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IMPROVING HIROSHIMA AIR-OVER-GROUND THERMAL/EPITHERMAL ACTIVATION CALCULATIONS USING A MUSH MODEL TO SHOW THE IMPORTANCE OF LOCAL SHIELDING

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ABSTRACT

Achieving agreement between measured and calculated neutron activation data resulting from Hiroshima and Nagasaki A-bomb detonations has been a major problem since the early 1980's. This has been particularly true for the materials that are activated by thermal and epithermal neutrons. Since thermal and epithermal neutrons are not transported very far from the weapon, the local shielding environment around the measurement location can be very important. A set of calculations incorporating an average density local-environment material (mush) has been made to demonstrate that the local environment plays an important role in the calculation-measurement agreement process. The optimum solution would be to include the local environment in all thermal neutron response calculations.

1. INTRODUCTION

One of the difficulties of the analysis of the Hiroshima A-bomb effects, has been achieving agreement between measured and calculated neutron activation data. This has been particularly true for the materials that are activated by thermal and epithermal neutrons, e.g., cobalt, europium and chlorine. A standard was adopted to calculate neutron fluence distributions in air-over-ground environments using calculated weapon neutron leakage spectra and detailed descriptions of the ground and atmospheric conditions at the time of the events. Dose and activation responses were calculated at 1 m above the ground and as a function of distance from the burst.

The measured and calculated thermal neutron activation data, however, were found to differ depending on the location at which the measured responses were obtained. The inference here is that locations where irradiated material resided at the time of the explosions caused modifications to the incident neutron spectrum. For example, the activated material may have initially been in the ground, in concrete, or in structures or buildings that were destroyed by the bomb blasts. Historically, the air-over-ground models do not account for local effects. That is, the air-ground interface is a flat surface: no local environment such as rolling hills, houses, buildings, etc. Moreover, the ground contained the same moisture content at all ground ranges. Measured and calculated data were found to differ by as much as 20 to 50% depending on location and distance from the detonation. Interestingly, measured samples taken at the same ground range also show marked differences among themselves.

In the actual weapon environment, thermal neutrons at points of interest are, for the most part, produced in the ground and, to a lesser extent, in the air. Neutrons are further moderated in materials that were above the surface at the time of the explosion, i.e., wood, concrete, glass, etc.

2. ACHIEVING ADDITIONAL NEUTRON THERMALIZATION IN THE CALCULATIONAL MODELS

In 1982, J. Marcum[1] suggested that the air-over-ground calculations should be tailored to include an average density material that he referred to as "mush", which would account for the perturbation of the free-in-air environment by the presence of buildings and other structures.

Little information is available on the specific locations and construction details of the buildings and other structures within the blast damage radius at Hiroshima. In order to construct a representative "mush" model for inclusion in the discrete ordinates and Monte Carlo calculational models, it was assumed that only houses were present on the surface at the time of the explosions, and that they were the only buildings extending to 2 km from the hypocenter.

3. DESCRIPTION OF THE MUSH MODEL

The air-over-ground geometry was modeled in cylindrical RZ geometry with a lower layer of ground, a middle layer of mush, and an upper layer of air. The compositions for the air and ground in the calculational models were taken from DS86 Report[2] and correspond to the atmospheric and soil conditions reconstructed by DS86 for the time of the event. These data are summarized in Tables 1 and 2.

The compositions for the mush were derived from the data given in Table 4, Chapter 7, of DS86[2]. The mush was calculated by assuming that a house was made of 4 equal-volume rooms, wall thickness of 6 cm, roof tile/mud thickness of 2 cm, roof-wood thickness of 2 cm, with outside house walls of length 8 m by 7 m. These data are summarized in Table 3.

Table 1. Hiroshima Atmospheric Density and Composition Profiles[2]

Air Zone	Height	Atmospheric Density (g cm^{-3})			Atom Density (atom b^{-1} cm^{-1})[a]			
	(m)	Moist Air	Dry Air	Water Vapor	Hydrogen	Nitrogen	Oxygen	Argon
Mean	0-500	1.141E-3*	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} cm^2.

* Read as 1.141x10^{-3} g cm^{-3}

Table 2. Hiroshima Wet Ground Composition[(2)]

Chemical Composition	Atom Density (atom b^{-1} cm^{-1})[a]	Percent by Mass
H	3.085E-2*	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 x 10^{-24} cm^2.

• Read as 3.085x10^{-2} g cm^{-3}

Table 3. Hiroshima House Mush Composition[(2)]

		Atom Density (atom b^{-1} cm^{-1})[a]					
Element	Isotope	Roof Wood	Roof Tile & Mud	Wall	Air	Mush (Element)	Mush (Isotope)
H		4.050E-2*	4.946E-3	8.301E-3	1.323E-6	5.427E-4	
C		2.131E-2	2.533E-4	2.215E-3		1.759E-4	
N		3.655E-4		3.406E-5	3.715E-5	3.796E-5	
	N14						3.783E-5
	N15						1.367E-7
O		1.878E-2	1.866E-2	1.871E-2	1.063E-5	1.014E-3	
	O16						1.012E-03
	O17						4.057E-7
Na			3.597E-4	3.264E-4		1.654E-5	
Mg			2.765E-4	2.509E-4		1.271E-5	
Al			4.373E-3	3.968E-3		2.011E-4	
Si			3.714E-3	3.365E-3		1.705E-4	
K			7.101E_4	6.443E-4		3.265E-5	
Ca			1.988E-4	1.804E-4		9.141E-6	
Ti			1.359E-4	1.266E-4		6.403E-6	
Fe			2.792E-4	2.534E-4		1.284E-5	
	Fe54						7.447E-7
	Fe56						1.179E-5
	Fe57						2.696E-7
	Fe58						3.852e-8

[a] b = barn = 1 x 10^{-24} cm^2.

* Read as 4.050x10^{-2} atoms.b^{-1}.cm^{-1}

4. METHODS OF CALCULATION

4.1 DISCRETE ORDINATES

The energy- and angle-dependent source was located on the axis of the cylinder at a height of 580 m above the ground-mush interface. 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, the mush was a 6-m-thick layer divided into 2 mesh intervals, and the air region was a 2000-m-high layer divided into 90 mesh intervals. The radius of the geometry extended to 3000 m in 130 mesh intervals. A complete description of the air-mush-ground geometry used in the transport calculations is given in Appendix A.

The neutron and photon leakage[3] from the Hiroshima weapon was calculated by the Los Alamos National Laboratory (LANL) staff. 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 energy groups correspond to the VITAMIN-B6[4] neutron fine group structure and are the same as those used to express the cross-sections in the transport calculations.

The calculations were carried out in several steps. First, the GRTUNCL[5] code was used to obtain the uncollided neutron fluence and first collision sources throughout the geometric mesh. This calculation is essential for mitigating ray effects that occur when the mesh size is small compared to the mean free path of the transported neutrons. To further minimize these effects, a 240-angle quadrature (Appendix B) was used in the calculations.

The first collision source was then used, along with the cross-sections and air-over-ground geometry description, as the input to the DORT[6] two-dimensional discrete ordinates transport code in order 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 $^{59}Co(n,\gamma)^{60}Co$ response functions to obtain the activation at 1 m above the ground.

4.2 MONTE CARLO

Monte Carlo calculations were performed using the MCNP4C code[7]. 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 mean composition specified in Table 1. The neutron fluence was estimated using neutron cell flux tallies and the transport was executed using ENDF/B-VI (v6.2) cross sections.

The mush layer was modeled as a 6-m-high layer that extended over the 2000 m radial dimension. The mush composition was the same as that used on the DORT calculation and given in Table 3.

Three separate Monte Carlo calculations were carried out to assess the merits of different mush-air-ground compositions and dispositions. These included:

1. The 6-m-high mush layer.
2. Discrete 200-m-wide mush layers separated by 25-m-wide air-over-ground layers to simulate the presence of mush "buildings."[8]
3. A 6-m-high mush layer over air replaced the ground layer.

The fluences, calculated at one meter above the ground, were folded with the $^{59}Co(n,\gamma)^{60}Co$-activation cross-section. 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. Fractional standard deviations in the responses between 0 and ~600 m were generally <3%. At greater distances, the uncertainties in the responses increase to 5–15%. The large statistical fluctuations in the data at distances beyond 500m do not significantly impact the trend in the Co response at these distances. Improved statistics can be achieved by increasing the number of neutron source particles (longer running times) or by incorporating variance reduction schemes such as splitting or biasing to increase the thermal neutron population at long distances.

5. RESULTS

The calculated ^{60}Co responses obtained using Monte Carlo and Discrete Ordinates methods are compared as a function of ground range in Figure 1 and Table 4. The standard air-over-ground results are shown as open circles. The results obtained using the DORT code are shown by the solid line and are in good agreement with the similar MCNP results. Inclusion of the 6-m-high mush layer above the ground, shown by the open squares, lowers the Co responses by a factor of ~1.7. When the mush buildings and streets are modeled, the Co response fluctuates about the air-over-ground results and reproduces the air-over-mush results where there are "buildings" and the air-over-ground results where there are "streets."

An interesting phenomenon is observed when the ground layer is replaced by air. In this case, the Co response is lower than the air-over-ground results by almost a factor of four and lower than the air-over-mush results by about a factor of two. The important point to note is that the ground plays a major role in thermalizing the weapon neutrons. Accurate modeling of the ground composition - in addition to the local environment - is essential to achieve agreement between measured and calculated thermal neutron responses.

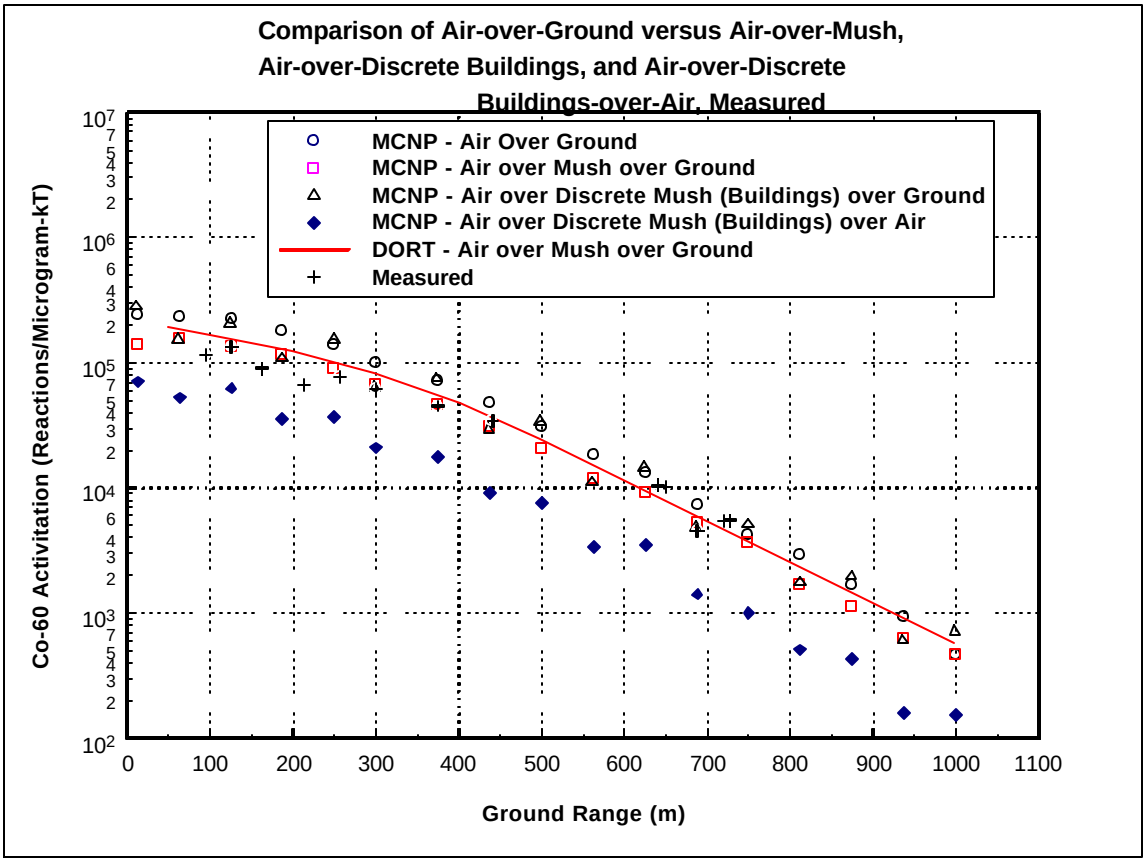

Figure 1. Comparison of Air-over-Ground versus Air-over-Mush, Air-over-Discrete Buildings, and Air-over-Discrete Buildings-over-Air, Measured.

Table 4. Results of MCNP and DORT Calculations for Different Air-over-MUSH Geometry Configurations

Ground Range (m)	Slant Range (m)	MCNP Air over Ground	MCNP Air over Mush	MCNP Air and Mush Buildings	MCNP Air over Mush over Air	DORT
		Reactions /(microgram•kT)				
12.50	580.13	2.46E+05	1.38E+05	2.79E+05	7.06E+04	
50.00	582.15					1.91E+05
62.50	583.36	2.37E+05	1.53E+05	1.53E+05	5.27E+04	
100.00	588.56					1.66E+05
125.00	593.32	2.21E+05	1.33E+05	2.03E+05	6.31E+04	
187.50	609.55	1.80E+05	1.14E+05	1.08E+05	3.58E+04	
200.00	613.51					1.24E+05
250.00	631.59	1.40E+05	8.86E+04	1.51E+05	3.73E+04	
300.00	652.99	1.00E+05	6.70E+04	6.33E+04	2.10E+04	8.09E+04
375.00	690.67	7.14E+04	4.69E+04	7.51E+04	1.78E+04	
400.00	706.26					4.66E+04
437.50	726.50	4.73E+04	3.03E+04	2.91E+04	9.06E+03	

Ground Range (m)	Slant Range (m)	MCNP Air over Ground	MCNP Air over Mush	MCNP Air and Mush Buildings	MCNP Air over Mush over Air	DORT
			Reactions /(microgram•kT)			
500.00	765.77	3.03E+04	2.06E+04	3.36E+04	7.56E+03	2.46E+04
562.50	807.96	1.87E+04	1.18E+04	1.10E+04	3.42E+03	
625.00	852.66	1.31E+04	9.00E+03	1.46E+04	3.54E+03	
687.50	899.48	7.38E+03	5.22E+03	4.79E+03	1.43E+03	
750.00	948.10	4.19E+03	3.64E+03	5.03E+03	1.01E+03	
812.50	998.28	2.94E+03	1.70E+03	1.73E+03	5.11E+02	
875.00	1049.77	1.71E+03	1.13E+03	1.95E+03	4.36E+02	
937.50	1102.41	9.25E+02	6.33E+02	6.01E+02	1.59E+02	
1000.00	1156.03	4.71E+02	4.71E+02	7.06E+02	1.55E+02	5.65E+02

* Read as 2.46×10^5

6. CONCLUSIONS

In all air-over-ground (other material) calculations, doses/reactions are usually determined at 1 m above the ground-(other material) interface, but are compared to measured values that are not located at 1 m above the ground. For line-of-sight, high-energy measurements, agreement should be fairly good. However, for thermal reactions where the measurement might be at the correct ground range, but not at one meter above the interface, and where other local shielding is not included in the calculational models, agreement between measured and calculated thermal fluxes will certainly vary by a wide margin. A comparison of the MCNP air-over-mush and air-over-ground (Table 4) shows that the Co activation was reduced by the mush of approximately 60 percent. The set of mush calculations summarized here was an attempt ONLY to indicate that the local environment plays an important role in the calculation-measurement agreement process. It was NOT to indicate that a mush should be used or otherwise modeled in the calculations. The optimum solution would be to include the local environment in all thermal neutron response calculations.

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8. The discrete mush "building"-air interval model was suggested by D. Kaul, SAIC, and a member of the U.S. Working Group on Hiroshima Dose Reassessment.

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A P P E N D I X A

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

#	Radius	Mid-point	Delta R	#	Height	Mid-point	Delta Z
1	0.00000E+00	5.00000E+02	1.00000E+03	1	-5.00000E+01	-4.75000E+01	5.00000E+00
2	1.00000E+03	1.10000E+03	2.00000E+02	2	-4.50000E+01	-4.25000E+01	5.00000E+00
3	1.20000E+03	1.32000E+03	2.40000E+02	3	-4.00000E+01	-3.75000E+01	5.00000E+00
4	1.44000E+03	1.58500E+03	2.90000E+02	4	-3.50000E+01	-3.25000E+01	5.00000E+00
5	1.73000E+03	1.90000E+03	3.40000E+02	5	-3.00000E+01	-2.75000E+01	5.00000E+00
6	2.07000E+03	2.28000E+03	4.20000E+02	6	-2.50000E+01	-2.25000E+01	5.00000E+00
7	2.49000E+03	2.74000E+03	5.00000E+02	7	-2.00000E+01	-1.90000E+01	2.00000E+00
8	2.99000E+03	3.28500E+03	5.90000E+02	8	-1.80000E+01	-1.70000E+01	2.00000E+00
9	3.58000E+03	3.94000E+03	7.20000E+02	9	-1.60000E+01	-1.50000E+01	2.00000E+00
10	4.30000E+03	4.73000E+03	8.60000E+02	10	-1.40000E+01	-1.30000E+01	2.00000E+00
11	5.16000E+03	5.67500E+03	1.03000E+03	11	-1.20000E+01	-1.10000E+01	2.00000E+00
12	6.19000E+03	6.81000E+03	1.24000E+03	12	-1.00000E+01	-9.50000E+00	1.00000E+00
13	7.43000E+03	8.09000E+03	1.32000E+03	13	-9.00000E+00	-8.50000E+00	1.00000E+00
14	8.75000E+03	1.00000E+04	2.50000E+03	14	-8.00000E+00	-7.50000E+00	1.00000E+00
15	1.12500E+04	1.25000E+04	2.50000E+03	15	-7.00000E+00	-6.50000E+00	1.00000E+00
16	1.37500E+04	1.50000E+04	2.50000E+03	16	-6.00000E+00	-5.50000E+00	1.00000E+00
17	1.62500E+04	1.75000E+04	2.50000E+03	17	-5.00000E+00	-4.50000E+00	1.00000E+00
18	1.87500E+04	2.00000E+04	2.50000E+03	18	-4.00000E+00	-3.50000E+00	1.00000E+00
19	2.12500E+04	2.25000E+04	2.50000E+03	19	-3.00000E+00	-2.50000E+00	1.00000E+00
20	2.37500E+0	2.50000E+0	2.50000E+0	20	-	-	1.00000E+0

	4	4	3		2.00000E+00	1.50000E+00	0
21	2.62500E+04	2.75000E+04	2.50000E+03	21	-1.00000E+00	-5.00000E-01	1.00000E+00
22	2.87500E+04	3.00000E+04	2.50000E+03	22	0.00000E+00	1.00000E+02	2.00000E+02
23	3.12500E+04	3.25000E+04	2.50000E+03	23	2.00000E+02	4.00000E+02	4.00000E+02
24	3.37500E+04	3.50000E+04	2.50000E+03	24	6.00000E+02	9.00000E+02	6.00000E+02
25	3.62500E+04	3.75000E+04	2.50000E+03	25	1.20000E+03	1.50000E+03	6.00000E+02
26	3.87500E+04	4.00000E+04	2.50000E+03	26	1.80000E+03	2.20000E+03	8.00000E+02
27	4.12500E+04	4.25000E+04	2.50000E+03	27	2.60000E+03	3.17500E+03	1.15000E+03
28	4.37500E+04	4.50000E+04	2.50000E+03	28	3.75000E+03	5.00000E+03	2.50000E+03
29	4.62500E+04	4.75000E+04	2.50000E+03	29	6.25000E+03	7.50000E+03	2.50000E+03
30	4.87500E+04	5.00000E+04	2.50000E+03	30	8.75000E+03	1.00000E+04	2.50000E+03
31	5.12500E+04	5.25000E+04	2.50000E+03	31	1.12500E+04	1.25000E+04	2.50000E+03
32	5.37500E+04	5.50000E+04	2.50000E+03	32	1.37500E+04	1.50000E+04	2.50000E+03
33	5.62500E+04	5.75000E+04	2.50000E+03	33	1.62500E+04	1.75000E+04	2.50000E+03
34	5.87500E+04	6.00000E+04	2.50000E+03	34	1.87500E+04	2.00000E+04	2.50000E+03
35	6.12500E+04	6.25000E+04	2.50000E+03	35	2.12500E+04	2.25000E+04	2.50000E+03
36	6.37500E+04	6.50000E+04	2.50000E+03	36	2.37500E+04	2.50000E+04	2.50000E+03
37	6.62500E+04	6.75000E+04	2.50000E+03	37	2.62500E+04	2.75000E+04	2.50000E+03
38	6.87500E+04	7.00000E+04	2.50000E+03	38	2.87500E+04	3.00000E+04	2.50000E+03
39	7.12500E+04	7.25000E+04	2.50000E+03	39	3.12500E+04	3.25000E+04	2.50000E+03
40	7.37500E+04	7.50000E+04	2.50000E+03	40	3.37500E+04	3.50000E+04	2.50000E+03
41	7.62500E+04	7.75000E+04	2.50000E+03	41	3.62500E+04	3.75000E+04	2.50000E+03
42	7.87500E+04	8.00000E+04	2.50000E+03	42	3.87500E+04	4.00000E+04	2.50000E+03
43	8.12500E+04	8.25000E+04	2.50000E+03	43	4.12500E+04	4.25000E+04	2.50000E+03
44	8.37500E+04	8.50000E+04	2.50000E+03	44	4.37500E+04	4.47750E+04	2.05000E+03
45	8.62500E+04	8.75000E+04	2.50000E+03	45	4.58000E+04	4.67000E+04	1.80000E+03
46	8.87500E+04	9.00000E+04	2.50000E+03	46	4.76000E+04	4.84000E+04	1.60000E+03
47	9.12500E+04	9.25000E+04	2.50000E+03	47	4.92000E+04	4.99000E+04	1.40000E+03
48	9.37500E+04	9.50000E+04	2.50000E+03	48	5.06000E+04	5.12000E+04	1.20000E+03
49	9.62500E+04	9.75000E+04	2.50000E+03	49	5.18000E+04	5.23000E+04	1.00000E+03

50	9.87500E+04	1.00000E+05	2.50000E+03	50	5.28000E+04	5.32500E+04	9.00000E+02
51	1.01250E+05	1.02500E+05	2.50000E+03	51	5.37000E+04	5.41000E+04	8.00000E+02
52	1.03750E+05	1.05000E+05	2.50000E+03	52	5.45000E+04	5.47500E+04	5.00000E+02
53	1.06250E+05	1.07500E+05	2.50000E+03	53	5.50000E+04	5.52500E+04	5.00000E+02
54	1.08750E+05	1.10000E+05	2.50000E+03	54	5.55000E+04	5.57000E+04	4.00000E+02
55	1.11250E+05	1.12500E+05	2.50000E+03	55	5.59000E+04	5.61000E+04	4.00000E+02
56	1.13750E+05	1.15000E+05	2.50000E+03	56	5.63000E+04	5.64500E+04	3.00000E+02
57	1.16250E+05	1.17500E+05	2.50000E+03	57	5.66000E+04	5.67000E+04	2.00000E+02
58	1.18750E+05	1.20000E+05	2.50000E+03	58	5.68000E+04	5.69000E+04	2.00000E+02
59	1.21250E+05	1.22500E+05	2.50000E+03	59	5.70000E+04	5.75000E+04	1.00000E+03
60	1.23750E+05	1.25000E+05	2.50000E+03	60	5.80000E+04	5.85000E+04	1.00000E+03
61	1.26250E+05	1.27500E+05	2.50000E+03	61	5.90000E+04	5.91000E+04	2.00000E+02
62	1.28750E+05	1.30000E+05	2.50000E+03	62	5.92000E+04	5.93000E+04	2.00000E+02
63	1.31250E+05	1.32500E+05	2.50000E+03	63	5.94000E+04	5.95500E+04	3.00000E+02
64	1.33750E+05	1.35000E+05	2.50000E+03	64	5.97000E+04	5.99000E+04	4.00000E+02
65	1.36250E+05	1.37500E+05	2.50000E+03	65	6.01000E+04	6.03000E+04	4.00000E+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+0	1.75000E+0	2.50000E+0	80	8.35000E+0	8.47500E+0	2.50000E+0

	5	5	3		4	4	3
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				

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Appendix B. 20 Angle DORT Quadrature

	weight	mu	tau
1	0.00000+00	-6.41230-02	-9.97942-01
2	1.02900-03	-4.21582-02	-9.97942-01
3	1.02900-03	4.21582-02	-9.97942-01
4	0.00000+00	-1.42963-01	-9.89728-01
5	3.07825-03	-9.39923-02	-9.89728-01
6	3.07825-03	9.39923-02	-9.89728-01
7	0.00000+00	-2.29252-01	-9.73367-01
8	5.10200-03	-1.50724-01	-9.73367-01
9	5.10200-03	1.50724-01	-9.73367-01
10	0.00000+00	-3.15291-01	-9.48995-01
11	7.08425-03	-2.07291-01	-9.48995-01
12	7.08425-03	2.07291-01	-9.48995-01
13	0.00000+00	-3.99349-01	-9.16799-01
14	9.01350-03	-2.62555-01	-9.16799-01
15	9.01350-03	2.62555-01	-9.16799-01
16	0.00000+00	-4.72796-01	-8.81172-01
17	5.63869-03	-4.11087-01	-8.81172-01
18	3.16131-03	-1.43488-01	-8.81172-01
19	3.16131-03	1.43488-01	-8.81172-01
20	5.63869-03	4.11087-01	-8.81172-01
21	0.00000+00	-5.37046-01	-8.43553-01
22	6.41385-03	-4.66952-01	-8.43553-01
23	3.59590-03	-1.62988-01	-8.43553-01
24	3.59590-03	1.62988-01	-8.43553-01
25	6.41385-03	4.66952-01	-8.43553-01
26	0.00000+00	-5.98374-01	-8.01217-01
27	7.14976-03	-5.20275-01	-8.01217-01
28	4.00849-03	-1.81600-01	-8.01217-01
29	4.00849-03	1.81600-01	-8.01217-01
30	7.14976-03	5.20275-01	-8.01217-01
31	0.00000+00	-6.56401-01	-7.54412-01
32	7.84547-03	-5.70729-01	-7.54412-01
33	4.39853-03	-1.99211-01	-7.54412-01
34	4.39853-03	1.99211-01	-7.54412-01
35	7.84547-03	5.70729-01	-7.54412-01
36	0.00000+00	-7.11034-01	-7.03158-01
37	8.57529-03	-6.18231-01	-7.03158-01
38	4.80771-03	-2.15791-01	-7.03158-01
39	4.80771-03	2.15791-01	-7.03158-01
40	8.57529-03	6.18231-01	-7.03158-01
41	0.00000+00	-7.61567-01	-6.48086-01
42	6.42875-03	-7.13133-01	-6.48086-01
43	2.93289-03	-4.70428-01	-6.48086-01
44	4.79164-03	-1.64201-01	-6.48086-01
45	4.79164-03	1.64201-01	-6.48086-01
46	2.93289-03	4.70428-01	-6.48086-01
47	6.42875-03	7.13133-01	-6.48086-01
48	0.00000+00	-8.07567-01	-5.89776-01
49	6.81415-03	-7.56207-01	-5.89776-01
50	3.10872-03	-4.98843-01	-5.89776-01
51	5.07890-03	-1.74119-01	-5.89776-01
52	5.07890-03	1.74119-01	-5.89776-01
53	3.10872-03	4.98843-01	-5.89776-01
54	6.81415-03	7.56207-01	-5.89776-01
55	0.00000+00	-8.49108-01	-5.28222-01
56	7.16550-03	-7.95106-01	-5.28222-01
57	3.26901-03	-5.24503-01	-5.28222-01

58	5.34077-03	-1.83075-01	-5.28222-01
59	5.34077-03	1.83075-01	-5.28222-01
60	3.26901-03	5.24503-01	-5.28222-01
61	7.16550-03	7.95106-01	-5.28222-01
62	0.00000+00	-8.85925-01	-4.63828-01
63	7.45915-03	-8.29582-01	-4.63828-01
64	3.40298-03	-5.47246-01	-4.63828-01
65	5.55965-03	-1.91013-01	-4.63828-01
66	5.55965-03	1.91013-01	-4.63828-01
67	3.40298-03	5.47246-01	-4.63828-01
68	7.45915-03	8.29582-01	-4.63828-01
69	0.00000+00	-9.17890-01	-3.96835-01
70	7.75565-03	-8.59514-01	-3.96835-01
71	3.53825-03	-5.66991-01	-3.96835-01
72	5.78064-03	-1.97905-01	-3.96835-01
73	5.78064-03	1.97905-01	-3.96835-01
74	3.53825-03	5.66991-01	-3.96835-01
75	7.75565-03	8.59514-01	-3.96835-01
76	0.00000+00	-9.44812-01	-3.27613-01
77	4.89468-03	-9.22954-01	-3.27613-01
78	3.86282-03	-7.65692-01	-3.27613-01
79	5.13536-03	-5.05099-01	-3.27613-01
80	3.64389-03	-1.76303-01	-3.27613-01
81	3.64389-03	1.76303-01	-3.27613-01
82	5.13536-03	5.05099-01	-3.27613-01
83	3.86282-03	7.65692-01	-3.27613-01
84	4.89468-03	9.22954-01	-3.27613-01
85	0.00000+00	-9.66490-01	-2.56704-01
86	5.00102-03	-9.44130-01	-2.56704-01
87	3.94674-03	-7.83260-01	-2.56704-01
88	5.24693-03	-5.16688-01	-2.56704-01
89	3.72306-03	-1.80348-01	-2.56704-01
90	3.72306-03	1.80348-01	-2.56704-01
91	5.24693-03	5.16688-01	-2.56704-01
92	3.94674-03	7.83260-01	-2.56704-01
93	5.00102-03	9.44130-01	-2.56704-01
94	0.00000+00	-9.82847-01	-1.84425-01
95	5.08580-03	-9.60108-01	-1.84425-01
96	4.01365-03	-7.96516-01	-1.84425-01
97	5.33587-03	-5.25433-01	-1.84425-01
98	3.78617-03	-1.83400-01	-1.84425-01
99	3.78617-03	1.83400-01	-1.84425-01
100	5.33587-03	5.25433-01	-1.84425-01
101	4.01365-03	7.96516-01	-1.84425-01
102	5.08580-03	9.60108-01	-1.84425-01
103	0.00000+00	-9.93815-01	-1.11045-01
104	5.15474-03	-9.70823-01	-1.11045-01
105	4.06806-03	-8.05405-01	-1.11045-01
106	5.40820-03	-5.31297-01	-1.11045-01
107	3.83750-03	-1.85447-01	-1.11045-01
108	3.83750-03	1.85447-01	-1.11045-01
109	5.40820-03	5.31297-01	-1.11045-01
110	4.06806-03	8.05405-01	-1.11045-01
111	5.15474-03	9.70823-01	-1.11045-01
112	0.00000+00	-9.99313-01	-3.70540-02
113	5.17107-03	-9.76194-01	-3.70540-02
114	4.08094-03	-8.09860-01	-3.70540-02
115	5.42534-03	-5.34236-01	-3.70540-02
116	3.84965-03	-1.86473-01	-3.70540-02
117	3.84965-03	1.86473-01	-3.70540-02
118	5.42534-03	5.34236-01	-3.70540-02

119	4.08094-03	8.09860-01	-3.70540-02
120	5.17107-03	9.76194-01	-3.70540-02
121	0.00000+00	-6.41230-02	9.97942-01
122	1.02900-03	-4.21582-02	9.97942-01
123	1.02900-03	4.21582-02	9.97942-01
124	0.00000+00	-1.42963-01	9.89728-01
125	3.07825-03	-9.39923-02	9.89728-01
126	3.07825-03	9.39923-02	9.89728-01
127	0.00000+00	-2.29252-01	9.73367-01
128	5.10200-03	-1.50724-01	9.73367-01
129	5.10200-03	1.50724-01	9.73367-01
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
134	9.01350-03	-2.62555-01	9.16799-01
135	9.01350-03	2.62555-01	9.16799-01
136	0.00000+00	-4.72796-01	8.81172-01
137	5.63869-03	-4.11087-01	8.81172-01
138	3.16131-03	-1.43488-01	8.81172-01
139	3.16131-03	1.43488-01	8.81172-01
140	5.63869-03	4.11087-01	8.81172-01
141	0.00000+00	-5.37046-01	8.43553-01
142	6.41385-03	-4.66952-01	8.43553-01
143	3.59590-03	-1.62988-01	8.43553-01
144	3.59590-03	1.62988-01	8.43553-01
145	6.41385-03	4.66952-01	8.43553-01
146	0.00000+00	-5.98374-01	8.01217-01
147	7.14976-03	-5.20275-01	8.01217-01
148	4.00849-03	-1.81600-01	8.01217-01
149	4.00849-03	1.81600-01	8.01217-01
150	7.14976-03	5.20275-01	8.01217-01
151	0.00000+00	-6.56401-01	7.54412-01
152	7.84547-03	-5.70729-01	7.54412-01
153	4.39853-03	-1.99211-01	7.54412-01
154	4.39853-03	1.99211-01	7.54412-01
155	7.84547-03	5.70729-01	7.54412-01
156	0.00000+00	-7.11034-01	7.03158-01
157	8.57529-03	-6.18231-01	7.03158-01
158	4.80771-03	-2.15791-01	7.03158-01
159	4.80771-03	2.15791-01	7.03158-01
160	8.57529-03	6.18231-01	7.03158-01
161	0.00000+00	-7.61567-01	6.48086-01
162	6.42875-03	-7.13133-01	6.48086-01
163	2.93289-03	-4.70428-01	6.48086-01
164	4.79164-03	-1.64201-01	6.48086-01
165	4.79164-03	1.64201-01	6.48086-01
166	2.93289-03	4.70428-01	6.48086-01
167	6.42875-03	7.13133-01	6.48086-01
168	0.00000+00	-8.07567-01	5.89776-01
169	6.81415-03	-7.56207-01	5.89776-01
170	3.10872-03	-4.98843-01	5.89776-01
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
203	3.86282-03	7.65692-01	3.27613-01
204	4.89468-03	9.22954-01	3.27613-01
205	0.00000+00	-9.66490-01	2.56704-01
206	5.00102-03	-9.44130-01	2.56704-01
207	3.94674-03	-7.83260-01	2.56704-01
208	5.24693-03	-5.16688-01	2.56704-01
209	3.72306-03	-1.80348-01	2.56704-01
210	3.72306-03	1.80348-01	2.56704-01
211	5.24693-03	5.16688-01	2.56704-01
212	3.94674-03	7.83260-01	2.56704-01
213	5.00102-03	9.44130-01	2.56704-01
214	0.00000+00	-9.82847-01	1.84425-01
215	5.08580-03	-9.60108-01	1.84425-01
216	4.01365-03	-7.96516-01	1.84425-01
217	5.33587-03	-5.25433-01	1.84425-01
218	3.78617-03	-1.83400-01	1.84425-01
219	3.78617-03	1.83400-01	1.84425-01
220	5.33587-03	5.25433-01	1.84425-01
221	4.01365-03	7.96516-01	1.84425-01
222	5.08580-03	9.60108-01	1.84425-01
223	0.00000+00	-9.93815-01	1.11045-01
224	5.15474-03	-9.70823-01	1.11045-01
225	4.06806-03	-8.05405-01	1.11045-01
226	5.40820-03	-5.31297-01	1.11045-01
227	3.83750-03	-1.85447-01	1.11045-01
228	3.83750-03	1.85447-01	1.11045-01
229	5.40820-03	5.31297-01	1.11045-01
230	4.06806-03	8.05405-01	1.11045-01
231	5.15474-03	9.70823-01	1.11045-01
232	0.00000+00	-9.99313-01	3.70540-02
233	5.17107-03	-9.76194-01	3.70540-02
234	4.08094-03	-8.09860-01	3.70540-02
235	5.42534-03	-5.34236-01	3.70540-02
236	3.84965-03	-1.86473-01	3.70540-02
237	3.84965-03	1.86473-01	3.70540-02
238	5.42534-03	5.34236-01	3.70540-02
239	4.08094-03	8.09860-01	3.70540-02
240	5.17107-03	9.76194-01	3.70540-02

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