Naval Research Laboratory
Washington, DC 20375-5000

DTIC FILE COPY

NRL Memorandum Report 6134

Approximate Analytical Formulae for Electron Density and Collision Frequency in the Natural and Nuclear-Disturbed Ionosphere and Inner Magnetosphere

M. J. KESKINEN AND J. A. FEDDER

Geophysical and Plasma Dynamics Branch
Plasma Physics Division

AD-A193 129

February 22, 1988

DTIC
ELECTE
MAR 1 1 1988
S D
D

Approved for public release; distribution unlimited

88 3 09 039

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 6134	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b OFFICE SYMBOL (If applicable) Code 4780	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING / SPONSORING ORGANIZATION SDIO 8b OFFICE SYMBOL (If applicable) SDIO/T/SN	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) The Pentagon Washington, DC	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO 63220 0 PROJECT NO 0000S10 30X00 TASK NO WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
Approximate Analytical Formulae for Electron Density and Collision Frequency in the Natural and Nuclear-Disturbed Ionosphere and Inner Magnetosphere

12. PERSONAL AUTHOR(S)
Keskinen, M.J. and Fedder, J.A.

13a. TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM _____ TO _____	1988 February 22	28

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Electron density; Ionosphere; Collision frequency; Nuclear environment.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The phenomenological models of global electron density for the natural ionosphere of Ching and Chiu (1973) and Chiu (1975) have been extended to both lower (60 km) and higher (36,000 km) altitudes. Computer simulations of a high altitude nuclear explosion are analyzed to develop a phenomenological model of electron density. Approximate analytical formulae for electron density and associated electron collision frequency in both the natural and nuclear-disturbed near earth space plasma environment are derived. Keywords

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL M.J. Keskinen	22b TELEPHONE (Include Area Code) (202) 767-3630 22c OFFICE SYMBOL Code 4780

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

I. INTRODUCTION 1

II. NATURAL IONOSPHERE AND INNER MAGNETOSPHERE 2

III. NUCLEAR-DISTURBED IONOSPHERE AND INNER MAGNETOSPHERE 5

IV. SUMMARY 7

Appendix A 9

Acknowledgment 12

References 13

APPROXIMATE ANALYTICAL FORMULAE FOR ELECTRON DENSITY AND COLLISION FREQUENCY IN THE NATURAL AND NUCLEAR-DISTURBED IONOSPHERE AND INNER MAGNETOSPHERE

I. INTRODUCTION

Radiowave propagation through the natural and nuclear-disturbed space environment has been the subject of intense study over the last several decades [see, for example, Budden, 1966; Davies, 1966; Cornwall et al., 1981, and references therein]. It is well known that these environments can lead to refraction, reflection, and absorption of radio waves propagating in and through these regions. Two fundamental quantities needed to assess the impact of the atmosphere, ionosphere, and magnetosphere on radio wave propagation are the electron density and electron-ion collision frequency.

Much effort has been devoted to the development of models of electron density in the earth's ionosphere [Kohnlein, 1978 and references therein]. Several experimental tools, e.g., ionospheric sounders, satellites, incoherent scatter radars, have been used to both generate and validate these models. The density models developed thus far can be most easily classified as either phenomenological, empirical, or physical. The Bent model [Bent et al., 1972; Llewellyn and Bent, 1973], which is a purely phenomenological electron density model covering the altitude range from about 150 to 1000 km, was developed from ground station observations, F_2 peak layer models, and satellite measurements. The principal goal of the Bent model is to maximize, on a global scale, the accuracy of the determination of the total electron content.

Ching and Chiu [1973] and Chiu [1975] have also developed a phenomenological electron density model which is global and is valid in the altitude range 110-1000 km. This model, which is based on a large data base of ionospheric sounding data, attempts to give analytical formulae to describe not only the large scale changes of electron density with altitude, latitude, and longitude, but also seasonal, diurnal, and solar cycle variations.

Nisbet [1970a, 1970b] has developed a physical model based upon an empirical framework of electron density of the earth's ionosphere in the altitude range 100-1000 km.

Kohnlein [1977] has developed a purely empirical model of the global morphology of electron density and its variation with space, time, and geophysical conditions which covers the altitude interval 60-3500 km and is limited to quiet geomagnetic conditions ($K_p \leq 2$).

Manuscript approved October 1, 1987.

Thomason et al. [1979] have developed an empirical model of electron density which includes topside ionospheric variations and some high latitude ionospheric effects.

For the nuclear disturbed ionosphere, electron densities and associated quantities, e.g., electron temperature have been derived, for the most part, from computer simulations of high altitude nuclear explosions [see, e.g., Kilb, 1977 and Cornwall et al., 1981].

In this report we extend the analysis of the model of electron density for natural ionosphere of Ching and Chiu [1973] and Chiu [1975] to both lower ($\simeq$ 60 km) and higher ($\simeq$ 36,000 km) altitudes. In addition, we investigate the evolution of electron density derived from a computer simulation of a high altitude nuclear burst. Finally, we develop approximate analytical formulae for the electron density and associated collision frequency for both the natural and nuclear disturbed near earth space plasma environment.

II. NATURAL IONOSPHERE AND INNER MAGNETOSPHERE

As discussed in the previous section, several phenomenological or empirical models of electron density in the earth's ionosphere have been advanced in recent years. The model of Ching and Chiu [1973] and Chiu [1975] is the only model that provides analytical formulae not only for electron density as functions of altitude, geomagnetic latitude, and longitude but also for diurnal, local time, annual, and solar cycle variation. The input parameters of the model are the altitude z, the annual time t, the geographic latitude λ, the geomagnetic latitude λ_m. The local time ϕ, the monthly relative sunspot number ρ, the geomagnetic longitude l_m, and the geomagnetic dip angle δ_m. The electron density in the model of Ching and Chiu [1973] and Chiu [1975] is computed using three independent Chapman function profiles representing the E, F_1, and F_2 layers

$$N_e = \sum_{i=1}^{3} A_i H_i\left(z, \lambda_m, \phi\right) V_i\left(t, \lambda, \lambda_m, \phi, \rho\right) \tag{1}$$

with

$$H_i = \exp\left\{a_i\left[1 - \bar{z}_i - \exp\left(-\bar{z}_i\right)\right]\right\}$$

and $\bar{z}_i = (z - p_i)/h_i$ and $V_i = f_i(\lambda, \lambda_m, \rho)P_i(t, \lambda, \lambda_m, \phi, \rho) + (1 - f_i(\lambda, \lambda_m, \rho))U_i(t, \lambda, \lambda_m, \phi, \rho)$. The density for each layer is the product of an amplitude parameter A_i, an exponential Chapman profile function H, and a layer peak function V. The exponential Chapman profile function is given in terms of standard Chapman parameters a_i [Chiu, 1975], the peak layer altitude $p_i(\lambda_m, \lambda, t, \phi, \rho)$ and the scale height function h_i. The layer peak function consists of a polar function $P_i(\lambda_m, \lambda, t, \phi, \rho)$ and a nonpolar function $U_i = S_i D_i L_i T_i E_i \Lambda_i \Delta_i$ where $S_i(\rho)$ gives solar cycle variations, $D_i(\phi, \lambda_m, \rho, \chi, \delta)$ is a diurnal function with χ and δ the solar zenith angle and solar declination, respectively, $L_i(\lambda_m, \phi)$ a latitudinal function, $T_i(\lambda, \lambda_m, t, \phi, \rho)$ represents annual variation, and $E_i(\lambda_m, \phi, \rho)$ an equatorial anomaly function, $\Lambda_i(\lambda_m, l_m)$ a longitudinal function, and $\Delta_i(t, \delta_m)$ a magnetic dip function. The analytical formulae for f_i, P_i, and U_i can be found in Appendix A.

However, the analytical model of Ching and Chiu [1973] and Chiu [1975] is valid only in the altitude range 100 - 1000 km. The model severely underestimates the electron density at both D-region ($\simeq$ 60 - 80 km) and topside ionospheric and inner magnetospheric altitudes ($\gtrsim$ 1000 km). We have generalized the altitudinal dependence of the electron density as derived from the model of Ching and Chiu [1973] by adding (1) an exponential variation to represent D-layer variation and (2) a power law to model topside ionospheric and inner magnetospheric variation. In this expanded model we have

$$N_e = \begin{cases} \sum_{i=1}^{3} A_i H_i V_i + A_D H_D(z) & 60 \text{ km} \leq z \leq 1000 \text{ km} \\ A_m H_m(z) & z \geq 1000 \text{ km} \end{cases}$$

where $A_D = 1 \times 10^2$, $H_D(z) = \exp\left[-\left|\left(\frac{z - 65}{5}\right)\right|\right]$, $H_m(z) = (1 \times 10^3/z)^3$,

and $A_m = \sum_{i=1}^{3} A_i H_i(z = 1000 \text{ km})V_i + A_D H_D(z = 1000 \text{ km})$.

DTIC COPY INSPECTED 1

Accesion For
NTIS CRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution /
Availability Codes
Dist
A-1

We have constructed, based on this generalized model, a computer program entitled DENSITY which computes electron density as a function of altitude, geomagnetic latitude, longitude, diurnal time, local time, annual time, and solar cycle variation. Figure 1 displays a typical variation of electron density with altitude in the generalized model at three different geomagnetic latitudes. An approximate analytical functional form for the electron density as a function of altitude only in this extended model of Ching and Chiu [1973] can be expressed as

$$N_e(z) = \sum_{i=1}^{5} g_i(z) \tag{2}$$

where $g_i(z) = A_i \Lambda_i(z)$, $A_1 = 1 \times 10^2$, $A_2 = 1.36 \times 10^5$, $A_3 = 2.44 \times 10^5$, $A_4 = 6.6 \times 10^4$, and $A_5 = 1.20305 \times 10^3$ with (60 km $\leq z \leq$ 1000 km)

$$\Lambda_1(z) = \exp\left[-\left|\left(\frac{z-65}{5}\right)\right|\right]$$

$$\Lambda_2(z) = \exp\left[1-\left(\frac{z-110}{10}\right) - \exp\left\{-\left(\frac{z-110}{10}\right)\right\}\right]$$

$$\Lambda_3(z) = \exp\left[1-\left(\frac{z-180}{34}\right) - \exp\left\{-\left(\frac{z-180}{34}\right)\right\}\right]$$

$$\Lambda_4(z) = \exp\left[1-\left(\frac{z-240}{L_4(z)}\right) - \exp\left\{-\left(\frac{z-240}{L_4(z)}\right)\right\}\right]$$

$$L_4(z) = \begin{cases} 40 + 0.2\,z & 60 \text{ km} \leq z \leq 400 \text{ km} \\ 120 & 400 \text{ km} < z \leq 1000 \text{ km} \end{cases}$$

and ($z \gtrsim 1000$ km)

$$\Lambda_5(z) = (1. \times 10^3/z)^3$$

Figure 2 illustrates the variation of electron density at a fixed altitude ($z = 300$ km) as a function of geomagnetic latitude. One can note the decrease in density in the equatorial regions ($\lambda_m = 0°$) with subsequent increases as the auroral zones ($60° < |\lambda_m| < 75°$).

Figure 3 displays the approximate total electron collision frequency $\nu_e(\sec^{-1})$ vs. altitude z(km) based on the previous generalized electron density model at the same three geomagnetic latitudes used in Fig. 1. Here

$$\nu_e(z) = \nu_{ei}(z) + \nu_{en}(z) \tag{3}$$

with [Hanson, 1966]

$$\nu_{en}(z) = 3 \times 10^{-8}\, N_n(z)$$

and

$$\nu_{ei}(z) = \left[2 \times 10^{-4} + 2.5 \times 10^{-5} \ln \frac{3 \times 10^{10}}{N_e(z)}\right] N_e(z)$$

where

$$N_n(z) = 1 \times 10^{15} \exp\left[-(z - 60)/8\right] \text{ cm}^{-3}$$

III. NUCLEAR-DISTURBED IONOSPHERE AND INNER MAGNETOSPHERE

A high altitude (> 150 km) nuclear explosion can severely disrupt the ambient ionosphere and magnetosphere on temporal scales from seconds to hours and on spatial scales from meters to thousands of kilometers. Typical high altitude nuclear explosions (HANE) evolve in time through several stages in which the local plasma and neutral gas parameters, e.g., density, temperature, magnetic field, etc. can change over several orders of magnitude. At early times, on the order of a few seconds after burst, the ambient magnetic field is severely perturbed with the blast energy, in the form of electromagnetic radiation and energetic particles, coupled to and deposited in the ionosphere and atmosphere. At later times, on the order of a few minutes to hours, the ambient geomagnetic field relaxes to its pre-burst state with the HANE plasma expanding to global dimensions

and finally decaying to ambient values. In order to compute analytical formulae for electron density and collision frequency following a HANE we take typical electron densities in the later time regime. We use electron densities derived from a computer simulation of a large yield (1 MTON) HANE at high altitudes (150 km) over the central Rocky Mountain region of the U.S. [Hain et al., 1985]. The total global electron density resulting from a single nuclear burst can be written, in approximate form, as

$$N_e = N_{e,A}(r,t,\lambda,\lambda_m,l_m,\delta_m,\phi,\rho) + N_{e,N}(r,\lambda_m,l_m)$$

where $N_{e,A}$ is the contribution from the ambient ionosphere as outlined in Sec. 2 and $N_{e,N}$ is the HANE contribution. The nuclear part $N_{e,N}$ can be expressed, to lowest order, in the following form

$$N_{e,N}(r,\lambda_m,l_m) = g_1(r)g_2(\lambda_m)g_3(l_m)$$

$$g_1(r) = \begin{cases} 2.9583333 \times 10^5 \exp\{(r-120)/2.052023\} & 60 \text{ km} \leq r \leq 120 \text{ km} \\ 4.16667 \times 10^1 \, [3 \times 10^6 - (r - 1850)^2] & 120 \text{ km} \leq r \leq 2.8717 \times 10^3 \text{ km} \\ 8.15032 \times 10^7 (2.871725 \times 10^3/r)^3 & 2.8717 \times 10^3 \text{ km} \leq r \leq 3.6 \times 10^4 \text{ km} \end{cases}$$

$$g_2(\lambda_m) = \exp\left[-\{(\lambda_m - \lambda_{mo})/0.034\}^2\right]$$

and

$$g_3(l_m) = \exp\left[-\{l_m - l_{mo})/0.034\}^2\right]$$

where λ_m, l_m are the geomagnetic latitude and longitude, respectively measured in radians from the burst coordinates (λ_{mo}, l_{mo}). Figure 4 gives the total electron density at the burst latitude and longitude as a function of altitude $g_1(r)$ at t = 300 sec following the burst simulated by Hain et al. [1985]. As can be seen comparing Fig. 4 with Fig. 1 a HANE can increase the electron density by several orders of magnitude over ambient values.

Fig. 5 displays the electron collision frequencies at t = 300 sec following the burst as a function of altitude. An approximate analytical form for the electron collision frequency can be written:

$$\nu_e(r) = \nu_{en}(r) + \nu_{ei}(r)$$

with

$$\nu_{en}(r) = 5.61 \times 10^{-8}\ N_n(r)\ \text{sec}^{-1}$$

$$N_n(r) = 1 \times 10^6 \exp\{-(r-60)/500\}$$

and

$$\nu_{ei}(r) = \left[34 + 4.18 \ln\left(\frac{1.33 \times 10^{12}}{N_e(r)}\right)\right] \frac{N_e(r)}{1.15 \times 10^6}$$

where $N_e(r)$ is expressed in cm^{-3}. Fig. 5 also indicates that the electron collision frequencies following a HANE can also be increased by several orders of magnitude with respect to ambient values due to large increases in neutral and plasma density.

IV. SUMMARY

In this report we have extended and generalized to both lower and higher altitudes the phenomenological models of Ching and Chiu [1973] and Chiu [1975] for electron density in the earth's ionosphere. In addition, we have analyzed computer simulations of a high altitude nuclear explosion in the ionosphere to develop an approximate model of electron density. Finally, we have derived approximate analytical formulae for electron density and collision frequency as functions of altitude in both the natural and nuclear-disturbed ionosphere and inner magnetosphere.

Appendix A

In this appendix we give the functional forms for the quantities A_i, f_i, P_i, u_i, a_i, p_i, h_i occurring in Eq. (1) as discussed in Chiu [1975]. The global electron density N_e is given in units of 10^5 cm^{-3}. The independent variables are

z = altitude in km

t = annual time (days of year) in units of months as measured from December 15 of previous year

λ = geographic latitude in radians

λ_m = geomagnetic latitude in radians

l_m = geomagnetic longitude in radians measured eastward

δ_m = geomagnetic dip angle in radians

ϕ = local time in radians measured from local midnight

ρ = R/100 where R is the monthly smoothed Zurich relative sunspot number

The dependent angular variables are

δ = solar declination angle defined by $\sin \delta = 0.398 \sin [\pi/6(t - 3.17)]$

χ = solar zenith angle defined by $\cos \chi = - \cos \lambda \cos \delta \cos \phi + \sin \lambda \sin \delta$

$\psi(\xi, \eta)$ = seasonal anomaly function defined by $\psi(\xi, \eta) = \xi + \delta \cos \eta$

ζ = seasonal anomaly function defined by $\zeta = \sin \delta \sin \lambda_m$

μ, ω = shifted local times with $\mu = \phi + \pi/4$ and $\omega = \phi - 0.873$

The functions listed in Eq. (1) are given in Table A1 with $U_i = S_i(\rho)D_i(\phi, \chi, \delta, \lambda_m, \rho)L_i(\lambda_m, \phi, \rho)\, T_i(t, \lambda, \lambda_m, \phi, \rho)E_i(\lambda_m, \phi, \rho)\Lambda_i(\lambda_m, l_m)\Delta_i(t, \delta_m)$.

The functions listed in Table A1 are as follows:

$$D(a,b) = \exp\{[a + b \ln(1 + 30\rho)][\mathrm{sign}\ (\cos \chi)\cos^{1/2}|\chi|-1]\}$$

where

$$W(b, \xi, \eta) = \exp\{- b[\cos \psi(\xi, \eta) - \cos \xi]\}$$

$$P_3 = [2 + \rho + 0.5 \cos(\phi - 0.873)] \exp\{\cos \psi(\lambda_m, \phi)\}$$

$$S_3 = \sigma(\rho) \text{ if } \rho \leq 1.1$$
$$= 2.39 + 1.53[\sigma(\rho) - 2.39] \sin^2\lambda_m \text{ if } \rho \geq 1.1$$
$$\sigma(\rho) = 1 + \rho + 0.204 \rho^2 + 0.03\rho^3$$

$$D_3 = (0.9 + 0.32\zeta)(1 + \zeta \cos^2 \mu) \exp[- 1.1(1 + \cos \omega)]$$

$$L_3 = (1.2 - 0.5 \cos^2 \lambda_m)(1 + 0.05\rho \sin^3 \lambda_m \cos \pi t/6)L'q$$

$$L' = \exp\left\{3 \cos \left[\frac{\lambda_m}{2} (\sin \phi - 1)\right]\right\}$$

$$q = 1 - 0.15 \exp\{- [(12 \lambda_m + 1.05)^2 + (t/2 - 3)^2]^{1/2}$$

$$T_3 = X(t, \lambda_m, \phi, \rho) + Y(t, \lambda^m, \phi)/S_3$$

$$X = 0.7\left[\kappa + 0.178 \rho^2 S_3^{-1} \cos\frac{\pi}{3}- (t = 4.3\right]W(\beta, \lambda_m, \phi)$$

$$Y = 0.2\left[1 - \sin\left(|\lambda_m| - \frac{\pi}{6}\right)\left[1 + 0.6 \cos \frac{\pi}{3} (t - 3.94)\right] \cos \frac{\pi}{6} (t - 1)\right.$$
$$+ \left[0.13 - 0.06 \sin |\lambda_m| - \frac{\pi}{9}\right] \cos \frac{\pi}{3} (t - 4.5)$$
$$- (0.15 + 0.3 \sin |\lambda_m|)(1 - \cos \phi)^{1/4} \cos^3 \psi(\lambda_m, 0)$$

$$\beta = 1.3 + 0.278 \rho^2 \cos^2 \frac{1}{2}\left(\lambda_m - \frac{\pi}{4}\right) + 0.051 \rho^3$$

$$\kappa = 1 + 0.085\left[\cos\left(\lambda_m - \frac{\pi}{6}\right) \cos^3 \frac{\pi}{12} (t - 2) + \cos\left(\lambda_m + \frac{\pi}{4}\right) \cos^2 \frac{\pi}{12} (t - 8)\right]$$

$$E_3 = \gamma(0.05, 0.5)\left[1 + G(\phi, \rho)\right](1 - 0.4 \cos^{10} \lambda_m)(1 + 0.6 \cos^{10} \lambda_m \cos^2 \mu)$$
$$\times \cos^8 \lambda_m \cos^{12} (|\lambda_m| - 0.262)$$

$$G(\phi, \rho) = \left(1 + 0.6\ \rho^{1/2} - 0.2\rho\right)\ \exp 0.25\left[1 + \cos(\phi - 4)\right]$$

$$\gamma(a, b) = 1 + a\left(b - \cos\frac{\pi}{3}\ t + \cos\frac{\pi}{6}\ t\right)$$

$$\Lambda_3 = 1 + 0.1\ \cos^3\lambda_m\ \cos^2\left(1_m - \frac{7\pi}{18}\right)$$

$$\Delta_3 = \gamma(0.03,\ 0.5)\left[1 + g(\rho,\ \lambda_m,\ t)\ \exp\left\{-\ 18\left(|\delta_m| - \frac{2}{9}\ \pi\right)^2\right\}\right]$$

$$g\left(\rho,\ \lambda_m,\ t\right) = 0.15 - (1 + \rho)\ \sin^2\frac{1}{2}\ \lambda_m\ \exp - 0.33(t - 6)^2$$

$$f_3 = \exp\left\{-\ \left[2.4 + (0.4 + 0.1\rho)\ \sin\lambda_m\right]^6\right\}\ \cos^6\lambda_m$$

$$p_3 = 240 + 75\rho + 83\rho\zeta\ \cos\lambda_m + 30\ \cos(\phi - 4.5|\lambda_m| - \pi) - 10\ \cos\lambda_m\ \cos\frac{\pi}{3}\ (t - 4.5)$$

$$\begin{aligned} h_3 &= 2H_J(z) \text{ if } z \leq p_3 \\ &= 2H_J(p_3) \text{ if } z \geq p_3 \end{aligned}$$

$$H_J(x) = 20 + 0.1x$$

Table A1

Functions in Eq. (1)

Function	i = 1	i = 2	i = 3
A_i	1.36	2.44	0.66
a_i	0.5	0.5	1.0
p_i	110.0	180.0	p_3
h_i	10.0	34.0	h_3
f_i	0.0	0.0	f_3
P_i	1.0	1.0	P_3
S_i	$(1 - 1.15\rho)^{1/2}$	$(1 + 1.24\rho + .25\rho^2)^{1/2}$	S_3
D_i	D(2,0)	D(1,30)	D_3
L_i	1.0	1.0	L_3
T_i	$W(0.4, \lambda, \phi)$	$W(0.25, \lambda, \phi)$	T_3
E_i	1.0	1.0	E_3
Λ_i	1.0	1.0	Λ_3
Δ_i	1.0	1.0	Δ_3

Acknowledgment

We thank Mike Kaplan, Eric Mokole, and Mike Reilly for useful discussions. This work was supported by SDIO/Sensors.

References

Bent, R.B., S.K. Llewellyn, and M.K. Wallock, Description and evaluation of the Bent ionospheric model, vol. I, Rep. SAMSO TR-72-239, Space and Missile Syst. Organ., Los Angeles, CA, 1972. [AD753-081]

Budden, K.G., Radio Waves in the Ionosphere, Cambridge, Cambridge, U.P., 1961.

Ching, B.K. and Y.T. Chiu, A phenomenological model of global ionospheric electron density in the E-, F1-, and F2-regions, J. Atmos. Terr., 35, 1615, 1973.

Chiu, Y.T., An improved phenomenological model of ionospheric density, J. Atmos. Terr. Phys., 37, 1563, 1975.

Cornwall, M., S. Flatté, D. Hammer, and J. Vesecky, Studies of the Effect of Striations on Radio Communications, JASON, SRI International Report JSR-81-31, 1981.

Davies, K., Ionospheric Radio Propagation, Dover, New York, 1966.

Hain, K., G. Hain, and J.A. Fedder, Cheyenne Mountain late time simulation results, NRL Memo Rept. 5565, 1985. [AD A155-425]

Hanson, W.B., Structure of the ionosphere, Satellite Environment Handbook, 2d ed., F.S. Johnson, Stanford University Press, Stanford, CA, 1965. pp. 21.

Kilb, R.W., Striation formation, in Physics of High Altitude Nuclear Burst Effects, DNA 4501F, 1977.

Kohnlein, W., Electron density models of the ionosphere, Rev. Geophys. and Space Phys., 16, 341, 1978.

Llewellyn, S.K. and R.B. Bent, Documentation and description of the Bent ionospheric model, Rep. SAMSO TR-73-252, Space and Missile Syst. Organ., Los Angeles, CA 1973. [AD722-733]

Nisbet, J.S., On the construction and use of the Penn State MKI model, Sci. Rep. 355, Ionos. Res. Lab, Penn State Univ., University Park, 1970.

Thomason, J., G. Skaggs, and J. Lloyd, A global ionospheric model, NRL Rept. 8321, 1979. [AD A074-370]

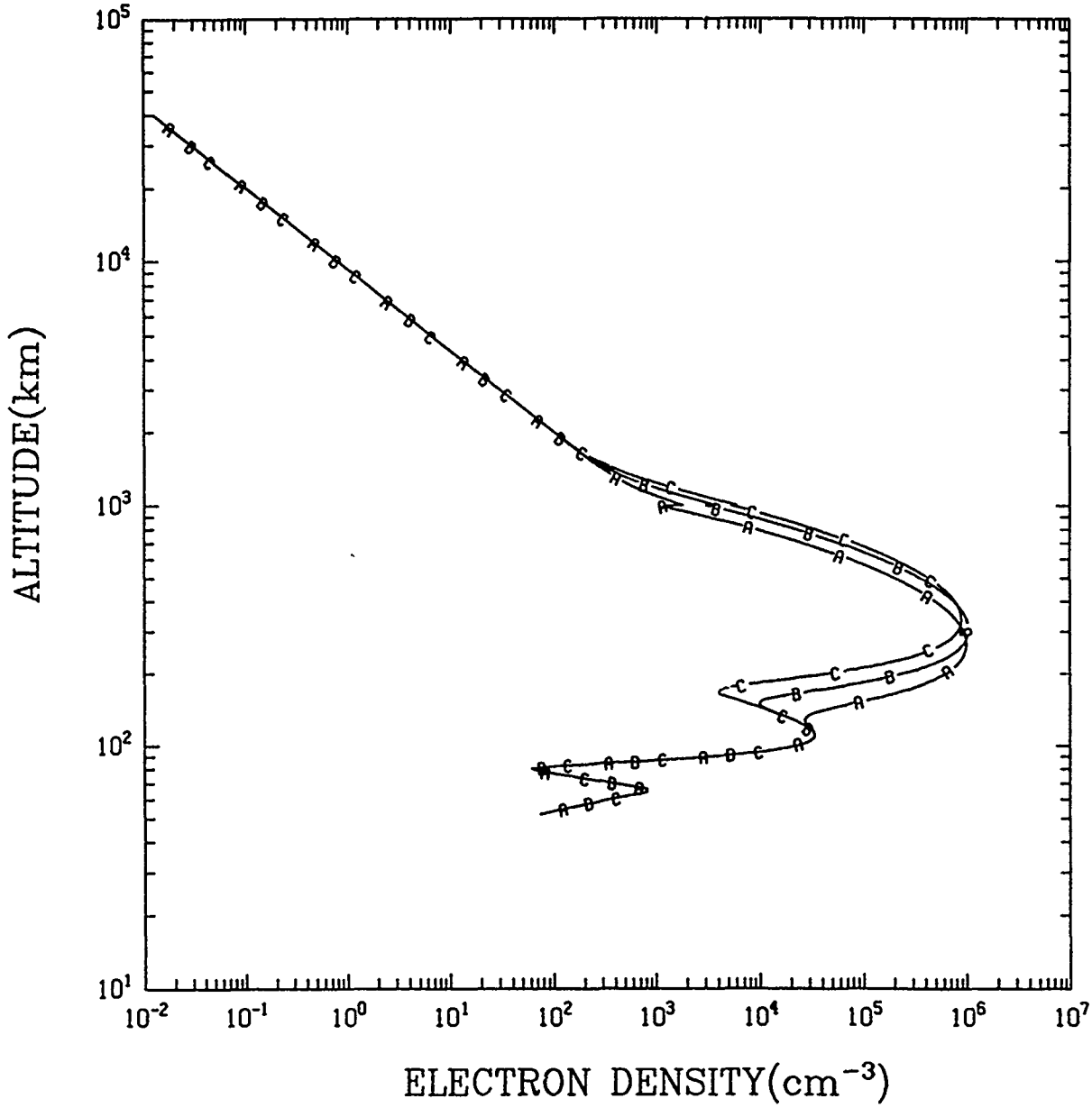

Fig. 1 Plot of electron density in cm^{-3} vs. altitude in km for three different geomagnetic latitudes. Curve A . presents midlatitude (λ_m = 45°), curve B, auroral (λ_m = 60°) and curve C, polar (λ_m = 80°) in the northern hemisphere. Values for the other parameters are: t = 1, λ = 1.2, l_m = 3.1, ϕ = 3.14, p = 1.

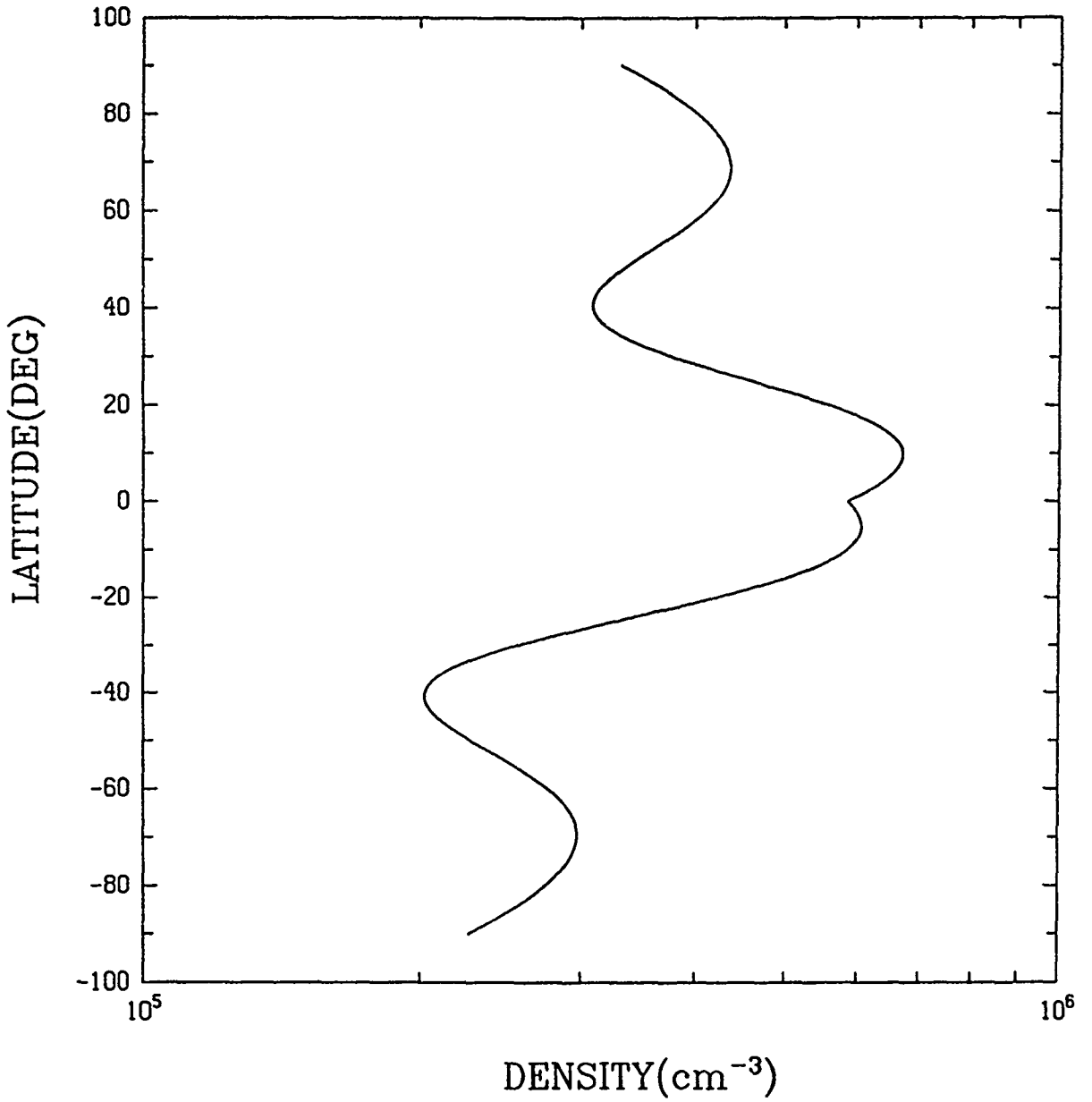

Fig. 2 Plot of electron density (cm^{-3}) vs. geomagnetic latitude at a fixed altitude (z = 300 km) using the same parameters as in Fig. 1.

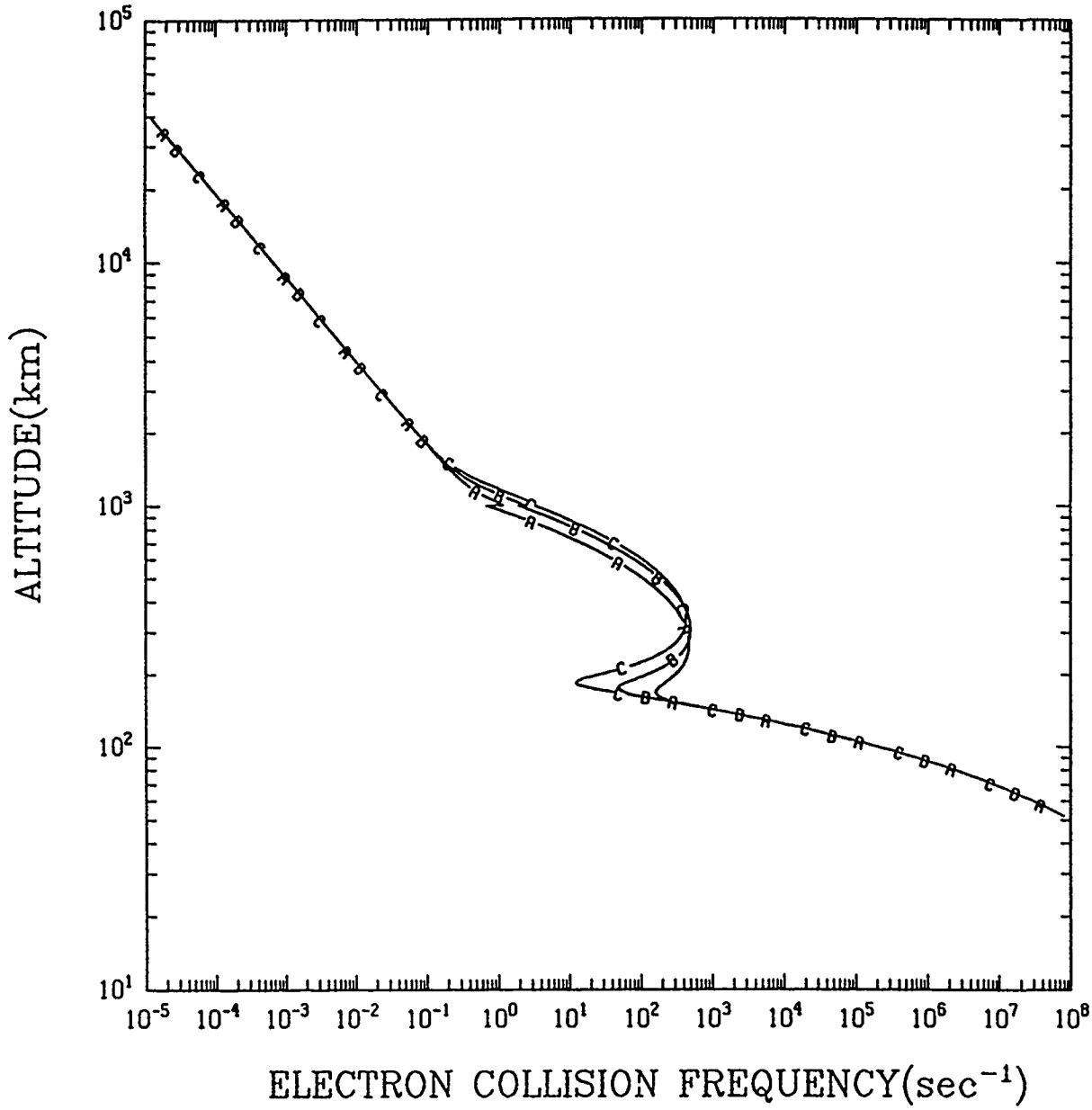

Fig. 3 Plot of electron collision frequency (sec^{-1}) vs. altitude (km) at the same geomagnetic latitudes as shown in Fig. 1.

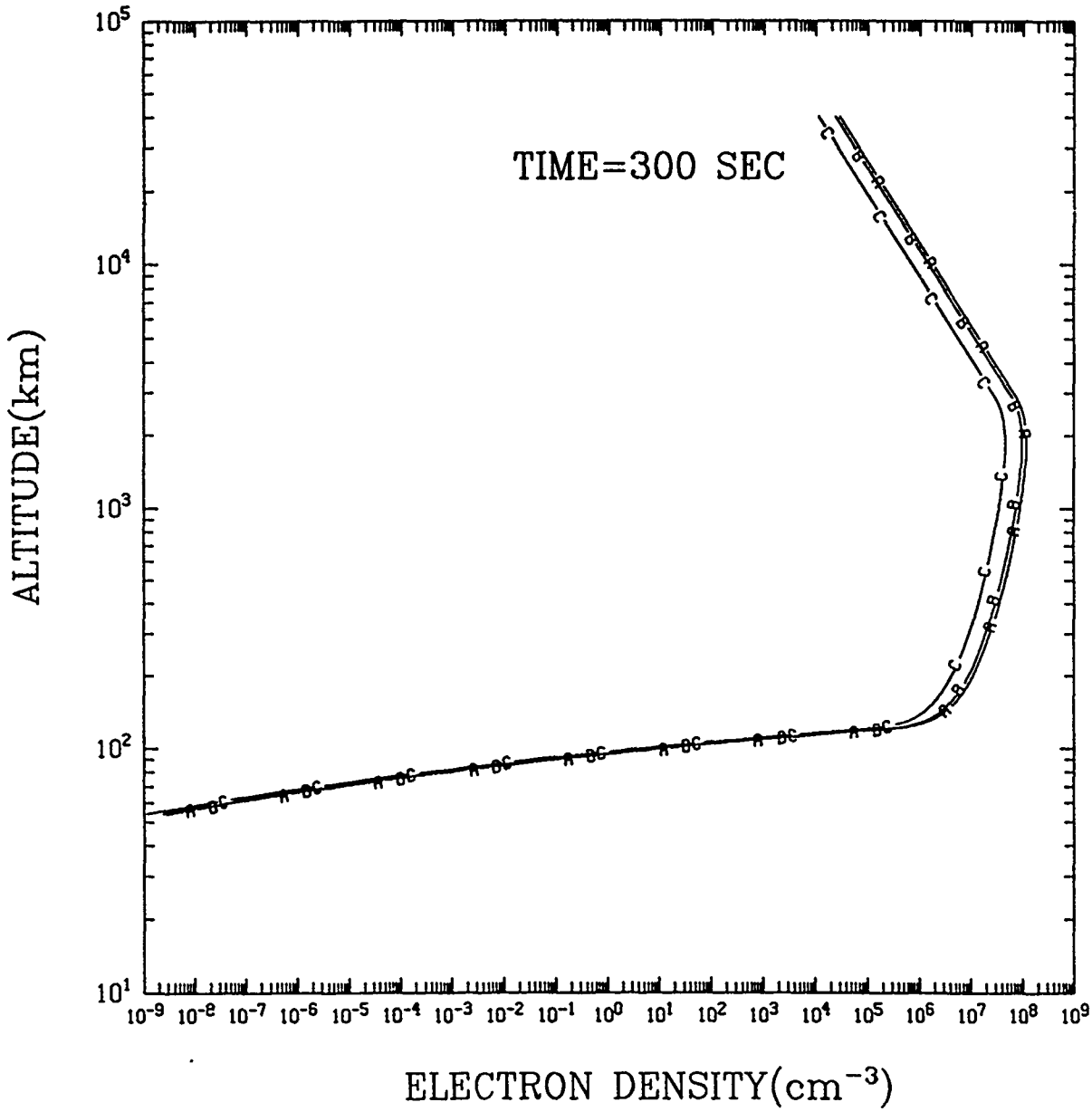

Fig. 4 Plot of electron density (cm^{-3}) vs. altitude (km) for a typical nuclear disturbed ionosphere at t = 300 sec following burst using the parameters from Hain et al. [1985]. Curve A is computed at 20 km from the burst magnetic field line in a direction perpendicular to the magnetic field. Curve B is computed at 50 km while curve C is at 100 km.

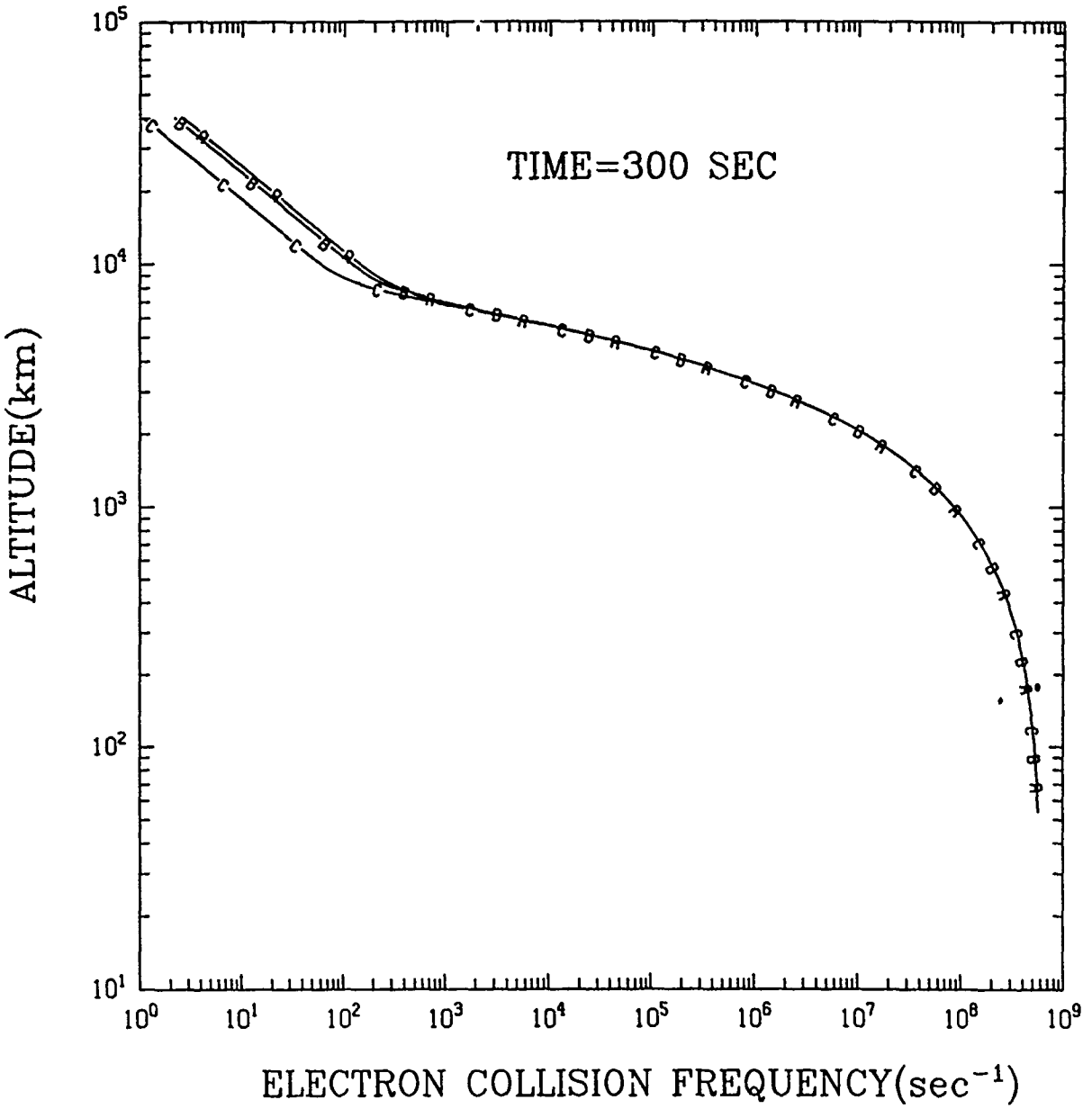

Fig. 5 Plot of electron collision frequency (sec^{-1}) vs. altitude (km) using the same notation as in Fig. 4.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

ASSISTANT SECRETARY OF DEFENSE
COMM, CMD, CONT 7 INTELL
WASHINGTON, DC 20301

DIRECTOR
COMMAND CONTROL TECHNICAL CENTER
PENTAGON RM BE 685
WASHINGTON, DC 20301
01CY ATTN C-650
01CY ATTN C-312 R. MASON

DIRECTOR
DEFENSE ADVANCED RSCH PROJ AGENCY
ARCHITECT BUILDING
1400 WILSON BLVD.
ARLINGTON, VA 22209
01CY ATTN NUCLEAR MONITORING RESEARCH
01CY ATTN STRATEGIC TECH OFFICE

DEFENSE COMMUNICATION ENGINEER CENTER
1860 WIEHLE AVENUE
RESTON, VA 22090
01CY ATTN CODE R410
01CY ATTN CODE R812

DIRECTOR
DEFENSE NUCLEAR AGENCY
WASHINGTON, DC 20305
01CY ATTN STVL
04CY ATTN TITL
01CY ATTN DDST
03CY ATTN RAAE

COMMANDER
FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRTLAND, AFB, NM 87115
01CY ATTN FCPR

DEFENSE NUCLEAR AGENCY
SAO/DNA
BUILDING 20676
KIRTLAND AFB, NM 87115
01CY D.C. THORNBURG

DIRECTOR
INTERSERVICE NUCLEAR WEAPONS SCHOOL
KIRTLAND AFB, NM 87115
01CY ATTN DOCUMENT CONTROL

JOINT PROGRAM MANAGEMENT OFFICE
WASHINGTON, DC 20330
01CY ATTN J-3 WWMCCS EVALUATION OFFICE

DIRECTOR
JOINT STRAT TGT PLANNING STAFF
OFFUTT AFB
OMAHA, NB 68113
01CY ATTN JSTPS/JLKS
01CY ATTN JPST G. GOETZ

CHIEF
LIVERMORE DIVISION FLD COMMAND DNA
DEPARTMENT OF DEFENSE
LAWRENCE LIVERMORE LABORATORY
P.O. BOX 808
LIVERMORE, CA 94550
01CY ATTN FCPRL

COMMANDANT
NATO SCHOOL (SHAPE)
APO NEW YORK 09172
01CY ATTN U.S. DOCUMENTS OFFICER

UNDER SECY OF DEF FOR RSCH & ENGRG
DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301
01CY ATTN STRATEGIC & SPACE SYSTEMS (OS)

COMMANDER/DIRECTOR
ATMOSPHERIC SCIENCES LABORATORY
U.S. ARMY ELECTRONICS COMMAND
WHITE SANDS MISSILE RANGE, NM 88002
01CY ATTN DELAS-EO, F. NILES

DIRECTOR
BMD ADVANCED TECH CTR
HUNTSVILLE OFFICE
P.O. BOX 1500
HUNTSVILLE, AL 35807
01CY ATTN ATC-T MELVIN T. CAPPS
01CY ATTN ATC-O W. DAVIES
01CY ATTN ATC-R DON RUSS

PROGRAM MANAGER
BMD PROGRAM OFFICE
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333
01CY ATTN DACS-BMT J. SHEA

COMMANDER
U.S. ARMY COMM-ELEC ENGRG INSTAL AGY
FT. HUACHUCA, AZ 85613
01CY ATTN CCC-EMEO GEORGE LANE

COMMANDER
U.S. ARMY FOREIGN SCIENCE & TECH CTR
220 7TH STREET, NE
CHARLOTTESVILLE, VA 22901
01CY ATTN DRXST-SD

COMMANDER
U.S. ARMY MATERIAL DEV & READINESS CMD
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333
01CY ATTN DRCLDC J.A. BENDER

COMMANDER
U.S. ARMY NUCLEAR AND CHEMICAL AGENCY
7500 BACKLICK ROAD
BLDG 2073
SPRINGFIELD, VA 22150
01CY ATTN LIBRARY

DIRECTOR
U.S. ARMY BALLISTIC RESEARCH
LABORATORY
ABERDEEN PROVING GROUND, MD 21005
01CY ATTN TECH LIBRARY,
EDWARD BAICY

COMMANDER
U.S. ARMY SATCOM AGENCY
FT. MONMOUTH, NJ 07703
01CY ATTN DOCUMENT CONTROL

COMMANDER
U.S. ARMY MISSILE INTELLIGENCE AGENCY
REDSTONE ARSENAL, AL 35809
01CY ATTN JIM GAMBLE

DIRECTOR
U.S. ARMY TRADOC SYSTEMS ANALYSIS
ACTIVITY
WHITE SANDS MISSILE RANGE, NM 88002
01CY ATTN ATAA-SA
01CY ATTN TCC/F. PAYAN JR.
01CY ATTN ATTA-TAC LTC J. HESSE

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
WASHINGTON, DC 20360
01CY ATTN NAVALEX 034 T. HUGHES
01CY ATTN PME 117
01CY ATTN PME 117-T
01CY ATTN CODE 5011

COMMANDING OFFICER
NAVAL INTELLIGENCE SUPPORT CTR
4301 SUITLAND ROAD, BLDG. 5
WASHINGTON, DC 20390
01CY ATTN MR. DUBBIN STIC 12
01CY ATTN NISC-50
01CY ATTN CODE 5404 J. GALET

COMMANDER
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152
01CY ATTN J. FERGUSON

NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375
01CY ATTN CODE 4700 S.L. Ossako
26 CYS IF UNCLASS
(01CY IF CLASS)
ATTN CODE 4780 J.D. HUBA,
CYS IF UNCLASS, 01CY IF CL
01CY ATTN CODE 4701 I. VITKOVIT
01CY ATTN CODE 7500
01CY ATTN CODE 7550
01CY ATTN CODE 7580
01CY ATTN CODE 7551
01CY ATTN CODE 7555
01CY ATTN CODE 4730 E. MCLEAN
01CY ATTN CODE 4752
01CY ATTN CODE 4730 B. RIPIN
22CY ATTN CODE 2628
01CY ATTN CODE 1004 (P. MANGE)
02CY ATTN CODE 8344 (M. KAPLAN)

COMMANDER
NAVAL SPACE SURVEILLANCE SYSTEM
DAHLGREN, VA 22448
01CY ATTN CAPT J.H. BURTON

OFFICER-IN-CHARGE
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD 20910
01CY ATTN CODE F31

DIRECTOR
STRATEGIC SYSTEMS PROJECT OFFICE
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20376
01CY ATTN NSP-2141
01CY ATTN NSSP-2722 FRED WIMBERLY

COMMANDER
NAVAL SURFACE WEAPONS CENTER
DAHLGREN LABORATORY
DAHLGREN, VA 22448
01CY ATTN CODE DF-14 R. BUTLER

OFFICER OF NAVAL RESEARCH
ARLINGTON, VA 22217
01CY ATTN CODE 465
01CY ATTN CODE 461
01CY ATTN CODE 402
01CY ATTN CODE 420
01CY ATTN CODE 421

COMMANDER
AEROSPACE DEFENSE COMMAND/XPD
DEPARTMENT OF THE AIR FORCE
ENT AFB, CO 80912
01CY ATTN XPDQQ
01CY ATTN XP

AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731
01CY ATTN OPR HAROLD GARDNER
01CY ATTN LKB
KENNETH S.W. CHAMPION
01CY ATTN OPR ALVA T. STAIR
01CY ATTN PHD JURGEN BUCHAU
01CY ATTN PHD JOHN P. MULLEN

AF WEAPONS LABORATORY
KIRTLAND AFT, NM 87117
01CY ATTN SUL
01CY ATTN CA ARTHUR H. GUENTHER

AFTAC
PATRICK AFB, FL 32925
01CY ATTN TN

WRIGHT AERONAUTICAL LABORATORIES
WRIGHT-PATTERSON AFB, OH 45433-6543
01CY ATTN AAAI WADE HUNT
01CY ATTN AAAI ALLEN JOHNSON

DEPUTY CHIEF OF STAFF
RESEARCH, DEVELOPMENT, & ACQ
DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC 20330
01CY ATTN AFRDQ

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION
DEPARTMENT OF THE AIR FORCE
HANSCOM AFB, MA 01731-5000
01CY ATTN J. DEAS
ESD/SCD-4

COMMANDER
FOREIGN TECHNOLOGY DIVISION, AFSC
WRIGHT-PATTERSON AFB, OH 45433
01CY ATTN NICD LIBRARY
01CY ATTN ETDP B. BALLARD

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
GRIFFISS AFB, NY 13441
01CY ATTN DOC LIBRARY/TSLD
01CY ATTN OCSE V. COYNE

STRATEGIC AIR COMMAND XPFS
OFFUTT AFB, NB 68113
01CY ATTN XPFS

SAMSO/MN
NORTON AFB, CA 92409
(MINUTEMAN)
01CY ATTN MNNL

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
HANSCOM AFB, MA 01731
01CY ATTN EEP A. LORENTZEN

DEPARTMENT OF ENERGY
LIBRARY ROOM G-042
WASHINGTON, DC 20545
01CY ATTN DOC CON FOR A. LABOWITZ

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
P.O. BOX 5400
ALBUQUERQUE, NM 87115
01CY ATTN DOC CON FOR D. SHERWOOI

EG&G, INC.
LOS ALAMOS DIVISION
P.O. BOX 809
LOS ALAMOS, NM 85544
01CY ATTN DOC CON FOR J. BREEDLOVE

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
P.O. BOX 808
LIVERMORE, CA 94550
01CY ATTN DOC CON FOR TECH INFO DEPT
01CY ATTN DOC CON FOR L-389 R. OTT
01CY ATTN DOC CON FOR L-31 R. HAGER

LOS ALAMOS NATIONAL LABORATORY
P.O. BOX 1663
LOS ALAMOS, NM 87545
01CY ATTN DOC CON FOR J. WOLCOTT
01CY ATTN DOC CON FOR R.F. TASCHEK
01CY ATTN DOC CON FOR E. JONES
01CY ATTN DOC CON FOR J. MALIK
01CY ATTN DOC CON FOR R. JEFFRIES
01CY ATTN DOC CON FOR J. ZINN
01CY ATTN DOC CON FOR D. WESTERVELT
01CY ATTN D. SAPPENFIELD

LOS ALAMOS NATIONAL LABORATORY
MS D438
LOS ALAMOS, NM 87545
01CY ATTN S.P. GARY
01CY ATTN J. BOROVSKY

SANDIA LABORATORIES
P.O. BOX 5800
ALBUQUERQUE, NM 87115
01CY ATTN DOC CON FOR W. BROWN
01CY ATTN DOC CON FOR A. THORNBROUGH
01CY ATTN DOC CON FOR T. WRIGHT
01CY ATTN DOC CON FOR D. DAHLGREN
01CY ATTN DOC CON FOR 3141
01CY ATTN DOC CON FOR SPACE PROJECT DIV

SANDIA LABORATORIES
LIVERMORE LABORATORY
P.O. BOX 969
LIVERMORE, CA 94550
01CY ATTN DOC CON FOR B. MURPHEY
01CY ATTN DOC CON FOR T. COOK

OFFICE OF MILITARY APPLICATION
DEPARTMENT OF ENERGY
WASHINGTON, DC 20545
01CY ATTN DOC CON DR. YO SONG

NATIONAL OCEANIC & ATMOSPHERIC ADMIN
ENVIRONMENTAL RESEARCH LABORATORIES
DEPARTMENT OF COMMERCE
BOULDER, CO 80302
01CY ATTN R. GRUBB

DEPARTMENT OF DEFENSE CONTRACTORS

AEROSPACE CORPORATION
P.O. BOX 92957
LOS ANGELES, CA 90009
01CY ATTN I. GARFUNKEL
01CY ATTN T. SALMI
01CY ATTN V. JOSEPHSON
01CY ATTN S. BOWER
01CY ATTN D. OLSEN

ANALYTICAL SYSTEMS ENGINEERING CORP
5 OLD CONCORD ROAD
BURLINGTON, MA 01803
01CY ATTN RADIO SCIENCES

AUSTIN RESEARCH ASSOC., INC.
1901 RUTLAND DRIVE
AUSTIN, TX 78758
01CY ATTN L. SLOAN
01CY ATTN R. THOMPSON

BERKELEY RESEARCH ASSOCIATES, INC.
P.O. BOX 983
BERKELEY, CA 94701
01CY ATTN J. WORKMAN
01CY ATTN C. PRETTIE
01CY ATTN S. BRECHT

BOEING COMPANY, THE
P.O. BOX 3707
SEATTLE, WA 98124
01CY ATTN G. KEISTER
01CY ATTN D. MURRAY
01CY ATTN G. HALL
01CY ATTN J. KENNEY

CHARLES STARK DRAPER LABORATORY, INC
555 TECHNOLOGY SQUARE
CAMBRIDGE, MA 02139
01CY ATTN D.B. COX
01CY ATTN J.P. GILMORE

COMSAT LABORATORIES
22300 COMSAT DRIVE
CLARKSBURG, MD 20871
01CY ATTN G. HYDE

CORNELL UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING
ITHACA, NY 14850
01CY ATTN D.T. FARLEY, JR.

ELECTROSPACE SYSTEMS, INC.
BOX 1359
RICHARDSON, TX 75080
01CY ATTN H. LOGSTON
01CY ATTN SECURITY (PAUL PHILLIPS)

EOS TECHNOLOGIES, INC.
606 Wilshire Blvd.
Santa Monica, CA 90401
01CY ATTN C.B. GABBARD
01CY ATTN R. LELEVIER

GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
FAIRBANKS, AK 99701
(ALL CLASS ATTN: SECURITY OFFICER)
01CY ATTN T.N. DAVIS (UNCLASS ONLY)
01CY ATTN NEAL BROWN (UNCLASS ONLY)

GTE SYLVANIA, INC.
ELECTRONICS SYSTEMS GRP-EASTERN DIV
77 A STREET
NEEDHAM, MA 02194
01CY ATTN DICK STEINHOF

HSS, INC.
2 ALFRED CIRCLE
BEDFORD, MA 01730
01CY ATTN DONALD HANSEN

ILLINOIS, UNIVERSITY OF
107 COBLE HALL
150 DAVENPORT HOUSE
CHAMPAIGN, IL 61820
(ALL CORRES ATTN DAN MCCLELLAND)
01CY ATTN K. YEH

INSTITUTE FOR DEFENSE ANALYSES
1801 NO. BEAUREGARD STREET
ALEXANDRIA, VA 22311
01CY ATTN J.M. AEIN
01CY ATTN ERNEST BAUER
01CY ATTN HANS WOLFARD
01CY ATTN JOEL BENGSTON

INTL TEL & TELEGRAPH CORPORATION
500 WASHINGTON AVENUE
NUTLEY, NJ 07110
01CY ATTN TECHNICAL LIBRARY

JAYCOR
11011 TORREYANA ROAD
P.O. BOX 85154
SAN DIEGO, CA 92138
01CY ATTN J.L. SPERLING

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
01CY ATTN DOCUMENT LIBRARIAN
01CY ATTN THOMAS POTEMRA
01CY ATTN JOHN DASSOULAS

KAMAN SCIENCES CORP
P.O. BOX 7463
COLORADO SPRINGS, CO 80933
01CY ATTN T. MEAGHER

KAMAN TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET (P.O DRAWER QQ)
SANTA BARBARA, CA 93102
01CY ATTN DASIAC
01CY ATTN WARREN S. KNAPP
01CY ATTN WILLIAM MCNAMARA
01CY ATTN B. GAMBILL

LINKABIT CORP
10453 ROSELLE
SAN DIEGO, CA 92121
01CY ATTN IRWIN JACOBS

LOCKHEED MISSILES & SPACE CO., INC
P.O. BOX 504
SUNNYVALE, CA 94088
01CY ATTN DEPT 60-12
01CY ATTN D.R. CHURCHILL

LOCKHEED MISSILES & SPACE CO., INC.
3251 HANOVER STREET
PALO ALTO, CA 94304
01CY ATTN MARTIN WALT DEPT 52-12
01CY ATTN W.L. IMHOF DEPT 52-12
01CY ATTN RICHARD G. JOHNSON DEPT 52-12
01CY ATTN J.B. CLADIS DEPT 52-12

MARTIN MARIETTA CORP
ORLANDO DIVISION
P.O. BOX 5837
ORLANDO, FL 32805
01CY ATTN R. HEFFNER

MCDONNEL DOUGLAS CORPORATION
5301 BOLSA AVENUE
HUNTINGTON BEACH, CA 92647
01CY ATTN N. HARRIS
01CY ATTN J. MOULE
01CY ATTN GEORGE MROZ
01CY ATTN W. OLSON
01CY ATTN R.W. HALPRIN
01CY ATTN TECHNICAL LIBRARY SERVICES

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
01CY ATTN P. FISCHER
01CY ATTN W.F. CREVIER
01CY ATTN STEVEN L. GUTSCHE
01CY ATTN R. BOGUSCH
01CY ATTN R. HENDRICK
01CY ATTN RALPH KILB
01CY ATTN DAVE SOWLE
01CY ATTN F. FAJEN
01CY ATTN M. SCHEIBE
01CY ATTN CONRAD L. LONGMIRE
01CY ATTN B. WHITE
01CY ATTN R. STAGAT
01CY ATTN D. KNEPP
01CY ATTN C. RINO

MISSION RESEARCH CORP.
1720 RANDOLPH ROAD, S.E.
ALBUQUERQUE, NM 87106
01CY R. STELLINGWERF
01CY M. ALME
01CY L. WRIGHT

MITRE CORP
WESTGATE RESEARCH PARK
1820 DOLLY MADISON BLVD
MCLEAN, VA 22101
01CY ATTN W. HALL
01CY ATTN W. FOSTER

PACIFIC-SIERRA RESEARCH CORP
12340 SANTA MONICA BLVD.
LOS ANGELES, CA 90025
01CY ATTN E.C. FIELD, JR.

PENNSYLVANIA STATE UNIVERSITY
IONOSPHERE RESEARCH LAB
318 ELECTRICAL ENGINEERING EAST
UNIVERSITY PARK, PA 16802
(NO CLASS TO THIS ADDRESS)
01CY ATTN IONOSPHERIC RESEARCH LA

PHOTOMETRICS, INC.
4 ARROW DRIVE
WOBURN, MA 01801
01CY ATTN IRVING L. KOFSKY

PHYSICAL DYNAMICS, INC.
P.O. BOX 3027
BELLEVUE, WA 98009
01CY ATTN E.J. FREMOUW

PHYSICAL DYNAMICS, INC.
P.O. BOX 10367
OAKLAND, CA 94610
ATTN A. THOMSON

R & D ASSOCIATES
P.O. BOX 9695
MARINA DEL REY, CA 90291
01CY ATTN FORREST GILMORE
01CY ATTN WILLIAM B. WRIGHT, JR.
01CY ATTN WILLIAM J. KARZAS
01CY ATTN H. ORY
01CY ATTN C. MACDONALD
01CY ATTN BRIAN LAMB
01CY ATTN MORGAN GROVER

RAYTHEON CO.
528 BOSTON POST ROAD
SUDBURY, MA 01776
01CY ATTN BARBARA ADAMS

RIVERSIDE RESEARCH INSTITUTE
330 WEST 42nd STREET
NEW YORK, NY 10036
01CY ATTN VINCE TRAPANI

SCIENCE APPLICATIONS
INTERNATIONAL INCORPORATED
1150 PROSPECT PLAZA
LA JOLLA, CA 92037
01CY ATTN LEWIS M. LINSON
01CY ATTN DANIEL A. HAMLIN
01CY ATTN E. FRIEMAN
01CY ATTN E.A. STRAKER
01CY ATTN CURTIS A. SMITH

SCIENCE APPLICATIONS
INTERNATIONAL CORPORATION
1710 GOODRIDGE DR.
MCLEAN, VA 22102
01CY J. COCKAYNE
01CY E. HYMAN

SRI INTERNATIONAL
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025
01CY ATTN J. CASPER
01CY ATTN DONALD NEILSON
01CY ATTN ALAN BURNS
01CY ATTN G. SMITH
01CY ATTN R. TSUNODA
01CY ATTN DAVID A. JOHNSON
01CY ATTN WALTER G. CHESNUT
01CY ATTN CHARLES L. RINO
01CY ATTN WALTER JAYE
01CY ATTN J. VICKREY
01CY ATTN RAY L. LEADABRAND
01CY ATTN G. CARPENTER
01CY ATTN G. PRICE
01CY ATTN R. LIVINGSTON
01CY ATTN V. GONZALES
01CY ATTN D. MCDANIEL

TECHNOLOGY INTERNATIONAL CORP
75 WIGGINS AVENUE
BEDFORD, MA 01730
01CY ATTN W.P. BOQUIST

TRW DEFENSE & SPACE SYS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
01CY ATTN R. K. PLEBUCH
01CY ATTN S. ALTSCHULER
01CY ATTN D. DEE
01CY ATTN D/ STOCKWELL
SNTF/1575

VISIDYNE
SOUTH BEDFORD STREET
BURLINGTON, MA 01803
01CY ATTN W. REIDY
01CY ATTN J. CARPENTER
01CY ATTN C. HUMPHREY

UNIVERSITY OF PITTSBURGH
PITTSBURGH, PA 15213
01CY ATTN: N. ZABUSKY

Director of Research
U.S. Naval Academy
Annapolis, MD 21402
2 Copies

Code 1220 1Copy