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QADS: A Multidimensional Point Kernel Analysis Module

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ABSTRACT

QADS is a multidimensional point kernel computer code that utilizes the simplified free-form input of the SCALE system as well as compatibility with ORIGEN-S produced sources, SCALE cross section libraries, and standard composition data sets. QADS consists of a preprocessor that takes the free-form input and prepares input for the widely available QAD-CGGP code, which is then automatically executed by a driver module. This report describes the point kernel theory briefly, followed by numerous tips on successfully applying the theory to various types of shielding problems. The remainder of the document is devoted to input and output descriptions of the QADS code with several illustrative sample problems.

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1. INTRODUCTION

QADS is a module that performs multidimensional point kernel estimation of gamma transport through practically any type of shielding materials using a simplified input scheme that follows the general input philosophy of the SCALE[1] shielding sequences, SAS1, SAS2, etc. Conceptually, QADS was designed to capture the flexibility and power of the QAD technique for problems amenable to point kernel solution while allowing for an efficient and user-friendly input interface. Functionally, the QADS module is called via the SCALE driver and first reads the free-form input values and then preprocesses the actual input for the QAD-CGGP code.[2] The driver then calls and executes QAD-CGGP automatically. For this version of QADS, QAD-CGGP was unchanged from the RSIC-distributed version to allow future updates of the QAD-CGGP code to be easily implemented into QADS. The QADS module has a number of similarities with other SCALE modules that facilitate rapid transfer of input data from other setups. The SCALE standard composition library is used to allow simplified input of materials. The problem geometry is coded using the well-known MORSE combinatorial geometry package. Finally, the dose portion of the input follows similarly the XSDOSE input data in module SAS1. The combined use of the SCALE standard compositions and free-form input with the multidimensional geometry capabilities and generally short running time of point kernel techniques produces a very powerful procedure for shielding analysis of a wide variety of problems.

2. POINT KERNEL DOSE ESTIMATION THEORY

2.1 POINT KERNEL THEORY

Point kernel techniques have been widely used in gamma-ray radiation shielding analyses through the years and the methods are well known. However, for completeness the discussion of the method in ref. 2 is repeated herein. For gamma-ray calculations the QADS module uses the point-kernel ray-tracing technique. In this method, the point kernel representing the transfer of energy by the uncollided flux along a line-of-sight path is combined with an appropriate buildup factor to account for the contribution from the scattered photons. With a distributed source, the point kernel is integrated over the source volume for each source energy considered. Expressed as an equation, the gamma-ray dose rate at any point due to an anisotropic source emitting s photons of energy E per second per unit volume is

$$\mathrm{D}(\bar{r}) = \frac{\mathrm{K}\int_v s(\bar{r}\prime)\mathrm{B}(\mu \mid \bar{r}-\bar{r}\prime \mid, E)\exp(-\mu \mid \bar{r}-\bar{r}\prime \mid)dv}{4\pi \mid \bar{r}-\bar{r}\prime \mid^2}, \qquad (1)$$

where

$\bar{r}$ = point at which gamma dose rate is to be calculated,
$\bar{r}\prime$ = location of source in volume v,
v = volume of source region,
μ = total attenuation coefficient at energy E,
$\mid \bar{r}-\bar{r}\prime \mid$ = distance between source point and point at which gamma intensity is to be calculated.

2.2 BUILDUP FACTOR OPTIONS

2.2.1 Governing Equations

Two buildup factor options are available in the QADS module. The first option is the use of the original QAD-P5A code[2] values based on the Goldstein and Wilkins moments method calculations for gamma-ray transporting infinite homogeneous media. This method uses Capo's fit to the Goldstein-Wilkins data with bivariant polynomial expressions to calculate the appropriate buildup factors as a function of the gamma-ray energy and the number of mean free paths (mfp) from the source to the detector. For high atomic number materials, the polynomial fit has the form

$$\mathrm{B}(\mu \mid \overline{r} - \overline{r\prime} \mid, \mathrm{E}) = \sum_{j=0}^{4} \sum_{i=0}^{3} \mathrm{C}^{ij} (\mu \mid \overline{r} - \overline{r\prime} \mid)^{i} (\mathrm{E})^{j} \ , \tag{2a}$$

and for low atomic number materials it has the form

$$\mathrm{B}(\mu \mid \overline{r} - \overline{r\prime} \mid, \mathrm{E}) = \sum_{j=0}^{4} \sum_{i=0}^{3} \mathrm{C}^{ij} (\mu \mid \overline{r} - \overline{r\prime} \mid)^{i} (\frac{1}{\mathrm{E}})^{j} \ , \tag{2b}$$

where the $C_{ij}^{\prime}s$ are the coefficients of the expansion.

The second buildup factor method that can be selected is the geometrical progression approximation (GP method).[3] This method has recently received a lot of attention and appears to more closely reproduce actual calculations than other methods. The buildup factors are approximated by the equations

$$\begin{aligned} B(X,E) &= 1 + (b-1)\frac{K^{x}-1}{K-1} \qquad (K \neq 1) \ ; \\ &= 1 + (b-1)X \qquad (K = 1) \ ; \end{aligned} \tag{3a}$$

$$K(X) = cX^{a} + d \bullet \frac{tanh(X/X_{k} - 2) - tanh(-2)}{1 - tanh(-2)} \ ; \tag{3b}$$

where X is the source-detector distance in mean-free-paths of the medium, b is the value of the buildup factor at 1 mfp, and K represents the photon dose multiplication per mfp penetration. The parameters *a, c, d,* and X_k are the fitting parameters and are allowed to vary with energy. A differing form of Eq. (3b) is used for penetrations greater than 40 mfp.

2.2.2 Buildup Factor Usage Guidelines

Using these infinite-medium buildup factors should result in an overestimate of the dose rate at a surface external to the source region since it implies that reflecting material is located beyond the surface. However, because of the strong preferential forward scattering of photons, the error will usually not be more than a few percent and only in rather unusual cases will it reach 20 or 30%.

Using single-material buildup factors for multilayered shields or for shields made up of mixtures of materials can be another source of error. For multilayered structures having an outer layer that is thicker than 2 or 3 mfp, the buildup factor used should be the one representing the outer layer, but the total number of mean free paths should be the number along the line-of-sight through all materials in the structure. This is a reasonable procedure since the gamma-ray spectrum would read just to the new medium and tend to approach the spectrum that would exist if the whole structure consisted of the outer layer, particularly when a low atomic number material is followed by a high atomic number material. For homogeneous mixtures or compounds, the so-called equivalent Z (atomic number) method can be used.

For multilayered structures in which each layer is less than 2 mfp thick, no clear-cut procedure is available. If one assumes that the structure is made entirely of the material having the largest buildup factor, then the dose is overestimated. Conversely, if one assumes that the material having the lowest buildup factor is representative of the structure, then the dose is underestimated.

2.3 DOSE ESTIMATION

The QADS module calculates the dose at a detector for each source energy group j with the following equation, which is a finite difference form of Eq. (1):

$$D_j = \sum_i K_j \frac{S_{ij}}{4\pi R_i^2} \exp[-\sum_k (\mu_j t)_k] B_{jk} \ , \tag{4}$$

where

j = energy group index,
i = source point index,
k = region index,
K = flux-to-dose conversion factor (rads/unit flux),
S = volume-weighted gamma-ray point source strength (photons/s),
R = distance from source point to detector (cm),
B = dose buildup factor,
μ = total attenuation coefficient (cm^{-1}),
t = zone penetration distance (cm).

The i index is used to completely describe the source. The source is broken into i mesh cells with each mesh treated as a point source. The energy index j is treated in a similar manner. The source energy is assumed to be at the midpoint of the jth energy or group interval. All revelant constants are then evaluated at j points in energy. The total dose is obtained by summing the contribution from each of the source energies.

The QADS module also will perform a neutron calculation, although the range of applicability of the solutions is fairly limited. The methods used for the neutron calculations are discussed in ref. 2. The neutron calculations are performed in a fixed 10-group structure and a fission spectrum source.

3. INPUT SPECIFICATIONS

3.1 INPUT OVERVIEW

The QADS module input can be broken into the following areas: (1) material component specification, (2) source specification, (3) problem geometry, and (4) selection of built-in data and detector options. A brief description of each input group follows.

3.1.1 Material Component Specification

The selection of the constituent material compositions is straightforward since the SCALE standard composition library and material input processor are utilized by QADS. Therefore the input specifications for QADS materials should be unchanged from those of the SCALE sequences. Unlike the SCALE shielding sequences, the QADS module does not call the BONAMI and NITAWL modules (see Sections F2 and F3 of the SCALE manual) since the data in QADS are fixed and do not require any resonance processing.

3.1.2 Source Specification

The specification of a source in QADS allows for a great deal of flexibility to handle a large number of source situations ranging from a flat source to one that has arbitrary shape and limitations in any of the three directions. The input is such that the description of most source situations is straightforward; however, as the source complexity increases so does the detail necessary to describe the given situation. This section is designed to give the user sufficient understanding to describe practically any given source configuration. The source description internal to the code includes an overall normalization, a spatial mesh and corresponding spatial distribution by mesh point, an energy structure and corresponding energy spectral shape, and a specified coordinate system. The source description can use a Cartesian, cylindrical, or a spherical coordinate system; however, the Cartesian system is recommended if the source is off-centered or if there are multiple sources. The technique utilized for off-centered or multiple sources is to describe one source geometry that encloses the origin and all sources, then selectively zero-out nonsource regions by use of zero weights. [See Eq. (6).]

The use of keywords in the source geometry and shape, and defaults in the source mesh points, energy group structure, and in some cases the source spectrum, greatly simplifies the typical source description and will suffice for many practical applications. The source shape description for a flat (keyword FLATS) or a cosine (keyword COSIN) shape are handled internally by the following equation for the point variation in the source:

$$\begin{aligned} P(a,b,c) = cos\{xiso(1,1)[a - xiso(2,1)]\} * cos\{xiso(1,2)[b - xiso(2,2)]\} \ ; \\ *cos\{xiso(1,3)[c - xiso(2,3)]\} \ ; \end{aligned} \tag{5}$$

where a, b, and c are the coordinates of the point in the appropriate coordinate systems, and the $xiso$ values are either calculated internally by the code or input by the user. For the FLATS and COSIN options the values of $xiso$ are computed internally (e.g., all $xiso$ values are zero for the flat option). For the COSIN options the values of $xiso$ are computed such that the power or source strength peak occurs at the midplane and is equal to zero at the external boundary. Only for the Cartesian coordinates are COSIN specifications allowed in all three directions. As an option, the QADS module allows the user to input a unique set of $xiso$ values.

The final option for specifying the source shape is to input the relative shape by mesh point along each axis. This option assumes separability in each of the three directions and

the user inputs the power or source shape independently along each axis. The relative magnitudes of each different axis are not important since the code normalizes to the input value ASO. The overall normalization is performed (for cylindrical geometry) by using the input shapes P(r), P(z), and P(θ), to calculate the weights F_l, F_m, and F'_n:

$$\begin{aligned} F_l &= \int_{r_l}^{r_l+1} rP(r)dr \ ; \\ F_m &= \int_{z_m}^{z_m+1} P(z)dz \ ; \\ F'_n &= \int_{\theta_n}^{\theta_n+1} P(\theta)d\theta \ . \end{aligned} \tag{6}$$

The F_n value is primed to allow overall normalization to be performed as follows:

$$\begin{aligned} A &= \frac{ASO}{(\sum_{l=1}^{L} F_l)(\sum_{m=1}^{M} F_m)(\sum_{n=1}^{N} F_n)} \ ; \\ F_n &= A \ F'_n \ . \end{aligned} \tag{7}$$

Thus, the total power and the input value ASO can be equated,

$$P = ASO = (\sum_{l=1}^{L} F_l)(\sum_{m=1}^{M} F_m)(\sum_{n=1}^{N} F_n) \ , \tag{8}$$

and the power at any point is given by

$$P_{lmn} = F_l \ F_m \ F_n \ . \tag{9}$$

In this manner the correct normalization is given regardless of the relative magnitudes of the individual coordinates.

3.1.3 Problem Geometry Specification

The problem geometry input uses the MORSE combinatorial geometry description. The input includes first a description of each body type, where the nine different body types are defined in the next section. The user then defines the corresponding body types for each zone and finally, the mixtures numbers for each zone. The input geometry description should be obvious to MORSE combinatorial geometry users; for those unfamiliar with MORSE geometry input the user is referred to Sect. F9 in the SCALE manual (ref. 1) or Appendix A.

3.1.4 Built-In Database Description

QADS contains a large database of built-in quantities, which simplifies the user input for most problems of interest. This built-in data consists of (1) buildup factors for both the standard and GP techniques; (2) dose factors that can be user input, read from a SCALE library or internally computed using the ANSI-standard description; and (3) mass attenuation coefficients for any element.

3.2 INPUT DESCRIPTION

The user input to QADS is designed to be very similar to other SCALE sequences. Thus, with minimal effort a problem set up for another sequence can be rerun using the QADS sequence. Also, a user who is familiar with SCALE input and execution should have little problem becoming proficient in the operation of QADS.

3.2.1 Sequence Specifier

Under the SCALE driver, QADS is invoked by the use of the sequence specifier "=QADS" and corresponding data shown in Table 1. The input sections following the sequence specifier consist of a title; cross-section library name; calculation type; standard composition data; QADS source specification; QADS problem geometry specification; QADS dose and detector specifications; and, finally, a QADS input terminator.

3.2.2 Title Card

The sequence specifier card is followed by an 80-character title card. Any descriptive title containing 80 or fewer characters is allowed.

3.2.3 Cross-Section Library Name

The input value for the cross-section library name has four options: 27N-18COUPLE, 22N-18COUPLE, ORIGENGP-SRC, and READINGP-SRC. The first two options specify that the problem group structure will be read from the corresponding SCALE library, while the input source spectrum will be read in the job input stream. Note that the cross sections on the SCALE library are not used, since QADS has built-in attenuation coefficients. The third option, ORIGENGP-SRC, signals the code to read both the problem group structure and the source spectrum and magnitude from the ORIGEN-S output saved on disk. This is a useful option for coupling ORIGEN-S source calculations and QADS shielding calculations. The final option, READINGP-SRC, directs the code to read both the problem group structure and source spectrum from the job input stream. While more cumbersome in preparing the input, this option provides flexibility in that any group structure can be used and it gives QADS the option of easily specifying gamma line sources. This is accomplished by specifying narrow energy bins with the mid-point energy equal to the gamma line source energy.

3.2.4 Calculation Type

The next input value, the calculational type, is included simply to minimize changes to existing decks that have been used in other SCALE sequences. The only value that is acceptable for this input is INFHOMMEDIUM. QADS does not perform any resonance processing on the cross sections since it uses built-in attenuation coefficients.

3.2.5 Standard Composition Data

The QADS standard composition data input is exactly like that of the standard SCALE input; thus, problem input descriptions should be easily transported from other applications to QADS. A brief input description is given in Table 2; for more detailed explanations of each input value see the description given in the SCALE users manual (Sect. M7.4) ref. 1.

3.2.6 QADS Source Specification

The QADS source specification input follows and is summarized in Table 3. Following selection of the appropriate source geometry, the user enters the source strength, normally

Table 1. Outline of material information processor data for QADS

Data position	Type of data	Data entry	Comments
1	Sequence specifier	=QADS	Begin in column 1. PARM=CHK beginning in column 11 checks the input for errors
2	Title	Enter a title	80 characters
3	Cross-section library name	27N-18COUPLE 22N-18COUPLE ORIGENGP-SRC READINGP-SRC	These keywords are used to select the problem group structure only. QADS has built-in cross sections
4	Calculation type	INFHOMMEDIUM	This is only valid option for QADS calculation
5	Standard composition data	Enter the appropriate data	Terminate this data block with END COMP. See Table 2 for further details
6	QADS source specification	Enter the appropriate data	End this data block with END SOURCE. See Table 3 for more information
7	QADS problem geometry specification	Enter the combinatorial geometry data	End this data block with END GEOM. See Table 4 for details
8	QADS dose and detector specification	Enter the appropriate data	Terminate this block with an END DOSE card. See Table 5 for explanation of input
9	Terminate QADS sequence	END	Must begin in column 1

Table 2. Outline of standard composition specification data

Entry number	Variable name	Type of data	Entry requirement	Comments
1	SC	Standard composition component name	Always	Enter once for each standard composition. Additional allowed names include those beginning with arbitrary materials and SOLN for solutions.
A1	ROTH	Theoretical density of material (g/cc)	ARBM	Enter once for each standard composition component that is an arbitrary material.
A2	NEL	Number of elements in the material	ARBM	Enter once for each standard composition component that is an arbitrary material.
A3	IVIS	Multiple isotope indicator	ARBM	Enter once for each standard composition component that is an arbitrary material. Enter 0 for a material that does not contain multiple isotope elements. Enter 1 if the material contains a multiple isotope element. An arbitrary material cannot have more than one multiple isotope element. If necessary, several arbitrary materials may be used in a single mixture.
A4	ICP	Compound indicator	ARBM	Enter once for each standard composition component that is an arbitrary material. Enter 1 for a compound, 0 for alloys, mixture, etc.
A5	IRS	Resonance indicator	ARBM	Enter once for each standard composition component that is an arbitrary material. Enter 0 if all the nuclides in the material are nonresonance nuclides; enter 1 if one or more have resonance data.
A6	NCZA	ID number	ARBM	Repeat the sequence A6 and A7 for each element in the arbitrary material before entering item 2. Only elements can be used in an arbitrary material.
A7	ATPM	Number of atoms of this element per molecule or arbitrary material OR Weight percent of this element in this arbitrary material	ARBM & ICP=1 ARBM & ICP=0	Repeat the sequence A6 and A7 for each element in arbitrary material before entering item 2. Do not enter a value unless ICP=1. Repeat the sequence A6 and A7 for each element in the arbitrary material before entering item 2. Do not enter a value unless ICP=0.
2	MX	Mixture ID number	Always	Enter once for each standard composition component.
S1	FD	Fuel density (grams of U or Pu per liter of solution)	SOLN	Enter once for a solution.
S2	AML	Acid molarity of the solution	SOLN	Enter once for a solution. AML=0 if there is no acid in the solution.

Table 2 (continued)

Entry number	Variable name	Type of data	Entry requirement	Comments
O1	SPGR or ROTH	Specify gravity of the solution OR Density of the standard composition	Optional	If the specific gravity (SPGR) of the solution is known, it should be entered as SPG=SPGR. If the density of a basic standard composition (ROTH) is to be entered, use DEN=ROTH.
3	VF	Density multiplier	See comment column	Enter the density multiplier (density fraction, volume fraction, or a combination). Default value is 1.0. This item can be omitted if items 4, 5, 6a, and 6b are also omitted. VF=0 is not allowed for SOLN and ARB.
4	ADEN	Number density (atoms/barn-cm) for the nuclide	VF=0	Enter only if VF=0.0.
5	TEMP	Temperature, in degrees K	See comment column	Default value is 293 K. This item can be omitted if items 6a and 6b are also omitted.
6a	IZA	Isotope's ZA number	VF≠0	Enter for each isotope in the standard composition component. Omit if VF=0. Items 6a and 6b are entered in pairs until each isotope in tho component is defined.
6b	WTP	Weight percent of the isotope	VF≠0	Enter for each isotope in the standard composition component. Omit if VF=0.0. Items 6a and 6b are entered in pairs until each isotope in the component is defined.
7[a]	END	Terminate a standard composition	Always	Enter once for each standard composition component. This terminates the data for a standard composition component. Enter END to terminate the component. Repeat items 1–7 until all the mixtures have been defined.
	END COMP	Terminate the data block	Terminus	Enter once for a problem. Enter the words END COMP when all the standard composition components have been described.

[a] Item 7 should not begin in column 1 unless a name is associated with it. At least two blanks should separate the last entry 7 from the END COMP.

Table 3. Input data description for QADS source specification

Data position	Type of data	Data entry	Comments
1	Source geometry	CYLINDRICAL CARTESIAN SPHERICAL	Select the appropriate source geometry
2	Source strength	Enter the appropriate data	Enter the number of source particles/sec. Enter 0 for source read from ORIGEN-S
3	Source shape	FLATS COSINX COSINY COSINZ COSINR COSINRHO XISOS WEIGHTS	Terminate with an END card
4	Group structure (optional)	Enter number of groups, then group bounds (high-to-low in eV)	Input only if READING-SRC is specified
5	Particle spectrum (optional)	Enter value for each group	Input only if READINGP-SRC or SCALE library is specified
6	More Data array (optional)	NZS= INU= NSO= NPS= XIS= MSH= WAT=	[1] - body # for source [0] - neutron calculation if > 0 [71] - ORIGEN-S unit number [0] - source position number, 0=last [0] - xiso values (6 values) [0] - number of mesh intervals (values for each coordinate direction) [0] - weights read in[a]
7	End Source array	END SOURCE	Terminate source input

[a]The mesh intervals and weights for each axis are input in the following order: Cartesian (X,Z,Y), cylindrical (R,Z,θ), and spherical (ρ, θ, ψ).

in units of photons/s. This is the value ASO discussed in the previous section. For the ORIGENGP-SRC option this value should be entered as zero, since the overall normalization is read directly from the ORIGEN-S output. (See Sect. F7 of the SCALE Manual.) If a number other than zero is entered, the value from ORIGEN-S is discarded and the new value is used as the normalization. The use of eight different keyword inputs describes the spatial shape of the source within the defined source body. The first six options give a simple definition of the spatial variation of the source and no further information is needed to describe this variation. If either XISOS or WEIGHTS are specified, then a more detailed description of the spatial shape of the source is given in the More Data array parameters, XIS or WAT, respectively. Specifying XISOS directs the code to read the six values of XIS [$xiso$ values of Eq. (5)] in the following order:

XIS=XIS(1,1),XIS(2,1),XIS(1,2),XIS(2,2),XIS(1,3),XIS(2,3).

If the user specifies WEIGHTS, then the relative shapes for each mesh point for each coordinate axis should follow the WAT=keyword in the More Data array. The order of weights by axis is R, Z, θ for cylindrical; X, Z, Y for Cartesian; and ρ, θ, ψ for spherical. The optional fields of group structure and particle spectrum are read in next; the option is determined by the value of the cross-section library name specified previously. The group structure array is read in only if the cross-section library input value READINGP-SRC is specified. Similarly, the particle spectrum array is read in only if the cross-section library input value is specified as either READINGP-SRC or one of the SCALE libraries (27N-18COUPLE or 22N-18COUPLE).

The More Data array contains seven different keywords that in many instances will not have to be changed from their default values; however, using the keyword options increases the module's flexibility. This is easily illustrated by the first keyword, NZS. The value of NZS defaults to 1 and describes the body number corresponding to the source body. In many instances, the source will be the central body in the problem description and a common convention is to number the innermost body as 1. However, in some instances the source may incorporate several boundaries and simply specifying the body number for the outermost body will effectively spread the source out over all intermediate boundaries. An example of this is given in the sample problems. This is an important parameter since the source mesh is generated from the body data corresponding to the body number specified. The procedure used internally is to determine, based on the data for the specified body number, the innermost and outermost dimensions of the source body and then construct the mesh based on the specified number of equally spaced meshes (determined by the MSH= parameter). If MSH=0, then the number of mesh intervals is set to 30 for the R, X, Y, Z, and ρ axes and 20 for the θ and ψ axes. These values can be changed by specifying MSH= and entering the new number of mesh intervals for each of the three coordinate axes in the same order as previously given for the weights. Should changes from the defaults be attempted, care should be exercised in the selection of an appropriate number of mesh cells. Since the source representation is completely described by the source mesh, the mesh should be fine enough to adequately model the source body. This is particulary important for surface or near-surface doses where errors can occur if the mesh size is larger than the surface-to-detector distance. Alternately, if the value of MSH is entered as a negative number, the actual mesh can then be entered immediately after each MSH value has been input (e.g., if MSH= -15 then enter 16 r mesh values; if -10, enter 11 Z mesh values; if -5, enter 6 θ mesh values). This will allow for special situations when the intermediate boundaries, not just the endpoints, need to be specified.

The NSO and NPS parameters give the ORIGEN-S unit number and source position for the ORIGEN-S data saved to disk in an earlier run. Only in a few instances should

values other than the defaults have to be entered. The XIS and WAT parameters allow the user to enter their own set of source shapes. The last optional parameter is INU. Specifying INU greater than 0 allows the user to perform a neutron calculation. This document assumes that a gamma only calculation is the intent of most users and further information on the neutron capabilities is given in the original QAD document, ref. 2.

3.2.7 QADS Problem Geometry Specification

Tables 4 and 5 outline the user input for the QADS problem geometry input. This input is very similar to that of the MORSE-SGC. See Sect. F9 in the SCALE manual for more detailed information.

3.2.8 QADS Dose and Detector Specification

The description of the final input section, QADS detector and buildup factor specification, is given in Table 6. This section consists of buildup factor selection followed by two optional inputs: the number and type of flux-to-dose conversion factors and the number and position of detectors for the problem. The first 8 options for the buildup factors given in Table 6 correspond to the standard buildup factors [Eq. (2)], while the 43 options given in Table 7 correspond to the GP buildup factor data [Eq. (3)]. For the standard buildup factor data, the DOSE keyword indicates that the buildup factors are for an air exposure response with penetration through the given material and the ENG keyword indicates a response of the energy absorbed in the material itself. Similarly for the GP buildup factor data, the ABS keyword indicates a response of the energy absorbed in the material, while the keyword EXP indicates the air exposure response with penetration through the given material.

The next input parameter is NFACTR, which specifies the number and/or type of flux-to-dose conversion factors. For all but a very few cases, the default value is sufficient. If the default value is used, ANSI-standard dose factors are either read from the SCALE library or calculated internally. The user can optionally specify other dose IDs from the SCALE library if that option is being utilized in the problem. Lastly, the user can input dose response values by specifying a number between 0 and 9000. This allows NFACTR sets of conversion factor sets to be read from the job input stream. The default for the number of detectors is four, NDETEC=0, and the detectors are located at 0, 1, 2, and 4 m from the outermost edge of the outermost nonvoid cylinder along the midplane of the cylinder. This default option is valid only for cylindrical source geometries. For other geometries and/or other detector locations the user enters the number of detectors desired, NDETEC=number of detectors, followed by the location of each detector. The default detector geometry is cylindrical and need not be entered unless the user desires another geometry for the detector.

3.2.9 Terminate QADS Sequence

An END card should be included to terminate the user input to QADS. No built-in mechanisms for stacking several cases within a QADS sequence exist. The use of the SCALE driver provides such an option since additional cases can be stacked by simply respecifying the entire QADS sequence input following the END card (i.e., including an =QADS as the card following the END card).

4. SAMPLE PROBLEMS AND OUTPUT DESCRIPTION

QADS was developed largely to provide a simplified input scheme to expedite shielding analyses of spent fuel shipping casks. Of course, many other applications are well suited

Table 4. Input data description for QADS geometry specification

Data position	Type of data	Data entry	Comments
1A	Body type	BOX RPP SPH RCC REC ELL TRC WED ARB	See Table 5 for body definitions. See Appendix A for more information
1B	Body number	enter appropriate body number	Enter body number corresponding to above body type
1C	Body data	enter appropriate data for given body	See Table 7 for required data for each body type
1D	Terminate body data	END BODY	After all body descriptions have been entered, terminate with END BODY
2A	Zone name	Three letter Zone title e.g., ZN1, ZN3	The first zone name corresponds to zone 1, second to zone 2, etc., regardless of its title
2B	Number of adjacent zones	integer #	Enter number of zones that can be entered from this zone
2C	Body numbers for this zone	+integer -integer OR +integer OR -integer	Enter the body numbers that comprise this zone. See Appendix A for more information
2D	Terminate zone data	END ZONE	After all zones have been described, terminate with END ZONE
3	Mixtures by zone	integer for each zone	Enter the mixture number for each zone. Enter 1000 for internal voids, 0 for external voids
4	End geometry input	END GEOM	

Table 5. Input required for each body type

Body description	Body type	Body number	Real data defining particular body[a]					
Box	BOX	Number assigned by the user	Vx H2x	Vy H2y	Vz H2z	H1x H3x	H1y H3y	H1z H3z
Right parallelepiped	RPP		Xmin	Xmax	Ymin	Ymax	Zmin	Zmax
Sphere	SPH		Vx	Vy	Vz	R		
Right circular cylinder	RCC		Vx R	Vy	Vz	Hx	Hy	Hz
Right elliptic cylinder	REC		Vx R1x	Vy R1y	Vz R1z	Hx R2x	Hy R2y	Hz R2z
Ellipsoid	ELL		V1x R	V1y	V1z	Hx	Hy	Hz
Truncated right cone	TRC		Vx R1	Vy R2	Vz	Hx	Hy	Hz
Right angle wedge	WED		Vx H2x	Vy H2y	Vz H2z	H1x H3x	H1y H3y	H1z H3z
Arbitrary convex polyhedron	ARB		V1x V3x V5x V7x Face descriptions[b]	V1y V3y V5y V7y	V1z V3z V5z V7z	V2x V4x V6x V8x	V2y V4y V6y V8y	V2z V4z V6z V8z

[a]For definitions of these values see Appendix A.

[b]Card 5 of the arbitrary polyhedron input contains a four-digit integer for each of the six faces of an ARB body.

Table 6. Input data description for QADS detector specification

Data position	Type of data	Data entry	Comments
1	Buildup factors	WATE DOSE or ENG ALUM ENG IRON DOSE or ENG LEAD DOSE or ENG CONC DOSE	These buildup factors correspond to the standard exponential buildup factor data. For GP values see Table 6
2	Number/type flux-to-dose conversion factor (optional)	NFACTR=[0] NFACTR > 9000 0 < NFACTR < 9000 END	Use ANSI-Standard Dose ID from SCALE read NFACTR responses from input[a] Terminate with END
3	Number of detectors (optional)	NDETEC= [0]	Defaults of 0, 1, 2, 4 m from mid-plane (valid only for CYLINDRICAL source)
4	Detector data (NDETEC $\neq$ 0)	RRC ZRC PHIRC NRCOP for each detector	R, X, or ρ value Z, Z, or θ value θ, Y, or ψ value CYLINDRICAL (default) CARTESIAN SPHERICAL
5	Terminate input	END DOSE	Terminate dose input

[a] NFACTR for values between 0 and 9000 is the number of response sets, not the total number of values entered. After the value of NFACTR is entered, response values are entered by group for each of the NFACTR responses.

Table 7. Index of materials and responses used in QADS

MATGP	Material	ICGP	Response	ICGP	Response
BERY	Beryllium	_ABS	Beryllium	_EXP	Air
BORO	Boron	_ABS	Boron	_EXP	Air
CARB	Carbon	_ABS	Carbon	_EXP	Air
NITR	Nitrogen	_ABS	Nitrogen	_EXP	Air
OXYG	Oxygen	_ABS	Oxygen	_EXP	Air
SODI	Sodium	_ABS	Sodium	_EXP	Air
MAGN	Magnesium	_ABS	Magnesium	_EXP	Air
ALUM	Aluminum	_ABS	Aliminum	_EXP	Air
SILI	Silicon	_ABS	Silicon	_EXP	Air
PHOS	Phosphorus	_ABS	Phosphorus	_EXP	Air
SULP	Sulphur	_ABS	Sulphur	_EXP	Air
ARGO	Argon	_ABS	Argon	_EXP	Air
POTA	Potassium	_ABS	Potassium	_EXP	Air
CALC	Calcium	_ABS	Calcium	_EXP	Air
IRON	Iron	_ABS	Iron	_EXP	Air
COPP	Copper	_ABS	Copper	_EXP	Air
MOLY	Molybdenum	_ABS	Molybdenum	_EXP	Air
LEAD	Lead	_ABS	Lead	_EXP	Air
URAN	Uranium	_ABS	Uranium	_EXP	Air
WATE	Water	_ABS	Water	_EXP	Air
AIR_	Air	_ABS	Air		
CONC	Concrete	_ABS	Concrete	_EXP	Air

cf) _ means blank

for analysis using the QADS module. However, the two sample problems and their corresponding outputs given here are examples of how QADS could be used in shipping cask analysis. The examples were designed to use as many options as possible, in some cases more than are actually necessary, to give the user insight into how the particular options can be best utilized.

The first sample problem involves a 38-cm-thick cylindrical cast-iron shipping cask with a dry 40-cm radius inner cavity shown in Fig. 1. The source has a total source strength of 5.078×10^{16} photons/s and is distributed into an 18-group structure as shown in the input. This spectrum was derived from individual line sources by binning into the specified energy ranges while conserving energy. The weights option was specified to show its use; however, the actual weights are all set to 1, thus specifying a flat source. The problem geometry described is a cylindrical shield 38 cm thick with a 40-cm radius cavity. The bottom of the cask is also 38 cm thick with the top cover 42 cm in thickness. These body descriptions are followed by surrounding bodies of first internal void and lastly external void in order that dose estimations external to the cask can be performed in QADS. In this case, these regions were made arbitrarily large.

The results for receiver 1 (i.e., a detector at the outer cask surface on the axial midplane) are shown in Fig. 2. The calculated dose rates are shown in the sixth column, both as a total dose rate and by group. The value of 3.46×10^{-2} rem/h agrees well with both 1-D and 2-D transport results as was reported earlier.[4]

The second sample problem illustrates one of many shielding situations that QADS can handle quite easily. The physical situation is a storage container consisting of 52 cans of enriched uranium. The cans are stacked 4 high in 13 compartments as shown in Fig. 3. QADS cannot handle the source geometry exactly for this case. The cylinders themselves can be modeled but only one distinct source body can be input. There are several ways to approximate this shielding situation. The first is to make the geometry 1-D by modeling the middle cylinder exactly, then smearing the remaining 12 cylinders into an outer cylindrical ring. This method was chosen as an approximation since one aim of the code checkout was to compare QADS results with 1-D transport calculations. Another possibility is to model all 13 cylinders in Cartesian geometry with checkerboard patterns approximating the cylinders and the use of zero and nonzero weights to selectively "punchout" the "cylindrical" regions of the source. This approach more closely reproduces the actual configuration but at the expense of simplicity in setting the problem up. This sample problem (see Fig. 4) also demonstrates the use of the optional parameter NZS. The default value for NZS is 1, which describes the body number of the source description. In many applications the innermost body is both the source body and body 1; thus the default should be appropriate for many situations. In this and other similar situations, however, there are multiple source bodies. The procedure used here specifies the outermost source body number as NZS. This designation incorporates all the remaining internal bodies. It also places a portion of the source in the structural regions which, if desired, can be assigned zero weights. The error in this problem was deemed small enough to ignore. The comparisons in Table 8 at four detector locations with a similar 1-D treatment show excellent agreement.

Extractions of the resulting QADS output for the two sample problems are shown in Figs. 2 and 4. Figure 5 contains the complete QADS output of the first sample problem with appropriate notations made to aid the user in understanding the printed results. The complete listing includes first an input listing and then output for the QAD-CGGP portion, followed by an abbreviated SCALE-like description of the input and finally an echo of the QADS input values.

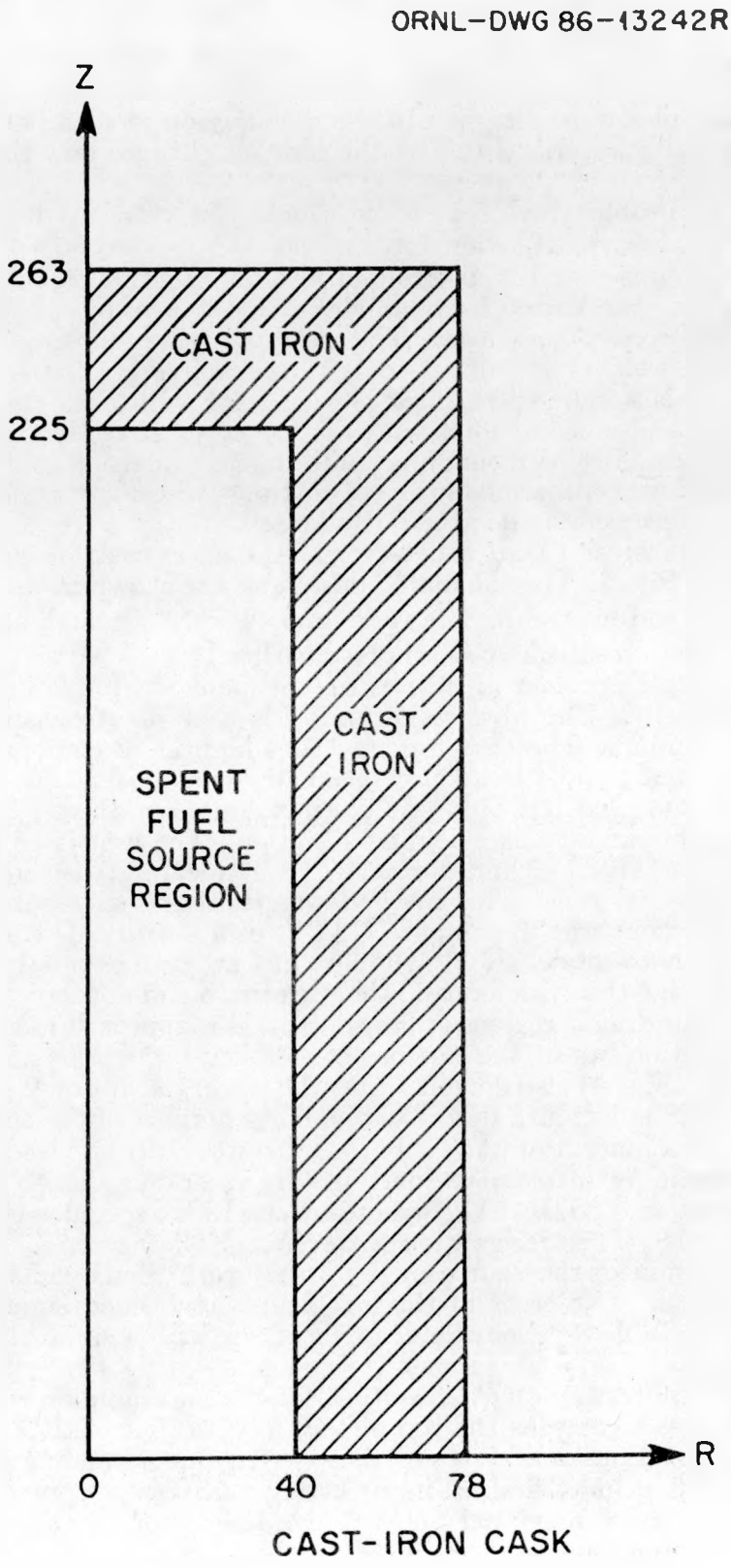

Fig. 1. Geometry of cast-iron cask specified by OECD working group.

```
MODULE QADS     WILL BE CALLED  TIME OF DAY 10.31.01  DATE 88.018

  QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK
  READINGP-SRC INFHOMMEDIUM
  ARBM-CASTFE 7.0 4 0 0 1 6012 3.25 14000 1.4 28000 1.1 26000 94.25 2 END
  ARBM-POLY .91 2 0 1 0 6012 2 1001 4 3 END
  ARBM-1.4541 2.81 4 0 0 1 25055 2. 24000 18. 28000 10. 26000 70. 1 .186 END
  ARBM-ZIRC4 2.81 3 0 0 1 40000 97.9 50000 1.6 26000 0.5 1 .116 END
  ARBM-U235 2.81 1 0 0 1 92235 100. 1 .011 END
  ARBM-U238 2.81 1 0 0 1 92238 100. 1 .344 END
  ARBM-OXYGEN 2.81 1 0 0 0 8016 100. 1 .043 END
  END COMP
  CYLINDRICAL 5.078E16 WEIGHTS END
  18 10+6 8+6 6.5+6 5+6 4+6 3+6 2.5+6 2+6 1.66+6 1.33+6 1+6 8+5
  6+5 4+5 3+5 2+5 1+5 5+4 1+4
  5Z 2.64-5 5.02-3 1.13-4 0 1.80-2 7.60-3 6.70-1 2.99-1 5Z
  MSH=15 15 10 WAT=43*1
  END SOURCE
  CYLINDRICAL SHELL CASK
  RCC 1 0 0 38 0 0 450 40
  RCC 2 0 0 0 0 0 488 78
  RCC 3 0 0 488 0 0 42 78
  RCC 4 0 0 -10000 0 0 20000 20000
  RCC 5 0 0 -10001 0 0 20002 20002
  END BODY
  ZN1 2 1
  ZN2 2 2 -1
  ZN3 2 3
  ZN4 2 4 -3 -2
  ZN5 2 5 -4
  END ZONE
  1 2 2 1000 0
  END GEOM
  IRON EXP
  NDETEC=2
  78. 265. 0. 178. 265. 0.
  END DOSE
  END

SECONDARY MODULE QADCGGP  HAS BEEN CALLED

MODULE QADCGGP  IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED    15.80 (SECONDS). I/O'S USED     108.

MODULE QADS     IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED    16.33 (SECONDS). I/O'S USED     313.
```

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

RECEIVER NUMBER 1 COORDINATES - R 7.8000E+01 PHI 0.0000E+00 Z 2.6500E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	2.1102	0.01 -10.00	7.2838E+02	1.3931E+01	2.4825E-03	3.4583E-02	0.0000E+00	0.0000E+00
W/BU	2.2002							
1	9.0000	10.00 - 8.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	9.5472E+00	1.1054E+01	3.7804E-05	4.1789E-04	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	6.8125E+02	1.3369E+01	2.3630E-03	3.1592E-02	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	4.7368E+00	1.6729E+01	1.4301E-05	2.3925E-04	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	2.5036E+01	3.0056E+01	5.5207E-05	1.6593E-03	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	9.9446E-01	4.1316E+01	1.8224E-06	7.5296E-05	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	6.7553E+00	5.7775E+01	1.0287E-05	5.9432E-04	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	6.0533E-02	7.9634E+01	7.0972E-08	5.6518E-06	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Fig. 2. Abbreviated output listing for Sample Problem 1.

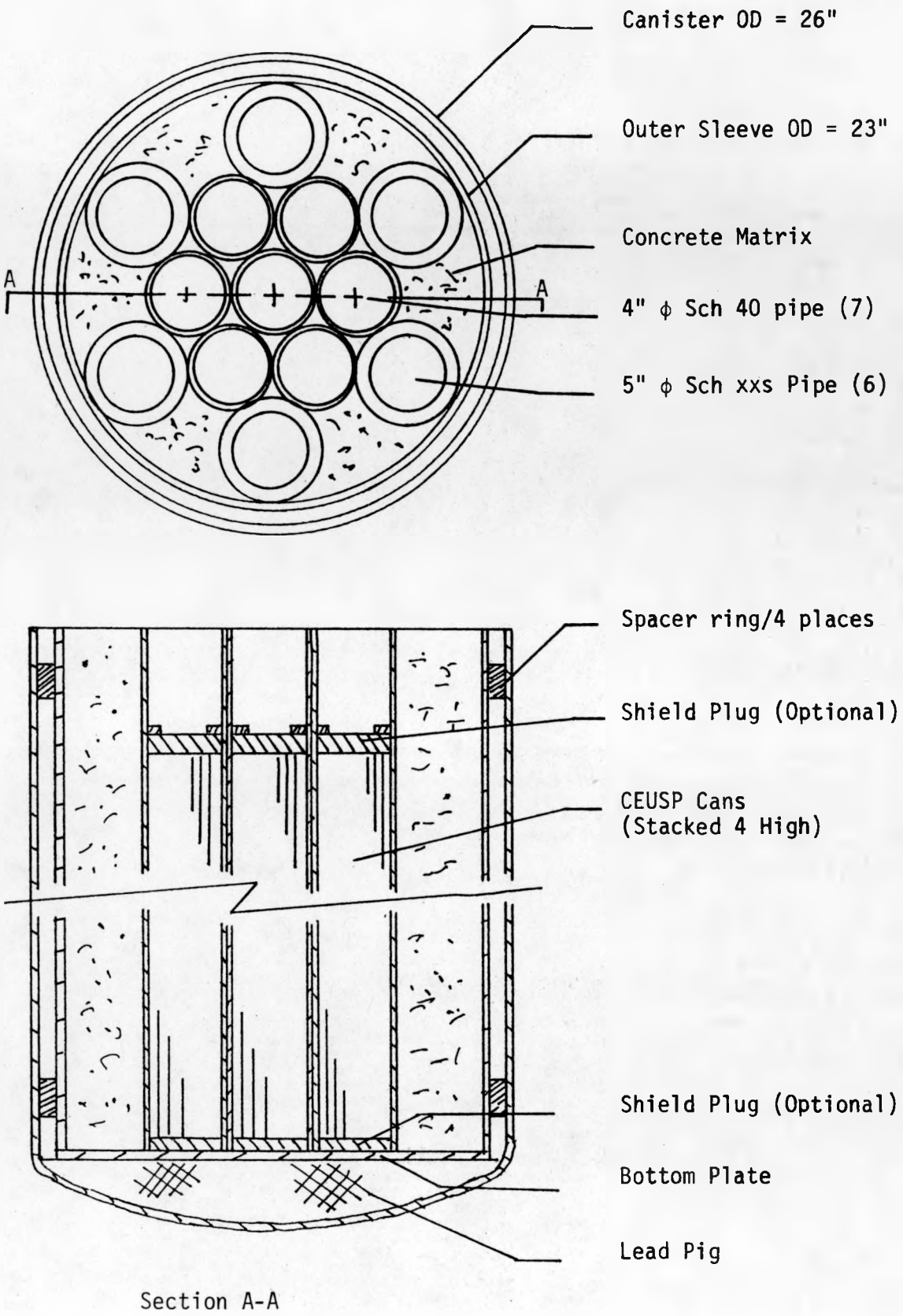

Fig. 3. Sample Problem 2 storage containers.

```
MODULE QADS     WILL BE CALLED  TIME OF DAY 14.13.39  DATE 88.019

  CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL
  ORIGENGP-SRC INFHOMMEDIUM
  URANIUM 1 .03045 293 92233 9.700 92234 1.400 92235 76.5
          92236 5.600 92238 6.800 END
  O 1 .13591 END
  CD 1 .02141 END
  GD 1 .02788 END
  URANIUM 5 .01473 293 92233 9.700 92234 1.400 92235 76.5
          92236 5.600 92238 6.800 END
  O 5 .06575 END
  CD 5 .01035 END
  GD 5 .01349 END
  SS304 2 END
  CARBONSTEEL 3 END
  MGCONCRETE 4 END
  END COMP
  CYLINDRICAL 0. FLATS END
  NZS=4
  END SOURCE
  CYLINDRICAL SHELL CASK
  RCC 1 0 0 .940 0 0 246.28 4.808
  RCC 2 0 0 .635 0 0 247.58 5.113
  RCC 3 0 0 .635 0 0 271.78 5.715
  RCC 4 0 0 .940 0 0 246.28 24.620
  RCC 5 0 0 .635 0 0 247.58 24.925
  RCC 6 0 0 .635 0 0 271.78 26.797
  RCC 7 0 0 .635 0 0 271.78 32.385
  RCC 8 0 0 .635 0 0 271.78 33.020
  RCC 9 0 0 -10000 0 0 20000 20000
  RCC 10 0 0 -10001 0 0 20002 20002
  END BODY
  ZN1 2 1
  ZN2 2 2 -1
  ZN3 2 3 -2
  ZN4 2 4 -3
  ZN5 2 5 -4
  ZN6 2 6 -5
  ZN7 2 7 -6
  ZN8 2 8 -7
  ZN9 2 9 -8
  ZN10 2 10 -9
  END ZONE
  1 2 3 5 2 3 1000 2 1000 0
  END GEOM
  IRON EXP
  END DOSE
  END

SECONDARY MODULE QADCGGP  HAS BEEN CALLED

MODULE QADCGGP  IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED   289.54 (SECONDS). I/O'S USED     150.

MODULE QADS     IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED   290.21 (SECONDS). I/O'S USED     381.
```

Fig. 4. Listing of Sample Problem 2.

CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL

RECEIVER NUMBER 1 COORDINATES - R 3.3020E+01 PHI 0.0000E+00 Z 1.2361E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	1.8212	0.01 -10.00	4.8085E+05	2.3288E+00	1.5647E+00	3.6437E+00	0.0000E+00	0.0000E+00
W/BU	2.1613							
1	9.0000	10.00 - 8.00	1.7830E-06	1.4564E+00	1.5640E-11	2.2778E-11	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	1.3427E-05	1.5434E+00	1.0041E-10	1.5498E-10	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	1.0404E-04	1.6453E+00	6.6324E-10	1.0912E-09	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	3.4418E-04	1.7591E+00	1.8633E-09	3.2777E-09	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	1.2668E-03	1.9182E+00	5.8554E-09	1.1232E-08	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	3.3674E+05	2.0827E+00	1.3334E+00	2.7770E+00	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	2.9797E-01	2.2427E+00	1.0335E-06	2.3179E-06	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	2.4551E+03	2.4221E+00	7.4125E-03	1.7954E-02	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	2.2338E+04	2.6378E+00	5.8696E-02	1.5483E-01	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	5.2795E+03	3.0111E+00	1.1642E-02	3.5054E-02	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	1.7851E+04	3.5037E+00	3.2713E-02	1.1462E-01	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	3.4969E+04	4.0468E+00	5.3250E-02	2.1549E-01	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	5.2956E+04	4.8307E+00	6.2088E-02	2.9993E-01	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	1.1996E+03	5.3729E+00	1.0508E-03	5.6458E-03	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	7.0270E+03	5.2352E+00	4.4313E-03	2.3198E-02	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	3.9401E+01	3.7748E+00	1.5105E-05	5.7021E-05	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	9.0040E-04	1.9880E+00	2.4034E-10	4.7780E-10	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	1.1236E-24	1.0915E+00	1.0503E-30	1.1464E-30	0.0000E+00	0.0000E+00

CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL

RECEIVER NUMBER 2 COORDINATES - R 1.3302E+02 PHI 0.0000E+00 Z 1.2361E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	1.7434	0.01 -10.00	9.3051E+04	2.2130E+00	2.9666E-01	6.5651E-01	0.0000E+00	0.0000E+00
W/BU	2.1079							
1	9.0000	10.00 - 8.00	3.2260E-07	1.4008E+00	2.8297E-12	3.9639E-12	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	2.4227E-06	1.4762E+00	1.8118E-11	2.6746E-11	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	1.8841E-05	1.5617E+00	1.2011E-10	1.8757E-10	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	6.2663E-05	1.6672E+00	3.3923E-10	5.6557E-10	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	2.3342E-04	1.8024E+00	1.0789E-09	1.9446E-09	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	6.2874E+04	1.9507E+00	2.4896E-01	4.8563E-01	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	5.6392E-02	2.0965E+00	1.9560E-07	4.1009E-07	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	4.7081E+02	2.2677E+00	1.4215E-03	3.2234E-03	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	4.3639E+03	2.4612E+00	1.1467E-02	2.8221E-02	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	1.0538E+03	2.8273E+00	2.3238E-03	6.5700E-03	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	3.6571E+03	3.2835E+00	6.7020E-03	2.2006E-02	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	7.3198E+03	3.8280E+00	1.1146E-02	4.2668E-02	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	1.1410E+04	4.6175E+00	1.3377E-02	6.1770E-02	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	2.6764E+02	5.1708E+00	2.3444E-04	1.2122E-03	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	1.6241E+03	5.0732E+00	1.0242E-03	5.1960E-03	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	1.0302E+01	3.6531E+00	3.9495E-06	1.4428E-05	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	8.0183E-04	1.9258E+00	2.1403E-10	4.1218E-10	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	1.4483E-25	1.0919E+00	1.3538E-31	1.4782E-31	0.0000E+00	0.0000E+00

Fig. 4 (continued)

CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL

RECEIVER NUMBER 3 COORDINATES - R 2.3302E+02 PHI 0.0000E+00 Z 1.2361E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	1.7105	0.01 -10.00	3.7943E+04	2.1713E+00	1.1947E-01	2.5939E-01	0.0000E+00	0.0000E+00
W/BU	2.0759							
1	9.0000	10.00 - 8.00	1.2728E-07	1.3818E+00	1.1165E-12	1.5427E-12	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	9.5838E-07	1.4513E+00	7.1672E-12	1.0402E-11	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	7.4452E-06	1.5369E+00	4.7462E-11	7.2942E-11	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	2.4811E-05	1.6330E+00	1.3432E-10	2.1934E-10	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	9.2701E-05	1.7663E+00	4.2847E-10	7.5683E-10	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	2.5094E+04	1.9073E+00	9.9363E-02	1.8952E-01	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	2.2626E-02	2.0457E+00	7.8482E-08	1.6055E-07	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	1.9051E+02	2.1998E+00	5.7518E-04	1.2653E-03	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	1.7761E+03	2.3906E+00	4.6668E-03	1.1156E-02	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	4.3416E+02	2.7300E+00	9.5737E-04	2.6136E-03	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	1.5259E+03	3.1722E+00	2.7963E-03	8.8706E-03	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	3.1049E+03	3.6762E+00	4.7281E-03	1.7382E-02	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	4.9512E+03	4.4340E+00	5.8051E-03	2.5740E-02	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	1.1896E+02	4.9956E+00	1.0420E-04	5.2055E-04	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	7.4258E+02	4.9504E+00	4.6828E-04	2.3182E-03	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	5.0041E+00	3.6057E+00	1.9185E-06	6.9174E-06	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	4.4773E-04	1.9241E+00	1.1951E-10	2.2995E-10	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	5.3581E-26	1.0912E+00	5.0085E-32	5.4651E-32	0.0000E+00	0.0000E+00

CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL

RECEIVER NUMBER 4 COORDINATES - R 4.3302E+02 PHI 0.0000E+00 Z 1.2361E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	1.6959	0.01 -10.00	1.2077E+04	2.1517E+00	3.7811E-02	8.1357E-02	0.0000E+00	0.0000E+00
W/BU	2.0617							
1	9.0000	10.00 - 8.00	4.0023E-08	1.3740E+00	3.5107E-13	4.8237E-13	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	3.0058E-07	1.4442E+00	2.2479E-12	3.2464E-12	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	2.3349E-06	1.5261E+00	1.4885E-11	2.2715E-11	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	7.8060E-06	1.6208E+00	4.2259E-11	6.8494E-11	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	2.9161E-05	1.7491E+00	1.3478E-10	2.3576E-10	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	7.9103E+03	1.8870E+00	3.1322E-02	5.9103E-02	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	7.1499E-03	2.0215E+00	2.4800E-08	5.0134E-08	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	6.0342E+01	2.1767E+00	1.8218E-04	3.9657E-04	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	5.6437E+02	2.3587E+00	1.4829E-03	3.4978E-03	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	1.3896E+02	2.6861E+00	3.0642E-04	8.2308E-04	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	4.9053E+02	3.1202E+00	8.9894E-04	2.8049E-03	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	1.0041E+03	3.6213E+00	1.5290E-03	5.5370E-03	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	1.6182E+03	4.3530E+00	1.8972E-03	8.2586E-03	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	3.9283E+01	4.9275E+00	3.4410E-05	1.6955E-04	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	2.4946E+02	4.8592E+00	1.5731E-04	7.6440E-04	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	1.7458E+00	3.5652E+00	6.6929E-07	2.3862E-06	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	1.9094E-04	1.9188E+00	5.0968E-11	9.7797E-11	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	1.6371E-26	1.0918E+00	1.5303E-32	1.6708E-32	0.0000E+00	0.0000E+00

Fig. 4 (continued)

```
CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL


**** PROBLEM PARAMETERS ****

LIB ORIGENGP-SRC LIBRARY
MXX             5 MIXTURES
MSC            11 COMPOSITION SPECIFICATIONS
IZM             1 MATERIAL ZONES
GE  INFHOMMEDIUM GEOMETRY
MORE            0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
MSLN            0 FUEL SOLUTIONS


**** PROBLEM COMPOSITION DESCRIPTION ****

SC  URANIUM      STANDARD COMPOSITION
MX              1 MIXTURE NO.
VF         0.0304 VOLUME FRACTION
TEMP        293.0 DEG KELVIN
            92233  9.70%
            92234  1.40%
            92235 76.50%
            92236  5.60%
            92238  6.80%
END

SC  O            STANDARD COMPOSITION
MX              1 MIXTURE NO.
VF         0.1359 VOLUME FRACTION
END

SC  CD           STANDARD COMPOSITION
MX              1 MIXTURE NO.
VF         0.0214 VOLUME FRACTION
END

SC  GD           STANDARD COMPOSITION
MX              1 MIXTURE NO.
VF         0.0279 VOLUME FRACTION
END

SC  URANIUM      STANDARD COMPOSITION
MX              5 MIXTURE NO.
VF         0.0147 VOLUME FRACTION
TEMP        293.0 DEG KELVIN
            92233  9.70%
            92234  1.40%
            92235 76.50%
            92236  5.60%
            92238  6.80%
END

SC  O            STANDARD COMPOSITION
MX              5 MIXTURE NO.
VF         0.0657 VOLUME FRACTION
END

SC  CD           STANDARD COMPOSITION
MX              5 MIXTURE NO.
VF         0.0103 VOLUME FRACTION
END
```

Fig. 4 (continued)

```
SC  GD            STANDARD COMPOSITION
MX              5 MIXTURE NO.
VF         0.0135 VOLUME FRACTION
END

SC  SS304         STANDARD COMPOSITION
MX              2 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
END

SC  CARBONSTEEL   STANDARD COMPOSITION
MX              3 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
END

SC  MGCONCRETE    STANDARD COMPOSITION
MX              4 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
END


**** INFINITE HOMOGENEOUS MEDIUM ****
MFUEL           1 MIXTURE NO. OF THE INFINITE HOMOGENEOUS MEDIUM



**** SOURCE PARAMETERS ****

CEUSP CANISTER, NO. 4 SCH. 40, .5" BARREL


SRC     CYLINDRICAL   SOURCE COORDINATE SYSTEM
ASO      0.00000E+00  SOURCE STRENGTH
SHAPE       FLATS     SOURCE SHAPE



OPTIONAL PARAMETERS


NZS          4  ZONE OF SOURCE

GROUP STRUCTURE AND SOURCE SPECTRUM READ FROM UNIT 71 POSITION     0


**** DOSE DATA ****

BFMAT       IRON  BUILDUP FACTOR MATERIAL
BFRSP        EXP  BUILDUP FACTOR RESPONSE


NFACTR          0  DOSE FACTOR ID (READ FROM CARDS IF       < 9000)
NDETEC          4  NUMBER OF DETECTORS

DETECTOR NO.  1
RRC= 3.3020E+01 ZRC= 1.2361E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
DETECTOR NO.  2
RRC= 1.3302E+02 ZRC= 1.2361E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
DETECTOR NO.  3
RRC= 2.3302E+02 ZRC= 1.2361E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
DETECTOR NO.  4
RRC= 4.3302E+02 ZRC= 1.2361E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
```

Fig. 4 (continued)

Table 8. Dose comparisons for QADS Sample Problem 2 with SAS1 (1-D transport) at four radial detector locations

R(cm)[a]	SAS1[b]	QADS[b]
33 cm	3.277	3.644
133 cm	0.626	0.657
233 cm	0.260	0.259
433 cm	0.081	0.081

[a] All doses are at Z = 123 cm, the axial centerline of the configuration.

[b] Units are rem/hr/can.

```
INPUT DATA LIST
  1  QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK
  2     15  15   10  11    3   1   18   0    0   1    2   0    0   0    0   0
  3    0.5077999910E+17  0.0000000000E+00  0.0000000000E+00  0.0000000000E+00
  4    0.0000000000E+00  0.0000000000E+00  0.0000000000E+00
  5    0.0000000000E+00   2.66666603        5.33333206        7.99999809
  6     10.6666641        13.3333302        15.9999962        18.6666565
  7     21.3333130        23.9999695        26.6666260        29.3332825
  8     31.9999390        34.6665955        37.3332520        39.9999084
  9     38.0000000        68.0000000        98.0000000        128.000000
 10     158.000000        188.000000        218.000000        248.000000
 11     278.000000        308.000000        338.000000        368.000000
 12     398.000000        428.000000        458.000000        488.000000
 13    0.0000000000E+00  0.628318012       1.25663567        1.88495350
 14     2.51327133        3.14158916        3.76990700        4.39822483
 15     5.02654266        5.65486050        6.28317833
 16     1.00000000        1.00000000        1.00000000        1.00000000
 17     1.00000000        1.00000000        1.00000000        1.00000000
 18     1.00000000        1.00000000        1.00000000        1.00000000
 19     1.00000000        1.00000000        1.00000000        1.00000000
 20     1.00000000        1.00000000        1.00000000        1.00000000
 21     1.00000000        1.00000000        1.00000000        1.00000000
 22     1.00000000        1.00000000        1.00000000        1.00000000
 23     1.00000000        1.00000000        1.00000000        1.00000000
 24     1.00000000        1.00000000        1.00000000        1.00000000
 25     1.00000000        1.00000000        1.00000000        1.00000000
 26     1.00000000        1.00000000        1.00000000
 27      0    0          CYLINDRICAL SHELL CASK
 28    RCC    1 0.000E+00 0.000E+00 3.800E+01 0.000E+00 0.000E+00 4.500E+02
 29              4.000E+01
 30    RCC    2 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.880E+02
 31              7.800E+01
 32    RCC    3 0.000E+00 0.000E+00 4.880E+02 0.000E+00 0.000E+00 4.200E+01
 33              7.800E+01
 34    RCC    4 0.000E+00 0.000E+00-1.000E+04 0.000E+00 0.000E+00 2.000E+04
 35              2.000E+04
 36    RCC    5 0.000E+00 0.000E+00-1.000E+04 0.000E+00 0.000E+00 2.000E+04
 37              2.000E+04
 38    END
 39    ZN1    2      1
 40    ZN2    2      2     -1
 41    ZN3    2      3
 42    ZN4    2      4     -3     -2
 43    ZN5    2      5     -4
 44    END
 45      1    1    1    1    1
 46      1    2    2 1000    0
 47     11   6   14  28   26   1   25  24   40  50   92   8
```

Listing of actual QAD-CGGP input

Fig. 5. Complete listing of Sample Problem 1 output.

```
IRON EXP
 0.000000000E+00  0.000000000E+00  0.522659309E-01  0.367491066
 0.000000000E+00  0.104531907E-01  0.940787196E-01  0.319114685
 0.521535054E-02  0.997549534      0.120829821
 0.227499902      0.979999304E-01  0.769999027E-01   6.59749794
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.779130936      0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.130867958      0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00
  8.99999905       7.25000095       5.75000000       4.49999905
  3.49999905       2.74999905       2.24999905       1.82999897
  1.49499798       1.16499805      0.899999976      0.699999988
 0.500000119      0.350000024      0.250000000      0.149999976
 0.749999881E-01  0.300000049E-01
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.263999973E-04  0.501999632E-02  0.112999987E-03
 0.000000000E+00  0.179999992E-01  0.759999827E-02  0.669999957
 0.298999965      0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00
 0.877162984E-05  0.747850208E-05  0.637482208E-05  0.541364716E-05
 0.462207481E-05  0.395963525E-05  0.346859906E-05  0.301917771E-05
 0.262759841E-05  0.220512084E-05  0.183257725E-05  0.152275879E-05
 0.117245236E-05  0.875940259E-06  0.630605655E-06  0.383376232E-06
 0.266929817E-06  0.934760521E-06
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00
0.01 -10.00
10.00 - 8.00 8.00 - 6.50 6.50 - 5.00 5.00 - 4.00 4.00 - 3.00 3.00 - 2.50
2.50 - 2.00 2.00 - 1.66 1.66 - 1.33 1.33 - 1.00 1.00 - 0.80 0.80 - 0.60
0.60 - 0.40 0.40 - 0.30 0.30 - 0.20 0.20   0.10 0.10 - 0.05 0.05 - 0.01

  78.0000000       265.000000       0.000000000E+00          0          0
           0                0
 178.000000       265.000000       0.000000000E+00          0          0
           0                0

 0.000000000E+00  0.000000000E+00  0.000000000E+00         -1          0
           0                0
```

```
QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

CONTROL    15    15    10    11     3     1    18     0     0     1     2     0     0     0     0     0
                       0    -9     1    10     0     0     0     0     0     0     0     0     0     0

SOURCE  5.0780E+16  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

     R  0.0000E+00  2.6667E+00  5.3333E+00  8.0000E+00  1.0667E+01  1.3333E+01  1.6000E+01  1.8667E+01
        2.1333E+01  2.4000E+01  2.6667E+01  2.9333E+01  3.2000E+01  3.4667E+01  3.7333E+01  4.0000E+01

     Z  3.8000E+01  6.8000E+01  9.8000E+01  1.2800E+02  1.5800E+02  1.8800E+02  2.1800E+02  2.4800E+02
        2.7800E+02  3.0800E+02  3.3800E+02  3.6800E+02  3.9800E+02  4.2800E+02  4.5800E+02  4.8800E+02

   PHI  0.0000E+00  6.2832E-01  1.2566E+00  1.8850E+00  2.5133E+00  3.1416E+00  3.7699E+00  4.3982E+00
        5.0265E+00  5.6549E+00  6.2832E+00

  F(L)  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
        1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

  F(M)  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
        1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

  F(N)  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
        1.0000E+00  1.0000E+00  1.0000E+00
```

Control parameters

3-dimensional mesh description

Weight factors

Fig. 5 (continued)

```
        CYLINDRICAL SHELL CASK

                  IVOPT = 0          IDBG = 0
```

Geometry description

```
                                                    BODY DATA
 RCC    1  0.0000000D+00  0.0000000D+00  0.3800000D+02  0.0000000D+00  0.0000000D+00  0.4500000D+03    3
           0.4000000D+02
 RCC    2  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.4880000D+03   12
           0.7800000D+02
 RCC    3  0.0000000D+00  0.0000000D+00  0.4880000D+03  0.0000000D+00  0.0000000D+00  0.4200000D+02   21
           0.7800000D+02
 RCC    4  0.0000000D+00  0.0000000D+00 -0.1000000D+05  0.0000000D+00  0.0000000D+00  0.2000000D+05   30
           0.2000000D+05
 RCC    5  0.0000000D+00  0.0000000D+00 -0.1000000D+05  0.0000000D+00  0.0000000D+00  0.2000000D+05   39
           0.2000000D+05
 END    6  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00   48
NUMBER OF BODIES       5
LENGTH OF FPD-ARRAY   53


                                                    INPUT ZONE DATA
 ZN1    2     1     0     0     0     0     0     0     0     0  Z  1
 ZN2    2     2    -1     0     0     0     0     0     0     0  Z  2
 ZN3    2     3     0     0     0     0     0     0     0     0  Z  3
 ZN4    2     4    -3    -2     0     0     0     0     0     0  Z  4
 ZN5    2     5    -4     0     0     0     0     0     0     0  Z  5
 END    0     0     0     0     0     0     0     0     0     0  Z  6
NUMBER OF INPUT ZONES       5
NUMBER OF  CODE ZONES       5
LENGTH OF INTEGER ARRAY    97


CODE ZONE     INPUT ZONE     ZONE DATA LOC.     NO. OF BODIES     REGION NO.     MEDIA NO.
     1             1              36                 1               1              1
     2             2              41                 2               1              2
     3             3              50                 1               1              2
     4             4              55                 3               1           1000
     5             5              68                 2               1              0


   I    KR1(I)    KR2(I)
   1       1         1
   2       2         2
   3       3         3
   4       4         4
   5       5         5


        MORSE REGION IN INPUT ZONE(I) ARRAY   MRIZ(I),I=1, 5)

           1   1   1   1   1


        MORSE MEDIA IN INPUT ZONE(I) ARRAY  MMIZ(I),I=1, 5)

           1   2   21000   0
```

mixture numbers by zone

```
 OPTION 0 WAS USED IN CALCULATING VOLUMES, FOR  1 REGIONS
0-SET VOLUMES = 1, 1-CONCENTRIC SPHERES, 2-SLABS, 3-INPUTVOLUMES.


        VOLUMES (CM**) USED IN COLLISIONS DENSITY AND TRACK LENGTH ESTIMATORS.
   REG       1
VOLUME  1.000D+00
```

Fig. 5 (continued)

COMP/MAT	C	SI	NI	FE	H	MN	CR	ZR	SN
1	0.0000E+00	0.0000E+00	5.2266E-02	3.6749E-01	0.0000E+00	1.0453E-02	9.4079E-02	3.1911E-01	5.2154E-03
2	2.2750E-01	9.8000E-02	7.7000E-02	6.5975E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	7.7913E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.3087E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

partial densities by material

COMP/MAT	U	O
1	9.9755E-01	1.2083E-01
2	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00

GRP/MAT	C	SI	NI	FE	H	MN	CR	ZR	SN	
	NEUTRON REMOVAL CROSS-SECTION									
	4.0630E-02	2.8980E-02	1.9400E-02	2.1360E-02	6.0200E-01	2.0500E-02	2.1090E-02	1.5590E-02	1.3780E-02	
	MATERIAL HYDROGEN DENSITY									
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
	GAMMA ATTENUATION COEFFICIENT									
1	2.0493E-02	2.5143E-02	3.1563E-02	2.9911E-02	3.4777E-02	2.8667E-02	2.8551E-02	3.4782E-02	3.8123E-02	9.00
2	2.2570E-02	2.6453E-02	3.1724E-02	3.0114E-02	3.9880E-02	2.9025E-02	2.8945E-02	3.4052E-02	3.6731E-02	7.25
3	2.5228E-02	2.8288E-02	3.2325E-02	3.0755E-02	4.6210E-02	2.9803E-02	2.9801E-02	3.3761E-02	3.5723E-02	5.75
4	2.8631E-02	3.0925E-02	3.3621E-02	3.2209E-02	5.3937E-02	3.1230E-02	3.1400E-02	3.4059E-02	3.5487E-02	4.50
5	3.2756E-02	3.4354E-02	3.5721E-02	3.4486E-02	6.3007E-02	3.3498E-02	3.3794E-02	3.5250E-02	3.6092E-02	3.50
6	3.7340E-02	3.8357E-02	3.8580E-02	3.7455E-02	7.2847E-02	3.6464E-02	3.6791E-02	3.7231E-02	3.7588E-02	2.75
7	4.1657E-02	4.2282E-02	4.1678E-02	4.0596E-02	8.1924E-02	3.9555E-02	3.9974E-02	3.9673E-02	3.9618E-02	2.25
8	4.6568E-02	4.6827E-02	4.5451E-02	4.4366E-02	9.2133E-02	4.3229E-02	4.3760E-02	4.2769E-02	4.2237E-02	1.83
9	5.1848E-02	5.1867E-02	4.9943E-02	4.8771E-02	1.0288E-01	4.7469E-02	4.8130E-02	4.6629E-02	4.5575E-02	1.49
10	5.8846E-02	5.8803E-02	5.6533E-02	5.5241E-02	1.1683E-01	5.3785E-02	5.4529E-02	5.2918E-02	5.2352E-02	1.16
11	6.6867E-02	6.6772E-02	6.4223E-02	6.2762E-02	1.3282E-01	6.1115E-02	6.1911E-02	6.0447E-02	6.0654E-02	0.90
12	7.5125E-02	7.5038E-02	7.2455E-02	7.0800E-02	1.4919E-01	6.8852E-02	6.9682E-02	6.9061E-02	7.0897E-02	0.70
13	8.7040E-02	8.7030E-02	8.4920E-02	8.2860E-02	1.7290E-01	8.0300E-02	8.1210E-02	8.3650E-02	8.9690E-02	0.50
14	1.0031E-01	1.0059E-01	1.0130E-01	9.8381E-02	1.9921E-01	9.4648E-02	9.5407E-02	1.0777E-01	1.2779E-01	0.35
15	1.1332E-01	1.1461E-01	1.2483E-01	1.1958E-01	2.2497E-01	1.1332E-01	1.1339E-01	1.5370E-01	2.0752E-01	0.25
16	1.3370E-01	1.3990E-01	1.9940E-01	1.8250E-01	2.6510E-01	1.6670E-01	1.6250E-01	3.4530E-01	5.6650E-01	0.15
17	1.6030E-01	2.2231E-01	7.8250E-01	6.4343E-01	3.1284E-01	5.5827E-01	5.1177E-01	1.9138E+00	3.4391E+00	0.07
18	2.3470E-01	1.3230E+00	9.9060E+00	7.8630E+00	3.5710E-01	6.8250E+00	6.1530E+00	2.4210E+01	4.0310E+01	0.03

GRP/MAT	U	O
	NEUTRON REMOVAL CROSS-SECTION	
	9.1100E-03	3.7280E-02
	MATERIAL HYDROGEN DENSITY	
	0.0000E+00	0.0000E+00
	GAMMA ATTENUATION COEFFICIENT	
1	5.0464E-02	2.1694E-02 9.0000E+00
2	4.7744E-02	2.3583E-02 7.2500E+00
3	4.5482E-02	2.6036E-02 5.7500E+00
4	4.4196E-02	2.9246E-02 4.5000E+00
5	4.3928E-02	3.3201E-02 3.5000E+00
6	4.4897E-02	3.7647E-02 2.7500E+00
7	4.6767E-02	4.1872E-02 2.2500E+00
8	4.9811E-02	4.6699E-02 1.8300E+00
9	5.4519E-02	5.1928E-02 1.4950E+00
10	6.6850E-02	5.8921E-02 1.1650E+00
11	8.4972E-02	6.6937E-02 9.0000E-01
12	1.1493E-01	7.5200E-02 7.0000E-01
13	1.8540E-01	8.7130E-02 5.0000E-01
14	3.5766E-01	1.0046E-01 3.5000E-01
15	7.3894E-01	1.1356E-01 2.5000E-01
16	2.4760E+00	1.3440E-01 1.5000E-01
17	3.6193E+00	1.6610E-01 7.5000E-02
18	3.9750E+01	3.3980E-01 3.0000E-02

attenuation coefficients by group for each material

Fig. 5 (continued)

***** CONVERSION FACTORS AND BUILD FACTORS

***** BUILDUP FACTORS OF GEOMETRIC-PROGRESSION METHOD ARE USED
***** IRON MEDIUM, AIR RESPONSE

GP method build-up factors

GRP	ENERGY	CONV.	B	C	A	XK	D	
1	0.0000E+00	8.7716E-06	1.3233	0.9584	0.0371	14.046	-0.05257	9.00
2	0.0000E+00	7.4785E-06	1.3848	0.9750	0.0270	13.554	-0.03994	7.25
3	0.0000E+00	6.3748E-06	1.4514	0.9865	0.0205	13.310	-0.03325	5.75
4	0.0000E+00	5.4136E-06	1.5154	1.0178	0.0083	13.052	-0.02217	4.50
5	0.0000E+00	4.6221E-06	1.5892	1.0398	0.0005	12.664	-0.01618	3.50
6	2.6400E-05	3.9596E-06	1.6477	1.0707	-0.0081	10.332	-0.01206	2.75
7	5.0200E-03	3.4686E-06	1.6904	1.1033	-0.0164	7.884	-0.00800	2.25
8	1.1300E-04	3.0192E-06	1.7234	1.1492	-0.0282	10.125	0.00117	1.83
9	0.0000E+00	2.6276E-06	1.7507	1.1974	-0.0400	15.850	0.01084	1.49
10	1.8000E-02	2.2051E-06	1.8079	1.2174	-0.0394	10.925	-0.00278	1.16
11	7.6000E-03	1.8326E-06	1.8684	1.2335	-0.0383	6.579	-0.01344	0.90
12	6.7000E-01	1.5228E-06	1.9158	1.2517	-0.0413	7.242	-0.01044	0.70
13	2.9900E-01	1.1725E-06	1.9740	1.2300	-0.0360	9.300	-0.01100	0.50
14	0.0000E+00	8.7594E-07	1.9901	1.1488	-0.0197	11.306	-0.01563	0.35
15	0.0000E+00	6.3061E-07	1.9291	1.0200	0.0076	12.502	-0.02408	0.25
16	0.0000E+00	3.8338E-07	1.6600	0.7430	0.0790	14.120	-0.04760	0.15
17	0.0000E+00	2.6693E-07	1.2362	0.4529	0.1867	14.446	-0.10061	0.07
18	0.0000E+00	9.3476E-07	1.0280	0.3740	0.1900	29.340	-0.31700	0.03

GRP	EG	0.5MFP	1.0MFP	2.0MFP	4.0MFP	8.0MFP	10.0MFP	20.0MFP	40.0MFP	60.0MFP
1	9.00	1.164E+00	1.323E+00	1.641E+00	2.309E+00	3.908E+00	4.898E+00	1.277E+01	4.462E+01	1.247E+02
2	7.25	1.195E+00	1.385E+00	1.767E+00	2.566E+00	4.420E+00	5.521E+00	1.338E+01	3.990E+01	9.645E+01
3	5.75	1.227E+00	1.451E+00	1.903E+00	2.845E+00	4.987E+00	6.227E+00	1.449E+01	3.884E+01	8.288E+01
4	4.50	1.257E+00	1.515E+00	2.043E+00	3.154E+00	5.659E+00	7.077E+00	1.595E+01	3.957E+01	7.539E+01
5	3.50	1.292E+00	1.589E+00	2.202E+00	3.503E+00	6.433E+00	8.074E+00	1.797E+01	4.265E+01	7.624E+01
6	2.75	1.318E+00	1.648E+00	2.337E+00	3.827E+00	7.232E+00	9.140E+00	2.020E+01	4.713E+01	8.340E+01
7	2.25	1.336E+00	1.690E+00	2.443E+00	4.103E+00	7.969E+00	1.015E+01	2.255E+01	5.379E+01	9.284E+01
8	1.83	1.347E+00	1.723E+00	2.539E+00	4.383E+00	8.803E+00	1.134E+01	2.669E+01	6.488E+01	1.068E+02
9	1.49	1.356E+00	1.751E+00	2.625E+00	4.656E+00	9.650E+00	1.254E+01	2.981E+01	7.403E+01	1.263E+02
10	1.16	1.381E+00	1.808E+00	2.765E+00	5.049E+00	1.099E+01	1.460E+01	3.821E+01	9.826E+01	1.633E+02
11	0.90	1.409E+00	1.868E+00	2.911E+00	5.458E+00	1.236E+01	1.667E+01	4.431E+01	1.269E+02	2.344E+02
12	0.70	1.429E+00	1.916E+00	3.030E+00	5.788E+00	1.345E+01	1.836E+01	5.191E+01	1.587E+02	3.079E+02
13	0.50	1.459E+00	1.974E+00	3.142E+00	6.006E+00	1.391E+01	1.901E+01	5.554E+01	1.771E+02	3.712E+02
14	0.35	1.476E+00	1.990E+00	3.112E+00	5.715E+00	1.240E+01	1.652E+01	4.484E+01	1.305E+02	2.672E+02
15	0.25	1.463E+00	1.929E+00	2.882E+00	4.889E+00	9.414E+00	1.197E+01	2.762E+01	6.633E+01	1.227E+02
16	0.15	1.359E+00	1.660E+00	2.178E+00	3.035E+00	4.454E+00	5.108E+00	8.262E+00	1.325E+01	1.815E+01
17	0.07	1.145E+00	1.236E+00	1.358E+00	1.503E+00	1.677E+00	1.745E+00	2.026E+00	2.306E+00	2.534E+00
18	0.03	1.018E+00	1.028E+00	1.040E+00	1.051E+00	1.062E+00	1.065E+00	1.079E+00	1.090E+00	1.092E+00

ALBERT-WELTON COEFFICIENTS

7.7200E-09 3.4900E-01 4.2200E-01 6.9800E-01

Fig. 5 (continued)

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EG-

  9.0000E+00  7.2500E+00  5.7500E+00  4.5000E+00  3.5000E+00  2.7500E+00  2.2500E+00  1.8300E+00  1.4950E+00
  1.1650E+00  9.0000E-01  7.0000E-01  5.0000E-01  3.5000E-01  2.5000E-01  1.5000E-01  7.5000E-02  3.0000E-02

FE ABS G-

  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

EN-

  1.0000E+01  8.0000E+00  6.0000E+00  5.0000E+00  4.0000E+00  3.0000E+00  2.0000E+00  1.0000E+00  6.7000E-01
  3.3000E-01

FE ABS N-

  2.2500E-15  9.2700E-16  5.4700E-16  4.6800E-16  3.8000E-16  3.0700E-16  2.1600E-16  1.0400E-16  8.3500E-17
  4.6700E-17

WIDTH T-
                    0.01 -10.00 12.0-0.10

WIDTH G-
                  10.00 - 8.00 8.00 - 6.50 6.50 - 5.00 5.00 - 4.00 4.00 - 3.00 3.00 - 2.50
                   2.50 - 2.00 2.00 - 1.66 1.66 - 1.33 1.33 - 1.00 1.00 - 0.80 0.80 - 0.60
                   0.60 - 0.40 0.40 - 0.30 0.30 - 0.20 0.20 - 0.10 0.10 - 0.05 0.05 - 0.01

WIDTH N-
                    12.0-9.00   9.00-7.00   7.00-5.50   5.50-4.50   4.50-3.50   3.50-2.50
                    2.50-1.50   1.50-0.835  0.835-0.50  0.50-0.10

UNIT G-


UNIT N-
                      RAD       WATTS PER    PER HOUR     GRAM      RAD PER  HR
```

Fig. 5 (continued)

COORDINATE TYPE 0 SOURCE INTENSITY OPTION 2

R COORDINATE

	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY
1	1.3333E+00	2.1333E+01	4.0000E+00	6.4000E+01	6.6667E+00	1.0667E+02	9.3333E+00	1.4933E+02
5	1.2000E+01	1.9200E+02	1.4667E+01	2.3467E+02	1.7333E+01	2.7733E+02	2.0000E+01	3.2000E+02
9	2.2667E+01	3.6267E+02	2.5333E+01	4.0533E+02	2.8000E+01	4.4800E+02	3.0667E+01	4.9066E+02
13	3.3333E+01	5.3333E+02	3.6000E+01	5.7600E+02	3.8667E+01	6.1866E+02		

PHI COORDINATE

	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY
1	3.1416E-01	1.2566E+00	9.4248E-01	1.2566E+00	1.5708E+00	1.2566E+00	2.1991E+00	1.2566E+00
5	2.8274E+00	1.2566E+00	3.4557E+00	1.2566E+00	4.0841E+00	1.2566E+00	4.7124E+00	1.2566E+00
9	5.3407E+00	1.2566E+00	5.9690E+00	1.2566E+00				

Z COORDINATE

	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY	COORDINATE	INTENSITY
1	5.3000E+01	5.6125E+10	8.3000E+01	5.6125E+10	1.1300E+02	5.6125E+10	1.4300E+02	5.6125E+10
5	1.7300E+02	5.6125E+10	2.0300E+02	5.6125E+10	2.3300E+02	5.6125E+10	2.6300E+02	5.6125E+10
9	2.9300E+02	5.6125E+10	3.2300E+02	5.6125E+10	3.5300E+02	5.6125E+10	3.8300E+02	5.6125E+10
13	4.1300E+02	5.6125E+10	4.4300E+02	5.6125E+10	4.7300E+02	5.6125E+10		

source intensity by mesh intervals

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

RECEIVER NUMBER 1 COORDINATES - R 7.8000E+01 PHI 0.0000E+00 Z 2.6500E+02

GEOMETRY PRINT FOR PSEUDO SOURCE POINT AT THE COORDINATE ORIGIN

ZONE	DISTANCE	X	Y	Z
	SOURCE PNT	0.0000E+00	0.0000E+00	0.0000E+00
2	3.9612E+01	1.1185E+01	0.0000E+00	3.8000E+01
1	1.0205E+02	4.0000E+01	0.0000E+00	1.3590E+02
2	1.3458E+02	7.8000E+01	0.0000E+00	2.6500E+02

Fig. 5 (continued)

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

RECEIVER NUMBER 1 COORDINATES - R 7.8000E+01 PHI 0.0000E+00 Z 2.6500E+02

detector coordinates

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	2.1102	0.01 -10.00	7.2838E+02	1.3931E+01	2.4825E-03	3.4583E-02	0.0000E+00	0.0000E+00
W/BU	2.2002							
1	9.0000	10.00 - 8.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	9.5472E+00	1.1054E+01	3.7804E-05	4.1789E-04	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	6.8125E+02	1.3369E+01	2.3630E-03	3.1592E-02	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	4.7368E+00	1.6729E+01	1.4301E-05	2.3925E-04	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	2.5036E+01	3.0056E+01	5.5207E-05	1.6593E-03	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	9.9446E-01	4.1316E+01	1.8224E-06	7.5296E-05	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	6.7553E+00	5.7775E+01	1.0287E-05	5.9432E-04	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	6.0533E-02	7.9634E+01	7.0972E-08	5.6518E-06	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

total dose rate

dose rate by group

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

RECEIVER NUMBER 2 COORDINATES - R 1.7800E+02 PHI 0.0000E+00 Z 2.6500E+02

GEOMETRY PRINT FOR PSEUDO SOURCE POINT AT THE COORDINATE ORIGIN

ZONE	DISTANCE	X	Y	Z
	SOURCE PNT	0.0000E+00	0.0000E+00	0.0000E+00
2	4.5777E+01	2.5525E+01	0.0000E+00	3.8000E+01
1	2.5961E+01	4.0000E+01	0.0000E+00	5.9551E+01
2	6.8151E+01	7.8000E+01	0.0000E+00	1.1612E+02
1000	1.7934E+02	1.7800E+02	0.0000E+00	2.6500E+02

Fig. 5 (continued)

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

RECEIVER NUMBER 2 COORDINATES - R 1.7800E+02 PHI 0.0000E+00 Z 2.6500E+02

GRP NO	MEAN ENERGY MEV	ENERGY GROUP LIMITS MEV	DIRECT BEAM FLUX	MEAN BUILDUP FACTORS	DOSE RATE DIRECT BEAM	DOSE RATE WITH BUILDUP	HEATING RATES IN IRON DIRECT BEAM	HEATING RATES IN IRON WITH BUILDUP
TOTAL	2.1002	0.01 -10.00	3.2941E+02	1.3838E+01	1.1211E-03	1.5513E-02	0.0000E+00	0.0000E+00
W/BU	2.1962							
1	9.0000	10.00 - 8.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	7.2500	8.00 - 6.50	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	5.7500	6.50 - 5.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	4.5000	5.00 - 4.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	3.5000	4.00 - 3.00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	2.7500	3.00 - 2.50	4.2728E+00	1.0959E+01	1.6919E-05	1.8541E-04	0.0000E+00	0.0000E+00
7	2.2500	2.50 - 2.00	3.0714E+02	1.3245E+01	1.0653E-03	1.4111E-02	0.0000E+00	0.0000E+00
8	1.8300	2.00 - 1.66	2.1550E+00	1.6550E+01	6.5062E-06	1.0768E-04	0.0000E+00	0.0000E+00
9	1.4950	1.66 - 1.33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	1.1650	1.33 - 1.00	1.1822E+01	2.9573E+01	2.6069E-05	7.7094E-04	0.0000E+00	0.0000E+00
11	0.9000	1.00 - 0.80	4.8714E-01	4.0482E+01	8.9272E-07	3.6139E-05	0.0000E+00	0.0000E+00
12	0.7000	0.80 - 0.60	3.4989E+00	5.6179E+01	5.3279E-06	2.9932E-04	0.0000E+00	0.0000E+00
13	0.5000	0.60 - 0.40	3.5367E-02	7.6564E+01	4.1467E-08	3.1749E-06	0.0000E+00	0.0000E+00
14	0.3500	0.40 - 0.30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	0.2500	0.30 - 0.20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1500	0.20 - 0.10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0750	0.10 - 0.05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0300	0.05 - 0.01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

SUBROUTINE EXIT HAS BEEN CALLED. PROBABLY FROM INPUT.

Fig. 5 (continued)

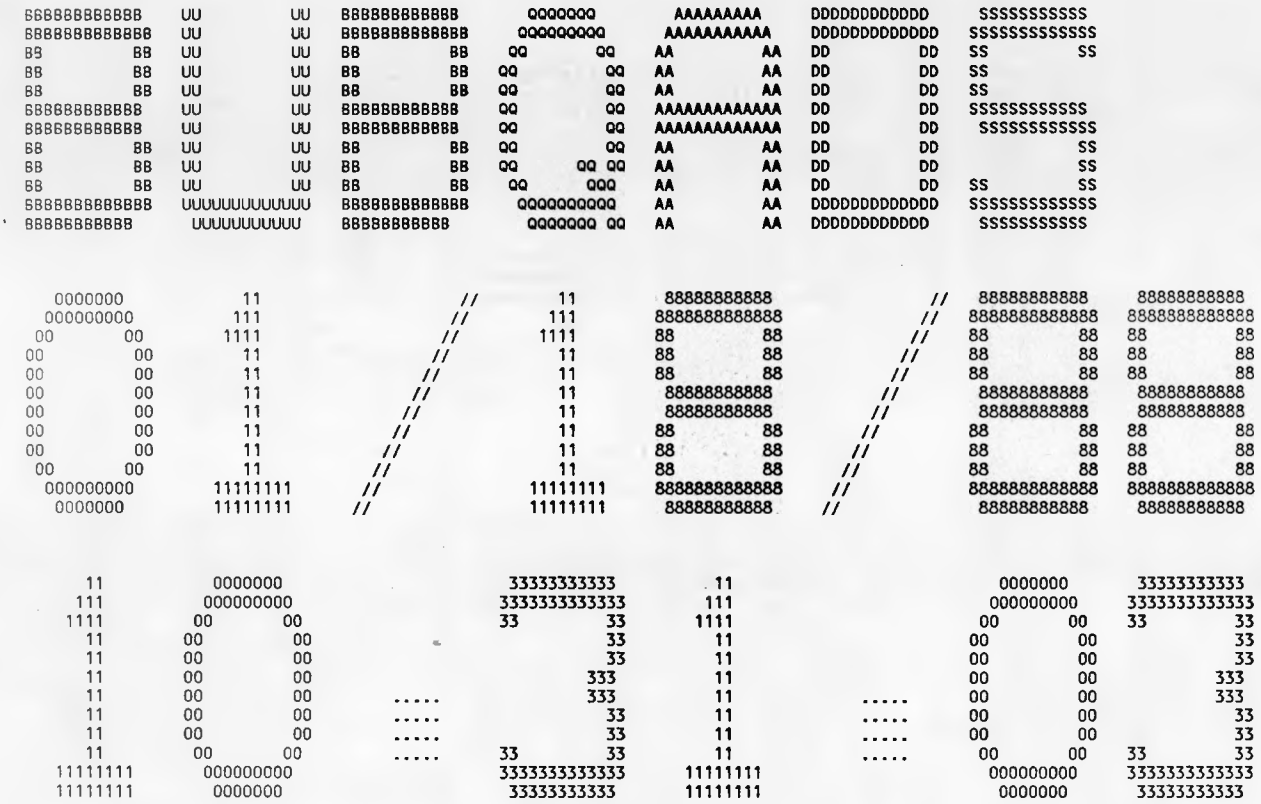


Fig. 5 (continued)

```
PROGRAM VERIFICATION INFORMATION

VERSION:  SCALE 4.0

PROGRAM:  QADS

CREATION DATE:  88.018

LIBRARY:  SYS88018.T101328.RA000.BUBQADS.LIBRARY

JOBNAME:  BUBQADS

DATE OF EXECUTION:  01/18/88

TIME OF EXECUTION:  10.31.04
```

Fig. 5 (continued)

```
QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK

**** PROBLEM PARAMETERS ****

LIB READINGP-SRC LIBRARY
MXX            3 MIXTURES
MSC            7 COMPOSITION SPECIFICATIONS
IZM            1 MATERIAL ZONES
GE  INFHOMMEDIUM GEOMETRY
MORE           0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
MSLN           0 FUEL SOLUTIONS

**** PROBLEM COMPOSITION DESCRIPTION ****

SC  ARBM-CASTFE  STANDARD COMPOSITION
MX             2 MIXTURE NO.
VF        1.0000 VOLUME FRACTION
ROTH      7.0000 DENSITY
NEL            4 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            1 0/1 NO RESONANCE MTL./RESONANCE MTL.

           6012   3.25
          14000   1.40
          28000   1.10
          26000  94.25
END

SC  ARBM-POLY    STANDARD COMPOSITION
MX             3 MIXTURE NO.
VF        1.0000 VOLUME FRACTION
ROTH      0.9100 DENSITY
NEL            2 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            1 0/1 MIXTURE/COMPOUND
IRS            0 0/1 NO RESONANCE MTL./RESONANCE MTL.

           6012   2.00
           1001   4.00
END
SC  ARBM-1.4541  STANDARD COMPOSITION
MX             1 MIXTURE NO.
VF        0.1860 VOLUME FRACTION
ROTH      2.8100 DENSITY
NEL            4 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            1 0/1 NO RESONANCE MTL./RESONANCE MTL.

          25055   2.00
          24000  18.00
          28000  10.00
          26000  70.00
END

SC  ARBM-ZIRC4   STANDARD COMPOSITION
MX             1 MIXTURE NO.
VF        0.1160 VOLUME FRACTION
ROTH      2.8100 DENSITY
NEL            3 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            1 0/1 NO RESONANCE MTL./RESONANCE MTL.

          40000  97.90
          50000   1.60
          26000   0.50
END
```

SCALE
material processor input

Fig. 5 (continued)

```
SC  ARBM-U235    STANDARD COMPOSITION
MX             1 MIXTURE NO.
VF        0.0110 VOLUME FRACTION
ROTH      2.8100 DENSITY
NEL            1 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            1 0/1 NO RESONANCE MTL./RESONANCE MTL.

         92235 100.00
END

SC  ARBM-U238    STANDARD COMPOSITION
MX             1 MIXTURE NO.

VF        0.3440 VOLUME FRACTION
ROTH      2.8100 DENSITY
NEL            1 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            1 0/1 NO RESONANCE MTL./RESONANCE MTL.

         92238 100.00
END

SC  ARBM-OXYGEN  STANDARD COMPOSITION
MX             1 MIXTURE NO.
VF        0.0430 VOLUME FRACTION
ROTH      2.8100 DENSITY
NEL            1 NO. ELEMENTS
IVIS           0 0/1 NO VARIABLE ISOTOPE/VARIABLE ISOTOPE
ICP            0 0/1 MIXTURE/COMPOUND
IRS            0 0/1 NO RESONANCE MTL./RESONANCE MTL.

          8016 100.00
END


**** INFINITE HOMOGENEOUS MEDIUM ****
MFUEL          1 MIXTURE NO. OF THE INFINITE HOMOGENEOUS MEDIUM


**** SOURCE PARAMETERS ****

QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK


SRC    CYLINDRICAL   SOURCE COORDINATE SYSTEM
ASO     5.07800E+16  SOURCE STRENGTH
SHAPE      WEIGHTS   SOURCE SHAPE

GROUP STRUCTURE READ FROM CARDS
SOURCE SPECTRUM READ FROM CARDS


OPTIONAL PARAMETERS


MSH VALUES READ FROM CARDS


OPTIONAL PARAMETERS


    43 WAT VALUES READ FROM CARDS


**** DOSE DATA ****

BFMAT       IRON  BUILDUP FACTOR MATERIAL
BFRSP        EXP  BUILDUP FACTOR RESPONSE


NFACTR         0  DOSE FACTOR ID (READ FROM CARDS IF      < 9000)
NDETEC         2  NUMBER OF DETECTORS

DETECTOR NO.  1
RRC= 7.8000E+01 ZRC= 2.6500E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
DETECTOR NO.  2
RRC= 1.7800E+02 ZRC= 2.6500E+02 PHIRC= 0.0000E+00 NRCOP= CYLINDRICAL
```

source description

detector and dose data

Fig. 5 (continued)

```
MODULE QADS     WILL BE CALLED  TIME OF DAY 10.31.01  DATE 88.018

  QADS SAMPLE PROBLEM #1 - OECD BENCHMARK SHIPPING CASK
  READINGP-SRC INFHOMMEDIUM
  ARBM-CASTFE 7.0 4 0 0 1 6012 3.25 14000 1.4 28000 1.1 26000 94.25 2 END
  ARBM-POLY .91 2 0 1 0 6012 2 1001 4 3 END
  ARBM-1.4541 2.81 4 0 0 1 25055 2. 24000 18. 28000 10. 26000 70. 1 .186 END
  ARBM-ZIRC4 2.81 3 0 0 1 40000 97.9 50000 1.6 26000 0.5 1 .116 END
  ARBM-U235 2.81 1 0 0 1 92235 100. 1 .011 END
  ARBM-U238 2.81 1 0 0 1 92238 100. 1 .344 END
  ARBM-OXYGEN 2.81 1 0 0 0 8016 100. 1 .043 END
  END COMP
  CYLINDRICAL 5.078E16 WEIGHTS END
  18 10+6 8+6 6.5+6 5+6 4+6 3+6 2.5+6 2+6 1.66+6 1.33+6 1+6 8+5
  6+5 4+5 3+5 2+5 1+5 5+4 1+4
  5Z 2.64-5 5.02-3 1.13-4 0 1.80-2 7.60-3 6.70-1 2.99-1 5Z
  MSH=15 15 10 WAT=43*1
  END SOURCE
  CYLINDRICAL SHELL CASK
  RCC 1 0 0 38 0 0 450 40
  RCC 2 0 0 0 0 0 488 78
  RCC 3 0 0 488 0 0 42 78
  RCC 4 0 0 -10000 0 0 20000 20000
  RCC 5 0 0 -10001 0 0 20002 20002
  END BODY
  ZN1 2 1
  ZN2 2 2 -1
  ZN3 2 3
  ZN4 2 4 -3 -2
  ZN5 2 5 -4
  END ZONE
  1 2 2 1000 0
  END GEOM
  IRON EXP
  NDETEC=2
  78. 265. 0. 178. 265. 0.
  END DOSE
  END

SECONDARY MODULE QADCGGP  HAS BEEN CALLED

MODULE QADCGGP  IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED    15.80 (SECONDS). I/O'S USED     108.

MODULE QADS     IS FINISHED.  COMPLETION CODE - SYSTEM 000 USER  0000. CPU TIME USED    16.33 (SECONDS). I/O'S USED     313.
```

QADS sample problem input list

Fig. 5 (continued)

5. REFERENCES

1. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, Vols. 1-3, NUREG/CR-0200, U.S. Nuclear Regulatory Commission, December 1984. Available from Radiation Shielding Information Center at Oak Ridge National Laboratory as CCC-466/SCALE-3.1.
2. *QAD-CGGP: A Combinatorial Geometry Version of QAD-P5A, A Point Kernel Code System for Neutron and Gamma-Ray Shielding Calculations Using the GP Buildup Factor,* Available from Radiation Shielding Information Center at Oak Ridge National Laboratory as CCC-493/QAD-CGGP.
3. Y. Harima, Y. Sakamoto, S. Tanalca, and M. Kawai,"Validity of the Geometrical Progression Formula in Approximating Gamma-Ray Buildup Factors," *Nucl. Sci. Eng.* **94**, 24-35, September 1986.
4. C. V. Parks et al., *Assessment of Shielding Analysis Methods, Codes, and Data for Spent Fuel Transport/Storage Applications*, ORNL/CSD/TM-246, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1988.

APPENDIX A

COMBINATORIAL GEOMETRY THEORY AND TRACKING LOGIC

The combinatorial geometry package in the QADS system was obtained from earlier versions of the MORSE Monte Carlo code. Combinatorial geometry allows the description of physical structures by the combination of certain basic geometric shapes (bodies) such as rectangular parallelepipeds, right circular cylinders, etc. These basic shapes are combined using three logical operators: the AND operator using the "+" notation, the NOT operator using the "−" notation, and the OR operator using the "OR" notation. This section discusses simple geometric bodies, the operators to combine bodies into zones, and two types of zones − the input zone and its subset, the code zone.

A.1 BODY DESCRIPTIONS

Combinatorial geometry (CG or COMJOM) describes general three-dimensional material configurations by considering unions, differences, and intersections of simple bodies such as spheres, boxes, cylinders, etc. Material zones are described by simple bodies and their relationships (i.e., space can to be subdivided into unique zones of arbitrary shape). Each zone is the result of combining one or more of the following geometric bodies:

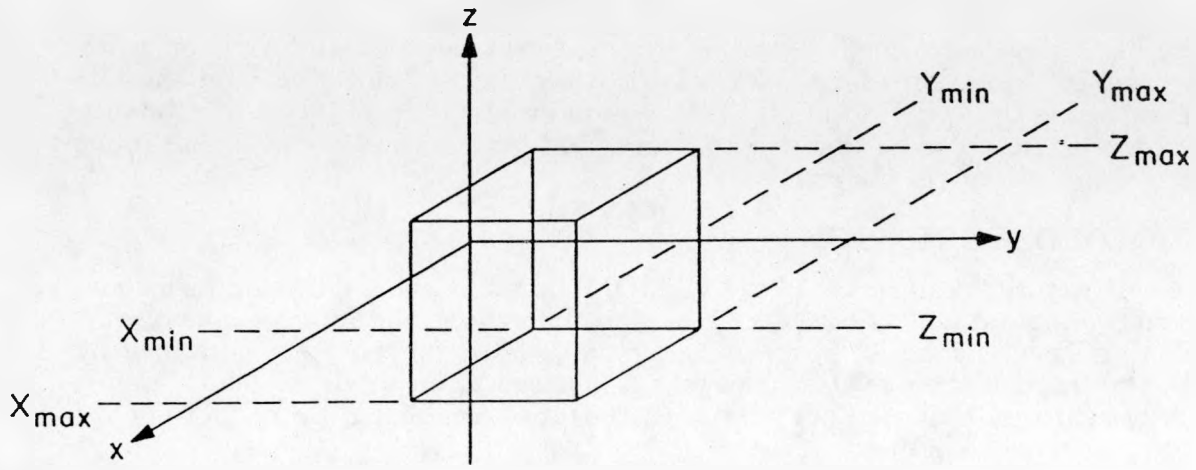
1. rectangular parallelepiped (RPP);
2. sphere (SPH);
3. right circular cylinder (RCC);
4. right elliptical cylinder (REC);
5. truncated right angle cone (TRC);
6. ellipsoid of revolution (ELL);
7. right angle wedge (WED or RAW);
8. box, an RPP arbitrarily rotated in space (BOX); and
9. arbitrary convex polyhedron of 4, 5, or 6 sides (ARB).

Body types 2 through 9 may be arbitrarily oriented with respect to the x, y, and z coordinate axes. Body 1, the RPP, must have all sides parallel to coordinate planes. Alternate input descriptions for the BOX and the WED are described later in this section.

The information required to specify each type of body is as follows:

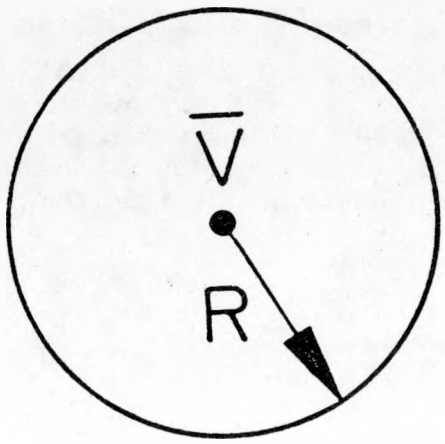
1. Rectangular parallelepiped (RPP) - Specify the minimum and maximum values of the x, y, and z coordinates that bound the parallelepiped.

ORNL Dwg. 74-6762



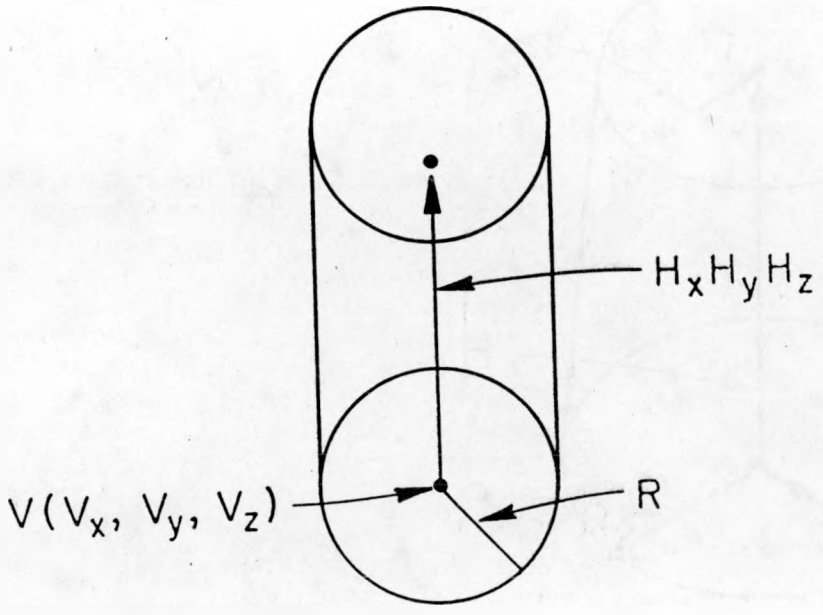
2. Sphere (SPH) - Specify the vertex, V, at the center and the scalar, R, denoting the radius.

ORNL Dwg. 74-6763



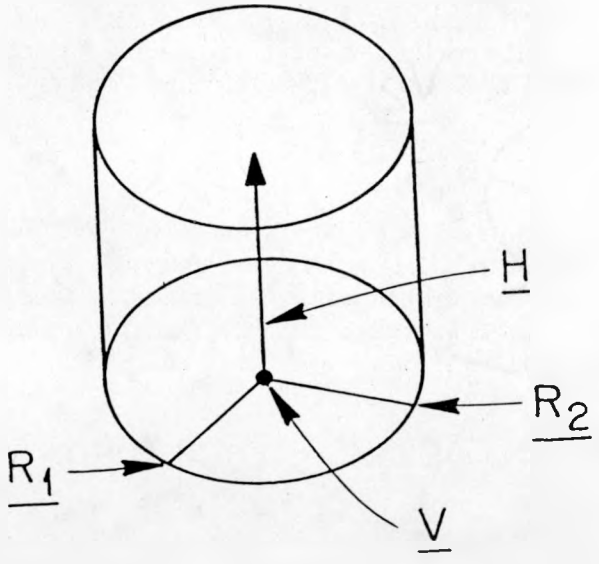
3. Right circular cylinder (RCC) - Specify the vertex, V, at the center of one base; a height vector, H, expressed in terms of its x, y, and z components; and a scalar, R, denoting the radius.

ORNL Dwg. 74-6764



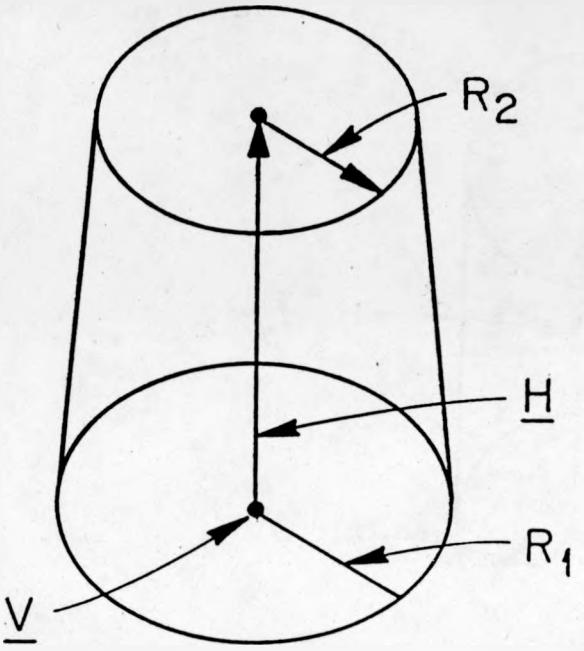
4. Right elliptical cylinder (REC) - Specify coordinates of the center of the base ellipse, a height vector, and two vectors in the plane of the base defining the major and minor axes.

ORNL Dwg. 74-6765



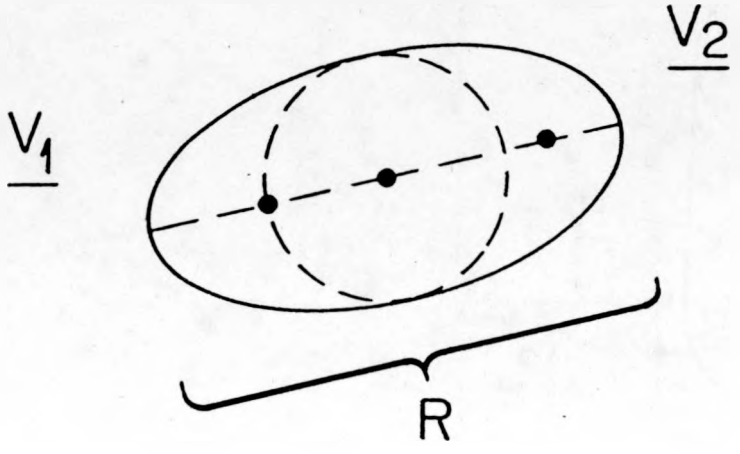
5. Truncated right angle cone (TRC) - Specify a vertex, V, at the center of the lower base; the height vector, H, expressed in terms of its x, y, and z components; and two scalars, R_1 and R_2, denoting the radii of the lower and upper bases.

ORNL Dwg. 74-6766



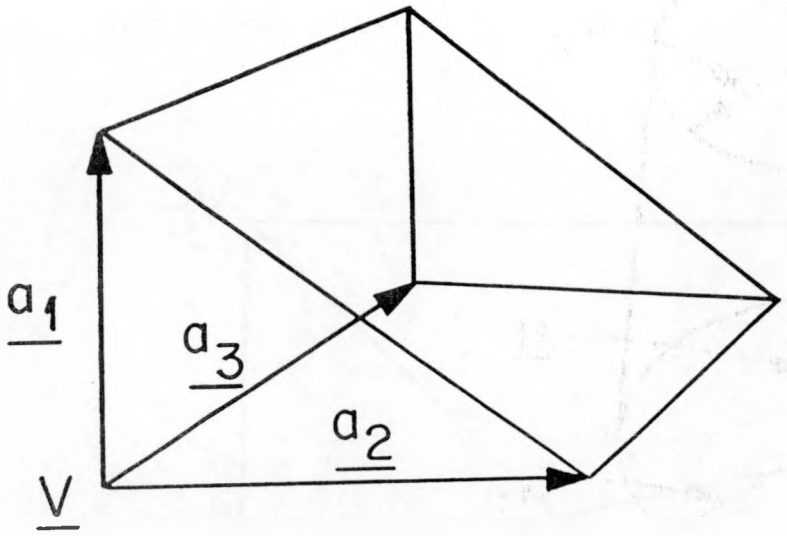
6. Ellipsoid (ELL) - Specify two vertices, V_1 and V_2 , denoting the coordinates of the foci and a scalar, R, denoting the length of the major axis.

ORNL Dwg. 74-6767



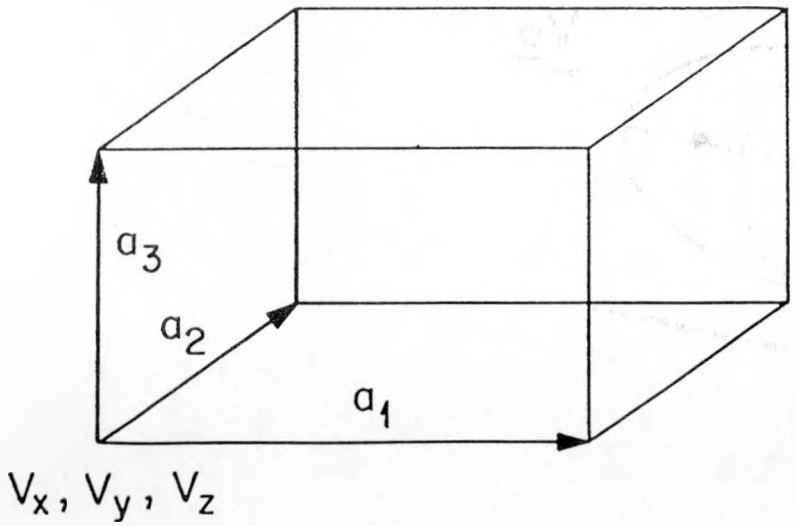
7. Right angle wedge (WED or RAW) - Specify the vertex, V, at one of the corners by giving its x, y, and z and coordinates. Specify a set of three mutually perpendicular vectors, a_1, with a_1 and a_2 describing the two legs of the right triangle of the wedge. That is, specify the x, y, and z components of the height, width, and length vectors.

ORNL Dwg. 74-6768



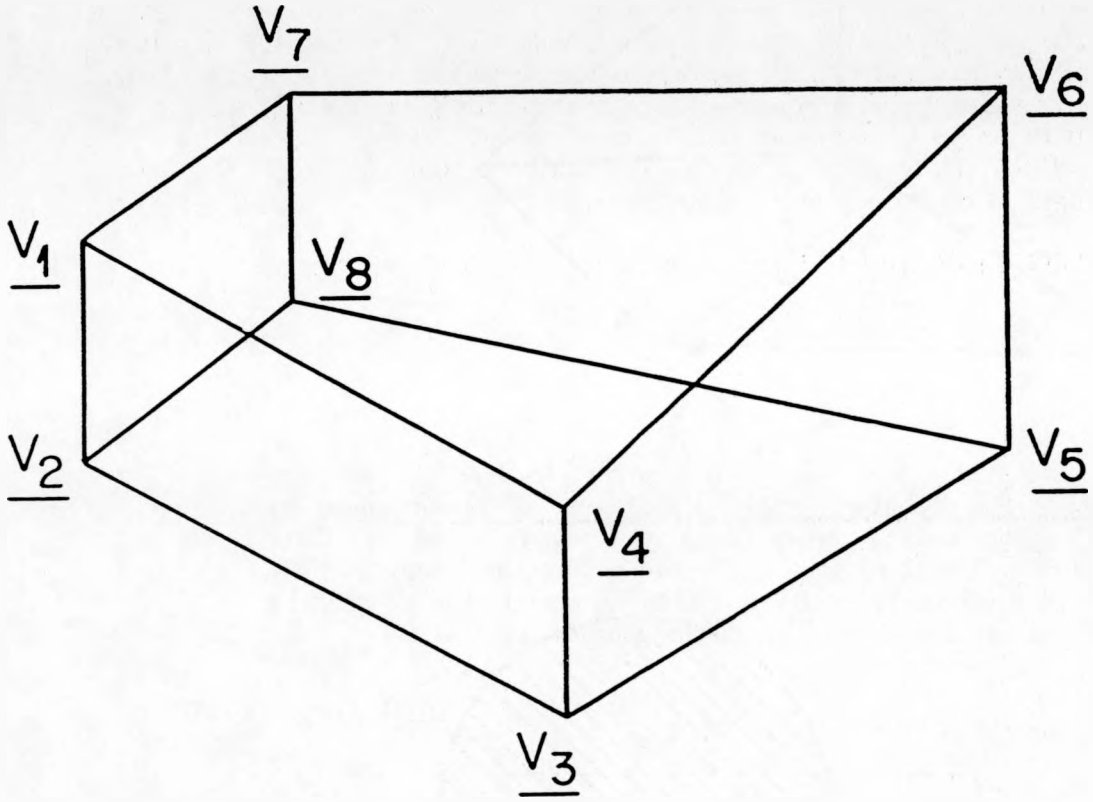
8. Box (BOX) - Specify the vertex, V, at one of the corners by giving its x, y, and z coordinates. Specify a set of three mutually perpendicular vectors, a_1, representing the height, width, and length of the box, respectively. That is, specify the x, y, and z components of the height, width, and length vectors.

ORNL Dwg. 74-6769



9. Arbitrary polyhedron (ARB) - Assign an index (1 to 8) to each vertex. For each vertex, give the x, y, and z coordinates. Each of the six faces is then described by a four-digit number giving the indices of the four vertex points in that face. For each face, these indices must be entered in either clockwise or counterclockwise order.

ORNL Dwg. 74-6770



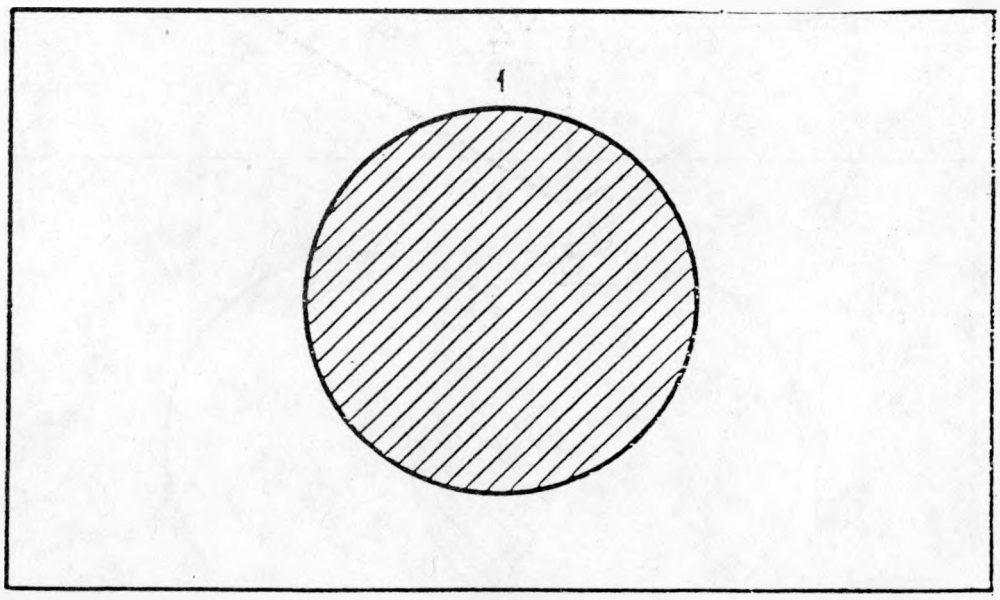
A.2 COMBINATORIAL OPERATORS

The basic technique for the description of geometry consists of defining the location and shape of various zones in terms of the intersections and unions of geometric bodies. A special operator notation involving the symbols (+), (−), and (OR)is used to describe the intersections and unions. These symbols are used by the program to construct information relating material descriptions to the body definitions.

If a body appears in a zone description with a (+) operator, the zone being described is wholly contained in the body. If a body appears in a zone description with a (−) operator, the zone being described is wholly outside the body. If the body appears with an (OR) operator, the input zone being described includes all points in the code zone following the "OR." OR may be considered as a union operator. In some instances, an input zone may be described in terms of subzones, called code zones, lumped together by (OR) statements. Body numbers after an "OR" describe a code zone, and code zones may be thought of as subsets of an input zone.

For example, let Body 1 be a sphere with vertex (−0.75, 0.0,0.0) and radius 1.0.

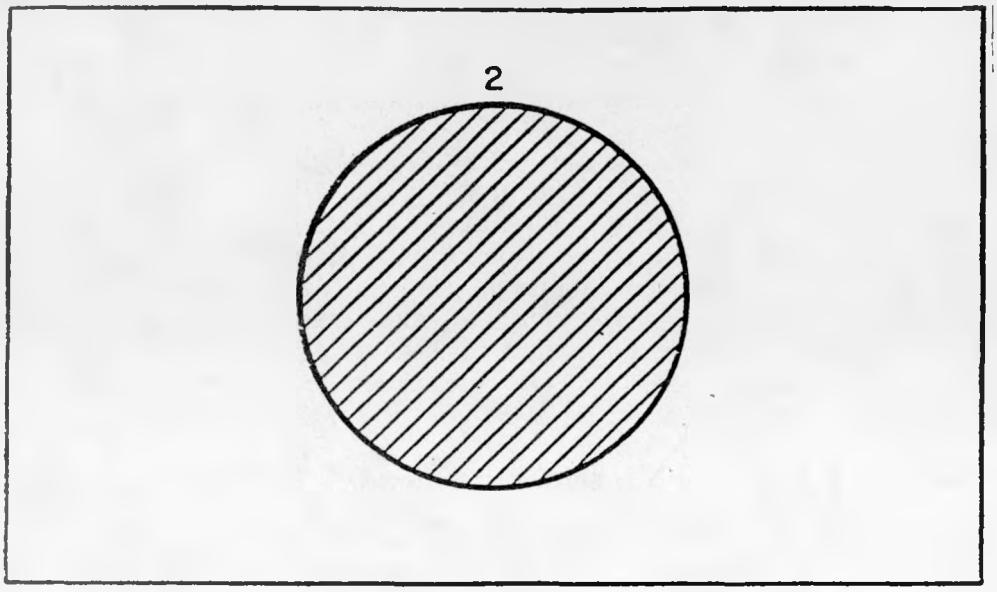
ORNL Dwg. 79-7900



BODY 1

And let Body 2 be a sphere with vertex (0.75, 0.0, 0.0) and radius 1.0.

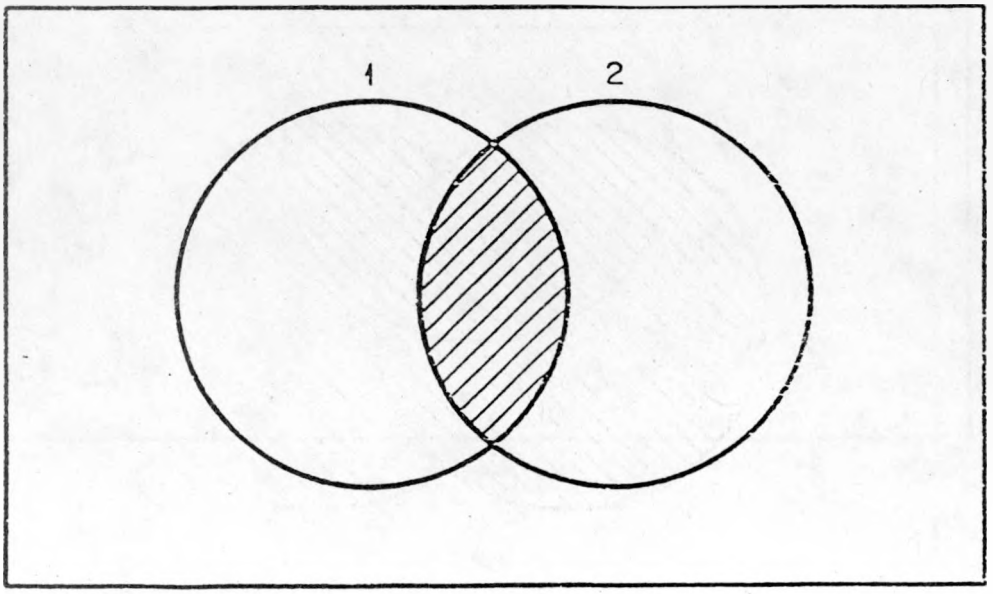
ORNL Dwg. 79-7901



BODY 2

The zone "1 AND 2" (represented as "+1 +2") consists of all points that are in Body 1 and are also in Body 2.

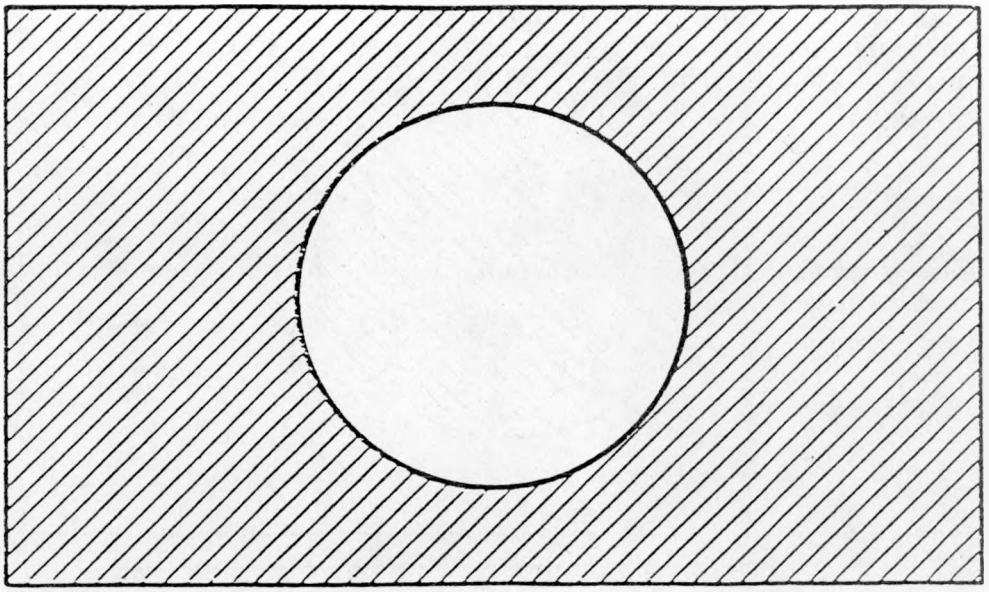
ORNL Dwg. 79-7904



1 AND 2

The zone "NOT 1" (respresented by "-1") consists of all points that are not in Body 1.

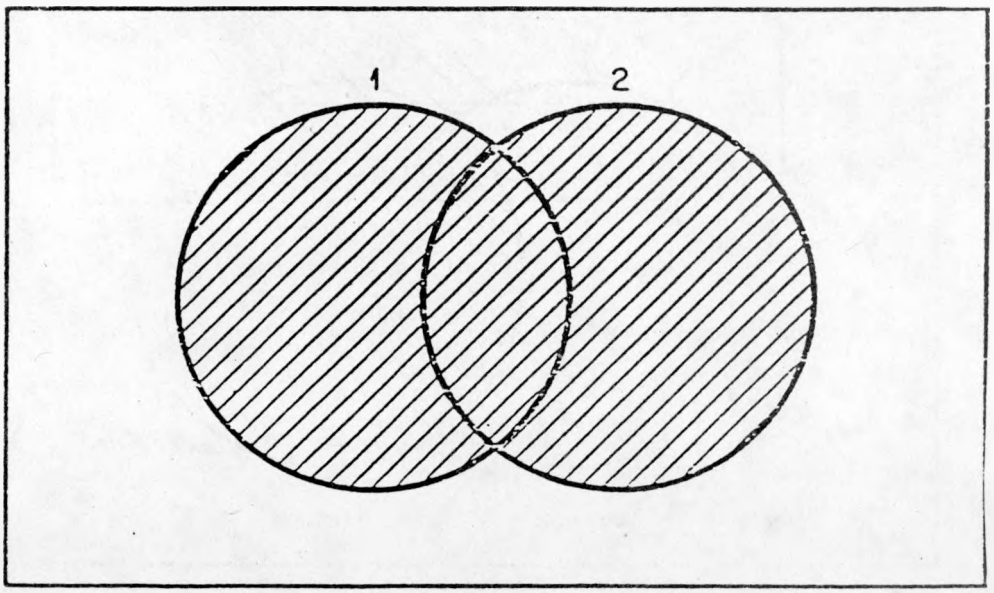
ORNL Dwg. 79-7902



NOT 1

And zone "1 OR 2" consists of all points that are in Body 1 and in Body 2 (or in both, the OR operation is not an exclusive or).

ORNL Dwg. 79-7903



1 OR 2

Techniques for describing a particular geometry are best illustrated by examples. Consider an object composed of a sphere and a cylinder as shown in Fig. A.1. To describe the object, one takes a spherical body penetrated by a cylindrical body (Fig. A.1, Items 2 and 3); if the materials in the sphere and cylinder are the same, then they can be considered as one zone, say Zone I (Fig. A.1, Item c). The description of Zone I would be

$$\text{I} = \text{OR} +2 \text{ OR} +3 \, .$$

Notice that the OR operator refers to all following body numbers until the next OR operator is reached.

ORNL Dwg. 74-6761

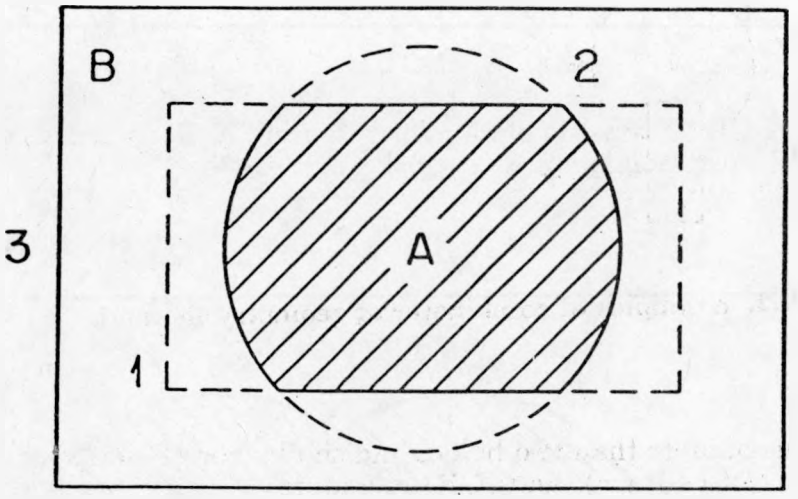


Fig. A.1. Use of OR operators.

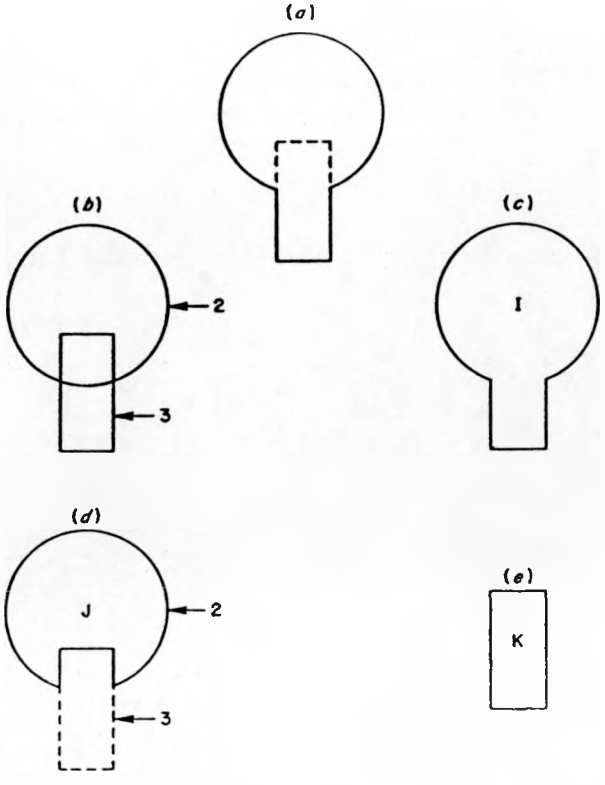


Fig. A.2. Examples of combinatorial geometry method.

Combinations of more than two bodies and similar zone descriptions could contain a long string of (+), (=), and (OR) operators. It is important, however, to remember that every spatial point in the geometry must be located in one and only one zone.

As a more complicated example of the use of the (OR) operator, space consider the system shown in Fig. A.2 consisting of the shaded zone, A, and the unshaded zone, B. These zones can be described by the two BOXes, Bodies 1 and 3, and the RCC, Body 2. The zone description would be

$$A = +1 \ +2 \ ;$$

$$B = \text{OR} \ +3 \ -1 \ \text{OR} \ +3 \ -2 \ .$$

A.3 COMBINATORIAL ZONE CONSTRUCTION

In combinatorial geometry the most elementary zone description is called a "code zone." The code zone description uses only the "+" and "−" operators to describe a material zone. Code zones may be combined with the "OR" operator to define an "input zone" containing more than one code zone, or an input zone may be composed of only one code zone. An input zone is a material zone of only one media, containing one or more code zones. An input zone may describe volumes of space that are not continuous. Figure A.3 illustrates the difference between input zones and code zones.

ORNL Dwg. 80-17841

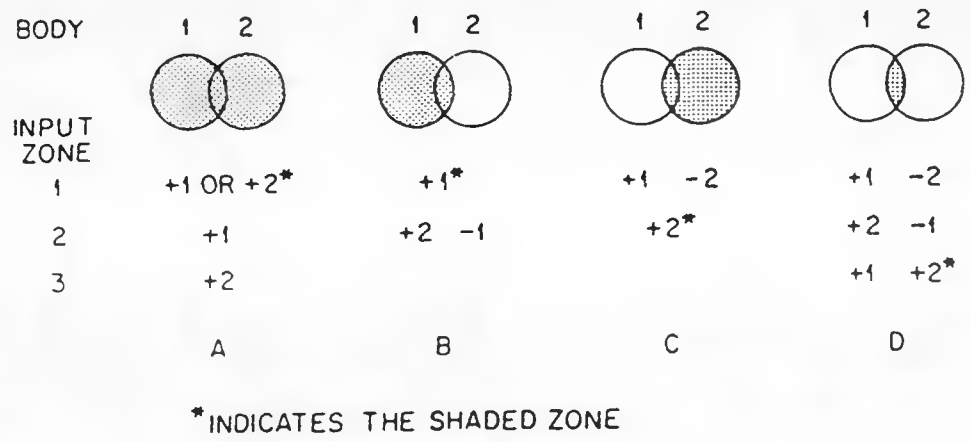


Fig. A.3. Illustrative input zone descriptions.

Figure A.3-A shows the shaded zone, Input Zone 1, as all points in Body 1 "OR" all points in Body 2. Input Zone 1 in Fig. A.3-A contains two code zones. The first code zone is +1 and the second code zone is +2. Alternatively, this material zone could have been described as two input zones, each with only one code zone as illustrated by Zones 2 and 3 of Fig. A.3-A. In both methods, the set of points shared by Bodies 1 and 2 have been doubly defined; this is valid since both zones contain the same media. If Bodies 1 and 2 contained different material media, then the two bodies could not be combined into a single input zone; and the overlap between the two bodies would be erroneous. Figure A.3-B's shaded zone is all points in Body 1; and the clear zone is all points in Body 2 that are "not" in Body 1. The shaded

zone, Zone 1, is described as +1. The clear zone, Zone 2, is described as +2 -1. Figure A.3-C's shaded area is all points in Body 2 and is the opposite description of Fig. A.3-B. Figure A.3-D's shaded zone is all points in Body 1 that are also in Body 2; that is, points that are common to both bodies. This zone is described as +1 +2. Figure A.3 demonstrates the use of the "OR," "+," and "−" operators. Note the user is not required to use the "OR" operator. (See Fig. A.3-A.) The "OR" operator gives the user a shorthand input notation to lump "code zones" logically together into a single "input zone." All combinatorial geometry tracking is done with "code zones." Tracking across code zones is transparent to the user. Program action occurs only when a particle track crosses an input zone boundary. Input zones are a user convenience for consolidating code zones in a more logical, understandable manner.

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11. ABSTRACT (200 words or less)

QADS is a multidimensional point kernel computer code that utilizes the simplified free-form input of the SCALE system as well as compatibility with ORIGEN-S produced sources, SCALE cross section libraries, and standard composition data sets. QADS consists of a preprocessor that takes the free-form input and prepares input for the widely available QAD-CGGP code, which is then automatically executed by a driver module. This report describes the point kernel theory briefly, followed by numerous tips on successfully applying the theory to various types of shielding problems. The remainder of the document is devoted to input and output descriptions of the QADS code with several illustrative sample problems.

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