2.20	0.01			
FLOW Gallons/Minute				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
Gallons/Hour				0	0	0	0	0	0	0	0	0			
Gallons/Day	0														
Gallons/Month	0	0.00%													
COSINE FACTOR				0.61	0.76	0.89	0.97	1.00	0.97	0.89	0.76	0.61			
FRACTION NOT SHADED				0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68			
COLLECTOR REFLECTIVITY				80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%			
GALLONS PER YEAR	7,338,670														

Appendix E

TOTAL FIELD COST ESTIMATE DETAILS

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
0.0	LAND	3	AC		0						0	0
1.0	BUILDINGS AND SITE IMPROVEMENTS											
1.10	CLEAR AND GRUB	2.2	AC		1,350						2,970	2,970
1.20	ROADS - GRADING	700	SY		0.50						350	350
	8 in. BASE	110	CY		12						1,320	1,320
	3 in. ASPHALT	500	SY		6						3,000	3,000
1.30	SITE FENCING	1,230	LF		13.50						16,605	16,605
1.50	CONTROL AND ELECTRICAL BUILDING	1,500	SF		70						105,000	105,000
	- INSULATED SHEET METAL WALLS AND ROOF											
	- CONCRETE FOUNDATION											
	- ELECTRIC EQUIPMENT AND BULK MATERIALS											
	Subtotal										129,245	129,245
1.90	SALES TAX											0
1.0	Total: BUILDINGS AND SITE IMPROVEMENTS										129,245	129,245
2.0	PRETREATMENT SYSTEM											
2.10	PUMPS AND DRIVES											
	- RAW WATER: 100 GPM, 105 FT TDH, 4 BHP MOTOR, 304 STAINLESS STEEL	1	EA	5,800		25.00	39	39	5,800	1,820		7,620
	- HCl METERING: 1 GPM, 1/4 BHP MOTOR, PLASTIC	2	EA	5,300		25.00	17	34	10,600	1,590		12,190
	- HYDROGEN PEROXIDE METERING: 1/2 GPH, 1/4 BHP MOTOR, 316 STAINLESS STEEL	2	EA	1,200		25.00	17	34	2,400	1,590		3,990

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
Subtotal: Pumps and Drives								18,800	5,000		23,800
2.20 TANKS AND VESSELS											
- FEED STRAINERS: POLYETHYLENE	2	EA	1,000		25.00	5	11	2,000	510		2,510
- RAW WATER TANK: 6,000 GAL. CAPACITY, FIBERGLASS, CONE ROOF, 10 FT DIA x 10 FT HIGH	1	EA	5,500		25.00	43	43	5,500	2,000		7,500
- CATION EXCHANGE PACKAGE: 304 STAINLESS STEEL, 4 FT 6 in. DIA. x 4 FT 6 in. LONG	1	EA	42,000		25.00	43	43	42,000	2,000		44,000
- HCl STORAGE TANK: 2,000 GAL. CAPACITY, CROSS LINKED POLYETHYLENE	1	EA	2,500		25.00	21	21	2,500	980		3,480
- CARTRIDGE FILTER: 5 MICRON, 304 STAINLESS STEEL	1	EA	1,764		25.00	11	11	1,764	510		2,274
Subtotal: Tanks and Vessels								53,764	6,000		59,764
2.30 PIPING AND INSTRUMENTATION											
- PRIMARY: 6 in. CARBON STEEL, SCHEDULE 40	80	FT	20		25.00	1.11	89	1,600	4,150		5,750
- SECONDARY: 2 in. CARBON STEEL, SCHEDULE 40	80	FT	5		25.00	0.80	64	400	2,980		3,380
- METERING: 0.5 in. STAINLESS STEEL	100	FT	2		25.00	0.64	64	200	2,980		3,180
- VALVES (60% PIPE MATERIAL COST)	1	LT						1,320			1,320
- HANGERS AND SUPPORTS (15% PIPE AND VALVE MATERIAL COST AND 25% LABOR HOURS)	1	LT			25.00		54	528	2,530		3,058
- MISCELLANEOUS LABOR OPERATIONS (55%)	1	LT			25.00		119		5,560		5,560
- INSTRUMENTATION (20% PIPE AND VALVE INSTALLED COST)	1	LT		4,450						4,450	4,450
Subtotal: Piping and Instrumentation								4,048	18,200	4,450	26,698
2.40 MOTIONLESS MIXER	1	EA	500		25.00	5	5	500	230		730
2.50 ELECTRIC EQUIPMENT AND BULK MATERIALS (12% OF INSTALLED EQUIPMENT COST)	1	LT		10,028						10,028	10,028
Subtotal								77,112	29,430	14,477	121,019

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
2.90	SALES TAX								3,239			3,239
2.0	Total: PRETREATMENT SYSTEM								80,351	29,430	14,477	124,258
3.0	COLLECTOR SYSTEM											
3.10	COLLECTORS: INCLUDES SA-85 ALUMINUM REFLECTOR, PEDESTALS, FOUNDATIONS, SHADOW WELL SUN SENSOR, DRIVE MOTORS, FLEXIBLE HOSE CONNECTIONS	1,145	M2		215						246,180	246,180
3.30	FIELD WIRING: POWER TO DRIVE MOTORS AND GROUNDING	1,145	M2		6						6,870	6,870
3.40	SUPERVISORY CONTROLLER	1	LT	(Included with Master Control System)								
3.50	FIELD PIPING											
	- SUPPLY HEADER: 6 in. PVC, SCHEDULE 80	500	LF	1.25		25.00	0.07	35	625	1,630		2,255
	- FLEXIBLE CONNECTIONS TO RECEIVER TUBES	22	EA	(Included with Collectors)								
	- RETURN HEADER: 6 in. PVC, SCHEDULE 80	400	LF	1.25		25.00	0.07	28	500	1,310		1,810
	- RETURN HEADER PIPE SUPPORTS (42 EACH)	925	LB	2.00		25.00	0.21	194	1,850	9,040		10,890
	- HEADER EXCAVATION AND BACKFILL	156	CY			25.00	0.54	84		3,920		3,920
	- PIPE SUPPORT EXCAVATION AND BACKFILL	42	CY			25.00	0.54	23		1,070		1,070
	- PIPE SUPPORT CONCRETE FOUNDATIONS	13	CY	80		25.00	7	97	1,040	4,520		5,560
	- MISCELLANEOUS LABOR OPERATIONS (55%)	1	LT			25.00		254		11,820		11,820
	Subtotal: Field Piping								4,015	33,310		37,325
	Subtotal								4,015	33,310	253,050	290,375
3.90	SALES TAX								169			169
3.0	Total: COLLECTOR SYSTEM								4,184		253,050	290,544

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
4.0	RECEIVER TUBES											
4.10	2 in. DIAMETER BOROSILICATE GLASS WITH TITANIUM DIOXIDE CATALYST IMPREGNATED IN FIBERGLASS MESH	1,760	LF	26.70		25.00	0.11	194	46,992	9,040		56,032
4.90	SALES TAX								1,974			1,974
4.0	Total: RECEIVER TUBES								48,966	9,040		58,006
5.0	POSTTREATMENT SYSTEM											
5.10	PUMPS AND DRIVES											
	- CLEAN WATER: 100 GPM, 35 FT TDH, 2 BHP MOTOR, 304 STAINLESS STEEL	1	EA	4,800		25.00	39	39	4,800	1,820		6,620
	- RECYCLE WATER: 100 GPM, 105 FT TDH, 4 BHP MOTOR, 304 STAINLESS STEEL	1	EA	5,800		25.00	39	39	5,800	1,820		7,620
	- RECHARGE WATER: 100 GPM, 25 FT TDH, 1 BHP MOTOR, 304 STAINLESS STEEL	1	EA	(Included with Degasifier)								
	- FERRIC CHLORIDE METERING: 1/2 GPH, 1/4 BHP MOTOR, 316 STAINLESS STEEL	2	EA	800		25.00	17	34	1,600	1,590		3,190
	- pH CONTROL (NaOH): 1/2 GPH, 1/4 BHP MOTOR, 316 STAINLESS STEEL	2	EA	800		25.00	17	34	1,600	1,590		3,190
	- HEAT EXCHANGER SPRAY WATER: 5 GPM, 30 FT TDH, 0.25 BHP MOTOR, 304 STAINLESS STEEL	2	EA									
	Subtotal: Pumps and Drives								13,800	6,820		20,620
5.20	TANKS AND VESSELS											
	- CLEAN WATER TANK: 10,000 GAL. CAPACITY, FIBERGLASS, CONE ROOF, 12 FT DIA x 12 FT HIGH	1	EA	8,000		25.00	70	70	8,000	3,260		11,260
	- RECYCLE WATER TANK: 6,000 GAL. CAPACITY, FIBERGLASS, CONE ROOF, 10 FT DIA x 10 FT HIGH	1	EA	5,500		25.00	43	43	5,500	2,000		7,500
	- CATION EXCHANGE PACKAGE: 304 STAINLESS STEEL, 4 FT DIA. x 5 FT LONG	1	EA	45,000		25.00	43	43	45,000	2,000		47,000
	- DEGASIFIER: PLASTIC WITH AIR/WATER SEPARATOR, 2 FT DIA. x 10 FT HIGH	1	EA	12,000		25.00	27	27	12,000	1,260		13,260

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
	- SURGE TANK: 3,000 GAL. CAPACITY, FIBERGLASS, HORIZONTAL, 8 FT DIA. x 8 FT LONG	1	EA	(Included with Degasifier)								
	- GRANULATED ACTIVATED CARBON FILTERS: VERTICAL CYLINDRICAL CARBON STEEL TANKS, EPOXY LINED											
	o CLEAN WATER TANK DISCHARGE: 86.5 in. HIGH x 45 in. DIA, 65 LBS CARBON	2	EA	7,200		25.00	11	21	14,400	980		15,380
	o RECYCLE WATER TANK VENT: 20 in. DIA. x 30 in. HIGH, 5 LBS CARBON	1	EA	650		25.00	5	5	650	230		880
	Subtotal: Tanks and Vessels								85,550	9,730		95,280
5.30	CLEAN WATER COOLER - FORCED DRAFT, FINNED TUBE WATER TO AIR HEAT EXCHANGER WITH WATER SPRAY NOZZLES, 304 STAINLESS STEEL	1	EA	25,400		25.00	32	32	25,400	1,490		26,890
5.40	MOTIONLESS MIXER	1	EA	500		25.00	5	5	500	230		730
5.50	DEGASIFIER BLOWER: 400 SCFM, 2 in. H20, 0.5 BHP MOTOR	1	EA	(Included with Degasifier)								
5.50	PIPING AND INSTRUMENTATION											
	- PRIMARY: 6 in. CARBON STEEL, SCHEDULE 40	120	FT	20		25.00	1.11	133	2,400	6,200		8,600
	- SECONDARY: 2 in. CARBON STEEL, SCHEDULE 40	120	FT	5		25.00	0.80	96	600	4,480		5,080
	- METERING: 0.5 in. STAINLESS STEEL	100	FT	2		25.00	0.64	64	200	2,980		3,180
	- VALVES (60% PIPE MATERIAL COST)	1	LT						1,920			1,920
	- HANGERS AND SUPPORTS (15% PIPE AND VALVE MATERIAL COST AND 25% LABOR HOURS)	1	LT			25.00		73	768	3,410		4,178
	- MISCELLANEOUS LABOR OPERATIONS (55%)	1	LT			25.00		161		7,510		7,510
	- INSTRUMENTATION (20% PIPE AND VALVE INSTALLED COST)	1	LT		6,094						6,094	6,094
	Subtotal: Piping and Instrumentation								5,888	24,580	6,094	36,562
5.60	TOTAL ORGANIC COMPOUNDS ANALYZER: GAS CHROMATOGRAPH WITH FLAME IONIZATION DETECTOR	1	EA	45,000		25.00	43	43	45,000	2,000		47,000
5.70	ELECTRIC EQUIPMENT AND BULK MATERIALS (12% OF INSTALLED EQUIPMENT COST)	1	LT		17,222						17,222	17,222

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
5.80	MISCELLANEOUS CIVIL/STRUCTURAL											
	- CONCRETE FOOTING AND FOUNDATIONS	15	CY	80		25.00	7	112	1,200	5,220		6,420
	- STRUCTURAL STEEL AND MISCELLANEOUS IRON											
	o PIPE AND ELECTRICAL RACK SUPPORTS	2	T		1,500						3,000	3,000
	o GRATING AND LADDERS	1	T		2,000						2,000	2,000
	Subtotal: Miscellaneous Civil/Structural								1,200	5,220	5,000	11,420
	Subtotal								177,338	50,070	28,316	255,724
5.90	SALES TAX								7,448			7,448
5.0	Total: POSTTREATMENT SYSTEM								184,786	50,070	28,316	263,172
6.0	AUXILIARY SYSTEMS											
6.10	PUMPS AND DRIVES											
	- NEUTRALIZATION WASTE WATER: 100 GPM, 35 FT TDH, 2 BHP MOTOR	1	EA	4,000		25.00	32	32	4,000	1,490		5,490
	- DECANT WATER: 30 GPM, 35 FT TDH, 1 BHP MOTOR, 304 STAINLESS STEEL	1	EA	2,800		25.00	39	39	2,800	1,820		4,620
	- SLURRY WATER: 20 GPM, AIR OPERATED, PLASTIC	1	EA	1,500		25.00	28	28	1,500	1,310		2,810
	- NEUTRALIZATION (NaOH): 1/2 GPH, 1/4 BHP MOTOR, 316 STAINLESS STEEL	2	EA	1,200		25.00	17	34	2,400	1,590		3,990
	Subtotal: Pumps and Drives								10,700	6,210		16,910
6.20	TANKS AND VESSELS											
	- NEUTRALIZATION TANK: 5,000 GAL. CAPACITY, FIBERGLASS, CONE ROOF, 10 FT DIA x 10 FT HIGH	1	EA	4,500		25.00	32	32	4,500	1,490		5,990
	- DECANT WATER TANK: 2,000 GAL. CAPACITY, FIBERGLASS, CONE ROOF, 7 FT DIA x 7 FT HIGH	1	EA	2,500		25.00	21	21	2,500	980		3,480
	Subtotal: Tanks and Vessels								7,000	2,470		9,470

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
6.30	SLUDGE FILTER PRESS: 1 FT3, PLASTIC	1	EA	10,950		25.00	21	21	10,950	980		11,930
6.40	NEUTRALIZATION TANK MIXER	1	EA	6,000		25.00	32	32	6,000	1,490		7,490
6.50	COMPRESSED AIR SYSTEM											
	- AIR RECEIVER: VERTICAL AXIS CYLINDER, SKIRT MOUNTED CS WITH DISHED HEADS, 2.5 FT DIA x 5 FT H, 25 FT3 CAPACITY	1	EA	700		25.00	27	27	700	1,260		1,960
	- COMPRESSOR: SINGLE STAGE, SINGLE ACTING, NON-LUBRICATED, RECIPROCATING TYPE, MOTOR DRIVEN WITH INLET FILTER AND SILENCER, AFTERCOOLERS OF CARBON STEEL, 15 CFM, 110 PSIG, 3 HP	1	EA	2,000		25.00	60	60	2,000	2,800		4,800
	- AIR DRYER: DUAL TOWER DESICCANT TYPE WITH CONTROLS AND MOISTURE SENSOR, AUTOMATIC REGENERATION, 15 SCFM, 110 PSIG	1	LT	1,500		25.00	54	54	1,500	2,520		4,020
	Subtotal: Compressed Air System								4,200	6,580		10,780
6.60	PIPING AND INSTRUMENTATION											
	- PRIMARY: 2 in. CARBON STEEL, SCHEDULE 40	60	FT	5		25.00	1.11	67	300	3,120		3,420
	- METERING: 0.5 in. STAINLESS STEEL	60	FT	2		25.00	0.64	38	120	1,770		1,890
	- COMPRESSED AIR: 1.0 in. CARBON STEEL	100	FT	3		25.00	0.64	64	300	2,980		3,280
	- VALVES (60% PIPE MATERIAL COST)	1	LT						432			432
	- HANGERS AND SUPPORTS (15% PIPE AND VALVE MATERIAL COST AND 25% LABOR HOURS)	1	LT			25.00		42	173	1,970		2,143
	- MISCELLANEOUS LABOR OPERATIONS (55%)	1	LT			25.00		93		4,330		4,330
	- INSTRUMENTATION (20% PIPE AND VALVE INSTALLED COST)	1	LT		3,099						3,099	3,099
	Subtotal: Piping and Instrumentation								1,325	14,170	3,099	18,594
6.70	ELECTRIC EQUIPMENT AND BULK MATERIALS (12% OF INSTALLED EQUIPMENT COST)	1	LT		6,790						6,790	6,790
	Subtotal								40,175	31,900	9,889	81,963
6.90	SALES TAX								1,687			1,687

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

	DESCRIPTION	QTY	UNIT	UNIT COST MAT'L	UNIT COST S/C	UNIT COST LABOR	UNIT MH	TOTAL MH	$ MAT'L	$ LABOR	$ S/C	$ TOTAL
6.0	Total: AUXILIARY SYSTEMS								41,862	31,900	9,889	83,650
7.0	CONTROL SYSTEM											
	SUPERVISORY CONTROLLER	1	LT	10,000		25.00	300	300	10,000	13,990		23,990
	DATA ACQUISITION SYSTEM	1	LT	20,000		25.00	300	300	20,000	13,990		33,990
	Subtotal								30,000	27,980		57,980
7.90	SALES TAX								1,260			1,260
7.0	Total: CONTROL SYSTEM								31,260	27,980		59,240

SOLAR DETOXIFICATION FACILITY TOTAL FIELD COST ESTIMATE

			UNIT COST			UNIT	TOTAL	$			
DESCRIPTION	QTY	UNIT	MAT'L	S/C	LABOR	MH	MH	MAT'L	LABOR	S/C	TOTAL
BASIS FOR DISTRIBUTABLE COSTS:											
OVERALL PRODUCTIVITY FOR ROCKY FLATS PLANT (OUTSIDE PLUTONIUM SECURITY ZONE)	1.07										
DISTRIBUTABLE MANUAL LABOR AS A PERCENTAGE OF DIRECT MANUAL LABOR	20%										
NON-MANUAL LABOR AS A PERCENTAGE OF DIRECT MANUAL LABOR	10%										
DISTRIBUTABLE MATERIAL COST PER DIRECT HOUR	$7.00										
DISTRIBUTABLE MANUAL WAGE RATE	$25.00										
NON-MANUAL WAGE RATE, INCLUDING PAYROLL ADDITIVES	$32.50										
PERCENT OVERHEAD AND PROFIT APPLICABLE TO DIRECT LABOR, DISTRIBUTABLE MATERIAL AND MANUAL LABOR, AND NONMANUAL LABOR	15%										
SALES TAX	4.2%										
DISTRIBUTABLE COST PER DIRECT MANUAL HOUR	$15.54										

{(Distributable Material + Sales Tax on Distributable Material) +
(Distributable Manual Labor Percentage * Distributable Manual Wage Rate) +
(Distributable Non-manual Labor Percentage * Non-manual Wage Rate)}

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