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MECHANICAL WORK ENERGY FOR
SODIUM-FUEL THERMAL INTERACTION

June 1971

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UNITED STATES ATOMIC ENERGY COMMISSION

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A. Padilla, Jr.

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MECHANICAL WORK ENERGY FOR SODIUM-FUEL THERMAL INTERACTION

ABSTRACT

Methods for calculating the mechanical work energy in hypothetical maximum accidents for sodium-cooled fast reactors are reviewed with particular emphasis on the basis for sodium vapor explosions. Three methods for analyzing the thermal interaction of molten fuel with sodium are presented: SOCCOOL-I, SOCCOOL-II, and SOCCOOL-IIA.

SOCOOL-I utilizes a thermodynamic approach. Molten fuel and sodium are assumed to attain instantaneous thermal equilibrium. The resulting expansion of the sodium is calculated by assuming either (a) an infinite rate of heat transfer between the fuel and the sodium during the expansion or (b) no heat transfer. The properties of sodium above the critical point is obtained by use of corresponding states theory.

SOCOOL-II calculates the rate of heat transfer from a spherical molten fuel particle to the sodium using an acoustic constraint. Heat transfer is assumed to be negligible once vaporization is initiated. SOCCOOL-IIA determines the kinetic energy in the coolant slug above the core for adiabatic sodium expansion resulting from thermal interactions occurring at discrete arbitrary times.

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I. INTRODUCTION

Hypothetical maximum accidents are analyzed in order to assess the adequacy of the reactor containment to withstand the consequences even though these accidents cannot be identified with credible initiating mechanisms. A considerable amount of energy may be generated and deposited in core materials. Rapid release of a portion of this stored energy could result in mechanical damage to reactor and primary system components, thereby increasing the potential for escape of radionuclides to containment barriers.

A. Methods for Calculation of Work Energy

Methods for calculating the conversion of stored thermal energy into mechanical work energy can be arbitrarily divided into three categories:

- efficiency and threshold models
- fuel expansion models, and
- sodium expansion models

The simplest method is to assume an efficiency factor or conversion efficiency; that is, a certain fraction of the total energy generated during the accident is assumed to be converted to mechanical work. This factor can be estimated from either analysis or experimental data. For example, the efficiency factor for the FARET reactor⁽¹⁾ was chosen as 10% of the total energy generated during the accident based on calculations with the AX-1 disassembly code. Another approach is to assume that the energy generated above some threshold can be converted to mechanical work. For the EBR-II reactor⁽²⁾, the threshold was taken as the "threshold" in the fuel equation of state and in the analysis of the SL-1 accident⁽³⁾, the threshold was taken as the fuel melting point. In both cases, the energy above the threshold was converted to an equivalent amount of TNT and the characteristics of the TNT explosion was used to estimate the mechanical damage.

If the core is voided of coolant during the accident, expansion of the extremely hot fuel may be the mechanism for causing mechanical damage.

If it is assumed that the expanding fuel does not lose any energy by heat transfer, a thermodynamic upper limit for the mechanical work energy can be obtained from an isentropic expansion process. This upper limit has been compared to the results of calculations using the AX-1 disassembly code⁽⁴⁾. The isentropic fuel expansion was used in the safety analyses for the Fermi⁽⁵⁾ and SEFOR⁽⁶⁾ reactors.

If the coolant is still in the core during the accident, the fuel can come into intimate contact with the coolant as the fuel expands. Since the critical temperature and pressure for the coolant are much lower than those for the fuel, the coolant is a more efficient expansion fluid than the fuel and much higher mechanical work energies can be obtained if a substantial amount of thermal energy can be transferred rapidly from the fuel to the coolant. Thus, in sodium-cooled fast reactors, sodium becomes the potential working fluid and one is concerned with sodium vapor explosions. Before launching into the details of predicting the consequences of sodium vapor explosions, it might be useful to review the historical precedent for using vapor explosions to determine the mechanical work energy.

B. Vapor Explosions

The possibility of violent steam explosions when molten metals, such as aluminum⁽⁷⁾ and steel⁽⁸⁾, come into contact with water have been known for years. Explosions of this type have also been experienced with non-metals, such as the interaction of water with molten smelt (mixture of sodium carbonate and sodium sulfide) in the paper pulp industry⁽⁹⁾.

Destructive pressures which destroyed the aluminum-plate reactors BORAX-I⁽¹⁰⁾, SL-1⁽¹¹⁾, and SPERT-ID⁽¹²⁾ during meltdown power excursions are believed to have been caused by steam explosions. The efficient dispersal of molten aluminum into the water was probably caused by partial fuel vaporization in the cases of BORAX-I and SL-1. Although fuel vaporization temperatures were not attained in the case of SPERT-ID, experiments have shown that the water impact pressure from vapor collapse could have produced the delayed dispersal and high pressures which occurred in that reactor⁽¹³⁾.

The possibility of sodium vapor explosions in LMFBR accidents was pointed out by Judd⁽¹⁴⁾ and Hicks and Menzies⁽¹⁵⁾ in 1965. Violent-appearing thermal interactions but of low efficiency have been observed in laboratory experiments in which molten uranium dioxide has been poured into sodium⁽¹⁶⁾. In-reactor meltdown power excursion experiments have yielded more carefully measured conversion efficiencies which are orders of magnitude lower than the thermodynamic upper limit.

II. ANALYTICAL MODELS FOR SODIUM VAPOR EXPLOSIONS

A. Previous Methods

Hicks and Menzies⁽¹⁵⁾ were the first to propose a method for calculating the mechanical work energy from a sodium vapor explosion arising from the thermal interaction of sodium with molten fuel. They assumed somewhat unrealistic conditions of instantaneous mixing of the fuel and sodium and an infinite rate of heat transfer. Thus, the sodium and the fuel attained thermal equilibrium with each other instantaneously after mixing and remained in thermal equilibrium as the mixture was expanded to some terminal pressure. By assuming constant properties for both the sodium and the fuel, they were able to derive a simple limiting expression for calculating the mechanical work energy. They found that the work energy exhibited a maximum as the sodium-to-fuel mass ratio was increased and that this maximum corresponded to complete vaporization of the sodium liquid with insignificant superheating of the vapor.

The method of Hicks and Menzies has been used extensively because of its simplicity and because it is intended to give the thermodynamic upper limit for the mechanical work energy. In order to understand the motivation for development of other models, some of the deficiencies of the Hicks and Menzies should be pointed out:

- By assuming a constant sodium heat of vaporization, the sodium could not be heated above its critical point.
- By assuming a constant fuel specific heat, the fuel heat of fusion could not be taken into account.
- Although it was intended to heat the sodium to thermal equilibrium with the fuel in a constant-volume process, the thermal equilibrium

point is approached along the vapor-pressure curve instead of through the subcooled liquid region.

- Although it may be possible to heat the sodium close to thermal equilibrium with the fuel initially, the continued thermal equilibrium between the fuel and sodium during the expansion becomes less reasonable as the sodium volume becomes very much larger than the fuel volume.

One variation of the Hicks and Menzies approach, sometimes called the "modified Hicks and Menzies" method, is to assume that after the initial thermal equilibrium is attained upon mixing, the heat transfer between the fuel and sodium during the expansion process is negligible due to vapor blanketing⁽¹⁷⁾. For this method, the mechanical work energy also exhibits a maximum as the sodium-to-fuel mass ratio is increased but the maximum does not correspond to any simple mixture condition.

Another modification of the Hicks and Menzies approach has allowed the sodium to be heated above its critical point by accounting for the temperature-dependent sodium heat of vaporization⁽¹⁸⁾.

B. SOCOOL-I

In order to eliminate the deficiencies of the Hicks and Menzies method due to constant properties, the SOCOOL-I model was developed⁽¹⁹⁾. Figure 1 shows the assumed heating and expansion paths on a schematic temperature-entropy diagram for sodium. The sodium is heated from its original temperature T_1 to thermal equilibrium with the molten fuel at T_2 along the vapor pressure curve. For the example chosen, T_2 is above both the sodium critical point and the fuel melting point, which corresponds to a very high initial fuel temperature or a very low sodium-to-fuel mass ratio.

Two extremes can be assumed for the expansion process. If the rate of heat transfer is assumed to be infinite (Hicks and Menzies approach), the sodium can expand from T_2 to the terminal pressure P_3 along the path T_2 - T_3 in three distinct phases. The sodium first expands to the melting

Figure 1. Sodium Heating and Expansion Paths in SOC00L-II Model.

point of the fuel in thermal equilibrium with the molten fuel, then undergoes an isothermal expansion as the fuel solidifies, and finally expands to T_3 in thermal equilibrium with the solid fuel. On the other extreme, if it is assumed that no heat transfer occurs during the expansion phase (modified Hicks and Menzies approach), the sodium expands from T_2 to the terminal pressure P_3 along the path $T_2-T'_3$ corresponding to an isentropic expansion.

When the initial thermal equilibrium point is above the sodium critical point, the expansion process which assumes an infinite rate of heat transfer occurs entirely outside the two-phase region. When the initial thermal equilibrium point is below the sodium critical point, the corresponding expansion process occurs in the two-phase region until all of the liquid is vaporized and then continues in the superheated vapor region.

The SOCOOL-I model accounts for the fuel heat of fusion and allows for variable specific heats of the molten and solid fuel. The sodium properties proposed by Golden and Tokar⁽²⁰⁾ are used up to 2500°F and the theory of corresponding states⁽²¹⁾ is used above the sodium critical point. Between 2500°F and the sodium critical point, the heat of vaporization and the vapor and liquid densities proposed by Miller⁽²²⁾ are used to extrapolate the properties proposed by Golden and Tokar. A more complete discussion of sodium properties is contained in Appendix A.

Figure 2 shows some results obtained with the SOCOOL-I model. There are two peaks in the mechanical work energy as the sodium-to-fuel mass ratio is increased. The second peak, which appears to be the larger, is associated with the initial thermal equilibrium occurring at the sodium critical point. Some of the oscillations in the curves are associated with the prediction of the rapidly changing sodium properties near the critical point.

Since the mechanical work energy for the isentropic expansion process is substantially lower than for the thermal equilibrium expansion process, a significant gain can be made by showing that the thermal equilibrium expansion process is very unlikely. Figure 3 shows the results of a trial-

FIGURE 2. Effect of Sodium-To-Fuel Mass Ratio on Mechanical Work Energy.

FIGURE 3. Effect of Heat Transfer on Expansion Process.

and-error technique in which SOC00L-I calculations were matched with a transient heat conduction calculation⁽²³⁾. These results indicate that the fuel particle size has to be of the order of 1 micron to approach the thermal equilibrium expansion and that the expansion is nearly adiabatic for fuel particles of the order of 100 microns.

C. SOC00L-II

A logical step in the development of the SOC00L model was to do away with the assumption that the sodium would be heated to thermal equilibrium with the fuel initially, and this led to the development of the SOC00L-II model.

In the SOC00L-II model (see Figure 4), it is assumed that the molten fuel is instantaneously fragmented into spherical particles and uniformly dispersed in the sodium. The mixing region is surrounded by unheated liquid and there is no heat transfer between these two regions. If a substantial amount of heat transfer occurs before the acoustic time period, which is the time for a pressure wave to travel outward and return as a rarefaction wave, the expansion of the heated liquid in the mixing region is restrained by the unheated liquid resulting in high pressures which suppress normal boiling. The mixing region is under acoustic restraint, the unheated liquid can be considered to be compressible, and the expansion of the heated liquid can be approximated by the one-dimensional acoustic equation⁽²⁴⁾. Vaporization can take place when sufficient expansion relieves the high pressures generated by the rapid heating or upon the arrival of the rarefaction wave which "unloads" the high pressures. In either case, the heated liquid may be superheated by many hundreds of degrees over the normal boiling temperature.

The rate of heat transfer is determined by considering a single spherical fuel particle concentrically surrounded by sodium. The parabolic heat conduction equation with internal heat generation,

$$\rho c_p \frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial r^2} + \frac{2}{r} \frac{\partial T}{\partial r} \right) + Q''' \quad (1)$$

is solved using an implicit numerical technique assuming that the thermal

$$\tau_{\text{ACOUSTIC}} = \frac{2L}{c_0}$$

ACOUSTIC RESTRAINT

$$t < \tau_{\text{ACOUSTIC}}$$

UNHEATED LIQUID
COMPRESSIBLE

$$\frac{dz}{dt} = \frac{P(t) - P_0}{\rho_0 c_0}$$

INERTIAL RESTRAINT

$$t \gg \tau_{\text{ACOUSTIC}}$$

UNHEATED LIQUID
INCOMPRESSIBLE

$$\frac{d^2 z}{dt^2} = \frac{P(t) - P_0}{\rho_0 L}$$

Figure 4. Geometry for SOCOOL-II Model.

resistance at the fuel-sodium interface is negligible. Variable thermal properties for the fuel and sodium are taken into account.

The rate of change of pressure is obtained by starting with the general thermodynamic relationship,

$$dP = \left(\frac{\partial P}{\partial T} \right)_V dT + \left(\frac{\partial P}{\partial V} \right)_T dV \quad (2)$$

which becomes

$$\frac{dP}{dt} = \gamma_V \frac{dT}{dt} - \frac{1}{\beta_T V} \frac{dV}{dt} \quad (3)$$

where

$$\gamma_V = \left(\frac{\partial P}{\partial T} \right)_V = \text{thermal pressure coefficient}$$

$$\beta_T = - \frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T = \text{isothermal compressibility} \quad (4)$$

The rate of change of temperature, $\frac{dT}{dt}$, is calculated from the heat conduction equation (Equation 1) and the rate of change of volume, $\frac{dV}{dt}$, is calculated from the one-dimensional acoustic equation in Figure 4.

Figure 5 shows some typical results when the SOCCOL-II model is applied to a single fuel subassembly. Initially, the sodium is heated up at essentially constant volume and attains a peak pressure of 4000 atm at 2 μ sec. As the sodium begins to expand, the pressure falls and the vaporization condition is attained at 1.2 msec when the pressure becomes equal to the saturation pressure corresponding to the sodium temperature. For these conditions, the sodium is heated to only 74% of thermal equilibrium with the fuel.

The mechanical work energy is divided into two parts: acoustic work and inertial work. The acoustic work is associated with the compression and expansion of the subcooled liquid until vaporization conditions are attained and is calculated by integrating under the pressure-volume curve until the pressure in the mixing region falls below the sodium vapor

FIGURE 5. Expansion of Sodium.

pressure curve either by gradual expansion or "unloading" by a rarefaction wave. The inertial work is calculated by an isentropic expansion of the superheated sodium.

In the analysis of hypothetical maximum accidents, the amounts of molten fuel and sodium in each fuel subassembly must be predicted by a multi-channel accident analysis model such as the MELT-II/VENUS computational system⁽²⁵⁾. The total mechanical work energy for the entire reactor core can be obtained by summing the contributions from each fuel subassembly.

D. SOC00L-IIA

The SOC00L-I and SOC00L-II models were developed without the benefit of experimental data on the thermal interaction of molten fuel with sodium. Since the development of these two models, several experiments in the TREAT reactor have been carried out by Argonne National Laboratory⁽²⁶⁾. Figure 6 shows the transient pressures which were observed during the last three tests of the sodium piston autoclave in the TREAT reactor. The following qualitative observations can be made:

- The pressure history is characterized by series of sharp pressure pulses rather than a large initial pressurization followed by a gradual decay.
- The series of pressure pulses occur over a considerable time period.
- There appears to be a "ringing" behavior, particularly for the later series of pressure pulses.

The pressure pulses (except for the ringing behavior) are assumed to be individual thermal interactions between small amounts of molten fuel and sodium. The sharp pressure decrease is felt to be indicative of condensation or a heat-transfer cutoff or a combination of both. The large amount of incoherence of the thermal interactions indicate that the assumption of instantaneous mixing of the molten fuel and sodium may be extremely pessimistic.

However, the extrapolation of the TREAT data to fast reactor hypothet-

FIGURE 6. ANL TREAT Autoclave Data (Results of Pressure Pulses)

ical accident conditions is not straightforward and may not even be possible. In addition to the non-prototypic geometry and conditions, the limitations of the piston autoclave and of the TREAT reactor may require much more understanding in order to apply the data.

Nevertheless, the SOCOOL-IIA was developed to investigate the effect of incoherence on the transient pressures. Figure 7 shows the one-dimensional model used. The core region is assumed to be composed of several regions in which the thermal interaction between molten fuel and sodium can take place at different times. Acoustic-type pressures are neglected and the saturation condition to which the sodium is heated is specified rather than calculated.

As the heated sodium expands (assumed to be an isentropic expansion), it accelerates the coolant above the core towards the reactor cover in a manner similar to a water hammer phenomenon. Deformations in the vessel wall are not taken into account and the pressure in the gas gap region is assumed to remain constant during the acceleration process. The kinetic energy of the coolant slug at the time of impact with the reactor cover represents the work done by the expansion of the heated sodium up to that time. The calculation is terminated at slug impact and does not account for thermal interactions which occur after that time.

Since structural deformations are not taken into account, all of the work done appears as kinetic energy of the coolant slug. However, a substantial amount of energy can be absorbed as the core structures deform and the actual coolant slug kinetic energy will then be smaller than the total work.

Figure 8 shows some typical results where the thermal interaction between the molten fuel and sodium is assumed to occur over several different time scales. The theoretical mechanical work energy calculated on the basis of expansion to 1 atm is the same for all cases but the transient pressures and, therefore, the slug energies at impact are significantly different.

$$\frac{d^2z}{dt^2} = \frac{du}{dt} = \frac{p_{bot} - p_{top}}{M/A} - g$$

FIGURE 7. Geometry for SOCOOL-IIA Model.

FIGURE 8. Effect of Incoherence on Pressure-Time History.

compared to the thermodynamic upper limit are very encouraging. Further experimental and analytical efforts currently in progress should provide an understanding of the basic phenomena which prevent the thermal interaction of molten core materials with sodium from becoming a sodium vapor explosion.

III. SUMMARY

Three models for predicting the mechanical work energy based on the thermal interaction between molten fuel and sodium have been developed and compared. The trend has been from a thermodynamic upper limit model (SOCOOL-I), to the use of a conservative rate-limited process, and finally to an initial attempt to utilize the results of recent experiments. The further development of analytical models should consider the following phenomena which could have significant effects on the thermal interaction process:

- The effect of voids on both compressibility and heat transfer.
- The rate of fragmentation and mixing of molten core materials into sodium.
- The incoherence of the thermal interactions between different regions of the core.
- A consistent set of thermophysical properties for sodium in the subcooled liquid, superheated vapor, two-phase mixture, and supercritical fluid.
- The effect of further heat transfer from the molten fuel to the sodium after vaporization and/or acoustic unloading and the effect of condensation of sodium vapor on core structures and/or subcooled liquid.

The experimental data which show very low conversion efficiencies

NOMENCLATURE

c_o	Sonic velocity, cm/sec
c_p	Heat capacity at constant pressure, j/g-°K
c_v	Heat capacity at constant volume, j/g-°
H	Enthalpy, j/g
ΔH_{vap}	Latent heat of vaporization, j/g
P	Pressure, atm
R	Gas constant, atm-cc/g mole - °K
T	Temperature, °K
t	Time, sec
U	Internal energy, j/g
V	Volume, cc
Z	Compressibility factor

Greek Symbols

α_p	Thermal expansion coefficient, °K ⁻¹
β_s	Adiabatic compressibility, atm ⁻¹
β_T	Isothermal compressibility, atm ⁻¹
γ_v	Thermal pressure coefficient, atm/°K
ρ	Density, g/cc

Subscripts

c	At the critical point
liq	Liquid property
sat	Saturation condition
vap	Vapor property

REFERENCES

1. J. D. Geier, "Fast Reactor Test Facility (FARET), Volume II - Summary of Preliminary Safety Analysis", ANL-7168, Argonne National Laboratory, April, 1966.
2. L. J. Koch, et al., "Hazard Summary Report - Experimental Breeder Reactor-II (EBR-II)", ANL-5719, Argonne National Laboratory, May, 1957.
3. J. F. Proctor, "Adequacy of Explosion-Response Data in Estimating Reactor-Vessel Damage", Nuclear Safety, Vol. 8, No. 6, November-December, 1967.
4. V. Z. Jankus, "A Theoretical Study of Destructive Nuclear Bursts in Fast Power Reactors", ANL-6512, Argonne National Laboratory, February, 1962.
5. "Enrico Fermi Atomic Power Plant, Technical Information and Hazards Summary Report, Part B, Volume 7", NP-11526, 1961, Available from Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia.
6. "Preliminary Safeguards Summary Report, Southwest Experimental Fast Oxide Reactor, Part I", NP-15077, General Electric Company, May, 1965.
7. G. Long, "Explosions of Molten Aluminum in Water - Cause and Prevention", Metal Progress, 71, 107 (May, 1957).
8. S. G. Lipsett, "Explosions from Molten Materials and Water", Fire Technology, 2, 118 (1966).
9. W. Nelson and E. H. Kennedy, "What Causes Kraft Dissolving Tank Explosions", Paper Trade Journal 140 (29), 50 (July, 1966).
10. J. R. Dietrich, "Experimental Investigation of the Self Limitation of Power During Reactivity Transients in a Subcooled, Water-Moderated Reactor, Borax-I Experiment", ANL-5323, March, 1957.
11. General Electric Co., "Final Report of SL-I Recovery Operation", IDO-19311, July, 1962.
12. R. W. Miller, Alain Sola, and R. K. McCardell, "Report of the SPERT I Destructive Test Program on an Aluminum, Plate-Type Water-Moderated Reactor, IDO-16883, June, 1964.
13. "Kinetic Studies of Heterogeneous Water Reactors, Annual Summary Report 1966", USAEC Report STL-372-50, TRW Systems, December, 1966.

REFERENCES (Continued)

14. A. M. Judd, "Loss-of-Coolant Accidents in a Large Sodium-Cooled Fast Reactor", Proceedings of the Conference on Safety, Fuels, and Core Design in Large Fast Power Reactors, October 11-14, 1965, ANL-7120.
15. E. P. Hicks and D. C. Menzies, "Theoretical Studies on the Fast Reactor Maximum Accident", Proceedings of the Conference on Safety, Fuels, and Core Design in Large Fast Power Reactors, October 11-14, 1965, ANL-7120, Argonne National Laboratory.
16. D. R. Armstrong, F. J. Testa, and D. Raridon, Jr., "Molten UO_2 -Sodium Dropping Experiments", Trans. Am. Nucl. Soc., 13, 660 (1970).²
17. A. R. Edwards, "Thermodynamic Limits on the Conversion of Heat to Mechanical Energy", Safeguards Division, A.H.S.B., Risley, England.
18. A. E. Klickman, "Summary of Energy Release Analyses of the Hypothetical Meltdown Design Accident for Core A of the Enrico Fermi Reactor", APDA-LA-7, Atomic Power Development Associates, Inc., July, 1969.
19. A. E. Waltar, R. A. Harris, and A. Padilla, Jr., "Considerations of Sodium Conditions and Molten Fuel/Sodium Interactions for Fast Reactor Excursion Calculations", ANS Transactions, Vol. 11, No. 2, November, 1968.
20. G. H. Golden and J. V. Tokar, "Thermophysical Properties of Sodium", ANL-7323, Argonne National Laboratory, August, 1967.
21. O. A. Hougen, K. M. Watson, and R. A. Ragatz, Chemical Process Principles, Part II, Thermodynamics, John Wiley & Sons, Inc., New York, 1959, p. 569.
22. D. Miller, A. B. Cohen, and C. E. Dickerman, "Estimation of Vapor and Liquid Density and Heat of Vaporization of Alkali Metals to the Critical Point", Paper presented at the International Conference on the Safety of Fast Breeder Reactors, Aix-en-Provence, France, September 19-22, 1967.
23. A. Padilla, Jr., "Lecture Series, Fast Reactor Safety Technology and Practices, Volume II - Accident Analysis, Number XVII - Energy Release Mechanisms", BNWL-SA-3093, Volume II, March, 1970.
24. R. H. Cole, Underwater Explosions, Dover Publications, Inc., New York, 1958, p. 19.
25. A. E. Waltar and W. T. Sha, "A New Computational System for Fast Reactor Accident Investigation", ANS Transactions, Vol. 13, No. 1, June, 1970.

REFERENCES (Continued)

26. Reactor Development Program Progress Report, January 1971, ANL-7776, p. 119.
27. B. J. McBride et al., "Thermodynamic Properties to 6000 °K for 210 Substances Involving the First 18 Elements", NASA SP-3001, National Aeronautics and Space Administration, 1963.
28. A. M. Judd, "Calculation of the Thermodynamic Efficiency of Molten Fuel-Coolant Interactions", Trans. Am. Nucl. Soc., 13, 369 (1970).
29. J. L. Oldham, "Thermodynamic Properties of Sodium and Potassium", UCID-15271, Lawrence Radiation Lab., February 1967.

APPENDIX A
SODIUM PROPERTIES

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SODIUM PROPERTIES

1. Critical Constants

The critical constants (pressure, temperature, density) must be specified for SOC00L-I and SOC00L-II. However, SOC00L-IIA uses the critical constants suggested by Miller⁽²²⁾.

2. Enthalpy

The saturation liquid and vapor enthalpies in ANL-7323⁽²⁰⁾ are used up to 2500 °F. Beyond 2500 °F, the curve of the average enthalpy (one-half of the sum of vapor plus liquid) was linearly extrapolated to the critical point and the heat of vaporization suggested by Miller⁽²²⁾ was used:

$$\frac{\Delta H_{\text{vap}}}{RT} = 4.83 \left(1 - \frac{T}{T_c} \right)^{.377} \quad (\text{A-1})$$

Using Equation (A-1), the saturation liquid and vapor enthalpies at 2500 °F do not agree exactly with the values in ANL-7323. In SOC00L-II and SOC00L-IIA, the constants in Equation (A-1) were adjusted so that the values and the slopes of the curves approaching 2500 °F from above and below are the same.

In SOC00L-I, the theory of corresponding states is used above the critical point. In addition to the critical constants, the thermodynamic properties for the ideal sodium gas are required for the corresponding states calculations. These properties are determined at the critical point: using the predicted sodium enthalpy at the critical point and the predicted departures from the ideal gas from the corresponding states tables, the enthalpy of the ideal sodium gas can be calculated. Using the heat capacity of the ideal sodium gas (assumed to be 5 cal/mole-°K⁽²⁷⁾), the enthalpy of the ideal sodium gas at any other temperature can be determined.

3. Entropy

The saturation liquid and vapor enthalpies in ANL-7323 are used up to 2500 °F. Beyond 2500 °F, the curve of the average entropy (one-half the sum of vapor plus liquid) is assumed to be vertical up to the critical point and the entropy of vaporization, $\Delta H_{\text{vap}}/T$, is obtained using Equation (A-1).

In SOC00L-I, the theory of corresponding states is used above the critical point and the entropies are determined in the same way as previously discussed for the enthalpies.

4. Vapor Pressure

The vapor pressures in ANL-7323 are used up to 2500 °F. Beyond 2500 °F, the 2500 °F point and the critical point are used to determine the constants A and B in an empirical equation:

$$\ln P = A - \frac{B}{T}. \quad (\text{A-2})$$

5. Vapor and Liquid Densities

The saturation vapor and liquid densities in ANL-7323 are used up to 2500 °F. Between 2500 °F and the critical point, the densities suggested by Miller⁽²²⁾ were used:

$$1 - \frac{\rho_{\text{vap}}}{\rho_c} = 1.422 \left(1 - \frac{T}{T_c} \right)^{.389} \quad (\text{A-3})$$

$$\frac{\rho_{\text{liq}}}{\rho_c} - 1 = 3.982 \left(1 - \frac{T}{T_c} \right)^{.5435} \quad (\text{A-4})$$

Using Equations (A-3) and (A-4), the saturation densities at 2500 °F do not agree exactly with the values in ANL-7323. In SOC00L-II and SOC00L-IIA, the constants in Equations (A-3) and (A-4) were adjusted so that the values and the slopes of the curves approaching 2500 °F from above and below are the same.

In SOC00L-I, the theory of corresponding states is used above the critical point to determine the compressibility factor Z for use in the equation:

$$V = ZRT/P \quad (A-5)$$

where

$$V = \text{Specific volume} = 1/\rho$$

6. Internal Energy

The internal energy is calculated from properties previously determined using the thermodynamic relationship:

$$U = H - P/\rho \quad (A-6)$$

7. Isothermal Compressibility and Thermal Pressure Coefficient

a. Saturated Liquid

The technique recommended in ANL-7323 can be used as one of the options in SOC00L-II:

$$\alpha_{\text{sat}} = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_{\text{sat}} \quad (A-7)$$

$$\beta_{\text{s,sat}} = 1/\rho_{\text{sat}} c_{\text{o,sat}}^2 \quad (A-8)$$

$$\beta_{\text{T,sat}} = \beta_{\text{s,sat}} + \frac{T\alpha_{\text{sat}}^2}{\rho_{\text{sat}} c_p} \quad (A-9)$$

$$\gamma_{\text{v,sat}} = \frac{\alpha_{\text{sat}}}{\beta_{\text{T,sat}}} \quad (A-10)$$

b. Subcooled Liquid

The values calculated by Equations (A-9) and (A-10) can be extrapolated to the subcooled liquid using the following equations:

$$c_{\text{o}}^2 = c_{\text{o,sat}}^2 \left(\frac{\rho}{\rho_{\text{sat}}} \right)^{2\gamma} \quad (A-11)$$

where

$$\gamma = \frac{\alpha_{\text{sat}}}{\rho_{\text{sat}} c_p \beta_{s,\text{sat}}} \quad (\text{A-12})$$

$$\beta_s = 1/\rho c_0^2 \quad (\text{A-13})$$

$$\alpha_p = \alpha_{\text{sat}} + \beta_{T,\text{sat}} \left(\frac{\partial P}{\partial T} \right)_{\text{sat}} \quad (\text{A-14})$$

$$\beta_T = \beta_s + \frac{T \alpha_p^2}{\rho c_p} \quad (\text{A-15})$$

$$\gamma_V = \alpha_p / \beta_T \quad (\text{A-16})$$

c. Himpan Equation of State⁽²⁸⁾

The Himpan equation of state can be differentiated as one of the options in SOC00L-II:

$$\left[P + \frac{a}{(V-b)(TV-c)} \right] (V-d) = RT \quad (\text{A-17})$$

Where a,b,c,d are constant.

$$\beta_T = - \frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T = \frac{RT}{V(V-d)^2} - \frac{a}{V(V-b)(TV-c)} \left(\frac{1}{V-b} + \frac{T}{TV-c} \right) \quad (\text{A-18})$$

$$\gamma_V = \left(\frac{\partial P}{\partial T} \right)_V = \frac{R}{V-d} + \frac{aV}{(V-b)(TV-c)^2} \quad (\text{A-19})$$

8. Heat Capacities

a. Constant Pressure

The saturation values in ANL-7323 are used up to 2500 °F. Beyond 2500 °F, the enthalpy curve is differentiated

$$c_p = \left(\frac{\partial H}{\partial T} \right)_p \sim \left(\frac{\partial H}{\partial T} \right)_{\text{sat}} \quad (\text{A-20})$$

b. Constant Volume

The following relationship is used:

$$c_v = \frac{\beta_s}{\beta_T} c_p \quad (\text{A-21})$$

9. Thermal Conductivity (SOC00L-II)

The values in ANL-7323 are used up to 2500 °F. Beyond 2500 °F, the curve is linearly extrapolated to the critical point and assumed to be constant beyond that point.

10. Virial Equation of State

In SOC00L-I, the virial equation of state suggested by Oldham⁽²⁹⁾ has been used to determine the thermodynamic properties of the superheated vapor between 2500 °F and the critical point. Given the temperature and pressure, the enthalpy, entropy, specific volume, and specific heat can be calculated from thermodynamic relationships.

APPENDIX B

FLOW DIAGRAMS

APPENDIX B
FLOW DIAGRAMS

1. SOCCOOL-I

Figure B-1 shows the calling sequence of all the subroutines. A brief description of the function of each subroutine is given below.

DEPART	Determines thermodynamic properties of sodium based on corresponding states theory.
EQUIL	Determines initial thermal equilibrium between the molten fuel and sodium.
HWR	Contains the corresponding states theory tables.
INIT	Sets up the corresponding states theory tables in a common block.
MILLER	Determines thermodynamic properties of sodium below 2500 °F.
NAPROP	Determines thermodynamic properties of sodium between 2500 °F and the critical point.
PRESSS	Determines the pressure when the temperature and entropy are known based on corresponding states theory.
SOCOOL	Main program which reads input data, calls on EQUIL to determine initial thermal equilibrium, calculates expansion processes, and prints output results.
TABLEF	Obtains the interpolated and adjusted value from the corresponding states theory table.
TBLF	Obtains the value in the corresponding states theory table when the reduced temperature and pressure are known.

TEMPP Determines the temperature when the pressure and entropy are known based on corresponding states theory.

VIRIAL Determines the thermodynamic properties of superheated sodium vapor based on the virial equation of state.

FIGURE B-1. Subroutine Calling Sequence for SOC00L-I.

FIGURE B-1. (Continued)

2. SOCCOOL-II

Figure B-2 shows the calling sequence of all the subroutines. A brief description of the function of each subroutine is given below.

BLAST	Calculates the inertial work from the isentropic expansion of sodium.
HEAT	Calculates the temperatures of the molten material and sodium.
PRES	Determines the pressure in the acoustically-restrained mixing region.
PROP	The first section calculates geometric constants and initializes temperatures, properties, and other parameters. The second and third sections determine the thermal properties of the sodium and molten material. The fourth section checks for freezing or melting in the molten material. The fifth section determines the mechanical properties of sodium.
SOCOOL	Main program which reads input data, calls on subroutines to calculate temperatures, pressures, and work, and prints output results.
SPLOTT	Dummy subroutine to handle future capability for plotting of results.

FIGURE B-2. Subroutine Calling Sequence for SOCOOL-II.

3. SOCOOL-IIA

Figure B-3 shows the calling sequence of all the subroutines. A brief description of the function of each subroutine is given below.

PSOLVE Determines the pressure from the known entropy and specific volume based on isentropic expansion or compression of two-phase sodium.

RUNGE Solves a system of first-order differential equations using the fourth-order Runge-Kutta method.

SOCOOL Main program which reads input data, sets up Runge-Kutta calculation, and prints output results.

FIGURE B-3. Subroutine Calling Sequence for SOCOOL-IIA.

APPENDIX C

SAMPLE CASES

APPENDIX C

SAMPLE CASES

A listing of the input data cards followed by the computer print-out for the sample case are provided for each of the SOC00L codes. The input instructions for each code are contained within the program listing (see Appendix D).

a DAY HWR.1
 an XQT SOC00L
 .3884 -.8093E-4 .2927E-7 3040. 280. .548
 408.2 2733. .1818 .27 .909921
 INITIAL SODIUM TEMP=672 K. INITIAL FUEL TEMP=4000 K. MASS RATIO=.0877
 672. 4000. .0877 1.0 3.1E6

C-2

SOC00L-1

INITIAL SODIUM TEMP=672 K. INITIAL FUEL TEMP=4000 K. MASS RATIO=.0877

INITIAL DATA	T (SODIUM) DEG K	T (FUEL) DEG K	P ATM
	672.00	4000.00	1.000

FUEL DATA	TOTAL MASS (GM)	MELT PT DEG K	CP-LIQ J/GM-DEG K	CP-SOLID J/GM-DEG K	HT-FUSION JOULES/GM
	.3100*07	3040.00	.548	.388	280.000

SODIUM DATA	RATIO NA-TO-FUEL	CR PRESSURE ATM	CR TEMP DEG K	CR COMPR FACTOR	CP-IDEAL J/GM-DEG K
	.0877	408.2	2733.00	.27000	.90992

CALCULATED VALUES

STAGE	TEMP	PRESSURE	ENTHALPY	ENTROPY	INTERNAL ENERGY	SPECIFIC VOLUME
1	672.00	.00	886.53	3.610	886.53	1.167
2	3246.43	822.96	6047.21	6.113	5396.08	7.808
3	1154.86	1.00	3598.93	6.113	3395.75	2005.149
4	3040.00	398.34	6816.12	6.523	6021.63	19.684
5	3040.00	44.64	7841.94	7.573	6770.74	236.820
6	2550.00	1.00	7484.39	8.820	6562.15	9101.518

FLOW		NON-FLOW	
WORK	WORK ENERGY	WORK	WORK ENERGY
J/GM	MW-SEC	J/GM	MW-SEC

ISENTROPIC EXPANSION TO INPUT PRESSURE P3	2448.286	665.615	2000.328	543.829
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FRACTION OF SODIUM LIQUIFIED .457737

THERMAL EQUILIBRIUM EXPANSION FOR EQUILIBRIUM ABOVE TC

A) FROM T2 TO FUEL MELTING POINT	664.324	180.610	520.977	141.638
B) ISOTHERMAL EXPANSION DURING FUEL FREEZING	2166.819	589.093	2443.531	664.323
C) FROM FUEL MELTING POINT TO P3	3693.526	1004.159	3842.484	1044.656
TOTAL WORK DONE FOR THIS PATH	6524.670	1773.862	6806.991	1850.617

FRACTION OF FUEL FROZEN .999980

FRACTION OF SODIUM LIQUIFIED .000000

S0000L-1

AN XQT SOCCOL

FUEL DIA=1000 MICRONS. FUEL TEMP=3097 K. SODIUM TEMP=672 K

50	14	9	1	2	2	0	0										
.123333		210.		3967.		3097.		672.		1.		1.	1.-07	1.-02			
.7163		.8564		1.040		0.	2.368+5	2.593-5		10.73		2733.	408.2	.1818			
.0255		8.74		.548		0.	3097.	280.		.0255		8.74	.548	0.			

C-4

SOCCOL-11

FUEL DIA=1000 MICRONS, FUEL TEMP=3097 K, SODIUM TEMP=672 K

C-6

*** INPUT DATA ***

*** INTEGER DATA ***

INTERVALS IN FUEL INTF	INTERVALS IN SODIUM INTNA	TIME STEPS PER DECADE NSTEP	TIME STEPS PER POINT NPRINT	SWITCH FOR SODIUM PROP NAPROP	SWITCH FOR FUEL PROP NFPROP	SWITCH FOR TEMP INPUT NTEMP	NUMBER OF PLOTS NPLOTS
60	14	9	1	2	2	0	0

*** GEOMETRY AND CONDITIONS ***

DIAMETER OF UNIT SPHERE DIA	INTERFACE AREA AREAI	INITIAL SODIUM VOLUME VNAIN	INITIAL FUEL TEMP TFIN	INITIAL SODIUM TEMP TNAIN	INITIAL PRESSURE PIN	FINAL PRESSURE POUT	INITIAL TIME TAUMIN	MAXIMUM TIME TAUMAX
1.23333-01	2.10000+02	3.96700+03	3.09700+03	6.72000+02	1.00000+00	1.00000+00	1.00000-07	1.00000-02

CS

*** SODIUM THERMAL AND MECHANICAL PROPERTIES ***

THERMAL CONDUCTIVITY CONDNA	DENSITY RHONA	CONST-VOL HEAT CAPACITY CVNA	HEAT GENERATION QNA	SONIC VELOCITY SONVEL	ISOTHERMAL COMPRESS BETAT	THERM PRESS COEFFICIENT GAMMAV	CRITICAL TEMPERATURE TC	CRITICAL PRESSURE PC	CRITICAL DENSITY RHOC
7.16300-01	8.56400+01	1.04000+00	0.00000	2.36800+05	2.59300-05	1.07300+01	2.73300+03	4.08200+02	1.81800-01

SOCCOL-11

*** FUEL THERMAL PROPERTIES ***

LIQ THERMAL CONDUCTIVITY CONDF	LIQUID DENSITY RHOF	LIQ C-P HEAT CAPACITY CPF	LIQ HEAT GENERATION OF	MELTING POINT TFMELT	HEAT OF FUSION HFMELT	SOLID THERMAL CONDUCTIVITY CONDFS	SOLID DENSITY RHOFs	SOLID C-P HEAT CAPACITY CPFS	SOLID HEAT GENERATION GFS
2.55000-02	8.74000+00	5.48000-01	0.00000	3.09700+03	2.80000+02	2.55000-02	8.74000+00	5.48000-01	0.00000

FUEL DIA=1000 MICRONS, FUEL TEMP=3097 K, SODIUM TEMP=672 K

*** SUMMARY OF RESULTS ***

	T-F	T-FUEL	T-SODIUM	VELOCITY	VOLUME	PRESSURE	PSAT	A. ENERGY
	1.00-07	3096.9910	682.7156	.1582+04	.3967+04	.3167+03	.6740-03	.2940-00
	2.00-07	3096.9821	691.7894	.3749+04	.3967+04	.7503+03	.8506-03	.3611+01
	3.00-07	3096.9729	699.5616	.5572+04	.3967+04	.1115+04	.1033-02	.1375+02
	4.00-07	3096.9634	706.2912	.7118+04	.3967+04	.1425+04	.1219-02	.3255+02
	5.00-07	3096.9537	712.1773	.8438+04	.3968+04	.1689+04	.1404-02	.6079+02
	6.00-07	3096.9433	717.3744	.9573+04	.3968+04	.1916+04	.1589-02	.9866+02
	7.00-07	3096.9337	722.0039	.1055+05	.3968+04	.2112+04	.1770-02	.1459+03
	8.00-07	3096.9233	726.1617	.1141+05	.3968+04	.2283+04	.1949-02	.2022+03
	9.00-07	3096.9130	729.9243	.1215+05	.3968+04	.2432+04	.2124-02	.2670+03
	1.00-06	3096.9023	733.3534	.1280+05	.3969+04	.2563+04	.2295-02	.3397+03
	2.00-06	3096.8913	734.4270	.1585+05	.3972+04	.3171+04	.3642-02	.1286+04
	3.00-06	3096.8737	769.2823	.1707+05	.3976+04	.3417+04	.4966-02	.2535+04
	4.00-06	3096.8543	781.0184	.1744+05	.3980+04	.3490+04	.6292-02	.3909+04
	5.00-06	3096.8329	791.0301	.1738+05	.3984+04	.3476+04	.7657-02	.5307+04
	6.00-06	3096.8105	800.0093	.1712+05	.3988+04	.3425+04	.9093-02	.6679+04
	7.00-06	3096.1873	808.3277	.1676+05	.3991+04	.3354+04	.1063-01	.8003+04
	8.00-05	3096.0638	816.1988	.1636+05	.3995+04	.3275+04	.1228-01	.9269+04
	9.00-05	3095.9411	823.7517	.1596+05	.3999+04	.3195+04	.1407-01	.1047+05
	1.00-05	3095.8164	831.0683	.1558+05	.4002+04	.3117+04	.1601-01	.1162+05
	2.00-05	3094.5996	897.7017	.1276+05	.4034+04	.2554+04	.4726-01	.2071+05
	3.00-05	3093.4283	958.4366	.1155+05	.4062+04	.2312+04	.1112+00	.2752+05
	4.00-05	3092.3052	1015.0172	.1085+05	.4088+04	.2171+04	.2249-00	.3332+05
	5.00-05	3089.7894	1054.3523	.8654+04	.4111+04	.1732+04	.3511-00	.3794+05
	6.00-05	3013.6127	1082.7817	.6903+04	.4128+04	.1382+04	.4747-00	.4069+05
	7.00-05	3016.4022	1109.6464	.6073+04	.4143+04	.1216+04	.6225-00	.4260+05
	8.00-05	3018.5307	1135.7313	.5665+04	.4156+04	.1134+04	.7999-00	.4417+05
	9.00-05	3020.2063	1161.2079	.5434+04	.4169+04	.1088+04	.1011+01	.4559+05
	1.00-04	3021.5647	1186.1228	.5286+04	.4181+04	.1058+04	.1259+01	.4691+05
	2.00-04	2989.7313	1382.3355	.3706+04	.4282+04	.7417+03	.5365+01	.5619+05
	3.00-04	2973.9140	1520.2317	.2933+04	.4357+04	.5870+03	.1188+02	.6118+05
	4.00-04	2973.1632	1627.3644	.2402+04	.4417+04	.4808+03	.2008+02	.6443+05
	5.00-04	2967.3167	1714.5523	.2046+04	.4468+04	.4095+03	.2932+02	.6670+05
	6.00-04	2964.8737	1788.2296	.1785+04	.4511+04	.3572+03	.3923+02	.6839+05
	7.00-04	2963.6655	1851.4206	.1571+04	.4549+04	.3144+03	.4944+02	.6969+05
	8.00-04	2963.4426	1906.4082	.1399+04	.4583+04	.2799+03	.5971+02	.7071+05
	9.00-04	2958.9296	1955.0269	.1261+04	.4613+04	.2524+03	.6993+02	.7152+05
	1.00-03	2958.4321	1998.5849	.1149+04	.4641+04	.2299+03	.8005+02	.7219+05
	1.68-03	2958.8612	2210.9474	.7129+03	.4779+04	.1427+03	.1433+03	.7475+05

FINAL TEMPERATURE DISTRIBUTION

11-700005

AN XOT SOCOOL

17 PULSES OF 45.4 LB SODIUM AT 1 MSEC INTERVALS. INITIAL PRESSURE = 200 ATM

10	200.	1.	1200.	278000.	10.	1.5	.0005		
	.000	.001	.002	.003	.004	.005	.006	.007	.008
	45.4	45.4	45.4	45.4	45.4	45.4	45.4	45.4	45.4

C-8

SOCOOL-11A

10 PULSES OF 45.4 LB SODIUM AT 1 MSEC INTERVALS. INITIAL PRESSURE = 200 ATM

*** INPUT DATA ***

NO. OF PULSES NPULSE	INITIAL PULSE PIN	GAP PRESSURE PTOP	INITIAL NA TEMP TINIT	COOLANT SLUG MASS SLUG	VESSEL RADIUS RAD	INITIAL GAP GAP	TIME STEP DTAU
10	2.00000+02	1.00000+00	1.20000+03	2.78000+05	1.00000+01	1.50000+00	5.00000-04

PULSE I	TIME TAU(I)	MASS WT(I)
1	.0000	45.40
2	.0010	45.40
3	.0020	45.40
4	.0030	45.40
5	.0040	45.40
6	.0050	45.40
7	.0060	45.40
8	.0070	45.40
9	.0080	45.40
10	.0090	45.40

S0C00L-11A

10 PULSES OF 45.4 LB SODIUM AT 1 MSEC INTERVALS. INITIAL PRESSURE = 200 ATM

*** CALCULATED RESULTS ***

TIME (SEC)	PRESSURE (ATM)	VELOCITY (FT/SEC)	DISTANCE (FT)	VOLUME (CU FT)	ENERGY (MW-SEC)
.0000	200.0	.00	.000	1.74	.00
.0005	187.2	7.47	.002	2.33	.33
.0010	155.7	14.06	.007	4.04	1.16
.0010	184.2	14.06	.007	4.95	1.16
.0015	158.9	20.62	.016	7.69	2.49
.0020	131.8	26.16	.028	11.37	4.01
.0020	154.7	26.16	.028	12.29	4.01
.0025	132.7	31.63	.042	16.84	5.86
.0030	112.2	36.28	.059	22.18	7.71
.0030	130.6	36.28	.059	23.09	7.71
.0035	113.3	40.92	.079	29.17	9.81
.0040	97.8	44.92	.100	35.92	11.82
.0040	112.5	44.92	.100	36.83	11.82
.0045	98.9	48.93	.124	44.21	14.02
.0050	87.0	52.44	.149	52.17	16.11
.0050	98.9	52.44	.149	53.09	16.11
.0055	88.1	55.98	.176	61.61	18.36
.0060	78.6	59.13	.205	70.65	20.48
.0060	88.4	59.13	.205	71.57	20.48
.0065	79.7	62.31	.235	81.11	22.74
.0070	72.0	65.17	.267	91.13	24.88
.0070	80.2	65.17	.267	92.04	24.88
.0075	73.1	68.06	.300	102.51	27.14
.0080	66.7	70.70	.335	113.41	29.28
.0080	73.6	70.70	.335	114.32	29.28
.0085	67.6	73.36	.371	125.64	31.52
.0090	62.3	75.80	.408	137.36	33.66
.0090	68.2	75.80	.408	138.27	33.66
.0095	63.1	78.27	.447	150.37	35.89
.0100	58.6	80.56	.487	162.85	38.01
.0105	54.4	82.68	.527	175.67	40.04
.0110	50.7	84.64	.569	188.82	41.96
.0115	47.4	86.47	.612	202.26	43.80
.0120	44.4	88.18	.656	215.98	45.55
.0125	41.7	89.78	.700	229.95	47.22
.0130	39.2	91.28	.746	244.18	48.81
.0135	37.0	92.69	.792	258.63	50.33
.0140	35.0	94.02	.838	273.29	51.78
.0145	33.2	95.28	.886	288.16	53.18

C-10

S0C00L-11A

.0150	31.5	96.47	.934	303.22	54.51
.0155	30.0	97.60	.982	318.47	55.79
.0160	28.6	98.67	1.031	333.88	57.03
.0165	27.4	99.69	1.081	349.46	58.21
.0170	26.2	100.67	1.131	365.20	59.36
.0175	25.1	101.60	1.181	381.09	60.47
.0180	24.2	102.50	1.232	397.12	61.53
.0185	23.3	103.35	1.284	413.28	62.57
.0190	22.4	104.18	1.336	429.58	63.57
.0195	21.7	104.97	1.388	446.01	64.54
.0200	20.9	105.73	1.441	462.56	65.48
.0205	20.2	106.47	1.494	479.23	66.40
.0210	19.5	107.18	1.547	496.01	67.28

APPENDIX D

PROGRAM LISTINGS

APPENDIX D
PROGRAM LISTINGS

A listing of the program for each of the SOC00L codes is provided.

a FOR SOCOOL

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00100 1* C      SOCOOL I — A PROGRAM TO DETERMINE THE THERMODYNAMIC WORK FOR THE
00100 2* C      EXPANSION OF SODIUM FOLLOWING A MOLTEN FUEL-SODIUM INTERACTION
00100 3* C
00100 4* C      INPUT DATA FOR SOCOOL I
00100 5* C
00100 6* C      CARD 1 FUEL PROPERTIES (8E10.2)
00100 7* C      COL 1-10 CPFS1  CONSTANTS IN THE EQUATION FOR AVG SOLID HEAT CAPACITY
00100 8* C      11-20 CPFS2  CPFS = CPFS1 + CPFS2*(T1+T2) + CPFS3*(T1+T1+T2+T2)
00100 9* C      21-30 CPFS3  CPFS = J/6-DEG K, T1,T2 = DEG K
00100 10* C      31-40 TFM   MELTING POINT, DEG K
00100 11* C      41-50 HFF   HEAT OF FUSION, J/G
00100 12* C      51-60 CPFL1  CONSTANTS IN THE EQUATION FOR AVG LIQUID HEAT CAPACITY
00100 13* C      61-70 CPFL2  CLFL = CPFL1 + CPFL2*(T1+T2) + CPFL3*(T1+T1+T2+T2)
00100 14* C      71-80 CPFL3  CLFL = J/6-DEG K, T1,T2 = DEG K
00100 15* C
00100 16* C      CARD 2 SODIUM PROPERTIES (8E10.2)
00100 17* C      COL 1-10 PC     CRITICAL PRESSURE, ATM
00100 18* C      11-20 TC     CRITICAL TEMPERATURE, DEG K
00100 19* C      21-30 RHOC   CRITICAL DENSITY, G/CC
00100 20* C      31-40 ZC     CRITICAL COMPRESSIBILITY FACTOR
00100 21* C      41-50 CPIDNA  CONSTANT-PRESSURE HEAT CAPACITY OF IDEAL SODIUM GAS
00100 22* C
00100 23* C      CARD 2-1/2 (OPTIONAL)
00100 24* C      COL 1-5 DEBUG  SWITCH TO PRINT DEBUG OUTPUT
00100 25* C
00100 26* C      CARD 3 TITLE
00100 27* C      COL 1-80
00100 28* C
00100 29* C      CARD 4 CONDITIONS AND QUANTITIES (8E10.2)
00100 30* C      COL 1-10 TINA  INITIAL SODIUM TEMPERATURE, DEG K
00100 31* C      11-20 TIF   INITIAL FUEL TEMPERATURE, DEG K
00100 32* C      21-30 RNAFM  SODIUM-TO-FUEL MASS RATIO
00100 33* C      31-40 P3IN   FINAL PRESSURE FOR EXPANSION PROCESS, ATM
00100 34* C      41-50 FMASS  FUEL MASS, G
00100 35* C
00100 36* C      AFTER CARDS 1 AND 2, MULTIPLE CASES CAN BE RUN BY REPEATING
00100 37* C      CARDS 2-1/2 THROUGH 4 AS OFTEN AS NECESSARY
00100 38* C
00100 39* C
00101 40* C      COMMON R, RS, RAT, CAT, CTOJ, P3IN, TNAPMN, TNAPMX, ASAT, BSAT
00103 41* C      COMMON /FUEL/ CPFS1,CPFS2,CPFS3,TFM,HFF,CPFL1,CPFL2,CPFL3,
00103 42* C      1 TIF,FMASS,FFF
00104 43* C      COMMON /SODIUM/ ATUTNA, PC, RHOC, RNAFM, SONASS, TC, TINA, ZC
00105 44* C      COMMON /TAB/ TA,H1A,SLA,VSATA,HGA,SGA,DLA,
00105 45* C      1 PA,ZA,HA,SA,UA,CPIDNA,CVIDNA,
00105 46* C      2 T1,H1,S1,ZC1,P1,U1,D11,D12,
00105 47* C      3 T2,H2,S2,Z2,P2,U2,Q2,V2,

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00105 48*      4          T3=H3.S3.23.P3.U3.D31.D32.
00105 49*      5          T4=H4.S4.24.P4.U4.D41.D42.
00105 50*      6          T5=H5.S5.25.P5.U5.D51.D52.
00105 51*      7          T6=H6.S6.26.P6.U6.D61.D62.
00105 52*      8          T7=H7.S7.27.P7.U7.D71.D72.
00105 53*      9          T8=H8.S8.28.P8.U8.D81.D82
00106 54*      COMMON/SAVE/DEBUG,IERRO,ISTAGE,SAVED(9,50)
00107 55*      COMMON /TABLES/ NTRED, NPRED, TRED(33), PRED(25),
00107 56*      1          DEPZ(33,25), DEPU(33,25), DEPS(33,25), DEPH(33,25),
00107 57*      2          DAZ(33,15), DBZ(33,15), DAU(33,15), OBU(33,15),
00107 58*      3          DAS(33,15), DBS(33,15), DAH(33,15), OBH(33,15)
00110 59*      LOGICAL  DEBUG
00111 60*      LOGICAL  LF/.FALSE./, LT/.TRUE./
00114 61*      LOGICAL  RFL/.TRUE./
00116 62*      DATA  DEBUG /'DEBUG '/
00120 63*      DIMENSION  TITLE(14)
00120 64*      C
00120 65*      C
00120 66*      C      ENTROPY FUNCTION — IDEAL FROM REFERENCE TA, AT TEMPERATURE T, PRESSURE P
00121 67*      S(T,P)=SA+CPIDNA*LOG(T/TA)-RS*LOG(P/PA)
00121 68*      C
00122 69*      1 FORMAT (8E10.2)
00123 70*      2 FORMAT (13A6,A2)
00124 71*      3 FORMAT ('OFUEL DATA',10X'TOTAL',6X'MELT PT',5X'CP-LIQ',
00124 72*      1          5X'CP-SOLID',5X'MT-FUSION'/
00124 73*      2          18X'MASS (GM)',5X'DEG K',4X'J/GM-DEG K',2X'J/GM-DEG K',
00124 74*      3          3X'JOULES/GM'/
00124 75*      4          E26.4,F12.2,F11.3,F12.3,F14.3,E11.4,2E12.4)
00125 76*      4 FORMAT ('OSODIUM DATA',8X'RATIO',4X'CR PRESSURE',3X'CR TEMP',
00125 77*      A          5X'CR COMPR',
00125 78*      1          4X'CP-IDEAL',17X'NA-T0-FUEL',6X'ATM',8X'DEG K',
00125 79*      2          6X'FACTOR',4X'J/GM-DEG K',
00125 80*      3          F25.4,F12.1,F13.2,2F12.5,4E12.4)
00126 81*      5 FORMAT ('OINITIAL DATA',4X'T (SODIUM)',3X'T (FUEL)',5X'P',
00126 82*      1          20X'DEG K',7X'DEG K',6X'ATM',
00126 83*      2          F26.2,F12.2,F9.3)
00127 84*      6 FORMAT ('O34X*CALCULATED VALUES',/' STAGE TEMP PRESSURE'
00127 85*      1          7X'ENTHALPY',12X'ENTROPY',7X'INTERNAL ENERGY'
00127 86*      2          7X'SPECIFIC VOLUME')
00130 87*      7 FORMAT (I4,2F8.2,6F10.2,2F11.2,2X2F11.2)
00131 88*      8 FORMAT(1H1,13A6,A2)
00132 89*      9 FORMAT (I4,2F8.2,F16.2,F19.3,F18.2,F23.3)
00133 90*      10 FORMAT (I4,2F8.2,4F10.2,F16.2,4X2F11.2,2X2F11.2)
00133 91*      C
00134 92*      CALL TRAP ('SOCOOL')
00135 93*      ZERO=0.0
00136 94*      R=1.987
00137 95*      ATWTNA=22.991
00140 96*      RAT=R/ATWTNA

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C/G-DEG K

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00141  97*      CTOJ=4.184      J/CAL
00142  98*      RS=RAT*CTOJ      J/G-DEG K
00143  99*      CAT=CTOJ/ATWTNA      J*M/G-C
00144  100*     TNAPMN=598.      DEG K
00145  101*     TNAPMX=1644.28      DEG K
00146  102*     CALL INIT
00147  103*     CALL ERROUT (2)
00147  104*     C
00147  105*     C      READ THERMODYNAMIC PROPERTIES OF MOLTEN FUEL AND SODIUM
00147  106*     C
00150  107*     READ (5,1) CPFS1,CPFS2,CPFS3,TFM,HFF,CPFL1,CPFL2,CPFL3
00162  108*     READ (5,1) PC,TC,RHOC,ZC,CPIDNA,POVIC
00162  109*     C
00172  110*     CVIDNA = CPIDNA - RS
00172  111*     C      CALCULATE CONSTANTS IN VAPOR PRESSURE EQUATION
00172  112*     C      LOG(PSAT)=ASAT-BSAT/TSAT
00172  113*     C
00173  114*     BSAT=LOG(PC/21.6779)/(1./1644.28-1./TC)
00174  115*     ASAT=LOG(21.6779)+BSAT/1644.28
00174  116*     C
00174  117*     C      READ DEBUG OPTION AND/OR TITLE
00174  118*     C
00175  119*     50 CONTINUE
00176  120*     DEBUG=.FALSE.
00177  121*     60 READ (5,2,END=1000) TITLE
00205  122*     IF (TITLE(1).NE. 'DEBUG') GO TO 70
00207  123*     DEBUG=.TRUE.
00210  124*     GO TO 60
00211  125*     70 PRINT 8, TITLE
00211  126*     C
00211  127*     C      READ INITIAL SODIUM AND FUEL CONDITIONS, SODIUM-TO-FUEL MASS RATIO
00211  128*     C      FINAL PRESSURE AND TOTAL FUEL MASS
00211  129*     C
00217  130*     READ (5,1) TINA,TIF,RNAFM,P3IN,FMASS
00226  131*     SOMASS = RNAFM * FMASS
00227  132*     PRINT 5, TINA,TIF,P3IN
00234  133*     PRINT 3, FMASS,TFM,CPFL1,CPFS1,HFF
00243  134*     PRINT 4, RNAFM,PC,TC,ZC,CPIDNA
00243  135*     C
00252  136*     PRINT 6
00252  137*     C
00252  138*     C      STAGE 1 -- INITIAL SODIUM CONDITIONS
00252  139*     C
00254  140*     P1NA=0.
00255  141*     ISTATE=1
00256  142*     T1=TINA
00257  143*     CALL NAPROP (T1,P1,H1,S1,VG1,HG1,S61,DL1,PSAT1,ZC1)
00260  144*     VLI=1./DL1
00261  145*     U1=H1-1013278*P1/VLI

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DEG K

CC/GM
J/GM

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00262 146* PRINT 9, ISTAGE, T1, P1, H1, S1, U1, VL1
00262 147* C
00262 148* C STAGE 2 -- EQUILIBRIUM BETWEEN MOLTEN FUEL AND SODIUM BEFORE
00262 149* C EXPANSION DETERMINED BY SUBROUTINE EQUIL
00262 150* C T2 ASSUMED TO BE ABOVE CRITICAL POINT
00262 151* C
00273 152* ISTAGE=2
00274 153* CALL EQUIL
00275 154* CALL ERROUT(1)
00276 155* PRINT 9, ISTAGE, T2, P2, H2, S2, U2, V2
00276 156* C
00276 157* C STAGE 3 ADIABATIC EXPANSION TO FINAL PRESSURE P3
00276 158* C P3 IS ASSUMED TO BE LESS THAN OR EQUAL TO PC
00276 159* C
00307 160* ISTAGE=3
00310 161* P3=P3IN
00311 162* S3=S2
00312 163* IF (P3.GT.21.6779) GO TO 320
00312 164* C SATURATION TEMPERATURE AS F(P3), FROM CURVE FIT TO TOKAR-GOLDEN DATA
00314 165* Y=LOG(P3)
00315 166* T3=EXP(7.3896+.12221*Y+.004815*Y**2+.37742E-3*Y**3
00315 167* 1+.20459E-4*Y**4+.52247E-6*Y**5)
00316 168* T3=0.55555555*(T3+.59.69)
00316 169* C** REMAINING SATURATION PROPERTIES
00317 170* CALL NBPROP(T3, P3, HL3, SL3, VLG3, HLG3, SGL3, PSAT3, ZC3)
00320 171* VL3=1./DL3 CC/GM
00321 172* CALL ERROUT(3)
00322 173* GO TO 350
00322 174* C P3 IS BETWEEN 21.6779 ATM AND PC. SOLVE FOR T3 BY TRIAL-AND-ERROR
00323 175* 320 T3=TC
00324 176* 321 P3LAST=P3CALC
00325 177* P3CALC=EXP(ASAT-BSAT/T3)
00326 178* IF (P3CALC.LE.P3) GO TO 330
00330 179* T3=T3-10.
00331 180* GO TO 321
00332 181* 330 T3=T3+10.*(P3-P3CALC)/(P3LAST-P3CALC)
00332 182* C CALCULATE REMAINING SATURATION PROPERTIES
00333 183* CALL MILLER(T3, HL3, HLG3, VL3, VLG3, SL3, SGL3)
00334 184* UL3=HL3-.1013278*P3*VL3 J/GM
00335 185* ULG3=HLG3-.1013278*P3*VLG3 J/GM
00336 186* 350 CONTINUE
00336 187* C** MASS FRACTIONS, LIQUID AND VAPOR
00337 188* FML=(S3-SGL3)/(SL3-SGL3)
00340 189* FMV=1.-FML
00340 190* C** TOTAL ENTHALPY, FLOW WORK, AND NON-FLOW WORK
00341 191* H3=FMV*HL3+FML*HGL3 J/GM
00342 192* UL3=HL3-.1013278*P3*VL3 J/GM
00343 193* UG3=HLG3-.1013278*P3*VLG3 J/GM
00344 194* U3=FMV*UL3+FML*UG3 J/GM

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00345	195*	V3=FML*VL3*FMV*VG3	CC/6M
00346	196*	PRINT 9, ISTAGE,T3,P3,H3,S3,U3,V3	
00357	197*	WNFL3=U2-U3	J/6M
00360	198*	WNFLE3=WNFL3*SOMASS*1.E-6	MW-SEC
00361	199*	WFL3=H2-H3	J/6M
00362	200*	WFLE3=WFL3*SOMASS*1.E-6	MW-SEC
00362	201*		
00362	202*		
00362	203*		
00362	204*		
00363	205*		
00364	206*		
00365	207*		
00366	208*		
00367	209*		
00370	210*		
00371	211*		
00372	212*		
00373	213*		
00374	214*		
00375	215*		
00376	216*		
00377	217*		
00400	218*		
00401	219*		
00402	220*		
00403	221*		
00404	222*		
00405	223*		
00406	224*		
00407	225*		
00407	226*		
00407	227*		
00407	228*		
00411	229*		
00412	230*		
00415	231*		
00416	232*		
00417	233*		
00420	234*		
00421	235*		
00422	236*		
00423	237*		
00424	238*		
00425	239*		
00426	240*		
00427	241*		
00430	242*		
00431	243*		

STAGES 4,5,6 THERMAL EQUILIBRIUM EXPANSION TO FINAL PRESSURE P3
EQUILIBRIUM BEFORE EXPANSION IS ABOVE TC

WFL4=0.
WNFL4=0.
WFL4=0.
WNFLE4=0.
WFL5=0.
WNFL5=0.
WFL5=0.
WNFLE5=0.
WFL6=0.
WNFL6=0.
WFL6=0.
WNFLE6=0.
WFL7=0.
WNFL7=0.
WFL7=0.
WNFLE7=0.
WFL8=0.
WNFL8=0.
WFL8=0.
WNFLE8=0.

IF (T2.LE.TC) GO TO 700

PART 1: FROM T2 TO MELTING POINT OF FUEL

ISTAGE=4
IF (T2-TFM) 410,400,420

400

T4=T2
P4=P2
H4=H2
U4=U2
S4=S2
V4=V2

GO TO 500

410

T5=T2
P5=P2
H5=H2
U5=U2
S5=S2
V5=V2

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00432 244* GO TO 600
00433 245* 420 CPFL=CPFL1+CPFL2*(T2+TFM)+CPFL3*(T2+T2+T2+TFM+TFM+TFM)
00434 246* HLOST=CPFL*(T2-TFM)
00434 247* C ENTROPY INCREASE, SODIUM
00435 248* DS24=HLOST/(1.5*(T2+TFM)*RANFM) J/G-DEGC
00436 249* S4=S2+DS24 J/G-DEGC
00437 250* MAXIT=50
00440 251* ERROR2=.001
00440 252* C DETERMINE IF EXPANSION TO TFM GIVES A PRESSURE LOWER THAN P3
00441 253* T4=TFM
00442 254* TR4=T4/TC
00443 255* P4=P3
00444 256* PR4=P4/PC
00445 257* SD=TABLEF(DEPS,DAS,TR4,PR4,ZC)*CAT
00446 258* SI=S(T4,P4)
00447 259* S4MAX=SI-SD
00450 260* IF (S4MAX-S4) 440,460,450
00450 261* C T4 IS BETWEEN T2 AND TFM. USE SUBROUTINE TEMPP TO FIND T4.
00453 262* 440 CALL TEMPP(P4,T4,S4,S4MAX,ERROR2,MAXIT)
00454 263* IF (IERROR.EQ.0) GO TO 460
00456 264* PRINT 1114, Istage,P4,T4,S4,S4MAX
00465 265* GO TO 50
00465 266* C USE SUBROUTINE PRESSS TO OBTAIN PRESSURE AT T4,S4
00466 267* 450 CALL PRESSS(S4,T4,SOUT,P4,ERROR2,MAXIT)
00467 268* IF (IERROR.EQ.0) GO TO 460
00471 269* PRINT 1112, Istage,S2,S4,SOUT,P2,P4,ERROR2
00502 270* GO TO 50
00502 271* C ENTHALPY, INTERNAL ENERGY BY DEPARTURE METHOD
00502 272* C DEPART'S FIVE ARGUMENTS ARE STAGE AND TRUE OR FALSE FOR Z, U, S, H
00503 273* 460 CALL DEPART(4,Z,LF,LF,LT)
00504 274* V4=82.06+Z4*T4/(P4*ATVNA) CC/GM
00505 275* U4=H4-P4*V4*.1013278
00506 276* PRINT 9, Istage,T4,P4,H4,S4,U4,V4
00517 277* WFL4=0.5*(T2+T4)*(S4-S2)-(H4-H2)
00520 278* WFL4=WFL4+SOMASS*.1E-6
00521 279* WFL4=0.5*(T2+T4)*(S4-S2)-(U4-U2)
00522 280* WFL4=WFL4+SOMASS*.1E-6
00523 281* IF (P4.EQ.P3) GO TO 699
00523 282* C
00523 283* C PART 2. SOLIDIFICATION OF FUEL
00523 284* C
00525 285* 500 Istage=5
00526 286* T5=T4
00527 287* TR5=TR4
00530 288* P5=P3 ATM
00531 289* DS45=(1.-FFF)*HFF/(TFM*RANFM)
00532 290* S5MAX=S4+DS45
00533 291* IF (DEBUG) PRINT 909
00536 292* 520 PR5=P5/PC

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00537 293*      SSSAVE=SS
00540 294*      IF (PRS.GE.0.01) GO TO 530
00542 295*      SS=S(TS,P5)
00543 296*      GO TO 540
00544 297*      530 CALL DEPART (S,LF,LF,LT,LT)
00545 298*      540 IF (DEBUG) PRINT 9, ISTAGE,TS,P5,S5,SSMAX
00555 299*      IF (SS.LE.SSMAX) GO TO 545
00557 300*      P5=P5+1.0
00560 301*      GO TO 520
00561 302*      545 IF (P5.EQ.P3) GO TO 546
00563 303*      P5=P5-(SSMAX-SS)/(SSSAVE-SS)
00564 304*      PR5=P5/PC
00565 305*      546 IF (PRS.GE.0.01) GO TO 550
00567 306*      SS=S(TS,P5)
00570 307*      HS=HA+CPIDNA*(TS-TA)
00571 308*      VS=82.06*TS/(P5*ATWTNA)
00572 309*      GO TO 560
00573 310*      550 CALL DEPART (S,LT,LF,LT,LT)
00574 311*      VS=82.06*VS*TS/(P5*ATWTNA)
00575 312*      560 US=HS-P5*VS*.1013278
00576 313*      FFF=FFF+(1.-FFF)*(SS-S4)/DS45
00577 314*      PRINT 9, ISTAGE,TS,P5,HS,SS,US,VS
00610 315*      WFLS=TS*(SS-S4)-(HS-H4)
00611 316*      WFLS=TS*(SS-S4)-(US-U4)
00612 317*      WFLS=WFLS*SOMASS*.1E-6
00613 318*      WFLS=WFLS*SOMASS*.1E-6
00614 319*      IF (P5.EQ.P3) GO TO 699
00614 320*      C
00614 321*      C      PART 3. FROM MELTING POINT OF FUEL TO FINAL PRESSURE
00614 322*      C
00616 323*      600 ISTAGE=6
00617 324*      P6=P3
00620 325*      PR6=P6/PC
00621 326*      T6=TS
00622 327*      IF (DEBUG) PRINT 910
00625 328*      610 T6=T6-10.
00626 329*      TR6=T6/TC
00627 330*      IF (PR6.GE.0.01 .AND. TR6.GE.0.5) GO TO 620
00631 331*      S6MAX=S(T6,P6)
00632 332*      GO TO 630
00633 333*      620 CALL DEPART (S,LF,LF,LT,LT)
00634 334*      S6MAX=S6
00635 335*      630 CPFS=CPFS1+CPFS2*(TS-T6)+CPFS3*(TS+TS+T6+T6+T6)
00636 336*      HLOST=(TS-T6)*CPFS
00636 337*      C      ENTROPY INCREASE, SODIUM
00637 338*      DS6=HLOST/(1.5*(TS+T6)*RNAFM)
00640 339*      S6=S+DS6
00641 340*      IF (DEBUG) PRINT 9, ISTAGE,T6,P6,S6,S6MAX
00651 341*      IF (S6.LT.S6MAX) GO TO 610

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J/GM

J/GM

MW-SEC

J/GM

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00653 342* IF (PR6.GE.0.01 .AND. TR6.GE.0.5) GO TO 640
00655 343* H6=HA+CPIDNA*(T6-TA)
00656 344* V6=82.06*T6/(P6*ATMNA)
00657 345* GO TO 650
00660 346* 640 CALL DEPART (6,LT,LF,LT)
00661 347* V6=82.06*T6/(P6*ATMNA)
00662 348* 650 U6=H6-P6*V6*.1013278
00663 349* PRINT 9,ISTAGE,T6,P6,H6,S6,U6,V6
00674 350* WFL6=D.5*(T5+T6)*(S6-S5)-(U6-U5)
00675 351* WNFL6=D.5*(T5+T6)*(S6-S5)-(H6-H5)
00676 352* WFL6=WFL6/SOMASS*.1E-6
00677 353* WNFL6=WNFL6/SOMASS*.1E-6
00677 354* C
00677 355* C SUMMARIZE WORK DONE
00677 356* C
00700 357* 699 WFT=WFL4+WFL5+WFL6
00701 358* WNT=WNFL4+WNFL5+WNFL6
00702 359* WFE=WFL4+WFL5+WFL6
00703 360* WNE=WNFL4+WNFL5+WNFL6
00704 361* GO TO 900
00704 362* C
00704 363* C STAGES 7-8 THERMAL EQUILIBRIUM EXPANSION TO FINAL PRESSURE P3
00704 364* C EQUILIBRIUM BEFORE EXPANSION IS EQUAL TO OR BELOW TC
00704 365* C
00704 366* C PART 1. EXPANSION WITHIN TWO-PHASE REGION UNTIL ALL VAPOR
00704 367* C
00705 368* 700 ISTAGE=7
00706 369* T7=T2
00707 370* P7=P2
00710 371* S7=S2
00711 372* IF (DEBUG) PRINT 911
00714 373* DQ7=0.
00715 374* 710 TOLD=T7
00716 375* T7=T7-10.
00717 376* TR7=T7/TC
00717 377* C CALCULATE ENTROPY INCREASE OF SODIUM
00720 378* CPFS=CPFS1+CPFS2*(TOLD+T7)+CPFS3*(TOLD+TOLD+TOLD+T7+T7+T7)
00721 379* HLOST=CPFS*(TOLD-T7)
00722 380* DQ7=DQ7+HLOST/RNAFM
00723 381* DS7=HLOST/(.5*(TOLD+T7)*RNAFM)
00724 382* S7=S7+DS7
00724 383* C CALCULATE SATURATED LIQUID AND VAPOR PROPERTIES
00725 384* IF (T7-1644.28) 721,721,720
00730 385* 720 CALL MILLER (TR7,HL7,HG7,VL7,VG7,SL7,SG7)
00731 386* P7=EXPIASAT-BSAT/T7)
00732 387* GO TO 722
00733 388* 721 CALL NAPROP (T7,P7,HL7,SL7,VG7,HG7,SG7,DL7,PSAT7,TC7)
00734 389* P7=PSAT7
00735 390* VL7=1./DL7

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00736 391* 722 CONTINUE
00737 392* IF (DEBUG) PRINT 9, ISTAGE, T7, P7, S7, SG7
00747 393* IF (P7.LE.P3) GO TO 730
00751 394* IF (S7.GE.SG7) GO TO 750
00753 395* GO TO 710
00753 396* C P7 EQUAL TO P3. CALCULATE VAPOR AND LIQUID MASS FRACTIONS
00754 397* 730 P7=P3
00755 398* FHL7=(SG7-S7)/(SG7-SL7)
00756 399* FHV7=1.-FHL7
00757 400* H7=FHL7*HL7+FHV7*HG7
00760 401* V7=FHL7*VL7+FHV7*VG7
00761 402* U7=H7-P7*V7*.1013278
00762 403* GO TO 790
00762 404* C ALL LIQUID VAPORIZED
00763 405* 750 FHL7=0.
00764 406* S7=SG7
00765 407* H7=HG7
00766 408* V7=VG7
00767 409* U7=H7-P7*V7*.1013278
00770 410* 790 PRINT 9, ISTAGE, T7, P7, H7, S7, U7, V7
01001 411* VFL7=DQ7-(H7-H2)
01002 412* WFL7=DQ7-(U7-U2)
01003 413* VFLE7=VFL7*SOHMASS*.1E-6
01004 414* WFLE7=WFL7*SOHMASS*.1E-6
01005 415* IF (P7.EQ.P3) GO TO 899
01005 416* C
01005 417* C PART 2. EXPANSION OF SUPERHEATED VAPOR
01005 418* C
01007 419* 800 ISTAGE=8
01010 420* T8=T7
01011 421* S8=S7
01012 422* PR3=P3/PC
01013 423* IF (DEBUG) PRINT 912
01016 424* DQ8=0.
01017 425* 810 TOLD=T8
01020 426* T8=T8-10.
01021 427* TR8=T8/TC
01021 428* C CALCULATE ENTROPY INCREASE OF SODIUM
01022 429* CPFS=CPFS1+CPFS2*(TOLD-T8)+CPFS3*(TOLD+TOLD+TOLD+T8+T8+T8)
01023 430* HLOST=CPFS*(TOLD-T8)
01024 431* DQ8=DQ8+HLOST/RNAFM
01025 432* DS8=HLOST/(.5*(TOLD+T8)*RNAFM)
01026 433* S8=S8+DS8
01026 434* C CALCULATE ENTROPY OF SUPERHEATED VAPOR AT SAME TEMPERATURE AND
01026 435* C FINAL PRESSURE P3
01027 436* CALL VIRIAL (T8, P3, PSAT8, VG8, HG8, SG8, CPG8)
01030 437* IF (DEBUG) PRINT 9, ISTAGE, T8, PSAT8, SG8, S8
01040 438* IF (S8.GE.SG8) GO TO 850
01042 439* GO TO 810

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01042 440* C CALCULATE REMAINING PROPERTIES
01043 441* 850 H8=HG8
01044 442* V8=VG8
01045 443* U8=M8-P3*V8+.1013278
01046 444* PRINT 9. ISTAGE.T8.P3.H8.S8.U8.V8
01047 445* WFL8=DQ8-(H8-M7)
01048 446* WNFL8=DQ8-(U8-U7)
01049 447* WFL8=WFL8+SOHASS*1.E-6
01050 448* WNFL8=WNFL8+SOHASS*1.E-6
01051 449* C
01052 450* C SUMMARIZE WORK DONE
01053 451* C
01054 452* 899 WFT=WFL7+WFL8
01055 453* WNT=WNFL7+WNFL8
01056 454* WFE=WFL7+WFL8
01057 455* WNE=WNFL7+WNFL8
01058 456* C
01059 457* 900 PRINT 901
01060 458* 901 FORMAT (1H054X,'FLOW',16X,'NON-FLOW' /
01061 459* 1 50X'WORK WORK ENERGY WORK WORK ENERGY' /
01062 460* 2 50X'J/GM MW-SEC',7X'J/GM MW-SEC')
01063 461* PRINT 902, WFL3,WFL3,WNFL3,WNFL3
01064 462* 902 FORMAT ('OISENTROPIC EXPANSION TO INPUT PRESSURE P3',F10.3,F10.3,
01065 463* 1 F12.3,F10.3)
01066 464* PRINT 907, FHL
01067 465* 907 FORMAT ('O FRACTION OF SODIUM LIQUIFIED',F8.6)
01068 466* IF (T2.LE.TC) GO TO 920
01069 467* PRINT 903, WFL4,WFL4,WNFL4,WNFL4
01070 468* 903 FORMAT ('OTHERMAL EQUILIBRIUM EXPANSION FOR EQUILIBRIUM ABOVE TC' /
01071 469* 1 'O A) FROM T2 TO FUEL MELTING POINT',F22.3,F10.3,F12.3,F10.3)
01072 470* PRINT 904, WFL5,WFL5,WNFL5,WNFL5
01073 471* 904 FORMAT (' B) ISOTHERMAL EXPANSION DURING FUEL FREEZING',
01074 472* 1 2F10.3,F12.3,F10.3)
01075 473* PRINT 905, WFL6,WFL6,WNFL6,WNFL6
01076 474* 905 FORMAT (' C) FROM FUEL MELTING POINT TO P3',F22.3,F10.3,F12.3,
01077 475* 1 F10.3)
01078 476* GO TO 950
01079 477* 920 PRINT 921, WFL7,WFL7,WNFL7,WNFL7
01080 478* 921 FORMAT ('OTHERMAL EQUILIBRIUM EXPANSION FOR EQUILIBRIUM BELOW TC' /
01081 479* 1 'O A) EXPANSION WITHIN TWO-PHASE REGION',
01082 480* 2 F10.3,F10.3,F12.3,F10.3)
01083 481* PRINT 922, WFL8,WFL8,WNFL8,WNFL8
01084 482* 922 FORMAT (' B) EXPANSION OF SUPERHEATED VAPOR',
01085 483* 1 F21.3,F10.3,F12.3,F10.3)
01086 484* 950 PRINT 906, WFT,WFE,WNT,WNE
01087 485* 906 FORMAT (' TOTAL WORK DONE FOR THIS PATH',F22.3,F10.3,F12.3,
01088 486* 1 F10.3)
01089 487* PRINT 908, FFF
01090 488* PRINT 907, FHL7

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01170 489*      908 FORMAT ('O FRACTION OF FUEL FROZEN',F8.6)
01171 490*      909 FORMAT ('O ITERATIVE OUTPUT FOR T5, P5, S5, S5MAX')
01172 491*      910 FORMAT ('O ITERATIVE OUTPUT FOR T6, P6, S6, S6MAX')
01173 492*      911 FORMAT ('O ITERATIVE OUTPUT FOR T7,P7,S7,S67')
01174 493*      912 FORMAT ('O ITERATIVE OUTPUT FOR T8,PSAT8,S68,S8')
01175 494*      1112 FORMAT('O MAX NUMBER ITERATIONS EXCEEDED IN PRESSS (PRESSURE (T.S))')
01175 495*          1  /* STAGE%, I2, 6X'ENTROPY',22X'PRESSURE',17X'ERRORS' /
01175 496*          2  10E12.6)
01176 497*      1114 FORMAT ('O MAX NUMBER ITERATIONS EXCEEDED IN SUBROUTINE TEMPP')
01176 498*          1  /* STAGE%, I2, 6X'PRESSURE',6X'TEMPERATURE',6X'ENTROPIFS' /
01176 499*          2  F21.2,F15.2,4F14.4)
01177 500*          GO TO 50
01200 501*      1000 PRINT 1001
01202 502*      1001 FORMAT ('1 ALL DATA PROCESSED')
01203 503*          STOP
01204 504*          SUBROUTINE  ERRUT (K)
01207 505*          DIMENSION SUBRTN(10)
01210 506*          DATA (SUBRTN(I),I=1,8)
01210 507*              1  /*EQUIL', 'INIT', 'NAPROP', 'PRESSS', 'REF',
01210 508*              2  'TEMPP', 'TABLEF', 'DEPART' /
01212 509*          1 FORMAT ('O ERROR TYPE',I3,' IN SUBROUTINE',A7)
01213 510*          IF (IERROR .EQ. 0) RETURN
01215 511*          PRINT 1,IERROR,SUBRTN(K)
01221 512*          IERROR=0
01222 513*          IF (.NOT. DEBUG) RETURN
01224 514*          RETURN
01225 515*          END
END COMPILATION **      0 MESSAGES **

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2 FOR DEPART

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00101 1* SUBROUTINE DEPART (ISTAGE,LZ,LU,LS,LH)
00101 2* C
00101 3* C DEPART'S FIVE ARGUMENTS ARE STAGE, TRUE OR FALSE FOR Z, U, S, H
00101 4* C
00101 5* C FIRST SUBSCRIPT OF TT CORRESPONDS TO THE FOLLOWING QUANTITY
00101 6* C 1 TEMPERATURE
00101 7* C 2 ENTHALPY (H)
00101 8* C 3 ENTROPY (S)
00101 9* C 4 Z (Z)
00101 10* C 5 PRESSURE
00101 11* C 6 INTERNAL ENERGY (U)
00101 12* C 7 AND 8 ARE DUMMIES USED DIFFERENTLY AT DIFFERENT STAGES.
00101 13* C
00103 14* COMMON R, RS, RAT, CAT, CTOJ, P3IN, TNAPMN, TNAPMX, ASAT, BSAT
00104 15* COMMON /SAVE/ DEBUG, IERROR, SAVED (9,50)
00105 16* LOGICAL DEBUG
00106 17* COMMON /SODIUM/ ATWTNA, PC, RHOC, RNAFM, SOMASS, TC, TINA, ZC
00107 18* COMMON /TAB/ TA,HLA,SLA,VSATA,HGA,SGA,DLA,
00107 19* 1 PA,ZA,HA,SA,UA,CPIDNA,CVIDNA,
00107 20* 2 TT (8,8)
00110 21* COMMON /TABLES/ NTRED,NPRED, TRED(33), PRED(25),
00110 22* 1 DEPU(33,25), DEPU(33,25), DEPS(33,25), DEPH(33,25),
00110 23* 2 DAZ(33,15), DBZ(33,15), DAU(33,15), DBU(33,15),
00110 24* 3 DAS(33,15), DBS(33,15), DAH(33,15), DBH(33,15)
00110 25* C
00111 26* LOGICAL LZ, LU, LS, LH
00111 27* C
00112 28* I=ISTAGE
00113 29* T=TT(1,I)
00114 30* TR=T/TC
00115 31* P=TT(5,I)
00116 32* PR=P/PC
00116 33* C
00116 34* C
00117 35* IF (.NOT.LZ) GO TO 10
00121 36* TT(4,I)=TABLEF(DEPU,DAU,TR,PR,ZC)
00121 37* C
00122 38* 10 IF(.NOT.LU) GO TO 20
00124 39* UD=TABLEF(DEPU,DAU,TR,PR,ZC)
00125 40* UI=UA+CVIDNA*(T-TA)
00126 41* TT(6,I)=UI-TC*UD*CAT
00126 42* C
00127 43* 20 IF (.NOT.LS) GO TO 30
00131 44* SD=TABLEF(DEPS,DAS,TR,PR,ZC)
00132 45* SI=SA+CPIDNA*LOG(T/TA)-RS*LOG(P/PA)
00133 46* TT(3,I)=SI-SD*CAT
00133 47* C

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00134  48*      30 IF (.NOT.LH) GO TO 100
00136  49*      HD=TABLEF (DEPH,DAH,TR,PR,ZC)
00137  50*      HI=HA*CPIDNA*(T-TA)
00140  51*      TT(2,I) = HI-TC*HD*CAT
00141  52*      100 RETURN
00142  53*      END
END COMPILATION **      0 MESSAGES **

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a FOR EQUIL

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00101      1*      SUBROUTINE EQUIL
00101      2*      C
00101      3*      C      EQUIL DETERMINES EQUILIBRIUM TEMPERATURE T2 AND CORRESPONDING PROPERTIES
00101      4*      C      WITH SODIUM AND FUEL STARTING AT TEMPERATURES T1NA AND T1F RESPECTIVELY.
00101      5*      C
00101      6*      C      THIS VERSION HEATS SODIUM UP ALONG VAPOR PRESSURE CURVE IN
00101      7*      C      INCREMENTS OF REDUCED TEMPERATURE CORRESPONDING TO HWR TABLE.
00101      8*      C      THE AMOUNT OF HEAT USED BY SODIUM, QNA, IS COMPARED WITH THE
00101      9*      C      AMOUNT LOST BY FUEL, QF, IN GOING TO THE SAME TEMPERATURE.
00101     10*      C
00101     11*      C      EQUIL PRODUCES T2,P2,U2,Q2,Z2,V2,S2,H2 AND FFF
00101     12*      C
00103     13*      COMMON R,RS,RAT,CAT,CTOJ,P3IN,TNAPMN,TNAPMX,ASAT,BSAT
00104     14*      COMMON /FUEL/ CPFS1,CPFS2,CPFS3,TFM,HFF,CPFL1,CPFL2,CPFL3,
00104     15*      1      T1F,FMASS,FFF
00105     16*      COMMON /SAVE/ DEBUG,IERROR,ISTAGE,SAVE(4,50)
00106     17*      LOGICAL DEBUG
00107     18*      LOGICAL LF, FALSE, /, LT, /, TRUE, /
00112     19*      COMMON /SODIUM/ ATWTNA, PC, RHOC, RNAFM, SOMASS, TC, T1NA, ZC
00113     20*      COMMON /TAB/ TA,HLA,SLA,VSATA,HGA,SGA,DLA,
00113     21*      1      PA,ZA,HA,SA,UA,CPIDNA,CVIDNA,
00113     22*      2      T1,H1,S1,ZC1,P1,U1,D11,Q12,
00113     23*      3      T2,H2,S2,Z2,P2,U2,Q2,V2,
00113     24*      4      T3,H3,S3,Z3,P3,U3,D31,D32,
00113     25*      5      T4,H4,S4,Z4,P4,U4,D41,D42,
00113     26*      6      T5,H5,S5,Z5,P5,U5,D51,D52,
00113     27*      7      T6,H6,S6,Z6,P6,U6,D61,D62,
00113     28*      8      T7,H7,S7,Z7,P7,U7,D71,D72,
00113     29*      9      T8,H8,S8,Z8,P8,U8,D81,D82
00114     30*      COMMON /TABLES/ NTRED,NPREO,TRED(33),PRED(25),
00114     31*      1      DEPZ(33,25),DEPU(33,25),DEPS(33,25),DEPH(33,25),
00114     32*      2      DAZ(33,15),DBZ(33,15),DAU(33,15),DBU(33,15),
00114     33*      3      DAS(33,15),DBS(33,15),DAH(33,15),DBH(33,15)
00114     34*      C
00114     35*      C      INITIALLY, ESTIMATE T2 IS BETWEEN 2500 DEGF AND TC
00114     36*      C      NEGLECT PDV WORK BETWEEN T1 AND 2500 DEGF
00114     37*      C      USE SUBROUTINE MILLER TO DETERMINE SODIUM PROPERTIES
00114     38*      C
00115     39*      T2=1644.28
00116     40*      P2=21.6779
00117     41*      TR2=T2/TC
00120     42*      CALL MILLER (TR2,H2,H62,V2,V62,SL2,S62)
00121     43*      V2=VL2
00121     44*      C      DIVIDE INTERVAL BETWEEN 2500 DEGF AND TC INTO 50 INCREMENTS
00122     45*      DELT2=(TC-1644.28)/50.
00123     46*      PDV12=0.
00124     47*      IF (DEBUG) PRINT 1

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00127 48* 1 FORMAT ('ITERATIVE OUTPUT FROM SUBROUTINE EQUIL',
00127 49* 1 ' * TR2,T2,PR2,P2,Z2,U2,PDV12,QDIFF')
00130 50* DO 20 IT=1,50
00133 51* TLAST=T2
00134 52* PLAST=P2
00135 53* VLAST=V2
00136 54* T2=T2+DEL T2
00137 55* TR2=T2/TC
00140 56* CALL MILLER (TR2,HL2,HG2,VL2,VG2,SL2,SG2)
00141 57* H2=HL2
00142 58* S2=SL2
00143 59* V2=VL2
00144 60* P2=EXP (ASAT-B SAT/T2)
00145 61* U2=H2-P2*V2*.1013278
00146 62* PDV12=PDV12+(PLAST+P2)*(V2-VLAST)*0.0506639
00147 63* QNA=U2-U1+PDV12
00150 64* QLAST=QF
00151 65* IF (T2.GT.TFM) GO TO 15
00153 66* CPFL=CPFL1+CPFL2*(T1F+TFM)+CPFL3*(T1F+T1F+T1F+TFM+TFM+TFM) J/G-DESK
00154 67* CPFS=CPFS1+CPFS2*(T2+TFM)+CPFS3*(T2+T2+T2+TFM+TFM+TFM)
00155 68* QF=(CPFL*(T1F-TFM)+HFF+CPFS*(TFM-T2))/RNAFM J/GM
00156 69* GO TO 16
00157 70* 15 CPFL=CPFL1+CPFL2*(T1F+T2)+CPFL3*(T1F+T1F+T1F+T2+T2+T2) J/G-DESK
00160 71* QF=CPFL*(T1F-T2)/RNAFM J/GM
00161 72* 16 QDIFF2=QDIFF
00162 73* QDIFF=QF-QNA
00163 74* IF (DEBUG) PRINT 2, TR2,T2,PR2,P2,Z2,U2,PDV12,QDIFF
00176 75* IF (QDIFF) 25,100,20
00201 76* 20 CONTINUE
00201 77* C ACTUAL T2 IS ABOVE TC
00203 78* GO TO 40
00203 79* C ACTUAL T2 IS BETWEEN T2 AND TLAST
00204 80* 25 FRACT=QDIFF2/(QDIFF2-QDIFF)
00205 81* T2=TLAST+FRACT*(T2-TLAST)
00206 82* TR2=T2/TC
00207 83* P2=EXP (ASAT-B SAT/T2)
00210 84* CALL MILLER (TR2,HL2,HG2,VL2,VG2,SL2,SG2)
00211 85* H2=HL2
00212 86* S2=SL2
00213 87* V2=VL2
00214 88* U2=H2-P2*V2*.1013278
00215 89* GO TO 100
00215 90* C
00215 91* C EQUILIBRIUM IS ABOVE TC. BEGIN STEPPING T2 UP ALONG V-P CURVE
00215 92* C
00215 93* C CALCULATE PROPERTIES OF IDEAL SODIUM GAS AT CRITICAL POINT
00216 94* 40 TA=TC
00217 95* PA=PC ATM
00220 96* PR2=P2/PC

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00221  97*    DEPHC=TABLEF(DEPM,DAH,TR2,PR2,ZCI)*CAT
00222  98*    HA=H2+T2*DEPHC
00223  99*    UA=HA-CAT*H*TA
00224  100*   DEPSC=TABLEF(DEPS,DAS,TR2,PR2,ZCI)*CAT
00225  101*   SA=S2+DEPSC
00226  102*   IF (DEBUG) PRINT 4, TA,PA,HA,UA,SA
00236  103*   4 FORMAT ('PROPERTIES OF IDEAL SODIUM GAS, TA,PA,HA,UA,SA /
00236  104*   1      4F12.2,F12.4)
00237  105*   DO 50 IT=11,NTRED
00242  106*   TLAST=T2
00243  107*   TR2=TRED(IT)
00244  108*   T2=TR2+TC
00245  109*   PLAST=P2
00246  110*   P2=EXP(SAT-B*SA/T2)
00246  111*   C
00246  112*   C
00246  113*   C   DEPART CALCULATES QUALITIES BASED ON DEPARTURE METHOD
00246  114*   C   DEPART'S FIVE ARGUMENTS ARE STAGE AND TRUE OR FALSE FOR Z, U, S, H
00246  115*   C
00247  116*   CALL DEPART (Z,LT,LF,LF,LT)
00247  117*   C
00250  118*   VLAST=V2
00251  119*   V2=82.06+Z2*(T2/TP2+ATWTNA)
00252  120*   U2=H2-P2+V2*.1013278
00252  121*   C
00253  122*   PDV12=PDV12+(PLAST-P2)*(V2-VLAST)*0.0506639
00254  123*   QNA=U2-U1+PDV12
00255  124*   QLAST=QF
00256  125*   IF (T2.GT.TFM) GO TO 45
00260  126*   CPFL=CPFL1+CPFL2*(T1F+TFM)+CPFL3*(T1F+T1F+T1F+TFM+TFM+TFM)
00261  127*   CPFS=CPFS1+CPFS2*(T2+TFM)+CPFS3*(T2+T2+T2+TFM+TFM+TFM)
00262  128*   QF=(CPFL*(T1F-TFM)+HFF+CPFS*(TFM-T2))/RNAFM
00263  129*   GO TO 46
00264  130*   45 CPFL=CPFL1+CPFL2*(T1F+T2)+CPFL3*(T1F+T1F+T1F+T2+T2+T2)
00265  131*   QF=CPFL*(T1F-T2)/RNAFM
00266  132*   46 QDIFF2=QDIFF
00267  133*   QDIFF=QF-QNA
00270  134*   IF (DEBUG) PRINT 2, TR2,T2,PR2,P2,Z2,U2,PDV12,QDIFF
00303  135*   2 FORMAT (F6.2,F9.2,F9.4,F9.2,F9.5,F9.2)
00304  136*   IF (QDIFF) 60,100,50
00307  137*   50 CONTINUE
00307  138*   C
00311  139*   IERROR=2
00312  140*   GO TO 100
00312  141*   C
00312  142*   C   ACTUAL T2 IS BETWEEN T2 AND TLAST
00312  143*   C
00313  144*   60 IF (TLAST.LT.TFM .AND. T2.GT.TFM) GO TO 70
00315  145*   FRACT=QDIFF2/(QDIFF2-QDIFF)

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J/GM

J/GM

J/G-DEG K

DEG K

J/G-DEG K

J/GM

J/G-DEG K

J/GM

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00316 146* T2=TLAST+FRAC*(T2-TLAST)
00317 147* P2=EXP(ASAT-BSAT/T2)
00320 148* CALL DEPART (Z,LT,LF,LT,LT)
00321 149* V2=B2.06*Z2*(T2/IP2*ATWTNA)
00322 150* U2=M2-P2*V2*.1013278
00323 151* GO TO 100
00323 152* C
00323 153* C EQUILIBRIUM IS AT TFM. DETERMINE FRACTION OF FUEL SOLIDIFIED.
00323 154* C
00324 155* 70 T2=TFM
00325 156* P2=EXP(ASAT-BSAT/T2)
00326 157* CALL DEPART (Z,LT,LF,LT,LT)
00327 158* V2=B2.06*Z2*(T2/IP2*ATWTNA)
00330 159* U2=M2-P2*V2*.1013278
00331 160* PDV12=PDV12+(PLAST*P2)*(V2-VLAST)*0.0506639
00332 161* QNA=U2-U1+PDV12
00333 162* FFF=(QNA*RNAFM-CPFL*(TIF-TFM))/HFF
00334 163* IF (FFF.GT.1.0) GO TO 80
00336 164* IF (DEBUG) PRINT 3, FFF
00342 165* 3 FORMAT ('FRACTION OF FUEL FROZEN',F8.6)
00343 166* GO TO 100
00343 167* C
00343 168* C EQUILIBRIUM IS SLIGHTLY BELOW TFM
00343 169* C
00344 170* 80 QF=(CPFL*(TIF-TFM)+HFF)/RNAFM
00345 171* QDIFF=QF-QNA
00346 172* FRAC=QDIFF2/(QDIFF2-QDIFF)
00347 173* T2=TLAST+FRAC*(TFM-TLAST)
00350 174* P2=EXP(ASAT-BSAT/T2)
00351 175* CALL DEPART (Z,LT,LF,LT,LT)
00352 176* V2=B2.06*Z2*(T2/IP2*ATWTNA)
00353 177* U2=M2-P2*V2*.1013278
00353 178* C
00353 179* C
00354 180* 100 IF (T2-TFM) 101,103,102
00357 181* 101 FFF=1.0
00360 182* GO TO 103
00361 183* 102 FFF=0.0
00362 184* 103 RETURN
00363 185* END
END COMPILATION ** 0 MESSAGES **

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AI UPD HWR

1.		.01		.05		.1		.2		.3		.4	
2.		.5		.6		.7		.8		.9		1.0	
3.		1.05		1.1		1.2		1.4		1.6		1.8	
4.		2.0		4.0		6.0		8.0		10.0		20.0	
5.		30.0											
6.	0.50	0.002	0.009	0.0184	0.0367	0.0551	0.0734	0.0918	0.1100	0.128	0.147	0.165	0.183
7.	0.192	0.201	0.220	0.256	0.293	0.329	0.365	0.402	0.439	0.476	0.513	0.551	0.588
8.	0.60	0.990	0.008	0.0164	0.0328	0.0491	0.0654	0.0817	0.0980	0.113	0.130	0.147	0.163
9.	0.171	0.179	0.195	0.227	0.259	0.291	0.323	0.354	0.386	0.418	0.450	0.482	0.514
10.	0.70	0.992	0.943	0.0152	0.0304	0.0456	0.0605	0.0758	0.0906	0.106	0.121	0.136	0.151
11.	0.158	0.165	0.180	0.210	0.239	0.268	0.297	0.326	0.354	0.382	0.410	0.438	0.466
12.	0.80	0.993	0.960	0.920	0.0295	0.0441	0.0588	0.0735	0.0879	0.102	0.116	0.131	0.145
13.	0.152	0.159	0.173	0.201	0.229	0.257	0.284	0.311	0.338	0.365	0.392	0.419	0.446
14.	0.90	0.994	0.973	0.947	0.890	0.825	0.763	0.701	0.639	0.577	0.515	0.453	0.391
15.	0.155	0.162	0.176	0.203	0.230	0.257	0.283	0.310	0.336	0.362	0.388	0.414	0.440
16.	0.92	0.995	0.975	0.951	0.900	0.840	0.783	0.726	0.669	0.612	0.555	0.498	0.441
17.	0.158	0.165	0.179	0.206	0.233	0.259	0.284	0.310	0.336	0.362	0.388	0.414	0.440
18.	0.94	0.995	0.977	0.954	0.908	0.854	0.800	0.735	0.660	0.585	0.510	0.435	0.360
19.	0.162	0.169	0.183	0.210	0.237	0.262	0.287	0.310	0.333	0.356	0.379	0.402	0.425
20.	0.96	0.995	0.978	0.958	0.915	0.868	0.817	0.760	0.700	0.633	0.563	0.493	0.423
21.	0.169	0.176	0.189	0.217	0.242	0.267	0.291	0.314	0.337	0.360	0.383	0.406	0.429
22.	0.98	0.996	0.980	0.961	0.921	0.879	0.832	0.781	0.729	0.665	0.580	0.491	0.401
23.	0.182	0.189	0.202	0.228	0.253	0.276	0.298	0.320	0.342	0.364	0.386	0.408	0.430
24.	1.00	0.996	0.982	0.964	0.927	0.889	0.845	0.800	0.755	0.709	0.663	0.617	0.571
25.	0.230	0.224	0.220	0.234	0.254	0.279	0.306	0.336	0.366	0.395	0.424	0.453	0.482
26.	1.01	0.996	0.983	0.966	0.930	0.894	0.852	0.809	0.765	0.718	0.659	0.568	0.474
27.	0.365	0.256	0.242	0.246	0.262	0.287	0.312	0.338	0.363	0.388	0.413	0.438	0.463
28.	1.02	0.996	0.983	0.967	0.933	0.897	0.858	0.817	0.775	0.732	0.678	0.600	0.509
29.	0.447	0.374	0.295	0.264	0.276	0.296	0.318	0.340	0.362	0.384	0.406	0.428	0.450
30.	1.03	0.996	0.984	0.968	0.935	0.902	0.863	0.825	0.786	0.745	0.696	0.627	0.555
31.	0.505	0.461	0.369	0.288	0.289	0.307	0.326	0.343	0.359	0.372	0.381	0.389	0.396
32.	1.04	0.996	0.985	0.970	0.938	0.905	0.869	0.832	0.794	0.755	0.710	0.642	0.585
33.	0.546	0.505	0.422	0.323	0.305	0.317	0.333	0.346	0.360	0.372	0.381	0.389	0.396
34.	1.05	0.996	0.985	0.971	0.940	0.909	0.873	0.838	0.802	0.765	0.723	0.670	0.611
35.	0.577	0.541	0.478	0.366	0.323	0.332	0.341	0.348	0.354	0.359	0.364	0.369	0.374
36.	1.06	0.996	0.986	0.972	0.942	0.913	0.878	0.845	0.810	0.773	0.735	0.687	0.633
37.	0.603	0.568	0.517	0.403	0.347	0.347	0.351	0.352	0.352	0.351	0.349	0.347	0.345
38.	1.07	0.996	0.986	0.973	0.944	0.916	0.883	0.850	0.817	0.781	0.745	0.700	0.654
39.	0.627	0.594	0.548	0.438	0.370	0.365	0.361	0.354	0.346	0.337	0.328	0.319	0.310
40.	1.08	0.996	0.987	0.974	0.946	0.918	0.886	0.856	0.824	0.790	0.755	0.715	0.671
41.	0.647	0.616	0.573	0.472	0.396	0.380	0.372	0.358	0.344	0.329	0.314	0.299	0.284
42.	1.09	0.997	0.987	0.975	0.948	0.922	0.890	0.862	0.830	0.798	0.764	0.726	0.686
43.	0.662	0.637	0.600	0.507	0.424	0.398	0.386	0.362	0.346	0.329	0.312	0.295	0.278
44.	1.10	0.997	0.988	0.976	0.950	0.924	0.894	0.867	0.836	0.805	0.773	0.738	0.700
45.	0.678	0.655	0.620	0.534	0.455	0.416	0.400	0.365	0.348	0.329	0.310	0.291	0.272
46.	1.12	0.997	0.988	0.977	0.953	0.928	0.900	0.876	0.848	0.818	0.789	0.756	0.723

47.	0.704	0.686	0.654	0.577	0.505	0.454	0.432	0.572	0.772	0.970	1.156	2.068	2.89
48.	1.14	0.997	0.989	0.979	0.956	0.933	0.907	0.884	0.859	0.830	0.803	0.773	0.745
49.	0.731	0.712	0.683	0.615	0.549	0.494	0.466	0.581	0.776	0.970	1.153	2.049	2.85
50.	1.16	0.997	0.990	0.980	0.960	0.937	0.913	0.891	0.868	0.842	0.816	0.790	0.764
51.	0.750	0.735	0.707	0.647	0.588	0.540	0.503	0.589	0.780	0.972	1.151	2.030	2.81
52.	1.18	0.997	0.991	0.982	0.962	0.942	0.918	0.898	0.877	0.852	0.830	0.805	0.780
53.	0.771	0.756	0.730	0.677	0.622	0.583	0.542	0.599	0.786	0.973	1.150	2.013	2.78
54.	1.20	0.998	0.991	0.983	0.965	0.945	0.924	0.905	0.885	0.862	0.841	0.818	0.795
55.	0.787	0.775	0.751	0.705	0.653	0.620	0.573	0.609	0.792	0.975	1.148	1.995	2.74
56.	1.30	0.998	0.993	0.987	0.974	0.960	0.944	0.931	0.916	0.900	0.888	0.874	0.857
57.	0.849	0.841	0.827	0.795	0.768	0.742	0.716	0.687	0.624	0.984	1.144	1.921	2.63
58.	1.40	0.998	0.995	0.990	0.982	0.971	0.959	0.949	0.937	0.928	0.920	0.912	0.899
59.	0.890	0.888	0.875	0.855	0.837	0.819	0.801	0.783	0.863	0.996	1.144	1.862	2.56
60.	1.50	0.999	0.995	0.991	0.986	0.980	0.970	0.963	0.952	0.948	0.945	0.938	0.927
61.	0.922	0.918	0.911	0.894	0.882	0.869	0.852	0.813	0.893	1.012	1.146	1.818	2.49
62.	1.60	0.999	0.996	0.992	0.988	0.986	0.978	0.973	0.965	0.964	0.960	0.955	0.948
63.	0.944	0.940	0.935	0.923	0.914	0.904	0.888	0.852	0.918	1.028	1.150	1.790	2.44
64.	1.70	0.999	0.996	0.992	0.989	0.989	0.983	0.980	0.974	0.974	0.970	0.968	0.964
65.	0.958	0.956	0.951	0.945	0.934	0.929	0.915	0.883	0.940	1.041	1.154	1.767	2.39
66.	1.80	0.999	0.996	0.993	0.991	0.991	0.987	0.985	0.982	0.982	0.980	0.976	0.974
67.	0.968	0.968	0.963	0.960	0.950	0.946	0.935	0.909	0.960	1.052	1.156	1.744	2.33
68.	1.90	1.000	0.996	0.993	0.992	0.993	0.991	0.989	0.987	0.987	0.987	0.985	0.983
69.	0.978	0.978	0.974	0.972	0.965	0.960	0.952	0.932	0.977	1.061	1.158	1.714	2.29
70.	2.00	1.000	0.997	0.994	0.994	0.995	0.994	0.993	0.992	0.992	0.989	0.990	0.988
71.	0.986	0.984	0.981	0.979	0.974	0.971	0.966	0.952	0.993	1.070	1.159	1.691	2.24
72.	0.50	13.80	13.81	13.82	13.84	13.86	13.88	13.90	13.92	13.94	13.96	13.98	14.00
73.	14.02	14.02	14.04	14.08	14.12	14.16	14.20	14.47	14.70	14.92	15.15	15.91	16.62
74.	0.60	0.045	12.58	12.58	12.61	12.63	12.65	12.67	12.70	12.71	12.73	12.75	12.77
75.	12.78	12.79	12.85	12.88	12.87	12.89	12.91	13.06	13.24	13.45	13.64	14.40	14.86
76.	0.70	0.031	0.150	11.15	11.18	11.21	11.24	11.27	11.30	11.32	11.34	11.36	11.40
77.	11.39	11.40	11.41	11.44	11.46	11.49	11.51	11.65	11.83	12.07	12.14	12.82	13.23
78.	0.80	0.025	0.125	0.25	9.82	9.85	9.88	9.92	9.95	9.97	9.99	10.02	10.04
79.	10.05	10.06	10.09	10.13	10.17	10.22	10.24	10.50	10.71	10.93	11.06	11.77	12.30
80.	0.90	0.020	0.110	0.20	0.44	0.72	0.96	8.26	8.28	8.30	8.34	8.37	8.42
81.	8.45	8.49	8.56	8.70	8.82	8.93	9.01	9.42	9.73	10.03	10.25	11.14	11.87
82.	0.92	0.019	0.100	0.19	0.42	0.68	0.91	1.24	7.86	7.89	7.92	7.97	8.04
83.	8.07	8.11	8.18	8.35	8.51	8.65	8.73	9.19	9.54	9.85	10.09	11.02	11.76
84.	0.94	0.018	0.090	0.18	0.39	0.64	0.84	1.15	1.49	7.47	7.51	7.56	7.61
85.	7.65	7.69	7.77	7.99	8.16	8.30	8.43	8.93	9.35	9.67	9.92	10.90	11.66
86.	0.96	0.017	0.085	0.17	0.37	0.60	0.78	1.06	1.37	1.82	6.91	6.97	7.07
87.	7.12	7.17	7.30	7.59	7.75	7.94	8.09	8.70	9.14	9.47	9.76	10.76	11.53
88.	0.98	0.017	0.085	0.17	0.35	0.55	0.74	0.99	1.28	1.65	2.16	6.21	6.35
89.	6.43	6.56	6.80	7.15	7.33	7.55	7.71	8.45	8.92	9.29	9.60	10.62	11.39
90.	1.00	0.017	0.085	0.17	0.33	0.52	0.69	0.93	1.17	1.49	1.92	2.33	4.35
91.	5.13	5.56	6.14	6.62	6.84	7.12	7.31	8.13	8.69	9.07	9.40	10.44	11.31
92.	1.01	0.016	0.080	0.16	0.32	0.50	0.66	0.90	1.13	1.43	1.78	2.21	3.10
93.	4.22	4.81	5.61	6.38	6.52	6.91	7.08	7.98	8.57	8.97	9.30	10.32	11.24
94.	1.02	0.015	0.075	0.15	0.31	0.48	0.64	0.87	1.09	1.38	1.73	2.11	2.87
95.	3.64	4.13	4.95	5.92	6.33	6.68	6.88	7.83	8.46	8.86	9.19	10.20	11.12

96.	1.03	0.014	0.072	0.245	0.31	0.46	0.63	0.85	1.05	1.32	1.66	2.06	2.65
97.	3.07	3.45	4.16	5.36	6.02	6.41	6.63	7.70	8.34	8.74	9.07	10.09	11.00
98.	1.04	0.014	0.070	0.14	0.30	0.44	0.61	0.81	1.01	1.27	1.59	1.96	2.45
99.	2.76	3.07	3.63	4.76	5.66	6.11	6.39	7.54	8.21	8.63	8.97	9.98	10.99
100.	1.05	0.013	0.065	0.13	0.29	0.43	0.59	0.78	0.99	1.22	1.52	1.87	2.29
101.	2.53	2.80	3.21	4.23	5.24	5.77	6.11	7.50	8.10	8.52	8.84	9.89	10.78
102.	1.06	0.012	0.062	0.125	0.28	0.41	0.56	0.76	0.96	1.18	1.47	1.80	2.16
103.	2.36	2.55	2.92	3.84	4.87	5.44	5.79	7.22	7.94	8.39	8.72	9.78	10.70
104.	1.07	0.012	0.060	0.12	0.27	0.40	0.55	0.74	0.92	1.14	1.41	1.73	2.05
105.	2.23	2.37	2.73	3.50	4.34	5.01	5.45	7.05	7.80	8.25	8.58	9.67	10.62
106.	1.08	0.012	0.060	0.12	0.26	0.38	0.54	0.73	0.90	1.09	1.36	1.67	1.95
107.	2.09	2.25	2.55	3.26	3.88	4.58	5.09	6.87	7.65	8.12	8.49	9.58	10.51
108.	1.09	0.012	0.060	0.12	0.26	0.38	0.52	0.70	0.87	1.05	1.31	1.60	1.84
109.	1.99	2.13	2.41	2.97	3.63	4.22	4.76	6.71	7.51	7.98	8.35	9.44	10.43
110.	1.10	0.011	0.055	0.11	0.25	0.36	0.51	0.68	0.84	1.04	1.26	1.54	1.76
111.	1.90	2.03	2.29	2.85	3.44	3.94	4.41	6.54	7.37	7.84	8.25	9.32	10.25
112.	1.12	0.011	0.055	0.11	0.235	0.34	0.48	0.64	0.80	0.97	1.19	1.43	1.62
113.	1.74	1.87	2.11	2.58	3.08	3.51	3.92	6.27	7.15	7.63	8.01	9.12	9.94
114.	1.14	0.010	0.050	0.10	0.22	0.33	0.45	0.61	0.76	0.92	1.12	1.33	1.52
115.	1.63	1.74	1.96	2.38	2.83	3.25	3.59	6.02	6.93	7.43	7.80	8.94	9.74
116.	1.16	0.009	0.045	0.09	0.21	0.31	0.42	0.57	0.72	0.88	1.06	1.26	1.45
117.	1.52	1.63	1.82	2.21	2.61	2.98	3.35	5.77	6.71	7.23	7.58	8.73	9.55
118.	1.18	0.009	0.045	0.09	0.20	0.29	0.40	0.54	0.69	0.83	1.00	1.19	1.35
119.	1.45	1.50	1.74	2.09	2.47	2.84	3.17	5.52	6.50	7.04	7.38	8.56	9.36
120.	1.20	0.008	0.040	0.08	0.19	0.27	0.38	0.52	0.66	0.80	0.95	1.13	1.29
121.	1.39	1.48	1.66	1.93	2.29	2.65	2.98	5.25	6.28	6.83	7.21	8.37	9.16
122.	1.30	0.007	0.035	0.07	0.145	0.22	0.28	0.42	0.51	0.66	0.77	0.89	1.03
123.	1.10	1.18	1.30	1.53	1.82	2.01	2.32	4.31	5.37	5.94	6.33	7.54	8.39
124.	1.40	0.005	0.025	0.05	0.12	0.16	0.23	0.34	0.42	0.54	0.63	0.73	0.85
125.	0.91	0.98	1.10	1.25	1.46	1.66	1.83	3.55	4.56	5.10	5.58	6.84	7.78
126.	1.50	0.004	0.022	0.045	0.10	0.14	0.19	0.27	0.34	0.45	0.54	0.63	0.70
127.	0.75	0.80	0.89	1.05	1.23	1.41	1.59	2.99	3.85	4.40	5.42	6.22	7.26
128.	1.60	0.004	0.020	0.040	0.08	0.12	0.17	0.23	0.29	0.39	0.45	0.50	0.58
129.	0.61	0.66	0.74	0.85	0.98	1.18	1.27	2.43	3.30	3.87	4.38	5.76	6.82
130.	1.70	0.003	0.015	0.03	0.06	0.10	0.15	0.21	0.26	0.33	0.40	0.45	0.51
131.	0.52	0.56	0.64	0.62	0.82	1.02	1.10	2.03	2.88	3.46	3.96	5.39	6.48
132.	1.80	0.002	0.012	0.025	0.05	0.09	0.13	0.19	0.24	0.30	0.34	0.40	0.45
133.	0.46	0.47	0.55	0.49	0.70	0.88	0.95	1.78	2.57	3.16	3.63	5.11	6.21
134.	1.90	0.002	0.010	0.02	0.04	0.08	0.12	0.17	0.20	0.27	0.31	0.37	0.42
135.	0.43	0.45	0.49	0.41	0.65	0.77	0.85	1.64	2.33	2.94	3.39	4.89	6.00
136.	2.00	0.001	0.005	0.01	0.03	0.07	0.10	0.13	0.19	0.25	0.28	0.35	0.38
137.	0.40	0.42	0.45	0.52	0.60	0.68	0.75	1.38	2.25	2.82	3.25	4.73	5.86
138.	0.50	21.94	21.27	20.51	19.18	18.41	17.89	17.48	17.15	16.87	16.64	16.43	16.31
139.	16.15	16.08	15.95	15.71	15.53	15.35	15.22	14.43	14.17	14.05	14.09	14.60	15.30
140.	0.60	0.083	19.44	18.59	17.26	16.49	15.95	15.53	15.23	14.95	14.82	14.65	14.43
141.	14.26	14.19	14.02	13.78	13.56	13.36	13.15	12.06	11.59	11.45	11.35	11.19	11.25
142.	0.70	0.057	28.01	17.01	15.69	14.92	14.41	13.99	13.66	13.38	13.15	12.95	12.77
143.	12.69	12.60	12.40	12.18	11.95	11.77	11.59	10.45	9.91	9.60	9.37	9.04	8.93
144.	0.80	0.040	20.00	13.40	13.87	13.10	12.58	12.18	11.84	11.56	11.32	11.14	10.96

145.	10.89	10.83	10.68	10.37	10.16	9.94	9.81	8.80	8.26	7.99	7.77	7.47	7.41
146.	0.90	.028	.140	.28	.55	.83	1.20	10.45	10.12	9.84	9.62	9.42	9.26
147.	9.19	9.14	9.05	8.91	8.78	8.67	8.55	7.69	7.25	7.05	6.92	6.71	6.91
148.	0.92	.026	.130	.26	.50	.77	1.10	1.46	9.70	9.43	9.19	9.02	8.88
149.	8.83	8.78	8.68	8.56	8.43	8.40	8.29	7.47	7.07	6.87	6.78	6.60	6.79
150.	0.94	.024	.120	.24	.47	.72	1.01	1.32	1.72	9.00	8.78	8.59	8.49
151.	8.40	8.35	8.27	8.21	8.12	8.05	7.98	7.21	6.89	6.70	6.53	6.41	6.62
152.	0.96	.022	.110	.22	.44	.66	.91	1.19	1.53	2.07	8.18	8.02	7.95
153.	7.86	7.83	7.79	7.78	7.71	7.70	7.63	6.97	6.67	6.48	6.40	6.30	6.50
154.	0.98	.021	.105	.21	.40	.61	.83	1.08	1.39	1.81	2.40	7.23	7.20
155.	7.20	7.20	7.29	7.33	7.27	7.27	7.25	6.72	6.45	6.29	6.24	6.15	6.35
156.	1.00	.019	.085	.19	.37	.56	.74	.99	1.25	1.58	2.05	2.60	4.99
157.	6.10	6.40	6.60	6.82	6.84	6.85	6.84	6.40	6.25	6.13	6.04	5.96	6.17
158.	1.01	.018	.090	.18	.36	.53	.71	.95	1.19	1.50	1.91	2.40	3.46
159.	4.60	5.25	6.05	6.42	6.49	6.65	6.62	6.27	6.11	5.99	5.93	5.82	6.05
160.	1.02	.017	.085	.17	.35	.51	.68	.91	1.13	1.43	1.80	2.24	3.07
161.	3.87	4.40	5.30	6.10	6.30	6.43	6.44	6.14	6.01	5.89	5.82	5.69	5.92
162.	1.03	.016	.080	.16	.33	.48	.65	.87	1.08	1.35	1.70	2.13	2.78
163.	3.24	3.66	4.40	5.53	5.99	6.17	6.20	6.01	5.91	5.80	5.72	5.62	5.83
164.	1.04	.016	.080	.16	.32	.46	.63	.83	1.04	1.28	1.62	2.01	2.54
165.	2.87	3.19	3.78	4.89	5.63	5.88	5.98	5.88	5.79	5.69	5.62	5.49	5.72
166.	1.05	.015	.075	.15	.30	.44	.60	.79	0.99	1.22	1.53	1.89	2.33
167.	2.59	2.84	3.30	4.30	5.19	5.52	5.69	5.72	5.68	5.58	5.50	5.40	5.60
168.	1.06	.014	.070	.14	.29	.42	.57	.77	0.96	1.17	1.46	1.80	2.17
169.	2.39	2.58	2.97	3.89	4.80	5.19	5.38	5.57	5.53	5.45	5.37	5.28	5.51
170.	1.07	.014	.070	.14	.28	.40	.55	.74	0.91	1.12	1.48	1.70	2.04
171.	2.22	2.38	2.71	3.52	4.28	4.77	5.05	5.41	5.39	5.32	5.22	5.17	5.41
172.	1.08	.014	.070	.14	.27	.39	.52	.72	0.88	1.06	1.33	1.63	1.92
173.	2.08	2.23	2.52	3.23	3.81	4.35	4.71	5.24	5.25	5.19	5.12	5.14	5.37
174.	1.09	.013	.065	.13	.26	.38	.51	.68	0.84	1.01	1.26	1.54	1.78
175.	1.93	2.07	2.36	2.97	3.53	3.98	4.38	5.08	5.11	5.06	5.06	5.00	5.26
176.	1.10	.012	.060	.12	.25	.36	.50	.66	0.81	0.98	1.21	1.47	1.69
177.	1.82	1.95	2.21	2.80	3.31	3.71	4.04	4.92	4.99	4.97	4.96	4.88	5.17
178.	1.12	.012	.060	.12	.24	.33	.46	.61	0.75	0.91	1.11	1.34	1.53
179.	1.64	1.78	2.00	2.44	2.91	3.27	3.56	4.68	4.78	4.74	4.71	4.66	4.97
180.	1.14	.011	.055	.11	.22	.31	.43	.57	0.70	0.85	1.03	1.23	1.41
181.	1.50	1.60	1.80	2.20	2.62	2.99	3.23	4.45	4.58	4.56	4.56	4.47	4.81
182.	1.16	.010	.050	.10	.20	.29	.40	.52	0.65	0.80	0.96	1.13	1.29
183.	1.37	1.47	1.65	2.00	2.36	2.67	2.97	4.27	4.38	4.38	4.33	4.32	4.63
184.	1.18	.010	.050	.10	.19	.27	.37	.49	0.62	0.75	0.89	1.06	1.20
185.	1.28	1.37	1.54	1.85	2.20	2.50	2.76	4.01	4.21	4.23	4.22	4.21	4.51
186.	1.20	.009	.045	.091	.173	.25	.342	.46	0.578	.709	.84	.99	1.13
187.	1.21	1.29	1.44	1.72	2.00	2.29	2.57	3.79	4.04	4.06	4.03	4.03	4.32
188.	1.30	.007	.035	.071	.121	.182	.240	.320	0.416	.534	.61	.70	.82
189.	0.87	0.93	1.03	1.23	1.43	1.58	1.81	2.95	3.26	3.35	3.37	3.41	3.66
190.	1.40	.006	.030	.061	.091	.125	.176	.254	.311	.401	.46	.53	.62
191.	0.67	0.71	0.79	0.92	1.06	1.20	1.32	2.29	2.66	2.74	2.80	2.90	3.15
192.	1.50	0.005	0.023	0.046	0.067	0.100	0.133	0.184	0.233	0.300	0.35	0.39	0.46
193.	0.50	0.54	0.60	0.69	0.82	0.94	1.00	1.82	2.14	2.23	2.36	2.48	2.74

194.	1.60	0.004	0.019	0.038	0.053	0.085	0.106	0.144	0.172	0.235	0.268	0.30	0.35
195.	0.38	0.41	0.46	0.55	0.64	0.72	0.79	1.39	1.70	1.80	1.90	2.10	2.34
196.	1.70	0.003	0.014	0.029	0.037	0.062	0.083	0.117	0.140	0.183	0.221	0.25	0.283
197.	0.30	0.32	0.37	0.45	0.51	0.59	0.65	1.08	1.42	1.55	1.67	1.85	2.10
198.	1.80	0.002	0.011	0.022	0.024	0.050	0.066	0.093	0.117	0.150	0.171	0.20	0.231
199.	0.25	0.27	0.30	0.36	0.41	0.48	0.53	0.88	1.21	1.36	1.47	1.67	1.92
200.	1.90	0.002	0.010	0.020	0.011	0.037	0.049	0.076	0.094	0.126	0.144	0.18	0.2000
201.	0.21	0.22	0.25	0.30	0.35	0.40	0.45	0.81	1.06	1.21	1.31	1.52	1.74
202.	2.00	0.001	0.007	0.015	0.010	0.028	0.039	0.055	0.076	0.104	0.122	0.16	0.178
203.	0.19	0.20	0.21	0.25	0.28	0.32	0.36	0.72	0.97	1.11	1.20	1.39	1.62
204.	0.01	0.07	0.14	0.27	0.40	0.53	0.66	0.81	0.95	1.07	1.20	1.35	1.48
205.	0.02	0.07	0.12	0.25	0.37	0.49	0.60	0.71	0.82	0.95	1.05	1.17	1.23
206.	0.02	0.35	0.12	0.23	0.34	0.45	0.55	0.65	0.77	0.88	0.99	1.10	1.15
207.	0.02	0.18	0.40	0.20	0.31	0.40	0.52	0.62	0.73	0.85	0.95	1.05	1.10
208.	0.02	0.10	0.20	0.36	0.50	0.63	0.50	0.60	0.71	0.82	0.92	1.02	1.07
209.	0.02	0.10	0.19	0.34	0.47	0.59	0.70	0.60	0.70	0.82	0.92	1.02	1.06
210.	0.02	0.10	0.18	0.33	0.44	0.55	0.64	0.73	0.70	0.82	0.92	1.01	1.06
211.	0.02	0.09	0.17	0.30	0.40	0.51	0.59	0.67	0.76	0.82	0.92	1.01	1.05
212.	0.02	0.09	0.16	0.28	0.37	0.47	0.54	0.62	0.68	0.76	0.92	1.00	1.05
213.	0.02	0.09	0.15	0.24	0.34	0.42	0.48	0.54	0.60	0.65	0.82	1.00	1.05
214.	0.02	0.08	0.15	0.24	0.33	0.42	0.47	0.51	0.56	0.61	0.68	0.75	0.79
215.	0.02	0.08	0.15	0.23	0.34	0.39	0.44	0.48	0.52	0.56	0.62	0.67	0.70
216.	0.02	0.08	0.14	0.22	0.32	0.37	0.42	0.46	0.50	0.54	0.57	0.60	0.62
217.	0.02	0.08	0.14	0.21	0.29	0.34	0.38	0.40	0.44	0.46	0.49	0.51	0.53
218.	0.02	0.08	0.14	0.20	0.28	0.30	0.33	0.35	0.38	0.39	0.41	0.43	0.44
219.	0.02	0.08	0.14	0.20	0.26	0.29	0.32	0.33	0.35	0.36	0.38	0.39	0.40
220.	0.02	0.07	0.14	0.19	0.25	0.27	0.28	0.30	0.31	0.33	0.34	0.35	0.35
221.	0.02	0.07	0.13	0.18	0.24	0.26	0.27	0.28	0.28	0.29	0.29	0.30	0.30
222.	0.01	0.07	0.12	0.17	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
223.	0.01	0.07	0.12	0.17	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23
224.	0.01	0.06	0.12	0.16	0.20	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.21
225.	0.01	0.06	0.11	0.14	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
226.	0.01	0.05	0.09	0.13	0.16	0.19	0.20	0.20	0.20	0.18	0.18	0.18	0.18
227.	0.01	0.04	0.09	0.12	0.15	0.16	0.17	0.18	0.18	0.17	0.17	0.17	0.18
228.	0.01	0.03	0.07	0.10	0.13	0.15	0.15	0.15	0.14	0.15	0.15	0.15	0.15
229.	0.01	0.02	0.05	0.08	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.13
230.	0.00	0.01	0.03	0.05	0.07	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10
231.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.08	0.08	0.08	0.08
232.	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.08
233.	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.06
234.	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05
235.	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03
236.	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.03	0.03
237.	180.	0.180	0.180	0.180	0.182	0.183	0.184	0.185	0.186	0.187	0.188	0.189	0.190
238.		0.149	0.150	0.150	0.151	0.151	0.151	0.152	0.152	0.152	0.153	0.153	0.153
239.		0.1	1.1122	0.121	0.121	0.121	0.121	0.121	0.120	0.119	0.117	0.114	0.112
240.		0.1	1.0	2.1	6.0	5.0	3.0	91.0	89.0	87.0	84.0	80.0	76.0
241.		0.2	1.0	2.1	6.0	9.4	13.0	56.0	55.0	54.0	53.0	52.0	50.0
242.		0.2	1.0	2.1	5.2	8.2	11.2	13.7	48.0	48.0	47.0	46.0	45.8

243.	.2	1.0	2.0	4.5	7.0	9.4	12.0	14.2	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0
244.	.2	1.0	2.0	4.4	6.8	9.1	11.5	13.7	16.4	32.0	33.0	34.8	35.0	38.0	36.0	
245.	.2	1.0	2.1	4.4	6.6	8.8	11.0	13.2	15.4	18.0	28.0	30.8	31.0	32.0	34.0	
246.	.2	1.0	2.0	4.1	6.3	8.3	10.2	12.4	14.6	17.2	19.8	23.6	25.0	28.0	33.0	
247.	.2	1.0	2.0	4.1	6.1	8.1	10.2	12.2	14.6	17.0	19.4	20.0	24.4	26.4	30.4	
248.	.2	1.0	2.0	4.1	6.1	8.0	10.1	12.1	14.3	16.3	18.9	20.7	23.6	25.3	29.2	
249.	.2	1.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.4	21.3	22.8	24.3	28.0	
250.	.2	1.0	2.0	4.0	6.0	7.9	09.7	11.6	13.6	15.7	18.0	20.7	22.0	23.4	27.0	
251.	.2	1.0	2.0	4.1	6.0	7.8	09.4	11.2	13.2	15.4	17.6	20.0	21.3	22.6	26.0	
252.	.2	1.0	2.0	3.9	5.8	7.6	09.2	11.0	12.9	13.0	17.0	19.2	20.4	21.6	24.3	
253.	.2	1.0	2.0	3.8	5.6	7.4	09.0	10.8	12.6	10.6	16.5	18.5	19.5	20.6	22.6	
254.	.2	1.0	1.9	3.8	5.5	7.2	08.8	10.5	12.3	12.2	16.1	18.1	19.0	20.1	22.1	
255.	.2	1.0	1.8	3.9	5.4	7.0	08.7	10.3	12.1	13.9	15.8	17.7	18.6	19.6	21.6	
256.	.2	0.9	1.8	3.8	5.4	7.0	08.5	10.1	11.8	13.4	15.0	16.7	17.5	18.3	20.0	
257.	.2	0.8	1.9	3.8	5.4	7.0	08.4	10.0	11.5	13.0	14.3	15.8	16.4	17.0	18.4	
258.	.2	0.8	1.7	3.5	5.0	6.5	08.0	09.3	10.6	11.9	13.1	14.4	14.9	15.6	16.7	
259.	.2	0.8	1.6	3.2	4.6	6.1	07.7	08.6	09.8	10.9	12.0	13.0	13.4	14.2	15.0	
260.	.2	0.7	1.5	2.9	4.3	5.7	07.0	08.1	09.2	10.1	11.0	11.8	12.1	12.6	13.0	
261.	.2	0.7	1.4	2.6	4.0	5.4	06.4	07.6	08.6	09.4	10.1	10.6	10.8	11.0	11.0	
262.	.1	0.4	1.0	1.9	2.8	4.0	04.6	05.4	05.8	06.1	06.4	06.5	06.5	06.6	06.6	
263.	.1	0.4	0.7	1.3	2.0	2.5	03.0	03.4	03.6	03.8	03.8	03.8	03.8	03.8	03.8	
264.	.0	0.2	0.4	0.9	1.4	1.7	02.1	02.4	02.6	02.7	02.8	02.8	02.8	02.9	02.9	
265.	.0	0.1	0.2	0.5	0.8	1.0	01.2	01.4	01.6	01.7	01.8	01.9	01.9	02.0	02.0	
266.	.0	0.0	0.1	0.3	0.5	0.7	00.2	01.0	01.1	01.2	01.3	01.3	01.3	01.4	00.6	
267.	.0	0.0	0.1	0.2	0.2	0.4	00.5	00.6	00.6	00.8	00.8	00.8	00.8	00.9	00.9	
268.	.0	0.0	0.1	0.1	0.1	0.2	00.3	00.4	00.4	00.5	00.5	00.5	00.5	00.6	00.6	
269.	.0	0.0	0.0	0.0	0.0	0.1	00.1	00.2	00.2	00.2	00.2	00.2	00.2	00.3	00.3	
270.	210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0210.	0
271.	.3183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0183.	0
272.	.4	1.1148.	0148.	0147.	0146.	0145.	0143.	0141.	0138.	0135.	0131.	0128.	0125.	0115.	0	
273.	.5	1.2	4.01	09.0	105.	0102.	0	98.0	93.0	89.0	85.0	81.0	76.8	73.0	71.0	65.0
274.	.3	1.1	3.0	5.2	8.0	1.0	6.0	69.0	62.0	57.0	52.0	47.0	46.0	44.0	43.0	
275.	.2	1.1	2.8	5.0	7.6	10.2	17.9	65.0	58.0	52.0	47.0	42.8	41.0	40.1	40.0	
276.	.2	1.1	2.3	4.6	7.0	9.2	11.6	14.0	56.0	50.0	44.0	40.0	39.0	38.0	37.0	
277.	.2	1.1	2.2	4.4	6.6	8.6	10.9	13.4	15.4	46.0	41.0	36.8	35.0	34.0	34.0	
278.	.2	1.1	2.1	4.0	6.2	8.2	10.2	12.6	15.0	19.0	38.0	34.0	32.0	32.0	31.0	
279.	.2	1.1	2.0	3.8	5.6	7.8	9.6	11.8	14.8	17.8	21.0	25.0	28.0	29.0	29.5	
280.	.2	1.1	2.0	3.8	5.5	7.6	9.2	12.4	13.6	17.0	20.0	23.0	25.0	26.0	28.0	
281.	.2	1.1	1.9	3.7	5.3	7.4	9.0	11.2	13.0	16.2	19.0	21.5	23.2	24.2	26.5	
282.	.2	1.1	1.8	3.6	5.1	7.2	8.6	11.0	13.0	15.2	18.0	20.6	21.4	22.5	25.0	
283.	.2	1.1	1.7	3.5	4.9	7.0	8.4	10.6	12.7	14.9	17.4	19.8	20.2	21.7	23.5	
284.	.2	1.1	1.6	3.4	4.8	6.8	8.0	10.2	12.4	14.6	16.8	19.8	20.0	21.0	22.0	
285.	.2	1.0	1.6	3.3	4.6	6.5	7.9	09.9	11.9	14.3	16.0	18.0	18.0	20.0	21.0	
286.	.2	1.0	1.6	3.2	4.5	6.2	7.8	09.6	11.4	14.0	15.2	17.1	17.0	19.0	20.0	
287.	.2	1.0	1.5	3.1	4.3	6.0	7.6	09.3	11.0	13.5	14.5	16.2	16.0	18.1	19.3	
288.	.2	1.0	1.4	3.0	4.2	5.8	7.4	09.0	10.6	13.0	13.8	15.4	15.0	17.2	18.6	
289.	.2	1.0	1.3	2.9	4.0	5.6	7.0	09.0	10.0	12.0	13.0	15.8	15.0	16.0	17.0	
290.	.2	1.0	1.2	2.8	3.8	5.2	6.6	08.0	09.8	11.4	12.0	13.8	14.4	15.0	15.1	
291.	.2	0.9	1.2	2.6	3.5	4.9	6.2	07.5	09.0	10.3	11.0	12.4	12.5	13.3	13.5	

292.	.2	0.9	1.1	2.4	3.3	4.6	5.8	07.0	08.2	09.2	10.0	11.8	10.6	11.6	12.0
293.	.2	0.8	1.1	2.2	3.0	4.3	5.4	06.5	07.7	08.3	09.0	09.7	09.6	10.1	10.9
294.	.2	0.8	1.0	2.0	2.8	4.0	5.0	06.0	07.2	07.4	08.0	08.4	08.6	08.7	09.9
295.	.2	0.6	0.7	1.4	2.0	2.9	3.5	04.1	04.8	05.0	05.3	06.2	05.6	05.6	06.9
296.	.2	0.4	0.4	0.8	0.5	1.9	2.0	02.2	02.4	02.6	02.6	04.0	02.6	02.6	04.0
297.	.1	0.2	0.2	0.6	0.6	1.4	1.5	01.7	01.6	01.7	01.7	02.0	01.8	01.8	02.9
298.	.0	0.1	0.0	0.5	0.7	0.9	1.1	01.2	00.8	00.8	00.8	01.8	01.0	01.0	01.8
299.	.0	0.1	0.0	0.2	0.3	0.4	0.5	00.6	00.4	00.4	00.3	00.9	00.6	00.6	01.0
300.	.0	0.0	0.0	0.0	0.0	0.0	0.0	00.0	00.0	00.1	-0.2	00.1	00.2	00.2	00.2
301.	.0	0.0	0.0	-0.1	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.4	-0.2	-0.2	-0.2	-0.2
302.	.0	0.0	0.0	-0.2	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.5
303.	14.81	0.		14.81	-180.0		14.81	-180.0	14.82		-180.0	14.82		-180.5	
304.	0.057	-1.0		13.75	-150.0		13.75	-150.0	13.76		-150.0	13.76		-150.0	
305.	0.047	-1.0		0.23	0.		12.52	-121.0	12.53		-121.0	12.54		-121.0	
306.	0.038	-1.0		0.19	-1.2		0.38	-2.5	11.36		-94.0	11.37		-93.0	
307.	0.030	-1.0		0.15	-2.0		0.30	-3.0	0.64		-5.0	1.00		-8.0	
308.	0.028	-1.0		0.14	-1.6		0.28	-3.8	0.60		-6.0	0.94		-8.0	
309.	0.027	-1.0		0.135	-1.2		0.27	-2.5	0.57		-6.5	0.89		-8.0	
310.	0.025	-1.0		0.125	-1.1		0.25	-2.0	0.54		-5.5	0.84		-7.5	
311.	0.024	-1.0		0.12	-1.1		0.24	-2.0	0.51		-5.0	0.79		-7.5	
312.	0.023	-1.0		0.115	-1.0		0.23	-2.0	0.48		-4.5	0.74		-7.5	
313.	0.022	-1.0		0.11	-1.0		0.22	-2.0	0.47		-4.4	0.71		-7.0	
314.	0.021	-1.0		0.105	-1.0		0.21	-2.0	0.45		-4.2	0.69		-6.5	
315.	0.020	-1.0		0.10	-1.0		0.20	-2.0	0.44		-4.0	0.66		-6.5	
316.	0.020	-1.0		0.10	-1.0		0.20	-2.0	0.43		-3.9	0.64		-6.0	
317.	0.019	-1.0		0.095	-1.0		0.19	-2.0	0.41		-3.8	0.62		-6.0	
318.	0.018	-1.0		0.09	-1.0		0.18	-2.0	0.40		-3.7	0.60		-6.0	
319.	0.018	-1.0		0.09	-1.0		0.18	-2.0	0.39		-3.5	0.58		-5.5	
320.	0.018	-1.0		0.09	-1.0		0.18	-2.0	0.38		-3.3	0.56		-5.5	
321.	0.017	-1.0		0.085	-1.0		0.17	-2.0	0.37		-3.2	0.55		-5.5	
322.	0.016	-1.0		0.08	-1.0		0.16	-2.0	0.36		-3.0	0.53		-5.0	
323.	0.016	-1.0		0.08	-1.0		0.16	-2.0	0.34		-3.0	0.50		-5.0	
324.	0.015	-1.0		0.075	-1.0		0.15	-2.0	0.32		-3.0	0.48		-5.0	
325.	0.014	-1.0		0.07	-1.0		0.14	-2.0	0.30		-3.0	0.45		-5.0	
326.	0.013	-1.0		0.067	-1.0		0.135	-2.0	0.29		-3.0	0.42		-5.0	
327.	0.013	-1.0		0.065	-1.0		0.13	-2.0	0.27		-3.0	0.40		-5.0	
328.	0.011	-1.0		0.055			0.11	-1.5	0.21		-2.2	0.32		-3.5	
329.	0.010	-1.0		0.05	-1.0		0.10	-1.0	0.17		-2.0	0.26		-3.0	
330.	0.008	-1.0		0.04	-1.0		0.08	-1.0	0.14		-1.0	0.21		-2.0	
331.	0.007	-1.0		0.035	-1.0		0.07	-1.0	0.12		-1.0	0.19		-2.0	
332.	0.006	-1.0		0.03	-1.0		0.06	-1.0	0.10		-1.0	0.16		-1.0	
333.	0.005	-1.0		0.025	-1.0		0.05	-1.0	0.08		-1.0	0.14		-1.0	
334.	0.004	-1.0		0.02	-1.0		0.04	-1.0	0.07		-1.0	0.12		-1.0	
335.	0.003	-1.0		0.015	-1.0		0.03	-1.0	0.06		-1.0	0.10		-1.0	
336.	14.82	-181.5		14.82	-183.0		14.82	-185.0	14.82		-187.0	14.82		-189.0	
337.	13.76	-150.0		13.76	-150.0		13.77	-150.0	13.77		-151.0	13.77		-152.0	
338.	12.55	-121.0		12.55	-121.0		12.56	-121.0	12.56		-120.0	12.56		-119.0	
339.	11.38	-92.0		11.39	-91.0		11.39	-89.0	11.39		-87.0	11.39		-85.0	
340.	1.48	-11.0		9.90	-69.0		9.90	-64.0	9.90		-60.0	9.91		-56.0	

341.	1.36	-11.0	1.78	-12.5	9.52	-63.0	9.52	-56.0	9.52	-51.0
342.	1.25	-11.0	1.64	-11.0	2.12	-12.5	9.13	-56.0	9.14	-49.0
343.	1.16	-10.0	1.52	-11.0	1.94	-13.0	2.56	-19.0	8.56	-49.0
344.	1.08	-10.0	1.41	-11.0	1.80	-13.0	2.30	-17.0	2.98	-16.0
345.	1.00	-9.0	1.32	-11.0	1.66	-13.0	2.08	-15.0	2.63	-17.0
346.	0.96	-8.5	1.28	-11.0	1.60	-13.0	2.00	-15.0	2.49	-17.0
347.	0.93	-8.5	1.24	-10.5	1.54	-12.5	1.92	-14.5	2.38	-16.5
348.	0.91	-8.5	1.20	-10.5	1.49	-12.5	1.84	-14.5	2.28	-16.5
349.	0.88	-8.0	1.16	-10.0	1.44	-12.0	1.77	-14.5	2.19	-16.0
350.	0.85	-8.0	1.12	-10.0	1.40	-12.0	1.71	-14.0	2.10	-16.0
351.	0.82	-8.0	1.09	-10.0	1.36	-12.0	1.65	-14.0	2.03	-16.0
352.	0.80	-7.5	1.06	-9.5	1.31	-11.5	1.60	-13.5	1.95	-15.5
353.	0.78	-7.5	1.02	-9.5	1.28	-11.5	1.54	-13.5	1.89	-15.5
354.	0.76	-7.5	1.00	-9.0	1.24	-11.0	1.49	-13.0	1.82	-15.0
355.	0.74	-7.0	0.97	-9.0	1.20	-11.0	1.45	-13.0	1.76	-15.0
356.	0.70	-6.5	0.92	-8.5	1.14	-10.5	1.37	-12.5	1.66	-14.0
357.	0.66	-6.5	0.87	-8.5	1.08	-10.5	1.30	-12.0	1.56	-13.0
358.	0.62	-6.5	0.82	-8.5	1.02	-10.0	1.24	-11.5	1.48	-12.0
359.	0.59	-6.0	0.78	-8.5	0.98	-9.5	1.18	-11.0	1.40	-11.0
360.	0.56	-6.0	0.75	-8.0	0.93	-9.0	1.13	-10.0	1.33	-10.0
361.	0.42	-5.0	0.60	-6.0	0.73		0.92		1.06	-7.5
362.	0.34	-4.0	0.48	-5.0	0.59	-5.0	0.74	-5.0	0.85	-5.0
363.	0.28	-3.0	0.38	-4.0	0.48	-4.0	0.60	-4.0	0.70	-4.0
364.	0.24	-2.0	0.32	-3.0	0.40	-3.0	0.50	-3.0	0.58	-3.0
365.	0.21	-1.0	0.28	-2.0	0.35	-2.0	0.42	-2.0	0.49	-2.0
366.	0.18	-1.0	0.24	-1.0	0.30	-1.0	0.36	-1.0	0.41	-1.0
367.	0.15	-1.0	0.21	-1.0	0.25	-1.0	0.32	-1.0	0.36	-1.0
368.	0.13	-1.0	0.17	-1.0	0.22	-1.0	0.28	-1.0	0.32	-1.0
369.	14.81	-191.0	14.81	-192.0	14.80	-192.0	14.80	-192.5	14.80	-193.0
370.	13.77	-154.0	13.77	-155.0	13.77	-155.0	13.77	-155.0	13.76	-155.0
371.	12.56	-117.0	12.56	-114.0	12.56	-111.5	12.55	-118.0	12.54	-105.0
372.	11.40	-82.0	11.40	-78.0	11.40	-72.0	11.40	-72.0	11.40	-66.0
373.	9.92	-52.0	9.94	-50.0	9.96	-49.0	9.98	-48.0	10.03	-47.0
374.	9.55	-47.0	9.60	-45.0	9.61	-44.0	9.63	-44.0	9.68	-44.0
375.	9.16	-44.0	9.19	-41.0	9.21	-40.0	9.24	-40.0	9.29	-40.0
376.	8.60	-42.0	8.67	-37.0	8.70	-36.0	8.74	-38.0	8.84	-38.0
377.	7.84	-39.0	7.99	-33.0	8.02	-32.5	8.14	-33.5	8.38	-35.0
378.	3.28	-20.0	5.80	-25.0	6.58	-27.0	7.16	-30.0	7.68	-32.0
379.	3.08	-20.0	4.26	-24.5	5.47	-26.5	6.68	-29.0	7.12	-30.0
380.	2.92	-20.0	3.86	-24.0	4.73	-26.0	5.60	-27.5	6.40	-29.0
381.	2.80	-20.5	3.56	-23.0	4.08	-25.0	4.60	-26.0	5.48	-28.0
382.	2.68	-20.0	3.31	-22.0	3.70	-23.5	4.10	-24.5	4.48	-26.0
383.	2.56	-20.0	3.10	-21.0	3.41	-22.0	3.73	-23.0	4.30	-24.0
384.	2.46	-19.5	2.93	-20.0	3.20	-21.5	3.47	-28.5	3.92	-23.0
385.	2.36	-19.0	2.79	-19.5	3.02	-21.0	3.26	-22.0	3.64	-22.5
386.	2.28	-18.5	2.66	-19.0	2.87	-20.5	3.08	-21.0	3.43	-22.0
387.	2.19	-18.0	2.52	-18.5	2.72	-20.0	2.92	-20.0	3.26	-21.0
388.	2.11	-17.0	2.42	-18.0	2.60	-19.0	2.79	-19.0	3.12	-20.0
389.	1.97	-16.0	2.24	-16.5	2.40	-17.0	2.56	-18.0	2.88	-18.0

439.	.11	.10	.09	.28	.14	.13	.12	.11	.10	.10	.10	.10	.09	.09	.08	.08
440.	.08	.08	.07	.07	.06	.06	.06	.06	.06	.04	.03	.01				
441.	.22	.20	.19	.18	.28	.26	.24	.22	.21	.21	.2	.19	.18	.18	.17	.17
442.	.16	.16	.15	.14	.13	.12	.12	.12	.09	.07	.05	.03	.01			
443.	.35	.31	.29	.28	.44	.40	.37	.33	.31	.28	.26	.25	.24	.24	.23	.22
444.	.21	.20	.19	.18	.17	.16	.14	.12	.11	.07	.06	.02	.01			
445.	.46	.41	.39	.37	.73	.6	.5	.44	.39	.34	.33	.30	.29	.28	.27	.26
446.	.25	.24	.22	.21	.19	.18	.15	.13	.12	.09	.06	.04	.02	.01		
447.	.57	.52	.49	.47	.45	.81	.63	.53	.46	.41	.38	.36	.34	.32	.3	.29
448.	.27	.26	.24	.23	.21	.18	.16	.14	.13	.1	.07	.04	.02	.01		
449.	.7	.63	.59	.57	.55	.55	.77	.65	.54	.47	.44	.41	.38	.35	.33	.31
450.	.29	.28	.26	.24	.21	.19	.17	.15	.13	.1	.07	.05	.03	.02	.01	
451.	.81	.74	.69	.66	.64	.65	.65	.75	.62	.52	.50	.45	.42	.39	.36	.34
452.	.32	.30	.23	.25	.22	.19	.17	.15	.14	.1	.07	.05	.03	.02	.01	
453.	.93	.84	.79	.76	.74	.74	.74	.76	.70	.6	.55	.50	.46	.43	.39	.35
454.	.33	.31	.28	.25	.22	.19	.17	.15	.14	.1	.07	.05	.03	.02	.01	
455.	1.05	.95	.90	.86	.83	.83	.83	.85	.87	.70	.60	.55	.49	.44	.40	.37
456.	.34	.32	.28	.25	.22	.19	.18	.17	.15	.11	.07	.05	.03	.01		
457.	1.17	1.05	1.0	.95	.92	.92	.93	.94	.97	1.0	.65	.58	.51	.45	.41	.38
458.	.35	.32	.28	.25	.22	.19	.18	.17	.15	.11	.07	.05	.03	.02		
459.	1.22	1.11	1.05	1.0	.97	.97	.98	.99	1.02	1.06	.67	.59	.52	.45	.41	.38
460.	.35	.32	.28	.25	.22	.19	.18	.17	.15	.11	.07	.05	.03	.02		
461.	1.28	1.16	1.1	1.05	1.01	1.01	1.01	1.03	1.07	1.14	.68	.6	.52	.45	.41	.38
462.	.35	.32	.28	.25	.22	.19	.18	.17	.15	.11	.07	.05	.03	.03		
463.	1.4	1.27	1.2	1.15	1.1	1.1	1.1	1.13	1.16	1.2	.7	.6	.52	.45	.41	.38
464.	.35	.32	.28	.25	.22	.19	.18	.17	.15	.11	.07	.05	.03	.03	.02	.01
465.	0.	.7	.5	.3	.2	.2	.2	.1	.1	.1	.1	.1	.1	.1	.1	.1
466.	.1	.1	.1	.1	.1	.1	.1	.1	.1							
467.	0.	.52	.3.9	2.1	1.	.8	.7	.6	.5	.4	.4	.4	.4	.4	.4	.4
468.	.3	.3	.3	.3	.3	.3	.3	.3	.2	.1	.1	.1	.1			
469.	0.	.52	.53	.4.3	2.	1.8	1.6	1.4	1.2	1.1	1.	1.	.9	.9	.8	.8
470.	.7	.6	.6	.6	.5	.4	.4	.4	.4	.3	.2	.2	.1	.1	.1	.1
471.	0.	.52	.53	.38	3.5	3.4	2.9	2.5	2.3	2.1	2.	1.9	1.8	1.8	1.7	1.6
472.	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	.7	.5	.4	.3	.3	.2	.2
473.	0.	.52	.52	.39	6.1	5.3	4.7	4.1	3.7	3.3	3.1	3.0	2.8	2.7	2.6	2.6
474.	2.4	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.3	1.	.8	.7	.5	.4	.3	.2
475.	0.	.51	.51	.41	.8	.7	6.2	5.5	5.1	4.7	4.4	4.2	3.9	3.7	3.5	3.4
476.	0.	.51	.51	.41	.8	.7	6.2	5.5	5.1	4.7	4.4	4.2	3.9	3.7	3.5	3.4
477.	3.2	3.	2.9	2.8	2.5	2.3	2.2	2.1	2.0	1.4	1.1	.9	.7	.5	.4	.3
478.	0.	.51	.51	.42	.32	10.	8.9	7.8	6.9	6.1	5.8	5.5	5.1	4.7	4.4	4.2
479.	3.9	3.7	3.5	3.3	3.	2.8	2.7	2.6	2.4	1.8	1.4	1.1	.9	.7	.5	.4
480.	0.	.51	.50	.43	.32	30.	12.	10.3	9.	7.8	7.3	6.8	6.3	5.8	5.4	5.0
481.	4.6	4.3	4.3	4.2	3.7	3.3	3.1	2.9	2.7	1.9	1.6	1.3	1.0	.8	.6	.5
482.	0.	.51	.50	.43	.33	31.	28.	13.	11.	9.8	8.5	8.	7.4	6.8	6.2	5.7
483.	5.3	4.9	4.7	4.5	4.1	3.8	3.5	3.2	3.0	2.2	1.8	1.5	1.2	.9	.7	.5
484.	0.	.50	.49	.44	.35	32.	28.	24.	14.	12.	10.9	9.8	8.9	8.0	7.2	6.4
485.	5.9	5.5	5.1	4.8	4.5	4.2	3.8	3.5	3.3	2.5	2.0	1.6	1.3	1.0	.8	.6
486.	0.	.50	.49	.45	.35	32.	29.	25.	19.	14.2	12.8	11.5	10.2	9.	8.	7.
487.	6.5	6.	5.6	5.3	4.9	4.5	4.2	4.0	3.7	2.7	2.2	1.8	1.4	1.1	.8	.6

488.	0.	50.	49.	46.	35.	32.	29.	25.	21.	16.5	14.7	13.	11.5	10.1	8.8	7.6
489.	7.	6.5	6.1	5.8	5.3	4.8	4.5	4.2	3.0	2.9	2.4	1.9	1.5	1.2	.9	.6
490.	0.	50.	49.	46.	35.	33.	29.	26.	21.	17.8	15.9	14.	12.3	10.7	9.3	7.9
491.	7.3	6.7	6.3	6.	5.4	4.9	4.5	4.2	3.8	2.9	2.4	1.9	1.5	1.2	.9	.6
492.	0.	50.	49.	46.	36.	33.	29.	26.	22.	19.	15.2	14.	10.6	10.	9.5	8.1
493.	7.5	6.9	6.5	6.1	5.5	5.0	5.6	4.2	4.	3.	2.5	2.	1.6	1.3	1.	.7
494.	0.	50.	49.	46.	36.	33.	30.	26.	23.	21.	16.7	14.	11.2	10.	10.	8.5
495.	7.9	7.3	6.9	6.5	6.9	7.3	5.9	4.5	4.1	3.	2.5	2.	1.6	1.2	.9	.7
496.	0.	1.4	.9	.6	.4	.2	.2	.2	.2	.2	.1	.1	.1	.1	.1	.1
497.	.1	.1	.1	.1	.1	.1	.1	.1	.1							
498.	0.	40.	5.4	2.6	1.2	1.1	.9	.8	.7	.7	.7	.7	.7	.7	.6	.6
499.	.5	.4	.3	.3	.3	.2	.2	.2	.2	.2	.1	.1	.1	.1	.1	
500.	0.	40.	5.4	5.4	2.5	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
501.	.9	.8	.8	.8	.7	.6	.5	.5	.5	.3	.2	.2	.1	.1	.1	.1
502.	0.	38.	5.4	3.9	4.6	3.9	3.4	3.0	2.7	2.5	2.4	2.3	2.1	2.0	1.9	1.8
503.	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	.9	.8	.5	.3	.3	.3	.3	.3
504.	0.	37.	5.4	40.	7.	6.1	5.3	4.7	4.1	3.4	3.5	3.2	3.1	3.0	2.8	2.6
505.	2.4	2.2	2.1	2.0	1.8	1.7	1.5	1.4	1.2	.7	.6	.6	.6	.5	.5	.5
506.	0.	37.	5.4	41.	10.	8.2	7.	6.	5.	4.6	4.3	4.	3.8	3.6	3.4	3.2
507.	3.1	3.	2.9	2.8	2.5	2.2	2.1	2.0	1.5	1.2	.9	.6	.6	.5	.5	.5
508.	0.	37.	53.	43.	33.	13.	10.	8.	7.	6.	5.7	5.4	5.	4.6	4.3	4.0
509.	3.8	3.6	3.4	3.2	2.9	2.6	2.3	2.1	1.9	1.3	1.	.8	.6	.5	.5	.5
510.	0.	37.	51.9	46.	34.	28.9	15.	11.	9.	8.	7.5	7.	6.4	5.9	5.4	5.0
511.	4.6	4.2	4.0	3.8	3.4	3.0	2.9	2.8	2.4	1.4	1.1	.8	.8	.8	.8	.8
512.	0.	38.	51.	46.	35.	31.	29.7	16.	12.	11.	10.	9.	8.	7.	6.2	5.4
513.	5.1	4.8	4.5	4.2	3.8	3.4	3.2	3.0	2.5	1.6	1.3	1.	.9	.8	.8	.8
514.	0.	38.	50.	45.	35.	33.	31.	29.	17.	13.	11.3	9.6	8.8	8.0	7.3	6.6
515.	5.9	5.3	5.0	4.7	4.1	3.6	3.3	3.1	3.0	1.6	1.3	1.0	.9	.8	.8	.8
516.	0.	39.	48.	43.	35.	33.	31.	28.	25.	17.	15.	13.6	11.4	9.2	8.1	7.
517.	6.5	6.0	5.5	5.0	4.4	3.8	3.5	3.3	3.1	1.8	1.4	1.	.9	.8	.8	.8
518.	0.	40.	45.	40.	35.	33.	30.	28.	26.	24.	17.	14	12.	10.	8.3	6.7
519.	6.3	6.0	5.5	5.0	4.4	3.8	3.5	3.3	3.1	2.0	1.5	1.0	.9	.8	.8	.8
520.	0.	40.	44.	40.	34.	32.	29.	28.	25.3	24.	17.	14.	11.9	9.9	8.3	6.8
521.	6.4	6.0	5.5	5.0	4.4	3.8	3.5	3.3	3.1	2.0	1.5	1.0	.9	.8	.8	.8
522.	0.	40.	43.	38.	33.	31.	28.1	27.	25.	23.	17.	13.8	11.9	10.	8.4	6.9
523.	6.5	6.1	5.5	5.	4.4	3.8	3.5	3.3	3.1	2.	1.5	1.	.9	.8	.8	.8
524.	0.	42.	38.9	35.	29.	28.	27.	25.	22.	20.	15.	13.	10.5	8.	7.4	6.8
525.	6.3	5.8	5.4	5.	4.4	3.8	3.5	3.3	3.1	2.	1.5	1.	.9	.8	.8	.8
526.	0.	1.2	.9	.4	.3	.2	.2	.1	.1	.1	.1	.1	.1	.1	.1	.1
527.	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1						
528.	0.	50.	4.	2.2	1.5	1.0	.8	.7	.7	.7	.7	.7	.7	.7	.7	.6
529.	.6	.6	.5	.5	.5	.4	.4	.4	.3	.3	.3	.2	.1			
530.	0.	51.	4.4	4.	2.	2.	1.7	1.5	1.7	2.	1.7	1.5	1.5	1.5	1.4	1.3
531.	1.3	1.2	1.1	1.0	.9	.8	.8	.7	.7	.6	.6	.5	.3	.1		
532.	0.	52.	45.	39.	4.	4.	3.7	3.5	3.3	3.0	2.8	2.5	2.5	2.5	2.2	2.0
533.	1.8	1.5	1.2	1.0	.9	.8	.8	.7	.7	.6	.6	.6	.4	.2		
534.	0.	52.	47.	41.	6.	4.	5.	4.5	4.	3.	4.	4.	3.7	3.5	3.3	3.2
535.	3.	2.8	2.6	2.5	2.4	2.2	2.0	1.9	1.8	1.7	1.3	.9	.6	.3		
536.	0.	52.	48.	42.	9.	7.5	6.	5.	5.	4.	4.	4.	4.	4.	4.	3.5

537.	3.5	3.5	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0	1.0	.8	.5	.1
538.	0.	53.	48.	43.	33.	11.	9.	7.	6.	5.	5.	5.	5.	5.	4.
539.	4.	3.5	3.	3.	3.	3.	2.5	2.5	2.0	2.0	1.5	1.2	.9	.6	.1
540.	0.	53.	49.	45.	36.	32.	14.	11.	8.	7.	6.5	6.0	5.5	5.0	4.5
541.	4.5	4.5	4.0	4.	3.5	3.5	3.0	3.	2.5	2.	1.5	1.4	1.1	.8	.3
542.	0.	53.	49.	46.	38.	35.	31.	16.	12.	9.	8.5	8.0	7.5	7.	6.5
543.	5.5	5.0	4.5	4.0	4.	4.	3.5	3.	3.	2.5	2.	1.6	1.3	1.	.3
544.	0.	53.	50.	46.	38.	36.	34.	30.	17.	12.	11.	10.	9.	8.	7.5
545.	6.5	6.	5.5	5.	4.5	4.5	4.	3.5	3.5	3.	2.5	1.8	1.4	1.	.4
546.	0.	52.	50.	46.	38.	36.	34.	31.	26.	16.	14.	12.	11.	10.	9.
547.	7.5	7.	6.5	6.	5.	4.5	4.	3.5	3.5	3.	2.5	1.9	1.4	1.1	.5
548.	0.	52.	49.	45.	37.	35.	33.	29.	26.	20.	17.	14.	12.5	11.	9.
549.	7.5	7.	6.5	6.	5.	4.5	4.	3.5	3.5	3.0	2.5	2.	1.5	1.2	.5
550.	0.	52.	49.	45.	36.	34.	32.	28.	25.	20.	17.5	15.	13.	11.	9.5
551.	7.5	7.	6.5	6.	5.5	5.	4.5	4.	3.5	3.	2.5	2.	1.5	1.2	.5
552.	0.	51.	48.	44.	36.	34.	31.	27.	24.	20.	17.5	15.	13.	11.5	9.
553.	7.5	7.	6.5	6.	5.5	5.	4.5	4.	3.5	3.	2.5	2.	1.5	1.2	.5
554.	0.	50.	47.	43.	34.	31.	28.	24.	21.	18.	16.	14.	12.5	11.	9.5
555.	7.5	7.	6.5	6.	5.5	5.	4.5	4.	3.5	3.	2.5	2.	1.5	1.2	.5

```

a FOR INIT
00101 1* SUBROUTINE INIT
00101 2* C INITIALIZE DATA TABLES IN /TABLES/
00103 3* COMMON /TABLES/ NTRED, NPRED, TRED(33), PRED(25),
00103 4* 1 DEPZ(33,25), DEPU(33,25), DEPS(33,25), DEPH(33,25),
00103 5* 2 DAZ(33,15), DBZ(33,15), DAU(33,15), DBU(33,15),
00103 6* 3 DAS(33,15), DBS(33,15), DAH(33,15), DBH(33,15)
00104 7* DIMENSION HWR(7)
00105 8* 1 FORMAT(6E12.4)
00106 9* 2 FORMAT(13F6.3)
00107 10* 3 FORMAT(9F4.2,6F5.2)
00110 11* 4 FORMAT(15F5.2)
00110 12* C
00111 13* 7 FORMAT(10E8.0)
00112 14* ND=1
00113 15* CALL SETDAR(ND,1,HWR)
00113 16* C
00114 17* NPRED=25
00115 18* NTRED=33
00116 19* NPRED0=15
00116 20* C
00117 21* READ (ND,1) (PRED(I),I=1,NPRED)
00125 22* READ (ND,2) (TRED(I),(DEPZ(I,J),J=1,NPRED),I=1,NTRED)
00137 23* READ (ND,2) (TRED(I),(DEPU(I,J),J=1,NPRED),I=1,NTRED)
00151 24* READ (ND,2) (TRED(I),(DEPS(I,J),J=1,NPRED),I=1,NTRED)
00163 25* READ (ND,3) ((DAZ(I,J),J=1,NPRED0),I=1,NTRED)
00174 26* READ (ND,4) ((DAU(I,J),J=1,NPRED0),I=1,NTRED)
00205 27* READ (ND,4) ((DAS(I,J),J=1,NPRED0),I=1,NTRED)
00205 28* C
00216 29* DO 20 I=1,NTRED
00221 30* DO 20 J=1,NPRED0
00224 31* DAU(I,J)=-DAU(I,J)
00225 32* DAS(I,J)=-DAS(I,J)
00225 33* C
00230 34* IP2=0
00231 35* DO 30 IP1=1,3
00234 36* IP1=IP2+1
00235 37* IP2=IP1+5
00236 38* DO 30 I=1,33
00241 39* READ (ND,7) (DEPH(I,J),DAH(I,J),J=IP1,IP2)
00250 40* 30 CONTINUE
00250 41* C
00253 42* READ (ND,7) ((DEPH(I,J),J=16,25),I=1,33)
00253 43* C
00264 44* N=0
00265 45* CALL ININIT(DBZ)
00266 46* DBZ(33,15)=-.01
00267 47* N=1

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00270 48*      CALL INIIT (DBU)
00271 49*      CALL INIIT (DBS)
00272 50*      CALL INIIT (DBH)
00273 51*      RETURN
00273 52*      C
00274 53*      SUBROUTINE INIIT (A)
00277 54*      DIMENSION A (33,15)
00300 55*      5 FORMAT (16F5.0)
00301 56*      DO 50 J=1,NPREDD
00304 57*      READ (ND,5) (A(I,J),I=1,32)
00312 58*      A(33,J)=0.
00313 59*      IF (N.EQ.0) GO TO 50
00315 60*      DO 40 I=1,32
00320 61*      40 A(I,J)=-A(I,J)
00322 62*      50 CONTINUE
00324 63*      RETURN
00325 64*      END
END COMPILATION **      0 MESSAGES **

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2 FOR MILLER

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00101 1* SUBROUTINE MILLER (TR, HL, H6, VL, V6, SL, SG)
00101 2* C
00101 3* C THE METHOD OF DAVID MILLER FOR ESTIMATING THE HEAT OF VAPORIZATION
00101 4* C AND VAPOR AND LIQUID DENSITIES OF ALKALI METALS IS USED.
00101 5* C
00101 6* C THE THERMODYNAMIC PROPERTIES OF SODIUM FROM NAPROP ARE
00101 7* C EXTRAPOLATED TO THE CRITICAL POINT
00101 8* C
00101 9* C FOR ENTHALPY, THE SLOPE OF THE MIDPOINT OF THE SATURATED VAPOR
00101 10* C AND LIQUID ENTHALPIES IS EXTRAPOLATED TO THE CRITICAL POINT
00101 11* C
00101 12* C FOR ENTROPY, THE EXTRAPOLATED SLOPE OF THE MIDPOINT OF THE
00101 13* C SATURATED VAPOR AND LIQUID ENTROPIES IS ASSUMED TO BE VERTICAL
00101 14* C
00101 15* C TR -- REDUCED TEMPERATURE
00101 16* C TC -- CRITICAL TEMPERATURE, DEG K
00101 17* C RHOC -- CRITICAL DENSITY, GM/CC
00101 18* C HL -- ENTHALPY OF SAT'D LIQUID, JOULES/GM
00101 19* C H6 -- ENTHALPY OF SAT'D VAPOR, JOULES/GM
00101 20* C VL -- SPECIFIC VOLUME OF SAT'D LIQUID, CC/GM
00101 21* C V6 -- SPECIFIC VOLUME OF SAT'D VAPOR, CC/GM
00101 22* C SL -- ENTROPY OF SAT'D LIQUID, JOULES/GM-DEG K
00101 23* C SG -- ENTROPY OF SAT'D VAPOR, JOULES/GM-DEG K
00101 24* C
00101 25* C TR, TC, AND RHOC ARE INPUT
00101 26* C ALL OTHER QUANTITIES ARE CALCULATED
00101 27* C
00103 28* COMMON R, RS, RAT, CAT, CTOJ, P3IN, TNAPMN, TNAPMX, ASAT, BSAT
00104 29* COMMON /SODIUM/ ATWTNA, PC, RHOC, RNAFM, SOMASS, TC, TINA, ZC
00105 30* LOGICAL DEBUG
00106 31* COMMON /SAVE/ DEBUG, IERROR, ISTATE, SAVED(9,50)
00106 32* C
00106 33* C
00107 34* T=TR*TC
00110 35* DHV=RS*TC*(4.83*(1.-TR)**0.377)
00111 36* DHV02=.5*DHV
00112 37* HL=3841.89+0.855628*(T-1644.28)-DHV02
00113 38* H6=HL+DHV
00113 39* C
00114 40* RHO1=RHOC*(1.+3.982*(1.-TR)**.5435)
00115 41* VL=1./RHO1
00116 42* RHO6=RHOC*(1.-1.422*(1.-TR)**.389)
00117 43* V6=1./RHO6
00117 44* C
00120 45* DS=DHV02/T
00121 46* SL=5.79461-DS
00122 47* SG=5.79461+DS

```

DEG K

J/GM

J/GM

GM/CC

GM/CC

J/G-DEG K

J/G-DEG K

J/G-DEG K

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00122 48* C
00123 49* IF (DEBUG) PRINT 1, TR, T, HL, HG, VL, VG, SL, SG
00136 50* 1 FORMAT (10 MILLER CALCULATIONS FOR TR = F5.2, T = F9.3,
00136 51* 1 * DEG K, HL, HG, VL, VG, SL, SG /
00136 52* 2 6F12.4)
00136 53* C
00137 54* RETURN
00140 55* END
END COMPILATION ** 0 MESSAGES **

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2 FOR NAPROP

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00101 1* SUBROUTINE NAPROP (TK,P,HLS,SLS,VSAT,HGS,S6S,DL,PSAT,Z)
00101 2* C
00101 3* C AN ADAPTATION OF THE TOKAR-GOLDEN THERMODYNAMIC PROPERTIES
00101 4* C ROUTINE FOR SODIUM. INTERNAL CALCULATIONS ARE BRITISH
00101 5* C SYSTEM. INTERFACES ARE METRIC SYSTEM.
00101 6* C TK -- INPUT TEMPERATURE, DEG K (T=DEG R) 598 <TK< 1650
00101 7* C P -- INPUT PRESSURE, ATM
00101 8* C HLS -- ENTHALPY OF SATURATED LIQUID, JOULES/GM
00101 9* C SLS -- ENTROPY OF SATURATED LIQUID, JOULES/GM-DEG K
00101 10* C VSAT -- SPECIFIC VOLUME OF SATURATED VAPOR, CC/GM
00101 11* C HGS -- ENTHALPY OF SATURATED VAPOR, JOULES/GM
00101 12* C S6S -- ENTROPY OF SATURATED VAPOR, JOULES/GM-DEG K
00101 13* C DL -- DENSITY OF SATURATED LIQUID, GM/CC
00101 14* C PSAT -- SATURATION VAPOR PRESSURE, ATM
00101 15* C ZC -- CRITICAL COMPRESSIBILITY FACTOR
00101 16* C
00103 17* COMMON/SAVE/DEBUG,IERROR,IS,SI(9,50)
00104 18* LOGICAL DEBUG
00104 19* C
00105 20* IERROR=0
00106 21* IF (TK.GE.533.17 .AND. TK.LE.1644.28) GO TO 100
00110 22* IF (DEBUG) PRINT 1, TK
00114 23* IERROR=1
00115 24* 1 FORMAT ('TEMPERATURE IS OUTSIDE NAPROP BOUNDS (533-1644) T =')
00115 25* 1 F12.5)
00116 26* GO TO 1000
00116 27* C
00117 28* 100 T=1.8*TK
00120 29* TF=T-459.7
00121 30* IF (T-2059.7) 110,110,112
00124 31* 110 PSAT=(3.03266E6/SQR(T))*EXP(-2.30733E4/T)
00125 32* GO TO 120
00126 33* 112 PSAT=(6.8817602E6/(T+.61344))*EXP(-22981.96/T)
00126 34* C
00127 35* 120 HLS=-.389352*T-5529955E-4*T+.2+.113726E-7*T+.3-29.02
00130 36* SLS=-.389344*LOG(T)-1.10557E-4*T+.170408E-7*T+.2-1.792026
00131 37* DL=59.566-7.9504E-3*TF-.2872E-6*TF+.2+.06035E-9*TF+.3
00132 38* TWO=EXP(-9.95845+16588.3/T)
00133 39* FOUR=EXP(-24.59115+37589.7/T)
00134 40* U=PSAT*TWO
00135 41* W=PSAT*.3*FOUR
00136 42* X1=D.8
00137 43* 200 X1P=X1
00140 44* X1=X1-(W*X1+.4*U*X1+.2*X1-1.0)/(4.*W*X1+.3+2.*U*X1+1.0)
00141 45* IF (ABS(X1-X1P)/X1-1.E-6) 210,210,200
00144 46* 210 X2=U*X1+.2
00145 47* X4=1.-X1-X2

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DEG R

DEG F

BTU/LB

BTU/LB

LB/FT³

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00146 48*      ABAR=22.991*(X1+2.*X2+4.*X4)
00147 49*      VSAT=(.730229*T)/(ABAR*PSAT)      FT3/LB
00150 50*      Z=22.991/ABAR
00151 51*      DHF1=25980.7-2.21312*T+7.06278E-4*T**2-1.4526E-7*T**3      CAL/MNA 1
00152 52*      DHF2=2.*DHF1-18304.      CAL/MNA 2
00153 53*      DHF4=4.*DHF1-41478.      CAL/MNA 4
00154 54*      DHV=1.8*(X1*DHF1+X2*DHF2+X4*DHF4)/ABAR      BTU/LB
00155 55*      HGS=HLS+DHV      BTU/LB
00156 56*      SGS=SLS+DMV/T      BTU/LB
00156 57*      C
00156 58*      C      CONVERT TO METRIC UNITS      1 BTU/LB = 2.3259 JOULE/GM
00156 59*      C
00157 60*      HLS=2.3259*HLS
00160 61*      HGS=2.3259*HGS
00161 62*      SLS=4.184*SLS
00162 63*      SGS=4.184*SGS
00163 64*      DL=.01602*DL      GM/CC
00164 65*      VSAT=62.43*VSAT      CC/GM
00165 66*      DHV=2.3259*DHV
00165 67*      C
00166 68*      S(1,ISI)=TK
00167 69*      S(2,ISI)=PSAT
00170 70*      S(3,ISI)=VSAT
00171 71*      S(4,ISI)=DL
00172 72*      S(5,ISI)=HLS
00173 73*      S(6,ISI)=DHV
00174 74*      S(7,ISI)=HGS
00175 75*      S(8,ISI)=SLS
00176 76*      S(9,ISI)=SGS
00176 77*      C
00177 78*      1000 RETURN
00200 79*      END
END COMPILATION **      0 MESSAGES **

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a FOR PRESSS

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00101 1* SUBROUTINE PRESSS (SI, T, SOUT, P, ERROR, MAXIT)
00101 2* C
00101 3* C DETERMINE PRESSURE FROM S
00101 4* C SI IS FIXED (INPUT) ENTROPY, JOULES/GM-DEG K
00101 5* C T IS KNOWN TEMPERATURE, DEG K
00101 6* C SOUT IS ENTROPY COMPUTED IN PRESSS (W/IN ERROR OF SI)
00101 7* C P IS CORRESPONDING PRESSURE (CALLING PROGRAM MAY PROVIDE
00101 8* C ESTIMATE)
00101 9* C ERROR - RELATIVE ACCURACY DESIRED, (S-SOUT)/S L= ERROR
00101 10* C MAXIT IS MAXIMUM ITERATIONS ALLOWED -- PRESSS SETS
00101 11* C MAXIT TO -1 WHEN CONVERGENCE NOT ATTAINED
00101 12* C
00103 13* COMMON R, RS, RAT, CAT, CTOJ, P3IN, TNAPMN, TNAPMX, ASAT, BSAT
00104 14* COMMON /FUEL/ CPFS1, CPFS2, CPFS3, TFM, HFF, CPFL1, CPFL2, CPFL3,
00104 15* 1 TIF, FMASS, FFF
00105 16* COMMON /SODIUM/ ATWTNA, PC, RHOC, RNAFM, SOMASS, TC, TINA, ZC
00106 17* COMMON /TAB/ TA, HLA, SLA, VSATA, HGA, SGA, DLA,
00106 18* 1 PA, ZA, HA, SA, UA, CPIDNA, CVIDNA,
00106 19* 2 T1, H1, S1, ZC1, P1, U1, D11, D12,
00106 20* 3 T2, H2, S2, Z2, P2, U2, D2, V2,
00106 21* 4 T3, H3, S3, Z3, P3, U3, D31, D32,
00106 22* 5 T4, H4, S4, Z4, P4, U4, D41, D42,
00106 23* 6 T5, H5, S5, Z5, P5, U5, D51, D52,
00106 24* 7 T6, H6, S6, Z6, P6, U6, D61, D62,
00106 25* 8 T7, H7, S7, Z7, P7, U7, D71, D72,
00106 26* 9 T8, H8, S8, Z8, P8, U8, D81, D82
00107 27* COMMON /SAVE /DEBUG, IERROR, ISTAGE, SAVED (9, 50)
00110 28* LOGICAL DEBUG
00111 29* COMMON /TABLES/ NTRED, NPRED, TRED (33), PRED (25),
00111 30* 1 DEPZ (33, 25), DEPU (33, 25), DEPS (33, 25), DEPH (33, 25),
00111 31* 2 DAZ (33, 15), DBZ (33, 15), DAU (33, 15), DBU (33, 15),
00111 32* 3 DAS (33, 15), DBS (33, 15), DAH (33, 15), DBH (33, 15)
00111 33* C
00111 34* C IDEAL ENTROPY -- FROM REFERENCE TA, AT T, P FUNCTION STATEMENT
00112 35* SIT, P) = SA + CPIDNA * LOG (T/TA) - RS * LOG (P/PA)
00112 36* C
00113 37* IERROR = 0
00114 38* ABSERR = SI * ERROR
00115 39* TR = T/TC
00116 40* IF (P LE 0.) P = 10.
00120 41* PR = P/PC
00120 42* C ITERATION INITIALIZATION
00121 43* POLD = P
00122 44* SD = TABLE (DEPS, DAS, TR, PR, ZC) * CAT J/G-DEG K
00123 45* SOLD = SIT, POLD) - SD J/G-DEG K
00124 46* EROLD = SOLD - SI
00125 47* PNEW = P + 1

```

```

00126 48*      IF (DEBUG) PRINT 15,SI,T,ABSERR,TR,PR,SD,SOLD,EROLD
00141 49*      15 FORMAT ('OPRESSS VALUES FOR SI,T,ABSERR,TR,PR,SD,SOLD,EROLD'
00141 50*      1 /10E12.5)
00141 51*      C      ITERATE TO FIND P SUCH THAT S(P)=SI
00142 52*      DO 35 I=1,MAXIT
00145 53*      PR=PNEW/PC
00146 54*      SNEW=SI(T,PNEW)-TABLEF(DEPS,DAS,TR,PR,ZC)*CAT          J/G-DEGK
00147 55*      ERNEW=SNEW-SI
00150 56*      IF (ABS(ERNEW)-ABSERR) 40,40,20
00153 57*      20 SDEV=SNEW-SOLD
00154 58*      PDEV=PNEW-POLD
00155 59*      IF (DEBUG) PRINT 25,I,PNEW,SNEW,ERNEW,SDEV,PDEV
00166 60*      25 FORMAT ('ITER'13,' PNEW,SNEW,ERNEW,SDEV,PDEV' / 10X,8E12.5)
00167 61*      IF (ABS(ERNEW) .GT. ABS(EROLD)) 60 TO 30
00171 62*      EROLD=ERNEW
00172 63*      POLD=PNEW
00173 64*      SOLD=SNEW
00174 65*      30 PNEW=POLD-(PDEV*EROLD)/SDEV
00175 66*      IF (PNEW .LE. 0.) PNEW=-.8*POLD
00177 67*      35 CONTINUE
00177 68*      C      MAXIMUM NUMBER ITERATIONS EXCEEDED
00201 69*      IERROR=1
00201 70*      C
00202 71*      40 SOUT=SNEW          J/G-DEGK
00203 72*      P=PNEW
00204 73*      RETURN
00205 74*      END
END COMPILATION **      0 MESSAGES **

```

2 FOR TABLEF

```

00101 1* FUNCTION TABLEF (TABLE,DT,TR,PR,ZC)
00101 2* C
00101 3* C TABLE IS THE INTERPOLATED RESULT FOR REDUCED TEMPERATURE, TR,
00101 4* C AND PRESSURE, PR, IN THE TABLE GIVEN (ZC,DEPH,DEPU,DEPS, OR
00101 5* C OTHER) THE VALUE TABLEF IS CORRECTED FOR ZC DEPARTURE BY
00101 6* C THE DA SUPPLIED AS DT: TABLEF=B+DT*(ZC-.27).
00101 7* C DT IS DIMENSIONED (NT,MP,2), WITH DA VALUES (Z>.27) IN FIRST ARRAY
00101 8* C AND DB (Z<-.27) VALUES IN THE SECOND ARRAY. STATEMENTS 90-94 EFFECT
00101 9* C CORRECT ARRAY.
00101 10* C
00101 11* C
00103 12* DIMENSION TABLE(33,25), DT(33,15)
00104 13* COMMON /TABLES/ NT, NP, T(33), P(25)
00105 14* COMMON /SAVE/ DEBUG, IERROR
00106 15* LOGICAL DEBUG
00107 16* LOGICAL NOD
00107 17* C
00110 18* NOD = .FALSE.
00110 19* C
00110 20* C
00110 21* C T(NTMIN) <= TR < T(NTMAX)
00110 22* C
00111 23* DO 20 I=2,NT
00114 24* IF (TR-T(I)) 10,20,20
00117 25* 10 NTMAX = I
00120 26* GO TO 30
00121 27* 20 CONTINUE
00121 28* C TR TOO LARGE FOR TABLE -- LINEAR EXTRAPOLATE
00123 29* NTMAX=NT
00123 30* C
00124 31* 30 NTMIN=NTMAX-1
00125 32* TFR=(TR-T(NTMIN))/(T(NTMAX)-T(NTMIN))
00125 33* C
00125 34* C P(NPMIN) <= PR < P(NPMAX)
00125 35* C
00126 36* DO 50 I=2,NP
00131 37* IF (PR-P(I)) 40,50,50
00134 38* 40 NPMAX=I
00135 39* GO TO 60
00136 40* 50 CONTINUE
00136 41* C PR TOO LARGE FOR TABLE -- LINEAR EXTRAPOLATE
00140 42* NPMAX=NP
00140 43* C
00141 44* 60 NPMIN=NPMAX-1
00142 45* PFR=(PR-P(NPMIN))/(P(NPMAX)-P(NPMIN))
00142 46* C
00142 47* C INTERPOLATE IN BASIC TABLE

```



```

00142 48* C
00143 49* TABLE=TB LF (TABLE+NTMIN+NP MIN+TFR+PFR)
00143 50* C
00144 51* IF (PR.LE.1.2) GO TO 90
00146 52* IF (TR.LE.0.8 .OR. TR.GE.1.2) GO TO 85
00150 53* IF (DEBUG) PRINT 80,PR,TR
00155 54* 80 FORMAT ('UNRELIABLE TABLE INTERPOLATIONS FOR PR .GT. 1.2 ('F5.2,
00155 55* 1 ' ) AND TR BETWEEN 0.8 AND 1.2 ('F5.2,')')
00156 56* 85 NOO=.TRUE.
00157 57* 90 IF (ZC-0.27) 92,100,94
00162 58* 92 CONTINUE
00163 59* IF (PR.GT.1.2) GO TO 94
00165 60* NP MIN=NP MIN+15
00166 61* NP MAX=NP MAX+15
00167 62* 94 CONTINUE
00170 63* DTT=DT (NTMIN, NP )+TFR*(DT (NTMAX, NP )-DT (NTMIN, NP ) )
00171 64* IF (NOO) GO TO 96
00171 65* C
00171 66* C INTERPOLATE IN Z-ADJUSTMENT TABLE
00171 67* C
00173 68* DTT=TB LF (DT+NTMIN+NP MIN+TFR+PFR)
00174 69* 96 TABLE=TABLEF+(ZC-0.27)*DTT
00174 70* C
00175 71* 100 RETURN
00176 72* END
END COMPILATION ** 0 MESSAGES **

```

a FOR TBLF

```
00101 1* FUNCTION TBLF (A,NTMN,NPMN,TF,PF)
00103 2* DIMENSION A(33,1)
00103 3* C
00104 4* NTMX=NTMN+1
00105 5* NPMX=NPMN+1
00105 6* C
00105 7* C BRACKET T
00105 8* C
00106 9* AMIN=A(NTMN,NPMN)+PF*(A(NTMN,NPMX)-A(NTMN,NPMN))
00107 10* AMAX=A(NTMX,NPMN)+PF*(A(NTMX,NPMX)-A(NTMX,NPMN))
00110 11* TBLF=AMIN+TF*(AMAX-AMIN)
00111 12* RETURN
00112 13* END
END COMPILATION ** 0 MESSAGES **
```

a FOR TEMPP

```

00101 1* SUBROUTINE TEMPP(P,T,S,SEST,ERROR,MAXIT)
00101 2* C
00101 3* C TEMPP DETERMINES THE TEMPERATURE BETWEEN EQUILIBRIUM T2 AND
00101 4* C FUEL MELTING TFM WHICH CORRESPONDS TO THE FINAL PRESSURE P3
00101 5* C P - KNOWN PRESSURE, ATM
00101 6* C T - TEMPERATURE TO BE FOUND IN TEMPP, DEG K
00101 7* C S - ENTROPY OF SODIUM AT T,P
00101 8* C SEST - ESTIMATE OF S
00101 9* C ERROR - RELATIVE ACCURACY DESIRED
00101 10* C MAXIT - MAXIMUM NUMBER OF ITERATIONS ALLOWED
00101 11* C
00103 12* COMMON R, RS, RAT, CAT, CTOJ, P3IN, TNAPMN, TNAPMX, ASAT, BSAT
00104 13* COMMON /FUEL/ CPF51,CPF52,CPF53,TFM,HFF,CPFL1,CPFL2,CPFL3
00104 14* 1 TIF,FMASS,FFF
00105 15* COMMON /SODIUM/ ATMTNA, PC, RHOC, RNAFM, SOMASS, TC, TINA, ZC
00106 16* COMMON /TAB/ TA,H1A,SLA,VSATA,HGA,SGA,D1A,
00106 17* 1 PA,ZA,HA,SA,UA,CPIDNA,CVIDNA,
00106 18* 2 T1,H1,S1,ZC1,P1,U1,D11,D12,
00106 19* 3 T2,H2,S2,Z2,P2,U2,D21,D22,
00106 20* 4 T3,H3,S3,Z3,P3,U3,D31,D32,
00106 21* 5 T4,H4,S4,Z4,P4,U4,D41,D42,
00106 22* 6 T5,H5,S5,Z5,P5,U5,D51,D52,
00106 23* 7 T6,H6,S6,Z6,P6,U6,D61,D62,
00106 24* 8 T7,H7,S7,Z7,P7,U7,D71,D72,
00106 25* 9 T8,H8,S8,Z8,P8,U8,D81,D82
00107 26* COMMON /SAVE /DEBUG, IERROR, ISTATE, SAVED(9,50)
00110 27* COMMON /TABLES/ NTRED, NPRED, TRED(33), PRED(25),
00110 28* 1 DEPZ(33,25), DEPU(33,25), DEPS(33,25), DEPH(33,25),
00110 29* 2 DAZ(33,15), DBZ(33,15), DAU(33,15), DBU(33,15),
00110 30* 3 DAS(33,15), DBS(33,15), DAH(33,15), DBH(33,15)
00111 31* LOGICAL DEBUG
00111 32* C
00112 33* 1 FORMAT ('*TEMPP VALUES FOR P,T,STP,SDS,ERR*/10E12.5)
00113 34* IERROR=0
00114 35* PR=P/PC
00114 36* C
00114 37* C ITERATION INITIALIZATION
00115 38* T=T2-(SEST-S2)*(T2-TFM)/(S4-S2)
00116 39* TR=T/TC
00117 40* SD=TABLEF(DEPS,DAS,TR,PR,ZC),CAT
00120 41* SI = SA+CPIDNA*LOG(T/TA)-RS*LOG(P/PA)
00121 42* STP=S1-SD
00122 43* CPFL=CPFL1+CPFL2*(T2-T)+CPFL3*(T2+T2+T2+T+T)
00123 44* HLOST=CPFL*(T2-T)
00124 45* DS=HLOST/(0.5*(T2+T)*RNAFM)
00125 46* SDS=S2+DS
00126 47* SAV6=D.5*(STP+SDS)

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D-42

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00127 48*      SERR=(STP-SDS)/SAVG
00130 49*      ERR=ABS(SERR)
00131 50*      IF (DEBUG) PRINT 1, P,T,STP,SDS,ERR
00141 51*      IF (ERR.LE.ERROR) GO TO 100
00141 52*      C
00141 53*      C      ITERATE TO FIND T SUCH THAT STP = SDS
00143 54*      DO 50 I=1,MAXIT
00146 55*      TOLD=T
00147 56*      T=T- (T2-TOLD)*(STP-SDS)/(SDS-S2)
00150 57*      TR=T/TC
00151 58*      SD=TABLEF(DEPS,DAS,TR,PR,ZC)*CAT
00152 59*      SI = SA+CPIDNA*LOG(T/TA)-RS*LOG(P/PA)
00153 60*      STP=SI-SD
00154 61*      CPFL=CPFL1+CPFL2*(T2+T)+CPFL3*(T2+T2+T2+T+T)
00155 62*      HLOST=CPFL*(T2-T)
00156 63*      DS=HLOST/(0.5*(T2+T)+RNAFM)
00157 64*      SDS=S2+DS
00160 65*      SAVG=0.5*(STP+SDS)
00161 66*      SERR=(STP-SDS)/SAVG
00162 67*      ERR=ABS(SERR)
00163 68*      IF (DEBUG) PRINT 1, P,T,STP,SDS,ERR
00173 69*      IF (ERR.LE.ERROR) GO TO 100
00175 70*      50 CONTINUE
00175 71*      C
00175 72*      C      MAXIMUM NUMBER OF ITERATIONS EXCEEDED
00177 73*      IERROR=1
00177 74*      C
00200 75*      100 S=SAVG
00201 76*      RETURN
00202 77*      END
END COMPILATION **      0 MESSAGES **

```

a FOR VIRIAL

```

00101 1* SUBROUTINE VIRIAL (TK,P,PS,VG,HG,SG,CPG)
00101 2* C THE VIRIAL CODE FROM UCID-15271 (THERMODYNAMIC PROPERTIES OF
00101 3* C SODIUM AND POTASSIUM, JL OLDHAM, FEB 1967)
00101 4* C
00101 5* C THE EQUATION IS OF THE FORM
00101 6* C
00101 7* C  $PV/RT = 1 + B/V + C/V^2 + D/V^3 + E/V^4$  (1144-1686 DEG K)
00101 8* C
00101 9* C FOR INPUT TEMPERATURE TK (DEG K) AND PRESSURE P (ATM), THE CODE
00101 10* C CALCULATES ENTHALPY, ENTROPY, SPECIFIC HEAT, AND SPECIFIC VOLUME
00101 11* C OF SUPERHEATED SODIUM VAPOR
00101 12* C
00101 13* C
00103 14* DIMENSION C(8),D(14)
00104 15* C(1)=-4.3519
00105 16* C(2)=6755.3
00106 17* C(3)=-0.6137
00107 18* C(4)=10839.
00110 19* C(5)=0.0
00111 20* C(6)=-0.0905
00112 21* C(7)=13539.
00113 22* C(8)=0.0
00114 23* D(1)=6.8377
00115 24* D(2)=-9980.94
00116 25* D(3)=-0.26641
00117 26* D(4)=2005.15
00120 27* D(5)=0.21598
00121 28* D(6)=17172.
00122 29* D(7)=-43830.
00123 30* D(8)=0.32559
00124 31* D(9)=0.21598
00125 32* D(10)=0.0
00126 33* D(11)=0.0
00127 34* D(12)=0.21598
00130 35* D(13)=-6.053
00131 36* D(14)=-37280.
00132 37* G1=2.30259
00133 38* G2=0.43429
00134 39* MAX=30
00135 40* DELTA=0.0001
00136 41* XM=22.991
00137 42* T=TK+1.8
00140 43* PS=EXP(G1*(D(1)+D(2)/T+D(3)+LOG(T)))
00141 44* B=-EXP(G1*(C(1)+C(2)/T+G2+LOG(T)))
00142 45* BS=G1*(G2-C(2)/T)/T
00143 46* BD=B*(G1*(2.-C(2)/T+G1*(G2-C(2)/T+2-G2)/(T+T)))
00144 47* F=EXP(G1*(C(3)+C(4)/T+C(5)/(T+T)))

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00145 48* FS=-G1*F*(C(4)+2.*C(5)/T)/T**2
00146 49* FD=2.*G1*F*(C(4)+3.*C(5)/T+G1*(C(4)+2.*C(5)/T)**2/(2.*T))/T**3
00147 50* V=-EXP(G1*(C(6)+C(7)/T))
00150 51* VS=-G1*C(7)*W/(T*T)
00151 52* VD=G1*C(7)*W*(2.*G1*C(7)/T)/T**3
00152 53* E=C(8)
00153 54* ES=0.0
00154 55* ED=0.0
00155 56* R=0.729679
00156 57* H=D(4)+D(5)*T+D(6)*EXP(D(7)/T)
00157 58* S=D(8)+D(9)*LOG(T)+D(10)*EXP(D(11)/T)
00160 59* CP0=D(12)+D(13)*EXP(D(14)/T)
00161 60* K=0
00162 61* V=R*T/P
00163 62* P1=R*T*(1./V+B/(V*V))*F/V**3+W/V**4+E/V**5)
00164 63* IF(ABS(P-P1)/P)-DELTA) 38,38,31
00167 64* 31 K=K+1
00170 65* IF(K.GT.MAX) 60 TO 35
00172 66* Z=P-P1
00173 67* DF=R*T*(1.+2.*B/V+3.*F/(V*V)+4.*W/V**3+5.*E/V**4)/(V*V)
00174 68* IF(DF.LE.0.0) 60 TO 32
00176 69* V=V-Z/DF
00177 70* 60 TO 33
00200 71* 32 V=0.8*V
00201 72* 33 IF(V).38,34
00204 73* V=0.8*(V+Z/DF)
00205 74* 34 P1=R*T*(1./V+B/(V*V))*F/V**3+W/V**4+E/V**5)
00206 75* IF(ABS(P-P1)/P)-DELTA) 38,38,31
00211 76* 35 PRINT 36
00213 77* 36 FORMAT('MAXIMUM ITERATIONS EXCEEDED FOR PRESSURE CONVERGENCE IN
00213 78* 1SUBROUTINE VIRIAL')
00214 79* 38 R=1.986
00215 80* H=H0+R*T*(B-T*BS*(F-FS*T/2.)/V+(W-T*VS/3.)/V**2*(E-D.25*T*ES)/V**3
00215 81* 1)/(X*V)
00216 82* S=S0-(R/X*H)*(LOG(P)-LOG(P*V/(R*T)))+(B-T*BS)/V+0.5*(F+T*FS)/V**2+
00216 83* 1*(W+T*VS)/(3.*V**3)+0.25*(E+T*ES)/V**4)
00217 84* U1=1.*(B-T*BS)/V*(F+T*FS)/V**2+(W+T*VS)/V**3*(E+T*ES)/V**4
00220 85* U2=1.+2.*B/V+3.*F/V**2+4.*W/V**3+5.*E/V**4
00221 86* U3=T*BS+2.*BS+0.5*(T*FD+2.*FS)/V*(T*VD+2.*VS)/3.*V**4+0.25*(T*ED+
00221 87* 12.*ES)/V**3
00222 88* CP=CP0*(R/X*H)*(U1*U1/U2-1.)-(R/T)/(V*X*H)*U3
00223 89* V=V/X*H
00224 90* V6=62.43*V
00225 91* H6=2.3259*H
00226 92* S6=4.184*S
00227 93* CP6=4.184*CP
00230 94* RETURN
00231 95* END

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CC/GM
J/GM
J/G-DEG K
J/G-DEG K

END COMPILATION ** 0 MESSAGES **

a FOR SOCOOL

```

00100 1* C      SOCOOL-II -- A PROGRAM FOR CALCULATING THE WORK ENERGY GENERATED
00100 2* C      FROM THE INTERACTION OF MOLTEN MATERIAL WITH SODIUM
00100 3* C
00100 4* C      INPUT DATA FOR SOCOOL-II
00100 5* C
00100 6* C      CARD 0 (OPTIONAL)
00100 7* C      COL 1-5  DEBUG   SWITCH TO PRINT DEBUG OUTPUT
00100 8* C
00100 9* C      CARD 1  TITLE
00100 10* C      COL 1-80
00100 11* C
00100 12* C      CARD 2  INTEGER DATA (2014)
00100 13* C      COL 1-4  INTF    NUMBER OF RADIAL INTERVALS IN MOLTEN PARTICLE
00100 14* C      5-8  INTNA    NUMBER OF RADIAL INTERVALS IN SODIUM
00100 15* C      9-12  NSTEP   NUMBER OF TIME STEPS PER TIME DECADE
00100 16* C      15-16  NPRINT  NUMBER OF TIME STEPS PER PRINT OF RESULTS
00100 17* C      IF NEGATIVE, EXTRA THERMAL PROPERTY RESULTS ARE OBTAINED
00100 18* C      17-20  NAPROP  SWITCH FOR CALCULATION OF SODIUM PROPERTIES
00100 19* C      0 - CONSTANT PROPERTIES
00100 20* C      1 - VARIABLE MECHANICAL PROPERTIES BASED ON SATURATED LIQUID
00100 21* C      2 - VARIABLE MECHANICAL PROPERTIES FROM HIMPAN EQUATION
00100 22* C      3 - VARIABLE MECHANICAL PROPERTIES BASED ON SATURATED UP TO
00100 23* C      2500 DEG F AND HIMPAN EQUATION OF STATE ABOVE 2500 DEG F
00100 24* C      21-24  NFPROP  SWITCH FOR CALCULATION OF MOLTEN MATERIAL PROPERTIES
00100 25* C      0 - CONSTANT PROPERTIES
00100 26* C      1 - CONSTANT PROPERTIES FOR LIQUID AND SOLID
00100 27* C      2 - VARIABLE PROPERTIES FOR (P-U) O2 FUEL
00100 28* C      25-28  NTEMP   SWITCH TO SET INITIAL TEMPERATURES
00100 29* C      0 - INITIAL TEMPERATURES SET TO TFIN AND TNAIN
00100 30* C      1 - READ INITIAL TEMPERATURES FROM CARDS 6
00100 31* C      29-32  NLOTS   NUMBER OF TYPES OF PLOTS DESIRED
00100 32* C
00100 33* C      CARD 3  GEOMETRY AND CONDITIONS (10E8.4)
00100 34* C      COL 1-8  DIA     DIAMETER OF UNIT SPHERE, CM
00100 35* C      9-16  AREA1    INTERFACE AREA BETWEEN HEATED AND UNHEATED SODIUM, SQ CM
00100 36* C      17-24  VMAIN   INITIAL VOLUME OF HEATED SODIUM, CC
00100 37* C      25-32  TFIN    INITIAL TEMPERATURE OF MOLTEN MATERIAL, DEG K
00100 38* C      33-40  TNAIN   INITIAL SODIUM TEMPERATURE, DEG K
00100 39* C      41-48  PIN     INITIAL PRESSURE, ATM
00100 40* C      49-56  POUT    FINAL PRESSURE AFTER ISENTROPIC EXPANSION, ATM
00100 41* C      57-64  TAUIN   INITIAL TIME, SEC
00100 42* C      65-72  TAUAX   MAXIMUM TIME, SEC
00100 43* C
00100 44* C      CARD 4  SODIUM THERMAL AND MECHANICAL PROPERTIES (10E8.4)
00100 45* C      COL 1-8  CONDNA  THERMAL CONDUCTIVITY, W/CM-DEG K
00100 46* C      9-16  RHONA    DENSITY, G/CC
00100 47* C      17-24  CVNA    CONSTANT-VOLUME HEAT CAPACITY, J/G-DEG K

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00100 48* C 25-32 QNA HEAT GENERATION RATE, W/CC
00100 49* C 33-40 SONVEL SONIC VELOCITY, CM/SEC
00100 50* C 41-48 BETAT ISOTHERMAL COMPRESSIBILITY, 1/ATM
00100 51* C 49-56 GAMMAV THERMAL PRESSURE COEFFICIENT, ATM/DEG K
00100 52* C 57-64 TC CRITICAL TEMPERATURE, DEG K
00100 53* C 65-72 PC CRITICAL PRESSURE, ATM
00100 54* C 73-80 RHOC CRITICAL DENSITY, G/CC
00100 55* C
00100 56* C CARD 5 PROPERTIES OF MOLTEN MATERIAL (10E8.4)
00100 57* C COL 1-8 CONDF LIQUID THERMAL CONDUCTIVITY
00100 58* C 9-16 RHOF LIQUID DENSITY, G/CC
00100 59* C 17-24 CPF LIQUID CONSTANT-PRESSURE HEAT CAPACITY, J/G-DEG K
00100 60* C 25-32 QF LIQUID HEAT GENERATION RATE
00100 61* C 33-40 TFMELT MELTING POINT, DEG K
00100 62* C 41-48 HFMELT HEAT OF FUSION, J/G
00100 63* C 49-56 CONDFS SOLID THERMAL CONDUCTIVITY, W/CM-DEG K
00100 64* C 57-64 RHDFS SOLID DENSITY, G/CC
00100 65* C 65-72 CPFS SOLID CONSTANT-PRESSURE HEAT CAPACITY, J/G-DEG K
00100 66* C 73-80 QFS SOLID HEAT GENERATION RATE, W/CC
00100 67* C
00100 68* C CARD(5) 6 INITIAL TEMPERATURES -- INTF+INTNA+1 VALUES (10E8.4)
00100 69* C
00100 70* C
00100 71* C
00100 72* C PARAMETERS PNT NUMBER OF THERMAL POINTS
00100 73* C PSN NUMBER OF TYPES OF DATA SAVED
00100 74* C PSL LENGTH OF SAVED DATA LISTS
00101 75* C PARAMETER PNT=200
00103 76* C PARAMETER PSN=8, PSL=500
00103 77* C
00104 78* C COMMON /THERMP/ ALPHA(PNT), COND(PNT), CP(PNT), Q3PRM(PNT),
00104 79* C 1 RHO(PNT), T(PNT), VOL(PNT), ALPHA1, ALPHA2, BK1, BK2, COND1,
00104 80* C 2 COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2
00104 81* C
00105 82* C COMMON AREA1, ASAT, BETAT, BSAT, CONDNA, CONDF, CONDFS, CPF,
00105 83* C A CPFS, CVNA, DEBUG, DIA, DTAU, DTNA, EBLAST, ESHOCK, GAMMAV,
00105 84* C 1 HFMELT, INTJ, INTR, INTL, INTH, INTN, IOUT, ISTOP, LAMBDA,
00105 85* C 2 NAPROP, NFPROP, NTEMP, PC, PIN, POUT, PSAT, P1, P2, QF, QFS,
00105 86* C 3 QNA, RHOC, RHOF, RHDFS, RHONA, SOMASS, SONVEL, TAU, TC, TF,
00105 87* C B CAPF, CAPNA, DELRSQ, NSTEP, RHOVEL, TAUMIN, VOUT,
00105 88* C 4 TFIN, TFMELT, TNA, TNAIN, TOUT, U1, U2, VNAIN, V1, V2
00105 89* C
00106 90* C REAL LAMBDA
00107 91* C LOGICAL DEBUG
00110 92* C INTEGER DEBUG, TITLE
00110 93* C
00111 94* C DIMENSION TITLE(14)
00112 95* C DIMENSION SAVOUT(PSN*PSL)
00113 96* C DATA DEBUG //DEBUG %/

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```

00113  97*  C
00115  98*
00116  99*
00117 100*
00120 101*
00121 102*
00121 103*
00121 104*
00121 105*
00121 106*
00121 107*
00121 108*
00122 109*
00122 110*
00122 111*
00122 112*
00122 113*
00122 114*
00122 115*
00122 116*
00123 117*
00123 118*
00123 119*
00123 120*
00123 121*
00123 122*
00123 123*
00123 124*
00124 125*
00124 126*
00124 127*
00124 128*
00124 129*
00124 130*
00124 131*
00124 132*
00124 133*
00124 134*
00125 135*
00125 136*
00126 137*
00127 138*
00127 139*
00130 140*
00131 141*
00131 142*
00132 143*
00132 144*
00132 145*

1 FORMAT(13A6,A2)
2 FORMAT(20I4)
3 FORMAT(10E8,A)
4 FORMAT(1H1,13A6,A2)
6 FORMAT(1///46X' *** INPUT DATA ***' ///' *** INTEGER DATA ***'//
1' INTERVALS INTERVALS TIME STEPS TIME STEPS SWITCH FOR
2 SWITCH FOR SWITCH FOR NUMBER/
3 IN FUEL IN SODIUM PER DECADE PER PRINT SODIUM PROP
4 FUEL PROP TEMP INPUT OF PLOTS/
5 INTF INTNA NSTEP NPRINT NAPROP
6 NFPROP NTEMP NPLOTS'//18,7I13 )
7 FORMAT(1///' *** GEOMETRY AND CONDITIONS ***'//
1' DIAMETER OF INTERFACE INITIAL INITIAL
2 INITIAL FINAL INITIAL MAXIMUM/
3 UNIT SPHERE AREA SODIUM VOLUME FUEL TEMP SODIUM TEMP
4 PRESSURE PRESSURE TIME TIME/
5 DIA AREA VNAIN TFIN TNAIN
6 PIN POUT TAUMIN TAUMAX'//
7 1PE12.5,9E13.5 )
8 FORMAT(1///' *** SODIUM THERMAL AND MECHANICAL PROPERTIES ***'//
1' THERMAL DENSITY CONST-VOL HEAT SONIC
2 ISOTHERMAL THERM PRESS CRITICAL CRITICAL CRITICAL/
3 CONDUCTIVITY HEAT CAPACITY GENERATION VELOCITY
4 COMPRESS COEFFICIENT TEMPERATURE PRESSURE DENSITY/
5 CONDNA RHONA CVNA DNA SONVEL
6 BETAT GAMMAV TC PC RHOC'//
7 1PE12.5,9E13.5 )
9 FORMAT(1///' *** FUEL THERMAL PROPERTIES ***'//
1' LIO THERMAL LIQUID LIO C-P LIO HEAT MELTING
2 HEAT OF SOLID THERMAL SOLID SOLID C-P SOLID HEAT
3 /
4 CONDUCTIVITY DENSITY HEAT CAPACITY GENERATION POINT
5 FUSION CONDUCTIVITY DENSITY HEAT CAPACITY GENERATION
6 /
7 CONDF RHOF CPF QF TFMELT
8 HFMELT CONDFS RHOF5 CPFS QFS'//
9 1PE12.5,9E13.5 )
19 FORMAT(1///20X'POINTWISE INITIAL TEMPERATURES'/
1 24X'I'5X'TEMPERATURE T(I)'// (125,F17.4))
20 FORMAT(1///42X' *** DEBUG CALCULATIONS ***'// )
21 FORMAT(1/13X'RADIAL TEMPERATURES AND THERMAL PROPERTIES AT TAU ='
1 1PE9.3/5X'I TEMPERATURE COND'9X'CP'10X'RH'8X'ALPHA'/)
22 FORMAT(1I6,F12.5,E11.5,8E12.5)
23 FORMAT('OOUTPUT SAVE ARRAY IS FULL WITH'14,' ENTRIES AT TIME TAU='
1 1PE15.8)
24 FORMAT(1// 26X' *** SUMMARY OF RESULTS ***'//
1 'O TIME T-FUEL T-SODIUM VELOCITY VOLUME PRESSURE
2 ' PSAT A. ENERGY//

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00133 146* 25 FORMAT (1PE8.2,DP2F10.4,10E10.4)
00134 147* 26 FORMAT ('VALUES FOR TNA, PSAT, P2, BETAT, GAMMAV = ',SE13.5)
00135 148* 27 FORMAT ('FINAL TEMPERATURE DISTRIBUTION'//10(2F6.0//))
00136 149* 28 FORMAT ('INERTIAL WORK FOR ISENTROPIC EXPANSION OF ',1PE13.6,' GM
00136 150* 1SODIUM FROM ',DPF8.1,' ATM AND ',1PE13.6,' CC /
00136 151* 2 68X'TO ',DPF8.1,' ATM AND ',1PE13.6,' CC = ',1PE13.6,' JOULES')
00137 152* 29 FORMAT ('CONVERSION OF THERMAL TO WORK ENERGY = ',1PE13.6)
00140 153* 30 FORMAT ('TERMINAL PRESSURE ('F6.1') IS .LE. ZERO')
00141 154* 31 FORMAT ('MAXIMUM PRESSURE DUE TO ACOUSTIC RESTRAINT = ',F6.0,
00141 155* 1 ' ATM')
00141 156* C
00142 157* IOUT=6
00143 158* IN=5
00143 159* C
00144 160* 100 CONTINUE
00145 161* ISTOP=0
00146 162* DEBUG=.FALSE.
00147 163* 101 READ (IN,1,END=1000) TITLE
00155 164* IF (TITLE(1).NE.DEBUG) GO TO 102
00157 165* DEBUG=.TRUE.
00160 166* GO TO 101
00161 167* 102 WRITE (IOUT,4) TITLE
00161 168* C
00167 169* READ (IN,2) INTF,INTNA,NSTEP,NPRINT,NAPROP,NFPROP,NTEMP,NPLOTS
00201 170* WRITE (IOUT,6) INTF,INTNA,NSTEP,NPRINT,NAPROP,NFPROP,NTEMP,NPLOTS
00213 171* INTJ=INTF
00214 172* INTM=INTF+INTNA
00215 173* INTN=INTM+1
00216 174* NPRINT=NPRINT
00217 175* IF (NPRINT.EQ.0) NPRINT=NSTEP
00221 176* NPRINT=ABS(NPRINT)
00222 177* LSAVED=0
00223 178* READ (IN,3) DIA,AREAI,VNAIN,TFIN,TNAIN,PIN,POUT,TAUMIN,TAUMAX
00236 179* WRITE (IOUT,7) DIA,AREAI,VNAIN,TFIN,TNAIN,PIN,POUT,TAUMIN,TAUMAX
00251 180* N RANGE=ALOG10(TAUMAX/TAUMIN) + 1
00252 181* READ (IN,3) COMONA,RHONA,CVNA,QNA,SONVEL,BETAT,GAMMAV,TC,PC,RHOC
00266 182* WRITE (IOUT,8) COMONA,RHONA,CVNA,QNA,SONVEL,BETAT,GAMMAV,TC,PC,RHOC
00302 183* READ (IN,3) CONDF,RHOF,CPF,QF,TFMELT,HFMELT,CONDFS,RHOF,CPFS,QFS
00316 184* WRITE (IOUT,9) CONDF,RHOF,CPF,QF,TFMELT,HFMELT,CONDFS,RHOF,CPFS,QFS
00332 185* IF (NTEMP.EQ.0) GO TO 105
00334 186* READ (IN,3) (T(I),I=1,INTN)
00342 187* WRITE (IOUT,19) (T(I),I=1,INTN)
00350 188* 105 CONTINUE
00350 189* C
00351 190* IF (DEBUG) WRITE (IOUT,4) TITLE
00360 191* IF (DEBUG) WRITE (IOUT,20)
00360 192* C
00363 193* CALL PROP(1)
00363 194* C

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00364 195*      EHEAT=0.
00365 196*      ESHOCK=0.
00366 197*      P1=PIN
00367 198*      PMAX=0.
00370 199*      U1=0.
00371 200*      V1=VNAIN
00371 201*      C
00372 202*      TAU=0.
00373 203*      NCOUNT=0
00373 204*      C
00374 205*      DO 400 K=1,NRANGE
00377 206*      DTAUMX=5.0*DELRSQ/ALPHA(INTN)
00400 207*      210 IF (DTAU.LE.DTAUMX) GO TO 220
00402 208*      DTAU=.5*DTAU
00403 209*      LAMBDAL=.5*LAMBDAL
00404 210*      NSTEP=2*NSTEP
00405 211*      NPRINT=2*NPRINT
00406 212*      GO TO 210
00407 213*      220 CONTINUE
00410 214*      JSTEP=NSTEP
00411 215*      IF (NPRIN.LT.0) NPRIN=-NPRINT
00413 216*      IF (K.EQ.1) JSTEP=NSTEP*NSTEP/9
00415 217*      DO 390 J=1,JSTEP
00420 218*      TAU=TAU+DTAU
00421 219*      IF (TAU.LE.TAUMAX) GO TO 230
00423 220*      ISTOP=3
00424 221*      GO TO 320
00425 222*      230 NCOUNT=NCOUNT+1
00426 223*      TOLDNA=TNA
00426 224*      C
00427 225*      CALL HEAT
00427 226*      C
00430 227*      DTNA=TNA-TOLDNA
00431 228*      EHEAT=EHEAT+CP(INTN)*SOMASS*DTNA
00431 229*      C
00432 230*      CALL PRES
00432 231*      C
00433 232*      IF (P2.GT.PMAX) PMAX=P2
00435 233*      IF (NPRIN.GE.0) GO TO 320
00437 234*      IF (NCOUNT+NPRIN.LT.0) GO TO 320
00441 235*      WRITE (IOUT,21) TAU
00444 236*      DO 310 I=1,INTN
00447 237*      310 WRITE (IOUT,22) I,T(I),COND(I),CP(I),RHO(I),ALPHA(I)
00460 238*      WRITE (IOUT,26) TNA,PSAT,P2,BETAT,GAMMAV
00460 239*      C
00467 240*      320 CONTINUE
00467 241*      C
00467 242*      C      SEE IF DATA AT THIS TIME IS TO BE SAVED FOR LATER PRINT OR PLOT.
00467 243*      C

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00470 244*      IF (ISTOP.GT.0) GO TO 325
00472 245*      IF (NPRINT.GT.NCOUNT) GO TO 350
00474 246*      325 LSAVED=LSAVED+1
00475 247*      IF (LSAVED.LT.PSL) GO TO 330
00477 248*      IF (LSAVED.EQ.PSL) PRINT 23,LSAVED,TAU
00504 249*      IF (LSAVED.GT.PSL) LSAVED=PSL
00506 250*      330 L=LSAVED
00507 251*      SAVOUT(1,L)=TAU
00510 252*      SAVOUT(3,L)=TNA
00511 253*      SAVOUT(2,L)=TF
00512 254*      SAVOUT(4,L)=U2
00513 255*      SAVOUT(5,L)=V2
00514 256*      SAVOUT(6,L)=P2
00515 257*      SAVOUT(7,L)=PSAT
00516 258*      SAVOUT(8,L)=ESHOCK
00517 259*      NCOUNT=0
00517 260*      C
00520 261*      350 CONTINUE
00521 262*      IF (ISTOP.GT.0) GO TO 405
00523 263*      390 CONTINUE
00525 264*      DTAU=DTAU*10.
00526 265*      LAMBDA=LAMBDA*10.
00527 266*      400 CONTINUE
00527 267*      C
00527 268*      C CALCULATE INERTIAL WORK
00531 269*      405 CONTINUE
00532 270*      IF (POUT.GT.0.) GO TO 410
00534 271*      WRITE (IOUT,30) POUT
00537 272*      GO TO 417
00540 273*      410 IF (POUT.NE.1.0) GO TO 411
00542 274*      TOUT=1154.611111
00543 275*      GO TO 414
00544 276*      411 Y=LOG(POUT)
00545 277*      IF (POUT.GT.21.6779) GO TO 412
00547 278*      TFF=EXP(17.3889580+.12512970*Y+.25367737E-2*Y**2+.89120865E-3*Y**3)
00550 279*      TOUT=(TFF*459.7)/1.8
00551 280*      GO TO 414
00552 281*      412 TOUT=BSAT/(ASAT-Y)
00553 282*      414 CONTINUE
00553 283*      C
00554 284*      416 CALL BLAST
00555 285*      EBLAST=EBLAST*SOMASS
00556 286*      VOUT=VOUT*SOMASS
00556 287*      C
00556 288*      C CALCULATE EFFICIENCY OF THERMAL TO MECHANICAL ENERGY CONVERSION
00557 289*      EFF=(ESHOCK*EBLAST)/EMFAT
00560 290*      417 CONTINUE
00560 291*      C
00560 292*      C OUTPUT SUMMARY RESULTS

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00561 293*      WRITE (IOUT*4) TITLE
00567 294*      WRITE (IOUT*24)
00571 295*      DO 420 I=1,NL SAVED
00574 296*      420 WRITE (IOUT*25) (SAVOUT(J,I),J=1,PSN)
00603 297*      WRITE (IOUT*27) (T(I),I=1,INTN)
00611 298*      WRITE (IOUT*31) PMAX
00614 299*      WRITE (IOUT*28) SOMASS,PSAT,V2,POUT,VOUT,EBLAST
00624 300*      WRITE (IOUT*29) EFF
00627 301*      IF (NPLOTS.LE.0) GO TO 100
00631 302*      CALL SPLOTT
00632 303*      GO TO 100
00633 304*      1000 PRINT 99
00635 305*      99 FORMAT('DALL DATA PROCESSED')
00636 306*      STOP
00637 307*      END
END COMPILEATION **      D MESSAGES **

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3 FOR BLAST

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00101 1* SUBROUTINE BLAST
00101 2* C
00101 3* C INERTIAL WORK CALCULATED BY ISENTROPIC EXPANSION FROM SATURATED
00101 4* C LIQUID TO TERMINAL PRESSURE
00101 5* C
00103 6* PARAMETER PNT=200
00103 7* C
00104 8* COMMON /THERMP/ ALPHA(PNT), COND(PNT), CP(PNT), Q3PRM(PNT),
00104 9* 1 RHO(PNT), T(PNT), VOL(PNT), ALPHA1, ALPHA2, BK1, BK2, COND1,
00104 10* 2 COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2
00104 11* C
00105 12* COMMON AREA1, ASAT, BETAT, BSAT, CONDNA, CONDF, CONDFS, CPF,
00105 13* A CPFS, CVNA, DEBUG, DIA, DTAU, DTNA, EBLAST, ESHOCK, GAMMAV,
00105 14* 1 MFELT, INTJ, INTK, INTL, INTM, INTN, IOUT, ISTOP, LAMBDA,
00105 15* 2 NAPROP, NFPROP, NTEMP, PC, PIN, POUT, PSAT, P1, P2, QF, QFS,
00105 16* 3 QNA, RHOC, RHOF, RHOF5, RHONA, SOMASS, SONVEL, TAU, TC, TF,
00105 17* B CAPF, CAPNA, DELRSQ, NSTEP, RHOVEL, TAUMIN, VOUT,
00105 18* 4 TFIN, TFELT, TNA, TNAIN, TOUT, U1, U2, VNAIN, V1, V2
00105 19* C
00106 20* REAL LAMBDA
00107 21* LOGICAL DEBUG
00107 22* C
00110 23* 1 FORMAT ('OBLAST RESULTS FOR TNA, SSAT, ESAT, TOUT, SLIQ, SVAP, ELI
00110 24* 10, EVAP, FRVAP, EOUT'/10E13.6)
00110 25* C
00111 26* IF (TNA.LE.D.) GO TO 1000
00113 27* IF (TNA.LT.TC) GO TO 100
00115 28* HSAT=3841.89+.855628*(TC-1644.28)
00116 29* ESAT=HSAT-.1013278*PC/RHOC
00117 30* SSAT=5.79461
00120 31* IF (TNA.GT.TC) GO TO 50
00122 32* PSAT=PC
00123 33* RHOSAT=RHOC
00124 34* GO TO 200
00125 35* 50 CONTINUE
00126 36* ESAT=ESAT+.545953*(TNA-TC)
00127 37* SSAT=SSAT+.545953*LOG(TNA/TC)
00130 38* RHOSAT=SOMASS/V2
00131 39* GO TO 200
00132 40* 100 TRR=1.8*TNA
00133 41* TFF=TRR-459.7
00133 42* C
00133 43* C CALCULATE ENTROPY AND INTERNAL ENERGY OF SATURATED LIQUID
00134 44* IF (TFF.GT.2500.) GO TO 150
00136 45* SSAT=4.184+.1389344*LOG(TRR)-1.10557E-4*TRR+.170408E-7*TRR*.2
00136 46* 1 -1.792026)
00137 47* ESAT=2.32593*1140.01172+.34375763*TFF-.37766993E-4*TFF*.2+

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DEG F

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00137 48*      1      .108011589E-7*TFF**3)
00140 49*      GO TO 200
00141 50*    150 TR=TNA/TC
00142 51*      RHOSAT=RHOC*(1.+.16077*(1.-TR)**.586885)
00143 52*      DHV=1.81658*TC*(1.-TR)**.427122
00144 53*      HSAI=3841.89+.855628*(TNA-1644.28)*.5*DHV
00145 54*      ESAI=HSAI-.1013278*PSAT/RHOSAT
00146 55*      SSAT=5.79461-.5*DHV/TNA
00146 56*
00146 57*    C      CALCULATE SATURATED PROPERTIES AT TERMINAL PRESSURE
00147 58*    200 CONTINUE
00150 59*      TRR=1.8*TOUT
00151 60*      TFF=TRR-459.7
00152 61*      IF (TFF.GT.2500.) GO TO 250
00154 62*      SLIQ=4.184*(.389344*LOG(TRR)-1.10557E-4*TRR+.170408E-7*TRR**2
00154 63*      -1.792026)
00155 64*      SVAP=4.184*(.0352173 -.34785271E-2*TFF +.22123568E-5*TFF**2 -
00155 65*      .69996985E-9*TFF**3 +.87069240E-13*TFF**4)
00156 66*      ELIQ=2.32593*(140.01172 +.34375763*TFF -.37766993E-4*TFF**2 +
00156 67*      .108011589E-7*TFF**3)
00157 68*      EVAP=2.32593*(2032.1250 +.30151367*TFF -.30040741E-3*TFF**2 +
00157 69*      .13061799E-6*TFF**3 -.19980461E-10*TFF**4)
00160 70*      RHOLIQ=(59.566-7.9504E-3*TFF-0.2872E-6*TFF**2+0.06035E-9*TFF**3)
00160 71*      /62.43
00161 72*      RHOVAP=1./((62.43*EXP((14.5181-0.856376E-2*TFF+0.130237E-5*TFF**2))
00162 73*      GO TO 300
00163 74*    250 TR=TOUT/TC
00164 75*      DHV=1.81658*TC*(1.-TR)**.427122
00165 76*      HLIQ=3841.89+.855628*(TOUT-1644.28)*.5*DHV
00166 77*      HVAP=HLIQ*DHV
00167 78*      RHOLIQ=RHOC*(1.+.16077*(1.-TR)**.586885)
00170 79*      RHOVAP=RHOC*(1.-1.08512*(1.-TR)**.116733)
00171 80*      ELIQ=HLIQ-.1013278*POUT/RHOLIQ
00172 81*      EVAP=HVAP-.1013278*POUT/RHOVAP
00173 82*      DSV=DHV/TOUT
00174 83*      SLIQ=5.79461-.5*DSV
00175 84*      SVAP=SLIQ*DSV
00175 85*
00175 86*    C      CALCULATE INERTIAL WORK
00176 87*    300 FRVAP=(SSAT-SLIQ)/(SVAP-SLIQ)
00177 88*      FRLIQ=1.-FRVAP
00200 89*      VOUT=FRVAP/RHOVAP+FRLIQ/RHOLIQ
00201 90*      EOUT=FRVAP*EVAP+FRLIQ*ELIQ
00202 91*      BLAST=ESAT-EOUT
00203 92*      IF (DEBUG) WRITE (IOUT,1) TNA,SSAT,ESAT,TOUT,SLIQ,SVAP,ELIQ,
00203 93*      EVAP,FRVAP,EOUT
00220 94*      RETURN
00221 95*    1000 WRITE (IOUT,1001) TNA
00224 96*    1001 FORMAT (10TNA =*,E12.5,*,(ZERO OR NEGATIVE) IN SUBROUTINE BLAST*)

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00225 97* EBLAST=0.
00226 98* RETURN
00227 99* END
END COMPILATION ** 0 MESSAGES **


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a FOR HEAT
00101 1* SUBROUTINE HEAT
00101 2* C
00101 3* C SUBROUTINE HEAT CALCULATES THE RADIAL TEMPERATURE DISTRIBUTION
00101 4* C AND RETURNS THE AVERAGE TEMPERATURES FOR CALCULATION OF PRESSURES
00101 5* C
00103 6* C
00103 7* C
00104 8* C
00104 9* 1 COMMON /THERMP/ ALPHA(PNT), COND(PNT), CP(PNT), Q3PRM(PNT),
00104 10* 2 RHO(PNT), T(PNT), VOL(PNT), ALPHA1, ALPHA2, BK1, BK2, COND1,
00104 11* 2 COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2
00105 12* C
00105 13* A COMMON AREA1, ASAT, BETAT, BSAT, CONDNA, CONDF, CONDFS, CPF,
00105 14* 1 CPFS, CVNA, DEBUG, DIA, DTAU, DTNA, EBLAST, ESHOCK, GAMMAV,
00105 15* 2 HF MELT, INTJ, INTK, INTL, INTM, INTN, IQUT, ISTOP, LAMBDA,
00105 16* 3 NAPROP, NFPROP, NTEMP, PC, PIN, POUT, PSAT, P1, P2, QF, QFS,
00105 17* 4 QNA, RHOC, RHOF, RHOF5, RHONA, SOMASS, SONVEL, TAU, TC, TF,
00105 18* 4 CAPF, CAPNA, DELRSQ, NSTEP, RHOVEL, TAUMIN, VOUT,
00105 19* 4 TF IN, TMELT, TNA, TNAIN, TOUT, U1, U2, VNAIN, V1, V2
00106 20* C
00106 21* REAL LAMBDA
00107 22* LOGICAL DEBUG
00110 23* DIMENSION A(PNT), AL(PNT), B(PNT), BB(PNT), C(PNT), D(PNT),
00110 24* 1 DD(PNT), BETA(PNT), GAMMA(PNT)
00111 25* C
00111 26* 1 FORMAT ('DEBUG INFORMATION FROM SUBROUTINE HEAT' /
00111 27* 1 ' ALPHA1, ALPHA2, BK1, BK2, COND1, COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2,
00111 28* 2 LAMBDA, AL1, AL2, B1, B2, D1, D2' / (10E12.6))
00112 29* 2 FORMAT (' A (I) COEFFICIENTS' / (10E12.6))
00113 30* 3 FORMAT (' B (I) COEFFICIENTS' / (10E12.6))
00114 31* 4 FORMAT (' C (I) COEFFICIENTS' / (10E12.6))
00115 32* 5 FORMAT (' D (I) COEFFICIENTS' / (10E12.6))
00116 33* 6 FORMAT (' BETA(I) ' / (10E12.6))
00117 34* 7 FORMAT (' GAMMA(I) ' / (10E12.6))
00120 35* 8 FORMAT (' T (I) VALUES' / (10E12.6))
00120 36* C
00121 37* IF (NAPROP.EQ.0 .AND. NFPROP.EQ.0) GO TO 100
00121 38* C
00123 39* IF (NAPROP.GT.0) CALL PROP(2)
00125 40* IF (NFPROP.GT.0) CALL PROP(3)
00125 41* C
00127 42* BK1=COND1*ALPHA2*(1.-1./INTJ)
00130 43* BK2=COND2*ALPHA1*(1.+1./INTJ)
00130 44* C
00131 45* 100 CONTINUE
00131 46* C
00132 47* DO 105 I=1, INTN
00135 48* AL(I)=ALPHA(I)*LAMBDA

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00136 48*      BB(I)=1.+2.*AL(I)
00137 49*      DD(I)=DTAU*Q3PRM(I)/(RHO(I)*CP(I))
00140 50*      105 CONTINUE
00142 51*      AL1=ALPHA1*LAMBDA
00143 52*      AL2=ALPHA2*LAMBDA
00144 53*      B1=1.+2.*AL1
00145 54*      B2=1.+2.*AL2
00146 55*      D1=DTAU*Q3PRM1/RHOC1
00147 56*      D2=DTAU*Q3PRM2/RHOC2
00150 57*      IF (DEBUG) WRITE (IOUT,1) ALPHA1,ALPHA2,BK1,BK2,COND1,COND2,
00150 58*      1 Q3PRM1,Q3PRM2,RHOC1,RHOC2,LAMBDA,AL1,AL2,B1,B2,D1,D2
00150 59*      C
00150 60*      C COEFFICIENTS OF TRIDIAGONAL ARRAY
00150 61*      C
00174 62*      C(I)=-6.*AL(I)
00175 63*      B(I)=1.-C(I)
00176 64*      DO 110 I=2,INTN
00201 65*      A(I)=-AL(I)*(1.-1/(I-1))
00202 66*      B(I)=BB(I)
00203 67*      110 C(I)=-AL(I)*(1.+1/(I-1))
00205 68*      A(INTK)=-2.*AL1*BK1
00206 69*      B(INTK)=BK1*B1+BK2*B2
00207 70*      C(INTK)=-2.*AL2*BK2
00210 71*      A(INTN)=-2.*AL(INTN)
00211 72*      B(INTN)=1.-A(INTN)
00211 73*      C
00212 74*      IF (DEBUG) WRITE (IOUT,2) (A(I),I=1,INTN)
00221 75*      IF (DEBUG) WRITE (IOUT,3) (B(I),I=1,INTN)
00230 76*      IF (DEBUG) WRITE (IOUT,4) (C(I),I=1,INTN)
00230 77*      C
00237 78*      DO 210 I=1,INTN
00242 79*      210 D(I)=DD(I)+T(I)
00244 80*      D(INTK)=BK1*(D1+T(INTK))+BK2*(D2+T(INTK))
00244 81*      C
00245 82*      IF (DEBUG) WRITE (IOUT,5) (D(I),I=1,INTN)
00245 83*      C
00245 84*      C SOLUTION OF TRIDIAGONAL MATRIX EQUATION BY A GAUSSIAN SCHEME
00245 85*      C
00254 86*      BETA(1)=B(1)
00255 87*      GAMMA(1)=D(1)/BETA(1)
00256 88*      DO 300 I=2,INTN
00261 89*      BETA(I)=B(I)-A(I)*C(I-1)/BETA(I-1)
00262 90*      300 GAMMA(I)=(D(I)-A(I)*GAMMA(I-1))/BETA(I)
00264 91*      T(INTN)=GAMMA(INTN)
00265 92*      DO 301 I=INTN,1,-1
00270 93*      301 T(I)=GAMMA(I)-C(I)*T(I+1)/BETA(I)
00270 94*      C
00272 95*      IF (DEBUG) WRITE (IOUT,6) (BETA(I),I=1,INTN)
00301 96*      IF (DEBUG) WRITE (IOUT,7) (GAMMA(I),I=1,INTN)

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00310  97*      IF (DEBUG) WRITE (IOUT,8) (T(I),I=1,INTN)
00310  98*      C
00317  99*      IF (INFPROP.GT.0) CALL PROP(4)
00317 100*      C
00317 101*      CALCULATE AVERAGE TEMPERATURES
00317 102*      C
00321 103*      TCAP=0.
00322 104*      DO 400 I=1,INTJ
00325 105*      400 TCAP=TCAP+VOL(I)*T(I)
00327 106*      TF=TCAP/CAPF
00330 107*      TCAP=0.
00330 108*      C
00331 109*      DO 410 I=INTL,INTN
00334 110*      410 TCAP=TCAP+VOL(I)*T(I)
00336 111*      TNA=TCAP/CAPNA
00336 112*      C
00337 113*      RETURN
00340 114*      END
END COMPILEATION **      0 MESSAGES **

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a FOR PRES

```

00101 1* SUBROUTINE PRES
00101 2* C
00101 3* C PRESSURE GENERATION AT TIME TAU, SODIUM TEMPERATURE TNA
00101 4* C
00103 5* C PARAMETER PNT=200
00103 6* C
00104 7* COMMON /THERMP/ ALPHA(PNT), COND(PNT), CP(PNT), Q3PRM(PNT),
00104 8* 1 RHO(PNT), T(PNT), VOL(PNT), ALPHA1, ALPHA2, BK1, BK2, COND1,
00104 9* 2 COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2
00104 10* C
00105 11* COMMON AREAI, ASAT, BETAT, BSAT, CONONA, CONOF, CONDFS, CPF,
00105 12* A CPFS, CVNA, DEBUG, DIA, DTAU, DTNA, EBLAST, ESHOCK, GAMMAV,
00105 13* 1 HFMEIT, INTJ, INTK, INTL, INTH, INTN, IOUT, ISTOP, LAMBDA,
00105 14* 2 NAPROP, NFPROP, NTEMP, PC, PIN, POUT, PSAT, P1, P2, QF, QFS,
00105 15* 3 QNA, RHOC, RHOF, RHOF5, RHONA, SOMASS, SONVEL, TAU, TC, TF,
00105 16* B CAPF, CAPNA, DELRSQ, NSTEP, RHOVEL, TAUMIN, VOUT,
00105 17* 4 TFIN, TFMEIT, TNA, TNAIN, TOUT, U1, U2, VNAIN, V1, V2
00105 18* C
00106 19* REAL LAMBDA
00107 20* LOGICAL DEBUG
00107 21* C
00110 22* 1001 FORMAT ('OV2 IS LESS THAN V1 (V2/V1=%E10.4%) AT TAU=%1PE9.3)
00111 23* 1101 FORMAT ('OP2 IS LESS THAN PSAT AT TAU=%1PE9.3% SEC')
00111 24* C
00112 25* GVOLD=GAMMAV
00113 26* BTOLD=BETAT
00113 27* C
00114 28* IF (NAPROP.GT.0) CALL PROP(5)
00114 29* C
00116 30* GVAVG=.5*(GAMMAV+GVOLD)
00117 31* BTAVG=.5*(BETAT+BTOLD)
00117 32* C
00117 33* C ESTIMATE PRESSURE INCREASE
00120 34* DPEST=GVAVG*DTNA
00121 35* PAVEST=P1+.5*DPEST
00121 36* C CALCULATE VOLUME INCREASE FROM PARTICLE VELOCITY
00122 37* 100 CONTINUE
00123 38* UAVG=1.103278E6*PAVEST/RHOVEL
00124 39* DV=AREAI*UAVG*DTAU
00125 40* V2=V1+DV
00126 41* VR=V2/V1
00127 42* IF (VR.LE.0.1) GO TO 1000
00127 43* C RECALCULATE PRESSURE INCREASE
00131 44* DP=DPEST*(1./BETAT)*ALOG(VR)
00132 45* PAVG=P1+.5*DP
00133 46* PERROR=ABS(PAVG-PAVEST)/PAVG
00134 47* IF (DEBUG) WRITE (IOUT,6) TAU,DPEST,UAVG,DV,DP,PAVG,PERROR

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00146 48*      6 FORMAT ('OPRES RESULTS FOR TAU, DPEST, UAVG, DV, DP, PAVG, PERROR '
00146 49*      1 /10E13.6)
00147 50*      IF (PERROR-.01) 200,200,150
00152 51*    150 PAVEST=PAVG
00153 52*      GO TO 100
00153 53*  C
00154 54*    200 P2=P1+DP
00155 55*      U2=1.013278E6+P2/RHOVEL
00155 56*  C      CALCULATE ACOUSTIC ENERGY
00156 57*      DE=.1013278*AREAI*PAVG*UAVG*DTAU
00157 58*      ESHOCK=ESHOCK+DE
00157 59*  C
00160 60*      IF (NAPROP.EQ.0) PSAT=EXP(ASAT-B SAT/TNA)
00162 61*      IF (P2.LE.PSAT) GO TO 1100
00162 62*  C
00164 63*      P1=P2
00165 64*      U1=U2
00166 65*      V1=V2
00166 66*  C
00167 67*      RETURN
00167 68*  C
00170 69*    1000 IF (DEBUG) WRITE (IOUT,1001) VR,TAU
00175 70*      ISTOP=1
00176 71*      RETURN
00176 72*  C
00177 73*    1100 IF (DEBUG) WRITE (IOUT,1101) TAU
00203 74*      ISTOP=2
00204 75*      RETURN
00205 76*      END
END COMPILATION **      0 MESSAGES **

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2 FOR PROP

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00101 1* SUBROUTINE PROP(KCALC)
00101 2* C
00103 3* PARAMETER PNT=200
00103 4* C
00104 5* COMMON /THERMP/ ALPHA(PNT), COND(PNT), CP(PNT), Q3PRM(PNT),
00104 6* 1 RHO(PNT), T(PNT), VOL(PNT), ALPHA1, ALPHA2, BK1, BK2, COND1,
00104 7* 2 COND2, Q3PRM1, Q3PRM2, RHOC1, RHOC2
00104 8* C
00105 9* COMMON AREAI, ASAT, BETAT, BSAT, CONDNA, CONDF, CONDFS, CPF,
00105 10* A CPFS, CVNA, DEBUG, DIA, DTAU, DTNA, EBLAST, ESHOCK, GAMMAV,
00105 11* MFELT, INTJ, INTK, INTL, INTM, INTN, IOUT, ISTOP, LAMBDA,
00105 12* 2 NAPROP, NFPROP, NTEMP, PC, PIN, POUT, PSAT, P1, P2, QF, QFS,
00105 13* 3 QNA, RHOC, RHOF, RHOF5, RHONA, SOMASS, SONVEL, TAU, TC, TF,
00105 14* 4 CAPF, CAPNA, DELRSQ, NSTEP, RHOVEL, TAUMIN, VOUT,
00105 15* 4 TFIN, TFMELT, TNA, TNAIN, TOUT, U1, U2, VNAIN, V1, V2
00105 16* C
00106 17* DIMENSION TFOLD(PNT)
00107 18* REAL LAMBDA
00110 19* LOGICAL DEBUG
00110 20* C
00110 21* C
00111 22* GO TO (100,200,300,400,500), KCALC
00111 23* C
00111 24* C CALCULATE GEOMETRIC CONSTANTS
00111 25* C
00112 26* 100 CONTINUE
00112 27* C
00113 28* INTK=INTJ+1
00114 29* INTL=INTJ+2
00115 30* INTJM1=INTJ-1
00116 31* RMAX=.5*DIA
00117 32* DELR=RMAX/INTM
00120 33* DELRSQ=DELR**2
00121 34* RF=DELR*INTJ
00121 35* C
00122 36* R2=0.5*DELR
00123 37* VOL(1)=R2**3
00124 38* CAPF=VOL(1)
00125 39* DO 104 I=2,INTJM1
00130 40* R1=R2
00131 41* R2=R1*DELR
00132 42* VOL(I)=R2**3-R1**3
00133 43* 104 CAPF=CAPF+VOL(I)
00135 44* VOL(INTJ)=RF**3-R2**3
00136 45* CAPF=CAPF+VOL(INTJ)
00137 46* R2=RF
00137 47* C

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00140 48*      CAPNA=0.
00141 49*      DO 105 I=INTL,INTM
00144 50*      R1=R2
00145 51*      R2=DELR*(I-0.5)
00146 52*      VOL(I)=R2**3-R1**3
00147 53*      105 CAPNA=CAPNA+VOL(I)
00151 54*      VOL(INTN)=RMAX**3-R2**3
00152 55*      CAPNA=CAPNA+VOL(INTN)
00152 56*      C
00153 57*      DTAU=TAUMIN*9/NSTEP
00154 58*      LAMBDA=DTAU/DELR50
00154 59*      C
00154 60*      C
00154 61*      C      INITIALIZE THERMAL PROPERTIES
00154 62*      C
00155 63*      DO 110 I=1,INTJ
00160 64*      COND(I)=CONDF
00161 65*      CP(I)=CPF
00162 66*      Q3PRM(I)=QF
00163 67*      RHO(I)=RHOF
00164 68*      ALPHA(I)=COND(I)/(RHO(I)*CP(I))
00165 69*      110 CONTINUE
00167 70*      COND1=CONDF
00170 71*      Q3PRM1=QF
00171 72*      RHOCPI=RHOF*CPF
00172 73*      ALPHA1=COND1/RHOCPI
00173 74*      IF (INFPROP.EQ.0) GO TO 115
00175 75*      IF (INFPROP.EQ.2) GO TO 114
00177 76*      TFSOL=TFMELT-1.
00200 77*      GO TO 115
00201 78*      114 TFMELT=3097.
00202 79*      TFSOL=3033.
00203 80*      115 CPSMAX=0.3884-1.6186E-4*TFSOL+8.781E-8*TFSOL**2
00203 81*      C
00204 82*      DO 120 I=INTL,INTN
00207 83*      COND(I)=CONDNA
00210 84*      CP(I)=CVNA
00211 85*      Q3PRM(I)=QNA
00212 86*      RHO(I)=RHONA
00213 87*      ALPHA(I)=COND(I)/(RHO(I)*CP(I))
00214 88*      120 CONTINUE
00216 89*      COND2=CONDNA
00217 90*      Q3PRM2=QNA
00220 91*      RHOC2=RHONA*CVNA
00221 92*      ALPHA2=COND2/RHOC2
00221 93*      C
00222 94*      BK1=COND1*ALPHA2*(1.-1./INTJ)
00223 95*      BK2=COND2*ALPHA1*(1.-1./INTJ)
00223 96*      C

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00223  97*  C   INITIALIZE TEMPERATURES IF NECESSARY
00223  98*  C
00224  99*  125 TF=TFIN
00225 100*      TNA=TNA IN
00226 101*      IF (INTEMP.NE.0) GO TO 150
00230 102*      DO 130 I=1,INT J
00233 103*  130 T(I)=TFIN
00233 104*  C
00235 105*      TERM=COND1/SQRT(ALPHA1)
00236 106*      TERM=TERM/(TERM+COND2/SQRT(ALPHA2))
00237 107*      T(INTK)=TNA IN+TERM*(TFIN-TNA IN)
00240 108*      IF (T(INTK).LT.TFMELT .AND. TFIN.GE.TFMELT)
00240 109*      1 T(INTK)=TFMELT-(CPF*(TFMELT-T(INTK))-HFMELT)/CPS
00240 110*  C
00242 111*      DO 140 I=INTL,INTN
00245 112*  140 T(I)=TNA IN
00245 113*  C
00247 114*  150 CONTINUE
00247 115*  C
00250 116*      DO 155 I=1,INTK
00253 117*  155 TFOLD(I)=T(I)
00253 118*  C
00253 119*  C   INITIALIZE PRESSURE GENERATION VARIABLES
00253 120*  C
00255 121*      SONASS=RHONA*VNAIN
00256 122*      RHOVEL=RHONA*SONVEL
00256 123*  C   CALCULATE CONSTANTS FOR SODIUM VAPOR PRESSURE EQUATION ABOVE 2500 F
00257 124*      BSAT=ALOG(IPC/21.6779)/(1./1644.28-1./TC)
00260 125*      ASAT=ALOG(21.6779)*BSAT/1644.28
00260 126*  C
00261 127*      RETURN
00261 128*  C
00261 129*  C   VARIABLE THERMAL PROPERTIES FOR SODIUM
00261 130*  C
00262 131*  200 CONTINUE
00262 132*  C
00263 133*      IF (TNA.GE.TC) GO TO 220
00265 134*      TFF=1.8*TNA-459.7
00266 135*      IF (TFF.GT.2500.) GO TO 210
00270 136*      CONDNA=(154.306-1.878E-2*TFF+2.0914E-6*TFF**2)/57.78
00271 137*      GO TO 230
00272 138*  210 CONDNA=(20.427-.008323*(TFF-2500.))/57.78
00273 139*      GO TO 230
00274 140*  220 TFF=1.8*TC-459.7
00275 141*      CONDNA=(20.427-.008323*(TFF-2500.))/57.78
00276 142*  230 CONTINUE
00276 143*  C
00276 144*  C   RHONA ASSUMED CONSTANT TO COMPENSATE FOR CONSTANT-GEOMETRY HEAT TRANSFER
00277 145*      DO 240 I=INTK,INTN

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00302 146*      COND(I)=CONDNA
00303 147*      RHO(I)=RHONA
00304 148*      CP(I)=CVNA
00305 149*      240 ALPHA(I)=COND(I)/(RHO(I)*CP(I))
00307 150*      COND2=COND(INTK)
00310 151*      ALPHA2=ALPHA(INTK)
00311 152*      RHOCP2=RHO(INTK)*CP(INTK)
00311 153*      C
00312 154*      RETURN
00312 155*      C
00312 156*      C
00312 157*      C      VARIABLE THERMAL PROPERTIES OF MOLTEN MATERIAL
00312 158*      C
00313 159*      300 CONTINUE
00313 160*      C
00314 161*      DO 399 I=1,INTK
00317 162*      IF (INFPROP.EQ.2) GO TO 350
00321 163*      IF (T(I).GT.TFMELT) GO TO 320
00323 164*      IF (T(I).LT.TFSOL) GO TO 310
00325 165*      CP(I)=HFMELT
00326 166*      COND(I)=CONDF-(TFMELT-T(I))*(CONDF-CONDFS)
00327 167*      RHO(I)=RHOF-(TFMELT-T(I))*(RHOF-RHOFS)
00330 168*      GO TO 399
00331 169*      310 CP(I)=CPFS
00332 170*      COND(I)=CONDFS
00333 171*      RHO(I)=RHOFS
00334 172*      GO TO 399
00335 173*      320 CP(I)=CPF
00336 174*      COND(I)=CONDF
00337 175*      RHO(I)=RHOF
00340 176*      GO TO 399
00341 177*      350 TCC=T(I)-273.16
00342 178*      IF (TCC.GT.1800.) GO TO 355
00342 179*      C      THERMAL CONDUCTIVITY OF (P-U)02
00344 180*      COND(I)=0.011+26.11/TCC
00345 181*      GO TO 370
00346 182*      355 COND(I)=0.0255
00347 183*      370 IF (T(I).LE.TFMELT) GO TO 375
00347 184*      C      HEAT CAPACITY OF LIQUID (P-U)02
00351 185*      CP(I)=548
00352 186*      RHO(I)=8.74
00353 187*      GO TO 399
00354 188*      375 IF (T(I).LT.TFSOL) GO TO 380
00354 189*      C      EFFECTIVE HEAT CAPACITY OF (P-U)02 IN MELTING RANGE
00356 190*      CP(I)=4.375
00357 191*      RHO(I)=8.74
00360 192*      GO TO 399
00360 193*      C      HEAT CAPACITY OF SOLID (P-U)02
00361 194*      380 CP(I)=0.3884-1.6186E-4*T(I)+8.781E-8*T(I)**2

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00362 195*      RHO(I)=8.74
00363 196*      399 ALPHA(I)=COND(I)/(RHO(I)*CP(I))
00365 197*      COND1=COND(INTK)
00366 198*      ALPHA1=ALPHA4(INTK)
00367 199*      RHOCP1=RHO4(INTK)*CP1(INTK)
00367 200*      C
00370 201*      RETURN
00370 202*      C
00370 203*      C
00370 204*      C      CHECK FOR SOLIDIFICATION OR MELTING AND CORRECT TEMPERATURES
00370 205*      C
00371 206*      400 CONTINUE
00371 207*      C
00372 208*      DO 499 I=1,INTK
00375 209*      IF(T(I).GT.TFMELT .AND. TFOLD(I).GT.TFMELT) GO TO 499
00377 210*      IF(T(I).LT.TFSOL .AND. TFOLD(I).LT.TFSOL) GO TO 499
00401 211*      IF(T(I).LT.TFMELT .AND. TFOLD(I).GT.TFMELT) GO TO (410,415)*NFPROP
00403 212*      IF(T(I).LT.TFSOL .AND. TFOLD(I).GT.TFSOL) GO TO (430,435)*NFPROP
00405 213*      IF(T(I).GT.TFSOL .AND. TFOLD(I).LT.TFSOL) GO TO (450,455)*NFPROP
00407 214*      IF(T(I).GT.TFMELT .AND. TFOLD(I).LT.TFMELT) GO TO (470,475)*NFPROP
00407 215*      C
00407 216*      C      CONTINUING TO SOLIDIFY OR MELT
00411 217*      GO TO 499
00411 218*      C
00411 219*      C      INITIAL SOLIDIFICATION
00412 220*      410 FR SOL=CPF*(TFMELT-T(I))/HFMELT
00413 221*      IF (FR SOL.LT.1.0) GO TO 420
00415 222*      T(I)=TFSOL-(FR SOL-1.0)*HFMELT/CPFS
00416 223*      GO TO 498
00417 224*      415 FR SOL=548*(TFMELT-T(I))/280.
00420 225*      IF (FR SOL.LT.1.0) GO TO 420
00422 226*      T(I)=TFSOL-(FR SOL-1.0)*280./CPSMAX
00423 227*      GO TO 498
00424 228*      420 T(I)=TFMELT-FR SOL
00425 229*      GO TO 498
00425 230*      C
00425 231*      C      COMPLETION OF SOLIDIFICATION
00426 232*      430 T(I)=TFSOL-HFMELT*(TFSOL-T(I))/CPFS
00427 233*      GO TO 498
00430 234*      435 T(I)=TFSOL-280.*(TFSOL-T(I))/CPSMAX
00431 235*      GO TO 498
00431 236*      C
00431 237*      C      INITIAL MELTING
00432 238*      450 FRLI0=CPFS*(T(I)-TFSOL)/HFMELT
00433 239*      IF (FRLI0.LT.1.0) GO TO 460
00435 240*      T(I)=TFSOL+(FRLI0-1.0)*HFMELT/CPF
00436 241*      GO TO 498
00437 242*      455 FRLI0=CP(I)*(T(I)-TFSOL)/280.
00440 243*      IF (FRLI0.LT.1.0) GO TO 460

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00442 244* T(I)=TF SOL*FRL I0-1.0)*280./-.548
00443 245* GO TO 498
00444 246* 460 T(I)=TF SOL*FRL I0
00445 247* GO TO 498
00445 248* C
00445 249* C COMPLETION OF MELTING
00446 250* 470 T(I)=TF MELT+HF MELT*(T(I)-TF MELT)/CPF
00447 251* GO TO 498
00450 252* 475 T(I)=TF MELT+280.* (T(I)-TF MELT)/.548
00450 253* C
00451 254* 498 TFOLD(I)=T(I)
00452 255* 499 CONTINUE
00452 256* C
00454 257* RETURN
00454 258* C
00454 259* C
00454 260* C MECHANICAL PROPERTIES OF SODIUM FOR PRESSURE GENERATION
00454 261* C
00455 262* 500 CONTINUE
00455 263* C
00456 264* IF (NAPROP.E0.2) GO TO 550
00460 265* IF (TNA.GT.1644.28 .AND. NAPROP.E0.3) GO TO 550
00462 266* IF (TNA.GE.TC) GO TO 599
00462 267* C
00462 268* C PROPERTIES OF SATURATED LIQUID
00464 269* SONVEL=2.526E5-52.4*(TNA-370.98)
00465 270* IF (TNA.GT.1644.28) GO TO 510
00467 271* TRR=1.8*TNA
00470 272* TFF=TRR-459.7
00471 273* CPNA=4.184*(0.389352-1.10599E-4*TRR+3.41178E-8*TRR*TRR)
00472 274* RHOST=(59.566-7.9504E-3*TFF-0.2872E-6*TFF**2+0.06035E-9*TFF**3)/
00472 275* 62.43
00473 276* DRHONA=(1-7.9504E-3-0.5744E-6*TFF+0.18105E-9*TFF**2)*1.8/62.43
00474 277* GO TO 520
00475 278* 510 TR=TNA/TC
00476 279* CPNA=0.855628+.387951/(1.-TR)**.572878
00477 280* RHOST=RHOC*(1.+4.16077*(1.-TR)**.586885)
00500 281* DRHONA=-2.44189*RHOC/(TC*(1.-TR)**.413115)
00501 282* 520 BETAS=1.013278E6/(RHOST*SONVEL**2)
00502 283* ALPHAP=-DRHONA/RHOST
00503 284* BETAT=BETAS+0.1013278*TNA*ALPHAP**2/(RHOST*CPNA)
00504 285* GAMMAV=ALPHAP/BETAT
00505 286* CVNA=CPNA*BETAS/BETAT
00505 287* C
00505 288* C EXTRAPOLATION TO SUBCOOLED LIQUID PROPERTIES
00506 289* GAMMA=.2026556*ALPHAP/(RHOST*CPNA*BETAS)
00507 290* SONVEL=SONT (SONVEL+.2*(RHONA/RHOST)**GAMMA)
00510 291* BETAS=1.013278E6/(RHONA*SONVEL**2)
00511 292* IF (TNA.GT.1644.28) GO TO 530

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DEG R

DEG F

J/GM-K

GM/CM3

1/ATM

1/ATM

ATM/K

1/ATM

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00513 293* PSAT=6.8817602E6*EXP(-22981.96/TRR)/TRR**0.61344 ATM
00514 294* DPSAT=1.8*PSAT*(22981.96/TRR-.61344)/TRR ATM/K
00515 295* GO TO 540
00516 296* 530 PSAT=EXP(ASAT-BSAT/TNA)
00517 297* DPSAT=PSAT*BSAT/TNA**2
00520 298* 540 ALPHAP=ALPHAP+BETAT*DPSAT
00521 299* BETAT=BETAS*0.1013278*TNA*ALPHAP**2/(RHONA*CPNA) 1/ATM
00522 300* GAMMAV=ALPHAP/BETAT ATM/K
00523 301* GO TO 599
00523 302* C
00523 303* C PROPERTIES OF SUBCOOLED SODIUM FROM HIMPAN EQUATION OF STATE
00524 304* 550 SPVOL=Y1/SOMASS
00525 305* TERM1=SPVOL-.0197235
00526 306* TERM2=TNA*SPVOL-(-0.866.64)
00527 307* TERM3=SPVOL-1.09038
00530 308* TERM4=TERM1+TERM2
00531 309* DPODV=(2.20976E8/TERM4)+1./TERM1+TNA/TERM2)-3.56913*TNA/TERM3**2
00532 310* DPODT=2.20976E8*SPVOL/(TERM4+TERM2)+3.56913/TERM3
00533 311* BETAT=-1./(SPVOL*DPODV)
00534 312* GAMMAV=DPODT
00535 313* PSAT=EXP(ASAT-BSAT/TNA)
00535 314* C
00536 315* 599 CONTINUE
00536 316* C
00537 317* RETURN
00537 318* C
00540 319* END
END COMPILATION ** 0 MESSAGES **

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@ FOR SLOTT

```
00101 1* SUBROUTINE SLOTT
00103 2* PRINT 1
00105 3* 1 FORMAT (1*YOU HAVE REACHED AN UNWORKING PLOT ROUTINE - - ->///
00105 4* 1 10X*NO PLOTS ARE POSSIBLE AT THIS TIME *)
00106 5* RETURN
00107 6* END
END COMPILATION ** 0 MESSAGES **
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a FOR SOCOOL

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00100 1* C
00100 2* C      SOCOOL-IIA COMPUTES THE KINETIC ENERGY IMPARTED TO A LIQUID SLUG
00100 3* C      BY A SERIES OF PRESSURE PULSES CORRESPONDING TO RAPID HEATING OF
00100 4* C      DISCRETE SODIUM MASSES
00100 5* C
00100 6* C
00100 7* C      INPUT DATA FOR SOCOOL-IIA
00100 8* C
00100 9* C      CARD 0 (OPTIONAL)
00100 10* C      COL 1-5  DEBUG  SWITCH TO PRINT DEBUG OUTPUT
00100 11* C
00100 12* C      CARD 1  TITLE
00100 13* C      COL 1-80
00100 14* C
00100 15* C      CARD 2  GENERAL DATA (I4,E12.4,8E8.4)
00100 16* C      COL 1-4  NPULSE  NUMBER OF DISCRETE INTERACTIONS (PRESSURE PULSES)
00100 17* C      5-16  PIN      INITIAL PRESSURE PULSE (DETERMINES HEATED NA TEMP), ATM
00100 18* C      17-24  PTOP    PRESSURE AT TOP OF COOLANT SLUG, ATM
00100 19* C      23-32  TINIT   TEMPERATURE OF SODIUM BEFORE HEATING, DEG F
00100 20* C      33-40  SLUG    COOLANT SLUG MASS, LB MASS
00100 21* C      41-48  RAD     RADIUS OF VESSEL CONTAINING COOLANT SLUG, FT
00100 22* C      49-56  GAP     INITIAL GAP BETWEEN TOP OF SLUG AND VESSEL COVER, FT
00100 23* C      57-64  DTAU    TIME STEP, SEC
00100 24* C
00100 25* C      CARD(S) 3  TIMES AT WHICH INTERACTIONS OCCUR, SEC (10E8.4)
00100 26* C
00100 27* C      CARD(S) 4  MASSES OF SODIUM INTERACTING AT CORRESPONDING TIMES, LB (10E8.4)
00100 28* C
00101 29* C      LOGICAL DEBUG
00103 30* C      INTEGER RUNGE,DEBUG, TITLE
00104 31* C      DIMENSION F(3), Y(3), TITLE(14), WT(100), TAU(100)
00105 32* C      DATA DEBUG /'DEBUG' /
00105 33* C
00107 34* C      1 FORMAT (I3A6,A2)
00110 35* C      2 FORMAT (I11,I3A6,A2)
00111 36* C      3 FORMAT (I4,E12.4,8E8.4)
00112 37* C      4 FORMAT (10E8.4)
00113 38* C      5 FORMAT ( //37X' *** INPUT DATA ***' //
00113 39* C      1* NO. OF      INITIAL      GAP      INITIAL      COOLANT
00113 40* C      2 VESSEL      INITIAL      TIME %
00113 41* C      3* PULSES      PULSE      PRESSURE      NA TEMP      SLUG MASS
00113 42* C      4 RADIUS      GAP      STEP %
00113 43* C      5* NPULSE      PIN      PTOP      TINIT      SLUG
00113 44* C      6 RAD      GAP      DTAU %//
00113 45* C      7 I6.1PE15.5-6E13.5 )
00114 46* C      6 FORMAT ( // ' * PULSE      TIME      MASS %
00114 47* C      1          *      I      TAU(I)      WT(I) %// (I5,F12.4,F12.2) )

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00115 48* 7 FORMAT ('DEBUG OUTPUT FOR X,PROT,Y(1),V(2),Y(3),F(1),F(2),F(3)')
00115 49* 1 10E12.6)
00116 50* 8 FORMAT ( '//18X' *** CALCULATED RESULTS *** // )
00116 51* 1* TIME PRESSURE VELOCITY DISTANCE VOLUME ENERGY % /
00116 52* 2* (SEC) (ATM) (FT/SEC) (FT) (CU FT) (MW-SEC) % /
00116 53* 3 )
00117 54* 9 FORMAT (F6.4,F10.1,F13.2,F11.3,F12.2,F10.2)
00117 55* C
00120 56* TC = 2733.
00121 57* PC = 408.2
00122 58* RHOC = 11.35
00123 59* PI = 3.1416
00124 60* GRAV = 32.174
00125 61* IN = 5
00126 62* IOUT = 6
00126 63* C
00126 64* C ..... READ AND PRINT DATA .....
00127 65* 100 CONTINUE
00130 66* DEBUG = .FALSE.
00131 67* 101 READ (IN,1,END=1000) TITLE
00137 68* IF ( TITLE(1).NE.DEBUG ) GO TO 102
00141 69* DEBUG = .TRUE.
00142 70* GO TO 101
00143 71* 102 WRITE (IOUT,2) TITLE
00143 72* C
00151 73* READ (IN,3) NPULSE, PIN, PTOP, TINIT, SLUG, RAD, GAP, DTAU
00163 74* READ (IN,4) ( I,TAU(I),I=1,NPULSE )
00171 75* READ (IN,4) ( VT(I),I=1,NPULSE )
00177 76* WRITE (IOUT,5) NPULSE, PIN, PTOP, TINIT, SLUG, RAD, GAP, DTAU
00211 77* WRITE (IOUT,6) ( I,TAU(I),VT(I), I=1,NPULSE )
00221 78* WRITE (IOUT,2) TITLE
00227 79* WRITE (IOUT,8)
00227 80* C
00231 81* AREA = PI*RAD**2
00232 82* RHOXL = SLUG/(AREA*14.7*144.*GRAV)
00232 83* C DENSITY OF ADDITIONAL INTERACTING SODIUM
00233 84* IF ( TINIT.GT.2500.0 ) GO TO 200
00235 85* ROINIT = 59.566-7.9504E-3*TINIT-0.2872E-6*TINIT**2
00235 86* 1 *.06035E-9*TINIT**3
00236 87* GO TO 250
00237 88* 200 TINIT = ( TINIT+59.7 )/1.8
00240 89* ROINIT = RHOC*( 1+.4.16077*( 1.-TINIT/TC )**0.586885 )
00241 90* 250 CONTINUE
00241 91* C ENTROPY OF SATURATED SODIUM LIQUID AT PIN
00242 92* TIN = 12116.43/( 10.44514-ALOG(PIN) )
00243 93* DHV = 1.81658*TC*( 1.-TIN/TC )**0.427122
00244 94* SSAT = ( 5.79461-0.5*DHV/TIN )/4.184
00244 95* C INITIAL VOLUME BEFORE EXPANSION
00245 96* RHOLIN = RHOC*( 1+.4.16077*( 1.-TIN/TC )**0.586885 )

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DEG K
ATM
LB/FT 3

LB/FT 3

DEG K

LB/FT 3

DEG K

J/G

BTU/LB-R

LB/FT 3

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00246 97*      TOTWT = WT(1)
00247 98*      VIN = TOTWT/RHOLIN
00247 99*      C
00247 100*     C      .... INITIALIZE PARAMETERS .....
00250 101*     X = TAU(1)
00251 102*     DX = DTAU
00252 103*     Y(1) = 0.0
00253 104*     Y(2) = 0.0
00254 105*     Y(3) = VIN
00255 106*     PBOT = PIN
00256 107*     ESLUG = 0.0
00257 108*     NCOUNT = 1
00260 109*     WRITE (IOUT,9) X, PBOT, Y(1), Y(2), Y(3), ESLUG
00260 110*     C
00260 111*     C      .... CHECK IF TIME FOR ANOTHER PULSE
00270 112*     300 CONTINUE
00271 113*     IF (NCOUNT.EQ.NPWLSE) GO TO 500
00273 114*     XTEST = X + 0.000001
00274 115*     IF (XTEST.LT.TAU(NCOUNT+1)) GO TO 500
00276 116*     NCOUNT = NCOUNT + 1
00276 117*     C
00277 118*     VOLD = Y(3)/TOTWT
00300 119*     Y(3) = Y(3) + WT(NCOUNT)/ROINIT
00301 120*     TOTWT = TOTWT + WT(NCOUNT)
00302 121*     VSAT = Y(3)/TOTWT
00303 122*     POLD = PBOT
00304 123*     PBOT = PSOLVE( SSAT, VSAT, POLD, VOLD, DEBUG )
00305 124*     WRITE (IOUT,9) X, PBOT, Y(1), Y(2), Y(3), ESLUG
00305 125*     C
00305 126*     C      .... CALL ON FOURTH-ORDER RUNGE-KUTTA FUNCTION
00315 127*     500 CONTINUE
00316 128*     VOLD = Y(3)/TOTWT
00317 129*     K = RUNGE( 3, Y, F, X, DX )
00320 130*     IF (DEBUG) WRITE (IOUT,7) X, PBOT, Y(1), Y(2), Y(3), F(1), F(2), F(3)
00333 131*     VSAT = Y(3)/TOTWT
00334 132*     POLD = PBOT
00335 133*     PBOT = PSOLVE( SSAT, VSAT, POLD, VOLD, DEBUG )
00335 134*     C
00335 135*     C      .... WHENEVER K=1, COMPUTE DERIVATIVE VALUES ....
00336 136*     IF (K.EQ.1) GO TO 900
00336 137*     C      ACCELERATION
00340 138*     F(1) = ( PBOT-PTOP )/RHOXL - GRAV
00340 139*     C      VELOCITY
00341 140*     F(2) = Y(1)
00341 141*     C      RATE OF VOLUME CHANGE
00342 142*     F(3) = AREA*Y(1)
00343 143*     GO TO 500
00343 144*     C
00344 145*     900 CONTINUE

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00345 146*      ESLUG = 1.3558*0.5*SLUG*Y(1)**2*1.E-6/GRAV
00346 147*      WRITE (IOUT,9) X, PBOY, Y(1), Y(2), Y(3), ESLUG
00356 148*      IF (Y(2).GE.6AP) GO TO 100
00360 149*      GO TO 300
00360 150*      C
00361 151*      1000 STOP
00362 152*      END
END COMPI LATION **      0 MESSAGES **

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8 FOR PSOLVE

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00101 1* FUNCTION PSOLVE( SSAT, VSAT, POLD, VOLD, DEBUG )
00101 2* C
00101 3* C DETERMINE SATURATION PRESSURE FROM THE ENTROPY AND SPECIFIC VOLUME
00101 4* C SSAT - KNOWN ENTROPY
00101 5* C VSAT - KNOWN SPECIFIC VOLUME AFTER ISENTROPIC EXPANSION
00101 6* C POLD - PREVIOUS SATURATION PRESSURE
00101 7* C VOLD - PREVIOUS SPECIFIC VOLUME
00101 8* C
00101 9* C ERROR - RELATIVE ACCURACY DESIRED
00101 10* C MAXIT - MAXIMUM NUMBER OF ITERATIONS
00101 11* C
00103 12* LOGICAL DEBUG
00104 13* DATA ERROR/.001/MAXIT/10/TC/2733./PC/408.2/RHOC/11.35/IOUT/6/
00104 14* C
00113 15* 1 FORMAT ('DEBUG OUTPUT FROM PSOLVE FOR IT, PNEW, VNEW, ERR')
00114 16* 2 FORMAT ('4.10E12.6')
00115 17* 3 FORMAT ('MAXIMUM NUMBER OF ITERATIONS ATTAINED IN PSOLVE')
00115 18* C
00115 19* C ..... ITERATION INITIALIZATION .....
00116 20* IF ( VSAT.GT.VOLD ) PNEW=POLD*0.9
00120 21* IF ( VSAT.EQ.VOLD ) PNEW=POLD
00122 22* IF ( VSAT.LT.VOLD ) PNEW=POLD*1.1
00122 23* C
00122 24* C ..... ITERATE TO FIND PNEW SUCH THAT VNEW = VSAT
00124 25* IF (DEBUG) WRITE(IOUT,1)
00127 26* DO 40 IT=1,MAXIT
00132 27* IF ( PNEW.GT.PC ) PNEW=PC
00134 28* IF ( PNEW.GT.21.6779 ) GO TO 10
00136 29* IF ( PNEW.LE.0.0 ) PNEW=-PNEW
00140 30* PLOG = ALOG(PNEW)
00141 31* TF = EXP( 7.3889580+0.12512970*PLOG+0.25367737E-2*PLOG**2 ) DEG F
00141 32* I 0.89120865E-3*PLOG**3 )
00142 33* TR = TF*459.7 DEG R
00143 34* RHOLIQ = 59.566-7.9504E-3*TF-0.2872E-6*TF**2+0.06035E-9*TF**3 LB/FT3
00144 35* RHOVAP = 1./EXP( 14.5181-0.856376E-2*TF+0.130237E-5*TF**2 ) LB/FT3
00145 36* SLIQ = 0.389344*ALOG(1R)-1.10557E-4*TR+0.170408E-7*TR**2-1.792026 BTU/LB-R
00146 37* SVAP = 4.0352173-0.34785271E-2*TF +0.22123568E-05*TF**2
00146 38* I -0.69996985E-9*TF**3+0.87069240E-13*TF**4 BTU/LB-R
00147 39* GO TO 20
00147 40* C
00150 41* 10 CONTINUE
00151 42* TK = 12116.43/( 10.44514-ALOG(PNEW) ) DEG K
00152 43* TRR = TK/TC
00153 44* RHOLIQ = RHOC*( 1.-4.16077*( 1.-TRR )**0.586885 ) LB/FT3
00154 45* RHOVAP = RHOC*( 1.-1.08512*( 1.-TRR )**0.116733 ) LB/FT3
00155 46* DHV = 1.81658*TC*( 1.-TRR )**0.427122 J/G
00156 47* DSV = DHV/TK J/G-K

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00157 48* SLIQ = 5.79461-0.5*DSV J/G-K
00160 49* SVAP = SLIQ*DSV J/G-K
00161 50* SLIQ = SLIQ/4.184 BTU/LB-R
00162 51* SVAP = SVAP/4.184 BTU/LB-R
00162 52* C
00163 53* 20 CONTINUE
00164 54* FRVAP = ( SSAT-SLIQ )/( SVAP-SLIQ )
00165 55* FRLIQ = 1.-FRVAP
00166 56* VNEW = FRVAP/RHOVAP + FRLIQ/RHOLIQ FT3/LB
00167 57* ABSERR = VNEW-VSAT
00170 58* ERR = ABSERR/VSAT
00171 59* IF (DEBUG) WRITE (IOUT,2) IT, PNEW, VNEW, ERR
00200 60* IF ( ABSERR).LE.ERROR ) GO TO 50
00200 61* C
00202 62* 30 CONTINUE
00203 63* PDEV = PNEW-POLD
00204 64* VDEV = VNEW-VOLD
00205 65* POLD = PNEW
00206 66* VOLD = VNEW
00207 67* PNEW = POLD-PDEV*ABSERR/VDEV
00207 68* C
00210 69* 40 CONTINUE
00210 70* C
00212 71* WRITE (IOUT,3)
00212 72* C
00214 73* 50 PSOLVE = PNEW
00215 74* RETURN
00216 75* END
END COMPILE ** D MESSAGES **

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a FOR RUNGE

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00101 1* FUNCTION RUNGE( N, Y, F, X, H )
00101 2* C
00101 3* C THE FUNCTION RUNGE EMPLOYS THE FOURTH-ORDER RUNGE-KUTTA METHOD
00101 4* C WITH RUNGE'S COEFFICIENTS TO INTEGRATE A SYSTEM OF N SIMULTANEOUS
00101 5* C FIRST ORDER ORDINARY DIFFERENTIAL EQUATIONS  $F(J)=DY(J)/DX$ ,
00101 6* C ( $J=1,2,...,N$ ), ACROSS ONE STEP OF LENGTH H IN THE INDEPENDENT
00101 7* C VARIABLE X, SUBJECT TO INITIAL CONDITIONS  $Y(J)$ , ( $J=1,2,...,N$ ).
00101 8* C EACH  $F(J)$ , THE DERIVATIVE OF  $Y(J)$ , MUST BE COMPUTED FOUR TIMES
00101 9* C PER INTEGRATION STEP BY THE CALLING PROGRAM. THE FUNCTION MUST
00101 10* C BE CALLED FIVE TIMES PER STEP (PASS(1)..PASS(5)) SO THAT THE
00101 11* C INDEPENDENT VARIABLE VALUE (X) AND THE SOLUTION VALUES
00101 12* C ( $Y(1)..Y(N)$ ) CAN BE UPDATED USING THE RUNGE-KUTTA ALGORITHM.
00101 13* C M IS THE PASS COUNTER. RUNGE RETURNS AS ITS VALUE 1.0 TO
00101 14* C SIGNAL THAT ALL DERIVATIVES (THE  $F(J)$ ) BE EVALUATED OR 0.0 TO
00101 15* C SIGNAL THAT THE INTEGRATION PROCESS FOR THE CURRENT STEP IS
00101 16* C FINISHED. SAVEY(J) IS USED TO SAVE THE INITIAL VALUE OF  $Y(J)$ 
00101 17* C AND PHI(J) IS THE INCREMENT FUNCTION FOR THE J(TH) EQUATION.
00101 18* C AS WRITTEN, N MAY BE NO LARGER THAN 5
00101 19* C
00103 20* INTEGER RUNGE
00104 21* DIMENSION PHI(5), SAVEY(5), Y(N), F(N)
00104 22* C
00105 23* M = N + 1
00106 24* GO TO (1,2,3,4,5), M
00106 25* C
00106 26* C ..... PASS 1 .....
00107 27* 1 RUNGE = 1
00110 28* RETURN
00110 29* C
00110 30* C ..... PASS 2 .....
00111 31* 2 DO 22 J = 1, N
00114 32* SAVEY(J) = Y(J)
00115 33* PHI(J) = F(J)
00116 34* 22 Y(J) = SAVEY(J) + 0.5*H*F(J)
00120 35* X = X + 0.5*H
00121 36* RUNGE = 1
00122 37* RETURN
00122 38* C
00122 39* C ..... PASS 3 .....
00123 40* 3 DO 33 J = 1, N
00126 41* PHI(J) = PHI(J) + 2.0*F(J)
00127 42* 33 Y(J) = SAVEY(J) + 0.5*H*F(J)
00131 43* RUNGE = 1
00132 44* RETURN
00132 45* C
00132 46* C ..... PASS 4 .....
00133 47* 4 DO 44 J = 1, N

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00136 48*      PHI(J) = PHI(J) + 2.0*F(J)
00137 49*      44  Y(J) = SAVEY(J) + H*F(J)
00141 50*      X = X + 0.5*H
00142 51*      RUNGE = 1
00143 52*      RETURN
00143 53*      C
00143 54*      C      ..... PASS 5 .....
00144 55*      5  DO 55  J = 1, N
00147 56*      55  Y(J) = SAVEY(J) + (PHI(J) + F(J))*H/6.0
00151 57*      H = 0
00152 58*      RUNGE = 0
00153 59*      RETURN
00154 60*      END
END COMPI LATION **      0 MESSAGES **

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