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Steady-State Multi-Ion Disturbed D-Region Model

WILLIAM SWIDER
CAROL I. FOLEY

15 June 1978

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A model with 78 reactions involving 21 positive ions and 8 negative ions has been developed for the disturbed D-region under steady-state conditions. Model examples are given for the 2 to 5 November 1969 and 3 to 11 August 1972 solar proton events. The computer program for the model is given in the Appendix.

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1. INTRODUCTION

Previously[1] we described a model for the nighttime disturbed D-region which treated negative ions in a highly simplified manner. Good agreement was attained[2] between the model and the nighttime observations of 3 November 1969 at Ft. Churchill, Canada, during a solar proton event (SPE). More recently, by incorporating the latest negative ion chemistry, exclusive of hydration processes, we have found[3] that good agreement can be obtained between our latest model and the three daytime observations of 2, 3, and 4 November 1969 for this same event and location. In this report we document the new program which includes not only a more satisfactory treatment of negative ions, but also includes some new positive ion chemistry involving NO^+ ions. We also provide here the numerical results obtained in applying this program to the solar proton events of 2 to 5 November 1969 and 3 to 11 August 1972.

(Received for publication 14 June 1978)

[1] Swider, W., and Foley, C.I. (1975) Computer Program for the Disturbed Steady-State Nighttime D-region, AFCRL-TR-75-0150.

[2] Swider, W., and Narcisi, R.S. (1975) A study of the nighttime D-region during a PCA event, J. Geophys. Res. **80**:655-664.

[3] Swider, W., Keneshea, T.J., and Foley, C.I. (1978) An SPE-disturbed D-region model, Planet. Space Sci. **26**:

2. OUTLINE OF MODEL

The computer program is reproduced in Appendix A. All photorates in this code are multiplied by DD which is set to 1 for daytime and 0 for nighttime.

The iterative scheme developed to solve for all species concentrations is similar to that derived before.[1] The present scheme is more complex; two initial concentrations are now needed, one for electrons and one for the positive ion sum. Using the initial concentrations for electrons [e], and the positive ion sum, SP, the individual negative ions are determined and then summed, the sum denoted by NSUM. Then the positive ions are individually calculated and summed, PSUM. A new $[e] = \{\text{previous } [e] + \text{PSUM}/(1+\lambda)\}/2$, where $\lambda = \text{NSUM}/\text{previous } [e]$, and a new $\text{SP} = \{\text{previous } [e] + \text{NSUM} + \text{PSUM}\}/2$ are then determined. This sequence is repeated until PSUM agrees with NSUM + [e] to some desired precision, usually ± 1 percent. In the examples to be shown later, not more than 9 iterations were required at any particular altitude (40-90 km) in order to attain this criterion.

Initial daytime electron concentrations were obtained from

$$[e] = (q/SI)^{1/2} \qquad (1)\ \text{L 189}$$

where $SI = \psi$ represents values for the effective electron loss coefficient as determined[4] for the 2 to 5 November 1969 SPE. The number following the equation number in the text, as L 189 above, means that Eq. (1) is or begins on line 189 of the program. Initial nighttime electron concentrations were estimated, as before,[1] from the equation[5]

$$[e] = \left\{(L(A)/2\alpha_D)^2 + q/\alpha_D\right\}^{1/2} - L(A)/2\alpha_D \qquad (2)\ \text{L 191}$$

where α_D is the mean dissociative recombination coefficient and

$$L(A) = k_{61}[O_2]^2 + k_{62}[O_2]\,[N_2] \qquad (3)\ \text{L 187}$$

is the loss rate (sec^{-1}) of electrons by attachment to O_2 with O_2 and N_2 as third bodies. The reaction rates and rate coefficients are listed later, the subscripts for k referring to the processes are as numbered in that listing

---

4. Swider, W., and Dean, W.A. (1975) Effective electron loss coefficient of the disturbed daytime D-region, J. Geophys. Res. **80**:1815-1819.

5. Swider, W., Narcisi, R.S., Keneshea, T.J., and Ulwick, J.C. (1971) Electron loss during a nighttime PCA event, J. Geophys. Res. **76**:4691-4694.

Initial total positive ion concentrations were determined from the expression

$$SP = \left\{ q \left(\frac{5[O]}{\alpha_D} + \frac{[O_3]}{\alpha_i} \right) \Big/ (5[O] + [O_3]) \right\}^{1/2} \qquad (4)\ \text{L193}$$

where α_i is the mean ion-ion recombination coefficient. The multiplicative factor for [O], somewhat arbitrary, was selected after some trial runs as a factor for improving SP vis-a-vis the final calculated positive ion sum. Equation (4) simplifies to the familiar expressions $(q/\alpha_D)^{1/2}$ at high D-region altitudes where $[O] >> [O_3]$ and $(q/\alpha_i)^{1/2}$ at low D-region altitudes where $([O_3] >> [O]$. Values chosen for α_D and α_i were 4×10^{-7} cm^3/sec (L 73) and 6×10^{-8} cm^3/sec (L 74) respectively. The former value was selected as that typical for a mixture of NO^+ and O_2^+ ions at D-region temperatures, whereas the latter value is based upon laboratory measurements by Smith et al.[6] The fact that all ion-ion recombination coefficients were set at 6×10^{-8} cm^3/sec in this program is in accord with the laboratory work. However, this constraint is not a necessary one in the operation of this program; one α_i being required only for initial SP.

The positive ion equations are similar to those listed before except that changes have been made because of our inclusion of photodissociation processes for O_4^+ and $O_2^+(H_2O)$ ions and by our addition of the ions $NO^+(N_2)$, $NO^+(H_2O)(N_2)$, $NO^+(H_2O)(CO_2)$, $NO^+(2H_2O)(N_2)$ and $NO^+(2H_2O)(CO_2)$. The list of positive ion reactions, numbered 4 through 52 in Table 1 for the 21 positive ions considered, is fairly complete. Rate coefficients are generally from the same sources already identified.[2,3] Rates for photodissociation processes 4 and 5 in Table 1 are from Vanderhoff and Niles,[7] while the rate coefficient k_{43} was taken from the work of Johnsen et al.[8] Rate coefficients for reactions 45 and 48 were set equal to that for k_{43}. The rate coefficient k_{51} is based[9] upon parameters measured by Johnsen et al.[8] High rate coefficients for processes 44, 46, 47, 49 and 50 were chosen in accordance with the fact that they are all "switching" reactions. Computation of the individual positive ions begins with O_2^+ (PION 4, J), line 204 of the program and is completed by line 257 with PION (24, J) = $H_9O_4^+$. Thus, this rather extensive list of positive ions (21) requires only 53 lines in the computer program.

---

6. Smith, D., Adams, N.G., and Church, M.J. (1976) Mutual neutralization rates of ionospherically important ions, Planet. Space Sci. 24:697-703.
7. Vanderhoff, J.A., and Niles, F.E. (1976) Recent development in measurements of photodissociation for atmospheric positive ions, EOS, 57:303.
8. Johnsen, R., Huang, C.-M., and Biondi, M.A. (1975) The formation and breakup of $NO^+ \cdot N_2$ clusters in N_2 at low temperatures, J. Chem Phys. 63:3374-3378.
9. Heimerl, J.M. (1976) Values for Selected Collisional Dissociation Rate Coefficients of Positive Clustered Ions, BRL-IMR-499.

Table 1. Positive Ion Reactions. Units for photo-processes, two-body and three-body processes are sec^{-1}, cm^3/sec and cm^6/sec, respectively. The various process coefficients, $\kappa = A\,(T/300)^B\,e^{D/T}$, are presented in the format A B D

		A	B	D
4	O4+ + HV = O2+ + O2	3.00E-01		
5	O2+.H2O + HV = O2+ + H2O	6.00E-01		
6	O2+ + NO = NO+ + O2	4.50E-10		
7	O2+ + O2 + O2 = O4+ + O2	3.90E-30	-3.2	
8	O4+ + O = O2+ + O3	3.00E-10		
9	O4+ + H2O = O2+H2O + O2	1.50E-09		
10	O2+H2O + H2O = H3O+OH + O2	1.00E-09		
11	O2+H2O + H2O = H3O+ + OH + O2	2.00E-10		
12	H3O+OH + H2O = H5O2+ + OH	1.40E-09		
13	H3O+ + N2 + N2 = H3O+.N2 + N2	1.40E-30	-2.0	
14	H3O+.N2 + CO2 = H3O+.CO2 + N2	1.00E-09		
15	H3O+.CO2 + H2O = H5O2+ + CO2	1.00E-10		
16	H5O2+ + CO2 + M = H5O2+.CO2+ M	3.00E-30		
17	H5O2+.CO2+ H2O = H7O3+ + CO2	1.00E-10		
18	H3O+ + H2O + M = H5O2+ + M	3.50E-27	-3.0	
19	H5O2+ + H2O + M = H7O3+ + M	2.20E-27	-3.0	
20	H7O3+ + H2O + M = H9O4+ + M	2.30E-27	-3.0	
21	NO+ + CO2 + N2 = NO+CO2 + N2	3.00E-29	-2.0	
22	NO+CO2 + H2O = NO+H2O + CO2	5.00E-10		
23	NO+H2O + H2O + N2 = NO+(H2O)2+ N2	1.10E-27	-4.7	
24	NO+(H2O)2+ H2O + N2 = NO+(H2O)3+ N2	1.60E-27	-4.7	
25	NO+(H2O)3+ H2O = H7O3+ + HNO2	7.00E-11		
26	NO+ + E = N + O	4.00E-07	-1.0	
27	O2+ + E = O + O	2.00E-07	-1.0	
28	O4+ + E = O2 + O2	2.00E-06		
29	O2+.H2O + E = O2 + H2O	2.00E-06		
30	H3O+.OH + E = 2H2O	2.00E-06		
31	H3O+ + E = H2 + OH	1.00E-06		
32	H5O2+ + E = H2O + H2 + OH	2.00E-06		
33	H7O3+ + E = 2H2O + H2 + OH	4.00E-06		
34	H9O4+ + E = 3H2O + H2 + OH	5.00E-06		
35	H3O+.N2 + E = H + H2O + N2	2.00E-06		
36	H3O+.CO2 + E = H + H2O + CO2	2.00E-06		
37	H5O2+.CO2+ E = H + 2H2O+ CO2	3.20E-06		
38	NO+.CO2 + E = NO + CO2	1.50E-06		
39	NO+H2O + E = NO + H2O	1.50E-06		
40	NO+(H2O)2+ E = NO + 2H2O	3.00E-06		
41	NO+(H2O)3+ E = NO + 3H2O	4.50E-06		
42	O4+ + M = O2+ + O2 +M	3.30E-06	-4.0	-5.03E+03
43	NO+ + N2 + N2 = NO+.N2 + N2	2.00E-31	-4.4	
44	NO+.N2 + CO2 = NO+.CO2 + N2	2.00E-09	0.0	
45	NO+.H2O + N2 + N2 = NO+H2ON2 + N2	2.00E-31	-4.4	
46	NO+H2ON2 + CO2 = NO+H2OCO2+ N2	2.00E-09	0.0	
47	NO+H2OCO2+ H2O = NO+.2H2O + CO2	2.00E-09	0.0	
48	NO+.2H2O + N2 + N2 = NO+2H2ON2+ N2	2.00E-31	-4.4	
49	NO+2H2ON2+ CO2 = NO+2H2OCO2+ N2	2.00E-09	0.0	
50	NO+2H2OCO2+ H2O = NO+.3H2O + CO2	2.00E-09	0.0	
51	NO+.N2 + N2 = NO+ + N2 + N2	1.00E-08	-4.4	-2.10E+03
52	H9O4+ + M = H7O3+ + H2O + M	1.20E-01	-4.0	-8.80E+03

Eight negative ions are included in this program, O_2^-, O_4^-, CO_4^-, CO_3^-, O^-, O_3^-, NO_2^- and NO_3^-. This is also the order in which the respective ion concentrations are solved. Considerable algebraic manipulation was required for these solutions which will not be described in the text but can be followed in the subroutine NEGION, lines 25-87. The ion concentrations of several ions are easily solved, but the main trick was to eliminate CO_3^- from the equation for O_2^- which was accomplished by reducing CO_3^- to a function of O_2^-. Thus, the solution of CO_3^- (line 64) is expressed simply as $S[O_2^-] / R$, but S, lines 35-39 and R, line 34, are quite complex terms involving the lengthy algebraic factors T, W, V, U, which are described on lines 29-32. The negative ion processes used in the calculations are given in Table 2. Rate coefficients for non-proton processes were taken mainly from the work of the Boulder group (for example, Ferguson)[10] including a recent update[11] for $k_{80} + k_{81}$, 8.8×10^{-10} cm^3/sec with product branches which we took as equal. Photodissociation/photodetachment rates are generally those listed by Peterson et al[12] or estimated by Niles[13] (NO_x^-).

Profiles of neutrals O, O_2, O_3, $O_2(^1\Delta)$, N_2, CO_2, H_2O, NO and NO_2 plus temperature were required inputs to the computations. Total concentrations, [M], and temperatures T, were taken from CIRA[*] 1972 for the appropriate month and latitude with $N_2 = 0.7808$ [M], $O_2 = 0.2095$ [M] and $CO_2 = 3 \times 10^{-4}$ [M]. Water vapor concentrations, $[H_2O]$ were set at 10^{-6} [M]. The choices for the other minor neutrals are described elsewhere.[3] Each output gives a complete account of all the neutral concentrations utilized. The daytime and nighttime minor neutral concentrations used in the computations will be presented in typical printouts for daytime and nighttime situations.

---

10. Ferguson, E. E. (1975) in *Atmospheres of Earth and the Planets* (Ed. B. M. McCormac) Reidel, Dordrecht, Holland, pp 197-210.

11. Ferguson, E. E. (1977) Paper presented at IAGA meeting in Seattle, Washington,

12. Peterson, J. R., Cosby, P. C., and Moseley, J. T. (1977) Photo-destruction of atmospheric negative and positive ions, *Space Res.* **17**:243-246.

13. Niles, F. E. (1976) private communication.

[*] COSPAR International Reference Atmosphere.

Table 2. Negative Ion Reactions. Units and format are as for Table 1

							A	B	D
60	O2-	+ O3		= O3-	+ O2		5.00E-10		
61	O2	+ E	+ O2	= O2-	+ O2		1.40E-29	-1.0	-6.00E+02
62	O2	+ E	+ N2	= O2-	+ N2		1.00E-31		
63	O2-	+ O		= O3	+ E		1.50E-10		
64	O2-	+ O		= O-	+ O2		1.50E-10		
65	O2-	+ O2(1D)		= O2	+ O2	+ E	2.00E-10		
66	O2-	+ O2	+ O2	= O4-	+ O2		3.50E-31	-1.0	
67	O4-	+ CO2		= CO4-	+ O2		4.30E-10		
68	CO4-	+ O3		= O3-	+ CO2	+ O2	1.30E-10		
69	CO4-	+ NO		= NO3-	+ CO2		4.80E-11		
70	CO4-	+ O		= CO3-	+ O2		1.50E-10		
71	O3-	+ O		= O2-	+ O2		3.20E-10		
72	O3-	+ CO2		= CO3-	+ O2		5.50E-10		
73	CO3-	+ O		= O2-	+ CO2		1.10E-10		
74	CO3-	+ NO		= NO2-	+ CO2		1.10E-11		
75	CO3-	+ NO2		= NO3-	+ CO2		2.00E-10		
76	NO2-	+ O3		= NO3-	+ O2		9.00E-11		
77	O-	+ O2	+ O2	= O3-	+ O2		1.10E-30	-1.0	
78	O-	+ O		= O2	+ E		2.00E-10		
79	O-	+ O2(1D)		= O3	+ E		3.00E-10		
80	O-	+ O3		= O3-	+ O		4.40E-10		
81	O-	+ O3		= O2-	+ O2		4.40E-10		
91	O2-	+ HV		= O2	+ E		6.60E-01		
92	O-	+ HV		= O	+ E		2.80E+00		
93	CO4-	+ HV		= CO2	+ O2	+ E	6.00E-01		
94	CO3-	+ HV		= CO2	+ O-		4.00E-01		
95	NO2-	+ HV		= NO2	+ E		6.00E-02		
96	NO3-	+ HV		= NO2-	+ O		6.00E-02		
97	NO3-	+ HV		= NO	+ O2	+ E	4.40E-03		

3. NUMERICAL EXAMPLE: 2 November 1969 SPE

Table 3 is a typical printout. It was generated specifically for the ionization production rate associated with the daytime electron SPE concentrations measured[14] on 2 November 1969, Flight B4 at Ft. Churchill, Canada. Photodetachment/photodissociation rates k_{91} - k_{97} have been doubled to improve the agreement between the data and the computations. The agreement is quite good, as seen in Figure 1. The results obtained with the "normal" Table 2 values for k_{91} - k_{97} are discussed elsewhere[3] in conjunction with the doubled rates. The rate coefficient k_{43} has been set to 0 in this example because NO^+ otherwise seemed to fall off faster with decreasing altitude than the data for this event admit.[15] This NO^+ behavior is shown in Figure 2 which is a plot of the principal positive ions listed in Table 3.

---

[14] Dean, W.A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 291-306.

[15] Narcisi, R.S., Philbrick, C.R., Thomas, D.M., Bailey, A.D., Wlodyka, L.E., Baker, D., Federico, G., Wlodyka, R., and Gardner, M.E. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 421-432.

Also shown in Figure 2 is an NO^+ profile obtained with $k_{43} \neq 0$, specifically, the the value given in Table 1. The output associated with $k_{43} \neq 0$ is given in Table 4 minus the first part of the output which is the same as that for Table 3. The electron concentrations are somewhat higher for the first case, the greatest difference being near 78-80 km. This is because with $k_{43} \neq 0$, O_2^+/NO^+ is higher at 80 km and O_2^+ has a lower dissociative recombination coefficient, twice that of NO^+ (as adopted here, Table 1). In other words, for the same ionization production rate the electron concentration will be a factor $(2)^{1/2}$ greater if only O_2^+ ions are present as compared to solely NO^+ ions. Slightly lower electron concentrations are encountered near 75 km for the $k_{43} \neq 0$ case because conversion of NO^+ to oxonium ions leads to slightly higher electron loss since the latter ions have greater dissociative recombination coefficients than NO^+ (Table 1). Below 75 km, there is virtually no difference in [e] for the two cases, because NO^+ contributes very little to the ion chemistry in either case. In fact, since O_2^+ is the precursor ion for the SPE situation, the choice of k_{43} is rather moot. Furthermore, inclusion of collisional breakup expressions for ions like $NO^+(N_2)(CO_2)$, would probably increase the NO^+ concentrations for the $k_{43} \neq 0$ case and further cloud the issue as to the role of NO^+ clustering in the D-region under SPE conditions. Another important factor not to be forgotten in regards to the NO^+ distribution is the fact that it depends strongly on the NO profile chosen. The NO profile selected is based in part upon its compatibility with the data[2] and is probably the strongest reason why our results should not be construed as giving a major clue as to the role of NO^+ clusters in the D-region.

Vanderhoff and Niles report[7] that the photodissociation of oxonium is negligible considering the small cross-sections for the process. On the other hand, photodissociation cross-sections for O_4^+, $O_2^+(H_2O)$, and $O_2^+(CO_2)$ are large.[16] We have included the recommended photodissociation rates for the first two species; processes 4 and 5 in Table 1. The inclusion of these rates had the effect of lowering the crossover point between the simple ions (NO^+, O_2^+) and the oxonium ions by about 2 km. Thus, the effect is not a major one. A negligible further change in crossover point altitude was found when these rates were doubled to account roughly for scattered and reflected light as has been done for the rates k_{91} - k_{97}. Photodissociation of $O_2^+(CO_2)$ is not significant in the D-region because this species is not produced effectively at these altitudes.

---

16. Moseley, J.T., Cosby, P.C., and Peterson, J.R. (1977) Laboratory measurements of photodissociation and photodetachment cross-sections of atmospheric ions, EOS **58**:698.

Although the daytime electron concentrations for 3 and 4 November 1969, besides the 2 November 1969 case shown here agree satisfactorily with the data,[3] it should not be assumed that the negative ion problem is settled. The hydration of negative ions has been ignored (Figure 3), and this is undoubtedly unrealistic. The agreement noted therefore, only implies that the negative ion chemistry is satisfactory in regards to the electron distribution in daytime. Thus, negative ions like NO_2^- and NO_3^- that appear to have negligible photodetachment rates, may be hydrated to an important extent but have no impact upon the electron chemistry because electrons are presumably even less readily detached from NO_x^- hydrates. Formation of CO_3^- (H_2O) has been shown[3] to be unimportant in the daytime because the photodestruction rate is large. Even sunset does not appear to be influenced[3] by the omission of hydration processes, but sunrise is another matter. The major reason for a poor match[3] of the November 1969 SPE sunrise data with time-dependent calculations using the same chemistry as here is quite likely due to the considerable hydration of negative ions that occurs unhindered by photodissociation processes at night.

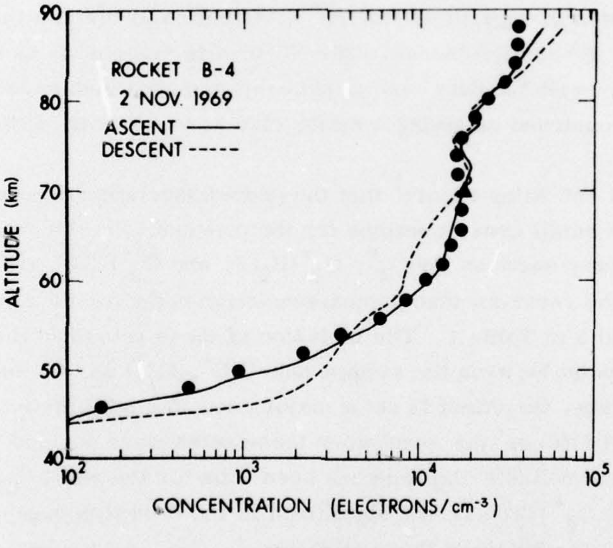

Figure 1. Measured and Computed Electron Concentrations for Rocket B-4 Launched at 2110 UT, 2 November 1969. The solar zenith angle was 83.2°. The computed electron concentrations are from Table 4

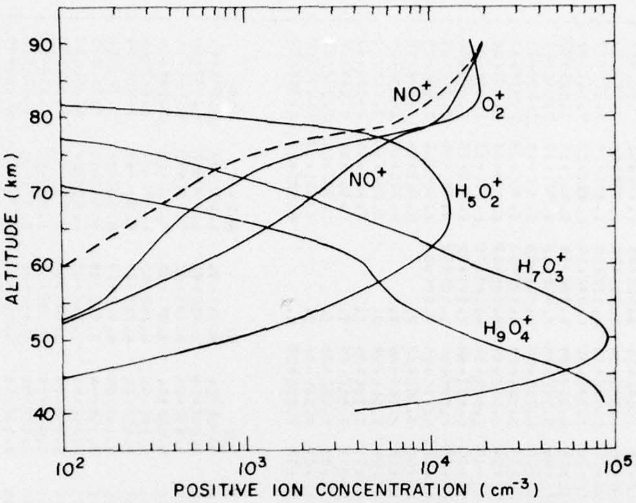

Figure 2. Principal Positive Ions Computed (Table 3) for Rocket B-4. Dashed curve from Table 4

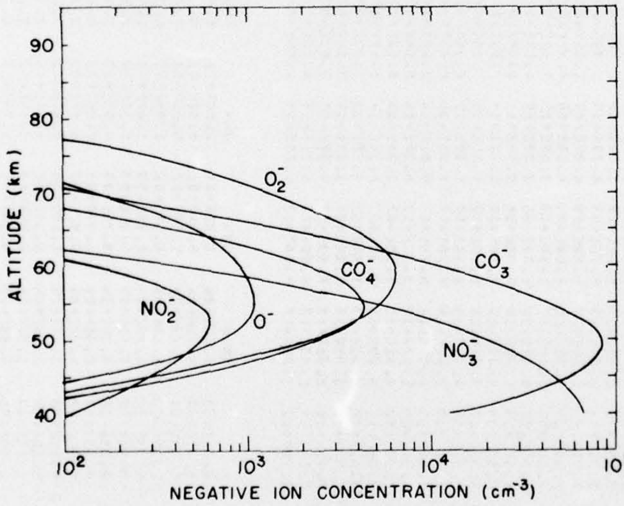

Figure 3. Principal Negative Ions Computed (Table 3) for Rocket B-4

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969. The first three sets of altitude listings give temperature (°K) and assumed (neutral) and calculated electron and ion concentrations in units of cm^{-3}. The last set of altitude listings shows parameters described in Section 2, Outline of Model such as L(A), Eq. (2) of text, λ, and $Q/[e]^2$, where Q is the ionization production rate, $cm^{-3}\ sec^{-1}$. (k_{43} set to zero)

```
ALTITUDE   O          O2         O3         N2         NO         CO2        H2O        O2(1D)     NO2        M          TEMP
   40.   1.00E+09   1.60E+16   4.50E+11   5.96E+16   1.00E+09   2.29E+13   7.63E+10   1.00E+10   2.00E+08   7.63E+16   2.35E+02
   42.   1.40E+09   1.17E+16   2.50E+11   4.37E+16   8.00E+08   1.68E+13   5.60E+10   1.50E+10   6.00E+07   5.60E+16   2.41E+02
   44.   1.80E+09   8.80E+15   1.50E+11   3.29E+16   6.00E+08   1.26E+13   4.20E+10   1.70E+10   2.00E+07   4.20E+16   2.46E+02
   46.   2.20E+09   6.49E+15   8.80E+10   2.42E+16   4.40E+08   9.30E+12   3.10E+10   1.90E+10   7.00E+06   3.10E+16   2.51E+02
   48.   2.50E+09   4.82E+15   5.00E+10   1.80E+16   3.20E+08   6.90E+12   2.30E+10   1.90E+10   2.30E+06   2.30E+16   2.55E+02
   50.   2.90E+09   3.71E+15   2.80E+10   1.39E+16   2.40E+08   5.31E+12   1.77E+10   1.80E+10   8.00E+05   1.77E+16   2.58E+02
   52.   3.10E+09   2.83E+15   1.50E+10   1.05E+16   1.70E+08   4.05E+12   1.35E+10   1.60E+10   3.00E+05   1.35E+16   2.58E+02
   54.   3.30E+09   2.20E+15   8.70E+09   8.20E+15   1.30E+08   3.15E+12   1.05E+10   1.40E+10   1.10E+05   1.05E+16   2.57E+02
   56.   3.50E+09   1.68E+15   5.00E+09   6.25E+15   1.00E+08   2.40E+12   8.00E+09   1.10E+10   4.00E+04   8.00E+15   2.54E+02
   58.   3.60E+09   1.34E+15   2.80E+09   5.00E+15   7.30E+07   1.92E+12   6.40E+09   9.00E+09   1.70E+04   6.40E+15   2.50E+02
   60.   3.60E+09   1.04E+15   1.60E+09   3.89E+15   5.70E+07   1.49E+12   4.97E+09   6.30E+09   7.00E+03   4.97E+15   2.45E+02
   62.   3.60E+09   8.17E+14   9.00E+08   3.05E+15   4.70E+07   1.17E+12   3.90E+09   4.70E+09   3.20E+03   3.90E+15   2.42E+02
   64.   3.50E+09   6.29E+14   5.00E+08   2.34E+15   4.00E+07   9.00E+11   3.00E+09   3.40E+09   1.50E+03   3.00E+15   2.37E+02
   66.   3.50E+09   4.71E+14   2.80E+08   1.75E+15   3.50E+07   6.75E+11   2.25E+09   2.40E+09   8.00E+02   2.25E+15   2.33E+02
   68.   3.30E+09   3.67E+14   1.70E+08   1.37E+15   3.20E+07   5.25E+11   1.75E+09   1.60E+09   4.60E+02   1.75E+15   2.28E+02
   70.   3.00E+09   2.74E+14   1.10E+08   1.02E+15   2.90E+07   3.93E+11   1.31E+09   1.10E+09   2.50E+02   1.31E+15   2.25E+02
   72.   3.00E+09   2.07E+14   7.00E+07   7.73E+14   2.70E+07   2.97E+11   9.90E+08   7.00E+08   1.50E+02   9.90E+14   2.22E+02
   74.   3.40E+09   1.57E+14   4.70E+07   5.85E+14   2.60E+07   2.25E+11   7.50E+08   4.70E+08   9.00E+01   7.50E+14   2.19E+02
   76.   4.50E+09   1.17E+14   3.30E+07   4.37E+14   2.50E+07   1.68E+11   5.60E+08   3.30E+08   0.         5.60E+14   2.16E+02
   78.   9.00E+09   8.80E+13   2.50E+07   3.29E+14   2.50E+07   1.26E+11   4.20E+08   2.50E+08   0.         4.20E+14   2.13E+02
   80.   3.00E+10   6.29E+13   2.00E+07   2.34E+14   2.50E+07   9.00E+10   3.00E+08   2.00E+08   0.         3.00E+14   2.11E+02
   82.   9.00E+10   4.61E+13   3.00E+07   1.72E+14   2.70E+07   6.60E+10   2.20E+08   3.00E+08   0.         2.20E+14   2.10E+02
   84.   1.50E+11   3.35E+13   5.00E+07   1.25E+14   3.00E+07   4.80E+10   1.50E+08   5.00E+08   0.         1.60E+14   2.09E+02
   86.   2.20E+11   2.51E+13   7.00E+07   9.37E+13   3.50E+07   3.60E+10   1.20E+08   7.00E+08   0.         1.20E+14   2.09E+02
   88.   2.70E+11   1.80E+13   9.00E+07   6.71E+13   4.00E+07   2.58E+10   8.50E+07   9.00E+08   0.         8.60E+13   2.10E+02
   90.   3.20E+11   1.28E+13   7.00E+07   4.78E+13   4.50E+07   1.84E+10   6.12E+07   7.00E+08   0.         6.12E+13   2.11E+02


ALTITUDE   E          NSUM       O2-        O4-        CO4-       O3-        CO3-       O-         NO2-       NO3-
   40.   4.65E+00   8.15E+04   1.02E+01   1.19E-01   1.96E+01   5.57E-01   1.26E+04   6.64E+00   1.05E+02   6.87E+04
   42.   1.72E+01   9.06E+04   4.66E+01   3.87E-01   8.38E+01   1.93E+00   2.92E+04   2.81E+01   1.74E+02   6.10E+04
   44.   5.43E+01   1.01E+05   1.59E+02   9.63E-01   2.56E+02   4.45E+00   5.03E+04   8.26E+01   2.46E+02   5.01E+04
   46.   1.53E+02   1.10E+05   4.43E+02   1.96E+00   6.31E+02   8.94E+00   6.94E+04   1.97E+02   3.32E+02   3.86E+04
   48.   4.31E+02   1.15E+05   1.06E+03   3.42E+00   1.35E+03   1.48E+01   8.28E+04   4.04E+02   4.37E+02   2.84E+04
   50.   9.97E+02   1.11E+05   2.17E+03   5.33E+00   2.59E+03   2.06E+01   8.40E+04   6.78E+02   5.62E+02   2.05E+04
   52.   2.11E+03   9.34E+04   3.70E+03   6.92E+00   3.98E+03   2.32E+01   7.14E+04   9.57E+02   6.33E+02   1.27E+04
   54.   3.69E+03   6.96E+04   4.97E+03   7.26E+00   4.40E+03   2.15E+01   5.13E+04   1.07E+03   5.98E+02   7.22E+03
   56.   5.97E+03   4.73E+04   5.93E+03   6.67E+00   3.86E+03   1.79E+01   3.25E+04   1.09E+03   4.61E+02   3.35E+03
   58.   8.46E+03   3.17E+04   6.42E+03   5.87E+00   3.21E+03   1.31E+01   1.94E+04   1.02E+03   2.93E+02   1.27E+03
   60.   1.14E+04   2.04E+04   6.19E+03   4.49E+00   2.13E+03   8.94E+00   1.06E+04   9.00E+02   1.58E+02   4.31E+02
   62.   1.39E+04   1.33E+04   5.55E+03   3.19E+00   1.27E+03   5.59E+00   5.45E+03   7.80E+02   7.87E+01   1.40E+02
   64.   1.60E+04   8.08E+03   4.34E+03   1.96E+00   6.37E+02   3.19E+00   2.43E+03   5.90E+02   3.34E+01   4.14E+01
   66.   1.75E+04   4.55E+03   2.94E+03   1.02E+00   2.53E+02   1.60E+00   9.25E+02   4.01E+02   1.17E+01   1.10E+01
   68.   1.82E+04   2.83E+03   2.04E+03   5.58E-01   1.12E+02   8.58E-01   3.97E+02   2.72E+02   4.76E+00   3.74E+00
   70.   1.82E+04   1.61E+03   1.25E+03   2.61E-01   4.13E+01   4.36E-01   1.54E+02   1.59E+02   1.64E+00   1.12E+00
   72.   1.75E+04   8.75E+02   7.14E+02   1.14E-01   1.37E+01   2.06E-01   5.44E+01   9.18E+01   5.26E-01   3.21E-01
   74.   1.73E+04   4.61E+02   3.83E+02   4.63E-02   4.06E+00   9.77E-02   1.83E+01   5.48E+01   1.61E-01   8.77E-02
   76.   1.81E+04   2.30E+02   1.89E+02   1.75E-02   9.88E-01   4.61E-02   5.50E+00   3.38E+01   4.24E-02   2.00E-02
   78.   2.17E+04   9.97E+01   7.64E+01   5.38E-03   1.49E-01   2.02E-02   1.15E+00   2.20E+01   7.81E-03   2.99E-03
   80.   2.83E+04   2.73E+01   1.80E+01   9.15E-04   6.94E-03   5.37E-03   8.02E-02   9.13E+00   4.97E-04   1.45E-04
   82.   3.20E+04   6.15E+00   3.73E+00   1.40E-04   2.81E-04   1.47E-03   5.55E-03   2.41E+00   3.18E-05   6.77E-06
   84.   3.37E+04   2.11E+00   1.25E+00   3.42E-05   3.06E-05   6.93E-04   1.12E-03   8.54E-01   6.57E-05   1.11E-06
   86.   3.46E+04   8.41E-01   4.94E-01   1.01E-05   4.67E-06   3.14E-04   2.59E-04   3.46E-01   1.70E-06   2.79E-07
   88.   3.54E+04   3.65E-01   2.14E-01   3.13E-06   8.43E-07   1.56E-04   7.46E-05   1.51E-01   5.45E-07   9.07E-08
   90.   3.55E+04   1.59E-01   9.24E-02   9.57E-07   1.55E-07   4.70E-05   1.35E-05   6.61E-02   1.12E-07   1.56E-08
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Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969 (Cont)

ALTITUDE	O2+	O4+	O2+.H2O	H3O+.OH	H3O+	H3O+.N2	H3O+.CO2	H5O2+	H5O+.CO2	NO+
40.	1.38E-01	3.17E+00	3.93E+00	2.81E+00	7.37E-03	2.61E-03	7.82E+00	1.13E+01	7.74E+00	6.01E-01
42.	4.83E-01	5.40E+00	6.69E+00	4.78E+00	1.80E-02	4.44E-03	1.33E+01	2.79E+01	1.40E+01	1.47E+00
44.	1.53E+00	9.24E+00	1.14E+01	8.15E+00	4.26E-02	7.57E-03	2.27E+01	6.66E+01	2.52E+01	3.49E+00
46.	5.21E+00	1.57E+01	1.93E+01	1.38E+01	1.02E-01	1.28E-02	3.84E+01	1.60E+02	4.46E+01	8.39E+00
48.	1.57E+01	2.66E+01	3.25E+01	2.32E+01	2.38E-01	2.16E-02	6.45E+01	3.77E+02	7.77E+01	1.98E+01
50.	3.94E+01	4.16E+01	5.06E+01	3.61E+01	4.93E-01	3.36E-02	1.00E+02	7.81E+02	1.24E+02	4.16E+01
52.	7.67E+01	6.19E+01	7.45E+01	5.32E+01	9.52E-01	4.94E-02	1.47E+02	1.50E+03	1.80E+02	8.10E+01
54.	1.23E+02	8.26E+01	9.85E+01	7.03E+01	1.61E+00	6.53E-02	1.94E+02	2.49E+03	2.32E+02	1.38E+02
56.	1.75E+02	1.10E+02	1.29E+02	9.21E+01	2.70E+00	8.56E-02	2.52E+02	4.05E+03	2.84E+02	2.32E+02
58.	2.05E+02	1.35E+02	1.57E+02	1.12E+02	3.96E+00	1.04E-01	3.03E+02	5.65E+03	3.11E+02	3.37E+02
60.	2.37E+02	1.71E+02	1.94E+02	1.38E+02	6.05E+00	1.28E-01	3.67E+02	7.83E+03	3.25E+02	5.10E+02
62.	2.98E+02	2.06E+02	2.27E+02	1.61E+02	8.81E+00	1.50E-01	4.20E+02	9.86E+03	3.10E+02	7.35E+02
64.	3.43E+02	2.52E+02	2.68E+02	1.90E+02	1.30E+01	1.78E-01	4.81E+02	1.17E+04	2.69E+02	1.06E+03
66.	4.33E+02	3.05E+02	3.09E+02	2.18E+02	1.92E+01	2.04E-01	5.29E+02	1.27E+04	2.05E+02	1.51E+03
68.	5.10E+02	3.62E+02	3.47E+02	2.44E+02	2.66E+01	2.29E-01	5.69E+02	1.28E+04	1.51E+02	1.96E+03
70.	7.22E+02	4.33E+02	3.85E+02	2.70E+02	3.83E+01	2.53E-01	5.94E+02	1.22E+04	9.93E+01	2.60E+03
72.	1.00E+03	4.90E+02	3.99E+02	2.78E+02	5.08E+01	2.61E-01	5.79E+02	1.07E+04	6.10E+01	3.18E+03
74.	1.56E+03	5.77E+02	4.23E+02	2.93E+02	6.87E+01	2.75E-01	5.65E+02	9.15E+03	3.56E+01	3.98E+03
76.	2.95E+03	7.08E+02	4.55E+02	3.11E+02	9.48E+01	2.91E-01	5.30E+02	7.12E+03	1.76E+01	5.39E+03
78.	7.00E+03	7.59E+02	4.17E+02	2.77E+02	1.09E+02	2.57E-01	3.80E+02	4.01E+03	5.71E+00	8.25E+03
80.	1.49E+04	3.38E+02	1.49E+02	9.37E+01	4.84E+01	8.34E-02	8.55E+01	7.18E+02	4.75E-01	1.22E+04
82.	1.73E+04	7.98E+01	2.84E+01	1.68E+01	1.07E+01	1.36E-02	1.05E+01	8.40E+01	2.94E-02	1.38E+04
84.	1.85E+04	2.69E+01	7.51E+00	4.12E+00	3.04E+00	2.35E-03	1.64E+00	1.40E+01	2.61E-03	1.51E+04
86.	1.78E+04	1.00E+01	2.22E+00	1.12E+00	8.86E-01	6.22E-04	2.76E-01	2.77E+00	2.93E-04	1.66E+04
88.	1.73E+04	4.01E+00	6.68E-01	3.00E-01	2.38E-01	1.18E-04	3.85E-02	5.16E-01	2.82E-05	1.80E+04
90.	1.63E+04	1.59E+00	1.97E-01	7.68E-02	5.73E-02	2.01E-05	4.78E-03	9.30E-02	2.62E-06	1.90E+04

ALTITUDE	NO+.CO2	NO+.H2O	NO+.H2O.N2	NO+H2O.CO2	NO+.2H2O	NO+.2H2ON2	NO+2H2OCO2	NO+.3H2O	H7O3+	H9O4+
40.	1.05E+00	1.91E-02	8.68E-04	2.60E-01	1.91E-02	8.65E-04	2.60E-01	7.49E+00	3.71E+03	7.77E+04
42.	1.79E+00	4.97E-02	1.48E-03	4.44E-01	4.95E-02	1.48E-03	4.43E-01	1.28E+01	1.26E+04	7.79E+04
44.	3.07E+00	1.24E-01	2.54E-03	7.61E-01	1.24E-01	2.53E-03	7.58E-01	2.19E+01	3.10E+04	7.01E+04
46.	5.22E+00	3.13E-01	4.32E-03	1.30E+00	3.12E-01	4.30E-03	1.29E+00	3.72E+01	5.96E+04	4.98E+04
48.	8.87E+00	7.68E-01	7.34E-03	2.20E+00	7.65E-01	7.31E-03	2.19E+00	6.30E+01	8.37E+04	3.04E+04
50.	1.40E+01	1.66E+00	1.15E-02	3.47E+00	1.65E+00	1.15E-02	3.46E+00	9.90E+01	9.27E+04	1.75E+04
52.	2.08E+01	3.22E+00	1.72E-02	5.15E+00	3.21E+00	1.71E-02	5.13E+00	1.46E+02	8.09E+04	1.17E+04
54.	2.76E+01	5.42E+00	2.23E-02	6.85E+00	5.40E+00	2.28E-02	6.82E+00	1.92E+02	6.17E+04	7.84E+03
56.	3.63E+01	8.67E+00	3.00E-02	8.93E+00	8.82E+00	2.98E-02	8.93E+00	2.45E+02	4.17E+04	5.90E+03
58.	4.35E+01	1.24E+01	3.59E-02	1.08E+01	1.23E+01	3.56E-02	1.07E+01	2.83E+02	2.74E+04	5.14E+03
60.	5.30E+01	1.73E+01	4.37E-02	1.31E+01	1.76E+01	4.32E-02	1.29E+01	3.24E+02	1.70E+04	4.49E+03
62.	6.12E+01	2.47E+01	5.04E-02	1.50E+01	2.43E+01	4.95E-02	1.47E+01	3.46E+02	1.13E+04	3.04E+03
64.	7.02E+01	3.35E+01	5.75E-02	1.72E+01	3.26E+01	5.61E-02	1.66E+01	3.57E+02	7.15E+03	2.00E+03
66.	7.72E+01	4.53E+01	6.23E-02	1.87E+01	4.34E+01	6.03E-02	1.78E+01	3.42E+02	4.50E+03	9.54E+02
68.	8.11E+01	5.51E+01	6.55E-02	1.94E+01	5.19E+01	6.17E-02	1.81E+01	3.13E+02	2.98E+03	4.67E+02
70.	8.18E+01	6.91E+01	6.53E-02	1.92E+01	6.29E+01	5.94E-02	1.73E+01	2.63E+02	1.78E+03	1.73E+02
72.	7.65E+01	7.91E+01	5.99E-02	1.75E+01	6.89E+01	5.21E-02	1.50E+01	2.03E+02	1.02E+03	6.32E+01
74.	7.36E+01	9.14E+01	5.56E-02	1.61E+01	7.42E+01	4.52E-02	1.29E+01	1.50E+02	5.48E+02	2.08E+01
76.	7.45E+01	1.09E+02	5.28E-02	1.51E+01	7.81E+01	3.77E-02	1.05E+01	9.89E+01	2.42E+02	5.13E+00
78.	8.36E+01	1.35E+02	5.19E-02	1.44E+01	7.49E+01	2.59E-02	7.76E+00	5.19E+01	6.96E+01	7.25E-01
80.	8.06E+01	1.27E+02	3.63E-02	9.53E+00	4.15E+01	1.19E-02	2.93E+00	1.18E+01	5.78E+00	2.38E-02
82.	6.06E+01	8.71E+01	1.87E-02	4.60E+00	1.64E+01	3.52E-03	7.96E-01	2.23E+00	4.76E-01	9.66E-04
84.	4.28E+01	5.18E+01	8.26E-03	1.88E+00	5.22E+00	8.31E-04	1.69E-01	3.37E-01	4.56E-02	4.71E-05
86.	3.09E+01	3.06E+01	3.65E-03	7.65E-01	1.65E+00	1.97E-04	3.59E-02	5.36E-02	5.16E-03	2.93E-06
88.	1.99E+01	1.48E+01	1.24E-03	2.30E-01	3.63E-01	3.04E-05	4.73E-03	5.04E-03	3.89E-04	1.09E-07
90.	1.21E+01	6.66E+00	3.88E-04	6.23E-02	7.11E-02	4.14E-06	5.39E-04	4.13E-04	2.81E-05	3.91E-09

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969 (Cont)

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ALTITUDE     LA        LAMBDA      Q/E**2      PSUM       NSUM+E     INT. SP    SP          INT. E      E          Q
     40.  4.51E+02   1.75E+04   1.84E+01   8.14E+04   8.15E+04   8.13E+04   8.15E+04   6.32E+00   4.66E+00   4.00E+02
     42.  2.50E+02   5.26E+03   1.69E+00   9.05E+04   9.06E+04   9.02E+04   9.06E+04   2.04E+01   1.72E+01   5.00E+02
     44.  1.44E+02   1.86E+03   2.17E-01   1.01E+05   1.01E+05   1.01E+05   1.01E+05   6.53E+01   5.43E+01   6.40E+02
     46.  8.04E+01   6.89E+02   3.16E-02   1.10E+05   1.10E+05   1.10E+05   1.10E+05   2.00E+02   1.59E+02   8.00E+02
     48.  4.50E+01   2.66E+02   5.39E-03   1.15E+05   1.15E+05   1.18E+05   1.15E+05   6.32E+02   4.31E+02   1.00E+03
     50.  2.70E+01   1.11E+02   1.21E-03   1.12E+05   1.12E+05   1.19E+05   1.12E+05   1.53E+03   9.97E+02   1.20E+03
     52.  1.57E+01   4.42E+01   3.02E-04   9.43E+04   9.55E+04   1.13E+05   9.53E+04   2.82E+03   2.11E+03   1.35E+03
     54.  9.45E+00   1.89E+01   1.02E-04   7.32E+04   7.33E+04   1.01E+05   7.33E+04   4.46E+03   3.69E+03   1.39E+03
     56.  5.42E+00   7.92E+00   3.91E-05   5.32E+04   5.32E+04   8.96E+04   5.32E+04   5.69E+03   5.97E+03   1.39E+03
     58.  3.41E+00   3.74E+00   1.89E-05   4.01E+04   4.01E+04   7.71E+04   4.01E+04   9.19E+03   8.46E+03   1.35E+03
     60.  2.01E+00   1.80E+00   1.01E-05   3.17E+04   3.18E+04   6.99E+04   3.18E+04   1.22E+04   1.14E+04   1.30E+03
     62.  1.22E+00   9.63E-01   6.31E-06   2.71E+04   2.71E+04   6.17E+04   2.70E+04   1.37E+04   1.38E+04   1.20E+03
     64.  7.04E-01   5.04E-01   4.27E-05   2.42E+04   2.41E+04   5.64E+04   2.41E+04   1.56E+04   1.60E+04   1.10E+03
     66.  3.89E-01   2.59E-01   3.12E-05   2.22E+04   2.21E+04   5.11E+04   2.21E+04   1.71E+04   1.75E+04   9.60E+02
     68.  2.23E-01   1.55E-01   2.55E-06   2.09E+04   2.11E+04   4.74E+04   2.11E+04   1.88E+04   1.82E+04   8.50E+02
     70.  1.26E-01   8.83E-02   2.17E-06   1.98E+04   1.98E+04   4.33E+04   1.98E+04   2.00E+04   1.82E+04   7.20E+02
     72.  7.06E-02   5.00E-02   1.89E-06   1.83E+04   1.84E+04   3.96E+04   1.84E+04   2.00E+04   1.75E+04   5.80E+02
     74.  3.93E-02   2.67E-02   1.64E-06   1.76E+04   1.77E+04   3.53E+04   1.77E+04   2.02E+04   1.73E+04   4.90E+02
     76.  2.13E-02   1.27E-02   1.34E-06   1.82E+04   1.84E+04   3.33E+04   1.84E+04   2.24E+04   1.81E+04   4.40E+02
     78.  1.20E-02   4.60E-03   9.03E-07   2.16E+04   2.18E+04   3.26E+04   2.18E+04   2.56E+04   2.17E+04   4.25E+02
     80.  6.05E-03   9.43E-04   5.03E-07   2.88E+04   2.89E+04   3.24E+04   2.89E+04   2.96E+04   2.89E+04   4.20E+02
     82.  3.23E-03   1.92E-04   4.30E-07   3.21E+04   3.20E+04   3.32E+04   3.32E+04   3.20E+04   3.20E+04   4.40E+02
     84.  1.70E-03   6.25E-05   4.22E-07   3.37E+04   3.37E+04   3.46E+04   3.37E+04   3.55E+04   3.37E+04   4.80E+02
     86.  9.55E-04   2.43E-05   4.27E-07   3.45E+04   3.46E+04   3.57E+04   3.46E+04   3.87E+04   3.46E+04   5.10E+02
     88.  4.94E-04   1.03E-05   4.31E-07   3.53E+04   3.54E+04   3.67E+04   3.54E+04   4.11E+04   3.54E+04   5.40E+02
     90.  2.52E-04   4.46E-06   4.36E-07   3.53E+04   3.55E+04   3.71E+04   3.55E+04   4.28E+04   3.55E+04   5.50E+02
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Table 4. Same as for Table 3 Except k_{43} as in Table 1. The first set of altitude listings is omitted since it is the same as for Table 3

ALTITUDE	E	NSUM	O2-	O4-	CO4-	O3-	CO3-	O-	NO2-	NO3-
40.	4.66E+00	8.15E+04	1.02E+01	1.18E-01	1.96E+01	5.57E-01	1.26E+04	6.64E+00	1.05E+02	6.87E+04
42.	1.72E+01	9.06E+04	4.65E+01	3.87E-01	8.38E+01	1.83E+00	2.92E+04	2.81E+01	1.74E+02	6.10E+04
44.	5.43E+01	1.01E+05	1.58E+02	9.63E-01	2.56E+02	4.45E+00	5.03E+04	8.26E+01	2.46E+02	5.01E+04
46.	1.53E+02	1.10E+05	4.43E+02	1.95E+00	6.31E+02	8.94E+00	6.94E+04	1.97E+02	3.32E+02	3.86E+04
48.	4.31E+02	1.15E+05	1.06E+03	3.42E+00	1.35E+03	1.48E+01	8.28E+04	4.04E+02	4.37E+02	2.84E+04
50.	9.97E+02	1.11E+05	2.17E+03	5.33E+00	2.59E+03	2.06E+01	8.40E+04	6.77E+02	5.62E+02	2.05E+04
52.	2.11E+03	9.34E+04	3.70E+03	6.92E+00	3.98E+03	2.32E+01	7.14E+04	9.56E+02	6.33E+02	1.27E+04
54.	3.69E+03	6.96E+04	4.97E+03	7.25E+00	4.39E+03	2.15E+01	5.13E+04	1.07E+03	5.97E+02	7.22E+03
56.	5.95E+03	4.72E+04	5.92E+03	6.66E+00	3.86E+03	1.79E+01	3.25E+04	1.08E+03	4.61E+02	3.35E+03
58.	8.44E+03	3.16E+04	6.40E+03	5.85E+00	3.20E+03	1.30E+01	1.94E+04	1.01E+03	2.92E+02	1.27E+03
60.	1.13E+04	2.03E+04	6.15E+03	4.45E+00	2.11E+03	8.39E+00	1.06E+04	8.95E+02	1.57E+02	4.28E+02
62.	1.37E+04	1.31E+04	5.50E+03	3.17E+00	1.26E+03	5.64E+00	5.38E+03	7.72E+02	7.22E+01	1.28E+02
64.	1.59E+04	7.95E+03	4.28E+03	1.93E+00	6.27E+02	3.14E+00	2.39E+03	5.81E+02	3.29E+01	4.08E+01
66.	1.71E+04	4.42E+03	2.86E+03	9.87E-01	2.46E+02	1.56E+00	8.97E+02	3.89E+02	1.08E+01	1.02E+01
68.	1.75E+04	2.71E+03	1.95E+03	5.35E-01	1.08E+02	8.24E-01	3.81E+02	2.61E+02	4.57E+00	3.59E+00
70.	1.73E+04	1.53E+03	1.19E+03	2.47E-01	3.92E+01	4.14E-01	1.46E+02	1.51E+02	1.56E+00	1.07E+00
72.	1.64E+04	8.18E+02	6.69E+02	1.06E-01	1.28E+01	1.32E-01	5.08E+01	8.58E+01	4.92E-01	3.01E-01
74.	1.59E+04	4.24E+02	3.52E+02	4.31E-02	3.73E+00	8.99E-02	1.68E+01	5.04E+01	1.48E-01	8.08E-02
76.	1.62E+04	2.05E+02	1.69E+02	1.57E-02	8.84E-01	4.13E-02	4.92E+00	3.02E+01	3.80E-02	1.80E-02
78.	1.92E+04	8.81E+01	6.75E+01	4.75E-03	1.32E-01	1.79E-02	1.02E+00	1.94E+01	6.92E-03	2.65E-03
80.	2.66E+04	2.51E+01	1.66E+01	8.43E-04	6.39E-03	4.94E-03	7.38E-02	8.41E+00	4.59E-04	1.33E-04
82.	3.06E+04	5.87E+00	3.56E+00	1.33E-04	2.68E-04	1.41E-03	5.30E-03	2.30E+00	3.04E-05	6.49E-06
84.	3.28E+04	2.05E+00	1.22E+00	3.33E-05	2.97E-05	6.74E-04	1.09E-03	8.30E-01	6.40E-06	1.08E-06
86.	3.40E+04	8.27E-01	4.86E-01	9.97E-06	4.59E-06	3.09E-04	2.55E-04	3.41E-01	1.68E-06	2.75E-07
88.	3.51E+04	3.62E-01	2.12E-01	3.10E-06	8.36E-07	1.55E-04	7.40E-05	1.50E-01	5.41E-07	9.00E-08
90.	3.54E+04	1.58E-01	9.28E-02	9.53E-07	1.55E-07	4.68E-05	1.35E-05	6.58E-02	1.11E-07	1.56E-08

ALTITUDE	O2+	O4+	O2+.H2O	H3O+.OH	H3O+	H3O+.N2	H3O+.CO2	H5O2+	H5O+.CO2	NO+	NO+.N2
40.	1.33E-01	3.17E+00	3.93E+00	2.81E+00	7.37E-03	2.61E-03	7.82E+00	1.13E+01	7.74E+00	9.71E-02	7.34E-04
42.	4.83E-01	5.40E+00	6.69E+00	4.79E+00	1.80E-02	4.44E-03	1.33E+01	2.79E+01	1.40E+01	2.70E-01	1.22E-03
44.	1.59E+00	9.24E+00	1.14E+01	8.15E+00	4.26E-02	7.57E-03	2.27E+01	6.66E+01	2.52E+01	7.09E-01	2.04E-03
46.	5.21E+00	1.57E+01	1.93E+01	1.38E+01	1.02E-01	1.28E-02	3.84E+01	1.60E+02	4.46E+01	1.87E+00	3.39E-03
48.	1.57E+01	2.66E+01	3.25E+01	2.32E+01	2.38E-01	2.16E-02	6.45E+01	3.77E+02	7.77E+01	4.75E+00	5.64E-03
50.	3.94E+01	4.16E+01	5.06E+01	3.61E+01	4.93E-01	3.36E-02	1.00E+02	7.81E+02	1.24E+02	1.05E+01	8.75E-03
52.	7.67E+01	6.19E+01	7.45E+01	5.32E+01	9.52E-01	4.94E-02	1.47E+02	1.50E+03	1.80E+02	2.04E+01	1.30E-02
54.	1.23E+02	8.26E+01	9.85E+01	7.03E+01	1.61E+00	6.53E-02	1.94E+02	2.49E+03	2.32E+02	3.42E+01	1.74E-02
56.	1.75E+02	1.10E+02	1.23E+02	9.21E+01	2.70E+00	8.56E-02	2.52E+02	4.05E+03	2.84E+02	5.49E+01	2.34E-02
58.	2.05E+02	1.35E+02	1.57E+02	1.12E+02	3.96E+00	1.04E-01	3.03E+02	5.65E+03	3.11E+02	7.46E+01	2.87E-02
60.	2.37E+02	1.71E+02	1.94E+02	1.38E+02	6.05E+00	1.28E-01	3.67E+02	7.83E+03	3.26E+02	1.04E+02	3.64E-02
62.	2.93E+02	2.06E+02	2.27E+02	1.61E+02	8.81E+00	1.50E-01	4.20E+02	9.88E+03	3.11E+02	1.43E+02	4.35E-02
64.	3.44E+02	2.52E+02	2.68E+02	1.90E+02	1.30E+01	1.78E-01	4.81E+02	1.18E+04	2.71E+02	1.91E+02	5.29E-02
66.	4.39E+02	3.05E+02	3.09E+02	2.18E+02	1.93E+01	2.04E-01	5.32E+02	1.29E+04	2.10E+02	2.64E+02	6.29E-02
68.	5.11E+02	3.62E+02	3.48E+02	2.45E+02	2.66E+01	2.30E-01	5.74E+02	1.32E+04	1.57E+02	3.30E+02	7.33E-02
70.	7.23E+02	4.33E+02	3.86E+02	2.71E+02	3.84E+01	2.54E-01	6.03E+02	1.27E+04	1.06E+02	4.61E+02	8.56E-02
72.	1.00E+03	4.91E+02	4.01E+02	2.80E+02	5.11E+01	2.63E-01	5.92E+02	1.15E+04	6.67E+01	6.11E+02	9.61E-02
74.	1.57E+03	5.81E+02	4.26E+02	2.96E+02	6.94E+01	2.78E-01	5.85E+02	1.00E+04	4.03E+01	8.84E+02	1.18E-01
76.	2.93E+03	7.18E+02	4.62E+02	3.17E+02	9.67E+01	2.97E-01	5.64E+02	8.11E+03	2.12E+01	1.52E+03	1.71E-01
78.	7.18E+03	7.79E+02	4.30E+02	2.89E+02	1.13E+02	2.58E-01	4.20E+02	4.73E+03	7.27E+00	3.32E+03	3.14E-01
80.	1.53E+04	3.48E+02	1.55E+02	9.81E+01	5.08E+01	8.76E-02	9.47E+01	8.19E+02	5.76E-01	7.48E+03	5.48E-01
82.	1.83E+04	8.14E+01	2.90E+01	1.73E+01	1.11E+01	1.41E-02	1.12E+01	9.08E+01	3.30E-02	1.04E+04	5.83E-01
84.	1.87E+04	2.72E+01	7.61E+00	4.21E+00	3.12E+00	2.32E-03	1.72E+00	1.47E+01	2.81E-03	1.29E+04	5.47E-01
86.	1.80E+04	1.61E+01	2.23E+00	1.14E+00	9.02E-01	6.33E-04	2.85E-01	2.86E+00	3.07E-04	1.52E+04	4.82E-01
88.	1.73E+04	4.02E+00	6.71E-01	3.03E-01	2.40E-01	1.20E-04	3.92E-02	5.24E-01	2.89E-05	1.72E+04	3.76E-01
90.	1.63E+04	1.60E+00	1.97E-01	7.71E-02	5.76E-02	2.02E-05	4.83E-03	9.38E-02	2.65E-06	1.86E+04	2.78E-01

Table 4. Same as for Table 3 Except k_{43} as in Table 1 (Cont)

ALTITUDE	NO+.CO2	NO+.H2O	NO+.H2O.N2	NO+H2O.CO2	NO+.2H2O	NO+.2H2ON2	NO+2H2OCO2	NO+.3H2O	H7O3+	H9O4+
40.	1.05E+00	1.91E-02	8.68E-04	2.61E-01	1.91E-02	8.65E-04	2.60E-01	7.49E+00	3.71E+03	7.77E+04
42.	1.79E+00	4.97E-02	1.48E-03	4.45E-01	4.95E-02	1.48E-03	4.43E-01	1.28E+01	1.26E+04	7.79E+04
44.	3.07E+00	1.24E-01	2.54E-03	7.61E-01	1.24E-01	2.53E-03	7.58E-01	2.19E+01	3.10E+04	7.01E+04
46.	5.22E+00	3.13E-01	4.32E-03	1.30E+00	3.12E-01	4.31E-03	1.29E+00	3.72E+01	5.96E+04	4.98E+04
48.	8.85E+00	7.69E-01	7.35E-03	2.20E+00	7.66E-01	7.32E-03	2.20E+00	6.31E+01	8.38E+04	3.04E+04
50.	1.40E+01	1.66E+00	1.16E-02	3.48E+00	1.65E+00	1.16E-02	3.46E+00	9.92E+01	9.27E+04	1.75E+04
52.	2.08E+01	3.23E+00	1.72E-02	5.15E+00	3.22E+00	1.72E-02	5.14E+00	1.46E+02	8.09E+04	1.17E+04
54.	2.78E+01	5.45E+00	2.30E-02	6.88E+00	5.42E+00	2.28E-02	6.89E+00	1.92E+02	6.17E+04	7.85E+03
56.	3.65E+01	8.93E+00	3.02E-02	9.05E+00	8.88E+00	3.00E-02	8.99E+00	2.47E+02	4.17E+04	5.92E+03
58.	4.40E+01	1.25E+01	3.63E-02	1.09E+01	1.24E+01	3.60E-02	1.08E+01	2.86E+02	2.75E+04	5.16E+03
60.	5.41E+01	1.81E+01	4.46E-02	1.33E+01	1.79E+01	4.41E-02	1.32E+01	3.31E+02	1.72E+04	4.54E+03
62.	6.35E+01	2.56E+01	5.23E-02	1.56E+01	2.52E+01	5.14E-02	1.53E+01	3.60E+02	1.14E+04	3.08E+03
64.	7.52E+01	3.59E+01	6.17E-02	1.84E+01	3.49E+01	6.01E-02	1.78E+01	3.84E+02	7.36E+03	2.08E+03
66.	8.73E+01	5.13E+01	7.13E-02	2.11E+01	4.92E+01	6.84E-02	2.02E+01	3.91E+02	4.77E+03	1.03E+03
68.	9.90E+01	6.74E+01	8.02E-02	2.37E+01	6.35E+01	7.56E-02	2.22E+01	3.90E+02	3.28E+03	5.34E+02
70.	1.13E+02	9.59E+01	9.05E-02	2.66E+01	8.76E+01	8.27E-02	2.41E+01	3.76E+02	2.08E+03	2.12E+02
72.	1.25E+02	1.29E+02	9.78E-02	2.85E+01	1.13E+02	8.58E-02	2.48E+01	3.47E+02	1.29E+03	8.52E+01
74.	1.50E+02	1.87E+02	1.14E-01	3.31E+01	1.54E+02	9.78E-02	2.69E+01	3.29E+02	7.80E+02	3.22E+01
76.	2.10E+02	3.13E+02	1.51E-01	4.34E+01	2.30E+02	1.11E-01	3.13E+01	3.16E+02	4.28E+02	1.01E+01
78.	3.66E+02	6.07E+02	2.34E-01	6.55E+01	3.57E+02	1.37E-01	3.74E+01	2.75E+02	1.74E+02	2.05E+00
80.	5.70E+02	9.30E+02	2.67E-01	7.05E+01	3.24E+02	9.27E-02	2.32E+01	1.00E+02	2.42E+01	1.08E-01
82.	5.40E+02	7.98E+02	1.71E-01	4.25E+01	1.57E+02	3.37E-02	7.70E+00	2.25E+01	3.06E+00	6.50E-03
84.	4.43E+02	5.49E+02	8.74E-02	2.01E+01	5.69E+01	9.06E-03	1.86E+00	3.81E+00	3.44E-01	3.65E-04
86.	3.41E+02	3.43E+02	4.10E-02	8.63E+00	1.89E+01	2.26E-03	4.14E-01	6.27E-01	4.07E-02	2.35E-05
88.	2.22E+02	1.67E+02	1.40E-02	2.61E+00	4.15E+00	3.47E-04	5.43E-02	5.82E-02	2.68E-03	7.56E-07
90.	1.34E+02	7.43E+01	4.33E-03	6.95E-01	7.99E-01	4.65E-05	6.07E-03	4.57E-03	1.57E-04	2.20E-08

ALTITUDE	LA	LAMBDA	Q/E**2	PSUM	NSUM+E	INT. SP	SP	INT. E	E	Q	ITER
40.	4.51E+02	1.75E+04	1.84E+01	8.14E+04	8.15E+04	8.13E+04	8.15E+04	6.32E+00	4.66E+00	4.00E+02	4
42.	2.50E+02	5.26E+03	1.69E+00	9.06E+04	9.06E+04	9.02E+04	9.06E+04	2.04E+01	1.72E+01	5.00E+02	4
44.	1.44E+02	1.86E+03	2.17E-01	1.01E+05	1.01E+05	1.01E+05	1.01E+05	6.53E+01	5.43E+01	6.40E+02	4
46.	8.04E+01	6.89E+02	3.16E-02	1.10E+05	1.10E+05	1.10E+05	1.10E+05	2.00E+02	1.59E+02	8.00E+02	4
48.	4.50E+01	2.66E+02	5.39E-03	1.15E+05	1.15E+05	1.18E+05	1.15E+05	6.32E+02	4.31E+02	1.00E+03	4
50.	2.70E+01	1.11E+02	1.21E-03	1.12E+05	1.12E+05	1.19E+05	1.12E+05	1.53E+03	9.97E+02	1.20E+03	4
52.	1.57E+01	4.42E+01	3.02E-04	9.43E+04	9.55E+04	1.13E+05	9.52E+04	2.82E+03	2.11E+03	1.35E+03	3
54.	9.46E+00	1.89E+01	1.02E-04	7.31E+04	7.33E+04	1.01E+05	7.32E+04	4.46E+03	3.69E+03	1.39E+03	3
56.	5.42E+00	7.92E+00	3.92E-05	5.31E+04	5.31E+04	8.86E+04	5.32E+04	5.69E+03	5.96E+03	1.39E+03	3
58.	3.41E+00	3.74E+00	1.90E-05	4.00E+04	4.00E+04	7.71E+04	4.00E+04	9.19E+03	8.44E+03	1.35E+03	3
60.	2.01E+00	1.80E+00	1.02E-05	3.16E+04	3.16E+04	6.99E+04	3.16E+04	1.22E+04	1.13E+04	1.30E+03	3
62.	1.22E+00	9.59E-01	6.40E-05	2.67E+04	2.68E+04	6.17E+04	6.17E+04	1.37E+04	1.37E+04	1.20E+03	1
64.	7.04E-01	5.04E-01	4.41E-05	2.38E+04	2.37E+04	5.54E+04	2.37E+04	1.56E+04	1.58E+04	1.10E+03	2
66.	3.88E-01	2.59E-01	3.30E-05	2.16E+04	2.15E+04	5.11E+04	5.11E+04	1.71E+04	1.71E+04	9.60E+02	1
68.	2.29E-01	1.55E-01	2.77E-05	2.02E+04	2.02E+04	4.74E+04	2.02E+04	1.88E+04	1.75E+04	8.50E+02	3
70.	1.26E-01	8.83E-02	2.40E-05	1.88E+04	1.88E+04	4.33E+04	1.88E+04	2.00E+04	1.73E+04	7.20E+02	3
72.	7.05E-02	5.00E-02	2.16E-06	1.71E+04	1.72E+04	3.86E+04	1.72E+04	2.00E+04	1.64E+04	5.80E+02	3
74.	3.99E-02	2.67E-02	1.95E-05	1.61E+04	1.63E+04	3.53E+04	1.63E+04	2.02E+04	1.59E+04	4.90E+02	3
76.	2.19E-02	1.27E-02	1.67E-05	1.64E+04	1.64E+04	3.33E+04	1.64E+04	2.24E+04	1.62E+04	4.40E+02	4
78.	1.20E-02	4.60E-03	1.16E-06	1.91E+04	1.93E+04	3.26E+04	1.93E+04	2.56E+04	1.92E+04	4.25E+02	4
80.	6.05E-03	9.43E-04	5.93E-07	2.64E+04	2.66E+04	3.24E+04	2.66E+04	2.36E+04	2.66E+04	4.20E+02	3
82.	3.23E-03	1.92E-04	4.71E-07	3.05E+04	3.06E+04	3.32E+04	3.06E+04	3.20E+04	3.06E+04	4.40E+02	3
84.	1.70E-03	6.25E-05	4.46E-07	3.27E+04	3.28E+04	3.46E+04	3.28E+04	3.55E+04	3.28E+04	4.80E+02	3
86.	9.55E-04	2.43E-05	4.42E-07	3.39E+04	3.40E+04	3.57E+04	3.40E+04	3.87E+04	3.40E+04	5.10E+02	3
88.	4.94E-04	1.03E-05	4.39E-07	3.49E+04	3.51E+04	3.67E+04	3.51E+04	4.11E+04	3.51E+04	5.40E+02	3
90.	2.52E-04	4.46E-06	4.40E-07	3.52E+04	3.54E+04	3.71E+04	3.54E+04	4.28E+04	3.54E+04	5.50E+02	3

4. NUMERICAL EXAMPLE: Nighttime

Table 5 contains charged particle concentrations appropriate to SPE conditions during the night of 3 November 1969 at Ft. Churchill, Canada. The ionization production rates, principal constituents, and temperatures are identical to those used in our report[1] dealing with a model for the nighttime steady-state disturbed D-region. Our current, more advanced model results are not extremely different in regards to [e] as compared to our previous effort. The major difference, a somewhat lower [e] now in the 80-65 km region is actually in better accord with the data. The results in Table 5 were obtained with $k_{43} \neq 0$. Uncertainties in the NO^+ chemistry and the chosen NO profile notwithstanding, it still is worthwhile to point out that the calculations accomplished with the Table 1 value for k_{43} resulted in an NO^+ concentration at 70 km of 2×10^2 cm^{-3}, far below the value in Table 5 which is in good agreement with the data.[2] The major positive ions are plotted in Figure 4. Below about 60-65 km, the positive ions are in thermodynamic equilibrium.

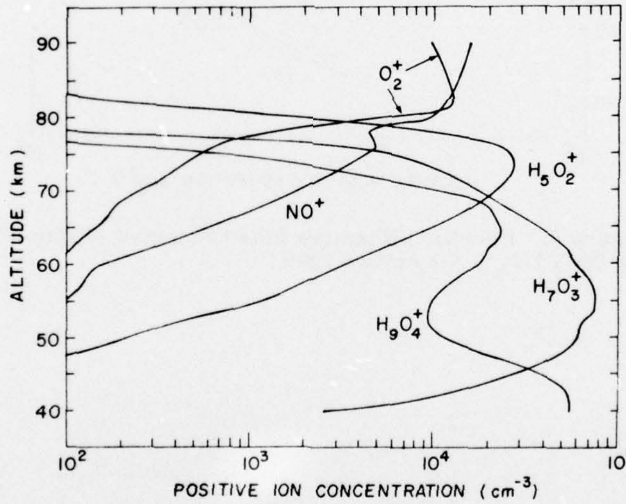

Figure 4. Principal Positive Ions Computed (Table 5) for 0605 UT, 3 November 1969, the Time of Launch for Black Brant Rocket 17.758

The negative ion populations (Figure 5) are, undoubtedly, as noted earlier, subject to considerable hydration at night. This possibility has little impact on [e] unless the hydrated negative ions have much different ion-ion recombination rates with oxonium ions than do the parent, unhydrated ions. The little experimental evidence in this regard does not favor this possibility which is attested to by the rather good agreement attained between model and data for [e].

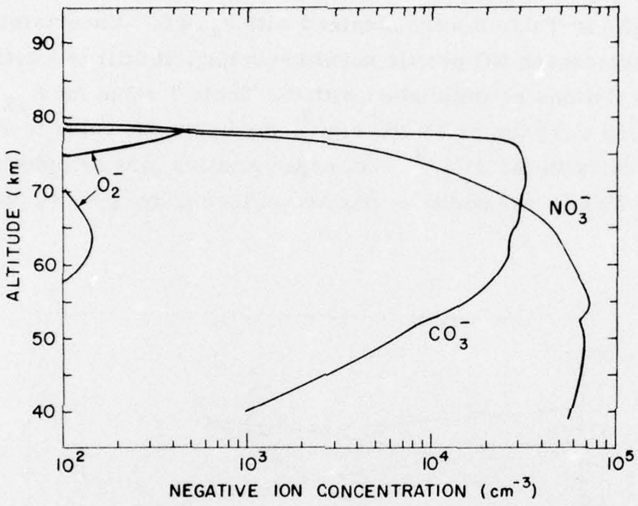

Figure 5. Principal Negative Ions Computed (Table 5) for 0605 UT, 3 November 1969

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969. See Table 3 caption for further description of the table. Rate coefficient k_{43} was set to zero

```
ALTITUDE  O         O2        O3        N2        NO        CO2       H2O       O2(1D)    NO2       M         TEMP
   40.    1.00E+00  1.60E+16  4.50E+11  5.96E+16  2.00E+00  2.29E+13  7.63E+10  0.        1.00E+09  7.63E+16  2.35E+02
   42.    1.60E+00  1.17E+16  2.50E+11  4.37E+16  9.00E+00  1.68E+13  5.60E+10  0.        9.00E+08  5.60E+16  2.41E+02
   44.    2.50E+00  8.80E+15  1.50E+11  3.29E+16  4.00E+01  1.26E+13  4.20E+10  0.        6.00E+08  4.20E+16  2.46E+02
   46.    3.90E+00  6.49E+15  8.80E+10  2.42E+16  2.00E+02  9.30E+12  3.10E+10  0.        4.40E+08  3.10E+16  2.51E+02
   48.    6.10E+00  4.82E+15  5.00E+10  1.80E+15  1.00E+03  6.90E+12  2.30E+10  0.        3.20E+08  2.30E+16  2.55E+02
   50.    1.00E+01  3.71E+15  3.10E+10  1.39E+15  5.00E+03  5.31E+12  1.77E+10  0.        2.40E+08  1.77E+16  2.58E+02
   52.    1.50E+01  2.83E+15  2.20E+10  1.05E+16  2.00E+04  4.05E+12  1.35E+10  0.        1.70E+08  1.35E+16  2.58E+02
   54.    2.40E+01  2.20E+15  1.30E+10  8.20E+15  9.00E+04  3.15E+12  1.05E+10  0.        1.30E+08  1.05E+16  2.57E+02
   56.    3.75E+01  1.68E+15  9.00E+09  6.25E+15  3.00E+05  2.40E+12  8.00E+09  0.        1.00E+08  8.00E+15  2.54E+02
   58.    6.10E+01  1.34E+15  6.60E+09  5.00E+15  7.00E+05  1.92E+12  6.40E+09  0.        7.30E+07  6.40E+15  2.50E+02
   60.    1.00E+02  1.04E+15  5.20E+09  3.83E+15  1.70E+06  1.49E+12  4.97E+09  0.        5.70E+07  4.97E+15  2.45E+02
   62.    2.40E+02  8.17E+14  4.80E+09  3.05E+15  4.00E+06  1.17E+12  3.90E+09  0.        4.70E+07  3.90E+15  2.42E+02
   64.    6.20E+02  6.29E+14  4.30E+09  2.34E+15  7.00E+06  9.00E+11  3.00E+09  0.        4.00E+07  3.00E+15  2.37E+02
   66.    2.10E+03  4.71E+14  4.10E+09  1.76E+15  1.30E+07  6.75E+11  2.25E+09  0.        2.60E+07  2.25E+15  2.33E+02
   68.    1.00E+04  3.67E+14  3.70E+09  1.37E+15  1.80E+07  5.25E+11  1.75E+09  0.        1.80E+07  1.75E+15  2.28E+02
   70.    3.00E+04  2.74E+14  3.30E+09  1.02E+15  2.20E+07  3.93E+11  1.31E+09  0.        1.00E+07  1.31E+15  2.25E+02
   72.    3.00E+05  2.07E+14  3.00E+09  7.73E+14  2.40E+07  2.97E+11  9.90E+08  0.        5.00E+06  9.90E+14  2.22E+02
   74.    3.00E+06  1.57E+14  2.90E+09  5.85E+14  2.60E+07  2.25E+11  7.50E+08  0.        2.00E+06  7.50E+14  2.19E+02
   76.    6.00E+07  1.17E+14  2.50E+09  4.37E+14  2.50E+07  1.68E+11  5.60E+08  0.        3.00E+05  5.60E+14  2.16E+02
   78.    1.50E+09  8.80E+13  8.00E+08  3.29E+14  2.50E+07  1.26E+11  4.20E+08  0.        3.00E+04  4.20E+14  2.13E+02
   80.    1.80E+10  6.29E+13  2.00E+07  2.34E+14  2.60E+07  9.00E+10  3.00E+08  0.        1.00E+02  3.00E+14  2.11E+02
   82.    9.00E+10  4.61E+13  3.00E+07  1.72E+14  2.70E+07  6.60E+10  2.20E+08  0.        0.        2.20E+14  2.10E+02
   84.    1.50E+11  3.35E+13  5.00E+07  1.25E+14  3.00E+07  4.80E+10  1.50E+08  0.        0.        1.60E+14  2.09E+02
   86.    2.20E+11  2.51E+13  7.00E+07  9.37E+13  3.50E+07  3.60E+10  1.20E+08  0.        0.        1.20E+14  2.09E+02
   88.    2.70E+11  1.80E+13  9.00E+07  6.71E+13  4.00E+07  2.58E+10  6.50E+07  0.        0.        8.60E+13  2.10E+02
   90.    3.20E+11  1.28E+13  7.00E+07  4.79E+13  4.50E+07  1.84E+10  6.12E+07  0.        0.        6.12E+13  2.11E+02


ALTITUDE  E         NSUM      O2-       O4-       CO4-      O3-       CO3-      O-        NO2-      NO3-
   40.    4.22E-01  5.63E+04  5.60E-01  6.50E-03  1.09E+00  1.51E-02  9.34E+02  1.11E-13  5.07E-10  5.53E+04
   42.    9.13E-01  6.19E+04  1.24E+00  1.03E-02  2.29E+00  2.49E-02  1.40E+03  7.31E-13  6.18E-09  6.05E+04
   44.    1.73E+00  6.56E+04  2.39E+00  1.46E-02  4.05E+00  3.72E-02  2.08E+03  3.80E-12  6.78E-08  6.35E+04
   46.    3.49E+00  6.83E+04  4.54E+00  2.00E-02  7.00E+00  5.47E-02  3.04E+03  2.00E-11  8.44E-07  6.53E+04
   48.    6.66E+00  7.07E+04  8.68E+00  2.80E-02  1.28E+01  7.30E-02  4.39E+03  1.07E-10  1.07E-05  6.63E+04
   50.    1.17E+01  7.26E+04  1.50E+01  3.68E-02  2.08E+01  1.08E-01  6.04E+03  5.01E-10  1.19E-04  6.65E+04
   52.    1.99E+01  7.20E+04  2.18E+01  4.08E-02  2.48E+01  1.40E-01  8.11E+03  1.66E-09  9.00E-04  6.38E+04
   54.    4.57E+01  8.48E+04  5.10E+01  7.44E-02  5.94E+01  2.49E-01  1.39E+04  1.04E-08  1.17E-02  7.08E+04
   56.    8.29E+01  8.64E+04  7.92E+01  8.91E-02  7.83E+01  3.39E-01  1.78E+04  3.85E-08  7.20E-02  6.85E+04
   58.    1.25E+02  8.41E+04  1.05E+02  9.60E-02  9.18E+01  4.02E-01  2.16E+04  1.17E-07  2.78E-01  6.23E+04
   60.    1.97E+02  8.08E+04  1.29E+02  9.32E-02  8.78E+01  4.90E-01  2.42E+04  3.19E-07  9.55E-01  5.65E+04
   62.    3.05E+02  7.82E+04  1.39E+02  7.95E-02  6.36E+01  5.76E-01  2.61E+04  9.67E-07  2.63E+00  5.18E+04
   64.    4.73E+02  7.39E+04  1.45E+02  6.54E-02  4.49E+01  6.79E-01  2.66E+04  3.10E-06  5.23E+00  4.72E+04
   66.    7.13E+02  6.79E+04  1.29E+02  4.46E-02  2.41E+01  7.49E-01  2.94E+04  1.04E-05  1.13E+01  3.83E+04
   68.    9.73E+02  6.05E+04  1.17E+02  3.20E-02  1.49E+01  7.73E-01  2.98E+04  5.07E-05  1.75E+01  3.06E+04
   70.    1.33E+03  5.32E+04  1.04E+02  2.16E-02  8.41E+00  8.08E-01  3.15E+04  1.55E-04  2.54E+01  2.15E+04
   72.    1.83E+03  4.61E+04  8.84E+01  1.41E-02  4.57E+00  8.23E-01  3.20E+04  1.47E-03  3.10E+01  1.39E+04
   74.    2.54E+03  3.96E+04  7.61E+01  9.31E-03  2.36E+00  8.39E-01  3.12E+04  1.32E-02  3.38E+01  8.34E+03
   76.    3.44E+03  3.28E+04  2.05E+02  1.91E-02  4.09E+00  2.92E+00  2.84E+04  8.31E-01  3.43E+01  4.22E+03
   78.    1.33E+04  2.27E+03  4.51E+02  3.18E-02  5.20E+00  3.12E+00  1.31E+03  9.98E+01  4.92E+00  3.95E+02
   80.    2.00E+04  3.96E+01  2.25E+01  1.14E-03  1.63E-02  8.61E-03  2.37E-01  1.68E+01  2.26E-02  5.07E-02
   82.    2.43E+04  5.22E+00  2.98E+00  1.12E-04  2.35E-04  1.25E-03  4.92E-03  2.23E+00  3.48E-04  8.32E-04
   84.    2.54E+04  1.68E+00  9.60E-01  2.63E-05  2.41E-05  5.53E-04  9.17E-04  7.19E-01  5.02E-05  1.71E-04
   86.    2.54E+04  6.43E-01  3.69E-01  7.54E-06  3.54E-06  2.40E-04  2.01E-04  2.75E-01  9.89E-06  4.48E-05
   88.    2.53E+04  2.70E-01  1.54E-01  2.26E-06  6.18E-07  1.15E-04  5.59E-05  1.16E-01  2.56E-06  1.44E-05
   90.    2.51E+04  1.15E-01  6.58E-02  6.82E-07  1.12E-07  3.41E-05  9.93E-06  4.93E-02  6.30E-07  2.80E-06
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Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	O2+	O4+	O2+.H2O	H3O+.OH	H3O+	H3O+.N2	H3O+.CO2	H5O2+	H5O+.CO2	NO+
40.	6.51E-02	1.49E+00	1.87E+00	1.33E+00	3.50E-03	1.24E-03	3.71E+00	5.36E+00	3.68E+00	2.85E-01
42.	2.23E-01	2.46E+00	3.08E+00	2.20E+00	8.28E-03	2.04E-03	6.12E+00	1.28E+01	6.46E+00	6.73E-01
44.	6.33E-01	3.69E+00	4.61E+00	3.29E+00	1.72E-02	3.06E-03	9.16E+00	2.69E+01	1.02E+01	1.40E+00
46.	1.79E+00	5.42E+00	6.77E+00	4.84E+00	3.57E-02	4.49E-03	1.35E+01	5.62E+01	1.57E+01	2.90E+00
48.	4.62E+00	7.82E+00	9.78E+00	6.98E+00	7.16E-02	6.49E-03	1.94E+01	1.14E+02	2.35E+01	5.83E+00
50.	1.02E+01	1.08E+01	1.36E+01	9.68E+00	1.32E-01	8.99E-03	2.69E+01	2.10E+02	3.34E+01	1.07E+01
52.	1.74E+01	1.41E+01	1.76E+01	1.25E+01	2.25E-01	1.17E-02	3.49E+01	3.57E+02	4.32E+01	1.83E+01
54.	3.79E+01	2.56E+01	3.20E+01	2.28E+01	5.21E-01	2.12E-02	6.33E+01	8.21E+02	7.72E+01	4.22E+01
56.	5.67E+01	3.58E+01	4.47E+01	3.19E+01	9.35E-01	2.97E-02	8.84E+01	1.45E+03	1.04E+02	7.56E+01
58.	6.55E+01	4.39E+01	5.48E+01	3.92E+01	1.39E+00	3.64E-02	1.08E+02	2.12E+03	1.21E+02	1.12E+02
60.	7.49E+01	5.54E+01	6.92E+01	4.94E+01	2.17E+00	4.59E-02	1.36E+02	3.24E+03	1.43E+02	1.74E+02
62.	1.00E+02	7.18E+01	8.97E+01	6.40E+01	3.49E+00	5.95E-02	1.76E+02	5.06E+03	1.75E+02	2.78E+02
64.	1.21E+02	9.47E+01	1.19E+02	8.43E+01	5.73E+00	7.93E-02	2.31E+02	7.90E+03	2.09E+02	4.52E+02
66.	1.60E+02	1.24E+02	1.55E+02	1.11E+02	9.69E+00	1.03E-01	3.01E+02	1.23E+04	2.42E+02	7.54E+02
68.	1.80E+02	1.51E+02	1.89E+02	1.35E+02	1.45E+01	1.25E-01	3.64E+02	1.66E+04	2.52E+02	1.11E+03
70.	2.51E+02	1.90E+02	2.37E+02	1.69E+02	2.36E+01	1.57E-01	4.49E+02	2.24E+04	2.49E+02	1.75E+03
72.	3.35E+02	2.29E+02	2.85E+02	2.03E+02	3.66E+01	1.88E-01	5.30E+02	2.61E+04	2.14E+02	2.57E+03
74.	4.52E+02	2.76E+02	3.42E+02	2.43E+02	5.64E+01	2.26E-01	6.16E+02	2.70E+04	1.60E+02	3.65E+03
76.	6.36E+02	3.34E+02	4.12E+02	2.91E+02	8.80E+01	2.70E-01	7.00E+02	2.44E+04	9.98E+01	4.88E+03
78.	1.27E+03	3.89E+02	4.61E+02	3.15E+02	1.24E+02	2.93E-01	5.37E+02	7.44E+03	1.39E+01	4.44E+03
80.	7.31E+03	2.73E+02	3.07E+02	2.00E+02	1.05E+02	1.90E-01	2.32E+02	2.24E+03	1.93E+00	9.03E+03
82.	1.24E+04	5.60E+01	5.89E+01	3.62E+01	2.36E+01	3.02E-02	2.77E+01	2.35E+02	1.01E-01	1.21E+04
84.	1.23E+04	1.80E+01	1.78E+01	1.04E+01	8.06E+00	7.55E-03	5.42E+00	4.72E+01	1.12E-02	1.30E+04
86.	1.13E+04	6.36E+00	5.87E+00	3.22E+00	2.77E+00	1.95E-03	1.12E+00	1.09E+01	1.52E-03	1.40E+04
88.	1.03E+04	2.41E+00	2.02E+00	1.01E+00	9.07E-01	4.52E-04	1.97E-01	2.44E+00	1.82E-04	1.47E+04
90.	9.53E+03	9.35E-01	6.94E-01	3.13E-01	2.69E-01	9.45E-05	3.08E-02	5.38E-01	2.10E-05	1.55E+04

ALTITUDE	NO+.CO2	NO+.H2O	NO+.H2O.N2	NO+H2O.CO2	NO+.2H2O	NO+.2H2ON2	NO+2H2OCO2	NO+.3H2O	H7O3+	H9O4+
40.	4.99E-01	9.07E-03	4.12E-04	1.24E-01	9.04E-03	4.10E-04	1.23E-01	3.55E+00	2.56E+03	5.37E+04
42.	8.21E-01	2.28E-02	6.79E-04	2.04E-01	2.27E-02	6.77E-04	2.03E-01	5.86E+00	8.57E+03	5.32E+04
44.	1.23E+00	4.97E-02	1.02E-03	3.05E-01	4.95E-02	1.01E-03	3.04E-01	8.76E+00	2.00E+04	4.53E+04
46.	1.81E+00	1.08E-01	1.40E-03	4.45E-01	1.06E-01	1.49E-03	4.46E-01	1.29E+01	3.70E+04	3.09E+04
48.	2.61E+00	2.26E-01	2.16E-03	6.47E-01	2.25E-01	2.15E-03	6.44E-01	1.86E+01	5.13E+04	1.87E+04
50.	3.61E+00	4.27E-01	2.99E-03	8.95E-01	4.26E-01	2.97E-03	8.92E-01	2.57E+01	6.08E+04	1.15E+04
52.	4.68E+00	7.27E-01	3.87E-03	1.15E+00	7.24E-01	3.86E-03	1.16E+00	3.33E+01	6.24E+04	9.03E+03
54.	8.49E+00	1.66E+00	7.02E-03	2.10E+00	1.66E+00	6.99E-03	2.10E+00	6.01E+01	7.42E+04	9.49E+03
56.	1.19E+01	2.89E+00	9.79E-03	2.94E+00	2.88E+00	9.75E-03	2.92E+00	8.36E+01	7.39E+04	1.06E+04
58.	1.45E+01	4.12E+00	1.29E-02	3.59E+00	4.10E+00	1.19E-02	3.57E+00	1.02E+02	6.82E+04	1.34E+04
60.	1.82E+01	6.09E+00	1.50E-02	4.50E+00	6.07E+00	1.49E-02	4.48E+00	1.27E+02	5.92E+04	1.80E+04
62.	2.33E+01	9.45E+00	1.93E-02	5.78E+00	9.41E+00	1.92E-02	5.75E+00	1.62E+02	5.33E+04	1.93E+04
64.	3.04E+01	1.46E+01	2.51E-02	7.52E+00	1.45E+01	2.50E-02	7.48E+00	2.09E+02	4.19E+04	2.31E+04
66.	3.94E+01	2.34E+01	3.25E-02	9.73E+00	2.32E+01	3.22E-02	9.65E+00	2.66E+02	3.22E+04	2.16E+04
68.	4.70E+01	3.25E+01	3.87E-02	1.16E+01	3.22E+01	3.83E-02	1.15E+01	3.11E+02	2.31E+04	1.91E+04
70.	5.69E+01	4.95E+01	4.67E-02	1.40E+01	4.87E+01	4.60E-02	1.38E+01	3.60E+02	1.78E+04	1.09E+04
72.	6.47E+01	6.96E+01	5.28E-02	1.58E+01	6.80E+01	5.15E-02	1.53E+01	3.81E+02	1.25E+04	4.73E+03
74.	7.09E+01	9.43E+01	5.74E-02	1.71E+01	9.01E+01	5.48E-02	1.63E+01	3.73E+02	7.52E+03	1.54E+03
76.	7.22E+01	1.19E+02	5.72E-02	1.70E+01	1.09E+02	5.25E-02	1.55E+01	3.10E+02	3.57E+03	3.51E+02
78.	4.75E+01	8.45E+01	3.26E-02	9.32E+00	5.71E+01	2.20E-02	6.16E+00	5.86E+01	1.91E+02	3.23E+00
80.	6.41E+01	1.17E+02	3.36E-02	9.16E+00	4.94E+01	1.41E-02	3.69E+00	2.02E+01	2.17E+01	1.29E-01
82.	5.69E+01	9.49E+01	2.04E-02	5.22E+00	2.24E+01	4.81E-03	1.15E+00	4.03E+00	1.37E+00	3.57E-03
84.	4.08E+01	6.09E+01	9.71E-03	2.35E+00	8.28E+00	1.32E-03	2.91E-01	7.53E-01	1.62E-01	2.21E-04
86.	2.97E+01	3.81E+01	4.55E-03	1.04E+00	2.96E+00	3.54E-04	7.18E-02	1.43E-01	2.20E-02	1.70E-05
88.	1.93E+01	1.96E+01	1.65E-03	3.42E-01	7.42E-01	6.21E-05	1.12E-02	1.64E-02	2.13E-03	8.36E-07
90.	1.21E+01	9.30E+00	5.43E-04	1.01E-01	1.62E-01	9.43E-06	1.47E-03	1.57E-03	1.95E-04	3.86E-08

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	LA	LAMBDA	Q/E**2	PSUM	NSUM+E	INT. SP	SP	INT. F	F	Q
40.	4.51E+02	1.33E+05	1.07E+03	5.62E+04	5.63E+04	5.63E+04	5.63E+04	4.22E-01	4.22E-01	1.90E+02
42.	2.50E+02	6.74E+04	2.72E+02	6.18E+04	6.19E+04	6.19E+04	6.19E+04	9.19E-01	9.19E-01	2.30E+02
44.	1.44E+02	3.66E+04	8.05E+01	6.54E+04	6.56E+04	6.56E+04	6.56E+04	1.79E+00	1.79E+00	2.58E+02
46.	8.04E+01	1.96E+04	2.31E+01	6.81E+04	6.83E+04	6.83E+04	6.83E+04	3.48E+00	3.48E+00	2.80E+02
48.	4.50E+01	1.06E+04	6.75E+00	7.02E+04	7.07E+04	7.07E+04	7.07E+04	6.66E+00	6.66E+00	3.00E+02
50.	2.70E+01	6.20E+03	2.33E+00	7.25E+04	7.26E+04	7.30E+04	7.26E+04	1.19E+01	1.17E+01	3.20E+02
52.	1.57E+01	3.63E+03	8.08E-01	7.20E+04	7.20E+04	7.27E+04	7.20E+04	2.02E+01	1.98E+01	3.17E+02
54.	9.46E+00	1.86E+03	2.15E-01	8.49E+04	8.49E+04	8.54E+04	8.49E+04	4.73E+01	4.57E+01	4.48E+02
56.	5.42E+00	1.04E+03	6.98E-02	8.66E+04	8.65E+04	8.93E+04	8.66E+04	8.31E+01	8.28E+01	4.78E+02
58.	3.41E+00	6.73E+02	3.00E-02	8.44E+04	8.42E+04	8.34E+04	8.44E+04	1.38E+02	1.25E+02	4.69E+02
60.	2.01E+00	4.11E+02	1.19E-02	8.13E+04	8.10E+04	8.76E+04	8.14E+04	2.29E+02	1.97E+02	4.60E+02
62.	1.22E+00	2.56E+02	5.03E-03	7.88E+04	7.85E+04	8.83E+04	7.93E+04	3.94E+02	3.05E+02	4.68E+02
64.	7.04E-01	1.55E+02	2.07E-03	7.45E+04	7.44E+04	8.90E+04	7.59E+04	6.75E+02	4.79E+02	4.75E+02
66.	3.89E-01	9.45E+01	9.08E-04	6.83E+04	6.86E+04	8.34E+04	6.84E+04	1.21E+03	7.19E+02	4.69E+02
68.	2.23E-01	6.18E+01	4.64E-04	6.17E+04	6.15E+04	8.51E+04	6.16E+04	1.94E+03	9.79E+02	4.45E+02
70.	1.25E-01	3.82E+01	2.17E-04	5.49E+04	5.45E+04	8.37E+04	5.48E+04	3.30E+03	1.39E+03	4.20E+02
72.	7.05E-02	2.43E+01	1.07E-04	4.84E+04	4.80E+04	8.01E+04	4.83E+04	5.30E+03	1.89E+03	3.85E+02
74.	3.99E-02	1.56E+01	5.49E-05	4.26E+04	4.21E+04	7.58E+04	4.26E+04	8.24E+03	2.54E+03	3.55E+02
76.	2.15E-02	9.55E+00	2.75E-05	3.64E+04	3.63E+04	7.02E+04	3.73E+04	1.22E+04	3.44E+03	3.25E+02
78.	1.20E-02	1.70E-01	1.72E-06	1.54E+04	1.56E+04	3.43E+04	1.56E+04	1.54E+04	1.33E+04	3.05E+02
80.	6.05E-03	1.98E-03	7.22E-07	2.00E+04	2.01E+04	2.69E+04	2.01E+04	2.04E+04	2.00E+04	2.90E+02
82.	3.23E-03	2.10E-04	4.67E-07	2.51E+04	2.49E+04	2.69E+04	2.49E+04	2.32E+04	2.49E+04	2.90E+02
84.	1.70E-03	6.61E-05	4.48E-07	2.55E+04	2.54E+04	2.69E+04	2.54E+04	2.49E+04	2.54E+04	2.90E+02
86.	9.55E-04	2.53E-05	4.50E-07	2.53E+04	2.54E+04	2.69E+04	2.54E+04	2.58E+04	2.54E+04	2.90E+02
88.	4.94E-04	1.07E-05	4.53E-07	2.51E+04	2.53E+04	2.69E+04	2.53E+04	2.63E+04	2.53E+04	2.90E+02
90.	2.52E-04	4.59E-06	4.61E-07	2.51E+04	2.51E+04	2.69E+04	2.51E+04	2.66E+04	2.51E+04	2.90E+02

5. NUMERICAL EXAMPLE: August 1972 SPE

The final example presented (Table 6) is for one instance during the 3 to 11 August 1972 SPE. The temperature, T, and total molecular concentration, [M] are for 1 August, 65° N, being interpolated from the CIRA 1972 models for 60° N and 70° N on 1 August. The ionization production rates are those for 1508 UT on 4 August.[17] Computed [e] agrees very well with data taken by the Chatanika backscatter radar at 62 km. However, above this altitude the model predicts electron concentrations 2 to 3 times greater than those reported.[17] The situation is more serious below 62 km where model electron concentrations fall off more rapidly with decreasing altitude than do the data, the lowest altitude (50 km) measurement being 1×10^4 cm^{-3} whereas we compute 2.5×10^3 cm^{-3} (Table 6).

The disagreement is disappointing in view of the good results obtained with the model and the 2 to 5 November 1969 SPE. However, different seasonal factors may influence the important minor neutral species in such a way as to account for the differences. Note that we have used the same minor neutral concentrations O, O_3, NO, NO_2 and O_2 ($^1\Delta$) as previously, but N_2, O_2, CO_2 and H_2O have changed since they are multiples of [M] which has been altered. We have suggested[18] that higher H_2O concentrations, say 10 ppmv, near the 80 km region would improve the model/data agreement considerably. The rationale for higher H_2O is that noctilucent-clouds are prevalent in the high latitude summer mesosphere. The situation near 50 km is much more serious since the discrepancy is nearly an order of magnitude. A higher O_3, and hence O concentration would help alleviate the problem, but in fact there is evidence[19] that O_3 may have declined during this event due to the enhanced formation of NO resulting from proton ionization processes. A decrease in O_3, and therefore O, not to mention an increase of NO, and hence NO_2^-, NO_3^-, would tend to make matters worse, if anything. The precision of the electron concentrations measured by the Chatanika radar below 60 km should be considered also. It may be that the [e] values have an important systematic error with decreasing altitude below 60 km. We note that no data is given below 50 km indicating that this is the last acceptable data point. Deterioration of the [e]-measurement may be setting in at a somewhat higher altitude. The Chatanika radar has been able to make D-region measurements only during this rather intense SPE.

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[17] Reagan, J. B., and Watt, T. M. (1976) Simultaneous satellite and radar studies of the D-region ionosphere during the intense solar particle events of August 1972, J. Geophys. Res. **81**:4579-4596.

[18] Swider, W., and Foley, C. I. (1977) The influence of minor atmospheric constituents on the electron loss rates of the August 4-11, 1972 and November 2-5 1969, solar proton events, EOS, **58**:465.

[19] Heath, D. F., Krueger, A. J., and Crutzen, P. J. (1971) Solar proton event: Influence on stratospheric ozone, Science **197**:886-889.

Reagan and Watt[17] claimed that ψ (or SI, see Eq. (1)) for this event agreed with the results[4] for the 2 to 5 November 1969 SPE. However, the events were not normalized in terms of their appropriate T and [M] values. The ψ curves for the two events thus agree well, save for the 80-km region problem, only if T and [M] for the August 1972 SPE was similar to that for the 2 to 5 November 1969 event. This possibility appears to be remote. The 1 November 60° N CIRA 1972 T and [M] values used for the November SPE are corroborated by experimental[20] evidence.

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[20] Faire, A. C., and Murphy, E. A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 445-455.

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 19λ2. See Table 3 caption for further description of the table. Rate coefficient k_{43} was set to zero. The solar zenith angle was 79.5°

ALTITUDE	O	O2	O3	N2	NO	CO2	H2O	O2(1D)	NO2	M	TEMP
40.	1.00E+09	1.94E+16	4.50E+11	7.23E+16	1.00E+09	2.78E+13	9.26E+10	1.00E+10	2.00E+08	9.26E+16	2.61E+02
42.	1.40E+09	1.45E+16	2.50E+11	5.39E+16	8.00E+08	2.07E+13	6.90E+10	1.50E+10	6.00E+07	6.90E+16	2.65E+02
44.	1.80E+09	1.13E+16	1.50E+11	4.22E+16	6.00E+08	1.62E+13	5.40E+10	1.70E+10	2.00E+07	5.40E+16	2.72E+02
46.	2.20E+09	8.80E+15	8.80E+10	3.28E+16	4.40E+08	1.26E+13	4.20E+10	1.90E+10	7.00E+06	4.20E+16	2.75E+02
48.	2.50E+09	6.91E+15	5.00E+10	2.59E+16	3.20E+08	9.90E+12	3.30E+10	1.90E+10	2.30E+06	3.30E+16	2.77E+02
50.	2.90E+09	5.28E+15	2.80E+10	1.97E+16	2.40E+08	7.56E+12	2.52E+10	1.80E+10	8.00E+05	2.52E+16	2.78E+02
52.	3.10E+09	4.19E+15	1.50E+10	1.56E+16	1.70E+08	6.00E+12	2.00E+10	1.60E+10	3.00E+05	2.00E+16	2.77E+02
54.	3.30E+09	3.25E+15	8.70E+09	1.21E+16	1.30E+08	4.65E+12	1.55E+10	1.40E+10	1.10E+05	1.55E+16	2.75E+02
56.	3.50E+09	2.62E+15	5.00E+09	9.75E+15	1.00E+08	3.75E+12	1.25E+10	1.10E+10	4.00E+04	1.25E+16	2.71E+02
58.	3.60E+09	2.05E+15	2.80E+09	7.65E+15	7.30E+07	2.94E+12	9.80E+09	9.00E+09	1.70E+04	9.80E+15	2.66E+02
60.	3.60E+09	1.64E+15	1.60E+09	6.11E+15	5.70E+07	2.35E+12	7.82E+09	6.80E+09	7.00E+03	7.82E+15	2.60E+02
62.	3.60E+09	1.32E+15	9.00E+08	4.92E+15	4.70E+07	1.89E+12	6.30E+09	4.70E+09	3.20E+03	6.30E+15	2.53E+02
64.	3.50E+09	1.03E+15	5.00E+08	3.83E+15	4.00E+07	1.47E+12	4.90E+09	3.40E+09	1.60E+03	4.90E+15	2.45E+02
66.	3.50E+09	7.96E+14	2.80E+08	2.97E+15	3.50E+07	1.14E+12	3.80E+09	2.40E+09	9.00E+02	3.80E+15	2.37E+02
68.	3.30E+09	6.29E+14	1.70E+08	2.34E+15	3.20E+07	9.00E+11	3.00E+09	1.60E+09	4.60E+02	3.00E+15	2.28E+02
70.	3.00E+09	4.84E+14	1.10E+08	1.80E+15	2.90E+07	6.93E+11	2.31E+09	1.10E+09	2.50E+02	2.31E+15	2.18E+02
72.	3.00E+09	3.67E+14	7.00E+07	1.37E+15	2.70E+07	5.25E+11	1.75E+09	7.00E+08	1.50E+02	1.75E+15	2.07E+02
74.	3.40E+09	2.72E+14	4.70E+07	1.02E+15	2.60E+07	3.90E+11	1.30E+09	4.70E+08	9.00E+01	1.30E+15	1.97E+02
76.	4.50E+09	2.10E+14	3.30E+07	7.81E+14	2.50E+07	3.00E+11	1.00E+09	3.30E+08	0.	1.00E+15	1.87E+02
78.	9.00E+09	1.55E+14	2.50E+07	5.79E+14	2.50E+07	2.22E+11	7.40E+08	2.50E+08	0.	7.40E+14	1.77E+02
80.	3.00E+10	1.10E+14	2.00E+07	4.10E+14	2.60E+07	1.58E+11	5.25E+08	2.00E+08	0.	5.25E+14	1.66E+02
82.	9.00E+10	7.54E+13	3.00E+07	2.81E+14	2.70E+07	1.08E+11	3.60E+08	3.00E+08	0.	3.60E+14	1.58E+02
84.	1.50E+11	5.03E+13	5.00E+07	1.87E+14	3.00E+07	7.20E+10	2.40E+08	5.00E+08	0.	2.40E+14	1.53E+02
86.	2.20E+11	3.35E+13	7.00E+07	1.25E+14	3.50E+07	4.80E+10	1.60E+08	7.00E+08	0.	1.60E+14	1.51E+02
88.	2.70E+11	2.10E+13	9.00E+07	7.81E+13	4.00E+07	3.00E+10	1.00E+08	9.00E+08	0.	1.00E+14	1.52E+02
90.	3.20E+11	1.34E+13	7.00E+07	4.99E+13	4.50E+07	1.91E+10	6.38E+07	7.10E+08	0.	6.39E+13	1.55E+02

ALTITUDE	E	NSUM	O2-	O4-	CO4-	O3-	CO3-	O-	NO2-	NO3-
40.	8.54E+01	7.04E+05	2.66E+02	3.37E+00	6.79E+02	1.33E+01	3.36E+05	1.53E+02	6.33E+02	3.66E+05
42.	1.88E+02	6.92E+05	7.19E+02	6.69E+00	1.78E+03	2.56E+01	4.74E+05	3.89E+02	7.54E+02	2.14E+05
44.	3.48E+02	6.81E+05	1.55E+03	1.10E+01	3.75E+03	3.97E+01	5.46E+05	7.40E+02	8.31E+02	1.28E+05
46.	6.59E+02	6.63E+05	3.10E+03	1.69E+01	7.38E+03	5.51E+01	5.68E+05	1.27E+03	9.54E+02	8.16E+04
48.	1.22E+03	6.33E+05	5.71E+03	2.43E+01	1.37E+04	7.22E+01	5.56E+05	2.04E+03	1.14E+03	5.46E+04
50.	2.52E+03	5.81E+05	1.04E+04	3.37E+01	2.32E+04	8.91E+01	5.03E+05	3.09E+03	1.41E+03	3.92E+04
52.	4.61E+03	5.07E+05	1.66E+04	4.28E+01	3.61E+04	9.37E+01	4.21E+05	4.16E+03	1.68E+03	2.72E+04
54.	8.27E+03	4.05E+05	2.31E+04	4.66E+01	4.13E+04	8.92E+01	3.15E+05	4.91E+03	1.84E+03	1.92E+04
56.	1.25E+04	3.12E+05	2.88E+04	4.75E+01	4.26E+04	7.54E+01	2.21E+05	5.28E+03	1.88E+03	1.26E+04
58.	1.89E+04	2.19E+05	3.26E+04	4.29E+01	3.56E+04	5.70E+01	1.37E+05	5.21E+03	1.54E+03	6.52E+03
60.	2.57E+04	1.55E+05	3.41E+04	3.66E+01	2.71E+04	4.15E+01	8.45E+04	5.03E+03	1.12E+03	3.14E+03
62.	3.20E+04	1.07E+05	3.28E+04	2.92E+01	1.87E+04	2.93E+01	4.91E+04	4.57E+03	7.29E+02	1.39E+03
64.	4.04E+04	6.94E+04	2.86E+04	2.04E+01	1.08E+04	1.76E+01	2.52E+04	3.93E+03	3.88E+02	5.38E+02
66.	4.74E+04	4.25E+04	2.22E+04	1.27E+01	5.33E+03	1.01E+01	1.16E+04	3.04E+03	1.76E+02	1.92E+02
68.	5.14E+04	2.67E+04	1.63E+04	7.64E+00	2.63E+03	5.76E+00	5.41E+03	2.19E+03	8.12E+01	7.65E+01
70.	5.42E+04	1.57E+04	1.08E+04	4.09E+00	1.14E+03	3.05E+00	2.28E+03	1.38E+03	3.23E+01	2.78E+01
72.	5.51E+04	8.30E+03	6.25E+03	1.89E+00	4.01E+02	1.45E+00	8.17E+02	8.08E+02	1.08E+01	8.62E+00
74.	5.55E+04	3.97E+03	3.15E+03	7.43E-01	1.11E+02	6.50E-01	2.52E+02	4.51E+02	3.04E+00	2.23E+00
76.	5.44E+04	1.82E+03	1.46E+03	2.79E-01	2.80E+01	2.99E-01	7.41E+01	2.60E+02	7.87E-01	5.31E-01
78.	5.51E+04	6.02E+02	4.55E+02	6.80E-02	3.31E+00	1.04E-01	1.23E+01	1.31E+02	1.09E-01	6.23E-02
80.	6.66E+04	1.33E+02	8.76E+01	9.90E-03	1.31E-01	2.42E-02	7.26E-01	4.43E+01	5.47E-03	2.54E-03
82.	8.40E+04	2.75E+01	1.67E+01	1.35E-03	4.47E-03	5.90E-03	3.99E-02	1.08E+01	2.58E-04	9.35E-05
84.	8.49E+04	7.24E+00	4.30E+00	2.41E-04	3.23E-04	2.15E-03	5.46E-03	2.93E+00	3.35E-05	8.86E-06
86.	8.20E+04	2.10E+00	1.24E+00	4.68E-05	2.87E-05	7.44E-04	8.37E-04	8.56E-01	5.53E-06	1.20E-06
88.	7.93E+04	6.59E-01	3.85E-01	9.05E-06	2.84E-06	2.76E-04	1.55E-04	2.73E-01	1.11E-06	2.09E-07
90.	7.74E+04	2.30E-01	1.34E-01	1.97E-06	3.34E-07	6.90E-05	2.06E-05	9.59E-02	1.65E-07	2.55E-08

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	O2+	O4+	O2+.H2O	H3O+.OH	H3O+	H3O+.N2	H3O+.CO2	H5O2+	H5O+.CO2	NO+
40.	4.31E+01	1.95E+02	2.43E+02	1.73E+02	4.63E-01	1.51E-01	4.81E+02	7.40E+02	6.14E+02	3.79E+01
42.	9.91E+01	2.56E+02	3.18E+02	2.27E+02	8.38E-01	2.11E-01	6.29E+02	1.35E+03	8.31E+02	6.91E+01
44.	2.50E+02	3.22E+02	3.98E+02	2.84E+02	1.41E+00	2.64E-01	7.87E+02	2.29E+03	1.10E+03	1.18E+02
46.	4.85E+02	4.03E+02	4.97E+02	3.55E+02	2.32E+00	3.30E-01	9.80E+02	3.75E+03	1.40E+03	1.96E+02
48.	8.60E+02	4.95E+02	6.09E+02	4.34E+02	3.67E+00	4.04E-01	1.20E+03	5.91E+03	1.73E+03	3.13E+02
50.	1.51E+03	6.25E+02	7.65E+02	5.46E+02	6.08E+00	5.08E-01	1.50E+03	9.74E+03	2.17E+03	5.28E+02
52.	2.16E+03	7.54E+02	9.18E+02	6.54E+02	9.12E+00	6.09E-01	1.79E+03	1.44E+04	2.54E+03	7.95E+02
54.	2.97E+03	9.06E+02	1.10E+03	7.81E+02	1.38E+01	7.27E-01	2.12E+03	2.15E+04	2.90E+03	1.21E+03
56.	3.30E+03	1.04E+03	1.25E+03	8.91E+02	1.90E+01	8.30E-01	2.41E+03	2.86E+04	3.07E+03	1.66E+03
58.	3.52E+03	1.21E+03	1.43E+03	1.02E+03	2.67E+01	9.47E-01	2.70E+03	3.77E+04	3.09E+03	2.29E+03
60.	3.37E+03	1.37E+03	1.60E+03	1.13E+03	3.57E+01	1.06E+00	2.95E+03	4.57E+04	2.88E+03	3.01E+03
62.	2.79E+03	1.47E+03	1.69E+03	1.19E+03	4.43E+01	1.12E+00	3.01E+03	4.94E+04	2.39E+03	3.65E+03
64.	2.33E+03	1.65E+03	1.85E+03	1.31E+03	5.86E+01	1.23E+00	3.13E+03	5.16E+04	1.79E+03	4.67E+03
66.	1.94E+03	1.82E+03	1.98E+03	1.39E+03	7.55E+01	1.31E+00	3.12E+03	4.90E+04	1.19E+03	5.71E+03
68.	1.57E+03	2.03E+03	2.12E+03	1.48E+03	9.46E+01	1.40E+00	3.11E+03	4.53E+04	7.87E+02	6.68E+03
70.	1.43E+03	2.34E+03	2.33E+03	1.61E+03	1.23E+02	1.54E+00	3.13E+03	4.11E+04	4.87E+02	7.85E+03
72.	1.56E+03	2.75E+03	2.57E+03	1.76E+03	1.61E+02	1.59E+00	3.10E+03	3.62E+04	2.84E+02	8.88E+03
74.	2.29E+03	3.39E+03	2.91E+03	1.95E+03	2.21E+02	1.30E+00	3.07E+03	3.16E+04	1.56E+02	1.00E+04
76.	3.59E+03	4.02E+03	3.16E+03	2.10E+03	2.79E+02	2.04E+00	2.93E+03	2.72E+04	8.91E+01	1.05E+04
78.	8.45E+03	4.64E+03	3.36E+03	2.17E+03	3.53E+02	2.14E+00	2.57E+03	2.09E+04	4.12E+01	1.15E+04
80.	3.15E+04	4.62E+03	2.67E+03	1.61E+03	3.33E+02	1.62E+00	1.38E+03	9.19E+03	8.58E+00	1.45E+04
82.	6.17E+04	1.81E+03	8.16E+02	4.37E+02	1.21E+02	4.46E-01	2.36E+02	1.35E+03	5.16E-01	1.70E+04
84.	6.52E+04	5.78E+02	1.97E+02	9.33E+01	3.43E+01	8.37E-02	3.33E+01	1.88E+02	3.30E-02	1.82E+04
86.	6.15E+04	1.73E+02	4.35E+01	1.80E+01	8.25E+00	1.48E-02	3.94E+00	2.49E+01	2.06E-03	1.98E+04
88.	5.73E+04	5.05E+01	8.63E+00	2.89E+00	1.53E+00	1.59E-03	3.00E-01	2.57E+00	8.77E-05	2.14E+04
90.	5.37E+04	1.53E+01	1.76E+00	4.60E-01	2.48E-01	1.67E-04	1.99E-02	2.66E-01	3.84E-06	2.31E+04

ALTITUDE	NO+.CO2	NO+.H2O	NO+.H2O.N2	NO+H2O.CO2	NO+.2H2O	NO+.2H2ON2	NO+2H2OCO2	NO+.3H2O	H7O3+	H9O4+
40.	6.51E+01	1.55E+00	5.39E-02	1.62E+01	1.55E+00	5.37E-02	1.61E+01	4.62E+02	4.17E+05	2.83E+05
42.	8.59E+01	2.93E+00	7.10E-02	2.13E+01	2.92E+00	7.07E-02	2.12E+01	6.07E+02	5.26E+05	1.62E+05
44.	1.09E+02	5.33E+00	9.00E-02	2.70E+01	5.31E+00	8.37E-02	2.69E+01	7.68E+02	6.10E+05	6.43E+04
46.	1.37E+02	9.07E+00	1.14E-01	3.41E+01	9.04E+00	1.13E-01	3.39E+01	9.65E+02	6.15E+05	3.58E+04
48.	1.70E+02	1.48E+01	1.41E-01	4.22E+01	1.47E+01	1.40E-01	4.20E+01	1.19E+03	5.95E+05	2.18E+04
50.	2.17E+02	2.51E+01	1.80E-01	5.38E+01	2.50E+01	1.79E-01	5.36E+01	1.51E+03	5.47E+05	1.37E+04
52.	2.61E+02	3.74E+01	2.16E-01	6.47E+01	3.72E+01	2.15E-01	6.43E+01	1.79E+03	4.74E+05	1.05E+04
54.	3.13E+02	5.61E+01	2.59E-01	7.76E+01	5.57E+01	2.57E-01	7.71E+01	2.11E+03	3.66E+05	7.85E+03
56.	3.54E+02	7.37E+01	2.93E-01	8.77E+01	7.32E+01	2.91E-01	8.69E+01	2.31E+03	2.71E+05	7.39E+03
58.	3.93E+02	9.72E+01	3.28E-01	9.82E+01	9.62E+01	3.25E-01	9.70E+01	2.45E+03	1.74E+05	6.67E+03
60.	4.35E+02	1.20E+02	3.59E-01	1.07E+02	1.19E+02	3.53E-01	1.05E+02	2.47E+03	1.08E+05	6.73E+03
62.	4.46E+02	1.36E+02	3.67E-01	1.09E+02	1.33E+02	3.59E-01	1.07E+02	2.29E+03	6.31E+04	7.18E+03
64.	4.69E+02	1.58E+02	3.85E-01	1.14E+02	1.53E+02	3.72E-01	1.10E+02	2.05E+03	3.22E+04	6.05E+03
66.	4.71E+02	1.76E+02	3.84E-01	1.13E+02	1.67E+02	3.65E-01	1.06E+02	1.70E+03	1.68E+04	3.46E+03
68.	4.63E+02	1.84E+02	3.75E-01	1.10E+02	1.71E+02	3.50E-01	1.01E+02	1.38E+03	1.02E+04	1.74E+03
70.	4.50E+02	1.89E+02	3.61E-01	1.05E+02	1.71E+02	3.28E-01	9.34E+01	1.07E+03	6.19E+03	7.21E+02
72.	4.19E+02	1.82E+02	3.32E-01	9.51E+01	1.60E+02	2.91E-01	8.15E+01	7.79E+02	3.67E+03	2.85E+02
74.	3.76E+02	1.74E+02	2.92E-01	8.24E+01	1.45E+02	2.43E-01	6.66E+01	5.14E+02	2.04E+03	1.01E+02
76.	3.28E+02	1.54E+02	2.50E-01	6.94E+01	1.22E+02	1.98E-01	5.29E+01	3.40E+02	1.23E+03	4.29E+01
78.	2.80E+02	1.35E+02	2.06E-01	5.57E+01	9.74E+01	1.49E-01	3.83E+01	1.92E+02	5.99E+02	1.33E+01
80.	2.53E+02	1.19E+02	1.71E-01	4.32E+01	6.95E+01	1.00E-01	2.34E+01	7.40E+01	1.34E+02	1.50E+00
82.	1.82E+02	8.34E+01	1.02E-01	2.27E+01	3.18E+01	3.30E-02	7.68E+00	1.40E+01	8.89E+00	4.32E-02
84.	1.15E+02	5.20E+01	4.90E-02	9.60E+00	1.19E+01	1.12E-02	1.87E+00	2.30E+00	6.44E-01	1.52E-03
86.	6.92E+01	2.95E+01	1.96E-02	3.33E+00	3.48E+00	2.31E-03	3.23E-01	2.79E-01	4.31E-02	4.85E-05
88.	3.47E+01	1.21E+01	4.88E-03	6.69E-01	5.19E-01	2.19E-04	2.25E-02	1.28E-02	1.66E-03	7.39E-07
90.	1.67E+01	4.26E+00	1.00E-03	1.07E-01	5.77E-02	1.35E-05	1.09E-03	4.12E-04	6.18E-05	1.08E-08

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	LA	LAMBDA	Q/E**2	PSUM	NSUM+E	INT. SP	SP	INT. E	E	Q
40.	7.48E+02	8.25E+03	4.11E+00	7.04E+05	7.05E+05	7.04E+05	7.06E+05	5.48E+01	8.54E+01	3.00E+04
42.	4.22E+02	3.68E+03	8.29E-01	6.92E+05	6.92E+05	6.91E+05	6.92E+05	1.56E+02	1.88E+02	2.93E+04
44.	2.65E+02	1.96E+03	2.38E-01	6.81E+05	6.81E+05	6.76E+05	6.81E+05	4.38E+02	3.48E+02	2.88E+04
46.	1.62E+02	1.01E+03	6.47E-02	6.60E+05	6.63E+05	6.50E+05	6.63E+05	1.18E+03	6.58E+02	2.80E+04
48.	1.01E+02	5.17E+02	1.80E-02	6.30E+05	6.34E+05	6.11E+05	6.32E+05	3.29E+03	1.22E+03	2.70E+04
50.	5.90E+01	2.31E+02	4.10E-03	5.80E+05	5.83E+05	5.55E+05	5.82E+05	7.14E+03	2.52E+03	2.60E+04
52.	3.71E+01	1.10E+02	1.17E-03	5.11E+05	5.12E+05	4.95E+05	5.11E+05	1.21E+04	4.61E+03	2.48E+04
54.	2.21E+01	4.90E+01	3.36E-04	4.10E+05	4.13E+05	4.12E+05	4.12E+05	1.81E+04	8.27E+03	2.30E+04
56.	1.42E+01	2.50E+01	1.36E-04	3.24E+05	3.24E+05	3.66E+05	3.24E+05	2.22E+04	1.25E+04	2.12E+04
58.	8.55E+00	1.16E+01	5.34E-05	2.37E+05	2.38E+05	2.99E+05	2.38E+05	3.45E+04	1.89E+04	1.90E+04
60.	5.31E+00	6.02E+00	2.56E-05	1.80E+05	1.81E+05	2.49E+05	1.81E+05	4.40E+04	2.57E+04	1.70E+04
62.	3.35E+00	3.35E+00	1.41E-05	1.39E+05	1.40E+05	2.15E+05	1.40E+05	4.76E+04	3.20E+04	1.45E+04
64.	1.95E+00	1.72E+00	7.66E-06	1.10E+05	1.10E+05	1.90E+05	1.10E+05	5.27E+04	4.04E+04	1.25E+04
66.	1.13E+00	8.96E-01	4.67E-06	8.93E+04	9.00E+04	1.59E+05	8.99E+04	5.64E+04	4.74E+04	1.05E+04
68.	6.71E-01	5.19E-01	3.41E-06	7.75E+04	7.80E+04	1.54E+05	7.80E+04	6.12E+04	5.14E+04	9.00E+03
70.	3.75E-01	2.89E-01	2.66E-06	6.94E+04	6.98E+04	1.42E+05	6.98E+04	6.58E+04	5.42E+04	7.80E+03
72.	2.00E-01	1.51E-01	2.21E-06	6.30E+04	6.34E+04	1.31E+05	6.34E+04	6.80E+04	5.51E+04	6.70E+03
74.	1.03E-01	7.16E-02	1.92E-06	5.91E+04	5.95E+04	1.22E+05	5.95E+04	7.01E+04	5.55E+04	5.90E+03
76.	5.62E-02	3.35E-02	1.75E-06	5.62E+04	5.63E+04	1.14E+05	5.63E+04	7.59E+04	5.44E+04	5.20E+03
78.	2.82E-02	1.09E-02	1.52E-06	5.56E+04	5.57E+04	1.07E+05	5.57E+04	8.41E+04	5.51E+04	4.60E+03
80.	1.28E-02	1.99E-03	9.47E-07	6.66E+04	6.67E+04	1.03E+05	6.67E+04	9.35E+04	6.66E+04	4.20E+03
82.	5.51E-03	3.28E-04	5.53E-07	8.39E+04	8.40E+04	9.98E+04	8.40E+04	9.52E+04	8.40E+04	3.90E+03
84.	2.32E-03	8.53E-05	4.99E-07	8.47E+04	8.49E+04	9.49E+04	8.49E+04	9.73E+04	8.49E+04	3.60E+03
86.	1.01E-03	2.57E-05	4.99E-07	8.17E+04	8.20E+04	9.15E+04	8.20E+04	9.93E+04	8.20E+04	3.35E+03
88.	3.98E-04	8.31E-06	5.01E-07	7.88E+04	7.93E+04	8.98E+04	7.93E+04	9.92E+04	7.93E+04	3.15E+03
90.	1.67E-04	2.97E-06	5.00E-07	7.68E+04	7.74E+04	8.56E+04	7.74E+04	1.00E+05	7.74E+04	3.00E+03

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Appendix A

Steady-State Multi-Ion Disturbed D-Region Model Program (Subroutine Initial, which contains input profiles of Q, M, T, minor neutrals and SI, has been omitted.)

```
C      40 - 90 KM IN INCREMENTS OF 2
C
C      78 REACTIONS
C
       PROGRAM DREGION(INPUT=65,OUTPUT=65,TAPE15=65,TAPE2)
       COMMON NEUT(9,26),TEMP(26),M(26),Z(26),Q(26),SI(26)
       DIMENSION NION(8,26),NSPECI(8),PION(30,26),K(100),ESAVE(26)
      1        , ISPECI(30), INEUT(9), A(100), B(100),D(100),IREAC(100),
      2          JDUM(26), ITER(26), REAC(6)
       DIMENSION ICOEFF(26),EINT(26),SPINT(26),ICOL(2),EVENT(2)
       REAL M,K,NEUT,NION
       INTEGER WATER,TPF,PCA
       REAL ICOEFF
       LOGICAL IONCF,DAY,FIRST,DIAGNOS
       DATA ICOL/10H INT. E   ,10H INT. SP  /
C
C      NALT=NUMBER OF ALTITUDES,  ISTART IS INDEX OF STARTING ALTITUDE,
C      NELE=NUMBER OF ELEMENTS IN PION ARRAY TO BE COMPUTED
C
       NELE=30
       FIRST=.TRUE.
C
C      READ IN COMPUTER RUN OPTIONS
C
       READ 72, ISTART,NALT
    72 FORMAT(2I5)
       IF(EOF(5LINPUT)) 99,73
    73 READ 69,SET,ISET
    69 FORMAT(A10,I5)
       PRINT 69, SET
    74 READ 70,DAY,WATER,TPF,PCA,IONCF,DIAGNOS,CRIT,OD,EVENT(1),EVENT(2)
    70 FORMAT(1L2,3A2,2L2,2F5.0,2A10)
       IF(EOF(5LINPUT)) 99,71
    71 PRINT 67,DAY,WATER,TPF,PCA,IONCF,OD,CRIT,EVENT(1),EVENT(2)
    67 FORMAT(* DAY=*,L2,* H2O=*,A2,* TPF=*,A2,* PCA=*,A2,* IONCF=*,L2,
      1        * OD=*,F5.0* CRITERIA=*,F5.0* PERCENT*,
      2        /*   *,2A10)
C
C      DETERMINE SPECIE PROFILES AND OTHER PARAMETERS WHICH DECRIBE THIS
C      COMPUTER RUN - FOUND IN SUBROUTINE INITIAL
C
       CALL INITIAL(DAY,WATER,TPF,PCA)
C
       PRINT 75 ,Z(ISTART),Z(NALT)
    75 FORMAT(5X,*ALTITUDE RANGE  *, F5.0,* -*,F5.0,* KM*)
       OD=0.
       IF(DAY) OD=1.
       IYES=0    $    NOS=NALT-ISTART+1
C
C      OD= OPTICAL DEPTH FACTOR
C
C      COMPUTE THE IONIZATION COEFFICIENTS FOR EACH ALTITUDE
C
       SIGMA=1.0E-20
       IF(IONCF) 7,9
```

```
    7 DO 8 J=ISTART,NALT
      H=(3032.*TEMP(J))/((6370./(6370.+Z(J)))**2)
      ICOEFF(J)=4.7E-07*EXP(-(NEUT(2,J)*H*SIGMA*OD))
      PION(30,J)=ICOEFF(J)*NEUT(5,J)
    8 CONTINUE
      GO TO 15
C           (NO)*I WILL NOT BE COMUTED THIS RUN
    9 NELE=29
   15 CONTINUE
      TODAY=10H
      RUNDY=DATE(TODAY)
      WRITE(2,150) RUNDY,SET
  150 FORMAT(1H1,15X,*RUN DATE*,A10,15X,*REACTION SET OF*,A10)
      ALPHAD=4.0E-07
      ALPHAI=6.0E-08
      TIME=10HDAY
      IF( .NOT. DAY) TIME=10HNIGHT
      WRITE(2,151) ALPHAD,ALPHAI,TIME,WATER,TPF,PCA,CRIT,
     1                EVENT(1),EVENT(2)
  151 FORMAT(5X,*AD=*,1PE8.1,* AI=*,1PE8.1,2X,A10,*, H2O=*,A2,
     1      *, TEMP=*,A2,*, PCA=*,A2,* CRITERIA=*,0PF5.0,* PERCENT*,
     2   *, EVENT  *,2A10)
      CRIT=CRIT/100.
      IF(IIONCF) 11,13
   11 WRITE(2,12) OD,SIGMA
   12 FORMAT(10X,*OPTICAL DEPTH FACTOR = *,F5.2,*  SIGMA = *,1PE9.1)
   13 NREAC=78
      IF( .NOT. FIRST) GO TO 19
      IF( PCA .EQ. 2HLO .OR. PCA .EQ. 2HHI ) GO TO 18
      IF(PCA .EQ. 2H72) 36,37
   36 READ 16, (Q(I),I=1,25)
   17 FORMAT(12F6.0)
   16 FORMAT(1P7E10.2)
      IF(EOF(5LINPUT)) 99,18
   37 READ 17, (Q(I),I=1,25)
      IF(EOF(5LINPUT))99,18
   18 CONTINUE
C
C     READ IN CHEMICAL REACTIONS FROM TAPE15
C
      DO 20 II=1,NREAC
      READ(15,1) I,(REAC(L),L=1,6),A(I),B(I),D(I)
    1 FORMAT(I4,A10,2A6,1X,A10,2A6,1PE9.2,0PF5.1,1PE9.2)
      IREAC(II)=I
      IF(EOF(15)) 22,21
   21 IF(TSET .EQ. 0) GO TO 20
      WRITE(2,2) IREAC(I),(REAC(L),L=1,6),A(I),B(I),D(I)
    2 FORMAT(I4,A10,2A6,1H=,A10,2A6,1PE9.2,0PF5.1,1PE9.2)
   20 CONTINUE
       GO TO 19
   22  NREAC=I-1
   19 CONTINUE
      WRITE(2,805) NREAC
  805 FORMAT(*   THE NUMBER OF REACTIONS THIS RUN *,I10)
C
```

```
C     ISPECI IS A HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF PION
C     ARRAY ( POSITIVE ION ARRAY)
C
C
C     NSPECI IS HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF
C             NION ARRAY   (NEGATIVE ION ARRAY)
C
      ISPECI(1)=10HE                         $    NSPECI(1)=10HO2-
      ISPECI(2)=10HSP                        $    NSPECI(2)=10HO4-
      ISPECI(3)=10HNSUM                      $    NSPECI(3)=10HCO4-
      ISPECI(4)=10HO2+                       $    NSPECI(4)=10HO3-
      ISPECI(5)=10HO4+                       $    NSPECI(5)=10HCO3-
      ISPECI(6)=10HO2+.H2O                   $    NSPECI(6)=10HO-
      ISPECI(7)=10HH30+.OH                   $    NSPECI(7)=10HNO2-
      ISPECI(8)=10HH30+                      $    NSPECI(8)=10HNO3-
      ISPECI( 9)=10HH30+.N2
      ISPECI(10)=10HH30+.CO2
      ISPECI(11)=10HH5O2+
      ISPECI(12)=10HH50+.CO2
      ISPECI(13)=10HNO+
      ISPECI(14)=10HNO+.N2
      ISPECI(15)=10HNO+.CO2
      ISPECI(16)=10HNO+.H2O
      ISPECI(17)=10HNO+.H2O.N2
      ISPECI(18)=10HNO+H2O.CO2
      ISPECI(19)=10HNO+.2H2O
      ISPECI(20)=10HNO+.2H2ON2
      ISPECI(21)=10HNO+2H2OCO2
      ISPECI(22)=10HNO+.3H2O
      ISPECI(23)=10HH7O3+
      ISPECI(24)=10HH9O4+
      ISPECI(25)=10H  LA
      ISPECI(26)=10HLAMBDA
      ISPECI(27)=10HQ/E**2
      ISPECI(28)=10HPSUM
      ISPECI(29)=10HNSUM+E
      ISPECI(30)=10H(NO).I
C
C     INEUT IS A HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF NEUTRAL
C     SPECIES
C
      INEUT(1)=10HO
      INEUT(2)=10HO2
      INEUT(3)=10HO3
      INEUT(4)=10HN2
      INEUT(5)=10HNO
      INEUT(6)=10HCO2
      INEUT(7)=10HH2O
      INEUT(8)=10HO2(1D)
      INEUT(9)=10HNO2
C
      IF(.NOT. DIAGNOS) GO TO 48
      WRITE(2,271) (ISPECI(J),J=25,29),ICOL(2),ISPECI(2),
     1                       ICOL(1),ISPECI(1)
   48 CONTINUE
C
C
C     ITER ARRAY OF NUMBER OF ITERATIONS TO COMPUTE E
C
C     JOUN$ARRAY OF SWICHES INDICATING CRITERIA SATISFIED
```

```
C
      DO 25 J=ISTART,NALT
      ITER(J)=0
   25 JDUN(J)=3H NO
C
C     DO LOOP 100 CALCULATES ALL THE POSITIVE IONS
C
   50 DO 100 J=ISTART,NALT
      IF(JDUN(J) .EQ. 3HYES) GO TO 100
      ITER(J)=ITER(J)+1
      CALL RATECN(K,A,B,D,IREAC,TEMP,J,NREAC)
      IF(ITER(J) .GT. 1) GO TO 90
      PION(25,J)=NEUT(2,J)*(K(61)*NEUT(2,J)+K(62)*NEUT(4,J))
      IF(DAY) 51,52
   51 PION(1,J)=SQRT(Q(J)/SI(J))
      GO TO 53
   52 PION(1,J)=SQRT((PION(25,J)/(2.*ALPHAD))**2+Q(J)/ALPHAD)
     1               -PION(25,J)/(2.*ALPHAD)
   53 PION(2,J)=SQRT((Q(J)*(5.*NEUT(1,J)/ALPHAD+NEUT(3,J)/ALPHAI))/
     1                   (5.*NEUT(1,J)+NEUT(3,J)))
      EINT(J)=PION(1,J)
      SPINT(J)=PION(2,J)
   90 AISP=ALPHAI*PION(2,J)
      CALL NEGION(DAY,NION,K,PION(25,J),PION(1,J),J,AISP,PION(3,J))
      AISN=ALPHAI*PION(3,J)
      CON1=K(8)*NEUT(1,J)+K(9)*NEUT(7,J)+K(42)*M(J)+DD*K(4)+AISN
      CON2=K(7)*NEUT(2,J)*M(J)
      CON4=NEUT(7,J)*(K(10)+K(11))+AISN+K(30)*PION(1,J)+DD*K(5)
      CON5=DD*K(4)+(DD*K(5)*K(9)*NEUT(7,J)/CON4)
      PION(4,J)=.9*Q(J)/(AISN+K(27)*PION(1,J)+CON2+K(6)*
     1           NEUT(5,J)-(CON2*(K(8)*NEUT(1,J)+K(42)*M(J)+CON5)/
     1           (CON1+K(28)*PION(1,J))))
      PION(5,J)=PION(4,J)*(CON2/(CON1+K(28)*PION(1,J)))
      PION(6,J)=PION(5,J)*K(9)*NEUT(7,J)/CON4
      PION(7,J)=K(10)*NEUT(7,J)*PION(6,J)/
     1                 (K(12)*NEUT(7,J)+AISN+K(30)*PION(1,J))
      PION(8,J)=PION(6,J)*K(11)*NEUT(7,J)/
     1                     (K(31)*PION(1,J)+K(18)*NEUT(7,J)*M(J)+
     2                      K(13)*NEUT(4,J)**2+AISN)
      CON1=K(14)*NEUT(6,J)
      CON2=K(32)*PION(1,J)+AISN
      PION( 9,J)=(K(13)*NEUT(4,J)*NEUT(4,J)*PION(8,J))/
     1                  (CON1+K(35)*PION(1,J)+AISN)
      CON3=K(15)*NEUT(7,J)
      PION(10,J)=(CON1*PION( 9,J))/(CON3+K(36)*PION(1,J)+AISN)
      H2OM1=NEUT(7,J)*M(J)
      PION(11,J)=(PION(7,J)*K(12)*NEUT(7,J)+K(18)*PION(8,J)*H2OM1+
     1   PION(10,J)*CON3)/
     1              (K(32)*PION(1,J)+K(19)*H2OM1+AISN+
     1     K(16)*NEUT(6,J)*M(J))
      PION(12,J)=(K(16)*NEUT(6,J)*PION(11,J)*M(J))/
     1                  (K(37)*PION(1,J)+AISN+K(17)*NEUT(7,J))
      CON1=K(21)*NEUT(6,J)*NEUT(4,J)
      CON2=K(22)*NEUT(7,J)
      SQN2=NEUT(4,J)*NEUT(4,J)
```

```
      PION(13,J)=(.1*Q(J)+K(6)*NEUT(5,J)*PION(4,J)+PION(30,J))/
     1             (K(26)*PION(1,J)+CON1+AISN
     2    +K(43)*SQN2-(K(43)*SQN2*NEUT(4,J)*K(51)/
     3   (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+K(51)*NEUT(4,J))))
      PION(14,J)=(K(43)*PION(13,J)*SQN2)/
     1       (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+K(51)*NEUT(4,J))
      PION(15,J)=(CON1*PION(13,J)+K(44)*NEUT(6,J)*PION(14,J))/
     1                  (CON2+K(38)*PION(1,J)+AISN)
      CON1=K(23)*NEUT(7,J)*NEUT(4,J)
      PION(16,J)=CON2*PION(15,J)/(CON1+K(39)*PION(1,J)+AISN
     1                                 +K(45)*SQN2)
      PION(17,J)=(PION(16,J)*K(45)*SQN2)/
     1                           (K(46)*NEUT(6,J)+K(40)*PION(1,J)+AISN)
      PION(18,J)=(PION(17,J)*K(46)*NEUT(6,J))/
     1                       (K(47)*NEUT(7,J)+K(40)*PION(1,J)+AISN)
      CON2=K(24)*NEUT(7,J)*NEUT(4,J)
      PION(19,J)=(CON1*PION(16,J)+PION(18,J)*K(47)*NEUT(7,J))/
     1                 (K(40)*PION(1,J)+CON2+AISN+K(48)*SQN2)
      PION(20,J)=(PION(19,J)*K(48)*SQN2)/
     1                        (K(49)*NEUT(6,J)+K(41)*PION(1,J)+AISN)
      PION(21,J)=(PION(20,J)*K(49)*NEUT(6,J))/
     1                           (K(50)*NEUT(7,J)+K(41)*PION(1,J)+AISN)
      PION(22,J)=(CON2*PION(19,J)+PION(21,J)*K(50)*NEUT(7,J))/
     1                 (K(25)*NEUT(7,J)+K(41)*PION(1,J)+AISN)
      G=K(34)*PION(1,J)+AISN+K(52)*M(J)
      PION(23,J)=(PION(11,J)*K(19)*H2OM1+PION(22,J)*K(25)*NEUT(7,J)+
     1   K(17)*PION(12,J)*NEUT(7,J))/
     1          (K(33)*PION(1,J)+K(20)*H2OM1*(1-K(52)*M(J)/G)+AISN)
      PION(24,J)=(PION(23,J)*K(20)*H2OM1)/G
      PION(26,J)=PION(3,J)/PION(1,J)
      PION(27,J)=Q(J)/PION(1,J)**2
      PION(29,J)=PION(3,J)+PION(1,J)
  100 CONTINUE
C     IF(JUMP .EQ. 2) GO TO 126
C
C
C     COMPUTE THE SUM OF THE POSITIVE IONS
C
      DO 120 J=ISTART,NALT
      IF( ITER(J) .GE. 20) JDUN(J)=3HNO
      IF(JDUN(J) .EQ. 3HYES) GO TO 120
      ESAVE(J)=PION(1,J)
      PION(28,J)=0.
      DO 121 I=4,24
  121 PION(28,J)=PION(28,J)+PION(I,J)
      IF( ABS(1.-PION(29,J)/PION(28,J)) .LE. CRIT) JDUN(J)=3HYES
      IF( JDUN(J) .EQ. 3HYES) GO TO 119
      PION(2,J)=.5*(ESAVE(J)+PION(28,J)+PION(3,J))
  118 PION(1,J)=.5*(ESAVE(J)+PION(28,J)/(1.+PION(26,J)))
      GO TO 120
  119 IYES=IYES+1
      NOS=NOS-1
  120 CONTINUE
      IF(DIAGNOS)40,49
   40 J=ISTART
      WRITE(2,269) Z(J),(PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),
```

```
     1              PION(1,J),ITER(J),JDUN(J)
      IF(ITER(J) .GE. 20) 125,50
   49 CONTINUE
C     IF(ITER(ISTART) .EQ. 1) GO TO 122
      DO 125 J=ISTART,NALT
      IF(JDUN(J) .EQ. 3H NO) GO TO 50
  125  CONTINUE
      PRINT*," THE SCORE IS  ",IYES," YES  AND ",NOS, "NO"
  122 WRITE(2,200) (INEUT(I),I=1,9)
  200 FORMAT(/*  ALTITUDE*,3X,9(A10),2X,*M*,9X,*TEMP*)
      DO 235 J=ISTART,NALT
      WRITE(2,240) Z(J),(NEUT(I,J),I=1,9),M(J),TEMP(J)
  240 FORMAT(0PF10.0,11(1X,1PE9.2))
  235 CONTINUE
      WRITE(2,273) ISPECI(1),ISPECI(3),(NSPECI(J),J=1,8)
  273 FORMAT(//* ALTITUDE *,2X,11(1X,A10))
      DO 272 J=ISTART,NALT
      WRITE(2,274) Z(J), PION(1,J),PION(3,J),(NION(I,J),I=1,8)
  274 FORMAT(F10.0,11(2X,1PE9.2))
  272 CONTINUE
      IL=3
      DO 270 I=1,2
      IM=IL+1
      IL=IM+10
      IF(IL .GT. 24) IL=24
      WRITE(2,273) (ISPECI(J),J=IM,IL)
      DO 276 J=ISTART,NALT
      WRITE(2,274) Z(J),(PION(N,J),N=IM,IL)
  276 CONTINUE
  270 CONTINUE
      WRITE(2,271) (ISPECI(J),J=25,29),ICOL(2),ISPECI(2),
     1                ICOL(1),ISPECI(1)
  271 FORMAT(//* ALTITUDE *,2X,9(1X,A10),2X,*Q*,7X,*  ITER*)
      DO 275 J=ISTART,NALT
      WRITE(2,269) Z(J),(PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),
     1                   PION(1,J),Q(J),ITER(J)
  269 FORMAT(0PF10.0,10(2X,1PE9.2),2X,I5)
  275 CONTINUE
C     IF(ITER(ISTART) .EQ. 1) GO TO 50
      FIRST=.FALSE.
      GO TO 74
   99 CONTINUE
      CALL EXIT
      END
```

SUBROUTINE NEGION

```
      SUBROUTINE NEGION(DAY,NION,K,LA,E,J,AISP,SUM)
C
C     SUBROUTINE NEGION COMPUTES THE CONCENTRATION OF NEGATIVE IONS
C
C     NEGATIVE ION SPECIES ARE STORED IN ARRAY NION
C
C INDEX NION
C     1  O2-
C     2  O4-
C     3  CO4-
C     4  O3-
C     5  CO3-
C     6  O-
C     7  NO2-
C     8  NO3-
C
      COMMON NEUT(9,26)
      DIMENSION NION(8,26),K(100)
      REAL NION,K,LA,NEUT
      LOGICAL DAY
      IF(DAY) 1,2
    1 D=1
      GO TO 3
    2 D=0
    3 O2SQ=NEUT(2,J)*NEUT(2,J)
      X=K(77)*O2SQ+K(80)*NEUT(3,J)
      B=NEUT(1,J)*(K(63)+K(64))+K(65)*NEUT(8,J)+
     1  K(66)*O2SQ+D*K(91)+K(60)*NEUT(3,J)+AISP
      T=K(73)*NEUT(1,J)+K(74)*NEUT(5,J)+K(75)*NEUT(9,J)+D*K(94)+AISP
      W=K(71)*NEUT(1,J)+K(72)*NEUT(6,J)+AISP
      V=K(68)*NEUT(3,J)+K(69)*NEUT(5,J)+K(70)*NEUT(1,J)+D*K(93)+AISP
      U=K(78)*NEUT(1,J)+X+D*K(92)+K(79)*NEUT(8,J)+AISP
     1        +K(81)*NEUT(3,J)
      R=V*(U*W*T-D*K(94)*K(72)*NEUT(6,J)*X)
      S=O2SQ*(W*U*K(66)*K(70)*NEUT(1,J)+U*K(66)*K(68)*K(72)*
     1          NEUT(6,J)*NEUT(3,J)+V*K(64)*K(72)*K(77)*NEUT(1,J)*
     2         NEUT(6,J))
     3        +V*K(72)*NEUT(5,J)*NEUT(3,J)*(U*K(60)+K(64)*K(80)*
     4                                      NEUT(1,J))
C
C     NION(1,J)=O2-
C
      NION(1,J)=(V*U*W*R*E*LA)/(R*B*V*U*W
     1          -U*R*K(65)*K(68)*K(71)*NEUT(1,J)*NEUT(3,J)*O2SQ-
     2           V*R*K(64)*K(71)*X*NEUT(1,J)**2-
     3           S*V*NEUT(1,J)*(K(71)*X*D*K(94)+U*W*K(73))-
     4           U*R*V*K(60)*K(71)*NEUT(3,J)*NEUT(1,J)
     1         -W*V*K(64)*K(81)*NEUT(1,J)*NEUT(3,J)
     6         -(S*W*V*K(81)*NEUT(3,J)*D*K(94))/R)
C
C     NION(2,J)=O4-
C
      NION(2,J)=(K(66)*O2SQ*NION(1,J))/
     1          (K(67)*NEUT(6,J))
C
C     NION(3,J)=CO4-
C
      NION(3,J)=(K(66)*O2SQ*NION(1,J))/
     1          (K(68)*NEUT(3,J)+K(69)*NEUT(5,J)+K(70)*NEUT(1,J)
```

```
     2               +D*K(93)+AISP)
C
C     NION(5,J)=CO3-
C
      NION(5,J)=S*NION(1,J)/R
C
C     NION(6,J)=O-
C
      NION(6,J)=(K(64)*NEUT(1,J)*NION(1,J)+D*K(94)*NION(5,J))/U
C
C     NION(4,J)=O3-
C
      NION(4,J)=(K(68)*NEUT(3,J)*NION(3,J)+K(77)*NION(6,J)*O2SQ+
     1                   NEUT(3,J)*(K(60)*NION(1,J)+K(80)*NION(6,J)))/W
C
C     NION(7,J)=NO2-
C
      C=(D*K(96))/(D*(K(96)+K(97))+AISP)
      NION(7,J)=(K(74)*NEUT(5,J)*NION(5,J)+C*(K(75)*NEUT(9,J)*NION(5,J)+
     1               K(69)*NEUT(5,J)*NION(3,J)))/
     2          (K(76)*NEUT(3,J)+D*K(95)+AISP-C*K(75)*NEUT(3,J))
C
C     NION(8,J)=NO3-
C
      NION(8,J)=(K(75)*NEUT(9,J)*NION(5,J)+K(76)*NEUT(3,J)*NION(7,J)+
     1                   K(69)*NEUT(5,J)*NION(3,J))/
     2               (D*(K(96)+K(97))+AISP)
      SUM=0.
      DO 10 I=1,8
   10 SUM=SUM+NION(I,J)
      RETURN
      END
```

SUBROUTINE RATECN

```
      SUBROUTINE RATECN(K,A,B,D,IREAC,TEMP,IALT,NREAC)
      DIMENSION K(1),A(1),B(1),D(1),IREAC(1),TEMP(1)
      REAL K
      DO 10 J=1,NREAC
      ID=IREAC(J)
      K(ID)=A(ID)*(TEMP (IALT)/300.)**B(ID)*EXP(D(ID)/TEMP(IALT))
   10 CONTINUE
      RETURN
      END
```

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