Hoja 3

Método de Clarkson

Tissue-Air Ratios for Rectangular or Irregular Fields

Tables of tissue-air ratios for a wide range of beam sizes and shapes can be prepared from relatively few measurements by using data for circular beams. Such data can be measured directly as was done by Johns (J10) or may be obtained from measurements made in square beams as discussed in section 10.08. Tissue-air ratios for rectangular beams can then be obtained from data for circular beams by the sector integration procedure first introduced by Clarkson (C7). The method will be illustrated by determining the tissue-air ratio for a 4 × 15 cm field of cobalt radiation at a depth of 10 cm. Figure 10-6 shows tissue-air ratios for a depth of 10 cm (Table B-5c) plotted as a function of beam radius. The insert shows the 4 × 15 cm field, and radii have been drawn from its center at angles of 5°, 15°, 25°, to 85° so that the rectangular field may be replaced by a series of sectors of circular fields as indicated. The angles, radii, and corresponding tissue-air ratios, read from the graph in Figure 10-6, are shown in Table 10-1. The tissue-air ratio for the rectangular field is 0.660. The area of the rectangular field is 4 × 15 = 60 cm². A circular field with this area has a radius of 4.36 cm and gives a tissue-air ratio of 0.681 for 10 cm depth whereas that for the rectangular field is only 0.660. The rectangular field contributes less scatter to its center than would a circular field of equal area because some of its scatter, coming from points near the ends of the rectangle, must travel further than from points near the edge of the circle. The scatter coming from farther away will be attenuated more.

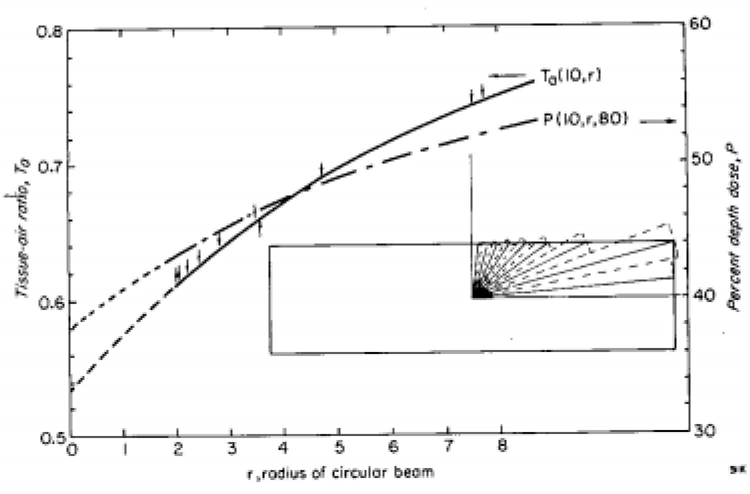

Figure 10-6. Diagram to illustrate how a rectangular field can be broken up into a number of sectors allowing one to calculate the tissue-air ratio, T_a, or the percentage depth dose, P, for a rectangular field from the corresponding data from circular fields.

TABLE 10-1

Calculation of Tissue-Air Ratio for a 4 × 15 Field at Depth 10 cm for ^{60}Co Radiation

Angles	5	15	25	35	45	55	65	75	85	
Radius, r_i	2.01	2.07	2.21	2.44	2.83	3.49	4.73	7.73	7.53	
$T_a(10,r_i)$	.612	.613	.618	.626	.638	.658	.690	.745	.742	total = 5.942

Tissue-air ratio for 4 × 15 cm field = 5.942 × 4/36 = 0.660

A rectangular field, and in fact even a field having an irregular outline, can be resolved into sectors of circular beams. The tissue-air ratio for a rectangular or irregular beam having a field area A at depth d can be calculated from the equation:

$$T_a(d,A) = \frac{1}{n} \sum_{i=1}^{n} T_a(d,r_i) \qquad (10\text{-}8)$$

where n is the number of sectors in 360°, r_i are the radii from the center to the edge of the field at the center of each sector, and $T_a(d,r_i)$ are the tissue-air ratios for circular fields of radius r_i at depth d. In Table 10-1 the sectors have an angular width of 10°. Although there are 36 such sectors in 360° only 9 of them need be considered in this example because of symmetry. The accuracy of the calculation is improved by using more sectors with smaller angular widths, but little gain is achieved by going below 10°.

Sector Integration of Scattered Radiation

One of the most useful applications of scatter-air ratios is the calculation of relative dose in rectangular or irregularly shaped beams. The sector integration technique was discussed in sections 10.04 and 10.06 but will be described in more detail here. Figure 10-24a shows a cross section of a rectangular beam 5 × 15 cm. The dose is to be calculated at point P, which is at the center of the field and at a depth 5 cm below the surface of a phantom. Six radial lines, spaced at equal angular intervals ($\Delta\theta = 15°$), have been drawn from P to the edge of the field. One of them, r_4, is used as the radius to draw a complete circle about point P. Scatter-air ratio values, for a depth of 5 cm, are plotted against radii (Fig. 10-24). The radius r_4 is 4.11 cm and the curve shows that the scatter-air ratio for a circular field of this radius is 0.136. This means that if the dose in air at point P were 1.0, then the dose due to scatter at a depth of 5 cm on the axis of a circular beam of radius r_4 would be 0.136.

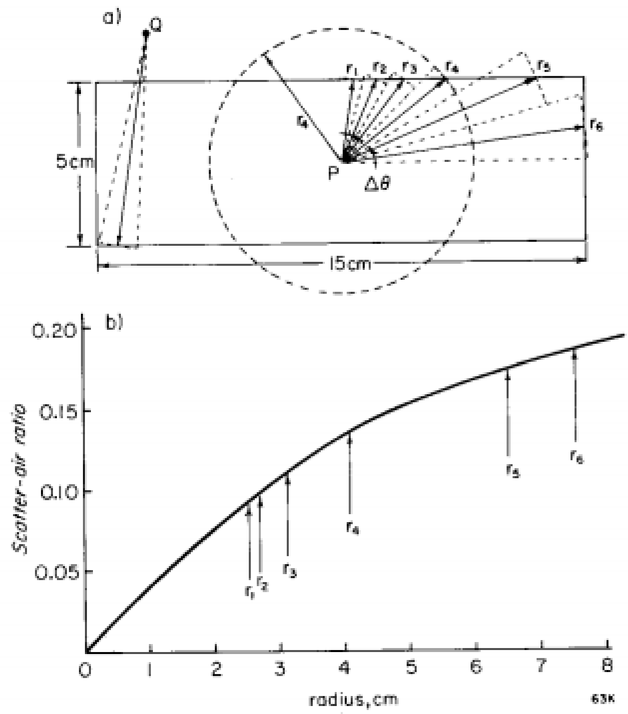

Figure 10-24. Diagram illustrating the use of scatter-air ratios to calculate the dose at two points. (a) Point P is inside the beam and receives both primary and scattered radiation. Point Q is outside and receives only scattered radiation. The dashed circle indicates a circular beam of radius r_4, one sector of which is considered to be part of the rectangular field. (b) Scatter-air ratio plotted against radius for a depth of 5 cm. The arrows indicate the radii of sectors in a.

The scatter that comes from the sector of angular width $\Delta\theta$ in the circular beam of radius r_4 would be 0.136 $(\Delta\theta/2\pi)$. The amount of radiation reaching point P from the sector of angular width $\Delta\theta$ and radius r_4 but in the rectangular beam shown would be very similar to this. A similar argument can be made for each of the sectors r_1 through r_6 in Figure 10-24a. These 6 sectors cover one quadrant of the beam and the total dose at point P due to scatter would be:

$$D_{scat} = \frac{\Delta\theta}{2\pi} \sum_{i=1}^{n} S(d,r_i) \qquad (10\text{-}19)$$

where n is the number of sectors required to cover the entire area of the field, that is $n\Delta\theta = 2\pi$.

Although point P was chosen to be at the center of the field for the above example, the procedure applies equally well to the calculation of the amount of scattered radiation at any point either in or out of the field. Points such as Q outside of the field, however, require some special treatment, because for each sector, two radii are involved, one from the point to the first reached boundary of the field, the second for the second boundary. The scatter from the former must be subtracted and from the latter added. The total dose at point P will be:

$$D_p = D_{prim} + D_{scat} = D_{X'}\left[f(x) \cdot T(d,0) + \frac{\Delta\theta}{2\pi} \sum_{i=1}^{n} S(d,r_i)\right] \qquad (10\text{-}20)$$

where f(x) is a factor allowing for attenuation of primary by a filter. Two examples will illustrate such calculations.

Example 10-6. Using scatter-air ratios, calculate the tissue-air ratio for a 4 × 15 cm field at a depth of 10 cm in a water phantom. Use 10° intervals over one quadrant, as shown in Figures 10-6 and 10-24.

Angles = 5°, 15°, . . . 85°.

radii, r_i = 2.01, 2.07, 2.21, 2.44, 2.83, 3.49, 4.73, 7.73, 7.53

$S(10,r_i)$ = .076, .078, .082, .090, .104, .124, .155, .211, .208

T(10.0), the zero area tissue-air ratio = .534 (Table B-5d).

f(x) = 1.0 on the beam axis

$$\text{Tissue-air ratio} = .534 + 4 \times \frac{1}{36} \sum_1^9 S(10,r_i) = .534 + .125 = .659$$

Ejercicios

1. Determina el TAR para un punto en el borde de un campo circular de 14 cm de diámetro de Co-60 usando el método de Clarkson y los datos representados en la figura 10-6.
2. Calcula la dosis en un punto a 10 cm de profundidad y a 5 cm fuera del área de irradiación para un campo de 15x15 cm de Co-60. Asume 1 Gy a la misma profundidad en el eje. Utiliza las razones dispersión-aire.

Tissue-Air Ratios for Circular Fields, T_a (d, r, hν)

	Radius (cm)	*0*	*2.52*	*3.34*	*3.99*	*5.05*	*5.64*	*6.77*	*7.98*	*11.3*
	Area (cm²)	*0*	*20*	*35*	*50*	*80*	*100*	*150*	*200*	*400*
(a)	*d, (cm)*					HVL 1.0 mm Cu				
	*0	1.00	1.20	1.25	1.29	1.34	1.37	1.40	1.42	1.49
	2	.682	1.08	1.18	1.25	1.33	1.36	1.42	1.48	1.58
	4	.472	.844	.948	1.02	1.13	1.18	1.27	1.33	1.43
	6	.330	.631	.726	.799	.900	.954	1.04	1.10	1.24
	8	.232	.466	.546	.612	.695	.741	.835	.894	1.04
	10	.163	.341	.406	.452	.527	.569	.646	.703	.838
	12	.114	.246	.294	.339	.400	.432	.499	.549	.675
	14	.079	.178	.218	.250	.300	.325	.382	.425	.534
	16	.055	.128	.158	.184	.225	.245	.290	.326	.421
	18	.039	.093	.116	.135	.167	.183	.219	.248	.327
	20	.027	.067	.084	.099	.125	.138	.168	.190	.254
(b)						HVL 3.0 mm Cu				
	*0	1.00	1.13	1.16	1.19	1.23	1.24	1.27	1.29	1.33
	2	.736	1.03	1.10	1.15	1.20	1.22	1.27	1.30	1.39
	4	.542	.828	.912	.968	1.05	1.08	1.14	1.18	1.29
	6	.404	.651	.727	.785	.861	.905	.975	1.03	1.14
	8	.296	.500	.565	.617	.694	.738	.800	.855	.974
	10	.222	.382	.435	.480	.552	.591	.659	.703	.820
	12	.164	.290	.335	.372	.430	.465	.519	.565	.676
	14	.123	.220	.256	.284	.332	.364	.410	.455	.552
	16	.092	.167	.197	.219	.258	.283	.325	.365	.452
	18	.068	.128	.152	.169	.201	.220	.259	.290	.370
	20	.051	.098	.116	.130	.157	.171	.204	.232	.299
(c)						Cobalt 60				
	*0.5	1.000	1.016	1.021	1.025	1.032	1.035	1.042	1.048	1.064
	2	.905	.956	.961	.975	.985	.998	1.014	1.022	1.041
	4	.792	.880	.900	.914	.932	.941	.953	.964	.987
	6	.694	.795	.820	.835	.856	.867	.883	.898	.925
	8	.608	.708	.734	.752	.776	.787	.805	.824	.858
	10	.534	.627	.653	.672	.696	.708	.730	.751	.790
	12	.469	.553	.578	.596	.622	.636	.658	.678	.723
	14	.412	.489	.513	.531	.557	.571	.595	.616	.662
	16	.361	.435	.455	.472	.497	.509	.533	.557	.605
	18	.317	.384	.405	.421	.444	.457	.480	.501	.552
	20	.278	.339	.359	.375	.399	.411	.431	.454	.503

* This entry is also the backscatter factor.

(d)

Tissue-Air Ratios for Rectangular Fields

Cobalt-60

d (cm)	0×0	4×4	4×6	4×8	4×10	4×15	5×5	6×6	6×8	6×10	6×15	7×7	8×8	8×10
*0.5	1.000	1.015	1.018	1.020	1.022	1.025	1.018	1.022	1.025	1.027	1.031	1.025	1.029	1.032
1	.965	.996	1.001	1.005	1.008	1.012	1.003	1.009	1.014	1.018	1.023	1.015	1.021	1.025
2	.905	.956	.965	.970	.973	.978	.967	.976	.983	.988	.994	.985	.992	.997
3	.845	.915	.926	.932	.936	.942	.928	.940	.948	.954	.961	.950	.959	.966
4	.792	.872	.885	.893	.897	.903	.888	.902	.912	.918	.926	.914	.924	.931
5	.742	.829	.843	.852	.856	.863	.847	.862	.873	.880	.889	.875	.887	.895
6	.694	.786	.801	.810	.815	.823	.805	.821	.833	.840	.851	.835	.847	.856
7	.650	.743	.758	.767	.773	.781	.762	.778	.791	.799	.810	.793	.807	.819
8	.608	.700	.715	.725	.731	.740	.719	.736	.749	.757	.769	.751	.765	.775
9	.570	.659	.674	.684	.689	.700	.677	.695	.708	.716	.730	.710	.724	.734
10	.534	.620	.635	.644	.650	.661	.638	.655	.668	.677	.691	.671	.685	.695
11	.501	.581	.596	.606	.612	.623	.600	.616	.630	.639	.652	.632	.647	.658
12	.469	.546	.560	.570	.576	.587	.563	.580	.594	.603	.617	.596	.611	.622
13	.440	.513	.527	.537	.544	.555	.530	.547	.561	.570	.584	.563	.578	.589
14	.412	.482	.496	.505	.512	.523	.499	.515	.528	.538	.552	.531	.345	.557
15	.386	.454	.467	.476	.483	.494	.470	.485	.498	.507	.522	.501	.515	.526
16	.361	.427	.440	.449	.455	.466	.443	.458	.470	.479	.494	.472	.485	.496
17	.338	.402	.414	.423	.429	.440	.417	.431	.443	.452	.467	.445	.458	.469
18	.317	.378	.390	.398	.404	.415	.393	.406	.418	.426	.441	.420	.433	.443
19	.297	.355	.366	.375	.381	.391	.369	.383	.394	.403	.417	.396	.409	.420
20	.278	.333	.344	.353	.358	.369	.347	.361	.372	.380	.394	.374	.386	.396
22	.246	.293	.304	.312	.317	.327	.306	.318	.328	.336	.350	.330	.342	.352
24	.215	.258	.268	.275	.280	.290	.270	.281	.290	.298	.311	.292	.303	.312
26	.187	.228	.236	.243	.248	.257	.238	.249	.258	.264	.277	.259	.270	.278
28	.164	.200	.210	.215	.219	.228	.210	.221	.228	.234	.246	.230	.239	.246
30	.144	.178	.185	.190	.194	.202	.186	.195	.202	.208	.218	.203	.212	.219

d (cm)	8×15	8×20	10×10	10×15	10×20	12×12	15×15	15×20	20×20	20×30	25×25	30×30	35×35
*0.5	1.027	1.041	1.035	1.042	1.046	1.041	1.051	1.056	1.063	1.071	1.073	1.080	1.084
1	1.032	1.035	1.031	1.038	1.043	1.038	1.048	1.054	1.062	1.069	1.072	1.079	1.084
2	1.005	1.009	1.004	1.013	1.018	1.014	1.025	1.032	1.040	1.049	1.052	1.059	1.065
3	.975	.980	.974	.985	.990	.985	.999	1.006	1.016	1.026	1.029	1.038	1.044
4	.942	.947	.940	.952	.959	.953	.968	.977	.987	.999	1.002	1.014	1.021
5	.907	.913	.905	.918	.925	.919	.936	.946	.957	.971	.974	.988	.998
6	.869	.876	.867	.882	.890	.883	.902	.912	.925	.940	.944	.959	.970
7	.830	.837	.827	.844	.853	.845	.866	.878	.893	.909	.913	.929	.941
8	.790	.798	.787	.805	.815	.806	.830	.843	.859	.877	.881	.899	.912
9	.751	.760	.747	.767	.778	.768	.793	.806	.825	.845	.849	.869	.882
10	.713	.722	.709	.729	.741	.730	.756	.771	.790	.811	.816	.837	.852
11	.675	.685	.672	.692	.704	.692	.719	.736	.755	.777	.782	.803	.820
12	.640	.650	.636	.657	.670	.658	.685	.702	.722	.744	.750	.772	.790
13	.607	.618	.603	.625	.638	.626	.653	.670	.690	.713	.720	.743	.762
14	.575	.586	.571	.593	.606	.594	.622	.639	.660	.684	.691	.715	.734
15	.545	.556	.540	.563	.576	.563	.593	.610	.633	.656	.662	.687	.706
16	.516	.527	.510	.533	.547	.533	.564	.582	.605	.628	.634	.660	.679
17	.488	.499	.483	.506	.519	.506	.536	.554	.577	.601	.608	.633	.653
18	.462	.474	.457	.479	.493	.479	.509	.528	.551	.575	.582	.607	.627
19	.438	.449	.433	.455	.469	.455	.485	.503	.526	.550	.557	.583	.603
20	.415	.426	.410	.431	.445	.431	.461	.479	.502	.527	.534	.560	.580
22	.369	.380	.364	.385	.398	.384	.413	.431	.456	.481	.488	.515	.535
24	.329	.340	.324	.345	.358	.345	.373	.390	.412	.438	.446	.471	.492
26	.294	.304	.290	.309	.322	.308	.336	.352	.373	.398	.405	.431	.451
28	.263	.270	.257	.276	.288	.276	.302	.320	.339	.362	.368	.393	.413
30	.233	.242	.228	.245	.257	.244	.268	.286	.305	.328	.335	.358	.377

*This entry is also the backscatter factor.

Scatter-Air Ratios for Circular Fields, S(d, r, $h\nu$)

(c) Cobalt-60 radiation

Depth d (cm)	Field radius in cm at depth d: 1	2	3	4	5	6	7	8	9	10	11	12
0.5	.007	.014	.019	.026	.032	.037	.043	.048	.054	.058	.063	.067
1	.013	.025	.037	.048	.058	.066	.073	.078	.084	.089	.094	.098
2	.023	.045	.064	.080	.091	.102	.110	.116	.122	.127	.133	.139
3	.032	.061	.084	.103	.118	.130	.139	.147	.154	.161	.166	.172
4	.038	.071	.099	.121	.137	.151	.162	.170	.179	.186	.191	.197
5	.041	.076	.107	.134	.152	.166	.178	.189	.198	.206	.212	.218
6	.042	.080	.114	.141	.160	.176	.190	.201	.211	.219	.226	.234
7	.042	.081	.115	.143	.164	.181	.196	.209	.220	.229	.239	.246
8	.041	.080	.114	.142	.165	.185	.199	.214	.225	.236	.246	.254
9	.040	.078	.112	.140	.164	.183	.200	.216	.228	.240	.251	.260
10	.038	.075	.109	.136	.161	.181	.199	.215	.229	.242	.252	.262
11	.036	.071	.104	.132	.157	.178	.197	.213	.227	.241	.252	.262
12	.035	.069	.099	.128	.153	.174	.194	.210	.225	.239	.251	.261
13	.034	.066	.095	.124	.149	.170	.190	.207	.223	.237	.249	.260
14	.032	.063	.092	.120	.145	.168	.186	.204	.220	.235	.247	.258
15	.031	.060	.089	.116	.140	.162	.182	.200	.216	.231	.244	.255
16	.030	.058	.086	.112	.136	.157	.177	.196	.212	.227	.240	.252
17	.029	.056	.083	.108	.132	.153	.172	.191	.207	.223	.236	.248
18	.027	.054	.080	.104	.128	.148	.167	.186	.202	.218	.232	.244
19	.026	.052	.077	.101	.124	.144	.162	.181	.197	.213	.226	.239
20	.024	.049	.074	.097	.119	.139	.157	.176	.192	.207	.221	.234
22	.022	.044	.067	.088	.109	.128	.146	.163	.180	.194	.208	.222
24	.020	.040	.060	.080	.099	.118	.136	.152	.168	.182	.196	.208
26	.018	.036	.054	.073	.091	.108	.125	.142	.156	.170	.184	.196
28	.016	.032	.049	.067	.083	.098	.115	.132	.156	.159	.172	.184
30	.015	.030	.045	.061	.076	.089	.105	.121	.134	.146	.159	.170

d (cm)	13	14	15	16	17	18	19	20	21	22	23	24	25
0.5	.070	.073	.076	.078	.080	.082	.084	.085	.086	.087	.088	.088	.089
1	.101	.104	.107	.109	.112	.114	.116	.118	.119	.120	.121	.122	.123
2	.142	.146	.149	.152	.154	.156	.158	.160	.161	.162	.164	.166	.167
3	.176	.180	.184	.187	.190	.193	.195	.198	.200	.202	.203	.204	.205
4	.201	.205	.210	.215	.218	.222	.225	.228	.231	.233	.235	.237	.239
5	.224	.229	.235	.240	.245	.248	.252	.255	.258	.261	.263	.264	.266
6	.241	.246	.252	.257	.262	.265	.269	.272	.275	.278	.280	.282	.284
7	.254	.260	.267	.273	.278	.282	.287	.290	.294	.296	.299	.302	.304
8	.263	.271	.278	.285	.289	.294	.298	.301	.305	.309	.311	.313	.315
9	.269	.277	.284	.292	.298	.303	.308	.312	.316	.319	.322	.324	.327
10	.271	.279	.288	.295	.302	.308	.314	.318	.324	.327	.331	.333	.336
11	.272	.280	.289	.296	.304	.311	.316	.322	.328	.331	.334	.337	.339
12	.272	.281	.290	.297	.305	.312	.318	.324	.330	.333	.337	.340	.342
13	.270	.280	.290	.298	.306	.313	.319	.325	.332	.335	.340	.342	.345
14	.268	.279	.288	.297	.305	.313	.320	.326	.333	.337	.341	.344	.347
15	.266	.277	.286	.295	.303	.311	.318	.325	.331	.336	.340	.344	.347
16	.263	.274	.283	.292	.300	.308	.315	.322	.328	.333	.337	.342	.346
17	.259	.271	.279	.288	.296	.304	.311	.318	.324	.329	.334	.339	.343
18	.255	.266	.275	.284	.292	.300	.307	.313	.320	.325	.330	.335	.339
19	.251	.261	.270	.280	.288	.295	.303	.309	.315	.321	.326	.331	.335
20	.246	.257	.265	.275	.284	.291	.299	.305	.311	.316	.321	.326	.329
22	.233	.246	.255	.264	.273	.280	.288	.295	.301	.306	.311	.316	.319
24	.220	.235	.243	.252	.259	.267	.275	.281	.288	.294	.299	.304	.309
26	.207	.219	.229	.236	.245	.253	.260	.266	.272	.279	.284	.289	.295
28	.194	.205	.214	.222	.230	.238	.245	.251	.258	.264	.269	.274	.279
30	.181	.191	.200	.208	.215	.223	.230	.236	.242	.249	.255	.260	.265