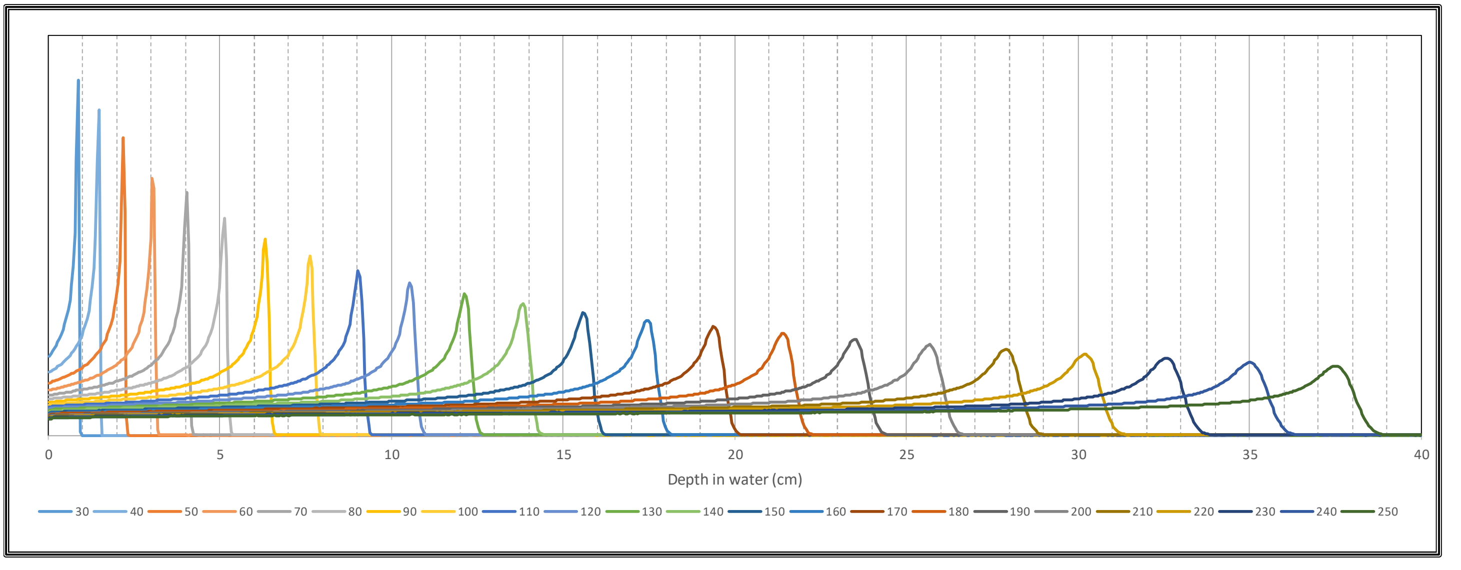
Technical Note

TN0007

Local dose in water

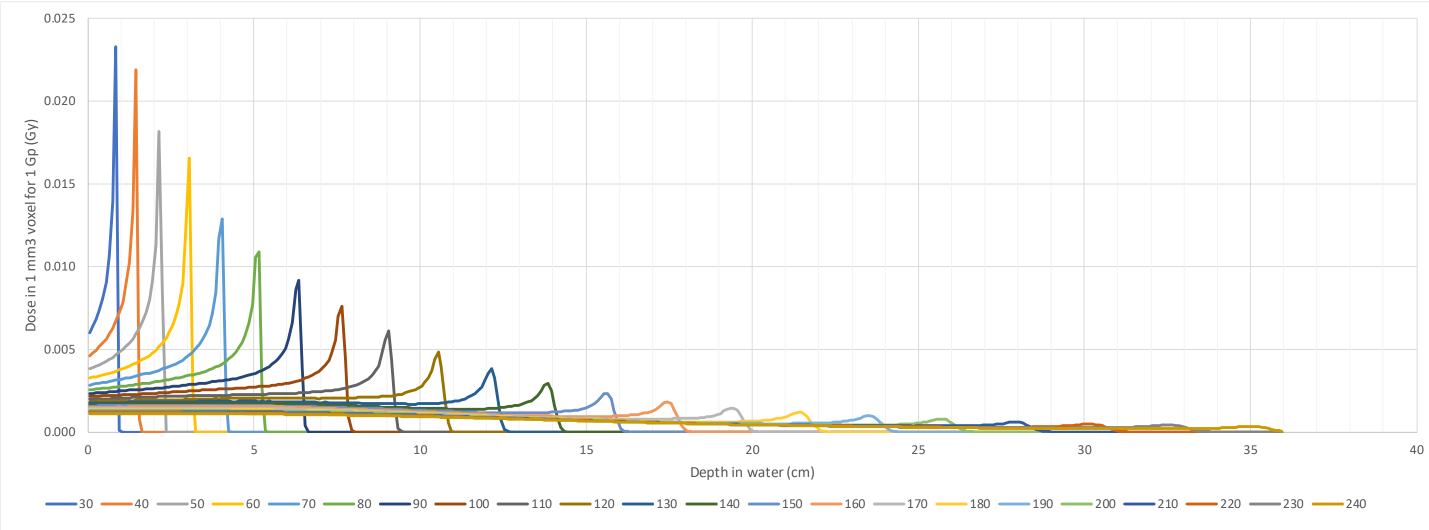
Dose delivered in water is a key metric for proton therapy. The human body is predominately water to a fair approximation, so performance measures and quality assurance procedures are often based on the dose distribution in water.

The depth-dose curve in water as a function of proton energy is familiar. Here is the relative dose delivered to layers for proton energies over the usual proton therapy range.

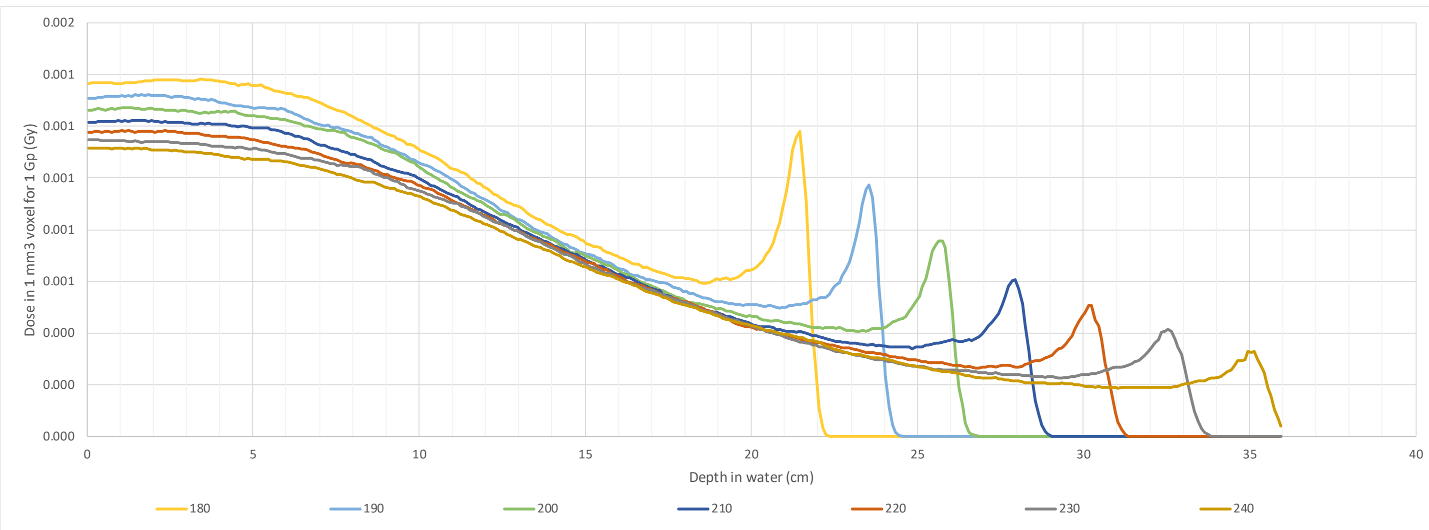


These are the relative curves that would be measured if there is a broad uniform transverse distribution of beam over an area much larger than the (water equivalent) dose sensor. They are also what you would see if you pass a small pencil beam through a large area (water equivalent) sensor. In other words, information about the transverse distribution is not included.

At any moment, pencil beam scanning delivers dose locally, and the full three-dimensional distribution must be considered if the maximum dose in a small voxel is required. Consider a 2 mm sigma beam entering the water, which is around the smallest lateral dimensions available in normal proton therapy systems, and then only at higher beam energies. If we calculate the local dose in 1 mm voxels along the beam axis for an incident one gigaproton of beam current, the dose curves are notably different. One gigaproton is delivered in 160 msec by a 1 nA proton beam current.



Lateral spreading of the beam reduces the maximum local dose on axis at greater depths, and the maximum of the depth-dose curve is not at the end of range for energies of 180 MeV and higher:



The effect becomes less pronounced as the beam sigma increases, and the local on-axis depth-dose curves tend towards the familiar shapes of the first plot.

The peak dose in a voxel as a function of energy (30 to 240 MeV) and beam width (2 to 6 mm one sigma) is as follows for one gigaproton incident beam. The light coloured entries (small sigma at low energy) are unlikely to be achievable in most systems due to generally higher emittance of lower energy beams and due to prior scattering in the treatment nozzle components and air path. Thus the peak local dose per incident beam charge is likely to occur in the 70 to 100 MeV range for most systems, depending on the lateral dimensions of the beam entering the treatment nozzle. To determine the actual maximum local dose for a specific machine, the entering beam emittance and the materials in the nozzle and air path must be added to the calculation.

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In 1 mm voxels

	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
2	46.60	43.75	36.30	33.12	25.76	21.80	18.31	15.18	12.14	9.62	7.59	5.86	4.64	3.58	2.89	2.76	2.64	2.54	2.45	2.36	2.30	2.23
3	21.11	20.02	16.85	15.91	12.92	11.43	9.95	8.69	7.28	6.18	5.26	4.09	3.45	2.82	2.35	1.98	1.66	1.37	1.14	1.08	1.03	1.00
4	11.80	11.31	9.68	9.48	7.77	6.83	6.19	5.52	4.79	4.19	3.54	3.01	2.57	2.20	1.88	1.56	1.34	1.14	1.00	0.82	0.70	0.62
5	7.62	7.33	6.27	6.04	4.96	4.50	4.23	3.87	3.46	3.05	2.64	2.23	1.97	1.69	1.50	1.30	1.13	0.99	0.84	0.72	0.62	0.54
6	5.32	5.06	4.43	4.41	3.65	3.17	2.98	2.74	2.45	2.30	2.03	1.78	1.54	1.35	1.19	1.05	0.92	0.80	0.71	0.65	0.54	0.48

In 3 mm voxels

	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
2	27.25	25.91	16.20	16.60	15.76	14.50	12.39	11.42	8.52	7.00	6.53	4.73	3.97	3.21	2.70	2.36	2.25	2.17	2.08	2.01	1.96	1.90
3	13.41	12.89	8.17	8.56	8.34	7.94	7.15	6.87	5.31	4.65	4.52	3.41	2.98	2.50	2.20	1.83	1.54	1.26	1.03	0.99	0.97	0.94
4	7.88	7.59	4.86	5.09	5.05	4.94	4.51	4.43	3.57	3.16	3.17	2.48	2.24	1.95	1.78	1.45	1.25	1.08	0.86	0.77	0.67	0.56
5	5.11	4.96	3.17	3.36	3.33	3.31	3.07	3.10	2.49	2.27	2.34	1.85	1.71	1.50	1.41	1.19	1.05	0.91	0.75	0.66	0.56	0.49
6	3.58	3.47	2.25	2.40	2.35	2.36	2.21	2.23	1.83	1.68	1.77	1.42	1.32	1.16	1.12	0.97	0.85	0.75	0.63	0.57	0.48	0.43