NAVSWC TR 90-364

PROGRAM TO PRODUCE TABULATED DATA SET DESCRIBING NSWC BURN MODEL FOR HYDRODYNAMIC COMPUTATIONS

BY LEWIS C. HUDSON III and KIBONG KIM

RESEARCH AND TECHNOLOGY DEPARTMENT

11 SEPTEMBER 1990

NAVAL SURFACE WARFARE CENTER

Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

FOREWORD

The research effort documented in this report was performed under the Advanced Technology Torpedo Thrust Program and funded by Office of Naval Technology. A general purpose program has been developed which applies the concepts of the NSWC Burn Model and generates a tabulated data set. From this tabulated data set, any one-, two-, or three-dimensional hydrocode containing a reactive mixture scheme can determine a new burn fraction based on a previous burn fraction, pressure, and time step.

The illustrations in this report appear after the body of the report.

The author wishes to acknowledge the helpful insights of Dr. Raafat Guirguis of the Naval Surface Warfare Center on how the NSWC Burn Model works, and Drs. Schittke and Feisler of Industrieanlagen-Betriebsgesellschaft for their suggestion to develop a general purpose program to tabulate the data and an example of how to proceed with the effort.

Approved by:

William H. Bohli

WILLIAM H. BOHLI, Acting
Energetic Materials Division

CONTENTS

ILLUSTRATIONS

TABLES

SECTION 1

INTRODUCTION

This report describes the transformation of the NSWC Burn Model, described in Reference 1, into a general purpose program which produces a simple set of information. This information can be transformed into a tabular database that can be used by any one-, two-, or three-dimensional hydrocode which contains a reactive mixture scheme. The term, general purpose program, is used throughout this report to emphasis the fact that the computer program which produces the tabulated data set is separate from the hydrocode run which uses the tabulated data set.

The basic equations, described in Reference 1, which present the concepts of the NSWC Burn Model are solved explicitly by a general purpose program in a Lagrangian coordinate system. These equations and the solution method are described in Section 2. Relationships which prescribe the necessary parameters for a hydrocode computation are shown in Section 3. Section 4 presents some conclusions and direction of future work.

SECTION 2

HOW THE NSWC BURN MODEL IS USED IN A GENERAL PURPOSE PROGRAM

The NSWC Burn Model assumes that a typical pore and binder in a high explosive can be modeled by a void region inside a sphere. Therefore, it is referred to as a hollow sphere model. The size of the hollow portion of the sphere representing the void and binder is in proportion with the global percentages of the component explosive, binder, and pore. The solid portion of the hollow sphere located between r_i, the minimum radius of the solid portion of the hollow sphere, and r_o, the maximum radius of the solid portion of the hollow sphere, is composed of the component explosive. Figure 1-a shows a typical situation in a real component explosive. Figure 1-b shows how the NSWC Burn Model views a typical situation in a real component explosive. Figure 1-c shows the region of computation of the NSWC Burn Model.

The NSWC Burn Model divides the portion of the sphere between r_i and r_o into a number of one-dimensional subcells which can be equally or geometrically spaced. In general, it seems that geometric spacing is more advantageous since the region requiring the greatest resolution is near r_i. This is due to the fact that the NSWC Burn Model is only used to determine the global burn fraction until a certain criteria is reached, indicating that surface burning has become predominant in determining the burn fraction. Then the global burn fraction can be determined according to a surface burn model.

It is assumed in the general purpose program presented here that the temperature throughout the hollow portion of the sphere representing the void and binder is constant. The value used for this region is equal to the value of the temperature at the location r_i initially, and at the location corresponding to the inner surface of the solid portion of the sphere as it moves into the solid region due to the conversion of solid subcells into burned gas products as time progresses. As time progresses, the small portion of burned gas products over all the subcells is collected in the hollow portion of the sphere in a cumulative manner.

In the general purpose program describing the NSWC Burn Model, each subcell is bounded by two location values, the difference of which is the subcell width. The local burn fraction and temperature are found at the center of each subcell. The velocity is found at the two locations which bound the subcell region. Initially, it is assumed that the local burn fraction is zero, the temperature is the ambient temperature, and the velocity is zero for all subcells.

Initially, a pressure due to the surroundings, p_o, is applied at r_o and the pressure of the gas in the hollow portion, p_g, of the sphere is ambient pressure or some specified condition and applied at r_i. As the pressure, p_o, is applied to the outer surface of the hollow sphere model, it is assumed that there is a global mechanical deformation in progress near the pore, and that the material behavior is such that the stress is dependent on strain and strain rate. This results in an increase in p_g. The processes which occur are described in greater detail in Reference 1. Two assumptions are made, the elastic portion of mechanical deformation can be ignored and the bulk compressibility of the component explosive can be neglected. This greatly simplifies the equations needed to describe the NSWC Burn Model for a hollow sphere.

Also, the location of the subcells in the hollow sphere model moves toward the center of the sphere as the pressure, p_o, is applied to the outer surface of the hollow sphere model. Likewise, as the component explosive begins to burn, the gas pressure, p_g, in the hollow portion of the sphere begins to increase, resulting in a force being applied to the surface located at r_i and directed toward the outer surface of the sphere. This results in additional changes to subcell boundary locations. The equation used to determine the velocity, $v(r,x,t)$, of the boundaries associated with each subcell is the following,[1]

$$v(r,x,t) = \frac{\gamma \left(p_o - p_g - 2\sqrt{3}\ k\ \ln(r_0/r_i)\right)}{2\left(r_o^{-3} - r_i^{-3}\right) r^2\ k} \quad . \tag{1}$$

The variables used in Equation (1) are described below.

The basic equations used in the general purpose program to describe a hollow sphere model representative of the NSWC Burn Model in which an Arrhenius reaction is applied to the hot spot temperature which is modified by thermal diffusion, are the following,[1]

$$\frac{d\lambda(x,t)}{dt} = \int_{r_i}^{r_0} \frac{\frac{d\Lambda(r,x,t)}{dt}\ 4\ \pi\ r^2}{\frac{4}{3}\ \pi\left(r_o^3 - r_i^3\right)}\ dr \quad , \tag{2}$$

$$\frac{d\Lambda(r,x,t)}{dt} = (1 - \Lambda(r,x,t))\ Z\ \exp\left(-\frac{T^*}{T(r,x,t)}\right) \quad , \tag{3}$$

$$T(r,x,t) = T_0(r,x,t) + \int_0^t \frac{dT}{dt}(r,x,t)\,dt \quad , \text{ and} \tag{4}$$

$$\frac{dT(r,x,t)}{dt} = \frac{2.25\ \gamma \left(p_o - p_g - 2\sqrt{3}\ k\ \ln(r_o/r_i)\right)^2}{\rho\ C_p \left(r_i^{-3} - r_o^{-3}\right) r^6\ k}$$

$$+ \frac{1}{\rho\ C_p}\ \frac{1}{r^2}\ \frac{\partial}{\partial r}\left(r^2\ k^*\ \frac{\partial T(r,x,t)}{\partial r}\right) + \frac{Q}{C_p}\ \frac{d\Lambda(r,x,t)}{dt}\ , \qquad (5)$$

where r is the location of the subcell being evaluated at time, t; $\lambda(x,t)$ is the global burn fraction of the system; $\Lambda(r,x,t)$ is the local burn fraction of an individual subcell in the hollow sphere model; and $T(r,x,t)$ is the temperature of an individual subcell in the hollow sphere model. Equations (3) through (5) are solved explicitly in the Lagrangian subcell coordinate system. The variable x indicates the global computational cell for which the hollow sphere model is being computed. For example, in a three-dimensional Cartesian coordinate system, x would be a function describing a unique X, Y, and Z location for the global computational cell. In the general purpose program described in this paper, the hollow sphere model is evaluated for one computational cell. Therefore, x is set to 1. $T_0(r,x,t)$ is the initial temperature of an individual subcell in the hollow sphere model, Z is the pre-exponential factor in the Arrhenius kinetics, T^* is the activation temperature, ρ is the density, k^* is the thermal conductivity, C_p is the heat capacity, Q is the heat of reaction of the explosive, and γ is a number which affects how fast the global burn fraction rises but not the asymptote to which the global burn fraction approaches. The values for the constants used to model PBX-9404[1] are shown in Table 1 on the next page.

Due to the nature of Equation (4) for $dT(r,x,t)/dt$, it is necessary to determine the quantity,

$$\frac{1}{\rho\ C_p}\ \frac{1}{r^2}\ \frac{\partial}{\partial r}\left(r^2\ k^*\ \frac{\partial T(r,x,t)}{\partial r}\right), \qquad (6)$$

TABLE 1. PBX-9404 PARAMETERS USED IN THE NSWC BURN MODEL

Z	5.0×10^{13}	μsec^{-1}
T^*	26500	^oK
T_0	300	^oK
ρ	1.84	g/cm^3
C_p	1.4×10^{-5}	$cm^2/\mu sec^2/^oK$
k	8.0×10^{-5}	Mbar
Q	5.439×10^{-2}	$cm^2/\mu sec^2$
k^*	8×10^{-14}	$cm/\mu sec/^oK$
r_i	0.0039	cm
r_o	0.01	cm

for both boundaries of a subcell. This takes into account both the temperature transferred from the neighboring subcell on one side of a particular subcell and the temperature transferred to the neighboring subcell on the other side of a particular subcell.

The general purpose program which uses Equations (1) through (6) is shown in Appendix A. When running this program, the user is required to enter the time step for which the equations will be solved explicitly and the initial pressure, p_o, applied to the hollow sphere. The user may specify, in the form of data statements in the general purpose program, the number of subcells in the component explosive portion of the sphere and, if geometric cell size expansion is used, the initial cell size and expansion factor from one cell to the next. The parameters shown in Table 1 are included in the form of data statements in the general purpose program.

The general purpose program iterates twice through the section which determines $d\lambda(x,t)/dt$, $d\Lambda(r,x,t)/dt$, $T(r,x,t)$, and $dT(r,x,t)/dt$ to converge to the solution. Iterations greater than two do not add significant improvements in convergence. The pressure of the gas is determined by using a JWL (Jones-Wilkens-Lee) Equation of State to model the component explosive gas products. The JWL Equation of State has the following form,

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)\exp(-R_1 V) + B\left(1 - \frac{\omega}{R_2 V}\right)\exp(-R_2 V) + \frac{\omega}{V} E \quad (7)$$

where V, the relative volume, equals v/v_o or ρ_o/ρ. The values for the JWL Equation of State parameters used to model PBX-9404[2] are shown in Table 2.

TABLE 2. JWL EQUATION OF STATE PARAMETERS USED FOR PBX-9404

ρ	1.84	g/cm^3
P_{CJ}	0.37	Mbar
D	0.88	cm/μsec
E_o	0.102	Mbar-cc/cc
R_1	4.6	
R_2	1.3	
ω	0.38	
A	8.524	Mbar
B	0.1802	Mbar
C	0.0121	Mbar

The relative volume, V, is found by the following method. First one multiplies the volume between r_1 and r_2 by the global burn fraction. This results in a quantity, v_g, which takes into account the relative volume of the high explosive gas products from the component explosive. If v_g is less than 1.E-11, it is set equal to 1.E-11. The current

volume of the hollow sphere, v_{hs}, and the volume of the binder, v_b, are also included in the determination of the relative volume which is given by the following expression,

$$V = \frac{v_{hs} + v_g - v_b}{v_g} \quad . \tag{8}$$

Initially, it was desirable to create a model with constants that were solely determined by the physical parameters of the component explosive. However, the use of the JWL Equation of State to model the component explosive gas products introduces another set of unknowns which are usually determined through experiments such as cylinder tests or similitude data. In future applications of the general purpose program for high explosives that do not have JWL Equation of State parameters, it will be assumed that a generic set of JWL Equation of State parameters will be sufficient to model the gas products.

SECTION 3

HOW TO APPLY THE GENERAL PURPOSE PROGRAM RESULTS TO A HYDRODYNAMIC COMPUTATION

The general purpose program developed in the previous section for the NSWC Burn Model was designed to evaluate one hot spot formation caused by a constant pressure applied at the outer surface of the hollow sphere for the duration of the run. In a one-, two-, or three-dimensional hydrodynamic computation, there are many cells; each cell experiences varying pressure levels throughout the computation. In this section, a scheme for using the results of the general purpose program describing the NSWC Burn Model will be presented.

The first characteristic which needs to be defined is the transition from exponential growth of the reaction due to mechanical deformation to a slower growth of the reaction due to surface burning. This exponential growth of the reaction due to mechanical deformation can be thought of as the ignition phase of a hot spot. The equations and general purpose program presented in Section 2 describe this phenomena. The growth phase in which a transition to surface burning occurs is described with a different, simpler expression for the global burn fraction, such as a surface burn model. This expression is described in more detail in Reference 1.

After evaluating how different system parameters changed as the growth of the reaction slowed, it was observed that the quantity,

$$\log_{10}\left(\frac{\lambda(x,t) * \sum_{j=1}^{n} T(j,x,t) * dr(j,x,t)}{n * (r_o - r_i)\, p_o}\right), \qquad (9)$$

changed sign, from a negative to a positive value, when the exponential growth of the reaction due to mechanical deformation slowed for every applied pressure (from 5 to 200 kilobar). The quantity represented by Equation (9) is independent of the time step step selected. In Equation (9), $\lambda(x,t)$ is the global burn fraction, $T(j,x,t)$ is the temperature in the subcell, n is the number of subcells describing the component explosive, $dr(j,x,t)$ is the width of the subcell, r_o and r_i are the current values of the solid portion of the sphere which bound the component explosive region in the model, and p_o is the applied pressure as described in the previous section. When the quantity represented by Equation (9) changed sign in the general purpose program, it was assumed that the global burn fraction reached the transition point, λ_{hs}, at time, t_{hs}, where surface burning becomes the predominant mechanism.

When running a one-, two-, or three-dimensional hydrodynamic computation, another criteria, based on the computation, is used to determine when the transition from ignition to growth should be made. This transition to growth is based upon a minimum burn rate computed from both the ignition model and the growth model. This method of determining transition (presented above) provides enough information to reach and go slightly beyond the criteria of a hydrodynamic computation.

Important consideration also needs to be given when determining the minimum pressure below which a burn fraction will not accumulate in hydrodynamic computations. The general purpose program was run starting at a pressure of

200 kilobar. In each successive run, the pressure was reduced by 1 kilobar. It was determined that 5 kilobars is the lowest pressure that produced a smooth transition of λ_{hs} from one pressure to the next. At 6 kilobars, the value of λ_{hs} was 4.92e-3; at 5 kilobars, the value of λ_{hs} was 4.15e-3; and at 4 kilobars, the value of λ_{hs} was 1.22e-8. Therefore, the lowest acceptable pressure has been selected as 5 kilobars. The data generated at 1 kilobar intervals includes the global burn fraction at transition, λ_{hs}, and the associated time at which this occurs, t_{hs} for each pressure.

For pressures of 5 kilobars, pressures of 10 to 100 kilobars at 10-kilobar intervals, and pressures of 100 to 200 kilobars at 20-kilobar intervals, the burn fraction versus time data is written out for every time step. This produced a large amount of data which was reduced to be easily handled by a hydrodynamic computation. The program which reduces the data, SLIM, is shown in Appendix B. In addition to data reduction, SLIM also normalizes the data, determines the length of the line resulting from the normalized data points, and determines the coordinates of points which divide the normalized line up into 400 equally spaced segments based on the original normalized data points. This allows the hydrodynamic computation to interpolate between two ranges of pressure to generate a normalized burn fraction versus time curve for any pressure. It also can be used to find the new burn fraction.

After much investigation, the following normalization scheme was found,

$$\log_{10}\left(\left(\frac{X}{X_{H.S.}}\right)^{\frac{P_{CJ}^{Y}}{P}}\right), \qquad (10)$$

where Y is 0.15 when X is the time, Y is 0.05 when X is the burn fraction, P is the pressure in the cell, and P_{CJ} is

the Chapman-Jouguet pressure of the high explosive. This normalization scheme seemed to work fairly well in creating curves from which one could interpolate. The normalized curves for 5 kilobars, 10 through 100 kilobars at 10-kilobar intervals, and 100 through 200 kilobars at 20-kilobar intervals are shown in Figure 2.

In order to use this information in a hydrodynamic computation, one tabulates the normalized curves in the form of data statements so that a hydrodynamic computation can determine the required information. The two programs, MAKEHS and MAKELAM, used to create the necessary data statements are shown in Appendix C. A sample subroutine which uses this information is shown in Appendix D. Currently, this subroutine is used in the Eulerian hydrocode DYSMAS.

The first time a cell experiences a pressure greater than a predetermined minimum, such as 5 kilobars for the case of PBX-9404, the value of the normalized time is determined using the time step as t, the current pressure in the cell as p_o, t_{hs} based on current p_o, and the Chapman-Jouguet pressure of the component explosive. From this, the associated burn fraction and burn rate can be determined. On subsequent cycles, the previous burn fraction is used to determine an old normalized time based on the current value of p_o. Then the current time step is used to determine a new normalized time and associated burn fraction and burn rate. Using this method, it is quite feasible to model the ignition phase with the NSWC Burn Model in conjunction with a simple surface burn growth phase model, and to run one-, two-, or three-dimensional hydrodynamic computations.

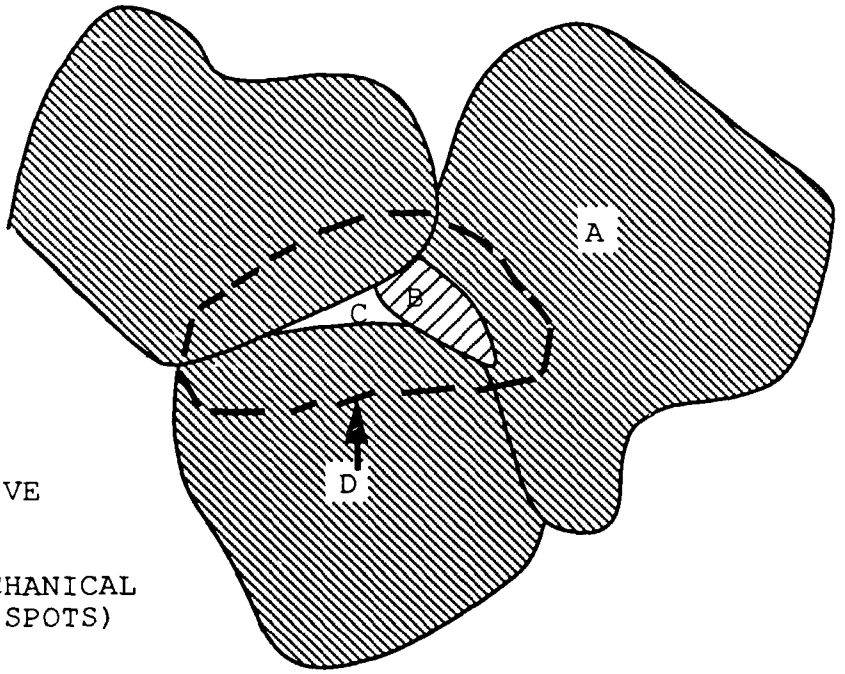
SECTION 4

CONCLUSIONS AND FUTURE WORK

The development of a general purpose program to incorporate the concepts of the NSWC Burn Model into a tabular data set have been successful. Future work will involve comparing results from inclusion of the tabulated data set into various hydrocodes to results shown in Reference 1. To complete this work, constants in the surface burn model may need to be modified to match the results shown in Reference 1.

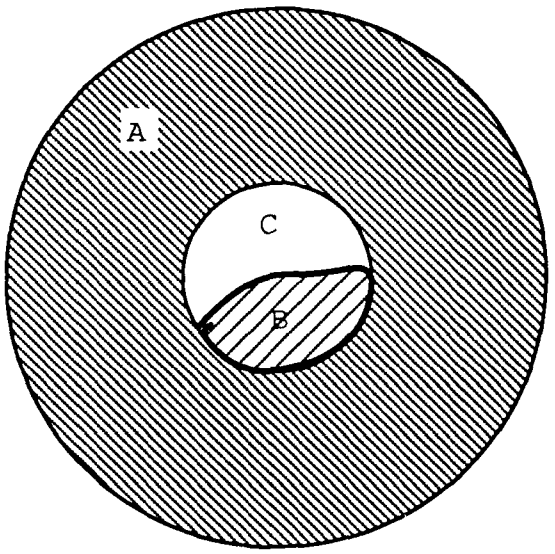
Future work also will involve (1) verifying the assumption (discussed in Section 2) that a generic JWL Equation of State is sufficient because the parameters of the NSWC Burn Model will compensate as needed, and (2) investigating whether the criteria for transition from ignition to growth phase will always be the quantity, shown in Equation (9), changing sign for different explosive components and/or similar explosive components with varying particle sizes, initial porosities, initial temperatures, and/or initial mass distributions between the component explosive and binder.

Planned improvements to the general purpose program include (1) implementing a numerical expression for the bulk compressibility of the binder to take into account the energy loss of compressing the binder, and (2) investigating a method of including shear-induced hot spot temperature effects.

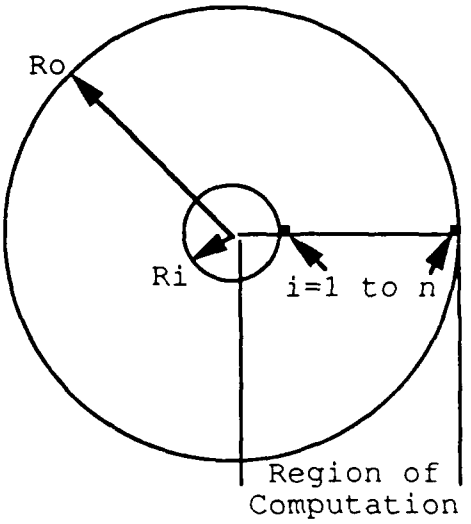


A - COMPONENT EXPLOSIVE
B - BINDER
C - PORE (VOID)
D - AREAS OF HIGH MECHANICAL DEFORMATION (HOT SPOTS)

(a) real situation in composite explosive

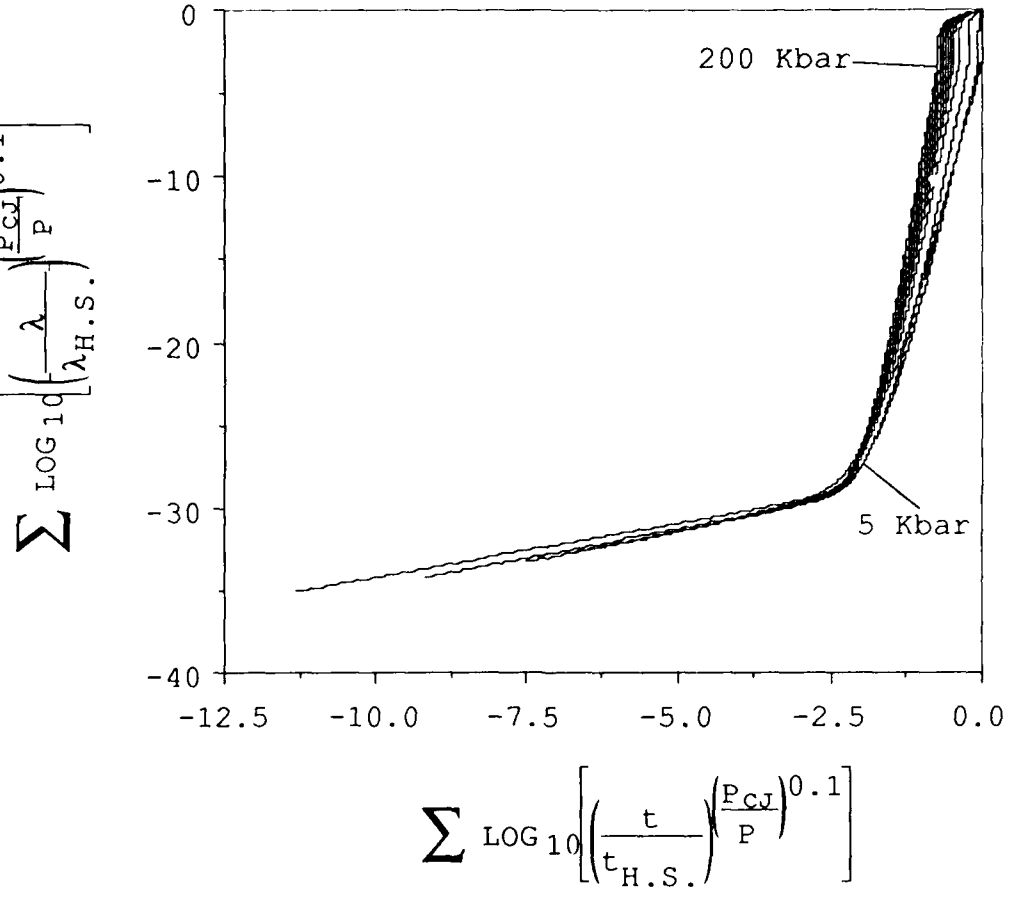


(b) one-dimensional approach of the NSWC Burn Model



(c) schematic of one-dimensional computational region of the NSWC Burn Model

FIGURE 1. THE NSWC BURN MODEL



NOTE: LINES CORRESPONDING TO INITIAL PRESSURES OF 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, AND 180 KILOBARS BOUNDED BY THE LINES CORRESPONDING TO 5 AND 200 KILOBARS

FIGURE 2. NORMALIZED DATA AT PRESSURES OF 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, AND 200 KILOBARS FOR PBX-9404

REFERENCES

1. Kim, K., "Development of a Model of Reaction Rates in Shocked Composite Explosives," in Proceedings of the 9th Symposium (International) on Detonation (Preprints), Vol. 3, pp. 946-957, 1989.

2. Dobratz, B. M. and Crawford, P. C., LLNL Explosives Handbook: Properties of Chemical Explosives and Explosive Simulants, UCRL-52997, 31 Jan 1985.

APPENDIX A

GENERAL PURPOSE PROGRAM WHICH IMPLEMENTS THE CONCEPTS OF THE NSWC BURN MODEL

```
c  3/4/91 version
      program test
      implicit double precision(a-h,o-z)
      dimension temp(450),clam(450),drrl3(450),rm(450),
     1  tburn(450),dslmax(450),tempold(450),rmold(450)
      dimension rbd(451),rbd3(451),dr(450)
      data m/415/,factin/1.01/,cellin/0.000001/
      data z/5.e13/, tstar/2.65e4/, tambi/300./, rho/1.84/
      data cp/1.4e-5/, bulk/8.e-5/, q/5.439e-2/, stark/8.e-14/
      data ri/0.0039/, ro/0.01/, thrd/0.33333333/
      data ajwl/8.524011/, bjwl/0.1801812/, omjwl/0.38/
      data r1jwl/4.6/, r2jwl/1.3/, cjwl/0.012066373/
      write(6,*) 'input time step'
      read(5,*) dto
      compold=10000.
      totlen=ro-ri
      gam=0.025
      po=25.e-3
      type *,'Enter initial pressure'
      read(*,*)po
      ms=1+(m-1)/10
      mp1=m+1
      nc=0
      tt=0.
c hot spots will not form if it takes longer than 1 microseconds
      t1=1.
      dt=dto
      ib=1
      istr=1
      rg=ri
      rg3=rg*rg*rg
      rbd(1)=ri
      rbd3(1)=rbd(1)**3
      ro3=ro**3
      ri3=rbd3(1)
      ro3mri3=ro3-ri3
      fako=2.25*gam/(rho*cp*bulk*(1./ri3-1./ro3)**2)
      fakr=3./(ro3mri3)
      fakp=po-3.464102*bulk*dlog(ro/ri)
      fakq=q/cp
      faks=1./cp/rho
      fakv=gam/2./bulk
      prev = cellin/factin
```

```
      sum = ri
      do i=1,m
        ip1=i+1
        prev=factin*prev
        dr(i)=prev
        if(sum+prev.lt.ro)sum=sum+prev
        if(i.eq.m)dr(i)=ro-sum
        temp(i)=tambi
        tempold(i)=tambi
        clam(i)=1.e-30
        tburn(i)=0.
        dslmax(i)=0.
        rbd(ip1)=dr(i)+rbd(i)
        rbd3(ip1)=rbd(ip1)**3
        drrl3(i)=rbd3(ip1)-rbd3(i)
        rm(i)=rbd(ip1)-0.5*dr(i)
        rmold(i)=rm(i)
      end do
   10 continue
c
c     determine volume of gas if not first time through
c
      vo=slam*(rbd3(mp1)-rbd3(1))
      if(vo.lt.1.d-11)vo=1.d-11
      vbold=vb
      vb=0.01*rbd3(mp1)
      spvolg=(rbd3(1)+vo-vb)/vo
      pgold=pg
      pg=ajwl*dexp(-r1jwl*spvolg)+bjwl*dexp(-r2jwl*spvolg)+
     1  cjwl*spvolg**(-omjwl-1)
      if(istr.eq.1)pgbaseline=pg
      if(istr.eq.1)pg=1.01323e-6
      if(istr.ne.1)pg=pg+1.01323e-6-pgbaseline
c
c     determine new radial positions based on velocity
c
      if(istr.ne.1)then
        riold=rbd(1)
        roold=rbd(mp1)
        do i=1,mp1
          v=fakv*(fakp-pg)/(1/ro3-1/ri3)/rbd(i)**2
          rbd(i)=rbd(i)+v*dt
          rbd3(i)=rbd(i)**3
        end do
        ro=rbd(mp1)
        ri=rbd(1)
        totlen=ro-ri
        ro3=rbd3(mp1)
        ri3=rbd3(1)
        ro3mri3=ro3-ri3
        do i=1,m
          dr(i)=rbd(i+1)-rbd(i)
          rm(i)=rbd(i)+dr(i)/2.
        end do
        fakp=po-3.464102*bulk*dlog(ro/ri)
        fako=2.25*qam/(rho*cp*bulk*(1./ri3-1./ro3)**2)
        fakr=3./(ro3mri3)
```

```
      endif
      tt=tt+dt
      dslam=0.0
      tempave=0.0
      dtempave=0.0
      do i=1,m
       if(clam(i).eq.1.d0)goto 55
       r=rm(i)
       r2dr=r*r*dr(i)
       clamold=clam(i)
       dslamold=dslam
       if(i.ne.1.and.i.ne.m)then
         deltempr=(tempold(i+1)-tempold(i))/(rmold(i+1)-rmold(i))
         deltempl=(tempold(i)-tempold(i-1))/(rmold(i)-rmold(i-1))
       elseif(i.eq.1)then
         deltempr=(tempold(i+1)-tempold(i))/(rmold(i+1)-rmold(i))
         deltempl=0.0
       elseif(i.eq.m)then
         deltempr=0.0
         deltempl=(tempold(i)-tempold(i-1))/(rmold(i)-rmold(i-1))
       endif
       subdtempr=deltempr*((rm(i+1)+rm(i))/2.)**2
       subdtempl=deltempl*((rm(i)+rm(i-1))/2.)**2
       subdtemp=faks*stark*(subdtempr-subdtempl)/r2dr
         do 54 jj=1,2
           tdt=tstar/temp(i)
           if(tdt.gt.100.)type *,'tstar/temp(i)',tdt
           if(tdt.gt.100.)tdt=100.
           dclam=(1.-clam(i))*z*dexp(-tstar/temp(i))
           dtemp=fako*(fakp-pg)**2/r**6+fakq*dclam+subdtemp
           clam(i)=dmin1(1.d0,clamold+dclam*dt)
           if(clam(i).eq.1.d0)then
             dclam=(1.-clamold)/dt
             dtemp=fako*(fakp-pg)**2/r**6+fakq*dclam+subdtempr+subtempl
           endif
           temp(i)=tempold(i)+dtemp*dt
           dslam=dslamold+fakr*dclam*r2dr
           if(clam(i).eq.1.d0)goto 55
54       continue
55       continue
      tempave=tempave+temp(i)*dr(i)
      dtempave=dtempave+dtemp*dr(i)
      end do
      istr=0
      slam=slam+dslam*dt
      do 56 i=1,m
        tempold(i)=temp(i)
        rmold(i)=rm(i)
56    continue
      rg3=rbd3(ib)+clam(ib)*drr13(ib)
      rg=rg3**thrd
      if(clam(ib).ge.0.999999d0) then
        tburn(ib)=tt
        dslmax(ib)=dslam
        ib=ib+1
      end if
      nc=mod(nc+1,10)
```

```
      mss=5
      mdum=25
      comp=tempave/m/totlen*slam/po
      if(comp.eq.0.)comp=compold-1.
      comp=dlog10(comp)
c  hot spot lambda is reached according to criteria on next line
      if(comp.gt.0.0)goto 35
      compold=comp
      slamold=slam
       if(po.eq.0.01.or.po.eq.0.02.or.po.eq.0.03.or.po.eq.0.04
     1  .or.po.eq.0.05.or.po.eq.0.06.or.po.eq.0.07
     2  .or.po.eq.0.08.or.po.eq.0.09.or.po.eq.0.10
     3  .or.po.eq.0.11.or.po.eq.0.12.or.po.eq.0.13
     4  .or.po.eq.0.14.or.po.eq.0.15.or.po.eq.0.005)
     1  write(8,'(1x,1p,5e13.5)')slam,dslam,comp,tt,pg
      if(tt.lt.t1.and.clam(m).lt.1.) goto 10
c  the next line is designed to crash the batch job when t hot spot
greater than
c  1 microsecond.
      if(tt.ge.t1)acrash=1./0.
35    continue
      open(22,file='hs.info',status='unknown')
      do 838 ids=1,10000
        read(22,*,end=839,err=839)a,b,c
838   continue
839   continue
      write(22,'(7(1x,e15.7))')
     1     po,tt-dt,slamold,pgold,riold,roold,vbold
      close(22)
      type *,'t hot spot = ',tt-dt,' slam = ',slamold
      stop
      end
```

APPENDIX B

PROGRAM TO REDUCE AND NORMALIZE OUTPUT FROM THE GENERAL PURPOSE PROGRAM

```
c  compile with for/g_float
       implicit double precision(a-h,o-z)
       dimension asave(1000),dsave(1000)
       character*14 afile
       character*10 bfile
       aold=1000000.
       type *,'enter file name to read'
       read(*,100)afile
100    format(a14)
       bfile(1:1)=afile(1:1)
       bfile(2:10)=afile(6:14)
       open(82,file=afile,status='old')
       open(84,file=bfile,status='new')
       inum=0
       do 120 i=1,1000000
       read(82,*,end=999)a,b,c,d,e
       anew=dlog10(a)
       if(dabs(anew-aold).gt..1.or.
     1   (a.gt.0.0001.and.dabs(anew-aold).gt..01))then
         inum=inum+1
         if(inum.gt.1000)stop
         asave(inum)=a
         dsave(inum)=d
         ipr=1
         aold=anew
       else
         ipr=0
       endif
120    continue
999    continue
       if(ipr.eq.0)then
         inum=inum+1
         if(inum.gt.1000)stop
         asave(inum)=a
         dsave(inum)=d
       endif
       type *,'what is pressure,pcj'
       read(*,*)pres,pcj
       quanx=(pcj/pres)**.15
       quany=(pcj/pres)**.05
c  convert to scaled quantities
       do 200 iic=1,inum
         asave(iic)=dlog10((asave(iic)/asave(inum))**quany)
```

```
          dsave(iic)=dlog10((dsave(iic)/dsave(inum))**quanx)
200     continue
c  find total length
        inumm1=inum-1
        sumlen=0.
        do 210 iic=1,inumm1
          sumlen=sumlen+dsqrt((asave(iic+1)-asave(iic))**2+
     1                        (dsave(iic+1)-dsave(iic))**2)
210     continue
        icar=2
        icarm1=icar-1
        dellen=sumlen/400.
        curlen=0.0
        ruflen=0.0
        iflr=1
        write(84,431)dsave(1),asave(1)
        do 220 i=1,399
          curlen=curlen+dellen
230       if(iflr.eq.1)ruflen=ruflen+
     1      dsqrt((asave(icar)-asave(icarm1))**2+
     2            (dsave(icar)-dsave(icarm1))**2)
          if(curlen.gt.ruflen)then
            icarm1=icar
            icar=icar+1
            iflr=1
            goto 230
          endif
          iflr=0
          dbtp=dsqrt((asave(icar)-asave(icarm1))**2+
     2               (dsave(icar)-dsave(icarm1))**2)
          ari=dbtp-(ruflen-curlen)
          aval=ari*(asave(icar)-asave(icarm1))/dbtp+asave(icarm1)
          dval=ari*(dsave(icar)-dsave(icarm1))/dbtp+dsave(icarm1)
          write(84,431)dval,aval
220     continue
431     format(1x,f11.7,4x,f11.7)
        write(84,431)dsave(inum),asave(inum)
        stop
        end
```

APPENDIX C

PROGRAMS TO CREATE FORTRAN DATA STATEMENTS FROM THE TABULATED DATA SET FOR INCLUSION INTO A SUBROUTINE CALLED BY ANY ONE-, TWO-, OR THREE-DIMENSIONAL HYDROCODE

```
      program makehs
      parameter iam=500
      dimension po(iam),ths(iam),alamhs(iam),pg(iam),ri(iam),
     1          ro(iam),vb(iam)
      open(81,file='hs.info',status='old')
      icou=0
      do 100 i=1,1000
      read(81,*,end=999)po(i),ths(i),alamhs(i),pg(i),ri(i),
     1                  ro(i),vb(i)
      icou=icou+1
100   continue
999   continue
      open(82,file='hsdata.for',status='new')
      write(82,110)icou,icou,icou,icou,icou
110   format(6x,'dimension po(',i3,'),ri(',i3,'),ro(',i3,
     1       '),',/,5x,'1  alamhs(',i3,'),ths(',i3,')')
      write(82,115)icou
115   format(6x,'data nrs/',i3,'/')
      do 200 i=1,icou
      write(82,120)i,ri(i),i,ro(i),i,po(i)
120   format(6x,'data ri(',i3,')/',e13.7,
     1  '/,ro(',i3,')/',e13.7,'/,po(',i3,')/',f5.3,'/')
200   continue
      do 210 i=1,icou
      write(82,130)i,alamhs(i),i,ths(i)
130   format(6x,'data alamhs(',i3,')/',e13.7,'/, ths(',i3,')/',
     1       e13.7,'/')
210   continue
      stop
      end
```

```
      program makelam
      implicit double precision (a-h,o-z)
      character*10 filename
      parameter iam=1000
      dimension adum(iam),tdum(iam)
      numfil=16
      pcj=.370
      filename(1:2)='f8'
      filename(7:10)='.dat'
      open(82,file='lamfile.for',status='new')
      do 90 iiu=1,numfil
      if(iiu.eq.12)isep=iiu
      if(iiu.gt.12)isep=isep+2
      if(iiu.eq.16)filename(3:6)='p200'
      if(iiu.eq.15)filename(3:6)='p180'
      if(iiu.eq.14)filename(3:6)='p160'
      if(iiu.eq.13)filename(3:6)='p140'
      if(iiu.eq.12)filename(3:6)='p120'
      if(iiu.eq.11)filename(3:6)='p100'
      if(iiu.eq.10)filename(3:6)='p090'
      if(iiu.eq.9)filename(3:6)='p080'
      if(iiu.eq.8)filename(3:6)='p070'
      if(iiu.eq.7)filename(3:6)='p060'
      if(iiu.eq.6)filename(3:6)='p050'
      if(iiu.eq.5)filename(3:6)='p040'
      if(iiu.eq.4)filename(3:6)='p030'
      if(iiu.eq.3)filename(3:6)='p020'
      if(iiu.eq.2)filename(3:6)='p010'
      if(iiu.eq.1)filename(3:6)='p005'
      open(81,file=filename,status='old')
      icou=0
      do 100 i=1,1000
      read(81,*,end=999)adum(i),tdum(i)
100   icou=icou+1
999   if(iiu.lt.11)write(82,110)iiu-1,icou,iiu-1,icou
      if(iiu.eq.11)write(82,111)iiu-1,icou,iiu-1,icou
      if(iiu.gt.11)write(82,111)isep,icou,isep,icou
110   format(6x,'dimension al',i1,'0(',i3,'),t',i1,'0(',i3,')')
111   format(6x,'dimension al',i2,'0(',i3,'),t',i2,'0(',i3,')')
      if(iiu.lt.11)write(82,115)iiu-1,icou
      if(iiu.eq.11)write(82,116)iiu-1,icou
      if(iiu.gt.11)write(82,116)isep,icou
115   format(6x,'data n',i1,'0/',i3,'/')
116   format(6x,'data n',i2,'0/',i3,'/')
      do 200 i=1,icou
      if(iiu.lt.11)write(82,120)iiu-1,i,adum(i),iiu-1,i,tdum(i)
      if(iiu.eq.11)write(82,121)iiu-1,i,adum(i),iiu-1,i,tdum(i)
      if(iiu.gt.11)write(82,121)isep,i,adum(i),isep,i,tdum(i)
120   format(6x,'data al',i1,'0(',i3,')/',e13.7,
     1   '/,t',i1,'0(',i3,')/',e13.7,'/')
121   format(6x,'data al',i2,'0(',i3,')/',e13.7,
     1   '/,t',i2,'0(',i3,')/',e13.7,'/')
200   continue
      close(81)
90    continue
      stop
      end
```

APPENDIX D

SAMPLE OF SUBROUTINE TO BE INCLUDED INTO A ONE-, TWO-, OR THREE-DIMENSIONAL HYDRODYNAMIC COMPUTATION TO DETERMINE A NEW BURN FRACTION

```
CDECK USRDFB
      FUNCTION USRDFB(FBRN,TIM,DT,PRS,SMP,NP,I,J,K,IMAX,JMAX,KMAX,
     1                SDETIN,PDETIN,PBREF,BUSR,CUSR,DUSR)
C
C  ****************************************************************
C
C  *** THIS IS A SAMPLE USER-INPUT FUNCTION FOR THE EVALUATION
C      OF EXPLOSIVE DECOMPOSITION
C
C  *** THIS MODULE IS ACCESSED WHENEVER BURN MODEL KBURN=-9 IS CHOSEN
C      FROM INPUT
C
C  *** DEFINITION OF INPUT PARAMETERS -
C         USRDFB  OUT   CURRENT VALUE OF BURN RATE
C         FBRN    INP   'OLD' VALUE OF BURN FRACTION
C                 OUT   'NEW' VALUE OF BURN FRACTION
C         TIM     INP   CURRENT TIME
C         DT      INP   CURRENT TIME STEP
C         PRS     INP   CURRENT LOCAL PRESSURE
C         SMP     INP   CURRENT LOCAL TEMPERATURE
C         NP      INP   CURRENT EXTERNAL MATERIAL NUMBER
C         I       INP   CELL INDEX  (I-DIRECTION)
C         J       INP   CELL INDEX  (J-DIRECTION)
C         K       INP   CELL INDEX  (K-DIRECTION)
C         IMAX    INP   MAXIMUM NUMBER OF CELLS  (I-DIRECTION)
C         JMAX    INP   MAXIMUM NUMBER OF CELLS  (J-DIRECTION)
C         KMAX    INP   MAXIMUM NUMBER OF CELLS  (K-DIRECTION)
C         SDETIN  INP   USER DEFINED - SUGGESTED: INITIATION TIME
C         PDETIN  INP   USER DEFINED - SUGGESTED: INITIATION PRESSURE
C         PBREF   INP   USER DEFINED - SUGGESTED: REFERENCE PRESSURE
C         BUSR    INP   USER DEFINED - SUGGESTED: NONE
C         CUSR    INP   USER DEFINED - SUGGESTED: NONE
C         DUSR    INP   USER DEFINED - SUGGESTED: NONE
C
C
C
C  *** THIS ROUTINE SHOULD RETURN -
C         EITHER  A BURN RATE BY MEANS OF THE FUNCTION NAME
C         OR      AN UPDATED VALUE OF THE BURN FRACTION VIA FBRN
C      THE APPROPRIATE DEFINITION IS DONE DEPENDING ON -
C         IF ON OUTPUT FBRN IS FOUND TO HAVE CHANGED ITS VALUE,
C         THEN THE UPDATED VALUE OF FBRN IS USED
```

```
C          (IN THIS CASE IT IS ADVISABLE TO DEFINE USRDFB=0.)
C          OTHERWISE A BURN RATE DEFINITION IS ASSUMED
C
C  ********************************************************************
       IF(PRS.LT.5.E9)RETURN
       SFB=FBRN
       ZZFD=0.0
       IF(FBRN.GE.1.E-5)ZZFD=FBRN
       CALL BEEN(ZZFD,TIM,DT,PRS,SMP,NP,I,J,K,IMAX,JMAX,KMAX,
      1                  SDETIN,PDETIN,PBREF,BUSR,CUSR,DUSR)
       IF(ZZFD.GE.1.E-5)THEN
         FBRN=ZZFD
         URSDFB=0.0
       ELSE
         FBRN=SFB
         URSDFB=1.E-20
       ENDIF
       RETURN
       END
       SUBROUTINE BEEN(FBRN,TIM,DT,PRS,SMP,NP,I,J,K,IMAX,JMAX,KMAX,
      1                  SDETIN,PDETIN,PBREF,BUSR,CUSR,DUSR)
       DATA CV/2.09E-5/, AJWL/8.524011/, BJWL/0.1801812/, OMJWL/0.38/
       DATA R1JWL/4.6/, R2JWL/1.3/, CJWL/0.012066373/
       DATA TDT/.6666667/,TLIM/1.E-3/
       INCLUDE 'LAMFILE.FOR'
       INCLUDE 'HSDATA.FOR'
       common/icjckc/ IC(1000),JC(1000),KC(1000),FCC(1000)
C  PUT DT INTO MICROSECOND UNITS AND SAVE ORIGINAL VALUE OF DT
       SAVEDT=DT
       DT=DT*1.E6
C  IN GENERAL, PCJ SHOULD EQUAL PBREF, THE CJ PRESSURE IN THE INPUT
C  IE PCJ = PBREF/1.E12 TO GET TO MEGABARS.
       PCJ=PBREF/1.E12
C  PRES IS IN UNITS OF MEGABARS, PRS IN UNITS OF MICROBARS
       PRES=PRS/1.E12
C  USE 5 KBAR AS MINIMUM PRESSURE FOR REACTION TO OCCUR BASED ON GENERAL
C  PURPOSE PROGRAM RESULTS
C  MINIMUM PRESSURE SHOULD CORRESPOND TO VALUE IN PO(NRS) FROM HS.INFO
C  THE POINT BELOW WHICH THE GENERAL PURPOSE PROGRAM DOES NOT GO
       IF(PRES.LT.0.00501)THEN
         DT=SAVEDT
         RETURN
       ENDIF
       IGOTOSUR=0
       IF(PRES.GT.0.200)IGOTOSUR=1
C  DETERMINE ALAMHS BY LOOKING UP TABLE OF DATA
C  IF FBRN GE AHS USE SURFACE BURN, IF FBRN LT AHS USE NSWC MODEL
       IREAD=0
       IPICK=0
       IF(BUSR.LT.1.E10.AND.FBRN.LT.TLIM.AND.FBRN.GE.0.0)THEN
         IBUSR=IFIX(BUSR+0.00001)
         DO 95 KDC=1,IBUSR
         IF(IC(KDC).EQ.I.AND.JC(KDC).EQ.J.AND.KC(KDC).EQ.K)THEN
           IPICK=1
           FBRN=FBRN+FCC(KDC)
         ENDIF
95       CONTINUE
```

```
      IREAD=1
      ENDIF
      SAVEFBRN=FBRN
      IF(IGOTOSUR.EQ.1)GOTO 338
      NRSM1=NRS-1
      DO 400 ICP=1,NRSM1
        IF(PRES.GE.PO(ICP+1).AND.PRES.LT.PO(ICP))THEN
          ICP1=ICP+1
          AHS=(ALAMHS(ICP1)-ALAMHS(ICP))*(PRES-PO(ICP))/
     1          (PO(ICP1)-PO(ICP))+ALAMHS(ICP)
          TAHS=(THS(ICP1)-THS(ICP))*(PRES-PO(ICP))/
     1          (PO(ICP1)-PO(ICP))+THS(ICP)
          GOTO 401
        ENDIF
400   CONTINUE
401   CONTINUE
      IF(FBRN.LT.AHS.AND.FBRN.GE.0.0)THEN
C   USE NSWC MODEL RELATIONS TO FIND FBRN
      IF(PRES.GE.0.18)THEN
      CALL AFORP(AL180,T180,AL200,T200,N180,N200,FBRN,
     1   DT,PRES,PO(21),PO(1),PCJ,THS(21),THS(1),AHS,TAHS)
      ELSEIF(PRES.LT.0.18.AND.PRES.GE.0.16)THEN
      CALL AFORP(AL160,T160,AL180,T180,N160,N180,FBRN,
     1   DT,PRES,PO(41),PO(21),PCJ,THS(41),THS(21),AHS,TAHS)
      ELSEIF(PRES.LT.0.16.AND.PRES.GE.0.14)THEN
      CALL AFORP(AL140,T140,AL160,T160,N140,N160,FBRN,
     1   DT,PRES,PO(61),PO(41),PCJ,THS(61),THS(41),AHS,TAHS)
      ELSEIF(PRES.LT.0.14.AND.PRES.GE.0.12)THEN
      CALL AFORP(AL120,T120,AL140,T140,N120,N140,FBRN,
     1   DT,PRES,PO(81),PO(61),PCJ,THS(81),THS(61),AHS,TAHS)
      ELSEIF(PRES.LT.0.12.AND.PRES.GE.0.1)THEN
      CALL AFORP(AL100,T100,AL120,T120,N100,N120,FBRN,
     1   DT,PRES,PO(101),PO(81),PCJ,THS(101),THS(81),AHS,TAHS)
      ELSEIF(PRES.LT.0.1.AND.PRES.GE.0.09)THEN
      CALL AFORP(AL90,T90,AL100,T100,N90,N100,FBRN,
     1   DT,PRES,PO(111),PO(101),PCJ,THS(111),THS(101),AHS,TAHS)
      ELSEIF(PRES.LT.0.09.AND.PRES.GE.0.08)THEN
      CALL AFORP(AL80,T80,AL90,T90,N80,N90,FBRN,
     1   DT,PRES,PO(121),PO(111),PCJ,THS(121),THS(111),AHS,TAHS)
      ELSEIF(PRES.LT.0.08.AND.PRES.GE.0.07)THEN
      CALL AFORP(AL70,T70,AL80,T80,N70,N80,FBRN,
     1   DT,PRES,PO(131),PO(121),PCJ,THS(131),THS(121),AHS,TAHS)
      ELSEIF(PRES.LT.0.07.AND.PRES.GE.0.06)THEN
      CALL AFORP(AL60,T60,AL70,T70,N60,N70,FBRN,
     1   DT,PRES,PO(141),PO(131),PCJ,THS(141),THS(131),AHS,TAHS)
      ELSEIF(PRES.LT.0.06.AND.PRES.GE.0.05)THEN
      CALL AFORP(AL50,T50,AL60,T60,N50,N60,FBRN,
     1   DT,PRES,PO(151),PO(141),PCJ,THS(151),THS(141),AHS,TAHS)
      ELSEIF(PRES.LT.0.05.AND.PRES.GE.0.04)THEN
      CALL AFORP(AL40,T40,AL50,T50,N80,N90,FBRN,
     1   DT,PRES,PO(161),PO(151),PCJ,THS(161),THS(151),AHS,TAHS)
      ELSEIF(PRES.LT.0.04.AND.PRES.GE.0.03)THEN
      CALL AFORP(AL30,T30,AL40,T40,N30,N40,FBRN,
     1   DT,PRES,PO(171),PO(161),PCJ,THS(171),THS(161),AHS,TAHS)
      ELSEIF(PRES.LT.0.03.AND.PRES.GE.0.02)THEN
      CALL AFORP(AL20,T20,AL30,T30,N20,N30,FBRN,
     1   DT,PRES,PO(181),PO(171),PCJ,THS(181),THS(171),AHS,TAHS)
```

```
      ELSEIF(PRES.LT.0.02.AND.PRES.GE.0.01)THEN
      CALL AFORP(AL10,T10,AL20,T20,N10,N20,FBRN,
     1   DT,PRES,PO(191),PO(181),PCJ,THS(191),THS(181),AHS,TAHS)
      ELSEIF(PRES.LT.0.01)THEN
      CALL AFORP(AL00,T00,AL10,T10,N00,N10,FBRN,
     1   DT,PRES,PO(NRS),PO(191),PCJ,THS(NRS),THS(191),AHS,TAHS)
      ENDIF
      ENDIF
      AFORPFBRN=FBRN
338   CONTINUE
C      IF(FBRN.GE.AHS.AND.FBRN.LT.1.0)THEN
      IF(FBRN.LT.1.0)THEN
      FBRN=SAVEFBRN
C   USE SURFACE BURN RELATIONS TO FIND FBRN
      CALL SURKIM(PRES,FBRN,DT,AHS)
      ENDIF
      SURKIMFBRN=FBRN
      BRATE1=(AFORPFBRN-SAVEFBRN)/DT
      BRATE2=(SURKIMFBRN-SAVEFBRN)/DT
C  FBRN IS CURRENTLY FROM SURKIM, CHANGE IF BRATE1 FBRN FROM AFORP IS
LESS
      IF(BRATE1.LE.BRATE2)FBRN=AFORPFBRN
      DT=SAVEDT
      IF(FBRN.GE.TLIM.AND.IREAD.EQ.0)GOTO 774
      IF(FBRN.EQ.0.0.AND.IREAD.EQ.0)GOTO 774
      IF(FBRN.LT.TLIM.AND.IREAD.EQ.0.AND.FBRN.GT.0.0)THEN
        IF(BUSR.LT.1.E10)BUSR=BUSR+1.
        IF(BUSR.GT.1.E10)BUSR=1.
        IBUSR=IFIX(BUSR+0.00001)
        IC(IBUSR)=I
        JC(IBUSR)=J
        KC(IBUSR)=K
        FCC(IBUSR)=FBRN
      ELSEIF(FBRN.GE.TLIM.AND.IREAD.EQ.1.AND.IPICK.EQ.1)THEN
        IKF=0
        DO 96 KDC=1,IBUSR
          IF(IKF.EQ.1)IC(KDC-1)=IC(KDC)
          IF(IKF.EQ.1)JC(KDC-1)=JC(KDC)
          IF(IKF.EQ.1)KC(KDC-1)=KC(KDC)
          IF(IKF.EQ.1)FCC(KDC-1)=FCC(KDC)
          IF(IC(KDC).EQ.I.AND.JC(KDC).EQ.J.AND.KC(KDC).EQ.K)IKF=1
96      CONTINUE
        IBUSR=IBUSR-1
        BUSR=BUSR-1.
      ELSEIF(FBRN.LT.TLIM.AND.IREAD.EQ.1.AND.IPICK.EQ.1)THEN
        DO 97 KDC=1,IBUSR
        IF(IC(KDC).EQ.I.AND.JC(KDC).EQ.J.AND.KC(KDC).EQ.K)
     1     FCC(KDC)=FBRN
97      CONTINUE
      ELSEIF(FBRN.LT.TLIM.AND.IREAD.EQ.1.AND.IPICK.EQ.0)THEN
        BUSR=BUSR+1
        IBUSR=IFIX(BUSR+0.00001)
        IC(IBUSR)=I
        JC(IBUSR)=J
        KC(IBUSR)=K
        FCC(IBUSR)=FBRN
      ENDIF
```

```
774    CONTINUE
       RETURN
       END
       SUBROUTINE AFORP(A1,T1,A2,T2,N1,N2,FBRN,DT,PRES,PRES1,PRES2,PCJ,
      1                 THS1,THS2,AHS,TAHS)
C FBRN:      INPUT -OLD BURN FRACTION
C           OUTPUT -NEW BURN FRACTION
       DIMENSION A1(N1),T1(N1),A2(N2),T2(N2),AAVE(1000),TAVE(1000)
       INCLUDE 'HSDATA.FOR'
       IF(N1.NE.N2)STOP 123
       QUANX=(PCJ/PRES)**.15
       QUANY=(PCJ/PRES)**.05
       N1M1=N1-1
       DO 100 IR=1,N1
         AAVE(IR)=(A2(IR)-A1(IR))*(PRES-PRES1)/(PRES2-PRES1)+A1(IR)
         TAVE(IR)=(T2(IR)-T1(IR))*(PRES-PRES1)/(PRES2-PRES1)+T1(IR)
100    CONTINUE
       IF(FBRN.EQ.0.0)THEN
         TBN=DT
       ELSE
         FBNSCL=ALOG10((FBRN/AHS)**QUANY)
C  NEED TO FIND OLD TIME
         DO 110 I=1,N1M1
         IF(AAVE(I).LT.FBNSCL.AND.AAVE(I+1).GE.FBNSCL)THEN
           TBOSCL=(FBNSCL-AAVE(I))*(TAVE(I+1)-TAVE(I))/
      1           (AAVE(I+1)-AAVE(I))+TAVE(I)
           GOTO 111
         ENDIF
110      CONTINUE
111      CONTINUE
         TBO=TAHS*((10.**TBOSCL)**(1./QUANX))
         TBN=TBO+DT
       ENDIF
       IF(TBN.GT.TAHS)THEN
         FBRN=AHS
         USEDT=TAHS-TBO
         SDT=DT-USEDT
         IF(SDT.GT.0.0)DT=SDT
         RETURN
       ELSE
         TBNSCL=ALOG10((TBN/TAHS)**QUANX)
         DO 120 I=1,N1M1
           IF(TAVE(I).LT.TBNSCL.AND.TAVE(I+1).GE.TBNSCL)THEN
             FBNSCL=(TBNSCL-TAVE(I))*(AAVE(I+1)-AAVE(I))/
      1             (TAVE(I+1)-TAVE(I))+AAVE(I)
             GOTO 121
           ENDIF
120      CONTINUE
121      CONTINUE
       ENDIF
       FBRN=AHS*((10.**FBNSCL)**(1./QUANY))
       RETURN
       END
       SUBROUTINE SURKIM(PRES,FBRN,DT,AHS)
       DATA CV/2.09E-5/, AJWL/8.524011/, BJWL/0.1801812/, OMJWL/0.38/
       DATA R1JWL/4.6/, R2JWL/1.3/, CJWL/0.012066373/
       DATA TDT/.6666667/,ALP/1.2/,BET/-0.4/,DEL/32500./,EP/2.5/
```

```
      DATA ROORG/.01/,RIORG/.0039/,ANVAL/0.9/
      SBR=3.*.00627/ROORG
      DSLAM=SBR*(FBRN**TDT*ALP*PRES**(BET+ANVAL)+
     1          (1.-FBRN)**TDT*DEL*PRES**(EP+ANVAL))
      FBRN=FBRN+DT*DSLAM
      FBRN=AMIN1(FBRN,1.)
      RETURN
      END
```

DISTRIBUTION

	Copies
OUSDRE/R&AT-MST Attn: R. Siewart The Pentagon Washington, DC 20301	1
OUSDRE/TWP-NW&M Attn: D. Anderson The Pentagon Washington, DC 20301	1
OUSDRE/TWP-OM Attn: G. Kopcsak The Pentagon Washington, DC 20301	1
Defense Science Board Attn: C. Fowler The Pentagon Washington, DC 20301	1
USD(A)/DDRE (R/AT/ET) Staff Specialist for Weapons Technology Attn: R. Menz The Pentagon Washington, DC 20301	1
Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
Director Defense Research and Engineering Attn: Library Washington, DC 20305	1
Director Defense Advanced Research Projects Agency Attn: Library 1400 Wilson Blvd. Arlington, VA 22209	1
Institute for Defense Analyses Attn: Technical Library 1801 N. Beauregard St. Alexandria, VA 22311	1
Director Defense Nuclear Agency Attn: Technical Library Washington, DC 20305	1
Chairman Department of Defense Explosives Safety Board Attn: 6-A-145 DDESB-KT Hoffman Building 1 2461 Eisenhower Avenue Alexandria, VA 22331	1 1
OASN/RE&S - Surface Warfare - Air Warfare - Subs/ASW Navy Department Washington, DC 20301	1 1 1
Office of the Chief of Naval Research Attn: ONR 1132P (R. Miller) ONT 20T (L. V. Schmidt) ONT 21 (E. Zimet) ONT 213 (D. Siegel) ONT 23 (A. Faulstich) ONT 232 (D. Houser) 800 N. Quincy Street, BCT 1 Arlington, VA 22217-5000	1 1 1 1 1 1
Commander Center for Naval Analyses Attn: Technical Library 2000 N. Beauregard Street Alexandria, VA 22311	1

DISTRIBUTION (Cont.)

	Copies
Commanding Officer Naval Research Laboratory Attn: Technical Library Washington, DC 20375	1
Commander Naval Air Systems Command Attn: Technical Library Washington, DC 20361	1
Commander Naval Sea Systems Command Attn: SEA-66I (R. Bowen) Washington, DC 20362-5105	1
Commander Space and Naval Warfare Systems Command Attn: SPAWAR-05 Washington, DC 20363-5100	1
Commanding Officer Naval Coastal Systems Center Attn: Technical Library Panama City, FL 32407-5000	1
Commander David Taylor Research Center Attn: Technical Library S. Wang Bethesda, MD 20084	1 1
Commander David Taylor Research Center Attn: Code 177 Technical Library Portsmouth, VA 23709	1 1
Commander Naval Ocean Systems Center Attn: Technical Library San Diego, CA 92152	1
Commander Naval Underwater Systems Center Attn: Technical Library Code 363 (R. Nadolink) Newport, RI 02840	1 1
Commander Naval Weapons Center Attn: Code 38 (R. Derr) Code 389 (T. Boggs) Code 32 (E. Lumdstrom Code 326B (L. Josephson) Technical Library China Lake, CA 93555	1 1 1 1 1
Commanding Officer Naval Amphibious Base, Coronado Attn: RDT Officer SEAL Team Underwater Demolition Team San Diego, CA 92155	1 1 1
Commanding Officer Naval Amphibious Base, Little Creek Attn: RDT Officer Norfolk, VA 23511	1
Commanding General Marine Corps Development and Education Command Attn: Library Marine Corps Landing Force Development Center Quantico, VA 22134	1
Commanding Officer Naval Explosive Ordnance Disposal Technology Center Attn: Technical Library Indian Head, MD 20640	1
Commanding Officer Naval Intelligence Support Center 4301 Suitland Road Washington, DC 20390-5140	1
Commander Pacific Missile Test Center Attn: Code 2145 Point Mugu, CA 93042	1

DISTRIBUTION (Cont.)

	Copies
Commanding Officer	
Naval Ordnance Station	
Attn: Code 2730D	1
Technical Library	1
J. Chang	1
P. Dendor	1
L. Newman	1
Indian Head, MD 20640-5000	
Superintendent	
Naval Postgraduate School	
Attn: Library	1
Monterey, CA 93940	
Commanding Officer	
SEAL Team 2	
FPO New York 09501-4633	1
Commanding Officer	
Naval Ship Weapons Systems Engineering Station	
Port Hueneme, CA 93043	1
Commanding Officer	
Naval Undersea Warfare Engineering Station	
Keyport, WA 98345	1
President	
Naval War College	
Attn: Technical Library	1
Newport, RI 02841	
Commander	
Naval Weapons Evaluation Facility	
Kirtland Air Force Base	
Albuquerque, NM 87117	1
Commanding Officer	
Naval Weapons Station	
Attn: Code 321 (M. Bucher)	1
Concord, CA 94520-5000	
Commanding Officer	
Naval Weapons Station	
Attn: Code 470A	1
Library	1
Yorktown, VA 23691-5000	
Commanding Officer	
Naval Weapons Support Center	
Attn: Code 3031 (E. Neal)	1
Code 50D (A. Norris)	1
Code 505 (J. E. Short)	1
Code 90 (A. E. Whitner)	1
Crane, IN 47522	
Army Armament Munitions and Chemical Command	
Attn: DRSAR-IRC	1
DRSAR-LEM (R. Freeman)	1
DRSAR-SF (R. Young)	1
Rock Island, IL 61299-6000	
U.S. Army Armament Research, Development and Engineering Center	
Attn: Technical Library	1
Dover, NJ 07806-5000	
U. S. Army Ballistic Research Laboratory	
Attn: DRDAR-BLP	1
DRDAR-BLT (R. Frey)	1
SLCRBR-IB-I (P. Kaste)	1
Technical Library	1
Aberdeen Proving Ground, MD 21005	
Commander	
USA Chemical Research, Development and Engineering Center	
Attn: SMCCR-DDP	1
Aberdeen Proving Ground, MD 21010-5423	
Army Environmental Hygience Agency	
Attn: HSHB-EA-A	1
Aberdeen Proving Ground, MD 21005	
Commanding Officer	
Harry Diamond Laboratories	
Attn: Library	1
2800 Powder Mill Road	
Adelphi, MD 20783	

DISTRIBUTION (Cont.)

	Copies
Army Medical Bioengineering Research and Development Laboratory	
Attn: J. Barkeley	1
Fort Dietrick, MD 21701	
Commander	
U.S. Army Research Office	
Attn: G.R. Husk	1
P.O. Box 12211	
Research Triangle Park, NC 27709-2211	
Army Toxic and Hazardous Materials Agency	
Attn: DRXTH-TE-D	1
Aberdeen Proving Ground, MD 21005	
Air Force Armament Division	
Attn: AFATL/MNE	1
AFATL/MNW	1
AFATL/DLODL	1
Library	1
Eglin Air Force Base, FL 32542-6009	
Air Force Office of Scientific Research	
Attn: T. Matusko	1
Bolling Air Force Base	
Washington, DC 20332	
Lawrence Livermore National Laboratory	
Attn: Technical Library	1
M. Finger	1
C. Tarver	1
E. Lee	1
P.O. Box 808	
Livermore, CA 94550	
Los Alamos National Laboratory	
Attn: Library	1
J. Repa	1
P. Howe	1
P. Tang	1
A. Bowman	1
C. Forest	1
P.O. Box 1663	
Los Alamos, NM 87545	

	Copies
Sandia National Laboratories	
Attn: Technical Library	1
M Baer	1
Albuquerque, NM 87185	
Sandia National Laboratory	
Attn: Technical Library	1
P.O. Box 969	
Livermore, CA 94550-0096	
Argonne National Laboratory	
Attn: Records Control	1
Richard Anderson	1
Technical Library	1
9700 South Cass Avenue	
Argonne, IL 60439	
The Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency	
Attn: T. W. Christian	1
Johns Hopkins Road	
Laurel, MD 20707	
The Johns Hopkins University Applied Physics Laboratory	
Attn: Technical Library	1
Johns Hopkins Road	
Laurel, MD 20707	
New Mexico Institute of Mining Technology	
Attn: Code TERA (T. Joyner)	1
Code CETR (P. Persson)	1
Socorro, NM 87801	
Applied Research Laboratory Pennsylvania State University	
Attn: Library	1
E. Liska	1
P.O. Box 30, University Park	
State College, PA 16801	

DISTRIBUTION (Cont.)

		Copies
Internal Distribution:		
D4		1
E231		2
E232		3
G22	(W. Holt)	1
G22	(M. Vittoria)	1
R		1
R10		1
R101	(L. Roslund)	1
R10A		1
R10C	(R. Doherty)	1
R12		1
R12	(D. Betancourt)	1
R12	(D. Chung)	1
R12	(L. Hudson III)	10
R12	(L. Mensi)	1
R12	(P. Walter)	1
R13		1
R13	(R. Guirguis)	1
R13	(P. Miller)	1
R13	(K. Kim)	2
R13	(C. Coffey)	1
R13	(H. Sandusky)	1
R13	(D. Tasker)	1
R13	(E. Lemar)	1
R13	(J. Forbes)	1
R13	(R. Bernecker)	1
R13	(G. Sutherland)	1
R14	(H. Mair)	1
R44	(C. Hsieh)	1
U12	(N. Hinckley)	1
U12	(W. Walker)	1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	11 September 1990	Final/May 1990-June 1990

4. TITLE AND SUBTITLE
Program to Produce Tabulated Data Set Describing NSWC Burn Model for Hydrodynamic Computations

5. FUNDING NUMBERS
PE 62314N PR-RJ14J12
TA-NS3A WU-R4TBD

6. AUTHOR(S)
Lewis C. Hudson III and Kibong Kim.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center
10901 New Hampshire Avenue
Silver Spring MD 20903-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NAVSWC TR 90-364

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Technology
Washington, DC 20362-5105

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The concepts of the NSWC Burn Model are put into a genera purpose program which runs the one-dimensional hollow sphere pore collapse model for a given input pressure. The general purpose program is run for a series of pressures and the results, at specified intervals, are saved. Other programs which normalize and create FORTRAN statements for inclusion of the tabulated data set into any one-, two-, or three-dimensional hydrocode are presented. The result is an indirect way of describing the NSWC Burn Model via a tabulated data set for use in hydroynamic computations.

14. SUBJECT TERMS
NSWC Kim Burn Model
FORTRAN
PBX 9404
Composite explosives
Hydrocode

15. NUMBER OF PAGES
43

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and its title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	**PR**	- Project
G	- Grant	**TA**	- Task
PE	- Program Element	**WU**	- Work Unit Accession No.

BLOCK 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If Known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with ...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD	- See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE	- See authorities.
NASA	- See Handbook NHB 2200.2
NTIS	- Leave blank.

Block 12b. Distribution Code.

DOD	- Leave blank.
DOE	- Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA	- Leave blank.
NTIS	- Leave blank.

Block 13. Abstract. Include a brief ***(Maximum 200 words)*** factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code ***(NTIS only)***

Blocks 17.-19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.