AD-A070 545 NAVAL RESEARCH LAB WASHINGTON DC F/G 20/9
DIRECT SOLUTION OF THE EQUATION OF TRANSFER USING FREQUENCY-AND--ETC(U)
JUN 79 J P APRUZESE, J DAVIS

UNCLASSIFIED NRL-MR-4017 NL

1 OF 1
AD
A070545

END
8-79
DDC

NRL Memorandum Report 4017

12

Direct Solution of the Equation of Transfer Using Frequency- and Angle-Averaged Photon Escape Probabilities

J. P. APRUZESE

Science Applications Inc.
McLean, VA 22102

AND

J. DAVIS

Plasma Radiation Group
Plasma Physics Division

June 21, 1979

This research was sponsored by the Defense Nuclear Agency under subtask T99QAXLA014 and subtask title Pulsed Power Advanced Simulation Concepts; work unit code 52 and work unit title Intermediate Baccarat.

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 4017	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ⑥ DIRECT SOLUTION OF THE EQUATION OF TRANSFER USING FREQUENCY- AND ANGLE-AVERAGED PHOTON ESCAPE PROBABILITIES,		5. TYPE OF REPORT & PERIOD COVERED ⑨ Interim report on a continuing ~~NRL problem.~~
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) ⑩ J.P. Apruzese, ~~SAI and~~ J. Davis, ~~NRL~~ 62704H		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem H02-26L DNA Subtask T99QAXLA014
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Nuclear Agency Washington, D.C. 20305 ⑪ 21 Jun 79		12. REPORT DATE June 21, 1979
		13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) ⑭ NRL-MR-4017		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

⑫ 23p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

⑯ T99QAXL ⑰ A014

18. SUPPLEMENTARY NOTES

This research was sponsored by the Defense Nuclear Agency under subtask T99QAXLA014 and subtask title Pulsed Power Advanced Simulation Concepts; work unit code 52 and work unit title Intermediate Baccarat.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Absorption
Emission
Radiative transport
Escape probabilities

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

A formalism is developed which permits direct steady-state solution of the transfer equation using escape probabilities averaged over angle and frequency. A matrix of probability-based coupling coefficients, which are related to the kernel function $K_1^{\frown}$ is used to obtain the source function for a doppler profile in plane-parallel geometry. Comparison is made with exact solutions, establishing the high accuracy of the technique. The method is extendable to different physical situations by simply modifying the coupling coefficients.

251 950

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

i

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

DIRECT SOLUTION OF THE EQUATION OF TRANSFER USING FREQUENCY- AND ANGLE-AVERAGED PHOTON ESCAPE PROBABILITIES

I. Introduction

In the literature of radiative transfer theory, much attention has been devoted to photon escape-probability concepts as a means of aiding in the interpretation of detailed solutions to the transfer equation in astrophysical and laboratory contexts. In this paper we develop a formalism which permits utilization of such concepts to obtain direct solutions of the steady-state source function. When applied to a plane-parallel, doppler-broadened medium, the technique eliminates entirely the need for either frequency or angle integration, while yielding generally excellent agreement with previous results obtained by Avrett and Hummer.(1)

II. Multicell Radiative Coupling Equations

If a medium which is finite in extent in at least one direction is divided into a number N of smaller regions line photons emitted in each region will have a finite probability of being absorbed in any of the other N-1 regions, as well as being re-absorbed in the local region or escaping entirely from the medium. Let C_{ij} be the probability that a line photon emitted in geometrical region i traverses the distance between regions i and j and is absorbed in region j. N_{ui} will refer to the total upper level population of region i, and $A_{u\ell}$ stands for the spontaneous transition probability ($\sec^{-1}$) for the line in question. In each region i, W_1 and D_i will stand for the total collisional population and depopulation rates, respectively, of the upper level (N_{ui}). The above concepts and notation clearly imply the following equation for the rate of change of the line upper level population in region i.

Note: Manuscript submitted March 19, 1979.

$$\frac{dN_{ui}}{dt} = N_{ei} W_i + \sum_{j=1}^{N} N_{uj} A_{u\ell} C_{ji} - N_{ui} (A_{u\ell} + D_i) \qquad (1)$$

The first two terms on the right-hand-side account for local collisional population of the upper level, and radiative population of the level by photons emitted from all the cells j into cell i, respectively. The final term is the sum of spontaneous and collisional depopulation of the upper level. In this paper we will confine outselves to the case where $dN_{ui}/dt = 0$, that is, utilization of equation (1) to obtain the steady state upper level population in each region, which is equivalent to finding the source function when the lower level population is known. For a large class of problems, such as those treated by Avrett and Hummer(1), the ground state (lower level) population is much larger than that of the upper level and the absorption coefficient is known with high accuracy. In these cases, the steady-state version of equation (1) requires for its solution the inversion of one NxN matrix - to solve N linear equations in N unknowns - once the C_{ji} are calculated from the absorption coefficients. When the absorption coefficient is not known a priori, the appropriate version of equation (1) must be set up for each level considered and populations for each level must be obtained iteratively using the C_{ji} calculated from the populations (hence, absorption coefficients), of the previous iteration.

Aside from the atomic constants, calculation of the C_{ji} from the absorption coefficients to enable solution of equation (1) forms the heart of the mathematical problem, and is now detailed.

III. Calculation of the Coupling Constants

For the case of plane-parallel geometry and doppler profile with a spatially constant doppler width, it has proven possible to develop very fast and extremely accurate algorithms for obtaining the C_{ji}, primarily because of the vast amount of effort by other workers which has been devoted to probability concepts for this case.

Consider a line photon emitted at a point in cell j, in the direction of cell i, in the medium. The probability P_{ji} that the photon is absorbed in cell i is given by

$$P_{ji} = \bar{P}_e(\tau_{ji}) - \bar{P}_e(\tau_{ji} + \Delta\tau_i) \tag{2}$$

where $\bar{P}_e(\tau)$ is the angle-averaged probability that a photon traverses an optical depth τ without being absorbed or scattered. In equation (2), τ_{ji} is the line-center optical depth from cell j to the boundary of cell i <u>closest</u> to cell j, and $\Delta\tau_i$ is the optical depth of cell i itself. The practicality of the method here described is obviously dependent upon having an efficient technique for obtaining the $\bar{P}_e$'s. Holstein(2) obtained an expression for the monodirectional escape probability P_e valid for completely redistributed doppler-profile line photons at large optical depths. We have numerically calculated the integral

$$\bar{P}_e(\tau_o) = \int_0^1 P_e\left(\frac{\tau_o}{\mu}\right) d\mu \tag{3}$$

for a large range of optical depths, and have adopted the following algorithm to obtain $\bar{P}_e$ quickly and accurately.

(a.) at $\tau_o \leq 3$ a cubic spline polynomial has been fitted to the exact result at 20 points roughly equally spaced from $\tau_o = 0$ to $\tau_o = 3$.

(b) for $\tau_o > 3$; the following analytic expression is accurate to 5 percent for $\tilde{\tau} < 3 \times 10^4$.

$$\overline{P_e} \; (\tau_o) = \frac{0.286}{\tau_o \sqrt{\ell n \; (1.95 \, \tau_o)}}$$

At this point it should be noted that in calculating the C_{ji} coupling cells of finite width, $\overline{P_e}$ must be averaged over the cell originating the photons. This is especially important when the originating and receiving cells are adjacent, since $\overline{P_e}$ can vary by an order of magnitude or more, in some cases, from the front to the back of the originating cell. This averaging process is easily accomplished by analytically integrating the above expressions across the originating cell j so that

$$C_{ji} = \frac{1}{2(\Delta\tau)_j} \left\{ \int_{\tau_{ji}}^{\tau_{ji} + \Delta\tau_j} \overline{P_e}(\tau) d\tau - \int_{\tau_{ji} + \Delta\tau_i}^{\tau_{ji} + (\Delta\tau)_i + (\Delta\tau)_j} \overline{P_e}(\tau) d\tau \right\} \qquad (4)$$

In equation (4), $(\Delta\tau)_j$ and $(\Delta\tau)_i$ are the line-center perpendicular optical depths of cells j and i and τ_{ji} is the optical depth between cells j and i, measured between the two closest boundaries. The factor of 1/2 in equation (4) accounts for the assumed equal probability of photon emission in either direction from cell j.

IV. Relation to the Exact Transfer Equation

Avrett and Hummer$^{(1)}$ have written the formal solution for the source function $S(\tau)$ in a plane-parallel atmosphere of optical depth T as

$$S(\tau) = (1-P_Q) \int_0^T K_1(|t-\tau|) \, S(t)dt + P_Q B \qquad (5)$$

where B is the Planck function for the local electron temperature, P_Q is the "quenching parameter", or probability per scattering that the photon is lost from the line, and K_1 is the kernel function. In reference 1, Avrett and Hummer developed a useful asymptotic expansion for the Doppler kernel function and showed that, for large τ (measured at line center)

$$K_1(\tau) \sim \frac{1}{4\pi\tau^2 \sqrt{\ln \tau}} \tag{6}$$

Inspection of equation (5) reveals that $K_1(\tau)$ is the analog of the discrete probability-based coupling coefficients which are used in the present treatment. $K_1(\tau)$ couples the regions of the medium together and, since the integral is carried out over τ, it is, in analogy with equations (1) and (2)

$$K_1(\tau_o) = -\frac{1}{2} \left. \frac{d\overline{P_e}}{d\tau} \right|_{\tau_o} \tag{7}$$

The rate of change of the angle-averaged escape probability $\overline{P_e}$ across optical path τ_o determines the efficiency with which photons are absorbed per unit optical depth after crossing the path τ_o.

The analytic expression

$$\overline{P_e}\,(\tau_o) = 0.286 \,/\, \tau_o \sqrt{\ln (1.95\tau_o)} \tag{8}$$

which we have used computationally in the calculations presented below should, when differentiated, approach closely equation (7) in the limit of large τ.

Differentiating equation 8 yields, as $\tau \to \infty$

$$-\frac{1}{2} \left. \frac{d\overline{P_e}}{d\tau} \right|_{\tau \to \infty} = \frac{1}{13.99\, \tau^2 \sqrt{\ln \tau}} \tag{9}$$

(τ measured at line center)

which differs by 11% from the exact expression (6.). Even though our expression is not as accurate at $\tau = \infty$ as at $\tau < 3 \times 10^{+4}$, no divergence occurs. For most cases of interest, nearly all of the coupling occurs within optical depths much smaller than 3×10^4, where equation (8) is accurate to better than 5%. Also, as seen below, errors of a few percent in the coupling matrix do not result in large source function errors when the method is applied to specific media of finite optical depth.

V. Calculations and Discussion

a) Numerical Results

To explore the computational viability of the approach detailed above, we have applied equation (1) to a range of plane-parallel media of varying optical depths and quenching parameters. The cases presented in figures 1 and 2 reflect comparisons of the presently discussed approach with exact solutions obtained by Avrett and Hummer$^{(1)}$. The physical interpretation of the solutions has been thoroughly discussed in reference 1 by Avrett and Hummer. Since the media are symmetric about the midplane, the calculation has been set up by establishing 25 or 75 cells in half the medium and coupling each cell "to itself" and to others across the symmetry plane as well as by direct photon coupling within the same half of the medium. In each case the cells are spaced logarithmically in optical depth ($\Delta\tau/\tau \sim$ constant) and the optical depths of the cells close to the boundary are less than unity to allow for the anticipated rapid change of the source function near the edge of the medium. We have also computed results for 50 cells per half-slab, which are not plotted for reasons of clarity.

To obtain solutions within a few percent of the exact values, only 25 cells need be used for optical depths of $\sim 10^2$, but 50-75 cells are necessary at $\tau \sim 10^4$. These considerations apply for both the effectively thick and the effectively thin cases. As is seen in figure 2, for $\tau = 2.8 \times 10^7$, the 25-cell calculation yields source functions a factor of 2.5 greater than the exact solution at small optical depths, but goes to the Planck function (B = 1) at the correct optical depth. The 75-cell model yields source functions about 25% too high in the nonthermalized "effectively thin" regions at this very high optical depth.

b) Applications and Discussion

The technique described above appears to hold considerable promise for computationally efficient modeling of laboratory plasmas. Detailed multi-angle, multi-frequency calculations have shown(3) that the ionization dynamics and energetics of high-temperature plasmas are significantly affected by the trapping of line and continuum radiation. Accurate simulation of such plasmas and computation of diagnostically useful line ratios requires that all optically thick lines be transported. The elimination of angle- and frequency-integrations inherent in this technique can lead to both accurate and rapid computation of detailed radiation transport in plasma simulations such as those described in reference 3. Extending the usefulness of the method will require attention to obtaining accurate coupling coefficients including the effects of continuum processes, Voigt profiles (whose width may vary temporally and spatially), and non-planar geometry. The numerical consequences of this additional physics will appear solely in the use of different coupling coefficients. Work on obtaining efficient algorithms for the calculation of such coefficients is proceeding, and will be reported in later papers. In addition, other transitions will be incorporated to study multi-level, multi-ionization-stage effects.

ACKNOWLEDGMENT

This work was supported in part by the Defense Nuclear Agency

REFERENCES

1. E. H. Avrett and D. G. Hummer, MNRAS 130, 295 (1965).

2. T. Holstein, Phys. Rev. 72, 1212 (1947).

3. J. Davis, K. G. Whitney, and J. P. Apruzese, JQSRT, 20, 353 (1978).

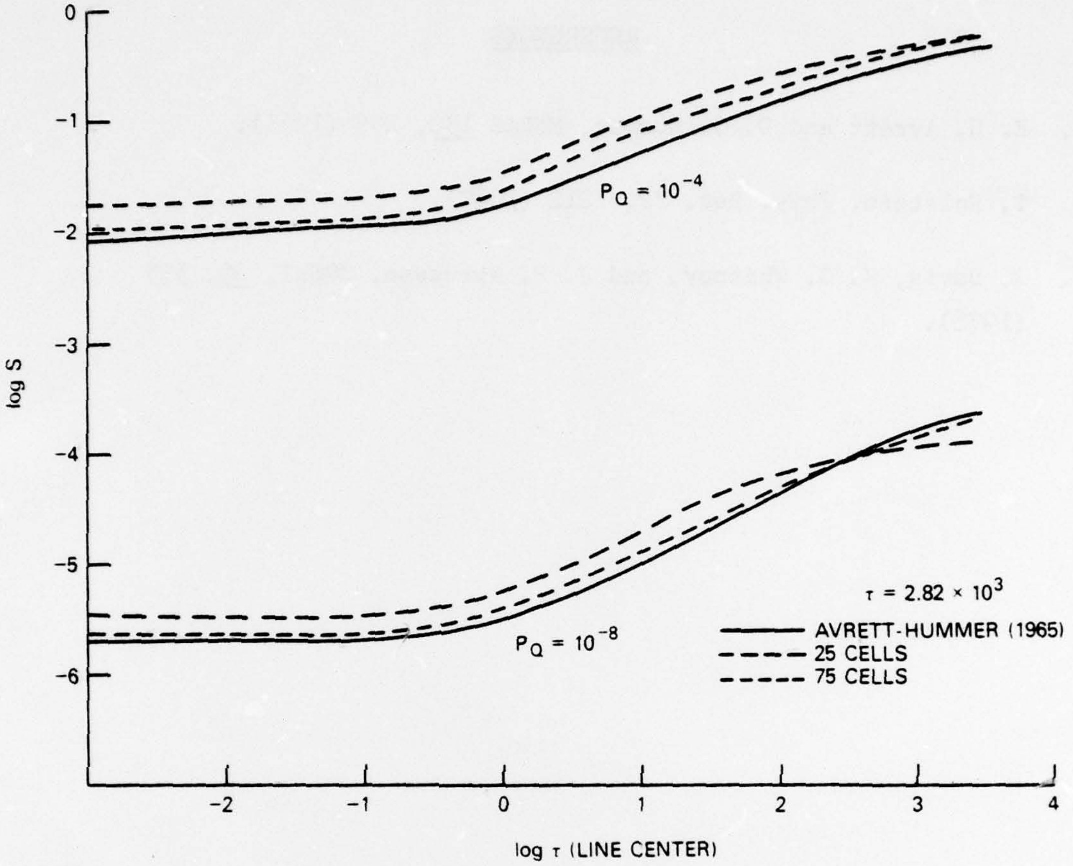

Fig. 1

The steady state source function for a doppler profile is shown for an optical depth of 2.82×10^3 and a Planck function $B = 1$. Results obtained from the present treatment are shown along with the exact solutions obtained by Avrett and Hummer in Ref. 1. The optical depth is measured from the center of the plane - parallel medium to the edge and at line center. Quenching parameters of 10^{-4} (effectively thick) and 10^{-8} (effectively thin) are assumed in the curves shown.

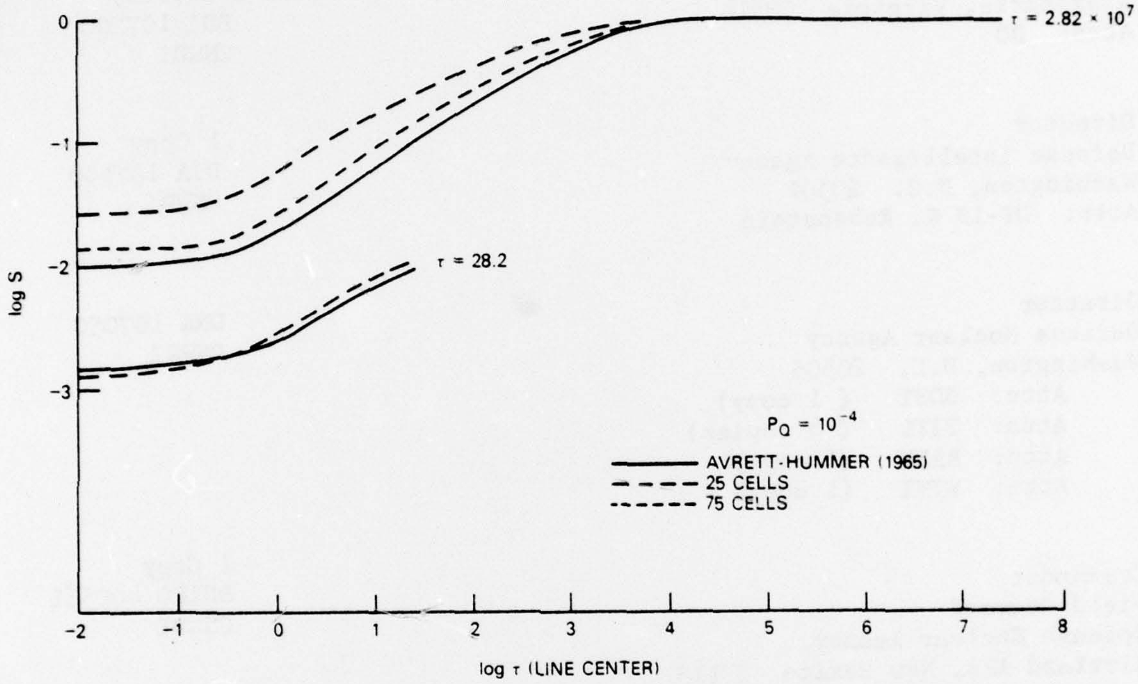

Fig. 2

Same as Figure 1, except that optical depths of 28.2 and 2.82×10^7 are shown, and only one quenching parameter, 10^{-4}, is considered.

DISTRIBUTION LIST

Assistant to the Secretary of Defense Atomic Energy Washington, D.C. 20301 Attn: Executive Assistant	1 Copy ATSDAE 600208 CNWDI
Defense Documentation Center Cameron Station Alexandria, Virginia 22314 Attn: DD	(12 copies if open publication, otherwise 2 copies) DDC 107200 CNWDI
Director Defense Intelligence Agency Washington, D.C. 20301 Attn: DT-1B R. Rubenstein	1 Copy DIA 107300 CNWDI
Director Defense Nuclear Agency Washington, D.C. 20305 Attn: DDST (1 copy) Attn: TITL (4 copies) Attn: RAEV (1 copy) Attn: STVI (1 copy)	DNA 107050 CNWDI
Commander Field Command Defense Nuclear Agency Kirtland AFB, New Mexico 87115 Attn: FCPR	1 Copy DNAFO 400361 CNWDI
Chief Field Command Livermore Division Department of Defense P. O. Box 808 Livermore, California 94550 Attn: FCPRL	1 Copy LIVDNA 600158 CNWDI
Director Joint Strat TGT Planning Staff Offutt AFB Omaha, Nebraska 68113 Attn: JSAS	1 Copy JSTPS 600189 CNWDI

Under Secretary of Defense
For RSCH and ENGRG
Department of Defense
Washington, D.C. 20301
Attn: Strategic and Space Systems (OS)

1 Copy
USDRE 266200
CNWDI

Deputy Chief of Staff for RSCH DEV and ACQ
Department of the Army
Washington, D.C. 20301
Attn: DAMA-CSS-N

1 Copy
DCSRDA 265950
CNWDI

Commander
Harry Diamond Laboratories
Department of the Army
2800 Powder Mill Road
Adelphi, Maryland 20783
(CNWDI-Inner Envelope: Attn: DELHD-RBH)
Attn: P. Caldwell
Attn: DELHD-N-NP
Attn: DELHD-N-RBA J. Rosado
Attn: DELHD-N-TI (Tech. Lib)

HDL 163050
CNWDI
(1 copy each)

Commander
Redstone Scientific Information Center
U.S. Army R and D Command
Redstone Arsenal, Alabama 35809
Attn: Chief, Documents

REDSCI 600593
3 copies

Commander
U.S. Army Missile R and D Command
Redstone Arsenal, Alabama 35809
Attn: DRCPM-PE-EA

1 copy
AMICOM 040050
CNWDI

Commander
U.S. Army Nuclear and Chemical Agency
7500 Backlick Road
Building 2073
Springfield, Virginia 22150
Attn: Library

USANA 600492
CNWDI
1 Copy

Commander
U.S. Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland 21005
Attn: DRSTE-EL

1 Copy
ATFCOM 041750
CNWDI

Commanding Officer Naval Intelligence Support Center 4301 Suitland Road, Bldg. 5 Washington, D.C. 20390 Attn: NISC-45	1 COPY NISC 252080
Commander Naval Weapons Center China Lake, California 93555 Attn: Code 233 (Tech. Lib.)	1 Copy NWC 403019 CNWDI
Office of the Chief of Naval Operations Washington, D.C. 20350 Attn: R. Blaise	1 Copy CNO 264850 CNWDI
Officer in Charge White Oak Laboratory Naval Surface Weapons Center Silver Spring, Maryland 20910 Attn: Code R40 (1 copy) Attn: Code F31 (1 copy)	NSWC 250650 CNWDI
Air Force Weapons Laboratory Kirtland AFB, New Mexico 87117 Attn: SUL Attn: CA Attn: DYC Attn: DT Attn: CA Attn: DYP (1 copy each)	AFWL 013150 CNWDI
Deputy Chief of Staff Research, Development and Accounting Department of the Air Force Washington, D.C. 20330 Attn: AFRDQSM	1 Copy USAFRD 611421
Space and Missile Systems Organization/DY Air Force Systems Command Post Office Box 92960 Worldway Postal Center Los Angeles, California 90009 Attn: DYS (Technology)	1 Copy SAMSO 611357 CNWDI

Space and Missile Systems Organization/IN
Air Force Systems Command
Post Office Box 92960
Worldway Postal Center
Los Angeles, California 90009
Attn: IND D. Muskin (Intelligence)

1 Copy
SAMSO 611392
CNWDI

Space and Missile Systems Organization/MN
Air Force Systems Command
Norton AFB, California 92409
Attn: MNNH (Minuteman)

1 Copy
NORTON 600190
CNWDI

Space and Missile Systems Organization/SK
Air Force Systems Command
Post Office Box 92960
Worldway Postal Center
Los Angeles, California 90009
Attn; SKF P. Stadler (Space Comm. Systems)

1 Copy
SAMSO 611397
CNWDI

AVCO Research and Systems Group
201 Lowell Street
Wilmington, Massachusetts 01887
Attn: Library A830

1 Copy
AVNIL 403996
Fac Clear T CNDWI
Stor Capability T

BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22101
Attn: Corporate Library)

1 Copy
BDMVA 404435
Fac Clear T CNWDI
Stor Capability T

Boeing Company
P. O. Box 3707
Seattle, Washington 98124
Attn: Aerospace Library

1 Copy
BOE 059600
Fac Clear T CNWDI
Stor Capability T

Dikewood Industries, Inc.
1009 Bradbury Drive, S.E.
Albuquerque, New Mexico 87106
Attn: L. Davis

1 Copy
DIKEWD 112850
Fac Clear T CNWDI
Stor Capability T

EG and G Washington Analytical Services Center, Inc.
P. O. Box 10218
Albuquerque, New Mexico 87114
Attn: Library

1 Copy
EGGALB 388316
Fac Clear T CNWDI
Stor Capability S

General Electric Company
Space Division
Valley Forge Space Center
P. O. Box 8555
Philadelphia, Pa. 19101
Attn: J. Peden

1 Copy
GESD 149070
Fac Clear T CNWDI
Stor Capability T

General Electric Company - Tempo
Center for Advanced Studies
816 State Street
P. O. Drawer QQ
Santa Barbara, California 93102
Attn: DASIAC

1 Copy
TEMPO 346420
Fac Clear T CNWDI
Stor Capability T

Institute for Defense Analyses
400 Army-Navy Drive
Arlington, Va. 22202
Attn: Classified Library

1 Copy
IDA 179350
Fac Clear T CNWDI
Stor Capability T

IRT Corporation
P.O. Box 81087
San Diego, California 92138
Attn: R. Mertz

1 Copy
IRT 601410
Fac Clear T CNWDI
Stor Capability T

JAYCOR
1401 Camino Del Mar
Del Mar, California 92014
Attn: E. Wenaas

1 Copy
JAYCA 611545
Fac Clear T CNWDI
Stor Capability S

JAYCOR
205 S Whiting Street, Suite 500
Alexandria, Virginia 22304
Attn: R. Sullivan

1 Copy
JAYVA 611580
Fac Clear T CNWDI
Stor Capability S

KAMAN Sciences Corp.
P. O. Box 7463
Colorado Springs, Colorado 80933
Attn: J. Hoffman
Attn: A. Bridges
Attn: D. Bryce
Attn: W. Ware
(1 copy each)

KN 195000
FAC Clear T CNWDI
Stor Capability T

Lawrence Livermore Laboratory
University of California
P. O. Box 808
Livermore, California 94550
Attn: DOC CDN for L-545 J. Nickolls
Attn: DOC CDN for L-153
Attn: DOC CDN for L-47 L. Wouters
Attn: DOC CDN for Technical Infor. Dept. Lib.

LLI 204150
CNWDI
(1 copy each)

Lockheed Missiles and Space Co., Inc.
P. O. Box 504
Sunnyvale, California 94086
Attn: S. Taimlty

LMSC 210120
Fac Clear T CNWDI
Stor Capability T

Lockheed Missiles and Space Co., Inc.
3251 Hanover Street
Palo Alto, California 94304
Attn: L. Chase

1 Copy
LMSCPA 210110
Fac Clear T CNWDI
Stor Capability T

Maxwell Laboratory, Inc.
9244 Balboa Avenue
San Diego, California 92123
Attn: A. Kolb
Attn: W. Clark

1 Copy each
MAXLAB 387218
Fac Clear T CNWDI
Stor Capability S

McDonnell Douglas Corp.
5301 Bolsa Avenue
Huntington Beach, California 92647
Attn: S. Schneider

1 Copy
MDCHB 404770
Fac Clear T CNWDI
Stor Capability T

Mission Research Corp. P.O. Drawer 719 Santa Barbara, California 93102 Attn: C. Longmire Attn: W. Hart	1 Copy each MRC 600289 Fac Clear T CNWDI Stor Capability S
Mission Research Corp.-San Diego P. O. Box 1209 La Jolla, California 92038 Attn: Victor J. Van Lint	1 Copy MRCVLN 400205 Fac Clear T CNWDI Stor Capability S
Northrop Corporation Northrop Research and Technology Center 1 Research Park Palos Verdes Peninsula, California 90274 Attn: Library	1 Copy NCPVP Fac Clear T CNWDI Stor Capability S
Northrop Corporation Electronic Division 2301 120th Street Hawthorne, California 90250 Attn: V. Damarting	1 Copy NOREL 600302 Fac Clear T CNWDI Stor Capability T
Physics International Company 2700 Merced Street San Leandro, California 94577 Attn: P. Spence Attn: C. Stallings Attn: B. Bernstein	1 Copy each PIC 282760 Fac Clear S CNWDI Stor Capability S
R and D Associates P. O. Box 9695 Marina Del Rey, California 90291 Attn: W. Graham, Jr. Attn: C. MacDonald	1 Copy each RDA 600466 Fac Clear T CNWDI Stor Capability T
Sandia Laboratories P.O. Box 5800 Albuquerque, New Mexico 87115 Attn: Doc Con For G. Yonas Attn: Doc Con For 3141	1 Copy each SANALB 315300 CNWDI

Science Applications, Inc.
P. O. Box 2351
La Jolla, California 92038
Attn: J. Beyster

SAI 600100
Fac Clear T CNWDI
Stor Capability T

Spire Corporation
P. O. Box D
Bedford, Massachusetts 01730
Attn: R. Little

SPI 600215
Fac Clear T CNWDI
Stor Capability S

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
Attn: S. Dairiki

SRI 332500
Fac Clear T CNWDI
Stor Capability T

Systems, Science and Software, Inc.
P. O. Box 1620
La Jolla, California 92038
Attn: A. Wilson

Se 388507
Fac Clear T CNWDI
Stor Capability S

Texas Tech University
P. O. Box 5404, North College Station
Lubbock, Texas 79417
Attn: T. Simpson

TXTECU 405703
Fac Clear S
Stor Capability S

TRW Defense and Space Systems Group
One Space Park
Redondo Beach, California 90278
Attn: Technical Information Center

1 Copy
TRWRB 354595
Fac Clear T CNWDI
Stor Capability T

Vought Corporation
Michigan Division
38111 Van Dyke Road
Sterling Heights, Maine 48077
Attn: Technical Information Center
(Formerly LTV Aerospace Corp.)

1 Copy
Vought 611546
Fac Clear T
Stor Capability T

60. Naval Research Laboratory
Plasma Radiation Group
Washington, D.C. 20375

Code 6707	-	25 Copies
Code 6700	-	1 Copy