



The Integral Quality Monitor (IQM) System is a real-time beam verification system that monitors the accuracy of radiation delivery throughout each patient treatment without any user interaction. IQM continuously monitors every single beam segment in real-time during every treatment fraction. The IQM detector is capable of measuring deviations related to dose (incorrect photon energy or MU's), beam direction (monitoring both collimator and gantry angles), individual beam size, beam segment shape and intensity maps.

IQM detector characteristics such as signal reproducibility, linearity and sensitivity are fundamental for the successful application of the IQM principle of operation.

IQM has been thoroughly evaluated at some of the world's leading Radiation Therapy Centers. 21 clinical centers equipped with state-of-the-art treatment planning and delivery systems have performed a variety of tests to ensure and improve the clinical usefulness of the IQM System. Measurements verifying signal reproducibility (short-term and long-term), signal linearity, dose rate dependency and sensitivity were performed as part of the installation routine at every clinical center.



These centers have carried out additional measurements as part of the pre-clinical evaluation of the IQM System. The results outlined in this publication are based on measurements performed on the following types of Linear Accelerators

- Elekta Versa HD (1)
- Elekta Infinity (1)
- Elekta Synergy with Agility Collimator (7)
- Elekta Synergy with MLCi2 Collimator (6)
- Varian TrueBeam (4)
- Varian TrueBeam STX (2)
- Varian C-Series (1)

Each Linear Accelerator (Linac) was fully commissioned and verified for clinical use at the time of the measurement.

### Signal reproducibility (short-term)

The short-term signal reproducibility test verifies the detector's capability to measure the same signal when the same beam is repeated multiple times. The signal reproducibility test uses the reference field size of 10cm x 10cm (defined by MLC and Jaws) for a 6MV photon beam delivering 100 MU's. The test is passed if the variation of the measured signal is 0.50% or less

Table 2 shows the results of the short-term signal reproducibility test in IQM Counts. The coefficient of variation (%SD) varies for all sites from 0.03% to 0.13% and is diagrammed in figure 1.

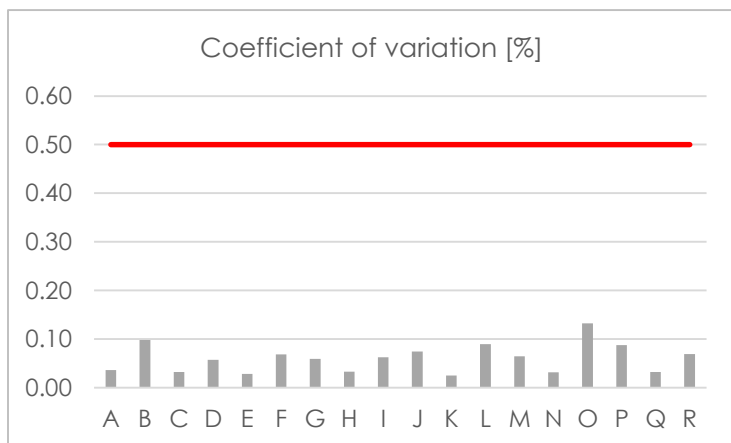
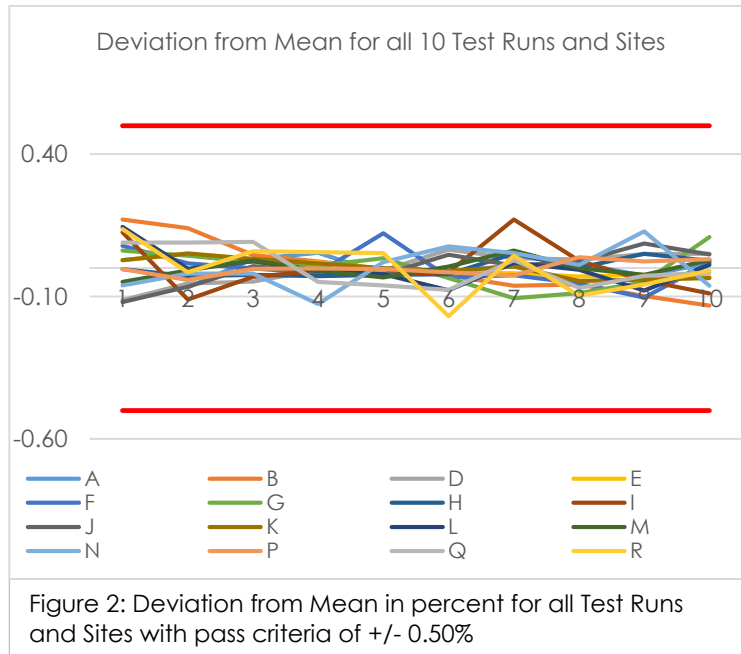


Figure 1: Coefficient of variation for all sites and test runs with criteria of 0.50% (red line)



Table 2: IQM Signal in IQM Counts for all sites and all ten test runs of 10cm x 10cm field for a 6 MV photon beam delivering 100 MU's with mean in IQM Counts, standard deviation (SD) in IQM Counts and coefficient of variation (%SD) in percent

Site	Test #										Mean	SD	%SD	
	1	2	3	4	5	6	7	8	9	10				
Elekta	A		242378.19	242141.11	242084.67	242265.30	242243.75	242194.48	242176.01	242282.75	242171.90	242215.35	87.19	0.04
	B	223170.12	223237.67	223447.44	223498.40	223557.65	223609.80	223689.20	223679.72	223769.79	223845.64	223550.54	183.64	0.10
	C	294326.69	294145.83	294246.54	294123.23	294156.11	294256.82	294255.79	294272.23	294418.15	294353.41	294255.48	94.79	0.03
	D	265742.59	265588.79	265569.95	265458.00	265464.28	265271.76	265352.32	265364.88	265312.57	265310.47	265443.56	115.47	0.06
	E	298555.79	298491.96	298574.03	298581.12	298649.00	298685.47	298694.59	298727.01	298708.78	298730.05	298639.78	83.24	0.03
	F	337673.59	337732.89	337812.31	337851.49	337764.66	338001.87	338238.01	338178.71	338049.52	337513.69	337881.67	231.83	0.07
	G	242388.53	242257.72	242083.99	242127.93	242156.55	241987.93	242078.88	242046.18	241891.86	241984.86	242100.44	143.31	0.06
	H	226437.17	226384.93	226427.95	226463.79	226501.69	226525.24	226489.40	226604.10	226591.81	226581.57	226500.77	75.72	0.03
	I	219065.00	219388.00	219328.00	219405.00	219430.00	219552.00	219341.00	219395.00	219556.00	219358.00	219381.80	136.58	0.06
	J	241483.88	241383.26	241383.26	241641.85	241284.65	241151.83	241210.19	241310.81	241026.05	241486.90	241336.27	180.04	0.07
	K	243646.14	243737.76	243641.88	243639.74	243646.14	243672.77	243701.54	243543.86	243579.02	243559.84	243636.87	61.27	0.03
L	304506.59	304970.12	304744.08	304754.50	304764.92	305439.91	304793.04	305219.08	305100.33	304952.41	304924.50	271.84	0.09	
Varian	M	192372.96	192492.12	192526.02	192555.81	192288.73	192586.63	192571.22	192627.72	192722.23	192485.96	192522.94	118.77	0.06
	N	201579.00	201630.00	201620.00	201630.00	201620.00	201615.00	201470.00	201570.00	201470.00	201520.00	201572.40	63.90	0.03
	O	213563.26	213828.85	213617.61	214247.42	214101.48	214096.60	214091.45	214316.81	214282.85	214321.95	214046.83	282.36	0.13
	P	228014.67	228553.85	228371.77	228325.23	228352.54	228335.35	227913.51	228244.30	228401.10	228504.29	228301.66	183.21	0.09
	Q	233453.76	233357.71	233278.37	233360.84	233416.17	233326.39	233195.89	233339.96	233395.29	233275.23	233339.96	68.10	0.03
	R	219693.90	219691.89	219686.89	219998.10	220024.11	220058.13	219828.98	220043.12	219950.06	219925.05	219890.02	144.12	0.07



For further analysis the individual deviation from the average for every single test run was investigated. The same pass criteria as for the coefficient of variation (namely 0.50% or less) was applied for the deviation from mean. The results are listed in table 3 and shown in figure 2. The deviation from mean varies from 0.01% to 0.23% which indicates a small variation for the different test runs.

This is confirmed when taking a closer look at each individual signal in table 2. Within each site, test run results show minimal variation. This small variation is due to tolerances from the IQM (<+/- 0.50%) and slight Linac output variations.

Table 3: Relative error from mean in percent for each site, for all ten runs of a 10cm x 10cm field for 6 MV photon beam delivering 100 MU's

Site	Test #										Mean	
	1	2	3	4	5	6	7	8	9	10		
Elekta	A		-0.07	0.03	0.05	-0.02	-0.01	0.01	0.02	-0.03	0.02	0.03
	B	0.17	0.14	0.05	0.02	0.00	-0.03	-0.06	-0.06	-0.10	-0.13	0.08
	C	-0.02	0.04	0.00	0.04	0.03	0.00	0.00	-0.01	-0.06	-0.03	0.02
	D	-0.11	-0.05	-0.05	-0.01	-0.01	0.06	0.03	0.03	0.05	0.05	0.05
	E	0.03	0.05	0.02	0.02	0.00	-0.02	-0.02	-0.03	-0.02	-0.03	0.02
	F	0.08	0.02	0.00	-0.02	0.12	-0.03	-0.03	-0.05	-0.10	0.02	0.05
	G	0.06	0.04	0.02	0.01	0.03	-0.04	-0.11	-0.09	-0.05	0.11	0.06
	H	0.00	-0.03	-0.02	-0.03	-0.02	-0.02	0.05	0.00	0.05	0.03	0.03
	I	0.13	-0.11	-0.03	-0.01	-0.02	-0.01	0.17	0.03	-0.04	-0.09	0.06
	J	-0.12	-0.06	0.01	-0.01	-0.02	0.05	0.01	0.02	0.09	0.05	0.04
	K	0.03	0.05	0.03	0.02	0.00	-0.01	0.01	-0.05	-0.04	-0.04	0.03
	L	0.14	0.00	0.02	-0.01	-0.02	-0.08	0.02	-0.01	-0.08	0.01	0.04
Varian	M	-0.05	-0.01	0.03	-0.01	-0.03	0.01	0.06	0.00	-0.02	0.03	0.02
	N	-0.06	-0.02	-0.02	-0.13	0.02	0.08	0.05	0.01	0.13	-0.06	0.06
	O	0.23	0.10	0.20	-0.09	-0.03	-0.02	-0.02	-0.13	-0.11	-0.13	0.11
	P	0.00	-0.04	0.00	0.00	0.00	-0.01	-0.03	0.04	0.02	0.03	0.02
	Q	0.09	0.09	0.09	-0.05	-0.06	-0.08	0.03	-0.07	-0.03	-0.02	0.06
	R	0.14	-0.01	0.06	0.06	0.05	-0.17	0.04	-0.10	-0.06	-0.01	0.07

Conclusion:

Every IQM installed at each RT department passed the criteria for reproducibility, with a coefficient of variation under 0.50%. The results indicate a high reproducibility with low variation within all 10 test runs for each of the IQM systems installed.

### Signal reproducibility (long-term)

Once the IQM system was successfully installed on site, ten of the research partners were asked to perform another signal reproducibility test over a longer period of time. This test verifies the detector's capability to measure the same signal when the same beam is repeated multiple times over a longer period. The sub-group of 10 beta test sites ran six different fields for a 6MV photon beam delivering 100 MU's. The fields used are a centered 10cm x 10cm field and five 4cm x 4cm fields (defined by MLC and Jaws). The distribution of the segment openings is shown in figure 3. The fields were chosen to ensure the reproducibility of the signal for different field sizes and positions. Passing criteria for the test was that the variation of the measured signal for every beam segment be 1.00% or less.

The research partners were asked to repeat the test on different days over a time period of multiple weeks. 10 beta test sites measured the fields on average 16.3 (2 – 59) times on 6.4 (1 – 19) different days. The test results are listed in table 4 and diagrammed in figure 4.

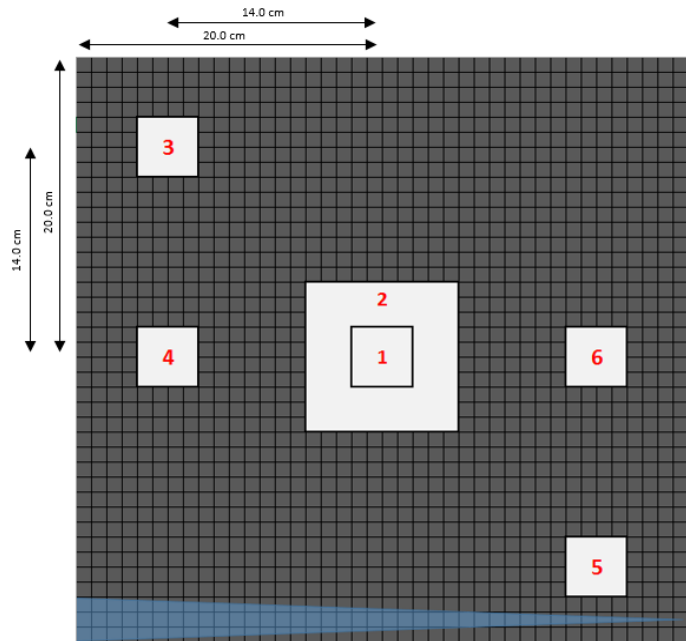


Figure 3: Distribution and position of segment openings

Table 4: Coefficient of variation for 6 test fields at all 10 participating sites

Site	1	2	3	4	5	6	Mean
A	0.46	0.39	0.36	0.25	0.32	0.35	0.36
B	0.10	0.31	0.72	0.39	0.26	0.96	0.45
D	0.75	0.56	0.77	0.62	0.70	0.93	0.72
F	0.82	0.73	0.97	0.91	0.95	0.97	0.89
G	0.99	0.98	0.89	0.95	0.96	0.96	0.96
H	0.30	0.02	0.10	0.20	0.12	0.08	0.13
I	0.43	0.37	0.48	0.42	0.43	0.44	0.43
K	0.43	0.11	0.44	0.01	0.01	0.64	0.27
L	0.95	0.79	0.53	0.67	0.91	0.94	0.80
M	0.83	0.55	0.65	0.73	0.24	0.34	0.56

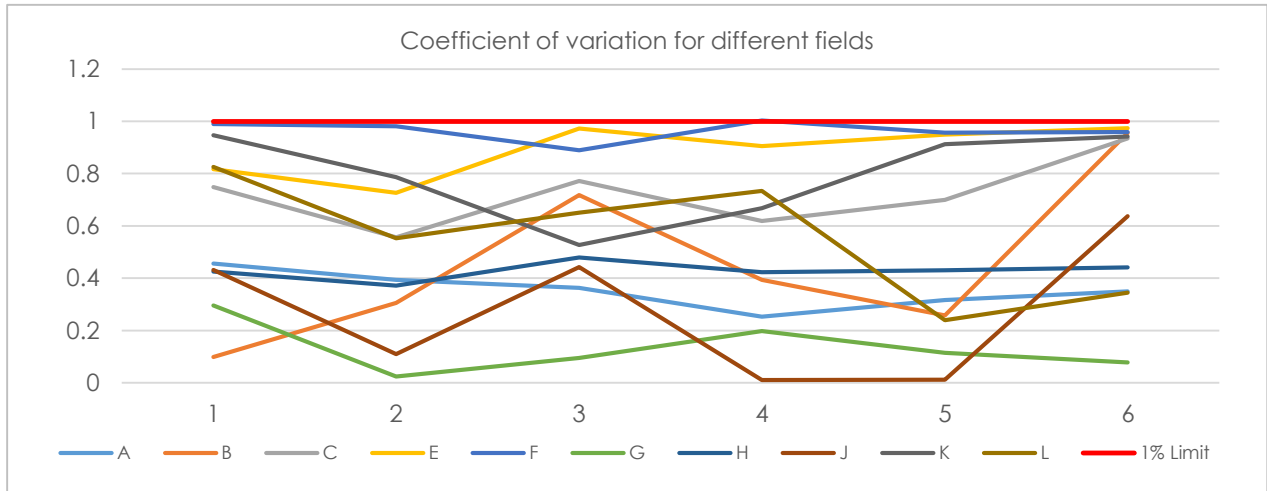


Figure 4: Coefficient of variation for 6 test fields and all 10 participating sites with the corresponding pass criteria of 1% (red line)

The coefficient of variation for the selected fields varies from 0.01% to 0.99% and the mean variation ranges from 0.13% to 0.96%. For all sites the coefficient of variation is within the criteria of 1%. Figure 4 gives an overview of the variation. The results indicate a variation in the signal, which is due to Linac output variations on different days.

Conclusion: All measurements passed the acceptance criteria for reproducibility, with the coefficient of variation being 1.00% or less. The results indicate high long term reproducibility.

### Overall conclusion

Both short-term and long-term reproducibility measurements show high signal reproducibility of the IQM Signal independent from field size and field position. All measured variations are well within the acceptance levels.