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Analysis: Comparison of DORT and
MCNP Calculations**

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Computational Physics and Engineering Division (10)

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ABSTRACT

Monte Carlo (MCNP4B) and Discrete Ordinates (DORT) calculations were carried out to estimate ^{60}Co and ^{152}Eu activation as a function of ground range due to neutrons emitted from the Hiroshima A-bomb. Results of ORNL DORT and MCNP calculations using RZ cylindrical air-over-ground models are compared with LANL MCNP results obtained with an XYZ air-over-ground model. All of the calculations were carried out using ENDF/B-VI cross-section data and detailed angle and energy resolved neutron emission spectra from the weapon. Favorable agreement was achieved for the ^{60}Co and ^{152}Eu activation for ground ranges out to 1000m from the three calculations.

1. Introduction

Monte Carlo and Discrete Ordinates calculations have been carried out to estimate ^{60}Co and ^{152}Eu activation as a function of ground range from neutrons emitted from the Hiroshima A-bomb. These calculations were performed as part of the US Working Group effort to resolve differences in the measured and calculated ^{60}Co and ^{152}Eu responses as a function of ground ranges to 1000m and to identify differences between results obtained using stochastic and deterministic methods with different air-over-ground models.

Calculations were carried out for detonation of the Hiroshima weapon at 580m above a flat ground surface. The neutron leakage spectrum from the weapon was calculated by the Los Alamos National Laboratory (LANL) and provided to the Oak Ridge National Laboratory (ORNL) and other analysts. The spectrum was provided as a function of neutron energy and emission angle from the weapon surface in formats suitable for use in both the Monte Carlo and Discrete Ordinates calculations. The Monte Carlo calculations were carried out taking into account the tilt of the weapon at time of detonation. Since the bomb was dropped from an airplane, its forward momentum caused the explosion to approximately occur at an angle of 15° with respect to the vertical. The Discrete Ordinates calculations cannot account for the tilt, so the weapon was assumed to be perpendicular to the ground at detonation.

Results are given here only for the angle-energy dependent source. The radioisotope production was shown to be insensitive to the energy-angle emission from the weapon. Results obtained for the ^{59}Co and ^{151}Eu production at a height of 1m above the ground for isotropic and anisotropic neutron emission were essentially the same.

2. Methods of Calculation

2.1 Discrete Ordinates Calculation

ORNL performed air-over-ground calculations using the two-dimensional discrete ordinates code DORT⁽¹⁾. The air-over-ground geometry was modeled in cylindrical RZ geometry with the lower portion of the geometry composed of ground and the upper portion composed of air. The source was located on the axis of the cylinder at an altitude of 580-m above the ground surface. The air extended to an altitude of 2000-m and was divided into seven axial zones with air density decreasing as a function of altitude. (See Table 1.) The ground was taken to be a 50-cm-thick layer divided into 20 mesh intervals while the 2000-m-high air region was divided into 90 mesh intervals. The radius of the air-ground geometry extended to 3000 m in 130 mesh intervals. A complete description of the air-ground geometry used in the DORT calculations is given in Appendix A.

The compositions for the air and ground in the calculational models were taken from DS86⁽²⁾ and correspond to the atmospheric and soil conditions at the time of the event. These data are summarized in Tables 1 and 2.

The neutron and photon leakage from the Hiroshima weapon was calculated by the LANL staff and distributed to the US and Japanese Working Groups. Neutron spectra were provided in 199 energy groups and 40 angular intervals to account for the angle-energy dependence of the neutron emission from the weapon. The source energy groups correspond to the group structure of the VITAMIN-B6⁽³⁾ cross-section library which was used for the transport calculations.

Table 1. Hiroshima Atmospheric Density and Composition Profiles⁽²⁾

Air Zone	Height (m)	Atmospheric Density (g cm ⁻³)			Atom Density (atom b ⁻¹ cm ⁻²) ^a			
		Moist Air	Dry Air	Water Vapor	Hydrogen	Nitrogen	Oxygen	Argon
Mean	0-500	1.141E-3 ^b	1.123E-3	1.820E-5	1.217E-6	3.646E-5	1.039E-5	2.181E-7
1	0-125	1.164E-3	1.144E-3	1.978E-5	1.323E-6	3.715E-5	1.063E-5	2.222E-7
2	125-275	1.150E-3	1.131E-3	1.879E-5	1.256E-6	3.673E-5	1.048E-5	2.196E-7
3	275-449	1.134E-3	1.116E-3	1.768E-5	1.182E-6	3.622E-5	1.031E-5	2.166E-7
4	449-635	1.115E-3	1.099E-3	1.650E-5	1.104E-6	2.567E-5	1.012E-5	2.143E-7
5	635-835	1.096E-3	1.081E-3	1.533E-5	1.025E-6	3.508E-5	9.925E-6	2.098E-7
6	835-1095	1.073E-3	1.059E-3	1.502E-5	9.370E-7	3.439E-5	9.695E-6	2.057E-7
7	1095-1500	1.041E-3	1.029E-3	1.229E-5	8.217E-7	3.340E-5	9.371E-6	1.998E-7

^a b = barn = 1 x 10⁻²⁴ cm².

^b Read as 1.141x10⁻³ g cm⁻³

Table 2. Hiroshima Wet Ground Chemical Composition⁽²⁾

Element	Atom Density (atom b ⁻¹ cm ⁻²) ^a	Percent by Mass
H	3.085E-2 ^b	3.04
C	7.0432-4	0.83
O	3.759E-2	58.74
Na	5.451E-4	1.22
Al	2.061E-3	5.43
Si	9.315E-3	25.55
Cl	2.541E-6	0.01
K	7.191E-4	2.75
Ca	1.583E-4	0.62
Ti	2.567E-5	0.12
Mn	6.659E-6	0.04
Fe	2.482E-4	1.35

^a One barn = 1×10^{-24} cm².

^b Read as 3.085×10^{-2} g cm⁻³

The calculations were carried out in several steps. First, the GRTUNCL⁽⁴⁾ code was used to obtain the uncollided neutron fluence and first collision sources throughout the geometric mesh. This calculation is essential for eliminating ray effects that occur when the spatial mesh intervals are small compared to the mean free path of the transported neutrons. Ray effects can be reduced or even eliminated by using a high order angular quadrature in discrete-ordinates calculations but this is generally much more computationally costly. To further minimize ray effects, a 240-angle quadrature was used in the calculations reported here. See Appendix B.

The first collision source was then used as the input to the DORT code along with the cross-section and air-over-ground geometry description to calculate the collided neutron fluence at all locations in the geometry mesh. The uncollided and collided neutron fluences were summed and folded with the ⁵⁹Co(n,γ) ⁶⁰Co and ¹⁵¹Eu(n,γ) ¹⁵²Eu response functions to obtain the activation at 1-m above the ground.

The cross-sections for the elements comprising the air and ground were obtained from Ref. 3 and mixed according to the compositions given in Tables 1 and 2. The DORT calculations were performed using a P₃ Legendre expansion to describe the angular dependence of the cross section data.

2.2 MCNP Calculations

Monte Carlo calculations using the MCNP4B⁽⁵⁾ code were performed separately at ORNL and LANL. The Oak Ridge analysts modeled the air-ground environment using a cylindrical model similar to that used in the DORT calculations. LANL utilized a three-dimensional XYZ model to better estimate the spatial effects of the anisotropic neutron source and to better account for the tilt of the weapon on the fast neutron activation of sulfur at ground ranges <500m.

ORNL MCNP Calculations: The air-ground geometry was modeled in RZ geometry with the ground represented as a 50-cm-thick layer. The air extended to an altitude of 1500m and the radius of the geometry was 2000m. The neutron source was located on the axis of symmetry at 580m above the ground plane. The 15°-weapon tilt and anisotropic neutron emission were taken into account. The ground composition was the same as that given in Table 2. The air was modeled as a single 1500-m-high layer using the average composition specified in Table 1.

The neutron fluence was estimated using neutron cell flux tallies. The radiation transport was executed using ENDF/B-VI (6.2) cross sections and the fluences, calculated at one meter above the ground, were folded with the Cobalt and Europium activation cross-sections. Calculations were run for ten million source neutrons using a low energy cut-off of 10^{-11} MeV to correspond with the lower energy bound of the multigroup cross-sections used in the DORT calculations. The standard deviation in the responses between 0 and ~600 m is <3%. At greater distances, the uncertainties in the responses were 10-16%. The large statistical fluctuations in the data at distances beyond 500m do not significantly impact the trend in the behavior of the responses at these distances. Improved statistics can be readily achieved by increasing the number of neutron source particles (longer running times) or by splitting or biasing to achieve greater thermal neutron populations at long distances.

LANL MCNP Calculations: The LANL MCNP calculation was performed using an XYZ geometry that was designed to emphasize the activation responses about the hypocenter. In the geometry, 40m x 40m x 2m cells were constructed above a 50-cm-thick ground layer. The air and ground regions extended ± 535 m in the X and Y directions. The air extended to an altitude in the Z direction of 1500m.

The air and ground compositions used were the same as those in the DORT calculation with the air also modeled in seven altitude dependent layers having compositions corresponding to those in Table 1. The transport and activation cross-sections were taken from the ENDF/B VI (6.2).

The neutron source was represented using the detailed angle and energy resolved spectra that were binned into the same angle and energy structure used in the DORT calculations. The 15° tilt of the weapon at detonation was taken into account. The neutron fluence was estimated in the geometry using cell flux tallies and folded with the activation cross-sections to assess the ^{60}Co and ^{152}Eu production. Calculations were performed for >30 million source neutrons resulting in <2-3% fractional standard deviations in the ^{60}Co and ^{152}Eu responses for ground ranges between 0 and ~535 m. The long runs were made mainly to accurately calculate the ^{32}S fast neutron responses about the hypocenter. The neutron energy cut-off was 10^{-11} MeV.

3. Results

The calculated ^{60}Co and ^{152}Eu responses obtained using Monte Carlo and Discrete Ordinates methods are compared as a function of ground range in Figure 1 and Table 3. The LANL MCNP results were obtained by interpolating among the responses in the XY plane at 1m above the soil surface. Since the ORNL RZ models were each slightly different and LANL used a three-dimensional XYZ geometry, the activation data are given at slightly different ground ranges in each case.

The activation data agree very well at ground ranges between 0 and 500 m. The ORNL DORT and MCNP results at ground ranges beyond 500m are also in good agreement. The MCNP results exhibit a more rapid roll-off than the discrete ordinates results beyond 700m. This may be attributed to the statistical uncertainty in the MCNP responses at long distances from the source.

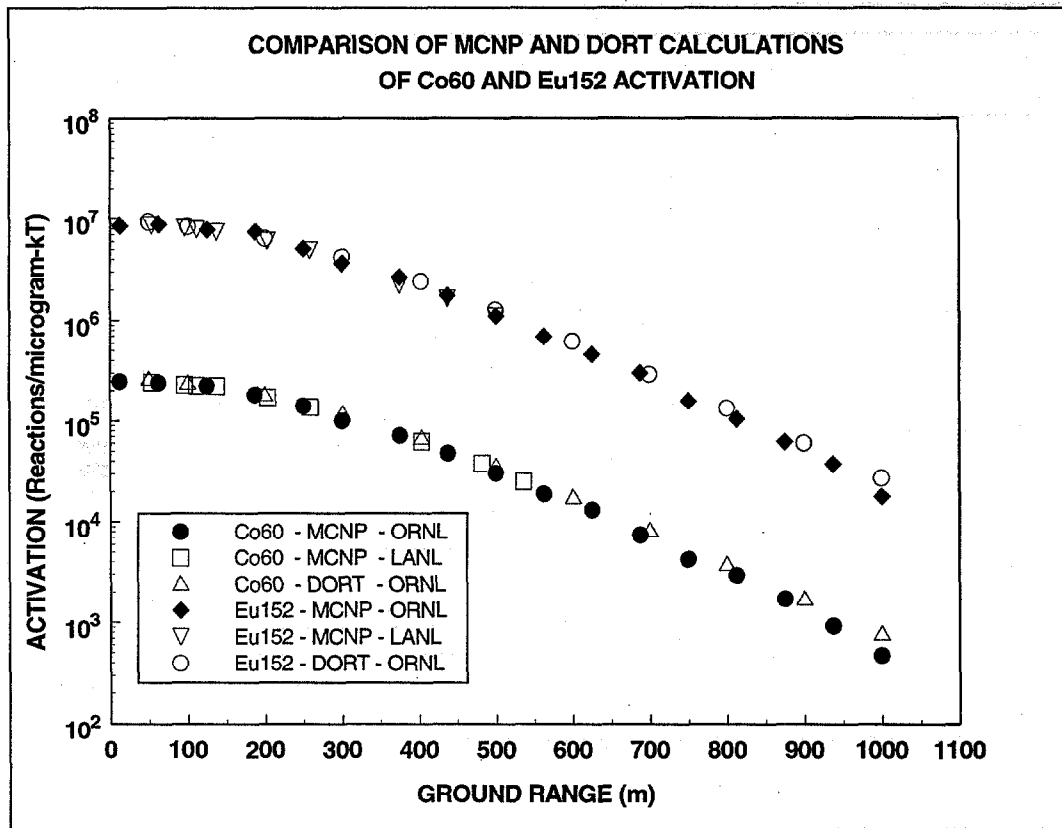


Figure 1. ^{60}Co and ^{152}Eu Activation as a Function of Ground Range

Table 3. Calculated ⁶⁰Co and ¹⁵²Eu Responses as a Function of Ground Range

Ground Range (m)	Co-60			Eu-152		
	Reactions/ microgram-kT					
	MCNP ORNL	MCNP LANL	DORT ORNL	MCNP ORNL	MCNP LANL	DORT ORNL
12.50	2.46E+05			8.49E+06		
50.00			2.59E+05			9.23E+06
53.30		2.41E+05			8.60E+06	
62.50	2.37E+05			8.86E+06		
96.13		2.27E+05			8.10E+06	
100.00			2.35E+05			8.38E+06
111.54		2.22E+05			7.87E+06	
125.00	2.21E+05			7.78E+06		
137.26		2.21E+05			7.46E+06	
187.50	1.80E+05			7.46E+06		
200.00			1.79E+05			6.38E+06
203.00		1.70E+05			6.05E+06	
250.00	1.40E+05			5.10E+06		
258.00		1.37E+05			4.90E+06	
300.00	1.00E+05		1.17E+05	3.64E+06		4.17E+06
312.50						
375.00	7.14E+04			2.65E+06	2.22E+06	
403.00		6.22E+04	6.72E+04			2.40E+06
437.50	4.73E+04			1.74E+06	1.63E+06	
482.00		3.78E+04				
500.00	3.03E+04		3.53E+04	1.10E+06	1.10E+06	1.26E+06
536.00		2.50E+04				
562.50	1.87E+04			6.91E+05		
600.00			1.74E+04			6.17E+05
625.00	1.31E+04			4.59E+05		
687.50	7.38E+03			2.98E+05		
700.00			8.15E+03			2.89E+05
750.00	4.19E+03			1.56E+05		
800.00			3.73E+03			1.32E+05
812.50	2.94E+03			1.04E+05		
875.00	1.71E+03			6.18E+04		
900.00			1.70E+03			5.68E+04
937.590	9.25E+02			3.74E+04		
1000.00	4.71E+02		6.36E+02	1.77E+04		2.71E+04

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APPENDIX A

Appendix A. DORT: Seven Layer Air-over-Ground DORT Geometry

#	Radius	Mid-point	Delta R	#	Height	Mid-point	Delta Z
1	0.0000E+00	5.0000E+02	1.0000E+03	1	-5.0000E+01	-4.7500E+01	5.0000E+00
2	1.0000E+03	1.1000E+03	2.0000E+02	2	-4.5000E+01	-4.2500E+01	5.0000E+00
3	1.2000E+03	1.3200E+03	2.4000E+02	3	-4.0000E+01	-3.7500E+01	5.0000E+00
4	1.4400E+03	1.5850E+03	2.9000E+02	4	-3.5000E+01	-3.2500E+01	5.0000E+00
5	1.7300E+03	1.9000E+03	3.4000E+02	5	-3.0000E+01	-2.7500E+01	5.0000E+00
6	2.0700E+03	2.2800E+03	4.2000E+02	6	-2.5000E+01	-2.2500E+01	5.0000E+00
7	2.4900E+03	2.7400E+03	5.0000E+02	7	-2.0000E+01	-1.9000E+01	2.0000E+00
8	2.9900E+03	3.2850E+03	5.9000E+02	8	-1.8000E+01	-1.7000E+01	2.0000E+00
9	3.5800E+03	3.9400E+03	7.2000E+02	9	-1.6000E+01	-1.5000E+01	2.0000E+00
10	4.3000E+03	4.7300E+03	8.6000E+02	10	-1.4000E+01	-1.3000E+01	2.0000E+00
11	5.1600E+03	5.6750E+03	1.0300E+03	11	-1.2000E+01	-1.1000E+01	2.0000E+00
12	6.1900E+03	6.8100E+03	1.2400E+03	12	-1.0000E+01	-9.5000E+00	1.0000E+00
13	7.4300E+03	8.0900E+03	1.3200E+03	13	-9.0000E+00	-8.5000E+00	1.0000E+00
14	8.7500E+03	1.0000E+04	2.5000E+03	14	-8.0000E+00	-7.5000E+00	1.0000E+00
15	1.1250E+04	1.2500E+04	2.5000E+03	15	-7.0000E+00	-6.5000E+00	1.0000E+00
16	1.3750E+04	1.5000E+04	2.5000E+03	16	-6.0000E+00	-5.5000E+00	1.0000E+00
17	1.6250E+04	1.7500E+04	2.5000E+03	17	-5.0000E+00	-4.5000E+00	1.0000E+00
18	1.8750E+04	2.0000E+04	2.5000E+03	18	-4.0000E+00	-3.5000E+00	1.0000E+00
19	2.1250E+04	2.2500E+04	2.5000E+03	19	-3.0000E+00	-2.5000E+00	1.0000E+00
20	2.3750E+04	2.5000E+04	2.5000E+03	20	-2.0000E+00	-1.5000E+00	1.0000E+00
21	2.6250E+04	2.7500E+04	2.5000E+03	21	-1.0000E+00	-5.0000E-01	1.0000E+00
22	2.8750E+04	3.0000E+04	2.5000E+03	22	0.0000E+00	1.0000E+02	2.0000E+02
23	3.1250E+04	3.2500E+04	2.5000E+03	23	2.0000E+02	4.0000E+02	4.0000E+02
24	3.3750E+04	3.5000E+04	2.5000E+03	24	6.0000E+02	9.0000E+02	6.0000E+02
25	3.6250E+04	3.7500E+04	2.5000E+03	25	1.2000E+03	1.5000E+03	6.0000E+02
26	3.8750E+04	4.0000E+04	2.5000E+03	26	1.8000E+03	2.2000E+03	8.0000E+02
27	4.1250E+04	4.2500E+04	2.5000E+03	27	2.6000E+03	3.1750E+03	1.1500E+03
28	4.3750E+04	4.5000E+04	2.5000E+03	28	3.7500E+03	5.0000E+03	2.5000E+03
29	4.6250E+04	4.7500E+04	2.5000E+03	29	6.2500E+03	7.5000E+03	2.5000E+03
30	4.8750E+04	5.0000E+04	2.5000E+03	30	8.7500E+03	1.0000E+04	2.5000E+03
31	5.1250E+04	5.2500E+04	2.5000E+03	31	1.1250E+04	1.2500E+04	2.5000E+03
32	5.3750E+04	5.5000E+04	2.5000E+03	32	1.3750E+04	1.5000E+04	2.5000E+03
33	5.6250E+04	5.7500E+04	2.5000E+03	33	1.6250E+04	1.7500E+04	2.5000E+03
34	5.8750E+04	6.0000E+04	2.5000E+03	34	1.8750E+04	2.0000E+04	2.5000E+03
35	6.1250E+04	6.2500E+04	2.5000E+03	35	2.1250E+04	2.2500E+04	2.5000E+03
36	6.3750E+04	6.5000E+04	2.5000E+03	36	2.3750E+04	2.5000E+04	2.5000E+03
37	6.6250E+04	6.7500E+04	2.5000E+03	37	2.6250E+04	2.7500E+04	2.5000E+03
38	6.8750E+04	7.0000E+04	2.5000E+03	38	2.8750E+04	3.0000E+04	2.5000E+03
39	7.1250E+04	7.2500E+04	2.5000E+03	39	3.1250E+04	3.2500E+04	2.5000E+03
40	7.3750E+04	7.5000E+04	2.5000E+03	40	3.3750E+04	3.5000E+04	2.5000E+03
41	7.6250E+04	7.7500E+04	2.5000E+03	41	3.6250E+04	3.7500E+04	2.5000E+03
42	7.8750E+04	8.0000E+04	2.5000E+03	42	3.8750E+04	4.0000E+04	2.5000E+03
43	8.1250E+04	8.2500E+04	2.5000E+03	43	4.1250E+04	4.2500E+04	2.5000E+03
44	8.3750E+04	8.5000E+04	2.5000E+03	44	4.3750E+04	4.4775E+04	2.0500E+03
45	8.6250E+04	8.7500E+04	2.5000E+03	45	4.5800E+04	4.6700E+04	1.8000E+03
46	8.8750E+04	9.0000E+04	2.5000E+03	46	4.7600E+04	4.8400E+04	1.6000E+03
47	9.1250E+04	9.2500E+04	2.5000E+03	47	4.9200E+04	4.9900E+04	1.4000E+03
48	9.3750E+04	9.5000E+04	2.5000E+03	48	5.0600E+04	5.1200E+04	1.2000E+03
49	9.6250E+04	9.7500E+04	2.5000E+03	49	5.1800E+04	5.2300E+04	1.0000E+03
50	9.8750E+04	1.0000E+05	2.5000E+03	50	5.2800E+04	5.3250E+04	9.0000E+02
51	1.0125E+05	1.0250E+05	2.5000E+03	51	5.3700E+04	5.4100E+04	8.0000E+02
52	1.0375E+05	1.0500E+05	2.5000E+03	52	5.4500E+04	5.4750E+04	5.0000E+02
53	1.0625E+05	1.0750E+05	2.5000E+03	53	5.5000E+04	5.5250E+04	5.0000E+02
54	1.0875E+05	1.1000E+05	2.5000E+03	54	5.5500E+04	5.5700E+04	4.0000E+02
55	1.1125E+05	1.1250E+05	2.5000E+03	55	5.5900E+04	5.6100E+04	4.0000E+02
56	1.1375E+05	1.1500E+05	2.5000E+03	56	5.6300E+04	5.6450E+04	3.0000E+02
57	1.1625E+05	1.1750E+05	2.5000E+03	57	5.6600E+04	5.6700E+04	2.0000E+02
58	1.1875E+05	1.2000E+05	2.5000E+03	58	5.6800E+04	5.6900E+04	2.0000E+02
59	1.2125E+05	1.2250E+05	2.5000E+03	59	5.7000E+04	5.7500E+04	1.0000E+03
60	1.2375E+05	1.2500E+05	2.5000E+03	60	5.8000E+04	5.8500E+04	1.0000E+03
61	1.2625E+05	1.2750E+05	2.5000E+03	61	5.9000E+04	5.9100E+04	2.0000E+02
62	1.2875E+05	1.3000E+05	2.5000E+03	62	5.9200E+04	5.9300E+04	2.0000E+02
63	1.3125E+05	1.3250E+05	2.5000E+03	63	5.9400E+04	5.9550E+04	3.0000E+02
64	1.3375E+05	1.3500E+05	2.5000E+03	64	5.9700E+04	5.9900E+04	4.0000E+02
65	1.3625E+05	1.3750E+05	2.5000E+03	65	6.0100E+04	6.0300E+04	4.0000E+02

66	1.38750E+05	1.40000E+05	2.50000E+03	66	6.05000E+04	6.07500E+04	5.00000E+02
67	1.41250E+05	1.42500E+05	2.50000E+03	67	6.10000E+04	6.13500E+04	7.00000E+02
68	1.43750E+05	1.45000E+05	2.50000E+03	68	6.17000E+04	6.21000E+04	8.00000E+02
69	1.46250E+05	1.47500E+05	2.50000E+03	69	6.25000E+04	6.30000E+04	1.00000E+03
70	1.48750E+05	1.50000E+05	2.50000E+03	70	6.35000E+04	6.38500E+04	7.00000E+02
71	1.51250E+05	1.52500E+05	2.50000E+03	71	6.42000E+04	6.48000E+04	1.20000E+03
72	1.53750E+05	1.55000E+05	2.50000E+03	72	6.54000E+04	6.61500E+04	1.50000E+03
73	1.56250E+05	1.57500E+05	2.50000E+03	73	6.69000E+04	6.77000E+04	1.60000E+03
74	1.58750E+05	1.60000E+05	2.50000E+03	74	6.85000E+04	6.97500E+04	2.50000E+03
75	1.61250E+05	1.62500E+05	2.50000E+03	75	7.10000E+04	7.22500E+04	2.50000E+03
76	1.63750E+05	1.65000E+05	2.50000E+03	76	7.35000E+04	7.47500E+04	2.50000E+03
77	1.66250E+05	1.67500E+05	2.50000E+03	77	7.60000E+04	7.72500E+04	2.50000E+03
78	1.68750E+05	1.70000E+05	2.50000E+03	78	7.85000E+04	7.97500E+04	2.50000E+03
79	1.71250E+05	1.72500E+05	2.50000E+03	79	8.10000E+04	8.22500E+04	2.50000E+03
80	1.73750E+05	1.75000E+05	2.50000E+03	80	8.35000E+04	8.47500E+04	2.50000E+03
81	1.76250E+05	1.77500E+05	2.50000E+03	81	8.60000E+04	8.72500E+04	2.50000E+03
82	1.78750E+05	1.80000E+05	2.50000E+03	82	8.85000E+04	9.00000E+04	3.00000E+03
83	1.81250E+05	1.82500E+05	2.50000E+03	83	9.15000E+04	9.30000E+04	3.00000E+03
84	1.83750E+05	1.85000E+05	2.50000E+03	84	9.45000E+04	9.60000E+04	3.00000E+03
85	1.86250E+05	1.87500E+05	2.50000E+03	85	9.75000E+04	9.90000E+04	3.00000E+03
86	1.88750E+05	1.90000E+05	2.50000E+03	86	1.00500E+05	1.02000E+05	3.00000E+03
87	1.91250E+05	1.92500E+05	2.50000E+03	87	1.03500E+05	1.05000E+05	3.00000E+03
88	1.93750E+05	1.95000E+05	2.50000E+03	88	1.06500E+05	1.08000E+05	3.00000E+03
89	1.96250E+05	1.97500E+05	2.50000E+03	89	1.09500E+05	1.11000E+05	3.00000E+03
90	1.98750E+05	2.00000E+05	2.50000E+03	90	1.12500E+05	1.14000E+05	3.00000E+03
91	2.01250E+05	2.02500E+05	2.50000E+03	91	1.15500E+05	1.17000E+05	3.00000E+03
92	2.03750E+05	2.05000E+05	2.50000E+03	92	1.18500E+05	1.20250E+05	3.50000E+03
93	2.06250E+05	2.07500E+05	2.50000E+03	93	1.22000E+05	1.23750E+05	3.50000E+03
94	2.08750E+05	2.10000E+05	2.50000E+03	94	1.25500E+05	1.27250E+05	3.50000E+03
95	2.11250E+05	2.12500E+05	2.50000E+03	95	1.29000E+05	1.30750E+05	3.50000E+03
96	2.13750E+05	2.15000E+05	2.50000E+03	96	1.32500E+05	1.34250E+05	3.50000E+03
97	2.16250E+05	2.17500E+05	2.50000E+03	97	1.36000E+05	1.37750E+05	3.50000E+03
98	2.18750E+05	2.20000E+05	2.50000E+03	98	1.39500E+05	1.41250E+05	3.50000E+03
99	2.21250E+05	2.22500E+05	2.50000E+03	99	1.43000E+05	1.44750E+05	3.50000E+03
100	2.23750E+05	2.25000E+05	2.50000E+03	100	1.46500E+05	1.48250E+05	3.50000E+03
101	2.26250E+05	2.27500E+05	2.50000E+03	101	1.50000E+05	1.52500E+05	5.00000E+03
102	2.28750E+05	2.30000E+05	2.50000E+03	102	1.55000E+05	1.57500E+05	5.00000E+03
103	2.31250E+05	2.32500E+05	2.50000E+03	103	1.60000E+05	1.62500E+05	5.00000E+03
104	2.33750E+05	2.35000E+05	2.50000E+03	104	1.65000E+05	1.67500E+05	5.00000E+03
105	2.36250E+05	2.37500E+05	2.50000E+03	105	1.70000E+05	1.72500E+05	5.00000E+03
106	2.38750E+05	2.40000E+05	2.50000E+03	106	1.75000E+05	1.77500E+05	5.00000E+03
107	2.41250E+05	2.42500E+05	2.50000E+03	107	1.80000E+05	1.82500E+05	5.00000E+03
108	2.43750E+05	2.45000E+05	2.50000E+03	108	1.85000E+05	1.87500E+05	5.00000E+03
109	2.46250E+05	2.47500E+05	2.50000E+03	109	1.90000E+05	1.92500E+05	5.00000E+03
110	2.48750E+05	2.50000E+05	2.50000E+03	110	1.95000E+05	1.97500E+05	5.00000E+03
111	2.51250E+05	2.52500E+05	2.50000E+03	111	2.00000E+05		
112	2.53750E+05	2.55000E+05	2.50000E+03				
113	2.56250E+05	2.57500E+05	2.50000E+03				
114	2.58750E+05	2.60000E+05	2.50000E+03				
115	2.61250E+05	2.62500E+05	2.50000E+03				
116	2.63750E+05	2.65000E+05	2.50000E+03				
117	2.66250E+05	2.67500E+05	2.50000E+03				
118	2.68750E+05	2.70000E+05	2.50000E+03				
119	2.71250E+05	2.72500E+05	2.50000E+03				
120	2.73750E+05	2.75000E+05	2.50000E+03				
121	2.76250E+05	2.77500E+05	2.50000E+03				
122	2.78750E+05	2.80000E+05	2.50000E+03				
123	2.81250E+05	2.82500E+05	2.50000E+03				
124	2.83750E+05	2.85000E+05	2.50000E+03				
125	2.86250E+05	2.87500E+05	2.50000E+03				
126	2.88750E+05	2.90000E+05	2.50000E+03				
127	2.91250E+05	2.92500E+05	2.50000E+03				
128	2.93750E+05	2.95000E+05	2.50000E+03				
129	2.96250E+05	2.97500E+05	2.50000E+03				
130	2.98750E+05	3.00000E+05	2.50000E+03				
131	3.01250E+05						

APPENDIX B

Appendix B. 240-Angle DORT Quadrature

	weight	mu	tau				
1	0.00000+00	-6.41230-02	-9.97942-01	66	5.55965-03	1.91013-01	-4.63828-01
2	1.02900-03	-4.21582-02	-9.97942-01	67	3.40298-03	5.47246-01	-4.63828-01
3	1.02900-03	4.21582-02	-9.97942-01	68	7.45915-03	8.29582-01	-4.63828-01
4	0.00000+00	-1.42963-01	-9.89728-01	69	0.00000+00	-9.17890-01	-3.96835-01
5	3.07825-03	-9.39923-02	-9.89728-01	70	7.75565-03	-8.59514-01	-3.96835-01
6	3.07825-03	9.39923-02	-9.89728-01	71	3.53825-03	-5.66991-01	-3.96835-01
7	0.00000+00	-2.29252-01	-9.73367-01	72	5.78064-03	-1.97905-01	-3.96835-01
8	5.10200-03	-1.50724-01	-9.73367-01	73	5.78064-03	1.97905-01	-3.96835-01
9	5.10200-03	1.50724-01	-9.73367-01	74	3.53825-03	5.66991-01	-3.96835-01
10	0.00000+00	-3.15291-01	-9.48995-01	75	7.75565-03	8.59514-01	-3.96835-01
11	7.08425-03	-2.07291-01	-9.48995-01	76	0.00000+00	-9.44812-01	-3.27613-01
12	7.08425-03	2.07291-01	-9.48995-01	77	4.89468-03	-9.22954-01	-3.27613-01
13	0.00000+00	-3.99349-01	-9.16799-01	78	3.86282-03	-7.65692-01	-3.27613-01
14	9.01350-03	-2.62555-01	-9.16799-01	79	5.13536-03	-5.05099-01	-3.27613-01
15	9.01350-03	2.62555-01	-9.16799-01	80	3.64389-03	-1.76303-01	-3.27613-01
16	0.00000+00	-4.72796-01	-8.81172-01	81	3.64389-03	1.76303-01	-3.27613-01
17	5.63869-03	-4.11087-01	-8.81172-01	82	5.13536-03	5.05099-01	-3.27613-01
18	3.16131-03	-1.43488-01	-8.81172-01	83	3.86282-03	7.65692-01	-3.27613-01
19	3.16131-03	1.43488-01	-8.81172-01	84	4.89468-03	9.22954-01	-3.27613-01
20	5.63869-03	4.11087-01	-8.81172-01	85	0.00000+00	-9.66490-01	-2.56704-01
21	0.00000+00	-5.37046-01	-8.43553-01	86	5.00102-03	-9.44130-01	-2.56704-01
22	6.41385-03	-4.66952-01	-8.43553-01	87	3.94674-03	-7.83260-01	-2.56704-01
23	3.59590-03	-1.62988-01	-8.43553-01	88	5.24693-03	-5.16688-01	-2.56704-01
24	3.59590-03	1.62988-01	-8.43553-01	89	3.72306-03	-1.80348-01	-2.56704-01
25	6.41385-03	4.66952-01	-8.43553-01	90	3.72306-03	1.80348-01	-2.56704-01
26	0.00000+00	-5.98374-01	-8.01217-01	91	5.24693-03	5.16688-01	-2.56704-01
27	7.14976-03	-5.20275-01	-8.01217-01	92	3.94674-03	7.83260-01	-2.56704-01
28	4.00849-03	-1.81600-01	-8.01217-01	93	5.00102-03	9.44130-01	-2.56704-01
29	4.00849-03	1.81600-01	-8.01217-01	94	0.00000+00	-9.82847-01	-1.84425-01
30	7.14976-03	5.20275-01	-8.01217-01	95	5.08580-03	-9.60108-01	-1.84425-01
31	0.00000+00	-6.56401-01	-7.54412-01	96	4.01365-03	-7.96516-01	-1.84425-01
32	7.84547-03	-5.70729-01	-7.54412-01	97	5.33587-03	-5.25433-01	-1.84425-01
33	4.39853-03	-1.99211-01	-7.54412-01	98	3.78617-03	-1.83400-01	-1.84425-01
34	4.39853-03	1.99211-01	-7.54412-01	99	3.78617-03	1.83400-01	-1.84425-01
35	7.84547-03	5.70729-01	-7.54412-01	100	5.33587-03	5.25433-01	-1.84425-01
36	0.00000+00	-7.11034-01	-7.03158-01	101	4.01365-03	7.96516-01	-1.84425-01
37	8.57529-03	-6.18231-01	-7.03158-01	102	5.08580-03	9.60108-01	-1.84425-01
38	4.80771-03	-2.15791-01	-7.03158-01	103	0.00000+00	-9.93815-01	-1.11045-01
39	4.80771-03	2.15791-01	-7.03158-01	104	5.15474-03	-9.70823-01	-1.11045-01
40	8.57529-03	6.18231-01	-7.03158-01	105	4.06806-03	-8.05405-01	-1.11045-01
41	0.00000+00	-7.61567-01	-6.48086-01	106	5.40820-03	-5.31297-01	-1.11045-01
42	6.42875-03	-7.13133-01	-6.48086-01	107	3.83750-03	-1.85447-01	-1.11045-01
43	2.93289-03	-4.70428-01	-6.48086-01	108	3.83750-03	1.85447-01	-1.11045-01
44	4.79164-03	-1.64201-01	-6.48086-01	109	5.40820-03	5.31297-01	-1.11045-01
45	4.79164-03	1.64201-01	-6.48086-01	110	4.06806-03	8.05405-01	-1.11045-01
46	2.93289-03	4.70428-01	-6.48086-01	111	5.15474-03	9.70823-01	-1.11045-01
47	6.42875-03	7.13133-01	-6.48086-01	112	0.00000+00	-9.99313-01	-3.70540-02
48	0.00000+00	-8.07567-01	-5.89776-01	113	5.17107-03	-9.76194-01	-3.70540-02
49	6.81415-03	-7.56207-01	-5.89776-01	114	4.08094-03	-8.09860-01	-3.70540-02
50	3.10872-03	-4.98843-01	-5.89776-01	115	5.42534-03	-5.34236-01	-3.70540-02
51	5.07890-03	-1.74119-01	-5.89776-01	116	3.84965-03	-1.86473-01	-3.70540-02
52	5.07890-03	1.74119-01	-5.89776-01	117	3.84965-03	1.86473-01	-3.70540-02
53	3.10872-03	4.98843-01	-5.89776-01	118	5.42534-03	5.34236-01	-3.70540-02
54	6.81415-03	7.56207-01	-5.89776-01	119	4.08094-03	8.09860-01	-3.70540-02
55	0.00000+00	-8.49108-01	-5.28222-01	120	5.17107-03	9.76194-01	-3.70540-02
56	7.16550-03	-7.95106-01	-5.28222-01	121	0.00000+00	-6.41230-02	9.97942-01
57	3.26901-03	-5.24503-01	-5.28222-01	122	1.02900-03	-4.21582-02	9.97942-01
58	5.34077-03	-1.83075-01	-5.28222-01	123	1.02900-03	4.21582-02	9.97942-01
59	5.34077-03	1.83075-01	-5.28222-01	124	0.00000+00	-1.42963-01	9.89728-01
60	3.26901-03	5.24503-01	-5.28222-01	125	3.07825-03	-9.39923-02	9.89728-01
61	7.16550-03	7.95106-01	-5.28222-01	126	3.07825-03	9.39923-02	9.89728-01
62	0.00000+00	-8.85925-01	-4.63828-01	127	0.00000+00	-2.29252-01	9.73367-01
63	7.45915-03	-8.29582-01	-4.63828-01	128	5.10200-03	-1.50724-01	9.73367-01
64	3.40298-03	-5.47246-01	-4.63828-01	129	5.10200-03	1.50724-01	9.73367-01
65	5.55965-03	-1.91013-01	-4.63828-01	130	0.00000+00	-3.15291-01	9.48995-01
				131	7.08425-03	-2.07291-01	9.48995-01
				132	7.08425-03	2.07291-01	9.48995-01

133	0.00000+00	-3.99349-01	9.16799-01	203	3.86282-03	7.65692-01	3.27613-01
134	9.01350-03	-2.62555-01	9.16799-01	204	4.89468-03	9.22954-01	3.27613-01
135	9.01350-03	2.62555-01	9.16799-01	205	0.00000+00	-9.66490-01	2.56704-01
136	0.00000+00	-4.72796-01	8.81172-01	206	5.00102-03	-9.44130-01	2.56704-01
137	5.63869-03	-4.11087-01	8.81172-01	207	3.94674-03	-7.83260-01	2.56704-01
138	3.16131-03	-1.43488-01	8.81172-01	208	5.24693-03	-5.16688-01	2.56704-01
139	3.16131-03	1.43488-01	8.81172-01	209	3.72306-03	-1.80348-01	2.56704-01
140	5.63869-03	4.11087-01	8.81172-01	210	3.72306-03	1.80348-01	2.56704-01
141	0.00000+00	-5.37046-01	8.43553-01	211	5.24693-03	5.16688-01	2.56704-01
142	6.41385-03	-4.66952-01	8.43553-01	212	3.94674-03	7.83260-01	2.56704-01
143	3.59590-03	-1.62988-01	8.43553-01	213	5.00102-03	9.44130-01	2.56704-01
144	3.59590-03	1.62988-01	8.43553-01	214	0.00000+00	-9.82847-01	1.84425-01
145	6.41385-03	4.66952-01	8.43553-01	215	5.08580-03	-9.60108-01	1.84425-01
146	0.00000+00	-5.98374-01	8.01217-01	216	4.01365-03	-7.96516-01	1.84425-01
147	7.14976-03	-5.20275-01	8.01217-01	217	5.33587-03	-5.25433-01	1.84425-01
148	4.00849-03	-1.81600-01	8.01217-01	218	3.78617-03	-1.83400-01	1.84425-01
149	4.00849-03	1.81600-01	8.01217-01	219	3.78617-03	1.83400-01	1.84425-01
150	7.14976-03	5.20275-01	8.01217-01	220	5.33587-03	5.25433-01	1.84425-01
151	0.00000+00	-6.56401-01	7.54412-01	221	4.01365-03	7.96516-01	1.84425-01
152	7.84547-03	-5.70729-01	7.54412-01	222	5.08580-03	9.60108-01	1.84425-01
153	4.39853-03	-1.99211-01	7.54412-01	223	0.00000+00	-9.93815-01	1.11045-01
154	4.39853-03	1.99211-01	7.54412-01	224	5.15474-03	-9.70823-01	1.11045-01
155	7.84547-03	5.70729-01	7.54412-01	225	4.06806-03	-8.05405-01	1.11045-01
156	0.00000+00	-7.11034-01	7.03158-01	226	5.40820-03	-5.31297-01	1.11045-01
157	8.57529-03	-6.18231-01	7.03158-01	227	3.83750-03	-1.85447-01	1.11045-01
158	4.80771-03	-2.15791-01	7.03158-01	228	3.83750-03	1.85447-01	1.11045-01
159	4.80771-03	2.15791-01	7.03158-01	229	5.40820-03	5.31297-01	1.11045-01
160	8.57529-03	6.18231-01	7.03158-01	230	4.06806-03	8.05405-01	1.11045-01
161	0.00000+00	-7.61567-01	6.48086-01	231	5.15474-03	9.70823-01	1.11045-01
162	6.42875-03	-7.13133-01	6.48086-01	232	0.00000+00	-9.99313-01	3.70540-02
163	2.93289-03	-4.70428-01	6.48086-01	233	5.17107-03	-9.76194-01	3.70540-02
164	4.79164-03	-1.64201-01	6.48086-01	234	4.08094-03	-8.09860-01	3.70540-02
165	4.79164-03	1.64201-01	6.48086-01	235	5.42534-03	-5.34236-01	3.70540-02
166	2.93289-03	4.70428-01	6.48086-01	236	3.84965-03	-1.86473-01	3.70540-02
167	6.42875-03	7.13133-01	6.48086-01	237	3.84965-03	1.86473-01	3.70540-02
168	0.00000+00	-8.07567-01	5.89776-01	238	5.42534-03	5.34236-01	3.70540-02
169	6.81415-03	-7.56207-01	5.89776-01	239	4.08094-03	8.09860-01	3.70540-02
170	3.10872-03	-4.98843-01	5.89776-01	240	5.17107-03	9.76194-01	3.70540-02
171	5.07890-03	-1.74119-01	5.89776-01				
172	5.07890-03	1.74119-01	5.89776-01				
173	3.10872-03	4.98843-01	5.89776-01				
174	6.81415-03	7.56207-01	5.89776-01				
175	0.00000+00	-8.49108-01	5.28222-01				
176	7.16550-03	-7.95106-01	5.28222-01				
177	3.26901-03	-5.24503-01	5.28222-01				
178	5.34077-03	-1.83075-01	5.28222-01				
179	5.34077-03	1.83075-01	5.28222-01				
180	3.26901-03	5.24503-01	5.28222-01				
181	7.16550-03	7.95106-01	5.28222-01				
182	0.00000+00	-8.85925-01	4.63828-01				
183	7.45915-03	-8.29582-01	4.63828-01				
184	3.40298-03	-5.47246-01	4.63828-01				
185	5.55965-03	-1.91013-01	4.63828-01				
186	5.55965-03	1.91013-01	4.63828-01				
187	3.40298-03	5.47246-01	4.63828-01				
188	7.45915-03	8.29582-01	4.63828-01				
189	0.00000+00	-9.17890-01	3.96835-01				
190	7.75565-03	-8.59514-01	3.96835-01				
191	3.53825-03	-5.66991-01	3.96835-01				
192	5.78064-03	-1.97905-01	3.96835-01				
193	5.78064-03	1.97905-01	3.96835-01				
194	3.53825-03	5.66991-01	3.96835-01				
195	7.75565-03	8.59514-01	3.96835-01				
196	0.00000+00	-9.44812-01	3.27613-01				
197	4.89468-03	-9.22954-01	3.27613-01				
198	3.86282-03	-7.65692-01	3.27613-01				
199	5.13536-03	-5.05099-01	3.27613-01				
200	3.64389-03	-1.76303-01	3.27613-01				
201	3.64389-03	1.76303-01	3.27613-01				
202	5.13536-03	5.05099-01	3.27613-01				

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