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SHIELDING COMPUTER PROGRAMS

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GENERAL  ELECTRIC
ATOMIC PRODUCTS DIVISION
AIRCRAFT NUCLEAR PROPULSION DEPARTMENT



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Printed in USA. Price 75 cents. Available from the

Office of Technical Services
U.S. Department of Commerce
Washington 25, D.C.

APEX-387

UC-34 Physics and Mathematics
(TID 4500, 14th Ed.)

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Nuclear Development Laboratories Sub-Section


October 29, 1957

United States Air Force

Contract No. AF 33(600)-38062

United States Atomic Energy Commission

Contract No. AT (11-1)-171

GENERAL  ELECTRIC
ATOMIC PRODUCTS DIVISION
AIRCRAFT NUCLEAR PROPULSION DEPARTMENT
Cincinnati 15, Ohio

Published by
Technical Publications Sub-Section
November 21, 1958

Abstract

Digital-computer shielding-nuclear analysis programs are described. Each description includes (1) the purpose of the program, (2) the theoretical or physical assumptions, and (3) the major computer equipment required by the program.

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Introduction

Brief descriptions of ANPD shielding computer programs are presented. These programs may be categorized as follows: (1) those that pertain to reactor-shield analysis, (2) those that pertain to crew-shield analysis, (3) those that pertain to air-scattering calculations, and (4) a Monte Carlo study.

The program descriptions are designed to enable one to determine the application of a particular program to a given problem. The various physical or theoretical assumptions in each program are discussed.

Table 1 summarizes the programs and indicates the type of computer and the number of memory frames required.

TABLE 1

ANPD SHIELDING-COMPUTER-PROGRAM SUMMARY

Program No.		IBM Computer	No. of Memory Frames	No. of Words
01-0	Reactor-shield analysis; fast neutron dose rates	701	2	5,000 estimated
02-0	Reactor-shield analysis; gamma ray dose rates	701	2	7,000 estimated
03-0	Reactor-shield analysis; shield weights	701	2	5,000 estimated
04-0	Reactor-shield analysis; unification of 01-0, 02-0, 03-0	704	2	8,000
04-1	Reactor-shield analysis; revision of 04-0 (rectangular source)	704	4	15,000
04-2	Reactor-shield analysis; revision of 04-0 (cylindrical source)	704	4	16,000
05-0	Gamma ray single-scattering analysis	704	2	4,600
06-0	Neutron detector shield analysis	704	1	3,400
07-0	Gamma ray detector shield analysis	704	2	5,500
07-1	Gamma ray detector shield analysis; revision of 07-0	704	2	6,000
08-0	Monte Carlo gamma ray penetration	704	2	5,000
09-0	Neutron single scattering analysis	704	2	4,600
10-0	Neutron detector shield analysis	704	2	6,000
11-0	Neutron penetration; point source	704	1	4,000
12-0	Gamma ray penetration; point source	704	1	4,000

Shielding Computer Program 01-0

Shielding Computer Program 01-0 was coded for calculating direct-beam, fast-neutron dose rates in and around cylindrical reactor-shield assemblies. This program combines the use of point-to-point attenuation functions with integration over volume-distributed sources and is able to recognize and evaluate the effect of regions of inhomogeneity that exist within complex reactor shields.

Program 01-0 is applicable only for cylindrical geometry, that is, the core and shield component regions are formed by rotation of rectangles about the reactor-shield axis. Regions within the shield that are not cylindrical must be approximated by cylindrical regions. A bulk material may be present in the shield without being described by specific regions.

A modification of the point-to-point attenuation function, suggested by Albert and Welton in their theory of neutron attenuation in hydrogenous media, is used in this program for calculating the direct-beam, fast-neutron dose rates. This theory combines a theoretical hydrogen cross section with integration over the U^{235} fission neutron spectrum to obtain the uncollided flux as a function of penetration distance into the medium. The effects on attenuation of materials other than hydrogen are included by assuming exponential attenuation and by treating the cross sections as energy-independent adjustable parameters to be determined by best fit to experimental data. It is therefore evident that this treatment is based on the assumption that all heavy materials are backed by sufficient hydrogenous material to validate use of effective removal cross sections.

It is further assumed that the point-to-point attenuation function depends only on the quantity of each material encountered by the primary ray that connects a point in the source region to the detector. This condition is reasonably well satisfied in many cases in which the important part of the scattered radiation is well collimated along the path of the primary ray. The attenuation function then is a function of path length, path fractions, source energy, and macroscopic cross section.

Source region nodal points* are located in rings formed by the intersection of concentric shells and planes normal to the axis. There may be two to ten equally spaced planes. Independently, there may be two to ten equally spaced shells. Finally, there may be two to ten equally spaced source points in each ring, but the number per ring must be the same.

The source distribution is assumed flat in the radial direction, but a cosine distribution is used in the axial direction.

The program computes and stores in memory the path length, path fractions, and attenuation function for each source - receiver path. Finally, the program multiplies

*Throughout this report, source region nodal points will be called source points.

the attenuation function by the axial source distribution function, and integration over the volume source is performed using the trapezoidal method. The distances traversed in each region, which are used to compute path fractions, are determined by a stepping procedure.

A total of 99 regions, 50 materials, and 10 source points in each space variable can be handled by the program.

Program 01-0 was programmed for computation on the IBM 701 digital computer. The IBM 701 components required are two memory frames, one magnetic drum, and two tape units.

Shielding Computer Program 02-0

Shielding Computer Program 02-0 calculates direct-beam gamma ray dose rates in and around cylindrical reactor-shield assemblies. This program is exactly like Program 01-0 except for a different point-to-point attenuation function, a permissible radial source-distribution function, and a final summation of the dose rates computed for each source energy.

An uncollided point-to-point attenuation function in conjunction with Nuclear Development Corporation of America (NDA) buildup factors was incorporated in the program. The buildup factors are expressed by a third degree polynomial. In view of the uncertainties existing in the use of buildup factors for inhomogeneous and non-infinite media at the time the program was coded, an expression for combining buildup factors was written in the program so that considerable versatility was achieved. Thus, either the actual or shielding-equivalent thickness of any or all materials encountered by a ray can be replaced by any desired material, or products of buildup factors for materials encountered may be taken.

The source distribution is assumed separable in energy and spatial coordinates. In addition, the source distribution is assumed separable along the axis and radius and is expressed by cosine functions along the radius and the axis of the source region.

A total of 80 shield regions, 10 equally spaced source points in each space variable, and a source of 20 energy levels can be handled by the program. The number of regions times the number of materials cannot exceed 800.

Program 02-0 was programmed for computation on an IBM 701 computer. The IBM 701 components required are two memory frames, one magnetic drum, and two tape units.

Shielding Computer Program 03-0

Shielding Computer Program 03-0 was coded to make possible the quick computation of shield weights. The weight of the reactor-shield assembly computed by the program can be only as precise as the description of the shield regions that comprise the total volume. A total of 100 regions can be handled by the program.

Program 03-0 was written for computation on an IBM 701 digital computer. The IBM 701 components required are two memory frames, one magnetic drum, and two tape units.

Shielding Computer Program 04-0

Shielding Computer Program 04-0 was coded for an IBM 704 digital computer and is a unification of Programs 01-0, 02-0, and 03-0. Thus, this program combines the fast neutron and gamma ray point-to-point attenuation functions previously discussed, with integration over cylindrical volume-distributed sources to compute the fast neutron and gamma ray dose rates in and around complex reactor-shield assemblies, as well as to compute the weights of these assemblies. The program output may also include the material attenuation functions divided by the square of the source - detector path length for each source point under consideration.

Shield geometry may be described by a combination of regions formed by rotating rectangles or trapezoids about the reactor axis, or by translating rectangles parallel to the reactor axis. A cylindrical coordinate system is used to describe the location and dimensions of the volume-distributed source.

The number of allowable equally spaced source points in each space integral is 15. Input data was modified to include a code number before each region description to indicate both the composition and geometry of the region.

Program 04-0 was written for an IBM 704 digital computer. The program utilizes two frames of magnetic core memory and four tape units of the IBM 704 computer. No magnetic drum memory is required.

Shielding Computer Program 04-1

Shielding Computer Program 04-1 is a modification of Program 04-0 for computing fast neutron and gamma ray dose rates in and around complex reactor-shield assemblies and the weights of these assemblies.

This program is applicable only for integration over sources described in a rectangular coordinate system. The shield geometry is described in exactly the same manner as in Program 04-0, but the allowable number of regions has been increased to 500.

Integration limits for any space variable may be equal. There may be 1 to 15 equally or unequally spaced planes of source points between the integration limits of each space variable. Consequently, rectangular parallelepiped volume, rectangular plane surface, line, or point sources may be described.

Separability of the source spatial distribution is not assumed. A continuous source distribution may be described, or one that is discontinuous in the horizontal plane. A table of source densities must be supplied as input data. The source distribution may be the same or different for neutrons or gammas.

The uncollided gamma ray point-to-point attenuation function is used in conjunction with empirical expressions for combining buildup factors in light and heavy materials. Thus, this expression differs from that written for Program 04-0.

Program 04-1 utilizes four frames of magnetic core memory of the IBM 704 computer. No magnetic drum memory is required. Tape units are used only for input and output of data.

Shielding Computer Program 04-2

Shielding Computer Program 04-2 is a modification of Program 04-0 for computing fast neutron and gamma ray dose rates in and around complex reactor-shield assemblies, and the weights of these assemblies. The program is applicable only for integration over sources described in a cylindrical coordinate system.

Shield geometry is described in the same manner as in Program 04-0, but the allowable number of regions has been increased to 500.

Integration limits for any space variable may be equal. Source points are located in rings formed by the intersection of concentric shells and planes normal to the axis. There may be 1 to 30 equally or unequally spaced planes. Independently, there may be 1 to 30 equally or unequally spaced shells. Finally, there may be 1 to 30 equally or unequally spaced lines of source points in each shell. The number of lines of points per shell may differ. Consequently, cylindrical volume, cylindrical or plane surface, axial or radial line, or point sources may be described.

Separability of the source distribution is assumed and can be expressed either as a cosine or exponential function. The distribution may be the same or different for fast neutrons and gammas and may differ in as many as four ranges along either the axis or radius of the source region.

The uncollided gamma ray point-to-point attenuation function is used in conjunction with empirical expressions for combining buildup factors in light and heavy materials.

This program utilizes four frames of magnetic core memory of the IBM 704 computer. No magnetic drum memory is required. Tape units are used only for input and output of data.

Shielding Computer Program 05-0

Shielding Computer Program 05-0 calculates the gamma ray dose rate due to single scattering in an infinite homogeneous medium from an anisotropic point source, at any unshielded, isotropic-point detector.

Direct-beam dose rates on the surface of a sphere of specified radius from the point source are used to define the source. The source energy spectrum is defined by assuming separability fractions of the direct-beam dose rate contributed by each of a maximum of ten energy levels. Different fractions may be specified for each of three space regions.

Exponential attenuation may be considered either along the distance between the source and scattering point or along the distance between the scattering point and detector point, or along both distances. Attenuation coefficients and conversion factors for gamma rays from Compton scattering are computed for the energies after scattering. The scattered energies are computed by means of the Compton formula

The dose rate from the source spectrum is obtained by summation of the dose rates computed for each initial energy.

The differential-scattering cross section is computed by means of the Klein-Nishina formula.

This program was prepared for use in computing single-scattered dose rates in air from anisotropic sources. It may be used for computing single-scattered dose rates in any other infinite homogeneous medium.

Program 05-0 utilizes two memory frames on an IBM 704 computer. No magnetic drums are required. Two tape units are used for utility routines.

Shielding Computer Program 06-0

Shielding Computer Program 06-0 is useful principally in parametric studies. The program computes the thickness of neutron shielding required for a specific neutron dose rate inside the crew shield; conversely, if the thicknesses are known, the program computes the neutron dose rate inside the crew shield.

The crew shield must be in the form of a long, right circular cylinder, the axis of which is collinear with the axis of symmetry of the reactor shield.

It is assumed that the radiation penetrating the rear is predominately direct, whereas air-scattering is assumed to be responsible for all radiation entering the front and sides of the crew shield.

The program performs the successive iterations necessary to determine the optimum (with respect to neutron-shielding weight) division of the total fast neutron dose inside the crew shield into direct and air-scattered dose.

The neutron-shielding thickness at the rear of the crew shield is determined by exponential attenuation of the direct-beam dose rate and by using energy-independent cross sections. Side thicknesses are computed by applying exponential attenuation to the air-scattered dose rate at an unshielded crew position, using experimentally determined, thickness-dependent cross sections. In the air-scattering calculation single, isotropic air scattering with no attenuation is assumed. The front thickness is assumed to be a constant fraction of the side thickness.

Program 06-0 was written for an IBM 704 digital computer. The program utilizes one frame of magnetic core memory on the IBM 704. Two tape units are needed for utility routines, and no magnetic drum memory is required.

Shielding Computer Program 07-0

Shielding Computer Program 07-0 calculates the gamma ray dose rate due to single scattering in a homogeneous infinite medium at a shielded, isotropic-point detector. The detector shield and the angular distribution associated with the point source are both assumed to be symmetric about the source - detector axis.

Direct-beam dose rates on the surface of a sphere of specified radius from the point source are used to define the source. These direct-beam dose rates are considered as a function of energy and the angle between the direction of unscattered radiation leaving the source and the source - detector axis. Since only two variables are involved, no separability fractions are required as in Program 05-0.

The gamma-ray-source energy spectrum may be approximated by ten energy levels. The dose rate arising from this spectrum is obtained by summation of the dose rates computed for each initial energy and for the rear, side, and front of the detector shield.

Exponential attenuation may be considered either along the distance between the source point and scattering point or along the distance between the scattering point and detector point, or along both distances. Attenuation coefficients and conversion factors for gamma rays from Compton scattering are computed for the energies after scattering. The scattered energies are computed by means of the Compton formula.

Program 07-0 may be used to compute the detector response to the single-scattered radiation penetrating the side, front, and rear of the detector shield. This shield is symmetric about the source - detector axis and consists of conically shaped side, rear, and front sections that fit together to form a closed volume. Independent integration limits are required for the front, side, and rear portions of the shield.

Attenuation due to the detector shield is computed by an exponential function preceded by the buildup factor. The buildup factors are expressed by a third degree polynomial. Because of the uncertainty in the use of buildup factors for multiregion shields existing at the time the program was coded, the program was written so that various means of combining buildup could be examined.

Program 07-0 was written for an IBM 704 computer. The program requires two frames of magnetic core memory on the IBM 704. Two magnetic tape units are required for utility routines. No magnetic drum memory is required.

Shielding Computer Program 07-1

Shielding Computer Program 07-1 is essentially a revision of Program 07-0. This program calculates the direct-beam dose rate contribution to the gamma ray dose rate inside the detector shield, as well as the contribution due to single scattering in a homogeneous infinite medium.

Direct-beam dose rates on the surface of a sphere of specified radius from the point source must be used to define the source. The program then applies the usual r^2 geometry correction to obtain the direct dose at the unshielded detector point. The effect of attenuation through the detector shield is then determined by an exponential function preceded by the buildup factor. In Program 07-1, an empirical expression, established by the Monte Carlo method, for combining buildup factors in light and heavy materials is utilized.

The program input and machine requirements are the same as for Program 07-0.

Shielding Computer Program 08-0

Shielding Computer Program 08-0 utilizes the Monte Carlo method for studying the penetration of gamma rays through a semi-infinite, homogeneous slab shield. The gamma ray source is assumed to consist of a uniform infinite beam of monoenergetic gamma rays incident on the shield surface at a specified angle with respect to the shield normal.

The calculation is based on the assumption that only three fundamental collision processes occur: photoelectric effect, pair production, and Compton scattering. The first two effects are treated as outright absorption. The third is a scattering process described quantitatively by the Klein-Nishina differential scattering cross section for gamma rays and by the Compton scattering law.

A straightforward Monte Carlo method is used in the program. This procedure is an exact mathematical analog to the physical process, in which each photon is carried from the source through the shield by random sampling from known probability density functions until the photon escapes or is absorbed. This method, however, is not useful for a thick shield because the number of case histories required to give a reasonably small, relative probable error is prohibitively large.

Both the energy and direction, specified by two angles referred to a fixed reference system in the shield, of the photons that leave the rear face of the shield are recorded.

Program 08-0 was written for an IBM 704 digital computer. The program requires two frames of magnetic core memory on the IBM 704. Two tape units are needed for utility routines. No magnetic drum memory is required.

Shielding Computer Program 09-0

Shielding Computer Program 09-0 calculates the neutron dose rate due to single scattering in an infinite homogeneous medium from an anisotropic point source at a specified, unshielded isotropic-point detector.

Direct-beam dose rates on the surface of a sphere of specified radius from the point source are used to define the source. The source energy spectrum is defined by assuming separability fractions of the direct-beam dose rate contributed by each of a maximum of 10 energy levels. Different fractions may be specified for each of three space regions.

Exponential attenuation may be considered either along the distance between the source point and scattering point or along the distance between the scattering point and detector point, or along both distances. Attenuation coefficients and conversion factors for the scattered neutrons are computed for the scattered energies. The billiard-ball model was used to establish the equations for computing the scattered energy.

The dose rate from the source spectrum is obtained by summation of the dose rates computed for each initial energy.

Although the form of the differential scattering cross section for the scattering of neutrons in air is not known, it was assumed that a power series approximation was valid.

Although Program 09-0 was prepared for use in computing single-scattered dose rates in air from anisotropic sources, it may be used for computing single-scattered dose rates in any other infinite homogeneous medium.

Program 09-0 utilizes two memory frames on an IBM 704 computer. No magnetic drums are required. Two tape units are used for utility routines.

Shielding Computer Program 10-0

Shielding Computer Program 10-0 calculates the fast neutron dose rate due to single scattering in a homogeneous infinite medium at a shielded, isotropic-point detector. Both the detector shield and the angular distribution associated with the point source are assumed symmetric about the source - detector axis.

Direct-beam dose rates on the surface of a sphere of specified radius from the point source are used to define the source. These direct-beam dose rates are considered as a function of energy and the angle between direction of the unscattered radiation leaving the source and the source - detector axis. Since only two variables are involved, no separability fractions are required as in Program 09-0.

The neutron-source energy spectrum may be approximated by 10 energy levels. The dose rate from this spectrum is obtained by summation of the dose rates computed for each initial energy and for the rear, side, and front of the detector shield.

As in the other air scattering programs, exponential attenuation may be considered along the distance between the source and scattering point, along the distance between the scattering point and detector point, or along both distances. Attenuation coefficients and conversion factors for the scattered neutrons are computed for the scattered energies. The billiard-ball model was used to establish the equations for computing the scattered energy.

Program 10-0 may be used to compute the detector response to the single-scattered radiation penetrating the side, front, and rear of the detector shield. This shield is symmetric about the source - detector axis and consists of conically shaped side, rear, and front sections that fit together to form a closed volume. Independent integration limits are required for the front, side, and rear sections of the shield.

Although the form of the differential scattering cross section for the scattering of neutrons in air is not known, it was assumed that a power series approximation was valid.

Attenuation due to the detector shield is computed by an exponential expression that is a function of the angle of scattering. This expression was obtained empirically.

Program 10-0 was written for an IBM 704 computer. The program utilizes two frames of magnetic core memory on the IBM 704. Two magnetic tape units are needed for utility routines. No magnetic drum memory is required.

Shielding Computer Program 11-0

Shielding Computer Program 11-0 computes the fast neutron dose rate from an isotropic point fission source at a detector point in an infinite homogeneous medium.

The point-to-point attenuation function used in this program is a modification of the one suggested by Albert and Welton in their theory of neutron attenuation in homogeneous media. (The assumptions involved were discussed previously in the section on Program 01-0.)

Material path fractions along the straight line that connects the source and detector, as well as the source-receiver distance, are specified as input data. A total of 20 materials may be handled by the program.

Program 11-0 utilizes two frames of magnetic core memory on an IBM 704 digital computer. No magnetic drum memory is needed. Two tape units are used for input and output of data.

Shielding Computer Program 12-0

Shielding Computer Program 12-0 computes the gamma ray flux from an isotropic point source that has as many as 20 energy levels when the source-receiver distance and the material path fractions along the straight-line that connects the source and receiver are specified. Gamma ray absorption rates or dose rates are computed by incorporating the appropriate conversion factors. Empirical expressions (established by Monte Carlo techniques) for computing buildup factors through light and heavy materials are employed in the program.

Program 12-0 was written for an IBM 704 computer. The program utilizes one frame of magnetic core memory on the IBM 704. No magnetic drum memory is required. Two tape units are needed for utility routines.