The Radiation Streaming Calculation of the Wave Guide using DUCT-III

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1. Introduction

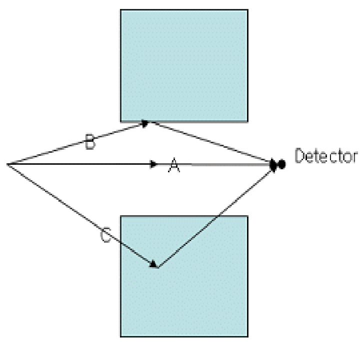
There are many penetrations in accelerator facility, such as a cable, a cooling water pipe or an air conditioning duct. The estimation of the radiation streaming through these penetrations is one of the most difficult parts in shielding design. The Shin's semi-empirical formula describing energy-space distributions of neutrons and gamma-rays streaming in ducts or labyrinths is very useful for application to accelerator facility.[1] A streaming calculation code DUCT-III is based on the Shin's formula with the albedo data up to 3GeV.[2]

In this paper, the source term was calculated by MCNPX[3] and the radiation streaming through the bended wave guide by DUCT-III.

2. Calculation Method

2.1 Streaming Components

Radiation streams through or across penetrations (such as ducts) passing through various paths. There are typically three types of the paths. Three paths are illustrated in Fig.1.



A: Direct component B: Albedo component

C: Penetration component

Fig. 1. Radiation streaming through duct

The path 'A' expressed the direct component is radiations directly coming to a detector, passing the duct inlet. The path 'B' is the abedo component, which shows that passes the duct mouth and then comes to the detector after many times reflections on the duct wall. The remainder which enters into duct wall first, then penetrates the wall and finally enters into the duct is the penetration component.

The direct component dominates the radiation flux in a case where a detector is close to the source, or a case of very narrow duct. In very narrow ducts, the penetration component is also important.

The DUCT-III code is based on the Shin's semi-empirical formula. The formula, which describes the direct and albedo components, is derived in generic straight duct geometry. It is expressed by the product of spatial distributions which are represented by twice and eight-time reflected components, and power of an albedo matrix. This formula was then extended to bent ducts. The inflow of radiations to downstream at a corner of multibent ducts is formulated with the flux in the upstream leg. Using the obtained inflow current as the source term to downstream, the formula predicts the radiation flux in the downstream leg.

Also, the DUCT-III code has been linked with a point kernel program PKN-H, in order to do the penetration component calculation.

2.2 Source term (using MCNPX)

MCNPX was used to obtain neutron source terms for DUCT-III and PKN-H codes. Fig. 2 shows the simple geometry for source term calculation. Proton beam impinges at the center of a Cu target of which shape is a hexahedron. The length of each side is 1.5 cm. The beam loss rate of the accelerator components is assumed 1 W/m and beam energy is 100 MeV. The two meter long line source, which is divided into 50 equal parts and the point sources calculated by MCNPX are assumed to be set in the center of the subdivisions in the DUCT-III input. So, the source proton beam intensity is 0.4 nA per 4 cm (2.50E+9 p/sec). Table 1 shows the neutron source term for DUCT-III code input.

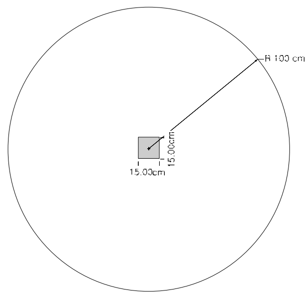


Fig. 2. Geometry model for the source term calculation in MCNPX

Table 1: Source Term calculated by MCNPX for DUCT-III input

Energy [MeV]	Flux [#/cm^2/primary]	Intensity [#/sec]
4.14E-07	1.98E-13	6.23E+01
5.04E-06	3.97E-12	1.25E+03
1.01E-04	9.60E-11	3.01E+04
3.35E-03	4.15E-09	1.30E+06
8.65E-02	8.85E-08	2.78E+07
1.35E+00	5.44E-07	1.71E+08
2.00E+01	6.69E-07	2.10E+08
1.00E+02	1.66E-07	5.19E+07
4.00E+02	0.00E+00	0.00E+00
8.00E+02	0.00E+00	0.00E+00
1.50E+03	0.00E+00	0.00E+00
3.00E+03	0.00E+00	0.00E+00
total	1.47E-06	4.62E+08

2.3 Calculation Models for DUCT-III and PKN-H

The length of the first, second and third legs are 125 cm, 132 cm and 125 cm respectively, and each bent angle is 90 degree. Two cases were calculated according to the line source position and three cases according to the size of the wave-guide duct. The line source is positioned at the coordinate (0, -153, -260 cm) or (0, -131, -260 cm) respectively, relative to the center of the duct inlet. The width and height of the duct are 40 cm and 70 cm respectively. Another has 27cm and 70 cm. The remainder is 16.5 cm and 60 cm.

The calculation models of the wave ducts are shown in Fig. 3.

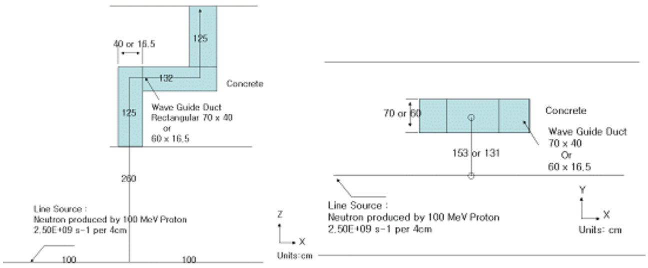


Fig. 3. The calculation model of wave guide duct in DUCT-III and PKN-H code

3. Calculation Results

When the area of duct becomes narrower or the duct inlet closer to the source, the penetration component is more important. Also, the direct and albedo component is of little importance when the parallel side (width) of duct with the line source gets smaller.

In table 2 is given the results of the calculations for each case described at chapter 2.3.

Table 2 Calculated Dose Rates using the DUCT-III and PKN-H code

Source Position [cm]	Duct Size [cm]	Calculated Dose Rate [uSv/hr]		
		DUCT-III	PKN-H	DUCT +PKN-H
153	70 x 40	10.6	7.97	18.57
	70 x 27	1.55	2.23	3.78
	60 x 16.5	0.0483	0.796	0.8443
131	70 x 40	12.3	18.6	30.9
	70 x 27	1.81	5.18	6.99
	60 x 16.5	0.063	0.925	0.988

REFERENCES

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[3] D.B.Pelowitz, ed., MCNPX User's Manual, Version 2.6.0, LA-CP-07-1473, 2008.

[4] F. Masukawa et al., Analyses of High Energy Neutron Streaming Experiments Using DUCT-III, JNST, Supplement 2, p 1268-1271, 2002.