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DEVELOPMENT AND VERIFICATION OF DESIGN METHODS FOR DUCTS IN A SPACE NUCLEAR SHIELD

PHASES 1, 2, 3

Final Report

R. J. Cerbone, W. E. Selph, and P. A. Read

PREPARED FOR THE U.S. ATOMIC ENERGY COMMISSION
SPACE NUCLEAR SYSTEMS DIVISION
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GULF RADIATION TECHNOLOGY
A DIVISION OF GULF ENERGY & ENVIRONMENTAL SYSTEMS COMPANY
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Final Report

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1. INTRODUCTION

This Final Report describes the work performed and the results thereof on the first three phases in the development of a practical method for calculating the effects of ducts and cavities in a space nuclear shield and the verification of the accuracy of these methods by analytical and experimental means. This research is divided into four phases; namely,

1. Formulation and programming of a code for calculating the effect of shield irregularities on the space craft environment. This method consists of using the solution of a two-dimensional transport code as a starting point and making perturbations to that solution to account for shield irregularities such as coolant ducts and other shield perturbations.
2. Performance of analytical tests to determine the range of validity of the code developed in Phase 1.
3. Performance of an experimental program using a geometry and material similar to real space-power shielding problems but "clean" enough to provide a good check on the analysis.
4. Extend the experimental-analytical comparison to include neutron and secondary gamma production and transport in a NERVA-BATH shield assembly.

A variety of techniques are available for estimating the streaming of radiation down ducts. Some of these techniques are summarized in Ref. 1. The majority of the duct streaming work, both experimental and analytical, has been concentrated on void ducts whose dimensions are large compared to the radiation mean free path in the material. For these

cases, the radiation incident on the mouth of the duct is the predominant source of radiation reaching the duct exit either by direct streaming or by albedo from the duct wall. Relatively simplified analyses of these two components provide answers that are in reasonable agreement with experiment for cases such as shelter entry ways or beam ports through reactor shields.

Ducts through shields in space reactors are, however, more likely to be filled either by metal or by some fluid so that radiative exchange between the duct material and the shield material becomes an important contribution to the radiation exiting the duct. Evaluating the effect of a filled duct is therefore a more complicated process and is not amenable to an unsophisticated approach. An exact solution requires the use of a radiation transport code with a three-dimensional generalized geometry capability (a Monte Carlo code). The motive behind the work reported here is to arrive at an approximate method that can be applied to iterative design studies without the large expenditure of computer time required for a series of Monte Carlo calculations.

This report will concentrate on the development of the DUCT code, analytical tests, and comparison with experiments designed to simulate a SNAP — lithium hydride shield with sodium coolant holes. A production version of the DUCT code complete with manual is expected to be published by January 30, 1971.

2. DEVELOPMENT OF THE DUCT CODE

Except for isolated irregularities, we assumed that the shield could be approximated by use of a two-dimensional model. Neglecting these irregularities, a two-dimensional calculation can be performed using a transport code such as TWOTRAN,⁽²⁾ or DOT.⁽³⁾ These codes can be made to generate a "flux tape" which is a complete listing of fluxes within a spatial energy and angle mesh specified in the calculation. The DUCT code that we have written takes these fluxes as input and solves for perturbations in the flux at specified detector points caused by the presence of irregularities in the shield. In the present form the code only considers cylindrical ducts. In some parts of the code the 2D angular flux mesh is used in a discrete manner, in other parts, interpolations in angle are made. Spatial interpolations are made in all cases and the fixed energy grouping is used throughout.

The primary assumption attendant to the derivation of the method is that the inward-directed current passing through the surface of a duct is given by integrating over the angular flux predicted from the unducted 2D solution. In other words, it is assumed that changing the material in the duct region does not change the level of radiation passing into the region. Analytical justification for the assumption is illustrated in Eq. 2.4 below.

2.1 ESTIMATOR FOR THE SCATTERED RADIATION

The last collision kernel volume integral is given below

$$\varphi(E)_S = \int_{dv} \int_{E'} \int_{\Omega'} \frac{\varphi(\Omega', r, Z, E') P(\Omega \rightarrow \Omega', E' \rightarrow E) \exp(-\Sigma_T(E')R)}{R^2}, \quad (2.1)$$

where

$\varphi(\Omega', r, Z, E')$ are flux components in phase space where r, Z are space coordinates in cylindrical geometry centered in dv ;

Ω' is direction of incoming flux, and E' is energy of incoming flux;

R is the distance from dv to the detector;

Ω is the direction from dv to the detector;

E is the energy after collision;

$P(\Omega' \rightarrow \Omega, E' \rightarrow E)$ is the scattering cross section per steradian per cc for transitions from Ω' to Ω and E' to E . These two transitions are not independent since for a given scattering species the energy lost in a collision depends on the scattering angle. Where dv is filled with a variety of scattering species more than one E can result from a given incident E' and Ω' flux component.

To simplify the evaluation of the last collision integral, group-averaged cross sections are used and group fluxes are used for both the incident and scattered radiation. This allows us to use the same cross section set in the perturbation calculation as that used in the 2D transport analysis of the idealized shield.

Another simplification is to restrict the duct shape to cylinders and divide the duct volume by planes perpendicular to the duct axis. Each of the volume elements can then be treated as an equivalent disk source. The uncollided flux from an isotropic disk source of strength S_A per unit

area at a detector on the axis is given by

$$\varphi = \frac{S_A}{2} \left[E_1(\mu t) - E_1(\mu t \sec \theta) \right] , \quad (2.2)$$

where μt is the integral of total cross sections along the axis between the two points and θ is the angle between a ray on the axis and a ray from the detector to the outer rim of the disk and the function $E_1(x)$ is given by

$$\int_x^\infty \frac{e^{-t}}{t} dt . \quad (2.3)$$

Using the group averaging approach the flux at a detector on the duct centerline at the exit plane is then given by

$$\varphi_S(g') = \sum_g \sum_m \sum_n P_S(g \rightarrow g', m) W_m \varphi_m(n, g) \quad (2.4)$$

$$* 2\pi \Delta t_n \left[E_1(-\mu(g)R(n)) - E_1(-\mu(g)R(n) \sec \theta_n) \right] ,$$

where $P_S(g \rightarrow g', m)$ is the unit volume probability of scattering from group g to group g' from the m th angle to the direction of the detector.

$P_S(g \rightarrow g', m)$ is given by

$$P_S(g \rightarrow g'; \theta_S) = \frac{1}{4\pi} \sum_{\ell=0}^n S_\ell(g \rightarrow g') P_\ell(\theta_S) , \quad (2.5)$$

where

$S_{\ell}(g \rightarrow g')$ are given by the group average cross sections generated by GGC4.⁽⁴⁾

W_m is the quadrature weight of the mth angle increment = solid angle/ 4π .

$\phi_m(n, g)$ is the angular flux at the nth duct point in the mth angle in group g (4π x neutrons cm^{-2} STER $^{-1}$).

$\mu(g)R(n)$ is the total number of mean free paths from the nth duct point to the detector for group g.

2.2 ESTIMATOR FOR THE UNCOLLIDED FLUX TO ON-AXIS DETECTOR

The uncollided flux from radiation passing through the duct wall is given by

$$\phi(E)_D = \int \phi(\Omega, r, Z, E) \vec{\Omega} \cdot \vec{n} dS \exp(-\Sigma_r(E)R)/R^2, \quad (2.6)$$

where

$\phi(\Omega, r, Z, E)$ are the flux components

Ω is the direction from the surface element dS to the detector

n is a unit vector normal to the surface increment

r, Z are the space coordinates centered in dS

R is the distance from r, Z to the detector.

Using the same numerical approach to evaluate this integral as was used in the scattering calculations detailed above,

$$\varphi_D(g) = \frac{1}{4\pi} \sum_n \bar{\varphi}(n,g) \Delta S \cos \theta \exp(-\mu(g)R(n))/R^2(n) \quad , \quad (2.7)$$

where

ΔS is the duct surface area associated with the particular duct segment

$\bar{\varphi}(n,g)/4\pi$ is the flux per steradian in the detector direction averaged over ΔS . (See the discussion of flux interpolation and averaging in Section 3.2.)

θ is the angle between the surface normal and a ray to the detector.

The perturbation caused by the material filling the duct is assumed to express itself as a change in the scattering intensity within that geometric region and as a change in the component which streams from the duct wall to the detector without suffering a collision. The scattered flux is thus obtained by integrating a last flight estimator over the volume based on a collision density given by the unperturbed flux times the differential angular scattering probability. The direct flux is obtained by integrating an uncollided kernel over the surface of the duct where the local source is given by interpolating the 2D fluxes. The perturbation is then obtained by comparing the results of these calculations with calculations where the volume of concern is filled with shield material.

2.3 ESTIMATOR FOR THE UNCOLLIDED COMPONENT FOR OFF-AXIS DETECTORS

Formulations have been made for calculating the uncollided component to detectors off the duct axis. It will be recalled that the basic method is capable of calculating both a collided and uncollided component on the duct axis, but for off-axis detectors it can only calculate the

collided contribution. The formulation presented here permits an estimate to be made of the enhanced penetration of flux vectors whose paths lie partially within the duct and partially within the surrounding shield.

Consider the case of a ducted shield configuration shown below.

Fig. 2.1. Off-axis detector

In prior formulations the duct was split into increments of lengths and the flux penetrating the duct wall in the inward direction was determined by interpolation between DOT mesh points in the assembly. We now wish to consider only those inward-directed flux components that are in the direction of the detector and pass through some portion of the duct. Since the mesh point-to-detector direction varies from one mesh point to the next a search and interpolation will have to be made to determine the value of the flux vector for each mesh point and energy group.

The complicated geometry is one of the major obstacles in formulating the estimator. The effective area on the duct wall that can radiate toward the detector is given by integrating over all surface areas associated with the duct increment whose normal has a component in the detector direction

$$\int_{\Delta A} \vec{r} \cdot \vec{n} dA \quad , \quad (2.8)$$

where $\bar{r}$ is a unit vector in the direction of the detector and $\bar{n}$ is a unit vector normal to the tangent plane to the surface. It is assumed that the direction $\bar{r}$ is essentially the same for all points on the duct increment or that the distance to the detector is large when compared to the radius of the duct.

It is possible to evaluate the integral over the appropriate area and multiply by the flux vector to get a total "source" in the detector direction but this is inappropriate because it does not account for the varying path lengths through the duct. To account properly for the varying path lengths the surface must be split into azimuthal increments. Some trial and error cases showed that splitting the 180° band into six equal 30° increments provides a reasonable approximation of the projected area. The actual area of each increment is $\frac{\pi r}{6} \Delta t$ and the flux contribution to the detector is

$$\phi(E)_0 = \phi(\bar{r}, E) \bar{r} \cdot \bar{n} \frac{\pi r}{6} e^{-b_1/R^2}, \quad (2.9)$$

where Δt is the length increment, R is the detector-to-area increment separation distance, and b_1 is the integral of total cross section along R . Only three estimates need be made for each length increment because of symmetry effects.

The practical problems in implementing this approach are in the determination of the coordinates of the area mesh points and the vectors $\bar{n}$. Methods for obtaining the other quantities have been mechanized in the estimators for the on-axis detectors. The following sequence of calculations is used in obtaining the coordinates and normal vectors.

1. The end points of the duct centerline are input quantities. Determine the equation of the duct centerline and the equation of a line between the detector and the closest point of approach of the duct axis to the detector.

2. Project the mesh centerpoints along the direction of this line to define a $\varphi = 0$ point on each of the incremental rings around the duct wall. Define circles centered at the duct midpoint passing through these $\varphi = 0$ points.
3. Define points on the circles which are rotated 15° , 45° , and 75° from the $\varphi = 0$ points. Determine the direction cosines of lines from the point to the center of the circle.
4. Determine the direction cosines from each mesh centerpoint to the detector.

This procedure was coded in subroutine OFFAX. It is called on only for evaluating the uncollided component to off-axis detectors. The total off-axis detector response in the presence of the duct is given by

$$\varphi_D(E) = \varphi_{DS}(E) - \left[\left(\varphi_S(E) + \varphi_u(E) \right)_{\text{shield}} - \left(\varphi_S(E) - \varphi_u(E) \right)_F \right], \quad (2.10)$$

where

$\varphi_D(E)$ = the total scalar flux

$\varphi_{DS}(E)$ = the flux at the detector from an unducted shield

$\left(\varphi_S(E) + \varphi_u(E) \right)_{\text{shield}}$ = the sum of collided and uncollided components from the duct assuming the duct is filled with shielding material

$\varphi_S(E) + \varphi_u(E)_R$ = the sum of collided and uncollided components from the duct filling material. $\varphi_S(E) = 0$ if void filled.

2.4 1DF SENSITIVITY CALCULATIONS

To test some of the basic assumptions made in developing the DUCT code, calculations were performed with the cylindrical option of the 1DF⁽⁵⁾ code. The problem coded was a large cylinder of lithium hydride with a fission source in the outer region and a duct in the inner region. The duct was alternately filled with NaK, void, or LiH and was either 1 cm or 2 cm in radius (six calculations total). These calculations were performed to test the assumption that changing the material in the duct region will not have an appreciable effect on the flux components entering the duct wall but will perturb the flux inside the duct and exiting the duct wall.

The geometries associated with the calculations are given in Fig. 2.2 and representative results are given in Tables 2.1 through 2.4. Table 2.1 shows the differences in the flux entering normally through the duct wall are less than 1% in all cases. This close comparison holds even for the lowest energy group, which extends down to 0.4 eV. Table 2.2 compares the flux entering the duct at an angle of 45° . Differences here are on the order of 1% to 2% for the small duct and 1% to 10% for the large duct. From these results it appears that the assumption is quite valid within the range of these tests. Tables 2.3 and 2.4 show that the flux exiting the duct and the flux along the duct centerline are much more seriously perturbed.

SMALL DUCT CALCULATION

LARGE DUCT CALCULATION

Fig. 2.2. Geometry for 1DF DUCT sensitivity calculations

Table 2.1
COMPARISON OF THE FLUX ENTERING NORMALLY
THROUGH THE DUCT WALL

Group	Energy	SMALL DUCT (1 cm Radius)			LARGE DUCT (1 cm Radius)		
		Duct Material					
		NaK	Void	LiH	NaK	Void	LiH
1	14.492	5.37 /-5 [*]	5.38 /-5	5.36 /-5	2.11/-5	2.12/-5	2.11/-5
2	10.00	2.93 /-4	2.94 /-4	2.93 /-4	1.32/-4	1.32/-4	1.32/-4
3	6.703	3.506/-4	3.507/-4	3.502/-4	1.66/-4	1.66/-4	1.66/-4
4	5.488	7.32 /-4	7.32 /-4	7.315/-4	3.51/-4	3.51/-4	3.51/-4
5	4.066	2.90 /-4	2.90 /-4	2.90 /-4	1.33/-4	1.33/-4	1.33/-4
6	3.679	6.72 /-4	6.72 /-4	6.705/-4	2.80/-4	2.84/-4	2.83/-4
7	3.012	8.9 /-4	8.9 /-4	8.87 /-4	3.84/-4	3.85/-4	3.83/-4
8	2.466	4.47 /-4	4.47 /-4	4.46 /-4	1.87/-4	1.87/-4	1.86/-4
9	2.231	4.50 /-4	4.50 /-4	4.48 /-4	1.84/-4	1.87/-4	1.83/-4
10	2.019	1.04 /-3	1.04 /-3	1.04 /-3	4.42/-4	4.42/-4	4.39/-4
11	1.653	1.04 /-3	1.04 /-3	1.036/-3	4.27/-4	4.27/-4	4.24/-4
12	1.353	5.7 /-4	5.69 /-4	5.67 /-4	2.45/-4	2.45/-4	2.43/-4
13	1.224	5.75 /-4	5.75 /-4	5.74 /-4	2.43/-4	2.43/-4	2.42/-4
14	1.108	1.123/-3	1.123/-3	1.12 /-3	4.67/-4	4.67/-4	4.64/-4
15	.907	2.89 /-2	2.89 /-2	2.88 /-2	8.86/-3	8.85/-3	8.71/-3

^{*}(5.37/-5 = 5.37×10^{-5})

Table 2.2
COMPARISON OF THE FLUX ENTERING THE DUCT WALL
AT 45° TO THE AXIS

Group	Energy	SMALL DUCT (1 cm Radius)			LARGE DUCT (1 cm Radius)		
		Duct Material					
		NaK	Void	LiH	NaK	Void	LiH
1	14.492	4.87/-5*	4.86/-5	4.91/-5	2.05/-5	2.05/-5	2.04/-5
2	10.00	2.67/-4	2.67/-4	2.69/-4	1.28/-4	1.35/-4	1.27/-4
3	6.703	3.65/-4	3.20/-4	3.24/-4	1.59/-4	1.59/-4	1.59/-4
4	5.488	6.73/-4	6.72/-4	6.79/-4	3.35/-4	3.35/-4	3.03/-4
5	4.066	2.66/-4	2.66/-4	2.69/-4	1.28/-4	1.28/-4	1.16/-4
6	3.679	6.15/-4	6.13/-4	6.19/-4	2.74/-4	2.74/-4	2.52/-4
7	3.012	8.17/-4	8.16/-4	8.22/-4	3.69/-4	3.69/-4	3.67/-4
8	2.466	4.11/-4	4.11/-4	4.14/-4	1.80/-4	1.80/-4	1.79/-4
9	2.231	4.15/-4	4.14/-4	4.17/-4	1.77/-4	1.78/-4	1.76/-4
10	2.019	9.65/-4	9.64/-4	9.70/-4	4.24/-4	4.24/-4	4.21/-4
11	1.653	9.65/-4	9.65/-4	9.70/-4	4.11/-4	4.11/-4	4.07/-4
12	1.353	5.31/-4	5.31/-4	5.34/-4	2.34/-4	2.33/-4	2.32/-4
13	1.224	5.38/-4	5.38/-4	5.41/-4	2.33/-4	2.33/-4	2.31/-4
14	1.108	1.05/-3	1.05/-3	1.06/-3	4.48/-4	4.48/-4	4.44/-4
15	.907	2.09/-2	2.89/-2	2.87/-2	8.69/-3	8.69/-3	8.19/-3

*(4.87/-5 - 4.87×10^{-5})

Table 2.3
COMPARISON OF THE FLUX EXITING NORMALLY
THROUGH THE DUCT WALL

Group	Energy	SMALL DUCT (1 cm Radius)			LARGE DUCT (1 cm Radius)		
		Duct Material					
		NaK	Void	LiH	NaK	Void	LiH
1	14.492	1.36 /-5 [*]	1.36/-5	1.28/-5	1.97/-5	2.12/-5	1.71/-5
2	10.00	7.29 /-5	7.46/-5	6.69/-5	1.24/-4	1.32/-4	1.04/-4
3	6.703	8.734/-5	8.84/-5	7.82/-5	1.57/-4	1.66/-4	1.26/-4
4	5.488	1.844/-4	1.83/-4	1.63/-4	3.35/-4	3.51/-4	2.61/-4
5	4.066	7.48 /-5	7.29/-5	6.58/-5	1.29/-4	1.33/-4	1.01/-4
6	3.679	1.73 /-4	1.69/-4	1.57/-4	2.76/-4	2.84/-4	2.24/-4
7	3.012	2.3 /-4	2.23/-4	2.06/-4	3.73/-4	3.84/-4	2.96/-4
8	2.466	1.18 /-4	1.12/-4	1.05/-4	1.86/-4	1.87/-4	1.47/-4
9	2.231	1.185/-4	1.13/-4	1.07/-4	1.83/-4	1.84/-4	1.46/-4
10	2.019	2.72 /-4	2.61/-4	2.46/-4	4.37/-4	4.41/-4	3.41/-4
11	1.653	2.71 /-4	2.61/-4	2.50/-4	4.25/-4	4.26/-4	3.35/-4
12	1.353	1.47 /-4	1.41/-4	1.34/-4	2.41/-4	2.44/-4	1.84/-4
13	1.224	1.49 /-4	1.43/-4	1.36/-4	2.41/-4	2.43/-4	1.85/-4
14	1.108	2.9 /-4	2.8 /-4	2.7 /-4	4.60/-4	4.67/-4	3.59/-4
15	.907	7.69 /-3	7.20/-3	9.95/-3	8.85/-3	8.84/-3	7.83/-4

* (1.36/-5 = 1.36×10^{-5})

Table 2.4

COMPARISON OF THE FLUX IN THE DIRECTION OF
THE DUCT AXIS ALONG THE CENTERLINE

Group	Energy	SMALL DUCT (1 cm Radius)			LARGE DUCT (1 cm Radius)		
		Duct Material					
		NaK	Void	LiH	NaK	Void	LiH
1	14.492	2.10/-5*	2.23/-5	1.99/-5	9.11/-6	1.00/-5	8.64/-6
2	10.00	9.25/-5	8.94/-5	7.91/-5	5.39/-5	5.01/-5	3.98/-5
3	6.703	1.07/-4	9.77/-4	8.67/-5	6.50/-5	5.29/-5	4.40/-5
4	5.488	2.50/-4	2.19/-4	1.93/-4	1.55/-5	1.13/-4	9.70/-5
5	4.066	1.19/-4	1.03/-4	9.10/-5	7.28/-5	5.22/-5	4.54/-5
6	3.679	3.18/-4	2.93/-4	2.57/-4	1.77/-4	1.42/-4	1.25/-4
7	3.012	4.11/-4	3.71/-4	3.26/-4	2.29/-4	1.75/-4	1.55/-4
8	2.466	2.28/-4	2.03/-4	1.78/-4	1.27/-4	9.42/-5	8.35/-5
9	2.231	2.39/-4	2.18/-4	1.90/-4	1.28/-4	9.98/-5	8.88/-5
10	2.019	5.32/-4	4.84/-4	4.20/-4	2.83/-4	2.18/-4	1.94/-5
11	1.653	5.64/-4	5.24/-4	4.53/-4	2.90/-4	2.34/-4	2.09/-4
12	1.353	2.94/-4	2.75/-4	2.36/-4	1.49/-4	1.21/-4	1.08/-4
13	1.224	3.06/-4	2.86/-4	2.46/-4	1.55/-4	1.26/-4	1.13/-4
14	1.108	6.18/-4	5.86/-4	5.02/-4	3.08/-4	2.58/-4	2.30/-4
15	.907	2.62/-2	2.70/-2	2.01/-2	8.46/-3	8.39/-3	7.01/-3

* (2.10/-5 = 2.10×10^{-5})

3. DUCT CODE IMPLEMENTATION

3.1 GENERAL DESCRIPTION OF THE CODE

The duct analysis program consists of these modules:

1. Group averaged cross-section routines
2. Two-dimensional discrete ordinates calculation (DOT)
3. Duct flux perturbation analysis program (DUCT).

The first module produces group-averaged cross sections in DTF-IV⁽⁵⁾ or DOT⁽³⁾ format on punched cards. For neutron problems, GGC-4⁽⁴⁾ has been used; GAMLEG⁽⁶⁾ could be used for gamma-ray problems; for coupled neutron-gamma problems, one would use a neutron code such as GAM, a gamma-ray code GAMLEG, a secondary gamma-ray production code like POPOP4,⁽⁷⁾ and a coupling code to combine the cross sections into one set. The cross section cards are input to both the DOT and DUCT modules.

The second module consists of a two-dimensional discrete ordinates calculation of the unducted shield. The DOT calculation produces an "angular flux tape" containing the unperturbed angular flux for every radial, axial, and quadrature angular integral in the region of interest, which contains all, or part of, the shield and perhaps a small void volume nearby. The DOT angular flux tape may then be used for many different duct configurations. The DUCT module contains the general O5R⁽⁸⁾ geometry package (GEOM) for tracing last flight paths through complex geometries.

Briefly, the DUCT code sets up a mesh within the duct. It then calculates two flux contributions from each mesh point to each detector. The first contributions are uncollided particles crossing the duct wall; the second consists of particles which have scattered in the duct. The two contributions are summed over the duct for the original shield configurations and then again for some duct-filling material (coolant or void). The difference between the flux estimates at a detector constitutes a perturbation to the flux at that detector point, resulting from the presence of the new material in the duct. Adding the perturbation to the unperturbed flux gives an estimate of the perturbed flux.

The list of the FORTRAN coding of the various subroutines are given in Appendix A. A production version incorporating coupled neutron and gamma calculations will be published on January 30, 1971.

3.2 CALCULATIONAL FLOW SEQUENCE

The principal functions of the main routine of the DUCT program are to set up the addresses in blank common for variable dimensioned arrays and to call subroutines. As shown in Fig. 3.1, it calls seven subroutines, some of which call other subroutines. A description of the function of each of the seven subroutines may help clarify the logic of the DUCT program. Calculations performed by satellite routines will be, for purposes of this discussion, part of the function of the calling routine.

AFTRD, the first subroutine called, reads everything of value on the angular flux tape, except the angular fluxes themselves. That is, it reads control integers, array sizes, quadrature weights, radii, and axii. Then it positions the tape ready for reading the angular fluxes. Incidentally, it calculates the midpoints of radial and axial intervals.

PRELEV reads the r- and z-quadrature cosines, $\mu(m)$ and $\eta(m)$, respectively, from cards and prints the r-, z- and ϕ -quadrature cosines (μ, η, ξ) and the weights $W_o(m)$.

Fig. 3. 1. Calculational flow sequence for DUCT
(Sheet 1 of 2)

Fig. 3.1. Calculational flow sequence for DUCT
(Sheet 2 of 2)

DUCTRD reads information on cards about the duct, but its main function is to set up integration meshes. For example, it divides the duct into subintervals called "duct points". They are not, in fact "points"; but, for the purpose of the uncollided calculation, segments of the surface of the duct wall; and, for the purpose of the once-collided calculation, segments of the duct's volume. The "end-plate", or the flat surface of the duct nearest the source, is subdivided into annular rings. The quadrature angles are grouped into "levels". Pertinent information about each mesh interval is calculated and stored.

JOMIN reads information for the GEOM package about the shield geometry, checks for obvious blunders, and stores the information in a form usable later by the GEOM package. (See RSIC CCC-17 for details about GEOM input - ORNL 3622.)

SHIELD reads the cross sections, but its main function is to determine, for each duct material, mesh point (duct point or end plate ring), energy group, detector, and uncollided and once-collided flux contributions from a unit angular flux vector. Scattering probability is not considered here. SHIELD makes use of the GEOM package to determine the mean free paths between mesh point and detector.

COEFF searches the DOT spacial mesh to find points in the vicinity of each duct mesh point. When it finds them, it assigns them coefficients based on their proximity to the duct point and tags them. This will be used to determine the angular flux at duct points by interpolation.

SCATSB has the function of folding the angular fluxes with the unit vector contributions to produce scalar fluxes at the detectors, which it prints. For each energy group, it reads the angular fluxes from the tape and interpolates to determine the angular fluxes at the mesh points. For the uncollided flux, the most appropriate angular flux vector or "level" is selected from the quadrature set, multiplied by the unit vector contribution

determined by SHIELD, and summed over mesh points. For the once-collided flux, each angular flux vector is multiplied by $P(\theta)$, the probability of scattering from that angle toward the detector, then multiplied by the unit vector contribution determined by SHIELD, and then summed over all angles in the quadrature set and over mesh points. Scalar fluxes are printed as a function of energy group, duct material, and detector.

3.3 CALCULATION OF THE LITHIUM HYDRIDE SHIELD EXPERIMENT

The first test for the DUCT code was an attempt to simulate a neutron shield applicable to the SNAP type shield. This shield consists of a lithium hydride shield with sodium coolant holes.

Fifteen-group P_3 neutron cross sections for lithium hydride, steel, and sodium were generated by GGC-4. The atomic densities used are listed in Table 3.1; the energy group structure is listed in Table 3.2. The same cross sections were used for the DOT, DUCT, and MORSE⁽⁹⁾ calculations to follow, except that the format had to be converted for DOT.

The shield was represented in the DOT calculation as a cylinder with radius 25.4 cm and height 25.4 cm, having 22 radial intervals and 22 axial intervals. The top two and bottom two axial intervals and the outermost two radial intervals used steel cross sections; the others were LiH. An asymmetric 100-angle quadrature set with 76 downward and 24 upward angles was selected in an attempt to prevent ray effects. The spacial mesh was nonuniform, but a rule was followed that no interval be more than twice as wide as its neighbor.

The source was represented by a top boundary source in the first six downward angles. The source varied with energy group according to the measured source spectrum and with radial interval according to the

Table 3.1
DENSITIES FOR DUCT SHIELD CALCULATION

Lithium Hydride
($\rho=0.55 \text{ gm/cm}^3$)

Element	Atomic Density (atoms/cm ³)
H	0.041735×10^{24}
Li ⁶	0.003097×10^{24}
Li ⁷	0.038638×10^{24}

Stainless Steel
No. 304

Element	Atomic Density (atoms/cm ³)
Cr	0.01851×10^{24}
Fe	0.05901×10^{24}
Ni	0.008529×10^{24}

Sodium
($\rho=0.96 \text{ gm/cm}^3$)

Element	Atomic Density (atoms/cm ³)
Na	0.02516×10^{24}

Table 3.2
BROAD GROUP ENERGY STRUCTURE FOR
LITHIUM HYDRIDE DUCT SHIELD CALCULATIONS

Group	Energy Interval		Lethargy Interval	
	(eV)			
1	1.491825+07	to 8.187308+06	-4.00000-01	to 2.00000-01
2	8.187308+06	to 5.488116+06	2.00000-01	to 6.00000-01
3	5.488116+06	to 4.493290+06	6.00000-01	to 8.00000-01
4	4.493290+06	to 3.678795+06	8.00000-01	to 1.00000+00
5	3.678795+06	to 3.011942+06	1.00000+00	to 1.20000+00
6	3.011942+06	to 2.465970+06	1.20000+00	to 1.40000+00
7	2.465970+06	to 2.018965+06	1.40000+00	to 1.60000+00
8	2.018965+06	to 1.652989+06	1.60000+00	to 1.80000+00
9	1.652989+06	to 1.353353+06	1.80000+00	to 2.00000+00
10	1.353353+06	to 1.108032+06	2.00000+00	to 2.20000+00
11	1.108032+06	to 7.427359+05	2.20000+00	to 2.60000+00
12	7.427359+05	to 4.978708+05	2.60000+00	to 3.00000+00
13	4.978708+05	to 1.110900+05	3.00000+00	to 4.50000+00
14	1.110900+05	to 1.013010+02	4.50000+00	to 1.15000+01
15	1.013010+02	to 4.139940-01	1.15000+01	to 1.70000+01

measured beam profile discussion in Section 4.2. The source-shield geometry is shown in Fig. 3.2.

The point scaling convergence acceleration technique was used, and the flux was required to converge everywhere to within 0.001. The calculation required 61 minutes on the UNIVAC 1108. Negative fluxes were observed in some groups for upward angles, where physically the flux should be zero or very close to zero. Nevertheless, we judged the DOT calculated to be quite satisfactory. The angular flux tape from the DOT calculations was used as input to numerous DUCT calculations.

In the DUCT calculations, the duct was represented by a cylinder 2.54 cm in radius completely penetrating the shield with its axis coinciding with the axis-of-symmetry of the shield. The rest of the geometry of the shield was input to the GEOM package, with the requirement that the duct be re-input as the first quadratic surface for GEOM.

DUCT calculations were run for three detector positions with shield, sodium, or void in the duct. In each case the objective is to calculate the flux crossing the duct wall or colliding within the duct and reaching the detector. Comparing such calculations for a shield-filled duct and a sodium- or void-filled duct gives $\Delta\phi = \phi_{Na}$ or $V^{-1}\phi_{Shield}$, the flux perturbation due to the duct. If the unperturbed flux ϕ_V is known at the detector location, then the predicted scalar flux is $\phi = \phi_V + \Delta\phi$.

To "know" the unperturbed flux at the detector location requires that it be available from the DOT calculation. For detectors at or in the shield, simple interpolation of the DOT fluxes will suffice. For detectors near the shield it is therefore recommended that the DOT calculation contain void intervals which themselves contain the proposed detector sites. For detectors far from the shield, surface integration of the DOT fluxes and their projection to the detector, such as is done in SPACETRAN,⁽¹⁰⁾ is required to determine the unperturbed flux.

Fig. 3. 2. Source-shield geometry for DUCT calculation of the lithium hydride duct shield experiment

Since the actual DOT calculation did not contain void intervals surrounding the detectors, the unperturbed fluxes were found from DUCT calculations with shield-filled ducts pointing at the detectors. This method is not recommended for general problems, but was adequate for the particular experimental configuration.

Besides comparison with the experiment and Monte Carlo, several checks were made on the range of validity of the DUCT method. Placing a point detector directly at the exit face of the duct provides an excellent opportunity to compare the shield-filled DUCT flux with an extrapolated DOT flux.

The first test consisted of comparing the DUCT-calculated scalar flux with the DOT-extrapolated scalar flux for a detector at the duct exit. The results are shown in Table 3.3. One can see that the differences between the two increase as the hole diameter increases. However, for the first two energy groups, $E > 5.0$ MeV, the agreement is only 15% even for a 1/2-in.-diameter hole. This is due to the extremely forward peaking of the angular flux in this energy region. Since this is an extreme test for the range of validity for a typical duct streaming problem, we feel the agreement is reasonable. Table 3.4 shows the effect of hole diameter on the detector scalar flux for a duct-filled with sodium.

The hole diameter used in the experiment was 5.08 cm. The calculated DOT extrapolated fluxes and the DUCT shield fluxes shown in Table 3.5 again are in good agreement for E below 4.0 MeV, but the agreement at higher energies is not as good. We believe, these discrepancies are partly due to the extrapolation of the DOT fluxes out to the void region. As will be shown in Section 5, agreement between the DUCT calculated and measured fluxes is much better.

Table 3.3
SHIELD FLUX VS HOLE DIAMETER

<u>Group</u>	<u>1.27 cm</u>	<u>2.54 cm</u>	<u>5.08 cm</u>	<u>10.16 cm</u>	<u>Extrapolated DOT FLUX</u>
1	0.72977-05	0.78604-05	0.86424-05	0.97884-05	0.61828-05
2	0.74886-05	0.80816-05	0.89906-05	0.10288-04	0.64556-05
3	0.61735-05	0.64946-05	0.70909-05	0.79679-05	0.57137-05
4	0.64153-05	0.65659-05	0.69793-05	0.76470-05	0.63515-05
5	0.76041-05	0.77412-05	0.82021-05	0.90074-05	0.78114-05
6	0.79929-05	0.81259-05	0.86508-05	0.95712-05	0.83798-05
7	0.72559-05	0.73799-05	0.78772-05	0.87099-05	0.76136-05
8	0.18037-04	0.17993-04	0.18741-04	0.19823-04	0.18916-04
9	0.20330-04	0.20578-04	0.21416-04	0.22011-04	0.21906-04
10	0.60966-05	0.61871-05	0.64095-05	0.65175-04	0.66287-05

Table 3.4
SODIUM FLUX VS HOLE DIAMETER

<u>Group</u>	<u>1.27 cm</u>	<u>2.54 cm</u>	<u>5.08 cm</u>	<u>10.16 cm</u>
1	0.95748-05	0.12445-04	0.13691-04	0.14236-04
2	0.94629-05	0.12137-04	0.13523-04	0.14361-04
3	0.79257-05	0.99711-05	0.11206-04	0.12223-04
4	0.78402-05	0.91916-05	0.10095-04	0.10979-04
5	0.10400-04	0.13186-04	0.14671-04	0.15623-04
6	0.12324-04	0.17313-04	0.19829-04	0.20646-04
7	0.83599-05	0.93225-05	0.99388-05	0.10450-04
8	0.21925-04	0.27135-04	0.30988-04	0.32545-04
9	0.24301-04	0.26319-04	0.29064-04	0.31028-04
10	0.75263-05	0.79921-05	0.89466-05	0.10189-04

Table 3.5

Group	Midpoint Energy (eV)	Sodium Flux	Shield Flux	Extrapolated DOT Flux
1	1.1553+07	2.9580-05	1.1438-05	8.0474-06
2	6.8377+06	2.9941-05	1.2401-05	8.6227-06
3	4.9907+06	1.3470-05	5.4256-06	4.0434-06
4	4.0860+06	1.1804-05	4.5934-06	3.7624-06
5	3.3454+06	1.1336-05	4.6786-06	4.0841-06
6	2.7390+06	9.3487-06	4.6561-06	4.1727-06
7	2.2425+06	1.1389-05	4.8759-06	4.5332-06
8	1.8360+06	2.1347-05	5.2789-06	5.0306-06
9	1.5032+06	2.6011-05	5.4839-06	5.2414-06
10	1.2307+06	2.3532-05	5.3740-06	5.0865-06
11	9.2538+05	1.9202-05	9.8211-06	9.2293-06
12	6.2030+05	1.8140-05	8.4662-06	8.0136-06
13	3.0448+05	3.7951-05	1.5699-05	1.5426-05
14	5.5596+04	3.6542-05	2.5518-05	2.5837-05
15	5.0857+01	1.1876-05	7.5485-06	7.7993-06

3.4 COMPARISON WITH MONTE CARLO CALCULATION

A MORSE⁽⁹⁾ Monte Carlo calculation was performed for the experimental configuration with sodium in the duct. Detector No. 1 was represented by a point one inch from the shield on the duct axis. The scattered flux was calculated by last-flight estimation from each collision site. The source was represented by a circular beam six inches in radius with its center on the duct axis. The general O5R geometry package (GEOM) was used.

A number of short preliminary calculations were run to check out coding of the user routines, variance reduction techniques (biasing), and proper representation of the problem.

The final calculation involved 84 batches of 100 neutrons each. Each neutron started from some point in the 6-in.-radius circle on the top surface of the shield. Its distance from the center of the circle was selected uniformly from 0 in. to 6 in. and its weight adjusted by

$$WATE = 2*WATE*RADIUS/BEAM \quad ,$$

where RADIUS is its distance and BEAM = 6 in., to account for the fact that the circular area was not sampled uniformly. Its direction from the center of the circle was selected randomly. Its starting direction cosines were (0,0,1), that is, normal incidence.

The initial energy group of the neutron was selected from the 15 groups not according to the natural source energy distribution but from a biased distribution which favored the higher energy groups; MORSE adjusted its weight to compensate for the source biasing.

The path length of each flight was selected not from the natural exponential distribution but from a transformed exponential distribution which encouraged longer paths near the favored downward direction and

shorter paths near the upward direction. The parameter PATH = 0.5 was used; MORSE adjusts the weight to account for the path length biasing.

At the end of each flight path is a collision site; since absorption is not allowed, the neutron's weight is suitably multiplied by a nonabsorption probability. A last-flight estimate is then made, contributing

$$P(\theta)*WATE*EXP(-ARG)/R^2$$

to the scalar scatter flux at the detector for every energy group into which the neutron could possibly scatter from its present group. Then the neutron is allowed to launch its next flight in a newly determined direction with path length selected from the transformed exponential distribution.

Whenever the neutron achieved a weight greater than 10, it was split. This happened rarely, only 622 times, and only below 1 MeV. When the neutron's weight was less than 0.1, it was forced to play Russian Roulette or escaped from the shield. After each batch of 100 initial neutrons was completed, the detector flux estimate and its square were accumulated.

At the end of the 84 batches, the scattered flux and its fractional standard deviation were calculated for each energy group, the scattered flux was added to the direct flux, and the results divided by the group width in MeV. The final units of the flux were (neutrons/cm²-MeV)/(incident neutron-cm⁻²). Eighty thousand, four-hundred eighty-two scattering events contributed to the flux estimates. The fractional standard deviation of the scattered flux ranged from 5 to 20 percent.

Fifteen-group P₃ group averaged cross sections generated by GGC-4 were used in the calculation. The discrete angle group-to-group scattering option in MORSE appeared to operate erratically in the

preliminary calculations. As a check on this option, the isotropic scattering option was used for particle track generation in combination with the full P_3 expansion to determine $P(\theta)$ for the last flight estimates.

A comparison with the DUCT calculation is shown in Fig. 3.3. In general the agreement varies between 10 to 20% with the DUCT calculations consistently higher, except for the lowest two energy groups. This could be due partly to the source area normalization used. Recall that the MORSE calculations were based on one incident neutron per cm^2 while the DOT calculation is based on one source neutron. The DUCT results were therefore multiplied by the source area. However, the MORSE calculations had a uniform source intensity with a 6-in. radius while the DOT source intensity (see Fig. 4.3) was uniform out to 4.2 in. and fell off linearly to 8.0 in. To normalize the two results to the same effective source, the DUCT calculations were multiplied by an effective area determined by the following:

$$A = 2\pi \int_0^8 I(r) r dr = 2\pi \int_0^{4.2} 1 \cdot r dr + 2\pi \int_0^{8.0} f(r) r dr,$$

where $f(r) = 2.10 - 0.263 r$.

Fig. 3. 3. Comparison between DUCT and MORSE calculated axial responses

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4. EXPERIMENTAL PROGRAM

4.1 PURPOSE OF EXPERIMENT

The experimental program for this research project is divided into two efforts. The first, which will be discussed in this report, is a simple, clean experiment to check the approximations and methods implemented in Section 3. The second experimental effort, to be performed during FY-71, is a shield mockup of the NERVA-BATH shield assembly with coolant holes; both neutron spectra and secondary gamma-ray production and transport will be measured.

The experiments conducted during the current reporting period consisted of measuring the effect of an axial void or sodium-filled duct on the neutron flux emerging from a 50.8-cm-diameter by 25.4-cm-thick cylindrical lithium hydride shield. This shield assembly is designed to simulate a SNAP shield.

4.2 DESCRIPTION OF EXPERIMENT

4.2.1 Neutron Source

The experimental layout for the experiment is shown in Fig. 4.1. Photo-neutrons were produced in the tantalum-beryllium converter bombarded by 50-MeV electrons from the Gulf Radiation Technology (GRT) linear accelerator. This converter has been extensively used in several previous programs^(11, 12) at GRT and has provided the source spectrum shown in Fig. 4.2; this is the measured spectrum with a 2.54-cm-thick lead and 3.08-cm-thick uranium filter to attenuate the gamma flash overload.

Fig. 4.1. Experimental layout for the lithium hydride duct shield experiment

Fig. 4. 2. Measured source spectrum for the lithium hydride duct shield experiment

Neutrons produced in the tantalum-beryllium target were then collimated to provide a parallel plane circular beam at 52 meters. The calculated beam profile is shown in Fig. 4.3. This profile was calculated with the CAP code and was verified experimentally. The source spectrum was then multiplied by this spatial distribution function and the resulting product was then used as the boundary input source for the DOT calculation.

4.2.2 Duct Shield Assembly

The shield assembly for this study was a 50.8-cm-diameter by 25.4-cm-thick cylindrical assembly, as shown in Fig. 4.4. The assembly was fabricated with 3/16-in.-thick stainless steel for structural purposes. The duct for this study was a 5.08-cm-diameter axial hole. Stainless steel probes filled with either sodium or lithium hydride were then used for the duct material. A photograph of the assembly in situ at the end of the 50-meter flight path is shown in Fig. 4.5.

The shielding assembly was filled with lithium hydride powder obtained from the Lithium Corporation of America. Since lithium hydride powder is quite volatile when subjected to moisture, the assembly was filled in a large glove box arrangement. The assembly was vibrated to attain maximum compaction, the density as measured by the water displacement method was $\rho = 0.55$ gms/cc; the lithium hydride probe tube was filled in the same manner.

The second probe tube was filled with sodium in the following manner. Sodium pellets ranging from 1/8 in. to 1/4 in. in diameter were poured into the probe tube. The cylinder was then sealed and placed in an oven. Since metallic sodium melts at 97.5°C , a solid cylinder was obtained by repeating this procedure three times. The measured resulting density was 0.97 g/cc.

Fig. 4. 3. Calculated beam profile for the lithium hydride duct shield experiment

Fig. 4.4. Lithium hydride duct shield assembly

Fig. 4.5. Lithium hydride duct shield assembly

4.2.3 Source Monitoring System

All measurements were normalized to the source monitor as part of the data analysis. The source monitor used was the product of two terms: (1) the average neutron flux (neutrons/sec $\cdot$ cm²) at the flux monitor position; and (2) the counting time. Two identical flux monitors were used for each measurement. They were positioned together on the flight path axis at a distance of 31.8 inches (80.8 cm) from the center of the beryllium block. The flux monitors were 0.50-inch-diameter by 0.50-inch-thick disks of 1100 aluminum. Neutron flux was measured using the $^{27}\text{Al}(n, \alpha)^{24}\text{Na}$ reaction. This reaction was used because its threshold is in the MeV range (3.26 MeV), and the half-life of its product is well known ($\pm 0.1\%$) and is much longer than the half-lives of other reaction products present. The other reactions are the $^{27}\text{Al}(n, p)^{27}\text{Mg}$ reaction with threshold at 1.89 MeV and the $^{27}\text{Al}(n, \gamma)^{28}\text{Al}$ reaction. The half-life of ^{24}Na is 14.96 hours whereas the half-lives of ^{27}Mg and ^{28}Al are 9.5 minutes and 2.3 minutes, respectively. Hence, the activated aluminum disks were allowed to decay until the only significant reaction product remaining was ^{24}Na . The effect of $^{23}\text{Na}(n, \gamma)^{24}\text{Na}$ reactions which result from neutron capture by sodium impurities in the aluminum was measured and found to be negligible. Sodium 24 emits two gamma rays with energies of 1.369 and 2.754 MeV for each decay. These gamma rays were counted using a well type NaI(Tl) scintillator which was biased just above the Compton edge of the 1.369-MeV gamma ray. This bias level was selected as one where the counting efficiency is relatively high but the sensitivity of the efficiency to small gain changes is relatively low. The counts due to ^{24}Na decays were converted to neutron flux using the equation

$$\text{Flux} = \frac{K \left[F(t_c) - B(t_c) \right] e^{\lambda t_w}}{M(1 - e^{-\lambda t_i})(1 - e^{-\lambda t_c})}, \quad (4.1)$$

where

$F(t_c)$ = foreground counts obtained during counting time t_c

$B(t_c)$ = background counts obtained during equal time t_c

t_i = irradiation time of aluminum disk

t_w = waiting time between end of irradiation and the beginning of counting

M = mass of aluminum disk

λ = ^{24}Na decay constant = $\ln 2 / 14.96$ hours

K = constant depending on detector efficiency, activation cross section, atom number density, and decay constant.

Because only relative neutron flux is needed, $K = 1$ was used. Each activated disk was counted at least twice, and over 10,000 counts were obtained each time. Gain stability and background were monitored regularly. The aluminum disks were activated in pairs during each measurement and the two resulting neutron fluxes always agreed within 1%.

In addition to the aluminum monitors, two ^3He proportional counters located at the 16-meter station were used as additional monitors. These two detectors generally tracked each other to within $\pm 2\%$. By checking the ratio of the aluminum monitor response to each of the ^3He detector responses, it was possible to obtain a monitor reliability of $\pm 3\%$.

4.3 DATA ACQUISITION

During a previous GRT program,⁽¹²⁾ a new experimental method was developed for studying simultaneously fast-neutron transport and secondary gamma-ray production and transport in shields. With this method, an electron accelerator is used to produce intense 50-nsec pulses of photoneutrons. These neutrons stream down an evacuated 52-meter long drift tube to strike a shield assembly. An NE-213 detector is positioned immediately behind the shield assembly to detect both fast neutrons and secondary gamma rays produced in a shield assembly by $(n, x\gamma)$ and (n, γ) reactions.

A simplified block diagram of the three-parameter data acquisition system used with the NE-213 detector is shown in Fig. 4.6. Three parameters, t , h , and x , are recorded for each detection event. The time parameter t is the time interval between the Linac pulse and the detection event; the pulse-height parameter h is proportional to the light produced in the NE-213 scintillator by neutron and gamma-ray interactions; and the pulse-shape discrimination parameter x identifies detection events as due to neutrons or gamma rays. The key features of each parameter are discussed next.

4.3.1 Time Parameter

The time parameter is related to the energies of neutrons incident on the concrete rather than the energies of neutrons leaking from the concrete. This is true because the shield assembly is located at the end of the flight path near the detector rather than at the beginning near the pulsed neutron source as it would be for a conventional time-of-flight shielding experiment. The present geometry arrangement is also used for $(n, x\gamma)$ and (n, γ) reaction studies.⁽¹²⁾ The only approximation in uniquely relating time to incident neutron energy occurs because:

Fig. 4.6. Simplified diagram of the three-parameter data acquisition system

(1) downscattered neutrons take slightly longer to reach the detector than uncollided neutrons of the same incident energy, and (2) secondary gamma rays produced by $(n, x\gamma)$ reactions in the concrete may reach the detector slightly before or slightly after neutrons of the same incident energy as those which produced them. In both cases the time differences are small compared to the uncollided neutron flight times because: (1) the thickness of the shield is much less ($< 2\%$) than the length of the flight path and (2) most of the downscattered neutrons and secondary gamma rays which are detected result from first collision neutron interactions near the detector.

The time scale may be naturally divided into two regions. For short times ($t < 4 \mu\text{sec}$), detection events due to: (1) neutrons with energies above the detector threshold at 0.9 MeV ($t = 4.0 \mu\text{sec}$), and (2) gamma rays produced by $(n, x\gamma)$ reactions with threshold at 1.3 MeV ($t = 3.3 \mu\text{sec}$) are recorded. These events may be analyzed and interpreted in either the time domain or incident neutron energy domain. The results are completely equivalent within the abovementioned approximation.

However, for long times ($t > 4 \mu\text{sec}$), neutrons are not detected and only gamma rays produced by (n, γ) reactions are detected. Because these reactions may be due to uncollided neutrons, slowing-down neutrons, and/or thermalized neutrons, time and incident neutron energy cannot be uniquely related. Thus, these data are analyzed only in the long time domain. In summary, the data which are obtainable are categorized as due to:

1. Short time or fast neutrons ($E > 0.8 \text{ MeV}$, $t < 4.0 \mu\text{sec}$)
2. Short time $(n, x\gamma)$ or inelastic gamma rays ($t < 3.3 \mu\text{sec}$)
3. Long time (n, γ) or capture gamma rays ($t > 3.3 \mu\text{sec}$).

4.3.2 Pulse Height Parameter

Although the pulse height parameter varies linearly with the light produced in the NE-213 scintillator by neutron and gamma-ray interactions, the light varies between zero and some maximum energy which is near the energy of the incoming neutron or gamma ray. As a result, the pulse height parameter is most often used only to discriminate against noise or low-energy interactions. However, thanks to the work of Burrus and Verbinski,^(13,14) a reasonably good method for extracting energy spectra from such pulse height spectra is available. Burrus' code, FERDOR,⁽¹³⁾ is used with measured neutron and gamma-ray response matrices to unfold the pulse-height spectra due to neutrons and gamma rays, respectively. The resulting spectra are the energy spectra of the leakage neutrons and gamma rays from the shield assembly.

Recall that the time parameter t identifies the energies of the incident neutrons. If the pulse height spectrum for neutron events that were detected in some time bin Δt about t are unfolded, the resulting neutron energy spectrum shows a peak corresponding to the incident neutrons in E about E that traverse the concrete without collision and a lower energy portion due to downscattered neutrons. Also for short times ($t < 3.3 \mu\text{sec}$), the spectrum of leakage inelastic gamma rays can be correlated with the incident neutron energy. For longer times, the spectrum of leakage capture gamma rays is obtained as a function of time, but without correlation to the incident neutron energy.

4.3.3 Pulse Shape Discrimination Parameter

The conventional zero-crossover timing technique is used to identify detection events due to neutrons or gamma rays. Ordinarily, the pulse shape discrimination (PSD) parameter is not recorded for each event, but is used only on-line to tag events as due to neutrons or gamma

rays. To improve the accuracy of identification, the PSD parameter is recorded for each event; then the PSD parameters are analyzed off-line as a function of pulse height to tag events according to origin.

A simplified block diagram of the three-parameter data acquisition system is shown in Fig. 4.6. A detailed diagram is shown in Fig. 4.7. The only omissions from the latter diagram are impedance matching devices and eight scalars which were used to monitor data acquisition. The timing parameters shown on this figure are those used for the final measurements.

4.3.4 Three-Parameter Data Acquisition Code, TRIPAC

The three-parameter data acquisition code, TRIPAC,⁽¹¹⁾ was used to record (t,h,x) triplets on a magnetic disk. As options, TRIPAC performs both on-line and off-line analysis. TRIPAC is written in FORTRAN-IV (90%) and machine language (10%) for the CDC-1700 computer. After the magnetic disk is filled, data are transferred to magnetic tape for later off-line analysis using either the CDC-1700 or Univac 1108 computers.

During measurements, the on-line analysis option is used to provide information for monitoring the experiment. The analysis generates the seven spectra listed in Table 4.1.

TRIPAC consists of two principal routines: a main routine that controls computer operations except when preempted by the interrupt routine. The main routine transfers data from core buffers to a magnetic disk, controls scope display, and responds to input instructions from the teletype keyboard. The interrupt routine responds to interrupt signals from the time analyzer by transferring (t,h,x) triplets from the registers of the time analyzer and the two ADC to the core buffer and by performing analysis, if requested.

Fig. 4.7. Detailed block diagram of the three-parameter data acquisition system

Table 4. 1
ANALYSIS PERFORMED BY TRIPAC CODE

<u>Spectrum Number</u>	<u>Counts Due To</u>	<u>Variable</u>	<u>Range^a of t</u>	<u>Range^b of h</u>	<u>Range^c of x</u>	<u>No. of Channels</u>
1	fast neutrons	t_1	$0 < t \leq T_1$	$h > 0$	$0 < x \leq X$	300
2	inelastic gamma rays	t_1	$0 < t \leq T_1$	$h > 0$	$x > X$	300
3	capture gamma rays	t_2	$0 < t \leq T_2$	$h > 0$	$x > X$	100
4	fast neutrons	h	$0 < t \leq T_1$	$h > 0$	$0 < x \leq X$	256
5	inelastic gamma rays	h	$0 < t \leq T_1$	$h > 0$	$x > X$	256
6	capture gamma rays	h	$0 < t \leq T_2$	$h > 0$	$x > X$	256
7	fast neutrons and inelastic gamma rays	x	$0 < t \leq T_1$	$h > 0$	$x > 0$	256

^a $T_1 = 300$ (Δt_1) = 300 (20 nsec) = 6 μ sec and $T_2 = 100$ (Δt_2) = 100 (10 μ sec) = 1000 μ sec

^bFor off-line analysis, lower and upper h bounds are specified as input parameters

^c Δt_1 , Δt_2 , and X are input parameters.

The data presented in this report were obtained using the three-parameter data acquisition method. However, since the purpose of Phase I of the experimental program was to verify the DUCT code for neutrons only, the on-line analysis was used. The data are stored on tape for further analysis should it be warranted.

4.4 UNFOLDING

The mathematical procedure for unfolding is carried out in the FERDOR code. The method is discussed in Refs. 13 and 14. The results presented here are only the output from the FERDOR code. Each unfolded spectrum is not uniquely defined but instead gives a band of values within which the actual spectrum should lie.

The calculation of this band by FERDOR includes two contributions, one due to the statistical errors in the input pulse-height data, and the other to the suboptimal calculation of the "inverse" of the response matrix, because, in general, such errors are: (1) difficult to assess due to the indirect manner in which response matrices are produced by interpolation from calculation, and a measurement for example, and (2) difficult to propagate through the unfolding procedure. In our case, the response matrix was obtained entirely from a Monte-Carlo O6R calculation performed at the Oak Ridge National Laboratory.

Another important aspect of any unfolding is the extent to which the initial estimate is subsequently smoothed. In FERDOR this smoothing is performed with Gaussian functions called window functions. They can have widths that depend on the energy at which the spectrum is being smoothed. A guide to the variation of these Gaussian widths with energy can be obtained by taking the point of view that the unfolded spectrum corresponds to a true spectrum viewed by a spectrometer of a particular Gaussian resolution. It is clear, however, that this resolution is related

to the presentation of the data as well as to the energy resolution of the spectrometer; that is, the amount of smoothing should be suited to the shape of the unfolded spectrum to obtain a maximum of information from the signal consistent with the accompanying noise. In the unfolding procedure described here, the initial smoothing was made using Gaussian widths which varied approximately as the energy resolution of the NE-213 detector⁽¹¹⁾ as follows:

$$W(E) = W(E_o) \sqrt{E_o/E} , \quad (4.2)$$

where the width at energy $E_o = 14$ MeV was taken as $W(E_o) = 15\%$. The maximum width allowed was 45% for reasons which are based on the shape of the response functions for neutrons in NE-213. In general, the shape of these response functions features a sharp edge at high pulse heights followed by a region where the amplitude varies slowly as the pulse height decreases with, at low pulse heights, a fast rising tail. This means that in a spectrum with a large number of high energy neutrons, the high tail at low pulse heights of the response to these high energy neutrons makes progressively more uncertain the spectrum at low energies where the response is limited to low pulse heights. For the concrete data, the FERDOR band is beginning to expand more and more rapidly below 1.2 MeV where, according to the relationship of Eq. 4.2, the smoothing width would be more than 50%. Thus smoothing with too wide a width at the lower energies would "contaminate" reasonable parts of the unfolded spectrum with the inherently more unreliable low energy part. To tailor the smoothing to the spectrum shape, the smoothing widths are modified after an initial pass which uses the energy resolution widths described above. The spectrum is crudely divided into two regions of "high" and "low" intensity. The average fractional error

(the total width of the FERDOR band) in each region is calculated and the widths increased in each region if that error is greater than some arbitrary limit (30% was chosen here). The smoothing, error calculation, and test cycle is repeated until the criterion is reached in each region individually or until a maximum amount of extra smoothing has been added (15% in the "high" region, 30% in the "low" region were the actual maximum extra amounts used). To avoid abrupt changes of the Gaussian widths with energy, the variation of the widths with energy was itself smoothed by taking three cycles of a four-point averaging after each increment of the widths. Further, if in the lowest energy region the error band was increasing very rapidly, the smoothing there was limited to 40%.

In summary, the neutron unfolding was accomplished by using the FERDOR code. The contribution of the statistical errors in the measured response matrix to the final error band was estimated by increasing the statistical error (σ^2) of the input data by two. The smoothing strategy was to first use widths varying as the energy resolution (Eq. 4.2) from 15% at 14 MeV to 44.4% at 1.6 MeV with an arbitrary limit of 45%. The widths were then increased appropriately in the "high" and "low" regions of the spectrum until either the fractional error was less than 30% or a maximum extra amount of smoothing had been added. It was always ensured that the variation with energy of the smoothing widths was itself smooth.

4.5 EXPERIMENTAL RESULTS

An excellent check on the methods described in the previous section is provided by the time-of-flight spectrum. Note that this spectrum is always measured simultaneously by the three-parameter data acquisition system. The measured source spectrum (no shield assembly) obtained by time of flight should agree with that obtained by unfolding the

proton pulse height spectra. A comparison is shown in Fig. 4.8; the agreement is very good which lends confidence to the unfolding procedure used here.

The unfolded measured spectra are shown in Figs. 4.9 through 4.12. All measured spectra are given in terms of $\text{neutrons-cm}^{-2}\text{-MeV}^{-1}\text{-(monitor fluence)}^{-1}$. The neutron monitors were discussed in Section 4.2. 3. Figure 4.9 shows the measured axial fluxes measured at the duct exit for three cases: no shield present, sodium in the duct, and lithium hydride in the duct. Figure 4.10 shows the effect of removing the lithium hydride from the duct. Figure 4.11 shows a measurement for an axial collimated detector located 15.24 cm from the duct exit. Figure 4.12 shows the response for an off-axis detector located 12.7 cm from the duct exit; note the sodium-filled duct case is multiplied by 10. The two spectra essentially fall on each other. In other words, the effect of replacing the lithium hydride with sodium is negligible for this detector position.

Fig. 4.8. Comparison between the FERDOR unfolded and time-of-flight measured source spectra

Fig. 4. 9. Measured axial detector responses for the detector located at the duct exit

Fig. 4.10. Measured axial detector responses for the detector located at the duct exit

Fig. 4.11. Measured axial detector response for the detector located 15.24 cm from duct exit

Fig. 4.12. Measured off-axis detector responses for the detector located 12.7 cm from the duct axis

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5. COMPARISON OF DUCT CALCULATION AND EXPERIMENT

Comparisons between the experimental data and calculations performed with the DUCT code are shown in Figs. 5.1 through 5.4. The calculations yielded neutron flux per MeV per source neutron, the measurements yielded neutron flux per MeV per source monitor. To compare the two on a source neutron basis, the measured results were multiplied by a source normalization factor. This factor was obtained by integrating the calculational source spectrum and the measured source spectrum over the same energy limits, namely 2.0 MeV to 5.5 MeV, and then dividing the calculational source integral by the experimental source integral, that is

$$N_s = \frac{\left[\int_{2.0}^{5.5} \phi(E) dE \right]_{\text{DOT}}}{\left[\int_{2.0}^{5.5} \phi(E) dE \right]_{\text{EXP}}} = 0.674 \quad .$$

This was done for the source spectra only so that no further normalization is applied when comparing measurement with theory.

The comparison between the measured and axial detector responses is shown in Fig. 5.2 for the sodium and lithium hydride filled ducts. Figure 5.2 compares the measured and calculated fluxes for void and lithium hydride filled ducts. Figure 5.3 compares the calculated and measured axial detector responses for a collimated detector located

Fig. 5.1. Comparison between measured and DUCT calculated axial detector responses for a detector located at the duct exit

Fig. 5.2. Comparison between measured and DUCT calculated axial detector responses for a detector located at the duct exit

Fig. 5.3. Comparison between measured and DUCT calculated axial detector responses for a detector located 15.24 cm from the duct exit

Fig. 5.4. Comparison between measured and DUCT calculated off-axis detector response for a detector located 12.7 cm from the duct axis

15.24 cm for the duct exit. Figure 5.4 compares the results for an off-axis detector located 12.7 cm from the duct axis.

In general, the agreement is quite good (10 percent or better) for the axial detector positions; the agreement for the off-axis detector is not as good, especially for the lithium hydride filled duct case. This disagreement may be inherent in the DOT calculation of the angular fluxes since the measurements show that duct influence on the flux at this detector position should be negligible.

6. CONCLUSIONS AND RECOMMENDATIONS

In view of the over-all agreement between measurement, DUCT, and MORSE, we feel the DUCT code provides a good engineering code to calculate the effect of coolant type holes in shields. We have tested the method to its extreme limit for streaming.

The experiments were, however, limited to neutron energies above 1 MeV; as noted in Section 3.4, the agreement with MORSE was very good at the low energies ($E < 10$ keV) where the fluxes tend to be isotropic lending confidence to the DUCT calculations at these energies. It is important to note that the MORSE calculation required approximately 30 to 45 minutes to achieve a 10 to 20 percent variance on the scattered flux estimates for a single detector position. The DUCT calculations require approximately four minutes per detector with an additional 40-60 minutes for the DOT calculation. However, if one were making an engineering type analysis of a shield where many duct-detector configurations are to be studied, the DOT-DUCT running time would be considerably shorter than the MORSE running time, as seen in the following table:

MORSE VS DOT/DUCT RUNNING TIMES PER DETECTOR

	(min)			
Number of Ducts	1	2	4	6
MORSE	40	80	160	240
DOT/DUCT	64	68	72	80

We recommend that a void region be included in the DOT calculation for detectors near the shield/void region to minimize errors in extrapolating the DOT fluxes. For detectors quite distant from the shield, we recommend the use of SPACETRAN, which we plan to incorporate in the production version of DUCT.

The production version of DUCT to be released January 30, 1971, will also incorporate coupled neutron-gamma ray calculational capability.

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APPENDIX A
DUCT CODE

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1. INPUT INSTRUCTIONS

These input instructions will be revised before DUCT is released to RSIC. However, as of October 1970 these are the instructions:

[All distances in cm.]

CARD A (4IS)

NAFT	Logical unit number of the angular flux tape
NODET	Number of detectors
NMAT	(Number of materials) x (Legendres order +1)
KTIS	Number of downward angles in the quadrature set

CARDS B (3F12.0) (NODET cards)

XDET(I,NDO), I=1,3
x-, y-, and z-coordinates of detector NDO

CARD C (2F12.0)

ZS	Z-coordinate of the shield farthest from the source
RMAX	Radius of the shield

CARDS D (6E12.4) (A04/6 cards)

(HMU(I), I=1, A04)
The μ 's of the DOT quadrature set

CARDS E (6E12.4) (A04/6 cards)

(ETA(I), I=1, A04)
The η 's of the DOT quadrature set

CARD F (7F10.0)

XON(1)	X-coordinate of initial end of duct (nearest source)
XON(2)	Y-coordinate of initial end of duct
XON(3)	Z-coordinate of initial end of duct

XTW(1) X-coordinate of final end of duct (farthest from source)
 XTW(2) Y-coordinate of final end of duct
 XTW(3) Z-coordinate of final end of duct
 RD Radius of duct

CARD G (I5)

NDIVL Number of duct subintervals desired

CARDS H (7F10.0) (NDIVL/7 cards)

(VOLMOD(N), N=1, NDIVL)

Enter 1.'s for a cylindrical duct. Enter a volume modification factor for each duct subinterval otherwise.

 a b c
 CARD GA (I5, 5X, A6, 1X, A7)

- a. Enter 2
- b. Sex of the programmer
- c. Marital status of the programmer (optional if b=MALE)

 a b c
 CARD GB (A11, T(E10.6, A1))

- a. Enter ZONE X BNDS
- b. Zone boundaries in increasing order along x-axis
- c. Enter ", " to keep going; enter "blank" to indicate no more zonex bounds

CARD(S) GB' (6(E10.5, A1))

Continuation of card GB if number of zonex bounds exceeds 5

 a b c
 CARD GC (A11, 5(E10.5, A1))

- a. Enter ZONE Y BNDS
- b. Zone boundaries in increasing order along y-axis
- c. Enter ", " or "blank" as on card GB

CARDS GC' (6(E10.5,A1))

Continuation of card GC if needed

 a b c
CARD GD (A11,5(E10.5,A1))

- a. Enter ZONE Z BNDS
- b. Zone boundaries in increasing order along z-axis
- c. Enter ", " or "blank" as on card GB

CARDS GD'

If needed

 a l m n
CARD GE (A6,I5,I5,I5)

- a. Enter ZONE
- l, Each zone is located in the system by three integers: l, m, and n.
- m, These specify the zone as being the lth in the x-direction, the mth
- n. in the y-direction and the nth in the z-direction.

 a b c
CARD GF (A11,5(E10.5,A1))

- a. Enter BLOCK X BNDS
- b. Block boundaries in increasing order along x-axis
- c. Enter ", " to keep going; enter "blank" to stop

CARD(S) GF' (6(E10.5,A1))

Continuation of card GF is number of BLOCKX bounds exceeds 5

CARD(S) GG,GG'

The same as cards GF,GF', except that BLOCKY BNDS are listed.

CARD(S) GH, GH'

The same as cards GF, GF', except that BLOCKZ BNDS are listed

a ℓ m n

CARD GJ (A6, I5, I5, I5)

- a. Enter BLOCK
- ℓ , Each block is located in the ZONE by three integers: ℓ , m, and n.
- m, These specify the block as being the ℓ th in the x-direction, the m th
- n. in the y-direction, and the n th in the z-direction.

a b c

CARD GK (A12, 10(I5, A1), CARDS GK' (12(I5, A1)) if necessary

- a. Enter MEDIA
- b. A list of the media, sector by sector, in the block medium 1=1st cross-section material, medium 2=2nd cross-section material, etc., medium 1000=void
- c. Enter ", " to continue the list

a b c

CARD GL (A12, 10(I5, A1)) [Omit if only one sector in block.]

- a. Enter SURFACES
- b. A list of the quadric surfaces in the block. The numbers appearing in this list derive from the order in which the surfaces are mathematically derived on card GR.
- c. Enter ", " to continue the list. Add card(s) GL' if necessary

a b

CARDS GM (A6, 18I3) [Omit if only one sector in block.]

- a. Enter SECTOR
- b. For every surface in the block, in the order they were listed on card GL, enter "-1" if the sector is inside the surface (positive side), "0" if the surface is immaterial, "1" if the sector is outside the surface (negative side)
- If there are more blocks, go back to card GJ
- If there are more zones, go back to card GE

a b
CARD GQ (I5, 11A6)

- a. Enter the total number of quadric surfaces in the entire system
- b. Enter, alphanumerically, the same as (a). Example: "FOUR QUADRIC SURFACES"

a b c
CARDS GR (4(E10.5, A5, A1)

Each quadric surface is described by writing the quadratic function whose zeros define the surface, in a fixed field format resembling the normal manner of writing functions. The first surface must be the duct wall. Each term in the function is specified by

- a. The coefficient of the term
- b. May be XSQ, YSQ, ZSQ, XZ, YX, YZ, XY, ZX, YZ, X, Y, Z, or blank
- c. Enter "\$" to end the function, "blank" to continue it

CARD J (I5)

NMDUCT The medium number of the duct (may be 1, 2, 3, etc. or 1000, where 1000 indicates void) when the shield is replaced by some other material.

CARDS K (DTF-IV format)

NMAT	TITLE CARD	FORMAT (16A5)
Decks	((C(IH, IG, M), 1H-1, IHT), IG=1, IGM) Cross sections, cm ⁻¹	FORMAT (6E12.4)

CARD L (A6, 4X, A6)

NAME 1 The name of the material in the duct with medium number NMDUCT

NAME 2 The name of the shield material in the duct

CARD M (I5)

NANG The number of output uncollided on-axis angular bins
 desired

CARDS N (6E12.4) (NANG/6 cards)

(ANGLE(IANG), IANG=1, NANG)
 The upper bounds of the bins in degrees

CARDS O (6E12.4) (NANG/6 cards)

(CBEND(IANG), IANG=1, NANG)
 The cosines of the above angles

CARDS P (6E12.4) (NANG/6 cards)

(SA(IANG), IANG=1, NANG)
 The solid angles of the bins

CARDS Q (yE12.4) (IGM/6 cards)

(E(IG), IG=1, IGM)
 The midpoint energies of the energy groups

2. DESCRIPTION OF THE SUBROUTINES

PROGRAM GADUCT (Main)

The main program reads a few control integers, sets up addresses for variable dimensioning, and calls the following seven subroutines: AFTRD, PRELEV, DUCTRD, JOMIN, SHIELD, COEFF, SCATSB.

SUBROUTINE AFTRD

The Angular Flux Tape Reading subroutine reads various parameters on the angular flux tape produced by DOT, then positions the tape so that the angular fluxes are ready to be read. AFTRD also finds the

midpoints of each radial and axial interval. The contents of common/
BLANC /are printed.

Called from:	GADUCT	
Input variables:	NAFT	Unit number of the angular flux tape
Output variables:	RM(I)	Midpoint of radial interval I
	ZM(J)	Midpoints of axial interval J
	AO3	Legendre order
	AO4	Number of quadrature angles
	IM	Number of radial intervals
	JM	Number of axial intervals
	IGM	Number of energy groups
	IHT	Position of total cross section
	IHS	Position of self-scatter cross section
	ITL	Cross section table length
	WO(I)	Quadrature weights

SUBROUTINE COEFF

The Coefficient finding subroutine identifies, for each duct point, the four closest DOT points (a DOTpoint is a midpoint of a DOT r-z spacial interval). Then COEFF calculates coefficients for linear interpolation of the angular flux to provide a value of the angular flux at the duct point. A table of the four DOTpoints and four coefficients is printed for each ductpoint.

Called from:	GADUCT	
Input variables:	RM(I)	Midpoints of DOT radial intervals
	ZM(J)	Midpoints of DOT axial intervals
	RZR(N)	Radial location of the ductpoint

	Z(N)	Axial location of the ductpoint
	IM	Number of radial intervals
	JM	Number of axial intervals
	NDPT	Number of ductpoints plus one
Output variables:	COEF(N,I), I=1,4	Coefficients for flux interpolation
	IDOT(N,I), I=1,4	Nearest two RM's and two ZM's to the ductpoint.

SUBROUTINE CONTEST

The Quadrature Angle Rearranging subroutine conducts a contest to determine which quadrature angle points are in the direction nearest to the duct axis direction. The contestants' quadrature angle numbers are inscribed on stars, MSTAR(J) being set equal to the Jth place finisher, and his cosine with the duct axis being stored in COSS(J). Then the angles are arranged into "levels", with near-ties (difference in COSS less than .001) going into the same level. Wrong-pointing angles (COSS < 0.) are not considered. A table of quadrature angles by levels is printed.

Called from:	DUC TRD	
Input variables:	V1	r-direction cosine of duct
	V3	z-direction cosine of duct
	WO(M)	Weights of quadrature angles
	HMU(M)	r-direction cosines of quadrature angles
	ETA(M)	z-direction cosines of quadrature angles
	WIG(M)	ϕ -direction cosines of quadrature angles
	AO4	Number of quadrature angles

Output variables:	MSTAR(J)	Quadrature angle number of Jth "best" angle
	NLEV	Number of "levels"
	ATE(J)	Cosine with duct axis of Jth best angle
	NMU(LEV)	Number of angles in the LEVth level

SUBROUTINE CROSS

The Cross Product subroutine finds the vector product $\vec{C} = \vec{A} \times \vec{B}$.

Called from:	OFFAX	
Input variables:	A	Three-dimensional vector
	B	Three-dimensional vector
Output variable:	C	Vector product

SUBROUTINE DUCTFX

For a given energy group, the Duct Flux subroutine reads the angular fluxes for all angles, radial intervals, and axial intervals from the DOT angular flux tape and calculates the interpolated angular flux for each angle and duct point.

Called from:	SCATSB	
Input variables:	NAFT	Unit number of the angular flux tape
	KT15	Number of downward angles in the quadrature set
	NOPT	Number of duct points plus one
	MN	Number of quadrature angles
	IM	Number of radial intervals
	JM	Number of axial intervals

	IDOT(N,I),	Nearest two radii and axii to the
	I=1,4	duct point
	COEF(N,I),	Coefficients for flux interpolation
	I=1,4	
Output variable:	AFLUX	Angular flux in Mth angle at Nth
	(M,N)	duct point.

SUBROUTINE DUCTRD

The Duct Information Reading subroutine reads the coordinates of the endpoints of the duct, the radius of the duct, the number of duct points, and volume modification factors. It calculates, for each duct point, the x-y-z and r-z coordinates of the center, the volume, the effective wall area, and the distance to detector No. 1.

Called from:	GADUCT
Calls:	CONTES, PLATE
Output variables:	NDIVL Number of duct points
	NDPT Number of duct points plus one
	LNG Length of duct
	LN2 Square of length of duct
	XON(I), Coordinates of initial end of
	I=1,3 duct
	RD2 Square of radius of duct
	RD Radius of duct
	FDUCT(I,N), I=1,2
	x/r, y/r for Nth duct point
	RZR(N) r-coordinate of Nth duct point
	Z(N) z-coordinate of Nth duct point
	DUC TW(I), I=1,3
	Direction cosines of duct
	RSSQ(N) Square of distance from Nth duct
	point to detector No. 1

RS(N)	Distance from Nth duct point to detector No. 1
CBET(N)	Cosine of angle between duct wall and path to detector No. 1
AREA(N)	Effective area of duct wall of Nth duct point
VOLS(N)	Volume of Nth duct point
DUC TX(I, N), I=1, 3	x-y-z coordinates of Nth duct point

FUNCTION EXIN(X)

The Exponential Integral function calculates $E_1(x) = \int_x^{\infty} \frac{e^{-y}}{y} dy$.

Called from:	SHIELD
Input variable:	X
Output variable:	$E_1(x)$

The GEOMetry Routines

The geometry routines are DATAG (block data), ERROR, EUCLID, GEOM, JOMIN, JOM4, JOM5, JOM6, JOM7, JOM8, JOM9, JOM10, JOM11, JOM12, JOM13, JOM14, JOM15, JOM16, JOM17, LOOKZ. They are described in ORNL-3622, an O5R manual. Slight changes were made to EUCLID, JOM11, and JOM17 to plug the package into DUC T. Only three routines are called directly by DUC T routines: JOMIN, LOOKZ, and EUCLID. JOMIN reads in the geometry data. LOOKZ, given the coordinates of a point, returns the GEOM medium number of that point in the 8th location of COMMON/GEOMC. EUCLID, given two points, and a group number, returns the number of mean free paths between them.

SUBROUTINE IMLEV

There is an angle θ between the duct axis and the path from the duct wall (at interval N) to the detector. Subroutine IMLEV selects the quadrature angle level whose cosine with the duct wall is closest to $\cos\theta$.

Called from: SHIELD

Input variables: ET $\cos\theta$

N Number of the duct point

ATE(LEV) Cosine of the level

NLEV Number of levels

Output variable: LEVEL(N) The selected level for duct point N

SUBROUTINE OFFAX

The Uncollided Estimator for Detectors off the Duct Axis calculates, for each off-axis detector, energy group, duct point, and duct material, the uncollided angular flux at the detector due to a unit angular flux at the duct point. Also, for each off-axis detector, energy group, and duct material, it calculates the uncollided angular flux at the detector due to a unit angular flux at the end plate.

Called from: SHIELD

Calls: PYTHAG, CROSS, EUCLID

Input variables: NODET Number of detectors

IGM Number of energy groups

NDIVL Number of duct points

XDN(I), I=1, 3
Coordinates of initial end of duct

XDET(I, NDO), I=1, 3
Coordinates of detector NDO

	RD	Radius of the duct
	DUC TW (I), I=1, 3	Direction cosines of the duct
	DUC TX (I, N), I=1, 3	Coordinates of duct point N
	NMD	Medium number
Output variables:	(((UNCARG(IG, N, NDO, NMD), IG=1, IGM), N=1, NDIVL), NDO=2, NODET)	
	Flux contribution in group IG from duct point N through duct medium NMD to detector NDO	
	((OFFARG(IG, NDO, NMD), IG=1, IGM), NDO=2, NODET)	
	Flux contribution in group IG from end plate through duct medium NMD to detector NDO	

SUBROUTINE PICKIT

PICKIT selects the angle in the quadrature set nearest the direction from duct point N to detector NDO.

Called from:	SCATSB	
Input variables:	FD(M)	DOT product of angle M and detector direction
	MM	Number of angles in the quadrature set
	N	Number of the duct point
	NDO	Number of the detector
Output variable:	IMIT(N, NDO)	
	The selected angle number	

SUBROUTINE PLATE

The End Plate Subdividing subroutine decides how much of the area of the end plate to assign to each angular level for the purpose of

calculating the uncollided component from the end plate to Detector
No. 1.

Called from:	DUC TRD	
Input variables:	NLEV	Number of angular levels
	ATE(LEV)	Cosine with the duct axis of the LEVth level
	RD	Radius of the duct
Output variables:	LEVMAX	Number of levels involved in the end plate
	AIR(LEV)	Area assigned to the LEVth level

FUNCTION PLEG(X,L)

The Legendre Polynomial function calculates $P_{L-1}(x)$, where

$$P_0(x) = 1, P_1(x) = x, \text{ and } P_k(x) = \frac{(2k-1) \times P_{k-1}(x) - (k-1) P_{k-2}(x)}{K}$$

Called from:	PSCAT
Input variables:	X, L
Output variable:	$P_{L-1}(x)$

SUBROUTINE PRELEV

Subroutine PRELEV reads the r- and z-quadrature cosines and
prints the r-, z-, ϕ -quadrature cosines and the weights.

Called from:	GADUCT
Input variable:	MM Number of quadrature angles
Output variables:	NMU(I) Quadrature cosine with respect to r-axis
	ETA(I) Quadrature cosine with respect to z-axis
	WIG(I) Quadrature cosine with respect to ϕ -axis

SUBROUTINE PSCAT

For a given scattering angle $\cos^{-1} \mu$ and a given primary group g , the Probability of Scattering subroutine returns a table of scattering probabilities to secondary groups g' .

$$P_{g \rightarrow g'}(\mu) = \sum_{\ell=0}^{\ell_{\max}} \frac{(2\ell+1)}{4\pi} \sigma_{g \rightarrow g'} P_{\ell}(\mu)$$

Called from: SCATSB

Calls: PLEG

Input variables: XMU Cosine of the scattering angle
 IG Primary group number
 ITL Cross section table length
 NG Number of groups
 (((C(INK, IG, M), INK=1, ITL), IG=1, NG),
 M=1, NMAT)
 Cross sections
 M Material number
 L $\ell_{\max}$ in the formula

Output variables: (PST(IGP), IGP=IG, NG)
 Table of scattering probabilities

SUBROUTINE PYTHAG

The Pythagorean subroutine finds the distance and direction cosines between two points.

Called from: OFFAX, SCATSB

Input variables: (P1(I), I=1, 3)
 Coordinates of the initial point
 (P2(I), I=1, 3)
 Coordinates of the final point

Output variables: (W(I), I=1, 3) Direction cosines between the two points

D Distance between two points

D2 D squared

SUBROUTINE SCATSB

The function of subroutine SCATSB is to fold the unit vector estimates with the angular fluxes and print scalar fluxes at the detectors as a function of duct medium, energy group, and detector.

Called from: GADUC T

Calls: PYTHAG, PICKIT, DUCTFX, PSCAT

Input variables: XDET(I, NDO), I=1, 3
Coordinates of detector NDO

EXPARG(IG, N, NDO, NMED)
Once-collided unit vector estimator

((C(INK, IG, M), INK=1, ITL), IG=1, NG),
N=1, NMAT)
Cross sections

UNCARG(IG, N, NDO, NMED)
Uncollided unit vector estimators

DUCTX(I, N), I=1, 3
Coordinates of duct point N

RZR(N) R-coordinate of duct point N

WO(M) Quadrature weights

AO4 Number of quadrature angles

IGM Number of energy groups

NODET Number of detectors

LEVEL(N) Quadrature angle level associated with duct point N

NMU(LEV) Number of quadrature angles in level LEV

LEVMAX Number of levels involved in the
 end plate
 PLARG(IG, LEV, NMED)
 Once-collided end plate unit vector
 estimators
 AFLUX(M, N)
 Angular flux in Mth angle at Nth
 duct point
 PST(IGP), IGP=IG, IGM $P(\theta)$
 Probability of scattering from
 group IG to group IGP through θ
 AO3 Legendre order

SUBROUTINE SHIELD

Subroutine SHIELD reads the cross sections and prints them. It calculates the unit vector flux estimators for the once-collided contributions and the on-axis uncollided contributions for all energy groups, mesh points, detectors, and duct media. It prints duct mesh point information.

Called from: GADUCT
 Calls: STABLE, LOOKZ, IMLEV, EUCLID, EXIN,
 OFFAX
 Input variables: NMAT (Number of materials) x
 (Legendre order + 1)
 IGM Number of energy groups
 AO3 Legendre order
 NMED Current medium number found by
 LOOKZ
 NODET Number of detectors
 NDIVL Number of duct points
 DUCTX(I, N), I=1, 3
 Coordinates of Nth duct point
 XON(I), I=1, 3
 Coordinates of initial end of duct

	XDET(I, NDO), I=1, 3	Coordinates of detector NDO
	LEVMAX	Number of levels involved in the end plate
	NNX	Number of GEOM sectors in the duct
Output variables:	UNCARG(IG, N, NDO, NMD)	Uncollided unit vector estimators
	PLARG(IG, LEV, NMD)	Once-collided end plate unit vector estimators
	EXPARG(IG, N, NDO, NMD)	Once-collided unit vector estimators
	((C(IH, IG, MAT), IH=1, 1TL), IG=1, IGM), MAT=1, NMAT)	Cross sections
	NMAD(N)	GEOM medium number of Nth duct point for shield material

SUBROUTINE STABLE

Subroutine STABLE forms a table of total cross sections for use by EUCLID.

Called from:	SHIELD
Input variables:	((C(IH, IG, M), IH=1, 1TL), IG=1, NG), M=1, NM)
	Cross sections
	1TL Cross section table length
	1HT Location of total cross section in table
	NG Number of groups
	L Legendre order
	NM (Number of materials) x (Legendre order + 1)

Output variables: (GXSECT(IG, M), IG=1, NG), M=1, NM)
Total cross sections

3. FLOW DIAGRAM FOR THE DUCT CODE

The flow diagrams for the DUCT code are shown in Figs. A1 through A5.

Figure A1
(Sheet 1 of 2)

Figure A1
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Figure A2
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Figure A2
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Figure A3
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Figure A3
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Figure A4

Figure A5
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Figure A5
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4. FORTRAN LISTING OF DUCT CODE

Important Note:

Many of the subroutines contain the statement

INCLUDE BBLANC

This is equivalent to including the statement

COMMON/BLANC /ID(18),AO1,AO2,AO3,AO4,IGE,IZM,IM,JM,IO4,
EV, EVM, EPS

1 BO1,BO2,BO3,BO4,MO7,FXT,MT,MO1,MCR,MTP,IZ,JZ,SO2,SO3,
IGM,IHT,IHS,

2 ITL,SO1,MO5,MO6,SO4,DO5,GO7,GO5

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	SEG	GADUCT-*(S2,S3,S5)	DUCT	10
S2	SEG	AFTRD-PRELEV-DUCTRD-CONTESS-PLATE	DUCT	20
S3	SEG	JOMIN-SHIELD-EXIN-EUCLID	DUCT	30
S5	SEG	COEFF-SCATSB-DUCTFX-PSCAT-PLEG	DUCT	40
C	PROGRAM	GADUCT	GADU	10
	COMMON	/UNIT/NAFT,NMAT,KT15	GADU	20
	COMMON	STORAG(25000)	GADU	30
	INCLUDE	DDLANC	GADU	40
	COMMON	/DETECT/NODET,XDET(3,10)	GADU	50
	COMMON	/SPFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NDPT	GADU	60
	COMMON	/WMEDIA/IMEDIA(50),IKM(24),NNX,IKI(24),IMATER(50)	GADU	70
	COMMON	/SCALE/ZS,RMAX	GADU	80
	INTEGER	A04,A03	GADU	90
	INTEGER	ADDR1,ADDR2,ADDR3,ADDR0	GADU	100
	READ	1,NAFT,NODET,NMAT,KT15	GADU	110
1	FORMAT	(14I5)	GADU	120
	CALL	AFTRD	GADU	130
	NNX=0		GADU	140
	DO	2 NDO=1,NODET	GADU	150
2	READ	3,(XDET(I,NDO),I=1,3)	GADU	160
3	FORMAT	(3F12.0)	GADU	170
	READ	3,ZS,RMAX	GADU	180
	CALL	PRELEV(A04)	GADU	190
	CALL	DUCTRD	GADU	200
	ADDR0=IGM*NDIVL*NODET*2+1		GADU	210
	ADDR1=A04*NDPT+ADDR0		GADU	220
	ADDR2=ADDR1+2*NODET*IGM		GADU	230
	ADDR3=ADDR2+ITL*IGM*NMAT		GADU	240
	IADD=ADDR3+A04*NDIVL*NODET		GADU	250
	IADD1=IADD+IGM*NDIVL*NODET*2		GADU	260
	CALL	JOMIN(IADD1)	GADU	270
	CALL	SHIELD(STORAG(1),STORAG(ADDR2),STORAG(IADD1))	GADU	280
	CALL	COEFF	GADU	290
	CALL	SCATSB(STORAG(1),STORAG(ADDR0),STORAG(ADDR1),STORAG(ADDR2),	GADU	300
	1STORAG(ADDR3),STORAG(IADD))		GADU	310
	CALL	EXIT	GADU	320
	END		GADU	330

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	SUBROUTINE AFTRD	AFTR 10
	COMMON/UNIT/NAFT	AFTR 20
	COMMON/DOTPTS/RM(100),ZM(100),A(100)	AFTR 30
	INCLUDE BBLANC	AFTR 40
	COMMON/WEIGHT/WJ(100)	AFTR 50
	INTEGER AQ4	AFTR 60
	DIMENSION RI(100),ZI(100)	AFTR 70
	PRINT 3	AFTR 80
3	FORMAT(1H1,'PARAMETERS FROM UNPERTERBED CALCULATION'//)	AFTR 90
	READ(NAFT)(ID(I),I=1,55)	AFTR 100
	PRINT 2,(ID(I),I=1,55)	AFTR 110
2	FORMAT(18A4/ ' PROBLEM NO.',I4/' (REGULAR/ADJOINT=(0/1)',I4/' (PD/AFTR 120	
	1P1/P2/P3)=(0/1/2/3)',I4/' NO. OF ANGLES IN QUADRATURE SET',I4/' R-AFTR 130	
	2Z GEOMETRY=1',I4/' NO. OF MATERIAL ZONES',I4/' NO. OF RADIAL INTERAFTR 140	
	3VALS',I4/' NO. OF AXIAL INTERVALS',I4/' SOURCE TYPE (0/5)=(VOLUME/AFTR 150	
	4BOUNDARY',I4/' EV',F10.3/' EVM',F10.3/' EPSILON',F10.6/' LEFT BOUAFTR 160	
	5NDARY (VACUUM/REFLECTIVE)=(0/1)',I4/' RIGHT BOUNDARY (WHITE/SOURCEAFTR 170	
	6)=(3/4)',I4/' TOP BOUNDARY',I20/' BOTTOM BOUNDARY',I17/' M07',I4/'AFTR 180	
	7 MODE',I4/' NO. OF MATERIALS',I4/' M01',I4/' MCR',I4/' MTP',I4/' IAFTR 190	
	8Z',I4/' JZ',I4/' S02',I4/' S03',E12.5/' NO. OF ENERGY GROUPS',I4/'AFTR 200	
	9 TOTAL CROSS-SECTION POSITION',I4/' SELF-SCATTER POSITION',I4/' TAAAFTR 210	
	\$BLE LENGTH',I4/' NORMALIZATION FACT.',E12.5/' M05',I4/' M06',I4/' AFTR 220	
	\$INNER MAX',I4/' OUTER MAX',I4/' INNER MAX2',I4/' TMAX=0',I4)	AFTR 230
	DO 9 I=1,3	AFTR 240
9	READ(NAFT)DUMMY	AFTR 250
	MM=AQ4	AFTR 260
	READ(NAFT)(WJ(I),I=1,MM)	AFTR 270
	NSKIP=2+2*IGM*JM+IGM	AFTR 280
	DO 10 I=1,NSKIP	AFTR 290
10	READ(NAFT)DUMMY	AFTR 300
	IP=IM+1	AFTR 310
	JP=JM+1	AFTR 320
	READ(NAFT)(RI(I),I=1,IP)	AFTR 330
	READ(NAFT)(ZI(I),I=1,JP)	AFTR 340
	REWIND NAFT	AFTR 350
	OLDA=0.	AFTR 360
	DO 5 I=1,IP	AFTR 370
	TERM=3.1416*RI(I)*RI(I)	AFTR 380
	A(I)=TERM-OLDA	AFTR 390
5	OLDA=TERM	AFTR 400
	IMAX=IM	AFTR 410
	JMAX=JM	AFTR 420
	DO 1 I=1,IMAX	AFTR 430
1	RM(I)=.5*(RI(I)+RI(I+1))	AFTR 440
	DO 4 I=1,JMAX	AFTR 450
4	ZM(I)=.5*(ZI(I)+ZI(I+1))	AFTR 460
	NSKIP = 6+IGM	AFTR 470
	DO 11 I=1,NSKIP	AFTR 480
11	READ(NAFT) DUMMY	AFTR 490
	RETURN	AFTR 500
	END	AFTR 510

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SUBROUTINE COEFF	COEF 10
COMMON/COEFIC/COEF(50,4),IDOT(50,4)	COEF 20
COMMON/SPFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NDPT	COEF 30
COMMON/DOTPTS/RM(100),ZM(100)	COEF 40
INCLUDE BBLANC	COEF 50
DO 1 N=1,NDPT	COEF 60
DO 2 I=2,IM	COEF 70
IF(RM(I).LT.RZR(N)) GO TO 2	COEF 80
IDOT(N,3)=I	COEF 90
IDOT(N,1)=I-1	COEF 100
GO TO 3	COEF 110
2 CONTINUE	COEF 120
I=IM	COEF 130
IDOT(N,3)=I	COEF 140
IDOT(N,1)=I-1	COEF 150
3 DO 4 J=2,JM	COEF 160
IF(ZM(J).LT.Z(N)) GO TO 4	COEF 170
IDOT(N,4)=J	COEF 180
IDOT(N,2)=J-1	COEF 190
GO TO 5	COEF 200
4 CONTINUE	COEF 210
J=JM	COEF 220
IDOT(N,4)=J	COEF 230
IDOT(N,2)=J-1	COEF 240
5 DENOM=(RM(I)-RM(I-1))*(ZM(J)-ZM(J-1))	COEF 250
FACT=1./DENOM	COEF 260
COEF(N,1)=FACT*(RM(I)-RZR(N))*(ZM(J)-Z(N))	COEF 270
COEF(N,2)=FACT*(RZR(N)-RM(I-1))*(ZM(J)-Z(N))	COEF 280
COEF(N,3)=FACT*(RM(I)-RZR(N))*(Z(N)-ZM(J-1))	COEF 290
1 COEF(N,4)=FACT*(RZR(N)-RM(I-1))*(Z(N)-ZM(J-1))	COEF 300
PRINT 6	COEF 310
6 FORMAT(1H1,61X,'COEFFICIENTS FOR FLUX INTERPOLATION'//1X,'POINT',90CT	COEF 320
1X,'LOW R',8X,'HIGH R',9X,'LOW Z',8X,'HIGH Z',9X,'R1-Z1',9X,'R2-Z1'	COEF 330
2,9X,'R1-Z2',9X,'R2-Z2')	COEF 340
DO 7 N=1,NDPT	COEF 350
I=IDOT(N,3)	COEF 360
J=IDOT(N,4)	COEF 370
K=IDOT(N,1)	COEF 380
L=IDOT(N,2)	COEF 390
7 PRINT 8,N,RM(K),RM(I),ZM(L),ZM(J),(COEF(N,II),II=1,4)	COEF 400
8 FORMAT(1X,I5,8E14.5)	COEF 410
RETURN	COEF 420
END	COEF 430

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SUBROUTINE CONTES(V1,V3)	CONT 10
INCLUDE BBLANC	CONT 20
COMMON/STAR/NMU(30),WSUM(100),ATE(100),NLEV,MSTAR(100),LEVEL(50)	CONT 30
COMMON/WEIGHT/WO(100),HMU(100),ETA(100),WIG(100),JLEV(100)	CONT 40
DIMENSION COSS(100)	CONT 50
INTEGER A04	CONT 60
ARGH=1,-V1**2-V3**2	CONT 70
IF (ARGH.LT.0) ARGH=0.	CONT 80
V2=SQRT (ARGH)	CONT 90
DO 2 M=1,A04	CONT 100
MSTAR(M)=M	CONT 110
2 COSS(M)=-2.	CONT 120
DO 1 M=1,A04	CONT 130
IF (WO(M).LT..00001) GO TO 1	CONT 140
CC=HMU(M)*V1+WIG(M)*V2+ETA(M)*V3	CONT 150
DO 3 K=1,A04	CONT 160
IF (CC.LT.COSS(K)) GO TO 3	CONT 170
KP=K+1	CONT 180
DO 4 J=M,KP,-1	CONT 190
COSS(J)=COSS(J-1)	CONT 200
4 MSTAR(J)=MSTAR(J-1)	CONT 210
COSS(K)=CC	CONT 220
MSTAR(K)=M	CONT 230
GO TO 1	CONT 240
3 CONTINUE	CONT 250
1 CONTINUE	CONT 260
NLEV=0	CONT 270
OLDCOS=2.	CONT 280
DO 12 J=1,A04	CONT 290
IF (COSS(J).LT.0.) GO TO 13	CONT 300
M=MSTAR(J)	CONT 310
IF (ABS(COSS(J)-OLDCOS).LT..001) GO TO 14	CONT 320
OLDCOS=COSS(J)	CONT 330
NLEV=NLEV+1	CONT 340
JLEV(NLEV)=J	CONT 350
ATE(NLEV)=OLDCOS	CONT 360
NMU(NLEV)=1	CONT 370
WSUM(NLEV)=WO(M)	CONT 380
GO TO 12	CONT 390
14 NMU(NLEV)=NMU(NLEV)+1	CONT 400
WSUM(NLEV)=WSUM(NLEV)+WO(M)	CONT 410
12 CONTINUE	CONT 420
13 PRINT 15	CONT 430
15 FORMAT(1H1,'QUADRATURE ANGLES BY LEVELS'// ' NUMBER',2X,'LEVEL',4X,CONT 440	
1 'COSINE WITH DUCT',11X,'LEVEL COS',14X,'WEIGHT',8X,'LEVEL WEIGHT',CONT 450	

25X, 'ANGLE NO.')	CONT 460
J=0	CONT 470
DO 16 LEV=1,NLEV	CONT 480
NM=NMU(LEV)	CONT 490
DO 16 K=1,NM	CONT 500
J=J+1	CONT 510
M=MSTAR(J)	CONT 520
16 PRINT 17,J,LEV,COSS(J),ATE(LEV),WD(M),WSUM(LEV),M	CONT 530
17 FORMAT(1X,I6,I8,4E20.5,I14)	CONT 540
RETURN	CONT 550
END	CONT 560

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SUBROUTINE CROSS(A,B,C)	CROS 10
DIMENSION A(3),B(3),C(3)	CROS 20
C(1)=A(2)*B(3)-B(2)*A(3)	CROS 30
C(2)=A(3)*B(1)-B(3)*A(1)	CROS 40
C(3)=A(1)*B(2)-B(1)*A(2)	CROS 50
RETURN	CROS 60
END	CROS 70

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BLOCK DATA	DATA 10
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	DATA 20
1SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	DATA 30
COMMON/GEOM39/NERR	DATA 40
COMMON/NRC/NR(31)	DATA 50
DATA HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,SECTOR,	DATA 60
1(COFS(I),I=1,13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE/	DATA 70
26HMALE ,6HFEMALE,6HIT ,6H, ,6HZONE ,6HBLOCK ,6HMEDIA ,	DATA 80
36HSURFAC,6HSECTOR,6HXSQ ,6HYSQ ,6HZSQ ,6HXV ,6HXZ ,	DATA 90
46HYZ ,6HX ,6HY ,6HZ ,6H ,6HYX ,6HZX ,	DATA 100
56HZY ,6HREGION,6HSIR ,6HMADAM ,6HMISS ,6HMARRIE,6HSINGLE/	DATA 110
DATA NERR/D/	DATA 120
DATA(NR(I),I=1,31)/	DATA 130
1 1,2,4,8,16,32,64,128,256,512,1024,2048,4096,8192,16384,	DATA 140
2 32768,65536,131072,262144,524288,1048576,2097152,4194304,	DATA 150
3 8388608,16777216,33554432,67108864,134217728,268435456,	DATA 160
4 536870912,1073741824/	DATA 170
END	DATA 180

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE DETDOT	DETF 10
INCLUDE BBLANC	DETF 20
COMMON/SCALE/ZS,RMAX,DOTARG(50,10)	DETF 30
COMMON/WEIGHT/WJ(100),HMU(100),ETA(100),WIG(100)	DETF 40
COMMON/DETECT/NODET,XDET(3,10)	DETF 50
COMMON/DOTPTS/RM(100),ZM(100),A(100)	DETF 60
COMMON/UNIT/NAFT,NMAT,KT15	DETF 70
INTEGER A04	DETF 80
DIMENSION R2(100,10),IRPICK(100,10),IFLAG(10)	DETF 90
DIMENSION B(3000),SUM(100),AEFF(100,10)	DETF 100
IF(NODET.LT.2)RETURN	DETF 110
DO 1 NDO=2,NODET	DETF 120
DO 6 I=1,IM	DETF 130
6 SUM(I)=0.	DETF 140
DELTAZ=XDET(3,NDO)-ZS	DETF 150
K14=1	DETF 160
K15=KT15	DETF 170
PRINT 50,NDO	DETF 180
IFLAG(NDO)=1	DETF 190
2 R=DELTAZ/ETA(K14)	DETF 200
IF(R.GT.0)GO TO 3	DETF 210
K14=KT15+1	DETF 220
IFLAG(NDO)=K14	DETF 230
K15=A04	DETF 240
GO TO 2	DETF 250
3 R02=XDET(1,NDO)**2+XDET(2,NDO)**2	DETF 260
R0=SQRT(R02)	DETF 270
DO 4 M=K14,K15	DETF 280
IRPICK(M,NDO)=0	DETF 290
R=DELTAZ/ETA(M)	DETF 300
R2(M,NDO)=R*R	DETF 310
R1=ABS(R0+HMU(M)*R)	DETF 320
IF(WJ(M).LT..000001)GO TO 4	DETF 330
IF(R1.GT.RMAX)GO TO 4	DETF 340
DIST=1.0E+6	DETF 350
DO 5 I=1,IM	DETF 360
S=ABS(RM(I)-R1)	DETF 370
IF(S.GT.DIST)GO TO 5	DETF 380
DIST=S	DETF 390
IRPICK(M,NDO)=I	DETF 400
5 CONTINUE	DETF 410
I=IRPICK(M,NDO)	DETF 420
SUM(I)=SUM(I)+WJ(M)	DETF 430
4 PRINT 20,M,R1,IRPICK(M,NDO),R	DETF 440
20 FORMAT(I10,E20.5,I10,E20.5)	DETF 450

50	FORMAT(1H1,'BACKWARD RAY TRACINGS FOR DETECTOR NO.',I3//	DETF 460
	15X,'ANGLE',6X,'SURFACE RADIUS',2X,'INTERVAL',12X,'DISTANCE')	DETF 470
	DO 7 M=K14,K15	DETF 480
	I=IRPICK(M,NDO)	DETF 490
	IF(I.EQ.0)GO TO 7	DETF 500
	AEFF(M,NDO)=A(I)*ABS(ETA(M))*WD(M)/SUM(I)	DETF 510
7	CONTINUE	DETF 520
1	CONTINUE	DETF 530
	RETURN	DETF 540
	ENTRY DETFLX(B,IG,M1,M2)	DETF 550
	IF(NODET.LT.2)RETURN	DETF 560
	DO 10 NDO=2,NODET	DETF 570
	IF(IFLAG(NDO).NE.M1)GO TO 10	DETF 580
	DOTARG(IG,NDO)=0.	DETF 590
	INDEX=-IM	DETF 600
	DO 11 M=M1,M2	DETF 610
	INDEX=INDEX+IM	DETF 620
	I=IRPICK(M,NDO)	DETF 630
	IF(I.EQ.0)GO TO 11	DETF 640
	TERM=B(INDEX+I)	DETF 650
	DOTARG(IG,NDO)=DOTARG(IG,NDO)+WD(M)*TERM*AEFF(M,NDO)/R2(M,NDO)	DETF 660
11	CONTINUE	DETF 670
10	CONTINUE	DETF 680
	RETURN	DETF 690
	END	DETF 700

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE DUCTFX(MM,AFLUX,IG)	DUCT 10
COMMON/UNIT/NAFT,NMAT,KT15	DUCT 20
COMMON/COEFIC/COEF(50,4),IDOT(50,4)	DUCT 30
COMMON/SPFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NDPT	DUCT 40
COMMON/DOTPTS/RM(100),ZM(100)	DUCT 50
INCLUDE SBLANC	DUCT 60
DIMENSION B(3000),AFLUX(MM,1)	DUCT 70
INTEGER T15,T16	DUCT 80
T15=KT15	DUCT 90
T16=T15+1	DUCT 100
DO 1 M=1,MM	DUCT 110
DO 1 N=1,NDPT	DUCT 120
1 AFLUX(M,N)=0.0	DUCT 130
NREAD=T15*IM	DUCT 140
M1=1	DUCT 150
M2=T15	DUCT 160
J1=JM	DUCT 170
J2=1	DUCT 180
J3=-1	DUCT 190
7 DO 2 J=J1,J2,J3	DUCT 200
READ (NAFT) (B(I),I=1,NREAD)	DUCT 210
DO 3 N=1,NDPT	DUCT 220
I=IDOT(N,1)	DUCT 230
II=I+1	DUCT 240
IF(J.NE.IDOT(N,2))GO TO 4	DUCT 250
INDEX=-IM	DUCT 260
DO 5 M=M1,M2	DUCT 270
INDEX=INDEX+IM	DUCT 280
5 AFLUX(M,N)=AFLUX(M,N)+COEF(N,1)*B(INDEX+I)+COEF(N,2)*B(INDEX+II)	DUCT 290
4 IF(J.NE.IDOT(N,4))GO TO 3	DUCT 300
INDEX=-IM	DUCT 310
DO 6 M=M1,M2	DUCT 320
INDEX=INDEX+IM	DUCT 330
6 AFLUX(M,N)=AFLUX(M,N)+COEF(N,3)*B(INDEX+I)+COEF(N,4)*B(INDEX+II)	DUCT 340
3 CONTINUE	DUCT 350
IF(J.EQ.1)CALL DETFLX(B,IG,M1,M2)	DUCT 360
2 CONTINUE	DUCT 370
IF(M1.GT.1)RETURN	DUCT 380
M1=T16	DUCT 390
M2=MM	DUCT 400
J1=1	DUCT 410
J2=JM	DUCT 420
J3=1	DUCT 430
T15=MM-T15	DUCT 440
NREAD=T15*IM	DUCT 450
GO TO 7	DUCT 460
END	DUCT 470

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE DUCTRD	DUCT 10
COMMON/PL/AIR(20),LEVMAX,XON(3),LNG,LN2	DUCT 20
COMMON/DETECT/NODET,XDET(3,10),RD2,RD	DUCT 30
COMMON/SPFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NDPT	DUCT 40
COMMON/DUCT/DUCTW(3),DUCTX(3,50),RSSQ(50),RS(50),CBET(50),AREA(50)	DUCT 50
1,VOLS(50)	DUCT 60
DIMENSION DIV(50)	DUCT 70
DIMENSION XTW(3),VOLMOD(50)	DUCT 80
REAL LN2,LNG	DUCT 90
READ 1,(XON(I),I=1,3),(XTW(I),I=1,3),RD	DUCT 100
1 FORMAT(7F10.0)	DUCT 110
READ 2,NDIVL	DUCT 120
2 FORMAT(14I5)	DUCT 130
NDPT=NDIVL+1	DUCT 140
DO 10 I=1,3	DUCT 150
10 DUCTX(I,NDPT)=XDET(I,1)	DUCT 160
READ 1,(VOLMOD(I),I=1,NDIVL)	DUCT 170
LN2=0.0	DUCT 180
DO 3 I=1,3	DUCT 190
3 LN2=LN2+(XON(I)-XTW(I))**2	DUCT 200
LNG=SQRT(LN2)	DUCT 210
RD2=RD*RD	DUCT 220
DO 4 I=1,3	DUCT 230
4 DUCTW(I)=(XTW(I)-XON(I))/LNG	DUCT 240
V1=(SQRT(XTW(1)**2+XTW(2)**2)-SQRT(XON(1)**2+XON(2)**2))/LNG	DUCT 250
CALL CONTES(V1,DUCTW(3))	DUCT 260
CALL PLATE(RD,LNG)	DUCT 270
NDEN=NDIVL-4	DUCT 280
IDEN=1	DUCT 290
DISSUM=0.0	DUCT 300
DO 5 N=1,NDPT	DUCT 310
IF(N.EQ.NDPT)GO TO 11	DUCT 320
IF(N.GE.NDIVL-5) IDEN=2	DUCT 330
IF(N.GE.NDIVL-3) IDEN=4	DUCT 340
DIV(N)=LNG/(IDEN*NDEN)	DUCT 350
DISSUM=DISSUM+DIV(N)	DUCT 360
DISN=DISSUM-.5*DIV(N)	DUCT 370
DO 6 J=1,3	DUCT 380
6 DUCTX(J,N)=XON(J)+DUCTW(J)*DISN	DUCT 390
RSSQ(N)=RD2	DUCT 400
DO 12 I=1,3	DUCT 410
12 RSSQ(N)=RSSQ(N)+(XDET(I,1)-DUCTX(I,N))**2	DUCT 420
RS(N)=SQRT(RSSQ(N))	DUCT 430
CBET(N)=RD/RS(N)	DUCT 440
AREA(N)=6.2832*RD*DIV(N)*CBET(N)	DUCT 450
11 Z(N)=DUCTX(3,N)	DUCT 460
RZR(N)=SQRT(DUCTX(1,N)**2+DUCTX(2,N)**2)	DUCT 470
FDUCT(1,N)=DUCTX(1,N)/RZR(N)	DUCT 480
FDUCT(2,N)=DUCTX(2,N)/RZR(N)	DUCT 490
5 VOLS(N)=3.1416*RD2*DIV(N)*VOLMOD(N)	DUCT 500
RETURN	DUCT 510
END	DUCT 520

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE ERROR	ERRO	10
WRITE(6,100)	ERRO	20
100 FORMAT(25H0AN ERROR HAS BEEN FOUND.)	ERRO	30
CALL EXIT	ERRO	40
RETURN	ERRO	50
END	ERRO	60

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE EUCLID(X1,Y1,Z1,X2,Y2,Z2,P1P2,IG,ARG,NT)	EUCL	10
THIS EUCLID IS THE STANDARD SUBROUTINE FOR ANALYSIS	EUCL	20
INTERNAL VOIDS MUST BE MEDIUM NO. 500	EUCL	30
SET MARK=1 WHENEVER STARTING FROM A NEW COLLISION POINT	EUCL	40
LET PD AND P4 BE THE INITIAL AND FINAL POINT OF A NEUTRON FLT.	EUCL	50
PATH. LET P1 BE A BOUNDARY CROSSING PT. ALONG THE FLT. PATH.	EUCL	60
IF EUCLID IS CALLED WITH NT=0, THEN PD AND P4 WILL BE UNCHANGED	EUCL	70
AND ARG WILL BE THE TOTAL MFP FROM PD TO P4. IF EUCLID IS CALLED	EUCL	80
WITH NT=1, PD WILL BE DESTROYED AND REPLACED BY P1. ARG WILL BE	EUCL	90
THE MFP BETWEEN PD AND P1, AND P4 IS UNCHANGED	EUCL	100
COMMON/GEOMC/MARK,XTWO,YTWO,ZTWO,XONE,YONE,ZONE,NMED,NREG,ETA,ETAUSD	EUCL	110
1SD,BLZON	EUCL	120
COMMON/XSECT/GXSECT(25,10)	EUCL	130
DATA MARK/1/	EUCL	140
IF(MARK)51,1,51	EUCL	150
51 MARK=1	EUCL	160
ARG=0.	EUCL	170
CALL LOOKZ(X1,Y1,Z1)	EUCL	180
XONE=X1	EUCL	190
YONE=Y1	EUCL	200
ZONE=Z1	EUCL	210
ETA=P1P2	EUCL	220
1 IF(NMED-1000) 3,2,3	EUCL	230
2 SIGT=0.	EUCL	240
GO TO 4	EUCL	250
3 SIGT=-GXSECT(IG,NMED)	EUCL	260
4 XTWO=X2	EUCL	270
YTWO=Y2	EUCL	280
ZTWO=Z2	EUCL	290
CALL GEOM	EUCL	300
IF(MARK)6,5,7	EUCL	310
6 IF(MARK+1)5,8,9	EUCL	320
5 ARG=ARG+SIGT*ETAUSD	EUCL	330
ETA=ETA-ETAUSD	EUCL	340
XONE=XTWO	EUCL	350
YONE=YTWO	EUCL	360
ZONE=ZTWO	EUCL	370
IF(NT)13,1,13	EUCL	380
13 X1=XONE	EUCL	390
Y1=YONE	EUCL	400
Z1=ZONE	EUCL	410
19 RETURN	EUCL	420
7 ARG=ARG+SIGT*ETA	EUCL	430
XONE=XTWO	EUCL	440
YONE=YTWO	EUCL	450

ZONE=ZTWO	EUCL 460
IF (NT) 13,19,13	EUCL 470
8 ARG=ARG+SIGT*ETAUSD	EUCL 480
XONE=XTWO	EUCL 490
YONE=YTWO	EUCL 500
ZONE=ZTWO	EUCL 510
IF (NT) 17,19,17	EUCL 520
17 NT=-1	EUCL 530
GO TO 13	EUCL 540
9 CALL ERROR	EUCL 550
RETURN	EUCL 560
END	EUCL 570

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

EXPONENTIAL INTEGRAL FUNCTION. 4169A. READ.	EXIN 10
FUNCTION EXIN(Y)	EXIN 20
IF (Y) 19,20,21	EXIN 30
20 EXIN=1.E35	EXIN 40
AUG=0.	EXIN 50
23 PRINT 22,Y,EXIN,AUG	EXIN 60
22 FORMAT(24H) TRIED TO TAKE EXIN OF	EXIN 70
13 RETURN	EXIN 80
21 IF (Y-1.5) 26,26,25	EXIN 90
26 Z=Y	EXIN 100
GO TO 24	EXIN 110
19 Z=-Y	EXIN 120
24 X=-Y	EXIN 130
EXIN = -.577215665-ALOG(Z)	EXIN 140
FACT=1.	EXIN 150
XN=1.	EXIN 160
DO 30 I=1,20	EXIN 170
FI=I	EXIN 180
FACT=FACT*FI	EXIN 190
XN=XN*X	EXIN 200
AUG=XN/(FI*FACT)	EXIN 210
IF (ABS (AUG)-.000001) 13,30,30	EXIN 220
30 EXIN=EXIN-AUG	EXIN 230
GO TO 13	EXIN 240
25 DEN=(Y+3.330657)*Y+1.681534	EXIN 250
TOP=(Y+2.334733)*Y+0.250621	EXIN 260
EXIN=(EXP (-Y)/Y)*TOP/DEN	EXIN 270
GO TO 13	EXIN 280
END	EXIN 290

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE GEOM	GEOM 10
MARK=1 FOR COMPLETED PATH	GEOM 20
=0 FOR NORMAL BOUNDARY CROSSING	GEOM 30
=-1 FOR ESCAPED FROM SYSTEM	GEOM 40
=-2 ENTERED INTERIOR VOID	GEOM 50
COMMON/GEOMC/MARK,XTWO,YTWO,ZTWO,XONE,YONE,ZONE,	GEOM 60
1NMED,NREG,ETA,ETAUSD,BLZON	GEOM 70
COMMON/GEOM4/X1,Y1,Z1,X2,Y2,Z2,NCUE,DIST,NCR,	GEOM 80
1DISTQ	GEOM 90
COMMON/GEOMA/ID,NSTAT	GEOM 100
COMMON/JOMIN1/BIG	GEOM 110
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	GEOM 120
DATA I/2/	GEOM 130
100 IF (NMED-1000) 105,200,105	GEOM 140
105 IF (MARK) 165,170,110	GEOM 150
110 ID=1	GEOM 160
CALL JOM14	GEOM 170
JOM14 IS UNPCK	GEOM 180
115 X1=XONE	GEOM 190
Y1=YONE	GEOM 200
Z1=ZONE	GEOM 210
X2=XTWO	GEOM 220
Y2=YTWO	GEOM 230
Z2=ZTWO	GEOM 240
DISTD=0.0	GEOM 250
120 DIST=1.0-DISTD	GEOM 260
CALL JOM4	GEOM 270
JOM4 IS BOUND	GEOM 280
CALL JOM5	GEOM 290
IF (NCR) 150,150,125	GEOM 300
125 XTWO=X2	GEOM 310
YTWO=Y2	GEOM 320
ZTWO=Z2	GEOM 330
ETAUSD=ETA*(DIST*DISTQ+DISTD)	GEOM 340
IF (NMED) 130,140,130	GEOM 350
130 IF (NMED-1000) 135,145,135	GEOM 360
135 MARK=0	GEOM 370
GO TO 190	GEOM 380
140 MARK=-1	GEOM 390
GO TO 190	GEOM 400
145 MARK=-2	GEOM 410
GO TO 190	GEOM 420
150 IF (NCUE) 160,160,155	GEOM 430
155 DISTD=DIST+DISTQ	GEOM 440
X1=X2	GEOM 450

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Y1=Y2
Z1=Z2
X2=XTWO
Y2=YTWO
Z2=ZTWO
CALL JOM10
JOM10 IS NEWB
ID=1
IF (NZ) 175,175,120
160 MARK=1
ETAUSD=ETA
GO TO 180
165 IF (MARK+1) 170,110,110
170 ID=2
GO TO 115
175 MARK=-1
XTWO=X1
YTWO=Y1
ZTWO=Z1
ETAUSD=ETA*DISTD
NMED=0
BLZON=0.
GO TO 195
180 IF (NSTAT) 185,190,185
185 CALL JOM6 (XTWO,YTWO,ZTWO,3,NREG)
JOM6 IS FINDR JOM15 IS PCK
190 CALL JOM15
195 IF (I-1) 205,205,220
200 S=ABS (XTWO)+ABS (YTWO)+ABS (ZTWO)
XTWO=XONE+BIG*XTWO/S
YTWO=YONE+BIG*YTWO/S
ZTWO=ZONE+BIG*ZTWO/S
I=1
GO TO 105
205 I=2
ETAUSD=0.0
220 RETURN
END

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GEOM 460
GEOM 470
GEOM 480
GEOM 490
GEOM 500
GEOM 510
GEOM 520
GEOM 530
GEOM 540
GEOM 550
GEOM 560
GEOM 570
GEOM 580
GEOM 590
GEOM 600
GEOM 610
GEOM 620
GEOM 630
GEOM 640
GEOM 650
GEOM 660
GEOM 670
GEOM 680
GEOM 690
GEOM 700
GEOM 710
GEOM 720
GEOM 730
GEOM 740
GEOM 750
GEOM 760
GEOM 770
GEOM 780
GEOM 790
GEOM 800
GEOM 810
GEOM 820
GEOM 830

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DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE IMLEV(ET,N)	IMLE	10
COMMON/STAR/NMU(30),WSUM(100),ATE(100),NLEV,MSTAR(100),LEVEL(50)	IMLE	20
D=1.0E+6	IMLE	30
DO 1 LEV=1,NLEV	IMLE	40
S=ABS(ET-ATE(LEV))	IMLE	50
IF(S.GT.D)GO TO 1	IMLE	60
D=S	IMLE	70
LEVEL(N)=LEV	IMLE	80
1 CONTINUE	IMLE	90
RETURN	IMLE	100
END	IMLE	110

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

CC SUBROUTINE JOMIN(ADDR)	JOMI	10
SUBROUTINE JOMIN(NADD1)	JOMI	20
DIMENSION N(1),X(1)	JOMI	30
COMMON X	JOMI	40
COMMON/GEOMA/ID,NSTAT	JOMI	50
COMMON/JOMIN1/BIG	JOMI	60
COMMON/JOMIN2/NOX,NOY,NOZ,NOXY,NOXYZ,XPBD,XMBD,YPBD,YMBD,ZPBD,ZMBD	JOMI	70
COMMON/JOMIN3/NXZBD,NYZBD,NZZBD,NOXB,NOYB,NOZB,NNX,	JOMI	80
1NNY,NNZ,NM,NME1,NME2,NME3,NS,NB,NMS,NME1S,NME2S,NME3S,	JOMI	90
2NSS,NBS	JOMI	100
COMMON/GEOMT/TITLE	JOMI	110
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	JOMI	120
\$SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	JOMI	130
EQUIVALENCE(X,N)	JOMI	140
READ (5,8000) NSTAT,SEX,STATUS,STAT	JOMI	150
WRITE (6,8005) NSTAT,SEX,STATUS,STAT	JOMI	160
NSTAT=NSTAT-2	JOMI	170
IF (SEX-HMALE) 105,100,105	JOMI	180
100 TITLE=SIR	JOMI	190
GO TO 135	JOMI	200
105 IF (SEX-FEMALE) 130,110,130	JOMI	210
110 IF (STATUS-HMARR) 120,115,120	JOMI	220
115 TITLE=HMADAM	JOMI	230
GO TO 135	JOMI	240
120 IF (STATUS-SINGLE) 130,125,130	JOMI	250
125 TITLE=HMISS	JOMI	260
GO TO 135	JOMI	270
130 TITLE=HIT	JOMI	280
CALL JOM13(5)	JOMI	290
CC135 NADD1=LOC(ADDR)-LOC(X)+1	JOMI	300
135 CONTINUE	JOMI	310
NADD=NADD1+1	JOMI	320
NXZBD=NADD	JOMI	330
NOX=JOM16(NADD)	JOMI	340
NADD=NADD	JOMI	350
XPBD=X(NADD-1)	JOMI	360
XMBD=X(NXZBD)	JOMI	370
NYZBD=NADD	JOMI	380
NOY=JOM16(NADD)	JOMI	390
NADD=NADD	JOMI	400
YPBD=X(NADD-1)	JOMI	410
YMBD=X(NYZBD)	JOMI	420
NZZBD=NADD	JOMI	430
NOZ=JOM16(NADD)	JOMI	440
NADD=NADD	JOMI	450

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

ZPBD=X(NADD-1)	JOMI 460
ZMBD=X(NZZBD)	JOMI 470
NOXY=NOX*NOY	JOMI 480
NOXYZ=NOXY*NOZ	JOMI 490
NNX=NADD-1	JOMI 500
NNY=NNX+NOXYZ	JOMI 510
NNZ=NNY+NOXYZ	JOMI 520
NM=NNZ+NOXYZ	JOMI 530
NME1=NM+NOXYZ	JOMI 540
NME2=NME1+NOXYZ	JOMI 550
NME3=NME2+NOXYZ	JOMI 560
NS=NME3+NOXYZ	JOMI 570
NB=NS+NOXYZ	JOMI 580
NOYB=NB+NOXYZ	JOMI 590
NOXB=NOXB+NOXYZ	JOMI 600
NOZB=NOYB+NOXYZ	JOMI 610
NADD=NOZB+NOXYZ+1	JOMI 620
IF (NSTAT) 140,145,140	JOMI 630
140 NMS=NADD-1	JOMI 640
NME1S=NMS+NOXYZ	JOMI 650
NME2S=NME1S+NOXYZ	JOMI 660
NME3S=NME2S+NOXYZ	JOMI 670
NSS=NME3S+NOXYZ	JOMI 680
NBS=NSS+NOXYZ	JOMI 690
NADD=NBS+NOXYZ+1	JOMI 700
145 DO 220 IIZ=1,NOXYZ	JOMI 710
READ (5,8010) BCD,NXZNO,NYZNO,NZZNO	JOMI 720
WRITE (6,8015) BCD,NXZNO,NYZNO,NZZNO	JOMI 730
IF (BCD-ZONE) 150,155,150	JOMI 740
150 CALL JOM13(7)	JOMI 750
155 NZNO=(NZZNO-1)*NOXY+(NYZNO-1)*NOX+NXZNO	JOMI 760
LNK=NNX+NZNO	JOMI 770
N(LNK)=NADD	JOMI 780
NT1=NADD	JOMI 790
LOXB=NOXB+NZNO	JOMI 800
N(LOXB)=JOM16(NADD)	JOMI 810
NADD=NADD	JOMI 820
LXZ=NXZBD+NXZNO	JOMI 830
IF (X(NT1)-X(LXZ-1)) 225,160,225	JOMI 840
160 IF (X(NADD-1)-X(LXZ)) 225,165,225	JOMI 850
165 LNY=NNY+NZNO	JOMI 860
N(LNY)=NADD	JOMI 870
NT1=NADD	JOMI 880
LOYB=NOYB+NZNO	JOMI 890
N(LOYB)=JOM16(NADD)	JOMI 900
NADD=NADD	JOMI 910

	LYZ=NYZBD+NYZNO	JOMI 920
	IF (X (NT1) -X (LYZ-1)) 225,170,225	JOMI 930
170	IF (X (NADD-1) -X (LYZ)) 225,175,225	JOMI 940
175	LNZ=NNZ+NZNO	JOMI 950
	N (LNZ) =NADD	JOMI 960
	NT1=NADD	JOMI 970
	LOZB=NOZB+NZNO	JOMI 980
	N (LOZB) =JOM16 (NADD)	JOMI 990
	NADD=NADD	JOMI1000
	LZZ=NZZBD+NZZNO	JOMI1010
	IF (X (NT1) -X (LZZ-1)) 225,180,225	JOMI1020
180	IF (X (NADD-1) -X (LZZ)) 225,185,225	JOMI1030
185	NOB=N (LOXB) *N (LOYB) *N (LOZB)	JOMI1040
	NMA=NM+NZNO	JOMI1050
	NME1A=NME1+NZNO	JOMI1060
	NME2A=NME2+NZNO	JOMI1070
	NME3A=NME3+NZNO	JOMI1080
	NSA=NS+NZNO	JOMI1090
	NBA=NB+NZNO	JOMI1100
	NMB=NADD-1	JOMI1110
	N (NMA) =NMB	JOMI1120
	NME1B=NMB+NOB	JOMI1130
	N (NME1A) =NME1B	JOMI1140
	NME2B=NME1B+NOB	JOMI1150
	N (NME2A) =NME2B	JOMI1160
	NME3B=NME2B+NOB	JOMI1170
	N (NME3A) =NME3B	JOMI1180
	NSB=NME3B+NOB	JOMI1190
	N (NSA) =NSB	JOMI1200
	NBB=NSB+NOB	JOMI1210
	N (NBA) =NBB	JOMI1220
	NADD=NBB+NOB	JOMI1230
	IF (NSTAT) 190,195,190	JOMI1240
190	NMSA=NMS+NZNO	JOMI1250
	NME1SA=NME1S+NZNO	JOMI1260
	NME2SA=NME2S+NZNO	JOMI1270
	NME3SA=NME3S+NZNO	JOMI1280
	NSSA=NSS+NZNO	JOMI1290
	NBSA=NB+NZNO	JOMI1300
	NMSB=NADD	JOMI1310
	N (NMSA) =NADD	JOMI1320
	NME1SB=NADD+NOB	JOMI1330
	N (NME1SA) =NME1SB	JOMI1340
	NME2SB=NME1SB+NOB	JOMI1350
	N (NME2SA) =NME2SB	JOMI1360
	NME3SB=NME2SB+NOB	JOMI1370

N(NME3SA)=NME3SB	JOMI1380
NSSB=NME3SB+NOB	JOMI1390
N(NSSA)=NSSB	JOMI1400
NBSB=NSSB+NOB	JOMI1410
N(NBSA)=NBSB	JOMI1420
NADD=NBSB+NOB	JOMI1430
195 DO 215 IIB=1,NOB	JOMI1440
READ (5,8010) BCD,NXBNO,NYBNO,NZBNO	JOMI1450
WRITE (6,8015) BCD,NXBNO,NYBNO,NZBNO	JOMI1460
IF (BCD-BLOCK) 200,205,200	JOMI1470
200 CALL JOM13(7)	JOMI1480
205 NBNO=((NZBNO-1)*N(LOYB)+NYBNO-1)*N(LOXB)+NXBNO	JOMI1490
NMC=NMB+NBNO	JOMI1500
NME1C=NME1B+NBNO	JOMI1510
NME2C=NME2B+NBNO	JOMI1520
NME3C=NME3B+NBNO	JOMI1530
NSC=NSB+NBNO	JOMI1540
NBC=NBB+NBNO	JOMI1550
CALL JOM11(NADD,N(NMC),N(NSC),N(NME1C),N(NME2C),	JOMI1560
1N(NME3C),N(NBC),1)	JOMI1570
C JOM11 IS JOMR	JOMI1580
IF (NSTAT) 210,215,210	JOMI1590
210 NMSC=NMSB+NBNO	JOMI1600
NME1SC=NME1SB+NBNO	JOMI1610
NME2SC=NME2SB+NBNO	JOMI1620
NME3SC=NME3SB+NBNO	JOMI1630
NSSC=NSSB+NBNO	JOMI1640
NBSC=NBSB+NBNO	JOMI1650
CALL JOM11(NADD,N(NMSC),N(NSSC),N(NME1SC),	JOMI1660
1N(NME2SC),N(NME3SC),N(NBSC),-1)	JOMI1670
C JOM11 IS JOMR	JOMI1680
215 CONTINUE	JOMI1690
NADD=NADD+1	JOMI1700
220 CONTINUE	JOMI1710
CALL JOM12(NADD)	JOMI1720
C JOM12 IS JOMQ	JOMI1730
BIG=3.0*AMAX1(XPBD-XMBD,YPBD-YMBD,ZPBD-ZMBD)	JOMI1740
ID=1	JOMI1750
N(NADD1)=NADD-NADD1	JOMI1760
RETURN	JOMI1770
8000 FORMAT(I5,5X,A6,1X,A6,A1)	JOMI1780
8005 FORMAT(1H1,I5,5X,A6,1X,A6,A1)	JOMI1790
8010 FORMAT(A6,3I5)	JOMI1800
8015 FORMAT(1H0,A6,3I5)	JOMI1810
225 CALL JOM13(3)	JOMI1820
C JOM13 IS DGNSTK	JOMI1830
RETURN	JOMI1840
END	JOMI1850

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BOUND	JOM4	10
SUBROUTINE JOM4	JOM4	20
DIMENSION X(1),N(1)	JOM4	30
COMMON X	JOM4	40
COMMON/GEOM4/XONE,YONE,ZONE,XTWO,YTWO,ZTWO,NCUE,	JOM4	50
\$DIST,DUM1(2)	JOM4	60
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM4	70
COMMON/JOMIN3/DUM2(6),NX1,NY1,NZ1,DUM3(12)	JOM4	80
EQUIVALENCE(X,N)	JOM4	90
100 NX2=NX1+NZ	JOM4	100
NY2=NY1+NZ	JOM4	110
NZ2=NZ1+NZ	JOM4	120
NNX=N(NX2)+NXBL	JOM4	130
NNY=N(NY2)+NYBL	JOM4	140
NNZ=N(NZ2)+NZBL	JOM4	150
NB=0	JOM4	160
NBX=0	JOM4	170
NBY=0	JOM4	180
NBZ=0	JOM4	190
NCUE=0	JOM4	200
XDIST=XTWO-XONE	JOM4	210
YDIST=YTWO-YONE	JOM4	220
ZDIST=ZTWO-ZONE	JOM4	230
IF(XDIST)105,130,110	JOM4	240
105 IF(XTWO-X(NNX-1))115,130,130	JOM4	250
110 IF(XTWO-X(NNX))130,130,120	JOM4	260
115 NBX=-2	JOM4	270
GO TO 125	JOM4	280
120 NBX=1	JOM4	290
125 NB=1	JOM4	300
130 IF(YDIST)135,160,140	JOM4	310
135 IF(YTWO-X(NNY-1))145,160,160	JOM4	320
140 IF(YTWO-X(NNY))160,160,150	JOM4	330
145 NBY=-4	JOM4	340
GO TO 155	JOM4	350
150 NBY=3	JOM4	360
155 NB=1	JOM4	370
160 IF(ZDIST)165,190,170	JOM4	380
165 IF(ZTWO-X(NNZ-1))175,190,190	JOM4	390
170 IF(ZTWO-X(NNZ))190,190,180	JOM4	400
175 NBZ=-6	JOM4	410
GO TO 185	JOM4	420
180 NBZ=5	JOM4	430
185 NB=1	JOM4	440
190 IF(NB)315,315,195	JOM4	450

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195 DIST4=2.0
    IF (NBX) 200,215,205
200 XBOND=X (NNX-1)
    GO TO 210
205 XBOND=X (NNX)
210 DIST4=(XBOND-XONE)/XDIST
    NB=1
215 IF (NBY) 220,240,225
220 YBOND=X (NNY-1)
    GO TO 230
225 YBOND=X (NNY)
230 DIST2=(YBOND-YONE)/YDIST
    IF (DIST4-DIST2) 240,240,235
235 DIST4=DIST2
    NB=2
240 IF (NBZ) 245,265,250
245 ZBOND=X (NNZ-1)
    GO TO 255
250 ZBOND=X (NNZ)
255 DIST2=(ZBOND-ZONE)/ZDIST
    IF (DIST4-DIST2) 265,265,260
260 DIST4=DIST2
    NB=3
265 IF (NB-1) 275,270,275
270 XTWO=XBOND
    NCUE=IABS (NBX)
    GO TO 280
275 XTWO=XDIST*DIST4+XONE
280 IF (NB-2) 290,285,290
285 YTWO=YBOND
    NCUE=IABS (NBY)
    GO TO 295
290 YTWO=YDIST*DIST4+YONE
295 IF (NB-3) 305,300,305
300 ZTWO=ZBOND
    NCUE=IABS (NBZ)
    GO TO 310
305 ZTWO=ZDIST*DIST4+ZONE
310 DIST=DIST*DIST4
315 RETURN
    END

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JOM4 460
JOM4 470
JOM4 480
JOM4 490
JOM4 500
JOM4 510
JOM4 520
JOM4 530
JOM4 540
JOM4 550
JOM4 560
JOM4 570
JOM4 580
JOM4 590
JOM4 600
JOM4 610
JOM4 620
JOM4 630
JOM4 640
JOM4 650
JOM4 660
JOM4 670
JOM4 680
JOM4 690
JOM4 700
JOM4 710
JOM4 720
JOM4 730
JOM4 740
JOM4 750
JOM4 760
JOM4 770
JOM4 780
JOM4 790
JOM4 800
JOM4 810
JOM4 820
JOM4 830
JOM4 840
JOM4 850
JOM4 860

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INTER	JOM5	10
SUBROUTINE JOM5	JOM5	20
DIMENSION X(1),N(1),R(1)	JOM5	30
COMMON/NRC/NR(31)	JOM5	40
COMMON X	JOM5	50
COMMON/GEOM4/XONE,YONE,ZONE,XTWO,YTWO,ZTWO,NCUE,	JOM5	60
1DIST4,NCR,DIST	JOM5	70
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM5	80
COMMON/GEOM56/RGBD,NBBD	JOM5	90
COMMON/JOMIN3/DUM1(13),NS,NB,DUM2(6)	JOM5	100
COMMON/GEOM7/X1,Y1,Z1,X2,Y2,Z2,NCR1,DIST1	JOM5	110
COMMON/GEOMA/ID,NSTAT	JOM5	120
COMMON/GEOMC/DUM4(7),NMED,DUM5(4)	JOM5	130
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	JOM5	140
EQUIVALENCE(R,NR)	JOM5	150
EQUIVALENCE(X,N)	JOM5	160
EQUIVALENCE(OK,KO)	JOM5	170
IF (ID-1) 100,100,110	JOM5	180
100 CALL JOM6(XONE,YONE,ZONE,1,NEWMED)	JOM5	190
JOM6 IS FINDR	JOM5	200
NS1=NS+NZ	JOM5	210
NB1=NB+NZ	JOM5	220
NS2=N(NS1)+NBL	JOM5	230
NB2=N(NB1)+NBL	JOM5	240
NOS=N(NS2)	JOM5	250
NBD=N(NB2)	JOM5	260
IF (NEWMED-NMED) 105,110,105	JOM5	270
105 NMED=NEWMED	JOM5	280
XTWO=XONE	JOM5	290
YTWO=YONE	JOM5	300
ZTWO=ZONE	JOM5	310
DIST=0.	JOM5	320
NCR=1	JOM5	330
GO TO 185	JOM5	340
110 IF (NOS) 115,115,125	JOM5	350
115 NCR=0	JOM5	360
120 NBOUND=0	JOM5	370
SGNF=0.	JOM5	380
GO TO 185	JOM5	390
125 DIST=0.	JOM5	400
DIST2=1.0	JOM5	410
X1=XONE	JOM5	420
Y1=YONE	JOM5	430
Z1=ZONE	JOM5	440
130 X2=XTWO	JOM5	450

Y2=YTWO	JOM5 460
Z2=ZTWO	JOM5 470
NCR=0	JOM5 480
DO 145 I=1,NOS	JOM5 490
IF (BOOL (AND (RGRD,R(I)))) 135,145,135	JOM5 500
OK=AND (RGRD,R(I))	JOM5 510
IF (KO) 135,145,135	JOM5 520
135 NBD1=NBD+I	JOM5 530
CALL JOM7 (N(NBD1))	JOM5 540
JOM7 IS CROSS	JOM5 550
IF (NCR1) 145,145,140	JOM5 560
140 NCR=NCR1	JOM5 570
NBDD=I	JOM5 580
DIST2=DIST2+DIST1	JOM5 590
145 CONTINUE	JOM5 600
IF (NCR) 150,120,150	JOM5 610
150 NBOUND=NBD2	JOM5 620
SGNF=SGNF2	JOM5 630
155 CALL JOM6 (X2,Y2,Z2,2,NEWMED)	JOM5 640
JOM6 IS FINDR	JOM5 650
IF (NMED-NEWMED) 165,160,165	JOM5 660
160 X1=X2	JOM5 670
Y1=Y2	JOM5 680
Z1=Z2	JOM5 690
DIST=DIST+DIST2	JOM5 700
DIST2=1.0-DIST	JOM5 710
GO TO 130	JOM5 720
165 NMED=NEWMED	JOM5 730
XTWO=X2	JOM5 740
YTWO=Y2	JOM5 750
ZTWO=Z2	JOM5 760
DIST=DIST+DIST2	JOM5 770
185 RETURN	JOM5 780
END	JOM5 790

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FINDR	JOM6 10
SUBROUTINE JOM6 (XONE,YONE,ZONE,ID,NMED)	JOM6 20
DIMENSION X(1),R(1),N(1)	JOM6 30
COMMON X	JOM6 40
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM6 50
COMMON/GEOM56/RGBD,NOBD	JOM6 60
COMMON/JOMIN3/DUMMY(9),NM,NME1,NME2,NME3,NS,NB,NMS,	JOM6 70
\$NME1S,NME2S,NME3S,NSS,NBS	JOM6 80
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	JOM6 90
EQUIVALENCE (R,NR)	JOM6 100
EQUIVALENCE (X,N)	JOM6 110
COMMON/NRC/NR(31)	JOM6 120
REAL JOM8	JOM6 130
EQUIVALENCE (OK,KO)	JOM6 140
IF (ID-1) 100,100,100	JOM6 150
100 NS1=NS+NZ	JOM6 160
NB1=NB+NZ	JOM6 170
NM1=NM+NZ	JOM6 180
NME4=NME1+NZ	JOM6 190
NME5=NME2+NZ	JOM6 200
NME6=NME3+NZ	JOM6 210
105 NS2=N(NS1)+NBL	JOM6 220
NB2=N(NB1)+NBL	JOM6 230
NM2=N(NM1)+NBL	JOM6 240
NME7=N(NME4)+NBL	JOM6 250
NME8=N(NME5)+NBL	JOM6 260
NME9=N(NME6)+NBL	JOM6 270
NOR=N(NM2)	JOM6 280
NMD=N(NME9)	JOM6 290
IF (NOR-1) 110,110,115	JOM6 300
110 NMED=N(NMD+1)	JOM6 310
RGBD=0	JOM6 320
GO TO 205	JOM6 330
115 NOS=N(NS2)	JOM6 340
NBD=N(NB2)	JOM6 350
NPOS=N(NME7)	JOM6 360
NNEG=N(NME8)	JOM6 370
REG=0.	JOM6 380
DO 135 I=1,NOS	JOM6 390
NBD1=NBD+I	JOM6 400
IF (N(NBD1)-NBOUND) 125,120,125	JOM6 410
120 IF (SGNF) 135,130,130	JOM6 420
125 FO=JOM8 (XONE,YONE,ZONE,N(NBD1))	JOM6 430
JOM8 IS FUNC	JOM6 440
IF (FO) 135,130,130	JOM6 450

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130	REG=OR(REG,R(I))	JOM6 460
135	CONTINUE	JOM6 470
140	DO 150 I=1,NOR	JOM6 480
	NPOS1=NPOS+I	JOM6 490
	OK=AND(COMPL(REG),X(NPOS1))	JOM6 500
CC	IF(OK)150,145,150	JOM6 510
	IF(KO)150,145,150	JOM6 520
145	NNEG1=NNEG+I	JOM6 530
	OK=AND(REG,X(NNEG1))	JOM6 540
CC	IF(OK)150,155,150	JOM6 550
	IF(KO)150,155,150	JOM6 560
150	CONTINUE	JOM6 570
	CALL JOM13(1)	JOM6 580
C	JOM13 IS DGNSTK	JOM6 590
155	NMD1=NMD+I	JOM6 600
	NMED=N(NMD1)	JOM6 610
	RGBD=OR(X(NPOS1),X(NNEG1))	JOM6 620
	GO TO 205	JOM6 630
160	IF(ID-2)165,165,190	JOM6 640
165	REG=OR(AND(COMPL(REG),R(NOBD)),AND(REG,COMPL(R(NOBD))))	JOM6 650
	DO 185 I=1,NOS	JOM6 660
CC	IF(BOOL(AND(R(I),COMPL(RGBD)))) 170,185,170	JOM6 670
	OK=AND(R(I),COMPL(RGBD))	JOM6 680
	IF(KO)170,185,170	JOM6 690
170	NBD1=NBD+I	JOM6 700
	FO=JOM8(XONE,YONE,ZONE,N(NBD1))	JOM6 710
	IF(FO)175,180,180	JOM6 720
175	REG=AND(REG,COMPL(R(I)))	JOM6 730
	GO TO 185	JOM6 740
180	REG=OR(REG,R(I))	JOM6 750
185	CONTINUE	JOM6 760
	GO TO 140	JOM6 770
190	NS1=NSS+NZ	JOM6 780
	NB1=NBS+NZ	JOM6 790
	NM1=NMS+NZ	JOM6 800
	NME4=NME1S+NZ	JOM6 810
	NME5=NME2S+NZ	JOM6 820
	NME6=NME3S+NZ	JOM6 830
	GO TO 105	JOM6 840
205	RETURN	JOM6 850
	END	JOM6 860

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CROSS FOR O5R GEOMETRY	JOM7 10
SUBROUTINE JOM7(ID)	JOM7 20
DIMENSION X(1)	JOM7 30
COMMON X	JOM7 40
COMMON/GEOM7/XONE,YONE,ZONE,XTWO,YTWO,ZTWO,NCR,	JOM7 50
1DIST	JOM7 60
COMMON/JOMIN8/NA,NB,NC,ND,NE,NF,NG,NH,NI,NJ	JOM7 70
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	JOM7 80
REAL JOM8	JOM7 90
IF (ID-NBOUND) 105,100,105	JOM7 100
100 FUN=0.	JOM7 110
GO TO 110	JOM7 120
105 FUN=JOM8(XONE,YONE,ZONE,ID)	JOM7 130
JOM8 IS FUNC	JOM7 140
110 LA=NA+ID	JOM7 150
LB=NB+ID	JOM7 160
LC=NC+ID	JOM7 170
LD=ND+ID	JOM7 180
LE=NE+ID	JOM7 190
LF=NF+ID	JOM7 200
LG=NG+ID	JOM7 210
LH=NH+ID	JOM7 220
LI=NI+ID	JOM7 230
U=XTWO-XONE	JOM7 240
V=YTWO-YONE	JOM7 250
W=ZTWO-ZONE	JOM7 260
AU=X(LA)*U	JOM7 270
BV=X(LB)*V	JOM7 280
CW=X(LC)*W	JOM7 290
AUDVEW=AU+X(LD)*V+X(LE)*W	JOM7 300
BVFW=BV+X(LF)*W	JOM7 310
P=AUDVEW*U+BVFW*V+CW*W	JOM7 320
Q=(AU+AUDVEW)*XONE+(BV+BFW*W)*X(LD)*U*YONE+	JOM7 330
1 (CW+CW*X(LE)*U+X(LF)*V)*ZONE+X(LG)*U+X(LH)*V	JOM7 340
2+X(LI)*W	JOM7 350
NCR=0	JOM7 360
IF (P) 115,165,115	JOM7 370
115 IF (FUN) 120,180,120	JOM7 380
120 F1=FUN+P+Q	JOM7 390
Q=Q/2.0	JOM7 400
IF (FUN*F1) 160,125,125	JOM7 410
125 IF (P*Q) 130,155,155	JOM7 420
130 DISCR=P*FUN	JOM7 430
IF (DISCR) 155,135,135	JOM7 440
135 DISCR=Q*Q-DISCR	JOM7 450

IF (DISCR) 155,155,140	JOM7 460
140 IF (ABS (P)-ABS (Q)) 155,155,145	JOM7 470
145 DIST=(-Q+SIGN (SQRT (DISCR),Q))/P	JOM7 480
150 NCR=1	JOM7 490
XTWO=U*DIST+XONE	JOM7 500
YTWO=V*DIST+YONE	JOM7 510
ZTWO=W*DIST+ZONE	JOM7 520
NDD2=ID	JOM7 530
SGNF2=-FUN	JOM7 540
155 RETURN	JOM7 550
160 DIST=(-Q-SIGN (SQRT (Q**2-P*FUN),FUN))/P	JOM7 560
GO TO 150	JOM7 570
165 IF (Q) 170,155,170	JOM7 580
170 DIST=-FUN/Q	JOM7 590
IF (DIST) 155,155,175	JOM7 600
175 IF (1.0-DIST) 155,150,150	JOM7 610
180 IF (P*SGNF) 185,155,155	JOM7 620
185 DIST=-Q/P	JOM7 630
FUN=SGNF	JOM7 640
IF (1.0-DIST) 155,150,150	JOM7 650
END	JOM7 660

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LOOKB	JOM9 10
SUBROUTINE JOM9(XONE,YONE,ZONE)	JOM9 20
DIMENSION N(1),X(1)	JOM9 30
COMMON N	JOM9 40
COMMON/GEOM9/NZ,NB,NXB,NYB,NZB	JOM9 50
COMMON/JOMIN3/DUMMY(3),NOX,NOY,NOZ,NXBB,NYBB,NZBB,DUM2(12)	JOM9 60
COMMON/GEOM39/NERR	JOM9 70
EQUIVALENCE(X,N)	JOM9 80
100 LNOX=NOX+NZ	JOM9 90
LNOY=NOY+NZ	JOM9 100
LNOZ=NOZ+NZ	JOM9 110
LXBB=NXBB+NZ	JOM9 120
LYBB=NYBB+NZ	JOM9 130
LZBB=NZBB+NZ	JOM9 140
KXBB=N(LXBB)	JOM9 150
KYBB=N(LYBB)	JOM9 160
KZBB=N(LZBB)	JOM9 170
IF(XONE-X(KXBB))150,105,105	JOM9 180
105 IEND=N(LNOX)	JOM9 190
DO 110 I=1,IEND	JOM9 200
I=I	JOM9 210
MXBB=KXBB+I	JOM9 220
IF(XONE-X(MXBB))115,115,110	JOM9 230
110 CONTINUE	JOM9 240
GO TO 150	JOM9 250
115 NXB=I	JOM9 260
IF(YONE-X(KYBB))150,120,120	JOM9 270
120 IEND=N(LNOY)	JOM9 280
DO 125 I=1,IEND	JOM9 290
I=I	JOM9 300
MYBB=KYBB+I	JOM9 310
IF(YONE-X(MYBB))130,130,125	JOM9 320
125 CONTINUE	JOM9 330
GO TO 150	JOM9 340
130 NYB=I	JOM9 350
IF(ZONE-X(KZBB))150,135,135	JOM9 360
135 IEND=N(LNOZ)	JOM9 370
DO 140 I=1,IEND	JOM9 380
I=I	JOM9 390
MZBB=KZBB+I	JOM9 400
IF(ZONE-X(MZBB))145,145,140	JOM9 410
140 CONTINUE	JOM9 420
GO TO 150	JOM9 430
145 NZB=I	JOM9 440
NB=((NZB-1)*N(LNOY)+NYB-1)*N(LNOX)+NXB	JOM9 450
NERR=0	JOM9 460
RETURN	JOM9 470
150 IF(NERR)160,160,155	JOM9 480
155 CALL JOM13(4)	JOM9 490
160 NERR=1	JOM9 500
CALL LOOKZ(XONE,YONE,ZONE)	JOM9 510
GO TO 100	JOM9 520
END	JOM9 530

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

NEWS	JOM1 10
SUBROUTINE JOM10	JOM1 20
DIMENSION N(1)	JOM1 30
COMMON N	JOM1 40
COMMON/GEOM4/XONE,YONE,ZONE,X2,Y2,Z2,NCUE,DUM1(3)	JOM1 50
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM1 60
COMMON/JOMIN2/NOX,NOY,NOZ,NOXY,NOXYZ,XPBD,XMBD,YPBD,YMBD,ZPBD,ZMBD	JOM1 70
COMMON/JOMIN3/DUM2(3),NXB,NYB,NZB,DUM4(15)	JOM1 80
100 NOXB=NXB+NZ	JOM1 90
NOYB=NYB+NZ	JOM1 100
NOZB=NZB+NZ	JOM1 110
GO TO(105,115,125,135,145,155),NCUE	JOM1 120
105 NXBL=NXBL+1	JOM1 130
IF (NXBL-N(NOXB)) 110,110,165	JOM1 140
110 NBL=NBL+1	JOM1 150
GO TO 235	JOM1 160
115 NXBL=NXBL-1	JOM1 170
IF (NXBL) 175,175,120	JOM1 180
120 NBL=NBL-1	JOM1 190
GO TO 235	JOM1 200
125 NYBL=NYBL+1	JOM1 210
IF (NYBL-N(NOYB)) 130,130,185	JOM1 220
130 NBL=NBL+N(NOXB)	JOM1 230
GO TO 235	JOM1 240
135 NYBL=NYBL-1	JOM1 250
IF (NYBL) 195,195,140	JOM1 260
140 NBL=NBL-N(NOXB)	JOM1 270
GO TO 235	JOM1 280
145 NZBL=NZBL+1	JOM1 290
IF (NZBL-N(NOZB)) 150,150,205	JOM1 300
150 NBL=NBL+N(NOYB)*N(NOXB)	JOM1 310
GO TO 235	JOM1 320
155 NZBL=NZBL-1	JOM1 330
IF (NZBL) 215,215,160	JOM1 340
160 NBL=NBL-N(NOYB)*N(NOXB)	JOM1 350
GO TO 235	JOM1 360
165 IF (XPBD-XONE) 230,230,170	JOM1 370
170 NZ=NZ+1	JOM1 380
GO TO 225	JOM1 390
175 IF (XMBD-XONE) 180,230,230	JOM1 400
180 NZ=NZ-1	JOM1 410
GO TO 225	JOM1 420
185 IF (YPBD-YONE) 230,230,190	JOM1 430
190 NZ=NZ+NOX	JOM1 440
GO TO 225	JOM1 450
195 IF (YMBD-YONE) 200,230,230	JOM1 460
200 NZ=NZ-NOX	JOM1 470
GO TO 225	JOM1 480
205 IF (ZPBD-ZONE) 230,230,210	JOM1 490
210 NZ=NZ+NOXY	JOM1 500
GO TO 225	JOM1 510
215 IF (ZMBD-ZONE) 220,230,230	JOM1 520
220 NZ=NZ-NOXY	JOM1 530
225 CALL JOM9(XONE,YONE,ZONE)	JOM1 540
JOM9 IS LOOKB	JOM1 550
GO TO 235	JOM1 560
230 NZ=0	JOM1 570
235 RETURN	JOM1 580
END	JOM1 590

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

JOMR	JOM1 10
SUBROUTINE JOM11(NADD1,NOM,NOS,NME1,NME2,NME3,NBD,ID)	JOM1 20
DIMENSION IND(18)	JOM1 30
COMMON N(1)	JOM1 40
COMMON/WMEDIA/IMEDIA(50),IKM(24),NNX	JOM1 50
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	JOM1 60
\$SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	JOM1 70
NADD=NADD1+1	JOM1 80
NME3=NADD1	JOM1 90
IF (ID)100,105,105	JOM1 100
100 NOM=JOM17(NADD,REGION)	JOM1 110
GO TO 110	JOM1 120
105 NOM=JOM17(NADD,MEDIA)	JOM1 130
110 IF (NOM-1)115,115,120	JOM1 140
115 NADD1=NADD-1	JOM1 150
NOS=0	JOM1 160
GO TO 165	JOM1 170
120 NBD=NADD-1	JOM1 180
NOS=JOM17(NADD,SURFAC)	JOM1 190
IF (NOS-18)130,130,125	JOM1 200
125 CALL JOM13(2)	JOM1 210
JOM13 IS DGNSTK	JOM1 220
130 NME1=NADD-1	JOM1 230
NME2=NME1+NOM	JOM1 240
NADD1=NME2+NOM	JOM1 250
DO 160 I=1,NOM	JOM1 260
READ (5,8000) S1,(IND(J),J=1,NOS)	JOM1 270
WRITE (6,8005) S1,(IND(J),J=1,NOS)	JOM1 280
IF (S1-SECTOR) 135,140,135	JOM1 290
135 CALL JOM13(7)	JOM1 300
140 NSP=0	JOM1 310
NSN=0	JOM1 320
DO 155 J=1,NOS	JOM1 330
IF (IND(J))150,155,145	JOM1 340
145 NSP=NSP+2*(J-1)	JOM1 350
GO TO 155	JOM1 360
150 NSN=NSN+2*(J-1)	JOM1 370
155 CONTINUE	JOM1 380
NP=NME1+I	JOM1 390
NN=NME2+I	JOM1 400
N(NP)=NSP	JOM1 410
IF (MOD(NSN,2).EQ.0)GO TO 160	JOM1 420
NNX=NNX+1	JOM1 430
IMEDIA(NNX)=IKM(I)	JOM1 440
160 N(NN)=NSN	JOM1 450
165 RETURN	JOM1 460
8000 FORMAT(A6,18I3)	JOM1 470
8005 FORMAT(1X,A6,18I3)	JOM1 480
END	JOM1 490

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

JOMQ	JOM1 10
SUBROUTINE JOM12(NADD)	JOM1 20
DIMENSION X(1)	JOM1 30
DIMENSION BCD1(4),BCD2(4),COF(4),IO(11)	JOM1 40
COMMON X	JOM1 50
COMMON/JOMIN8/NA,NB,NC,ND,NE,NF,NG,NH,NI,NJ	JOM1 60
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	JOM1 70
\$SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	JOM1 80
EQUIVALENCE(BLANK,COFS(10))	JOM1 90
READ (5,8000) NOBD,(IO(I),I=1,11)	JOM1 100
WRITE (6,8005) NOBD,(IO(I),I=1,11)	JOM1 110
IF (NOBD) 145,145,100	JOM1 120
100 NA=NADD-1	JOM1 130
ND=NA+NOBD	JOM1 140
NC=NB+NOBD	JOM1 150
ND=NC+NOBD	JOM1 160
NE=ND+NOBD	JOM1 170
NF=NE+NOBD	JOM1 180
NG=NF+NOBD	JOM1 190
NH=NG+NOBD	JOM1 200
NI=NH+NOBD	JOM1 210
NJ=NI+NOBD	JOM1 220
NADD=NJ+NOBD+1	JOM1 230
M=NADD-2	JOM1 240
DO 105 I=NA,M	JOM1 250
105 X(I+1)=0.	JOM1 260
DO 140 I=1,NOBD	JOM1 270
110 READ (5,8010) (COF(J),BCD1(J),BCD2(J),J=1,4)	JOM1 280
DO 135 J=1,4	JOM1 290
DO 115 K=1,13	JOM1 300
IF (BCD1(J)-COFS(K)) 115,120,115	JOM1 310
115 CONTINUE	JOM1 320
WRITE (6,8015) (COF(JJ),BCD1(JJ),BCD2(JJ),JJ=1,J)	JOM1 330
CALL JOM13(8)	JOM1 340
120 IF (K-10) 130,130,125	JOM1 350
125 K=K-7	JOM1 360
130 NL=NA+(K-1)*NOBD+I	JOM1 370
X(NL)=X(NL)+COF(J)	JOM1 380
IF (BCD2(J)-BLANK) 140,135,140	JOM1 390
135 CONTINUE	JOM1 400
WRITE (6,8015) (COF(J),BCD1(J),BCD2(J),J=1,4)	JOM1 410
GO TO 110	JOM1 420
140 WRITE (6,8015) (COF(JJ),BCD1(JJ),BCD2(JJ),JJ=1,J)	JOM1 430
145 RETURN	JOM1 440
8000 FORMAT(I5,11A6)	JOM1 450
8005 FORMAT(1H0,I5,11A6)	JOM1 460
8010 FORMAT(4(E10.5,A5,A1))	JOM1 470
8015 FORMAT(1X,4(E13.5,A5,A1))	JOM1 480
END	JOM1 490

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

C	DGNSTK	JOM1	10
	SUBROUTINE JOM13(I)	JOM1	20
	COMMON/GEOM/TITLE	JOM1	30
	WRITE (6,8040) TITLE	JOM1	40
	GO TO (100,105,110,115,120,125,130,135),I	JOM1	50
	100 WRITE (6,8000)	JOM1	60
	GO TO 140	JOM1	70
	8000 FORMAT(120H THE PRESENT MEDIUM CANNOT BE DETERMINED. THE INPUT WAS	JOM1	80
	\$\$ PROBABLY INCORRECT. CHECK THIS BLOCK TO SEE IF IT WAS PROPERLY	JOM1	90
	122H DIVIDED INTO SECTORS.)	JOM1	100
	105 WRITE (6,8005)	JOM1	110
	GO TO 145	JOM1	120
	8005 FORMAT(63H YOU HAVE FOOLISHLY ASKED FOR MORE THAN 18 SURFACES IN A	JOM1	130
	1 BLOCK.)	JOM1	140
	110 WRITE (6,8010)	JOM1	150
	GO TO 145	JOM1	160
	8010 FORMAT(120H THE FIRST OR LAST ENTRIES IN A LIST OF BLOCK BOUNDARIE	JOM1	170
	\$\$ DOES NOT AGREE WITH THE ZONE BOUNDARIES. EITHER THE BOUNDARY	JOM1	180
	\$36H LIST OR THE ZONE NUMBERS ARE WRONG.)	JOM1	190
	115 WRITE (6,8015)	JOM1	200
	GO TO 140	JOM1	210
	8015 FORMAT(14H YOU ARE LOST.)	JOM1	220
	120 WRITE (6,8020)	JOM1	230
	GO TO 150	JOM1	240
	8020 FORMAT(56H YOU HAVE FAILED TO MENTION YOUR SEX AND MARITAL STATUS.	JOM1	250
	1)	JOM1	260
	125 WRITE (6,8025)	JOM1	270
	GO TO 145	JOM1	280
	8025 FORMAT(49H THIS BOUNDARY LIST SEEMS TO HAVE ONLY ONE ENTRY.)	JOM1	290
	130 WRITE (6,8030)	JOM1	300
	GO TO 145	JOM1	310
	8030 FORMAT(65H YOU HAVE EITHER MISPELLED A WORD OR YOUR CARDS ARE NOT	JOM1	320
	\$IN ORDER.)	JOM1	330
	135 WRITE (6,8035)	JOM1	340
	GO TO 145	JOM1	350
	8035 FORMAT(40H THIS QUADRATIC FUNCTION IS NOT CORRECT.)	JOM1	360
	140 WRITE (6,8045)	JOM1	370
	CALL ERROR	JOM1	380
	145 WRITE (6,8045)	JOM1	390
	CALL EXIT	JOM1	400
	150 WRITE (6,8045)	JOM1	410
	RETURN	JOM1	420
	8040 FORMAT(120HD * * * * * * * * * *	JOM1	430
	\$ * * * * * * * * * */	JOM1	440
	\$6H DEAR ,A8/86H WITH THE DEEPEST REGRET I MUST INFORM YOU THAT	JOM1	450
	1A DREADFUL MISFORTUNE HAS OCCURRED.)	JOM1	460
	8045 FORMAT(60X,19HRESPECTFULLY YOURS,/60X,4HGEOM)	JOM1	470
	END	JOM1	480

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

ENTRY JOM15	JOM1 10
SUBROUTINE JOM15	JOM1 20
COMMON N(1)	JOM1 30
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM1 40
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	JOM1 50
COMMON/JOMIN3/DUMMY(3),NOX,NOY,NOZ,NXBB,NYBB,NZBB,DUM2(12)	JOM1 60
COMMON/GEOMC/MARK,XTWO,YTWO,ZTWO,X1,Y1,Z1,NMED,NREG,	JOM1 70
2 ETA,ETAUSD,BLZON	JOM1 80
INTEGER BLZON,SGNF	JOM1 90
BLZON=ISIGN((((NBOUND*64+NZBL)*64+NYBL)*64+NXBL)*128+NZ),SGNF)	JOM1 100
100 RETURN	JOM1 110
END	JOM1 120

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE JOM14	JOM1 10
COMMON N(1)	JOM1 20
COMMON/GEOM9/NZ,NBL,NXBL,NYBL,NZBL	JOM1 30
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	JOM1 40
COMMON/JOMIN3/DUMMY(3),NOX,NOY,NOZ,NXBB,NYBB,NZBB,DUM2(12)	JOM1 50
COMMON/GEOMC/MARK,XTWO,YTWO,ZTWO,X1,Y1,Z1,NMED,NREG,	JOM1 60
2 ETA,ETAUSD,BLZON	JOM1 70
INTEGER BLZON,SGNF	JOM1 80
SGNF=BLZON	JOM1 90
IBLZON=IABS(BLZON)	JOM1 100
JBLZON=IBLZON/128	JOM1 110
NZ=IBLZON-128*JBLZON	JOM1 120
IBLZON=JBLZON/64	JOM1 130
NXBL=JBLZON-64*IBLZON	JOM1 140
JBLZON=IBLZON/64	JOM1 150
NYBL=IBLZON-64*JBLZON	JOM1 160
IBLZON=JBLZON/64	JOM1 170
NZBL=JBLZON-64*IBLZON	JOM1 180
NBOUND=IBLZON	JOM1 190
LNOX=NOX+NZ	JOM1 200
LNOY=NOY+NZ	JOM1 210
NBL=((NZBL-1)*N(LNOY)+NYBL-1)*N(LNOX)+NXBL	JOM1 220
GO TO 100	JOM1 230
RETURN	JOM1 240
END	JOM1 250

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

FUNCTION JOM16(NADD1)	JOM1 10
DIMENSION X(1),FIN(6),BCD(6)	JOM1 20
COMMON X	JOM1 30
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	JOM1 40
\$SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	JOM1 50
K=0	JOM1 60
NADD=NADD1	JOM1 70
READ (5,8000) A,B,(FIN(I),BCD(I),I=1,5)	JOM1 80
DO 105 I=1,5	JOM1 90
IF (BCD(I)-COMMA) 130,100,130	JOM1 100
100 X(NADD)=FIN(I)	JOM1 110
NADD=NADD+1	JOM1 120
105 K=K+1	JOM1 130
WRITE (6,8005) A,B,(FIN(I),BCD(I),I=1,5)	JOM1 140
K=5	JOM1 150
110 READ (5,8010) (FIN(I),BCD(I),I=1,6)	JOM1 160
DO 120 I=1,6	JOM1 170
IF (BCD(I)-COMMA) 125,115,125	JOM1 180
115 X(NADD)=FIN(I)	JOM1 190
NADD=NADD+1	JOM1 200
120 K=K+1	JOM1 210
WRITE (6,8015) (FIN(I),BCD(I),I=1,6)	JOM1 220
GO TO 110	JOM1 230
125 WRITE (6,8015) (FIN(II),BCD(II),II=1,I)	JOM1 240
GO TO 135	JOM1 250
130 WRITE (6,8005) A,B,(FIN(II),BCD(II),II=1,I)	JOM1 260
135 IF (K)145,145,140	JOM1 270
140 X(NADD)=FIN(I)	JOM1 280
NADD1=NADD+1	JOM1 290
JOM16=K	JOM1 300
RETURN	JOM1 310
145 CALL JOM13(6)	JOM1 320
8000 FORMAT (A6,A5,5(E10.5,A1))	JOM1 330
8005 FORMAT (1X,A6,A5,5(E13.5,A1))	JOM1 340
8010 FORMAT (6(E10.5,A1))	JOM1 350
8015 FORMAT (1X,6(E13.5,A1))	JOM1 360
RETURN	JOM1 370
END	JOM1 380

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

FUNCTION JOM17(NADD1,NAME1)	JOM1 10
DIMENSION N(1),BCD(12),INP(12)	JOM1 20
COMMON N	JOM1 30
COMMON/WMEDIA/IMEDIA(50),IKM(24),NNX	JOM1 40
COMMON/GEOMH/HMALE,FEMALE,HIT,COMMA,ZONE,BLOCK,MEDIA,SURFAC,	JOM1 50
\$SECTOR,COFS(13),REGION,SIR,HMADAM,HMISS,HMARR,SINGLE	JOM1 60
NADD=NADD1	JOM1 70
READ (5,8000) NAME2,DUMMY,(INP(I),BCD(I),I=1,10)	JOM1 80
IF (NAME1=NAME2) 100,105,100	JOM1 90
100 WRITE (6,8005) NAME2,DUMMY	JOM1 100
CALL JOM13(7)	JOM1 110
105 N(NADD)=INP(1)	JOM1 120
IF (NAME1.EQ.MEDIA) IKM(1)=NADD	JOM1 130
NADD=NADD+1	JOM1 140
DO 115 I=2,10	JOM1 150
IF (BCD(I-1)-COMMA) 140,110,140	JOM1 160
110 N(NADD)=INP(I)	JOM1 170
IF (NAME1.EQ.MEDIA) IKM(I)=NADD	JOM1 180
115 NADD=NADD+1	JOM1 190
WRITE (6,8005) NAME2,DUMMY,(INP(I),BCD(I),I=1,10)	JOM1 200
IF (BCD(10)-COMMA) 145,120,145	JOM1 210
120 READ (5,8010) (INP(I),BCD(I),I=1,12)	JOM1 220
N(NADD)=INP(1)	JOM1 230
IF (NAME1.EQ.MEDIA) IKM(13)=NADD	JOM1 240
NADD=NADD+1	JOM1 250
DO 130 I=2,12	JOM1 260
IF (BCD(I-1)-COMMA) 135,125,135	JOM1 270
125 N(NADD)=INP(I)	JOM1 280
IF (NAME1.EQ.MEDIA) IKM(I+12)=NADD	JOM1 290
130 NADD=NADD+1	JOM1 300
WRITE (6,8015) (INP(I),BCD(I),I=1,12)	JOM1 310
IF (BCD(12)-COMMA) 145,120,145	JOM1 320
135 WRITE (6,8015) (INP(II-1),BCD(II-1),II=2,I)	JOM1 330
GO TO 145	JOM1 340
140 WRITE (6,8005) NAME2,DUMMY,(INP(II-1),BCD(II-1),II=2,I)	JOM1 350
145 JOM17=NADD-NADD1	JOM1 360
NADD1=NADD	JOM1 370
RETURN	JOM1 380
8000 FORMAT(2A6,10(I5,A1))	JOM1 390
8005 FORMAT(1X,2A6,10(I5,A1))	JOM1 400
8010 FORMAT(12(I5,A1))	JOM1 410
8015 FORMAT(1X,12(I5,A1))	JOM1 420
END	JOM1 430

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE LOOKZ(XONE,YONE,ZONE)	LOOK 10
DIMENSION X(1)	LOOK 20
COMMON X	LOOK 30
COMMON/GEOMC/MARK,XTWO,YTWO,ZTWO,X1,Y1,Z1,NMED,NREG	LOOK 40
SETA,ETAUSD,BLZON	LOOK 50
COMMON/GEOM9/NZ,NB,NXBL,NYBL,NZBL	LOOK 60
COMMON/GEOMA/ID,NSTAT	LOOK 70
COMMON/JCMIN3/NXZB,NYZB,NZZB,DUMMY(18)	LOOK 80
COMMON/JCMIN2/NOX,NOY,NOZ,DUM2(8)	LOOK 90
COMMON/GEOM77/NBOUND,SGNF,NBD2,SGNF2	LOOK 100
COMMON/GEOM39/NERR	LOOK 110
IF(XONE-X(NXZB))165,100,100	LOOK 120
100 DO 105 I=1,NOX	LOOK 130
I=I	LOOK 140
LXZB=NXZB+I	LOOK 150
IF(XONE-X(LXZB))110,110,105	LOOK 160
105 CONTINUE	LOOK 170
GO TO 165	LOOK 180
110 NXZ=I	LOOK 190
IF(YONE-X(NYZB))165,115,115	LOOK 200
115 DO 120 I=1,NOY	LOOK 210
I=I	LOOK 220
LYZB=NYZB+I	LOOK 230
IF(YONE-X(LYZB))125,125,120	LOOK 240
120 CONTINUE	LOOK 250
GO TO 165	LOOK 260
125 NYZ=I	LOOK 270
IF(ZONE-X(NZZB))165,130,130	LOOK 280
130 DO 135 I=1,NOZ	LOOK 290
I=I	LOOK 300
LZZB=NZZB+I	LOOK 310
IF(ZONE-X(LZZB))140,140,135	LOOK 320
135 CONTINUE	LOOK 330
GO TO 165	LOOK 340
140 NZ=((I-1)*NOY+NYZ-1)*NOX+NXZ	LOOK 350
IF(NERR)150,150,160	LOOK 360
150 NERR=1	LOOK 370
CALL JOM9(XONE,YONE,ZONE)	LOOK 380
JOM9 IS LOOKB	LOOK 390
JOM15 IS PCK	LOOK 400
NBOUND=0	LOOK 410
SGNF=0.	LOOK 420
CALL JOM15	LOOK 430
CALL JOM6(XONE,YONE,ZONE,1,NMED)	LOOK 440
JOM6 IS FINDR	LOOK 450
NREG=1	LOOK 460
IF(NSTAT)155,160,155	LOOK 470
155 CALL JOM6(XONE,YONE,ZONE,3,NREG)	LOOK 480
JOM6 IS FINDR	LOOK 490
160 RETURN	LOOK 500
165 CALL JOM13(4)	LOOK 510
RETURN	LOOK 520
END	

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE OFFAX(UNCARG,NMD)	OFFA 10
C*****	OFFA 20
C***** UNCOLLIDED ESTIMATOR FOR DETECTORS OFF THE DUCT AXIS	OFFA 30
C*****	OFFA 40
COMMON/FIF/NMDUCT,OFFARG(25,10,2)	OFFA 50
COMMON/DUCT/DUCTW(3),DUCTX(3,50),RSSQ(200),VOLS(50)	OFFA 60
COMMON/SFFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NDPT	OFFA 70
COMMON/DETECT/NODET,XDET(3,10),RD2,RD	OFFA 80
COMMON/EIGHT/DETW(3,10,50)	OFFA 90
COMMON/PL/AIR(20),LEVMAX,XON(3)	OFFA 100
INCLUDE EBLANC	OFFA 110
INTEGER A03,A04	OFFA 120
DIMENSION A(3),ALPHA(3),OMEGA(3),BETA(3),CTHETA(3),STHETA(3)	OFFA 130
DIMENSION UNCARG(IGM,NDIVL,NODET,2),P(3),P2(3),Q(6),SPOT(3),U(6)	OFFA 140
DATA CTHETA/.96593,.70711,.25882/	OFFA 150
DATA STHETA/.25882,.70711,.96593/	OFFA 160
DATA Q/.654,.573,.344,.344,.573,.654/	OFFA 170
DATA U/-.833333,-.5,-.166667,.166667,.5,.833333/	OFFA 180
IF (NODET.LT.2) RETURN	OFFA 190
C*****	OFFA 200
C***** CONTRIBUTION FROM THE DUCT WALL	OFFA 210
C*****	OFFA 220
C***** FIND DIRECTION FROM DUCT START TO DETECTOR	OFFA 230
C*****	OFFA 240
DO 12 NDO=2,NODET	OFFA 250
DO 14 IG=1,IGM	OFFA 260
DO 14 N=1,NDIVL	OFFA 270
14 UNCARG(IG,N,NDO,NMD)=0.	OFFA 280
CALL PYTHAG(XON,XDET(1,NDO),A,SDET,SDET2)	OFFA 290
COSTH=0.0	OFFA 300
DO 3 I=1,3	OFFA 310
3 COSTH=COSTH+A(I)*DUCTW(I)	OFFA 320
DO 4 I=1,3	OFFA 330
4 P(I)=XON(I)+SDET*COSTH*DUCTW(I)	OFFA 340
C*****	OFFA 350
C***** P IS THE POINT ON THE DUCT AXIS NEAREST THE DETECTOR	OFFA 360
C***** OMEGA IS THE DIRECTION FROM P TO THE DETECTOR	OFFA 370
C*****	OFFA 380
CALL PYTHAG(P,XDET(1,NDO),OMEGA,DUMMY,DUMMY2)	OFFA 390
C***** ALPHA IS CROSS PRODUCT OF OMEGA AND DUCT AXIS VECTOR	OFFA 400
CALL CROSS(OMEGA,DUCTW,ALPHA)	OFFA 410
DO 1 ITH=1,3	OFFA 420
XLEG=RD*CTHETA(ITH)	OFFA 430
YLEG=RD*STHETA(ITH)	OFFA 440
DO 2 N=1,NDIVL	OFFA 450

DO 5 I=1,3	OFFA 460
C*****	OFFA 470
C***** P2 IS A POINT ON THE DUCT SURFACE THETA DEGREES FROM THE POINT	OFFA 480
C***** YOU WOULD GET GOING IN THE OMEGA DIRECTION FROM THE DUCT POINT	OFFA 490
C*****	OFFA 500
P1=DUCTX(I,N)-OMEGA(I)*XLEG	OFFA 510
5 P2(I)=P1+ALPHA(I)*YLEG	OFFA 520
C*****	OFFA 530
C***** BETA IS THE INWARD NORMAL TO THE DUCT SURFACE AT P2	OFFA 540
C*****	OFFA 550
CALL PYTHAG(P2,DUCTX(1,N),BETA,DUMMY,DUMMY2)	OFFA 560
DOT=0.	OFFA 570
C*****	OFFA 580
C***** DIST IS THE DISTANCE FROM P2 TO THE DETECTOR	OFFA 590
CALL PYTHAG(P2,XDET(1,NDO),A,DIST,D2)	OFFA 600
DO 6 I=1,3	OFFA 610
6 DOT=DOT+BETA(I)*A(I)	OFFA 620
C***** DOT PRODUCT OF INWARD NORMAL AND VECTOR TOWARD DETECTOR	OFFA 630
CONST=.0795773*DOT*VOLS(N)/(3.*RD*D2)	OFFA 640
DO 7 IG=1,IGM	OFFA 650
CALL EUCLID(P2(1),P2(2),P2(3),XDET(1,NDO),XDET(2,NDO),XDET(3,NDO),	OFFA 660
1DIST,IG,ARG,0)	OFFA 670
7 UNCARG(IG,N,NDO,NMD)=EXP(ARG)*CONST+UNCARG(IG,N,NDO,NMD)	OFFA 680
2 CONTINUE	OFFA 690
1 CONTINUE	OFFA 700
C*****	OFFA 710
C***** CONTRIBUTION FROM THE DUCT END PLATE	OFFA 720
C*****	OFFA 730
DO 10 IG=1,IGM	OFFA 740
10 OFFARG(IG,NDO,NMD)=0.	OFFA 750
DO 8 J=1,6	OFFA 760
CONST=.0795773*Q(J)*COSTH*RD2	OFFA 770
DO 9 I=1,3	OFFA 780
9 SPOT(I)=XON(I)+OMEGA(I)*U(J)*RD	OFFA 790
C*****	OFFA 800
C***** SPOT IS THE MIDPOINT OF A SLICE OF END PLATE	OFFA 810
C***** DUMMY IS THE DISTANCE FROM SPOT TO THE DETECTOR	OFFA 820
C*****	OFFA 830
CALL PYTHAG(SPOT,XDET(1,NDO),A,DUMMY,DUMMY2)	OFFA 840
DO 11 IG=1,IGM	OFFA 850
CALL EUCLID(SPOT(1),SPOT(2),SPOT(3),XDET(1,NDO),XDET(2,NDO),XDET(3,NDO),	OFFA 860
1,NDO),DUMMY,IG,ARG,0)	OFFA 870
11 OFFARG(IG,NDO,NMD)=OFFARG(IG,NDO,NMD)+CONST*EXP(ARG)/DUMMY2	OFFA 880
8 CONTINUE	OFFA 890
12 CONTINUE	OFFA 900
RETURN	OFFA 910
END	OFFA 920

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE PICKIT(IMIT,N,NDO,MM,FD)	PICK 10
DIMENSION IMIT(50,10),FD(MM)	PICK 20
BIGCOS=0.	PICK 30
DO 1 M=1,MM	PICK 40
IF (FD(M).LT.BIGCOS)GO TO 1	PICK 50
IMIT(N,NDO)=M	PICK 60
BIGCOS=FD(M)	PICK 70
CONTINUE	PICK 80
RETURN	PICK 90
END	PICK 100

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE PLATE(RD,SD)	PLAT 10
COMMON/STAR/NMU(30),WSUM(100),ATE(100),NLEV,MSTAR(100),LEVEL(50)	PLAT 20
COMMON/PL/AIR(20),LEVMAX	PLAT 30
DIMENSION R(20)	PLAT 40
OLDAIR=0.	PLAT 50
DO 1 LEV=1,NLEV	PLAT 60
R(LEV)=SD*SQRT(1./ATE(LEV)**2-1.)	PLAT 70
IF (R(LEV).LT.RD)GO TO 1	PLAT 80
LEVMAX=LEV	PLAT 90
GO TO 2	PLAT 100
1 CONTINUE	PLAT 110
LEVMAX=NLEV	PLAT 120
2 IF (LEVMAX.EQ.1)GO TO 5	PLAT 130
LM=LEVMAX-1	PLAT 140
DO 4 LEV=1,LM	PLAT 150
S=.5*(R(LEV)+R(LEV+1))	PLAT 160
IF (S.GT.RD)GO TO 3	PLAT 170
AIRE=3.1416*S**2	PLAT 180
AIR(LEV)=AIRE-OLDAIR	PLAT 190
4 OLDAIR=AIRE	PLAT 200
IF (S.LT.RD)GO TO 5	PLAT 210
LEVMAX=LM	PLAT 220
GO TO 13	PLAT 230
3 LEVMAX=LEV	PLAT 240
5 AIR(LEVMAX)=3.1416*RD*RD-OLDAIR	PLAT 250
13 RETURN	PLAT 260
END	PLAT 270

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

FUNCTION PLEG(X,L)	PLEG 10
DIMENSION P(10)	PLEG 20
P(1)=1.	PLEG 30
P(2)=X	PLEG 40
IF(L.LT.3)GO TO 13	PLEG 50
DO 1 K=3,L	PLEG 60
Y=K-1	PLEG 70
Z=2.*Y-1.	PLEG 80
W=Y-1.	PLEG 90
1 P(K)=(P(K-1)*Z*X-W*P(K-2))/Y	PLEG 100
13 PLEG=P(L)	PLEG 110
RETURN	PLEG 120
END	PLEG 130

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE PRELEV(MM)	PREL 10
COMMON/STAR/NMU(30),WSUM(100),ATE(100),NLEV,MSTAR(100),LEVEL(50)	PREL 20
COMMON/WEIGHT/WD(100),HMU(100),ETA(100),WIG(100)	PREL 30
READ 32,(HMU(I),I=1,MM)	PREL 40
READ 32,(ETA(I),I=1,MM)	PREL 50
32 FORMAT(6E12.4)	PREL 60
DO 33 I=1,MM	PREL 70
WIG(I)=0.0	PREL 80
ARGH=1.-HMU(I)**2-ETA(I)**2	PREL 90
IF(ARGH.LT.0.)GO TO 33	PREL 100
WIG(I)=SQRT(ARGH)	PREL 110
33 CONTINUE	PREL 120
PRINT 16	PREL 130
PRINT 15,(I,HMU(I),ETA(I),WIG(I),WD(I),I=1,MM)	PREL 140
16 FORMAT(1H1,20X,'QUADRATURE COSINES AND WEIGHTS'/1X,'ANGLE',18X,'MU'	PREL 150
1',17X,'ETA',18X,'XI',14X,'WEIGHT')	PREL 160
15 FORMAT(1X,I5,4F20.5)	PREL 170
NLEV=0	PREL 180
RETURN	PREL 190
END	PREL 200

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE PSCAT(XMU,IG,ITL,NG,C,M,PST,L)	PSCA 10
DIMENSION C(ITL,NG,1),PST(NG)	PSCA 20
LPMAX=L+1	PSCA 30
DO 1 IGP=IG,NG	PSCA 40
PST(IGP)=0.	PSCA 50
IF(M.GT.100)GO TO 1	PSCA 60
INK=ITL-NG+1+IGP-IG	PSCA 70
DO 2 LP=1,LPMAX	PSCA 80
MI=(M-1)*LPMAX+LP	PSCA 90
SCAT=C(INK,IGP,MI)	PSCA 100
FACTOR=2*LP-1	PSCA 110
2 PST(IGP)=PST(IGP)+FACTOR*SCAT*PLEG(XMU,LP)*.0795773	PSCA 120
1 CONTINUE	PSCA 130
RETURN	PSCA 140
END	PSCA 150

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

SUBROUTINE PYTHAG(P1,P2,W,D,D2)	PYTH 10
DIMENSION P1(3),P2(3),W(3)	PYTH 20
D2=0.	PYTH 30
DO 1 I=1,3	PYTH 40
W(I)=P2(I)-P1(I)	PYTH 50
1 D2=D2+W(I)**2	PYTH 60
D=SQRT(D2)	PYTH 70
DO 2 I=1,3	PYTH 80
2 W(I)=W(I)/D	PYTH 90
RETURN	PYTH 100
END	PYTH 110

DUCT. DUCT FLUX PERTURBATION ANALYSIS PROGRAM. OCT 1970.

	SUBROUTINE SCATSB (EXPARG, AFLUX, FLUX, C, FD, UNCARG)	SCAT 10
	COMMON/STAR/NMU (30), WSUM (100), ATE (100), NLEV, MSTAR (100), LEVEL (50)	SCAT 20
	COMMON/ENDPL/PLARG (25, 20, 2)	SCAT 30
	COMMON/PL/AIR (20), LEVMAX	SCAT 40
	COMMON/FIF/NMDUCT, OFFARG (25, 10, 2)	SCAT 50
	COMMON/SAVET/NMAD (50)	SCAT 60
	COMMON/EIGHT/DETW (3, 10, 50)	SCAT 70
	INCLUDE BBLANC	SCAT 80
	COMMON/WEIGHT/WO (100), HMU (100), ETA (100), WIG (100), JLEV (100)	SCAT 90
	COMMON/UNIT/NAFT, NMAT	SCAT 100
	COMMON/XSECT/GXSECT (25, 10)	SCAT 110
	COMMON/SPFACT/FDUCT (2, 50), RZR (50), Z (50), NDIVL, NODT	SCAT 120
	COMMON/DETECT/NODET, XDET (3, 10), RD2, RD	SCAT 130
	COMMON/DUCT/DUCTW (3), DUCTX (3, 50), RSSQ (50), RS (50), CBET (50), AREA (50)	SCAT 140
	1, VOLS (50)	SCAT 150
	COMMON/SCALE/ZS, RMAX, DOTARG (50, 10)	SCAT 160
	DIMENSION EXPARG (IGM, NDIVL, NODET, 2)	SCAT 170
	DIMENSION FLEXU (50, 2, 10), AFLEXU (50, 2, 6), SA (6)	SCAT 180
	DIMENSION PST (50), IMIT (50, 10), UNCARG (IGM, NDIVL, NODET, 2)	SCAT 190
	INTEGER A03, A04	SCAT 200
	DIMENSION AFLUX (A04, NDIVL), FLUX (2, NODET, IGM), C (ITL, IGM, 1)	SCAT 210
	DIMENSION FD (A04, NDIVL, NODET), OMEGA (3)	SCAT 220
	DIMENSION CBBND (6), E (50), ANGLE (6)	SCAT 230
	CALL DETDOT	SCAT 240
	READ 29, NAME1, NAME2	SCAT 250
29	FORMAT (A6, 4X, A6)	SCAT 260
32	FORMAT (6E12.4)	SCAT 270
	READ 10, NANG	SCAT 280
10	FORMAT (I5)	SCAT 290
	READ 32 (ANGLE (IANG), IANG=1, NANG)	SCAT 300
	READ 32, (CBBND (IANG), IANG=1, NANG)	SCAT 310
	READ 32, (SA (IANG), IANG=1, NANG)	SCAT 320
	DO 11 IG=1, IGM	SCAT 330
	DO 11 NMED=1, 2	SCAT 340
	DO 11 NDO=1, NODET	SCAT 350
	FLEXU (IG, NMED, NDO)=0.	SCAT 360
	DO 11 IANG=1, NANG	SCAT 370
11	AFLEXU (IG, NMED, IANG)=0.	SCAT 380
	READ 32, (E (IG), IG=1, IGM)	SCAT 390
	DO 7 NDO=1, NODET	SCAT 400
	RDET=SQRT (XDET (1, NDO)**2+XDET (2, NDO)**2)	SCAT 410
	DO 7 N=1, NDIVL	SCAT 420
	CALL PYTHAG (DUCTX (1, N), XDET (1, NDO), OMEGA, DIST, D2)	SCAT 430
	HMUP= (RDET-RZR (N))/DIST	SCAT 440
	ETAP=OMEGA (3)	SCAT 450

	WIGP=0.	SCAT 460
	TERM=1.-HMUP**2-ETAP**2	SCAT 470
	IF (TERM.LE.0.)GO TO 8	SCAT 480
	WIGP=SQRT (TERM)	SCAT 490
8	DO 9 M=1,A04	SCAT 500
	IF (WJ(M).LT..000001)GO TO 9	SCAT 510
	FD (M,N,NDO)=HMU(M)*HMUP+ETA(M)*ETAP+WIG(M)*WIGP	SCAT 520
9	CONTINUE	SCAT 530
7	CONTINUE	SCAT 540
	DO 12 NDO=1,NODET	SCAT 550
	DO 12 N=1,NDIVL	SCAT 560
	CALL PICKIT (IMIT,N,NDO,A04,FD (1,N,NDO))	SCAT 570
12	CONTINUE	SCAT 580
	DO 3 IG=1,IGM	SCAT 590
	CALL DUCTFX (A04,AFLUX,IG)	SCAT 600
	NMD=NMDUCT	SCAT 610
	DO 35 NMED=1,2	SCAT 620
	DO 35 NDO=1,NODET	SCAT 630
	DO 20 N=1,NDIVL	SCAT 640
	IF (NMED.EQ.2)NMD=NMD (N)	SCAT 650
57	DO 34 M=1,A04	SCAT 660
	IF (WJ(M).LT..000001)GO TO 34	SCAT 670
	SCOS=FD (M,N,NDO)	SCAT 680
	CALL PSCAT (SCOS,IG,ITL,IGM,C,NMD,PST,A03)	SCAT 690
	DO 21 IGP=IG,IGM	SCAT 700
91	IF (PST (IGP))21,21,5	SCAT 710
5	FLUX (NMED,NDO,IGP)=FLUX (NMED,NDO,IGP)+PST (IGP)*WJ (M)*AFLUX (M,N)	SCAT 720
	1*EXPARG (IGP,N,NDO,NMED)	SCAT 730
21	CONTINUE	SCAT 740
34	CONTINUE	SCAT 750
	IF (NDO.NE.1)GO TO 14	SCAT 760
	AFF=0.	SCAT 770
	LEV=LEVEL (N)	SCAT 780
	NST=NMU (LEV)	SCAT 790
	J=JLEV (LEV)-1	SCAT 800
	DO 1 I=1,NST	SCAT 810
	J=J+1	SCAT 820
	MST=MSTAR (J)	SCAT 830
1	AFF=AFF+AFLUX (MST,N)*WJ (MST)	SCAT 840
	AFF=AFF/WSUM (LEV)	SCAT 850
	TERM=AFF*UNCARG (IG,N,1,NMED)	SCAT 860
	IF (N.NE.1)GO TO 2	SCAT 870
	J=0	SCAT 880
	DO 4 LEV=1,LEVMAX	SCAT 890
	AFF=0.	SCAT 900
	NST=NMU (LEV)	SCAT 910

	DO 6 I=1,NST	SCAT 920
	J=J+1	SCAT 930
	MST=MSTAR(J)	SCAT 940
6	AFF=AFF+AFLUX(MST,1)*WD(MST)/WSUM(LEV)	SCAT 950
4	TERM=TERM+PLARG(IG,LEV,NMED)*AFF	SCAT 960
2	CONTINUE	SCAT 970
	TERM=TERM*.0795773	SCAT 980
	FLEXU(IG,NMED,1)=FLEXU(IG,NMED,1)+TERM	SCAT 990
	DO 36 IANG=1,NANG	SCAT1000
	IF(CBET(N).GT.CBBND(IANG))GO TO 37	SCAT1010
36	CONTINUE	SCAT1020
	IANB=NANG	SCAT1030
37	AFLEXU(IG,NMED,IANB)=AFLEXU(IG,NMED,IANB)+TERM/SA(IANG)	SCAT1040
	GO TO 20	SCAT1050
14	IMT=IMIT(N,NDO)	SCAT1060
	FLEXU(IG,NMED,NDO)=UNCARG(IG,N,NDO,NMED)*AFLUX(IMT,N)+FLEXU(IG,NMED,NDO)	SCAT1070
20	CONTINUE	SCAT1080
	IF(NDO.NE.1.OR.NMED.NE.2)GO TO 35	SCAT1090
	DCRT=0.	SCAT1100
	DO 22 M=1,AD4	SCAT1110
22	DCRT=DCRT+WD(M)*AFLUX(M,NDPT)	SCAT1120
	DOTARG(IG,1)=DCRT	SCAT1130
35	CONTINUE	SCAT1140
	IF(NODET.LT.2)GO TO 3	SCAT1150
	DO 15 NDO=2,NODET	SCAT1160
	DO 15 NMED=1,2	SCAT1170
	IMT=IMIT(1,NDO)	SCAT1180
15	FLEXU(IG,NMED,NDO)=FLEXU(IG,NMED,NDO)+OFFARG(IG,NDO,NMED)*AFLUX(IMT,NDO)	SCAT1190
	11T,1)	SCAT1200
3	CONTINUE	SCAT1210
	DO 38 NDO=1,NODET	SCAT1220
	PRINT 39,NDO	SCAT1230
39	FORMAT(1H1,20X,'SCALAR FLUX AT DETECTOR NO.',13)	SCAT1240
	PRINT 40,(XDET(I,NDO),I=1,3)	SCAT1250
40	FORMAT(1H0,5X,'LOCATED AT ',F10.2,1H,,F10.2,1H,,F10.2)	SCAT1260
	PRINT 41,NAME1,NAME2,NAME1,NAME2,NAME1,NAME2	SCAT1270
41	FORMAT(1H0,5HGROUP,4X,6HENERGY,10X,A6,2H-C,6X,A6,2H-C,6X,A6,2H-U,	SCAT1280
	16X,A6,2H-U,2X,A6,6H TOTAL,2X,A6,6H TOTAL,11X,3HDOT,6X,8HENHANCED)	SCAT1290
	DO 42 IG=1,IGM	SCAT1300
	FLUX3=FLEXU(IG,1,NDO)	SCAT1310
	FLUX4=FLEXU(IG,2,NDO)	SCAT1320
	FLUX1=FLUX(1,NDO,IG)+FLUX3	SCAT1330
	FLUX2=FLUX(2,NDO,IG)+FLUX4	SCAT1340
44	ANSWER=DOTARG(IG,NDO)+FLUX1-FLUX2	SCAT1350
42	PRINT 43,IG,E(IG),(FLUX(NMED,NDO,IG),NMED=1,2),FLUX3,FLUX4,	SCAT1360
		SCAT1370

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1	FLUX1,FLUX2,DOTARG(IG,NDO),ANSWER	SCAT1380
43	FORMAT(1X,I5,9E14.5)	SCAT1390
38	CONTINUE	SCAT1400
	NICK=NAME1	SCAT1410
	DO 45 NMED=1,2	SCAT1420
	PRINT 46,NICK	SCAT1430
46	FORMAT(1H1,'UNCOLLIDED ANGULAR FLUX AT EXIT OF DUCT FILLED WITH ',	SCAT1440
	1A6//80X,5HANGLE)	SCAT1450
	PRINT 47,(ANGLE(I),I=1,NANG)	SCAT1460
47	FORMAT(1H0,5HGROUP,4X,6HENERGY,4X,6F14.1)	SCAT1470
	DO 48 IG=1,IGM	SCAT1480
48	PRINT 43,IG,E(IG),(AFLEXU(IG,NMED,IANG),IANG=1,NANG)	SCAT1490
45	NICK = NAME2	SCAT1500
	PRINT 50	SCAT1510
50	FORMAT(1H1,'UNCOLLIDED ANGULAR FLUX PERTURBATION (1-2)/2'//20X,5H	SCAT1520
	ANGLE)	SCAT1530
	PRINT 47,(ANGLE (I) ,I=1,NANG)	SCAT1540
	DO 51 IG=1,IGM	SCAT1550
	DO 52 IANG=1,NANG	SCAT1560
52	AFLEXU(IG,1,IANG)=(AFLEXU(IG,1,IANG)-AFLEXU(IG,2,IANG))/	SCAT1570
	1AFLEXU(IG,2,IANG)	SCAT1580
51	PRINT 43,IG,E(IG),(AFLEXU(IG,1,IANG),IANG=1,NANG)	SCAT1590
	RETURN	SCAT1600
	END	SCAT1610

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SUBROUTINE SHIELD(EXPARG,C,UNCARG)	SHIE 10
COMMON/STAR/NMU(30),WSUM(100),ATE(100),NLEV,MSTAR(100),LEVEL(50)	SHIE 20
COMMON/ENDPL/PLARG(25,20,2)	SHIE 30
COMMON/PL/AIR(20),LEVMAX,XON(3),LNG,LN2	SHIE 40
COMMON/FIF/NMDUCT	SHIE 50
COMMON NSTOR(9)	SHIE 60
COMMON/WMEDIA/IMEDIA(50),IKM(24),NNX	SHIE 70
COMMON/UNIT/NAFT,NMAT	SHIE 80
COMMON/SAVET/NMAD(50)	SHIE 90
COMMON/GEOMC/Q(7),NMED	SHIE 100
COMMON/DUCT/DUCTW(3),DUCTX(3,50),RSSQ(50),RS(50),CBET(50),	SHIE 110
1 AREA(50),VOLS(50)	SHIE 120
COMMON/SPFACT/FDUCT(2,50),RZR(50),Z(50),NDIVL,NOPT	SHIE 130
COMMON/DETECT/NODET,XDET(3,10),RD2	SHIE 140
COMMON/EIGHT/DETW(3,10,50)	SHIE 150
INCLUDE BBLANC	SHIE 160
INTEGER A03,A04	SHIE 170
REAL LNG,LN2	SHIE 180
DIMENSION EXPARG(IGM,NDIVL,NODET,2),C(ITL,IGM,1)	SHIE 190
DIMENSION DETX(3),GARBGE(16)	SHIE 200
DIMENSION UNCARG(IGM,NDIVL,NODET,2)	SHIE 210
READ 10,NMDUCT	SHIE 220
10 FORMAT(I5)	SHIE 230
DO 30 MAT=1,NMAT	SHIE 240
READ 31,GARBGE	SHIE 250
PRINT 12,GARBGE	SHIE 260
31 FORMAT(16A5)	SHIE 270
12 FORMAT(1H0,16A5)	SHIE 280
DO 30 IG=1,IGM	SHIE 290
READ 82,(C(IH,IG,MAT),IH=1,ITL)	SHIE 300
82 FORMAT(24X,4E12.4/(6E12.4))	SHIE 310
30 PRINT 1,IG,(C(IH,IG,MAT),IH=1,ITL)	SHIE 320
1 FORMAT(1H+,85X,'GROUP',I3/(1X,6E19.5))	SHIE 330
NM=NMAT/(A03+1)	SHIE 340
CALL STABLE(C,ITL,IHT,IGM,A03,NM)	SHIE 350
DO 2 N=1,NDIVL	SHIE 360
CALL LOOKZ(DUCTX(1,N),DUCTX(2,N),DUCTX(3,N))	SHIE 370
2 NMAD(N)=NMED	SHIE 380
DO 5 NMD=2,1,-1	SHIE 390
DO 14 NDO=1,NODET	SHIE 400
DO 14 N=1,NDIVL	SHIE 410
SD2=0.	SHIE 420
DO 15 I=1,3	SHIE 430
DETX(I)=XDET(I,NDO)-DUCTX(I,N)	SHIE 440
15 SD2=DETX(I)**2+SD2	SHIE 450

	SD=SQRT(SD2)	SHIE 460
	IF(NDO.GT.1.OR.NMD.GT.1)GO TO 19	SHIE 470
	CALL IMLEV(SD/RS(N),N)	SHIE 480
19	CONTINUE	SHIE 490
	DO 17 I=1,3	SHIE 500
17	DETW(I,NDO,N)=DETX(I)/SD	SHIE 510
	DO 16 IG=1,IGM	SHIE 520
	CALL EUCLID(DUCTX(1,N),DUCTX(2,N),DUCTX(3,N),XDET(1,NDO),	SHIE 530
	1XDET(2,NDO),XDET(3,NDO),SD,IG,ARG,0)	SHIE 540
	IF(NDO.GT.1)GO TO 3	SHIE 550
	UNCARG(IG,N,1,NMD)=AREA(N)*EXP(ARG*RS(N)/SD)/RSSQ(N)	SHIE 560
	IF(NMDUCT.EQ.1000.AND.NMD.EQ.1)GO TO 16	SHIE 570
	EXPARG(IG,N,1,NMD)=(EXIN(-ARG)-EXIN(-ARG*RS(N)/SD))*2.*VOLS(N)/RD2	SHIE 580
	GO TO 16	SHIE 590
3	EXPARG(IG,N,NDO,NMD)=EXP(ARG)*VOLS(N)/SD2	SHIE 600
16	CONTINUE	SHIE 610
14	CONTINUE	SHIE 620
	CALL OFFAX(UNCARG,NMD)	SHIE 630
	RN2=0.	SHIE 640
	DO 20 I=1,3	SHIE 650
20	RN2=RN2+(XON(I)-XDET(I,1))**2	SHIE 660
	RN=SQRT(RN2)	SHIE 670
	DO 4 IG=1,IGM	SHIE 680
	CALL EUCLID(XON(1),XON(2),XON(3),XDET(1,1),XDET(2,1),XDET(3,1),	SHIE 690
	1RN,IG,ARG,0)	SHIE 700
	DO 4 LEV=1,LEVMAX	SHIE 710
4	PLARG(IG,LEV,NMD)=AIR(LEV)*EXP(ARG/ATE(LEV))*ATE(LEV)**2/RN2	SHIE 720
	DO 5 I=1,NNX	SHIE 730
	IME=IMEDIA(I)	SHIE 740
5	NSTOR(IME)=NMDUCT	SHIE 750
	DO 18 I=1,3	SHIE 760
18	DETW(I,1,NDPT)=DUCTW(I)	SHIE 770
	PRINT 8	SHIE 780
8	FORMAT(1H1,'DUCT MESH POINT INFORMATION'/'/' POINT MAT.',13X,'X',13SHIE 790	
	1X,'Y',11X,'Z',1X,'DIST. TO DET 1',8X,'COSINE',10X,'AREA',8X,'VOLUMSHIE 800	
	2E')	SHIE 810
	DO 7 N=1,NDIVL	SHIE 820
7	PRINT 9,N,NMAD(N),DUCTX(1,N),DUCTX(2,N),DUCTX(3,N),RS(N),CBET(N),	SHIE 830
	1AREA(N),VOLS(N)	SHIE 840
9	FORMAT(1X,2I5,7E14.5)	SHIE 850
	RETURN	SHIE 860
	END	SHIE 870

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	SUBROUTINE STABLE(C,ITL,INT,NG,L,NM)	STAB 10
	COMMON/XSECT/GXSECT(25,10)	STAB 20
	DIMENSION C(ITL,NG,1)	STAB 30
	LP=L+1	STAB 40
	DO 2 M=1,NM	STAB 50
	I=(M-1)*LP+1	STAB 60
	DO 2 IG=1,NG	STAB 70
2	GXSECT(IG,M)=C(INT,IG,I)	STAB 80
	RETURN	STAB 90
	END	STAB 100