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Reliability-Economics Analysis Models for Photovoltaic Power Systems

Volume 1

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Volume 1

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Abstract

This report describes the development of modeling techniques to characterize the reliability, availability, and maintenance costs of photovoltaic power systems. The developed models can be used by designers of PV systems in making design decisions and trade-offs to minimize life-cycle energy costs. Three actual intermediate PV system designs were modeled as examples. The input data estimates used and the results of the analyses are presented.

Prepared for Sandia National Laboratories Under Subcontract No. 62-8278.

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FINAL REPORT

on

RELIABILITY-ECONOMICS ANALYSIS MODELS FOR PHOTOVOLTAIC POWER SYSTEMS

VOLUME II

April 30, 1982

LAWRENCE H. STEMBER, WILLIAM R. HUSS, AND
MICHAEL S. BRIDGMAN

SYSTEM RELIABILITY ANALYSIS APPLICATION

General

Volume I of this report discussed photovoltaic (PV) systems, data, and the development of the Reliability-Economics Assessment Models. This volume, Volume II, provides the details of the analyses of three actual PV systems. The three DOE/Sandia PRDA systems chosen to represent a cross section of PV system designs are: Lea County Electric Company installation in Lovington, New Mexico (flat panel), the Arizona Public Service (APS) Phoenix Airport System with the Martin-Marietta array field (passively cooled concentrator), and BDM's Albuquerque System (actively cooled concentrator). Each system is analyzed using the two developed methodologies in separate sections of this volume. A comparison of the results using the two different techniques is given at the end of Section 3.

Appendixes A and B contain details of the mathematics and hand-held calculator programs for the state space methodology. Appendixes C and D include programming details of the SOLREL methodology.

Array Field Output Power Degradation Due to Solar Cell Failures

General

Analyses of array field power loss over time periods up to 30 years were conducted for the three PRDA-based* photovoltaic systems--the Lea County Electric Systems, the BDM installation in Albuquerque, New Mexico; and the APS Phoenix Airport installation. The JPL Array Design Methodology(3) will be employed.** It assumes a maintenance philosophy in which modules with failed cells are not replaced, but allowed to remain in the field. The analyses are based on a knowledge of the cell series-parallel interconnection scheme of each of the arrays, the bypass diode density (actually, the number of series cells per bypass diode), and assumed cell failure rates.

Normal cell failure rates (λ_{cell}) for specific cell and module designs, and particularly for current designs, have not been established. Estimates of λ_{cell} based on limited field experience with a number of disparate array field and module designs have been published by the Jet Propulsion Laboratory, MIT Lincoln Laboratories, and others(7).

Cell "allocations" have also been developed based on speculative projections of module technology. A commonly used λ_{cell} allocation for flat plate technology is 0.0001 failures per year. This failure rate includes both open and short-circuit cell failure modes. In order to produce a conservative prediction, the JPL methodology makes the assumption that any cell failure causes a substring failure, even though this is only assured for the open-circuit mode.

In the analysis of the Lea County Electric Company System Array, failure rate values of 0.001, 0.0001, and 0.00001 failures per year were used, and three separate array power degradation curves were generated. The largest (0.001) represents the high end of the data actually experienced.

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* PRDA - an acrynom used for a series of DOE-sponsored intermediate-size PV power system experimental designs.

** Superscripts refer to the References at the end of Volume I.

No meaningful data on cell failure rates for concentrator-type photovoltaic arrays exist, primarily because of the limited field experience with these arrays. In developing a number for use in the present analyses, it was projected that cells operating in concentrator arrays are subjected to higher stresses than those in flat panel modules due to potentially higher temperatures and/or thermal gradients. On this basis, a λ_{cell} of 0.0005 failures per year was assigned to the concentrator cells.

The key factors in determining the ability of a given array to maintain power output levels near its rated value despite individual cell failures, are the density of parallel interconnections of cells and the density of bypass diodes. Therefore, the first step in the analysis of array power loss behavior is an assessment of the electrical design of the array. Detailed data about the series block, branch circuit and bypass diode connections are required for each system to be analyzed. These will be presented with each system description.

Analysis Procedure

The first step in the JPL methodology's calculation of the array power loss as a function of time is the determination of the substring* failure density. The methodology uses the binomial equation

$$P_k = \frac{n!}{k!\,(n-k)!}\, p^k\,(1-p)^{n-k}$$

where n is the number of cells per substring, p is the cumulative cell failure density at time t, and k is the expected number of failed cells per substring. Additional assumptions relevant to the analyses are:

- One failed cell results in a failed substring.
- More than one failed cell in a given substring has no additional effect.

---

* The terms substring and series block are synonymous in the case of the two concentrator systems. In the case of the flat panel system, a series block contained 5 (parallel) substrings.

With these assumptions, it can be seen that the substring failure density (D) is given by

$$D = 1 - P_0$$

where P_0 is calculated from the binomial equation.

Once the substring failure density as a function of time has been determined, the array power loss as a function of time can be determined using computer-generated data developed by the Jet Propulsion Laboratory (JPL) group as part of their Flat Panel Photovoltaic Module and Array Circuit Design Optimization methodology (2,3). The computer program uses the failure density data and, providing for random distribution of the failures, and the I-V characteristics of the individual devices to assess the net impact on the array performance. The computer analyses include the effects of series-parallel interconnections and diodes. JPL has published the computer-generated data in the form of plots for a range of cases (e.g., 1, 4, 8, and 16 parallel substrings per series block; 0, 1, 4, 8, and 12 series blocks per bypass diode; etc.) which permit interpolation to a wide range of existing designs. An extensive set of these curves appears in the handbook from the JPL Workshop on Flat Panel Photovoltaic Module and Array Circuit Design Optimization(3). While the computer analyses were performed with flat panel systems in mind, the methodology is clearly applicable to cell failures in concentrator systems as well. Appropriate interpolations from the JPL generated plots of substring failure density versus array power loss fraction were used in the present analyses to arrive at an array power loss versus time curve for each of the three systems. These are shown as figures later in this report volume as applied to each of the three example systems. The curves are used as input data to each analysis methodology as shown later in Figure 1-2.

SECTION 1. ANALYSIS OF FLAT-PANEL PV SYSTEM

LEA COUNTY ELECTRIC FLAT PANEL PV SYSTEM

Description of System

The block diagram of this system is shown in Figure 1-1. As can be seen from the figure, the array field consists of two independent solar arrays with their wiring and power conditioning subsystems feeding independently into the power distribution system(19). Each of these photovoltaic power subsystems is capable of producing 51 kilowatts. The individual arrays are made up of groups, branch circuits, and subfields. A group is a parallel connection of five modules with one bypass diode connected across it. The branch circuit is a series-connection of 16 groups. These are joined in parallel at the inverter inputs. The subfield is an assemblage of 21 branch circuits which feeds a single inverter. The array field consists of 2 subfields, for a total peak power of 102 kW_p. The field voltage is approximately 250 volts dc. This design is two-thirds the size of the final Phase 1, PRDA system design.

The power conditioners convert the dc voltage to three-phase ac, synchronized with the utility grid frequency. Since the array is a fixed, flat panel system, no control functions of the physical positioning of the array are required by the power conditioning subsystem. The degradation in field output due to changes in insolation and to cell failures is described in the following section.

Input Data

Output Duration Curves. In order to represent the month-to-month variations in solar insolation, a set of 12 power output duration curves was provided for the availability simulation. This represented the time during any given month that the power would be at certain levels, assuming no system failures or degradation. These curves are generated by the SOLCEL design simulation and are shown in Figure C-1 and Table 1-10.

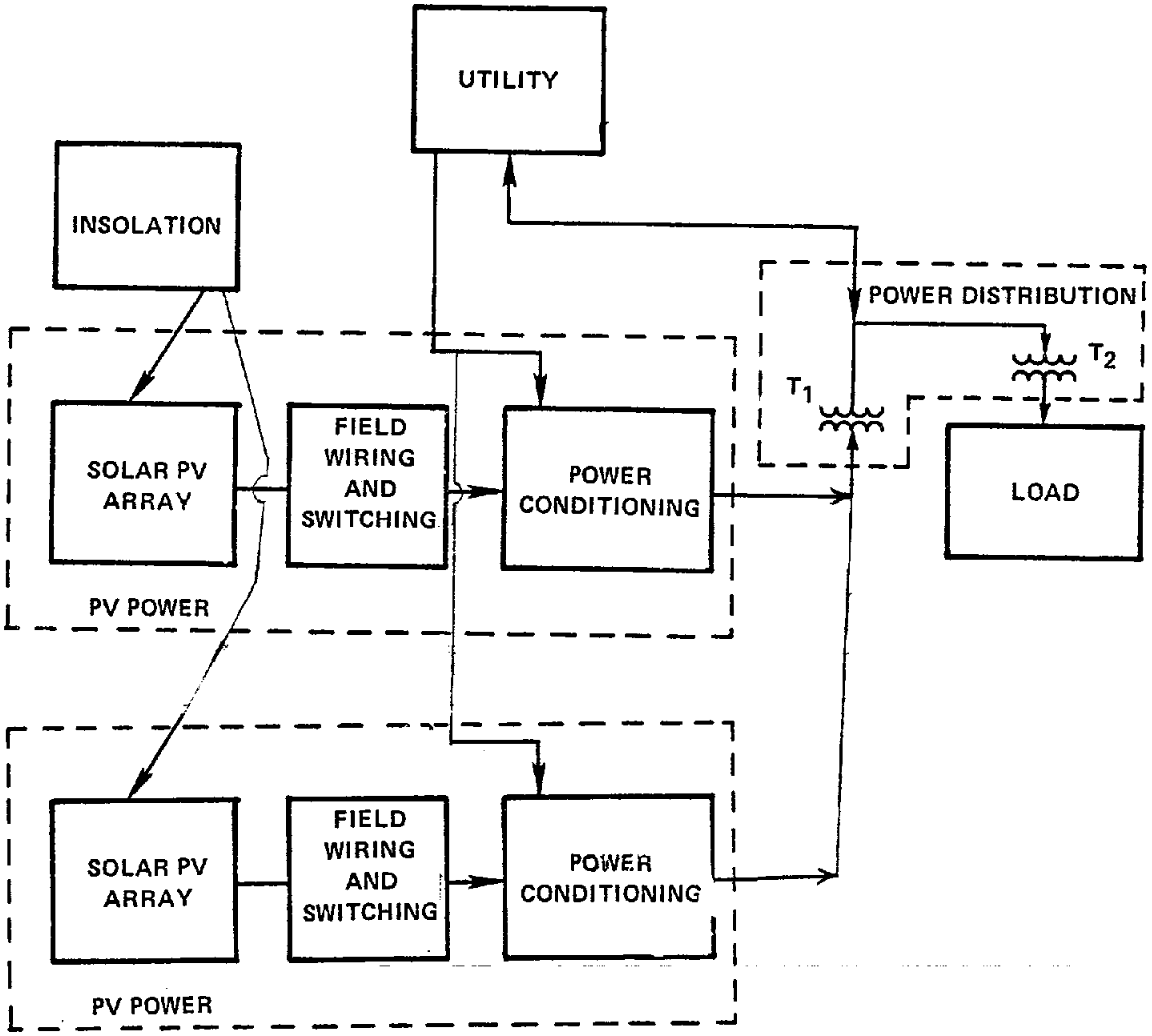

FIGURE 1-1. SIMPLIFIED FUNCTIONAL BLOCK DIAGRAM -- LEA COUNTY FLAT-PANEL PV POWER SYSTEM, INTERACTIVE WITH UTILITY, NO STORAGE

Data from Array Field Analysis Results. The salient features of the design of this installation for the analyses are:

- A series block consisting of 36 series cells by 5 parallel strings with one bypass diode per block.
- A branch circuit consisting of 16 series blocks connected in series.
- An array field consisting of 42 parallel branch circuits divided into 2 subfields of 21 branch circuits each. Using this information and a λ_{cell} assumption of 0.0001 failures per year, the JPL analysis (described in an earlier section of this volume) was conducted.

The results of the analysis are summarized in Figure 1-2. The plot for the Lovington, New Mexico, installation illustrates the sensitivity to the assumed λ_{cell} value. It can be seen that if the often used value of 0.0001 failures per year is achieved, then a drop in output of less than 20 percent over a 20-year period can be expected without module replacement. This may be an acceptable figure for some installations/applications. This curve is used as input to the availability models. However, if λ_{cell} were an order of magnitude higher (0.001), as Figure 1-2 shows, the 20-year decrease in power output would be an unacceptable 70 percent.

The JPL procedure also has sets of curves for evaluating the hot spot vulnerability of specified array field designs. An assessment of the Lovington, New Mexico, flat-panel installation by this technique indicates that the temperature rise of the degraded cell due to cracked cell heating will be substantially into the unacceptable range according to JPL's standards. Open circuit cell heating, however, is in the acceptable range for this array configuration. The results of these assessments are summarized in Table 1-1.

Reliability/Maintenance Data. The parameters and costs estimated for the reliability/maintenance parameters of this system are given in Table 1-2. These data are strictly estimates to be representative of a system in the mature stage of production and operation.

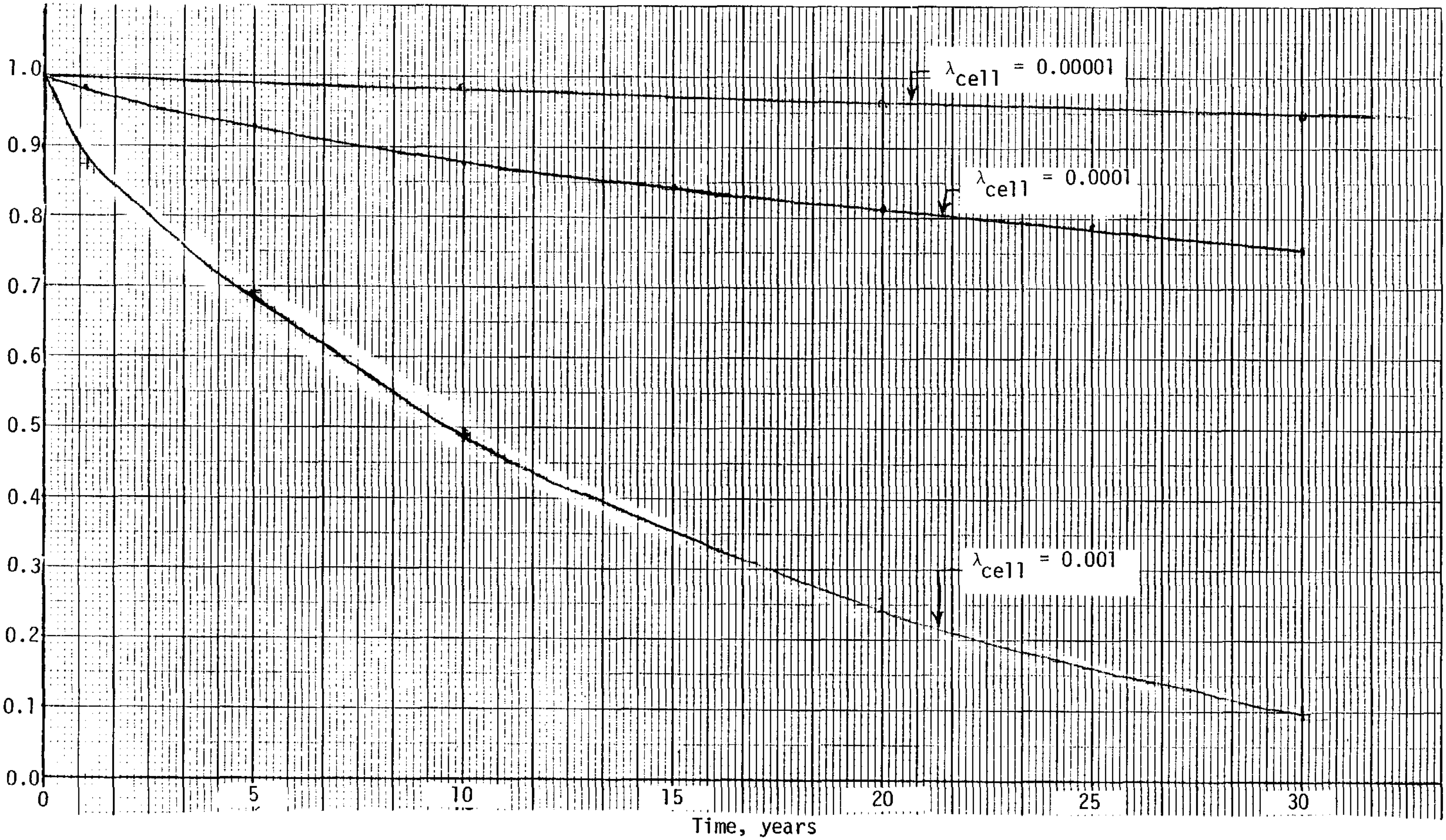

FIGURE 1-2. PERCENT OF PEAK OUTPUT CAPABILITY VERSUS PERIOD OF CONTINUOUS OPERATION WITH NO MODULE REPLACEMENT--LOVINGTON, NEW MEXICO, CONFIGURATION

TABLE 1-1. HOT SPOT HEATING - LOVINGTON, NEW MEXICO

(1) Cell shunt resistance = 100

Power dissipation (cracked cell)	$P/P^*_{max} = 48$
Power dissipation (open circuit)	$P/P_{max} = 0$
Temperature above ambient (cracked)	$T \geq 120C$
Temperature above ambient (open)	$T = 24C$

Cracked cell heating = Bad
Open circuit heating = OK

(2) Cell shunt resistance = 10

Power dissipation (cracked cell)	$P/P^*_{max} = 75$
Power dissipation (open circuit)	$P/P_{max} = 0$
Temperature above ambient (cracked)	$T \geq 120C$
Temperature above ambient (open)	$T = 24C$

Cracked cell heating = Bad
Open circuit heating = OK

---

* P/P_{max} is the ratio of the overheated cell power dissipation to its normal maximum rating in this design.

TABLE 1-2. ESTIMATED RELIABILITY AND MAINTENANCE DATA INPUTS FOR TASK 3 ANALYSIS OF FLAT PANEL PV POWER SYSTEM

	Maintenance							
	Corrective Maintenance					Preventive Maintenance		
	Maintenance Time[a], hr Lognormal					Maintenance Time[c], hr Lognormal[d]		
Subsystem/Component	50 Percentile	90 Percentile	Per hr Charge, $	Travel & Mat'ls (Fixed), $	Source	50 Percentile	90 Percentile	Fixed Costs/ Frequency
Field Wiring/Switching (all of field)	1	2	20	0	Class IV NBNM[b]	-	-	-
Inverter (2)	24	48	40	200+100	II NBNM	6 Replace main contactors	12	$100/every 30 K hr
Solar Array Field	1 (per module)	4	20	0	IV NBNM	32 cleaning	76	Every 12 mo
String Disconnect Switch (1 per string. Total = 21)	1	2	20	0	IV NBNM	-	-	-
Utility	2	3.6	0	0	Same as Rel.[e]	0	-	-
Distribution Subsystem	28	60	0	0	Same as Rel.	8	18	Every 12 mo
Power Switchgear	3.6	6 4 men x 30	120	100	Same as Rel.	0	-	-
General System-wide PM	-	-	-	-	-	40	70	$50/hr + $300 every 12 mo

Footnotes appear on following page.

TABLE 1-2. (Continued)

Subsystem/Component	Reliability				Degradation
	MTBF Clock hr	Parameters	Distribution	Source	
Field Wiring/Switching (all of field)	0.1×10^6	-	Exponential	BCL est.	-
Inverter (2)	8760 each	-	exp.	Ditto	
Solar Array Field (2 arrays)	87.6×10^6 (per cell)	(λcell = 0.0001/yr)	exp.	"	Dirt - 3% output/year[f] (removed by cleaning) Glass abrasion and yellowing of adhesive - 0.1% output/yr Power loss due to cell failures - JPL technique - Results ~25% in 30 yr. Input as power degradation curve.
String Disconnect Switch (1 per string. Total = 21)	10^7 each	-	exp.	"	
Utility	6257	-	exp.	IEEE Std 493-1980 p 214, Table II	-
Distr. Subsystem	8.76×10^6	-	exp.	IEEE Std 493-1980 p 123, Table I	-
Power Switchgear	1.4×10^6	-	exp.	IEEE Std 493-1980 p 123, Table 2 (switches)	-
Weather	-	-	-	-	No shutdown/losses due to Lovington, NM, weather except for infrequent dust storm which is included in SOLMET tape data.

(a) Includes [active repair time + travel time + logistics time + administrative time] (is therefore time to restore).
(b) NBNM = Natural Bridges National Monument Initial Experience in Maintenance (Solman 15th Annual PV Spec. Conf.)
(c) Each Unit or System is down for time being maintained - follow functional diagram.
(d) Same per hour charge as Corrective Maintenance.
(e) Refers to same source as Reliability section of this table.
(f) NBS Tech. Note 1132, 12/80.

State Space Analysis of Lea County System

For the purpose of the reliability analysis, the Lea County Flat-Panel PV System has been divided into three major subsystems:

- Subsystem 1 represents the two array subfields
- Subsystem 2 represents the two inverters
- Subsystem 3 represents all the other elements physically connected in a series configuration.

A diagrammatic representation of the system is shown in Figures 1-3 - 1-5.

Modeling Method

Subsystem 1 is made up of two subarray fields in parallel. A subarray field is a parallel arrangement of module groups (arrangement of cells into modules). The effect of Subsystem 1 on the system output is expressed in terms of the array degradation which is used in the output equation. Therefore, Subsystem 1 will no longer be addressed in the remaining discussion of the state space analysis.

Each of Subsystems 2 and 3 is represented by a number of states where each state is defined in terms of the status of the different elements of the subsystem. Markov model techniques are used to compute the steady-state occupancy probabilities of each subsystem state. These state probabilities are combined with their associated system capacity to obtain the expected system capacity.

The modeling method for Subsystems 2 and 3 follows. The expected capacity fraction β for the entire system is computed.

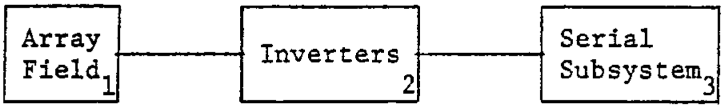

FIGURE 1-3. LEA COUNTY SYSTEM REPRESENTATION

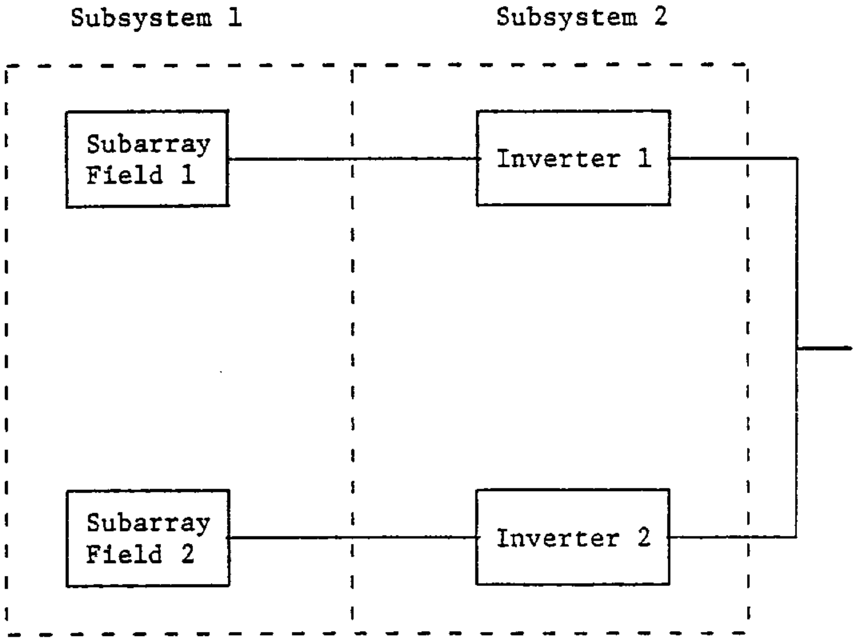

FIGURE 1-4. SUBSYSTEMS 1 AND 2

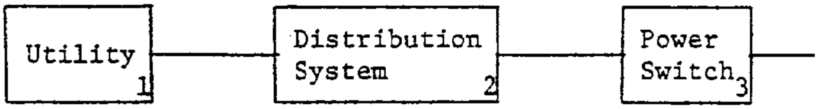

FIGURE 1-5. SUBSYSTEM 3

Subsystem 2 represents the two inverters in parallel and is characterized by three states (0, 1, 2) as shown in Figure 1-6. Each state corresponds to the number of the failed subsystem elements. For instance, state 2 corresponds to total subsystem failure (i.e., both inverters are failed). The steady-state probability for each state is obtained by the standard Markov technique (i.e., rate in equal rate out at steady state).

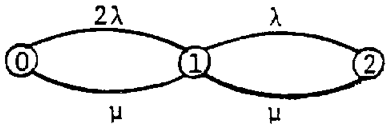

FIGURE 1-6. STATE SPACE MODEL FOR SUBSYSTEM 2

Hence,

$$\mu P_1 = 2\lambda P_0 \quad \text{and} \quad P_1 = \frac{2\lambda}{\mu} P_0$$

$$2\lambda P_0 + \mu P_2 = (\mu + \lambda) P_1 \quad \text{and} \quad P_2 = \frac{\mu + \lambda}{\mu} P_1 - \frac{2\lambda}{\mu} P_0$$

Substituting P_1 by its expressed equation,

$$\begin{aligned} P_2 &= \frac{\mu + \lambda}{\mu} \times \frac{2\lambda}{\mu} P_0 - \frac{2\lambda}{\mu} P_0 \\ &= \frac{2\lambda}{\mu}\left(\frac{\mu + \lambda}{\mu} - 1\right) P_0 = \left(\frac{2\lambda}{\mu} \times \frac{\lambda}{\mu}\right) P_0 \ . \end{aligned}$$

Since the sum of the state probabilities is unity, we can write

$$P_0 + P_1 + P_2 = P_0 + \frac{2\lambda}{\mu} P_0 + \left(\frac{2\lambda}{\mu} \times \frac{\lambda}{\mu}\right) P_0 = 1$$

$$P_0 = \frac{1}{1 + \frac{2\lambda}{\mu} + \frac{2\lambda}{\mu} \times \frac{\lambda}{\mu}}$$

$$\lambda = 1.14 \times 10^{-4}$$

$$\mu = .0120 \ .$$

TABLE 1-3. PROBABILITY TABLE FOR SUBSYSTEM 2

State	Steady-State Probability
0	.981164
1	.018658
2	.000177

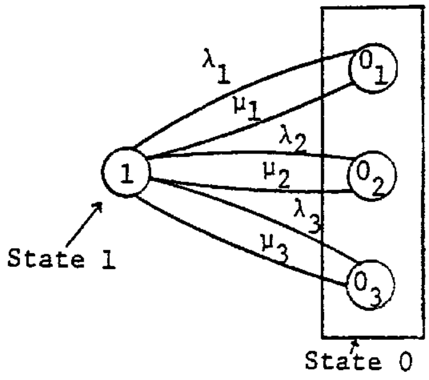

FIGURE 1-7. SUBSYSTEM 3 DIAGRAM

Subsystem 3 is characterized by two states (0,1). State 1 corresponds to "no element failure", and state 0 corresponds to "subsystem failed". Each 0_i indicates that the subsystem failure is a result of the failure of element i. By the same Markov model techniques used in Subsystem 2, the state probabilities can be computed.

$$\lambda_i P_1 = \mu_i P_{0_i}$$

$$\Rightarrow \quad P_{0_i} = \frac{\lambda_i}{\mu_i} P_1 .$$

Since the sum of all state probabilities is unity, we have:

$$P_1 + P_{0_1} + P_{0_2} + P_{0_3} = 1$$

$$\Rightarrow \quad P_1 + \frac{\lambda_1}{\mu_1} P_1 + \frac{\lambda_2}{\mu_2} P_1 + \frac{\lambda_3}{\mu_3} P_1 = 1$$

$$\Rightarrow \quad P_1 = \frac{1}{1 + \sum_{i=1}^{3} \frac{\lambda_i}{\mu_i}} .$$

Substituting the values of the different λ's and μ's yields the results in Table 1-4.

TABLE 1-4. PROBABILITY TABLE FOR SUBSYSTEM 3

State	Steady-State Probability	
1	.998916	
0_1	.001064	$\left.\right\} \sum_{i=1}^{3} P_{0_i} = .001084 = P_0$
0_2	.000011	
0_3	.000009	

Expected System Capacity Computation. For Subsystem 2, states 0, 1, and 2, respectively, are associated with 100 percent, 50 percent, and 0 percent system capacity. For Subsystem 3, state 1 is associated with 100 percent system capacity and state 0 with 0 percent system capacity. Table 1-5 depicts all subsystem states and their associated system capacity.

TABLE 1-5. SYSTEM CAPACITY FOR VARIOUS COMBINATIONS OF SUBSYSTEM STATES

Combination i	Subsystem 2	3	System Capacity (Fraction) F(i)	Probability P_i of Combination i
1	X	0	0%	$P_0(3)$
2	2	1	0%	$P_2(2) \cdot P_1(3)$
3	1	1	50%	$P_1(2) \cdot P_1(3)$
4	0	1	100%	$P_0(2) \cdot P_1(3)$

The 'X' in a column indicates that the subsystem can be in any of its states.

The 0, 1, 2 under the subsystem column indicate the status of each subsystem for each combination.

The system expected capacity β can then be computed as

$$\beta = \sum_{i=1}^{4} F(i) \cdot P_i$$

and

$$\beta = \left\{P_0\,(3) \times 0 + P_2(2) \cdot P_1(3) \times 0 + P_1(2) \cdot P_1(3) \times .5 + P_0(2) \cdot P_1(3) \times 1\right\}$$

$$= \left\{0 + 0 + .998916\ (.018658 \times 0.5 + .981164 \times 1)\right\}$$

$$= .989419\,.$$

Power Production. The system annual power production, A(y), for any given year y is computed by the following equation.*

$$A(y) = W \cdot \beta \cdot DP(y) \cdot DC(y) \cdot \sum_{n=1}^{12} I(n)D(n) \ .$$

The new factor DC(y) (which was not used in the Volume I example) represents the degradation in the system capacity resulting from cell failures as shown in Figure 1-2.

To be consistent with the SOLREL approach, the annual power production for one-half (i.e., 51 kW) of the flat panel system is computed. Since the two halves of the system are identical, the total system output may be obtained by multiplying the result by two.

$$\sum_{n=1}^{12} I(n) \cdot D(n) \quad = \quad 2409.26 \text{ hr}$$

$$\beta \ = \ .989419$$

$$W \ = \ 51 \text{ kW} \ .$$

The permanent degradation, DP, of the system capacity is assumed to be linear between consecutive years. The permanent degradation factor DP(y), for any year y is taken as the midpoint between the degradation factors at the beginning and end of year y. The system capacity degradation due to cell failure, DC (y), is computed in a similar manner.

---

* See 'State Space Approach' in Volume I of this report for further explanation.

For y = 10,

$$DP(10) = \frac{.991 + (.991 - [.991 - .988]/3}{2} = .9905$$

$$DC(10) = \frac{.890 + .880}{2} = .885$$

and

$$A(10) = 51 \times .989419 \times .9905 \times .885 \times 2409.26 = 106{,}569.27 \text{ kW} \quad .$$

The system power production for one-half of the system for years 1-30 is given in Table 1-6.

System Maintenance Cost.

$$ACCM = \sum_{i=1}^{m} (\lambda_i t_i n_i)(U_i C_i + FC_i)$$

where

ACCM = Annual corrective maintenance costs
m = Total number of system components
i = Failure rate of component i
t_i = Total operating or clock hours
n_i = Number of identical units of component i
U_i = Mean repair time of component i
C_i = Repair cost/hr
FC_i = Fixed cost/repair.

TABLE 1-6. LEA COUNTY SYSTEM ANNUAL POWER PRODUCTION
(One-half System Model)

Year	kWh	Year	kWh
1	120,293.94	16	100,116.91
2	117,745.83	17	99,238.05
3	115,808.93	18	98,360.77
4	114,481.38	19	97,544.74
5	113,156.27	20	96,849.35
6	111,833.60	21	96,155.19
7	110,513.34	22	95,478.51
8	109,195.53	23	94,818.99
9	107,880.14	24	94,160.28
10	106,567.18	25	93,486.43
11	105,256.67	26	92,797.74
12	103,948.58	27	92,110.26
13	103,041.98	28	91,424.00
14	101,942.31	29	90,738.95
15	100,937.14	30	90,055.12
		Total	3,065,938.09

The results of these calculations are presented in Table 1-7.

$$ACPM = \sum_{i=1}^{m} (n_i f_i)(C_i U_i + FC_i)$$

where

ACPM = Annual preventive maintenance costs

f_i = Frequency of preventive maintenance action on component i per year.

Other symbols are as defined under corrective maintenance.

The results of these calculations are presented in Table 1-8.

TABLE 1-7. RESULTS OF CORRECTIVE MAINTENANCE CALCULATIONS FOR LEA COUNTY SYSTEM (One-half System Model)

Subsystem/Component	Expected Failures		Corrective Maintenance Costs, $	
	Per Year	Per 30 Yrs	Average, Per Year	Per 30 Yrs
Field Wiring/Switching	8.72×10^{-2}	2.628	2.02	60.60
Inverter	1.0	30	1,411.6	42,348
String Disconnect (21)	1.84×10^{-2}	0.55	.426	12.78
Utility	1.4	42	0	0
Distribution Subsystem	1.4×10^{-2}	.34	0	0
Power Switchgear	6.26×10^{-3}	.188	3.56	106.80
Total Corrective Maintenance Costs			$1,417.61	$42,528.18

TABLE 1-8. RESULTS OF PREVENTIVE MAINTENANCE CALCULATIONS FOR LEA COUNTY SYSTEM (One-half System Model)

	Preventive Maintenance Costs, $	
	Average, per Year	Per 30 Yrs
Inverter	69.8	2,093.6
Distribution Subsystem	97.8	2,934
Cleaning	402.1	12,062.4
General System-wide PM	1,325	39,750
Total Preventive Maintenance Costs	$1,894.70	$56,840.00
Total Maintenance Cost (30 years) = $99,368		

SOLREL Analysis of Lea County System

As mentioned previously, a flat-panel system is characterized by a much larger number of cells than in a similarly sized concentrator system. These cells are connected in a series-parallel arrangement with bypass diodes which minimize the effect of individual cell failures. It is impractical to model each cell individually using SOLREL. Therefore, in modeling the flat panel system, Battelle made use of the JPL Flat Panel Module and Array Circuit Design Optimization Methodology to develop a degradation curve of output due to cell failures.* The resulting degradation curve (see Figure 1-2) shows how array output decreases over time as individual cells fail without replacement. In general, with a flat-panel system, the JPL technique has shown that nonreplacement of failed cells can be the optimal repair strategy. If desired, SOLREL will initiate repair when a user selected percentage of output has been lost due to cell failure.

Once a methodology has been developed for modeling cell failures, the remainder of the flat panel components are relatively easy to model. Since the Lea County PRDA consists of two identical subystems, it was not necessary to model both. Instead, SOLREL models only one 51 kW subsystem. Most subsystems such as an array subfield or an inverter are entirely contained within one of the two 51 kW subsystems. Others, such as the distribution subsystem interact simultaneously with both subsystems. In this application of SOLREL, the failure rates of those components interacting with both 51 kW subsystems have been cut in half to compensate for this functional relationship. Thus, to estimate the total costs and energy output of the entire 102 kW system, the analyst need only double all costs and electrical outputs from the 51 kW run of SOLREL. This saves substantially on both computer time and programming time.

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* Described earlier in the report.

Logic was designed into SOLREL so that the failure of any of the following subsystems would result in complete system shutdown:

- A disconnect switch
- An inverter
- The switchgear
- The wiring/switching
- The distribution system.

The input parameters associated with these components appear in Table 1-9 along with a list of other inputs.

In addition to general preventive maintenance and periodic cleaning of the cell surface, preventive maintenance activities were also modeled for the inverter and the distribution system. Maximum output for the flat-panel subsystem simulated was assumed to be 51 kW. The array cells surfaces were assumed to suffer permanent optical degradation of 0.1 percent per year. Dirt, however, is estimated to cause the output to be reduced at 3 percent per year without cleaning.

General inflation was set at 8 percent, the escalation of electricity cost was set at 2.5 percent above inflation; and discount rates were set at 13 percent (optimistic case) and 20 percent (pessimistic case), respectively.

The Battelle solar design simulation model, SOLCEL, was used to simulate a flat-panel system of this design. Phoenix, Arizona, weather tapes were used to approximate Lovington, New Mexico, conditions, as the two are within 1 degree in latitude and in a similar climate. The SOLCEL simulation does not consider reliability, but produces an output duration curve showing the amount of time various levels of output are achieved strictly as a result of changing insolation levels. This output duration curve appears in Table 1-10.

Using these data estimates the SOLREL outputs shown in Table 1-11 to 1-14 were produced for the flat-panel system. These outputs represent the one-half system model; therefore, annual energy produced and maintenance costs must be multiplied by a factor of two to get total system output or maintenance cost. The costs per kWh are unchanged, however.

General computer program details are given in Appendix C. The program source listing is reproduced in Appendix D. Computer tapes of this and other SOLREL listings will be available through Sandia. These listings do not include the GASP IV listing which is available elsewhere.

The SOLREL outputs are also shown in Figure 1-8 through 1-10. These curves also present the results in the form of annual energy output and maintenance costs for one-half of the system, since this modeling approach permitted a simplier calculation of the levelized costs of maintenance per kWh. These calculations were also made for two sets of financial assumptions.

TABLE 1-9. INPUT PARAMETERS FOR FLAT-PANEL SYSTEM

```
COMPONENT NAME          MTBF    MAINT TIME (HRS)  REPAIR COST ($)  NUM  PM TIME (HOURS)    PM COST ($)      PM INTERVAL  NUM
                      (MONTHS)   50PCT   90PCT    FIXED VARIABLE   MEN  50PCT     90PCT   FIXED  VARIABLE    (MONTHS)   MEN

PANEL CLEANING                                                          16.0      38.0     0.00   20.00         12.0     1

A DISCONNECT SWITCH   13700.0    1.0      2.0      0.00    20.00    1

AN INVERTER              12.0   24.0     48.0    300.00    40.00    1    3.0       6.0   100.00   40.00         41.0     1

THE SWITCHGEAR         1918.0    3.6      6.0    100.00   120.00    4

WIRING/SWITCHES      100000.0    1.0      2.0      0.00    20.00    1

THE DISTRIBUTION SYS  12000.0   28.0     60.0      0.00     0.00    1    4.0       9.0     0.00   20.00         12.0     1

THE UTILITY               8.6    2.0      3.6      0.00     0.00    1

GENERAL PREV MAINT                                                     100.0     175.0   300.00   50.00         12.0     5

FLAG1= 0 MEANS RESULTS FROM ALL PREVIOUS RUNS ARE BEING IGNORED
FLAG2= 0 MEANS RESULTS FROM THIS RUN WILL NOT BE SAVED ON PERMANENT FILES
FLAG3= 0 MEANS NO EVENT OR YEARLY SUMMARY MESSAGES WILL BE PRINTED
FLAG4= 1 MEANS TABLES FOR EACH INDIVIDUAL RUN WILL BE PRINTED
FLAG5= 1 MEANS PLOTS FOR INDIVIDUAL RUNS ONLY WILL BE PRODUCED

PERMANENT DEGRADATION -- 3 YEAR INTERVALS
  1.000   .997   .994   .991   .988   .985   .982   .979   .977   .974   .971

DEGRADATION DUE TO DIRT -- 3 YEAR INTERVALS
  1.000   .910   .820   .730   .640   .550   .460   .370   .280   .190

DEGRADATION DUE TO CELL FAILURES -- 1 YEAR INTERVALS
  1.000   .980   .960   .950   .940   .930   .920   .910   .900   .890
   .880   .870   .860   .855   .850   .840   .833   .827   .820   .815   .810
   .810   .805   .800   .795   .790   .785   .780   .775   .770   .765   .760

ARRAY CAPACITY IN KW.................     51.
INVERTER DESIGN CAPACITY IN KW......      51.
OVERALL INFLATION RATE..............     .080
DISCOUNT RATE.......................     .200
ELECTRICITY PRICE ESCALATION........     .105
LENGTH OF RUN IN MONTHS.............     360.
```

TABLE 1-10. MONTHLY OUTPUT DURATION CURVES FOR FLAT-PANEL SYSTEM

```
MONTHLY OUTPUT DURATION CURVES IN INTERVALS OF 8.50 HOURS PER MONTH

MONTH  1 1.013  .944  .926  .907  .890  .873  .856  .836  .814  .791  .765  .739  .715  .690  .664  .637
          .589  .563  .538  .502  .468  .437  .378  .288  .171  .142  .122  .104  .094  .084  .074  .064
          .054  .042  .031  .019  .008 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  2 1.120 1.051 1.024 1.004  .988  .972  .956  .937  .918  .895  .868  .843  .821  .797  .752  .713
          .673  .632  .600  .559  .514  .474  .439  .405  .372  .350  .328  .301  .272  .208  .105  .072
          .048  .034  .020  .006 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  3 1.173 1.112 1.099 1.085 1.071 1.057 1.042 1.027 1.012  .991  .970  .949  .928  .908  .887  .866
          .840  .808  .765  .731  .703  .668  .630  .595  .564  .535  .486  .451  .420  .389  .358  .324
          .290  .260  .237  .215  .175  .141  .112  .083  .053  .036  .019  .002 0.000 0.000 0.000

MONTH  4 1.173 1.120 1.109 1.098 1.086 1.075 1.064 1.050 1.037 1.024 1.010  .988  .966  .940  .912  .891
          .872  .853  .817  .785  .755  .724  .692  .663  .617  .568  .543  .505  .461  .422  .398  .373
          .314  .291  .267  .241  .216  .160  .142  .124  .107  .056  .037  .019  .002 0.000 0.000

MONTH  5 1.120 1.070 1.058 1.048 1.039 1.029 1.020 1.009  .996  .983  .970  .957  .942  .928  .913  .899
          .883  .868  .851  .820  .793  .773  .753  .722  .689  .667  .645  .584  .567  .549  .529  .468
          .433  .406  .381  .312  .296  .280  .240  .199  .182  .165  .106  .090  .073  .057 0.000

MONTH  6 1.067 1.046 1.018 1.005  .995  .985  .975  .965  .952  .936  .919  .902  .884  .866  .848  .828
          .808  .779  .746  .729  .712  .695  .667  .638  .618  .598  .570  .532  .511  .490  .446  .412
          .392  .367  .310  .292  .275  .219  .199  .183  .167  .102  .087  .073  .058 0.000 0.000

MONTH  7 1.013 1.003  .988  .973  .959  .946  .934  .922  .910  .894  .878  .861  .845  .829  .814  .797
          .774  .751  .732  .714  .696  .670  .642  .620  .598  .566  .529  .510  .491  .461  .422  .402
          .383  .353  .314  .266  .248  .230  .210  .158  .140  .122  .105  .091  .077  .062 0.000

MONTH  8 1.067 1.044 1.008  .998  .988  .978  .968  .958  .944  .930  .916  .901  .886  .871  .855  .837
          .819  .800  .759  .734  .716  .698  .640  .623  .605  .588  .532  .510  .488  .460  .430  .402
          .373  .350  .327  .263  .247  .231  .215  .156  .141  .125  .109  .089  .068  .043  .008

MONTH  9 1.067 1.045 1.022 1.007  .996  .985  .974  .963  .949  .934  .919  .904  .887  .871  .854  .837
          .819  .801  .768  .738  .714  .687  .654  .623  .595  .564  .530  .476  .450  .422  .362  .333
          .303  .270  .212  .192  .172  .123  .089  .068  .048  .032  .016 0.000 0.000 0.000 0.000

MONTH 10 1.067 1.019 1.003  .992  .981  .970  .958  .945  .931  .917  .902  .883  .864  .842  .819  .796
          .771  .747  .701  .670  .642  .599  .565  .535  .505  .472  .429  .405  .383  .351  .315  .289
          .261  .227  .192  .149  .072  .044  .032  .019  .007 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 11 1.120 1.005  .979  .956  .942  .928  .914  .900  .884  .869  .854  .829  .803  .778  .753  .724
          .693  .654  .622  .593  .561  .527  .489  .445  .369  .290  .160  .102  .091  .081  .070  .060
          .049  .038  .027  .016  .005 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 12  .960  .915  .894  .878  .863  .846  .828  .810  .781  .742  .713  .687  .666  .645  .611  .573
          .536  .507  .478  .440  .350  .257  .193  .153  .123  .102  .093  .084  .074  .065  .056  .044
          .032  .019  .007 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
```

TABLE 1-11. FLAT-PANEL SYSTEM AVAILABILITY

ANNUAL SYSTEM AVAILABILITY DURING DAYLIGHT
AS A PERCENT OF SYSTEM CAPACITY

SYSTEM CAPACITY = 51.0 KW NUMBER OF DAYLIGHT HOURS PER YEAR = 4205.0

YEAR	100-90%	90-80%	80-70%	70-60%	60-50%	50-40%	40-30%	30-20%	20-10%	10-0%	TOTAL
EORETICAL	22.59	12.17	8.65	7.85	7.46	6.79	6.20	6.30	7.18	14.81	100.00
1	22.62	12.53	8.72	7.89	7.59	6.80	6.23	6.55	7.11	13.97	100.00
2	17.97	13.69	9.61	8.60	7.88	7.12	6.09	6.61	7.63	14.81	100.00
3	16.71	14.16	9.71	8.70	7.99	7.39	6.88	7.17	7.34	13.96	100.00
4	15.09	14.63	10.11	8.96	8.15	7.46	6.85	7.04	7.56	14.16	100.00
5	13.12	14.78	10.75	9.17	8.14	7.39	6.50	6.78	7.61	15.76	100.00
6	12.27	15.13	11.22	9.27	8.29	7.64	7.14	7.12	7.44	14.49	100.00
7	10.24	15.07	11.99	9.49	8.32	7.67	7.04	6.98	7.59	15.61	100.00
8	8.32	15.53	12.54	9.45	8.48	7.99	7.54	7.26	7.64	15.25	100.00
9	6.93	15.53	13.17	9.71	8.76	8.04	7.46	7.13	7.43	15.79	100.00
10	6.82	14.92	13.77	9.60	8.60	8.13	7.58	7.27	7.67	15.64	100.00
11	5.20	14.97	14.51	10.04	8.95	8.35	7.73	7.31	7.72	15.21	100.00
12	3.86	14.35	15.30	10.56	9.15	8.43	7.82	7.34	7.97	15.23	100.00
13	2.68	14.25	15.41	10.53	9.37	8.58	7.92	7.37	7.77	16.12	100.00
14	2.45	13.64	15.87	10.91	9.49	8.72	8.11	7.51	7.97	15.34	100.00
15	1.67	13.23	16.19	10.95	9.86	8.94	8.18	7.58	7.91	15.49	100.00
16	1.59	12.21	16.98	11.17	9.18	8.70	8.03	7.48	7.55	17.11	100.00
17	1.32	11.15	16.33	11.27	9.55	8.72	8.09	7.48	7.85	18.25	100.00
18	.84	9.25	16.36	11.91	10.13	9.17	8.49	7.37	8.30	18.18	100.00
19	.40	9.30	17.64	12.34	9.99	9.15	8.56	7.93	8.12	16.58	100.00
20	.29	8.29	17.87	13.13	10.26	9.34	8.48	7.69	8.16	16.48	100.00
21	.27	7.26	17.76	13.53	10.59	9.55	8.84	7.88	8.40	15.94	100.00
22	.10	5.32	17.14	14.10	10.58	9.55	9.02	7.79	8.27	18.14	100.00
23	.17	6.33	16.65	14.07	10.57	9.47	8.96	7.96	8.48	17.34	100.00
24	.10	5.43	17.21	14.77	10.91	9.76	9.06	8.06	8.54	16.15	100.00
25	.04	4.99	16.91	15.10	10.89	9.83	8.76	8.04	8.39	17.05	100.00
26	0.00	4.23	17.07	15.55	10.93	9.78	9.07	8.29	8.34	16.73	100.00
27	0.00	3.32	16.46	16.16	11.16	9.87	9.19	8.36	8.79	16.67	100.00
28	0.00	3.27	15.14	16.29	11.01	9.75	9.37	8.32	8.83	18.03	100.00
29	0.00	2.09	15.59	17.14	11.44	10.28	9.38	8.61	8.76	16.72	100.00
30	0.00	2.03	14.95	17.43	11.70	10.31	9.46	8.78	8.79	16.56	100.00
AVERAGE	5.04	10.36	14.63	11.93	9.60	8.73	8.06	7.57	8.03	16.09	100.00

TABLE 1-12. ANNUAL FAILURES FLAT-PANEL SYSTEM (ONE-HALF SYSTEM MODEL)

COMPONENT FAILURE TABLE

NUMBER OF FAILURES PER COMPONENT BY YEAR

COMPONENT YEAR =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
A DISCONNECT SWITCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A BIPASS DIODE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A SHUNT RESISTOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AN INVERTER	0	0	0	0	1	0	1	1	2	1	1	0	1	0	0	2	2	3	4	1	0	3	1	0	2	2	2	2	0	0	32
THE SWITCHGEAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WIRING/SWITCHES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE DISTRIBUTION SYS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE 3 PHASE X-FORMER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE INVERTER CONTROL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE UTILITY	2	1	1	3	1	0	3	1	2	3	0	1	1	0	2	0	1	4	1	5	1	3	0	0	0	1	4	1	2	2	46
TOTALS	2	1	1	3	2	0	4	2	4	4	1	1	2	0	2	2	3	7	5	6	1	6	1	0	2	3	6	3	2	2	78

TABLE 1-13. FLAT-PANEL SYSTEM ANNUAL MAINTENANCE COST AND ENERGY PRODUCED (ONE-HALF SYSTEM MODEL), DISCOUNT RATE OF 13 PERCENT

ANNUAL MAINTENANCE COST AND OUTPUT

	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	0.00	119750.	0.00	0.00	118408.	0.00
2	2094.86	115275.	1.82	2002.17	111446.	1.80
3	2101.22	115059.	1.83	1919.38	108789.	1.76
4	2564.64	114242.	2.24	2233.76	105628.	2.11
5	2844.45	110563.	2.57	2355.76	99957.	2.36
6	2496.41	110986.	2.25	1990.87	98124.	2.03
7	4642.87	108251.	4.29	3504.98	93601.	3.74
8	3100.89	107551.	2.88	2221.05	90932.	2.44
9	4064.01	105356.	3.86	2789.60	87112.	3.20
10	2731.97	104762.	2.61	1805.64	84700.	2.13
11	2527.94	104299.	2.42	1596.26	82457.	1.94
12	1490.74	103638.	1.44	906.15	80119.	1.13
13	3965.79	100778.	3.94	2295.18	76181.	3.01
14	1713.25	101517.	1.69	947.24	75044.	1.26
15	1379.16	100166.	1.38	731.89	72409.	1.01
16	5932.62	99326.	5.97	2953.23	70212.	4.21
17	6192.56	95359.	6.49	2966.72	65916.	4.50
18	6742.92	93903.	7.18	3074.02	63485.	4.84
19	5992.62	96411.	6.22	2606.38	63735.	4.09
20	2197.16	96500.	2.28	919.32	62382.	1.47
21	2899.24	95491.	3.04	1171.39	60357.	1.94
22	5415.94	91288.	5.93	2062.88	56428.	3.66
23	3183.65	92111.	3.46	1165.99	55669.	2.09
24	1550.96	93496.	1.66	544.83	55259.	.99
25	3903.07	92158.	4.24	1294.29	53267.	2.43
26	3263.20	92494.	3.53	1025.97	52276.	1.96
27	3304.59	92146.	3.59	997.90	50921.	1.96
28	4558.27	88891.	5.13	1324.64	48045.	2.76
29	2092.80	89647.	2.33	589.38	47380.	1.24
30	3390.16	89470.	3.79	912.50	46238.	1.97
TOTALS	98337.94	3020886.		50909.37	2236475.	2.28 (LEVELIZED)

TABLE 1-14. FLAT-PANEL SYSTEM, ANNUAL MAINTENANCE COST AND ENERGY PRODUCED (ONE-HALF SYSTEM MODEL), DISCOUNT RATE OF 20 PERCENT

	ANNUAL MAINTENANCE COST AND OUTPUT					
	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	0.00	119750.	0.00	0.00	114897.	0.00
2	2094.86	115275.	1.82	1885.37	101796.	1.85
3	2101.22	115059.	1.83	1701.99	93601.	1.82
4	2564.64	114242.	2.24	1859.48	85581.	2.17
5	2844.45	110563.	2.57	1834.22	76249.	2.41
6	2496.41	110986.	2.25	1474.11	70492.	2.09
7	4642.87	108251.	4.29	2413.43	63342.	3.81
8	3100.89	107551.	2.88	1426.40	57936.	2.46
9	4064.01	105356.	3.86	1692.92	52276.	3.24
10	2731.97	104762.	2.61	1041.91	47857.	2.18
11	2527.94	104299.	2.42	866.97	43866.	1.98
12	1490.74	103638.	1.44	467.81	40134.	1.17
13	3965.79	100778.	3.94	1110.18	35930.	3.09
14	1713.25	101517.	1.69	431.26	33331.	1.29
15	1379.16	100166.	1.38	315.51	30287.	1.04
16	5932.62	99326.	5.97	1169.98	27655.	4.23
17	6192.56	95359.	6.49	1116.56	24447.	4.57
18	6742.92	93903.	7.18	1083.33	22183.	4.88
19	5992.62	96411.	6.22	862.99	20968.	4.12
20	2197.16	96500.	2.28	289.13	19325.	1.50
21	2899.24	95491.	3.04	351.57	17602.	2.00
22	5415.94	91288.	5.93	572.61	15499.	3.69
23	3183.65	92111.	3.46	307.17	14393.	2.13
24	1550.96	93496.	1.66	135.83	13456.	1.01
25	3903.07	92158.	4.24	298.90	12216.	2.45
26	3263.20	92494.	3.53	220.80	11288.	1.96
27	3304.59	92146.	3.59	203.54	10351.	1.97
28	4558.27	88891.	5.13	256.69	9201.	2.79
29	2092.80	89647.	2.33	109.53	8544.	1.28
30	3390.16	89470.	3.79	159.68	7851.	2.03
TOTALS	98337.94	3020836.		25659.87	1182553.	2.17 (LEVELIZED)

COST BY YEAR

SYSTEM OUTPUT BY YEAR

FIGURE 1-8. FLAT-PANEL SYSTEM RESULTS, CURRENT VALUE, ANNUAL MAINTENANCE COSTS AND ENERGY PRODUCED (ONE-HALF SYSTEM)

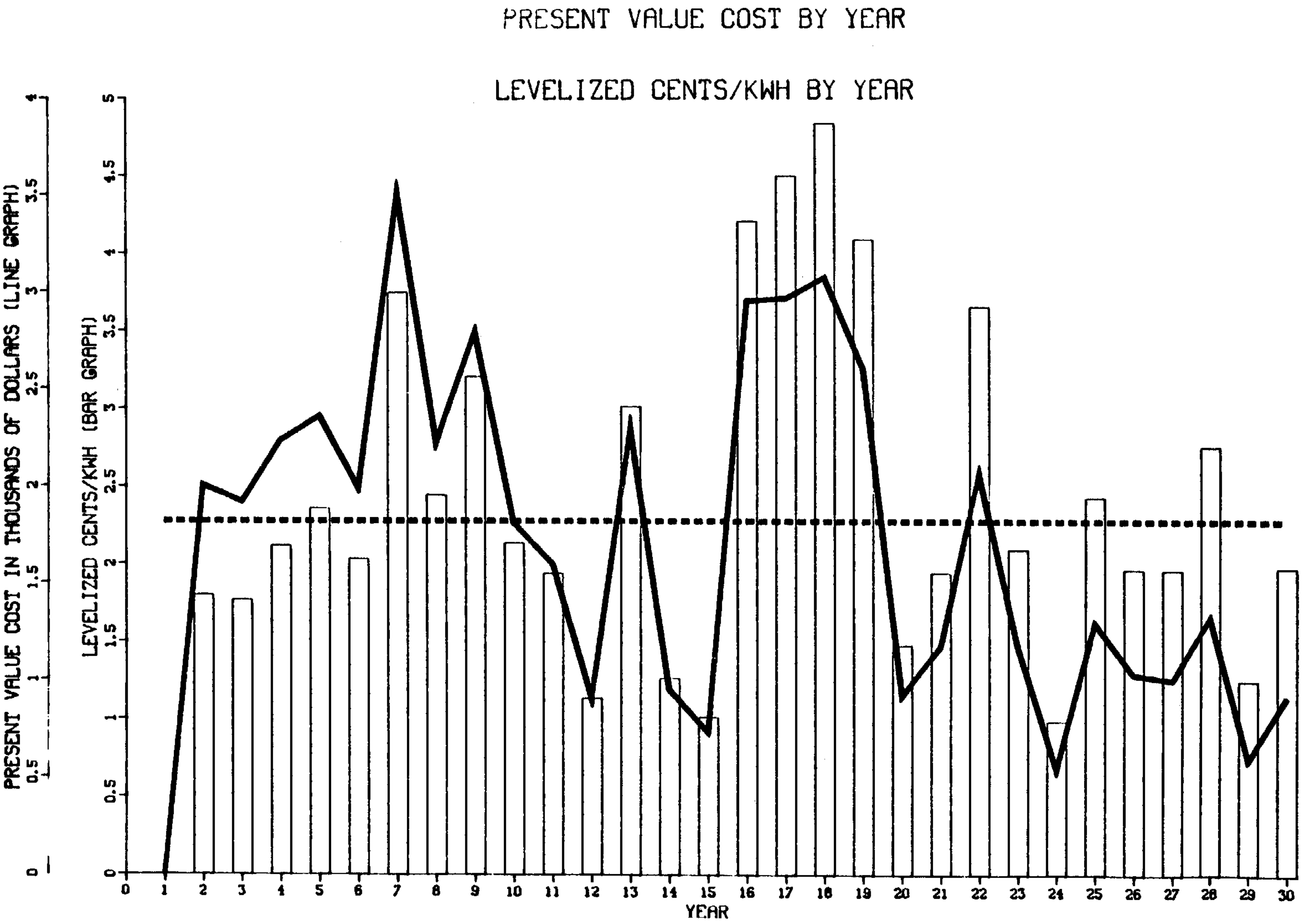


FIGURE 1-9. FLAT-PANEL SYSTEM SIMULATION RESULTS, DISCOUNT RATE OF 13 PERCENT

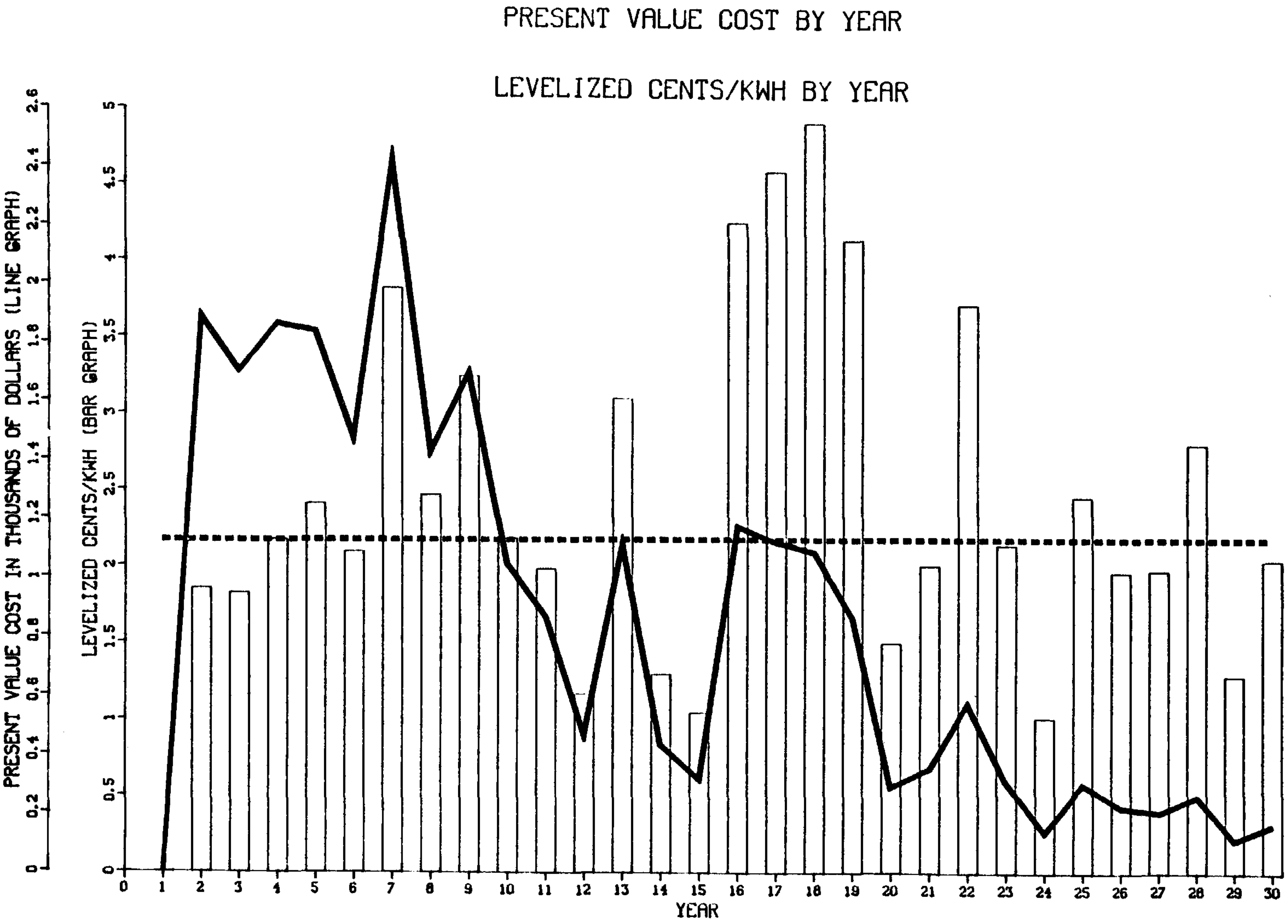


FIGURE 1-10. FLAT-PANEL SYSTEM SIMULATION RESULTS, DISCOUNT RATE OF 20 PERCENT

SECTION 2. ANALYSIS OF PASSIVELY COOLED PV CONCENTRATOR SYSTEM

ARIZONA PUBLIC SERVICE, PV CONCENTRATOR SYSTEM (PASSIVELY COOLED)

Description of System

This is a 225 kW peak photovoltaic power system consisting of 80 passively cooled photovoltaic concentrator arrays.(20) These arrays are arranged into 4 subfields each having eight branch circuits connected in parallel. Each branch consists of 2-1/2 array assemblies in series to achieve an operating voltage of approximately 300 volts dc. Each array assembly contains 68 concentrator modules, each made up of 4 cells behind 4 Fresnel lenses. A drive assembly, an electronic control unit for sun tracking, and supporting structure complete the array. This design is considerably different from the initial Phase 2, PRDA design which used 24 larger arrays with reflector-type concentrators.

The PV power system is shown in simplified block diagram form in Figure 2-1. It contains one 250 kW power conditioner. The array is designed to stow to protect itself in the event of high winds. It will also shut down upon loss of utility power.

Input Data

Output Duration Curves

In order to represent the month-to-month variations in solar insolation, a set of 12 power output duration curves was provided for the availability simulation. This represents the time during any given month that the power would be at certain levels (assuming no system failures or degradation). These curves are generated by the SOLCEL design simulation and are shown in Figure C-1 and Table 2-8.

Data From Array Field Analysis Results

The salient features of this design for input to the JPL analyses are:

- A series block consisting of 4 series cells with no parallel strings and one bypass diode per block. There are 68 series blocks in each array.

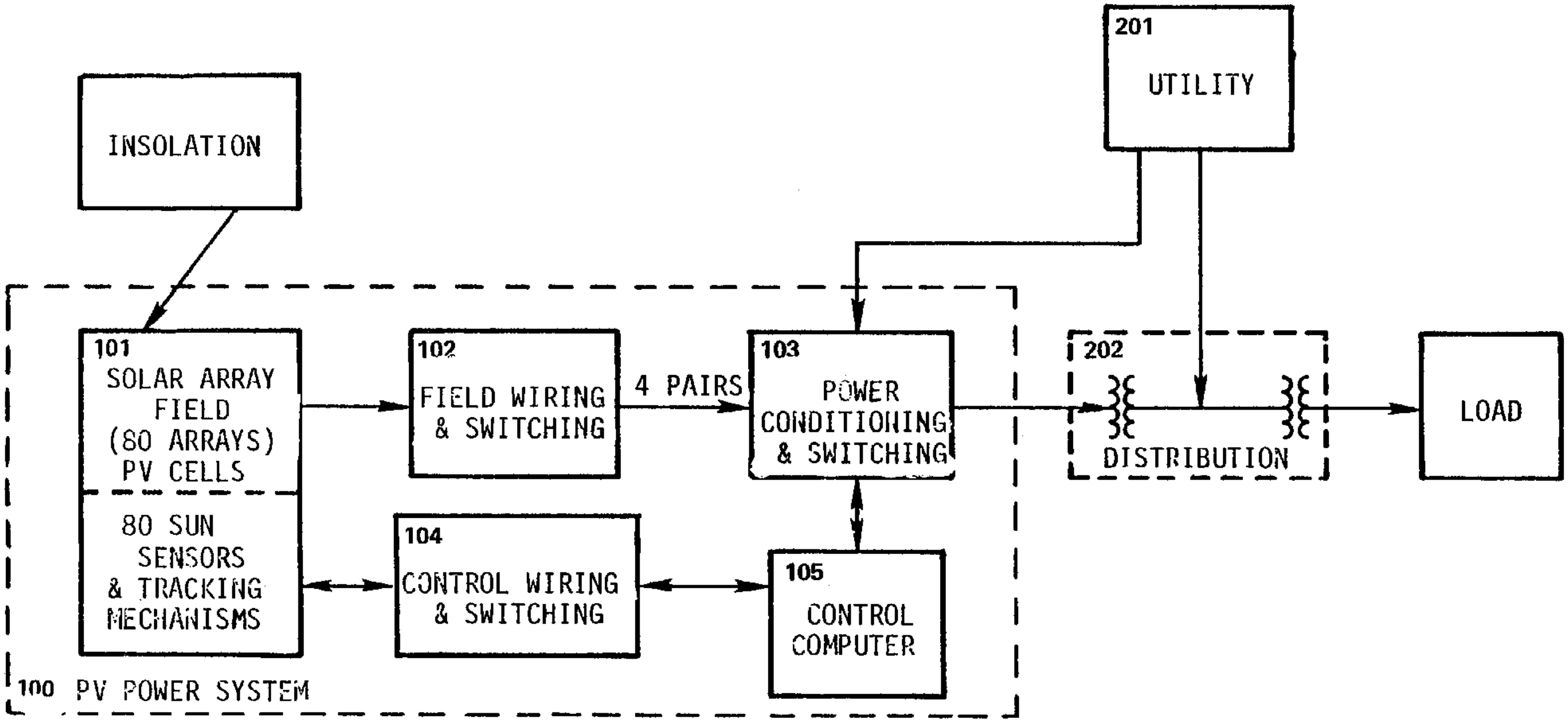


FIGURE 2-1. SIMPLIFIED FUNCTIONAL BLOCK DIAGRAM-APS CONCENTRATOR PV POWER SYSTEM, PASSIVELY COOLED, INTERACTIVE WITH UTILITY, NO STORAGE

- A branch circuit consisting of 170 series blocks connected in series. Two and one-half arrays make up one branch circuit.
- An array field consisting of 32 branch circuits grouped in 4 subfields of 8 branch circuits each (20 arrays per subfield). A cell failure rate of 0.0005 per year was used for the concentrator cells.

The results of the JPL Array Design analysis are summarized in Figure 2-2. This information is used as input data for these analyses to represent degradation in solar array field output caused by cell failures.

Reliability/Maintenance Data. The parameters and costs estimated for the reliability and maintenance inputs to the models are given in Table 2-1. These data are strictly estimates representative of a system in the mature stage of production and operation.

State Space Analysis of APS System

The APS system has been divided into two major subsystems for the reliability analysis, as shown in Figure 2-3.

- Subsystem A represents the array field.
- Subsystem B represents all the system elements logically connected in series.

The system and its subsystems are represented by the diagrams in the following sections.

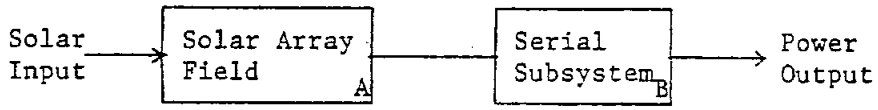


FIGURE 2-3. APS SYSTEM REPRESENTATION

APS AIRPORT SYSTEM (PHOENIX)

$\lambda_{cell} = 0.0005/yr$

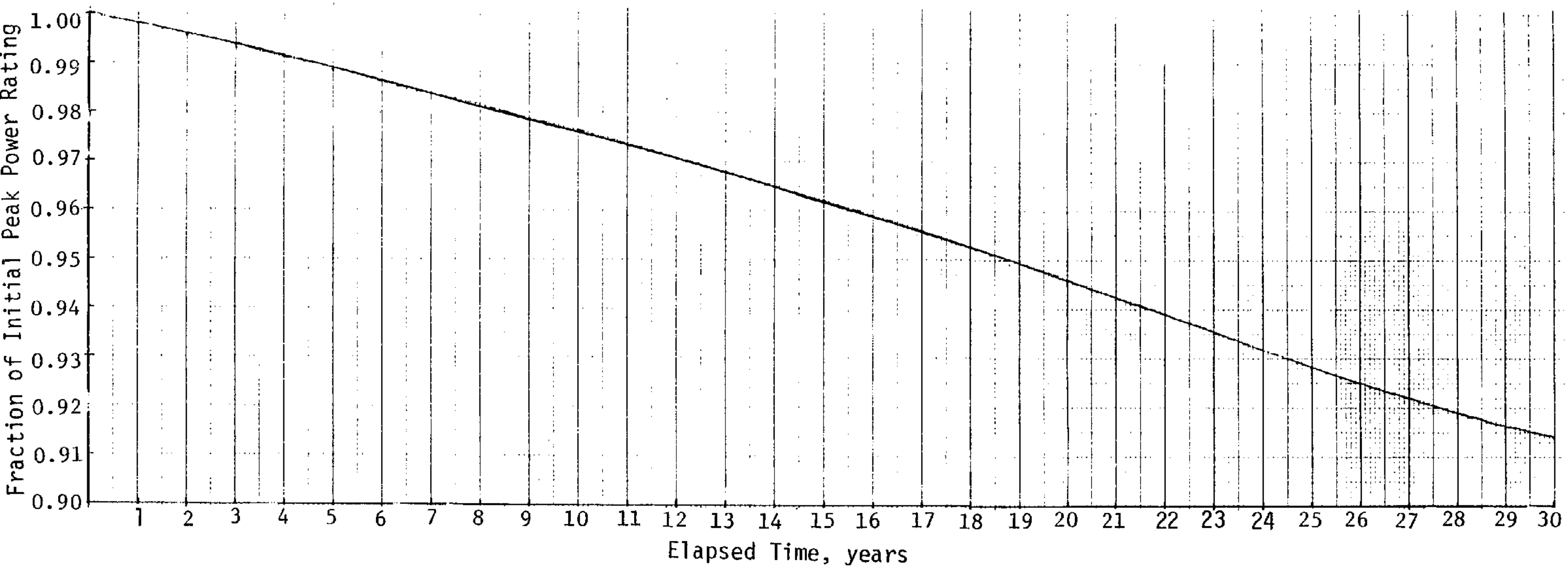


FIGURE 2-2. RESULTS OF ARRAY FIELD ANALYSIS

TABLE 2-1. ESTIMATED RELIABILITY AND MAINTENANCE DATA INPUTS FOR ANALYSIS OF PV CONCENTRATOR, PASSIVELY COOLED POWER SYSTEM

	Maintenance								
	Corrective Maintenance						Preventive Maintenance		
	Maintenance Time[a], hr Lognormal						Maintenance Time[c], hr Lognormal[d]		
Subsystem/Component	50 Percentile	90 Percentile	Per hr Charge, $	Travel & Mat'ls. (Fixed), $	Source		50 Percentile	90 Percentile	Fixed Costs/ Frequency
					Class				
Cells (21,760)	-	-	(replace at module level only)		-	-	-	-	-
Power Distr./Array Field Subsystems	5.6	12	20	0	IV	NBNM[b]	-	-	-
Inverter	24	48	40	1000	II	NBNM	6 (replace main contactors)	12	$100/every 30 K hr
Control & Display	24	48	40	1100	I	NBNM	-	-	-
Tracking (Electrical)(80)	1	4	20	-	IV	NBNM	-	-	-
Tracking Drive (80)	6	12	20	-	IV	NBNM	2	4	Adjust, align & check every 36 mo - $50 + labor
Array (Support tube & module/ heat exchanger assemblies)(80)	4	8	30	320	III	NBNM	-	-	-
Lens (80 subassemblies)	2	4	20	75	IV	NBNM	0.5	1	$0/Cleaning every 12 mo
Utility	2	∿ 3.6	0	0	As in Rel.[e]		0	-	$0
Distr. Subsystem	28	∿ 60	0	0	As in Rel.		8	18	∿ Every 12 mo
Power Switch	3.6	∿ 6	120	∿ 100	As in Rel.		0	-	-
General Systemwide P.M.	-	-	-	-	-		50	106	$100/hr + $300 every 12 mo
Cleaning - See Lens-Preventive Maintenance									
Weather	10	35	0	-	BCL Est.		-	-	-

Footnotes appear on following page.

TABLE 2-1. (Continued)

Subsystem/Component	Reliability MTBF Clock hr	 Other Parameters	 Distribution	 Source	Degradation
Cells (21,760)	-	(λ_{cell} = 0.0005/yr)	-	BCL, est.	(Determined by JPL method. See resulting system output degradation curves.)
Power Distr./Array Field Subsystem	250,000	-	Exponential	Ditto	Complete shutdown
Inverter( )	8,760	-	exp.	"	Complete shutdown
Control & Display( )	10,000	-	exp.	"	Complete shutdown
Tracking, Electrical (80)	200,000	-	exp.	"	1/32 power reduction(g)
Tracking Drive (80)	60,000	$\beta = 2.5$ $\eta = 67,623$	Weibull(f)	"	System maintenance policy - Repair after 1 to "η" tracking unit assembly failures. 1/32 power reduction(g)
Array (Support Tube & Module/ Heat Exchanger Assemblies (80)	10^8	-	**exp**	BCL, est.	1/32 power reduction
Lens (80 subassemblies of 68 each)	10^6	-	exp.	"	Dirt - 3% output/year (removed by cleaning) Abrasion - 3% output/year for 3 yr; - 0.1%/yr Bal. (Permanent)
Utility(a)	6,257	$\lambda = 160/10^6$ hr	exp.	IEEE Std 493-1980 p 214, Table II	Complete shutdown
Distr. Subsystem(a)	8.76×10^6	$\lambda = 0.1/10^6$ hr	exp.	IEEE Std 493-1980 p 219, Table I	Complete shutdown
Power Switch(a)	1.4×10^6	$\lambda = 0.7/10^6$ hr	exp.	IEEE Std 493-1980 p 123, Table 2 (switches)	Complete shutdown
Weather	2,190	-	exp.	BCL, ext.	Complete shutdown due to wind, if 26 to 30 mph.

(a) Includes [active repair time + travel time + logistics time + administrative time] and is therefore time to restore.

(b) NBNM = Natural Bridges National Monument Initial Experience in Maintenance (Solman 15th Annual PV Spec. Conf.)(10)

(c) Each unit or system is down for time being maintained--follow functional diagram.

(d) Same per hour charge as Corrective Maintenance.

(e) Refers to same source as in Reliability section of this table.

(f) Weibull density function: $f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]$, β = shape, η = scale, t = time.

(g) Since the first tracker failure eliminates power from an entire 2-1/2 array string, at least 2-1/2/80 or 1/32 of the array field power is lost. One out of five of these failures would cause a loss of 1/16 of the array field power.

Array Field

The array field is made up of 16 branch circuits logically connected in a parallel configuration. A simplified diagram of a branch circuit is given in Figure 2-4. The array field is shown in Figure 2-5.

Subsystem B: Serial Subsystem. Subsystem B represents all the system elements logically connected in series as shown in Figure 2-6.

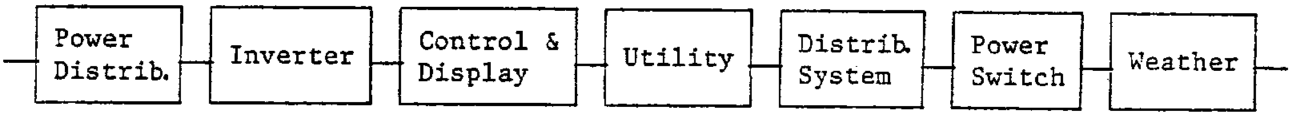


FIGURE 2-6. SUBSYSTEM B: SERIAL SUBSYSTEM COMPRISING ALL SYSTEM ELEMENTS LOGICALLY CONNECTED IN SERIES

Modeling Method

Each subsystem is represented by a number of states where each state is defined in terms of the status of each of the different elements of the subsystem. Markov model techniques are then used to compute the steady-state occupancy probabilities of each subsystem state. These state probabilities are combined with their associated system capacity to obtain the expected system capacity, β.

The following sections will illustrate this method for each of the two subsystems.

Subsystem A. Subsystem A is made up of 16 parallel branch circuits. Each branch as shown in Figure 2-4 comprises two circuits (modules 1 and 2 and 3 and 4) connected in parallel to module 5. When a failure occurs in either circuit, the branch loses half of its capacity, resulting in 1/32 reduction in the system capacity. When module 5 fails, the branch circuit is incapacitated, resulting in 1/16 reduction in the system capacity. Therefore, Subsystem

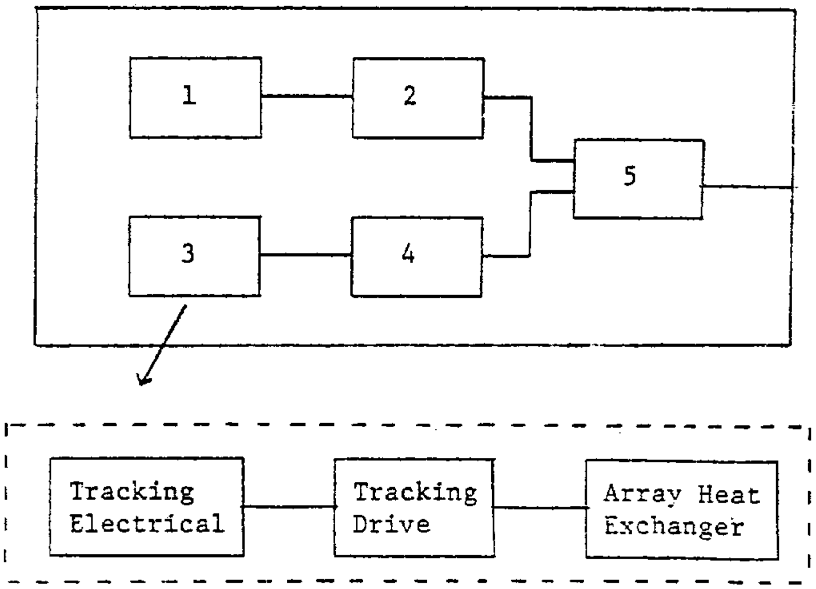


FIGURE 2-4. SIMPLIFIED DIAGRAM OF A BRANCH CIRCUIT

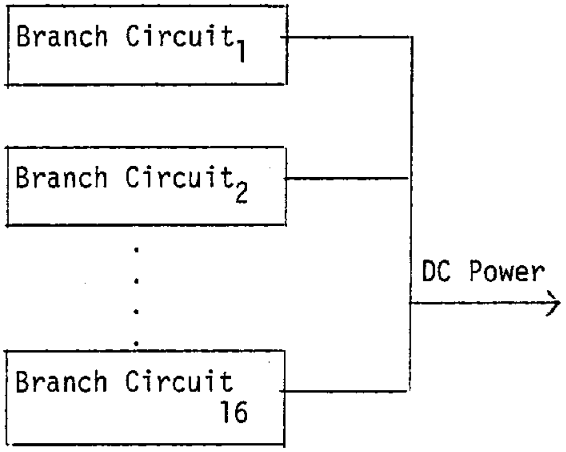


FIGURE 2-5. SUBSYSTEM A: 16 IDENTICAL BRANCH CIRCUITS IN PARALLEL

A is characterized by 33 states (i = 0, 1, 2, ..., 32) where each state i represents a fraction, i/32, reduction in the system capacity. However, due to the low failure rates of the array component and the repair policy (repair upon first failure), the subsystem never occupies any states beyond state 4, Subsystem A will therefore be modeled by its first five states as shown in Figure 2-7.

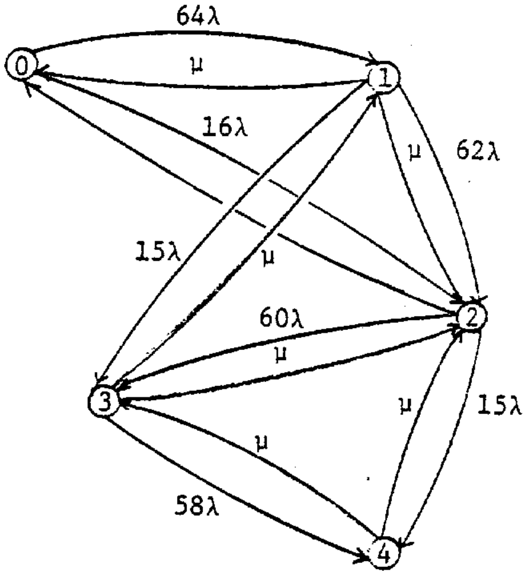


FIGURE 2-7. STATE SPACE MODEL FOR SUBSYSTEM A

The steady-state probability for each state can be obtained by Markov model techniques--that is, rate-in equals rate-out. The Markov model approach yields a set of simultaneous equations, $\dot{P}_i(t) = 0$ and (i = 0,1, ..., 5). The solutions, $P_i(t)$ and (i = 0, 1, ..., 5), to this set of equations represent the steady-state probabilities of the corresponding states. For expediency, this set of equations was solved by a Battelle-developed Markov chain computer model. The results are shown in Table 2-2.

<u>Subsystem B</u>. Subsystem B which comprises all the system components logically connected in series is characterized by two states (0,1) which represent respectively the subsystem failure and functional status. State 1 corresponds to the functional state and state 0 the failure state. Subsystem B is modeled as shown in Figure 2-8. The results of the calculations are shown in Table 2-3.

TABLE 2-2. PROBABILITY TABLE FOR SUBSYSTEM A

State	Steady-State Probability
0	.978612
1	.019018
2	.002304
3	.000060
4	.000005

TABLE 2-3. PROBABILITY TABLE FOR SUBSYSTEM B

State	Steady-State Probability
0	.960451
1	.039549

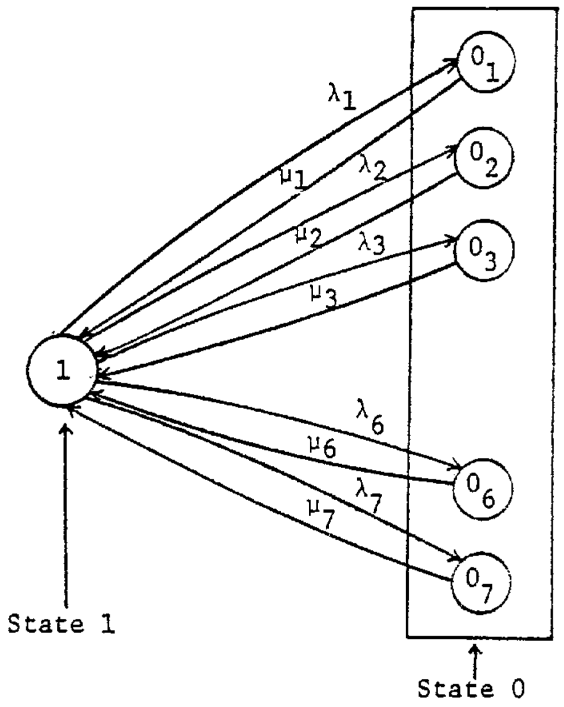


FIGURE 2-8. STATE SPACE MODEL FOR SUBSYSTEM B

Using the standard Markov techniques, the steady-state probability for each states is determined as follows:

$$\dot{P}_1(t) = 0$$

$$\dot{P}_{0_i} = \lambda_i P_1 - \mu_i P_{0_i} = 0 \Rightarrow P_{0_i} = \frac{\lambda_i}{\mu_i} P_1$$

Since $P_0 + P_1 = 1$,

$$P_0 + P_1 = \sum_{i=1}^{7} P_{0_i} + P_1 = \sum_{i=1}^{7} \frac{\lambda_i}{\mu_i} P_1 + P_1 = 1$$

and

$$P_1 = \frac{1}{1 + \sum_{i=1}^{7} \frac{\lambda_i}{\mu_i}}$$

$$P_0 = 1 - P_1.$$

Expected System Capacity

States 0 and 1 of Subsystem B are associated with 0 percent and 100 percent system capacity respectively. Each state i in Subsystem A is associated with a fraction, (32 - i)/32 of system capacity. Table 2-4 shows all subsystem states and their associated system capacity.

The 'X' in a column indicates that the subsystem can be in any of its states.

TABLE 2-4. SYSTEM CAPACITY FOR VARIOUS COMBINATIONS OF SUBSYSTEM STATES

Combination, i	Subsystem A	Subsystem B	System Capacity Fraction F(i)	Probability, P_i
1	X	0	0	$P_0(B)$
2	4	1	7/8	$P_4(A) \cdot P_1(B)$
3	3	1	29/32	$P_3(A) \cdot P_1(B)$
4	2	1	15/16	$P_2(A) \cdot P_1(B)$
5	1	1	31/32	$P_1(A) \cdot P_1(B)$
6	0	1	32/32	$P_0(A) \cdot P_1(B)$

The system expected capacity is computed as

$$\beta = \sum_{i=1}^{6} F(i) \cdot P_i$$

$$\beta = \Big\{ 0 + P_4(A) \cdot P_1(B) \cdot \frac{7}{8} + P_3(A) \cdot P_1(B) \cdot \frac{29}{32} + P_2(A) \cdot P_1(B) \cdot \frac{15}{16} + P_1(A) \cdot P_1(B) \cdot \frac{31}{32} + P_0(A) \cdot P_1(B) \cdot 1 \Big\}$$

$$\beta = 0 + .960451(5 \times 10^{-6} \times \frac{7}{8} + 6 \times 10^{-5} \times \frac{29}{32} + .002304 \times \frac{15}{16} + .019018 \times \frac{31}{32} + .978612 \times 1)$$

$$\beta = .959736.$$

System Power Production. The system power production in any year y, A(y), is computed by the equation:*

$$A(y) = W \cdot \beta \cdot DP(y) \cdot DC(y) \cdot \sum_{n=1}^{12} I(n)D(n).$$

The factor DC(y) represents the degradation in the system capacity resulting from the cell failures. See Figure 2-2.

$$\sum_{n=1}^{12} I(n) \cdot D(n) = 2660.1 \text{ hours}$$

$$\beta = .959736$$

$$W = 250 \text{ kW}.$$

The permanent degradation of the system capacity, DP, is assumed to be linear between consecutive years. Therefore, the permanent degradation factor, DP(y), for any year y is taken as the midpoint between the degradation factors at the beginning and end of year y. The degradation of system capacity due to cell failure, DC(y), is computed in a similar manner.

For y = 1,**

$$DP(1) = \frac{1.00 + .97}{2} = .985$$

$$DC(1) = \frac{1.00 + .998}{2} = .999$$

---

* See "State Space Approach", Volume 1, for derivation of equation and explanation of terms.

** The values for the degradation due to cell failures are the results of the JPL analysis as presented in Figure 2-2.

and $A(1) = 250 \times .959736 \times .985 \times .999 \times 2660.1 = 628053.9$ kW.

The system power production for years 1-30 is given in Table 2-5.

System Maintenance Cost.

$$ACCM = \sum_{i=1}^{m} (\lambda_i t_i n_i)(U_i C_i + FC_i)$$

where

$ACCM$ = Annual corrective maintenance costs

m = Total number of system components

λ_i = Failure rate of component i

t_i = Total operating or clock hours

n_i = Number of identical units of component i

U_i = Mean repair time of component i

C_i = Repair cost/hr

FC_i = Fixed cost/repair.

The results of these calculations are presented in Table 2-6.

$$ACPM = \sum_{i=1}^{m} (n_i f_i)(C_i U_i + FC_i)$$

where

$ACPM$ = Annual preventive maintenance costs

f_i = Frequency of preventive maintenance action on component i per year.

Other symbols are as defined under corrective maintenance.

The results of these calculations are given in Table 2-7.

TABLE 2-5. APS SYSTEM ANNUAL POWER PRODUCTION

Year	Annual Power Production, kWh	Year	Annual Power Production, kWh
1	628,053.97	16	550,208.22
2	607,706.35	17	547,878.59
3	587,435.33	18	545,552.77
4	576,140.59	19	542,945.33
5	574,057.47	20	540,342.37
6	571,977.55	21	538,028.69
7	569,900.83	22	535,434.34
8	567,827.29	23	532,560.26
9	565,468.29	24	529,975.17
10	563,401.47	25	527,394.54
11	561,625.83	26	524,818.38
12	559,565.06	27	522,529.58
13	557,220.11	28	520,244.63
14	555,166.04	29	517,963.50
15	552,828.42	30	515,968.16
		Total	16,590,219.12

TABLE 2-6. RESULTS OF CORRECTIVE MAINTENANCE CALCULATIONS FOR APS SYSTEM

	Expected Failures		Corrective Maintenance Costs, $	
	Per Year	Per 30 Yrs	Average, Per Yr	Per 30 Yrs
Power Distribution	0.35	1.05	4.68	140.49
Inverter	1.0	30	2,111.6	63,348
Control & Display	.876	26.28	1,937.4	58,120.1
Tracking, Electrical	3.52	105.5	126.7	3,801.6
Tracking Drive (80)	11.68	350.4	1,623.5	48,705.6
Heat Exchanger (Array)	7.0×10^{-3}	210×10^{-3}	3.21	96.4
Lens	.70	21.0	84.98	2,549.4
Utility	1.40	42.0	---	---
Distribution Subsystem	998.6×10^{-6}	29.96×10^{-3}	---	---
Power Switch	6.25×10^{-3}	187.6×10^{-3}	3.55	106.5
Total Corrective Maintenance Costs			$5,895.60	$176,869.10

TABLE 2-7. RESULTS OF PREVENTIVE MAINTENANCE CALCULATIONS FOR APS SYSTEM

Subsystem Component	Preventive Maintenance Costs, $ Per Yr (Average)	Per 30 Yrs
Inverter	29.20	876
Tracking Drive	1,254	37,620
Distribution Subsystem	195.6	5,868
General Maintenance	6,240.2	187,206.9
Lens (Cleaning)	928	27,840
Total Preventive Maintenance Cost	$8,647.03	$259,410.90
Total Maintenance Cost (30 years) = $436,280		

Note: All failure rate λ's, repair rate μ's, and cost information are computed from the data provided in Table 2-1.

SOLREL Analysis of APS System

The APS/Martin-Marietta passively cooled concentrator system is rated at 225 kW. As described earlier, the array field consists of 80 arrays each having an electrical tracking system, a tracking drive, solar cells, lens subassemblies, and an array substructure associated with it.

Failure of the tracking drive has the following effect on system output: The 80 arrays are electrically connected in 16 branch circuits consisting of 5 arrays each (see Figure 2-9).

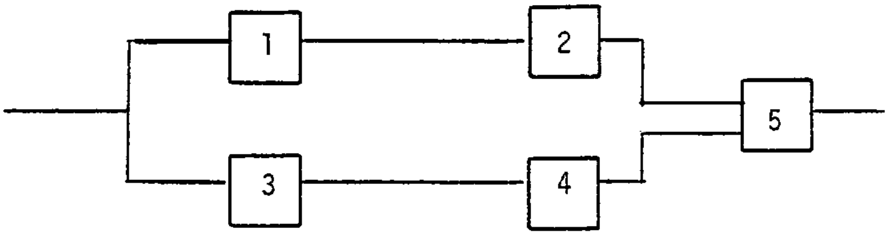


FIGURE 2-9. RELIABILITY FLOW DIAGRAM FOR A GROUP OF FIVE MODULES, PASSIVELY COOLED CONCENTRATOR SYSTEM

A failure of either tracking drive 1 or 2 will cause output to be lost from arrays 1-2 and half of array 5. A failure of either tracking drive 3 or 4 will cause output to be lost from arrays 3-4 and half of array 5. A failure of tracking drive 5, however, will cause output to be lost from all five arrays. This behavior is modeled in the same logical arrangement by SOLREL, i.e., array 5 causes all 5 to be lost, while failure of the other 4 only causes 2-1/2 arrays to be lost.

Cell failures were modeled using the JPL Array Circuit Design Optimization Methodology to develop the degradation curve described earlier. The resulting degradation curve is given in Figure 2-2. The user of SOLREL may opt to replace all damaged cells when cell output due to failures has degraded to a certain percentage of design output. This simulation used a "no cell replacement" policy.

The entire system will fail upon failure of either the utility, the distribution subsystem, the control/display, the inverter, or the power distributer/array field subsystem. In the event of high winds, all arrays will be stowed.

Array output was assumed to degrade at 3 percent per year due to dirt on the lenses, which can be removed by periodic cleaning. Permanent degradation was set at 3 percent per year for the first 3 years and 0.1 percent per year thereafter. A complete listing of the components and the associated data used for this system analysis appears in Table 2-1.

The Battelle solar design simulation model, SOLCEL was used to simulate a concentrator system of this design located in Phoenix. The SOLCEL simulation does not consider reliability, but assumes a fully functioning system to produce power output duration curves showing the amount of time various levels of output are achieved strictly as a result of changing insolation levels. This set of power output duration curves appears in Table 2-8.

Preventive maintenance was assumed to take place for the inverter, the tracking drives, and the distribution subsystem as well as for cleaning and systemwide preventive maintenance as described in Table 2-1.

All times between failures are selected from negative exponential distributions except for the tracking drives whose failure distributions were assumed to be Weibull. All repair times were selected randomly from lognormal distributions. All input parameters are repeated in Table 2-9 in computer output format.

The system simulation was run using an optimistic and a pessimistic set of financial parameters. For both cases, the general inflation rate was set at 8 percent with the electricity cost escalation rate being 2.5 percent above inflation. The discount rate was set at 20 percent for the pessimistic case and at 13 percent for the optimistic case. The results of these SOLREL runs appear in Tables 2-10 to 2-13. The program source listing is available on tape from Sandia.

The simulation output is also presented in Figures 2-10 through 2-12. These plots present the results in the form of annual energy output and maintenance costs as well as the levelized costs of maintenance per kWh for the two sets of financial assumptions.

TABLE 2-8. MONTHLY OUTPUT DURATION CURVES FOR APS/MARTIN-MARIETTA PASSIVELY COOLED CONCENTRATOR SYSTEM

```
MONTHLY OUTPUT DURATION CURVES IN INTERVALS OF 8.33 HOURS PER MONTH

MONTH  1  .960  .941  .923  .905  .893  .882  .870  .858  .845  .832  .818  .804  .786  .767  .747  .723
          .699  .675  .649  .622  .592  .557  .516  .444  .329  .223  .114  .089  .070  .053 0.000 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  2 1.013  .959  .953  .946  .940  .934  .928  .921  .915  .909  .900  .888  .877  .866  .855  .838
          .819  .800  .777  .754  .720  .684  .653  .612  .554  .443  .293  .172  .095  .065 0.000 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  3 1.013  .959  .955  .952  .948  .945  .941  .938  .935  .931  .928  .924  .921  .917  .914  .910
          .907  .900  .892  .885  .877  .870  .862  .855  .833  .809  .780  .750  .712  .663  .578  .473
          .364  .255  .141  .058  .032  .009 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  4  .960  .955  .951  .946  .941  .936  .932  .927  .922  .917  .913  .908  .904  .901  .897  .894
          .890  .887  .883  .880  .876  .873  .869  .866  .863  .859  .856  .844  .818  .790  .757  .728
          .701  .637  .592  .507  .391  .160  .050  .020 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  5  .960  .945  .931  .916  .906  .904  .902  .900  .898  .896  .895  .893  .891  .889  .887  .885
          .883  .881  .879  .877  .875  .874  .872  .870  .868  .866  .864  .862  .860  .858  .856  .854
          .846  .828  .810  .787  .758  .735  .715  .696  .665  .622  .503  .240  .067  .053 0.000

MONTH  6  .960  .905  .903  .900  .898  .895  .893  .890  .888  .886  .883  .881  .878  .876  .873  .871
          .869  .866  .864  .861  .859  .856  .854  .847  .838  .829  .820  .811  .802  .784  .763  .742
          .721  .701  .674  .644  .618  .594  .561  .524  .482  .439  .335  .173  .016 0.000 0.000

MONTH  7  .907  .903  .899  .895  .892  .888  .884  .880  .877  .873  .869  .865  .862  .858  .854  .848
          .841  .834  .827  .820  .813  .807  .799  .779  .759  .739  .717  .695  .662  .630  .603  .575
          .547  .509  .464  .413  .331  .270  .208  .160  .135  .111  .083  .053  .032  .010 0.000

MONTH  8  .907  .904  .901  .898  .895  .892  .889  .886  .882  .879  .876  .873  .870  .867  .864  .861
          .858  .855  .850  .840  .830  .821  .811  .801  .785  .768  .752  .727  .698  .668  .636  .604
          .562  .510  .446  .388  .336  .280  .237  .193  .120  .070 0.000 0.000 0.000 0.000 0.000

MONTH  9  .960  .906  .903  .900  .897  .893  .890  .887  .884  .881  .878  .875  .872  .869  .866  .863
          .860  .857  .854  .844  .834  .825  .815  .805  .790  .769  .748  .727  .707  .679  .640  .604
          .557  .510  .453  .256  .053 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 10  .960  .951  .927  .906  .903  .899  .896  .892  .889  .886  .882  .879  .876  .872  .869  .865
          .862  .859  .855  .845  .827  .809  .789  .768  .748  .717  .686  .655  .608  .552  .504  .433
          .276  .152  .079  .007 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 11  .960  .954  .948  .941  .935  .929  .923  .917  .911  .903  .894  .884  .874  .865  .855  .839
          .821  .803  .783  .762  .739  .708  .672  .628  .574  .502  .421  .320  .165  .045 0.000 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 12  .960  .932  .905  .894  .883  .871  .860  .847  .832  .817  .803  .783  .762  .740  .709  .680
          .653  .625  .595  .558  .514  .458  .341  .213  .107  .052  .034  .015 0.000 0.000 0.000 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
```

TABLE 2-9. INPUT PARAMETERS FOR APS-MARTIN MARIETTA PASSIVELY COOLED CONCENTRATOR SYSTEM

```
COMPONENT NAME            MTBF    MAINT TIME (HRS)  REPAIR COST ($)   NUM  PM TIME (HOURS)    PM COST ($)        PM INTERVAL  NUM
                        (MONTHS)   50PCT    90PCT   FIXED  VARIABLE   MEN  50PCT     90PCT   FIXED  VARIABLE     (MONTHS)    MEN

THE CELLS               *********    36.0    108.0     0.00     20.00   1

THE TRACKING SYSTEM        274.0     1.0      4.0     0.00     20.00   1

THE TRACKING DRIVE          82.2     6.0     12.0     0.00     20.00   1   160.0     320.0    50.00    20.00          36.0     1

THE ARRAY               137000.0     4.0      8.0   330.00     20.00   1

THE LENS                  1370.0     2.0      4.0    75.00     20.00   1    40.0      80.0     0.00    20.00          12.0     1

THE UTILITY                  8.6     2.0      3.6     0.00      0.00   1

THE DIST. SYSTEM         12000.0    28.0     60.0     0.00      0.00   1     8.0      18.0     0.00    20.00          12.0     1

THE POWER SWITCH          2000.0     3.6      6.0   100.00    120.00   4

THE ARRAY FIELD            342.5     5.6     12.0     0.00     20.00   1

THE INVERTER                12.0    24.0     48.0  1000.00     40.00   1     6.0      12.0   100.00     0.00          41.0     1

THE CONTROL-DISPLAY         13.7    24.0     48.0  1100.00     40.00   1

THE WEATHER                  3.0    10.0     35.0     0.00      0.00   1

GENERAL PREV MAINT                                                        250.0     530.0   300.00   100.00          12.0     5


FLAG1= 0 MEANS RESULTS FROM ALL PREVIOUS RUNS ARE BEING IGNORED
FLAG2= 0 MEANS RESULTS FROM THIS RUN WILL NOT BE SAVED ON PERMANENT FILES
FLAG3= 0 MEANS NO EVENT OR YEARLY SUMMARY MESSAGES WILL BE PRINTED
FLAG4= 1 MEANS TABLES FOR EACH INDIVIDUAL RUN WILL BE PRINTED
FLAG5= 1 MEANS PLOTS FOR INDIVIDUAL RUNS ONLY WILL BE PRODUCED


PERMANENT DEGRADATION -- 3 YEAR INTERVALS
  1.000   .910   .907   .904   .901   .898   .895   .892   .889   .886   .883

DEGRADATION DUE TO DIRT -- 3 YEAR INTERVALS
  1.000   .910   .820   .730   .640   .550   .460   .370   .280   .190


DEGRADATION DUE TO CELL FAILURE - 1 YEAR INTERVALS
  1.000   .998   .996   .994   .991   .989   .986   .984   .981   .978
   .976   .974   .971   .968   .966   .962   .959   .956   .953   .949
   .946   .943   .939   .935   .932   .928   .925   .922   .919   .916   .914
ARRAY CAPACITY IN KW................    250.
INVERTER DESIGN CAPACITY IN KW......    250.
OVERALL INFLATION RATE..............    .080
DISCOUNT RATE.......................    .130
ELECTRICITY PRICE ESCALATION........    .105
LENGTH OF RUN IN MONTHS.............    360.
CELLS REPAIRED AT FRACTION LOSS OF..     .30
MOTORS REPAIRED ON FAILURE NUMBER...      1.
```

TABLE 2-10. APS/MARTIN-MARIETTA CONCENTRATOR SYSTEM AVAILABILITY

ANNUAL SYSTEM AVAILABILITY DURING DAYLIGHT
AS A PERCENT OF SYSTEM CAPACITY

SYSTEM CAPACITY = 250.0 KW   NUMBER OF DAYLIGHT HOURS PER YEAR = 3729.5

YEAR	100-90%	90-80%	80-70%	70-60%	60-50%	50-40%	40-30%	30-20%	20-10%	10-0%	TOTAL
THEORETICAL	18.31	40.26	11.84	7.90	5.30	3.28	2.36	2.45	3.10	7.10	100.00
1	9.69	42.55	14.17	8.29	5.97	3.77	2.29	1.79	3.11	8.37	100.00
2	4.26	36.39	18.13	8.69	6.28	4.03	2.41	2.63	2.97	14.19	100.00
3	.27	27.04	30.43	10.66	7.34	4.52	2.59	2.47	2.65	12.05	100.00
4	.15	17.77	39.85	11.49	7.27	4.76	2.77	3.01	2.98	9.95	100.00
5	.06	15.10	41.12	11.59	7.59	4.81	2.90	2.71	2.79	11.33	100.00
6	.07	14.42	41.88	11.77	7.31	4.50	2.66	2.55	2.51	12.34	100.00
7	.03	12.89	42.57	12.75	7.93	4.98	2.67	2.57	2.72	10.99	100.00
8	.00	9.96	45.82	12.34	7.56	4.80	2.43	2.53	2.63	11.93	100.00
9	0.00	10.57	45.18	13.54	8.02	5.00	2.95	2.95	2.60	9.00	100.00
10	0.00	10.55	46.71	13.44	7.97	5.03	2.87	2.71	2.53	8.18	100.00
11	0.00	8.54	43.48	13.74	8.53	5.56	2.86	2.43	2.77	12.08	100.00
12	0.00	7.49	44.22	13.86	8.27	5.15	2.88	2.90	2.82	12.41	100.00
13	0.00	8.81	45.10	13.57	7.86	5.11	2.84	2.65	2.71	11.35	100.00
14	0.00	6.79	44.16	14.43	8.50	5.51	3.16	2.80	3.17	11.48	100.00
15	0.00	5.37	46.21	15.51	8.93	5.68	3.10	2.70	2.76	9.74	100.00
16	0.00	6.43	46.62	15.50	8.44	5.45	3.00	3.00	3.15	8.39	100.00
17	0.00	4.76	44.78	16.43	9.22	5.90	3.36	3.04	3.34	9.17	100.00
18	0.00	2.97	43.63	15.95	8.43	5.23	2.98	3.11	3.16	14.55	100.00
19	0.00	2.64	48.57	17.40	9.44	5.52	3.27	3.41	3.10	6.64	100.00
20	0.00	2.60	43.44	17.98	9.12	6.10	3.55	2.89	3.37	10.94	100.00
21	0.00	1.07	45.07	18.15	9.84	6.13	3.67	3.06	2.94	10.07	100.00
22	0.00	.77	44.77	18.73	9.39	5.64	3.17	3.18	3.01	11.33	100.00
23	0.00	.26	47.69	19.95	10.36	6.35	3.32	2.79	2.55	6.74	100.00
24	0.00	.19	42.04	22.29	10.49	6.56	3.50	2.74	2.42	9.77	100.00
25	0.00	.21	41.10	23.74	10.55	6.66	3.65	2.90	2.99	8.20	100.00
26	0.00	.35	38.41	22.79	9.82	5.55	3.29	3.16	2.65	13.99	100.00
27	0.00	.39	35.71	28.07	10.69	6.89	3.87	2.89	3.01	8.48	100.00
28	0.00	.36	34.68	28.17	10.21	5.96	3.38	3.13	2.97	11.14	100.00
29	0.00	.24	33.06	29.68	10.52	6.33	3.49	2.77	2.53	11.38	100.00
30	0.00	.15	30.07	32.17	10.88	6.58	3.78	3.30	2.98	10.09	100.00
AVERAGE	.49	8.61	40.29	17.08	8.75	5.47	3.09	2.83	2.87	10.54	100.00

TABLE 2-11. SYSTEM COMPONENT FAILURE TABLE

COMPONENT FAILURE TABLE

NUMBER OF FAILURES PER COMPONENT BY YEAR

COMPONENT YEAR =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
THE TRACKING SYSTEM	2	4	3	3	2	3	4	4	5	4	4	5	2	6	0	3	1	7	3	3	2	4	5	2	3	2	5	7	4	5	107
THE TRACKING DRIVE	0	0	2	9	10	10	18	8	11	15	15	17	9	14	12	6	11	14	8	17	10	19	4	13	10	10	14	9	10	9	314
THE ARRAY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE LENS	2	0	0	0	1	0	1	0	2	2	2	0	3	1	1	1	0	2	1	1	0	2	1	0	3	1	0	1	2	2	32
THE UTILITY	2	0	1	2	2	1	1	0	3	3	0	4	1	1	1	0	2	4	1	0	2	2	1	1	2	3	0	0	3	1	44
THE DIST. SYSTEM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THE POWER SWITCH	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
THE ARRAY FIELD	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
THE INVERTER	0	5	2	0	2	1	2	4	1	0	1	1	3	1	0	0	1	0	0	0	1	3	0	1	0	0	1	2	5	3	40
THE CONTROL-DISPLAY	0	0	0	1	1	2	0	1	1	0	1	2	1	1	1	1	0	1	0	0	2	1	0	1	0	2	1	3	1	0	25
THE WEATHER	5	4	6	2	6	6	4	5	4	5	4	3	2	6	6	4	4	8	3	1	6	5	3	3	4	3	1	4	0	4	121
TOTALS	11	13	14	17	24	23	30	22	27	30	28	32	21	30	21	15	19	35	16	22	23	36	14	21	22	21	22	26	25	24	685

TABLE 2-12. APS/MARTIN-MARIETTA PASSIVELY COOLED CONCENTRATOR SYSTEM
13 PERCENT DISCOUNT RATE

ANNUAL MAINTENANCE COST AND OUTPUT

	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	574.58	634462.	.09	557.06	627312.	.09
2	15801.74	566573.	2.79	14916.70	547906.	2.72
3	12552.53	555991.	2.26	11326.65	525735.	2.15
4	14409.06	571279.	2.52	12493.94	528325.	2.36
5	17812.99	549954.	3.24	14690.00	497220.	2.95
6	8805.45	544980.	1.62	6942.81	481843.	1.44
7	21841.52	545402.	4.00	16484.69	471756.	3.49
8	21528.04	545862.	3.94	15508.39	461387.	3.36
9	29085.80	558890.	5.20	20115.02	462139.	4.35
10	18462.02	570603.	3.24	12242.75	461403.	2.65
11	15771.92	523320.	3.01	9907.44	413720.	2.39
12	14009.35	528411.	2.65	8434.51	408516.	2.06
13	21146.03	549212.	3.85	12159.60	415279.	2.93
14	11961.35	531354.	2.25	6499.16	392884.	1.65
15	14729.40	532305.	2.77	7777.88	384716.	2.02
16	12842.55	557039.	2.31	6488.10	393866.	1.65
17	6028.53	538110.	1.12	2904.06	371949.	.78
18	11097.41	513562.	2.16	5096.40	347269.	1.47
19	10741.34	554072.	1.94	4739.98	366197.	1.29
20	15776.56	530675.	2.97	6645.05	343172.	1.94
21	15779.22	518403.	3.04	6325.34	327593.	1.93
22	23782.15	521556.	4.56	9095.53	322508.	2.82
23	11858.36	547629.	2.17	4375.06	331009.	1.32
24	11598.49	521231.	2.23	4033.50	308154.	1.31
25	11722.04	527559.	2.22	3944.10	304930.	1.29
26	21126.05	478960.	4.41	6787.55	270672.	2.51
27	9499.85	521799.	1.82	2878.99	288464.	1.00
28	23179.96	506573.	4.58	6769.00	273812.	2.47
29	18967.65	504242.	3.76	5263.79	266527.	1.97
30	11930.78	504039.	2.37	3155.43	260517.	1.21
TOTALS	454422.72	16154046.		248558.47	11856780.	2.10 (LEVELIZED)

TABLE 2-13. APS/MARTIN-MARIETTA PASSIVELY COOLED CONCENTRATOR SYSTEM, 20 PERCENT DISCOUNT RATE

ANNUAL MAINTENANCE COST AND OUTPUT

	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	574.58	634462.	.09	534.70	608606.	.09
2	15801.74	566573.	2.79	13820.52	500836.	2.76
3	12552.53	555991.	2.26	9885.11	452437.	2.18
4	14409.06	571279.	2.52	10340.06	428329.	2.41
5	17812.99	549954.	3.24	11375.05	379331.	3.00
6	8805.45	544980.	1.62	5064.53	346196.	1.46
7	21841.52	545402.	4.00	11348.33	319554.	3.55
8	21528.04	545862.	3.94	10035.47	293749.	3.42
9	29085.80	558890.	5.20	12329.95	277373.	4.45
10	18462.02	570603.	3.24	7096.06	260803.	2.72
11	15771.92	523320.	3.01	5344.41	220087.	2.43
12	14009.35	528411.	2.65	4300.05	204658.	2.10
13	21146.03	549212.	3.85	5833.12	196008.	2.98
14	11961.35	531354.	2.25	2892.60	174614.	1.66
15	14729.40	532305.	2.77	3331.30	160827.	2.07
16	12842.55	557039.	2.31	2620.28	155238.	1.69
17	6028.53	538110.	1.12	1101.02	137935.	.80
18	11097.41	513562.	2.16	1813.60	121401.	1.49
19	10741.34	554072.	1.94	1599.52	120396.	1.33
20	15776.56	530675.	2.97	2108.05	106408.	1.98
21	15779.22	518403.	3.04	1879.10	95476.	1.97
22	23782.15	521556.	4.56	2538.63	88668.	2.86
23	11858.36	547629.	2.17	1163.85	85607.	1.36
24	11598.49	521231.	2.23	992.21	75094.	1.32
25	11722.04	527559.	2.22	928.43	69934.	1.33
26	21126.05	478960.	4.41	1502.75	58432.	2.57
27	9499.85	521799.	1.82	590.00	58697.	1.01
28	23179.96	506573.	4.58	1320.22	52446.	2.52
29	18967.65	504242.	3.76	959.48	48075.	2.00
30	11930.78	504039.	2.37	539.66	44246.	1.22
TOTALS	454422.72	16154046.		135188.08	6141461.	2.20 (LEVELIZED)

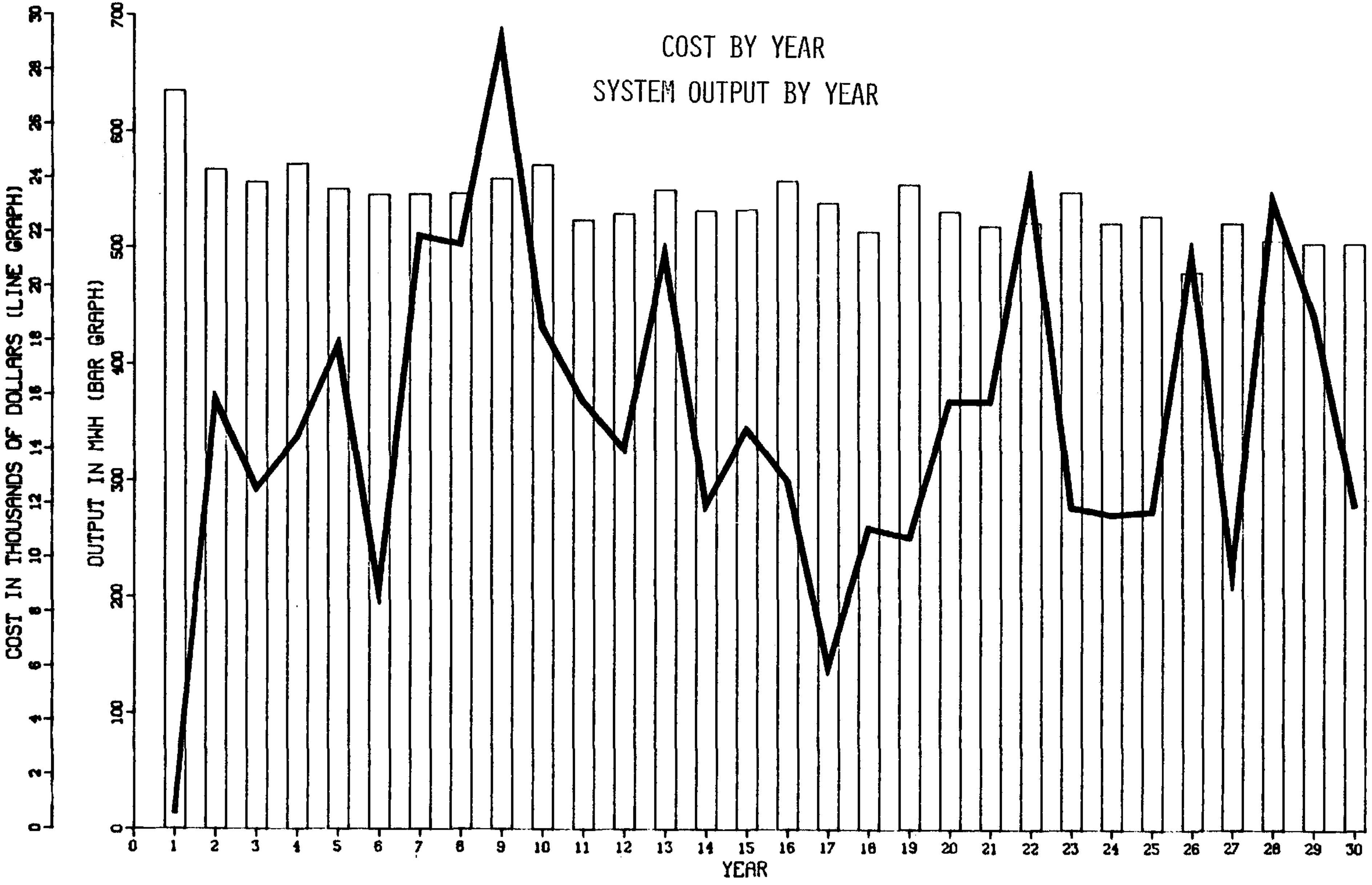


FIGURE 2-10. RESULTS OF APS ANALYSIS, CURRENT VALUE, ANNUAL MAINTENANCE COST AND ENERGY PRODUCED

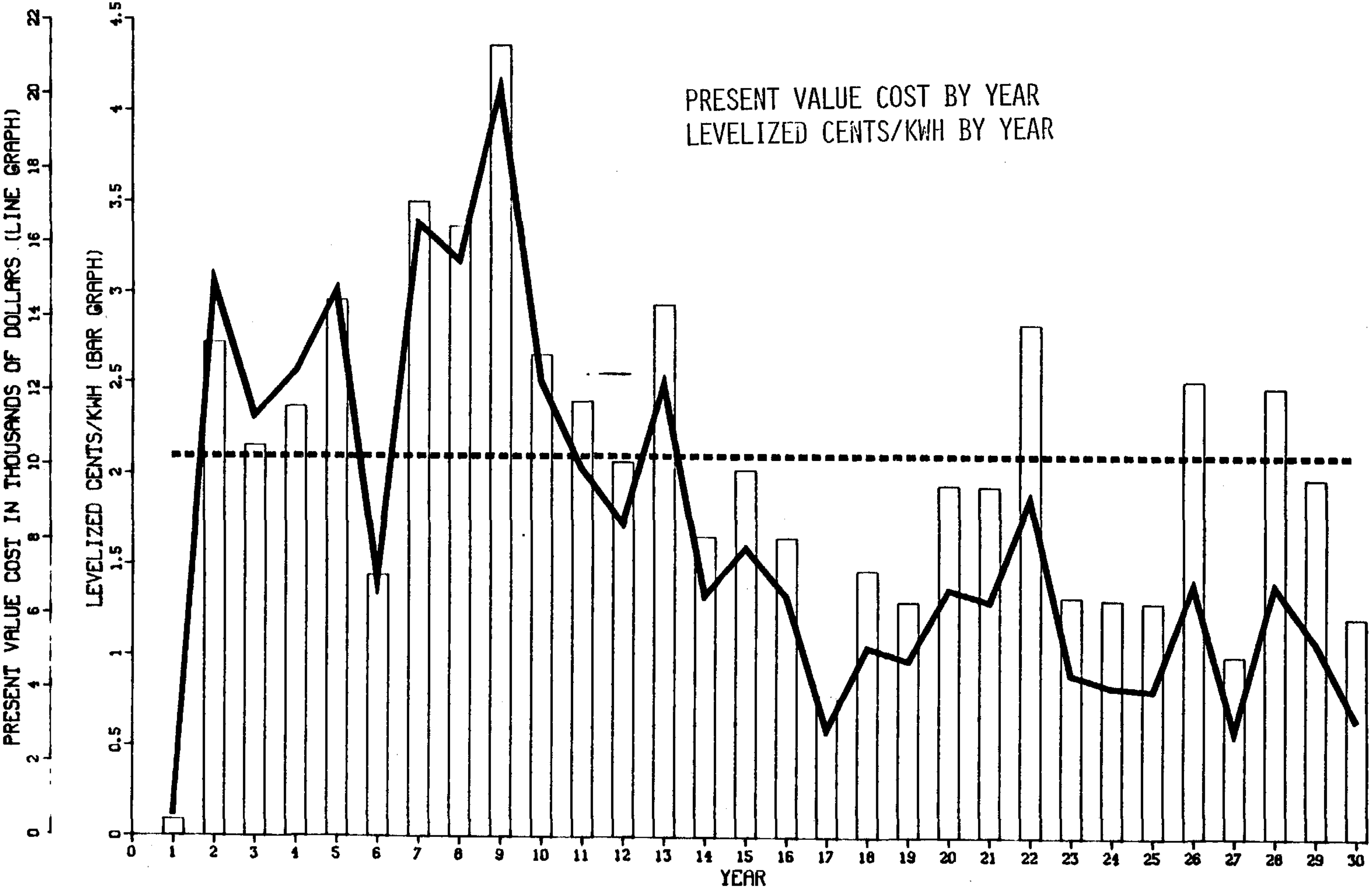


FIGURE 2-11. RESULTS OF APS SYSTEM SIMULATION, ASSUMING A 13 PERCENT DISCOUNT RATE

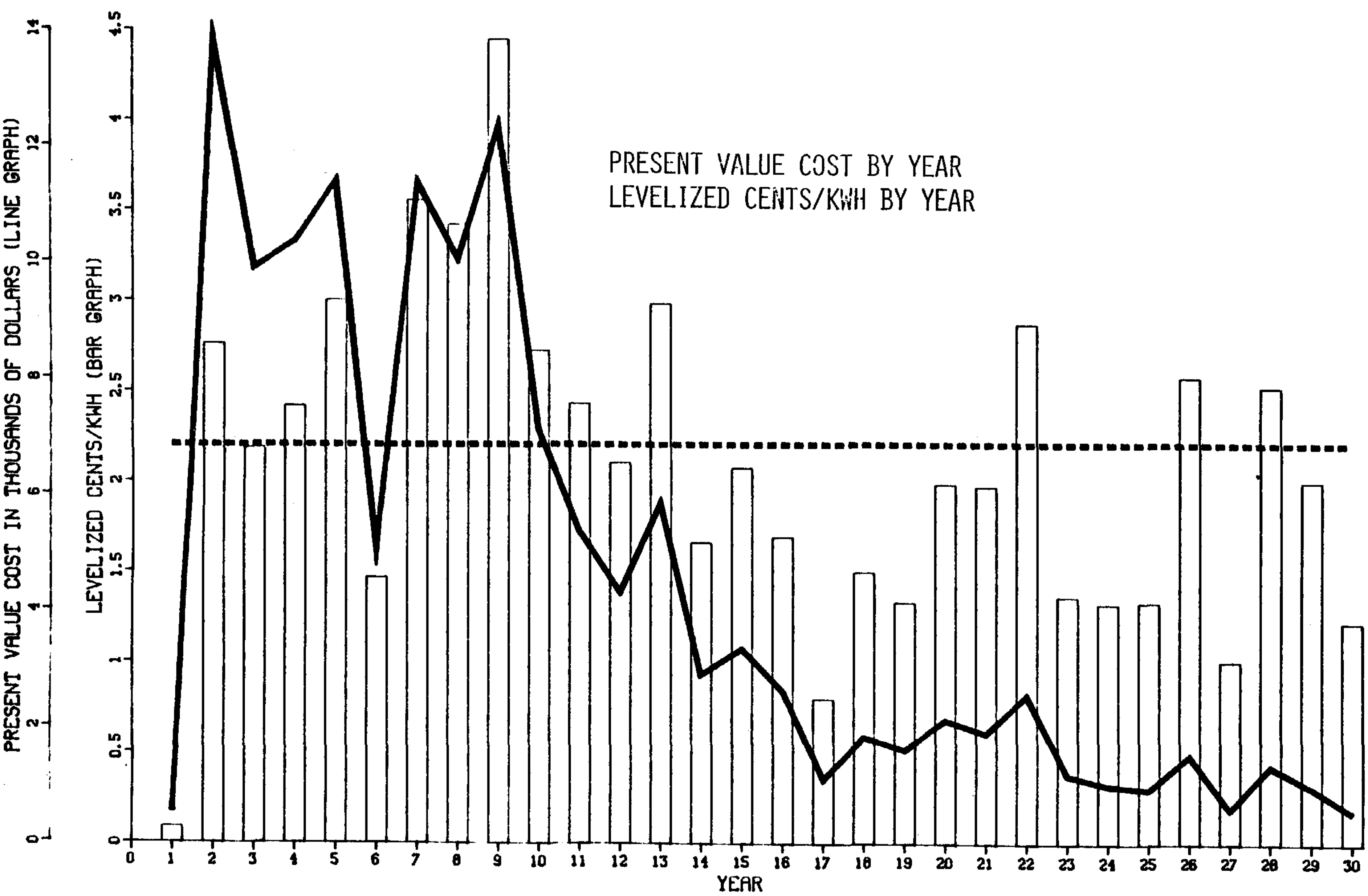


FIGURE 2-12. RESULTS OF APS SYSTEM SIMULATION, ASSUMING A 20 PERCENT DISCOUNT RATE

SECTION 3. ANALYSIS OF ACTIVELY COOLED PV CONCENTRATOR SYSTEM

BDM PV CONCENTRATOR SYSTEM (ACTIVELY COOLED)

Description of System

This 48 kW peak electrical system is comprised of 9 rows of parabolic troughs mounted on a roof top(21). Each row has six collectors mounted end-to-end. The solar cells are mounted at the focal point of these troughs and are cooled by liquid flowing through their heat sinks. A block diagram of the system is presented in Figure 3-1. Each row of collectors has two parallel electrical channels. Each channel in each row consists of 498 solar cells. One 50 kW power conditioner is used to convert the dc output voltage of the array (approximately 300 volts dc) to ac, synchronize it with the utility, and feed it to the load in parallel with the utility. This design is modified in detail and of a lower power level than the final Phase I, PRDA design.

There is a central control unit and a separate drive mechanism for each row of six collectors. The drive mechanism is hydraulic and consists of a ram, a motor, and an accumulator. Winds over 25 miles per hour or low insolation cause the system to stow automatically.

Input Data

Output Duration Curves. In order to represent the month-to-month variations in solar insolation, a set of 12 power output duration curves was provided for the availability simulation. This represented the time during any given month that the power would be at certain levels, assuming no system failures or degradation. These curves are generated by the SOLCEL design simulation and are shown in Figure C-1 and Table 3-10.

Data From Array Field Analysis Results. The salient features of this design for input to the analyses are:

- Series blocks consisting of either 5 or 6 series cells with no parallel strings (on the series block level) and one bypass diode per series block.
- A branch circuit consisting of 90 series blocks connected in series.

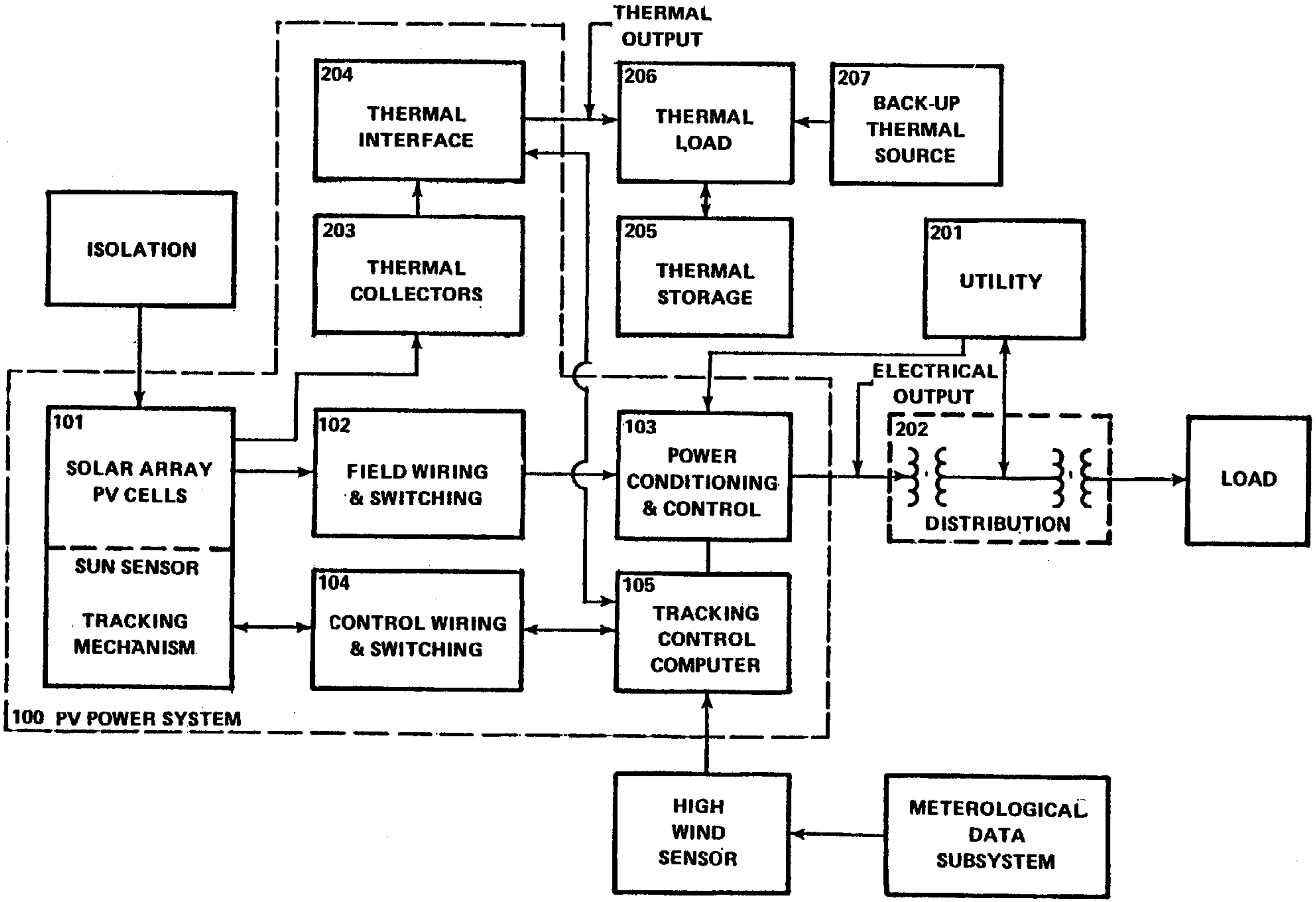


FIGURE 3-1. SIMPLIFIED FUNCTIONAL BLOCK DIAGRAM, GENERIC CONCENTRATOR PV POWER SYSTEM, ACTIVELY COOLED, INTERACTIVE WITH UTILITY, NO STORAGE

- An array field consisting of 18 parallel branch circuits. Using this information and a cell failure rate of 0.0005 failures per year, the JPL analysis (described earlier in this volume) was conducted. The results are presented in Figure 3-2.

Reliability/Maintenance Data. The parameters and costs estimated for the reliability and maintenance inputs to the model are given in Table 3-1. These data are estimates of such a system as it might be expected to be in the mature production stage.

State Space Analysis of BDM System

For the purpose of the reliability analysis, the BDM system has been divided into four major subsystems as follows:

- Subsystem A represents the array field.
- Subsystem B represents the inverter.
- Subsystem C represents the serial subsystem (all system component logically connected in series).
- Subsystem D represents the utility interface.

The logical functional representation of the system is depicted in Figures 3-3 through 3-7. Subsystems B and D could have been included in Subsystem C. These subsystems are distinguished to highlight effects of their relatively large failure rates.

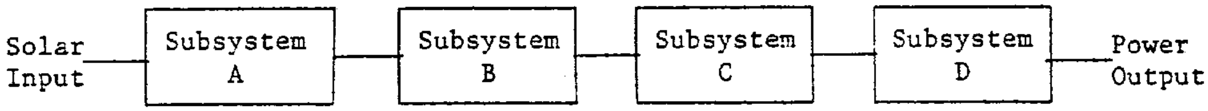


FIGURE 3-3. BDM SYSTEM AS A COLLECTION OF FOUR SUBSYSTEMS

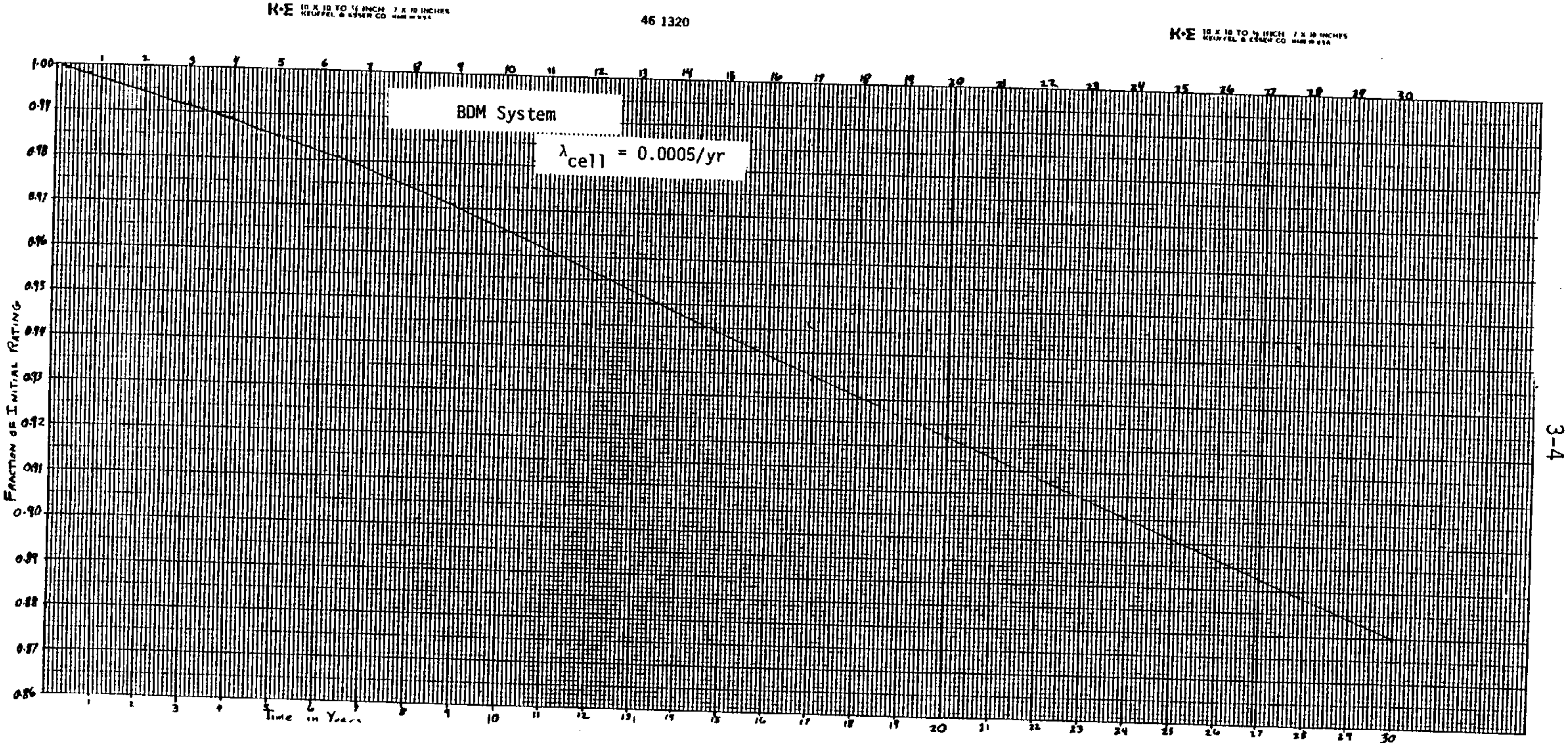


FIGURE 3-2. RESULTS OF ARRAY FIELD ANALYSIS FOR BDM SYSTEM

TABLE 3-1. ESTIMATED RELIABILITY AND MAINTENANCE DATA INPUTS FOR TASK 3 ANALYSIS OF SINGLE-AXIS ACTIVELY-COOLED CONCENTRATOR PV POWER SYSTEM

	Maintenance							
	Corrective Maintenance					Preventive Maintenance		
	Maintenance Time[(a)], hr Lognormal					Maintenance Time[(c)], hr Lognormal[(d)]		
Subsystem/Component	50 Percentile	90 Percentile	Per hr Cost, $	Travel + Materials (Fixed), $	Source	50 Percentile	90 Percentile	Fixed Costs/ Frequency
Cell String (2 per row)	2 (per row)	6	20	0	Class IV NBNM[(b)]	---	---	---
Receiver Tube	4	10	30	200	II NBNM	---	---	---
Collector Structure, One Row	8	12	30	120+100	III NBNM	2 Clean Surface	4	$20/hr;12 months; Shutdown Row
Tracking System, Electrical	1	4	20	10	IV NBNM	1 Adjust, Check	2	$30/hr; 12 months; Shutdown row
Tracking System, Other	6	12	20	20	IV NBNM			
Inverter	24	48	40	300	NBNM	6 Replace Main Contactors	12	$100; 30,000 hr; Shutdown
Switching/Wiring	5.6	12	20	0	IV NBNM	---	---	---
Instrumentation/Controls	24	48	40	1000+100	I NBNM	---	---	---
Main Fluid Pump	8	16	40	200+100	II NBNM	---	---	---
Heat Rejection/Heating	12	24	30	120+50	III NBNM	---	---	---
Fluid Piping, Global	4	8	30	120+20	III NBNM	---	---	---
Fluid Piping, Local	2	4	20	0	IV NBNM	---	---	---
Utility Interface	2	3.6	0	0	Same as Rel.[(e)]	---	---	---
Power Switchgear	3.6	6	120	100	Same as Rel.	---	---	---
System-wide PM	---	---	---	---	---	8	10	$20/hr; monthly; No Shutdown
						16	18	$20/hr; 6 months; Shutdown

Footnotes appear on following page.

TABLE 3-1. (Continued)

Subsystem/Component	Reliability				Degradation
	MTBF Clock hr	Other Parameters	Distribution	Source	
Cell String (2 per row)	17.5×10^6 per cell	(λcell = 0.0005/yr)	Exponential	BCL est.	Determined by results of JPL method. Output degrades over time. See curves from JPL method.
Receiver Tube	100,000	---	exp.	BCL est.	1/9 output lost
Collector Structure, One Row	200,000	---	exp.	BCL est.	1/9 output lost
Tracking System, Electrical	200,000	---	exp.	BCL est.	1/9 output lost
Tracking System, Other	60,000	$\beta = 2.5$ $\eta = 67{,}623$	Weibull(f)	BCL est.	1/9 output lost
Inverter	8,760	---	exp.	BCL est.	Complete shutdown
Switching/Wiring	500,000	---	exp.	BCL est.	Complete shutdown
Instrumentation/Controls	10,000	---	exp.	BCL est.	Complete shutdown
Main Fluid Pump	50,000	$\beta = 2.5$ $\eta = 56{,}353$	Weibull	BCL est.	Complete shutdown
Heat Rejection/Heating	25,000	$\beta = 2.5$ $\eta = 28{,}177$	Weibull	BCL est.	Complete shutdown
Fluid Piping, Global	200,000	---	exp.	BCL est.	Complete shutdown
Fluid Piping, Local	500,000	---	exp.	BCL est.	1/9 output lost
Utility Interface	6,257	$\lambda = 160/10^6$ hr	exp.	IEEE Std. 493-1980 p 214, Table II	Complete shutdown
Power Switchgear	1.4×10^6	$\lambda = 0.7/10^6$ hr	exp.	IEEE Std. 493-1980 p 123, Table 2	Complete shutdown

---

(a) Includes [active repair time + travel time + logistics time + administrative time] and is therefore time to restore.

(b) NBNM = Natural Bridges National Monument Initial Experience in Maintenance (Solman 15th Annual PV Spec. Conf.)

(c) Each unit or system is down for time being maintained--follow functional diagram.

(d) Same per hour charge as Corrective Maintenance.

(e) Refers to same source as in Reliability section of this table.

(f) Weibull density function: $f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]$, β = shape, η = scale, t = time.

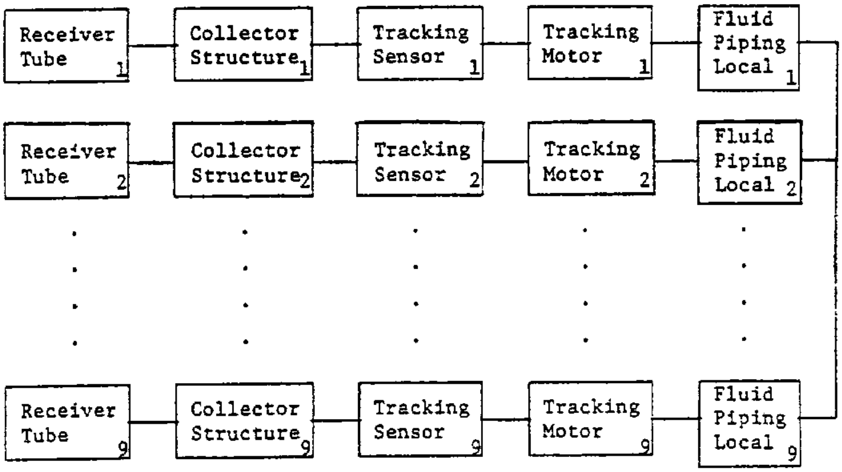


FIGURE 3-4. SUBSYSTEM A: NINE IDENTICAL ARRAYS IN PARALLEL

FIGURE 3-5. SUBSYSTEM B

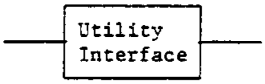


FIGURE 3-6. SUBSYSTEM D

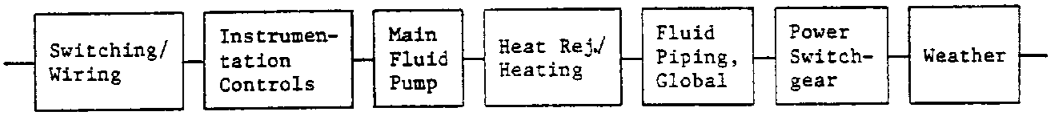


FIGURE 3-7. SUBSYSTEM C: ALL SYSTEM ELEMENTS LOGICALLY CONNECTED IN SERIES EXCEPT THE INVERTER AND THE UTILITY INTERFACE

Modeling Method

Each subsystem is represented by a number of states where each state is defined in terms of the status of each of the different elements of the subsystem. Markov model techniques are then used to compute the steady-state occupancy probabilities of each subsystem state. These state probabilities are combined with their associated system capacity to obtain the expected system capacity.

The following sections illustrate this method for each of the four subsystems.

Subsystem A. As shown in Figure 3-8, Subsystem A is characterized by ten different states (0,...,9). Each state corresponds to the number of failed subarray fields. The steady-state probability for each state can be obtained by the standard Markov technique; that is, at steady state the rate of change in any state is zero (see "State Space Approach" Volume 1). For example:

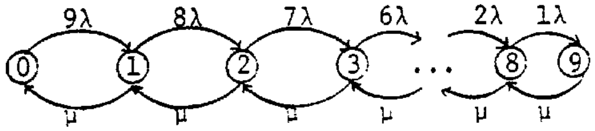


FIGURE 3-8. STATE SPACE MODEL FOR SUBSYSTEM A

$$\dot{P}_0(t) = -9\lambda P_0 + \mu P_1 = 0$$

$$\Rightarrow P_1 = \frac{9\lambda}{\mu} P_0$$

$$\dot{P}_i(t) = (9 - i - 1)\lambda P_{i-1} + \mu P_{i+1} - (9 - i)\lambda P_i - \mu P_i = 0$$

$$\Rightarrow P_{i+1} = \frac{[(9 - i)\lambda + \mu]}{\mu} P_i - \frac{(9 - i - 1)\lambda}{\mu} P_{i-1} .$$

Recursively, each P_i can be expressed in terms of P_0 by

$$P_i = \left[\prod_{j=10-i}^{9} \left(\frac{j\lambda}{\mu}\right)\right] P_0 \quad , \; i \neq 0$$

i = state number
j = 10 - i

Since $\sum_{i=0}^{9} P_i = 1$,

$$\Rightarrow P_0 + \sum_{i=1}^{9} \left[\prod_{j=10-i}^{9} \left(\frac{j\lambda}{\mu}\right)\right] P_0 = 1$$

$$P_0 = \frac{1}{1 + \sum_{i=1}^{9} \left[\prod_{j=10-i}^{9} \left(\frac{j\lambda}{\mu}\right)\right]} \; .$$

Each P_i can then be computed.

$$\lambda = \lambda_{REC} + \lambda_{COLL} + \lambda_{SENSOR} + \lambda_{MOTOR} + \lambda_{PIPING} = \sum \lambda_i$$

$$= (1.0 + 0.5 + 0.5 + 1.67 + 0.2) \times 10^{-5}$$

$$\Rightarrow \lambda = 3.87 \times 10^{-5}$$

$$\mu = \left(\sum \lambda_i \mu_i\right) \Big/ \sum \lambda_i$$

$$= (1 \times .064 + .5 \times .185 + .5 \times .040 + 1.67 \times .048 + .2 \times .144)/3.87$$

$$= 0.074.$$

The final results of these calculations are presented in Table 3-2.

TABLE 3-2. PROBABILITY TABLE FOR SUBSYSTEM A

State	Steady-State Probability
0	.995297
1	.004696
2	.000007
3 - 9	0

Subsystems B and D. Subsystems B and D are characterized by two states (state 0 corresponding to subsystem failure and state 1 corresponding to subsystem operating), as diagrammed in Figure 3-9.

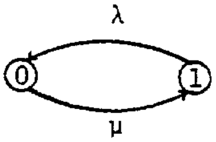


FIGURE 3-9. STATE SPACE MODEL FOR SUBSYSTEMS B and D

The steady-state probability for each state can be obtained in a manner similar to Subsystem A.

$$P_1 = \frac{1}{1 + \frac{\lambda}{\mu}}$$

$$P_0 = 1 - P_1$$

These results are shown in Table 3-3.

Subsystem C. Subsystem C is characterized by two states (0, 1). State 1 corresponds to no element failure, state 0 corresponds to subsystem failure (0_i = subsystem failed resulting from element i failure). See Figure 3-10.

TABLE 3-3. RESULTS OF COMPUTATIONS FOR SUBSYSTEMS B AND D

State	Probabilities Subsystem B	 Subsystem D
1	.990577	.998937
0	.009423	.001063

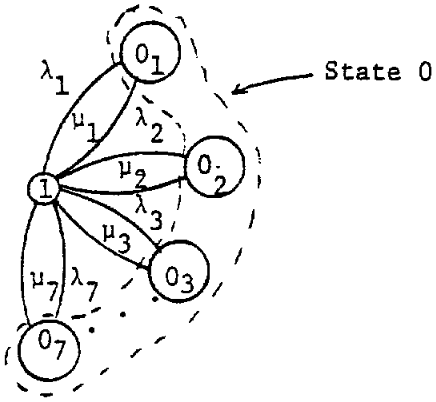


FIGURE 3-10. STATE SPACE MODEL FOR SUBSYSTEM C

The same standard Markov technique is followed here to obtain the state probabilities.

$$\dot{P}_i(t) = 0$$

therefore

$$\dot{P}_{0_i} = \lambda P_1 - \mu_i P_{0_i} = 0 ; \qquad P_{0_i} = \frac{\lambda_i}{\mu_i} P_1$$

and the results shown in Table 3-4 are obtained.

TABLE 3-4. PROBABILITY TABLE FOR SUBSYSTEM C

State	Probability	
1	.974986	
0_1	.000008	$\sum = .025014 = P_0$
0_2	.000827	
0_3	.000551	
0_4	.001653	
0_5	.000004	
0_6	.000005	
0_7	.021930	

Since the sum of all state probabilities is unity,

$$P_1 + \sum_{i=1}^{7} P_{0_i} = 1$$

$$= P_1 + \sum_{i=1}^{7} \frac{\lambda_i}{\mu_i} P_1 = 1$$

and

$$P_1 = \frac{1}{1 + \sum_{i=1}^{7} \frac{\lambda_i}{\mu_i}}$$

and $P_0 = 1 - P_1$.

Expected System Capacity Computation. For Subsystems B, C and D, 100 percent system capacity and 0 percent are respectively associated with states 1 and 0. For Subsystem A, each state i is associated with [(9 - i)/9] of system capacity. Table 3-5 shows all subsystem states and their associated system capacity.

The "X" in a column indicates that the subsystem can be in any one of its states.

The system expected capacity β can be then computed as follows:

$$\beta = \sum_{i=1}^{13} P_i \, F(i)$$

since

$$P_3(A), \ldots\ldots, P_9(A) = 0$$

$$\begin{aligned} \beta &= \Big\{ 0 + P_2(A)\, P_1(B)\, P_1(C)\, P_1(D) \times 7/9 + P_1(A)\, P_1(B)\, P_1(C)\, P_1(D) \times 8/9 \\ &\quad + P_0(A)\, P_1(B)\, P_1(C)\, P_1(D) \times 1 \Big\} \\ &= 0 + (.990577 \times .974986 \times .998937)\,[.000007 \times 7/9 + .004696 \times 8/9 \\ &\quad + .995297] \\ &= .964267. \end{aligned}$$

TABLE 3-5. SYSTEM CAPACITY FOR VARIOUS COMBINATIONS OF SUBSYSTEM STATES

Combinations i	A	B	C	D	System Capacity (Fraction) F(i)	Probability of Combination i P_i
1	X	X	X	0	0	$P_0(D)$
2	X	X	0	1	0	$P_0(C)\cdot P_1(D)$
3	X	0	1	1	0	$P_0(B)\cdot P_1(C)\cdot P_1(D)$
4	9	1	1	1	0	$P_9(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$
5	8	1	1	1	1/9	$P_8(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$
6	7	1	1	1	2/9	$P_7(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
11	2	1	1	1	7/9	$P_2(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$
12	1	1	1	1	8/9	$P_1(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$
13	0	1	1	1	1	$P_0(A)\cdot P_1(B)\cdot P_1(C)\cdot P_1(D)$

Annual Power Production. The power production in any year y is computed by the following basic approach desribed in the section "State Space Approach", Volume 1.

The annual power production in any year y, A(y), is obtained by:*

$$A(y) = W\cdot\beta\cdot DP(y)\cdot DC(y)\cdot\sum_{n=1}^{12} I(n)D(n).$$

---

* See "State Space Approach" in Volume 1, for explanation of terms.

The new factor DC(y) represents the degradation in the system power production resulting from the cell failures.* See Figure 3-2.

$$\sum_{n=1}^{12} I(n)\ D(n) \quad = \quad 2299.13 \text{ hours}$$

$$\beta \quad = \quad .964267$$

$$W \quad = \quad 48 \text{ kW.}$$

Assuming that the permanent degradation is linear between two consecutive years, the permanent degradation, DP(y), for any year y is the midpoint value between the beginning and the end of year y. The degradation due to cell failure DC(y) is computed in a similar manner.

For y = 1,**

$$DP(1) = \frac{1.0 + (1.0 - [1.0 - .910]/3)}{2} = .985$$

$$DC(1) = \frac{1.0 - .997}{2} = .9985.$$

A(1) = 48 x .96463 x .985 x .9985 x 2299.13 = 104,700 kW

The system power production for years 1-30 is given in Table 3-6.

---

* The values for the degradation due to cell failures are the results of the JPL analysis technique.

** Permanent degradation values are the result of a PV cell simulation.

TABLE 3-6. ANNUAL POWER PRODUCTION FOR BDM SYSTEM

Year	Production	Year	Production
1	105,474	16	90,570
2	101,954	17	90,084
3	98,503	18	89,600
4	96,609	19	89,068
5	96,162	20	88,537
6	95,715	21	88,055
7	95,270	22	87,574
8	94,776	23	87,046
9	94,283	24	86,519
10	93,792	25	86,041
11	93,252	26	85,563
12	92,714	27	85,039
13	92,176	28	84,516
14	91,640	29	84,041
15	91,104	30	83,567
		Total	2,739,262

System Maintenance Cost

Annual Corrective Maintenance Costs (ACCM).

$$\text{ACCM} = \sum_{i=1}^{m} (\lambda_i t_i n_i)(U_i C_i + FC_i)$$

where

m = Total number of system components

λ_i = Failure rate of component i

t_i = Total operating or clock hours

n_i = Number of identical units of component i

U_i = Mean repair time of component i

C_i = Repair cost/hr

FC_i = Fixed costs/repair.

The results of these computations are given in Table 3-7.

TABLE 3-7. RESULTS OF CORRECTIVE MAINTENANCE CALCULATIONS FOR ACTIVELY COOLED SYSTEM

	Expected Failures		Corrective Maintenace Costs, $	
	Per Yr	Per 30 Yrs	Average, Per Yr	Per 30 Yrs
Receiver Tube (9)	0.0876	2.628	279.96	8,398.82
Collector Structure (9)	0.0438	1.314	186.18	5,585.42
Tracking Syst., Elect. (9)	0.0438	1.314	18.13	543.996
Tracking Motor (9)	0.146	4.389	208.93	6,267.78
Inverter	1	30	1,411.6	42,348
Switching/Wiring	0.0175	0.53	2.34	70.24
Instr./Controls	8.760	26.28	1,937.40	58,122.0
Fluid Pump	0.175	5.23	117.32	3,519.6
Heat Reject/Heat	0.35	10.51	205.34	6,160.20
Fluid Piping, Global	0.0438	1.314	12.216	366.47
Fluid Piping, Local (9)	0.0175	0.526	7,308	219.24
Utility	1.4	42	0	0
Power Switchgear	.0063	.2	3.578	107.35
Weather	4	120	0	0
Total Corrective Maintenance Costs			$4,390.30	$131,709

<u>Annual Preventive Maintenance Costs (ACPM).</u>

$$ACPM = \sum_{i=1}^{m} (n_i f_i)(C_i U_i + FC_i)$$

where

f_i = Frequency of preventive maintenance action on component i per year.

For other symbols, refer to those defined under corrective maintenance.

The results of these calculations are listed in Table 3-8.

TABLE 3-8. RESULTS OF PREVENTIVE MAINTENANCE CALCULATIONS FOR ACTIVELY COOLED SYSTEMS

		Preventive Maintenance Costs, $	
		Average, Per Year	Per 30 Years
Collector Structure		$ 417.6	$ 12,528
Tracking Sensor and Tracking Motor		313.2	9,396
Inverter		29.2	876
General Maintenance	Monthly	1,948.8	58,464
	Annual	642.8	19,284
Total Preventive Maintenance Costs		$3,351.60	$100,548

Total Maintenance Cost (30 years) = $131,709 + 100,548 = $232,257

Note: All failure rate λ's, repair rate μ's, and cost information are computed from the data provided in Table 3-1.

SOLREL Analysis of BDM System

An actively cooled concentrator system not only produces electrical energy but thermal energy as well. At this time, the reliability of thermal system components has been considered only when their failure would affect electrical output. Consideration of thermal output is discussed at the end of this Section.

Table 3-9 gives a description of the subsystems and components modeled by SOLREL. The array field was modeled using the JPL Methodology which produced the output degradation curve shown in Figure 3-2. For this analysis, no module replacement was assumed. SOLREL has the capability, however, of initiating module replacement when a fixed amount of capacity has been lost. For example, the user can specify that when the output has been reduced by 10 percent due to cell failure, the system should be shut down and module replacement initiated.

The system is characterized by nine rows connected in parallel. Three outcomes were assumed to be possible due to component failures. The first is the steady degradation in output due to cell failures described above. The second is a 1/9 incremental reduction in output due to the failure of a component which causes the shutdown of one row. Components causing a partial shutdown are one of:

- The nine receiver tubes
- The nine tracking motors
- The nine tracking system sensors
- The nine local fluid piping systems.

A failure of any of the remaining components (see Table 3-9) causes a shutdown of the entire system. Note that a failure caused by an outage of the interconnected utility is treated as a failure having zero repair cost.

The system has a large number of electromechanical and mechanical components. Therefore, instead of assuming exponential time between failures, as was appropriate for electrical components, Weibull distributions were substituted. The components whose failure times were approximated using Weibull distributions are:

TABLE 3-9. INPUT PARAMETERS FOR ACTIVELY COOLED CONCENTRATOR SYSTEM

COMPONENT NAME	MTBF (MONTHS)	MAINT TIME (HRS) 50PCT	MAINT TIME (HRS) 90PCT	REPAIR COST ($) FIXED	REPAIR COST ($) VARIABLE	NUM MEN	PM TIME (HOURS) 50PCT	PM TIME (HOURS) 90PCT	PM COST ($) FIXED	PM COST ($) VARIABLE	PM INTERVAL (MONTHS)	NUM MEN
THE FIELD ARRAY	**********	36.0	108.0	0.00	20.00	1						
A RECEIVER TUBE	137.0	4.0	10.0	200.00	30.00	1						
A TRACKING MOTOR	82.2	6.0	12.0	20.00	20.00	1	9.0	18.0	0.00	15.00	12.0	1
A TRACKING SENSOR	274.0	1.0	4.0	10.00	20.00	1	9.0	18.0	0.00	15.00	12.0	1
AN INVERTER	12.0	24.0	48.0	300.00	40.00	1	6.0	12.0	100.00	0.00	41.0	1
THE SWITCHGEAR	1917.8	3.6	6.0	100.00	120.00	1						
THE INSTR. AND CONT.	13.7	24.0	48.0	1100.00	40.00	1						
SWITCHING/WIRING	684.9	5.6	12.0	0.00	20.00	1						
THE FLUID PUMP	68.5	8.0	16.0	300.00	40.00	1						
THE HEAT REJECT FAN	34.2	12.0	24.0	170.00	30.00	1						
GLOBAL FLUID PIPING	274.0	4.0	8.0	140.00	30.00	1						
THE UTILITY	8.6	2.0	3.6	0.00	0.00	1						
LOCAL FLUID PIPING	684.9	2.0	4.0	0.00	20.00	1						
COLLECTOR STRUCTURE	274.0	8.0	12.0	220.00	30.00	1	18.0	36.0	0.00	20.00	12.0	1
WEATHER	3.0	10.0	35.0	0.00	0.00	1						
GENERAL PREV MAINT							16.0	18.0	0.00	20.00	6.0	1
GENERAL PREV MAINT							8.0	10.0	0.00	20.00	1.0	1

```
FLAG1= 0 MEANS RESULTS FROM ALL PREVIOUS RUNS ARE BEING IGNORED
FLAG2= 0 MEANS RESULTS FROM THIS RUN WILL NOT BE SAVED ON PERMANENT FILES
FLAG3= 0 MEANS NO EVENT OR YEARLY SUMMARY MESSAGES WILL BE PRINTED
FLAG4= 1 MEANS TABLES FOR EACH INDIVIDUAL RUN WILL BE PRINTED
FLAG5= 1 MEANS PLOTS FOR INDIVIDUAL RUNS ONLY WILL BE PRODUCED

PERMANENT DEGRADATION -- 3 YEAR INTERVALS
  1.000   .910   .907   .904   .901   .898   .895   .892   .889   .886   .883

DEGRADATION DUE TO DIRT -- 3 YEAR INTERVALS
  1.000   .910   .820   .730   .640   .550   .460   .370   .280   .190

DEGRADATION DUE TO CELL FAILURE - 1 YEAR INTERVALS
  1.000   .997   .994   .992   .989   .985   .982   .978   .974   .970
   .966   .961   .957   .952   .948   .943   .939   .935   .931   .926
   .922   .918   .914   .909   .905   .901   .897   .892   .888   .884   .880
ARRAY CAPACITY IN KW................   48.
INVERTER DESIGN CAPACITY IN KW......   48.
OVERALL INFLATION RATE..............  .080
DISCOUNT RATE.......................  .130
ELECTRICITY PRICE ESCALATION........  .105
LENGTH OF RUN IN MONTHS.............  360.
```

- The tracking system motors
- The fluid pump
- The heat rejection fan
- The local fluid piping
- The global fluid piping.

In addition, preventive maintenance strategies were designed into the model for the tracking motors, the tracking sensors, the inverter, and the collector structure. General preventive maintenance and cleaning were also included.

The reflector surface was assumed to degrade permanently at a rate of 3 percent per year for the first 3 years and at a rate of 0.1 percent per year thereafter. The accumulation of dirt was assumed to cause a reduction in output of 3 percent per year. The design capacity of the inverter and array field is 48 kW. The monthly power output duration curves resulting from the SOLCEL design simulation of the system for Albuquerque are given in Table 3-10.

The inflation rate was set at 8 percent per year; the annual discount rate was set at 13 percent in the optimistic case and 20 percent in the pessimistic case; and the electricity price escalation rate was set at 10.5 percent (or 2.5 percent above inflation).

The values for points along each monthly output duration curve appear in Table 3-10. Using these estimates and engineering judgment for initial data input, the SOLREL model produces the outputs shown in Tables 3-11 -3-14. A source listing of the computer program is available through Sandia.

The simulation output is also shown in Figures 3-11 through 3-13. These curves present the results in the form of annual energy output and maintenance costs as well as the levelized cost of maintenance per kWh for the two sets of financial assumptions.

Thermal Output of BDM Systems. A special version of SOLREL which models both the thermal and electrical output of the actively cooled concentrated system was written. No runs have been made, however, since an input representing the monthly thermal system output was not available. Such a monthly thermal output would be void of any reliability/availability

TABLE 3-10. MONTHLY OUTPUT DURATION CURVES FOR ACTIVELY COOLED CONCENTRATOR SYSTEM

```
MONTHLY OUTPUT DURATION CURVES IN INTERVALS OF 8.33 HOURS PER MONTH

MONTH  1 1.000  .982  .963  .945  .930  .914  .898  .871  .842  .816  .790  .769  .748  .724  .696  .647
          .607  .573  .533  .486  .438  .391  .349  .306  .239  .191  .150  .096  .050  .033  .015 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  2 1.000  .991  .981  .972  .962  .953  .940  .922  .905  .886  .864  .842  .819  .797  .760  .721
          .687  .639  .600  .560  .513  .447  .393  .332  .270  .209  .177  .136  .095  .068  .028 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  3 1.000  .992  .985  .977  .969  .962  .954  .946  .931  .916  .900  .885  .868  .852  .835  .817
          .799  .734  .716  .697  .675  .648  .612  .563  .516  .475  .423  .374  .326  .288  .249  .200
          .154  .125  .089  .048  .031  .013 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  4 1.000  .993  .986  .980  .973  .966  .959  .952  .943  .926  .908  .891  .875  .859  .843  .826
          .808  .791  .769  .747  .715  .681  .663  .644  .594  .561  .541  .500  .453  .424  .380  .331
          .287  .241  .192  .148  .112  .080  .050  .029  .009 0.000 0.000 0.000 0.000 0.000 0.000

MONTH  5 1.000  .994  .987  .981  .975  .969  .962  .956  .950  .941  .930  .919  .908  .898  .879  .858
          .839  .824  .809  .793  .779  .764  .750  .735  .713  .690  .656  .626  .609  .592  .572  .545
          .518  .493  .467  .438  .406  .371  .315  .287  .255  .206  .175  .138  .086 0.000 0.000

MONTH  6 1.000  .996  .989  .982  .975  .968  .961  .954  .946  .938  .929  .920  .912  .903  .894  .876
          .858  .834  .782  .765  .748  .731  .715  .698  .680  .659  .637  .611  .584  .563  .544  .524
          .492  .464  .444  .423  .383  .345  .311  .283  .237  .192  .165  .134  .093  .025 0.000

MONTH  7 1.000  .991  .983  .974  .966  .957  .949  .938  .927  .915  .904  .891  .870  .849  .826  .803
          .783  .768  .752  .736  .720  .703  .687  .651  .620  .596  .571  .545  .519  .491  .460  .422
          .355  .320  .289  .256  .205  .159  .125  .096  .075  .053  .043  .033  .023  .014  .004

MONTH  8 1.000  .992  .985  .977  .969  .962  .954  .946  .931  .917  .902  .887  .873  .858  .844  .828
          .813  .797  .780  .761  .741  .688  .666  .646  .614  .557  .519  .493  .458  .411  .380  .343
          .299  .257  .235  .213  .171  .130  .098  .078  .059  .038  .017 0.000 0.000 0.000 0.000

MONTH  9 1.000  .993  .986  .978  .971  .964  .957  .950  .938  .924  .909  .895  .880  .864  .848  .833
          .817  .802  .781  .735  .715  .696  .666  .626  .604  .582  .525  .467  .444  .420  .350  .301
          .270  .223  .146  .105  .080  .056  .008 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 10 1.000  .993  .986  .979  .973  .966  .959  .952  .942  .927  .911  .895  .879  .863  .847  .829
          .812  .794  .730  .708  .685  .637  .593  .561  .536  .448  .398  .354  .321  .235  .191  .160
          .130  .099  .065  .007 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 11 1.000  .992  .984  .977  .969  .961  .953  .943  .927  .911  .895  .872  .848  .826  .805  .782
          .749  .716  .682  .644  .600  .549  .495  .412  .363  .295  .246  .198  .163  .070  .022 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

MONTH 12 1.000  .980  .959  .940  .922  .905  .886  .866  .845  .805  .771  .742  .713  .685  .648  .595
          .550  .513  .478  .393  .333  .298  .269  .205  .123  .063  .039  .023  .006 0.000 0.000 0.000
         0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
```

TABLE 3-11. ACTIVELY COOLED CONCENTRATOR SYSTEM AVAILABILITY

ANNUAL SYSTEM AVAILABILITY DURING DAYLIGHT
AS A PERCENT OF SYSTEM CAPACITY

SYSTEM CAPACITY = 48.0 KW NUMBER OF DAYLIGHT HOURS PER YEAR = 3757.5

YEAR	100-90%	90-80%	80-70%	70-60%	60-50%	50-40%	40-30%	30-20%	20-10%	10-0%	TOTAL
THEORETICAL	25.60	13.88	10.48	8.29	7.40	6.08	5.79	5.90	6.38	10.19	100.00
1	3.45	9.48	14.85	15.30	12.01	9.17	7.74	6.98	8.06	12.96	100.00
2	1.88	8.88	12.97	18.35	13.25	10.90	8.60	7.57	8.03	9.58	100.00
3	.34	6.57	12.51	16.81	15.49	11.32	8.78	7.64	7.93	12.61	100.00
4	0.00	4.85	14.01	17.32	16.07	11.41	8.99	7.83	8.34	11.19	100.00
5	0.00	4.71	13.59	16.19	16.27	12.24	9.36	7.72	8.33	11.59	100.00
6	0.00	3.61	12.87	17.69	15.86	12.32	9.53	8.30	9.13	10.69	100.00
7	0.00	4.26	10.88	18.77	17.22	11.24	9.20	8.06	8.84	11.54	100.00
8	0.00	3.94	12.76	15.36	17.08	12.82	9.86	7.83	8.33	12.02	100.00
9	0.00	3.32	12.23	19.16	17.11	11.81	9.49	8.23	8.52	10.12	100.00
10	0.00	2.07	9.77	19.72	18.28	12.70	10.10	8.24	8.66	10.47	100.00
11	0.00	2.44	12.03	18.87	17.76	11.75	9.47	8.10	8.61	10.95	100.00
12	0.00	2.45	8.56	18.27	19.24	12.82	10.15	8.29	8.85	11.38	100.00
13	0.00	2.12	11.47	15.74	18.98	13.00	10.04	8.21	9.86	11.60	100.00
14	0.00	1.26	7.99	20.20	19.46	12.60	10.12	8.49	8.96	10.92	100.00
15	0.00	.83	10.35	15.52	19.52	12.43	9.83	8.40	8.77	14.33	100.00
16	0.00	1.26	10.19	16.72	19.80	13.71	10.84	9.03	9.21	9.24	100.00
17	0.00	.98	8.71	16.65	19.65	14.77	10.93	8.78	8.89	10.63	100.00
18	0.00	.37	9.04	17.11	19.31	12.83	10.24	8.46	8.55	14.07	100.00
19	0.00	.60	7.67	18.94	19.77	13.17	10.72	8.58	8.83	11.74	100.00
20	0.00	.44	7.50	18.30	19.42	12.48	9.87	8.15	8.78	15.06	100.00
21	0.00	.32	8.74	16.73	19.01	14.33	11.31	8.77	9.13	11.65	100.00
22	0.00	.10	7.94	17.89	20.67	13.51	10.79	8.79	8.97	11.34	100.00
23	0.00	.06	7.22	14.53	20.16	13.46	10.25	8.52	8.86	16.93	100.00
24	0.00	0.00	5.46	15.92	20.18	16.99	11.98	8.95	9.50	11.03	100.00
25	0.00	0.00	6.36	16.55	19.49	15.83	11.65	9.10	9.56	11.46	100.00
26	0.00	0.00	6.46	15.94	19.71	15.32	11.87	9.22	9.62	11.85	100.00
27	0.00	0.00	5.06	14.73	21.07	16.41	11.82	9.17	9.33	12.41	100.00
28	0.00	0.00	3.30	14.77	20.71	17.68	12.02	9.48	9.42	12.61	100.00
29	0.00	0.00	4.63	14.09	23.47	15.90	11.77	9.64	9.74	10.75	100.00
30	0.00	0.00	3.82	14.80	21.98	15.65	11.40	8.89	9.18	14.28	100.00
AVERAGE	.19	2.16	9.30	16.90	18.60	13.35	10.29	8.45	8.86	11.90	100.00

TABLE 3-12. ACTIVELY COOLED CONCENTRATOR SYSTEM, COMPONENT FAILURE TABLE

COMPONENT FAILURE TABLE

NUMBER OF FAILURES PER COMPONENT BY YEAR

COMPONENT YEAR =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
RECEIVER TUBE	2	0	1	0	0	0	0	1	1	0	1	1	0	1	1	2	1	3	0	1	0	1	3	2	2	1	1	1	1	1	29
TRACKING MOTOR	0	0	0	1	0	1	4	1	1	0	1	3	1	2	1	2	2	1	0	0	2	1	5	1	1	1	1	2	2	1	38
TRACKING SENSOR	1	1	0	1	0	1	0	1	0	1	0	2	1	1	1	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	15
N INVERTER	0	1	2	0	1	0	1	1	2	1	0	1	1	0	0	1	2	0	1	2	1	0	0	1	1	0	1	0	1	0	22
HE SWITCHGEAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
HE INSTR. AND CONT.	2	0	1	0	0	2	2	1	0	1	0	2	2	0	3	0	2	2	1	1	2	4	0	0	1	1	4	1	0	0	35
WITCHING/WIRING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
HE FLUID PUMP	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	5
HE HEAT REJECT FAN	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	1	0	0	0	1	0	1	1	0	0	0	1	0	9
LOBAL FLUID PIPING	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
HE UTILITY	3	1	0	1	1	1	0	0	0	4	5	0	2	2	1	1	0	0	0	0	0	2	2	1	3	1	1	3	3	2	40
OCAL FLUID PIPING	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3
OLLECTOR STRUCTURE	0	0	1	0	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0	0	3	0	1	0	0	1	1	0	12
EATHER	1	5	6	4	2	6	1	3	2	1	5	5	4	6	7	2	4	3	2	4	5	4	3	5	3	4	7	2	2	3	111
TOTALS	9	8	12	7	5	13	9	9	7	8	12	16	13	13	15	9	11	10	4	10	10	15	17	12	15	9	16	11	11	7	323

TABLE 3-13. ACTIVELY COOLED CONCENTRATOR SYSTEM ANNUAL MAINTENANCE COST AND ENERGY PRODUCED, DISCOUNT RATE OF 13 PERCENT (OPTIMISTIC CASE)

ANNUAL MAINTENANCE COST AND OUTPUT

	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	7292.97	107362.	6.79	7086.70	106143.	6.68
2	4195.39	102340.	4.10	3949.78	98946.	3.99
3	9526.57	96818.	9.84	8467.73	91543.	9.25
4	3755.19	94770.	3.96	3228.35	87611.	3.68
5	5015.15	97507.	5.14	4127.26	88132.	4.68
6	7600.97	96571.	7.87	5950.46	85369.	6.97
7	11413.28	92945.	12.28	8547.99	80333.	10.64
8	7202.18	96302.	7.48	5140.79	81405.	6.32
9	8179.32	94543.	8.65	5571.46	78147.	7.13
10	7621.13	93944.	8.11	4953.60	75934.	6.52
11	3829.04	92510.	4.14	2395.20	73121.	3.28
12	11853.33	87497.	13.55	7060.42	67633.	10.44
13	9625.60	86267.	11.16	5483.74	65192.	8.41
14	5658.36	89335.	6.33	3091.23	66018.	4.68
15	10738.23	84646.	12.69	5598.52	61171.	9.15
16	6188.68	90003.	6.88	3086.01	63618.	4.85
17	12701.20	86496.	14.68	5973.89	59785.	9.99
18	10183.98	88383.	11.52	4665.03	59712.	7.81
19	6184.40	91876.	6.73	2684.98	60711.	4.42
20	8019.68	88970.	9.01	3317.76	57508.	5.77
21	7792.48	83886.	9.29	3088.25	53002.	5.83
22	14653.95	85095.	17.22	5587.00	52575.	10.63
23	6867.09	89477.	7.67	2488.11	54073.	4.60
24	4926.43	87465.	5.63	1709.92	51688.	3.31
25	8424.34	82462.	10.22	2783.32	47671.	5.84
26	7485.10	83906.	8.92	2364.83	47408.	4.99
27	16036.71	80070.	20.03	4843.56	44256.	10.94
28	6798.61	84872.	8.01	1961.12	45864.	4.28
29	6002.69	85026.	7.06	1664.27	44932.	3.70
30	3791.32	83046.	4.57	1005.54	42930.	2.34
TOTALS	239563.38	2704391.		127876.83	1992429.	6.42 (LEVELIZED)

TABLE 3-14. ACTIVELY COOLED CONCENTRATOR SYSTEM ANNUAL MAINTENANCE COST AND ENERGY PRODUCED, DISCOUNT RATE OF 20 PERCENT (PESSIMISTIC CASE)

	ANNUAL MAINTENANCE COST AND OUTPUT					
	CURRENT VALUE			PRESENT VALUE		
YEAR	COST ($)	KWH	CENTS/KWH	COST ($)	KWH	CENTS/KWH
1	7292.97	107362.	6.79	6822.77	102953.	6.63
2	4195.39	102340.	4.10	3646.51	90391.	4.03
3	9526.57	96818.	9.84	7243.46	78767.	9.20
4	3755.19	94770.	3.96	2641.86	70954.	3.72
5	5015.15	97507.	5.14	3187.09	67185.	4.74
6	7600.97	96571.	7.87	4299.83	61308.	7.01
7	11413.28	92945.	12.28	5824.96	54302.	10.73
8	7202.18	96302.	7.48	3285.95	51837.	6.34
9	8179.32	94543.	8.65	3346.69	46856.	7.14
10	7621.13	93944.	8.11	2796.46	42872.	6.52
11	3829.04	92510.	4.14	1284.95	38877.	3.31
12	11853.33	87497.	13.55	3548.67	33867.	10.48
13	9625.60	86267.	11.16	2598.06	30723.	8.46
14	5658.36	89335.	6.33	1385.30	29298.	4.73
15	10738.23	84646.	12.69	2357.72	25567.	9.22
16	6188.68	90003.	6.88	1225.08	25053.	4.89
17	12701.20	86496.	14.68	2194.42	22168.	9.90
18	10183.98	88383.	11.52	1654.44	20826.	7.94
19	6184.40	91876.	6.73	886.91	19950.	4.45
20	8019.68	88970.	9.01	1027.73	17810.	5.77
21	7792.48	83886.	9.29	903.62	15441.	5.85
22	14653.95	85095.	17.22	1552.72	14423.	10.77
23	6867.09	89477.	7.67	646.32	13978.	4.62
24	4926.43	87465.	5.63	419.53	12582.	3.33
25	8424.34	82462.	10.22	639.58	10938.	5.85
26	7485.10	83906.	8.92	512.17	10229.	5.01
27	16036.71	80070.	20.03	987.87	9000.	10.98
28	6798.61	84872.	8.01	376.36	8779.	4.29
29	6002.69	85026.	7.06	302.99	8100.	3.74
30	3791.32	83046.	4.57	172.60	7294.	2.37
TOTALS	239563.38	2704391.		67772.64	1042329.	6.50 (LEVELIZED)

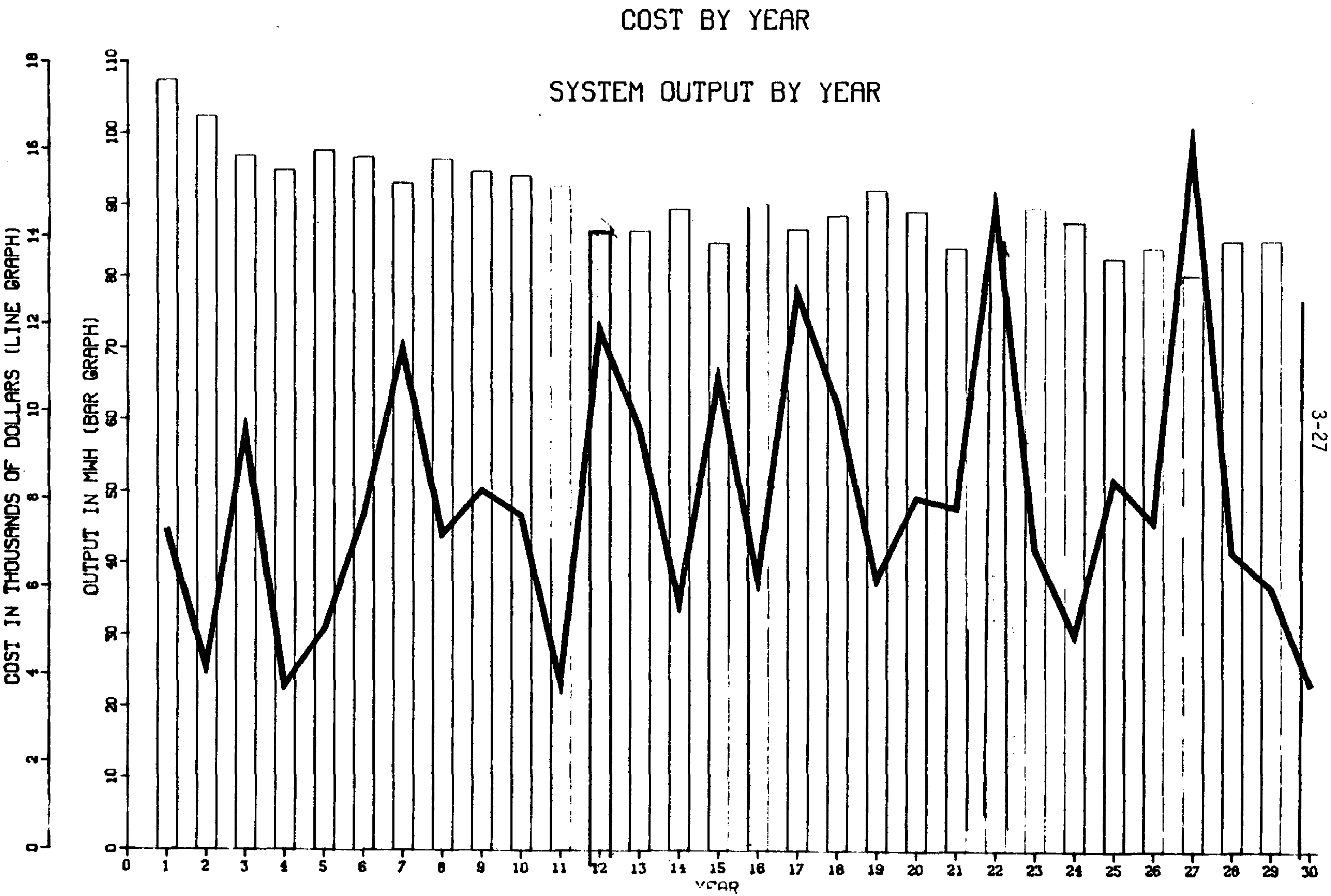


FIGURE 3-11. ACTIVELY COOLED CONCENTRATOR SYSTEM RESULTS, CURRENT VALUE, ANNUAL MAINTENANCE COSTS AND ENERGY PRODUCED

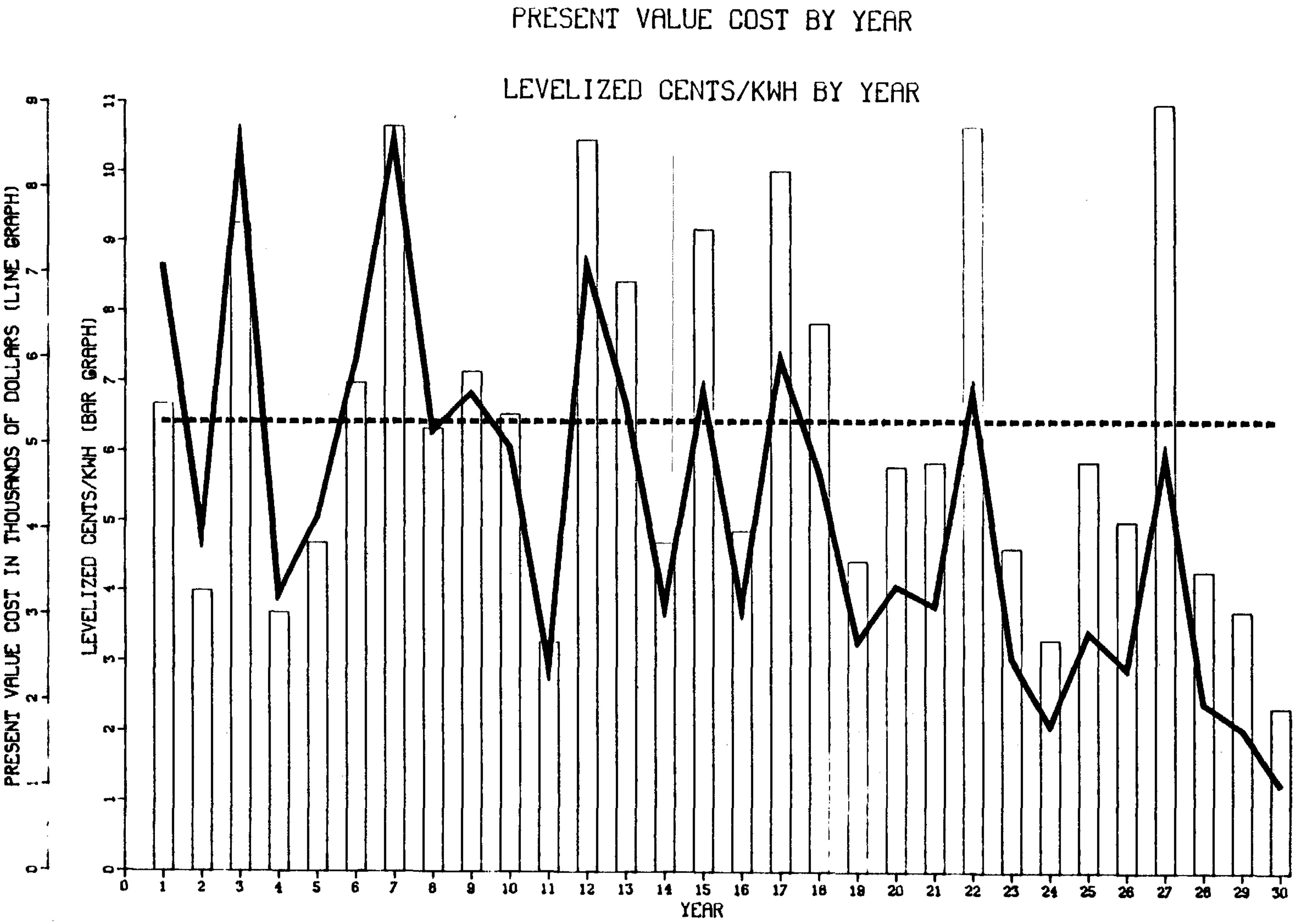


FIGURE 3-12. ACTIVELY COOLED CONCENTRATOR SYSTEM SIMULATION RESULTS - MAINTENANCE COSTS
(OPTIMISTIC CASE, 13 PERCENT DISCOUNT RATE)

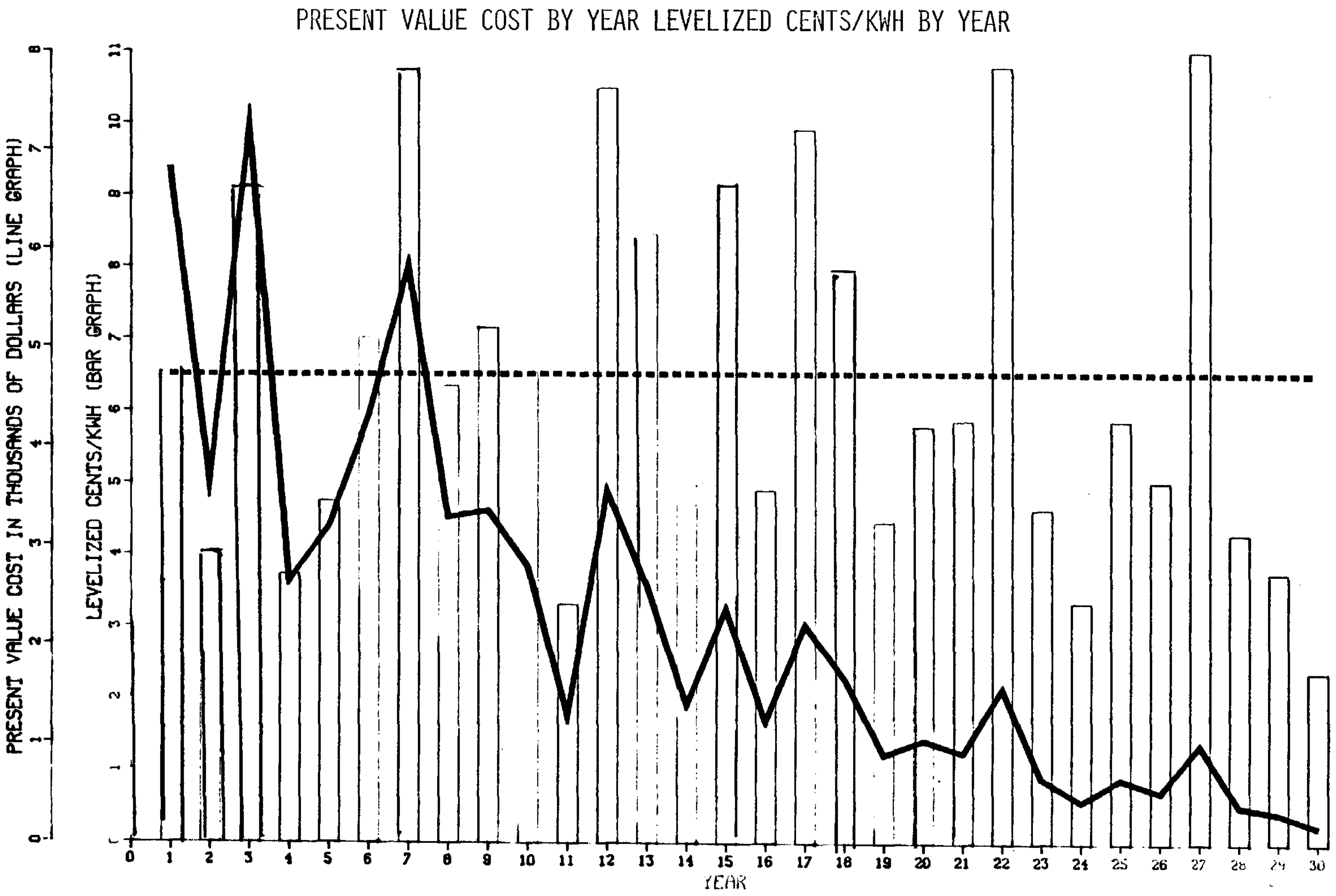


FIGURE 3-13. ACTIVELY COOLED CONCENTRATOR SYSTEM SIMULATION RESULTS - MAINTENANCE COSTS (PESSIMISTIC CASE, 20 PERCENT DISCOUNT RATE)

considerations. SOLREL would degrade this output in a manner similar to the procedure for degrading electrical output described earlier. In other words, the ideal thermal output would be degraded due to dirt on the array and permanent array deterioration. As with the electrical output, the thermal output would also be reduced or terminated upon failure of any one of the following:

- A receiver tube
- A tracking motor
- A tracking sensor
- The fluid pump
- The heat rejection fan
- The fluid piping
- The collector structure
- System shut down due to weather.

Unlike the electrical output, thermal output would continue even after failure of the inverter, switchgear, and instruments. The results of this portion of the SOLREL analysis would be a table of the monthly and annual thermal output of the system over its lifetime.

Comparison Between SOLREL and the State Space Models

Comparing the results of the two modeling approaches serves the purpose of (1) assuring that a consistent set of assumptions and parameters were used in both and (2) testing the bottom line effect of the modeling approach on the maintenance cost estimate. The system lifetime costs and electricity production results for each of the three generic systems for each modeling approach appear in Table 3-15. The slight differences which do occur can be explained as resulting from (1) the random treatment of failure/repair times in SOLREL, (2) differing methods of calculating preventive maintenance, and (3) SOLREL's ability to better incorporate complex component/system relationships such as with the tracking drives of the passively cooled concentrator system.

TABLE 3-15. COMPARISON OF PV SYSTEM MAINTENANCE COSTS AND ELECTRICITY PRODUCTION FOR SOLREL VERSUS STATE SPACE MODEL

		STATE SPACE MODEL	SOLREL	% DIFF.
Flat Panel (1/2 system)	Maint. Cost	$ 99,368	$ 98,338	-1.0
	Output (kWh)	3,065,939	3,020,886	-1.5
Passively Cooled Concentrator	Maint. Cost	$ 436,280	$ 454,423	+4.0
	Output (kWh)	16,590,219	16,154,046	-2.7
Actively Cooled Concentrator	Maint. Cost	$ 232,257	$ 239,563	+3.0
	Output (kWh)	2,739,262	2,704,391	-1.3

Random Effects. One of the primary differences between the modeling approaches is that SOLREL uses distributions for the time between failures and for repair times instead of using strictly the mean of the distribution as does the system state (Markov) model. This allows SOLREL to produce a distribution around its cost and output estimates by repeated runs of the simulation. Since output is defined primarily by fixed (no variance) power output duration and degradation curves, it is not affected significantly by the fact that failures and the resulting repairs occur randomly. Both corrective and preventive maintenance costs, however, are calculated directly as a result of random repair times which occur at a frequency directly related to the occurence of random failures. Although running SOLREL over a system life of 30 years tends to dampen random fluctuations, a range of approximately ± 5 percent can be expected in the cost estimates.

Table 3-16 shows four cost components which differ strictly due to the random nature of the SOLREL model for the passively cooled concentrator system. These results are presented to provide a sense of the magnitude of the random effects which occur within SOLREL.

TABLE 3-16. COMPARISON OF COST COMPONENTS FROM PASSIVELY COOLED PV CONCENTRATOR SYSTEM ANALYSES

	State Space	SOLREL
Tracking Drive Preventive Maintenance	$ 37,620	$ 44,245
General Preventive Maintenance	187,207	193,130
Inverter Corrective Maintenance	63,348	79,719
Control & Display Corrective Maintenance	58,120	54,071
	$325,295	$343,165

These cost components, which account for approximately 80 percent of total system maintenance cost, show a random difference of $17,870 ($343,165 minus 325,295). Note that the difference in total maintenance cost is only $11,143 ($426,423 - 415,280). Therefore, those maintenance costs not shown must be higher for the Markov model.

Calculating Preventive Maintenance. The difference in how each model calculates preventive maintenance can best be discussed through use of an example. General preventive maintenance is performed once a year for the passively cooled concentrator system. SOLREL, however, schedules the preventive maintenance for the first of every year except for the initial year. Therefore only 29 preventive maintenance events occur during the 30 year system life. The Markov model assumes 30 events in 30 years. The result would be a 1 or 2 percent lower maintenance cost in SOLREL.

<u>Complex Component Relationships</u>. For the passively cooled concentrator system, the Markov model assumes an output reduction of 1/32 for a failure of the tracking drive. SOLREL models each tracking drive individually, since approximately 20 percent of all tracking drive failures cause a 1/16 reduction in output instead of a 1/32 reduction. In other cases, the failure of two tracking drives within one module unit may cause only a 1/32 reduction in output. The effect of modeling each tracking drive individually would be a slightly lower output for SOLREL for the passively cooled concentrator system only.

<u>Statistical Tests</u>. Statistical tests can be used to determine whether or not the annual outputs of the Markov model are consistently higher or lower than the SOLREL model. For example, suppose that over 30 years' worth of output, the SOLREL model produced higher output in 25 of the 30 years. This result would seem unlikely to be caused by chance, but a test using the binomial distribution could estimate the probability of this relationship occurring at random. It may be that the SOLREL model is higher in only 15 of the 30 years but that those 15 are the first 15 years of operation. Again this seems unlikely to have occurred at random, but a "runs test" can be used to assign a probability to the random occurrence of this event.

Figure 3-14 shows a runs test comparing the outputs from the two models for the actively cooled concentrator. First, note that the SOLREL model produced higher output in 14 of the 30 years. Since it is intuitively obvious that this relationship could occur at random, no binomial test was run. The runs test counts the number of "runs" of +'s or -'s under the "comparison" column. In this case, 14 runs occurred where an average 15.93 would be expected. Using the standardized normal distribution. the

Year	State Model	SOLREL	Comparison	# Runs
1	104701	107362	-	1
2	101207	102340	+	2
3	97781	96818	-	3
4	95901	94770	-	
5	95457	97507	+	4
6	95014	96571	+	
7	94571	92945	-	5
8	94081	96302	+	6
9	93592	94543	+	
10	93104	93944	-	7
11	92568	92510	-	
12	92034	87497	-	6
13	91501	86267	-	
14	90968	89335	-	
15	90437	84646	-	
16	89906	90003	+	8
17	89424	86496	-	9
18	88943	88383	-	
19	88415	91876	+	10
20	87888	88970	+	
21	87410	83886	-	11
22	86932	85095	-	
23	86408	89477	+	12
24	85885	87465	+	
25	85410	82462	-	13
26	84936	83906	-	
27	84416	80070	-	
28	83896	84872	+	14
29	83425	85026	+	
30	82955	83046	+	
		Summary	16 (-) 14 (+)	

Expected No. of Runs $= \frac{2n_1n_2}{n_1 + n_2} + 1 = \frac{(2)(14)(16)}{14 + 16} + 1 = 15.93$

Actual No. of Runs (R) = 14

$R^2 = \frac{(448)(448-30)}{(30)^2\ (30-1)} = 7.175$ $\qquad R = 2.68$

$z = \frac{14 - 15.93}{2.68} = -.72$ (standardized normal distribution)

Probability of getting more than 14 runs = .74

Probability of getting less than 14 runs = .26

CONCLUSION: no reason to believe outputs from 2 models are different

FIGURE 3-14. ACTIVELY COOLED CONCENTRATOR - OUTPUT (kWh) "RUNS TEST" probability of randomly observing 14 or fewer runs in this case is approximately .26. Since .26 is not unusually small, there is no evidence that the output from the two models is different.

Figure 3-15 shows both the binomial and runs tests for the passively cooled concentrator. The runs test proves inconclusive but the binomial test shows there is less than a 1 percent chance of the SOLREL model being higher in 6 or fewer years out of 30. Therefore, the conclusion is that the Markov model yields consistently higher outputs probably due to a different treatment of the tracking drive failure. The magnitude, of these cost differences (see Table 3-15) is on the order of 2 to 3 percent. For the flat panel system, output was slightly lower in SOLREL for every year of the run, indicating that the difference is not due to random error. The magnitude of the difference is on the order of 1 percent.

$6(-) = n_1 \qquad 24(+) = n_2$

$$\text{Expected No. of Runs} = \frac{(2)(6)(24)}{30} + 1 = 10.6$$

Actual No. of Runs = 12

$$R^2 = \frac{(288)(288-30)}{(30)2\ (29)} = 2.85$$

$$R = 1.69$$

$$z = \frac{12 - 10.6}{1.69} = .828$$

Probability of getting more than 12 runs = .204

Probability of less than 12 runs = .796

Probability of getting 6 or less "negative" in 30 tries given 50-50 chance of "negative" = .0075 < 1%

CONCLUSION: State model yields higher output than SOLREL probably due to different treatment of tracking drive failures.

FIGURE 3-15. PASSIVELY COOLED CONCENTRATOR - OUTPUT (kWh) "RUNS TEST"

APPENDIXES

APPENDIX A

NETWORK REDUCTION FORMULAS - STATE SPACE

APPENDIX A

NETWORK REDUCTION FORMULAS - STATE SPACE

Network reduction is a technique to reduce a system of series and parallel components to a single component with equivalent success and failure probabiilties. Network reduction requries the time between failures and the repair times to have constant rates; that is, they must follow negative exponential distributions. In addition, the components must be mutually independent. Each component is assumed to have two possible states: success and failure.

This appendix develops network reduction formulas for the following cases:

- Series system with no dormant failures
- Series system with dormant failures
- Standby parallel system
- Active parallel system.

For each case, formulas are derived for the system failure rate (λ), repair rate (μ), success probabiity (P_S), and failure probability (P_F) such that the reduced system will have the same performance (i.e., steady-state probabilities) as the original series or parallel system. A system involving both series and parallel components can be reduced in steps using these formulas.

Notation

i = Subscript to identify components, $i = 1, 2, \ldots., n$
λ_i = Failure rate of component i
μ_i = Repair rate of component i
λ = Failure rate of the system
μ = Repair rate of the system
P_S = Probabiity of system success
P_F = Probability of system failure

Series System with No Dormant Failures

Figure A-1 shows the structure of the series system. Failure of any single component results in system failure. "No dormant failures" means that no additional component failures can occur while the system is in the failed state.

Figure A-2 shows the Markov model for this system. Applying the steady-state concept of "rate in = rate out" to each state, we have the following:

$$\dot{P}_0(t) = \sum_{i=1}^{n} \mu_i P_i(t) - \left(\sum_{i=1}^{n} \lambda_i\right) \cdot P_0(t) = 0$$

$$\dot{P}_i(t) = \lambda_i P_0(t) - \mu_i P_i(t) = 0 \quad \text{for } i = 1, 2, \ldots, n \quad .$$

Using the fact that $\sum_{i=0}^{n} P_i(t) = 1$ and solving the equations simultaneously, we obtain:

$$P_S = P_0 = \frac{1}{1 + \sum_{i=1}^{n} \frac{\lambda_i}{\mu_i}} \quad .$$

Of course, $P_F = 1 - P_S$. The system failure rate is the total rate of transitions out of state 0:

$$\lambda = \sum_{i=1}^{n} \lambda_i$$

The mean system repair rate is found by equating system availability with the success state probability P_0:

$$\frac{\mu}{\mu + \lambda} = P_S$$

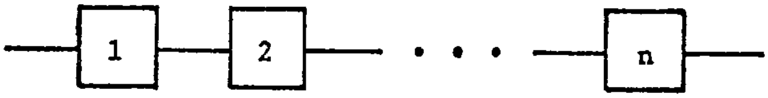


FIGURE A-1. SERIES SYSTEM

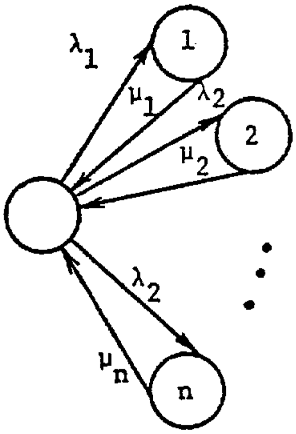


FIGURE A-2. MARKOV MODEL FOR SERIES SYSTEM WITH NO DORMANT FAILURES

State 0 Represents "System Success" and State i
(i = 1, 2, ..., n) Represents Failure of Component i.

Solving for μ,

$$\mu = \lambda \frac{P_S}{(1 - P_S)} = \lambda \frac{P_S}{P_F} .$$

Hence, for a serial subsystem with no dormant failures, we compute P_S, P_F, λ, and μ using the above formulas in the order of presentation.

Series System With Dormant Failures

The structure of this system is shown in Figure A-1. In this case, we assume each component has a fixed failure rate regardless of whether the system is failed or operating. This assumption implies the components are mutually independent. Hence, the probability of system success is the product of the individual component availabilities:

$$P_S = \prod_{i=1}^{n} \frac{\mu_i}{\mu_i + \lambda_i} .$$

Of course, $P_F = 1 - P_S$. The system failure rate is the sum of all transition rates out of the system operational state:

$$\lambda = \sum_{i=1}^{n} \lambda_i .$$

As shown in the preceding case, the system repair rate is:

$$\mu = \lambda \frac{P_S}{P_F} .$$

Standby Parallel System

Figure A-3 presents the structure of a standby parallel system. In this case, only component 1 is operating initially. When component 1 fails, component 2 is automatically (and instantaneously) switched on. Component 2 is not subject to failure prior to being switched on. This substitution process continues until all of the standby spares have been used. System failure corresponds to failure of the n^{th} component. Repair of all components is initiated upon system failure.

Figure A-4 depicts the Markov model for this case. The mean system repair time is assummed to be the sum of the individual component repair time:

$$\frac{1}{\mu} = \sum_{i=1}^{n} \frac{1}{\mu_i} .$$

The system repair rate is therefore:

$$\mu = \frac{1}{\sum_{i=1}^{n} \frac{1}{\mu_i}} .$$

Applying the steady-state concept of "rate in = rate out" to each state, we have:

$$\begin{aligned} \mu P_n &= \lambda_1 P_0 \\ \lambda_i P_{i-1} &= \lambda_{i+1} P_i \quad , i = 1, 2, \ldots, n-1 \\ \lambda_n P_{n-1} &= \mu P_n . \end{aligned}$$

Using the fact that $\sum_{i=0}^{n} P_i = 1$ and solving the equations simultaneously, we obtain:

$$P_0 = \frac{1}{1 + \sum_{i=1}^{n-1} \frac{\lambda_1}{\lambda_{i+1}} + \frac{\lambda_1}{\mu}}$$

$$P_n = \frac{\lambda_1}{\mu + \mu \sum_{i=1}^{n-1} \frac{\lambda_1}{\lambda_{i+1}} + \lambda_1} .$$

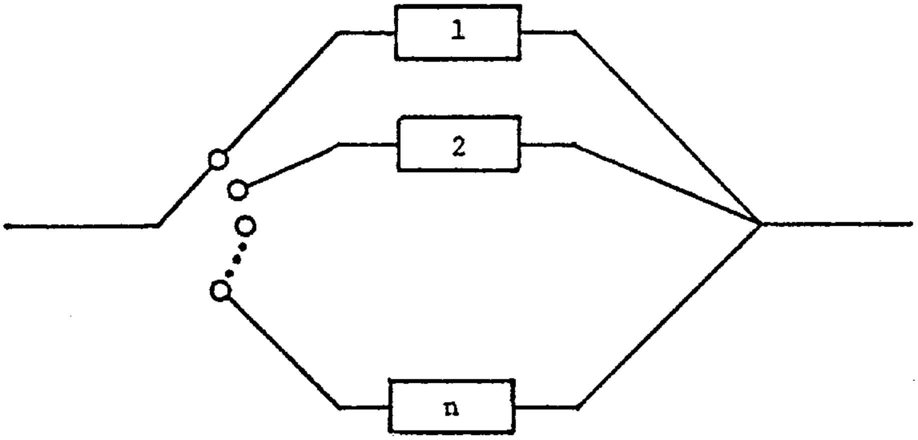


FIGURE A-3. STANDBY PARALLEL SYSTEM

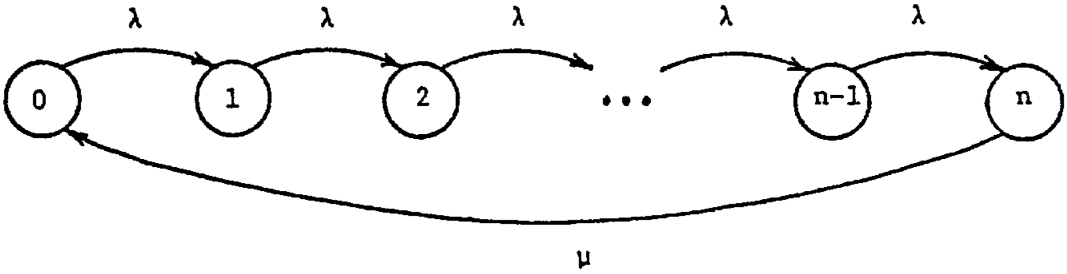


FIGURE A-4. MARKOV MODEL DIAGRAM FOR THE STANDBY PARALLEL SYSTEM

Since system failure corresponds to failure of the nth component, $P_F = P_n$. The system success probability is $P_S = 1 - P_F$. The system failure rate is found by equating system availability to the system success probability:

$$\frac{\mu}{\mu + \lambda} = P_S$$

$$\lambda = \mu \cdot \frac{P_F}{P_S} .$$

If all of the components are identical, the standby parallel system equations can be simplified to the following forms:

$$\mu = \frac{\mu_1}{n}$$

$$P_F = \frac{\lambda_1}{n\mu + \lambda_1}$$

$$P_S = 1 - P_F$$

$$\lambda = \mu \cdot \frac{P_F}{P_S} .$$

Active Parallel System

Figure A-5 presents the structure of an active parallel system. All components are subject to failure at all times. System failure corresponds to failure of all n components. Repair is initiated upon system failure. All components are assumed to be identical and to have failure rate λ_1 and repair rate μ_1.

Figure A-6 presents the Markov model diagram for this case. The system repair rate is assumed to be 1/n of the repair rate of a single component. Applying the steady-state concept of "rate in = rate out" to each state, we have:

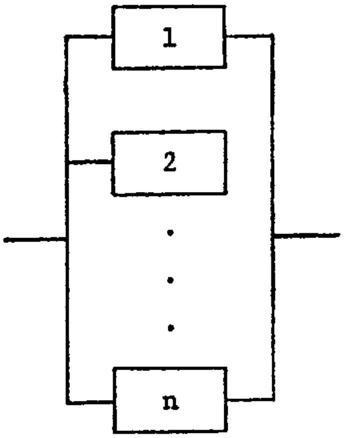


FIGURE A-5. ACTIVE PARALLEL SYSTEM

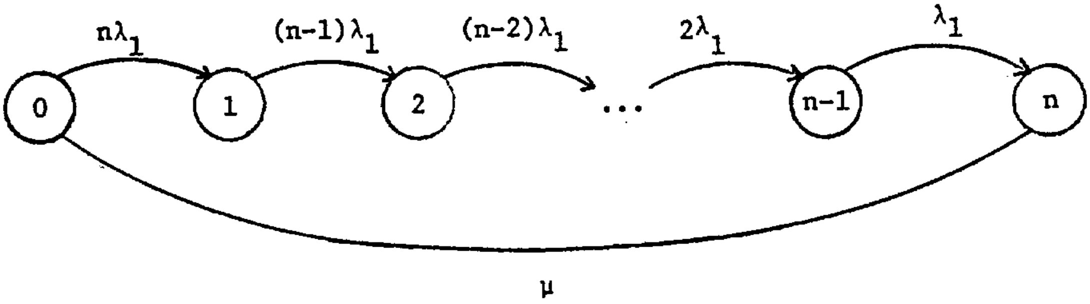


FIGURE A-6. MARKOV MODEL FOR AN ACTIVE PARALLEL SYSTEM

$$\mu P_n = n\lambda_1 P_0$$

$$(n - i + 1)\lambda_1 P_{i-1} = (n - i)\lambda_1 P_i \quad , i = 1, 2, \ldots, n-1$$

$$\lambda_1 P_{n-1} = \mu P_n \quad .$$

Using the fact $\sum_{i=0}^{n} P_i = 1$ and solving the equations simultaneously, we obtain:

$$P_0 = \frac{1}{1 + \frac{n\lambda_1}{\mu} + n\lambda_1 \sum_{i=1}^{n-1} \frac{1}{n-i}}$$

$$P_n = \frac{n\lambda_1}{\mu} P_0 \quad .$$

Since system failure corresponds to state n, $P_F = P_n$. Of course, $P_S = 1 - P_F$. The system failure rate is found by equating system availability to system success:

$$\frac{\mu}{\mu + \lambda} = P_S$$

which can be solved for λ:

$$\lambda = \mu \cdot \frac{P_F}{P_S} \quad .$$

Summary

The preceding sections describe the network reduction formulas for four types of systems. Formulas for variations on these systems (e.g., different repair policies) can be derived using the procedures described above.

APPENDIX B

PROGRAMS FOR HAND-HELD CALCULATOR SOLUTIONS OF STATE SPACE EQUATIONS

APPENDIX B

PROGRAMS FOR HAND-HELD CALCULATOR SOLUTIONS OF STATE SPACE EQUATIONS

CALCULATOR TI-59 PROGRAMS

Two programs were written on a hand-held TI-59 calculator to expedite the computations involved in the state space approach. The first program--Insolation Hours--computes the equivalent monthly peak insolation hours, I_i, which is the total amount of insolation received in terms of peak intensity. The subscript i (i = 1, 2, ..., 12) indicates the month, where i = 1 corresponds to January. These computation results, I_i, are then used together with the dirt accumulation and cleaning data to compute the annual equivalent peak insolation hours, I.

The second program--Power Production--takes the annual peak insolation hours, I, from the first program, combines it with the system expected capacity factor, β; the system rating, W; the sytem permanent degradation; and degradation due to cell failures data to determine the system's annual power production, P.

Input Data

(1) Insolation Hours Program

- Monthly degradation (degradation due to dirt) rate, d_r,

  $$d_r = \frac{\text{(System capacity in year 1) - (System capacity in year 2)}}{12}$$

  If there is no system degradation due to dirt, $d_r = 0$

- The annual cleaning frequency, f (i.e., number of cleaning events per year)
- The interval, t, between consecutive monthly output (see monthly output duration).

(2) Power Production Program

- System's equivalent annual peak insolation hours, I
- System's expected capacity factor, β
- System rating, W
- System permanent degradation, dP
- System degradation due to cell failures, dC
- Year of interest, K.

Output

(1) Insolation Hours Program

- Equivalent monthly peak insolation hours, I_i ($i = 1, 2, \ldots, 12$)
- Equivalent annual peak insolation hours, I.

(2) Power Production Program

- Annual power production, P.

TITLE Insolation Hours PAGE ____ OF ____

TI Programmable Program Record

PROGRAMMER JP Ehounou DATE 12/17/81

Partitioning (Op 17) 4 7 9 6 9 Library Module Master Printer ✓ Cards ✓

PROGRAM DESCRIPTION

(SEE ATTACHMENT)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Access program, enter interval t	t			A	20
2	Enter first value in monthly insolation					
	curve, X_1	X_1			A'	0
3	Enter 2nd value in monthly insolation					
	curve, X_2	X_2			B	X_2
	Program computes $(X_1 + X_2)/2$					
4	Enter subsequent values in monthly					
	insolation curve, X_i, until $X_i = 0$	X_i			B	X_i
5	Program computes month insolation					
	$I_i = t \times \sum_{i=1}^{n} (X_1 + X_{i+1})/2$				C	I_i
6	Repeat steps 2-5 for all 12 months					
7	Enter d_r (degradation rate	d_r			D	1
8	Enter f (cleaning frequency	f			R/S	I
	Program computes total annual insolation					
	$I = \sum_{i=1}^{12} (I \text{ x } d_{r_i})$					

USER DEFINED KEYS	DATA REGISTERS (INV [illegible])		LABELS (Op 08)
Ⓐ	0	0	
Ⓑ	1	1	
Ⓒ	2	2	
Ⓓ	3	3	
Ⓔ	4	4	
Ⓐ'	5	5	
B'	6	6	
C'	7	7	
D'	8	8	
E'	9	9	

LABELS (Op 08)

INV ___	lnx ___	(CE) ___	CLR ___	x⇌t ___	x^2 ___
$\sqrt{x}$ ___	1/x ___	STO ___	RCL ___	SUM ___	y^x ___
EE ___	(___	) ___	÷ ___	GTO ___	X ___
SBR ___	− ___	RST ___	+ ___	R/S ___	. ___
+/− ___	= ___	CLR ___	INV ___	[illegible] ___	[illegible] ___
[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___
[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___
[illegible] ___	Pause ___	x=t ___	[illegible] ___	[illegible] ___	[illegible] ___
[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___
[illegible] ___	DMS ___	[illegible] ___	[illegible] ___	[illegible] ___	[illegible] ___
[illegible] ___	[illegible] ___				

FLAGS 0	1	2	3	4	5	6	7	8	9

INSOLATION HOURS PROGRAM LISTING

```
LOC  CODE  KEY                  LOC  CODE  KEY

000   76  LBL                   051   76  LBL
001   11   A                    052   14   D
002   42  STO                   053   55   ÷
003   07   07                   054   01   1
004   02   2                    055   02   2
005   00   0                    056   95   =
006   42  STO                   057   42  STO
007   01   01                   058   01   01
008   91  R/S                   059   01   1
009   76  LBL                   060   42  STO
010   16  A'                    061   02   02
011   42  STO                   062   91  R/S
012   08   08                   063   35  1/X
013   00   0                    064   65   ×
014   42  STO                   065   01   1
015   04   04                   066   02   2
016   69  OP                    067   95   =
017   21   21                   068   42  STO
018   91  R/S                   069   05   05
019   76  LBL                   070   85   +
020   12   B                    071   01   1
021   42  STO                   072   95   =
022   09   09                   073   42  STO
023   85   +                    074   03   03
024   43  RCL                   075   01   1
025   08   08                   076   02   2
026   95   =                    077   42  STO
027   55   ÷                    078   04   04
028   02   2                    079   02   2
029   95   =                    080   00   0
030   44  SUM                   081   42  STO
031   04   04                   082   06   06
032   43  RCL                   083   00   0
033   09   09                   084   42  STO
034   42  STO                   085   09   09
035   08   08                   086   69  OP
036   91  R/S                   087   26   26
037   76  LBL                   088   43  RCL
038   13   C                    089   03   03
039   43  RCL                   090   32  X:T
040   04   04                   091   43  RCL
041   65   ×                    092   02   02
042   43  RCL                   093   77   GE
043   07   07                   094   15   E
044   95   =                    095   43  RCL
045   72  ST*                   096   02   02
046   01   01                   097   75   -
047   58  FIX                   098   93   .
048   02   02                   099   05   5
049   99  PRT                   100   95   =
050   91  R/S
```

INSOLATION HOURS PROGRAM LISTING
(Continued)

LOC	CODE	KEY
101	65	×
102	43	RCL
103	01	01
104	95	=
105	94	+/-
106	85	+
107	01	1
108	95	=
109	42	STO
110	18	18
111	65	×
112	73	RC*
113	06	06
114	95	=
115	44	SUM
116	09	09
117	69	OP
118	22	22
119	69	OP
120	34	34
121	61	GTO
122	24	CE
123	76	LBL
124	15	E
125	43	RCL
126	02	02
127	55	÷
128	43	RCL
129	05	05
130	95	=
131	59	INT
132	65	×
133	43	RCL
134	05	05
135	95	=
136	85	+
137	93	.
138	05	5
139	95	=
140	94	+/-
141	85	+
142	43	RCL
143	02	02
144	95	=
145	65	×
146	43	RCL
147	01	01
148	95	=
149	94	+/-
150	85	+
151	01	1
152	95	=
153	42	STO
154	19	19
155	65	×
156	73	RC*
157	06	06
158	95	=
159	44	SUM
160	09	09
161	69	OP
162	22	22
163	69	OP
164	34	34
165	76	LBL
166	24	CE
167	43	RCL
168	04	04
169	32	X:T
170	00	0
171	67	EQ
172	34	ΓX
173	61	GTO
174	00	0
175	86	STF
176	76	76
177	34	ΓX
178	43	RCL
179	09	09
180	91	R/S

TITLE Power Production PAGE B-6 OF

PROGRAMMER J-P Ehounou DATE 12/17/81

Partitioning (Op 17) 4,7,9,6,9 Library Module Printer ✓ Cards ✓

TI Programmable Program Record

PROGRAM DESCRIPTION

This program computes the system annual power production, P.

Input data:

- Total system equivalent annual peak insolation hours, I
- System expected capacity factor, β
- System rating, W
- System permanent degradation, dP
- System degradation due to cell failure, dC.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Enter Insolation factor I	I			A	I
2	Enter Reliability factor β				R/S	β
3	Enter system rating W	W			R/S	0
4	Enter system permanent degradation factors					
	in year i	dP_i			B	dP_i
	in year j	dP_j			R/S	dP_j
	$i \leq k \leq j$					
5	Enter year (k) of interest	k			C	$\text{Int}\left(\frac{k}{3}\right)$
6	Enter system degradation due to cell failure					
	in year k	dC_k			R/S	dC_k
	in year k+1	dC_{k+1}			R/S	dC_{k+1}
	Program computes power production in					
	year k (P_k)				R/S	Print - P_k
						& Display - dC_{k+1}
	Note: This program assumes that permanent degradation factors are taken on 3-year intervals.					

USER DEFINED KEYS	DATA REGISTERS (INV [illegible])		LABELS (Op 08)
A	0	0	
B	1	1	
C	2	2	
D	3	3	
E	4	4	
A'	5	5	
B'	6	6	
C'	7	7	
D'	8	8	
E'	9	9	

LABELS (Op 08)

INV _ lnx _ CE _ CLR _ x⇌t _ x² _
√x _ 1/x _ STO _ RCL _ SUM _ yˣ _
EE _ (_) _ ÷ _ GTO _ × _
SBR _ − _ RST _ + _ R/S _ . _
+/− _ = _ CLR _ INV _ log _ CP _
[illegible] _ Pgm _ P→R _ [illegible] _ cos _ [illegible] _
Exc _ Prd _ [illegible] _ [illegible] _ [illegible] _ [illegible] _
Deg _ Pause _ x=t _ Nop _ Op _ Rad _
[illegible] _ x≥t _ Σ+ _ x̄ _ Grad _ St flg _
If flg _ D.MS _ π _ Lst _ Write _ Dsz _
Adv _ Prt _

FLAGS	0	1	2	3	4	5	6	7	8	9

POWER PRODUCTION PROGRAM LISTING

```
LOC  CODE  KEY
000   76   LBL
001   11    A
002   42   STO
003   01    01
004   91   R/S
005   42   STO
006   02    02
007   91   R/S
008   42   STO
009   03    03
010   91   R/S
011   76   LBL
012   12    B
013   42   STO
014   14    14
015   91   R/S
016   42   STO
017   15    15
018   91   R/S
019   76   LBL
020   13    C
021   42   STO
022   16    16
023   75    -
024   01    1
025   95    =
026   55    ÷
027   03    3
028   95    =
029   59   INT
030   42   STO
031   08    08
032   91   R/S
033   42   STO
034   17    17
035   91   R/S
036   42   STO
037   18    18
038   91   R/S
039   43   RCL
040   18    18
041   85    +
042   43   RCL
043   17    17
044   95    =
045   55    ÷
046   02    2
047   95    =
048   42   STO
049   04    04
050   43   RCL

LOC  CODE  KEY
051   08    8
052   65    ×
053   03    3
054   95    =
055   94   +/-
056   85    +
057   43   RCL
058   16    16
059   95    =
060   42   STO
061   19    19
062   43   RCL
063   14    14
064   75    -
065   43   RCL
066   15    15
067   95    =
068   55    ÷
069   03    3
070   95    =
071   65    ×
072   53    (
073   43   RCL
074   19    19
075   75    -
076   93    .
077   05    5
078   54    )
079   95    =
080   94   +/-
081   85    +
082   43   RCL
083   14    14
084   95    =
085   65    ×
086   43   RCL
087   04    04
088   65    ×
089   43   RCL
090   03    03
091   65    ×
092   43   RCL
093   02    02
094   65    ×
095   43   RCL
096   01    01
097   95    =
098   99   PRT
099   43   RCL
100   18    18
101   91   R/S
```

APPENDIX C

DETAILS OF COMPUTER PROGRAM - SOLREL

APPENDIX C

DETAILS OF COMPUTER PROGRAM SOLREL

Inputs

User Data Cards

In addition to the standard GASP IV inputs, the following data items must be entered. These data cards follow immediately behind the GASP IV data cards. These cards are read in subrouting INTLC.

CARD 1: (A10) - The number of years of system simulation.
CARD 2: (611) - Set output flags.

- FLAG1:
  - = 1: Tables or plots saved during a previous run will be read and averaged with results from this run.
  - = 0: Results from previous runs will be ignored.
- FLAG2:
  - = 1: Plots produced during this run will be saved on file.
  - 2: Tables produced during this run will be saved on file.
  - 3: Both tables and plots will be saved.
  - 0: Both tables and plots will be saved.
- FLAG3:
  - = 1: Yearly summaries of the eents log will be printed.
  - 2: Both yearly summaries and events messages will be printed.
  - 0: No events will be printed.
- FLAG4:
  - = 1: Cost, availabilty and failure tables will be printed for each simulation run.
  - 2: If multiple simulation runs are made during a single execution of SOLREL, this flag will cause summary tables to be printed; the costs and availabiity tables will contain values obtained by averaging results from individual runs and the failure table will sum results.

3: Cost, availability, and failure tables will be produced for individual runs; summary tables will also be produced.

0: No tables will be produced.

FLAG5 = 1: Plots will be produced for each simulation.

2: If multiple simulation runs are made during a single execution of SOLREL, this flag will cause summary plot to be produced in which the values from individual run plots are averaged.

3: Both individual run plots and summary plots will be produced.

0: No plots will be produced.

CARD 3: (2F6.2, I3) The array output capacity, the inverter output capacity, and the number of components.

CARD 4: (3F5.3) The ovrall inflation rate, the discount rate, and the escalation rate for the price of electricity.

CARD 5: (11F6.3) The degradation curve for dirt. Each entry represents the percent of design output expected from "dirty" arrays at 3-year intervals.

CARD 6: (11F6.3) The degradation curve for permanent yellowing or lens deteriorization. Each entry represents the percent of output expected from "yellowed" or otherwise degraded arrays at 3-year intervals.

CARD 7: (11F6.3) (optional - see SUBROUTINE INTLC) The degradation curve due to array failure. Each entry represents the percent of output expected from the array field at 1 year intervals assuming no repairs (3 cards).

CARD 8: (F6.5) Percent of cell degrdation permitted before repair initiated (concentrator system only).

CARD 9: (F5.0) Number of motor failures allowed before repair initiated (2-axis tracking system only).

CARD 10: (5F5.0) Up to 5 preventive maintenance times (i.e., time intervals between five different preventive maintenance actions). Note that this input may differ slightly for each system design.

CARD 11: (20I1) For each component, the number of men needed to repair or perform preventive maintenance. The last five entries are for preventive maintenance.

CARD 12: (8F10.0) Monthly thermal design outouts in kWh - 6 per card (Actively cooled system only).

GASP Parameter Cards (Card type 10)

GASP's card type 10 is used to input the parameters for the failure and repair time distributions. The first NCOMP (NCOMP - number of components) cards define the failure distributions which are usually exponential or Weibull. For expontial distrbutions, columns 21-30 contain the mean, columns 31-40 the minimum value, columns 41-50 the maximum value and columns 51-60 a value of 1.0. For the Weibull distribution, the ALPHA value is in columns 21-30 and the BETA value in columns 31-40. The Weibull distribution is defined to be:

$$f(x) = (\mathrm{ALPHA})(\mathrm{BETA})x^{\mathrm{ALPHA}-1}\exp(-\mathrm{BETA}\ x^{\mathrm{ALPHA}}).$$

The next NCOMP cards contain the repair time parameters which are usually lognormal. Columns 21-30 contain the 50th percentile and Columns 31-40 the 90th percentile of expected repair times. The next five cards contain the parameters (usually for lognormal distributions) for the five types of preventive maintenance. Depending on the system being simulated, there may be more or less than five cards. Again columns 21-30 are reserved for the 50th percentile and columns 31-40 for the 90th percentile of expected repair times.

Failure times for the tracking device, array field and inverter were obtained using an equation derived from the Weibull distribution function.

$$t_{\mathrm{failure}} = \left(- \frac{\ln(1-\upsilon)}{\alpha}\right)^{1/\beta}$$

In this equation, ν is a random deviate generated by a uniform distribution and and β are parameters characterizing the Weibull distribution. These same parameters are used to compute mean failure times according to the following relationship:

$$\mu = \alpha \cdot \Gamma\left(1 + \frac{1}{\beta}\right)$$

where $\Gamma(\cdot)$ is the gamma function. In all such calculations, a value for β of 2.5 was used, resulting in a value for Γ of .88726.

External Data Files

Logical File 7: This file contains the repair costs information formatted (F4.0, 1X, 2F10.2). The first field contains the repair type code (200-299 series for unscheduled repairs and the 300-399 sreies for preventive maintenance). The second field contains the fixed cost per repair. The third field contains the variable cost in dollars per hour.

Logical File 12: This file contains the twelve monthly output duration curves used to compute system output. A sample output duration curve appears in Figure C-1. For this curve, an output of greater than 300 kW is obtained for 150 hours of the month. These curves are obtained from a system simulation which ignores all maintenance and degradation factors. The curve is divided into a series of points each representing an interval of roughly 8-1/3 hours/month depending on the design being tested. Each output value is then normalized on a scale of 0 to 1 with 1 being the maximum array output. The information is stored using a (2F6.1, 47F5.3) format. The first field is the number of daylight hours in that month. The second field is the number of daylight hours in that month times 12. The next 47 fields contain the normalized values of the output duration curve.

Logical File 13: This file contains the explanations of the report options specified by the user. The information is stored in a (2I1,7A10) format. The first field is the flag number. The second field is the value of that flag. The next seven fields are the explanation.

Logical File 8: If plot data are to be stored after run completion, this blank file must exist.

Logical Files 9-11: If table data are to be stored after run completion, these blank files must exist.

Random Number Streams

GASP IV uses a function called DRAND to generate random deviates from a uniform 0-1 distribution. The user need only designate the initial seed (starting point). These deviates can then be used to generate random numbers from whatever distribution the user desires. By using the same seed for subsequent runs, the user can reproduce the same sets of random numbers. This allows the user to repeat the same "environment" when testing alternative system designs. Otherwise it would be difficult to determine whether differences in the results were caused by (1) the random numbers or (2) the inherent differences in the alternatives. The only way to estimate the magnitude of these two types of variance would be to conduct a large number of expensive experiments and evaluate the results statistically.

Simply using the same seed for ecah run, however, does not guarantee a repeat of the same environment. For example, the first two random numbers generated in Run A might be used to generate the time needed to clean the array while the third random number might be used to generate the time of first inverter failure. Now, suppose Run B tests a new cleaning policy and uses the first three random numbers fo generate cleaning times with the fourth random number being used to generate the first inverter failure. Obviously, the environment has changed since the inverter is now scheduled to fail at a different time--a change resulting entirely by an unrelated change in array-cleaning policy. Therefore, it is often necessary to set up several independent randon number streams, each having a unique seed. The choice of which events to associate with which random number streams depends on what types of repair or design strategies are to be tested. A short description of the random number generation process will be included in the reports on actual or generic systems tested.

Description of Subroutines

INTLC

This subroutine is called from GASP IV at the beginning of each simulation run. It serves the following functions:

- Reads all user data cards
- Calculates theoretical or expected system availability
- Initializes variables
- Creates initial event file.

PRTDATA

This subroutine prints all user inputs including the 12 output duration curve values.

EVNTS

This subroutine is called at every event. It determines the event type and calls the appropriate subroutines.

FAILURE

This subroutine is called by EVNTS when a failure event has occurred. This subroutine

- Postpones failure if system down from previous failure
- Prints type of failure and time of occurrence (if log option selected)
- Calls OUTPUT to calculate output between events
- Computes repair time and schedules repair.

TIMEV

This subroutine is called by EVNTS if a time event has occurred. Time events are scheduled at periodic intervals for preventive maintenance and cleaning. This subroutine

- Maintains the monthly simulation clock
- Maintains the yearly simulation clock
- Maintains preventive maintenance schedules and clocks.

REPAIR

This subroutine is called by EVNTS when a repair has been completed. This subroutine

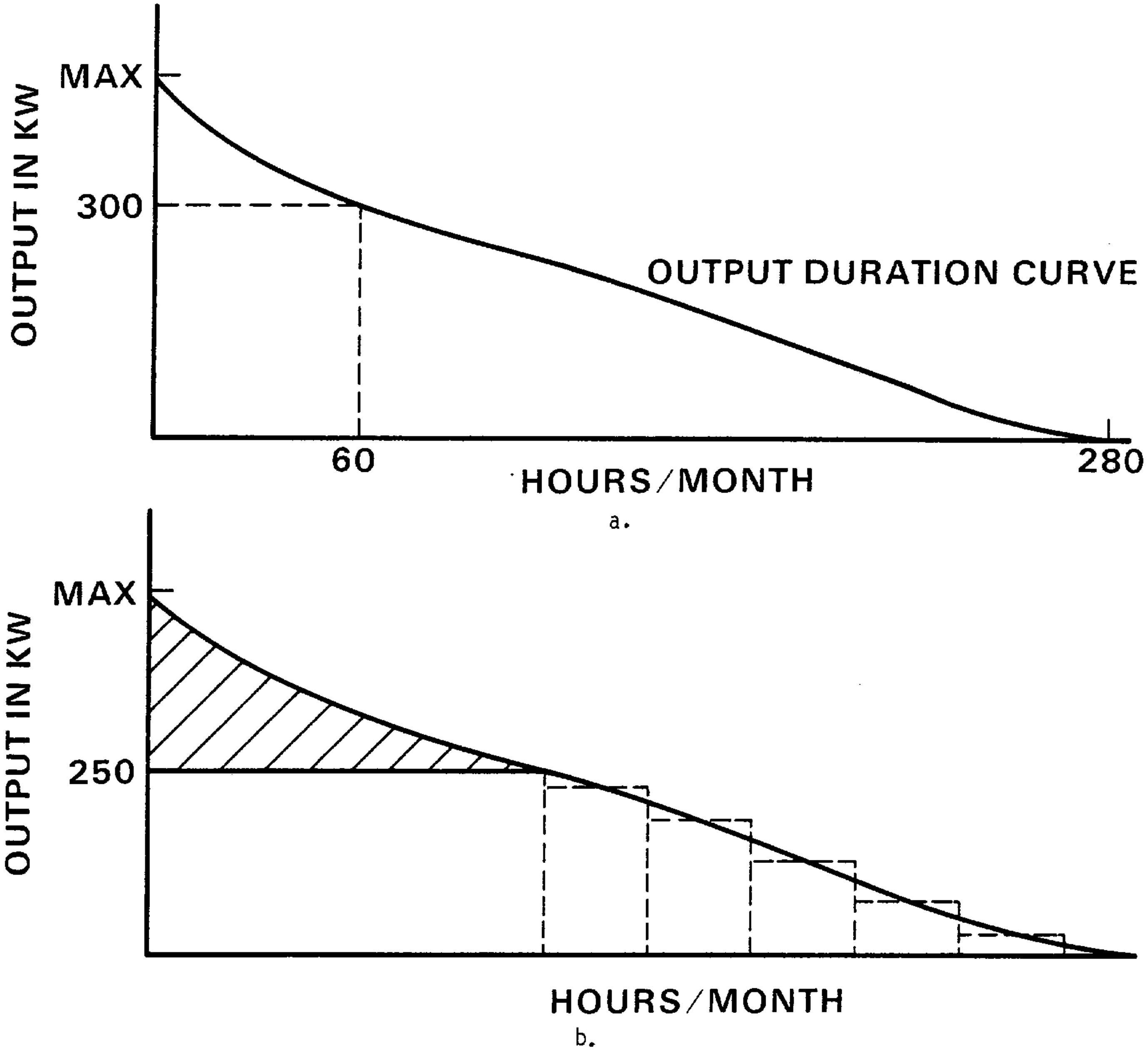
- Prints the type of repair completed, the repair time, and the repair cost
- Schedules the next failure of the component just repaired
- Adjusts output to normal.

COST

This subroutine is called from either REPAIR or TIMEV to calculate the cost of repair or preventive maintenance. Given the type of repair and the repair hours, this subroutine uses the cost file to calculate fixed and variable costs of repair. Costs are also calculated in terms of current and present value dollars.

OUTPUT

This subroutine computes the expected kWh production between two points in time using an output duration curve generated from the designer's simulation of nondegraded system performance given historical weather conditions. Figure C-1a shows an example of an output duration curve where some level of insolation exists for 280 hours per month. The example shows that for 60 hours per month, output from the PV system will exceed 300 kW given no degradation or failure. The procedure is as follows:



a.

b.

FIGURE C-1. SAMPLE OUTPUT DURATION CURVES

(1) Check if system is operating over the time interval. If not, output is zero.

(2) On systems with parallel components or components which may "partially" fail, compute loss of output from this type of failure. For example, for the generic concentrator system tested, two 250 kW inverters were connected in parallel to produce a maximum output of 500 kW. Should one fail, a maximum of 250 kW could be produced causing a loss of the upper portion of the output duration curve. Figure C-1b shows the effect of one inverter failure on the output duration curve. Electric production has been reduced by an amount equal to the area of the shaded portion.

(3) Adjust output duration downward to account for dirt, permanent degradation, array cell failures, and string failures.

(4) Integrate under the adjusted output duration curve and multiply by time interval to yield output.

This subroutine also computes system availability (i.e., how much time the system is producing at various levels of output up to full capacity). In addition, using the inflation rate of electricity and the discount rate, the present value of the output is calculated. Outputs are then printed and added to cumulative totals.

REPORT

Subroutine REPORT determines which types of output ultimately are provided by SOLREL. Based on the values of the output flags, FLAG1 through FLAG5, REPORT calls the appropriate output routines. These routines are UPLOT, BILITY, COTABLE, FAILTAB, BILRITE, CORITE and FAILRITE. Four different types of output are produced by REPORT:

(1) A pair of graphs showing: (a) maintenance and repair cost by year and system output in MWH per year; (b) present value of maintenance and repair costs by year and levelized cents per kWh by year. Subroutine UPLOT produces these plots.

(2) A table entitled "Annual System Availability During Daylight" which, for each year of operation, shows the percent of time the system operates at various levels of capacity. Subroutine BILITY sets up this table and BILRITE writes it to an output file.

(3) A table entitled "Annual Maintenance Cost and Output" displays in numeric form essentially the same information as do the plots described above. Subroutines COTABLE and CORITE produce this table.

(4) A component failure table which lists the array or system components and the number of failures each experiences during each operating year. Subroutines FAILTAB and FAILRITE produce this table.

APPENDIX D

SOLREL SOURCE LISTING - FLAT-PANEL SYSTEM

```
  1                 PROGRAM SOLRELY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7,TAPE8=
                   1/1300,TAPE9=/3500,TAPE10=/2100,TAPE11=/7000,TAPE12=/5800,TAPE13)
                    DIMENSION NSET(1000)
                    INTEGER F17
  5                 COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
                   1PQ,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
                   2TCLR,TTFIN,TTRIB(25),TTSET
                    COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
                   1HMON(12),HYR(12),ADEG(31),STRING(21)
 10                 COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
                   1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
                    COMMON/USER10/CS(30),PVS(30),CCS(30),PVCS(30)
                    COMMON/USER11/FARY,P(30,4),MEN(30)
                    COMMON QSET(1000)
 15           C
                    CALL CALCMP(11)
              C ENTER DATA CURVES FOR OUTPUT CHANGES DUE TO WEAROUT, DIRT, AND MIRROR DEGRAD.
                    DATA DEGRAD/1.00,1.00/
                    NCRDR=5
 20                 NPRNT=6
              C INITIALIZE FILE ARRAYS
                    DO 11 I=1,30
                    CS(I)=0.0
                    PVS(I)=0.0
 25                 CCS(I)=0.0
                 11 PVCS(I)=0.0
                    DO 21 I=1,31
                    DO 12 J=1,21
                 12 F17(J,I)=0
 30                 DO 14 J=1,6
                 14 F15(I,J)=0.0
                    DO 21 J=1,11
                 21 F12(I,J)=0.0
              C
 35           C READ IN OUTPUT DURATION CURVES
                    READ(12,800)(HMON(I),HYR(I),(OUTCURV(I,J),J=1,47),I=1,12)
                800 FORMAT(2F6.1,47F5.3)
                    CALL GASP
                    CALL DONEPL
 40                 STOP
                      END
```

```
 NR. SEVERITY  DETAILS     DIAGNOSIS OF PROBLEM

 37      I      23 CD 37  FIELD WIDTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
 37      I      26 CD 37  TOTAL RECORD LENGTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
```

```
      SUBROUTINE INTLC
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      DIMENSION THER(10)
      COMMON QSET(6000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
     1PQ,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
     2TCLR,TTFIN,TTRIB(25),TTSET
      COMMON/GCOM4/DTPLT(10),HHLOW(25),HHWID(25),IICRD,IITAP(10),JJCEL(5
     100),LLABC(25,2),LLABH(25,2),LLABP(11,2),LLABT(25,2),LLPHI(10),LLPL
     2O(10),LLPLT,LLSUP(15),LLSYM(10),MMPTS,NNCEL(25),NNCLT,NNHIS,NNPLT,
     3NNPTS(10),NNSTA,NNVAR(10),PPHI(10),PPLO(10)
      COMMON/GCOM5/IIFVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNCFI,
     1NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
     1HMON(12),HYR(12),ADEG(31),STRING(21)
      COMMON/USER2/OLOT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORD(60)
      COMMON/USER3/MCLOCK,CLOCK(5),TIME1,TIME2,PVTIME,PMTIME(5)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/USER9/THEO(10),QC(47)
      COMMON/USER11/FARY,P(30,4),MEN(30)
C
C DEFINE FAILURES
C     101= A MODULE GROUP
C     102= A DISCONNECT SWITCH
C     103= A BIPASS DIODE
C     104= A SHUNT RESISTOR
C     105= AN INVERTER
C     106= THE SWITCHGEAR
C     107= THE TRANSFORMER
C     108= THE TRANSMISSION SYSTEM
C     109= THE THREE PHASE TRANSFORMER
C     110= THE INVERTER CONTROL
C     111= THE UTILITY
       ATRIB(3)=0.0
C
C
C INITIALIZE AVAILABILITY ARRAY
       DO 16 I=1,10
    16 AVAIL(I)=0.0
C
C INITIALIZE CUMMULATIVE FAILURE BY TYPE BY YEAR
       DO 17 I=1,15
       DO 17 J=1,30
    17 IFNUM(I,J)=0.0
C
C INITIALIZE COST AND OUTPUT ARRAYS
       DO 18 I=1,31
       DO 19 J=1,2
       F8(I,J)=0.0
```

```
   19 F9(I,J)=0.0
      DO 20 J=1,10
   20 F10(I,J)=0.0
   18 CONTINUE
C
C READ FORMAT FOR COMPONENT FAILURE TABLE
      READ(5,806) FMT(2)
      READ(5,805)FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
C
C ENTER SYSTEM MAXIMUM OUTPUT (KWH), TOTAL INVERTER CAPACITY,
C     AND NUMBER OF SYSTEM COMPONENTS
      READ(5,803) OUT,OUTI,NCOMP
C
C READ IN INFLATION AND DISCOUNT RATES
      READ(5,801)RINF,RDISC,EINF
C READ IN DEGRADATION CURVES DUE TO DIRT AND MIRROR DETERIORIZATION
      READ(5,802)(DIRT(I),I=1,10)
      READ(5,802)(DMIRROR(I),I=1,11)
C
C READ IN CELL FAILURE DEGRADATION CURVE
      READ(5,802)(ADEG(I),I=1,10)
      READ(5,802)(ADEG(I),I=11,20)
      READ(5,802)(ADEG(I),I=21,31)
C
C READ IN PREVENTATIVE MAINT. TIMES FOR INVERTER, TRACKING UNITS, LENS CLEANING,
C DIST. SYSTEM, AND GENERAL SYSTEMWIDE
      READ(5,809)(PMTIME(I),I=1,4)
C
C READ IN NUMBER OF MEN NEEDED TO REPAIR
      NCOMPP=NCOMP+1
      READ(5,809)(MEN(I),I=NCOMPP,NNPRM)
C
C PRINT OUT INPUT PARAMETERS
      IF(NNRUN.GT.1.AND.LLSUP(10).EQ.2)GO TO 8
      DO 7 I=1,NNPRM
      DO 7 J=1,4
    7 P(I,J)=PPARM(I,J)
    8 CALL PRTDATA
C
C CONVERT LOG NORMAL REPAIR PARAMETERS TO NORMAL
      IF(NNRUN.GT.1.AND.LLSUP(10).EQ.2)GO TO 9
      DO 11 I=NCOMPP,NNPRM
      PPAPM(I,4)=(ALOG(PPARM(I,2)/730.)-ALOG(PPARM(I,1)/730.))/1.28
      PPARM(I,1)=ALOG(PPARM(I,1)/730.)
      PPARM(I,2)=-99999.
      PPARM(I,3)=999.0
   11 CONTINUE
    9 DO 94 I=1,10
   94 THEO(I)=0.0
      DO 155 L=1,12
      DO 100 J=1,47
  100 OC(J)=OUTCURV(L,J)
      DO 101 J=1,47
```

```
          IAHYR=J
      101 IF(OC(J).EQ.0.0) GO TO 102
      102 IF(OUTI.GE.OUT) GO TO 120
          DO 110 I=1,47
          OC(I)=(OUT/OUTI)*OC(I)
      110 IF(OC(I).GT.1.0) OC(I)=1.0
      120 DO 130 I=1,10
      130 THER(I)=0.0
          TEST=0.90
          J=1
          SUMT=0.0
          DO 140 I=2,IAHYR
          DIFE=(OC(I-1)-OC(I))
          IF (DIFF.NE.0) GO TO 135
          STHEO = 1.0
          GO TO 136
      135 STHEO=(OC(I-1)-AMAX1(TEST,OC(I)))/DIFF
      136 THER(J)=STHEO+THER(J)
          IF(OC(I).GE.TEST) GO TO 140
          TEST=TEST - .10
          J=J+1
          SUMT=SUMT+THER(J-1)
          THER(J)=1-STHEO
      140 CONTINUE
          SUMT=SUMT+THER(10)
          IF(SUMT.EQ.0.0) SUMT=IAHYR
          DO 150 I=1,10
          THER(I)=(THER(I)/SUMT)*100.0
      150 THEO(I)=THEO(I)+THER(I)/12.0
      155 CONTINUE
C
C CALCULATE THE NUMBER OF YEARS PER SIMULATION FROM TTFIN
          NYRS=TTFIN/12.0
C
C INITIALIZE FAILURE ARRAY
          DO 15 I=1,20
       15 F(I)=0.0
          DO 26 I=1,21
       26 STRING(I)=1.0
C
C SELECT FIRST FAILURE TIMES
          DO 5 I=1,21
          ATRIB(4)=I
          ATRIB(2)=102.0
          ATRIB(5)=0.0
          ATRIB(1)=ERLNG(2,1)
          CALL FILEM(1)
          ATRIB(2)=104.0
          ATRIB(1)=ERLNG(4,1)
          CALL FILEM(1)
          ATRIB(1)=10000.0
          DO 6 J=1,16
          ATRIB(2)=103.0
```

```
160                 A=ERLNG(3,1)
                    IF(ATRIB(1).GT.A)ATRIB(1)=A
                  6 CONTINUE
                    ATRIB(4)=I
                    CALL FILEM(1)
165               5 CONTINUE
                    ATRIB(4)=0.0
                    ATRIB(5)=0.0
                    DO 10 I=105,111
                    R=I
170                 J=I-100
                    ATRIB(2)=R
                    ATRIB(1)=ERLNG(J,1)
                 10 CALL FILEM(1)
              C
175           C SELECT FIRST TIME EVENT
                    ATRIB(2)=301.
                    ATRIB(1)=1.0
                    CALL FILEM(1)
                    OLDT=TTBEG
180                 ARRNUM=0.0
                    ICONT=0
                    MCLOCK=1
                    TIME1=0.0
                    IYR=1
185                 DO 12 I=1,5
                 12 CLOCK(I)=0.0
                    TIME2=0.0
                    TNUM=0.0
                    ANUM=0.0
190                 FNUM=0.0
                    MON=≠JANUARY≠
                801 FORMAT(3F5.3)
                802 FORMAT(11F6.3)
                803 FORMAT(2F6.2,1I3)
195             804 FORMAT(1X,≠INFLATION RATE= ≠,F4.3,/,≠ DISCOUNT RATE= ≠,F4.3,/,≠ EN
                   1RGY INFLATION RATE= ≠,F4.3,/,≠ MAXIMUM SYSTEM OUTPUT IN KW= ≠,F6.0
                   2)
                805 FORMAT(6I1)
                806 FORMAT(1A10)
200             807 FORMAT(F5.0)
                808 FORMAT(5F5.0)
                809 FORMAT(20I1)
                    RETURN
                    END
```

```
RD NR. SEVERITY  DETAILS   DIAGNOSIS OF PROBLEM

  195     I      39CD 195  FIELD WIDTH OF A CONVERSION DESCRIPTOR SHOULD BE AS LARGE AS THE MINIMUM SPECIFIED FOR THAT DESCRIPTOR.
  195     I      65CD 195  FIELD WIDTH OF A CONVERSION DESCRIPTOR SHOULD BE AS LARGE AS THE MINIMUM SPECIFIED FOR THAT DESCRIPTOR.
```

```
      SUBROUTINE PRTDATA
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      DIMENSION FTYPE(22),MES(7)
      DIMENSION OC(47),INDEX(5)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
     1PO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
     2TCLR,TTFIN,TTRIB(25),TTSET
      COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
     1HMON(12),HYR(12),ADEG(31),STRING(21)
      COMMON/USER3/MCLOCK,CLOCK(5),TIME1,TIME2,PVTIME,PMTIME(5)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/USER11/FARY,P(30,4),MEN(30)
      DATA FTYPE/≠A MODULE G≠,≠ROUP≠,≠A DISCONNE≠,≠CT SWITCH≠,≠A BIPASS
     1D≠,≠IODE≠,≠A SHUNT RE≠,≠SISTOR≠,≠AN INVERTE≠,≠R≠,≠THE SWITCH≠,≠GEA
     2R≠,≠WIRING/SWI≠,≠TCHES≠,≠THE DISTRI≠,≠BUTION SYS≠,≠THE 3 PHAS≠,≠E
     3X-FORMER≠,≠THE INVERT≠,≠ER CONTROL≠,≠THE UTILIT≠,≠Y≠/
C
C PRINT COMPONENT FAILURE/REPAIR/COST TABLE
      PRINT801
      PRINT*,≠ ≠
      PRINT802
      PRINT803
      PRINT*,≠ ≠
      DO 5 I=1,NCOMP
C
C *** MODULE GROUP FAILURES WILL BE SIMULATED BY A DEGRADATION CURVE
      IF(I.EQ.3.OR.I.EQ.4.OR.I.EQ.9.OR.I.EQ.10)GO TO 5
      REWIND 7
      R=200.+I
   10 READ(7,804)T,FC,VC
      IF(T.NE.R)GO TO 10
      R1=0.0
      IF(I.EQ.1)R1=301.
      IF(I.EQ.5)R1=302.
      IF(I.EQ.8)R1=303.
      IF(R1.EQ.0.0)GO TO 20
   15 READ(7,804)T,PMFC,PMVC
      IF(T.NE.R1)GO TO 15
      II=R1-300.0
      J=2*I-1
      KK=R1-278.0
      PM90=P(KK,2)
      PM50=P(KK,1)
      JJ=I+NCOMP
      JJJ=J+1
      IF(I.EQ.1)PRINT825,PM50,PM90,PMFC,PMVC,PMTIME(II),MEN(KK)
      IF(I.EQ.1)GO TO 14
      PRINT805,(FTYPE(K),K=J,JJJ),P(I,1),P(JJ,1),P(JJ,2),FC,
     1VC,MEN(JJ),PM50,PM90,PMFC,PMVC,PMTIME(II),MEN(KK)
   14 PRINT*,≠ ≠
      GO TO 5
```

```
   20 J=2*I-1
      JJ=I+NCOMP
      JJJ=J+1
      PRINT807,(FTYPE(K),K=J,JJJ),P(I,1),P(JJ,1),P(JJ,2),FC,VC,MEN(JJ)
      PRINT*,≠ ≠
    5 CONTINUE
      REWIND 7
   30 READ(7,804)T,FC,VC
      IF(T.NE.304.0)GO TO 30
      PRINT806,P(26,1),P(26,2),FC,VC,PMTIME(4),MEN(26)
C
C PRINT FLAGS USED AND MEANINGS
      PRINT*,≠ ≠
      PRINT*,≠ ≠
      INDEX(1)=10+FLAG1
      INDEX(2)=20+FLAG2
      INDEX(3)=30+FLAG3
      INDEX(4)=40+FLAG4
      INDEX(5)=50+FLAG5
      REWIND 13
      J=1
   40 READ(13,812)IN,(MES(I),I=1,7)
      IF(IN.NE.INDEX(J))GO TO 40
      K=INDEX(J)-10*J
      PRINT813,J,K,(MES(I),I=1,7)
      J=J+1
      IF(J.EQ.6)GO TO 45
      GO TO 40
C
C PRINT PERMANENT DEGRADATION AND DEGRADATION DUE TO DIRT
   45 PRINT*,≠ ≠
      PRINT*,≠ ≠
      PRINT814
      PRINT815,(DMIRROR(I),I=1,11)
      PRINT*,≠ ≠
      PRINT816
      PRINT815,(DIRT(I),I=1,10)
      PRINT*,≠ ≠
C
C PRINT CELL FAILURE DEGRADATION CURVE
      PRINT*,≠ ≠
      PRINT824
      PRINT815,(ADEG(I),I=1,10)
      PRINT815,(ADEG(I),I=11,21)
      PRINT815,(ADEG(I),I=21,31)
      PRINT*,≠ ≠
C
C PRINT REMAINDER OF DATA
      PRINT817,OUT
      PRINT818,OUTI
      PRINT819,RINF
      PRINT820,RDISC
      PRINT821,EINF
```

```
      PRINT822,TTFIN
C
C PRINT OUTPUT DURATION CURVES
      PRINT801
      PRINT*,≠ ≠
      PRINT808
      PRINT*,≠ ≠
      DO 35 I=1,12
      PRINT810,I,(OUTCURV(I,J),J=1,16)
      PRINT811,(OUTCURV(I,J),J=17,32)
      PRINT811,(OUTCURV(I,J),J=33,47)
   35 PRINT*,≠ ≠
C
C FORMATS
  801 FORMAT(1H1)
  802 FORMAT(1X,≠COMPONENT NAME≠,8X ≠MTBF   MAINT TIME (HRS)  REPAIR COS
     1T ($)  NUM  PM TIME (HOURS)    PM COST ($)    PM INTERVAL  NUM≠)
  803 FORMAT(21X,≠(MONTHS)    50PCT    90PCT   FIXED VARIABLE   MEN  50PCT
     1    90PCT   FIXED  VARIABLE      (MONTHS)  MEN≠)
  804 FORMAT(3F6.1)
  805 FORMAT(1X,2A10,F9.1,2X,F5.1,2X,F6.1,1X,F8.2,2X,F6.2,4X,,I1,4X,F5.1
     1,2X,F6.1,1X,F8.2,2X,F6.2,7X,F5.1,5X,I1)
  806 FORMAT(1X,≠GENERAL PREV MAINT  ≠,50X,F5.1,2X,F6.1,1X,F8.2,2X,F6.2,
     17X,F5.1,5X,I1)
  807 FORMAT(1X,2A10,F9.1,2X,F5.1,2X,F6.1,1X,F8.2,2X,F6.2,4X,I1)
  808 FORMAT(1X,≠MONTHLY OUTPUT DURATION CURVES IN INTERVALS OF 8.50 HOU
     1RS PER MONTH≠)
  809 FORMAT(2F6.1,47F5.3)
  810 FORMAT(1X,≠MONTH ≠,I2,16(1X,F5.3))
  811 FORMAT(9X,16(1X,F5.3))
  812 FORMAT(I2,7A10)
  813 FORMAT(1X,≠FLAG≠,I1,≠= ≠,I1,≠ MEANS ≠,7A10)
  814 FORMAT(1X,≠PERMANENT DEGRADATION -- 3 YEAR INTERVALS≠)
  815 FORMAT(1X,11(1X,F6.3))
  816 FORMAT(1X,≠DEGRADATION DUE TO DIRT -- 3 YEAR INTERVALS≠)
  817 FORMAT(1X,≠ARRAY CAPACITY IN KW.................  ≠,F5.0)
  818 FORMAT(1X,≠INVERTER DESIGN CAPACITY IN KW.......  ≠,F5.0)
  819 FORMAT(1X,≠OVERALL INFLATION RATE...............  ≠,F5.3)
  820 FORMAT(1X,≠DISCOUNT RATE........................  ≠,F5.3)
  821 FORMAT(1X,≠ELECTRICITY PRICE ESCALATION.........  ≠,F5.3)
  822 FORMAT(1X,≠LENGTH OF RUN IN MONTHS..............  ≠,F5.0)
  823 FORMAT(1X,≠UNACCEPTABLE NUMBER OF FAILED ARRAYS  ≠,F5.0)
  824 FORMAT(1X,≠DEGRADATION DUE TO CELL FAILURES -- 1 YEAR INTERVALS≠)
  825 FORMAT(1X,≠PANEL CLEANING≠,56X,F5.1,2X,F6.1,1X,F8.2,2X,F6.2,7X,F5.
     11,5X,I1)
      RETURN
      END
```

```
   SUBROUTINE EVNTS    74/74   OPT=1 TRACE             FTN 4.8+518      11/20/81  08.53.09          PAGE     1

   1          SUBROUTINE EVNTS(IX)
              IF(IX.GE.200)GO TO 5
              CALL FAILURE
              GO TO 999
   5        5 IF(IX.GE.300)GO TO 10
              CALL REPAIR
              GO TO 999
           10 CALL TIMEV
          999 RETURN
  10            END


   SYMBOLIC REFERENCE MAP (R=3)

ITRY POINTS     DEF LINE      REFERENCES
  4 EVNTS            1            9

ARIABLES     SN  TYPE             RELOCATION
  0 IX           INTEGER              F.P.        REFS        2        5    DEFINED        1

TERNALS          TYPE   ARGS          REFERENCES
   FAILURE                0                 3
   REPAIR                 0                 6
   TIMEV                  0                 8

TATEMENT LABELS               DEF LINE   REFERENCES
 14  5                           5           2
 21  10                          8           5
 22  999                         9           4          7

TATISTICS
 PROGRAM LENGTH                 238     19
     52000B CM USED
```

```
      SUBROUTINE FAILURE
      DIMENSION NSET(1000),FTYPE(22)
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON QSET(1000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCROR,NNA
     1PO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
     2TCLR,TTFIN,TTRIB(25),TTSET
      COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
     1HMON(12),HYR(12),ADEG(31),STRING(21)
      COMMON/USER2/OLDT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORO(60)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/USER11/FARY,P(30,4),MEN(30)
      EQUIVALENCE(QSET,NSET)
      DATA FTYPE/≠A MODULE G≠,≠ROUP≠,≠A DISCONNE≠,≠CT SWITCH≠,≠A BIPASS
     1D≠,≠IODE≠,≠A SHUNT RE≠,≠SISTOR≠,≠AN INVERTE≠,≠R≠,≠THE SWITCH≠,≠GEA
     2R≠,≠THE TRANSF≠,≠ORMER≠,≠THE TRANSM≠,≠ISSION SYS≠,≠THE 3 PHAS≠,≠E
     3X-FORMER≠,≠THE INVERT≠,≠ER CONTROL≠,≠THE UTILIT≠,≠Y≠/
    5 IDAY=ATRIB(1)
      RDAY=IDAY
      IDAY=(ATRIB(1)-RDAY)*30.
C
C UPDATE CUMMULATIVE FAILURE MATRIX
      I=ATRIB(2)-100.
      IFNUM(I,IYR)=IFNUM(I,IYR)+1
C
C PRINT TYPE OF FAILURE AND TIME OF OCCURANCE
      I=(ATRIB(2)-100)*2-1
      III=I+1
      IDAY=IDAY+1
      IF(FLAG1.EQ.0)PRINT801,(FTYPE(J),J=I,III),MON,IDAY,IYR
C
C CALCULATE OUTPUT BETWEEN EVENTS
      CALL OUTPUT
C
C SCHEDULE REPAIR TIME
      J=ATRIB(2)
    9 DO 10 I=101,111
      IF(J.NE.I)GO TO 10
      K=I-89
      ATRIB(2)=ATRIB(2)+100.
      ATRIB(3)=ATRIB(1)
      ATRIB(1)=(RLOGN(K,2)*3.)/MEN(K) + ATRIB(1)
   10 CONTINUE
   11 CALL FILEM(1)
C
C FORMATS
  801 FORMAT(2X,≠A FAILURE OF ≠,2A10,≠ HAS OCCURED ON ≠,13X,A10,I2,≠, YE
     1AR ≠,I2)
  802 FORMAT(1X,I2,≠ ARRAY/TRACKING SYSTEM COMBINATIONS ARE NOT OPERATIN
     1G≠)
  999 RETURN
```

```
      SUBROUTINE TIMEV
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      DIMENSION NSET(1000),MONTH(12),PM(8)
      COMMON QSET(1000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
     1PD,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
     2TCLR,TTFIN,TTRIB(25),TTSET
      COMMON/USER2/OLDT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORD(60)
      COMMON/USER3/MCLOCK,CLOCK(5),TIME1,TIME2,PVTIME,PMTIME(5)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/USER11/FARY,P(30,4),MEN(30)
      DATA PM/≠PM-PANEL C≠,≠LEANING≠,≠PM-INVERTE≠,≠R≠,≠PM-DIST SY≠,≠ST≠,
     1≠PM-SYSTEMW≠,≠IDE≠/
      DATA MONTH/≠JANUARY≠,≠FEBRUARY≠,≠MARCH≠,≠APRIL≠,≠MAY≠,≠JUNE≠,≠JULY
     1≠,≠AUGUST≠,≠SEPTEMBER≠,≠OCTOBER≠,≠NOVEMBER≠,≠DECEMBER≠/
C
C UPDATE MONTH
      ISW=0
      MCLOCK=MCLOCK+1
      IF(MCLOCK.LT.13)GO TO 5
      MCLOCK=1
      TIME1=0.0
      MON=MONTH(MCLOCK)
      ISW=1
      CALL OUTPUT
      IYR=IYR+1
C
C CHECK FOR END OF YEAR
      III=IYR
      DO 3 K=1,10
      F10(1,K)=F10(1,K)+AVAIL(K)
    3 F10(III,K)=F10(III,K)+AVAIL(K)
      PRINT803
      IIY=IYR-1
      PRINT804,IIY,F8(III,2),F9(III,2)
      PRINT806,F8(III,1),F9(III,1)
      CPERO=F8(III,1)/F9(III,1)*100.0
      PRINT807,CPERO
      PRINT803
      IF (TNOW.NE.TTFIN) GO TO 50
      PRINT803
      PRINT805,F8(1,2),F9(1,2)
      PRINT806,F8(1,1),F9(1,1)
      CPERO=F8(1,1)/F9(1,1)*100.0
      PRINT807,CPERO
      PRINT803
      CALL REPORT
   50 DO 4 I=1,10
    4 AVAIL(I)=0.0
```

```
                   5 MON=MONTH(MCLOCK)
  55             C
                 C UPDATE PREVENTATIVE MAINTENANCE CLOCKS
                       DO 51 I=1,4
                       CLOCK(I)=CLOCK(I)+1.0
                       IF(TNOW.EQ.TTFIN)GO TO 10
  60                   IF(CLOCK(I).LT.PMTIME(I))GO TO 51
                       TYPE=300.+I
                       KK=(NCOMP*2)+I
                       PVTIME=(RLOGN(KK,4)*730.*3.)/MEN(KK)
                       CALL COST(PV,CT,TYPE,PVTIME)
  65                   IPVTIM=PVTIME
                       IDAY=ATRIB(1)
                       RDAY=IDAY
                       IDAY=(ATRIB(1)-RDAY)*30.
                       IDAY=IDAY+1
  70                   J=2*I-1
                       IF(FLAG3.EQ.2)PRINT801,IPVTIM,PM(J),PM(J+1),MON,IDAY,IYR,CT,PV
                       CLOCK(I)=0.0
                       IF(I.EQ.5)TIME2=0.0
                    51 CONTINUE
  75                10 IF(ISW.EQ.0)CALL OUTPUT
                 C
                 C SCHEDULE NEXT TIME EVENT
                       ATRIB(1)=TNOW+1.0
                       ATRIB(3)=0.0
  80                   CALL FILEM(1)
                 C
                 C FORMATS
                   801 FORMAT(1X,≠THE SYSTEM WAS SHUTDOWN FOR≠,3X,I3,≠ HOURS FOR ≠,A10,A5
                      1      ,≠ ON ≠,A10,I2,≠, YEAR ≠,I2,≠ AT A COST OF $≠,F9.2,≠ $≠,F8.2)
  85               802 FORMAT(10F6.1)
                   803 FORMAT(135(≠-≠))
                   804 FORMAT(1X,≠TOTAL COSTS/OUTPUTS FOR YEAR ≠,I2,66X,≠$≠,F11.2,9X,F10.
                      10)
                   805 FORMAT(1X,≠GRAND TOTAL COSTS/OUTPUTS≠,72X,≠$≠,F11.2,9X,F10.0)
  90               806 FORMAT(1X,≠PRESENT VALUE≠,95X,≠$≠,F11.2,5X,F10.0)
                   807 FORMAT(1X,≠LEVELIZED CENTS PER KWH= ≠,F5.2)
                       RETURN
                       END
```

```
    SYMBOLIC REFERENCE MAP (R=3)

TRY POINTS      DEF LINE      REFERENCES
  2  TIMEV          1            92

RIABLES      SN  TYPE               RELOCATION
  6  ANUM        REAL                   USER2         REFS          8
  1  ARRNUM      REAL                   USER2         REFS          8
```

```
      1                 SUBROUTINE REPAIR
                        DIMENSION NSET(1000),FTYPE(26)
                        INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
                        COMMON QSET(1000)
      5                 COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
                       1PQ,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
                       2TCLR,TTFIN,TTRIB(25),TTSET
                        COMMON/USER2/OLDT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORD(60)
                        COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
     10                 DATA FTYPE/≠A MODULE G≠,≠ROUP≠,≠A DISCONNE≠,≠CT SWITCH≠,≠A BIPASS
                       1D≠,≠IODE≠,≠A SHUNT RE≠,≠SISTOR≠,≠AN INVERTE≠,≠R≠,≠THE SWITCH≠,≠GEA
                       2R≠,≠THE TRANSF≠,≠ORMER≠,≠THE TRANSM≠,≠ISSION SYS≠,≠THE 3 PHAS≠,≠E
                       3X-FORMER≠,≠THE INVERT≠,≠ER CONTROL≠,≠THE UTILIT≠,≠Y≠/
                  C
     15           C PRINT REPAIR TYPE, TIME, COST
                        TYPE=ATRIB(2)
                        I=(ATRIB(2)-200)*2-1
                        IDAY=ATRIB(1)
                        RDAY=IDAY
     20                 IDAY=(ATRIB(1)-RDAY)*30.
                        IDAY=IDAY+1
                        HR=730.*(ATRIB(1)-ATRIB(3))
                        CALL COST(PV,CT,TYPE,HR)
                        IR=HR
     25                 III=I+1
                        IF(FLAG1.EQ.0)PRINT801,(FTYPE(J),J=I,III),IR,MON,IDAY,IYR,CT,PV
                        CALL OUTPUT
                  C
                  C SCHEDULE NEXT FAILURE
     30                 ATRIB(2)=ATRIB(2)-100.
                        J=ATRIB(2)-100.
                        I=ATRIB(2)
                        IF(J.NE.3)GO TO 9
                        ATRIB(1)=10000.0
     35                 DO 11 K=1,16
                        A=TNOW+ERLNG(3,1)
                        IF(ATRIB(1).GT.A)ATRIB(1)=A
                     11 CONTINUE
                      9 ATRIB(1)=TNOW+ERLNG(J,1)
     40                 CALL FILEM(1)
                  C
                  C FORMATS
                    801 FORMAT(2X,≠A REPAIR OF ≠,2A10,≠ WAS COMPLETED IN≠, I3,≠ HOURS ON ≠
                       1,A10,I2,≠, YEAR ≠,I2,≠ AT A COST OF $≠,F9.2,≠ $≠,F8.2)
     45                 RETURN
                        END


C  D NR. SEVERITY  DETAILS    DIAGNOSIS OF PROBLEM

     10     I      FTYPE    DATA VARIABLE LIST EXCEEDS ITEM LIST, EXCESS VARIABLES NOT INITIALIZED.
```

```
  1                   SUBROUTINE COST(PV,CT,TYPE,HR)
                      DIMENSION NSET(1C00)
                      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
                     1PQ,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
  5                  2TCLR,TTFIN,TTRIB(25),TTSET
                      COMMON/USER2/OLDT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORD(60)
                      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
                      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
                     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
 10                   COMMON/USER11/FARY,P(30,4),MEN(30)
                      COMMON QSET(6000)
                C
                C READ FILE TO DETERMINE REPAIR COST
                      REWIND 7
 15                 5 READ(7,801)T,FC,VC
                      IF(TYPE.NE.T)GO TO 5
                      CT=FC+VC*HR/3.0
                      PV=CT/(1.+RDISC)**(TNOW/12.)*(1.+RINF)**(TNOW/12.)
                C
 20             C ADD COSTS TO CUMMULATIVE TOTALS
                      III=IYR+1
                      F8(1,1)=F8(1,1)+PV
                      F8(1,2)=F8(1,2)+CT
                      F8(III,1)=F8(III,1)+PV
 25                   F8(III,2)=F8(III,2)+CT
                C
                C FORMATS
                  801 FORMAT(3F6.1)
                  802 FORMAT(2F10.2)
 30                   RETURN
                      END



      SYMBOLIC REFERENCE MAP (R=3)

 ENTRY POINTS      DEF LINE      REFERENCES
    4  COST            1            30

 VARIABLES       SN  TYPE              RELOCATION
    6  ANUM          REAL                  USER2        REFS        6
    1  ARRNUM        REAL                  USER2        REFS        6
    0  ATRIB         REAL        ARRAY     GCOM1        REFS        3
   27  AVAIL         REAL        ARRAY     USER4        REFS        7
    0  CT            REAL                   F.P.        REFS       18        23        25   DEFINED        1        17
   44  EINF          REAL                  USER4        REFS        7
    3  F             REAL        ARRAY     USER4        REFS        7
    0  FARY          REAL                  USER11       REFS       10
   02  FC            REAL                               REFS       17    DEFINED       15
    7  FNUM          REAL                  USER2        REFS        6
   74  F10           REAL        ARRAY     USER5        REFS        8
```

```
      SUBROUTINE OUTPUT
      DIMENSION NSET(1000),OCURVE(47),OC(47)
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON QSET(1000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,NNA
     1PO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG,T
     2TCLR,TTFIN,TTRIB(25),TTSET
      COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
     1HMON(12),HYR(12),ADEG(31),STRING(21)
      COMMON/USER2/OLDT,ARRNUM,ICONT,MON,IYR,TNUM,ANUM,FNUM,ORD(60)
      COMMON/USER3/MCLOCK,CLOCK(5),TIME1,TIME2,PVTIME,PMTIME(5)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
C
C CHECK IF SYSTEM SHUTDOWN BETWEEN OLDT AND TNOW
      ISD=0
      SYSOUT=0.0
      SUMST=0.0
      DO 4 I=1,21
    4 SUMST=SUMST+STRING(I)
      FRACT=SUMST/21.0
      DO 5 I=5,13
      IF(F(I).GT.104.0)ISD=1
    5 CONTINUE
C
C UPDATE FAILURE VECTORS
      DO 20 I=1,13
      J=ATRIB(2)-100.
      IF(J.LT.4)GO TO 19
      IF(I.EQ.J)F(J)=ATRIB(2)
      J=J-100
      IF(I.EQ.J)F(J)=0.0
      GO TO 20
   19 K=ATRIB(4)
      J=ATRIB(2)
      IF(I.EQ.J)STRING(K)=0.0
      J=J-100
      IF(I.EQ.J)STRING(K)=1.0
   20 CONTINUE
      IF(ISD.EQ.1)GO TO 25
      SYSOUT=OUT
C
C MODIFY OUTPUT FOR STRING FAILURES
      SYSOUT=SYSOUT*FRACT
C
C MODIFY OUTPUT FOR GENERAL DEGRADATION
      A=OLDT/12.
      B=TNOW/12.
      SYSOUT=SYSOUT*(GTABL(DEGRAD,A,0.0,30.0,30.0)+GTABL(DEGRAD,B,0.0,30
     1.0,30.0))/2.0
```

```
C
C MODIFY OUTPUT FOR MIRROR DEGRADATION
      SYSOUT=SYSOUT*(GTABL(DMIRROR,A,0.0,30.0,3.0)+GTABL(DMIRROR,B,0.0,3
     10.0,3.0))/2.0
C
C MODIFY OUTPUT FOR CELL FAILURES
      SYSOUT=SYSOUT*(GTABL(ADEG,A,0.0,30.0,1.0)+GTABL(ADEG,B,0.0,30.0,1.
     10))/2.0
C
C MODIFY OUTPUT FOR DIRT
      D=PMTIME(1)/12.0
      YOLD=OLDT/12.0
      YTNOW=TNOW/12.0
      A=AMOD(YOLD,D)
      B=AMOD(YTNOW,D)
      SYSOUT=SYSOUT*(GTABL(DIRT,A,0.0,27.0,3.0)+GTABL(DIRT,B,0.0,27.0,3.
     10))/2.0
C
C
C COMPUTE YEARLY OUTPUT FROM OUTPUT CURVE
C TEST INVERTER CAPACITY
      RICAP=OUTI
      MAX=INT(HYR(MCLOCK)/100.)
      FRACT=HYR(MCLOCK)-(MAX*100.0)
      IF(FRACT.NE.0.0) MAX=MAX+1
      DO 35 J=1,47
   35 OCURVE(J)=OUTCURV(MCLOCK,J)*SYSOUT
      ANOUT=0.0
      MAXM1=MAX+1
      DO 40 I=1,MAXM1
      IF(OCURVE(I).GT.RICAP.AND.OCURVE(I+1).GT.RICAP)GO TO 48
      IF(OCURVE(I).GT.RICAP.AND.OCURVE(I+1).LT.RICAP)GO TO 45
      ADD=100.0*(OCURVE(I)+OCURVE(I+1))/2.0
      ANOUT=ANOUT+ADD
      GO TO 40
   45 ADD1=(RICAP-OCURVE(I+1))/(OCURVE(I)-OCURVE(I+1))*(RICAP+OCURVE(I+1
     1))/2.0
      ADD2=(OCURVE(I)-RICAP)/(OCURVE(I)-OCURVE(I+1))*RICAP
      ADD=100.*(ADD1+ADD2)
      ANOUT=ANOUT+ADD
      GO TO 40
   48 ADD=100.*RICAP
      ANOUT=ANOUT+ADD
   40 CONTINUE
C
C COMPUTE AVAILABILITY LEVEL
   46 TIM=TNOW-OLDT
      DO 36 J=1,MAX
      OC(J)=AMIN1(OCURVE(J),RICAP)/AMIN1(OUT,OUTI)
      IF(OC(J).GT.1.0)OC(J)=1.0
   36 CONTINUE
      TEST=0.90
      J=1
```

```
   38 IF(OC(1).GE.TEST)GO TO 37
      J=J+1
      TEST=TEST-0.1
      GO TO 38
   37 DO 140 K=2,MAX
      DIFF=(OC(K-1)-OC(K))
      IF (DIFF.NE.0) GO TO 135
      STHEO = 1.0
      GO TO 136
  135 STHEO=(OC(K-1)-AMAX1(TEST,OC(K)))/DIFF
  136 AVAIL(J)=AVAIL(J)+STHEO*TIM
      IF(OC(K).GE.TEST) GO TO 140
      TEST=TEST - .10
      J=J+1
      AVAIL(J)=AVAIL(J)+(1.0-STHEO)*TIM
  140 CONTINUE
C
C COMPUTE PRESENT VALUE OF OUTPUT
      SYSOUT=ANOUT/12.0*(TNOW-OLDT)
      PVOUT=SYSOUT/(1.+RDISC)**(TNOW/12.)*(1.+EINF)**(TNOW/12.)
      GO TO 41
   25 PVOUT=0.0
      SYSOUT=0.0
      TIM=TNOW-OLDT
      AVAIL(10)=AVAIL(10)+TIM*34.0
C
C ADD OUTPUT TO CUMMULATIVE TOTALS
   41 III=IYR+1
      F9(1,1)=F9(1,1)+PVOUT
      F9(1,2)=F9(1,2)+SYSOUT
      F9(III,1)=F9(III,1)+PVOUT
      F9(III,2)=F9(III,2)+SYSOUT
C
C PRINTOUT OUTPUTS
      I=TNOW
      R=I
      R=30.*(TNOW-R)
      IDAY=R
      IDAY=IDAY+1
      IF(FLAG1.EQ.0)PRINT802,MON,IDAY,IYR,SYSOUT,PVOUT
      IF(FLAG1.EQ.0)PRINT*,≠ ≠
      OLDT=TNOW
C
C FORMATS
  801 FORMAT(2F10.2)
  802 FORMAT(15X,≠THE SYSTEM OUTPUT IN KWHR FROM THE LAST EVENT TO≠,1X,A
     110,I2,≠, YEAR ≠,I2,≠ WAS (ACT-PV)≠,21X,F8.0,1X,F8.0)
      RETURN
      END
```

```
      SUBROUTINE BILITY
      COMMON/USER1/DEGRAD(2),DIRT(10),DMIRROR(11),OUTCURV(12,47),
     1HMON(12),HYR(12)
      COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER9/THEO(10),OC(47)
      TOTHRS=0.0
      DO 30 I=1,12
   30 TOTHRS=TOTHRS+HMON(I)
      NYRSP=NYRS+1
      TOT30 = 0.0
      DO 5 I=1,10
    5 F11(NYRSP,I)=0.0
      DO 50 I=2,NYRSP
      DO 40 K=1,10
   40 F11(NYRSP,K)=F11(NYRSP,K)+F10(I,K)
C
C           CALCULATE TOTAL AVAILABLE TIME
      TOT=0.
         DO 20 KK=1,10
   20    TOT = TOT + F10(I,KK)
         TOT30=TOT30 + TOT
C
C           CALCULATE PECENTAGE AVAILABILITY
         F11(I-1,11)=0.0
         DO 10 KK=1,10
         F11(I-1,KK)=(F10(I,KK)/TOT)*100.
   10    F11(I-1,11)=F11(I-1,11)+F11(I-1,KK)
   50 CONTINUE
C
C     CALCULATE PECENTAGE AVAILABILITY FOR FULL THIRTY YEARS
      F11(NYRSP,11)=0.0
      DO 60 I=1,10
      F11(NYRSP,I)=(F11(NYRSP,I)/TOT30)*100.
   60 F11(NYRSP,11)=F11(NYRSP,11)+F11(NYRSP,I)
      RETURN
      END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

 ENTRY POINTS     DEF LINE     REFERENCES
     2  BILITY          1          38

 VARIABLES      SN  TYPE              RELOCATION
    27  AVAIL       REAL         ARRAY    USER4        REFS        4
     0  DEGRAD      REAL         ARRAY    USER1        REFS        2
     2  DIRT        REAL         ARRAY    USER1        REFS        2
```

```
      SUBROUTINE UPLOT(CTOT,PVTOT,CCKWH,PVCKWH)
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      DIMENSION ZERO(30)
      DIMENSION    CTOT(30),PVTOT(30),CCKWH(30),PVCKWH(30)
      DIMENSION DASHL(30)
      DIMENSION YR(30)
      DIMENSION IWORK(50)
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/JUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USFR7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/GCOM5/IIFVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNCFI,
     1NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(5)
      COMMON/PLOTC/APCKWH
      Y=0.0
      YRSN=NYRS
      NYRSP=NYRS+1
      DO 10 I=2,NYRSP
       YP(I-1)=Y+1
       Y=Y+1.0
   10  ZERO(I-1)=0.
      CMXOUT=CTOT(1)
      PMXOUT=PVTOT(1)
      CMXCST=CCKWH(1)
      PMXCST=PVCKWH(1)
      DO 60 I=1,NYRS
      IF (CTOT(I).GT.CMXOUT) CMXOUT=CTOT(I)
      IF (PVTOT(I).GT.PMXOUT) PMXOUT=PVTOT(I)
      IF (CCKWH(I).GT.CMXCST) CMXCST=CCKWH(I)
   60 IF (PVCKWH(I).GT.PMXCST) PMXCST=PVCKWH(I)
* ... PLOT CURRENT OUTPUT
      CALL BGNPL(0)
      CALL NEWPEN(2)
      CALL HEIGHT(.10)
      CALL TITLE(1H ,-1,≠YEAR≠,4,≠OUTPUT IN MWH (BAR GRAPH)≠,25,9.,6.)
      CALL NEWPEN(2)
      CALL HEADIN(≠COST BY YEAR≠,12,2,2)
      CALL NEWPEN(1)
      CALL HEADIN(≠SYSTEM OUTPUT BY YEAR≠,21,2,2)
      CALL INTAXS
      CALL NEWPEN(2)
      CALL GRAF(0,1.,YRSN,0,≠SCALE≠,CMXOUT)
      CALL BARSHD(YR,ZERO,CTOT,NYRS,.15,0.,1.,0.,IWORK,50)
      CALL NEWPEN(1)
      CALL YGRAXS(0.,≠SCALE≠,CMXCST,6.,≠COST IN THOUSANDS OF DOLLARS (LI
     1NE GRAPH)≠,41,-0.6,0.)
      CALL THICRV(4)
      CALL CURVE(YR,CCKWH,NYRS,0)
      CALL ENDPL(0)
* ... PLOT PRESENT VALUE OUTPUT
      CALL BGNPL(0)
      CALL NEWPEN(2)
      CALL HEIGHT(.10)
```

```
                              CALL TITLE(1H ,-1,≠YEAR≠,4,≠LEVELIZED CENTS/KWH (BAR GRAPH)≠,31,9.
   55                        1,6.)
                              CALL NEWPEN(2)
                              CALL HEADIN(≠PRESENT VALUE COST BY YEAR≠,26,2,2)
                              CALL NEWPEN(1)
                              CALL HEADIN(≠LEVELIZED CENTS/KWH BY YEAR≠,27,2,2)
   60                         CALL INTAXS
                              CALL NEWPEN(2)
                              CALL GRAF(0,1.,YRSN,0,≠SCALE≠,PMXCST)
                              CALL BARSHD(YR,ZERO,PVCKWH,NYRS,.15,0.,1.,0.,IWORK,50)
                              DO 20 I=1,NYRS
   65                      20 DASHL(I)=APCKWH
                              CALL DASH
                              CALL THICRV(4)
                              CALL CURVE(YR,DASHL,NYRS,0)
                              CALL RESET(≠DASH≠)
   70                         CALL RESET(≠THICRV≠)
                              CALL NEWPEN(1)
                              CALL YGRAXS(0.,≠SCALE≠,PMXOUT,6.0,≠PRESENT VALUE COST IN THOUSANDS
                             1 OF DOLLARS (LINE GRAPH)≠,55,-0.6,0.)
                              CALL THICRV(4)
   75                         CALL CURVE(YR,PVTOT,NYRS,0)
                              CALL ENDPL(0)
                              RETURN
                              END
```

```
   SYMBOLIC REFERENCE MAP (R=3)

E  RY POINTS     DEF LINE     REFERENCES
    4  UPLOT        1            77

V  IABLES      SN  TYPE              RELOCATION
    0  APCKWH      REAL                    PLOTC          REFS      14        65
    0  CCKWH       REAL        ARRAY        F.P.          REFS       4        24        2*29        48   DEFINED        1
   34  CMXCST      REAL                                   REFS      29        45     DEFINED        24         29
   32  CMXOUT      REAL                                   REFS      27        42     DEFINED        22         27
    0  CTOT        REAL        ARRAY        F.P.          REFS       4        22        2*27        43   DEFINED        1
   74  DASHL       REAL        ARRAY                      REFS       5        68     DEFINED        65
    0  FLAG1       INTEGER                 USER7          REFS       2        11
    1  FLAG2       INTEGER                 USER7          REFS       2        11
    2  FLAG3       INTEGER                 USER7          REFS       2        11
    3  FLAG4       INTEGER                 USER7          REFS       2        11
    4  FLAG5       INTEGER                 USER7          REFS       2        11
    5  FLAG6       INTEGER                 USER7          REFS       2        11
    4  FMT         REAL        ARRAY       USER6          REFS      10
   74  F10         REAL        ARRAY       USER5          REFS       8
   62  F11         REAL        ARRAY       USER5          REFS       8
   07  F12         REAL        ARRAY       USER5          REFS       8
   34  F14         REAL        ARRAY       USER5          REFS       8
```

```
      SUBROUTINE COTABLE     74/74    OPT=1 TRACE                              FTN 4.8+518         11/20/81  08.53.09          PAGE      1

       1                       SUBROUTINE COTABLE
                               COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
                              1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
                               COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
       5                       COMMON/PLOTC/APCKWH
                               NYRSP=NYRS+1
                               F14(NYRSP,1)=0.0
                               F14(NYRSP,2)=0.0
                               F14(NYRSP,3)=0.0
      10                       F14(NYRSP,4)=0.0
                               F14(NYRSP,5)=0.0
                               DO 10 I=1,NYRS
                               F14(I,1)=F8(I+1,2)
                               F14(I,2)=F9(I+1,2)
      15                       F14(I,3)=(F8(I+1,2)/F9(I+1,2))*100.
                               F14(I,4)=F8(I+1,1)
                               F14(I,5)=F9(I+1,1)
                               F14(I,6)=(F8(I+1,1)/F9(I+1,1))*100.
                               F14(NYRSP,1)=F14(NYRSP,1)+F8(I+1,2)
      20                       F14(NYRSP,2)=F14(NYRSP,2)+F9(I+1,2)
                               F14(NYRSP,4)=F14(NYRSP,4)+F8(I+1,1)
                            10 F14(NYRSP,5)=F14(NYRSP,5)+F9(I+1,1)
                               F14(NYRSP,6)=(F14(NYRSP,4)/F14(NYRSP,5))*100.
                               APCKWH = F14(NYRSP,6)
      25                       RETURN
                               END


     SYMBOLIC REFERENCE MAP (R=3)

 E  RY POINTS     DEF LINE      REFERENCES
     2  COTABLE       1            25

 V  IABLES      SN  TYPE             RELOCATION
     0  APCKWH       REAL                    PLOTC         REFS         5    DEFINED        24
     4  FMT          REAL        ARRAY       USER6         REFS         4
    74  F10          REAL        ARRAY       USER5         REFS         2
    62  F11          REAL        ARRAY       USER5         REFS         2
    07  F12          REAL        ARRAY       USER5         REFS         2
   134  F14          REAL        ARRAY       USER5         REFS         2       19        20        21        22      2*23        24
                                                        DEFINED         7        8         9        10        11        13        14
                                                             15        16       17        18        19        20        21        22
                                                             23
    26  F15          REAL        ARRAY       USER5         REFS         2
    20  F16          REAL        ARRAY       USER5         REFS         2
    33  F17          REAL        ARRAY       USER5         REFS         2
     0  F8           REAL        ARRAY       USER5         REFS         2       13        15        16        18        19        21
    76  F9           REAL        ARRAY       USER5         REFS         2       14        15        17        18        20        22
    44  I            INTEGER                               REFS      2*13     2*14      3*15      2*16      2*17      3*18        19
                                                             20        21       22   DEFINED        12
```

```
    1                       SUBROUTINE FAILTAB
                            COMMON/USER4/RINF,RDISC,OUT,F(20),AVAIL(10),REP,IFNUM(15,30),EINF
                            COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
                           1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
    5                       INTEGER F16
                            COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
                            NYRSP=NYRS+1
                            NCOMPP=NCOMP+1
                            DO 10 I=1,NCOMPP
   10                    10 F16(I,NYRSP)=0
                            DO 15 J=1,NYRSP
                         15 F16(NCOMPP,J)=0
                            DO 30 I=1,NCOMP
                            DO 20 J=1,NYRS
   15                       F16(I,J)=IFNUM(I,J)
                            F16(I,NYRSP)=F16(I,NYRSP)+IFNUM(I,J)
                         20 F16(NCOMPP,J)=F16(NCOMPP,J)+IFNUM(I,J)
                         30 F16(NCOMPP,NYRSP)=F16(NCOMPP,NYRSP)+F16(I,NYRSP)
                            RETURN
   20                       END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

 E     Y POINTS      DEF LINE      REFERENCES
     2  FAILTAB          1          19

 V     ABLES      SN  TYPE               RELOCATION
     7  AVAIL       REAL        ARRAY     USER4          REFS         2
     4  EINF        REAL                  USER4          REFS         2
     3  F           REAL        ARRAY     USER4          REFS         2
     4  FMT         REAL        ARRAY     USER6          REFS         6
    74  F10         REAL        ARRAY     USER5          REFS         3
     2  F11         REAL        ARRAY     USER5          REFS         3
     7  F12         REAL        ARRAY     USER5          REFS         3
     4  F14         REAL        ARRAY     USER5          REFS         3
     6  F15         REAL        ARRAY     USER5          REFS         3
     0  F16         INTEGER     ARRAY     USER5          REFS         3        5       16       17       2*18
                                                      DEFINED        10       12       15       16       17        18
     3  F17         REAL        ARRAY     USER5          REFS         3
     0  F8          REAL        ARRAY     USER5          REFS         3
     6  F9          REAL        ARRAY     USER5          REFS         3
     7  I           INTEGER                              REFS         10      2*15     3*16      17       18
                                                      DEFINED        9        13
     2  IFNUM       INTEGER     ARRAY     USER4          REFS         2       15       16       17
     0  J           INTEGER                              REFS         12      2*15      16      3*17   DEFINED        11        14
     3  NCOMP       INTEGER               USER6          REFS         6        8       13
     6  NCOMPP      INTEGER                              REFS         9       12      2*17     2*18   DEFINED         8
     2  NYRS        INTEGER               USER6          REFS         6        7       14
        NYRSP       INTEGER                              REFS         10      11      2*16     3*18   DEFINED         7
```

```
  SUBROUTINE BILRITE    74/74    OPT=1 TRACE                        FTN 4.8+518        11/20/81  08.53.09        PAGE      1

   1                    SUBROUTINE BILRITE(F13)
                        DIMENSION F13(31,11)
                        COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
                       1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
   5                    COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
                        COMMON/USER9/THEO(10),OC(47)
                C
                C WRITE PAGE AND COLUMN HEADINGS
                C
  10                    WRITE(6,800)
                        WRITE(6,801) OUTI,TOTHRS
                        WRITE(6,804) (THEO(I),I=1,10)
                        DO 10 I=1,NYRS
                     10 WRITE(6,802) I,(F13(I,J),J=1,11)
  15                    WRITE(6,803)((F13(NYRS+1,J),J=1,11))
                C
                C FORMATS
                    800 FORMAT(1H1,//////////)
                    801 FORMAT(1H ,45X,42HANNUAL SYSTEM AVAILABILITY DURING DAYLIGHT,/1H ,
  20                   150X,31HAS A PERCENT OF SYSTEM CAPACITY,/1H0,30X,18HSYSTEM CAPACITY
                       1 = ,F5.1,3H KW,6X,36HNUMBER OF DAYLIGHT HOURS PER YEAR = ,F6.1,//1
                       1H0, 7X,4HYEAR,7X,7H100-90%,4X,6H90-80%,4X,6H80-70%,4X,6H70-60%,4X,
                       16H60-50%,4X,6H50-40%,4X,6H40-30%,4X,6H30-20%,4X,6H20-10%,5X,5H10-0
                       1%, 9X,5HTOTAL,/)
  25                802 FORMAT(1H , 9X,I2,8X,10(F6.2,4X),5X,F6.2)
                    803 FORMAT(/1H , 6X,7HAVERAGE,6X,10(F6.2,4X),4X,F6.2)
                    804 FORMAT(1H0,3X,11HTHEORETICAL,5X,10(F6.2,4X),4X,6H100.00,/)
                        RETURN
                        END



  SYMBOLIC REFERENCE MAP (R=3)

Y POINTS     DEF LINE      REFERENCES
4  BILRITE        1           28

ABLES      SN  TYPE            RELOCATION
4   FMT        REAL        ARRAY    USER6        REFS          5
4   F10        REAL        ARRAY    USER5        REFS          3
2   F11        REAL        ARRAY    USER5        REFS          3
7   F12        REAL        ARRAY    USER5        REFS          3
0   F13        REAL        ARRAY     F.P.        REFS          2          14          15    DEFINED          1
4   F14        REAL        ARRAY    USER5        REFS          3
6   F15        REAL        ARRAY    USER5        REFS          3
0   F16        REAL        ARRAY    USER5        REFS          3
3   F17        REAL        ARRAY    USER5        REFS          3
0   F8         REAL        ARRAY    USER5        REFS          3
6   F9         REAL        ARRAY    USER5        REFS          3
1   I          INTEGER                           REFS         12        2*14   DEFINED        12          13
2   J          INTEGER                           REFS         14          15   DEFINED        14          15
```

```
      SUBROUTINE CORITE      74/74    OPT=1 TRACE                       FTN 4.8+518        11/20/81  08.53.09        PAGE     1

       1                       SUBROUTINE CORITE(F18)
                               DIMENSION F18(31,6)
                               COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
                               NYRSP=NYRS+1
       5                       WRITE(6,800)
                               WRITE(6,801)
                               DO 10 I=1,NYRS
                            10 WRITE(6,802) I,(F18(I,J),J=1,6)
                               WRITE(6,803) (F18(NYRSP,J),J=1,2),(F18(NYRSP,J),J=4,6)
      10                C
                        C FORMATS
                          800 FORMAT(1H1,//////////)
                          801 FORMAT(1H ,48X,34HANNUAL MAINTENANCE COST AND OUTPUT,///1H ,38X,13
                             1HCURRENT VALUE,29X,13HPRESENT VALUE,/1H0,14X,4HYEAR,9X,8HCOST ($),
      15                     27X,3HKWH,6X,9HCENTS/KWH,10X,8HCOST ($),7X,3HKWH,6X,9HCENTS/KWH,//)
                          802 FORMAT(1H ,15X,I2,10X,F8.2,3X,F9.0,5X,F5.2,13X,F8.2,3X,F9.0,5X,F5.
                             12)
                          803 FORMAT(//1H ,13X,6HTOTALS,5X,F11.2,3X,F9.0,20X,F11.2,3X,F9.0,6X,F4
                             1.2,12H (LEVELIZED))
      20                       RETURN
                               END


      SYMBOLIC REFERENCE MAP (R=3)

  ENTRY POINTS      DEF LINE     REFERENCES
      4  CORITE          1           20

  VARIABLES        SN  TYPE              RELOCATION
      4  FMT           REAL          ARRAY    USER6       REFS         3
      0  F18           REAL          ARRAY     F.P.       REFS         2            8           2*9   DEFINED          1
    164  I             INTEGER                            REFS       2*8   DEFINED          7
    165  J             INTEGER                            REFS         8          2*9   DEFINED         8           2*9
      3  NCOMP         INTEGER                USER6       REFS         3
      2  NYRS          INTEGER                USER6       REFS         3            4           7
    163  NYRSP         INTEGER                            REFS       2*9   DEFINED          4
      0  OUTI          REAL                   USER6       REFS         3
      1  RNS           REAL                   USER6       REFS         3
     10  TOTHRS        REAL                   USER6       REFS         3

  FILE NAMES           MODE
         TAPE6         FMT                     WRITES          5          6           8           9

  STATEMENT LABELS                 DEF LINE    REFERENCES
      0  10                           8            7
    116  800        FMT              12            5
    121  801        FMT              13            6
    143  802        FMT              16            8
      2  803        FMT              18            9
```

```
      SUBROUTINE FAILRIT(F19)
      INTEGER F19
      DIMENSION F19(21,31)
      DIMENSION NYR(30)
      DIMENSION FTYPE(30)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      DATA FTYPE/≠A MODULE G≠,≠ROUP≠,≠A DISCONNE≠,≠CT SWITCH≠,≠A BIPASS
     1D≠,≠IODE≠,≠A SHUNT RE≠,≠SISTOR≠,≠AN INVERTE≠,≠R≠,≠THE SWITCH≠,≠GEA
     2R≠,≠WIRING/SWI≠,≠TCHES≠,≠THE DISTRI≠,≠BUTION SYS≠,≠THE 3 PHAS≠,≠E
     3X-FORMER≠,≠THE INVERT≠,≠ER CONTROL≠,≠THE UTILIT≠,≠Y≠/
      NYRSP=NYRS+1
      NCOMPP=NCOMP+1
      FMT(1)=≠(1H+,27X,  ≠
      FMT(3)=≠(I2,1X),4X≠
      FMT(4)=≠,5HTOTAL/)≠
      WRITE(6,800)
      WRITE(6,801)
      DO 10 I=1,NYRS
   10 NYR(I)=I
      WRITE(6,FMT)(NYR(I),I=1,NYRS)
      FMT(4)=≠,I4)      ≠
      DO 30 I=1,NCOMP
C
C *** NO MODULE GROUP FAILURES HAVE OCCURRED BECAUSE OF DEGRADATION
      IF(I.EQ.1)GO TO 30
      K=(2*I)-1
      WRITE(6,802) FTYPE(K),FTYPE(K+1)
      WRITE(6,FMT)(F19(I,J),J=1,NYRSP)
   30 CONTINUE
      WRITE(6,803)
      FMT(3)=≠(I3,3X)    ≠
      FMT(4)=≠ ≠
      WRITE(6,FMT)(F19(NCOMPP,J),J=1,NYRS,2)
      FMT(1)=≠(1H ,27X, ≠
      FMT(3)=≠(3X,I3)    ≠
      WRITE(6,FMT)(F19(NCOMPP,J),J=2,NYRS,2)
      FMT(1)=≠(1H+,27X, ≠
      FMT(3)=≠(3X),4X,I4≠
      FMT(4)=≠)≠
      WRITE(6,FMT) F19(NCOMPP,NYRSP)
C
C FORMATS
  800 FORMAT(1H1,//////////)
  801 FORMAT(1H ,54X,23HCOMPONENT FAILURE TABLE,//1H ,45X,40HNUMBER OF F
     1AILURES PER COMPONENT BY YEAR,///////1H ,5X,22HCOMPONENT      YEAR
     2 = )
  802 FORMAT(1H0,2A10)
  803 FORMAT(/1H0,10X,6HTOTALS)
      RETURN
      END
```

```
      SUBROUTINE REPORT
      INTEGER F16,F17
      INTEGER FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      DIMENSION CF(30),PVF(30),CCF(30),PVCF(30)
      DIMENSION   CTOT(30),PVTOT(30),CCKWH(30),PVCKWH(30)
      COMMON/GCOM5/IIFVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNCFI,
     1NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON/USER5/F8(31,2),F9(31,2),F10(31,10),F11(31,11),F12(31,11),
     1F14(31,6),F15(31,6),F16(21,31),F17(21,31)
      COMMON/USER6/OUTI,RNS,NYRS,NCOMP,FMT(4),TOTHRS
      COMMON/USER7/FLAG1,FLAG2,FLAG3,FLAG4,FLAG5,FLAG6
      COMMON/USER10/CS(30),PVS(30),CCS(30),PVCS(30)
      IF(NNRUN.EQ.1)  RNS =NNRNS
C
C   IF FLAG5=1 INITIALIZE ARRAYS FOR INDIVIDUAL SIMULATION PLOT
      NYRSP=NYRS+1
      NCOMPP=NCOMP+1
      CALL BILITY
      CALL FAILTAB
      CALL COTABLE
      IF(.NOT.(FLAG4.EQ.1 .OR. FLAG4.EQ.3)) GO TO 85
      CALL BILRITE(F11)
      CALL CORITE(F14)
      CALL FAILRIT(F16)
   85 DO 86 I=1,NYRSP
      DO 86 J=1,6
   86 F15(I,J)=F15(I,J)+(F14(I,J)/RNS)
      DO 87 I=1,NCOMPP
      DO 87  J=1,NYRSP
   87 F17(I,J)=F17(I,J)+F16(I,J)
      DO 90 I=1,NYRSP
      DO 90 J=1,11
   90 F12(I,J)=F12(I,J)+(F11(I,J)/RNS)
      IF(NNRNS.GT.1) GO TO 110
      IF(FLAG4.EQ.0 .OR. FLAG4 .EQ.1) GO TO 88
      CALL BILRITE(F12)
      CALL CORITE(F15)
      CALL FAILRIT(F17)
   88 IF(FLAG1.EQ.0) GO TO 105
      READ(9,802) PRNS,((F11(I,J),J=1,11),I=1,NYRSP)
      READ(10,803)((F14(I,J),J=1,6),I=1,NYRSP)
      READ(11,804)((F16(I,J),J=1,NYRSP),I=1,NCOMPP)
      FAC1=RNS/(RNS+PRNS)
      FAC2=PRNS/(RNS+PRNS)
      DO 100 I=1,NYRSP
      DO 89 J=1,6
   89 F15(I,J)= FAC1*F15(I,J) + FAC2*F14(I,J)
      DO 91 J=1,NCOMPP
   91 F17(J,I)=F16(J,I)+F17(J,I)
      DO 100 J=1,11
  100 F12(I,J)=FAC1*F12(I,J) + FAC2*F11(I,J)
      IF(FLAG4 .EQ. 0) GO TO 105
      CALL BILRITE(F11)
```

```
      CALL CWRITE(F14)
      CALL FAILRIT(F16)
  105 IF(.NOT.(FLAG2.GE.2 .AND. NNRNS.EQ.1)) GO TO 110
      WRITE(9,802) RNS,((F12(I,J),J=1,11),I=1,NYRSP)
      WRITE(10,803)((F15(I,J),J=1,6),I=1,NYRSP)
      WRITE(11,804)((F17(I,J),J=1,NYRSP),I=1,NCOMPP)
  110 CONTINUE
      DO 10 I=2,NYRSP
      CTOT(I-1) =F9(I,2)/1000.
      PVTOT(I-1)=F8(I,1)/1000.
      CCKWH(I-1)=F8(I,2)/1000.
   10 PVCKWH(I-1)=(F8(I,1)/F9(I,1))*100.
      IF(FLAG5.EQ.1 .OR. FLAG5.EQ.3) CALL UPLOT(CTOT,PVTOT,CCKWH,PVCKWH)
C
C     ACCUMULATE VALUES FOR MULTIPLE SIMULATIONS
C
      DO 20 I=1,NYRS
      CS(I)=CS(I)+(CTOT(I)/RNS)
      PVS(I)=PVS(I)+(PVTOT(I)/RNS)
      CCS(I)=CCS(I)+(CCKWH(I)/RNS)
   20 PVCS(I)=PVCS(I)+(PVCKWH(I)/RNS)
C
C     IF ALL SIMULATIONS COMPLETED PLOT SUMMARY
C
      IF(NNRUN .EQ. 1) GO TO 25
      IF(NNRNS.GT.1) GO TO 80
      IF(FLAG5.GE.2) CALL UPLOT(CS,PVS,CCS,PVCS)
   25 IF(FLAG1.EQ.0) GO TO 60
C
C     IF DATA STORED ON FILE FROM PREVIOUS RUNS IS TO BE INCORPORATED IN
C     SUMMARY REPORT, READ FILE, ADD TO DATA FROM CURRENT RUN, AND PLOT
C
      READ(8,800) PRNS,(CF(I),PVF(I),CCF(I),PVCF(I),I=1,NYRS)
      FAC1 = RNS/(RNS+PRNS)
      FAC2 = PRNS/(RNS+PRNS)
      DO 30 I=1,NYRS
      CS(I) = FAC1*CS(I) + FAC2*CF(I)
      PVS(I) = FAC1*PVS(I) + FAC2*PVF(I)
      CCS(I) = FAC1*CCS(I) + FAC2*CCF(I)
   30 PVCS(I) = FAC1*PVCS(I) + FAC2*PVCF(I)
      IF (FLAG5.NE.0) CALL UPLOT(CS,PVS,CCS,PVCS)
   60 IF((FLAG2.EQ.1.OR.FLAG2.EQ.3).AND.NNRNS.EQ.1) WRITE(8,800)
     1RNS,(CS(I),PVS(I),CCS(I),PVCS(I),I=1,NYRS)
   80 CONTINUE
C
C FORMATS
  800 FORMAT(F5.0,120F10.2)
  802 FORMAT(F5.0,341F10.2)
  803 FORMAT(186F11.2)
  804 FORMAT(651I4)
      RETURN
      END
```

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