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QADHD POINT-KERNEL RADIATION SHIELDING COMPUTER CODE TO EVALUATE PROPELLANT HEATING AND DOSE TO CREW DURING ENGINE OPERATION

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SUMMARY

A FORTRAN IV computer program, QADHD, based on the LASL code QAD4, was written to evaluate the propellant heating in a nuclear rocket stage and to calculate the gamma and fast neutron doses received by a crew from the radiation emitted by the nuclear engine during the operating period. The QADHD is a combination of three codes, QAD4, QADH, and QADD. The LASL QAD4 is a general purpose program written to calculate gamma and fast neutron doses due to a volume-distributed source in a complex source-shield geometry that is generally describable by quadratic surfaces. QAD4 is a point-kernel code that employs infinite-medium buildup factors to calculate the gamma dose and employs the Albert-Welton kernel to calculate the fast neutron dose. The QAD4 included here was revised slightly from the LASL version to facilitate its use in the QADHD, as well as to simplify data input.

QADH utilizes the QAD4 routines to evaluate local heating throughout the propellant (and tank wall) and then integrates these heating rates over the entire volume of the propellant. Assuming that this heat is distributed uniformly throughout the propellant by natural convection (the complete-mix model) permits the rate of temperature rise of the propellant to be determined. QADH then determines the total temperature rise and accumulative heat input to the propellant as a function of reactor operating time. In some nuclear rocket configurations, the propellant may serve to shield the crew from radiations emitted by the engine. In these cases QADD utilizes the QAD4 routines to calculate biological dose rates to the crew during engine operation while the propellant depth in the tank (or amount of shielding the propellant provides) changes with time. QADD then integrates these dose rates over engine operating time to obtain a total dose-time history.

INTRODUCTION

In nuclear rocket vehicles, some special problems that require evaluation are the propellant heating and the dose to the crew from radiation emitted during the operation of the reactor. Excessive heating of the propellant may produce pumping problems so that either shielding, additional pressurization, or venting of the propellant may be required to avoid the problem. In a manned stage, the dose to the crew can control the shielding requirements. In many configurations, the propellant can serve as a shield between the crew and the engine. During engine operation, however, the consumption of propellant results in a continuous reduction of this shielding.

The computer program QADHD was written to evaluate the heat deposition and temperature rise of the propellant and the dose to a crew during reactor operation. The code uses the Los Alamos Scientific Laboratory (LASL) point-kernel line-of-sight code QAD4 (ref. 1) as a basis for its calculations. QAD4 evaluates dose or heating occurring at a point due to a distributed volume source of radiation in a complex source-shield geometry that is generally describable by quadratic surfaces. QAD4 is used to determine the local heating values throughout the tank, and the QADH portion of QADH then integrates by Gauss quadrature to obtain the total heating rate in the propellant. By assuming that convective currents distribute the heat uniformly through the propellant (the complete-mix model), the rate of temperature rise of the propellant in the tank can be determined. By relating the propellant volume and heating rates and temperature rise rates to the engine operating time, the code determines a heat-absorption and temperature-rise-time history of the propellant.

QAD4 routines are used to determine the crew dose rate for a number of discrete propellant depths, and the QADD portion of QADHD determines the time for the propellant depth to change from one level to another from the engine run time, and then QADD integrates these dose rates over the total operating time to obtain the total dose incurred. In a line-of-sight code such as this, the dose incurred from scattered gammas is estimated by using infinite-medium buildup factors. Implicit in these buildup factors is the assumption that all material in the neighborhood of the line-of-sight path experiences a similar flux. In a nuclear rocket stage, there may be substantial amounts of propellant and parts of the propellant tank and other structures outside the direct line of sight from source to detector, which are in very much higher flux fields than those in the direct line of sight. From these regions, the scattered radiation received by the crew could be very much greater than that estimated by QADD; hence it is important to apply QADD (and QAD4) only to configurations where the calculations will be valid. Because of many similarities, the programs QAD4 (a slightly revised version of the LASL QAD4), QADH, and QADD were combined into a single code QADHD. The QAD4 included here has been revised slightly from the LASL version to facilitate its use in QADHD as well as to simplify data input. QADHD then may be used to perform three types of calculations: dose or heating rates at detectors, propellant heating history, or crew dose history.

To reduce data input normally required for the LASL QAD4, the version of QAD4 included here utilizes a library of gamma total cross sections, neutron-removal cross sections, parameters for infinite-medium buildup factors, and several gamma-response functions included internally in the code.

In general, in QADHD the geometry is that describable by quadratic surfaces identical to the LASL QAD4 with a limitation that the emptying propellant tank (used in the QADH and QADD calculations) must be parallel to the z-axis (the axis of source symmetry). Most nuclear rocket geometries fit this description.

DESCRIPTION OF CODE

QAD4 Method of Solution

Computer output. - The QAD4 method of solution, which is also that used to calculate local heating and dose rates in QADH and QADD, is a line-of-sight technique that proceeds as follows. QAD4 divides the source region into a number of small source volumes and concentrates the total source strength of this volume at its geometric center. Knowing the complete geometry and material arrangement, QAD4 traces a ray from the center of each small source volume (the source point) to the receiver point and keeps a tally of the geometric distance traveled and the mass thickness (g/cm^2) of each element encountered on the traverse.

The dose (or heating) rate from gamma rays is calculated as follows:

$$\dot{D}_{\gamma_{I_{un}}}(r_o, z_o, \varphi_o) = \sum_J \frac{S_{IJ}K_I}{4\pi r_J^2} \exp(-b_{IJ})$$

$$\dot{D}_{\gamma_I}(r_o, z_o, \varphi_o) = \sum_J \frac{S_{IJ}K_I B_I(b_{IJ})}{4\pi r_J^2} \exp(-b_{IJ})$$

$$\dot{D}_{\gamma_{un}}(r_o, z_o, \varphi_o) = \sum_I \dot{D}_{\gamma_{I_{un}}}(r_o, z_o, \varphi_o)$$

$$\dot{D}_{\gamma}(r_o, z_o, \varphi_o) = \sum_I \dot{D}_{\gamma_I}(r_o, z_o, \varphi_o)$$

where

$\dot{D}_{\gamma_{I_{un}}}(r_o, z_o, \varphi_o)$	uncollided gamma dose rate (or heating rate) at point r_o, z_o, φ_o from source gammas of group I
$\dot{D}_{\gamma_I}(r_o, z_o, \varphi_o)$	total (uncollided plus scattered) gamma dose rate (or heating rate) at point r_o, z_o, φ_o from source of gammas of energy group I
$\dot{D}_{\gamma_{un}}(r_o, z_o, \varphi_o)$	uncollided gamma dose rate (or heating rate) at point r_o, z_o, φ_o from all source gamma energy groups
$\dot{D}_{\gamma}(r_o, z_o, \varphi_o)$	total (uncollided plus scattered) gamma dose rate (or heating rate) at point r_o, z_o, φ_o from all gamma energy groups

(Units of $\dot{D}$ are rad/hr or other units depending on units of K_I.)

I	number of gamma energy group
J	number of source point
r_J	distance from J^{th} source to receiver point, cm
S_{IJ}	source strength of J^{th} source point in I^{th} energy group, MeV/sec
K_I	output conversion factor for I^{th} group for dose, (rad/hr)/(MeV)/cm^2-sec); for heating, (cal/g-sec)/(MeV/cm^2-sec)
b_{IJ}	$\sum_M \left(\frac{\mu}{\rho}\right)_{IM} (\rho t)_{MJ}$ dimensionless e-folding length encountered between J^{th} source point and receiver point for I^{th} energy group gammas

where

M	number of elements used
$\left(\frac{\mu}{\rho}\right)_{IM}$	total gamma mass absorption coefficient for M^{th} element, I^{th} energy group, cm^2/g
$(\rho t)_{MJ}$	total mass thickness of M^{th} element encountered between J^{th} source point and receiver point, g/cm^2
$B_I(b_{IJ})$	infinite-medium buildup factor corresponding to energy group I and e-folding length b_{IJ} for appropriate representative material and receiver response

The neutron dose rate, estimated from the Albert-Welton kernel, is as follows:

$$\dot{D}_n(r_o, z_o, \varphi_o) = \sum_J \frac{S_J \alpha_1}{4\pi r_J^2} \exp(-c) h_J^{\alpha_2} \exp\left(-\alpha_3 h_J^{\alpha_4}\right)$$

where

$\dot{D}_n(r_o, z_o, \varphi_o)$ dose rate from neutrons at point r_o, z_o, φ_o, rem/hr

J number of source point

S_J source strength of J^{th} source point, fissions/sec

c $\sum_M \left(\frac{\Sigma_R}{\rho}\right)_M (\rho t)_{MJ}$ dimensionless fast neutron e-folding lengths between J^{th} source point and receiver point from all elements except hydrogen

where

$\left(\frac{\Sigma_R}{\rho}\right)_M$ fast neutron removal cross section, cm^2/g for M^{th} element

h_J equivalent thickness of hydrogen with density 0.111 g/cm^3 encountered between J^{th} source point and receiver point, cm

The empirical constants are

α_1 2.187×10^{-3} cm^2 (rem/hr)/(fission/sec)

α_2 0.29 (dimensionless)

α_3 0.83 (dimensionless)

α_4 0.58 (dimensionless)

Note that with this set of constants the Albert-Welton attenuation kernel will give meaningful results only if $h_J \geq 0.5$ centimeter.

Output from the QAD4 section of QADHD is a table of r_o, z_o, φ_o, $\dot{D}_{\gamma_{un}}$, $\dot{D}_{\gamma}$, $\dot{D}_{neut}$, IERR3, $\dot{D}_{\gamma_{I_{un}}}$, and $\dot{D}_{\gamma_I}$, as defined previously. If IERR3 = 1 on the output, no hydrogen was encountered on the traverse and the $\dot{D}_{neut}$ is in error. If IERR3 = 0, some hydrogen was encountered; however, if h_J is less than 0.5 centimeter the $\dot{D}_{neut}$ may still be in error.

Library data. - To reduce data input normally required for the LASL QAD4, a library of basic data used by QAD4 (and subsequently by all other segments of this code) has been included in the program. This library includes for all elements from Z = 1 to Z = 92, the total mass absorption coefficients for gammas μ/ρ. Tables of μ/ρ against E are stored as FORTRAN BLOCK DATA for values of energy E of 0.05, 0.06, 0.08, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.80, 1.00, 1.50, 2.00, 3.00, 4.00, 5.00, 6.00, 8.00, and 10.00 MeV. Data are from NBS circular 583 (ref. 2) and from LA-2237 (ref. 3) without coherent scattering for the elements not in NBS-583. The gamma mass absorption coefficients for gamma energies listed as input for a given problem are then obtained from this master table by linear interpolation.

A number of infinite-medium buildup factors are fitted to polynomials of the form

$$B(b, E) = \sum_i \sum_j A_{ij} b^i E^j$$

or to other similar polynomials in APEX 510 (ref. 4). The bivariant coefficients A_{ij} were included in the QADHD library for dose and energy absorption buildup in water, aluminum, iron, and lead. The selection of one of these buildup factors is input to the program. QAD type buildup-factor coefficients are calculated from these A_{ij} for the given input gamma energies.

Neutron removal cross sections Σ_R/ρ (cm^2/g) are included for all elements from atomic number Z = 1 to Z = 100. These data are from reference 5. Cross sections for elements not in this reference were calculated from the fitted curves

$$\frac{\Sigma_R}{\rho} = \frac{0.6}{A} \qquad A < 15$$

$$= 0.162\, A^{-0.516} \qquad A > 15$$

where A is the atomic number.

The output conversion factor K_I, listed in the previous section, is assembled from two pieces of library data as follows. QAD calculates the energy flux $E\Phi$ at a receiver point in MeV/(cm^2-sec). This flux is then multiplied by the mass energy absorption coefficient μ_a/ρ (cm^2/g) and a numerical conversion factor to give the final desired output form:

$$E\Phi\left(\frac{\text{MeV}}{\text{cm}^2\text{-sec}}\right) * \frac{\mu_a}{\rho}\left(\frac{\text{cm}^2}{\text{g}}\right) * \text{conversion}\left(\frac{\text{rad/hr}}{\text{MeV/g-sec}}\right) = \left(\frac{\text{rad}}{\text{hr}}\right)$$

The library includes the mass energy absorption coefficients μ_a/ρ for muscle (table IA1 of ref. 6) that normally are used in QAD4 and QADD calculations, and it includes the mass energy absorption coefficients μ_a/ρ for hydrogen (ref. 6) that normally are used in QADH calculations. The tables of μ_a/ρ against E are stored for the same values of E as indicated for the μ/ρ tables. Again, values for input gamma energies are interpolated from this master table.

For dose rate, the numerical conversion factors in the library are 5.76756×10^{-5} (rad/hr)/(MeV/g-sec) and for heating in liquid hydrogen with a density of 0.07 gram per cubic centimeter 2.67557×10^{-5} (cal/cm^3 sec)/(MeV/g-sec). The QAD conversion factor K_I is then the appropriate product, $K_I = \text{conversion} \times (\mu_a/\rho)_I$. Although these μ_a/ρ and conversions are internal to the program, the user may load alternate ones if desired.

The constants in the semiempirical Albert-Welton fast-neutron-dose kernel are

$$\alpha_2 = 0.29$$

$$\alpha_3 = 0.83$$

$$\alpha_4 = 0.58$$

The leading coefficient α_1 actually consists of the product of two terms, a "flux-to-dose" conversion α_0 and a part to normalize the attenuation curve α^*, such that the extrapolation of the hydrogen attenuation kernel

$$\alpha^* h^{\alpha_2} \exp\left(-\alpha_3 h^{\alpha_4}\right)$$

approaches 1.0 as h approaches 0.

For neutron dose, values of α_1 stored as library data are $\alpha_1 = 2.187\times10^{-3}$ cm^2 (rem/hr)/(fission/sec) and for neutron heating of liquid hydrogen are $\alpha_1 = 9.14\times10^{-14}$ cm^2 (cal/cm^3-sec)/(fission/sec).

The value of 9.14×10^{-14} for calculating neutron heating in liquid hydrogen must be regarded as a rough estimate only. This value was obtained in the following manner from the α_1 used for dose calculations:

Assume:

1 tissue rad of fast neutrons = 10 rem

$$1 \text{ water rad} = 1 \text{ tissue rad}$$

All energy deposited by fast neutrons in water is due to recoils of hydrogen in water

Therefore,

$$
\begin{aligned}
1 \text{ rem} &= 0.1 \text{ tissue rad} \\
&= 0.1 \text{ water rad} \\
&= 10 \text{ erg/g water (since } 1 \text{ rad} = 100 \text{ erg/g)} \\
&= 10 \text{ erg/cm}^3 \text{ water} \\
&= 90 \text{ erg/g hydrogen (in } H_2O\text{) (since density of hydrogen is } 0.111 \text{ g/cm}^3 \text{ in } H_2O\text{)}
\end{aligned}
$$

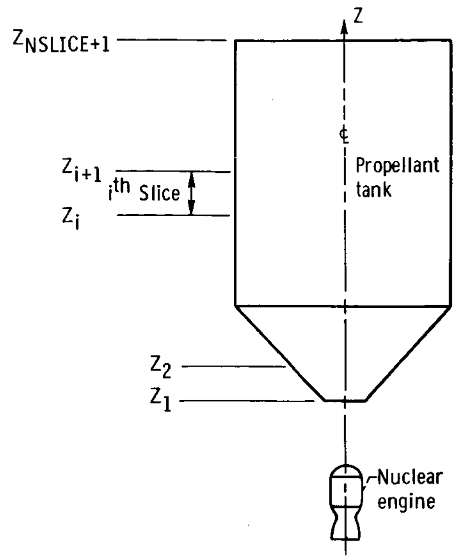
Therefore,

$$\alpha_1 = 2.19\ 10^{-3} \frac{\text{cm}^2(\text{rem/hr})}{(\text{fission/sec})} \times \frac{90\ \text{erg/g}_H}{\text{rem}} \times \frac{\text{hr}}{3600\ \text{sec}} \times \frac{0.239\ \text{cal}}{10^7\ \text{erg}} \times \frac{0.07\ \text{g}_H}{\text{cm}^3}$$

$$= 9.14\ 10^{-14}\ \text{cm}^2 \frac{(\text{cal/cm}^3\text{-sec})}{(\text{fission/sec})}$$

QADH Method of Solution

Computer output. - QADH calculates the temperature history of the propellant during reactor operation. The QAD4 routines compute local heating rates, and the QADH integrates these over the propellant volume to obtain the total heating rate as a function of the quantity of propellant in the tank. If it is desired, the contribution to propellant heating by energy deposited by gammas in the tank wall and tank bottom may also be evaluated. Assuming that convective currents distribute this heat uniformly throughout the propellant permits the temperature rise rates to be determined. When propellant volume is related to engine operating time, the code determines a heat absorption and temperature history of the propellant. The computation proceeds as follows. The propellant tank is divided into a number of axial slices, and the Z-coordinates of the slices are loaded as input, as indicated in sketch (a). A number of receiver points are located in each slice, the number of receivers being determined by the order of Gaussian integration (quadrature) specified for each of the three coordinate directions. This number may be 2, 4, 8, or 16 in the R-direction, 2, 4, 8, or 16 in the Z-direction (for each slice),



(a)

and 1, 2, 4, 8, or 16 in the φ-direction. (Only one point in the φ-direction is required when the tank and source are symmetrical about the same axis.) These receivers are located at abscissas corresponding to the order of Gaussian quadrature specified. Thus, as few as 4 or as many as 4096 receivers are located in each slice. At each receiver point, the local heating rate is calculated as indicated in the section QAD4 Method of Solution. The total heating rate in the slice is obtained by completing the Gaussian quadrature.

The heating rate for the i^{th} slice is obtained from

$$\dot{q}_i = \int_{Z_i}^{Z_{i+1}} \int_R \int_\varphi \dot{W}(R, Z, \varphi) R \, dR \, dZ \, d\varphi$$

by Gaussian numerical integration where $\dot{W}(R, Z, \varphi)$ is the local heating rate from neutrons or gammas in cal/(cm^3)(sec). The first page of QADH output is a table of

$$i \quad Z_i \quad (Z_{i+1} - Z_i) \quad VOL_i \quad DTIME_i \quad \dot{q}_{\gamma_i} \quad \dot{q}_{n_i} \quad \dot{q}_{t_i}$$

where

VOL_i	volume of i^{th} slice, cm^3
$DTIME_i$	time to expel volume of i^{th} slice from tank, sec
$\dot{q}_{\gamma_i}$	cal/sec deposited by gammas in i^{th} slice of propellant

$\dot{q}_{n_i}$ cal/sec deposited by neutrons in i^{th} slice of propellant

$\dot{q}_{t_i}$ $\dot{q}_{\gamma_i} + \dot{q}_{n_i}$

If wall heating is calculated, a table similar to that just given is printed out, and is followed by a single line of output calculated for bottom heating. The terms $\dot{q}_i$ in this table are the heating rates in the wall slices (which correspond to the propellant slices). These values are then summed by code with the $\dot{q}_i$ obtained for the propellant to obtain the total heating in each slice of propellant.

The total heating rate into the propellant when the propellant level is at any slice coordinate is obtained by summing up the heating rates of all the slices from the tank bottom up to that level. When it is assumed that this heat is then redistributed by convective currents uniformly throughout the propellant by turbulence within the propellant (the complete-mix model), then the rate of temperature rise is determined by using the density and specific heat and volume of propellant up to that level. Similarly, rates of heat input and temperature rise are computed for each position considered.

These data are presented in the next pages of QADH output as a table of

$$i \quad \dot{Z}_i \quad \dot{Q}_{\gamma i} \quad \dot{Q}_{ni} \quad \dot{Q}_{ti} \quad \dot{T}_{\gamma i} \quad \dot{T}_{ni} \quad \dot{T}_{ti}$$

where

$\dot{Q}_{\gamma i}$ cal/sec being added by gammas to entire tank when liquid level is Z_i

$\dot{Q}_{ni}$ cal/sec being added by neutrons to entire tank when liquid level is Z_i

$\dot{Q}_{ti}$ $\dot{Q}_{\gamma i} + \dot{Q}_{ni}$

$\dot{T}_{\gamma i}$ rate of temperature increase of propellant, $^{\circ}C$/sec from gamma heating when liquid level is Z_i

$\dot{T}_{ni}$ rate of temperature increase of propellant, $^{\circ}C$/sec from neutron heating when liquid level is Z_i

$\dot{T}_{ti}$ $\dot{T}_{\gamma i} + \dot{T}_{ni}$

and

$$\dot{Q}_{\gamma i} = \sum_{l=1}^{i} \dot{q}_{\gamma l}$$

$$\dot{Q}_{ni} = \sum_{l=1}^{i} \dot{q}_{nl}$$

$$\dot{T}_{\gamma i} = \frac{\dot{Q}_{\gamma i}}{\rho C_p \sum_{l=1}^{i} VOL_l}$$

$$\dot{T}_{ni} = \frac{\dot{Q}_{ni}}{\rho C_p \sum_{l=1}^{i} VOL_l}$$

where ρ is the density of liquid hydrogen, which is assumed constant (0.07 g/cm^3), and C_p is the specific heat of liquid hydrogen, assumed constant (2.25 cal/(g $^{\circ}$C).

From the time required for the propellant level to drop from one position to the next and the arithmetic average of the rate of temperature rise and rate of heat input over this interval, an incremental temperature increase and heat input is evaluated for this time period ($DTIME_i$).

These data are presented in the next page of QADH output as a table of

$$i \quad \Delta Q_{\gamma i} \quad \Delta Q_{ni} \quad \Delta Q_{ti} \quad \Delta T_{\gamma i} \quad \Delta T_{ni} \quad \Delta T_{ti}$$

where

$\Delta Q_{\gamma i}$	amount of heat from gammas added to propellant in time $DTIME_i$, cal
ΔQ_{ni}	amount of heat from neutrons added to propellant in time $DTIME_i$, cal
ΔQ_{ti}	$\Delta Q_{\gamma i} + \Delta Q_{ni}$
$\Delta T_{\gamma i}$	temperature rise of propellant from gammas in time $DTIME_i$, $^{\circ}$C
ΔT_{ni}	temperature rise of propellant from neutrons in time $DTIME_i$, $^{\circ}$C
ΔT_{ti}	$\Delta T_{\gamma i} + \Delta T_{ni}$

and where

$$\Delta Q_{\gamma i} = \frac{1}{2} (\dot{Q}_{\gamma i} + \dot{Q}_{\gamma i+1}) * DTIME_i$$

$$\Delta Q_{ni} = \frac{1}{2} (\dot{Q}_{ni} + \dot{Q}_{ni+1}) * DTIME_i$$

$$\Delta T_{\gamma i} = \frac{1}{2}(\dot{T}_{\gamma i} + \dot{T}_{\gamma i+1}) * DTIME_i$$

$$\Delta T_{ni} = \frac{1}{2}(\dot{T}_{ni} + \dot{T}_{ni+1}) * DTIME_i$$

Finally, to accumulate these values of incremental temperature rise and heat input and to present them as a function of reactor operating time, a new index j is defined as $j = NSLICE + 1 - i$. Thus, at any time $TIME_j$, where $TIME_{j=1} = DTIME_{i=NSLICE}$ and $TIME_j = TIME_{j-1} + DTIME_{i=NSLICE+1-j}$, the fluid level is at $Z_{i=NSLICE+1-j}$. $TIME_j$ is the time from start of engine operation.

The final page of output is then

$$j \quad TIME_j \quad Q_{\gamma j} \quad Q_{nj} \quad Q_{tj} \quad T_{\gamma j} \quad T_{nj} \quad T_{tj}$$

where

$Q_{\gamma j}$ heat absorbed in propellant from gammas from start of reactor operation to time $TIME_j$, cal

Q_{nj} heat absorbed in propellant from neutron from start of reactor operation to time $TIME_j$, cal

Q_{tj} $Q_{\gamma j} + Q_{nj}$

$T_{\gamma j}$ temperature rise in propellant due to gammas from start of reactor operation to time $TIME_j$, ^oC

T_{nj} temperature rise in propellant due to neutrons from start of reactor operation to time $TIME_j$, ^oC

T_{tj} $T_{\gamma j} + T_{nj}$

For initialization, it was assumed that

$$Q_{\gamma 1} = \Delta Q_{\gamma, i=NSLICE}$$

$$Q_{n1} = \Delta Q_{n, i=NSLICE}$$

$$T_{\gamma 1} = \Delta T_{\gamma, i=NSLICE}$$

$$T_{n1} = \Delta T_{n, i=NSLICE}$$

Then the following computations were made:

$$Q_{\gamma j} = Q_{\gamma j-1} + \Delta Q_{\gamma, i=NSLICE+1-j}$$

$$Q_{nj} = Q_{nj-1} + \Delta Q_{n, i=NSLICE+1-j}$$

$$T_{\gamma j} = T_{\gamma j-1} + \Delta T_{\gamma, i=NSLICE+1-j}$$

$$T_{nj} = T_{nj-1} + \Delta T_{n, i=NSLICE+1-j}$$

These accumulated increments then give the temperature rise history and total heat-added history.

It was assumed that all heat added to the propellant goes into raising the temperature of the propellant. If, however, one has a tank of propellant at a temperature near saturation at the start of operation, the temperature will increase only to saturation and then boiling will begin. For such a case, the total temperature rise calculated by QADH will of course have no real meaning. However, from the total heat-added-time history output of QADH and from the heat of vaporization (108 cal/g of LH_2), sufficient information is available to calculate the boiloff after saturation temperature has been attained.

Intermediate output. - If it is desired, intermediate output (local heating rates and results of various integrations) may be obtained, which may be of interest if regions of high local flux are anticipated (e.g., away from the shadow of a partial shadow shield). Control for this output is by the parameter NSKIP that is loaded as data on the tank emptying card QH1. The intermediate output is as follows. If NSKIP $\geq$ 3, write

$$\text{II} \quad R, Z, \varphi \qquad \dot{W}_\gamma/\text{Buildup} \quad \dot{W}_\gamma \quad \dot{W}_n$$

where

II	receiver point number
R, Z, φ	receiver coordinates, R and Z, cm, and φ, rad
$\dot{W}_\gamma$/Buildup	local heating rate at R, Z, φ due to uncollided gammas
$\dot{W}_\gamma$	local heating rate at R, Z, φ due to all gammas (uncollided rate times buildup factor)
$\dot{W}_n$	local heating rate at R, Z, φ due to neutrons

If NSKIP $\geq$ 2, write

$$\int_{\varphi} \dot{W}_{\gamma}\, d\varphi; \qquad \int_{\varphi} \dot{W}_{n}\, d\varphi; \qquad \int_{\varphi} (\dot{W}_{\gamma} + \dot{W}_{n}) d\varphi;$$

and

$$\int_{R} \int_{\varphi} \dot{W}_{\gamma}\, d\varphi R\, dR; \quad \int_{R} \int_{\varphi} \dot{W}_{n}\, d\varphi R\, dR; \quad \int_{R} \int_{\varphi} (\dot{W}_{\gamma} + \dot{W}_{n}) d\varphi$$

If NSKIP $\geq$ 1, write

$$\int_{Z_i}^{Z_{i+1}} \int_{R} \int_{\varphi} \dot{W}_{\gamma}\, d\varphi R\, dR\, dZ; \int_{Z_i}^{Z_{i+1}} \int_{R} \int_{\varphi} \dot{W}_{n}\, d\varphi R\, dR\, dZ; \int_{Z_i}^{Z_{i+1}} \int_{R} \int_{\varphi} (\dot{W}_{\gamma} + \dot{W}_{n}) d\varphi R\, dR\, dZ$$

All values are printed as soon as they are calculated. The integrals are of interest only in the checking of calculations.

QADD Calculations

Method of solution. - QADD calculates the time-integrated dose at a detector during the operating time of the reactor when the propellant level in the tank between the source and detector is dropping. The tank is divided into a number of axial slices and the Z-(axial) coordinates of these slices Z (I) are loaded as input. Gauss quadrature is used to evaluate the volumes of these slices, and the total tank volume is also determined. From the total tank volume and the propellant flow rate, the time for the propellant level to drop to any of the slice coordinates is determined. In the code, a boundary describing the propellant level is designated MOVER, and this boundary takes on successive values of the slice coordinates. The dose rate is calculated, as indicated in the preceding section, now with the MOVER positioned at each axial coordinate. For each discrete propellant level I, one then has total neutron and gamma dose rates $\dot{D}_n(I)$ and $\dot{D}_{\gamma}(I)$. The dose obtained while the propellant level drops from one position to the next lower position is equal to the product of the time elapsed during this level change and the average dose rate during the level change, or

$$\Delta DOSE_{\gamma}(I) = \frac{1}{2}\left[\dot{D}_{\gamma}(I) + \dot{D}_{\gamma}(I + 1)\right] \times \Delta TIME(I)$$

$$\Delta DOSE_{n}(I) = \frac{1}{2}\left[\dot{D}_{n}(I) + \dot{D}_{n}(I + 1)\right] \times \Delta TIME(I)$$

where

$\Delta DOSE_\gamma(I)$	gamma dose obtained while level drops from level (I + 1) to I, rad
$\dot{D}_\gamma(I)$	gamma dose rate with propellant at level (I), rad/hr
$\dot{D}_\gamma(I+1)$	gamma dose rate with propellant at level (I + 1), rad/hr
$\Delta TIME(I)$	time for propellant level to drop from level (I + 1) to I, sec
$\Delta DOSE_n(I)$	neutron dose obtained while level drops from level (I + 1) to I, rem
$\dot{D}_n(I)$	neutron dose rate with propellant at level (I), rem/hr
$\dot{D}_n(I+1)$	neutron dose rate with propellant at level (I + 1), rem/hr

QADD also evaluates the accumulative dose as a function of engine operating time:

$$DOSE_\gamma(I) = \sum_{J=I}^{NSLICE} \Delta DOSE_\gamma(J)$$

$$DOSE_n(I) = \sum_{J=I}^{NSLICE} \Delta DOSE_n(J)$$

$$TIME(I) = \sum_{J=I}^{NSLICE} \Delta TIME(J)$$

where

TIME(I)	time elapsed while propellant moves from initial level to level I, sec
$DOSE_\gamma(I)$	total gamma dose obtained from time = 0 to TIME(I), rad
$DOSE_n(I)$	total neutron dose obtained from time = 0 to TIME(I), rem
NSLICE	total number of tank slices considered

Computer output. - The computer output from the QADD section QADHD is a table of

$$I \quad Z(I) \quad \dot{D}_\gamma(I) \quad \Delta DOSE_\gamma(I) \quad DOSE_\gamma(I)$$

$$\dot{D}_n(I) \quad \Delta DOSE_n(I) \quad DOSE_n(I) \quad TOTDOS(I)$$

where TOTDOS(I) is $DOSE_\gamma(I) + DOSE_n(I)$. It should be reiterated that the dose calculated here is good only if the large propellant tank is fully shielded from the source which results in slowly varying fluxes in the propellant. If high flux regions are present in some parts of the tank, unnoticed by the line of sight, then the dose may be underestimated by orders of magnitude.

DATA INPUT DESCRIPTION

Source Specification

The source volume is subdivided into a desired number of smaller volume elements. The source strength of each of these is then represented by a point source at the center of the volume element. The source is specified by the total source strength So, the location of subdividing surfaces, and a relative source strength distribution. In QADHD the source must have cylindrical symmetry. The subdividing surfaces of the source are specified by inputting a set of R, Z, and φ; that is $(R_1, R_2, \ldots, R_L)$, $(Z_1, Z_2, \ldots, Z_M)$, and $(\varphi_1, \varphi_2, \ldots, \varphi_N)$. The source will then be contained in the volume R_1 to R_L, Z_1 to Z_M, and φ_1 to φ_N. Point sources will be located at the center of each of the orthogonal volumes described by these surfaces.

The relative spatial source strength in the R- and Z-directions is then specified in one of two ways (no φ variation is allowed). Values can be given for ξ_1, ξ_2, η_1, and η_2 in the cosine distribution

$$P(R, Z) = A \cos \xi_1(R - \xi_2)\cos \eta_1(Z - \eta_2)$$

where this expression is valid in the range $Z_1 \le Z \le Z_M$ and $R_1 \le R \le R_L$. The constant A is determined by the program by a normalizing definition,

$$S_o = \int_{R_1}^{R_L} \int_{Z_1}^{Z_M} \int_{\varphi_1}^{\varphi_N} P(R, Z)R \, dR \, dZ \, d\varphi$$

An alternate means of specifying relative source strength is to give a relative power on the R- and Z-coordinates previously given. The relative power at each point need only be consistent for its particular coordinate. Again, normalization similar to that just indicated will be performed by the program. The source strength for each equivalent point source will then in essence be calculated from

$$S_{lmn} = \int_{R_l}^{R_{l+1}} \int_{Z_m}^{Z_{m+1}} \int_{\varphi_n}^{\varphi_{n+1}} P(R, Z)R \, dR \, dZ \, d\varphi$$

where S_{lmn} is the source strength at point lmn and $P(R, Z)$ is the normalized relative source distribution. The source as specified does not have to fill a geometric QAD region and it is not necessary for the specified source to be in only one region; it may extend over several.

As used in QADHD, the units of the total source S_0 are in fissions per second or captures per second to correspond to a convenient gamma spectrum given in MeV per fission or MeV per capture (the final gamma source strength is MeV/sec) and an α_1 in the neutron dose kernel having units in dose rate per fission per second. However, other units may be used provided that dimensional consistency is maintained through the calculation.

Geometry

The geometric description of problems is the same as that used in the LASL QAD4. The geometry description is illustrated by the reactor-shield-propellant tank configuration shown in figure 1. This configuration could represent a stage of a space vehicle that uses a clustered set of nuclear rocket engines, where, because of the symmetry of the arrangement, only one engine, its associated propellant tank, and an adjacent propellant tank are sufficient for calculational purposes. It is assumed that the crew compartment is not in this stage and that propellant heating is an important problem in the stage. In figure 1, the entire reactor assembly is represented as a carbon core, the shadow shield is composed of zirconium hydride, and the tanks contain liquid hydrogen propellant.

Boundaries. - All space is divided into regions bounded by quadratic surfaces that are described by equations of the following types:

Type 1:

$$AX^2 + XXo + BY^2 + YYo + CZ^2 + ZZo - K = 0$$

Type 2:

$$A(X - Xo)^2 + B(Y - Yo)^2 + C(Z - Zo)^2 - K = 0$$

Type 3:

$$(X - Xo)^2 + (Y - Yo)^2 - K = 0$$

Type 4:

$$X - K = 0$$

Type 5:

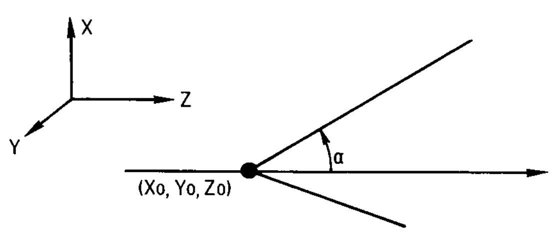
$$Y - K = 0$$

Type 6:

$$Z - K = 0$$

A, B, C, Xo, Yo, Zo, and K are constants for each surface specified in the input. Types 4, 5, and 6 are X-, Y-, and Z-planes, respectively. Type 3 is a circular cylinder parallel to the Z-axis. Types 1 and 2 may be used to obtain other geometric shapes. For example, a cone with its axis parallel to the Z-axis (sketch (b)) is described by

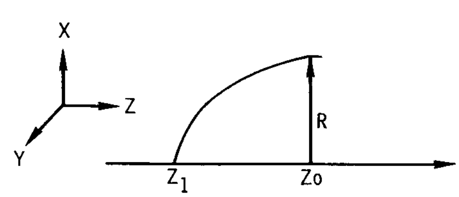
$$(X - Xo)^2 + (Y - Yo)^2 - (Z - Zo)^2 \tan^2\alpha = 0$$



(b)

An oblate (or prolate) spheroid with its axis parallel to the Z-axis (skecth (c)) is described by

$$(X - Xo)^2 + (Y - Yo)^2 + R^2\left\{\left[\frac{(Z - Zo)}{(Z_1 - Z_o)}\right]^2 - 1\right\} = 0$$

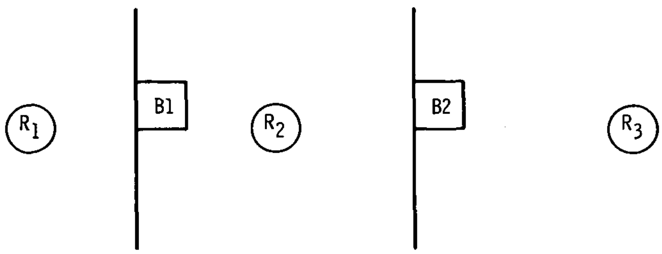


(c)

The configuration shown in figure 1 is arranged into a set of QAD regions by the use of bounding surfaces, as shown in figure 2. These bounding surfaces are presented in the following table.

Boundary, number	Equation	QAD equation type	Parameters for input
1	$Z = 0$	6	$K = 0$
2	$Z = 130$	6	$K = 130$
3	$Z = 160$	6	$K = 160$
4	$Z = 500$	6	$K = 500$
5	$Z = 750$	6	$K = 750$
6	$Z = 1600$	6	$K = 1600$
7	$X^2 + Y^2 = (50)^2$	3	Xo = 0, Yo = 0, K = 2500
8	$X^2 + Y^2 = 600^2$	3	Xo = 0, Yo = 0, K = 360000
9	$(X - 1250)^2 + Y^2 = 600^2$	3	Xo = 1250, Yo = 0, K = 360000
10	$X^2 + Y^2 = 2000^2$	3	Xo = 0, Yo = 0, $K = 4\times10^6$
11	$X^2 + Y^2 = (Z - 150)^2 \tan^2 45^\circ$	2	A = 1 B = 1 C = -1 Xo = 0 Yo = 0 Zo = 150 K = 0
12	$(X - 1250)^2 + Y^2 = (Z - 150)^2 \tan^2 45^\circ$	2	A = 1 B = 1 C = -1 Xo = 1250 Yo = 0 Zo = 150 K = 0

Regions. - Regions are defined as either positive or negative with respect to any of their boundaries. If $f(X, Y, Z) = K$ is a boundary of region R, then let a quantity called the residual be defined as $r(X, Y, Z) = f(X, Y, Z) - K$. If a point X_0, Y_0, Z_0 is in region R, then the geometry routine requires that the product $j * r(X_0, Y_0, Z_0)$ must be negative. The factor j is equal to +1 or -1 depending on whether $r(X_0, Y_0, Z_0)$ is negative or positive. If $j = +1$, then the region is considered positive with respect to the



(d)

boundary, or if j = -1, the region is negative with respect to the boundary. The sign of j (+ or -) is affixed to the QAD boundary number in the input QAD region description. For example, consider a region R_2 bounded by planes Z = 0 (boundary B1) and Z = 20 (boundary B2), shown in sketch (d). Consider any point in region R_2, such as $Z_o = 15$. For boundary B1 (type 6), K = 0; hence,

$$r(X_o, Y_o, Z_o) = f(X_o, Y_o, Z_o) - K = Z_o - 0 = 15$$

The residual is positive; thus j must be -1 and R_2 is negative with respect to B1. For boundary B2, K = 20, and

$$r(X_o, Y_o, Z_o) = f(X_o, Y_o, Z_o) - K = Z_o - 20 = 15 - 20 = -5$$

Since the residual is negative, j = +1 and R_2 is positive with respect to B2. Similarly, it is seen that the region within a cylinder is positive with respect to the cylindrical surface.

Another method of assigning signs to boundaries, which yields the same correct end result, is to determine, if a particle in region R crosses a Z-boundary, the sense of its motion in Z (+ or -). The boundary is then given that sign. Similarly for cylinders and cones, if the particle is going in the positive direction of r, then the radial boundary is +.

Regions are classified as either inside or outside regions. Once a ray from a source point passes into an outside region, it is assumed that it will encounter no other regions on its way to the receiver. Regions 11, 12, and 13 in figure 2 are outside regions. The input required for each region includes (1) the number of boundaries associated with the region (NBNDZN). NBNDZN is given a (+) sign if the region is an inside one and a (-) sign if the region is an outside one; (2) the composition number for the region (NCMPZN); (3) the boundary number of each boundary associated with the region, to which has been affixed the appropriate sign (+ or -) that defines whether the region is positive or negative with respect to that boundary; and the probable region entered after crossing a given boundary. On the region card (read in with a Format (7(I5, I4)), columns 1 to 5 contain ±NBNDZN, 6 to 9 contain NCMPZN, 10 to 14 contain ± boundary number, 15 to 18 contain the probable region entered when crossing this boundary, 19 to 23 contain ± another boundary number, 24 to 27 the probable region entered when crossing this boundary, and so forth for up to six boundaries per region. The region numbers are assigned in the order that the region cards are read in. For example, the region card for region R2 in sketch (c) is

Columns					
1-5	6-9	10-14	15-18	19-23	24-27
+2	Composition number	-B1	R_1	+B2	R_3

The material composition of each region is specified by assigning each composition a number and constructing a matrix with the appropriate densities of all elements used in the problem, as shown in the following sample problem. If an element is not used in a composition, its density in that particular composition would be zero. The composition number is then part of the region specification. For the sample problem, then:

Regions in which composition is used		Composition	Density, g/cm^3		
			Hydrogen, $_1H$	Carbon, $_6C$	Zirconium, $_{40}Zr$
(1)	Core	1	0	1.5	0
(2)	Shield	2	.11	0	5.49
(5, 7, 8, 10)	Liquid hydrogen	3	.07	0	0
All others	Void	4	0	0	0

The complete set of region cards for the sample problem (fig. 2) is then

Column												
1-5	6-9	10-14	15-18	19-23	24-27	28-32	33-36	37-41	42-45	46-50	51-54	73-80
Number of boundaries	Composition number	• Boundary, Probable region										Region
+3	1	-1	13	+7	3	+2	2					1
+3	2	-2	1	+7	3	+3	4					2
+4	4	-1	13	+10	12	+3	4	-7	1			3
+3	4	-3	2	+10	12	+4	5					4
+3	3	-4	4	+11	6	+5	8					5
+5	4	-4	4	+10	12	+5	9	-11	5	-12	7	6
+3	3	-4	4	+12	6	+5	10					7
+3	3	-5	5	+8	9	+6	11					8
+5	4	-5	6	+10	12	+6	11	-8	8	-9	10	9
+3	3	-5	7	+9	9	+6	11					10
-1	4	-6	8									11
-3	4	-10	3	-1	13	+6	11					12
-1	4	+1	1									13

QADH and QADD Tank-Emptying Geometry

General. - In addition to the general geometry described in the previous section, additional parameters are required to define the mode of tank emptying. QADD and QADH propellant tanks are constrained to be circular in cross section (in the X-Y plane), and the tank centerline must lie parallel to the Z-axis and in the $\varphi = 0$ plane. The tank may consist of only one part or two parts, a tank head and a main tank body. The surfaces describing the tank must be fully rotated type 2 or type 3 QAD boundaries. Several possible tank shapes are illustrated in figure 3. The QAD boundary numbers denoting the tank head and main tank body are specified in input as JHEAD and JTANK, respectively. Figure 3(c) shows that there are two ways to specify a one-piece tank; in this case the specification of JTANK = 0 or JHEAD = 0 is a flag to indicate a one-part tank and is not a QAD boundary number.

To simulate the propellant tank emptying, the tank is divided into a number of axial slices (NSLICE). The Z-coordinates of these are loaded as input. The i of that Z which divides the tank head from the body is designated KNUCKL. The volume of each slice is determined by Gauss quadrature and the total tank volume determined. From this and the reactor operating time (BURN), the flow rate and level of propellant in the tank as a function of time are determined. Up to this point, QADD and QADH function in the same manner.

QADH calculations. - The information given in the previous section is sufficient for QADH to calculate propellant heating, as indicated in the section QADH Method of Solution. However, if gamma heating in the tank wall is to be considered as part of the propellant heating, then the QAD boundaries defining the outside wall of the tank head and the main tank body must be specified. These are designated JWHED and JWTNK, respectively. (The inside walls are assumed to be the previously inputted JHEAD and JTANK, respectively.) Also, the Z-coordinate of the bottom of the tank wall must be specified to calculate the contribution from the tank bottom.

In the sample problem illustrated in figure 2, for heating calculations of tank I, JHEAD = 11 and JTANK = 8. For heating calculations of tank II, JHEAD = 12 and JTANK = 9. For both tanks, select NSLICE = 8, Z = 500, 550, 600, 650, 750, 900, 1100, 1300, and 1600 centimeters; therefore, KNUCKL is 5. For tank I, concentric with the core, no variation in local heating in the φ-direction is expected; hence, set NPHI equal to 0 because only one point in this direction ($\varphi = 0$) is necessary for heating calculations.

QADD calculations. - For the QADD calculation of dose received while the tank is emptying, a QAD boundary, defining the propellant level in the tank, is designated as MOVER. To simulate emptying, this boundary takes on the successive values of the Z-coordinates of the slice divisions. The dose rate is determined with the MOVER at its initial position and each of the NSLICE values of Z_i, which are input. (Note that only NSLICE values of Z_i are required for QADD while values of NSLICE + 1 are required for QADH.) The MOVER is the boundary that separates the liquid in the tank from the emptied portion of the tank. Thus, it is important to distinguish between the MOVER boundary and the upper boundary of the tank and to insert between them a region of void or pressurizing gas. As the position of MOVER changes, this region increases in size. For example, consider the configuration in figure 4, which represents a stage with a single nuclear engine and which contains the crew compartment (a wall of which is shown as region 10 in the figure). The dose to the crew is an important problem in the operation of this stage. The reactor, shield, tank sizes, composition, and arrangement are similar to those illustrated in figure 2. Note that the tank has been extended a small amount to distinguish between the upper tank boundary 9 and the MOVER boundary 6 and that region 8 inserted between these boundaries is considered to be a void region. The dose to the crew located at a position Z = 2100 centimeters, and R = 0 centimeters is desired.

For this QADD calculation, JHEAD = 11, JTANK = 8, and MOVER = 6. Select a set of values of Z_i = 500, 550, 600, 650, 750, 900, 1100, and 1300 centimeters (NSLICE = 8) for fluid levels. Also KNUCKL = 5. (Z_5 = 750 is the plane which divides the tank head from the main tank body.)

One additional piece of information is necessary for proper execution of the calculation. The MOVER boundary 6 ultimately will be the upper boundary of region 5 rather than boundary 5. To take care of this situation, boundary 6 is also specified as a boundary of region 5. For this case then, the QAD region card for region 5 must be

Card column									
1-5	6-9	10-14	15-18	19-23	24-27	28-32	33-36	37-41	42-45
+4	3	-4	4	+11	6	+5	7	+6	8

The boundary condition (+6 8) is redundant until the MOVER enters the tank head. Then (+5 7) becomes redundant.

QADHD DATA INPUT

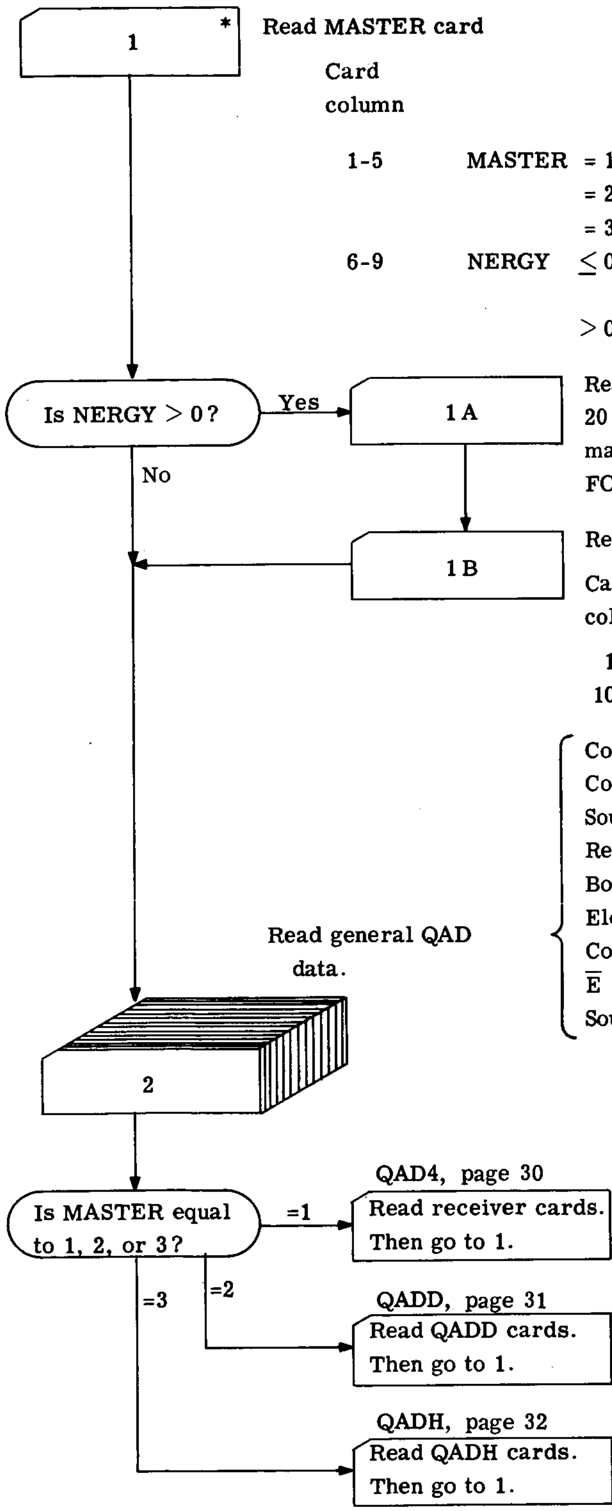
Program Notes

Data input to QADHD consists of (1) a control-card selecting mode of calculation for QAD4, QADD, or QADH; (2) a set of data, called general QAD data, that describes source, geometric regions and boundaries, composition and source spectrum; and (3) receiver cards for QAD4, tank geometry and receiver cards for QADD, or tank geometry cards for QADH. The detailed version of the general QAD data, although virtually the same as that for the LASL QAD, is presented here for the sake of completeness.

In its present form, the QADHD program is designed to handle 50 regions, 50 boundaries, 40 compositions, 20 elements, 30 energy groups, and 20 source points in each of the three coordinates, R, Z, and φ (a total of 8000 source points). With these limits, the program does not occupy the maximum 32K storage available in the core. The user, by increasing the dimensions of any or all of these arrays, may alter any of these limits.

A subroutine WEIGHT was added to calculate the volume (cm^3) and weight (g) of all inside QAD regions defined by planes QAD type-3 cylinders and QAD type-2 quadratic surfaces fully rotated about an axis parallel to the Z-axis. In a general purpose program such as this, most of the computation time is spent in tracing rays through the various regions. There is one ray traced from each source point to each receiver point, and the total running time was observed to be proportional to the number of these rays. QADHD calculates 3500 to 5000 source-to-receiver rays per minute on the IBM-7094 II, depending on the complexity of the geometry.

QADHD Input Flow



Read MASTER card FORMAT (I5, I4)

Card column		
1-5	MASTER	= 1 QAD4 problem
		= 2 QADD problem
		= 3 QADH problem
6-9	NERGY	≤ 0 Use output conversion factors internal to code (listed on p. 7)
		> 0 Read new output conversion factors

Read gamma energy absorption coefficients (cm^2/g); 20 values corresponding to energy grid for gamma mass attenuation coefficients listed on page 6. FORMAT (8E9. 4)

Read DOSE CONVERSION α_1 FORMAT (2E9. 4)

Card column	
1-9	Dose conversion factor for gammas
10-18	α_1 for Albert-Welton kernel

Comment
Control
Source cards
Region cards
Boundary cards
Element cards
Composition matrix
$\overline{E}$ for gamma energy groups
Source spectrum for gammas

See pages 26-29

* ▭ Symbol means read a card or set of cards as described.

General QAD Data For QADHD

The following block of data is required for all problem types (QAD4, D, H) and describes the source and geometry of the problem.

G1 — Read any alphabetic, numeric information FORMAT (12A6)
Card column 1 ⟶ 72

G2 — Read control card FORMAT (6(I5, I4))

Card column	Variable	
1-5	LSO	Number of source points on R coordinate axis
6-9	MSO	Number of source points on Z coordinate axis
10-14	NSO	Number of source points on φ coordinate axis
15-18	MAT	Number of elements used
19-23	NCOMP	Number of compositions
24-27	NREG	Number of regions
28-32	NRGY	Number of gamma energy groups
33-36	NBOUND	Number of boundaries
37-41		Not used
42-45	NZSO	Most probable region for source
46-50	ISRC	1 power defined by cosine distribution $P(R, Z) = \cos \xi_1(R - \xi_2)\cos \eta_1(Z - \eta_2)$ 2 power defined by point-by-point tabulation 0 use source defined by previous case
51-54	INEUT	>0 make neutron calculations $\leq$0 bypass neutron calculations

If ISRC=0, go to G10.

Otherwise

G3 — Read source card. FORMAT (5E9.4)

Card column	Variable	
1-9	S_o	Total source strength, fissions/sec or captures/sec
10-18	ξ_1	Parameters of cosine power distribution for ISRC=1 (not used if ISRC=2)
19-27	ξ_2	
28-36	η_1	
37-45	η_2	

G4	R-coordinates of source volumes (LSO+1) values	FORMAT (8E9.4)
G5	Z-coordinates of source volumes (MSO+1) values	FORMAT (8E9.4)
G6	φ-coordinates of source volumes (NSO+1) values	FORMAT (8E9.4)

($0 \longrightarrow \pi$ for QADH concentric tank)
($0 \longrightarrow 2\pi$ for QADH offset tank)

If ISRC $\neq$ 2, go to G10.

Otherwise read

G7	Relative value of source at R-coordinates of card G4	FORMAT (8E9.4)
G8	Relative value of source at Z-coordinates of card G5	FORMAT (8E9.4)
G9	Relative value of source at φ-coordinates of card G6 (Note: Regardless of values on this card, QADHD will assume no variation of power in φ-direction; the contents of this card are ignored.)	FORMAT (8E9.4)
G10	Region cards (NREG cards required) See pages 19-21 for more detail. The first card read is region 1, the second card is region 2, and so forth.	FORMAT (7(I5, I4))

Card column	
1-5	± number of boundaries for this region; if region is an outside region, the sign is -.
6-9	composition number for this region
10-14	± boundary number; region is + or - with respect to boundary
15-18	probable region entered if this boundary is crossed
19-23	± boundary
24-27	probable region
28-32	± boundary
33-36	probable region
37-41	± boundary
42-45	probable region
46-50	± boundary
51-54	probable region
55-59	± boundary
60-63	probable region

Up to six boundary surfaces may be used to define a region.

G11	Boundary cards (NBOUND cards required)	FORMAT (I5, I4, 7E9. 4)

Card column

1-5	Boundary number
6-9	Equation type (1) $AX^2+XXo+BY^2+YYo+CZ^2+ZZo-K = 0$ (general quadratic)
	(2) $A(X-Xo)^2+B(Y-Yo)^2+C(Z-Zo)^2-K = 0$ (spheroid, conic, or cylinder)
	(3) $(X-Xo)^2+(Y-Yo)^2-K = 0$ (circular cylinder parallel to Z-axis)
	(4) $X-K = 0$ (X-plane)
	(5) $Y-K = 0$ (Y-plane)
	(6) $Z-K = 0$ (Z-plane)
10-18	A
19-27	B
28-36	C
37-45	Xo
46-54	Yo
55-63	Zo
64-72	K

G12	NBLD, Element card	FORMAT (8(I5, I4))

Card column

1-5	NBLD = 1 Water dose buildup factor used
	2 Aluminum dose buildup factor used
	3 Iron dose buildup factor used
	4 Lead dose buildup factor used
	5 Water energy absorption buildup factor used
	6 Aluminum energy absorption buildup factor used
	7 Iron energy absorption buildup factor used
	8 Lead energy absorption buildup factor used
6-9	MATZ (1) Atomic number of first element used
10-14	MATZ (2) Atomic number of second element used
15-18	MATZ (3) Atomic number of third element used
.	. .
.	. .
.	. .
.	. .
	MATZ(MAT) Atomic number of MATth element used

G13	Composition matrix cards	FORMAT (8E9.4)

Enter the table of density (g/cm^3) of elements. At least one card per composition. The first card (cards) read are for composition number 1, and so forth.

Card column	
1-9	Density of element 1 in this composition
10-18	Density of element 2 in this composition
19-27	Density of element 3 in this composition
.	.
.	.
.	.

G14	Gamma energy card	FORMAT (8E9.4)

A list of the mean gamma energies (MeV) for each gamma energy group.
NRGY values required.

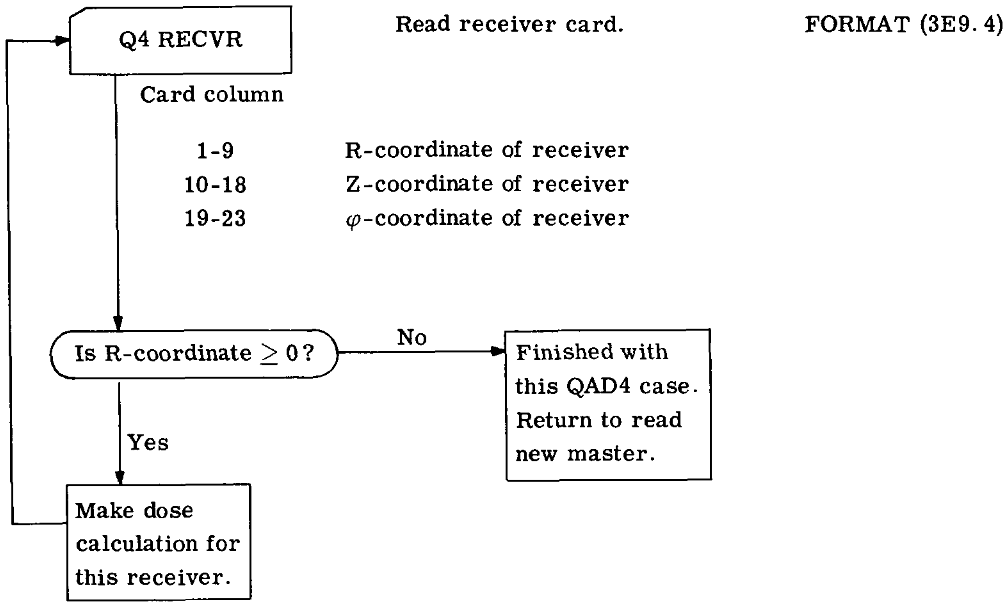
G15	Source spectrum, gammas	FORMAT (8E9.4)

A list of the MeV/fission or MeV/capture in each gamma energy group.
NRGY values required. Units to be consistent with S_0.

(S_0) * (Source spectrum) must be MeV/sec

QAD4 Receiver Cards

Read only if MASTER = 1.



(Note: The R-coordinate also functions as a signal for the ending of QAD4 case for proper return of the program for a new case. After the calculation for the final receiver is made, another receiver card with $R < 0$ is required for proper return to the main program.)

QADD Cards

Read only if MASTER = 2.

QD1 Tank emptying card FORMAT (3(I5, I4), E9. 4)

Card column	Variable	
1-5	MOVER	QAD boundary number of top of propellant at beginning of engine operation
6-9	NZ	1, 2, 3, or 4; 2^{NZ} points will be used to get the volume of each tank slice
10-14	NSLICE	Number of tank slices used to simulate emptying
15-18	KNUCKL	The KNUCKLth Z-slice divides tank head from body
19-23	JHEAD	QAD boundary number of tank head
24-27	JTANK	QAD boundary number of tank body
28-36	BURN	Engine run time, seconds

QD2 Z-slice coordinate card FORMAT (8E9. 4)

List of Z-coordinates of fluid level in tank used to simulate tank emptying. Begin with smallest value of Z (coordinate of tank bottom generally). NSLICE values required. The top of the propellant Z(NSLICE + 1) is taken as the Z-coordinate of the QAD boundary MOVER. Z(KNUCKL) divides the tank head from the tank body.

QD RECVR Receiver card FORMAT (3E9. 4)

Card column	
1-9	R-coordinate of receiver
10-18	Z-coordinate of receiver
19-27	φ-coordinate of receiver

Is R coordinate ≥ 0?

No → Finished with QADD case. Return to read new master.

Yes → Make QADD calculation. (then return to QD RECVR)

(Note: Make sure that the QAD region specification (card G10) for the tank head includes the redundant specification for the MOVER boundary as indicated on p. 23.)

QADH Cards

Read only if MASTER = 3.

QH1 Read tank emptying card. FORMAT (4(I5, I4), E9. 4, I5)

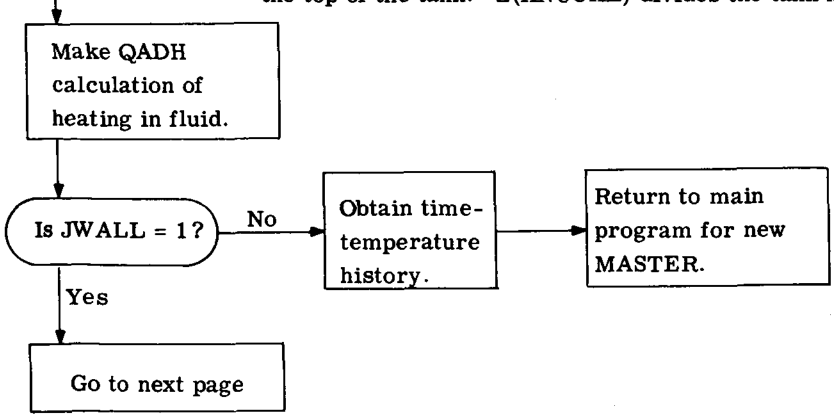
Card column

1-5	NPHI	= 0, 1, 2, 3, or 4. The number of Gaussian abscissas in the fluid in the φ-direction is Z^{NPHI}.
6-9	NR	= 1, 2, 3, or 4. The number of Gaussian abscissas in the fluid in the R-direction is 2^{NR}.
10-14	NZ	= 1, 2, 3, or 4. The number of Gaussian abscissas in the fluid in the Z-direction per slice is 2^{NZ}.
15-18	NSLICE	The number of tank slices used to simulate tank emptying
19-23	NSKIP	= 0. Print final values only (normal option).
		$\geq$1. Also print out integrals over the slice as soon as they are calculated.
		$\geq$2. Also print out integrals over φ and R as soon as they are calculated
		$\geq$3. Also print out local heating rates at all points.
24-27	KNUCKL	The KNUCKLth ZSLICE coordinate divides the tank head and body.
28-32	JHEAD	The QAD boundary number of the tank head
33-36	JTANK	The QAD boundary number of the tank body
37-45	BURN	The engine burn time, seconds
46-50	JWALL	= 1. Make wall heating calculation.
		≠ 1. Bypass wall heating calculation.

(Note: The total number of receivers in the propellant is NSLICE $*$ $2^{(NPHI+NR+NZ)}$.)

QH2 Read tank ZSLICE coordinates. FORMAT (8E9. 4)

A list of Z-coordinates of propellant level is used to simulate tank emptying. Begin with the smallest value of Z (coordinate of tank bottom). NSLICE + 1 values are required. The last coordinate is the top of the tank. Z(KNUCKL) divides the tank head from the tank body.



QW1 — Read wall heating control card — FORMAT (I5, I4, I5, 2I9, I4, E9.4)

Card column		
1-5	NPHI	= 0, 1, 2, 3, or 4. The number of Gaussian abscissas in the wall in the φ-direction is 2^{NPHI}.
6-9	NR	= 1, 2, 3, or 4. The number of Gaussian abscissas in the wall in the R-direction is 2^{NR}.
10-14	NZ	= 1, 2, 3, or 4. The number of Gaussian abscissas in the wall in the Z-direction is 2^{NZ}.
15-23	NSKIP	= 0. Print final values only (normal option). $\geq$1. Also print out integrals over the slice as soon as they are calculated. $\geq$2. Also print out integrals over R and φ as soon as they are calculated. $\geq$3. Also print out local heating rates at all points.
24-32	JWHED	The outer QAD boundary number of wall of tank head (inner boundary is assumed to be JHEAD)
33-36	JWTNK	The outer QAD boundary number of wall of tank body (inner boundary is assumed to be JTANK)
37-45	ZPRIME	Z-coordinate of bottom of tank wall

QW2 — Read $WCNV_i$, NRGY values required — FORMAT (8E9.4)

$$WCNV_i = \frac{cal/(cm^3 - sec)}{MeV/(cm^2 - sec)}$$

Wall heating conversion factors for the tank wall material for the i^{th} energy group of gammas.

↓

Make QADH calculation of heating in wall.

↓

Add heat from i^{th} wall slice to i^{th} fluid slice.

↓

Obtain time-temperature history. → Return to main program for new MASTER.

(Note: Sample problem II calculates wall heating. See p. 34 for details.)

EXAMPLES OF DATA INPUT

A complete set of data input for the calculation of propellant heating in tank I of figure 2 is presented in table I. Part of the input was specified in previous sections of this report. To complete the required data input, it is assumed that the total operating power is 3.3×10^{19} fissions per second (1000 MW) and the relative power distribution is constant in the R- and Z-directions. (The flat power distribution is conveniently given by specifying a cosine power distribution with coefficients ξ_1 and η_1 both equal zero.) The source is subdivided into volumes bounded by the surfaces R = 0, 15, 30, 40, 50 centimeters, Z = 0, 30, 60, 90, 105, 120, 130 centimeters, and φ = 0, 1.57, 3.14 radians. Thus, there are (4 × 6 × 2) 48 radiation source points defined for this case.

Thirteen gamma energy groups were selected for this sample problem; the mean gamma energy for each group is listed on cards G14 of table I; the gamma source strength (MeV/sec)/(fission/sec) corresponding to these energy groups is listed on cards G15.

Two-point Gauss quadrature has been selected for both R- and Z-integrations of heating in a tank slice. Because of symmetry, only one point is used in the φ-direction. Thus, there are (2 × 2 × 1) four receivers located in each tank slice (more are generally recommended in the R-direction). Eight tank slices are used; therefore, a total of (8 × 4) 32 receivers are spotted throughout the tank.

The total number of geometry rays traced by QAD is equal to the product of the number of source points and the number of receiver points. In this case, (48 × 32) 1536 such rays are drawn. Since the IBM 7094 II can handle 3500 to 5000 of these per minute, an execution time of less than 1/2 minute is expected.

A second sample problem is illustrated in figure 5. This calculation includes tank wall heating. Complete data input are presented in table II.

TABLE I. - FORMAT FOR CALCULATION OF PROPELLANT HEATING IN AXIAL TANK I OF FIGURE 2

TITLE: SAMPLE INPUT DATA | PROJECT NUMBER | ANALYST | SHEET 1 OF 2

STATEMENT NUMBER 1 2 3 4 5	CONT 6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66	67–72	IDENTIFICATION 73–80
3													MASTER-H
		HEATIN	G IN A	XIAL T	ANK I								G1
4		6	2 3	4	13	13 12		1	1 0				G2
3.3	0	+19	0		0	0		0					G3-SRC
		0.0	15.0	3	0.0	40.0	5	0.0					G4-R
		0.0	30.0	6	0.0	90.0	10	5.0	120.0	13	0.0		G5-Z
		0.0	1.57	3	.14								G6-PHI
+3		1	-1 13	+7	3	+2 2							G10REG1
+3		2	-2 1	+7	3	+3 4							G10REG2
+4		4	-1 13	+10	12	+3 4	-7	1					G10REG3
+3		4	-3 2	+10	12	+4 5							G10REG4
+3		3	-4 4	+11	6	+5 8							G10REG5
+5		4	-4 4	+10	12	+5 9	-11	5 -	12 7				G10REG6
+3		3	-4 4	+12	6	+5 10							G10REG7
+3		3	-5 5	+8	9	+6 11							G10REG8
+5		4	-5 6	+10	12	+6 11	-8	8	-9 10				G10REG9
+3		3	-5 7	+9	9	+6 11							G10REG10
-1		4	-6 8										G10REG11
-3		4 -	10 3	-1	13	+6 11							G10REG12
-1		4	+1 1										G10REG13

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TABLE I. - Concluded. FORMAT FOR CALCULATION OF PROPELLANT HEATING IN AXIAL TANK OF FIGURE 2

TITLE: SAMPLE INPUT DATA | PROJECT NUMBER | ANALYST | SHEET 2 OF 2

STATEMENT NUMBER (1-5)	CONT (6)	FORTRAN STATEMENT 7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	61-66	67-72	IDENTIFICATION (73-80)
1		6										0 0	G11B1
2		6										130.0	G11B2
3		6										160.0	G11B3
4		6										500.0	G11B4
5		6										750.0	G11B5
6		6										1600.0	G11B6
7		3						0.0	0.0			2500.0	G11B7
8		3						0.0	0.0			3.6+5	G11B8
9		3					125	0.0	0.0			3.6+5	G11B9
10		3						0.0	0.0			4.0+6	G11B10
11		2	1.0		1.0	-1.0		0.0	0.0	15	0.0	0.0	G11B11
12		2	1.0		1.0	-1.0	125	0.0	0.0	15	0.0	0.0	G11B12
5		1	6 40										G12ELMNT
		0.0	1.5		0.0								G13CMP1
	0	.11	0	5	.49								G13CMP2
	0	.07	0		0								G13CMP3
		0	0		0								G13CMP4
	0	.30	0.63	1	.10	1.55	1	.99	2.38	2	.75	3.25	G14
	3	.75	4.22	4	.70	5.25	6	.42					G14
1	.	247	3.236	2.	421	1.761	1.	282	1.049	0.	775	0.656	G15
0	.	507	0.326	0.	182	0.113	0.	120					G15
0		1	1 8	0	5	11 8	120	0.0	0				QH1
5	0	0.0	550.0	60	0.0	650.0	75	0.0	900.0	110	0.0	1300.0	QH2
16	0	0.0											QH2

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TABLE II. - FORMAT FOR CALCULATION OF CORE GAMMA HEATING IN TANK WITHOUT SHIELD

TITLE: SAMPLE INPUT DATA | PROJECT NUMBER | ANALYST | SHEET 1 OF 3

STATEMENT NUMBER 1-5	CONT 6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	61-66	67-72	IDENTIFICATION 73-80
3													MASTER
		SAMPLE	PROBL	EM II	CO	RE GAM	MA HE	ATING	NO SHI	ELD			G1
4		7	1 8	10	19	10 18	0	2	2 0				G2
1.65	0	+20											G3 SRC
		0.0	15.0	3	0.0	45.0	6	9.5					G4 R
	9	.84	30.16	50	.48	70.48	8	0.96	101.28	121	.60	141.91	G5 Z
		0.0	3.14										G6 THETA
		1.0	1.0		1.0	1.0		1.0					G7 S(R)
0	.	365	0.666	0.	876	0.994	0.	995	0.886	0.	636	0.343	G8 S(Z)
		1.0	1.0										G9 S(T)
3		1	-1 16	+12	5	+2 2							G10REG1
3		2	-2 1	+10	3	+3 7							G10REG2
4		3	-2 1	+11	4	+3 7	-10	2					G10REG3
4		4	-2 1	+12	5	+3 7	-11	3					G10REG4
4		5	-1 16	+13	6	+4 8	-12	4					G10REG5
4		10	-1 16	+14	15	+6 10	-13	5					G10REG6
3		6	-3 2	+12	5	+4 8							G10REG7
3		10	-4 7	+13	6	+5 9							G10REG8
3		10	-5 8	+13	6	+6 10							G10REG9
3		10	-6 9	+14	15	+18 17							G10REG10
4		9	-7 17	+15	18	+8 12	+9	14					G10REG11
-3		9	-8 11	+16	19	+9 14							G10REG12
-4		10 -	18 10	+14	15 -	17 18	+8	19					G10REG13
-1		10	-9 12										G10REG14
-3		10	-1 16	-14	6	+9 14							G10REG15

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TABLE II. - Continued. FORMAT FOR CALCULATION OF CORE GAMMA HEATING IN TANK WITHOUT SHIELD

TITLE: SAMPLE INPUT DATA | PROJECT NUMBER | ANALYST | SHEET 2 OF 3

STATEMENT NUMBER (1-5)	CONT (6)	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	61-66	67-72	IDENTIFICATION (73-80)
-1		10	+1 1										G1OREG16
3		5	-18 10	+17	13	+7 11							G1OREG17
4		5	-7 17	+17	13	+8 19	-15	11					G1OREG18
4		5	-8 18	+14	15	+9 14	-16	12					G1OREG19
1		6										0.0	G11B1
2		6										10.00	G11B2
3		6										160.00	G11B3
4		6										190.00	G11B4
5		6										200.00	G11B5
6		6										220.00	G11B6
7		6										531.00	G11B7
8		6										894.00	G11B8
9		6										3544.00	G11B9
10		3										4900.00	G11B10
11		3										6400.00	G11B11
12		3										9409.00	G11B12
13		3										10000.00	G11B13
14		3										254016.0	G11B14
15		2	1.0		1.0	-1.0		0	0		391.0	0	G11B15
16		3										253009.0	G11B16
17		2	1.0		1.0	-1.0		0	0		390.0	0	G11B17
18		6										530.0	G11B18
5		1	3 4	6	13	26 74	92						G12ELMNT

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TABLE II. - Concluded. FORMAT FOR CALCULATION OF CORE GAMMA HEATING IN TANK WITHOUT SHIELD

TITLE: SAMPLE INPUT DATA | PROJECT NUMBER: | ANALYST: | SHEET 3 OF 3

FORTRAN STATEMENT (columns 1–72) / IDENTIFICATION (columns 73–80)

```
        0        0        0    1.200        0   1.0000        0        0G13CMP1
        0        0        0    1.600        0   0.2000        0    0.150G13CMP2
        0        0        0    0.500     1.00        0        0        0G13CMP3
        0        0     1.85        0     0.10        0        0        0G13CMP4
        0        0        0        0   2.6990        0        0        0G13CMP5
        0        0        0        0   1.0000   0.5000        0        0G13CMP6
        0        0        0        0        0        0     19.3        0G13CMP7
   0.0930    0.635        0        0        0        0        0        0G13CMP8
   0.0700        0        0        0        0        0        0        0G13CMP9
        0        0        0        0        0        0        0        0G13CMP10
      0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5G14
      8.5      9.5                                                     G14
    7.545    5.565    3.447    1.135    0.849    0.271    0.155      0.0G15
      0.0      0.0                                                     G15
    0  1     1  20   0    7  15  16  1185.0     1                      QH1
    531.0    550.0    575.0    600.0    700.0    800.0    894.0   1000.0QH2
   1100.0   1200.0   1300.0   1400.0   1500.0   1600.0   1800.0   2000.0QH2
   2200.0   2400.0   2600.0   2800.0   3544.0                            QH2
    0  1     1       0       17  14   530.0                            QW1 WCON
 2.952-15 2.559-15 2.291-15 2.116-15 2.023-15 1.950-15 1.920-15 1.899-15QW2 WCNV
 1.889-15 1.878-15                                                     QW2 WCNV
```

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FORTRAN LISTING AND SAMPLE PROBLEM OUTPUT

The complete IBM 7094-II FORTRAN IV listing of the QADHD program is now presented along with the computer output of QADHD for the propellant heating calculation in tank I of figure 2 for which input data were previously described.

```
$IBFTC QADMST   DECK

      COMMON / DOSE/  XSECEB(20,2), ALF(2), DCON(2)
      COMMON /STDATA/
     1 NAME   (100)   , ENRG   (20)    , XSECO (20,100),XSECEA(20)    ,
     2 C     (4,6,9)  , EMIN33(8)      , NAMB(8)       , XSECNT(100)   ,DCONST
      COMMON /QADATA/
     1 NSET   (16)    , RSO    (21)    , ZSO     (21)  , PHISO (21)    ,
     2 NBNDZN(50)     , NCMPZN(50)     , LBD     (6,50) , NTRYZN(6,50) ,
     3 NEQBD (50)     , ABD    (50)    , BBD     (50)  , CBD    (50)   ,
     4 XOBD   (50)    , YOBD   (50)    , ZOBD    (50)  , DBD    (50)   ,
     5 HYDRAT(30)     , XSECN  (30)    , XSECG  (20,30), BILDO  (30)   ,
     6 BILD1  (30)    , BILD2  (30)    , BILD3   (30)  , GAMEN  (30)   ,
     7 CONV   (30)    , COMP   (20,40) , EBAR    (30)  , MATZ   (20)   ,
     8 FL     (21)    , FM     (21)    , FN   (21)     ,
     9 ASO    , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4   , EPSLN , FUDGE , NBLD
   10 FORMAT(I5,I4)
   11 FORMAT(8E9.4)
  101 READ(5,10) MASTER ,NERGY
      GO TO( 1,2,3), MASTER
    1 J=2
      IF(NERGY) 20,20,30
    2 J=2
      IF(NERGY) 20,20,30
    3 J=1
      IF(NERGY) 20,20,30
   20 DO 25 I=1,20
   25 XSECEA(I)=XSECEB(I,J)
      ALF1=ALF(J)
      DCONST=DCON(J)
      GO TO 6
   30 READ(5,11) (XSECEA(I), I=1,20)
      READ(5,11) DCONST, ALF1
    6 GO TO (7,8,9), MASTER
    7 CALL QAD4
      GO TO 101
    8 CALL QADD
      GO TO 101
    9 CALL QADH
      GO TO 101
      END
```

```
$IBFTC Q4QAD   DECK

      SUBROUTINE QAD4
      COMMON /QADATA/
     1 NSET  (16)    , RSO   (21)    , ZSO   (21)    , PHISO (21)    ,
     2 NBNDZN(50)    , NCMPZN(50)    , LBD   (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)    , ABD   (50)    , BBD   (50)    , CBD   (50)    ,
     4 XOBD  (50)    , YOBD  (50)    , ZOBD  (50)    , DBD   (50)    ,
     5 HYDRAT(30)    , XSECN (30)    , XSECG (20,30) , BILDO (30)    ,
     6 BILD1 (30)    , BILD2 (30)    , BILD3 (30)    , GAMEN (30)    ,
     7 CONV  (30)    , COMP  (20,40) , EBAR  (30)    , MATZ  (20)    ,
     8 FL    (21)    , FM    (21)    , FN  (21)      ,
     9 ASO   , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1  , ALF2  , ALF3  ,
     X ALF4  , EPSLN , FUDGE , NBLD
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON /QADMAN/
     1 SREG  (20)    , AGAM  (30)    , DGAM  (30)    , ID    (12)    ,
     2 UDGAM (30)    , UAGAM (30)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),             QADC0170
     1(NRGY,NSET(7)),(ISRC,NSET(11)),(NRCVR,NSET(9))                    QADC0180
    4 FORMAT(8E9.4)                                                     QADC0330
    5 FORMAT(119H0 RECEIVER      R(RCVR)      Z(RCVR)     PHI(RCVR)   MIN TQADC0340
     1OT G    MAX TOT G  NEUTR DOSE ER  GROUP    MIN G DOSE  MAX G DOSE) QADC0350
    6 FORMAT(1H0I6,5X1P6E12.4,I2,I5,5X2E12.4/(I91,5X2E12.4))            QADC0360
    7 FORMAT(7H0  RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,6H  PHI=E12.4,11H  SOQADC0370
     1URCE PT3I3 )                                                      QADC0380
   10 FORMAT(1H1,5X,12A6)                                               QADC0390
   11 FORMAT(7H0  RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,6H  PHI=E12.4,11H  SOQADC0400
     1URCE PT3I3,8H    TYPEI2,29H GEOMETRY ERROR AT THIS POINT)         QADC0410
   20 LIN1=55                                                           QADC0420
      II=0                                                              QADC0430
      NERR=0                                                            QADC0440
   21 CALL  INPUT(ID(1))                                                QADC0450
   23 IF(ISRC)25,25,24                                                  QADC0460
   24 CALL  SOURCE                                                      QADC0470
   25 READ  (5 ,4)RRC,ZRC,PHIRC
      IF(RRC)999,27,27
   27 II=II+1                                                           QADC0500
      XRC=RRC*COS(PHIRC)                                                QADC0510
      YRC=RRC*SIN(PHIRC)                                                QADC0520
      NSET(15)=0                                                        QADC0530
      IERR3 =0                                                          QADC0540
      ONEUT=0.0                                                         QADC0550
      DGAMT=0.0                                                         QADC0560
      UDGAMT=0.0                                                        QADC0570
      DO 30 J=1,NRGY                                                    QADC0580
      DGAM(J)=0.0                                                       QADC0590
   30 UDGAM(J)=0.0                                                      QADC0600
      DO 60 N=1,NSO                                                     QADC0610
      SINS=SIN(PHISO(N))                                                QADC0620
      COSS=COS(PHISO(N))                                                QADC0630
      DO 60 L=1,LSO                                                     QADC0640
```

```
      XSO=RSO(L)*COSS                                                   QADC0650
      YSO=RSO(L)*SINS                                                   QADC0660
      FLN=FL(L)*FN(N)                                                   QADC0670
      DO 60 M=1,MSO                                                     QADC0680
      NSET(15)=NSET(15)+1                                               QADC0690
      IF(NSET(15)-NSET(13))36,34,33                                     QADC0700
   33 IF(NSET(15)-NSET(14))35,35,36                                     QADC0710
   34 WRITE (6,10)(ID(I),I=1,12)
      LIN1=55                                                           QADC0730
   35 WRITE (6,7)II,RRC,ZRC,PHIRC,L,M,N
      CALL SLITE (1)                                                    QADC0750
   36 FLMN=FLN*FM(M)                                                    QADC0760
   39 CALL LENGTH(SREG(1),SSO,XSO,YSO,ZSO(M),XRC,YRC,ZRC,IERR1)         QADC0770
      IF(IERR1)40,40,73                                                 QADC0780
   40 CALL KERNEL(SREG(1),SSO,ANEUT,AGAM(1),UAGAM(1),IERR2)             QADC0790
      IERR3=MAXO(IERR3,IERR2)                                           QADC0800
      A=FLMN/SSO**2                                                     QADC0810
      DNEUT=DNEUT+A*ANEUT                                               QADC0820
      DO 45 J=1,NRGY                                                    QADC0830
      DGAM(J)=DGAM(J)+A*AGAM(J)                                         QADC0840
   45 UDGAM(J)=UDGAM(J)+A*UAGAM(J)                                      QADC0850
   60 CONTINUE                                                          QADC0860
      DNEUT=DNEUT/12.5663706                                            QADC0870
      DO 65 J=1,NRGY                                                    QADC0880
      A=GAMEN(J)*CONV(J)/12.5663706                                     QADC0890
      DGAM(J)=A*DGAM(J)                                                 QADC0900
      UDGAM(J)=A*UDGAM(J)                                               QADC0910
      UDGAMT=UDGAMT+UDGAM(J)                                            QADC0920
   65 DGAMT=DGAMT+DGAM(J)                                               QADC0930
   67 IF(55-LIN1)68,68,70                                               QADC0940
   68 WRITE (6,10)(ID(I),I=1,12)
      WRITE (6,5)
      LIN1=NRGY                                                         QADC0970
   70 WRITE (6,6)II,RRC,ZRC,PHIRC,UDGAMT,DGAMT,DNEUT,          IERR3,(J,UD
     1GAM(J),DGAM(J),J=1,NRGY)                                          QADC0990
      IF(NSET(9))  71,71,707
  707 PUNCH 708, RRC,ZRC,DNEUT
  708 FORMAT(2F8.2,1PE10.3)
      PUNCH 709, (DGAM(J),J=1,NRGY)
  709 FORMAT(1P8E9.2)
   71 LIN1=LIN1+NRGY+1                                                  QADC1000
      GO TO 25                                                          QADC1010
   73 WRITE (6,11)II,RRC,ZRC,PHIRC,L,M,N,IERR1
      NERR=NERR+1                                                       QADC1030
      LIN1=55                                                           QADC1040
      IF(2-NERR)74,74,25                                                QADC1050
   74 READ  (5 ,4)XX
      IF(XX)999,74,74
  999 RETURN
       END                                                              QADC1080
```

```
$IBFTC QDQAD   DECK

      SUBROUTINE QADD
      COMMON /QADATA/
     1 NSET   (16)     , RSO    (21)     , ZSO    (21)     , PHISO (21)     ,
     2 NBNDZN(50)      , NCMPZN(50)      , LBD    (6,50)   , NTRYZN(6,50)   ,
     3 NEQBD (50)      , ABD    (50)     , BBD    (50)     , CBD    (50)    ,
     4 XOBD   (50)     , YOBD   (50)     , ZOBD   (50)     , DBD    (50)    ,
     5 HYDRAT(30)      , XSECN  (30)     , XSECG  (20,30), BILDO  (30)     ,
     6 BILD1  (30)     , BILD2  (30)     , BILD3  (30)     , GAMEN  (30)    ,
     7 CONV   (30)     , COMP   (20,40), EBAR   (30)     , MATZ   (20)     ,
     8 FL     (21)     , FM     (21)     , FN   (21)       ,
     9 ASO    , XI1SO  , XI2SO  , ETA1SO, ETA2SO, ALF1    , ALF2    , ALF3    ,
     X ALF4   , EPSLN  , FUDGE  , NBLD
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON /QADHD/
     1 Z      (100)    , VZ     (16)     , WZ     (16)     , VR     (16)     ,
     2 WR     (16)     , VP     (16)     , WP     (16)     , VOL    (100)    ,
     3 DTIME (100)     , RANGE  (100)    , VV     (100)    ,
     4 CTIME (100)     , DEPTH  (100)    , DGDT   (100)    , DNDT   (100)    ,
     5 DAVE   (100)    , DNAVE  (100)    , DELG   (100)    , DELN   (100)    ,
     6 CUMG   (100)    , CUMN   (100)    , TOTAL  (100)    , DUMMY  (1600)
      COMMON /QADMAN/
     1 SREG   (20)     , AGAM   (30)     , DGAM   (30)     , ID     (12)     ,
     2 UDGAM  (30)     , UAGAM  (30)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),                QADC0170
     1(NRGY,NSET(7)),(ISRC,NSET(11)),(NRCVR,NSET(9))                       QADC0180
    2 FORMAT(14H0 FLOW RATE = 1PE12.4,9H   CM3/SEC/16H   TANK VOLUME =
     1E12.4,5H   CM3)
    3 FORMAT(20HL         QADD CONTROL,6I6,1PE12.4)
    4 FORMAT(8E9.4)
    5 FORMAT(1H I6,3X1PE12.4,36X,E12.4,12X,E12.4)
    6 FORMAT(1H I6,3X1P9E12.4)
    7 FORMAT(7H0   RCVRI3,4H   R=1PE12.4,4H   Z=E12.4,6H   PHI=E12.4,11H   SO
     1URCE PT3I3 )
    8 FORMAT(3(I5,I4),E9.4)
    9 FORMAT(27H0        RECEIVER R, Z, PHI  = 1P3E12.4/1HL62X,7HGAMMA--15X,
     X9HNEUTRON--/118H         I          DEPTH(I)        VOL(I)       DTIME(I)
     Y TIME(I)     DOSE RATE     CUM.DOSE     DOSE RATE     CUM.DOSE   TOTAL DO
     ZSE)
   10 FORMAT(1H1,5X,12A6)
   11 FORMAT(7H0   RCVRI3,4H   R=1PE12.4,4H   Z=E12.4,6H   PHI=E12.4,11H   SOQADC0400
     1URCE PT3I3,8H     TYPEI2,29H GEOMETRY ERROR AT THIS POINT)           QADC0410
      PI=3.141593
   20 II=0
      NERR=0
      CALL  INPUT(ID(1))
      IF(ISRC)25,25,24
   24 CALL  SOURCE
   25 READ(5,8)MOVER    ,NZ,NSLICE,        KNUCKL,JHEAD,JTANK,BURN
      WRITE(6,3) MOVER    ,NZ,NSLICE,       KNUCKL,JHEAD,JTANK,BURN
      NGAUSZ=2**NZ
```

```
      DO 252 I=1,NGAUSZ
      VZ(I)=V(NZ,I)
  252 WZ(I)=W(NZ,I)
      JJ=NSLICE+1
      READ (5,4)(Z(I),I=1,NSLICE)
      Z(JJ)=DBD(MOVER)
      IF(JTANK) 27,27,26
   26 IF(NEQBD(JTANK).EQ.3)  ABD(JTANK)=1.
   27 IF(JHEAD) 29,29,28
   28 IF(NEQBD(JHEAD).EQ.3)  ABD(JHEAD)=1.
C     CALCULATE VOLUME
   29 SUMV=0.
      DO 295 NSL=1,NSLICE
      SUMVZ=0.
      RANGE(NSL)= Z(NSL+1)-Z(NSL)
      JB=JHEAD
      IF(NSL.GE.KNUCKL) JB=JTANK
      DO 293 KZ=1,NGAUSZ
      ZZ  = RANGE(NSL)*VZ(KZ)+Z(NSL)
      RR=SQRT((DBD(JB)-CBD(JB)*(ZZ -ZOBD(JB))**2)/ABD(JB))
  293 SUMVZ=WZ(KZ)*PI*RR*RR+ SUMVZ
      VOL(NSL)= RANGE(NSL)*SUMVZ
  295 SUMV=SUMV+VOL(NSL)
      FLOW=SUMV/BURN
      WRITE(6,2) FLOW,SUMV
      FF=1./FLOW
      SUMT=0.
      DO 297 I=1,NSLICE
      IJ=JJ-I
      VV(I)=VOL(IJ)
      DTIME(I) = VV(I)*FF
      SUMT=SUMT+DTIME(I)
  297 CTIME(I)=SUMT
  298 READ (5,4) RRC,ZRC,PHIRC
      IF(RRC) 999,299,299
  299 XRC=RRC*COS(PHIRC)
      YRC=RRC*SIN(PHIRC)
      SUMG=0.
      SUMN=0.
      DO 99 NS=1,JJ
      IJ=NSLICE+2-NS
      DEPTH(NS)= Z(IJ)-Z(1)
      DBD(MOVER)=Z(IJ)
      II=II+1
      NSET(15)=0
      IERR3 =0
      DNEUT=0.0
      DGAMT=0.0
      UDGAMT=0.0
      DO 30 J=1,NRGY
      DGAM(J)=0.0
   30 UDGAM(J)=0.0
      DO 60 N=1,NSO                                                     QADC0610
      SINS=SIN(PHISO(N))                                                QADC0620
      COSS=COS(PHISO(N))                                                QADC0630
      DO 60 L=1,LSO                                                     QADC0640
```

```
      XSO=RSO(L)*COSS                                                   QADC0650
      YSO=RSO(L)*SINS                                                   QADC0660
      FLN=FL(L)*FN(N)                                                   QADC0670
      DO 60 M=1,MSO                                                     QADC0680
      NSET(15)=NSET(15)+1                                               QADC0690
      IF(NSET(15)-NSET(13))36,34,33                                     QADC0700
   33 IF(NSET(15)-NSET(14))35,35,36                                     QADC0710
   34 WRITE (6,10)(ID(I),I=1,12)
   35 WRITE (6,7)II,RRC,ZRC,PHIRC,L,M,N
      CALL SLITE (1)                                                    QADC0750
   36 FLMN=FLN*FM(M)                                                    QADC0760
      CALL LENGTH(SREG(1),SSO,XSO,YSO,ZSO(M),XRC,YRC,ZRC,IERR1)
      IF(IERR1)40,40,37
   37 WRITE (6,11)II,RRC,ZRC,PHIRC,L,M,N,IERR1
      NERR=NERR+1
      IF(2-NERR)298,40,40
   40 CALL KERNEL(SREG(1),SSO,ANEUT,AGAM(1),UAGAM(1),IERR2)             QADC0790
      IERR3=MAX0(IERR3,IERR2)                                           QADC0800
      A=FLMN/SSO**2                                                     QADC0810
      DNEUT=DNEUT+A*ANEUT                                               QADC0820
      DO 45 J=1,NRGY                                                    QADC0830
      DGAM(J)=DGAM(J)+A*AGAM(J)                                         QADC0840
   45 UDGAM(J)=UDGAM(J)+A*UAGAM(J)                                      QADC0850
   60 CONTINUE                                                          QADC0860
      DNEUT=DNEUT/12.5663706                                            QADC0870
      DO 65 J=1,NRGY                                                    QADC0880
      A=GAMEN(J)*CONV(J)/12.5663706                                     QADC0890
      DGAM(J)=A*DGAM(J)                                                 QADC0900
      UDGAM(J)=A*UDGAM(J)                                               QADC0910
      UDGAMT=UDGAMT+UDGAM(J)                                            QADC0920
   65 DGAMT=DGAMT+DGAM(J)                                               QADC0930
      DGDT(NS)=DGAMT
      DNDT(NS)=DNEUT
      IF(NS-1) 70,70,69
   69 DAVE(NS)=(DGTZ+DGDT(NS))*.5
      DNAVE(NS)=(DNTZ+DNDT(NS))*.5
      T= DTIME(NS-1)/3600.
      DELG(NS)=DAVE(NS)*T
      DELN(NS)=DNAVE(NS)*T
      SUMG=SUMG+DELG(NS)
      SUMN=SUMN+DELN(NS)
      CUMG(NS)=SUMG
      CUMN(NS)=SUMN
      TOTAL(NS)=SUMG+SUMN
   70 DGTZ=DGDT(NS)
   99 DNTZ=DNDT(NS)
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,2)  FLOW,SUMV
      WRITE(6,9) RRC,ZRC,PHIRC
      I=1
      WRITE(6,5) I,DEPTH(1),DGDT(1),DNDT(1)
      WRITE(6,6)(I,DEPTH(I),VV(I -1),DTIME(I-1),CTIME(I-1),DGDT(I),
     XCUMG(I)  ,DNDT(I),CUMN(I)   ,TOTAL(I)   ,I=2,JJ)
      GO TO 298
  999 RETURN
      END
```

```
$IBFTC QHQAD   DECK
      SUBROUTINE QADH
      COMMON /QADATA/
     1 NSET  (16)   , RSO   (21)    , ZSO   (21)   , PHISO (21)   ,
     2 NBNDZN(50)   , NCMPZN(50)    , LBD   (6,50) , NTRYZN(6,50) ,
     3 NEQBD (50)   , ABD   (50)    , BBD   (50)   , CBD   (50)   ,
     4 XOBD  (50)   , YOBD  (50)    , ZOBD  (50)   , DBD   (50)   ,
     5 HYDRAT(30)   , XSECN (30)    , XSECG (20,30), BILDO (30)   ,
     6 BILD1 (30)   , BILD2 (30)    , BILD3 (30)   , GAMEN (30)   ,
     7 CONV  (30)   , COMP  (20,40) , EBAR  (30)   , MATZ  (20)   ,
     8 FL    (21)   , FM    (21)    , FN   (21)    ,
     9 ASO   , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4  , EPSLN , FUDGE , NBLD
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON /QADHD/
     1 Z     (100)  , VZ    (16)    , WZ    (16)   , VR    (16)   ,
     2 WR    (16)   , VP    (16)    , WP    (16)   , VOL   (100)  ,
     3 DTIME (100)  , RANGE (100)   , VV    (100)  ,
     4 SRG   (16)   , SRN   (16)    , SPG   (16)   , SPN   (16)   ,
     5 SG    (100)  , SN    (100)   , ST    (100)  , QNDOT (100)  ,
     6 QGDOT (100)  , QTDOT (100)   , TGDOT (100)  , TNDOT (100)  ,
     7 TTDOT (100)  , DQG   (100)   , DQN   (100)  , DQT   (100)  ,
     8 DTG   (100)  , DTN   (100)   , DTT   (100)  , QG    (100)  ,
     9 QN    (100)  , QT    (100)   , TG    (100)  , TN    (100)  ,
     X TT    (100)  , T     (100)   , JTANK, JHEAD, KNUCKL, NSLICE
      COMMON /QADMAN/
     1 SREG  (20)   , AGAM  (30)    , DGAM  (30)   , ID    (12)   ,
     2 UDGAM (30)   , UAGAM (30)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),            QADC0170
     1(NRGY,NSET(7)),(ISRC,NSET(11)),(NRCVR,NSET(9))                   QADC0180
    2 FORMAT(14H0 FLOW RATE = 1PE12.4,9H  CM3/SEC/16H  TANK VOLUME =
     1E12.4,5H  CM3)
    3 FORMAT(20H1     HEATING CONTROL,8I6,1PE12.4,I5)
    4 FORMAT(8E9.4)
    5 FORMAT(1H0,68X,27HFLUID HEATING RATES CAL/SEC/7H      I,13X,76HZ(I
     1) Z(I+1)-Z(I)       VOL(I)     DTIME(I)        GAMMA         NEUT
     2  TOTAL)
    6 FORMAT(1H I6,5X1P7E12.4)
    7 FORMAT(7H0   RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,5H  PHI=E12.4,11H  SOQADC0370
     1URCE PT3I3 )                                                     QADC0380
    8 FORMAT(4(I5,I4),E9.4,I5)
    9 FORMAT(1P3E12.4)
   10 FORMAT(1H1,5X,12A6)                                               QADC0390
   11 FORMAT(7H0   RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,5H  PHI=E12.4,11H  SOQADC0400
     1URCE PT3I3,8H    TYPEI2,29H GEOMETRY ERROR AT THIS POINT)        QADC0410
   12 FORMAT(7HL  Z = /(1P10E12.4))
      PI=3.141593
   20 II=0
      NERR=0
      CALL  INPUT(ID(1))
      IF(ISRC)25,25,24
```

```
   24 CALL SOURCE
   25 READ(5,8) NPHI,NR,NZ,NSLICE,NSKIP,KNUCKL,JHEAD,JTANK,BURN,JWALL
      WRITE(6,3) NPHI,NR,NZ,NSLICE,NSKIP,KNUCKL,JHEAD,JTANK,BURN,JWALL
      NGAUSR=2**NR
      DO 251 I=1,NGAUSR
      VR(I)=V(NR,I)
  251 WR(I)=W(NR,I)
      NGAUSZ=2**NZ
      DO 252 I=1,NGAUSZ
      VZ(I)=V(NZ,I)
  252 WZ(I)=W(NZ,I)
      IF(NPHI) 253,253,254
  253 NPHI=0
      NGAUSP=1
      VP(1)=0.
      WP(1)=1.
      GO TO 256
  254 NGAUSP = 2**NPHI
      DO 255  I=1,NGAUSP
      VP(I) = V(NPHI,I)
  255 WP(I) = W(NPHI,I)
  256 JJ=NSLICE+1
      READ (5,4)(Z(I),I=1,JJ)
      WRITE(6,12)(Z(I),I=1,JJ)
      IF(JTANK+JHEAD) 999,999,259
  259 IF(JTANK) 27,27,26
   26 IF(NEQBD(JTANK).EQ.3)  ABD(JTANK)=1.
   27 IF(JHEAD) 29,29,28
   28 IF(NEQBD(JHEAD).EQ.3)  ABD(JHEAD)=1.
   29 SUMV=0.
      DO 99 NSL=1,NSLICE
      SUMZG=0.
      SUMZN=0.
      SUMVZ=0.
      RANGE(NSL)= Z(NSL+1)-Z(NSL)
      JB=JHEAD
      IF(NSL.GE.KNUCKL) JB=JTANK
      DO 85 KZ=1,NGAUSZ
      ZRC = RANGE(NSL)*VZ(KZ)+Z(NSL)
      RR=SQRT((DBD(JB)-CBD(JB)*(ZRC-ZOBD(JB))**2)/ABD(JB))
      SUMRG=0.
      SUMRN=0.
      DO 75 KR=1,NGAUSR
      RPRIME = RR*VR(KR)
      SUMPG = 0.
      SUMPN = 0.
      DO 70  KP = 1,NGAUSP
      PHRIME = PI*VP(KP)
      II=II+1
      XRC = RPRIME * COS(PHRIME) +XOBD(JB)
      YRC = RPRIME * SIN(PHRIME)
      RRC = SQRT(XRC*XRC+YRC*YRC)
      PHIRC = ATAN2 (YRC,XRC)
C     COMPUTE DOSES AT (RRC,ZRC,PHIRC) REGULAR QAD CALC. HERE TO 65
      NSET(15)=0                                                QADC0530
      IERR3 =0                                                  QADC0540
```

```
      DNEUT=0.0                                                         QADC0550
      DGAMT=0.0                                                         QADC0560
      UDGAMT=0.0                                                        QADC0570
      DO 30 J=1,NRGY                                                    QADC0580
      DGAM(J)=0.0                                                       QADC0590
   30 UDGAM(J)=0.0                                                      QADC0600
      DO 60 N=1,NSO                                                     QADC0610
      SINS=SIN(PHISO(N))                                                QADC0620
      COSS=COS(PHISO(N))                                                QADC0630
      DO 60 L=1,LSO                                                     QADC0640
      XSO=RSO(L)*COSS                                                   QADC0650
      YSO=RSO(L)*SINS                                                   QADC0660
      FLN=FL(L)*FN(N)                                                   QADC0670
      DO 60 M=1,MSO                                                     QADC0680
      NSET(15)=NSET(15)+1                                               QADC0690
      IF(NSET(15)-NSET(13))36,34,33                                     QADC0700
   33 IF(NSET(15)-NSET(14))35,35,36                                     QADC0710
   34 WRITE (6,10)(ID(I),I=1,12)
   35 WRITE (6,7)II,RRC,ZRC,PHIRC,L,M,N
      CALL SLITE (1)                                                    QADC0750
   36 FLMN=FLN*FM(M)                                                    QADC0760
      CALL LENGTH(SREG(1),SSO,XSO,YSO,ZSO(M),XRC,YRC,ZRC,IERR1)
      IF(IERR1)40,40,37
   37 WRITE (6,11)II,RRC,ZRC,PHIRC,L,M,N,IERR1
      NERR=NERR+1
      IF(2-NERR)20,40,40
   40 CALL KERNEL(SREG(1),SSO,ANEUT,AGAM(1),UAGAM(1),IERR2)             QADC0790
      IERR3=MAX0(IERR3,IERR2)                                           QADC0800
      A=FLMN/SSO**2                                                     QADC0810
      DNEUT=DNEUT+A*ANEUT                                               QADC0820
      DO 45 J=1,NRGY                                                    QADC0830
      DGAM(J)=DGAM(J)+A*AGAM(J)                                         QADC0840
   45 UDGAM(J)=UDGAM(J)+A*UAGAM(J)                                      QADC0850
   60 CONTINUE                                                          QADC0860
      DNEUT=DNEUT/12.5663706                                            QADC0870
      DO 65 J=1,NRGY                                                    QADC0880
      A=GAMEN(J)*CONV(J)/12.5663706                                     QADC0890
      DGAM(J)=A*DGAM(J)                                                 QADC0900
      UDGAM(J)=A*UDGAM(J)                                               QADC0910
      UDGAMT=UDGAMT+UDGAM(J)                                            QADC0920
   65 DGAMT=DGAMT+DGAM(J)                                               QADC0930
      IF(NSKIP.GE.3)WRITE(6,6)II,RRC,ZRC,PHIRC,UDGAMT,DGAMT,DNEUT
C     INTEGRATE OVER PHI
      SUMPG = SUMPG + WP(KP)*DGAMT
   70 SUMPN = SUMPN +WP(KP) * DNEUT
C     END PHI LOOP.  GET FINAL INTEGRALS OVER PHI
      SPG(KR) = 2.*PI*SUMPG
      SPN(KR) = 2.*PI*SUMPN
      IF(NSKIP.GE.2) WRITE(6,9) SPG(KR),SPN(KR)
C     INTEGRATE OVER R
      F = RPRIME*WR(KR)
      SUMRG = SUMRG + F*SPG(KR)
   75 SUMRN = SUMRN + F*SPN(KR)
C     END R LOOP.  GET FINAL VALUES OF INTEGRALS OVER R
      SRG(KZ)= SUMRG*RR
      SRN(KZ)= SUMRN*RR
```

```
      IF(NSKIP.GE.2) WRITE(6,9) SRG(KZ),SRN(KZ)
C     INTEGRATE OVER Z
      SUMVZ=WZ(KZ)*PI*RR*RR+ SUMVZ
      SUMZG  = WZ(KZ)*SRG(KZ)+SUMZG
   85 SUMZN  = WZ(KZ)*SRN(KZ)+SUMZN
C     END OF Z LOOP.  GET FINAL VALUES OF INTEGRALS OVER Z.
      SG(NSL)= RANGE(NSL)*SUMZG
      SN(NSL)= RANGE(NSL)*SUMZN
      ST(NSL)= SG(NSL)+SN(NSL)
      VOL(NSL)= RANGE(NSL)*SUMVZ
      SUMV=SUMV+VOL(NSL)
      IF(NSKIP.GE.1) WRITE(6,9) SG(NSL),SN(NSL),ST(NSL)
   99 CONTINUE
      FLOW=SUMV/BURN
      WRITE(6,2) FLOW,SUMV
      FF=1./FLOW
      DO 101 I=1,NSLICE
  101 DTIME(I)=VOL(I)*FF
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,5)
      WRITE(6,6)(I,Z(I),RANGE(I),VOL(I),DTIME(I),SG(I),SN(I),ST(I),I=1,
     XNSLICE)
      WRITE(6,6) JJ,Z(JJ)
      IF(JWALL.EQ.1)  CALL QADW
      CALL  FINAL(ID,NSLICE)
  999 RETURN
      END
```

```
$IBFTC QWQAD   DECK

      SUBROUTINE QADW
C     CALCULATE WALL HEATING
      DIMENSION WG(100), WN(100), WT(100), WOL(100), WCNV(30)
      COMMON /QADATA/
     1 NSET   (16)    , RSO    (21)     , ZSO    (21)     , PHISO (21)     ,
     2 NBNDZN(50)     , NCMPZN(50)      , LBD    (6,50)   , NTRYZN(6,50)   ,
     3 NEQBD (50)     , ABD    (50)     , BBD    (50)     , CBD    (50)    ,
     4 XOBD   (50)    , YOBD   (50)     , ZOBD   (50)     , DBD    (50)    ,
     5 HYDRAT(30)     , XSECN  (30)     , XSECG  (20,30), BILD0  (30)     ,
     6 BILD1 (30)     , BILD2  (30)     , BILD3  (30)     , GAMEN  (30)    ,
     7 CONV   (30)    , COMP   (20,40), FBAR   (30)     , MATZ   (20)     ,
     8 FL     (21)    , FM     (21)     , FN    (21)     ,
     9 ASO    , XI1SO  , XI2SO  , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4   , EPSLN  , FUDGE  , NBLD
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON /QADHD/
     1 Z      (100)   , VZ     (16)     , WZ     (16)     , VR     (16)    ,
     2 WR     (16)    , VP     (16)     , WP     (16)     , VOL    (100)   ,
     3 DTIME (100)    , RANGE  (100)    , VV     (100)    ,
     4 SRG    (16)    , SRN    (16)     , SPG    (16)     , SPN    (16)    ,
     5 SG     (100)   , SN     (100)    , ST     (100)    , QNDOT (100)    ,
     6 QGDOT (100)    , QTDOT  (100)    , TGDOT (100)     , TNDOT (100)    ,
     7 TTDOT (100)    , DQG    (100)    , DQN    (100)    , DQT    (100)   ,
     8 DTG    (100)   , DTN    (100)    , DTT    (100)    , QG     (100)   ,
     9 QN     (100)   , QT     (100)    , TG     (100)    , TN     (100)   ,
     X TT     (100)   , T      (100)    , JTANK, JHEAD, KNUCKL, NSLICE
      COMMON /QADMAN/
     1 SREG   (20)    , AGAM   (30)     , DGAM   (30)     , ID     (12)    ,
     2 UDGAM (30)     , UAGAM (30)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),
     1(NRGY,NSET(7)),(ISRC,NSET(11)),(NRCVR,NSET(9)), (INFJT,NSET(12))
    2 FORMAT(16H0 WALL VOLUME =   1PE12.4,5H   CM3)
    3 FORMAT(20H1   W-HEATING CONTROL,6I6,1PE12.4)
    4 FORMAT(8E9.4)
    5 FORMAT(1H0,68X,27H WALL HEATING RATES CAL/SEC/7H       I,13X,76HZ(I
     1) Z(I+1)-Z(I)         VOL(I)     DTIME(I)        GAMMA          NEUT
     2  TOTAL)
    6 FORMAT(1H I6,5X1P7E12.4)
    7 FORMAT(7H0   RCVRI3,4H   R=1PE12.4,4H   Z=E12.4,6H   PHI=E12.4,11H   SOQADC0370
     1URCE PT3I3 )                                                         QADC0380
    8 FORMAT(4(I5,I4),E9.4)
    9 FORMAT(1P3E12.4)
   10 FORMAT(1H1,5X,12A6)                                                  QADC0390
   11 FORMAT(7H0   RCVRI3,4H   R=1PE12.4,4H   Z=E12.4,5H   PHI=E12.4,11H   SOQADC0400
     1URCE PT3I3,8H     TYPEI2,29H GEOMETRY ERROR AT THIS POINT)          QADC0410
      PI=3.141593
      INEUT=0
   20 II=0
      NERR=0
      READ(5,8) NPHI,NR,NZ,NDUMMY,NSKIP,NDUM,JWHED,JWTNK,ZPRIME
```

```
      WRITE(6,3) NPHI,NR,NZ,NSKIP,   JWHED, JWTNK, ZPRIME
      READ(5,4)   (WCNV(I),I=1,NRGY)
      WRITE(6,12)(WCNV(I),I=1,NRGY)
   12 FORMAT(14HL   WALL CNV =   /(1P10E12.4))
      NGAUSR=2**NR
      DO 251 I=1,NGAUSR
      VR(I)=V(NR,I)
  251 WR(I)=W(NR,I)
      NGAUSZ=2**NZ
      DO 252 I=1,NGAUSZ
      VZ(I)=V(NZ,I)
  252 WZ(I)=W(NZ,I)
      IF(NPHI) 253,253,254
  253 NPHI=0
      NGAUSP=1
      VP(1)=0.
      WP(1)=1.
      GO TO 256
  254 NGAUSP = 2**NPHI
      DO 255  I=1,NGAUSP
      VP(I)  = V(NPHI,I)
  255 WP(I)  = W(NPHI,I)
  256 IF(JWHED+JWTNK) 999,999,259
  259 IF(JWTNK) 27,27,26
   26 IF(NEQBD(JWTNK).EQ.3)  ABD(JWTNK)=1.
   27 IF(JWHED) 29,29,28
   28 IF(NEQBD(JWHED).EQ.3)  ABD(JWHED)=1.
   29 SUMV=0.
      DO 99 NSL=1,NSLICE
      SUMZG=0.
      SUMZN=0.
      SUMVZ=0.
      RANGE(NSL)= Z(NSL+1)-Z(NSL)
      IF(NSL-KNUCKL)  295,296,296
  295 JB=JHEAD
      JC=JWHED
      GO TO 297
  296 JB=JTANK
      JC=JWTNK
  297 DO 85 KZ=1,NGAUSZ
      ZRC = RANGE(NSL)*VZ(KZ)+Z(NSL)
      RR=SQRT((DBD(JB)-CBD(JB)*(ZRC-ZOBD(JB))**2)/ABD(JB))
      RW=SQRT((DBD(JC)-CBD(JC)*(ZRC-ZOBD(JC))**2)/ABD(JC))
      SUMRG=0.
      SUMRN=0.
      DO 75 KR=1,NGAUSR
      RPRIME = RR +VR(KR)*(RW-RR)
      SUMPG = 0.
      SUMPN = 0.
      DO 70  KP = 1,NGAUSP
      PHRIME = PI*VP(KP)
      II=II+1
      XRC = RPRIME * COS(PHRIME) +XOBD(JB)
      YRC = RPRIME * SIN(PHRIME)
      RRC = SQRT(XRC*XRC+YRC*YRC)
      PHIRC = ATAN2 (YRC,XRC)
```

```
C     COMPUTE DOSES AT (RRC,ZRC,PHIRC) REGULAR QAD CALC. HERE TO 65
      NSET(15)=0                                                        QADC0530
      IERR3 =0                                                          QADC0540
      DNEUT=0.0                                                         QADC0550
      DGAMT=0.0                                                         QADC0560
      UDGAMT=0.0                                                        QADC0570
      DO 30 J=1,NRGY                                                    QADC0580
      DGAM(J)=0.0                                                       QADC0590
   30 UDGAM(J)=0.0                                                      QADC0600
      DO 60 N=1,NSO                                                     QADC0610
      SINS=SIN(PHISO(N))                                                QADC0620
      COSS=COS(PHISO(N))                                                QADC0630
      DO 60 L=1,LSO                                                     QADC0640
      XSO=RSO(L)*COSS                                                   QADC0650
      YSO=RSO(L)*SINS                                                   QADC0660
      FLN=FL(L)*FN(N)                                                   QADC0670
      DO 60 M=1,MSO                                                     QADC0680
      NSET(15)=NSET(15)+1                                               QADC0690
      IF(NSET(15)-NSET(13))36,34,33                                     QADC0700
   33 IF(NSET(15)-NSET(14))35,35,36                                     QADC0710
   34 WRITE (6,10)(ID(I),I=1,12)
   35 WRITE (6,7)II,RRC,ZRC,PHIRC,L,M,N
      CALL SLITE (1)                                                    QADC0750
   36 FLMN=FLN*FM(M)                                                    QADC0760
      CALL LENGTH(SREG(1),SSO,XSO,YSO,ZSO(M),XRC,YRC,ZRC,IERR1)
      IF(IERR1)40,40,37
   37 WRITE (6,11)II,RRC,ZRC,PHIRC,L,M,N,IERR1
      NERR=NERR+1
      IF(2-NERR)20,40,40
   40 CALL KERNEL(SREG(1),SSO,ANEUT,AGAM(1),UAGAM(1),IERR2)             QADC0790
      IERR3=MAXO(IERR3,IERR2)                                           QADC0800
      A=FLMN/SSO**2                                                     QADC0810
      DNEUT=DNEUT+A*ANEUT                                               QADC0820
      DO 45 J=1,NRGY                                                    QADC0830
      DGAM(J)=DGAM(J)+A*AGAM(J)                                         QADC0840
   45 UDGAM(J)=UDGAM(J)+A*UAGAM(J)                                      QADC0850
   60 CONTINUE                                                          QADC0860
      DNEUT=DNEUT/12.5663706                                            QADC0870
      DO 65 J=1,NRGY                                                    QADC0880
      A=GAMEN(J)*WCNV(J)/12.5663706
      DGAM(J)=A*DGAM(J)                                                 QADC0900
      UDGAM(J)=A*UDGAM(J)                                               QADC0910
      UDGAMT=UDGAMT+UDGAM(J)                                            QADC0920
   65 DGAMT=DGAMT+DGAM(J)                                               QADC0930
      IF(NSKIP.GE.3)WRITE(6,6)II,RRC,ZRC,PHIRC,UDGAMT,DGAMT,DNEUT
C     INTEGRATE OVER PHI
      SUMPG = SUMPG + WP(KP)*DGAMT
   70 SUMPN = SUMPN +WP(KP) * DNEUT
C     END PHI LOOP.  GET FINAL INTEGRALS OVER PHI
      SPG(KR) = 2.*PI*SUMPG
      SPN(KR) = 2.*PI*SUMPN
      IF(NSKIP.GE.2) WRITE(6,9) SPG(KR),SPN(KR)
C     INTEGRATE OVER R
      F = RPRIME*WR(KR)
      SUMRG = SUMRG + F*SPG(KR)
   75 SUMRN = SUMRN + F*SPN(KR)
```

```
C     END R LOOP.  GET FINAL VALUES OF INTEGRALS OVER R
      SRG(KZ)= SUMRG*(RW-RR)
      SRN(KZ)= SUMRN*(RW-RR)
      IF(NSKIP.GE.2) WRITE(6,9) SRG(KZ),SRN(KZ)
C     INTEGRATE OVER Z
      SUMVZ=WZ(KZ)*PI*(RW+RR)*(RW-RR) + SUMVZ
      SUMZG = WZ(KZ)*SRG(KZ)+SUMZG
   85 SUMZN = WZ(KZ)*SRN(KZ)+SUMZN
C     END OF Z LOOP.  GET FINAL VALUES OF INTEGRALS OVER Z.
      WG(NSL)= RANGE(NSL)*SUMZG
      WN(NSL)= RANGE(NSL)*SUMZN
      WT(NSL)= WG(NSL)+WN(NSL)
      WOL(NSL)= RANGE(NSL)*SUMVZ
      SUMV=SUMV+WOL(NSL)
      IF(NSKIP.GE.1) WRITE(6,9) WG(NSL),WN(NSL),WT(NSL)
   99 CONTINUE
      JJ=NSLICE+1
      WRITE(6,2) SUMV
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,5)
      WRITE(6,6)(I,Z(I),RANGE(I),WOL(I),DTIME(I),WG(I),WN(I),WT(I),I=1,
     XNSLICE)
      WRITE(6,6) JJ,Z(JJ)
      DO 101 I=1,NSLICE
      SG(I)=SG(I)+WG(I)
      SN(I)=SN(I)+WN(I)
  101 ST(I)=ST(I)+WT(I)
      IF(ZPRIME.NE. 0.0)  CALL QADB
     1 (NPHI,NR,NZ,NSKIP,JWHED,JWTNK,WCNV,ZPRIME)
  999 RETURN
      END
```

```
$IBFTC QBQAD   DECK
      SUBROUTINE QADB
     1 (NPHI,NR,NZ,NSKIP,JWHED,JWTNK,WCNV,ZPRIME)
C     CALCULATE HEATING FROM TANK BOTTOM
      DIMENSION WG(100), WN(100), WT(100), WOL(100), WCNV(30)
      COMMON /QADATA/
     1 NSET  (16)    , RSO   (21)    , ZSO   (21)    , PHISO (21)    ,
     2 NBNDZN(50)    , NCMPZN(50)    , LBD   (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)    , ABD   (50)    , BBD   (50)    , CBD   (50)    ,
     4 XOBD  (50)    , YOBD  (50)    , ZOBD  (50)    , DBD   (50)    ,
     5 HYDRAT(30)    , XSECN (30)    , XSECG (20,30), BILDO (30)    ,
     6 BILD1 (30)    , BILD2 (30)    , BILD3 (30)    , GAMEN (30)    ,
     7 CONV  (30)    , COMP  (20,40), EBAR  (30)    , MATZ  (20)    ,
     8 FL    (21)    , FM    (21)    , FN  (21)      ,
     9 ASO   , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4  , EPSLN , FUDGE , NBLD
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON /QADHD/
     1 Z     (100)   , VZ    (16)    , WZ    (16)    , VR    (16)    ,
     2 WR    (16)    , VP    (16)    , WP    (16)    , VOL   (100)   ,
     3 DTIME (100)   , RANGE (100)   , VV    (100)   ,
     4 SRG   (16)    , SRN   (16)    , SPG   (16)    , SPN   (16)    ,
     5 SG    (100)   , SN    (100)   , ST    (100)   , QNDOT (100)   ,
     6 QGDOT (100)   , QTDOT (100)   , TGDOT (100)   , TNDOT (100)   ,
     7 TTDOT (100)   , DQG   (100)   , DQN   (100)   , DQT   (100)   ,
     8 DTG   (100)   , DTN   (100)   , DTT   (100)   , QG    (100)   ,
     9 QN    (100)   , QT    (100)   , TG    (100)   , TN    (100)   ,
     X TT    (100)   , T     (100)   , JTANK, JHEAD, KNUCKL, NSLICE
      COMMON /QADMAN/
     1 SREG  (20)    , AGAM  (30)    , DGAM  (30)    , ID    (12)    ,
     2 UDGAM (30)    , UAGAM (30)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),             QADC0170
     1(NRGY,NSET(7)),(ISRC,NSET(11)),(NRCVR,NSET(9))                    QADC0180
    2 FORMAT(16HL BOTT VOLUME =  1PE12.4,5H  CM3)
    5 FORMAT(1H0,68X,27HBOTTM HEATING RATES CAL/SEC/7H       I,13X,76HZ(I
     1) Z(I+1)-Z(I)        VOL(I)      DTIME(I)         GAMMA         NEUT
     2  TOTAL)
    6 FORMAT(1H I6,5X1P7E12.4)
    7 FORMAT(7H0  RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,6H  PHI=E12.4,11H  SOQADC0370
     1URCE PT3I3 )                                                      QADC0380
    9 FORMAT(1P3E12.4)
   10 FORMAT(1HL,5X,12A6)
   11 FORMAT(7H0  RCVRI3,4H  R=1PE12.4,4H  Z=E12.4,6H  PHI=E12.4,11H  SOQADC0400
     1URCE PT3I3,8H    TYPEI2,29H GEOMETRY ERROR AT THIS POINT)         QADC0410
      PI=3.141593
   20 II=0
      NERR=0
      NGAUSR=2**NR
      DO 251 I=1,NGAUSR
      VR(I)=V(NR,I)
  251 WR(I)=W(NR,I)
```

```
      NGAUSZ=2**NZ
      DO 252 I=1,NGAUSZ
      VZ(I)=V(NZ,I)
  252 WZ(I)=W(NZ,I)
      IF(NPHI) 253,253,254
  253 NPHI=0
      NGAUSP=1
      VP(1)=0.
      WP(1)=1.
      GO TO 29
  254 NGAUSP = 2**NPHI
      DO 255  I=1,NGAUSP
      VP(I)  = V(NPHI,I)
  255 WP(I)  = W(NPHI,I)
   29 SUMV=0.
      NSL=1
      SUMZG=0.
      SUMZN=0.
      SUMVZ=0.
      RANGE(NSL)= Z(1)-ZPRIME
      IF(NSL-KNUCKL)  295,296,296
  295 JC=JWHED
      GO TO 297
  296 JC=JWTNK
  297 DO 85 KZ=1,NGAUSZ
      ZRC = RANGE(NSL)*VZ(KZ)+ZPRIME
      RW=SQRT((DBD(JC)-CBD(JC)*(ZRC-ZOBD(JC))**2)/ABD(JC))
      SUMRG=0.
      SUMRN=0.
      DO 75 KR=1,NGAUSR
      RPRIME =  RW*VR(KR)
      SUMPG = 0.
      SUMPN = 0.
      DO 70  KP = 1,NGAUSP
      PHRIME = PI*VP(KP)
      II=II+1
      XRC = RPRIME * COS(PHRIME) +XOBD(JB)
      YRC = RPRIME * SIN(PHRIME)
      RRC = SQRT(XRC*XRC+YRC*YRC)
      PHIRC = ATAN2 (YRC,XRC)
C     COMPUTE DOSES AT (RRC,ZRC,PHIRC) REGULAR QAD CALC. HERE TO 65
      NSET(15)=0                                                        QADC0530
      IERR3 =0                                                          QADC0540
      DNEUT=0.0                                                         QADC0550
      DGAMT=0.0                                                         QADC0560
      UDGAMT=0.0                                                        QADC0570
      DO 30 J=1,NRGY                                                    QADC0580
      DGAM(J)=0.0                                                       QADC0590
   30 UDGAM(J)=0.0                                                      QADC0600
      DO 60 N=1,NSO                                                     QADC0610
      SINS=SIN(PHISO(N))                                                QADC0620
      COSS=COS(PHISO(N))                                                QADC0630
      DO 60 L=1,LSO                                                     QADC0640
      XSO=RSO(L)*COSS                                                   QADC0650
      YSO=RSO(L)*SINS                                                   QADC0660
      FLN=FL(L)*FN(N)                                                   QADC0670
```

```
      DO 60 M=1,MSO                                                     QADC0680
      NSET(15)=NSET(15)+1                                               QADC0690
      IF(NSET(15)-NSET(13))36,34,33                                     QADC0700
   33 IF(NSET(15)-NSET(14))35,35,36                                     QADC0710
   34 WRITE (6,10)(ID(I),I=1,12)
   35 WRITE (6,7)II,RRC,ZRC,PHIRC,L,M,N
      CALL SLITE (1)                                                    QADC0750
   36 FLMN=FLN*FM(M)                                                    QADC0760
      CALL LENGTH(SREG(1),SSO,XSO,YSO,ZSO(M),XRC,YRC,ZRC,IERR1)
      IF(IERR1)40,40,37
   37 WRITE (6,11)II,RRC,ZRC,PHIRC,L,M,N,IERR1
      NERR=NERR+1
      IF(2-NERR)20,40,40
   40 CALL KERNEL(SREG(1),SSO,ANEUT,AGAM(1),UAGAM(1),IERR2)             QADC0790
      IERR3=MAX0(IERR3,IERR2)                                           QADC0800
      A=FLMN/SSO**2                                                     QADC0810
      DNEUT=DNEUT+A*ANEUT                                               QADC0820
      DO 45 J=1,NRGY                                                    QADC0830
      DGAM(J)=DGAM(J)+A*AGAM(J)                                         QADC0840
   45 UDGAM(J)=UDGAM(J)+A*UAGAM(J)                                      QADC0850
   60 CONTINUE                                                          QADC0860
      DNEUT=DNEUT/12.5663706                                            QADC0870
      DO 65 J=1,NRGY                                                    QADC0880
      A=GAMEN(J)*WCNV(J)/12.5663706
      DGAM(J)=A*DGAM(J)                                                 QADC0900
      UDGAM(J)=A*UDGAM(J)                                               QADC0910
      UDGAMT=UDGAMT+UDGAM(J)                                            QADC0920
   65 DGAMT=DGAMT+DGAM(J)                                               QADC0930
      IF(NSKIP.GE.3)WRITE(6,6)II,RRC,ZRC,PHIRC,UDGAMT,DGAMT,DNEUT
C     INTEGRATE OVER PHI
      SUMPG = SUMPG + WP(KP)*DGAMT
   70 SUMPN = SUMPN +WP(KP) * DNEUT
C     END PHI LOOP.  GET FINAL INTEGRALS OVER PHI
      SPG(KR) = 2.*PI*SUMPG
      SPN(KR) = 2.*PI*SUMPN
      IF(NSKIP.GE.2) WRITE(6,9) SPG(KR),SPN(KR)
C     INTEGRATE OVER R
      F = RPRIME*WR(KR)
      SUMRG = SUMRG + F*SPG(KR)
   75 SUMRN = SUMRN + F*SPN(KR)
C     END R LOOP.  GET FINAL VALUES OF INTEGRALS OVER R
      SRG(KZ)= SUMRG*RW
      SRN(KZ)= SUMRN*RW
      IF(NSKIP.GE.2) WRITE(6,9) SRG(KZ),SRN(KZ)
C     INTEGRATE OVER Z
      SUMVZ=WZ(KZ)*PI*RW*RW+SUMVZ
      SUMZG = WZ(KZ)*SRG(KZ)+SUMZG
   85 SUMZN = WZ(KZ)*SRN(KZ)+SUMZN
C     END OF Z LOOP.  GET FINAL VALUES OF INTEGRALS OVER Z.
      WG(NSL)= RANGE(NSL)*SUMZG
      WN(NSL)= RANGE(NSL)*SUMZN
      WT(NSL)= WG(NSL)+WN(NSL)
      WOL(NSL)= RANGE(NSL)*SUMVZ
      SUMV=SUMV+WOL(NSL)
      IF(NSKIP.GE.1) WRITE(6,9) WG(NSL),WN(NSL),WT(NSL)
   99 CONTINUE
```

```
      I=1
      WRITE(6,2) SUMV
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,5)
      WRITE(6,6) I,Z(I),RANGE(I),WOL(I),DTIME(I),WG(I),WN(I),WT(I)
      SG(1)=SG(1)+WG(1)
      SN(1)=SN(1)+WN(1)
      ST(1)=ST(1)+WT(1)
  999 RETURN
      END
```

```
$IBFTC INQAD   DECK

      SUBROUTINE INPUT(ID)
      COMMON /QADATA/
     1 NSET  (16)    , RSO   (21)    , ZSO   (21)    , PHISO (21)    ,
     2 NBNDZN(50)    , NCMPZN(50)    , LBD   (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)    , ABD   (50)    , BBD   (50)    , CBD   (50)    ,
     4 XOBD  (50)    , YOBD  (50)    , ZOBD  (50)    , DBD   (50)    ,
     5 HYDRAT(30)    , XSECN (30)    , XSECG (20,30) , BILDO (30)    ,
     6 BILD1 (30)    , BILD2 (30)    , BILD3 (30)    , GAMEN (30)    ,
     7 CONV  (30)    , COMP  (20,40) , EBAR  (30)    , MATZ  (20)    ,
     8 FL    (21)    , FM    (21)    , FN   (21)     ,
     9 ASO   , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1  , ALF2  , ALF3  ,
     X ALF4  , EPSLN , FUDGE , NBLD
      COMMON /STDATA/
     1 NAME  (100)   , ENRG  (20)    , XSECO (20,100),XSECEA(20)    ,
     2 C    (4,6,9)  , EMIN3B(8)     , NAMB(8)       , XSECNT(100)  ,DCONST
      DIMENSION ID(12), NAM(20)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),
     1(MAT,NSET(4)),(NCOMP,NSET(5)),(NREG,NSET(6)),(NRGY,NSET(7)),
     2(NBOUND,NSET(8)),(ISRC,NSET(11)),(INEUT,NSET(12))
    4 FORMAT(33H1      NO SOURCE.   RUN TERMINATED.)
    5 FORMAT(12A6)
    6 FORMAT(8(I5,I4))
    7 FORMAT(8E9.4)
    8 FORMAT(I5,I4,7E9.4)
    9 FORMAT(6H1      12A6/13H0      CONTROL16I6)
   11 FORMAT(18H0 ZONE  BNDS  COMP6(12H   BND     PK)//)
   12 FORMAT(15I6)
   13 FORMAT(27H0  BND    EQ  PARAMETERS...//)
   14 FORMAT(2I6,1P7E12.4)
   15 FORMAT(93H0      GRP          EPS/E       DELTA/K       A1/B0        A2/B
    11          A3/B2       A4/B3          EBAR//)
  151 FORMAT(5H1QADX, 10X, A6, 16H BUILDUP IS USED)
   16 FORMAT(I7,5X1P9E12.4)
   17 FORMAT(10HL COMP/GRP9(I9,3X))
   18 FORMAT(1H0,11X,9(5X,I3,2X,A2))
  100 FORMAT(12H0      SOURCE1P8E12.4)
  101 FORMAT(12H0           R1P8E12.4/(12X8E12.4))
  102 FORMAT(12H0           Z1P8E12.4/(12X8E12.4))
  103 FORMAT(12H0         PHI1P8E12.4/(12X8E12.4))
  104 FORMAT(12H0        F(L)1P8E12.4/(12X8E12.4))
  105 FORMAT(12H0        F(M)1P8E12.4/(12X8E12.4))
  106 FORMAT(12H0        F(N)1P8E12.4/(12X8E12.4))
      ZERO=0.0
      MONE=-1
      READ  (5 ,5)(ID(I),I=1,12)
      READ  (5 ,6)(NSET(I),I=1,14)
      WRITE (6,9)(ID(I),I=1,12),(NSET(I),I=1,14)
      IF(ISRC)19,19,20
   19 IF(ASO)191,191,30
  191 WRITE (6,9)(ID(I),I=1,12),(NSET(I),I=1,14)
```

```
      WRITE (6,4)
      CALL EXIT
   20 LU=LSO+1
      MU=MSO+1
      NU=NSO+1
      READ  (5 ,7)ASO,XI1SO,XI2SO,ETA1SO,ETA2SO
      WRITE (6,100)ASO,XI1SO,XI2SO,ETA1SO,ETA2SO
      READ  (5 ,7)(RSO(L),L=1,LU)
      READ  (5 ,7)(ZSO(M),M=1,MU)
      READ  (5 ,7)(PHISO(N),N=1,NU)
      WRITE (6,101)(RSO(L),L=1,LU)
      WRITE (6,102)(ZSO(M),M=1,MU)
      WRITE (6,103)(PHISO(N),N=1,NU)
      GO TO(30,22),ISRC
   22 READ  (5 ,7)(FL(L),L=1,LU)
      READ  (5 ,7)(FM(M),M=1,MU)
      READ  (5 ,7)(FN(N),N=1,NU)
      WRITE (6,104)(FL(L),L=1,LU)
      WRITE (6,105)(FM(M),M=1,MU)
      WRITE (6,106)(FN(N),N=1,NU)
   30 WRITE (6,11)
      DO 32 J=1,NREG
      READ  (5 ,6)IU,NCMPZN(J),(LBD(I,J),NTRYZN(I,J),I=1,IU)
      NBNDZN(J)=IU
   32 WRITE (6,12)J,IU,NCMPZN(J),(LBD(I,J),NTRYZN(I,J),I=1,IU)
      READ  (5 ,8)(K, NEQBD(K),ABD(K),BBD(K),CBD(K),XOBD(K),    YOBD(K),
     1ZOBD(K),DBD(K) ,I=1,NBOUND)
      WRITE (6,13)
      WRITE (6,14)(I,NEQBD(I),ABD(I),BBD(I),CBD(I),XOBD(I),  YOBD(I),ZOB
     1D(I),DBD(I),I=1,NBOUND)
      READ (5,6) NBLD,(MATZ(I),I=1,MAT)
      DO 45 J=1,NCOMP
   45 READ  (5 ,7)(COMP(I,J),I=1,MAT)
      DO 41 I=1,MAT
      L=MATZ(I)
      NAM(I)=NAME(L)
      HYDRAT(I)= 0.0
      IF(L.EQ.1) HYDRAT(I)= 9.0
   41 XSECN(I)=XSECNT(L)
      READ (5,7) (EBAR(I),I=1,NRGY)
      READ (5,7)(GAMEN(I),I=1,NRGY)
      ALF2=.29
      ALF3=.83
      ALF4=.58
      EPSLN=1.E-6
      FUDGE=1.E-3
      CALL XSECQD
      WRITE (6,151)  NAM3(NBLD)
      WRITE (6,16)ZERO,EPSLN,FUDGE,ALF1,ALF2,ALF3,ALF4
      WRITE (6,15)
      DO 65 I=1,NRGY
   65 WRITE (6,16)I,GAMEN(I),CONV(I),BILD0(I),BILD1(I),BILD2(I),BILD3(I)
     1 ,EBAR(I)
      DO 70 K=1,MAT,9
      IU=MIN0(K+8,MAT)
      WRITE (6,17)(I,I=K,IU)
```

```
      DO 69 J=1,NCOMP
   69 WRITE (6,16)J,(COMP(I,J),I=K,IU)
      WRITE (6,18)   (MATZ(I),NAM(I),I=K,IU)
      WRITE (6,16)MONE,(HYDRAT(I),I=K,IU)
      WRITE (6,16)ZERO,(XSECN(I),I=K,IU)
      DO 70 J=1,NRGY
   70 WRITE (6,16)J,(XSECG(I,J),I=K,IU)
      CALL WEIGHT
      RETURN
      END
```

```
$IBFTC WTQAD   DECK
      SUBROUTINE WEIGHT
      COMMON /QADATA/
     1 NSET   (16)     , RSO    (21)     , ZSO    (21)     , PHISO (21)    ,
     2 NBNDZN(50)      , NCMPZN(50)      , LBD    (6,50)   , NTRYZN(6,50)  ,
     3 NEQBD (50)      , ABD    (50)     , BBD    (50)     , CBD    (50)   ,
     4 XOBD   (50)     , YOBD   (50)     , ZOBD   (50)     , DBD    (50)   ,
     5 HYDRAT(30)      , XSECN  (30)     , XSECG  (20,30)  , BILDO  (30)   ,
     6 BILD1  (30)     , BILD2  (30)     , BILD3  (30)     , GAMEN  (30)   ,
     7 CONV   (30)     , COMP   (20,40)  , EBAR   (30)     , MATZ   (20)
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),
     1(MAT,NSET(4)),(NCOMP,NSET(5)),(NREG,NSET(6)),(NRGY,NSET(7)),
     2(NBOUND,NSET(8)),(ISRC,NSET(11)),(INEUT,NSET(12))
      DIMENSION RSQ(6), X(6), Y(6), Z(6), NQB(6), CFLAG(6), QFLAG(6),
     1 XFLAG(6), YFLAG(6), ZFLAG(6), V(16), W(16)
      DATA(V(I)   ,I=1,16)/0.529953E-2,0.277125E-1,0.671844E-1,0.122298,
     X0.191062,.270992,0.359198,0.452494,0.547506,0.640802,0.729008,
     Y0.808938,.877702,0.932816,0.972288,0.9947/
      DATA(W(I)   ,I=1,16)/0.0135762,0.0311268,0.0475793,0.0623145,
     X0.0747980,0.0845783,0.0913017,2*0.0947253,0.0913017,0.0845783,
     Y0.0747980,0.0623145,0.0475793,0.0311268,0.0135762/
      DATA PI/3.1415927/
  500 FORMAT(28H1   J            VOL        WEIGHT)
  501 FORMAT(I4,1P2E12.4)
  502 FORMAT(4H0SUM1P2E12.4)
      WRITE(6,500)
      VTOTAL=0.0
      WTOTAL=0.0
      DO 99 J=1,NREG
      IF(NBNDZN(J)) 99,99,10
   10 IU= NBNDZN(J)
      VOL=0.0
      NX=0
      NY=0
      NZ=0
      NC=0
      NQ=0
      DO 20  I=1,IU
      KK=LBD(I,J)
      K=IABS(KK)
      FLAG=KK/K
      NEQ=NEQBD(K)
      GO TO(99,12,13,14,15,16),NEQ
   12 NQ=NQ+1
      NQB(NQ)=K
      QFLAG(NQ)=FLAG
      GO TO 20
   13 NC=NC+1
      RSQ(NC)=DBD(K)
      CFLAG(NC)=FLAG
      GO TO 20
```

```
   14 NX=NX+1
      X(NX)=DBD(K)
      XFLAG(NX)=FLAG
      GO TO 20
   15 NY=NY+1
      Y(NY)=DBD(K)
      YFLAG(NY)=FLAG
      GO TO 20
   16 NZ=NZ+1
      Z(NZ)=DBD(K)
      ZFLAG(NZ)=FLAG
   20 CONTINUE
C     CALCULATE VOLUMES
      IF(NZ-2) 99,26,22
   22 ZMAX=+1.0E+8
      ZMIN=-ZMAX
      DO 25 I=1,NZ
      IF(ZFLAG(I))23,99,24
   23 ZMIN=AMAX1(ZMIN,Z(I))
      GO TO 25
   24 ZMAX=AMIN1(ZMAX,Z(I))
   25 CONTINUE
      DZ=ZMAX-ZMIN
      GO TO 261
   26 DZ = ZFLAG(1)*Z(1) + ZFLAG(2)*Z(2)
  261 IF( (NX.NE.2) .OR. (NY.NE.2) ) GO TO 27
      DX = XFLAG(1)*X(1) + XFLAG(2)*X(2)
      DY = YFLAG(1)*Y(1) + YFLAG(2)*Y(2)
C     RECTANGULAR PARALLELPIPED
      VOL=DX*DY*DZ
   27 IF(NC) 99,32,28
   28 DO 30 I=1,NC
C     CIRCULAR CYLINDER
      VV=CFLAG(I)*PI*RSQ(I)*DZ
   30 VOL=VOL+VV
   32 IF(NQ)99,75,35
   35 NQQ=NQ
      DO 50 L=1,NQQ
      NQ=NQB(L)
      VV=0.0
      DO 45 I=1,16
C     CALCULATE VOLUME OF FULLY ROTATED QUADRATIC SURFACE (TYPE 2),
C     BOUNDED BY Z(1) AND Z(2), BY 16 POINT GAUSS QUADRATURE.
      ZZ=Z(1)+V(I)*(Z(2)-Z(1))
      RR=(DBD(NQ)-CBD(NQ)*(ZZ-ZOBD(NQ))**2)/ABD(NQ)
C     CROSS-SECTION IS ASSUMED CIRCULAR IN Z PLANE
   45 VV =VV +W(I)*PI*RR
   50 VOL=VOL+ QFLAG(L)*VV*DZ
   75 WT=0.0
C     CALCULATE WEIGHT
      K=NCMPZN(J)
      DO 80 I=1,MAT
   80 WT=WT+VOL*COMP(I,K)
      WRITE(6,501) J,VOL,WT
      VTOTAL=VTOTAL+VOL
      WTOTAL=WTOTAL+WT
   99 CONTINUE
      WRITE(6,502) VTOTAL,WTOTAL
      RETURN
      END
```

```
$IBFTC XSQAD    DECK
      SUBROUTINE XSECQD
      COMMON /QADATA/
     1 NSET   (16)    , RSO    (21)    , ZSO    (21)    , PHISO (21)    ,
     2 NBNDZN(50)     , NCMPZN(50)     , LBD    (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)     , ABD    (50)    , BBD    (50)    , CBD    (50)   ,
     4 XOBD   (50)    , YOBD   (50)    , ZOBD   (50)    , DBD    (50)   ,
     5 HYDRAT(30)     , XSECN  (30)    , XSECG  (20,30), BILDO  (30)    ,
     6 BILD1  (30)    , BILD2  (30)    , BILD3  (30)    , GAMEN  (30)   ,
     7 CONV   (30)    , COMP   (20,40), EBAR   (30)    , MATZ   (20)    ,
     8 FL     (21)    , FM     (21)    , FN   (21)     ,
     9 ASO    , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4   , EPSLN , FUDGE , NBLD
      COMMON /STDATA/
     1 NAME   (100)   , ENRG   (20)    , XSECO (20,100),XSECEA(20)    ,
     2 C    (4,6,9)   , EMINBB(8)      , NAMB(8)        , XSECNT(100)   ,DCONST
      DIMENSION BILD(30,4), XSEC(19,30),SLOPE(19,30),SLOPEA(19)
      EQUIVALENCE (NSET(7),NRGY),(NSET(4),MAT)
C     CALCULATE QAD BUILDUP COEFFICIENTS.
C     NBLD=1, 2, 3, 4, = H2O, AL, FE, OR PB DOSE BUILDUP
C     NBLD=5, 6, 7, 8, = H2O, AL, FE, OR PB ENERGY ABSORPTION BUILDUP
      DO 12 I=1,NRGY
      E= EBAR(I)
      IF(NBLD.GE.8)  GO TO 5
      LIM=5
      IF(NBLD.EQ.4) LIM=6
      IF(E.LT.EMINBB(NBLD)) E=EMINBB(NBLD)
      IF(NBLD.NE.4) E=1.0/E
      NB=NBLD
      GO TO 9
    5 IF(E-4.0) 6,6,7
    6 LIM=4
      IF(E.LT. 0.5) E=0.5
      E=1.0/E
      NB=8
      GO TO 9
    7 LIM=3
      NB=9
    9 DO 10  II=1,4
      BILD(I,II)=0.
      DO 10  J=1,LIM
   10 BILD(I,II) = BILD(I,II)+ C(II,J,NB)    *E**(J-1)
      BILDO(I)= BILD(I,1)
      BILD1(I)= BILD(I,2)
      BILD2(I)= BILD(I,3)
   12 BILD3(I)= BILD(I,4)
C     SELECT CROSS-SECTIONS FROM LARGE TABLE
      DO 15  M=1,MAT
      L= MATZ(M)
      DO 15 NE=1,19
      XSEC(NE,M)= XSECO(NE,L)
```

```
   15 SLOPE(NE,M)= (XSECO(NE+1,L)-XSECO(NE,L))/(ENRG(NE+1)-ENRG(NE))
      DO 17 I=1,19
C     CALCULATES SLOPES FOR ENERGY ABSORPTION CROSS-SECTION
   17 SLOPEA(I)= (XSECEA(I+1)-XSECEA(I))/(ENRG( I+1)-ENRG(I))
C     CALCULATE CROSS-SECTIONS AT ENERGY EBAR(I)
      DO 25 I=1,NRGY
      DO 20 NE=1,19
      IF(EBAR(I)-ENRG(NE+1)) 22,22,20
   20 CONTINUE
      NE=19
   22 CONV(I)=DCONST*(XSECEA(NE)+ SLOPEA(NE)*(EBAR(I)-ENRG(NE)))
      DO 25 M=1,MAT
      XSECG(M,I) = XSEC(NE,M)+ SLOPE(NE,M)*(EBAR(I)-ENRG(NE))
   25 CONTINUE
      RETURN
      END
```

```
$IBFTC FLQAD   DECK
      SUBROUTINE FINAL(ID,NSLICE)
      COMMON /QADHD/
     1 Z     (100)  , VZ    (16)   , WZ    (16)   , VR    (16)   ,
     2 WR    (16)   , VP    (16)   , WP    (16)   , VOL   (100)  ,
     3 DTIME (100)  , RANGE (100)  , VV    (100)  ,
     4 SRG   (16)   , SRN   (16)   , SPG   (16)   , SPN   (16)   ,
     5 SG    (100)  , SN    (100)  , ST    (100)  , QNDOT (100)  ,
     6 QGDOT (100)  , QTDOT (100)  , TGDOT (100)  , TNDOT (100)  ,
     7 TTDOT (100)  , DQG   (100)  , DQN   (100)  , DQT   (100)  ,
     8 DTG   (100)  , DTN   (100)  , DTT   (100)  , QG    (100)  ,
     9 QN    (100)  , QT    (100)  , TG    (100)  , TN    (100)  ,
     X TT    (100)  , T     (100)
      DIMENSION ID(12)
    8 FORMAT(1H ,I5, 1P7E12.4)
    9 FORMAT(1H ,I5, 1P6E12.4)
   10 FORMAT(1H1,5X,12A6)
   90 FORMAT(37H0      WITH TANK LIQUID LEVEL AT Z(I),/1H0,19X,70HRATE OF
     A HEAT  INPUT TO TANK,CAL/SEC     RATE OF TEMP RISE--DEGREES C/SEC/90
     BH       I          Z(I)        GAMMA          NEUT         TOTAL        GAMM
     CA          NEUT        TOTAL)
   91 FORMAT(32H0      WHEN ITH SLICE IS EMPTYING/1H0,12X,21HHEAT INPUT--
     F-CALORIES,15X,29HTEMPERATURE RISE DEGREES CENT/78H       I        GAM
     GMA          NEUT        TOTAL        GAMMA         NEUT         TOTAL)
   92 FORMAT(46H0      ACCUMULATIVE VALUES AT TIME T(J),SECONDS/1H0,24X,
     J21HHEAT INPUT---CALORIES,15X,29HTEMPERATURE RISE DEGREES CENT/90H
     K     J          T(J)          GAMMA          NEUT         TOTAL        GAMMA
     L         NEUT         TOTAL)
      DATA RHO,CP/.07,2.25/
      CR=RHO*CP
      JJ=NSLICE+1
      QGDOT(2)=SG(1)
      QNDOT(2)=SN(1)
      QTDOT(2)=ST(1)
      QGDOT(1)=QGDOT(2)
      QNDOT(1)=QNDOT(2)
      QTDOT(1)=QTDOT(2)
      VV(1)=VOL(1)
      DO 50 I=3,JJ
      QNDOT(I)=QNDOT(I-1)+SN(I-1)
      QGDOT(I)=QGDOT(I-1)+SG(I-1)
      QTDOT(I)=QTDOT(I-1)+ST(I-1)
   50 VV(I-1)=VV(I-2)+VOL(I-1)
      DO 52 I=2,JJ
      V=1./(CR*VV(I-1))
      TGDOT(I)=QGDOT(I)*V
      TNDOT(I)=QNDOT(I)*V
   52 TTDOT(I)=QTDOT(I)*V
      TGDOT(1)=TGDOT(2)
      TNDOT(1)=TNDOT(2)
      TTDOT(1)=TTDOT(2)
```

```
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,90)
      WRITE(6,8)(I,Z(I),QGDOT(I),QNDOT(I),QTDOT(I),TGDOT(I),TNDOT(I),
     XTTDOT(I),I=1,JJ)
      DO 55 I=1,NSLICE
      AVQG=.5*(QGDOT(I)+QGDOT(I+1))
      AVQN=.5*(QNDOT(I)+QNDOT(I+1))
      AVQT=.5*(QTDOT(I)+QTDOT(I+1))
      AVTG=.5*(TGDOT(I)+TGDOT(I+1))
      AVTN=.5*(TNDOT(I)+TNDOT(I+1))
      AVTT=.5*(TTDOT(I)+TTDOT(I+1))
      DQG(I)=AVQG*DTIME(I)
      DQN(I)=AVQN*DTIME(I)
      DQT(I)=AVQT*DTIME(I)
      DTG(I)=AVTG*DTIME(I)
      DTN(I)=AVTN*DTIME(I)
   55 DTT(I)=AVTT*DTIME(I)
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,91)
      WRITE(6,9)(I,DQG(I),DQN(I),DQT(I),DTG(I),DTN(I),DTT(I),I=1,NSLICE)
C     REVERSAL
      QG(1)=DQG(NSLICE)
      QN(1)=DQN(NSLICE)
      QT(1)=DQT(NSLICE)
      TG(1)=DTG(NSLICE)
      TN(1)=DTN(NSLICE)
      TT(1)=DTT(NSLICE)
      T(1)=DTIME(NSLICE)
      DO 60 I=2,NSLICE
      N=JJ-I
      T(I)=T(I-1)+DTIME(N)
      QG(I)=QG(I-1)+DQG(N)
      QN(I)=QN(I-1)+DQN(N)
      QT(I)=QT(I-1)+DQT(N)
      TG(I)=TG(I-1)+DTG(N)
      TN(I)=TN(I-1)+DTN(N)
   60 TT(I)=TT(I-1)+DTT(N)
      WRITE(6,10)(ID(I),I=1,12)
      WRITE(6,92)
      WRITE(6,8)(I,T(I),QG(I),QN(I),QT(I),TG(I),TN(I),TT(I),I=1,NSLICE)
      RETURN
      END
```

```
$IBFTC SCQAD   DECK

      SUBROUTINE SOURCE
      COMMON /QADATA/
     1 NSET  (16)    , RSO   (21)    , ZSO   (21)    , PHISO (21)    ,
     2 NBNDZN(50)    , NCMPZN(50)    , LBD   (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)    , ABD   (50)    , BBD   (50)    , CBD   (50)    ,
     4 XOBD  (50)    , YOBD  (50)    , ZOBD  (50)    , DBD   (50)    ,
     5 HYDRAT(30)    , XSECN (30)    , XSECG (20,30) , BILD0 (30)    ,
     6 BILD1 (30)    , BILD2 (30)    , BILD3 (30)    , GAMEN (30)    ,
     7 CONV  (30)    , COMP  (20,40) , EBAR  (30)    , MATZ  (20)    ,
     8 FL    (21)    , FM    (21)    , FN   (21)     ,
     9 ASO   , XI1SO , XI2SO , ETA1SO, ETA2SO, ALF1  , ALF2  , ALF3  ,
     X ALF4  , EPSLN , FUDGE , NBLD
      EQUIVALENCE(LSO,NSET(1)),(MSO,NSET(2)),(NSO,NSET(3)),(ISRC,
     1  NSET(11))
   40 FORMAT(32H1      L          R(L)         F(L)//(I7,5X1P2E12.4))
   41 FORMAT(32H0      M          Z(M)         F(M)//(I7,5X1P2E12.4))
   42 FORMAT(32H0      N         PHI(N)        F(N)//(I7,5X1P2E12.4))
      FLT=0.0
      FMT=0.0
      DO 15 L=1,LSO
      GO TO (10,13),ISRC
   10 IF(XI1SO)12,11,12
   12 FL(L)=(COS(XI1SO*(RSO(L+1)-XI2SO))-COS(XI1SO*(RSO(L)-XI2SO)))/  XI
     11SO**2+(RSO(L+1)*SIN(XI1SO*(RSO(L+1)-XI2SO))                    -RS
     2O(L)*SIN(XI1SO*(RSO(L)-XI2SO)))/XI1SO
      GO TO 14
   11 FL(L)=(RSO(L+1)**2-RSO(L)**2)
      GO TO 14
   13 FL(L)=(FL(L+1)-FL(L))*(RSO(L+1)*(RSO(L)+RSO(L+1))+RSO(L)**2)/1.5
     1+(RSO(L)+RSO(L+1))*(FL(L)*RSO(L+1)-FL(L+1)*RSO(L))
   14 FLT=FLT+FL(L)
   15 RSO(L)=(RSO(L)+RSO(L+1))/2.0
      DO 25 M=1,MSO
      GO TO (20,23),ISRC
   20 IF(ETA1SO)21,22,21
   21 FM(M)=(SIN(ETA1SO*(ZSO(M+1)-ETA2SO))
     1SIN(ETA1SO*(ZSO(M)-ETA2SO)))/ETA1SO
      GO TO 24
   22 FM(M)=ZSO(M+1)-ZSO(M)
      GO TO 24
   23 FM(M)=(ZSO(M+1)-ZSO(M))*(FM(M)+FM(M+1))
   24 FMT=FMT+FM(M)
   25 ZSO(M)=(ZSO(M)+ZSO(M+1))/2.0
      ASO=ASO/(FLT*FMT*(PHISO(NSO+1)-PHISO(1)))
      DO 30 N=1,NSO
      FN(N)=(PHISO(N+1)-PHISO(N))*ASO
   30 PHISO(N)=(PHISO(N)+PHISO(N+1))/2.0
      WRITE (6,40)(L,RSO(L),FL(L),L=1,LSO)
      WRITE (6,41)(M,ZSO(M),FM(M),M=1,MSO)
      WRITE (6,42)(N,PHISO(N),FN(N),N=1,NSO)
      RETURN
       END
```

```
$IBFTC LNQAD    DECK
      SUBROUTINE LENGTH(SMAT,SSO,XSO,YSO,ZSO,XRC,YRC,ZRC,IERR)
      COMMON /QADATA/
     1 NSET   (16)    , RSO    (21)    , ZSO    (21)    , PHISO (21)    ,
     2 NBNDZN(50)     , NCMPZN(50)     , LBD    (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)     , ABD    (50)    , BBD    (50)    , CBD    (50)   ,
     4 XOBD  (50)     , YOBD   (50)    , ZOBD   (50)    , DBD    (50)   ,
     5 HYDRAT(30)     , XSECN  (30)    , XSECG  (20,30) , BILDO  (30)   ,
     6 BILD1  (30)    , BILD2  (30)    , BILD3  (30)    , GAMEN  (30)   ,
     7 CONV   (30)    , COMP   (20,40) , EBAR   (30)    , MATZ   (20)   ,
     8 FL     (21)    , FM     (21)    , FN   (21)      ,
     9 ASO    , XI1SO  , XI2SO  , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4   , EPSLN  , FUDGE  , NBLD
      DIMENSION R(6),SMAT(20)
      EQUIVALENCE(NREG,NSET(6)),(NZSO,NSET(10)),(MAT,NSET(4))
    5 FORMAT(67H0    ZONE        BOUNDARY     DISTANCE          X              Y
     1           Z)
    6 FORMAT(2( I7,5X),1P4E12.4)
    9 CALL  SLITET(4,K000FX)
       GO  TO(10,10),K000FX
   10 CALL  SLITET(1,K000FX)
       GO  TO(101,102),K000FX
  101 CALL  SLITE (1)
      WRITE  (6,5)
  102 DO  11  M=1,MAT
   11 SMAT(M)=0.0
      X=XSO
      Y=YSO
      Z=ZSO(1)
      ALPHA=XRC-X
      BETA=YRC-Y
      GAMMA=ZRC-Z
      SRC=SQRT(ALPHA**2+BETA**2+GAMMA**2)
      ALPHA=ALPHA/SRC
      BETA=BETA/SRC
      GAMMA=GAMMA/SRC
      SSO=SRC
      SMIN=FUDGE
      NP=NZSO
  100 X=X+ALPHA*SMIN
      Y=Y+BETA*SMIN
      Z=Z+GAMMA*SMIN
      SRC=SRC-SMIN
   20 IL=NP
      IU=NREG
   25 DO  42  I=IL,IU
      JU=NBNDZN(I)
      DO  41  J=1,JU
      K=LBD(J,I)
      NEQ=NEQBD(K)
      GO  TO( 31,32,33,34,35,36),NEQ
```

```
 31 R(J)=X*(ABD(K)*X+XOBD(K))+Y*(BBD(K)*Y+YOBD(K))
   1+Z*(CBD(K)*Z+ZOBD(K))-DBD(K)
    GO TO 40
 32 R(J)=ABD(K)*(X-XOBD(K))**2+BBD(K)*(Y-YOBD(K))**2
   1+CBD(K)*(Z-ZOBD(K))**2-DBD(K)
    GO TO 40
 33 R(J)=(X-XOBD(K))**2+(Y-YOBD(K))**2-DBD(K)
    GO TO 40
 34 R(J)=X-DBD(K)
    GO TO 40
 35 R(J)=Y-DBD(K)
    GO TO 40
 36 R(J)=Z-DBD(K)
 40 IF(SIGN(1.0,LBD(J,I))*R(J))  41,41,42
 41 CONTINUE
    GO TO 50
 42 CONTINUE
    IF(IU-NP)45,43,43
 43 IL=1
    IU=NP-1
    GO TO 25
 45 IERR=1
    CALL SLITET(1,KOOOFX)
     GO TO(300,46),KOOOFX
 46 CALL SLITE (1)
    GO TO 9
C
 50 SMIN=SRC
    KK=0
    IF(NBNDZN(I))99,99,51
 51 DO 98 J=1,JU
    K=LBD(J,I)
    NEQ=NEQBD(K)
    GO TO(61,62,63,64,65,66),NEQ
 61 E=(ABD(K)*X+XOBD(K)/2.0)*ALPHA+(BBD(K)*Y+YOBD(K)/2.0)*BETA
   1  +(CBD(K)*Z+ZOBD(K)/2.0)*GAMMA
    GO TO 620
 62 E=ABD(K)*ALPHA*(X-XOBD(K))+BBD(K)*BETA*(Y-YOBD(K))
   1+CBD(K)*GAMMA*(Z-ZOBD(K))
620 H=ABD(K)*ALPHA**2+BBD(K)*BETA**2+CBD(K)*GAMMA**2
    GO TO 70
 63 E=ALPHA*(X-XOBD(K))+BETA*(Y-YOBD(K))
    H=1.0-GAMMA**2
    GO TO 70
 64 E=ALPHA/2.0
    GO TO 660
 65 E=BETA/2.0
    GO TO 660
 66 E=GAMMA/2.0
660 H=0.0
 70 IF(H)71,75,75
 71 H=-H
    E=-E
    R(J)=-R(J)
    K=-K
 75 IF(H-EPSLN)76,76,85
```

```
 76 IF(R(J))80,77,80
 77 IERR=2
    CALL  SLITET(1,KOOOFX)
     GO  TO(300,78),KOOOFX
 78 CALL  SLITE (1)
    GO  TO  9
 80 IF(ABS(E)-EPSLN)98,98,81
 81 SBD=-R(J)/2.0/E
    IF(SBD)98,98,95
 85 IF(R(J))86,77,90
 86 IF(H*SMIN**2+2.0*E*SMIN+R(J))98,98,87
 87 QUAD=E**2-H*R(J)
    GO  TO  92
 90 IF(E)91,98,98
 91 QUAD=E**2-H*R(J)
    IF(QUAD-EPSLN)98,98,92
 92 SBD=(-E+SIGN(SQRT(QUAD),K))/H
 95 IF(SBD-SMIN)96,98,98
 96 CALL  SLITE (4)
    SMIN=SBD
    KK=K
    NP=NTRYZN(J,I)
 98 CONTINUE
C
 99 SMIN=SMIN+FUDGE
    CALL  SLITET(1,KOOOFX)
     GO  TO(991,992),KOOOFX
991 CALL  SLITE (1)
    WRITE (6,6)I,KK,SMIN,X,Y,Z
992 N=NCMPZN(I)
    DO  994  M=1,MAT
994 SMAT(M)=SMAT(M)+SMIN*COMP(M,N)
    CALL  SLITET(4,KOOOFX)
     GO  TO(100,105),KOOOFX
105 IERR=0
300 CALL  SLITE (0)
    RETURN
     END
```

```
$IBFTC KNQAD    DECK

      SUBROUTINE KERNEL(SMAT,SSO,ANEUT,AGAM,UAGAM,IERR)
      COMMON /QADATA/
     1 NSET  (16)    , RSO   (21)    , ZSO   (21)    , PHISO (21)    ,
     2 NBNDZN(50)    , NCMPZN(50)    , LBD   (6,50)  , NTRYZN(6,50)  ,
     3 NEQBD (50)    , ABD   (50)    , BBD   (50)    , CBD   (50)    ,
     4 XOBD  (50)    , YOBD  (50)    , ZOBD  (50)    , DBD   (50)    ,
     5 HYDRAT(30)    , XSECN (30)    , XSECG (20,30) , BILDO (30)    ,
     6 BILD1 (30)    , BILD2 (30)    , BILD3 (30)    , GAMEN (30)    ,
     7 CONV  (30)    , COMP  (20,40) , EBAR  (30)    , MATZ  (20)    ,
     8 FL    (21)    , FM    (21)    , FN   (21)     ,
     9 ASO    , XI1SO  , XI2SO  , ETA1SO, ETA2SO, ALF1   , ALF2   , ALF3   ,
     X ALF4   , EPSLN  , FUDGE  , NBLD
      DIMENSION SMAT(20),AGAM(20),UAGAM(20)
      EQUIVALENCE(MAT,NSET(4)),(NREG,NSET(6)),(NRGY,NSET(7)),
     1(INEUT,NSET(12))
      ANEUT=0.0
      IF(INEUT)21,21,15
   15 SHYD=0.0
      AN    =0.0
      DO 18  I=1,MAT
      AN=AN+SMAT(I)*XSECN(I)
   18 SHYD=SHYD+HYDRAT(I)*SMAT(I)
      ANEUT=ALF1*EXP(-AN)
      IF(SHYD)19,19,20
   19 IERR=1
      GO TO 22
   20 ANEUT=ANEUT*(SHYD      )**ALF2*EXP(-ALF3*(SHYD      )**ALF4)
   21 IERR=0
   22 DO 25  J=1,NRGY
      AG=0.0
      DO 24  I=1,MAT
   24 AG=AG+SMAT(I)*XSECG(I,J)
      UAGAM(J)=EXP(-AG)
   25 AGAM(J)=(BILDO(J)+BILD1(J)*AG+BILD2(J)*(AG**2)
     1+BILD3(J)*(AG**2)*AG)*UAGAM(J)
      RETURN
       END
```

```
$IBFTC XISECO  DECK

      BLOCK DATA
      COMMON /STDATA/
     1 NAME   (100)   , ENRG   (20)    , XSECO (20,100),XSECEA(20)    ,
     2 C     (4,6,9)  , EMINBB(8)      , NAMB(8)       , XSECNT(100)   ,DCONST
      COMMON /GAUSSQ/ V(4,16), W(4,16)
      COMMON / DOSE/  XSECEB(20,2), ALF(2), DCON(2)
      DATA  ALF/  9.1429E-14, 2.187E-3/,DCON/ 2.675568E-15, 5.76756E-5/
      DATA   (XSECEB(I,1),I=1,20)/ 0.0270,0.0305,0.0362,0.0406,0.0485,   HYD.ENRG
     A0.0530,0.0573,0.0587,0.0589,0.0588,0.0573,0.0555,0.0507,0.0464,    ABS.XSEC
     B0.0389,0.0351,0.0316,0.0288,0.0249,0.0222/                         NBS-H85H
      DATA   (XSECEB(I,2),I=1,20)/ 0.0409,0.0312,0.0255,0.0252,0.0276,   MUS.ENRG
     C0.0297,0.0317,0.0325,0.0327,0.0326,0.0318,0.0308,0.0281,0.0257,    ABS.XSEC
     D0.0225,0.0203,0.0188,0.0178,0.0163,0.0154/                         NBS-H85M
      DATA   XSECNT/ 0.0,0.14989,0.08763,0.07153,0.05401,0.04063,0.04283,  1-7
     1  0.03728,0.04091,0.03437,0.03213,0.03121,0.02925,0.02898,0.02755,  8-15
     2  0.02706,0.02570,0.02416,0.02443,0.02412,0.02270,0.02200,0.02131, 16-23
     3  0.02109,0.02050,0.02136,0.01977,0.01940,0.01934,0.01874,0.01813, 24-31
     4  0.01775,0.01747,0.01700,0.01690,0.01649,0.01632,0.01611,0.01599, 32-39
     5  0.01559,0.01563,0.01537,0.01513,0.01496,0.01483,0.01455,0.01447, 40-47
     6  0.01417,0.01401,0.01378,0.01360,0.01327,0.01331,0.01308,0.01299, 48-55
     7  0.01278,0.01270,0.01264,0.01261,0.01246,0.01242,0.01219,0.01212, 56-63
     8  0.01191,0.01185,0.01171,0.01162,0.01154,0.01148,0.01134,0.01128, 64-71
     9  0.01116,0.01108,0.01101,0.01092,0.01080,0.01074,0.01066,0.01061, 72-79
     X  0.01051,0.01041,0.01026,0.01006,0.01026,0.01024,0.00997,0.00994, 80-87
     Y  0.00988,0.00986,0.00974,0.00977,0.00911,0.00964,0.00954,0.00952, 88-95
     Z  0.00948,0.00940,0.00940,0.00930,0.00934/                         96-100
      DATA(V(1,I),    I=1,2)/.21132487,.78867513/,(W(1,I),I=1,2)/2*.5/
      DATA(V(2,I),I=1,4)/.06943184,.33000948,.66999052,.93056816/,
     E(W(2,I),I=1,4)/.17392742,2*.32607258,.17392742/
      DATA(V(3,I),I=1,8)/.01988507,.10166676,.23723379,.40828268,
     P.59171732,.76276621,.89833324,.98014493/,(W(3,I),I=1,8)/.050614268
     Q,.11119052,.15685332,2*.18134189,.15685332,.11119052,.050614268/
      DATA(V(4,I),I=1,16)/0.529953E-2,0.277125E-1,0.671844E-1,0.122298,
     X0.191062,.270992,0.359198,0.452494,0.547506,0.640802,0.729008,
     Y0.808938,.877702,0.932816,0.972288,0.9947/
      DATA(W(4,I),I=1,16)/0.0135762,0.0311268,0.0475793,0.0623145,
     X0.0747980,0.0845783,0.0913017,2*0.0947253,0.0913017,0.0845783,
     Y0.0747980,0.0623145,0.0475793,0.0311268,0.0135762/
      DATA (NAME(I),I=1,100) / 2H H,2HHE,2HLI,2HBE,2H B,2H C,2H N,2H O, 1-8
     S2H F,2HNE,2HNA,2HMG,2HAL,2HSI,2H P,2H S,2HCL,2HAR,2H K,2HCA,2HSC,  9-21
     T2HTI,2H V,2HCR,2HMN,2HFE,2HCO,2HNI,2HCU,2HZN,2HGA,2HGE,2HAS,2HSE, 22-34
     U2HBR,2HKR,2HRB,2HSR,2H Y,2HZR,2HNB,2HMO,2HTC,2HRU,2HRH,2HPD,2HAG, 35-47
     V2HCD,2HIN,2HSN,2HSB,2HTE,2H I,2HXE,2HCS,2HBA,2HLA,2HCE,2HPR,2HND, 48-60
     W2HPM,2HSM,2HEU,2HGD,2HTB,2HDY,2HHO,2HER,2HTM,2HYB,2HLU,2HHF,2HTA, 61-73
     X2H W,2HRE,2HOS,2HIR,2HPT,2HAU,2HHG,2HTL,2HPB,2HBI,2HPO,2HAT,2HRN, 74-86
     Y2HFR,2HRA,2HAC,2HTH,2HPA,2H U,2HNP,2HPU,2HAM,2HCM,2HBK,2HCF,2HES, 87-99
     Z2HFM /                                                             100
      DATA   EMINBB/ 0.255, 3*0.5, 0.255, 3*0.5/   ,
     1(C(I,1,1),I=1,4)/+1.01094E+0,+1.16772E-1,-7.65869E-3,+1.67068E-4/,
     2(C(I,2,1),I=1,4)/-6.00394E-2,+2.32125E+0,-1.79023E-2,+5.69295E-4/,
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3(C(I,3,1),I=1,4)/+7.20778E-2,-2.12801E+0,+2.41735E-1,-7.96332E-3/,
4(C(I,4,1),I=1,4)/-3.01498E-2,+7.67783E-1,-4.34443E-2,+7.23758E-3/,
5(C(I,5,1),I=1,4)/+3.94733E-3,-9.08139E-2,-1.34203E-3,-9.87237E-4/,
1(C(I,1,2),I=1,4)/+1.00768E+0,-1.03807E-2,+1.30705E-2,-3.29348E-4/,
2(C(I,2,2),I=1,4)/-4.98085E-2,+3.32216E+0,-1.58167E-1,+4.60315E-3/,
3(C(I,3,2),I=1,4)/+7.23425E-2,-5.52427E+0,+6.89496E-1,-2.04255E-2/,
4(C(I,4,2),I=1,4)/-3.93841E-2,+4.16700E+0,-5.59836E-1,+2.00554E-2/,
5(C(I,5,2),I=1,4)/+7.35778E-3,-1.04638E+0,+1.41308E-1,-5.29934E-3/,
1(C(I,1,3),I=1,4)/+1.01460E+0,-4.12104E-2,+1.88074E-3,+1.20198E-3/,
2(C(I,2,3),I=1,4)/-1.88657E-1,+2.72752E+0,+1.00217E-1,-9.83313E-3/,
3(C(I,3,3),I=1,4)/+6.38649E-1,-3.76728E+0,-1.31988E-1,+2.06002E-2/,
4(C(I,4,3),I=1,4)/-6.55159E-1,+2.42384E+0,+1.68976E-1,-1.75251E-2/,
5(C(I,5,3),I=1,4)/+1.90742E-1,-5.54657E-1,-5.80710E-2,+4.75673E-3/
 DATA NAMB/6HH2O DS, 6H AL DS, 6H FE DS, 6H PB DS,
X          6HH2O EA, 6H AL EA, 6H FE EA, 6H PB EA/ ,
1(C(I,1,4),I=1,4)/+9.59342E-1,+6.78254E-2,-2.26626E-2,+6.39872E-4/,
2(C(I,2,4),I=1,4)/+1.13722E-1,+4.50412E-1,+7.55191E-3,+1.52094E-4/,
3(C(I,3,4),I=1,4)/-7.39816E-2,-2.15037E-1,+5.10254E-3,-6.04837E-4/,
4(C(I,4,4),I=1,4)/+1.87767E-2,+4.05189E-2,-1.89332E-3,+2.42263E-4/,
5(C(I,5,4),I=1,4)/-2.04254E-3,-3.40802E-3,+1.93415E-4,-2.93865E-5/,
6(C(I,6,4),I=1,4)/+7.93621E-5,+1.06510E-4,-6.24306E-6,+1.13914E-6/,
1(C(I,1,5),I=1,4)/+1.00935E+0,+6.75909E-2,-2.88512E-3,+3.54158E-5/,
2(C(I,2,5),I=1,4)/-5.05187E-2,+2.73952E+0,-7.11806E-2,+1.98272E-3/,
3(C(I,3,5),I=1,4)/+5.93863E-2,-2.82306E+0,+3.98796E-1,-1.19564E-2/,
4(C(I,4,5),I=1,4)/-2.43717E-2,+1.11668E+0,-1.50948E-1,+9.52922E-3/,
5(C(I,5,5),I=1,4)/+3.14779E-3,-1.41350E-1,+1.65266E-2,-1.36541E-3/,
1(C(I,1,6),I=1,4)/+9.97130E-1,-3.85219E-2,+1.27816E-2,-3.39093E-4/,
2(C(I,2,6),I=1,4)/+6.54640E-2,+3.27946E+0,-1.64393E-1,+5.04304E-3/,
3(C(I,3,6),I=1,4)/-2.68716E-1,-4.74349E+0,+7.45795E-1,-2.38346E-2/,
4(C(I,4,6),I=1,4)/+2.84908E-1,+3.39495E+0,-6.26720E-1,+2.53658E-2/,
5(C(I,5,6),I=1,4)/-8.33177E-2,-8.37392E-1,+1.66032E-1,-7.07268E-3/
 DATA
1(C(I,1,7),I=1,4)/+1.00009E+0,-9.76981E-2,+3.07480E-3,+5.43036E-4/,
2(C(I,2,7),I=1,4)/-2.69391E-2,+2.81567E+0,+5.47069E-2,-3.05850E-3/,
3(C(I,3,7),I=1,4)/+1.06797E-1,-3.14590E+0,-1.33763E-4,+2.43681E-3/,
4(C(I,4,7),I=1,4)/-1.11725E-1,+1.91566E+0,+1.03003E-1,-1.57016E-3/,
5(C(I,5,7),I=1,4)/+3.27028E-2,-4.17820E-1,-4.79248E-2,+5.35111E-4/,
1(C(I,1,8),I=1,4)/+9.99305E-1,-3.49764E-1,+2.89886E-2,+1.28555E-3/,
2(C(I,2,8),I=1,4)/+1.13017E-2,+2.79914E+0,-7.10002E-2,-4.75607E-3/,
3(C(I,3,8),I=1,4)/-3.44367E-3,-2.20399E+0,-1.11108E-2,+7.04843E-3/,
4(C(I,4,8),I=1,4)/+2.04092E-3,+5.02301E-1,+1.45444E-2,-2.31052E-3/,
1(C(I,1,9),I=1,4)/+1.02626E+0,+4.15814E-1,+5.64179E-2,-4.83073E-3/,
2(C(I,2,9),I=1,4)/-7.44724E-3,-6.14701E-2,-1.42153E-2,+1.76866E-3/,
3(C(I,3,9),I=1,4)/+3.81090E-4,+3.09491E-3,+7.33689E-4,-1.07370E-4/
 DATA(ENRG(I),I=1,20)/.05,.06,.08,.1,.15,.2,.3,.4,.5,.6,.8,1.,1.5,
1 2.,3.,4.,5.,6.,8.,10. /
 DATA(XSECO(I,1),I=1,20)/.335,.326,.309,.295,.265,.243,.212,.189,   HYDROGEN
X.173,.160,.140,.126,.103,.0876,.0691,.0579,.0502,.0446,.0371,.0321  Z=1
Y /
 DATA(XSECO(I,2),I=1,20)/.1688,.1640,.1560,.1480,.1330,.1220,.1060,HE  0201
X.0953,.0870,.0805,.0707,.0635,.0516,.0442,                           0202
Y.0349,.0295,.0257,.0231,.0194,.0169/                                 0203
 DATA(XSECO(I,3),I=1,20)/.1469,.1423,.1347,.1268,.1150,.1060,.0921,LI  0301
X.0825,.0754,.0696,.0612,.0550,.0447,.0382,                           0302
Y.0304,.0257,.0225,.0203,.0172,.0152/                                 0303
 DATA(XSECO(I,4),I=1,20)/.151,.146,.138,.132,.119,.109,.0945,.0847,BERYLIUM
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X.0773,.0715,.0628,.0565,.0459,.0394,.0313,.0266,.0234,.0211,.018,     Z=4
Y.0161  /                                                               BE
 DATA(XSECO(I,5),I=1,20)/.1608,.1536,.1463,.1380,.1237,.1139,.0985,B    0501
X.0881,.0805,.0745,.0654,.0588,.0478,.0410,                             0502
Y.0321,.0279,.0247,.0224,.0193,.0175/                                   0503
 DATA(XSECO(I,6),I=1,20)/.178,.169,.157,.149,.134,.122,.106,.0953,    CARBON
X.087,.0805,.0707,.0636,.0518,.0444,.0356,.0304,.027,.0245,.0213,       Z=6
Y.0194 /                                                                C
 DATA(XSECO(I,7),I=1,20)/.185,.173,.159,.15,.134,.123,.106,.0955,.0NITROGEN
X869,.0805,.0707,.0636,.0517,.0445,.0357,.0305,.0273,.0249,.0218,       Z=7
Y .02/                                                                  N
 DATA(XSECO(I,8),I=1,20)/.197,.18,.162,.151,.134,.123,.107,.0953,       OXYGEN
X.087,.0806,.0708,.0636,.0518,.0445,.0359,.0309,.0276,.0254,.0224,      Z=8
Y.0206  /                                                               O
 DATA(XSECO(I,9),I=1,20)/.1987,.1786,.1565,.1448,.1275,.1780,.1016,F    0901
X.0905,.0826,.0762,.0670,.0602,.0491,.0422,                             0902
Y.0342,.0296,.0266,.0245,.0218,.0203/                                   0903
 DATA(XSECO(I,10),I=1,20)/.231,.1992,.1688,.1536,.1337,.1226,.1054,NE   1001
X.0947,.0863,.0797,.0701,.0630,.0514,.0442,                             1002
Y.0359,.0312,.0281,.0260,.0233,.0218/                                   1003
 DATA(XSECO(I,11),I=1,20)/.248,.206,.168,.151,.13,.118,.102,.0912,      SODIUM
X.0833,.077,.0676,.0608,.0496,.0427,.0348,.0303,.0274,.0254,.0229,      Z=11
Y.0215  /                                                               NA
 DATA(XSECO(I,12),I=1,20)/.293,.232,.181,.16,.135,.122,.106,.0944,    MAGNSIUM
X.086,.0795,.0699,.0627,.0512,.0442,.036,.0315,.0286,.0266,.0242,       Z=12
Y.0228  /                                                               MG
 DATA(XSECO(I,13),I=1,20)/.326,.248,.186,.161,.134,.12,.103,.0922,    ALUMINUM
X.084,.0777,.0683,.0614,.05,.0432,.0353,.031,.0282,.0264,.0241,         Z=13
Y.0229/                                                                 AL
 DATA(XSECO(I,14),I=1,20)/.389,.288,.205,.172,.139,.125,.107,.0954,    SILICON
X.0869,.0802,.0706,.0635,.0517,.0447,.0367,.0323,.0296,.0277,.0254,     Z=14
Y.0243   /                                                              SI
 DATA(XSECO(I,15),I=1,20)/.432,.311,.211,.174,.137,.122,.104,.0928,    PHOS-
X.0846,.078,.0685,.0617,.0502,.0436,.0358,.0316,.029,.0273,.0252,       PHORUS
Y.0242  /                                                               Z=15
 DATA(XSECO(I,16),I=1,20)/.518,.363,.234,.188,.144,.127,.108,.0958,    SULPHER
X.0874,.0806,.0707,.0635,.0519,.0448,.0371,.0328,.0302,.0284,.0266,     Z=16
Y.0255  /                                                               S
 DATA(XSECO(I,17),I=1,20)/.584,.3957,.2451,.1902,.1403,.1223,.1033,CL   1701
X.0922,.0839,.0775,.0680,.0609,.0498,.0432,                             1702
Y.0358,.0318,.0295,.0280,.0262,.0252/                                   1703
 DATA(XSECO(I,18),I=1,20)/.629,.420,.249,.188,.135,.117,.0977,.0867   ARGON
X,.079,.073,.0638,.0573,.0468,.0407,.0338,.0301,.0279,.0266,.0248,      Z=18
Y.0241  /                                                               A
 DATA(XSECO(I,19),I=1,20)/.782,.514,.293,.215,.149,.127,.106,.0936,POTASIUM
X.0852,.0786,.0689,.0618,.0505,.0438,.0365,.0327,.0305,.0289,.0274,     Z=19
Y.0267  /                                                               K
 DATA(XSECO(I,20),I=1,20)/.929,.597,.33,.238,.158,.132,.109,.0965,     CALCIUM
X.0876,.0809,.0708,.0634,.0518,.0451,.0376,.0338,.0316,.0302,.0285,     Z=20
Y.028   /                                                               CA
 DATA(XSECO(I,21),I=1,20)/.999,.6317,.3387,.2377,.1507,.1247,.1025,SC   2101
X.0902,.0819,.0755,.0662,.0593,.0484,.0421,                             2102
Y.0353,.0318,.0299,.0287,.0273,.0267/                                   2103
 DATA(XSECO(I,22),I=1,20)/1.125,.7062,.3677,.2517,.1531,.1253,.101,TI   2201
X.0892,.0809,.0745,.0653,.0586,.0478,.0416,                             2202
Y.0350,.0316,.0298,.0287,.0274,.0269/                                   2203
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 DATA(XSECO(I,23),I=1,20)/1.250,.7850,.3999,.2661,.1565,.1249,.100,V    2301
X.0880,.0797,.0734,.0642,.0576,.0470,.0410,                             2302
Y.0345,.0313,.0296,.0285,.0274,.0270/                                   2303
 DATA(XSECO(I,24),I=1,20)/1.443,.9005,.4516,.2930,.1665,.1302,.103,CR   2401
X.0904,.0817,.0751,.0657,.0589,.0482,.0419,                             2402
Y.0354,.0322,.0305,.0295,.0285,.0282/                                   2403
 DATA(XSECO(I,25),I=1,20)/1.599,.9942,.4925,.3108,.1709,.1318,.102,MN   2501
X.0895,.0807,.0742,.0648,.0582,.0474,.0414,                             2502
Y.0351,.0320,.0304,.0295,.0286,.0283/                                   2503
 DATA(XSECO(I,26),I=1,20)/1.83,1.13,.555,.344,.183,.138,.106,.0919,    IRON
X.0828,.0762,.0664,.0595,.0485,.0424,.036,.033,.0313,.0304,.0295,      Z=26
Y.0294 /                                                               FE
 END
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$IBFTC X2SECO  DECK

      BLOCK  DATA
      COMMON /STDATA/
     1 NAME   (100)   , ENRG   (20)     , XSECO (20,100),XSECEA(20)    ,
     2 C    (4,6,9)   , EMIN3B(8)       , NAMB(8)        , XSECNT(100)  ,DCONST
      DATA(XSECO(I,27),I=1,20)/2.01,1.235,.5999,.3669,.1880,.1387,.1052,CO  2701
     X.0910,.0817,.0750,.0655,.0588,.0479,.0419,                            2702
     Y.0356,.0327,.0312,.0304,.0297,.0296/                                  2703
      DATA(XSECO(I,28),I=1,20)/2.32,1.427,.6832,.4127,.2550,.1488,.1108,NI  2801
     X.0951,.0854,.0783,.0682,.0611,.0499,.0437,                            2802
     Y.0372,.0343,.0329,.0320,.0314,.0314/                                  2803
      DATA(XSECO(I,29),I=1,20)/2.45,1.51,.713,.427,.206,.147,.108,.0916,  COPPER
     X.082,.0751,.C654,.0585,.0476,.0418,.0357,.033,.0316,.0309,.0303,     Z=29
     Y.0305 /                                                              CU
      DATA(XSECO(I,30),I=1,20)/2.71,1.661,.7773,.4630,.2182,.1519,.1095,ZN  3001
     X.0927,.0827,.0756,.0659,.0590,.0481,.0422,                            3002
     Y.0362,.0335,.0322,.0316,.0312,.0313/                                  3003
      DATA(XSECO(I,31),I=1,20)/2.88,1.768,.8150,.4841,.2228,.1527,.1074,GA  3101
     X.0904,.0806,.0734,.0639,.0571,.0467,.0410,                            3102
     Y.0353,.0327,.0315,.0309,.0307,.0309/                                  3103
      DATA(XSECO(I,32),I=1,20)/3.12,1.905,.8876,.5194,.2320,.1562,.1081,GE  3201
     X.0904,.0802,.0731,.0634,.0568,.0463,.0407,                            3202
     Y.0351,.0327,.0315,.0310,.0308,.0311/                                  3203
      DATA(XSECO(I,33),I=1,20)/3.39,2.08,.9605,.5592,.2440,.1617,.1099, AS  3301
     X.0910,.0806,.0733,.0636,.0568,.0464,.0407,                            3302
     Y.0353,.0329,.0318,.0313,.0313,.0316/                                  3303
      DATA(XSECO(I,34),I=1,20)/3.62,2.20,1.029,.5586,.2515,.1634,.1087, SE  3401
     X.0897,.0792,.0720,.0623,.0556,.0454,.0399,                            3402
     Y.0346,.0324,.0315,.0310,.0310,.0314/                                  3403
      DATA(XSECO(I,35),I=1,20)/3.99,2.43,1.135,.6436,.2691,.1727,.1124, BR  3501
     X.0922,.0810,.0735,.0635,.0567,.0462,.0406,                            3502
     Y.0354,.0332,.0323,.0318,.0320,.0325/                                  3503
      DATA(XSECO(I,36),I=1,20)/4.24,2.56,1.203,.6791,.2785,.1753,.1122, KR  3601
     X.0913,.0800,.0727,.0625,.0557,.0454,.0400,                            3602
     Y.0349,.0329,.0320,.0317,.0318,.0324/                                  3603
      DATA(XSECO(I,37),I=1,20)/4.60,2.79,1.309,.7335,.2963,.1826,.1149, RB  3701
     X.0928,.0811,.0732,.0630,.0562,.0458,.0404,                            3702
     Y.0353,.0333,.0325,.0322,.0325,.0331/                                  3703
      DATA(XSECO(I,38),I=1,20)/4.96,3.03,1.406,.7882,.3122,.1900,.1176, SR  3801
     X.0941,.0817,.0736,.0633,.0564,.0459,.0405,                            3802
     Y.0355,.0336,.0329,.0326,.0330,.0337/                                  3803
      DATA(XSECO(I,39),I=1,20)/5.40,3.29,1.542,.8555,.3328,.2002,.1212, Y   3901
     X.0960,.0832,.0743,.0642,.0572,.0465,.0411,                            3902
     Y.0361,.0343,.0336,.0334,.0338,.0346/                                  3903
      DATA(XSECO(I,40),I=1,20)/5.78,3.52,1.658,.9100,.3517,.2085,.1239, ZR  4001
     X.0978,.0839,.0752,.0644,.0573,.0466,.0412,                            4002
     Y.0363,.0345,.0339,.0337,.0343,.0351/                                  4003
      DATA(XSECO(I,41),I=1,20)/6.23,3.80,1.764,.9820,.3724,.2178,.1275, NB  4101
     X.0996,.0850,.0766,.0650,.0578,.0470,.0416,                            4102
     Y.0367,.0350,.0344,.0343,.0349,.0359/                                  4103
      DATA(XSECO(I,42),I=1,20)/6.62,4.04,1.86,1.03,.389,.225,.13,.0998,   MOLYB-
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X.0851,.0761,.0648,.0575,.0467,.0414,.0365,.0349,.0344,.0344,.0349,    DENUM
Y.0359 /                                                               Z=42
 DATA(XSECO(I,43),I=1,20)/7.02,4.28,1.958,1.089,.4065,.2328,.1310, TC   4301
X.1003,.0851,.0757,.0646,.0573,.0465,.0412,                             4302
Y.0365,.0349,.0345,.0344,.0353,.0363/                                   4303
 DATA(XSECO(I,44),I=1,20)/7.43,4.54,2.075,1.156,.4274,.2411,.1327, RU   4401
X.1011,.0855,.0759,.0645,.0571,.0464,.0411,                             4402
Y.0365,.0351,.0347,.0347,.0356,.0367/                                   4403
 DATA(XSECO(I,45),I=1,20)/7.99,4.89,2.220,1.243,.4548,.2543,.1373, RH   4501
X.1039,.0872,.0773,.0655,.0579,.0470,.0417,                             4502
Y.0371,.0357,.0354,.0354,.0364,.0376/                                   4503
 DATA(XSECO(I,46),I=1,20)/8.39,5.12,2.330,1.301,.4710,.2608,.1391, PD   4601
X.1048,.0869,.0767,.0648,.0573,.0464,.0413,                             4602
Y.0368,.0354,.0352,.0353,.0363,.0375/                                   4603
 DATA(XSECO(I,47),I=1,20)/8.97,5.49,2.50,1.388,.5014,.2759,.1447,  AG   4701
X.1076,.0886,.0781,.0659,.0582,.0470,.0418,                             4702
Y.0374,.0361,.0359,.0360,.0371,.0384/                                   4703
 DATA(XSECO(I,48),I=1,20)/9.31,5.71,2.59,1.437,.5168,.2816,.1455,  CD   4801
X.1065,.0878,.0771,.0648,.0571,.0462,.0410,                             4802
Y.0368,.0356,.0355,.0357,.0368,.0382/                                   4803
 DATA(XSECO(I,49),I=1,20)/9.85,6.02,2.75,1.515,.5436,.2940,.1492,  IN   4901
X.1083,.0887,.0778,.0652,.0574,.0464,.0412,                             4902
Y.0370,.0359,.0358,.0360,.0372,.0387/                                   4903
 DATA(XSECO(I,50),I=1,20)/10.2,6.28,2.87,1.58,.563,.303,.153,.109,   TIN
X.0886,.0776,.0647,.0568,.0459,.0408,.0367,.0355,.0355,.0358,.0368,  Z=50
Y.0383 /                                                             SN
 DATA(XSECO(I,51),I=1,20)/10.74,6.57,3.01,1.650,.5980,.3150,.1557, SB   5101
X.1101,.0892,.0780,.0647,.0568,.0458,.0407,                             5102
Y.0367,.0357,.0357,.0361,.0374,.0389/                                   5103
 DATA(XSECO(I,52),I=1,20)/11.03,6.75,3.10,1.700,.6040,.3191,.1557, TE   5201
X.1090,.0879,.0767,.0633,.0555,.0447,.0397,                             5202
Y.0359,.0350,.0351,.0354,.0367,.0383/                                   5203
 DATA(XSECO(I,53),I=1,20)/11.9,7.26,3.34,1.83,.648,.339,.165,.114,   IODINE
X.0913,.0792,.0653,.0571,.046,.0409,.037,.036,.0361,.0365,.0377,     Z=53
Y.0394 /                                                             I
 DATA(XSECO(I,54),I=1,20)/12.11,7.47,3.46,1.905,.6640,.3471,.1679, XE   5401
X.1146,.0910,.0787,.0647,.0565,.0453,.0404,                             5402
Y.0366,.0358,.0360,.0365,.0379,.0396/                                   5403
 DATA(XSECO(I,55),I=1,20)/12.60,7.88,3.67,2.012,.7000,.3642,.1745, CS   5501
X.1174,.0929,.0800,.0655,.0572,.0458,.0408,                             5502
Y.0371,.0363,.0366,.0371,.0385,.0403/                                   5503
 DATA(XSECO(I,56),I=1,20)/13.10,8.16,3.79,2.079,.7180,.3719,.1763, BA   5601
X.1174,.0928,.0798,.0650,.0566,.0453,.0404,                             5602
Y.0367,.0360,.0363,.0369,.0384,.0402/                                   5603
 DATA(XSECO(I,57),I=1,20)/13.69,8.55,4.00,2.195,.7560,.3891,.1839, LA   5701
X.1211,.0947,.0812,.0659,.0573,.0458,.0408,                             5702
Y.0372,.0365,.0369,.0375,.0390,.0409/                                   5703
 DATA(XSECO(I,58),I=1,20)/14.28,8.99,4.22,2.312,.7990,.4081,.1869, CE   5801
X.1249,.0973,.0828,.0670,.0582,.0464,.0414,                             5802
Y.0377,.0370,.0375,.0382,.0398,.0417/                                   5803
 DATA(XSECO(I,59),I=1,20)/15.06,9.45,4.49,2.460,.8440,.4281,.1989, PR   5901
X.1286,.0991,.0847,.0683,.0591,.0470,.0420,                             5902
Y.0383,.0377,.0383,.0390,.0407,.0427/                                   5903
 END
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$IBFTC X3SECO  DECK

      BLOCK DATA
      COMMON /STDATA/
     1 NAME  (100)  , ENRG  (20)   , XSECO (20,100),XSECEA(20)   ,
     2 C   (4,6,9)  , EMIN33(8)    , NAMB(8)       , XSECNT(100)  ,DCONST
      DATA(XSECO(I,60),I=1,20)/15.56,9.75,4.64,2.550,.8720,.4425,.2037, ND   6001
     X.1304,.1000,.0852,.0684,.0591,.0469,.0419,                             6002
     Y.0383,.0378,.0384,.0391,.0408,.0429/                                   6003
      DATA(XSECO(I,61),I=1,20)/16.15,10.14,4.84,2.66,.910,.4578,.2093,   PM   6101
     X.1322,.1019,.0861,.0688,.0594,.0470,.0420,                             6102
     Y.0384,.0380,.0386,.0394,.0411,.0432/                                   6103
      DATA(XSECO(I,62),I=1,20)/16.54,10.44,5.02,2.76,.940,.4723,.2140,   SM   6201
     X.1351,.1028,.0867,.0690,.0594,.0469,.0419,                             6202
     Y.0384,.0380,.0387,.0395,.0412,.0434/                                   6203
      DATA(XSECO(I,63),I=1,20)/17.23,10.83,5.24,2.90,.986,.4924,.2216,   EK   6301
     X.1388,.1047,.0882,.0700,.0601,.0474,.0424,                             6302
     Y.0389,.0385,.0393,.0401,.0419,.0441/                                   6303
      DATA(XSECO(I,64),I=1,20)/2.56,10.93,5.35,2.96,1.015,.5031,.2245,   GD   6401
     X.1397,.1056,.0880,.0695,.0596,.0469,.0419,                             6402
     Y.0385,.0382,.0390,.0398,.0416,.0439/                                   6403
      DATA(XSECO(I,65),I=1,20)/2.64,11.32,5.57,3.09,1.054,.5233,.2311,   TB   6501
     X.1455,.1075,.0893,.0702,.0600,.0472,.0421,                             6502
     Y.0388,.0384,.0393,.0402,.0420,.0443/                                   6503
      DATA(XSECO(I,66),I=1,20)/2.75,11.52,5.76,3.20,1.093,.5407,.2368,   DY   6601
     X.1454,.1084,.0900,.0706,.0602,.0471,.0422,                             6602
     Y.0389,.0385,.0395,.0404,.0422,.0446/                                   6603
      DATA(XSECO(I,67),I=1,20)/2.91,11.80,5.98,3.32,1.131,.5599,.2434,   HO   6701
     X.1492,.1103,.0914,.0713,.0607,.0474,.0424,                             6702
     Y.0391,.0388,.0398,.0408,.0426,.0450/                                   6703
      DATA(XSECO(I,68),I=1,20)/3.05,12.10,6.21,3.45,1.180,.5791,.2510,   ER   6801
     X.1530,.1121,.0928,.0720,.0612,.0477,.0427,                             6802
     Y.0394,.0392,.0402,.0412,.0431,.0455/                                   6803
      DATA(XSECO(I,69),I=1,20)/3.19,12.39,6.42,3.58,1.228,.6012,.2586,   TM   6901
     X.1568,.1150,.0943,.0729,.0618,.0481,.0430,                             6902
     Y.0397,.0395,.0406,.0416,.0435,.0460/                                   6903
      DATA(XSECO(I,70),I=1,20)/3.34,2.01,6.60,3.70,1.257,.6177,.263,     YB   7001
     X.1596,.1159,.0951,.0732,.0620,.0481,.0428,                             7002
     Y.0398,.0396,.0406,.0417,.0436,.0462/                                   7003
      DATA(XSECO(I,71),I=1,20)/3.47,2.13,6.88,3.83,1.315,.6430,.2719,    LU   7101
     X.1634,.1188,.0966,.0743,.0627,.0486,.0433,                             7102
     Y.0402,.0400,.0411,.0421,.0441,.0467/                                   7103
      DATA(XSECO(I,72),I=1,20)/3.61,2.19,7.04,3.92,1.354,.6620,.2777,    HF   7201
     X.1662,.1206,.0975,.0747,.0628,.0485,.0433,                             7202
     Y.0402,.0401,.0411,.0422,.0442,.0469/                                   7203
      DATA(XSECO(I,73),I=1,20)/3.76,2.26,7.29,4.08,1.402,.6850,.2853,    TA   7301
     X.1700,.1225,.0994,.0757,.0635,.0489,.0435,                             7302
     Y.0404,.0405,.0415,.0426,.0447,.0474/                                   7303
      DATA(XSECO(I,74),I=1,20)/3.94,2.34,7.49,4.21,1.44,.708,.293,.174, TUNGSTEN
     X.125,.101,.0763,.064,.0492,.0437,.0405,.0402,.0409,.0418,.0438,        Z=74
     Y .0465/                                                                W
      DATA(XSECO(I,75),I=1,20)/4.12,2.43,7.72,4.35,1.500,.729,.3005,     RE   7501
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X.1787,.1272,.1022,.0774,.0645,.0494,.0441,                            7502
Y.0409,.0409,.0421,.0431,.0453,.0481/                                   7503
 DATA(XSECO(I,76),I=1,20)/4.25,2.50,7.92,4.46,1.539,.750,.3063,     OS 7601
X.1815,.1291,.1032,.0778,.0647,.0495,.0440,                            7602
Y.0409,.0410,.0421,.0431,.0454,.0482/                                   7603
 DATA(XSECO(I,77),I=1,20)/4.41,2.60,8.14,4.61,1.587,.771,.3140,     IR 7701
X.1862,.1310,.1051,.0787,.0652,.0496,.0443,                            7702
Y.0411,.0412,.0423,.0433,.0456,.0485/                                   7703
 DATA(XSECO(I,78),I=1,20)/4.58,2.71,8.61,4.75,1.64,.795,.324,.191, PLATINUM
X.135,.107,.08,.0659,.0501,.0445,.0414,.0411,.0418,.0427,.0448,      Z=78
Y .0477/
 DATA(XSECO(I,79),I=1,20)/4.75,2.83,1.31,4.91,1.694,.825,.3331,     GO 7901
X.1957,.1377,.1098,.0811,.0668,.0506,.0451,                            7902
Y.0419,.0421,.0432,.0442,.0466,.0495/                                   7903
 DATA(XSECO(I,80),I=1,20)/4.91,2.94,1.34,5.05,1.742,.848,.3398,     HG 8001
X.1995,.1396,.1108,.0819,.0673,.0508,.0452,                            8002
Y.0421,.0423,.0433,.0443,.0468,.0497/                                   8003
 DATA(XSECO(I,81),I=1,20)/5.03,3.01,1.36,5.16,1.8,.866,.346,.204,  THALLIUM
X.143,.112,.0824,.0675,.0508,.0452,.042,.0415,.0423,.0433,.0454,      Z=81
Y .0484/                                                           THALLIUM
 DATA(XSECO(I,82),I=1,20)/5.19,3.15,1.41,5.29,1.84,.896,.356,.208,   LEAD
X.145,.114,.0836,.0684,.0512,.0457,.0421,.042,.0426,.0436,.0459,      Z=82
Y .0489/                                                                PB
 DATA(XSECO(I,83),I=1,20)/5.38,3.29,1.46,5.46,1.908,.924,.3667,     BI 8301
X.2140,.1482,.1165,.0850,.0694,.0518,.0461,                            8302
Y.0429,.0432,.0442,.0450,.0477,.0507/                                   8303
 DATA(XSECO(I,84),I=1,20)/5.62,3.42,1.54,5.66,1.975,.962,.3772,     PO 8401
X.2207,.1530,.1193,.0871,.0707,.0527,.0468,                            8402
Y.0435,.0439,.0448,.0457,.0484,.0515/                                   8403
 DATA(XSECO(I,85),I=1,20)/5.85,3.58,1.62,5.87,2.053,1.001,.3916,    AT 8501
X.2284,.1577,.1232,.0891,.0722,.0536,.0476,                            8502
Y.0442,.0446,.0456,.0464,.0492,.0523/                                   8503
 DATA(XSECO(I,86),I=1,20)/5.80,3.57,1.62,5.79,2.025,.982,.3861,     RN 8601
X.2246,.1549,.1203,.0868,.0701,.0519,.0460,                            8602
Y.0428,.0432,.0441,.0449,.0476,.0507/                                   8603
 DATA(XSECO(I,87),I=1,20)/6.05,3.65,1.68,.920,2.103,1.02,.3986,     FR 8701
X.2323,.1587,.1241,.0887,.0716,.0528,.0467,                            8702
Y.0434,.0438,.0448,.0455,.0483,.0514/                                   8703
 DATA(XSECO(I,88),I=1,20)/6.26,3.79,1.72,.930,2.161,1.039,.4103,    RA 8801
X.2371,.1626,.1261,.0900,.0723,.0531,.0470,                            8802
Y.0436,.0440,.0448,.0458,.0485,.0517/                                   8803
 DATA(XSECO(I,89),I=1,20)/6.52,3.90,1.80,.970,2.239,1.078,.4227,    AC 8901
X.2448,.1674,.1299,.0921,.0738,.0540,.0477,                            8902
Y.0443,.0446,.0456,.0456,.0492,.0524/                                   8903
 DATA(XSECO(I,90),I=1,20)/6.70,4.06,1.82,1.00,2.269,1.097,.4307,    TH 9001
X.2478,.1693,.1309,.0925,.0739,.0539,.0476,                            9002
Y.0442,.0444,.0452,.0464,.0490,.0522/                                   9003
 DATA(XSECO(I,91),I=1,20)/7.04,4.23,1.90,1.05,2.376,1.146,.4489,    PA 9101
X.2583,.1760,.1357,.0954,.0762,.0553,.0488,                            9102
Y.0452,.0454,.0464,.0475,.0501,.0534/                                   9103
 DATA(XSECO(I,92),I=1,20)/7.17,4.28,1.93,1.06,2.42,1.17,.452,.259,  URANIUM
X.176,.136,.0952,.0757,.0548,.0484,.0445,.044,.0446,.0455,.0479,      Z=92
Y .0511/                                                                U
 END
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QADH 000799

HEATING IN AXIAL TANK

CONTROL	4	6	2	3	4	13	13	12	-0	1	1	0	-0	-0

SOURCE	3.3000E 19	-0.	-0.	-0.	-0.		
R	0.	1.5000E 01	3.0000E 01	4.0000E 01	5.0000E 01		
Z	0.	3.0000E 01	6.0000E 01	9.0000E 01	1.0500E 02	1.2000E 02	1.3000E 02
PHI	0.	1.5700E 00	3.1400E 00				

ZONE	BNDS	COMP	BND	PK	BND	PK	BND	PK	BND	PK	BND	PK	BND	PK
1	3	1	-1	13	7	3	2	2						
2	3	2	-2	1	7	3	3	4						
3	4	4	-1	13	10	12	3	4	-7	1				
4	3	4	-3	2	10	12	4	5						
5	4	3	-4	4	11	6	5	8	6	11				
6	5	4	-4	4	10	12	5	9	-11	5	-12	7		
7	3	3	-4	4	12	6	5	10						
8	3	3	-5	5	8	9	6	11						
9	5	4	-5	6	10	12	6	11	-8	8	-9	10		
10	3	3	-5	7	9	9	6	11						
11	-1	4	-6	8										
12	-3	4	-10	3	-1	13	6	11						
13	-1	4	1	1										

BND	EQ	PARAMETERS...						
1	6	-0.	-0.	-0.	-0.	-0.	-0.	0.
2	6	-0.	-0.	-0.	-0.	-0.	-0.	1.3000E 02
3	6	-0.	-0.	-0.	-0.	-0.	-0.	1.6000E 02
4	6	-0.	-0.	-0.	-0.	-0.	-0.	5.0000E 02
5	6	-0.	-0.	-0.	-0.	-0.	-0.	7.5000E 02
6	6	-0.	-0.	-0.	-0.	-0.	-0.	1.6000E 03
7	3	-0.	-0.	-0.	0.	0.	-0.	2.5000E 03
8	3	-0.	-0.	-0.	0.	0.	-0.	3.6000E 05
9	3	-0.	-0.	-0.	1.2500E 03	0.	-0.	3.6000E 05
10	3	-0.	-0.	-0.	0.	0.	-0.	4.0000E 06
11	2	1.0000E 00	1.0000E 00	-1.0000E 00	0.	0.	1.5000E 02	0.
12	2	1.0000E 00	1.0000E 00	-1.0000E 00	1.2500E 03	0.	1.5000E 02	0.

QADH

QADX PB EA BUILDUP IS USED

0	1.0000E-06	1.0000E-03	9.1429E-14	2.9000E-01	8.3000E-01	5.8000E-01

GRP	EPS/E	DELTA/K	A1/B0	A2/B1	A3/B2	A4/B3	EBAR
1	1.2470E 00	1.5331E-16	1.0245E 00	4.5096E-01	-4.1100E-02	1.4830E-03	3.0000E-01
2	3.2360E 00	1.5672E-16	1.0167E 00	5.4913E-01	-5.3537E-02	2.2546E-03	6.3000E-01
3	2.4210E 00	1.4593E-16	1.0083E 00	7.5082E-01	-3.3812E-02	1.0511E-03	1.1000E 00
4	1.7610E 00	1.3450E-16	1.0057E 00	6.7365E-01	-1.7537E-02	5.3045E-04	1.5500E 00
5	1.2820E 00	1.2438E-16	1.0044E 00	5.6403E-01	-7.6500E-03	3.8224E-04	1.9900E 00
6	1.0490E 00	1.1652E-16	1.0036E 00	4.7451E-01	-1.7261E-03	3.6015E-04	2.3800E 00
7	7.7500E-01	1.0910E-16	1.0031E 00	4.0082E-01	2.4005E-03	3.7699E-04	2.7500E 00
8	6.5600E-01	1.0154E-16	1.0025E 00	3.1748E-01	6.5142E-03	4.2214E-04	3.2500E 00
9	5.0700E-01	9.6454E-17	1.0021E 00	2.4947E-01	9.5409E-03	4.7467E-04	3.7500E 00
10	3.2600E-01	9.1852E-17	1.0016E 00	2.1153E-01	9.4952E-03	7.2093E-04	4.2200E 00
11	1.8200E-01	8.7357E-17	9.9968E-01	1.9527E-01	5.8132E-03	1.1102E-03	4.7000E 00
12	1.1300E-01	8.2675E-17	9.9767E-01	1.7840E-01	2.0099E-03	1.4953E-03	5.2500E 00
13	1.2000E-01	7.4865E-17	9.9416E-01	1.4874E-01	-4.6043E-03	2.0987E-03	6.4200E 00

COMP/GRP	1	2	3
1	0.	1.5000E 00	0.
2	1.1000E-01	0.	5.4900E 00
3	7.0000E-C2	0.	0.
4	0.	0.	0.

	1 H	6 C	40 ZR
-1	9.0000E 00	0.	0.
0	0.	4.0630E-02	1.5590E-02
1	2.1200E-01	1.0600E-01	1.2390E-01
2	1.5700E-01	7.9030E-02	7.3580E-02
3	1.2140E-01	6.1240E-02	5.5160E-02
4	1.0146E-01	5.1060E-02	4.6060E-02
5	8.7908E-02	4.4548E-02	4.1308E-02
6	8.0570E-02	4.1056E-02	3.9338E-02
7	7.3725E-02	3.7800E-02	3.7525E-02
8	6.6300E-02	3.4300E-02	3.5850E-02
9	6.0700E-02	3.1700E-02	3.4950E-02
10	5.6206E-02	2.9652E-02	3.4368E-02
11	5.2510E-02	2.8020E-02	3.4080E-02
12	4.8800E-02	2.6375E-02	3.3850E-02
13	4.3025E-02	2.3828E-02	3.3826E-02

J	VOL	WEIGHT
1	1.0210E 06	1.5315E 06
2	2.3562E 05	1.3195E 06
3	2.0094E 09	0.
4	4.2726E 09	0.
5	1.8130E 08	1.2691E 07
6	2.7790E 09	0.
7	1.8130E 08	1.2691E 07
8	9.6133E 08	6.7293E 07
9	8.7588E 09	0.
10	9.6133E 08	6.7293E 07
SUM	2.0106E 10	1.6282E 08

L	R(L)	QADH F(L)
1	7.5000E 00	2.2500E 02
2	2.2500E 01	6.7500E 02
3	3.5000E 01	7.0000E 02
4	4.5000E 01	9.0000E 02

M	Z(M)	F(M)
1	1.5000E 01	3.0000E 01
2	4.5000E 01	3.0000E 01
3	7.5000E 01	3.0000E 01
4	9.7500E 01	1.5000E 01
5	1.1250E 02	1.5000E 01
6	1.2500E 02	1.0000E 01

N	PHI(N)	F(N)
1	7.8500E-01	5.0769E 13
2	2.3550E 00	5.0769E 13

HEATING CONTROL 0 1 1 8 0 5 11 8 1.2000E 03 0

Z =
5.0000E 02 5.5000E 02 6.0000E 02 6.5000E 02 7.5000E 02 9.0000E 02 1.1000E 03 1.3000E 03 1.6000E 03

FLOW RATE = 9.5219E 05 CM3/SEC
TANK VOLUME = 1.1426E 09 CM3

HEATING IN AXIAL TANK

I	Z(I)	Z(I+1)-Z(I)	VOL(I)	DTIME(I)	FLUID HEATING RATES CAL/SEC GAMMA	NEUT	TOTAL
1	5.0000E 02	5.0000E 01	2.2122E 07	2.3233E 01	2.2756E 04	0.	2.2756E 04
2	5.5000E 02	5.0000E 01	2.8405E 07	2.9832E 01	1.7710E 04	0.	1.7710E 04
3	6.0000E 02	5.0000E 01	3.5474E 07	3.7255E 01	1.3562E 04	0.	1.3562E 04
4	6.5000E 02	1.0000E 02	9.5295E 07	1.0008E 02	1.8083E 04	0.	1.8083E 04
5	7.5000E 02	1.5000E 02	1.6965E 08	1.7816E 02	1.1454E 04	0.	1.1454E 04
6	9.0000E 02	2.0000E 02	2.2619E 08	2.3755E 02	3.9255E 03	0.	3.9255E 03
7	1.1000E 03	2.0000E 02	2.2619E 08	2.3755E 02	9.2389E 02	0.	9.2389E 02
8	1.3000E 03	3.0000E 02	3.3929E 08	3.5633E 02	2.8011E 02	0.	2.8011E 02
9	1.6000E 03						

QADH

HEATING IN AXIAL TANK

WITH TANK LIQUID LEVEL AT Z(I),

I	Z(I)	RATE OF HEAT INPUT TO TANK,CAL/SEC GAMMA	NEUT	TOTAL	RATE OF TEMP RISE—DEGREES C/SEC GAMMA	NEUT	TOTAL
1	5.0000E 02	2.2756E 04	0.	2.2756E 04	6.5310E-03	0.	6.5310E-03
2	5.5000E 02	2.2756E 04	0.	2.2756E 04	6.5310E-03	0.	6.5310E-03
3	6.0000E 02	4.0465E 04	0.	4.0465E 04	5.0848E-03	0.	5.0848E-03
4	6.5000E 02	5.4027E 04	0.	5.4027E 04	3.9887E-03	0.	3.9887E-03
5	7.5000E 02	7.2111E 04	0.	7.2111E 04	2.5254E-03	0.	2.5254E-03
6	9.0000E 02	8.3565E 04	0.	8.3565E 04	1.5118E-03	0.	1.5118E-03
7	1.1000E 03	8.7490E 04	0.	8.7490E 04	9.6250E-04	0.	9.6250E-04
8	1.3000E 03	8.8414E 04	0.	8.8414E 04	6.9879E-04	0.	6.9879E-04
9	1.6000E 03	8.8694E 04	0.	8.8694E 04	4.9285E-04	0.	4.9285E-04

HEATING IN AXIAL TANK

WHEN ITH SLICE IS EMPTYING

I	HEAT INPUT---CALORIES GAMMA	NEUT	TOTAL	TEMPERATURE RISE DEGREES CENT GAMMA	NEUT	TOTAL
1	5.2868E 05	0.	5.2868E 05	1.5173E-01	0.	1.5173E-01
2	9.4299E 05	0.	9.4299E 05	1.7326E-01	0.	1.7326E-01
3	1.7602E 06	0.	1.7602E 06	1.6902E-01	0.	1.6902E-01
4	6.3120E 06	0.	6.3120E 06	3.2597E-01	0.	3.2597E-01
5	1.3868E 07	0.	1.3868E 07	3.5965E-01	0.	3.5965E-01
6	2.0317E 07	0.	2.0317E 07	2.9389E-01	0.	2.9389E-01
7	2.0893E 07	0.	2.0893E 07	1.9732E-01	0.	1.9732E-01
8	3.1554E 07	0.	3.1554E 07	2.1231E-01	0.	2.1231E-01

HEATING IN AXIAL TANK

ACCUMULATIVE VALUES AT TIME T(J),SECONDS

J	T(J)	HEAT INPUT---CALORIES GAMMA	NEUT	TOTAL	TEMPERATURE RISE DEGREES CENT GAMMA	NEUT	TOTAL
1	3.5633E 02	3.1554E 07	0.	3.1554E 07	2.1231E-01	0.	2.1231E-01
2	5.9388E 02	5.2448E 07	0.	5.2448E 07	4.0963E-01	0.	4.0963E-01
3	8.3144E 02	7.2765E 07	0.	7.2765E 07	7.0352E-01	0.	7.0352E-01
4	1.0096E 03	8.6633E 07	0.	8.6633E 07	1.0632E 00	0.	1.0632E 00
5	1.1097E 03	9.2945E 07	0.	9.2945E 07	1.3891E 00	0.	1.3891E 00
6	1.1469E 03	9.4705E 07	0.	9.4705E 07	1.5582E 00	0.	1.5582E 00
7	1.1768E 03	9.5648E 07	0.	9.5648E 07	1.7314E 00	0.	1.7314E 00
8	1.2000E 03	9.6177E 07	0.	9.6177E 07	1.8831E 00	0.	1.8831E 00

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 24, 1967,
121-30-02-02-22.

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2. Grodstein, Gladys W.: X-Ray Attenuation Coefficients From 10 KeV to 100 MeV. Circ. 583, National Bureau of Standards, Apr. 30, 1957.

3. Storm, Ellery; Gilbert, Eugene; and Israel, Harvey: Gamma-Ray Absorption Coefficients for Elements 1 through 100 Derived from the Theoretical Values of the National Bureau of Standards. Rep. No. LA-2237, Los Alamos Scientific Lab., Apr. 1957.

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5. Blizard, E. P., ed.: Reactor Handbook. Second ed., vol. III, part B, Shielding. Interscience Publishers, 1962, Table 9-9.

6. Anon.: Physical Aspects of Irradiation. Handbook 85, National Bureau of Standards, Mar. 1964.

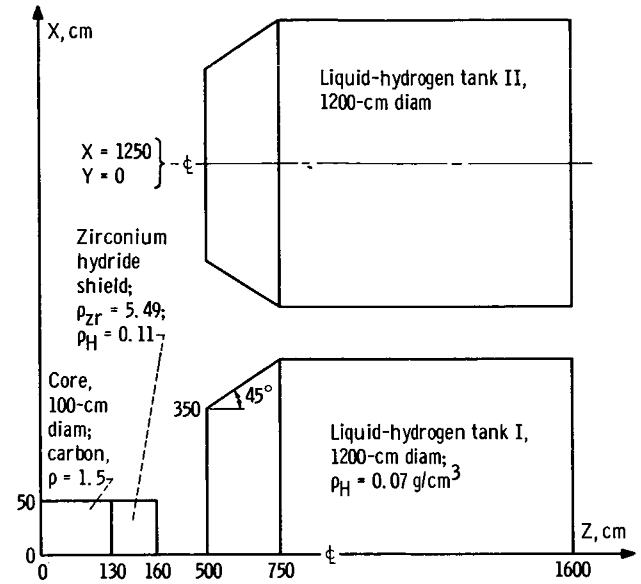


Figure 1. - Reactor-shield propellant tank configuration.

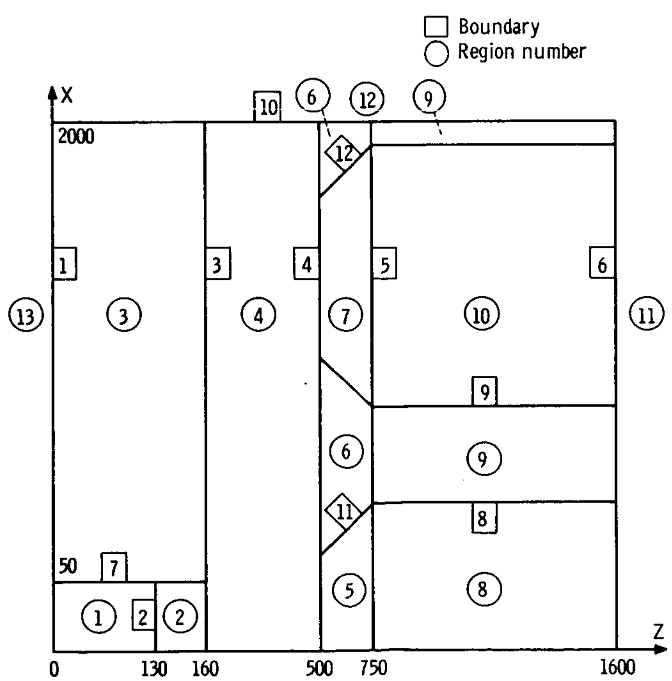
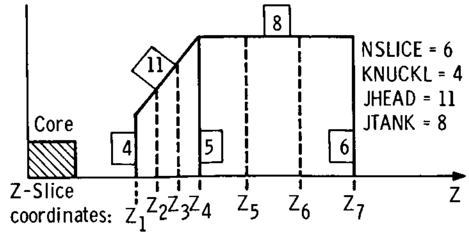
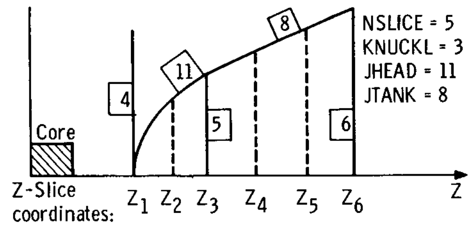


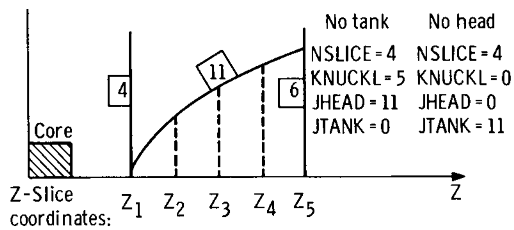
Figure 2. - QAD reactor-shield propellant tank configuration.



(a) Conical-head cylindrical tank.



(b) Elliptic-head conical tank.



(c) Elliptic-head, no tank, or no-head elliptic tank.

Figure 3. - QADH and QADD tank geometries.

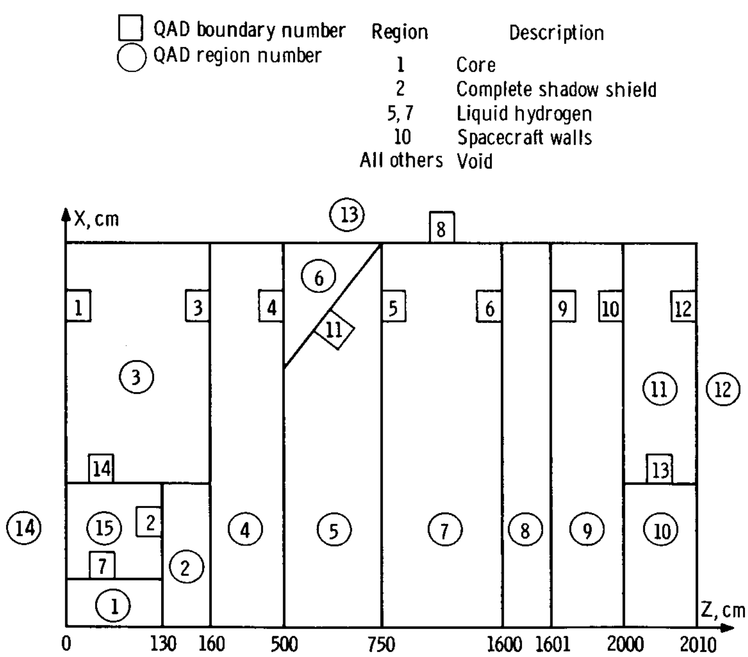


Figure 4. - QADD Core-shield propellant tank of spacecraft.

□ Boundary number
○ Region number

Region	Description	Tank emptying parameters	Value
1	Bottom support	JHEAD	15
2	Core	JTANK	16
3, 4	Reflector	JWHED	17
5	Pressure vessel	JWTNK	14
7	Top support	ZPRIME	530
8, 9	Shield	BURN	1185 sec
11, 12	Liquid hydrogen	Z-Slice coordinates (NSLICE = 20)	531, 550, 575, 600, 700, 800, 894, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3544
17, 18, 19	Tank wall		
6, 10, 13	Void		
14, 15, 16	Outside regions (also void)		
		KNUCKL	7

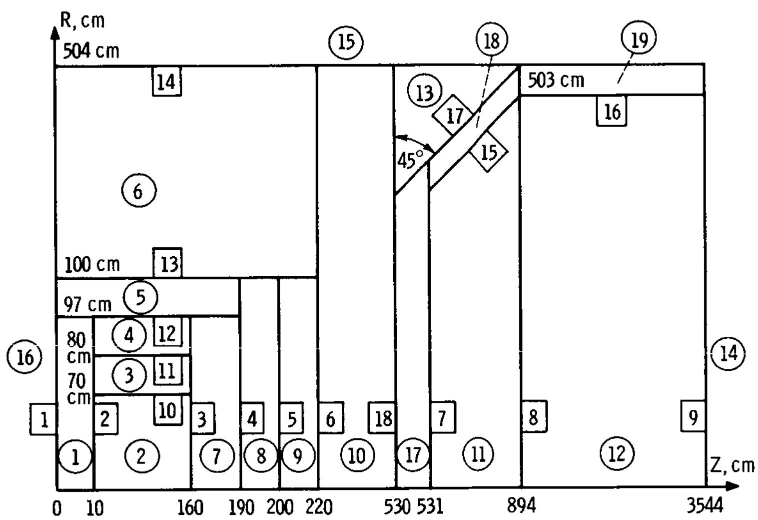


Figure 5. - Calculation of propellant and tank-wall heating.