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SUMMARY

A computer program MCFLARE that uses Monte Carlo methods to simulate solar flare occurrences during an interplanetary space voyage is described. The total biological dose inside a shielded crew compartment due to the flares encountered during the voyage is determined. The computer program evaluates the doses obtained on a large number of trips having identical trajectories. From these results, a dose D_p having a probability p of not being exceeded during the voyage can be determined as a function of p for any shield material configuration.

The user of the code selects any number of solar flares considered to be representative of the ones that will occur during future solar active periods (these flares are generally selected from the flares that occurred during the last solar active period 1956 to 1962). The flares are assumed to occur randomly during these periods. The dose at a distance of 1 astronomical unit (1.496×10^8 km) from the Sun from each of these flares behind any shield configuration investigated is input to the MCFLARE code. The code accounts for the dependence of the dose received from a flare on the distance from the Sun according to a $(1/r)^{\alpha}$ variation, where r is the distance from the Sun and the exponent α can be assigned any integral value including zero. From trajectory parameters, which are input to the computer program, the distance from the Sun as a function of time during the trip is calculated.

To illustrate the use of the code, a trip to Mars and return is calculated, and estimated doses behind several thicknesses of aluminum shield and water shield are presented. A FORTRAN IV listing, data input instructions, and sample output are given.

INTRODUCTION

The protons emitted by solar flares are the most hazardous source of space radiation encountered on an interplanetary space voyage which rapidly traverses the Van Allen belts. To define shielding requirements for biological protection from solar flare protons encountered in manned interplanetary missions, a computer program MCFLARE has been prepared which uses Monte Carlo methods to simulate solar flare occurrences during the trip and records the total associated biological doses for the trip behind various shield material configurations.

A set of flare events, considered to be representative of those that will occur during future solar active periods, is required. Generally, this set is selected from the flares that occurred during the last solar active period from 1956 to 1962. The flares are assumed to occur randomly during the trip (which is assumed to take place during the solar active period). The doses behind the various shield configurations investigated have to be evaluated for each flare, at a distance of 1 astronomical unit (1.496×10^8 km) from the Sun, by using another computer code such as one of those described in references 1 or 2. (Reference 3 presents doses from solar flare proton spectra behind two shield materials as calculated by using reference 1.) These dose values are input to the computer program MCFLARE. This program provides for including the dependence of the magnitude of the dose received from the flare on the distance r from the Sun. This dependence is taken to be of the form $(r_o/r)^\alpha$, where r_o is the distance between the Sun and the Earth, and the exponent α can be any arbitrarily selected integer including zero.

The Monte Carlo procedure (analogous to particle transport Monte Carlo) is used to determine when flares are encountered on the trip, which of the input flares occur, and the total dose obtained from all flares encountered during the trip behind each shield configuration. The computer program tallies the doses obtained for a large number of trips having identical trajectories and from this, the distribution of doses incurred on the mission for each shield configuration is obtained. Each dose distribution determines a dose D_p having the probability p of not being exceeded as a function of p.

METHOD OF ANALYSIS

Any N flare events can be selected as representative of the flare activity that will occur during the space voyage. The doses from each flare at a distance of 1 astronomical unit (1.496×10^8 km) from the Sun behind one or more shield material configurations investigated are input to the computer. Each flare is assumed to occur randomly on the average of once during the solar active period T_{ref}, which is of the order of 2000 days or $5\frac{1}{2}$ years.

Monte Carlo Method to Determine Occurrences of Flares During Trip

Inasmuch as flares are assumed to occur randomly in the solar active period, the probability of any flare occurring in the time interval dt is $(N/T_{ref})dt \equiv \mu\, dt$. Then the probability of no flare occurring for time t is $e^{-\mu t}$ and the probability of a flare occurring in dt at time t is $e^{-\mu t}\mu\, dt$.

In the Monte Carlo method, this probability of flare occurrence in the time interval dt at time t is equated to the probability of selecting a random number in an interval $d\xi$ about ξ. If a random number set uniformly distributed in the interval (0, 1) is selected, then the probability of selecting a random number in $d\xi$ about ξ is $d\xi$. Equating these two probabilities, one gets

$$e^{-\mu t}\mu\, dt = d\xi$$

$$\int_0^t e^{-\mu t'}\mu\, dt' = \int_0^\xi d\xi'$$

$$t = -\frac{1}{\mu}\ln(1 - \xi)$$

Inasmuch as both ξ and $1 - \xi$ are uniformly distributed in the interval (0, 1) an equivalent expression for t which results in the same exponential distribution is

$$t = -\frac{1}{\mu}\ln \xi \tag{1}$$

By selecting a random number from a uniformly distributed set in the interval (0, 1) the time between flare events is obtained from equation (1).

When an event has occurred, a particular flare of one of the N is also selected by random numbers. The i^{th} flare occurs when a new random number occurs in the interval

$$\frac{i - 1}{N} < \xi \leq \frac{i}{N} \qquad i = 1, 2, \ldots, N \tag{2}$$

Dose values input to the code are calculated by using the methods of reference 1, or 2, for each representative flare using the solar flare proton intensity and spectral shape as observed at the Earth. The code permits an effect of the distance from the Sun on the dose (or intensity) received from a flare of the form $(r_o/r)^\alpha$ where r_o is the distance from the Sun to the Earth, r is the distance of the spacecraft from the Sun during the flare, and α is an exponent that is assigned any interger value including zero.

The code evaluates r for any time during the trip by calculating the mission trajectory from input parameters describing the two transfer ellipses and the total trip time. The first ellipse is the trajectory from the Earth to the planet and the second describes the return trip. Details of determining position as a function of time are presented in appendix A.

The calculation proceeds as follows: Selecting a random number and using equation (1) determines the time in the mission when a flare occurs. Selecting another random number and using equation (2) determines the particular flare which occurs. Knowing the time in the mission (and, hence, distance from the Sun) and the particular flare, the dose received through each shield configuration is tallied. The duration of the flare event is then added to the time in the mission when the flare occurred to give the time when the event is over. From a new random number and equation (1), the time elapsed until the next flare occurs is calculated, and so on. This procedure is repeated until the total trip time has elapsed. The total dose from all flare events encountered on the trip is determined for each of the shields considered.

Selection of D_p

This procedure is repeated for a large number M of trips of identical trajectory. The code divides the dose range into dose intervals that are 1 dose unit wide and tabulates the number of trips $\Lambda(D)$ during which doses that lie within each dose interval are encountered. The cumulative fraction of the total trips that encounter doses less than the upper dose bound of each interval is also tabulated (this is an estimate of the probability p that a dose equal to the upper dose bound will not be exceeded). From this tabulation, for any specified p, a dose D_p which has the probability p of not being exceeded on the trip can be selected for any shield. The standard deviation of this value from the true value is shown in appendix B to be

$$\sigma_{D_p} = \sqrt{\frac{p(1 - p)}{Mf^2(D_p)}} \tag{B6}$$

where M is the number of trips in the group investigated, and $f(D_p)$ is the dose probability density at D_p (which is calculated from the tabulated output). If $\Lambda(D_p)$ is the number of trips contained in the interval in which D_p occurs, $f(D_p)$ is approximately given by

$$f(D_p) = \frac{\Lambda(D_p)}{M}$$

If $\Lambda(D)$ is a widely fluctuating value in the vicinity of D_p, averaged values of $\Lambda(D)$ can be hand calculated, and $f(D_p)$ is obtained from the averaged value of $\Lambda(D_p)$. Note that for a given p, because $f(D_p)$ is independent of the number of trips, σ_{D_p} varies inversely as $\sqrt{M}$.

To reduce the uncertainty associated with D_p for a given number of trips, the code is written so that the trips constitute a stratified sample for the time-to-first-flare selected in accordance with the exponential distribution $\exp[-(Nt/T_{ref})]$. This technique is described in appendix C.

ILLUSTRATIVE EXAMPLE

An interplanetary trip to Mars and return has been evaluated in order to illustrate details of the method and to present some representative shield requirements for such a mission. Water and aluminum were the shield materials considered.

Selection of Flare Events

The flare occurrences during the last solar active period 1956 to 1962 are assumed to be representative of those that will occur during a future active period. Webber in reference 4 has compiled a record of these flares, their time-integrated proton intensities, and spectra. From these records, the 20 largest flares, based on proton intensity, were selected (the effect of neglecting the rest of the flares is small for shields considered here). These flares are listed in table I which presents the integrated flux of protons having energies greater than 30 MeV (4.8×10^{-12} J) and some constants A and P_o associated with each flare. The spectral shape of each flare is assumed to vary as

$$N > E = A \exp\left(-\frac{\sqrt{E^2 + 1876E}}{P_o}\right)$$

where $N > E$ is the total number of protons per square centimeter with energies greater than E. The values of P_o were obtained from Webber's compilation, and the

TABLE I. - FLARES (FROM SOLAR ACTIVE PERIOD 1956 TO 1962)

SELECTED AS REPRESENTATIVE OF THOSE THAT WILL

OCCUR DURING FUTURE ACTIVE PERIODS

[Integral flux above 30 MeV (4.8×10^{-12} J), and spectral constants A and P_o for each flare are tabulated.]

Flare date	N > 30 MeV (4.8×10^{-12} J), protons/cm^2	P_o	A, protons/cm^2	
2-23-56	1.0×10^9	195	3.4×10^9	
1-20-57	2×10^8	61	1.0×10^9	
8-29-57	1.2×10^8	56	8.6×10^9	
10-20-57	5×10^7	127	3.3×10^8	
3-23-58	2.5×10^8	64	1.1×10^9	
7-7-58	2.5×10^8	62	1.2×10^9	
8-16-58	4×10^7	64	1.7×10^9	Clustered flare event
8-22-58	7×10^7	56	5.0×10^9	
8-26-58	1.1×10^8	51	1.2×10^{10}	
5-10-59	9.6×10^8	84	1.7×10^{10}	
6-13-59	8.5×10^7	[a]48	1.2×10^{10}	
7-10-59	1.0×10^9	104	1.0×10^{10}	Clustered flare event
7-14-59	1.3×10^9	80	2.6×10^{10}	
7-16-59	9.1×10^8	105	8.9×10^9	
9-3-60	3.5×10^7	127	2.3×10^8	
11-12-60	1.3×10^9	124	8.9×10^9	Clustered flare event
11-15-60	7.2×10^8	114	5.9×10^9	
11-20-60	4.5×10^7	118	3.4×10^9	
7-12-61	4×10^7	56	2.9×10^9	Clustered flare event
7-18-61	3×10^8	102	3.1×10^9	

[a]Estimated.

values of A were calculated to be consistent with flux values of N > 30 MeV (4.8×10^{-12} J).

It has been observed that some of the flares tend to occur in clusters. Table I indicates that such clusters occurred in August 1958, July 1959, November 1960, and July 1961. These four clusters were selected as representative of the clustered flare events that may occur and were assumed to be events of 12-, 8-, 10-, and 8-day durations, respectively. The other nine single flares were each assumed to have a duration of 2 days. During future solar active periods, each of the four clustered events and each of the nine single flare events are assumed to occur randomly with a frequency of once during the active period (taken to be 2000 days).

Doses For Selected Flare Events

Table II presents the doses obtained behind various shield thicknesses from each of these 13 events. These doses were calculated by using the Lewis Proton Shielding Code, described in reference 1, and are representative of doses received at the center of a spherical crew compartment having the given shield thicknesses when the vehicle is lo-

TABLE II. - RAD (cJ/kg) AND REM DOSES FROM SELECTED FLARE EVENTS BEHIND VARIOUS THICKNESSES OF WATER AND ALUMINUM SHIELD AT 1 ASTRONOMICAL UNIT (1.496×10^8 km) FROM SUN

(a) Rad (cJ/kg) dose behind water shield

Shield thickness, g/cm^2					Flare date
10	15	20	30	40	
Dose, rad(or cJ/kg)					
38.32	25.00	18.07	10.66	6.95	2-23-56
.90	.29	.12	.03	.01	1-20-57
.35	.10	.04	.01	.00	8-29-57
1.08	.58	.35	.16	.09	10-20-57
.94	.31	.13	.03	.01	3-23-58
1.06	.34	.14	.04	.01	7-7-58
.85	.26	.10	.03	.01	Aug. 1958 cluster
9.93	4.15	2.09	.71	.31	5-10-59
.49	.15	.06	.01	.01	6-13-59
44.01	20.39	11.19	4.37	2.07	July 1959 cluster
.76	.41	.25	.11	.06	9-3-60
44.32	23.31	14.13	6.35	3.34	Nov. 1960 cluster
4.88	2.31	1.28	.50	.24	July 1961 cluster

(b) Rem dose behind water shield

Shield thickness, g/cm^2					Flare date
10	15	20	30	40	
Dose, rem					
42.10	27.76	20.79	13.03	9.03	2-23-56
1.07	.38	.19	.07	.04	1-20-57
.43	.15	.07	.03	.01	8-29-57
1.20	.65	.42	.21	.12	10-20-57
1.12	.40	.19	.07	.04	3-23-58
1.26	.45	.22	.08	.04	7-7-58
1.03	.35	.17	.07	.04	Aug. 1958 cluster
11.30	4.93	2.67	1.09	.57	5-10-59
.60	.20	.10	.04	.02	6-13-59
49.59	23.68	13.76	6.11	3.36	July 1959 cluster
.84	.46	.29	.15	.09	9-3-60
49.34	26.49	16.79	8.30	4.85	Nov. 1960 cluster
5.48	2.67	1.57	.71	.39	July 1961 cluster

(c) Rad (cJ/kg) dose behind aluminum shield

Shield thickness, g/cm^2							Flare date
10	15	20	30	40	50	60	
Dose, rad (or cJ/kg)							
48.11	32.23	23.84	14.55	9.82	7.02	5.24	2-23-56
1.71	.60	.27	.09	.04	.03	.02	1-20-57
.71	.23	.10	.03	.02	.01	.01	8-29-57
1.52	.85	.54	.26	.15	.09	.06	10-20-57
1.78	.63	.28	.09	.04	.03	.02	3-23-58
2.01	.71	.32	.10	.05	.03	.02	7-7-58
1.69	.55	.24	.07	.04	.02	.02	Aug. 1958 cluster
16.15	7.19	3.84	1.45	.69	.39	.25	5-10-59
.99	.32	.14	.04	.02	.01	.01	6-13-59
67.55	32.90	18.94	7.97	4.10	2.41	1.57	July 1959 cluster
1.07	.59	.38	.18	.10	.06	.04	9-3-60
62.93	34.57	21.79	10.42	5.83	3.62	2.40	Nov. 1960 cluster
7.40	3.67	2.14	.92	.48	.28	.18	July 1961 cluster

(d) Rem dose behind aluminum shield

Shield thickness, g/cm^2							Flare date
10	15	20	30	40	50	60	
Dose, rem							
53.93	37.20	28.77	19.07	14.16	11.15	9.26	2.23-56
2.11	.86	.48	.24	.16	.12	.10	1-20-57
.90	.35	.19	.10	.07	.06	.05	8-29-57
1.73	1.00	.68	.38	.25	.18	.14	10-20-57
2.20	.89	.50	.25	.17	.12	.11	3-23-58
2.48	1.01	.56	.28	.19	.14	.12	7-7-58
2.12	.83	.45	.24	.17	.13	.11	Aug. 1958 cluster
18.98	9.06	5.36	2.59	1.63	1.18	.93	5-10-59
1.25	.49	.26	.14	.10	.08	.06	6-13-59
78.42	40.39	25.19	12.79	8.12	5.86	4.59	July 1959 cluster
1.22	.71	.48	.26	.17	.13	.10	9-3-60
71.89	41.17	27.59	15.09	9.87	7.17	5.61	Nov. 1960 cluster
8.57	4.49	2.82	1.44	.92	.66	.52	July 1961 cluster

cated at a distance of 1 astronomical unit (1.496×10^8 km) from the Sun. Table II(a) presents the rad (cJ/kg) doses behind various thicknesses of water shield, table II(b) the rem doses behind the water shield, table II(c) the rad (cJ/kg) doses behind various thicknesses of aluminum shield, and table II(d) the rem doses behind the aluminum shield. The data presented in this table are input to the computer code MCFLARE.

Trajectory

The trajectory selected for the trip is one that requires 556 days for the complete mission (and happens to be one that results in near minimum vehicle weight for a departure date in 1983). The outward journey from Earth to Mars requires 280 days, then there is a 40-day stay at Mars, then a 236-day return trip during which the vehicle approaches within 0.5 astronomical unit (0.75×10^8 km) of the Sun. Table III lists the

TABLE III. - TRANSFER ELLIPSE PARAMETERS

Parameter	Earth to Mars	Mars to Earth
Initial true anomaly, deg	-24.48	179.33
Final true anomaly, deg	192.57	486.33
Eccentricity	.1803	.4687
Semilatus rectum, km	1.712×10^8	1.099×10^8

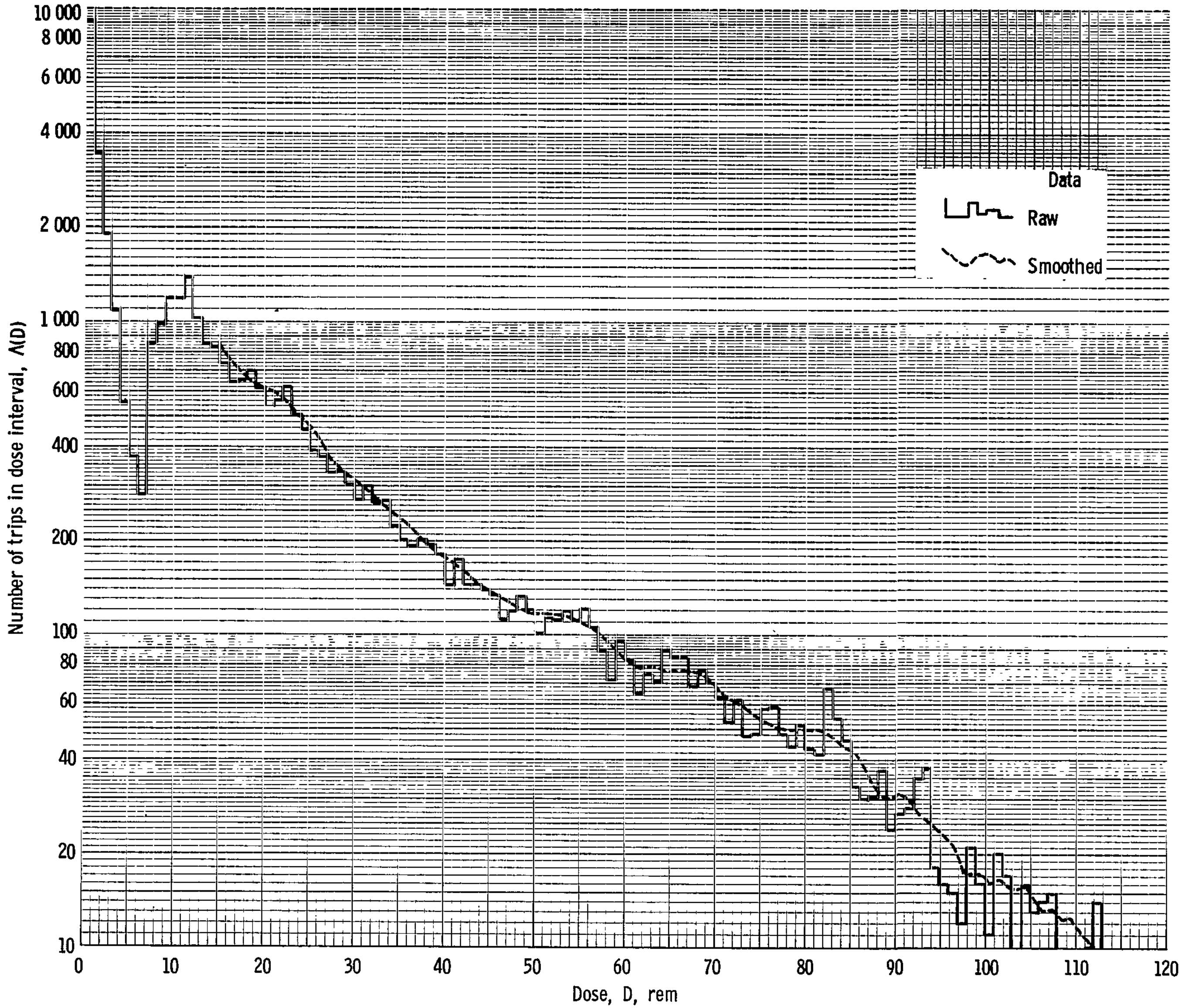
parameters which specify the outbound and return transfer ellipses. These are input to the computer code. Trajectory details are discussed in appendix A.

Discussion of Results

Figure 1 shows the distribution of dose obtained for a large number of identical trips. The figure presents the rem dose distribution behind 20 grams per square centimeter of water shield obtained from a computer run of 40 000 trips. The effect of distance on dose was assumed to vary as $(1/r)^2$.

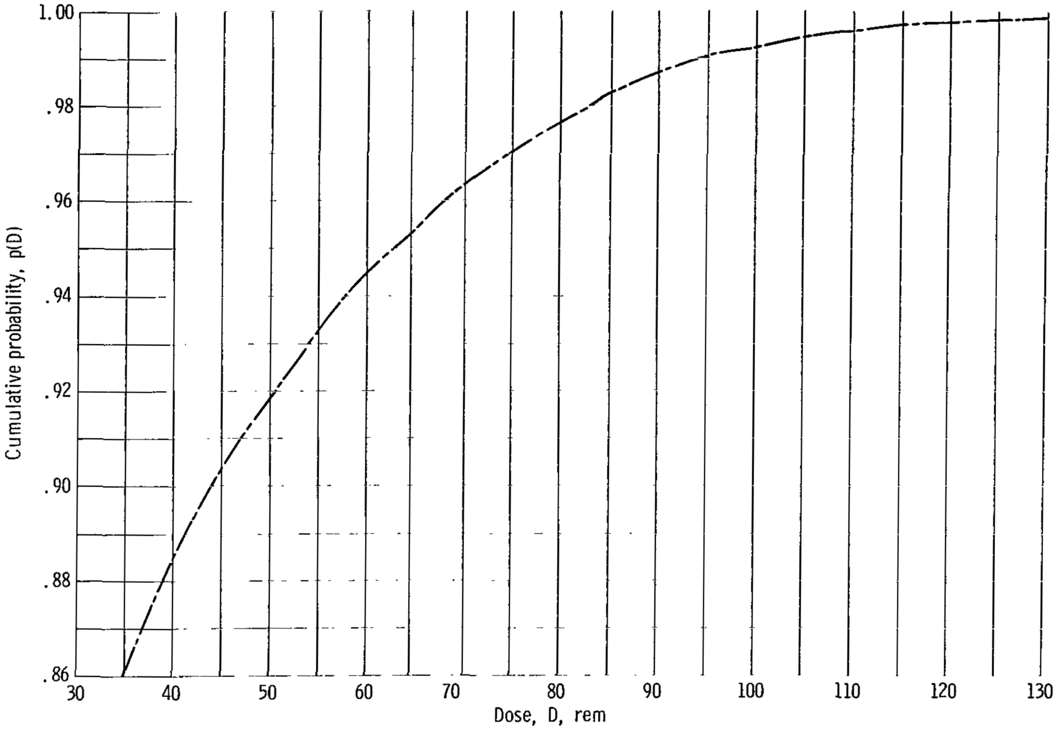
In figure 1(a), $\Lambda(D)$, the number of trips on which a dose between $D - 1$ and D has been encountered, is plotted against D. A smoothed curve of this distribution $\overline{\Lambda}(D)$ (obtained by averaging seven values centered about each $\Lambda(D)$) is also shown as a dashed line in this figure; that is,

$$\overline{\Lambda}(D) = \frac{\Lambda(D - 3) + \Lambda(D - 2) + \ldots + \Lambda(D) + \ldots + \Lambda(D + 3)}{7}$$



(a) Number of trips encountering doses lying within each dose interval.

Figure 1. - Distribution of trips encountering doses lying within each dose interval. Rem dose; water shield thickness, 20 grams per square centimeter; 40 000 trips; distance effect varies as $1/r^2$.



(b) Cumulative probability of trip encountering dose less than D.

Figure 1. - Concluded.

In figure 1(b), p(D) the probability of not exceeding any dose D is shown plotted against D

$$p(D) = \frac{1}{M} \sum_{i=1}^{D} \Lambda(i)$$

where M is the number of trips considered in a computer run. For the case of figure 1(b),

$$p(D) = \frac{1}{40\ 000} \sum_{i=1}^{D} \Lambda(i)$$

If D_p is defined as that dose which has a probability p of not being exceeded, then from figure 1(b), $D_{0.99}$ for the group of 40 000 trips, occurs in the dose interval between 93 and 94 rem and is selected as the upper bound of the interval, namely, 94 rem.

The dose probability density function f(D) is approximately equal to $\Lambda(D)/M$. At a $D_{0.99}$ of 94 rem, the value of f(D), evaluated by using the smoothed value of $\Lambda(D)$, is

$$f(D_{0.99}) = \frac{26}{40\ 000} = 0.00065/\text{rem}$$

and the standard deviation from equation (B6) is $\sigma_{D_{0.99}} = 0.77$ rem.

There is a 97.7 percent confidence that the true dose $D^*_{0.99}$ is less than $D_{0.99} + 2\sigma_{D_{0.99}}$; that is, $D^*_{0.99}$ is less than 95.5 rem.

Table IV presents values of $D_{0.99}$ determined by using the computer code for rem doses and rad (cJ/kg) doses behind various thicknesses (expressed as g/cm^2) of aluminum shield and water shield. These values are presented for both the case where the dose received from a flare event varies as $(1/r)^2$ and for the case where there is no effect of distance (i.e., distance effect, $g(r) = 1$). Also shown in the table are the values of $\sigma_{D_{0.99}}$ associated with each $D_{0.99}$ and the corresponding values of $D_{0.99} + 2\sigma_{D_{0.99}}$.

TABLE IV. - VALUES OF $D_{0.99}$ AND CORRESPONDING STANDARD DEVIATION BEHIND VARIOUS THICKNESSES OF WATER AND ALUMINUM DETERMINED FROM GROUP OF 40 000 TRIPS

(a) Rad (cJ/kg) dose behind water shield

Distance effect, g(r)	Quantity	Shield thickness, g/cm^2				
		10	15	20	30	40
		Dose, rad (or cJ/kg)				
$1/r^2$	$D_{0.99}$	227	124	81	44	28
	$\sigma_{D_{0.99}}$	2.0	1.2	.71	.34	.23
	$D_{0.99} + 2\sigma_{D_{0.99}}$	231	126.4	82.4	44.7	28.4
1	$D_{0.99}$	148	80	53	28	17
	$\sigma_{D_{0.99}}$	1.7	.91	.41	.24	.15
	$D_{0.99} + 2\sigma_{D_{0.99}}$	151.4	81.8	53.8	28.5	17.3

(b) Rem dose behind water shield

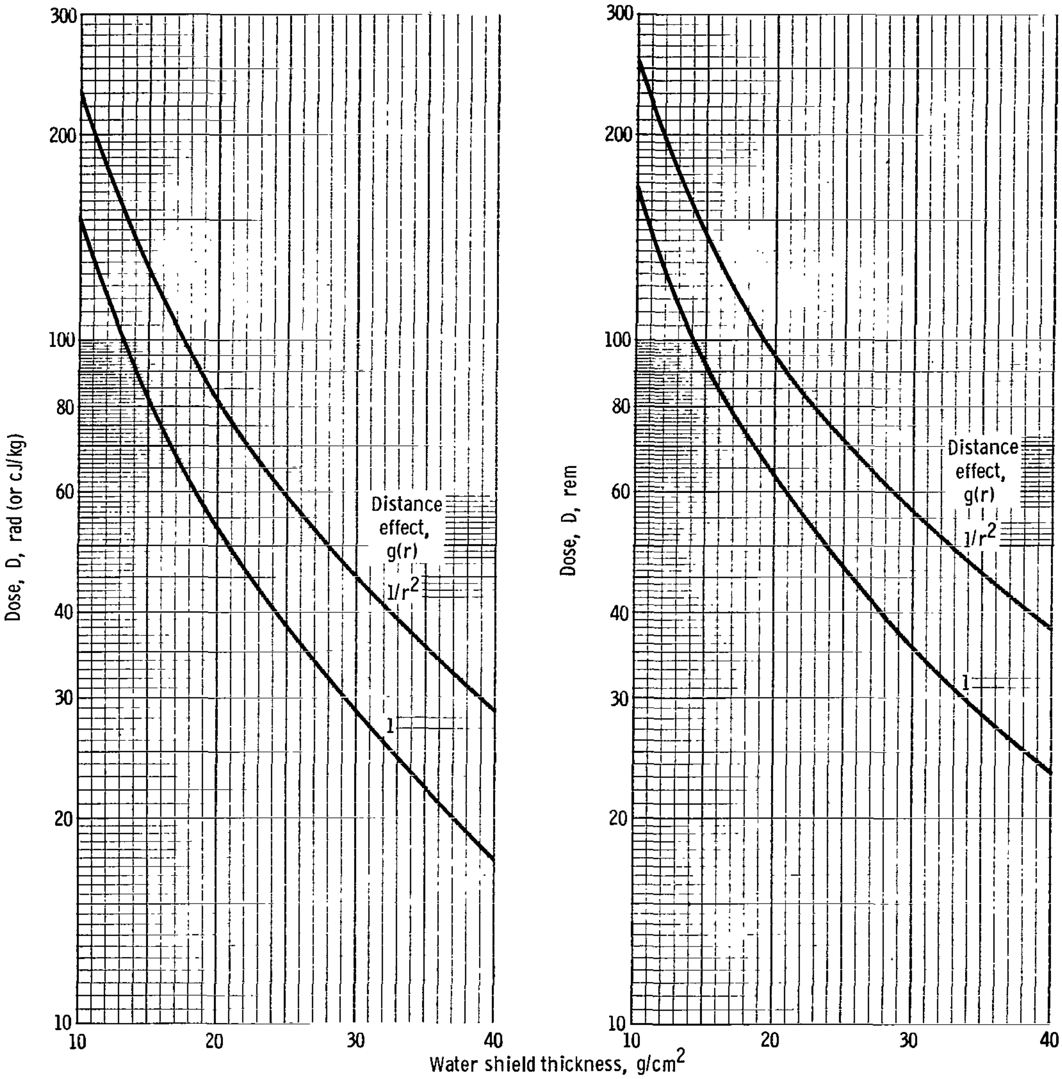
Distance effect, g(r)	Quantity	Shield thickness, g/cm^2				
		10	15	20	30	40
		Dose, rem				
$1/r^2$	$D_{0.99}$	254	139	94	55	37
	$\sigma_{D_{0.99}}$	2.0	1.3	.77	.44	.31
	$D_{0.99} + 2\sigma_{D_{0.99}}$	258	141.6	95.5	55.9	37.6
1	$D_{0.99}$	165	90	63	35	23
	$\sigma_{D_{0.99}}$	1.7	1.0	.57	.25	.2
	$D_{0.99} + 2\sigma_{D_{0.99}}$	168.4	92	64.1	35.5	23.4

(c) Rad (cJ/kg) dose behind aluminum shield

Distance effect, g(r)	Quantity	Shield thickness, g/cm^2						
		10	15	20	30	40	50	60
		Dose, rad (or cJ/kg)						
$1/r^2$	$D_{0.99}$	327	178	116	63	41	29	21
	$\sigma_{D_{0.99}}$	2.9	1.3	1.2	.54	.33	.25	.18
	$D_{0.99} + 2\sigma_{D_{0.99}}$	332.8	180.6	118.4	64.1	41.7	29.5	21.4
1	$D_{0.99}$	217	115	75	41	26	18	13
	$\sigma_{D_{0.99}}$	2.0	1.2	.67	.29	.2	.14	.10
	$D_{0.99} + 2\sigma_{D_{0.99}}$	221	117.4	76.3	41.6	26.4	18.3	13.2

(d) Rem dose behind aluminum shield

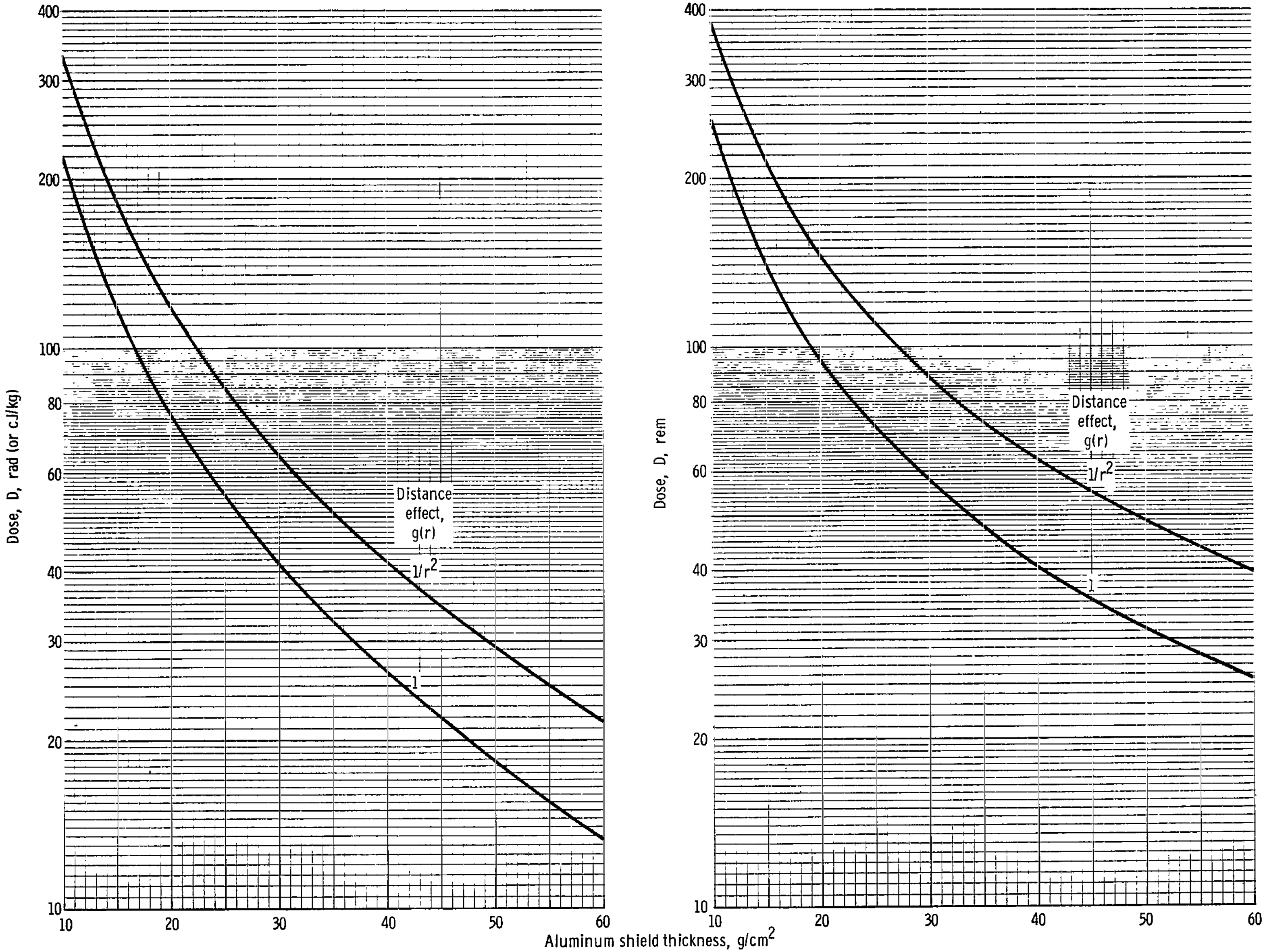
Distance effect, g(r)	Quantity	Shield thickness, g/cm^2						
		10	15	20	30	40	50	60
		Dose, rem						
$1/r^2$	$D_{0.99}$	376	213	146	87	62	48	39
	$\sigma_{D_{0.99}}$	3.3	1.8	1.4	.77	.54	.42	.31
	$D_{0.99} + 2\sigma_{D_{0.99}}$	382.6	216.3	148.8	88.5	63.1	48.8	39.6
1	$D_{0.99}$	250	138	94	58	40	31	25
	$\sigma_{D_{0.99}}$	2.2	1.5	.91	.59	.31	.23	.22
	$D_{0.99} + 2\sigma_{D_{0.99}}$	254.4	141	95.8	59.2	40.6	31.5	25.4



(a) Rad (cJ/kg) dose behind water shield.

(b) Rem dose behind water shield.

Figure 2. - Values of $D_{0.99} + 2\sigma_{D_{0.99}}$ for various thicknesses of water and aluminum shields, and for cases of distance effect varying as $1/r^2$ and no effect of distance. Number of trips, 40 000.



(c) Rad (cJ/kg) dose behind aluminum shield.

(d) Rem dose behind aluminum shield.

Figure 2. - Concluded.

In figure 2 the values of $D_{0.99} + 2\sigma_{D_{0.99}}$ are plotted against shield thickness. In figure 2(a), the rad (cJ/kg) dose is plotted against water shield thickness for cases of $g(r) = 1/r^2$ and $g(r) = 1$. Figure 2(b) is a similar plot of the rem dose behind the water shield, figure 2(c) is a similar plot of rad (cJ/kg) behind the aluminum shield, and figure 2(d) a similar plot of rem dose behind the aluminum shield.

These curves indicate how much more effective water is as a shield material than aluminum for shielding against solar flare protons on the basis of grams per square centimeter of material necessary to maintain a given dose level inside the crew compartment. Also shown for this mission is that a $1/r^2$ distance effect on dose received from a flare can have an appreciable effect on shield requirements when the mission trajectory brings the vehicle to within 0.5 astronomical unit (0.75×10^8 km) of the Sun. This result indicates a need for information regarding the effect of position from the Sun on radiation encountered from a flare.

COMPUTER PROGRAM

Complete data input instructions for the computer program MCFLARE are presented in this section. In its present form, MCFLARE will accept as many as 25 different flare types with up to seven different shield configurations. Doses are tallied in as many as 900 unit dose bins. With these limits, the program does not occupy the maximum 32 K storage available in the core. The user can increase the limits of any or all these arrays. The version of the code presented herein is operational on the Lewis Research Center IBM 7094-II/7044 computer system. Execution times for the examples discussed previously in this report were about 2 minutes per group of 40 000 trips.

Data Input Flow Chart

1 *

Read XYZ.

XYZ is the last random number used in a previous run. This number is punched out at the end of each case. If calculation is being started without a calculated XYZ, XYZ = 000000000001 should be used. XYZ is a 12-place octal integer, and punched in card columns 1 to 12.

2

Read 3 cards. Format (3(12A6))

These cards contain any alphanumeric information in columns 1 to 72. This information is used for titling output.

3

Read control card. Format (6I5, 2E10. 4)

Card column	Variable	
1-5	MTHOUS	MTHOUS is the number of thousands of trips considered. An intermediate printout is made after each NTHOUS thousand. If NTHOUS = 0, no intermediate printout will be made.
6-10	NTHOUS	
11-15	IXP	Exponent in $(1/r)^{IXP}$ dependence of dose with distance from Sun. If IXP = 0, there is no effect of distance on dose. (IXP is called α in this report.)
16-20	NTYPE	Number of different particular flare events considered (NTYPE $\leq$ 25)

Go to next page

* Symbol means read a card or set of cards as described.

Card column	Variable	
21-25	NSHELD	Number of different shields considered (NSHELD $\leq$ 7)
26-30	NBIN	Number of dose bins of unit width to be used (NBIN $\leq$ 900); (A final bin extending to infinity is used by the program to maintain a correct tally in each bin.)
31-40	TREF	The duration of the solar active period is given in days. Each flare event is assumed to occur with expected frequency of once every TREF days.
41-50	TOTALT	The length of the mission is given in days. This parameter is used only if IXP = 0 because no radius (trajectory) is calculated in this case. If IXP $\neq$ 0, TOTALT is calculated from input trajectory parameters. If IXP = 0, TOTALT must be given here.

4

Read output titling card. Format (8A6)

Card column	Variable	
1-6	UNITS	The dose units used in this problem, for example, RADS
7-12	$SHIELD_1$	A name for the first shield, for example, 10GMAL for 10 grams per square centimeter of aluminum
13-18	$SHIELD_2$	A name for the second shield
.		
.		(NSHELD values required)
.		

Go to next page

5

Read dose table. Format (7E9. 4)

For each particular flare, read a card listing the dose at 1 astronomical unit (1.496×10^8 km) with each NSHELD shield in place. One card is required for each particular flare used. NSHELD values are required per card.

Card column	
1-9	Dose with shield 1 for this particular flare
10-18	Dose with shield 2 for this particular flare
19-27	Dose with shield 3 for this particular flare
.	
.	
.	

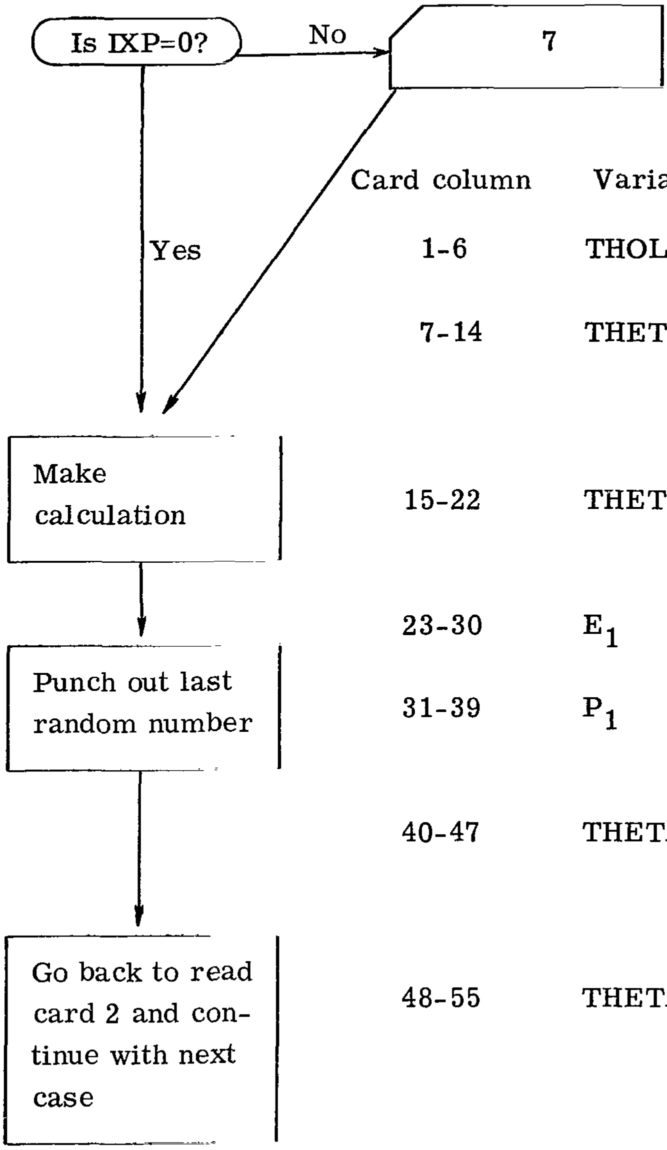
6

Read flare duration card(s) Format (8E9. 4)

For each particular flare event read in the flare duration in days. If clustered flares are considered to be single events, an appropriate time must be allotted. NTYPE values are required.

Card column	Variable	
1-9	TDUR(1)	Time duration of particular flare 1
10-18	TDUR(2)	Time duration of particular flare 2
.		
.		
.		

Go to next page



Read mission trajectory card. Format (F6.0, 3F8.0, E9.4, 3F8.0, E9.4)

Card column	Variable	
1-6	THOLD	Number of days stay time at planet
7-14	$THETA_1$	True anomaly (angle from perihelion) at the start of first transfer ellipse is in degrees.
15-22	$THETAF_1$	True anomaly at the end of first transfer ellipse is in degrees.
23-30	E_1	Eccentricity of first transfer ellipse
31-39	P_1	Semilatus rectum of first transfer ellipse is given in kilometers.
40-47	$THETA_2$	True anomaly at the start of second transfer ellipse is given in degrees.
48-55	$THETAF_2$	True anomaly at the end of second transfer ellipse is given in degrees.
56-63	E_2	Eccentricity of second transfer ellipse
64-72	P_2	Semilatus rectum of second transfer ellipse is given in kilometers.

(NOTE: THETAF must be greater than THETA.)

Sample Problem Input

To illustrate data input to the computer code, consider the case with water shielding, rem dose, $1/r^2$ distance dependence of dose, and the 556-day mission described in the section ILLUSTRATIVE EXAMPLE. The complete set of data input is illustrated in table V.

Parameters on the control card include

MTHOUS = 40	40 000 Trips will be considered
NTHOUS = 0	No intermediate printout will be made
IXP = 2	$1/r^2$ Spatial dependence
NTYPE = 13	13 Flare events will be considered, as indicated in table II
NSHELD = 5	5 Shields will be used
NBIN = 500	As many as 500 dose bins will be used
TREF = 2000.0	The observed flares were assumed representative of a 2000.0-day solar active period

The titling card includes

UNITS = REMS	Dose tables input in rems
$SHIELD_1$ = 10 H2O	10 g/cm^2 water is first shield
$SHIELD_2$ = 15 H2O	15 g/cm^2 water is second shield
$SHIELD_3$ = 20 H2O	20 g/cm^2 water is third shield
$SHIELD_4$ = 30 H2O	30 g/cm^2 water is fourth shield
$SHIELD_5$ = 40 H2O	40 g/cm^2 water is fifth shield

The dose table is taken directly from table II(b).

The duration time of each event, listed on the next cards, was taken to be 2.0 days for all single events, 8.0 days for the clustered events of July 1959 and July 1961, 10.0 days for the events of November 1960, and 12 days for the August 1958 events. The trajectory information on the next card is taken from table III. The hold time at the planet, THOLD, was taken to be 40.0 days. Note the subroutine RADIUS requires that the final true anomaly be greater than the initial true anomaly; thus, in the second transfer ellipse, the final true anomaly is given as 486.33 rather than 126.33 degrees. In the first transfer ellipse, the true anomaly ranges from -24.48 to 192.57 degrees. This transfer ellipse could also have been specified as $\theta = \theta + 360^{\circ}$ starting at 335.52 and ending at 552.57 degrees.

TABLE V. - DATA INPUT FOR SAMPLE CASE

TITLE	PROJECT NUMBER	ANALYST	
MCFLARE			SHEET ____ OF ____

STATEMENT NUMBER (1–5)	CONT (6)	FORTRAN STATEMENT (7–72)	IDENTIFICATION (73–80)

```
000000000001                                                            XYZ
      SAMPLE PROBLEM         556-DAY MARS MISSION     0.5 AU APPROACH   COMMENT1
      WATER SHIELDS           40-DAY MARS STOPOVER                      COMMENT2
      REM DOSES               1/R**2  SPATIAL DEPENDENCE                COMMENT3
   40     0     2    13     5   500      2000.0                         CONTROL
*REMS*10 H2015 H2020 H2030 H2040 H20                                    TITLES
   42.10      27.76      20.79      13.03       9.03                    2-23-56
    1.07       0.38       0.19       0.07       0.04                    1-20-57
    0.43       0.15       0.07       0.03       0.01                    8-29-57
    1.20       0.65       0.42       0.21       0.12                   10-20-57
    1.12       0.40       0.19       0.07       0.04                    3-23-58
    1.26       0.45       0.22       0.08       0.04                    7-07-58
    1.03       0.35       0.17       0.07       0.04                   CL-08-58
   11.30       4.93       2.67       1.09       0.57                    5-10-59
    0.60       0.20       0.10       0.04       0.02                    6-13-59
   49.59      23.68      13.76       6.11       3.36                   CL-07-59
    0.84       0.46       0.29       0.15       0.09                    9-03-60
   49.34      26.49      16.79       8.30       4.85                   CL-11-60
    5.48       2.67       1.57       0.71       0.39                   CL-07-61
    2.00       2.00       2.00       2.00       2.00      2.00     12.00      2.00TDUR-1
    2.00       8.00       2.00      10.00       8.00                   TDUR-2
  40.0  -24.48   192.57  0.1803  1.712+8  179.33  486.33  0.4687  1.099+8TRAJECTY
```

Sample Problem Output

The computer output generated from execution of the sample problem detailed in the previous section is shown in table VI. The first page of computer output is a printout of the input information of cards 2 to 6. If radius as a function of trip time is calculated (IXP ≠ 0), the next page of computer output is the trajectory information, namely, a listing of mission parameters and a 100-point table listing time elapsed in the trip and the corresponding distance to the Sun in astronomical units (1.496×10^8 km) at that time.

The next page of computer output is a table of the number of trips observed in this group having encountered the particular flares n times (n = 0, 1, 2, . . .). For example, the first input flare event did not occur on 30 586 of the executed 40 000 trips, occurred once on 8223 trips, occurred twice on 1092 trips, occurred three times on 92 trips, and occurred four times on 7 trips; all 40 000 trips were accounted for. The last column of this table indicates the number of trips observed which encountered n flares, independent of which particular flare occurred. For example, in table VI, 1074 trips encountered no flares at all, while 2 trips experienced a total of 13 flares. For comparison, the expected number per trip of each particular flare type (equal to the ratio of total trip time to reference time) and of any flare type (equal to the product of this ratio and the number of flare types considered) are calculated. Then, for an assumed Poisson distribution, the probability per trip of n flares (n = 0, 1, 2, . . ., 10) occurring are calculated and printed out. It should be pointed out here that the observed frequency tables should agree with this calculated table only in the case where the time allowed for a flare event to occur goes to zero. In this case, the problem reduces to a constant-rate process, one that obeys a Poisson distribution.

Finally, the tabulation of number of trips observed to have a dose lying in a unit dose bin against dose is printed out for each shield configuration. The first column is the upper limit of the dose bin of unit width; in the next column, for each shield is the number of trips which encountered a dose lying in this unit dose bin followed by the percentage of trips observed to have a dose less than or equal to this upper limit dose. From this list (or a smoothed one) the dose which will not be exceeded p percent of the time, D_p may be ascertained for each shield.

TABLE VI. - COMPUTER OUTPUT OF SAMPLE PROBLEM

SAMPLE PRCBLEM	556 DAY MARS MISSICN	0.5 AU APPRCACH
WATER SHIELDS	4C DAY MARS STOPOVER	
REM DOSES	1/R**2 SPATIAL DEPENCENCE	

THIS CALCULATICN CONSIDERS 13 FLARES, AND 5 SHIELDS, NAMELY 10 H2O 15 H2O 20 H2O 30 H2O 40 H2O

DCSE CALCULATICN USES UP TO 500 UNIT BINS

4C.000 TRIPS TO BE RUN WITH PRINTCUT AFTER EACH 40.000

DOSES BASED ON 1./R** 2

FLARE INPUT DATA | DOSES IN *REMS*

FLARE TYPE. I	OCCURRENCES OF ITH TYPE FLARE IN 2COC.0 DAYS	DURATION OF ITH TYPE FLARE, DAYS	DOSE FROM ITH TYPE FLARE AT 1 AU WITH JTH SHIELD- 10 H2O	15 H2O	20 H2O	30 H2O	4C H2O
1	1	C.200CE 01	0.4210E C2	0.2776E 02	0.2079E C2	0.1303E 02	C.9030E 01
2	1	C.200CE 01	0.1C70E 01	C.3800E C0	0.190CE 0C	C.7000E-C1	C.400CE-01
3	1	C.200CE 01	C.4300E 00	0.150CE 00	0.70C0E-01	0.30C0E-C1	0.100CE-01
4	1	C.2000E 01	C.1200E C1	C.650CE 00	0.420CE 00	0.2100E CC	C.120CE 00
5	1	C.200CE 01	0.1120E 01	C.400CE 00	0.190CE 00	C.7000E-01	C.40C0E-C1
6	1	C.20CCE C1	0.1260E 01	0.450CE 00	0.220CE 0C	0.8000E-01	C.400CE-01
7	1	C.1200E 02	0.1030E 01	0.350CE 00	0.17CCE 00	C.7000E-01	0.4000E-01
8	1	C.20CCE C1	0.1130E C2	0.4930E 01	0.2670E C1	0.1090E 01	C.570CE 00
9	1	C.20CCE C1	C.6000E C0	0.2000E 00	0.100CE 00	0.40C0E-01	C.20CCE-01
10	1	C.800CE 01	0.4959E C2	0.2368E 02	0.1376E 02	0.611CE 01	0.3360E 01
11	1	C.2000E 01	C.8400E 00	0.4600E 00	0.29C0E 00	0.1500E C0	C.90C0E-01
12	1	C.10CCE C2	0.4934E 02	0.2649E 02	0.1679E 02	0.8300E C1	0.485CE C1
13	1	C.800CE 01	0.5480E C1	0.2670E C1	0.1570E 01	C.7100E 00	C.390CE 00

MISSION PARAMETERS

TOTAL TRIP TIME, DAYS 556.533C

	EARTH TO PLANET,	TC EARTH	
SEMI-LATUS RECTUM	C.1712CE C9	C.1C99CE C9	KM
ECCENTRICITY	C.18C30	C.4687C	
TRUE ANOMALY AT START	-24.480	179.33C	DEGREES
TRUE ANOMALY AT END	192.57C	486.330	DEGREES
PERIOD, DAYS	469.9112	333.6709	
SEMI-MAJOR AXIS	0.17695E C9	C.14C84E 09	KM

ELAPSED TIME (DAYS) VS DISTANCE FROM SUN (AU)

1	0.	C.983	21	82.915	1.C61	41	207.336	1.363	61	429.898	0.942	81	490.659	C.502
2	4.042	C.979	22	87.7C0	1.074	42	215.195	1.372	62	436.113	0.889	82	492.535	0.505
3	8.050	C.975	23	92.6C3	1.087	43	223.156	1.381	63	441.652	C.840	83	494.442	0.510
4	12.033	C.972	24	97.631	1.101	44	231.203	1.387	64	446.600	0.794	84	496.396	0.517
5	15.998	C.971	25	102.793	1.116	45	239.316	1.392	65	451.C36	0.753	85	498.412	0.526
6	19.952	C.970	26	108.C95	1.131	46	247.475	1.395	66	455.03C	0.715	86	50C.510	C.538
7	23.902	C.970	27	113.545	1.147	47	255.658	1.396	67	458.645	0.682	87	5C2.7C8	0.552
8	27.855	C.971	28	119.150	1.163	48	263.845	1.396	68	461.937	0.651	88	5C5.C29	0.568
9	31.819	C.972	29	124.915	1.180	49	272.014	1.393	69	464.953	0.625	89	507.498	C.587
10	35.801	C.975	3C	130.845	1.197	50	280.144	1.389	70	467.735	0.601	90	51C.143	0.6C8
11	39.8C8	C.978	31	136.946	1.214	51	320.144	1.383	71	470.319	0.58C	91	512.997	0.633
12	43.848	C.983	32	143.220	1.231	52	334.289	1.377	72	472.736	0.562	92	516.098	0.661
13	47.927	C.988	33	149.669	1.248	53	348.173	1.357	73	475.014	0.547	93	519.490	0.692
14	52.054	C.994	34	156.295	1.264	54	361.529	1.325	74	477.177	0.534	94	523.223	C.727
15	56.236	1.CC1	35	163.C97	1.281	55	374.143	1.282	75	479.247	0.523	95	527.354	C.766
16	60.481	1.009	36	17C.073	1.296	56	385.862	1.231	76	481.241	0.514	96	531.948	C.809
17	64.795	1.018	37	177.217	1.312	57	396.602	1.175	77	483.178	0.508	97	537.081	0.855
18	69.188	1.C27	38	184.525	1.326	58	406.338	1.116	78	485.073	0.503	98	542.831	C.906
19	73.667	1.C38	39	191.988	1.339	59	415.C92	1.057	79	486.942	0.501	99	549.286	C.960
20	78.24C	1.C49	40	199.595	1.352	60	422.920	0.998	80	488.799	0.50C	1CC	556.533	1.017

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

THE NUMBER OF TRIPS IN WHICH I FLARES OF TYPE J OCCUR--
(THE LAST COLUMN IS THE NUMBER OF TRIPS IN WHICH I FLARES OF ANY TYPE OCCUR)

I	J = 1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	30586	30433	30585	30556	30554	30445	30573	30501	30484	30446	30459	30540	30467	1074
1	8223	8316	8155	8273	8183	8341	8277	8182	8302	8316	8390	8252	8338	4016
2	1092	1122	1175	1096	1164	1097	1057	1193	1113	1129	1075	1102	1092	7366
3	92	120	77	70	91	113	89	119	87	105	72	97	98	8703
4	7	8	8	5	8	4	4	4	11	4	4	9	5	7902
5	0	1	0	0	0	0	0	1	3	0	0	0	0	5412
6	0	0	0	0	0	0	0	0	0	0	0	0	0	3089
7	0	0	0	0	0	0	0	0	0	0	0	0	0	1454
8	0	0	0	0	0	0	0	0	0	0	0	0	0	643
9	0	0	0	0	0	0	0	0	0	0	0	0	0	233
10	0	0	0	0	0	0	0	0	0	0	0	0	0	75
11	0	0	0	0	0	0	0	0	0	0	0	0	0	25
12	0	0	0	0	0	0	0	0	0	0	0	0	0	6
13	0	0	0	0	0	0	0	0	0	0	0	0	0	2
SUMS	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000

THE EXPECTED NO. OF EACH TYPE IS ... 0.278
THE EXPECTED NO. OF ANY TYPE IS ... 3.617

CALCULATED PROBABLE OCCURRENCES PER TRIP USING POISSON DISTRIBUTION

NUMBER	EACH TYPE	ANY TYPE
0	7.57095E-01	2.68507E-02
1	2.10674E-01	9.71313E-02
2	2.93118E-02	1.75685E-01
3	2.71883E-03	2.11844E-01
4	1.89140E-04	1.91585E-01
5	1.05263E-05	1.38610E-01
6	4.88184E-07	8.35696E-02
7	1.94065E-08	4.31871E-02
8	6.75021E-10	1.95285E-02
9	2.08706E-11	7.84929E-03
10	5.80760E-13	2.83945E-03

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

DOSE DISTRIBUTION

DOSE *REMS* UPPER LIMIT	SHIELD-10 H2O NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD-15 H2O NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD-20 H2O NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD-30 H2O NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD-40 H2O NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD- NO. IN BIN	PERCENT LESSTHAN LIMIT	SHIELD- NO. IN BIN	PERCENT LESSTHAN LIMIT
1	3147	7.867	6764	16.910	9296	23.240	13489	33.722	16006	40.015				
2	2592	14.347	3035	24.497	3485	31.952	2701	40.475	2110	45.290				
3	1887	19.065	1985	29.460	1906	36.717	795	42.462	3237	53.382				
4	1339	22.412	1565	33.372	1099	39.465	1675	46.650	2400	59.382				
5	1138	25.257	949	35.745	555	40.852	2143	52.007	2101	64.635				
6	963	27.665	815	37.782	380	41.802	1566	55.922	2311	70.412				
7	879	29.862	586	39.247	280	42.502	1708	60.192	1459	74.060				
8	764	31.772	356	40.137	856	44.642	1700	64.442	1249	77.182				
9	572	33.202	305	40.900	967	47.060	1407	67.960	1136	80.022				
10	500	34.452	219	41.447	1190	50.035	1141	70.812	1255	83.160				
11	396	35.442	214	41.982	1185	52.997	951	73.190	852	85.290				
12	391	36.420	146	42.347	1377	56.440	878	75.385	659	86.937				
13	346	37.285	458	43.492	1023	58.997	779	77.332	604	88.447				
14	316	38.075	618	45.037	851	61.125	923	79.640	546	89.812				
15	276	38.765	1092	47.767	843	63.232	769	81.562	407	90.830				
16	221	39.317	1112	50.547	737	65.075	629	83.135	394	91.815				
17	184	39.777	911	52.825	642	66.680	497	84.377	331	92.642				
18	167	40.195	798	54.820	660	68.330	480	85.577	310	93.417				
19	152	40.575	753	56.702	705	70.092	425	86.640	267	94.085				
20	108	40.845	688	58.422	603	71.600	362	87.545	262	94.740				
21	122	41.150	590	59.897	548	72.970	336	88.385	185	95.202				
22	182	41.605	507	61.165	570	74.395	320	89.185	190	95.677				
23	291	42.332	438	62.260	628	75.965	292	89.915	147	96.045				
24	276	43.022	433	63.342	506	77.230	296	90.655	138	96.390				
25	273	43.705	440	64.442	443	78.337	282	91.360	119	96.687				
26	399	44.702	502	65.697	391	79.315	219	91.907	91	96.915				
27	541	46.055	473	66.880	374	80.250	215	92.445	97	97.157				
28	572	47.485	486	68.095	328	81.070	184	92.905	82	97.362				
29	566	48.900	559	69.492	332	81.900	188	93.375	92	97.592				
30	515	50.187	554	70.877	308	82.670	165	93.787	65	97.755				
31	454	51.322	508	72.147	261	83.322	174	94.222	80	97.955				
32	454	52.457	388	73.117	305	84.085	147	94.590	75	98.142				
33	431	53.535	363	74.025	271	84.762	164	95.000	59	98.290				
34	399	54.532	348	74.895	271	85.440	168	95.420	64	98.450				
35	402	55.537	316	75.685	219	85.987	107	95.687	84	98.660				
36	332	56.367	281	76.387	199	86.485	103	95.945	82	98.865				
37	357	57.260	268	77.057	192	86.965	93	96.177	84	99.075				
38	344	58.120	285	77.770	200	87.465	111	96.455	44	99.185				
39	312	58.900	255	78.407	205	87.977	87	96.672	59	99.332				
40	329	59.722	268	79.077	178	88.422	74	96.857	39	99.430				
41	293	60.455	232	79.657	140	88.772	71	97.035	38	99.525				
42	253	61.087	269	80.330	174	89.207	79	97.232	23	99.582				
43	262	61.742	256	80.970	149	89.580	62	97.387	25	99.645				
44	262	62.397	217	81.512	144	89.940	55	97.525	11	99.672				
45	332	63.227	231	82.090	134	90.275	49	97.647	20	99.722				
46	309	64.000	206	82.605	135	90.612	73	97.830	20	99.772				
47	269	64.672	217	83.147	115	90.900	58	97.975	15	99.810				
48	269	65.345	182	83.602	121	91.202	53	98.107	7	99.827				
49	241	65.947	162	84.007	130	91.527	45	98.220	11	99.855				
50	262	66.602	173	84.440	125	91.840	50	98.345	12	99.885				
51	244	67.212	169	84.862	104	92.100	66	98.510	5	99.897				
52	299	67.960	169	85.285	111	92.377	70	98.685	6	99.912				
53	338	68.805	135	85.622	110	92.652	63	98.842	3	99.920				

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

54	298	69.550	136	85.962	123	92.960	47	98.960	5	99.932
55	318	70.345	140	86.312	111	93.237	36	99.050	3	99.940
56	256	70.985	148	86.682	120	93.537	36	99.140	4	99.950
57	248	71.605	110	86.957	103	93.795	37	99.232	1	99.952
58	236	72.195	140	87.307	89	94.017	35	99.320	3	99.960
59	209	72.717	143	87.665	77	94.210	34	99.405	1	99.962
60	215	73.255	110	87.940	96	94.450	24	99.465	3	99.970
61	161	73.657	113	88.222	83	94.657	14	99.500	1	99.972
62	186	74.122	116	88.512	65	94.820	16	99.540	1	99.975
63	193	74.605	101	88.765	75	95.007	15	99.577	0	99.975
64	165	75.017	95	89.002	70	95.182	17	99.620	1	99.977
65	164	75.427	100	89.252	89	95.405	19	99.667	2	99.982
66	162	75.832	99	89.500	84	95.615	6	99.682	2	99.987
67	137	76.175	99	89.747	84	95.825	14	99.717	0	99.987
68	152	76.555	89	89.970	68	95.995	13	99.750	0	99.987
69	160	76.955	93	90.202	77	96.187	6	99.765	0	99.987
70	155	77.342	89	90.425	70	96.362	9	99.787	1	99.990
71	162	77.747	86	90.640	63	96.520	6	99.802	0	99.990
72	151	78.125	86	90.855	52	96.650	6	99.817	1	99.992
73	151	78.502	89	91.077	62	96.805	8	99.837	1	99.995
74	147	78.870	94	91.312	47	96.922	5	99.850	0	99.995
75	157	79.262	58	91.457	48	97.042	4	99.860	0	99.995
76	124	79.572	76	91.647	58	97.187	8	99.880	1	99.997
77	151	79.950	71	91.825	59	97.335	3	99.887	0	99.997
78	133	80.282	72	92.005	48	97.455	6	99.902	0	99.997
79	161	80.685	61	92.157	44	97.565	3	99.910	1	100.000
80	141	81.037	84	92.367	51	97.692	3	99.917	0	100.000
81	148	81.407	73	92.550	43	97.800	2	99.922	0	100.000
82	121	81.710	71	92.727	41	97.902	2	99.927	0	100.000
83	118	82.005	57	92.870	67	98.070	1	99.930	0	100.000
84	125	82.317	62	93.025	54	98.205	7	99.947	0	100.000
85	109	82.590	61	93.177	46	98.320	4	99.957	0	100.000
86	121	82.892	58	93.322	33	98.402	1	99.960	0	100.000
87	107	83.160	58	93.467	30	98.477	0	99.960	0	100.000
88	104	83.420	77	93.660	31	98.555	0	99.960	0	100.000
89	110	83.695	68	93.830	37	98.647	1	99.962	0	100.000
90	96	83.935	59	93.977	24	98.707	1	99.965	0	100.000
91	93	84.167	69	94.150	27	98.775	2	99.970	0	100.000
92	86	84.382	71	94.327	28	98.845	2	99.975	0	100.000
93	72	84.562	52	94.457	35	98.932	1	99.977	0	100.000
94	94	84.797	73	94.640	38	99.027	1	99.980	0	100.000
95	88	85.017	66	94.805	18	99.072	2	99.985	0	100.000
96	85	85.230	76	94.995	16	99.112	0	99.985	0	100.000
97	75	85.417	53	95.127	15	99.150	1	99.987	0	100.000
98	80	85.617	52	95.257	12	99.180	0	99.987	0	100.000
99	73	85.800	53	95.390	21	99.232	0	99.987	0	100.000
100	100	86.050	49	95.512	16	99.272	0	99.987	0	100.000
101	81	86.252	39	95.610	11	99.300	0	99.987	0	100.000
102	76	86.442	48	95.730	20	99.350	0	99.987	0	100.000
103	84	86.652	51	95.857	17	99.392	1	99.990	0	100.000
104	72	86.832	50	95.982	5	99.405	0	99.990	0	100.000
105	68	87.002	53	96.115	16	99.445	0	99.990	0	100.000
106	70	87.177	57	96.257	13	99.477	0	99.990	0	100.000
107	68	87.347	60	96.407	14	99.512	1	99.992	0	100.000
108	60	87.497	62	96.562	15	99.550	0	99.992	0	100.000
109	69	87.670	56	96.702	8	99.570	0	99.992	0	100.000
110	82	87.875	51	96.830	9	99.592	1	99.995	0	100.000
111	42	87.980	68	97.000	7	99.610	0	99.995	0	100.000
112	58	88.125	50	97.125	10	99.635	0	99.995	0	100.000
113	57	88.267	39	97.222	14	99.670	1	99.997	0	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

114	66	88.432	38	97.317	6	99.685	0	99.997	0	100.000
115	66	88.597	35	97.405	7	99.702	0	99.997	0	100.000
116	69	88.770	33	97.487	3	99.710	0	99.997	0	100.000
117	60	88.920	38	97.582	6	99.725	0	99.997	0	100.000
118	62	89.075	38	97.677	3	99.732	1	100.000	0	100.000
119	55	89.212	31	97.755	8	99.752	0	100.000	0	100.000
120	48	89.332	33	97.837	4	99.762	0	100.000	0	100.000
121	51	89.460	52	97.967	5	99.775	0	100.000	0	100.000
122	49	89.582	32	98.047	4	99.785	0	100.000	0	100.000
123	55	89.720	25	98.110	2	99.790	0	100.000	0	100.000
124	45	89.832	31	98.187	3	99.797	0	100.000	0	100.000
125	55	89.970	25	98.250	1	99.800	0	100.000	0	100.000
126	48	90.090	27	98.317	4	99.810	0	100.000	0	100.000
127	56	90.230	34	98.402	3	99.817	0	100.000	0	100.000
128	40	90.330	23	98.460	2	99.822	0	100.000	0	100.000
129	52	90.460	17	98.502	3	99.830	0	100.000	0	100.000
130	56	90.600	27	98.570	2	99.835	0	100.000	0	100.000
131	36	90.690	23	98.627	1	99.837	0	100.000	0	100.000
132	47	90.807	25	98.690	5	99.850	0	100.000	0	100.000
133	40	90.907	14	98.725	0	99.850	0	100.000	0	100.000
134	48	91.027	26	98.790	6	99.865	0	100.000	0	100.000
135	40	91.127	20	98.840	5	99.877	0	100.000	0	100.000
136	42	91.232	18	98.885	0	99.877	0	100.000	0	100.000
137	51	91.360	17	98.927	3	99.885	0	100.000	0	100.000
138	48	91.480	14	98.962	3	99.892	0	100.000	0	100.000
139	40	91.580	15	99.000	4	99.902	0	100.000	0	100.000
140	54	91.715	11	99.027	3	99.910	0	100.000	0	100.000
141	38	91.810	23	99.085	2	99.915	0	100.000	0	100.000
142	36	91.900	8	99.105	0	99.915	0	100.000	0	100.000
143	45	92.012	13	99.137	2	99.920	0	100.000	0	100.000
144	27	92.080	9	99.160	3	99.927	0	100.000	0	100.000
145	40	92.180	11	99.187	0	99.927	0	100.000	0	100.000
146	43	92.287	17	99.230	1	99.930	0	100.000	0	100.000
147	48	92.407	7	99.247	1	99.932	0	100.000	0	100.000
148	43	92.515	15	99.285	3	99.940	0	100.000	0	100.000
149	33	92.597	12	99.315	3	99.947	0	100.000	0	100.000
150	39	92.695	13	99.347	2	99.952	0	100.000	0	100.000
151	52	92.825	9	99.370	0	99.952	0	100.000	0	100.000
152	37	92.917	10	99.395	0	99.952	0	100.000	0	100.000
153	38	93.012	10	99.420	4	99.962	0	100.000	0	100.000
154	33	93.095	5	99.432	0	99.962	0	100.000	0	100.000
155	33	93.177	8	99.452	0	99.962	0	100.000	0	100.000
156	27	93.245	9	99.475	3	99.970	0	100.000	0	100.000
157	44	93.355	7	99.492	2	99.975	0	100.000	0	100.000
158	38	93.450	9	99.515	0	99.975	0	100.000	0	100.000
159	41	93.552	3	99.522	2	99.980	0	100.000	0	100.000
160	40	93.652	6	99.537	0	99.980	0	100.000	0	100.000
161	33	93.735	7	99.555	0	99.980	0	100.000	0	100.000
162	45	93.847	9	99.577	0	99.980	0	100.000	0	100.000
163	29	93.920	7	99.595	1	99.982	0	100.000	0	100.000
164	44	94.030	9	99.617	0	99.982	0	100.000	0	100.000
165	35	94.117	3	99.625	1	99.985	0	100.000	0	100.000
166	29	94.190	3	99.632	1	99.987	0	100.000	0	100.000
167	36	94.280	3	99.640	0	99.987	0	100.000	0	100.000
168	36	94.370	0	99.640	1	99.990	0	100.000	0	100.000
169	49	94.492	9	99.662	0	99.990	0	100.000	0	100.000
170	24	94.552	3	99.670	0	99.990	0	100.000	0	100.000
171	40	94.652	3	99.677	0	99.990	0	100.000	0	100.000
172	26	94.717	5	99.690	0	99.990	0	100.000	0	100.000
173	29	94.790	5	99.702	0	99.990	0	100.000	0	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

174	29	94.862	2	99.707	0	99.990	0	100.000	0	100.000
175	31	94.940	3	99.715	0	99.990	0	100.000	0	100.000
176	30	95.015	3	99.722	0	99.990	0	100.000	0	100.000
177	30	95.090	2	99.727	0	99.990	0	100.000	0	100.000
178	26	95.155	8	99.747	0	99.990	0	100.000	0	100.000
179	31	95.232	3	99.755	0	99.990	0	100.000	0	100.000
180	31	95.310	4	99.765	1	99.992	0	100.000	0	100.000
181	29	95.382	2	99.770	0	99.992	0	100.000	0	100.000
182	26	95.447	2	99.775	0	99.992	0	100.000	0	100.000
183	33	95.530	4	99.785	0	99.992	0	100.000	0	100.000
184	38	95.625	9	99.807	0	99.992	0	100.000	0	100.000
185	19	95.672	2	99.812	0	99.992	0	100.000	0	100.000
186	35	95.760	2	99.817	0	99.992	0	100.000	0	100.000
187	29	95.832	1	99.820	0	99.992	0	100.000	0	100.000
188	25	95.895	3	99.827	0	99.992	0	100.000	0	100.000
189	22	95.950	2	99.832	1	99.995	0	100.000	0	100.000
190	30	96.025	3	99.840	1	99.997	0	100.000	0	100.000
191	39	96.122	1	99.842	0	99.997	0	100.000	0	100.000
192	28	96.192	0	99.842	0	99.997	0	100.000	0	100.000
193	38	96.287	1	99.845	0	99.997	0	100.000	0	100.000
194	22	96.342	1	99.847	0	99.997	0	100.000	0	100.000
195	24	96.402	0	99.847	0	99.997	0	100.000	0	100.000
196	38	96.497	1	99.850	0	99.997	0	100.000	0	100.000
197	50	96.622	2	99.855	0	99.997	0	100.000	0	100.000
198	35	96.710	1	99.857	0	99.997	0	100.000	0	100.000
199	37	96.802	4	99.867	0	99.997	0	100.000	0	100.000
200	33	96.885	2	99.872	0	99.997	0	100.000	0	100.000
201	26	96.950	1	99.875	0	99.997	0	100.000	0	100.000
202	24	97.010	3	99.882	0	99.997	0	100.000	0	100.000
203	25	97.072	2	99.887	0	99.997	0	100.000	0	100.000
204	18	97.117	2	99.892	0	99.997	0	100.000	0	100.000
205	21	97.170	3	99.900	0	99.997	0	100.000	0	100.000
206	21	97.222	1	99.902	0	99.997	0	100.000	0	100.000
207	19	97.270	0	99.902	0	99.997	0	100.000	0	100.000
208	20	97.320	0	99.902	0	99.997	0	100.000	0	100.000
209	16	97.360	2	99.907	0	99.997	0	100.000	0	100.000
210	17	97.402	1	99.910	1	100.000	0	100.000	0	100.000
211	11	97.430	1	99.912	0	100.000	0	100.000	0	100.000
212	26	97.495	0	99.912	0	100.000	0	100.000	0	100.000
213	21	97.547	3	99.920	0	100.000	0	100.000	0	100.000
214	25	97.610	1	99.922	0	100.000	0	100.000	0	100.000
215	13	97.642	2	99.927	0	100.000	0	100.000	0	100.000
216	19	97.690	0	99.927	0	100.000	0	100.000	0	100.000
217	19	97.737	1	99.930	0	100.000	0	100.000	0	100.000
218	21	97.790	2	99.935	0	100.000	0	100.000	0	100.000
219	18	97.835	3	99.942	0	100.000	0	100.000	0	100.000
220	21	97.887	5	99.955	0	100.000	0	100.000	0	100.000
221	19	97.935	0	99.955	0	100.000	0	100.000	0	100.000
222	22	97.990	1	99.957	0	100.000	0	100.000	0	100.000
223	21	98.042	0	99.957	0	100.000	0	100.000	0	100.000
224	13	98.075	2	99.962	0	100.000	0	100.000	0	100.000
225	14	98.110	0	99.962	0	100.000	0	100.000	0	100.000
226	27	98.177	0	99.962	0	100.000	0	100.000	0	100.000
227	18	98.222	0	99.962	0	100.000	0	100.000	0	100.000
228	16	98.262	1	99.965	0	100.000	0	100.000	0	100.000
229	21	98.315	0	99.965	0	100.000	0	100.000	0	100.000
230	14	98.350	1	99.967	0	100.000	0	100.000	0	100.000
231	9	98.372	1	99.970	0	100.000	0	100.000	0	100.000
232	11	98.400	0	99.970	0	100.000	0	100.000	0	100.000
233	18	98.445	0	99.970	0	100.000	0	100.000	0	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

234	13	98.477	0	99.970	0	100.000	0	100.000	0	100.000
235	13	98.510	1	99.972	0	100.000	0	100.000	0	100.000
236	18	98.555	1	99.975	0	100.000	0	100.000	0	100.000
237	12	98.585	0	99.975	0	100.000	0	100.000	0	100.000
238	13	98.617	1	99.977	0	100.000	0	100.000	0	100.000
239	6	98.632	0	99.977	0	100.000	0	100.000	0	100.000
240	17	98.675	1	99.980	0	100.000	0	100.000	0	100.000
241	9	98.697	1	99.982	0	100.000	0	100.000	0	100.000
242	5	98.710	0	99.982	0	100.000	0	100.000	0	100.000
243	13	98.742	1	99.985	0	100.000	0	100.000	0	100.000
244	15	98.780	1	99.987	0	100.000	0	100.000	0	100.000
245	12	98.810	0	99.987	0	100.000	0	100.000	0	100.000
246	9	98.832	0	99.987	0	100.000	0	100.000	0	100.000
247	10	98.857	0	99.987	0	100.000	0	100.000	0	100.000
248	5	98.870	1	99.990	0	100.000	0	100.000	0	100.000
249	11	98.897	0	99.990	0	100.000	0	100.000	0	100.000
250	10	98.922	0	99.990	0	100.000	0	100.000	0	100.000
251	11	98.950	0	99.990	0	100.000	0	100.000	0	100.000
252	10	98.975	0	99.990	0	100.000	0	100.000	0	100.000
253	7	98.992	0	99.990	0	100.000	0	100.000	0	100.000
254	12	99.022	1	99.992	0	100.000	0	100.000	0	100.000
255	11	99.050	0	99.992	0	100.000	0	100.000	0	100.000
256	9	99.072	0	99.992	0	100.000	0	100.000	0	100.000
257	8	99.092	0	99.992	0	100.000	0	100.000	0	100.000
258	6	99.107	0	99.992	0	100.000	0	100.000	0	100.000
259	7	99.125	0	99.992	0	100.000	0	100.000	0	100.000
260	12	99.155	0	99.992	0	100.000	0	100.000	0	100.000
261	5	99.167	0	99.992	0	100.000	0	100.000	0	100.000
262	9	99.190	0	99.992	0	100.000	0	100.000	0	100.000
263	6	99.205	0	99.992	0	100.000	0	100.000	0	100.000
264	7	99.222	0	99.992	0	100.000	0	100.000	0	100.000
265	9	99.245	0	99.992	0	100.000	0	100.000	0	100.000
266	5	99.257	0	99.992	0	100.000	0	100.000	0	100.000
267	5	99.270	0	99.992	0	100.000	0	100.000	0	100.000
268	3	99.277	0	99.992	0	100.000	0	100.000	0	100.000
269	6	99.292	0	99.992	0	100.000	0	100.000	0	100.000
270	4	99.302	1	99.995	0	100.000	0	100.000	0	100.000
271	6	99.317	0	99.995	0	100.000	0	100.000	0	100.000
272	7	99.335	0	99.995	0	100.000	0	100.000	0	100.000
273	5	99.347	0	99.995	0	100.000	0	100.000	0	100.000
274	5	99.360	0	99.995	0	100.000	0	100.000	0	100.000
275	6	99.375	0	99.995	0	100.000	0	100.000	0	100.000
276	2	99.380	0	99.995	0	100.000	0	100.000	0	100.000
277	7	99.397	0	99.995	0	100.000	0	100.000	0	100.000
278	6	99.412	1	99.997	0	100.000	0	100.000	0	100.000
279	6	99.427	0	99.997	0	100.000	0	100.000	0	100.000
280	4	99.437	0	99.997	0	100.000	0	100.000	0	100.000
281	4	99.447	0	99.997	0	100.000	0	100.000	0	100.000
282	2	99.452	0	99.997	0	100.000	0	100.000	0	100.000
283	6	99.467	0	99.997	0	100.000	0	100.000	0	100.000
284	5	99.480	0	99.997	0	100.000	0	100.000	0	100.000
285	5	99.492	0	99.997	0	100.000	0	100.000	0	100.000
286	3	99.500	0	99.997	0	100.000	0	100.000	0	100.000
287	4	99.510	0	99.997	0	100.000	0	100.000	0	100.000
288	4	99.520	0	99.997	0	100.000	0	100.000	0	100.000
289	3	99.527	0	99.997	0	100.000	0	100.000	0	100.000
290	2	99.532	0	99.997	0	100.000	0	100.000	0	100.000
291	2	99.537	0	99.997	0	100.000	0	100.000	0	100.000
292	1	99.540	0	99.997	0	100.000	0	100.000	0	100.000
293	2	99.545	0	99.997	0	100.000	0	100.000	0	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

294	3	99.552	0	99.997	0	100.000	0	100.000	0	100.000
295	4	99.562	0	99.997	0	100.000	0	100.000	0	100.000
296	3	99.570	0	99.997	0	100.000	0	100.000	0	100.000
297	1	99.572	0	99.997	0	100.000	0	100.000	0	100.000
298	7	99.590	0	99.997	0	100.000	0	100.000	0	100.000
299	1	99.592	0	99.997	0	100.000	0	100.000	0	100.000
300	6	99.607	0	99.997	0	100.000	0	100.000	0	100.000
301	4	99.617	0	99.997	0	100.000	0	100.000	0	100.000
302	5	99.630	0	99.997	0	100.000	0	100.000	0	100.000
303	6	99.645	0	99.997	0	100.000	0	100.000	0	100.000
304	1	99.647	0	99.997	0	100.000	0	100.000	0	100.000
305	1	99.650	0	99.997	0	100.000	0	100.000	0	100.000
306	1	99.652	0	99.997	0	100.000	0	100.000	0	100.000
307	1	99.655	0	99.997	0	100.000	0	100.000	0	100.000
308	3	99.662	1	100.000	0	100.000	0	100.000	0	100.000
309	4	99.672	0	100.000	0	100.000	0	100.000	0	100.000
310	1	99.675	0	100.000	0	100.000	0	100.000	0	100.000
311	2	99.680	0	100.000	0	100.000	0	100.000	0	100.000
312	3	99.687	0	100.000	0	100.000	0	100.000	0	100.000
313	2	99.692	0	100.000	0	100.000	0	100.000	0	100.000
314	4	99.702	0	100.000	0	100.000	0	100.000	0	100.000
315	5	99.715	0	100.000	0	100.000	0	100.000	0	100.000
316	5	99.727	0	100.000	0	100.000	0	100.000	0	100.000
317	4	99.737	0	100.000	0	100.000	0	100.000	0	100.000
318	4	99.747	0	100.000	0	100.000	0	100.000	0	100.000
319	1	99.750	0	100.000	0	100.000	0	100.000	0	100.000
320	0	99.750	0	100.000	0	100.000	0	100.000	0	100.000
321	1	99.752	0	100.000	0	100.000	0	100.000	0	100.000
322	1	99.755	0	100.000	0	100.000	0	100.000	0	100.000
323	4	99.765	0	100.000	0	100.000	0	100.000	0	100.000
324	0	99.765	0	100.000	0	100.000	0	100.000	0	100.000
325	0	99.765	0	100.000	0	100.000	0	100.000	0	100.000
326	2	99.770	0	100.000	0	100.000	0	100.000	0	100.000
327	0	99.770	0	100.000	0	100.000	0	100.000	0	100.000
328	0	99.770	0	100.000	0	100.000	0	100.000	0	100.000
329	0	99.770	0	100.000	0	100.000	0	100.000	0	100.000
330	0	99.770	0	100.000	0	100.000	0	100.000	0	100.000
331	2	99.775	0	100.000	0	100.000	0	100.000	0	100.000
332	1	99.777	0	100.000	0	100.000	0	100.000	0	100.000
333	0	99.777	0	100.000	0	100.000	0	100.000	0	100.000
334	2	99.782	0	100.000	0	100.000	0	100.000	0	100.000
335	1	99.785	0	100.000	0	100.000	0	100.000	0	100.000
336	1	99.787	0	100.000	0	100.000	0	100.000	0	100.000
337	0	99.787	0	100.000	0	100.000	0	100.000	0	100.000
338	2	99.792	0	100.000	0	100.000	0	100.000	0	100.000
339	3	99.800	0	100.000	0	100.000	0	100.000	0	100.000
340	2	99.805	0	100.000	0	100.000	0	100.000	0	100.000
341	1	99.807	0	100.000	0	100.000	0	100.000	0	100.000
342	2	99.812	0	100.000	0	100.000	0	100.000	0	100.000
343	1	99.815	0	100.000	0	100.000	0	100.000	0	100.000
344	1	99.817	0	100.000	0	100.000	0	100.000	0	100.000
345	1	99.820	0	100.000	0	100.000	0	100.000	0	100.000
346	1	99.822	0	100.000	0	100.000	0	100.000	0	100.000
347	0	99.822	0	100.000	0	100.000	0	100.000	0	100.000
348	2	99.827	0	100.000	0	100.000	0	100.000	0	100.000
349	0	99.827	0	100.000	0	100.000	0	100.000	0	100.000
350	2	99.832	0	100.000	0	100.000	0	100.000	0	100.000
351	2	99.837	0	100.000	0	100.000	0	100.000	0	100.000
352	0	99.837	0	100.000	0	100.000	0	100.000	0	100.000
353	2	99.842	0	100.000	0	100.000	0	100.000	0	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

354	1	99.E45	C	1C0.000	0	10C.000	C	100.000	0	100.000
355	3	9S.E52	0	1C0.000	0	100.000	C	100.000	C	1C0.000
356	1	99.E55	0	1C0.000	0	100.000	0	10C.000	C	1CC.000
357	1	99.857	C	1CC.000	0	10C.000	0	100.000	0	100.000
358	3	9S.E65	0	1C0.000	0	10C.000	0	1CC.000	0	100.000
359	0	9S.865	0	1C0.000	0	100.000	0	10C.000	C	100.000
360	0	9S.E65	C	1CC.000	0	100.000	0	100.000	0	100.00C
361	1	99.E67	0	1C0.000	0	100.000	0	10C.000	0	1C0.000
362	3	9S.E75	0	1CC.C00	0	100.000	C	10C.000	C	1CC.C00
363	1	99.877	C	1CC.000	0	10C.000	0	100.000	C	100.000
364	0	99.E77	C	1C0.000	0	10C.000	0	1C0.000	C	100.000
365	1	9S.E80	0	1C0.000	0	100.000	0	10C.000	C	1C0.000
366	3	9S.8E7	C	1C0.000	0	10C.000	0	100.000	0	100.000
367	1	S9.E90	0	1C0.000	C	100.000	C	1CC.00C	C	100.000
368	2	9S.E95	C	1C0.000	C	10C.000	0	1CC.000	C	1CC.000
369	1	99.897	C	1CC.00C	C	10C.000	0	100.000	0	100.000
370	1	S9.9C0	0	1C0.000	0	10C.000	0	100.000	C	100.000
371	2	99.9C5	C	1C0.000	0	10C.000	C	1C0.000	C	100.000
372	0	S9.SC5	C	1CC.000	0	10C.000	0	10C.000	C	100.000
373	1	S9.S07	0	1C0.000	C	100.000	0	10C.000	0	1C0.000
374	1	99.91C	C	1CC.000	0	100.000	0	10C.00C	C	1CC.000
375	0	9S.910	C	1CC.000	0	10C.000	0	10C.000	C	1C0.000
376	1	S9.912	0	1CC.000	0	10C.000	C	100.000	C	1C0.000
377	3	99.S2C	0	1CC.0C0	C	100.000	0	100.000	0	1C0.000
378	C	SS.S2C	C	1C0.000	0	100.000	0	100.000	0	1C0.000
379	1	SS.S22	C	1CC.C00	0	10C.000	0	1CC.000	0	100.C00
380	0	99.S22	C	1CC.000	0	10C.000	0	1C0.000	C	1C0.C00
381	0	99.S22	0	1CC.000	0	10C.000	0	10C.00C	C	100.0C0
382	0	S9.S22	C	10C.000	0	100.000	0	100.000	0	1C0.000
383	1	99.925	C	100.000	C	10C.000	C	10C.000	C	1C0.000
384	2	99.S3C	0	1C0.000	0	100.000	0	1CC.000	C	1C0.C00
385	2	S9.S35	C	1CC.000	0	100.000	C	1C0.000	C	1C0.C00
386	1	S9.S37	0	1C0.000	0	100.000	0	1CC.000	C	1C0.0C0
387	0	99.S37	C	1CC.000	0	100.000	0	1C0.000	0	1C0.000
388	2	S9.S42	0	1CC.000	0	10C.00C	0	10C.000	0	1C0.000
389	C	S9.942	0	1C0.000	0	10C.000	0	1CC.000	C	1C0.000
390	1	S9.S45	C	1CC.000	0	100.000	C	10C.000	C	100.000
391	0	S9.S45	C	1CC.000	0	10C.000	C	10C.000	0	100.000
392	1	99.S47	0	1C0.000	C	100.000	0	1CC.000	0	1C0.000
393	0	99.S47	C	1C0.000	C	10C.000	0	100.00C	C	100.000
394	0	99.947	0	1C0.000	0	10C.C00	C	10C.000	C	1C0.0C0
395	1	S9.950	C	1C0.000	0	10C.000	0	10C.00C	C	1C0.000
396	0	SS.S5C	C	1CC.000	0	10C.000	0	10C.000	0	100.000
397	0	SS.S50	0	1CC.C00	0	100.000	0	1CC.00C	C	1CC.C00
398	0	S9.S5C	C	1C0.C00	0	10C.000	0	10C.000	0	1CC.000
399	1	S9.S52	C	1C0.000	0	10C.000	0	100.000	0	10C.0C0
400	0	99.S52	0	1CC.000	C	100.000	0	100.000	C	1CC.000
401	1	99.S55	C	1CC.000	0	100.000	0	100.000	C	1C0.000
402	C	S9.955	C	1CC.000	0	10C.000	0	1CC.00C	C	1C0.000
403	C	S9.S55	0	1C0.000	C	10C.000	0	10C.00C	C	100.000
404	0	99.S55	C	1CC.000	0	100.000	0	10C.000	C	1C0.000
405	0	99.S55	C	1CC.000	0	100.000	0	10C.000	0	100.000
406	0	99.S55	C	1CC.000	0	100.000	0	10C.000	0	1C0.000
407	0	99.955	C	1CC.000	C	100.000	C	1CC.00C	C	100.000
408	2	SS.96C	0	1C0.000	0	10C.000	0	10C.00C	0	1C0.000
409	1	S9.962	C	1C0.000	0	100.000	0	100.000	0	1C0.000
410	0	S9.S62	C	1CC.000	C	10C.000	0	10C.00C	C	100.000
411	0	S9.S62	0	1CC.000	0	100.000	C	1C0.000	C	100.000
412	C	99.S62	C	1C0.000	0	10C.C0C	0	1C0.000	C	100.000
413	2	99.967	0	1C0.000	0	100.000	0	10C.000	C	100.000

TABLE VI. - Continued. COMPUTER OUTPUT OF SAMPLE PROBLEM

414	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
415	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
416	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
417	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
418	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
419	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
420	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
421	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
422	0	99.967	0	100.000	0	100.000	0	100.000	0	100.000
423	1	99.970	0	100.000	0	100.000	0	100.000	0	100.000
424	0	99.970	0	100.000	0	100.000	0	100.000	0	100.000
425	0	99.970	0	100.000	0	100.000	0	100.000	0	100.000
426	1	99.972	0	100.000	0	100.000	0	100.000	0	100.000
427	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
428	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
429	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
430	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
431	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
432	0	99.972	0	100.000	0	100.000	0	100.000	0	100.000
433	1	99.975	0	100.000	0	100.000	0	100.000	0	100.000
434	1	99.977	0	100.000	0	100.000	0	100.000	0	100.000
435	0	99.977	0	100.000	0	100.000	0	100.000	0	100.000
436	0	99.977	0	100.000	0	100.000	0	100.000	0	100.000
437	0	99.977	0	100.000	0	100.000	0	100.000	0	100.000
438	0	99.977	0	100.000	0	100.000	0	100.000	0	100.000
439	1	99.980	0	100.000	0	100.000	0	100.000	0	100.000
440	0	99.980	0	100.000	0	100.000	0	100.000	0	100.000
441	0	99.980	0	100.000	0	100.000	0	100.000	0	100.000
442	0	99.980	0	100.000	0	100.000	0	100.000	0	100.000
443	1	99.982	0	100.000	0	100.000	0	100.000	0	100.000
444	0	99.982	0	100.000	0	100.000	0	100.000	0	100.000
445	0	99.982	0	100.000	0	100.000	0	100.000	0	100.000
446	0	99.982	0	100.000	0	100.000	0	100.000	0	100.000
447	0	99.982	0	100.000	0	100.000	0	100.000	0	100.000
448	1	99.985	0	100.000	0	100.000	0	100.000	0	100.000
449	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
450	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
451	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
452	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
453	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
454	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
455	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
456	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
457	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
458	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
459	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
460	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
461	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
462	0	99.985	0	100.000	0	100.000	0	100.000	0	100.000
463	1	99.987	0	100.000	0	100.000	0	100.000	0	100.000
464	0	99.987	0	100.000	0	100.000	0	100.000	0	100.000
465	0	99.987	0	100.000	0	100.000	0	100.000	0	100.000
466	0	99.987	0	100.000	0	100.000	0	100.000	0	100.000
467	1	99.990	0	100.000	0	100.000	0	100.000	0	100.000
468	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000
469	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000
470	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000
471	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000
472	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000
473	0	99.990	0	100.000	0	100.000	0	100.000	0	100.000

TABLE VI. - Concluded. COMPUTER OUTPUT OF SAMPLE PROBLEM

474	1 99.992	0 100.000	0 100.000	0 100.000	0 100.000
475	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
476	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
477	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
478	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
479	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
480	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
481	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
482	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
483	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
484	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
485	0 99.992	0 100.000	0 100.000	0 100.000	0 100.000
486	1 99.995	0 100.000	0 100.000	0 100.000	0 100.000
487	1 99.997	0 100.000	0 100.000	0 100.000	0 100.000
488	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
489	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
490	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
491	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
492	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
493	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
494	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
495	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
496	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
497	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
498	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
499	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
500	0 99.997	0 100.000	0 100.000	0 100.000	0 100.000
INFINITY	1 100.000	0 100.000	0 100.000	0 100.000	0 100.000

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, August 24, 1967,

124-09-01-03-22.

APPENDIX A

RADIUS AND DISTANCE EFFECT CALCULATION AT ANY TIME DURING MISSION

In this calculation, the mission is assumed to be composed of a transfer ellipse from the Earth to a planet, a hold time at the planet, and a transfer ellipse to return from the planet to the Earth. Both transfer ellipses have the Sun at one focus. One such transfer ellipse is shown in figure 3.

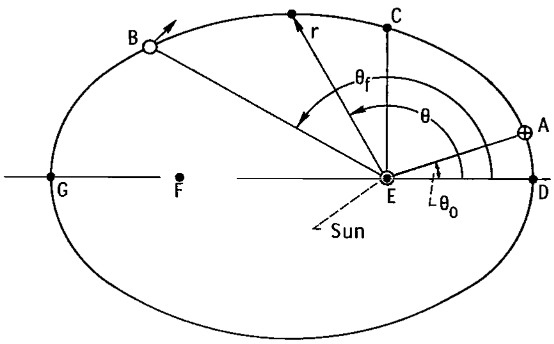


Figure 3. - Transfer ellipse.

The mission requires a transfer from the Earth at point A to the planet at point B along the ellipse. Some parameters of the ellipse are as follows: Points E and F are foci, D is the perihelion point, $\overline{DG}$ is the major axis, the eccentricity $e = \overline{EF}/\overline{DG}$, the semilatus rectum $P = \overline{CE}$ (which is perpendicular to the major axis), also $P = (1 - e^2)\overline{DG}/2.0$, and the true anomaly θ is the polar angle measured from the line between the Sun and perihelion.

The polar representation of the ellipse (with the Sun as the origin) is

$$r = \frac{P}{1 + e \cos \theta} \tag{A1}$$

which relates the distance r from the Sun and the true anomaly θ for known values of e and P.

The time elapsed in going from the perihelion position ($\theta = 0$) to any θ is (e.g., see ref. 5)

$$t(\theta) = \sqrt{\frac{P^3}{\mu}}\left(\frac{1}{1 - e^2}\right)\left[\frac{2}{\sqrt{1 - e^2}} \arctan\left(\sqrt{\frac{1 - e}{1 + e}} \tan\frac{\theta}{2}\right) - \frac{e \sin\theta}{1 + e \cos\theta}\right] \tag{A2}$$

where

μ central force constant, GM

M mass of central body

G universal gravitational constant = 6.668×10^{-23} $km^3/(sec^2)(g)$

For heliocentric orbits:

$$M = M_{\odot} = \text{Mass of Sun} = 1.989 \times 10^{33} \text{ g}$$

$$\mu = GM_{\odot} = 1.32 \times 10^{11} \text{ km}^3/\text{sec}^2 = 9.906 \times 10^{20} \text{ km}^3/\text{day}^2$$

The time $t(\theta_o)$ corresponding to the true anomaly at the start of the mission is determined, and the elapsed time to reach any position in the transfer is

$$T(\theta) = t(\theta) - t(\theta_o)$$

To relate the distance r to an elapsed time T requires determining the true anomaly θ corresponding to T by using equation (A2), and then the distance r corresponding to θ by using equation (A1). Because θ cannot be obtained explicitly from t in equation (A2), a numerical solution is necessary which requires a disproportionate amount of computation time. To improve computational efficiency, the code evaluates r corresponding to elapsed time T by the following procedure.

The total angle traversed on the transfer ellipse, θ_o to θ_f is divided into 49 equal intervals so that

$$\Delta\theta = \frac{\theta_f - \theta_o}{49}$$

and

$$\theta_i = \theta_o + i\,\Delta\theta$$

The values of $T(\theta_i)$ are determined for each of the 50 angles directly from equation (A2) and the distances determined for each of the angles directly from equation (A1). A similar set of values of θ, T, and r are obtained for the second transfer ellipse to return from the planet to the Earth. Then, interpolating between these values of T and r, a table of the distance effect $g(r) = (1/r)^{\alpha}$ at the beginning of each day of the trip is constructed. To find g(r) at any time T during the trip, the computer determines T to the nearest day and a g(r) corresponding to that day simply by noting its value at this position in the table. The g(r) for the first day is the first one in the table, the g(r) for the second day is the second entry in the table, and so on. Inasmuch as r varies slowly with time, this method of selecting g(r) does not introduce appreciable error.

APPENDIX B

UNCERTAINTY IN DETERMINATION OF D_p

For a given trip, let the actual dose probability density be f(D) so that f(D)dD represents the true probability that the dosage for a trip is in the interval dD about D. The cumulative probability that a trip has a dosage less than D is given by

$$p(D) = \int_0^D f(\zeta)d\zeta \tag{B1}$$

Equation (B1) yields p as a function of D (see fig. 4)

One is concerned with the inverse problem, that is, to find the dose corresponding to a given p. Let the true value of D corresponding to a given p be denoted by D_p^*, as shown in figure 4.

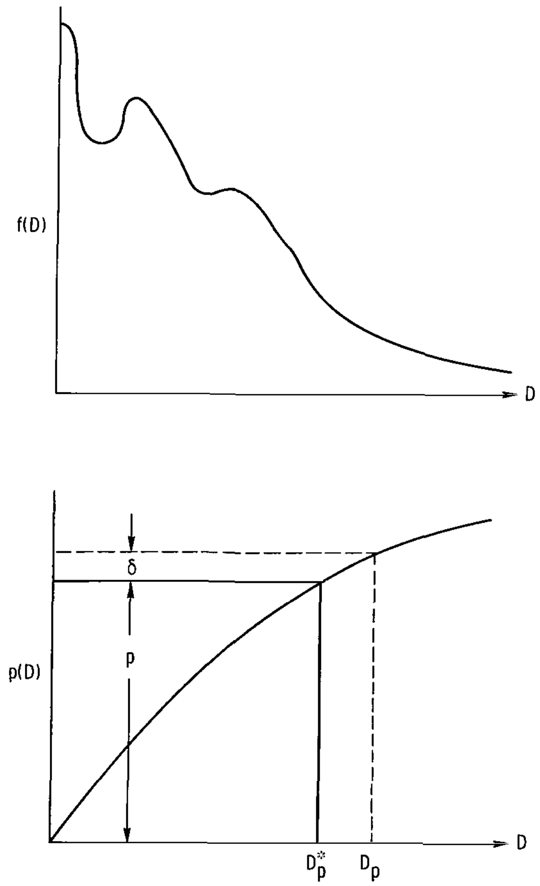


Figure 4. - Frequency and cumulative probability distributions.

It is desired to determine how much an estimate D_p (of D_p^*) might be in error when the estimate is based on a group of M identical trips simulated by the computer code.

The estimate D_p is taken to be the dosage encountered on the $(pM)^{th}$ trip, where the trips have first been arranged in order of increasing dosage (it is assumed that the number pM is an integer). Thus, in the group of M trips, $(pM - 1)$ of the trips encounter doses less than D_p and $(1 - p)M = qM$ of the trips encounter doses larger than D_p. The probability that the measured value of D_p lies in the interval dD lying at D_p is given by the trinomial expression

$$f_{D_p}(D_p)dD = \frac{M!}{(pM - 1)!\,(qM)!}(p + \delta)^{pM-1}(q - \delta)^{qM} f(D_p)dD \tag{B2}$$

where

$$p + \delta = \int_0^{D_p} f(\zeta)d\zeta \tag{B3}$$

is the true probability that the dosage encountered on a trip is less than D_p.

The situation is as depicted in figure 4. Note that equation (B3) may be broken down into the two equations:

$$p = \int_0^{D_p^*} f(\zeta)d\zeta \tag{B3a}$$

$$\delta = \int_{D_p^*}^{D_p} f(\zeta)d\zeta \tag{B3b}$$

If it is assumed that δ is much smaller in magnitude than either p or q and that numbers $(pM - 1)$ and qM are large with respect to p or q, equation (B2) may be written in approximate form as

$$f_{D_p}(D_p) = \sqrt{\frac{Mf^2(D_p)}{2\pi pq}} \exp\left(-\frac{1}{2}\frac{M\delta^2}{pq}\right) \tag{B4}$$

If D_p is sufficiently close to D_p^*, equation (B3b) may be approximated by

$$\delta = f(D_p)(D_p - D_p^*)$$

which when substituted into equation (B4) yields

$$f_{D_p}(D_p) = \sqrt{\frac{Mf^2(D_p)}{2\pi pq}} \exp\left\{-\frac{1}{2}\frac{M}{pq}\left[f^2(D_p)\right](D_p - D_p^*)^2\right\} \tag{B5}$$

The distribution, as given by equation (B5), is a normal distribution with a mean value equal to D_p^* and a standard deviation equal to

$$\sigma_{D_p} = \sqrt{\frac{pq}{Mf^2(D_p)}} = \sqrt{\frac{p(1 - p)}{Mf^2(D_p)}} \tag{B6}$$

Some of the algebra involved in arriving at equation (B4) from equation (B2) follows: From equation (B2)

$$\ln f_{D_p}(D_p) = (pM - 1)\ln(p + \delta) + qM \ln(q - \delta) + \ln M! - \ln(pM - 1)! - \ln(qM)! + \ln f(D_p)$$

This equation can be expanded as follows:

$$\begin{aligned}(pM - 1)\ln(p + \delta) &= (pM - 1)\ln p\left(1 + \frac{\delta}{p}\right)\\ &= (pM - 1)\ln p + (pM - 1)\ln\left(1 + \frac{\delta}{p}\right)\\ &= pM \ln p - \ln p + (pM - 1)\left[\frac{\delta}{p} - \frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \dots\right]\end{aligned}$$

$$qM \ln(q - \delta) = qM \ln q\left(1 - \frac{\delta}{q}\right)$$

$$= -qM \ln \frac{1}{q} + qM \ln\left(1 - \frac{\delta}{q}\right)$$

$$= -qM \ln \frac{1}{q} - qM\left[\frac{\delta}{q} + \frac{1}{2}\left(\frac{\delta}{q}\right)^2 + \frac{1}{3}\left(\frac{\delta}{q}\right)^3 + \ldots\right]$$

Using Stirling's formula for large M,

$$M! \cong \sqrt{2\pi}\, \frac{M^{M+(1/2)}}{e^M}$$

one may express

$$\ln M! = \frac{1}{2} \ln 2\pi + \left(M + \frac{1}{2}\right)\ln M - M$$

$$= \frac{1}{2} \ln 2\pi + M \ln M + \frac{1}{2} \ln M - M$$

Similarly

$$-\ln(pM - 1)! = -\frac{1}{2} \ln 2\pi - \left(pM - \frac{1}{2}\right)\ln(pM - 1) + (pM - 1)$$

and

$$-\ln(qM)! = -\frac{1}{2} \ln 2\pi - \left(qM + \frac{1}{2}\right)\ln(qM) + qM$$

$$= -\frac{1}{2} \ln 2\pi - qM \ln q - qM \ln M - \frac{1}{2} \ln q - \frac{1}{2} \ln M + qM$$

Adding yields

$$\ln M! - \ln(pM - 1)! - \ln(qM)! = -\frac{1}{2}\ln 2\pi + pM\ln M - pM\ln(pM - 1)$$

$$+ \frac{1}{2}\ln(pM - 1) + qM\ln\frac{1}{q} + \frac{1}{2}\ln\frac{1}{q} - 1$$

Also $\ln(pM - 1)$ can be expanded as follows:

$$\ln(pM - 1) = \ln(pM)\left(1 - \frac{1}{pM}\right)$$

$$= \ln p + \ln M - \left(\frac{1}{pM} + \frac{1}{2(pM)^2} + \frac{1}{3(pM)^3} + \ldots\right)$$

Combining these terms results in

$$\ln f_{D_p}(D_p) = -\frac{1}{2}\ln 2\pi + pM\left(\frac{1}{pM} + \frac{1}{2(pM)^2} + \frac{1}{3(pM)^3} + \ldots\right)$$

$$+ \frac{1}{2}\ln p + \frac{1}{2}\ln M - \frac{1}{2}\left(\frac{1}{pM} + \frac{1}{2(pM)^2} + \frac{1}{3(pM)^3} + \ldots\right)$$

$$+ \frac{1}{2}\ln\frac{1}{q} - 1 - \ln p + (pM - 1)\left[\frac{\delta}{p} - \frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \ldots\right]$$

$$- qM\left[\frac{\delta}{q} + \frac{1}{2}\left(\frac{\delta}{q}\right)^2 + \frac{1}{3}\left(\frac{\delta}{q}\right)^3 + \ldots\right] + \ln f(D_p)$$

and combining some terms

$$\ln f_{D_p}(D_p) = -\frac{1}{2}\ln\frac{2\pi pq}{Mf^2(D_p)} + pM\left[\frac{1}{pM} + \frac{1}{2(pM)^2} + \frac{1}{3(pM)^3} + \ldots\right] - 1$$

$$- \frac{1}{2}\left[\frac{1}{pM} + \frac{1}{2(pM)^2} + \frac{1}{3(pM)^3} + \ldots\right]$$

$$+ pM\left[\frac{\delta}{p} - \frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \ldots\right]$$

$$- \left[\frac{\delta}{p} - \frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \ldots\right]$$

$$- qM\left[\left(\frac{\delta}{q}\right) + \frac{1}{2}\left(\frac{\delta}{q}\right)^2 + \frac{1}{3}\left(\frac{\delta}{q}\right)^3 + \ldots\right]$$

Further simplifying yields

$$\ln f_{D_p}(D_p) = -\frac{1}{2}\ln\frac{2\pi pq}{Mf^2(D_p)} + \left[\frac{1}{3(pM)^2} - \frac{1}{4(pM)^2} + \frac{1}{4(pM)^3} - \frac{1}{6(pM)^3} + \ldots\right]$$

$$+ pM\left[-\frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \ldots\right]$$

$$- qM\left[\frac{1}{2}\left(\frac{\delta}{q}\right)^2 + \frac{1}{3}\left(\frac{\delta}{q}\right)^3 + \ldots\right]$$

$$- \left[\frac{\delta}{p} - \frac{1}{2}\left(\frac{\delta}{p}\right)^2 + \frac{1}{3}\left(\frac{\delta}{p}\right)^3 - \ldots\right]$$

Assume that δ is an order of magnitude less than either p or q and M is sufficiently large so that all terms in the brackets other than

$$-\frac{pM}{2}\left(\frac{\delta}{p}\right)^2 - \frac{qM}{2}\left(\frac{\delta}{q}\right)^2$$

can be neglected. Then

$$\ln f_{D_p}(D_p) = -\frac{1}{2} \ln \frac{2\pi pq}{Mf^2(D_p)} - \frac{1}{2} \frac{M\delta^2}{pq}$$

which leads to equation (B4).

APPENDIX C

STRATIFIED SAMPLING OF FIRST FLARE OCCURRENCE DURING TRIP

To reduce the uncertainty in D_p for a given number of trips, the occurrence of the first flare is forced to follow the exponential distribution by a stratified sampling technique (see ref. 6). This is accomplished as follows: The random number interval (0, 1) is subdivided into M equal parts (where M is the number of trips evaluated in a group). The midpoint of the first interval $\xi_1 = 1/2M$ is the random number used to determine (from eq. (1)) when the first flare occurs on the first trip, the midpoint of the second interval $\xi_2 = 3/2M$ is the random number used to determine when the first flare occurs on the second trip, and, in general, $\xi_i = (2i - 1)/2M$ for the i^{th} trip. When a ξ_k is obtained so that the time of occurrence exceeds the total trip time, no flares occur on that trip. After the time-to-first-flare is selected, the procedure for selecting the flare type and time to subsequent flares is as indicated in the METHOD OF ANALYSIS section.

APPENDIX D

FORTRAN IV LISTING

The complete IBM 7094-II FORTRAN IV listing of the MCFLARE program is presented here. The random number generator, RAND/SAND (DECK RANGPL) included here will execute properly <u>only</u> on a 36-bit word machine such as the IBM 7090/7094/ 7094-II with a FORTRAN IV compiler. If this program is used on a different computer, the user will have to supply his own random number generator and alter the two CALL RAND statements and one CALL SAND statements to suit.

```
$IBFTC RANGPL  DECK
      SUBROUTINE SAND(IR)
C      A RANDOM NUMBER GENERATOR FOR A 36 BIT MACHINE WITH
C        MAXIMUM INTEGER CAPABILITY OF 2**35-1
      IR=1
      ZR= 1.0/(2.0**35 -1.0)
      K= 5**15
      RETURN
      ENTRY RAND(R)
      IR=IR*K
      R= FLOAT(IR) * ZR
      RETURN
      END
```

```
$ID    *YU01520 G.P.LAHTI-MCFLARE
$IBJOB
$IBFTC MCFLAR  DECK
C      DOSE CALCULATION FOR SOLAR FLARES
C      G.P.LAHTI   NASA-LEWIS RESEARCH CENTER
C      MONTE CARLO FLARE OCCURRENCE CALCULATION
C      ALL DOSE BINS ARE UNIT BINS
C      EACH EVENT IS ASSUMED TO OCCUR ONLY ONCE DURING THE TIME TREF
C      MAX. NUMBER OF FLARE TYPES = 25
C      MAX. NUMBER OF SHIELDS     = 7
C      MAX. NUMBER OF DOSE BINS   = 900
       COMMON  NTYPE, NT, NBIN, NB, NSHELD, TOTALT, UNITS, PP, PPNT,
      1 PZFREQ(2), POFREQ(10,2), ID(36),              SHIELD(7)
       DIMENSION IFREQZ(26), IFREQ(50,26), JBIN(7,901)
       DIMENSION JFREQZ(26), JFREQ(50,26), KBIN(7,901)
       DIMENSION  CDOSE(25,7), NUM(26), TOTDOS(7), TDUR(25), R(1000)
  500 FORMAT(6I5,2E10.4)
  501 FORMAT(8E9.4)
  502 FORMAT(12A6)
  503 FORMAT(1H0/1H0/19H0TOTAL TRIP TIME =  F8.2,5H DAYS)
  504 FORMAT(1H1/(1H ,12A6))
  505 FORMAT(1H0,I6,48H,000    TRIPS TO BE RUN WITH PRINTOUT AFTER EACH,
     1I5, 4H,000)
  506 FORMAT (29H0         DOSES BASED ON 1./R**,I2)
  663 FORMAT(28H0 THIS CALCULATION CONSIDERS,I3,12H FLARES, AND,I3,16H S
     1HIELDS, NAMELY, 7(2X,A6)/ 42H0                 DOSE CALCULATION USES
     2UP TO,  I5,10H UNIT BINS )
  664 FORMAT(18H1 FLARE INPUT DATA, 25X, 9HDOSES IN  ,A6//
     167H  FLARE   OCCURRENCES OF      DURATION      DOSE FROM ITH TYPE F
     ALARE /
     267H  TYPE,   ITH TYPE FLARE   OF ITH TYPE     AT 1 AU WITH JTH SHI
     BELD- /
     34X,1HI,5X,2HINF7.1,19H DAYS   FLARE, DAYS, 7(6X,A6))
  665 FORMAT(I5,18X,1H1, E14.4, 7E12.4)
  699 FORMAT(O12)
       CALL SAND(XYZ)
       READ(5,699)  XYZ
       PUNCH 699, XYZ
    1 READ(5,502)  (ID(I), I=1,36)
       READ(5,500)MTHOUS,NTHOUS,IXP,NTYPE,NSHELD,NBIN, TREF,TOTALT
C      MTHOUS THOUSAND TRIPS ARE RUN
C      INTERMEDIATE PRINTOUT IS MADE AFTER EACH NTHOUS THOUSAND TRIPS
C      DISTANCE EFFECT (FROM SUN) IS ASSUMED TO BE 1/R**IXP
       IF( (NTHOUS.LE.0)  .OR. (NTHOUS.GT.MTHOUS) )  NTHOUS=MTHOUS
       MTIMES=MTHOUS/NTHOUS
       MTHOUS = MTIMES*NTHOUS
C      NTYPE = NUMBER OF DIFFERENT TYPES OF FLARE EVENTS CONSIDERED
C      NSHELD= NUMBER OF DIFFERENT SHIELDS CONSIDERED
C      NBIN  = NUMBER OF DOSE BINS
C      TREF  = LENGTH OF TIME OF REFERENCE PERIOD FOR INPUT FLARE OCCURRENCES
C      TOTALT= TOTAL TRIP TIME, DAYS  (USED ONLY IF IXP=0)
       READ (5,502) UNITS, (SHIELD(I), I=1,7)
C      UNITS = DOSE UNITS USED (E.G. *RADS*)    (USED IN TITLING OUTPUT)
C      SHIELD= SHIELD DESCRIPTION(FOR OUTPUT TITLING ONLY)
       WRITE(6,504)(ID(I),I=1,36)
```

```
      WRITE(6,663) NTYPE,NSHELD,(SHIELD(I),I=1,7), NBIN
      WRITE(6,5C5)MTHOUS,NTHOUS
      WRITE(6,5C6) IXP
      WRITF (6,664) UNITS, TREF, (SHIELD(I), I=1,7)
      DO  3 I=1,NTYPE
    3 READ (5,5C1) (DDOSE(I,J), J=1,NSHELD)
C     DDOSF(I,J) = DOSE AT 1 AU FROM ITH TYPE FLARE, WITH JTH SHIELD
      READ(5,5C1) (TDUR(I), I=1,NTYPE)
C     TDUR(I) = TIME DURATION OF ITH TYPE EVENT
      DO   4 I=1,NTYPE
    4 WRITE (6,665) I,        TDUR(I), (DDOSE(I,J), J=1,NSHELD)
C     START CALCULATION
      IF(IXP)6,5,6
    5 WRITF(6,5C3) TOTALT
      IF(TOTALT.LE. C.C)  CALL EXIT
      JDAYS=TOTALT+1.0
      DO 105 I=1,JDAYS
  105 R(I)=1.0
      GO TO 7
    6 CALL RADIUS(IXP, TOTALT, R)
    7 NT= NTYPE+1
      QNT=NTYPE
C     QNT=TOTAL NO OF EVENTS WHICH OCCUR IN TIME TREF
      PP=TOTALT/TREF
C     PP=EXPECTEC OCCURRENCES OF EACH FLARE TYPE ON TRIP
      PPNT=PP*CNT
C     PPNT=EXPECTED TOTAL NUMBER OF FLARE EVENTS TO OCCUR ON TRIP
      TSTAR = TREF/QNT
C     POISSON THEORETICAL PROBABILITIES FOR C TC 10 OCCURRENCES
C     PER TRIP    OF EACH FLARE TYPE
      PROB=PP/CNT
      DO 13 J=1,2
      PROB=PROB*CNT
      PZFRFQ(J) = EXP(-PROB)
C     PZFREQ(J)=PROBABILITY OF ZERO FLARES OCCURRING
      POFREQ(1,J) = PZFREQ(J)*PRCB
      DO 13 I=2,1C
      FI=I
C     FREQUENCIES ARE FOR I OCCURRENCES OF THE JTH TYPE FLARE
   13 POFREQ(I,J) = POFREQ(I-1,J)*PRCB/FI
      NB=    NBIN+1
      DO 16 I=1,NB
      DO 16 J=1,NSHELD
   16 KBIN(J,I) = 0
      DO 17 I=1,NT
      JFRFQZ(I) =C
      DO 17 J=1,5C
   17 JFREQ(J,I) =0
      KLUMP = 1CCC*NTHOUS
      XT=2*KLUMP
      XT=1.0/XT
      XXT=XT+XT
C
C     MAIN ITERATION LOOP
C
      DO 99 NTIMES =1,MTIMES
```

```
      DO 18  I=1,NB
      DO 18  J=1,NSHELD
   18 JBIN(J,I)= C
C     JBIN(J,I)= NO. OF   TRIPS   IN ITH DOSE BIN WITH JTH SHIELD
      DO 19  I=1,NT
      IFREQZ(I) =C
      DO 19  J=1,SC
   19 IFREQ(J,I)=C
C     IFREQZ(I)= NO. OF TRIPS    IN WHICH NO I TYPE FLARE OCCURRED
C     IFREQ(J,I)=NO. OF TRIPS    IN WHICH ITH TYPE FLARE OCCURREC JTIMES
C        NOTE-- I= NTYPE+1=NT  MEANS ANY TYPE FLARE
C     IFREQ(J,NT)= NO. OF TRIPS    WITH J FLARES OCCURRING (ALL TYPES)
      XN=-XT
C
C     INTERMEDIATE LOOP
C
      DO 60   INDEXN=1,NTHOUS
      DO 60   INDEXT=1,1000
      DO 21  I=1,NT
   21 NUM(I) = C
C     NUM(I)= NC. OF TIMES ITH TYPE FLARE OCCURS IN TRIP
C     NUM(NT) = TOTAL NC. OF FLARES THAT OCCURRED ON TRIP
      DO 22  I= 1, NSHELD
   22 TOTDOS(I)= C.
C     TOTDOS(I)= DOSE FOR ITH SHIELD
      DAYS = 0.
      XN=XN+XXT
C     SET UP FIRST FLARE FOR TRIP FROM STRATIFIEC SAMPLE
      PRAND=XN
      GO TO 233
   23 CALL RANC(PRAND)
  233 T = TSTAR*(-ALOG(PRAND))
      DAYS = DAYS+T
      IF( DAYS.GT. TOTALT)  GO TC 31
      NUM(NT) = NUM(NT)+1
C     SELECT FLARE TYPE OCCURRING IN THIS INTERVAL
      CALL RANC(PRAND)
C     FOR EACH FLARE OCCURRING ONLY ONCE IN THE REFERENCE PERIOD
      I=ONT*PRAND+1.0
C     AN I TYPE FLARE HAS OCCURRED
   26 NUM(I)=NUM(I)+1
C     CALCULATE DISTANCE EFFECT FACTOR, RR
      JDAY=DAYS+1.0
      RR=R(JDAY)
C     ITH TYPE FLARE HAS OCCURRED --MAKE DOSE CALC FOR ALL SHIELDS
      DO 28  K=1,NSHELD
   28 TOTDOS(K)= TOTDOS(K) + DDOSE(I,K) *RR
      DAYS = DAYS + TDUR(I)
      IF( DAYS-TOTALT)  23,31,31
C  31 END OF TRIP--- -- ANALYZE RESULTS
   31 IF(NUM(NT) ) 33, 33, 41
C  33 NO FLARES HAVE OCCURRED ON THIS TRIP
   33 DO 34  I=1,NT
   34 IFREQZ(I) = IFREQZ(I) + 1
      DO 35  J=1,NSHELD
   35 JBIN(J,1) = JBIN(J,1) +1
```

```
      GO TO 60
C  41 SOME FLARES HAVE OCCURRED ON THIS TRIP
   41 DO 50 I=1,NT
      IF( NUM(I)) 42, 42, 43
   42 IFREQZ(I) =IFREQZ(I) +1
C     NO FLARES OF TYPE I HAVE OCCURRED ON THIS TRIP
      GO TO 50
   43 NN= NUM(I)
C     NN FLARES OF TYPE I HAVE OCCURRED ON THIS TRIP
      IFREQ(NN,I)=IFREQ(NN,I)+1
   50 CONTINUE
      DO 54 J=1,NSHELD
C     PUT TOTAL DOSES IN CORRECT BINS
C     FOR UNIT DOSE BINS....
      I=TOTDOS(J)+1.0
      IF(I.GT.NB)  I=NB
   54 JBIN(J,I)= JBIN(J,I) +1
   60 CONTINUE
      CALL FINALE( IFREQZ, IFREQ, JBIN, KLUMP)
      DO 65 I=1,NB
      DO 65 J=1,NSHELD
   65 KBIN(J,I) = KBIN(J,I)+ JBIN(J,I)
      DO 70 I=1,NT
      JFREQZ(I) = JFREQZ(I)+ IFREQZ(I)
      DO 70 J=1,50
   70 JFREQ(J,I) = JFREQ(J,I) + IFREQ(J,I)
      IF( NTIMES .EQ. 1)  GO TO 99
      KLUMPS = NTIMES*KLUMP
      CALL FINALE( JFREQZ, JFREQ, KBIN, KLUMPS)
   99 CONTINUE
      PUNCH 699, XYZ
      GO TO 1
      END
```

```
$IBFTC FINAL    CECK
      SUBROUTINE FINALE(IFREQZ, IFREC, JBIN, MANY)
      COMMON  NTYPE, NT, NBIN, NB, NSHELD, TOTALT, UNITS, PP, PPNT,
     1 PZFREQ(2), POFREQ(1C,2), ID(36),            SHIELD(7)
      DIMENSION IFREQZ(26), IFREC(50,26), JBIN(7,901)
      DIMENSICN KSUM(26), CPCT(7,9C1)
  600 FORMAT(I3,16I8)
  601 FORMAT(5HCSUMS, I6, 15I8)
  602 FORMAT(I12, 4X   ,7(I6,F8.3))
  603 FORMAT(   4X,8HINFINITY, 4X, 7(I6,F8.3))
  660 FORMAT(61H1  THE NUMBER OF  TRIPS   IN WHICH I FLARES OF TYPE J OC
     1CUR--/ 86H        (THE LAST COLUMN IS THE NUMBER OF  TRIPS   IN WHI
     2CH I FLARES OF ANY TYPE OCCUR)/ 11HC I    J = 1, 15I8)
  661 FORMAT(2CH1  DOSE DISTRIBUTICN                /1HO,15X,7(8H SHIELC-A6
     1)// 16X,7(14H   NC. PERCENT)/ 5X,5HDOSE , A6,    7(14H   IN LESSTH
     2AN)/16H      UPPER LIMIT, 7(14H   BIN  LIMIT ))
  662 FORMAT(42HC      THE EXPECTED NC. OF EACH TYPE IS ...F8.3/
     1       42H       THE EXPECTED NC. OF ANY  TYPE IS ...F8.3)
  671 FORMAT(73HL CALCULATED PRCBABLE OCCURRENCES PER  TRIP   USING POIS
     1SON DISTRIBUTION  /35HC  NUMBER    EACH TYPE     ANY TYPE/
     29HO        C, 1P2E13.5)
  672 FORMAT(I9,1P2E13.5)
      DO 64 I=1,5C
      IMAX = 51-I
      IF (IFREQ(IMAX,NT))64, 64, 66
   64 CONTINUE
   66 DO 68 J=1,NT
      KSUM(J)= IFREQZ(J)
      DO 68 I=1,IMAX
   68 KSUM(J)= KSUM(J)+ IFREC(I,J)
C     SEARCH DCSE BINS FOR HIGHEST OCCURRENCE
      NBB= NB+1
      INFINY =1
      DO 70 I=1,NB
      MAXB= NBB-I
      DO 70 J=1,NSHELD
      IF( JBIN(J,MAXB) ) 7C,7C,72
   70 CONTINUE
   72 IF( I.EQ.1) INFINY=2
      FMISS = MANY
      SS= 100./FMISS
      DO 74 J=1,NSHELD
      NSUM   =C
      DO 74 I=1,MAXB
      NSUM    = NSUM   + JBIN(J,I)
      CSUM= NSUM
   74 CPCT(J,I)= CSUM*SS
      NM= MINO(16,NT)
      WRITE(6,66C)(J,J=2,NM)
      I=0
      WRITE (6,6CC) I,( IFREQZ(J),J=1,NM)
```

```
      DO 76  I=1,IMAX
   76 WRITE (6,6CO)  I,(IFREQ(I,J),J=1,NM)
      WRITE (6,6C1)     (KSUM(J),J=1,NM)
      IF(NT.LE.16)  GO TO 77C
      WRITE(6,663) (J, J=18,NT)
  663 FORMAT(1IHC I    J =17, 15I8)
      I=0
      WRITE (6,6CC) I,( IFRECZ(J),J=17,NT)
      DO 766I=1,IMAX
  766 WRITE (6,6CO)  I,(IFREC(I,J),J=17,NT)
      WRITE (6,6C1)     (KSUM(J),J=17,NT)
  770 WRITE(6,662) PP, PPNT
C     OUTPUT THEORETICAL OCCURRENCES PER TRIP
      WRITE(6,671) PZFREC(1), PZFREQ(2)
      WRITE(6,672)(I, POFREQ(I,1), POFREC(I,2), I=1,10)
      WRITE(6,661)  (SHIELD(I), I=1,7), UNITS
      GO TO (78,77), INFINY
   77 MX= MAXB -1
      GO TO 8C
   78 MX=MAXB
   8C DO 82  I=1,MX
   82 WRITE (6,602)  I,        (JBIN(J,I), CPCT(J,I), J=1,NSHELD)
      GO TO (99,84) ,INFINY
   84 WRITE(6,6C3)       (JBIN(J,MAXB), CPCT(J,MAXB), J=1,NSHELD)
   99 RETURN
      END
```

```
$IBFTC RADMCF  DECK
      SUBROUTINE RADIUS(IXPCN, TCTALT,RRR)
      DIMENSICN THETA(2), THETAF(2), E(2), P(2), AA(2), TAU(2), DAU(100)
     1 , TIME(1CC),             W(1), RR(100) , RRR(1000)
      DATA PI,AU,U/ 3.1415927, 1.4959E8,  9.90598E20/
C     U = PRODUCT OF MASS CF SUN AND UNIVERSAL GRAVITATICN CONSTANT
C     U HAS UNITS OF  KM**3/DAY**2
C     AU = MEAN DISTANCE BETWEEN EARTH AND SUN, KM
  601 FORMAT( F6.C,2(3F8.C,E9.4))
  75C FORMAT(2CH1 MISSICN PARAMETERS/
     123HO TOTAL TRIP TIME, DAYS, F9.4//
     217X,28HEARTH TO PLANET,     TC EARTH/
     319H  SEMI-LATUS RECTUM, E13.5, E13.5, 3X, 2HKM/
     414H  ECCENTRICITY, 5X, 2F13.5/
     523H  TRUE ANOMALY AT START,F9.3,F13.3,3X,7HDEGREES/
     621H  TRUE ANCMALY AT END, F11.3,F13.3,3X,7HDEGREES/
     714H  PERICD, DAYS,5X,2F13.4/
     817H  SEMI-MAJOR AXIS,E15.5,F13.5,3X,2HKM/
     947HL ELAPSED TIME (DAYS) VS DISTANCE FROM SUN (AU))
  751 FORMAT( 5(I5,F9.3,F7.3))
C     RADIUS GENERATICN SECTICN
      READ (5,6C1) THCLD, (THETA(I), THETAF(I), E(I), P(I), I=1,2)
C     THETA = TRUE ANOMALY --ANGLE FRCM PERIHELICN AT START--FOR ELLIPSE
C     THETAF= TRUE ANOMALY --ANGLE FRCM PERIHELICN AT END  --FCR ELLIPSE
C     *** THETA, THETAF UNITS ARE DEGREES**** THETAF MUST BE .GT.THETA
C     E     = ECCENTRICITY   (= O FOR CIRCULAR CRBIT)        FOR ELLIPSE
C     P     = SEMI-LATUS RECTUM IN KILOMETERS                FOR ELLIPSE
C     ELLIPSE 1 IS FOR EARTH TO PLANET
C     ELLIPSE 2 IS FOR PLANET TC EARTH
      TIME(1)= C.
      DO 60 J=1,2
      EM= 1.-E(J)
      EP= 1.+E(J)
      EE= EM*EP
      B     = SQRT(P(J)**3/U) / EE
      C     = 2./SQRT(EE)
      D     = SQRT(EM/EP)
      AA(J) =P(J)/EE
      TAU(J) =2.*PI*SQRT(AA(J)**3/U)
C     AA =  SEMI-MAJOR AXIS OF ELLIPSE
C     TAU =  PERIOD OF ELLIPSE (DAYS)
      DTHETA = (THETAF(J)-THETA(J))/49. *PI/180.
      X = THETA(J)  *PI/18C.
      GO TO (15,1C), J
   10 TIME(51)= TIME(5C)+ THOLD
   15 DO 50 I=1,5C
      K= (J-1)*5C +I
      DEN = 1.+E(J)* COS(X)
      IF(ABS(X-PI) -1.CE-8)  16,16,17
   16 Z = -PI/2.
      GO TO 18
```

```
    17 Z = ATAN(C*SIN(X/2.)/ COS(X/2.) )
    18 TT = B*(C*Z-E(J)*SIN(X)/DEN)
C      TT = TIME ELAPSED IN TRANSFER CONIC AS RECKONED FROM PERIHELION
       IF(I.EQ.1)  GO TO 22
       DT= TT-TTT
       TIME(K)= TIME(K-1) +DT
C      TIME(K) = TIME ELAPSED SINCE START OF TRIP
    19 IF( TIME(K) - TIME(K-1) )  20, 20, 22
C      DT IS SOMETIMES LOW BY A PERIOD OR TWO.. THIS OP CORRECTS THIS
    20 TIME(K)= TIME(K) + TAU(J)
       GO TO 19
    22 TTT=TT
       X= X+DTHETA
       DAU(K) = P(J)/DEN/AU
       RR(K)= DAU(K)**(-IXPON)
    50 CONTINUE
    60 CONTINUE
       TOTALT = TIME(100)
       WRITE(6,750) TIME(100), P(1), P(2), E(1), E(2), THETA(1),
      1THETA(2), THETAF(1), THETAF(2), TAU(1), TAU(2), AA(1), AA(2)
       DO 70 I=1,20
       I2= I+20
       I3= I+40
       I4= I+60
       I5= I+80
    70 WRITE(6,751) I, TIME(I), DAU(I), I2, TIME(I2), DAU(I2), I3,
      1 TIME(I3), DAU(I3), I4, TIME(I4), DAU(I4), I5, TIME(I5), DAU(I5)
C
C      SET UP 1/DAU**IXPON = RRR(I)  FOR EACH DAY IN THE TRIP
       JTIME=TOTALT
       NMIN=2
       DO 99  I=1,JTIME
       T=I
       DO 93 N=NMIN,100
       IF(T-TIME(N))  94,93,93
    93 CONTINUE
    94 NMIN=N
       R=(T-TIME(N-1))*( RR(N)- RR(N-1))/(TIME(N)-TIME(N-1))  + RR(N-1)
       RRR(I)=R
    99 CONTINUE
       RRR(JTIME+1) = RRR(JTIME)
       RETURN
       END
```

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