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A COMPUTER PROGRAM TO CALCULATE ARTIFICIAL RADIATION BELT DECAY FACTORS

by E. G. Stassinopoulos

Goddard Space Flight Center

Greenbelt, Md.

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SUMMARY

The computer code presented here is a FORTRAN II, Monitor-Controlled program for the IBM 7090-7094, and has been developed for calculating artificial radiation-belt decay factors to evaluate the time-dependent change in the intensity of the Starfish electrons injected into the upper atmosphere on July 9, 1962. The program (called subroutine DECAY) has been written in subroutine form as part of an orbital flux code for calculating omnidirectional, vehicle-encountered fluxes. Execution time for the program varies, but even in the worst case it is still insignificantly small (a fraction of a second). By means of this code, anticipated fluxes at any epoch may be predicted from known radiation levels at a given time.

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INTRODUCTION

A significant loss of Starfish electrons has occurred since their injection into the upper atmosphere on July 9, 1962. It is assumed that this artificial radiation-belt population decreases exponentially with time (References 1 and 2), thus, the remaining particle intensity may be adequately approximated by a decay factor of the form,

$$\exp\left(-\frac{\Delta t}{\tau}\right), \tag{1}$$

where τ is the mean lifetime of electrons with energies greater than 1.2 Mev (Reference 3) and Δt is the specified time difference $(t_2 - t_1)$. If the flux at time t_2 is then related to that of time t_1 by this decay factor, the expression,

$$\Phi(t_2) = \Phi(t_1)\exp\left(-\frac{(t_2 - t_1)}{\tau}\right), \tag{2}$$

is obtained which may be used readily in a computer calculation. author

Measurements of mean lifetime, τ, (by Van Allen and Lin with INJUN III and by Bostrom and Williams of APL with 1963-38c, References 1 and 2) have shown, that the decay constant is mainly a function of the magnetic shell parameter, L, and is almost independent of the field strength, B.

It should be noted, that the 1963-38c measurements were taken at a later epoch than the INJUN III and hence are consistently lower (Table 1 and Figure 1).

Table 1

Subroutine-DECAY Mean Lifetime Measurements of Artificial Radiation-Belt Electrons.

Measurement No.	Magnetic-Shell Parameter, L (earth radii)	Magnetic Field Strength, B (gauss)	Mean Lifetime, τ_1† (days)	Mean Lifetime, τ_2‡ (days)
1	(1.15)	----------	(0)	(0)
2	1.20	0.185-0.205	130	120
3	1.23	0.170-0.205	190	165
4	1.30	0.100-0.230	320	235
5	1.40	0.165-0.210	500	390
6	1.45*	----------	565*	445*
7	1.50	0.175-0.215	590	460
8	1.55*	----------	585*	445*
9	1.60	0.180-0.225	(500)	360
10	1.65*	----------	275*	225*
11	(1.70)	----------	(100)	(100)
12	1.725*	----------	50*	65*
13	1.75*	----------	25*	40*
14	(1.80)	----------	(0)	(0)

All values in parentheses are estimates not contained in original information.

*Values indicated were obtained by fitting the τ-curve (Figure 1) to the source and to the estimates.
†τ_1 measurements made by Van Allen and Lin with INJUN III.
‡τ_2 measurements made by Bostrom and Williams with 1963-38c.

METHOD OF COMPUTATION

The subroutine first calculates the time difference $\Delta t = t_2 - t_1$, where t_1, contained internally, defines the epoch of the electron grid used* and t_2, an input quantity, pertains to a given later date, for which flux information is being sought.

If $\Delta t \leq 0$, the subroutine will bypass the rest of the program and, since no decay is involved in that case, it will set the decay factor equal to unity and return to the main routine.

If $\Delta t > 0$ the subroutine continues, it then initiates computation of the decay factor by

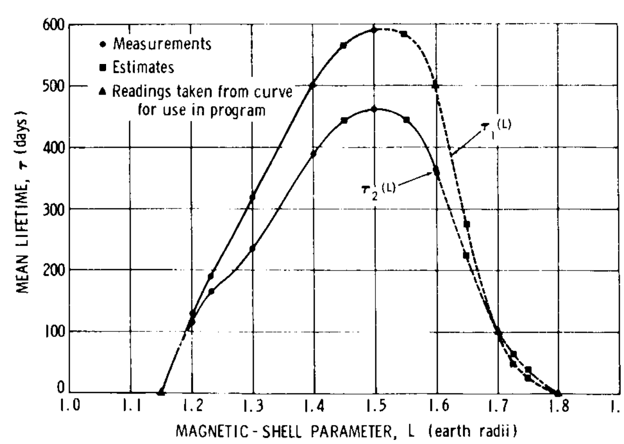


Figure 1—Function τ(L) fitted to measurements by Van Allen and Lin (τ_1) Bostrom and Williams (τ_2) for L $\leq$ 1.6 and to estimates by Hess for L $\geq$ 1.6.

*Presently the code is programmed for the E8 grid of November, 1962.

establishing once, in its first passage, the τ-to-L dependence in the form of a look-up table where $\tau(L) = 0$ for $L > 1.8$ (see Table 1). Subsequently, it tests the L of the orbital position under consideration and if $1.15 < L < 1.8$ it proceeds to obtain τ by a linear interpolation from both sources available (i.e., Van Allen and Lin, and Bostrom and Williams) and then either computes or defines the proper decay factor, $\exp(-\Delta t/\tau)$.

Finally, the subroutine sets up suitable control parameters in order to avoid, during its repetitive use by the Orbital Flux Code, recomputation of any quantity that is both invariant with respect to a given trajectory and permanently established for that orbit during the first passage. In this manner the subroutine also passes over the once initialized look-up table.

USAGE AND LIMITATIONS

No actual limitations exist with respect to computation of a decay factor by the subroutine. It is programmed to accept any epoch t_2 including those that fall on, or before, its critical or effective date t_1.

Epoch t_2 must be given in the form of year, month and day, and in that order. The subroutine will test each quantity separately, in the same order, and convert into days if necessary.

There is no difficulty in substituting another effective date t_1 (for different flux data) into the code as long as appropriate reference relations are included.

Similarly, the mean lifetimes may be changed easily without major modifications by simply inserting new tables of τ to L values between statements 551 and 550 and by adjusting the limits of statements 550 and Dimension (if necessary).

Due to the IBM 7094 floating point limitations, it is to be expected that the decay factors will be zero whenever the ratio $\Delta t/\tau$ becomes greater than that value, which will make the characteristic exceed the storage capacity of the register. When this happens, underflow occurs. Figure 2 shows the relationship of time difference, Δt, to mean lifetime, τ, where the shaded area indicates combinations causing such underflow. This however does not affect the results in any way. Contributions of such small magnitudes can be neglected. A sample computation with the τ_1 decay constant for various constant flux ratios (ϕ/ϕ_0) is shown in Figure 3.

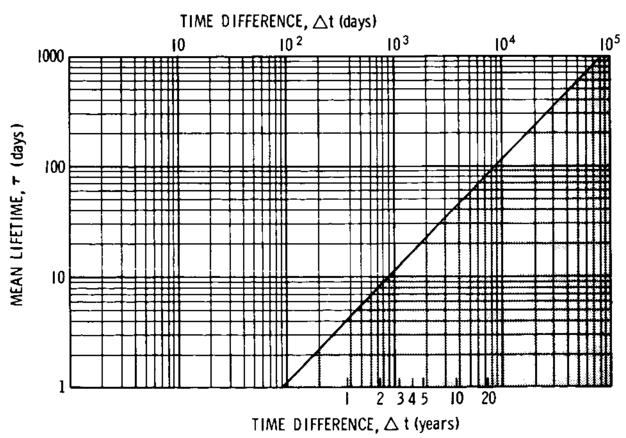


Figure 2—Underflow relationship of mean lifetime τ and time difference Δt. (Shaded area shows combinations causing decay factors to become zero.)

The constant τ_1 is that measured by Van Allen and Lin with INJUN III.

CONCLUSION

Whenever the orbital flux code is employed and its output is utilized, caution must be exercised in regard to the following shortcomings and restrictions:

1. The subroutine applies to Starfish electrons only. It does not consider or include natural electrons.*
2. The mean lifetime (and hence the flux) has been set equal to zero for $L \geq 1.8$.
3. The decay constants τ_1 and τ_2 were obtained from measurement of $E > 1.2$-Mev electrons. If used for all energy electrons, the resulting spectra may not be very accurate (values possibly inflated for low energy fluxes).*

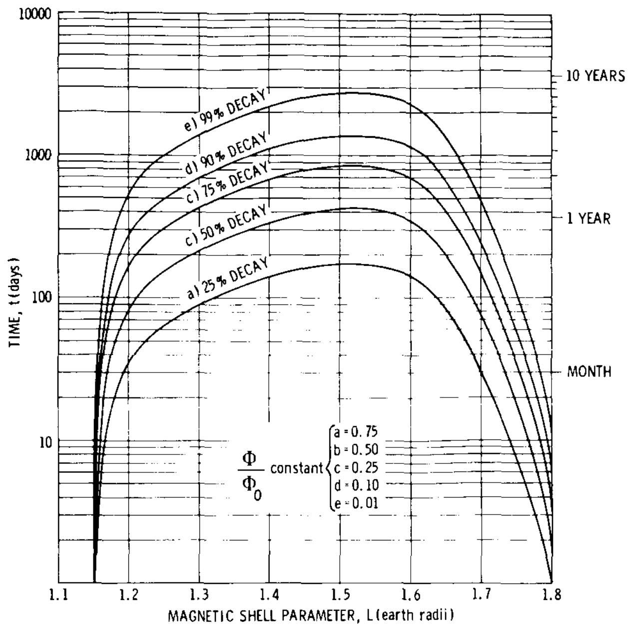


Figure 3—Contours of constant flux ratius Φ/Φ_0 as functions of L and t for Starfish electrons. (Each curve traces a given fixed percentage by which an initial flux is requested to decay.)

4. Since increasing solar activity in the years ahead will greatly affect the lifetimes of the Starfish electrons, the use of this routine for epochs later than 1966 is not advisable.*

REFERENCES

1. Van Allen, J. A., "Lifetimes of Geometrically Trapped Electrons of Several MeV Energy," *Nature*, vol. 203, no. 4949, pp. 1006-1007, London: Macmillan and Company, Ltd., September 1964.

2. Bostrom, C. O., Williams, D. J., "Time Decay of the Artificial Radiation Belt," *Journal of Geophysical Research*, vol. 70, no. 1, pp. 240-242, Richmond: The American Geophysical Union, January 1965.

*Private communication with Dr. Wilmot N. Hess, GSFC, "Circular to users of E8 grid," October 20, 1964.

Appendix A

Subroutine

Arguments and Parameters, Flow
Chart and Listing

1. Arguments and Parameters

A. Input:

IN - Control parameter; governs the calculation of Δt; may have values 0, 1 or 2; at the start it is set equal to zero in main routine and remains unaffected by it thereafter; it is redefined in subroutine; it performs as follows:

0: attempts to compute Δt ,

1: Δt is well defined, hence it bypasses section computing Δt and proceeds to obtain decay factors,

2: Δt cannot be defined, hence it bypasses section computing Δt , sets decay factors equal to one.

DL - Magnetic shell parameter L associated with orbital position under consideration.

YEAR - Year of date for which decay factor is to be calculated.

AMONTH - Month of date for which decay factor is to be calculated.

DAY - Day of date for which decay factor is to be calculated.

NOT - Control parameter; governs the initialization of the τ-L tables; may be -1, 0, +1; at the start it is set equal to zero in main routine and remains unaffected by it thereafter; it is redefined in subroutine; it performs as follows:

-1: skips initialization of tables

0, 1: initializes tables

B. Internal:

T1 - year(s) in days

T2 - month(s) in days

T3 - day(s)

(T1, T2, T3:) These arguments establish the time difference $\Delta t = (t_2 - t_1)$

T - time difference Δt in days, i.e., the sum of T1, T2, T3

TAL(I) - L_i values of the τ-L tables, where $i = 1, \cdots 14$

TA1(I) - τ_{1_i} values of the τ-L tables, where $i = 1, \cdots 14$

TA2(I) - τ_{2_i} values of the τ-L tables, where $i = 1, \cdots 14$

KK - Control parameter within L-testing loop; defines special cases.

TAU1 - decay constant τ_1

TAU2 - decay constant τ_2

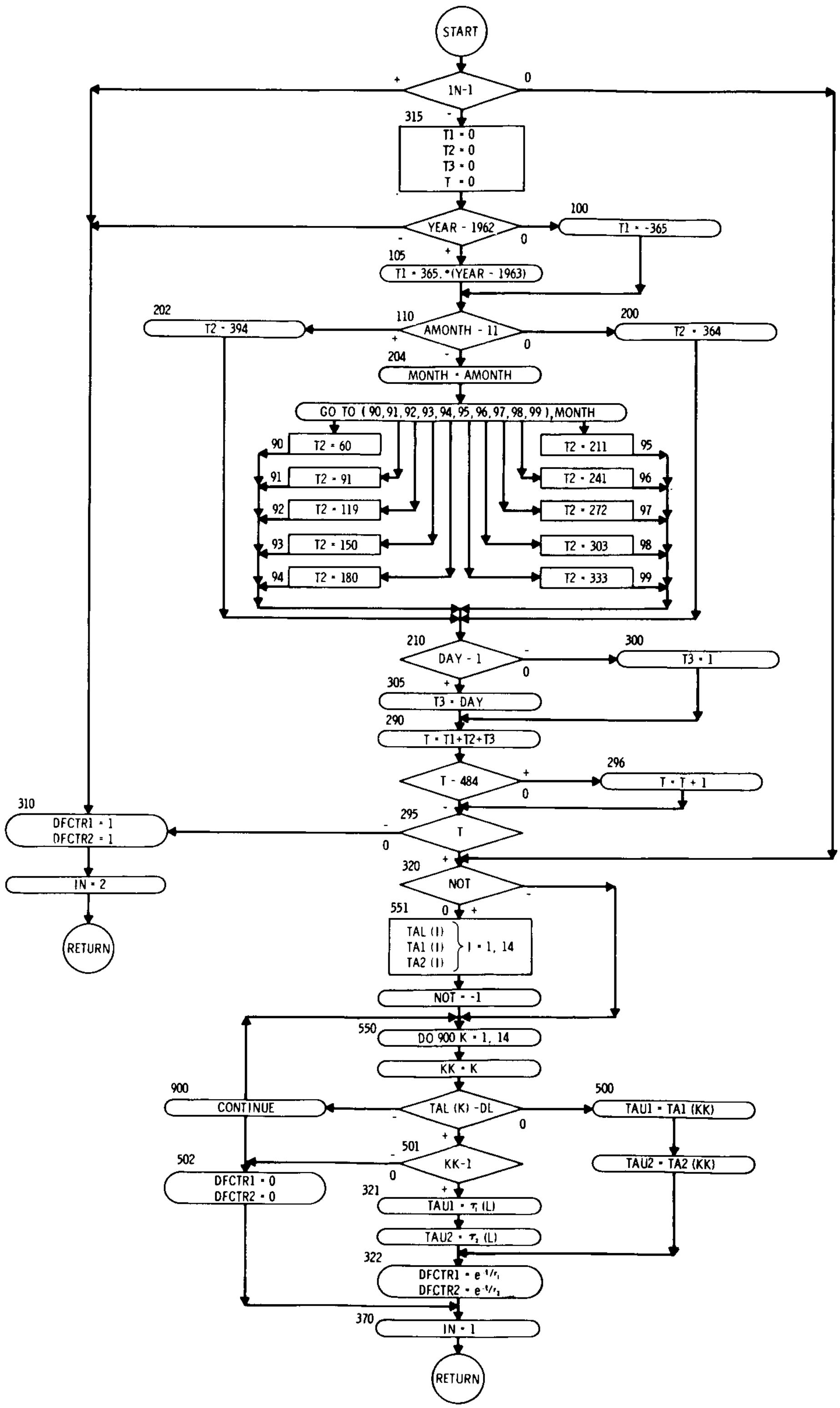
C. Output:

DFCTR1 - decay factor with respect to τ_1

DFCTR2 - decay factor with respect to τ_2

Note: All arguments are in floating point notation except the parameters IN, NOT, KK which are fixed point quantities.

2. Flow Chart


START
IN-1
315
T1 = 0
T2 = 0
T3 = 0
T = 0
YEAR - 1962
100
T1 = -365
105
T1 = 365.*(YEAR - 1963)
110
AMONTH - 11
202
T2 = 394
200
T2 = 364
204
MONTH = AMONTH
GO TO (90, 91, 92, 93, 94, 95, 96, 97, 98, 99), MONTH
90
T2 = 60
91
T2 = 91
92
T2 = 119
93
T2 = 150
94
T2 = 180
95
T2 = 211
96
T2 = 241
97
T2 = 272
98
T2 = 303
99
T2 = 333
210
DAY - 1
300
T3 = 1
305
T3 = DAY
290
T = T1+T2+T3
T - 484
296
T = T + 1
295
T
310
DFCTR1 = 1
DFCTR2 = 1
IN = 2
RETURN
320
NOT
551
TAL (I)
TA1 (I)
TA2 (I)
I = 1, 14
NOT = -1
550
DO 900 K = 1, 14
KK = K
TAL (K) -DL
900
CONTINUE
500
TAU1 = TA1 (KK)
TAU2 = TA2 (KK)
501
KK-1
502
DFCTR1 = 0
DFCTR2 = 0
321
TAU1 = τ1 (L)
TAU2 = τ2 (L)
322
DFCTR1 = e^-t/τ1
DFCTR2 = e^-t/τ2
370
IN = 1
RETURN

3. Listing

```
      SUBROUTINE DECAY(IN,DL,YEAR,AMONTH,DAY,DFCTR1,DFCTR2,NOT)
C     THE MEAN LIFE TIME TAU1 IS OBTAINED FROM MEASUREMENTS MADE WITH
C                        INJUN III
C     THE MEAN LIFE TIME TAU2 IS OBTAINED FROM MEASUREMENTS MADE WITH
C                        1963 38C
      DIMENSION TAL(20),TA1(20),TA2(20)
      IF(IN - 1)315,320,310
  315 T1 = 0.
      T2 = 0.
      T3 = 0.
      T = 0.
      IF(YEAR - 1962.)310,100,105
  100 T1 = -365.
      GO TO 110
  105 T1 = 365.*(YEAR - 1963.)
  110 IF(AMONTH - 11.)204,200,202
  200 T2 = 364.
      GO TO 210
  202 T2 = 394.
      GO TO 210
  204 MONTH = AMONTH
      GO TO (90,91,92,93,94,95,96,97,98,99),MONTH
   90 T2 = 60.
      GO TO 210
   91 T2 = 91.
      GO TO 210
   92 T2 = 119.
      GO TO 210
   93 T2 = 150.
      GO TO 210
   94 T2 = 180.
      GO TO 210
   95 T2 = 211.
      GO TO 210
   96 T2 = 241.
      GO TO 210
   97 T2 = 272.
      GO TO 210
   98 T2 = 303.
      GO TO 210
   99 T2 = 333.
  210 IF(DAY - 1.)300,300,305
  300 T3 = 1.
      GO TO 290
  305 T3 = DAY
  290 T = T1 + T2 + T3
      IF(T - 484.)295,296,296
  296 T = T + 1.
  295 IF(T)310,310,320
  310 DFCTR1 = 1.
      DFCTR2 = 1.
      IN = 2
      RETURN
  320 IF(NOT)550,551,551
  551 TAL(1) = 1.15
      TAL(2) = 1.20
      TAL(3) = 1.23
      TAL(4) = 1.30
```

```
      TAL(5)  = 1.40
      TAL(6)  = 1.45
      TAL(7)  = 1.50
      TAL(8)  = 1.55
      TAL(9)  = 1.60
      TAL(10)= 1.65
      TAL(11)= 1.70
      TAL(12)= 1.725
      TAL(13)= 1.75
      TAL(14)= 1.80
      TA1(1)  = 0.
      TA1(2)  = 130.
      TA1(3)  = 190.
      TA1(4)  = 320.
      TA1(5)  = 500.
      TA1(6)  = 565.
      TA1(7)  = 590.
      TA1(8)  = 585.
      TA1(9)  = 500.
      TA1(10)= 275.
      TA1(11)= 100.
      TA1(12)= 50.
      TA1(13)= 25.
      TA1(14)= 0.
      TA2(1)  = 0.
      TA2(2)  = 120.
      TA2(3)= 165.
      TA2(4)= 235.
      TA2(5)= 390.
      TA2(6)= 445.
      TA2(7)= 460.
      TA2(8)= 445.
      TA2(9)= 360.
      TA2(10)=225.
      TA2(11)=100.
      TA2(12)= 65.
      TA2(13)= 40.
      TA2(14)= 0.
      NOT = -1
  550 DO 900 K=1,14
      KK = K
      IF(TAL(K) - DL)900,500,501
  900 CONTINUE
      GO TO 502
  501 IF(KK-1)502,502,321
  502 DFCTR1 = 0.
      DFCTR2 = 0.
      GO TO 370
  500 TAU1 = TA1(KK)
      TAU2 = TA2(KK)
      GO TO 322
  321 TAU1 = TA1(KK)-((TA1(KK)-TA1(KK-1))/(TAL(KK)-TAL(KK-1)))*(TAL(KK)-
     1DL)
      TAU2 = TA2(KK)-((TA2(KK)-TA2(KK-1))/(TAL(KK)-TAL(KK-1)))*(TAL(KK)-
     1DL)
  322 DFCTR1 = EXPF(-T/TAU1)
      DFCTR2 = EXPF(-T/TAU2)
  370 IN=1
      RETURN
      END
```

Appendix B

List of Symbols

Δt = Time difference in days = $(t_2 - t_1)$

t_1 = November 1, 1962, effective date relating to epoch of electron data

t_2 = Any other date

τ = Mean lifetime of Starfish electrons in days

τ_1 = Mean lifetime by Van Allen and Lin from measurements with INJUN III

τ_2 = Mean lifetime by Bostrom and Williams from measurements with 1963-38c

L = Magnetic shell parameter in earth radii

B = Magnetic field strength in gauss

Φ = Omnidirectional flux in particles per square centimeter per second (particles/cm^2-second)