Quality Control Metrics in Radiation Oncology

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Objectives

1. Define the term "Process" as it relates to Quality Control

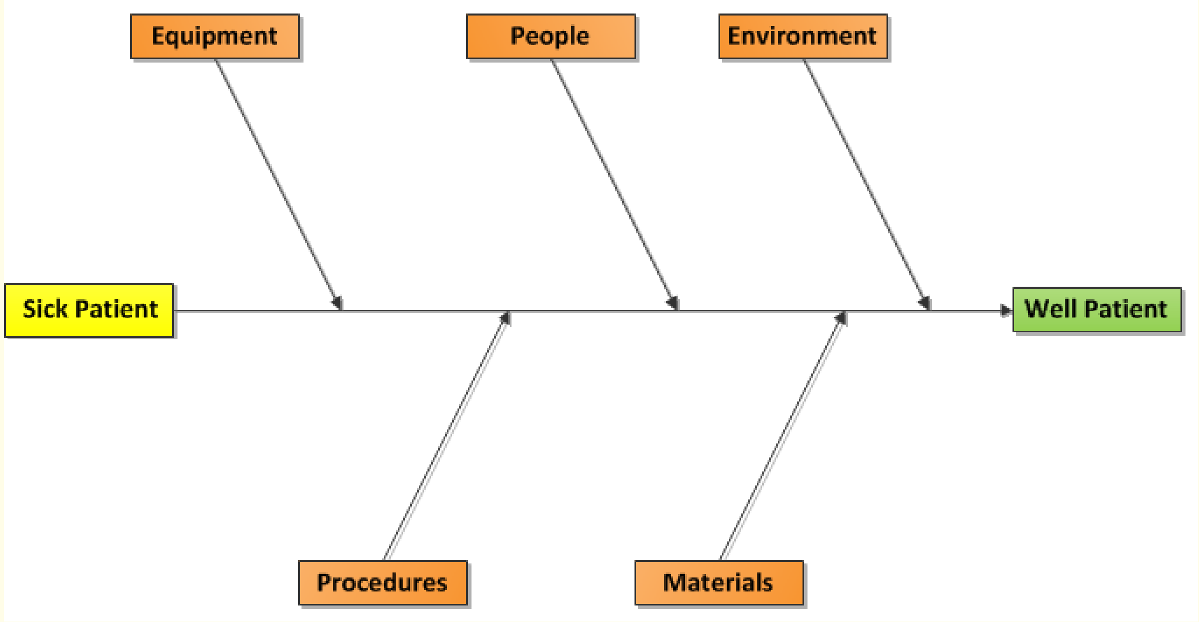
2. Describe two Statistical Process Control techniques for evaluating continuous data

    - Mean and Range (Xbar/R) Chart

    - Individual and Moving Range (I/MR) Chart

3. Describe several examples using these techniques

What is a "Process"



"Everything required to turn an input into an output for a patient"

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The inputs and outputs along the process exhibit variation.

- **Total time from simulation to plan approval**
- **Magnitude of daily shifts for IGRT patients**
- **Number of therapist logged on at the time of patient treatment**
- **Magnitude of setup deviation from plan values on the first day of treatment**
- **Measured dose deviation from plan dose during IMRT QA by body site or delivery technique**

Exceptional variation of inputs and outputs along the process impact the quality of care.

Statistical Process Control (SPC)

Statistical Process Control (SPC) methodology is used to detect exceptional variation in a process using performance data.

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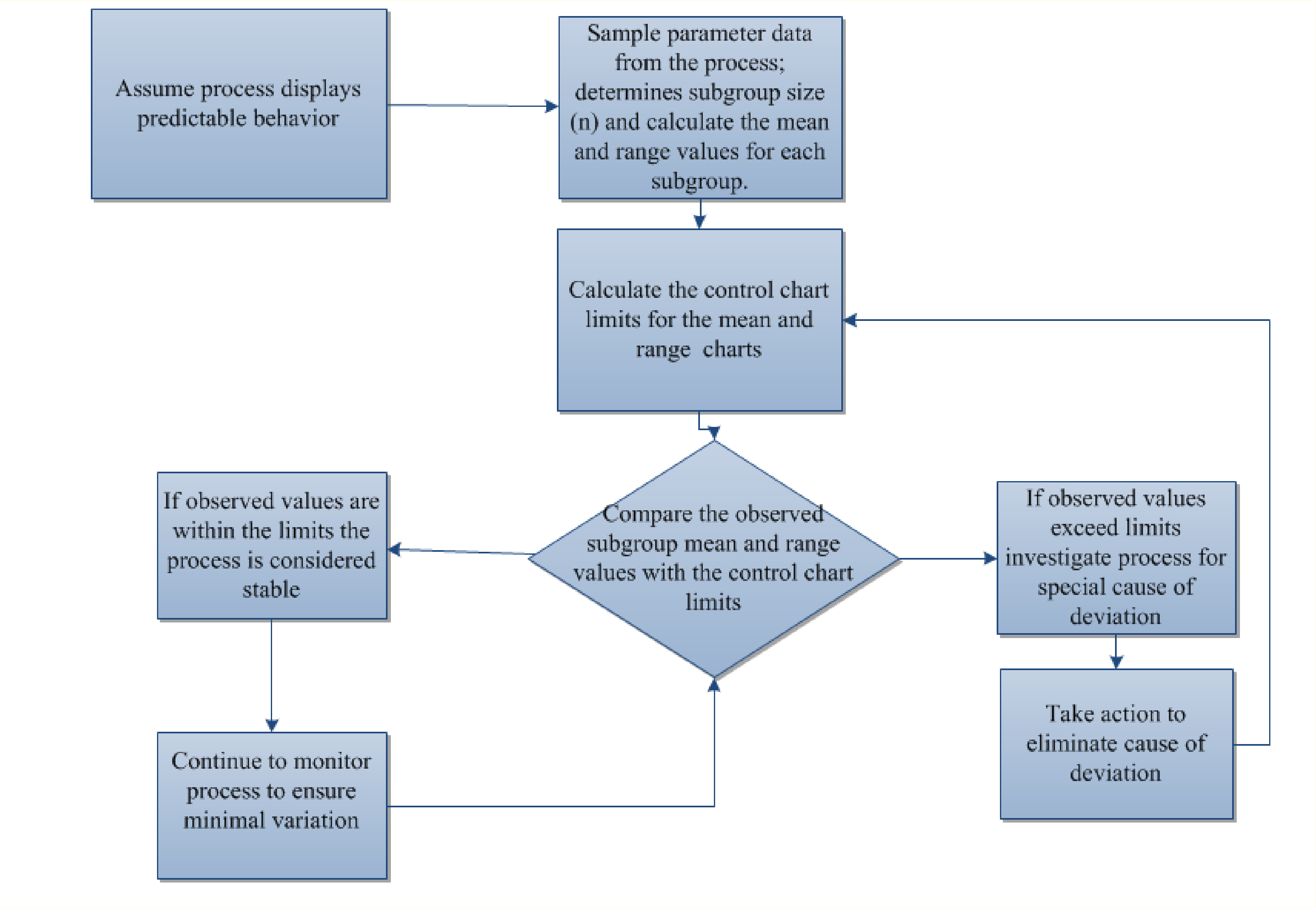
Statistical Process Control (SPC)

W. A. Shewhart, Bell Labs, 1924

- **Application of probability and statistics to quality control of mass production**
- **Introduced the control chart (or process behavior chart)**
- **Process behavior chart is the primary tool of all of the SPC techniques**

Statistical Process Control (SPC)



There are two basic evaluation and charting techniques for continuous data:

- **Xbar/R Charts - provides an evaluation of subgroups (n>1) using the mean (Xbar) and range (R) control charts.**

- **X/MR Charts - provides an evaluation of subgroups (n=1) using the individual value (X) and moving range (MR) control charts.**

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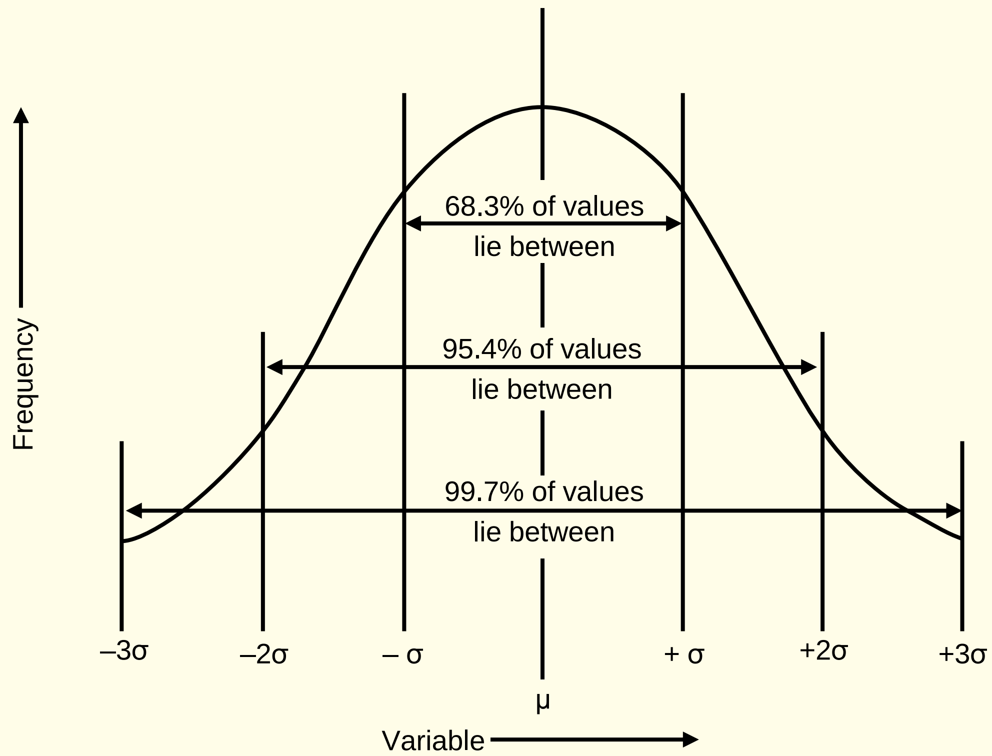
Normal Distribution of trials or samples



The normal distribution uses the standard deviation

$$\sigma = \sqrt{\sigma^2} \approx s = \sqrt{\frac{\Sigma_{i=1}^{n}(x_i - \overline{X})^2}{n-1}}$$

Oakland, JS. Statistical process control. Jordan Hill, Oxford, UK: Butterworth-Heinemann;2008.

Mean and Range Charts

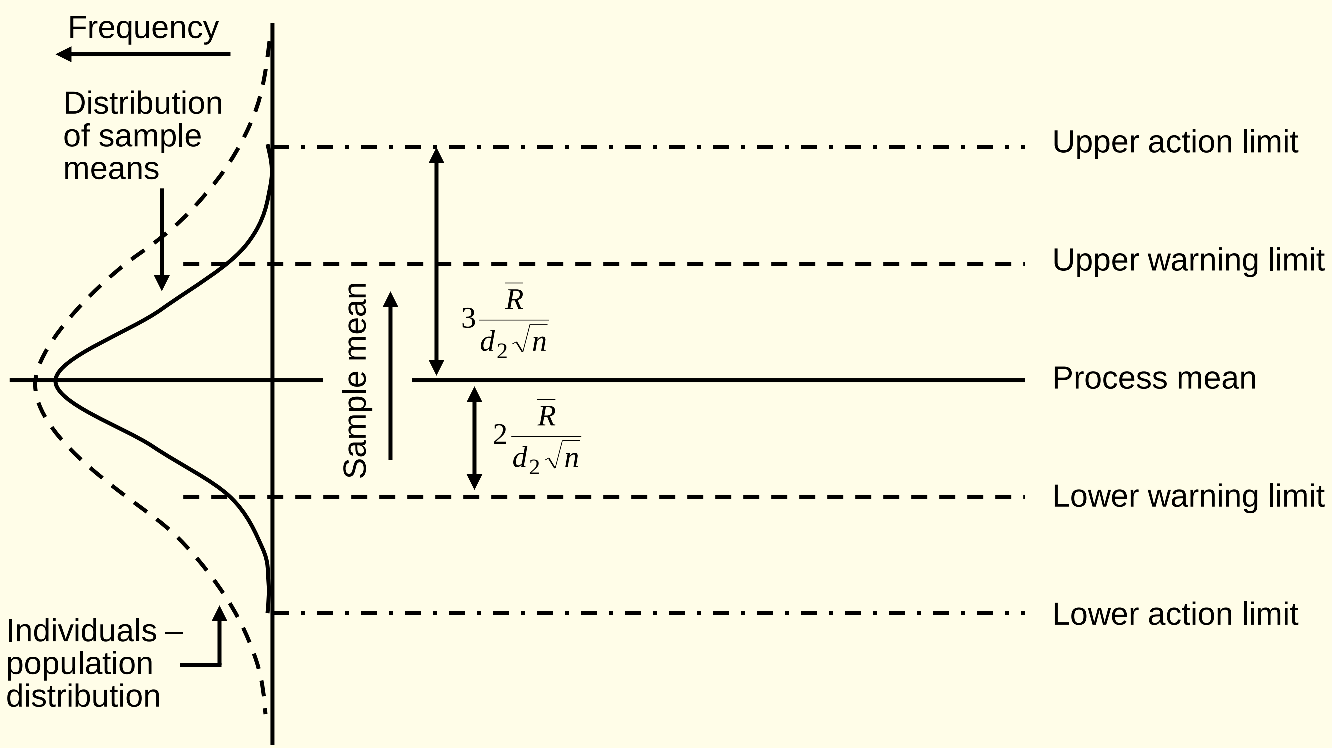
Mean (Xbar) charts use the mean value of a subgroup (n>1) of individual samples.

This results in a distribution of mean or average values and has variation that is equal to the standard error of means (SE)

$$SE = \frac{S}{\sqrt{n}} = \frac{\bar{R}}{d_3\sqrt{n}}$$

where n = subgroup size

Mean and Range Charts



Principle of mean control chart

Oakland, JS. Statistical process control. Jordan Hill, Oxford, UK: Butterworth-Heinemann;2008.

Typical formulation of control limits for the Mean Chart

$$A_u = \bar{\bar{x}} + 3\frac{\bar{R}}{d_2\sqrt{n}} = UAL$$

$$A_c = \bar{\bar{x}} = \sum_{1}^{T} \bar{x}_t \Big/ T$$

where T= number of subgroups

$$A_l = \bar{\bar{x}} - 3\frac{\bar{R}}{d_2\sqrt{n}} = LAL$$

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Range (R) charts use the range value from the subgroup (n>1) of individual samples.

This results in a distribution of range values that is asymmetrical about the mean and positively skewed.

$$R_l = \left(1 + 3\frac{d_3}{d_2}\right)\overline{R} = UAL$$

$$R_c = \overline{R} = \sum_1^T R_t \Big/ T$$

where $R_t = |x_{tmax} - x_{tmin}|$ and T= number of subgroups

$$R_u = \left(1 - 3\frac{d_3}{d_2}\right)\overline{R} = LAL$$

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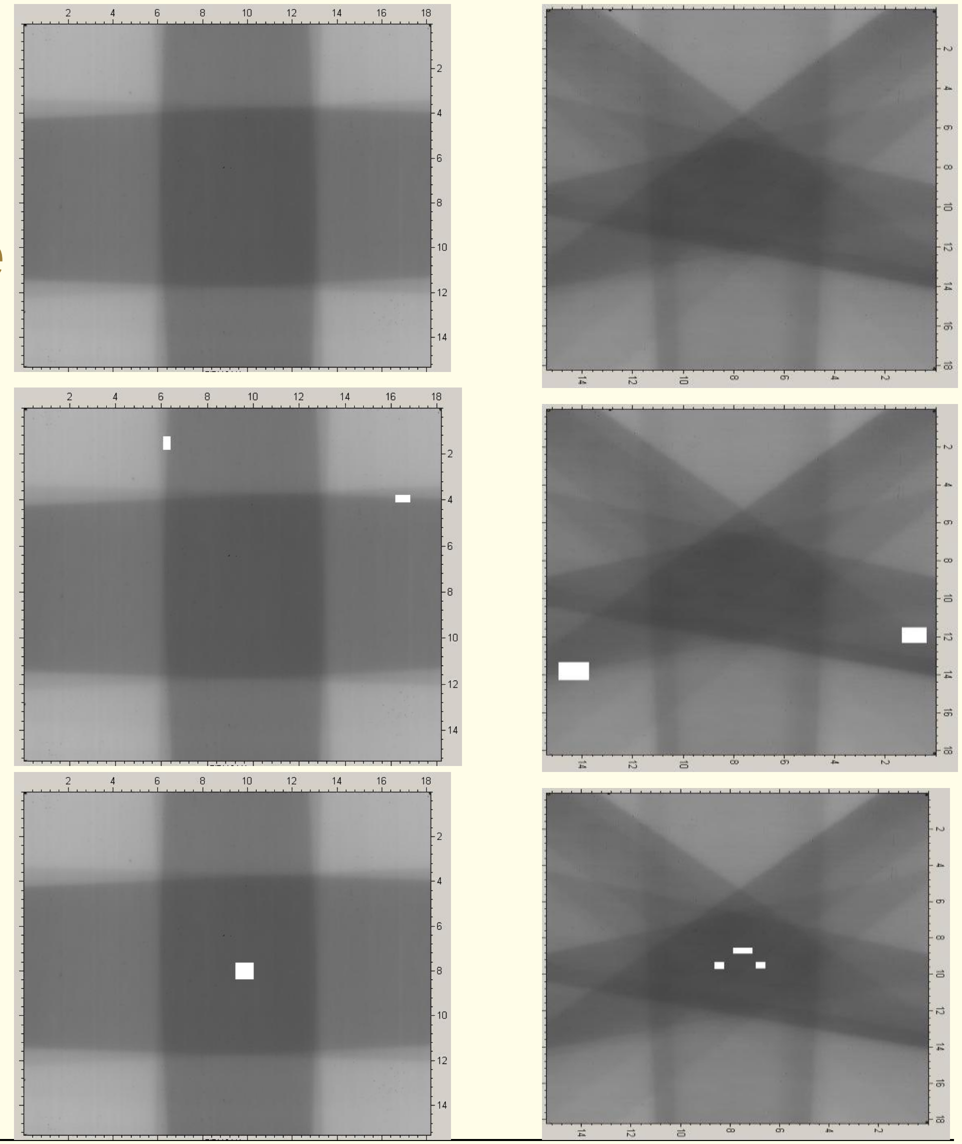
QC of Linear Accelerator Treatment Delivery

- Can sampling a clinical dose distribution satisfy the requirements of TG-142?

- If so, automated sampling and evaluation can help to more efficiently deploy physics resources.



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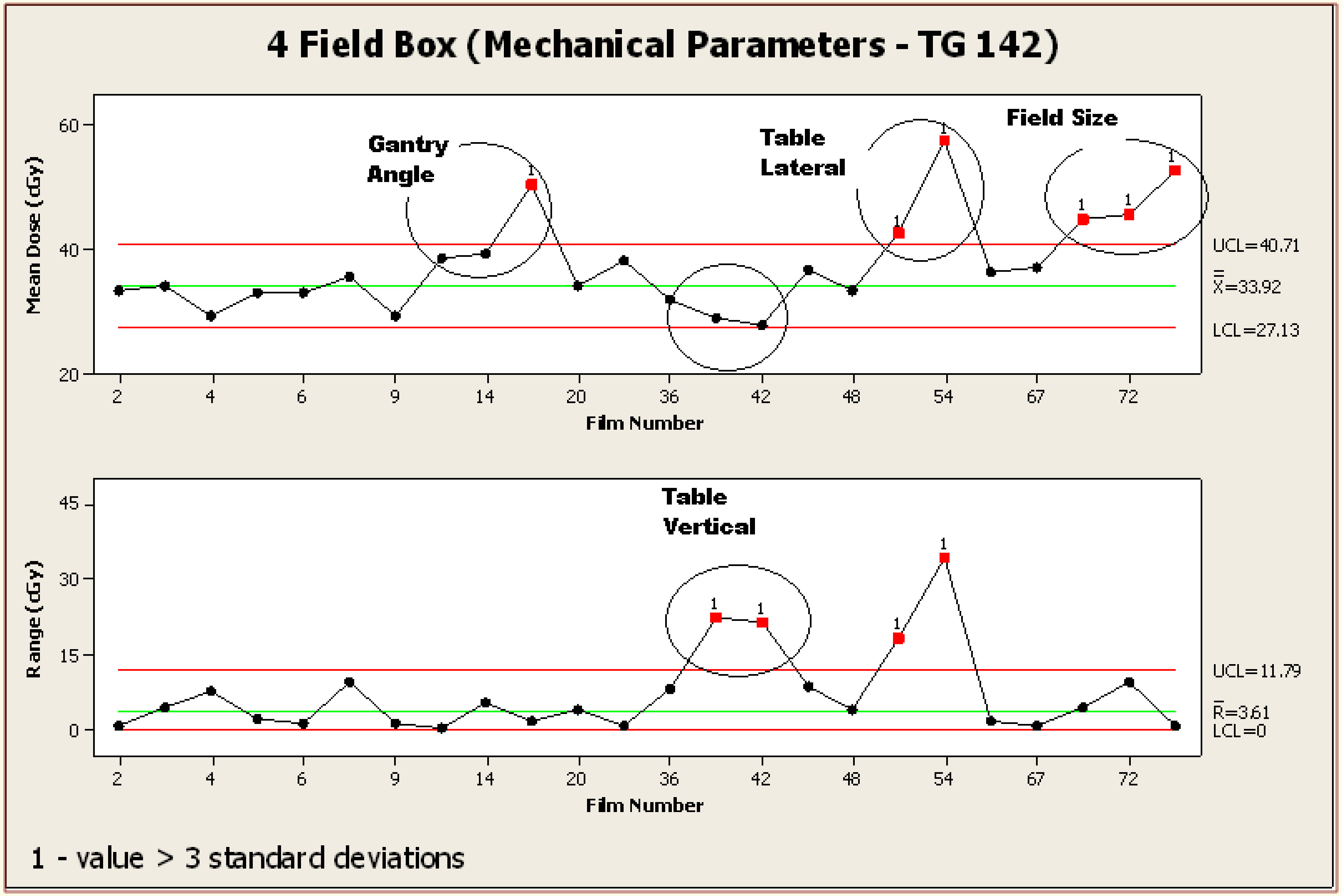
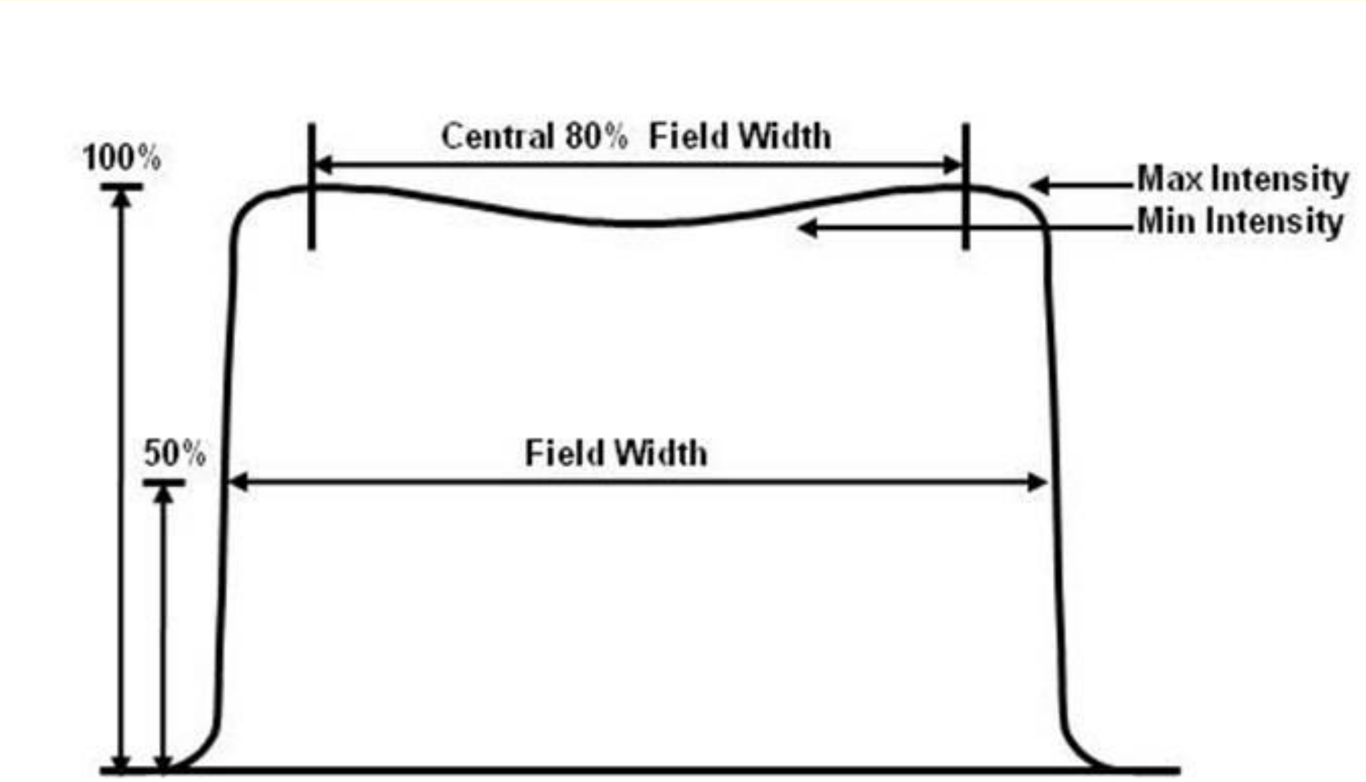
Future Directions



Able, C, Bright, M. Quality control of external beam treatment delivery: mechanical parameters. *Med Phys* 2009;36:2428

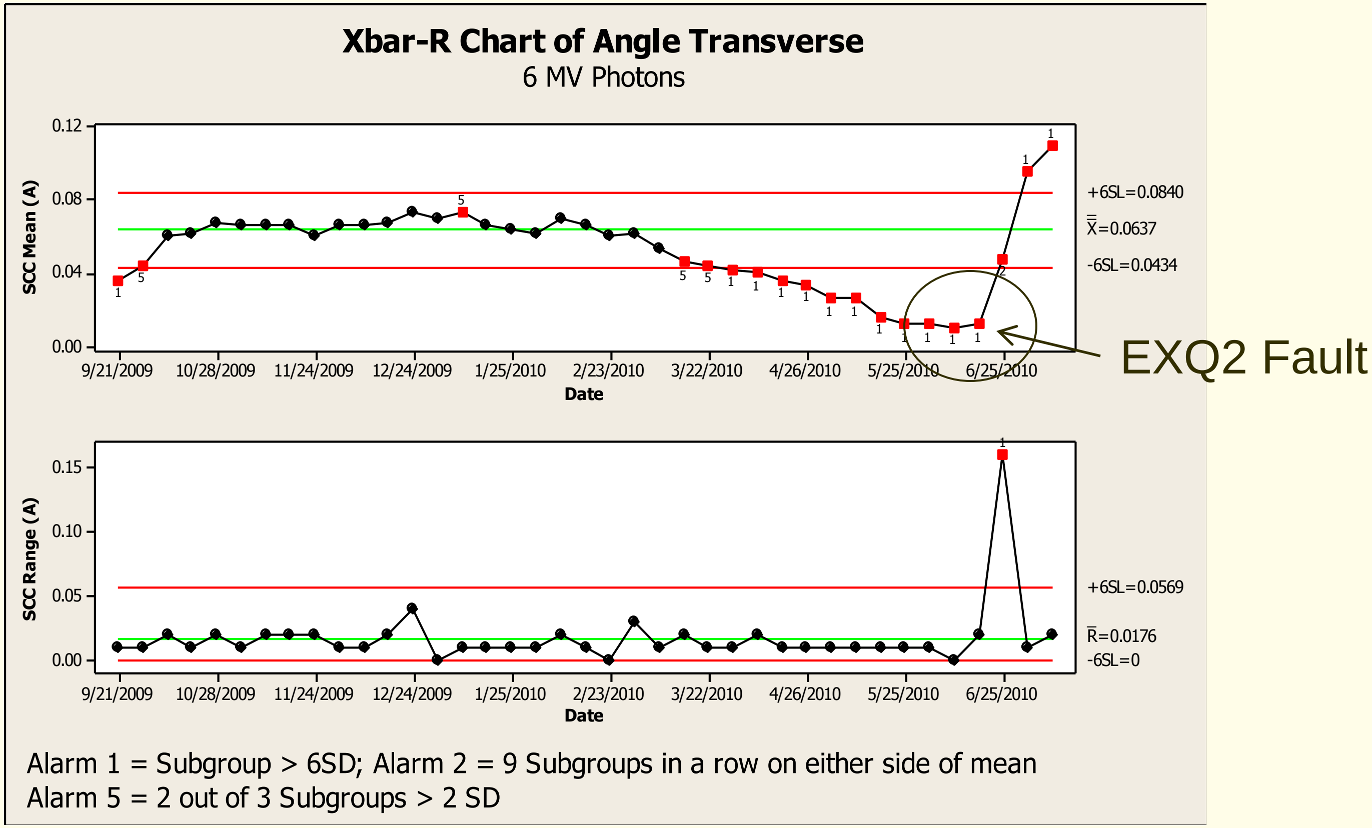
Beam Uniformity



2 types of steering coils in each plane: angle and position

Transverse angle & position steering coil
Radial angle and position steering coil

PdM: Beam Uniformity



SPC evaluation of steering coil currents (SCC) suggest changes in beam uniformity may have been detected prior to system interlock being actuated.

Able CM, Hampton CJ, Baydush AH, Munley MT.: Initial investigation using statistical process control for quality control of accelerator beam steering. Radiat Oncol. 2011 Dec 28;6(1):180

Typical formulation of control limits for the Individual Chart

$$I_u = \bar{x} + 3\frac{\overline{MR}}{d_2\sqrt{n}} = UAL$$

$$I_c = \bar{x} = \sum_{1}^{T} I_t \Big/ T$$

where T= number of subgroups

$$I_l = \bar{x} - 3\frac{\overline{MR}}{d_2\sqrt{n}} = LAL$$

Note that n=2 for calculation of individual and moving range charts

Typical formulation of control limits for the Moving Range Chart

$$MR_u = \left(1 + 3\frac{d_3}{d_2}\right)\overline{MR} = UAL$$

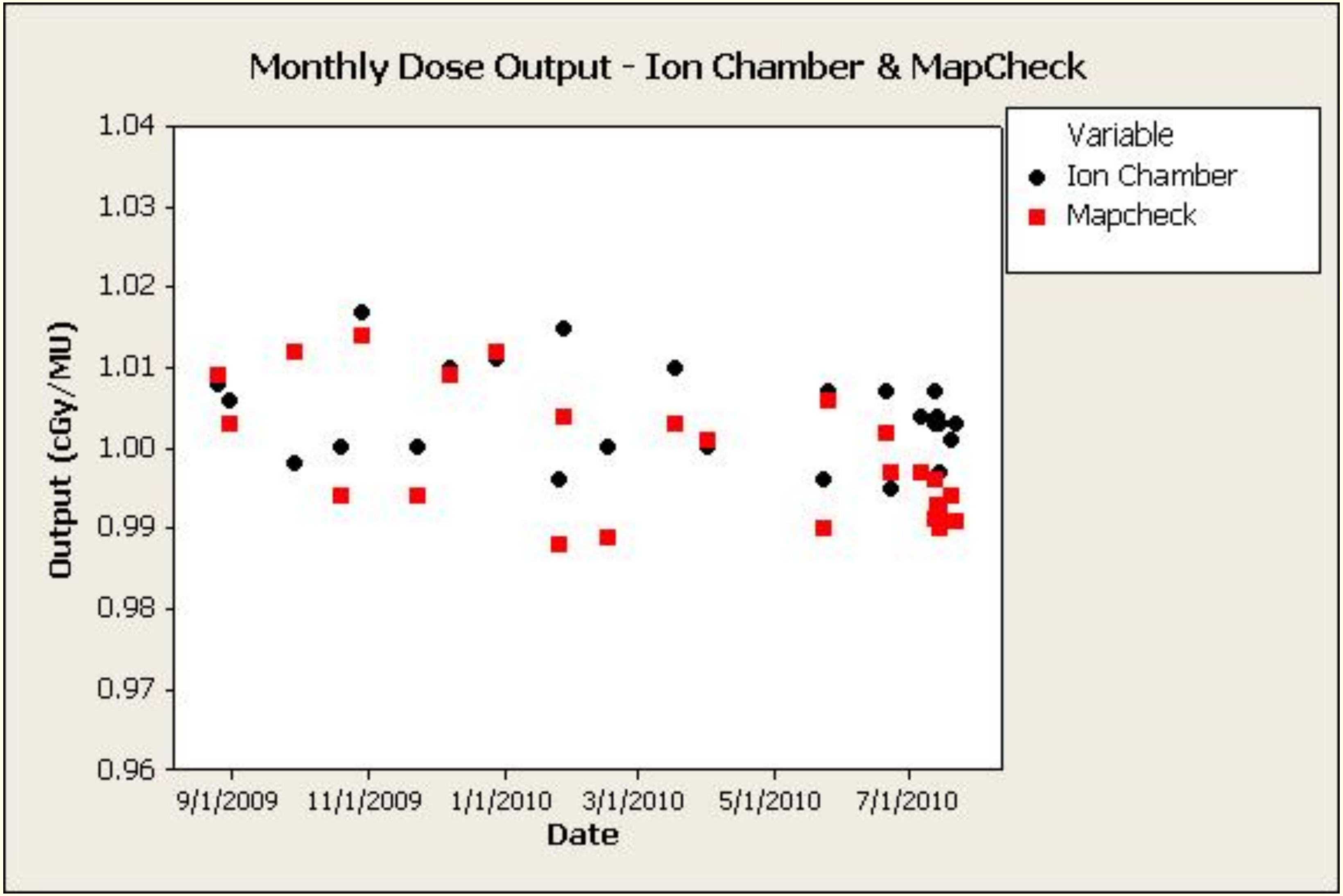
$$MR_c = \overline{MR} = \sum_{1}^{T-1} MR_t \Big/ (T-1)$$

where $MR_t = |I_t - I_{t+1}|$ and T= number of subgroups

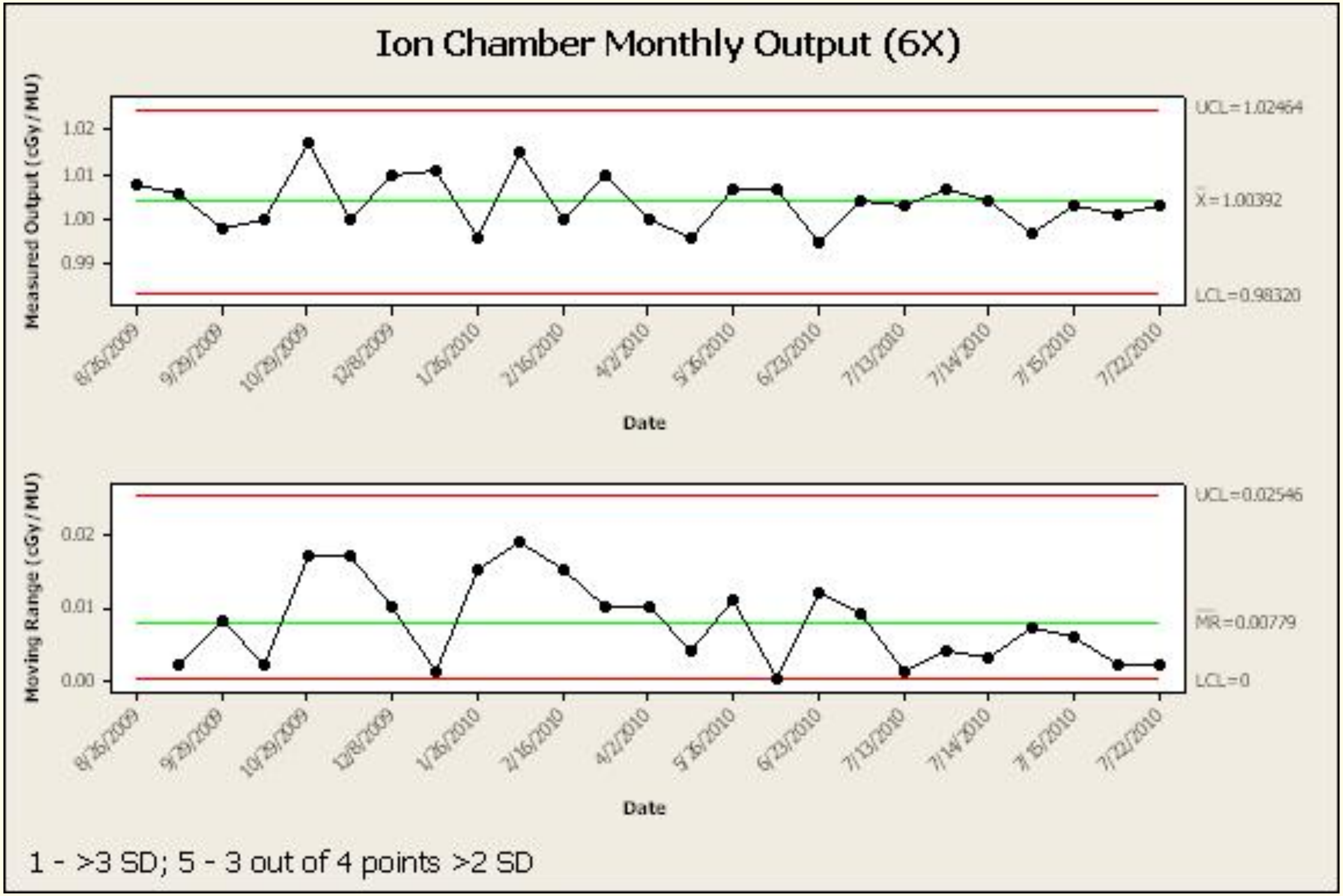
$$MR_l = \left(1 - 3\frac{d_3}{d_2}\right)\overline{MR} = LAL$$

Note that n=2 for calculation of individual and moving range charts

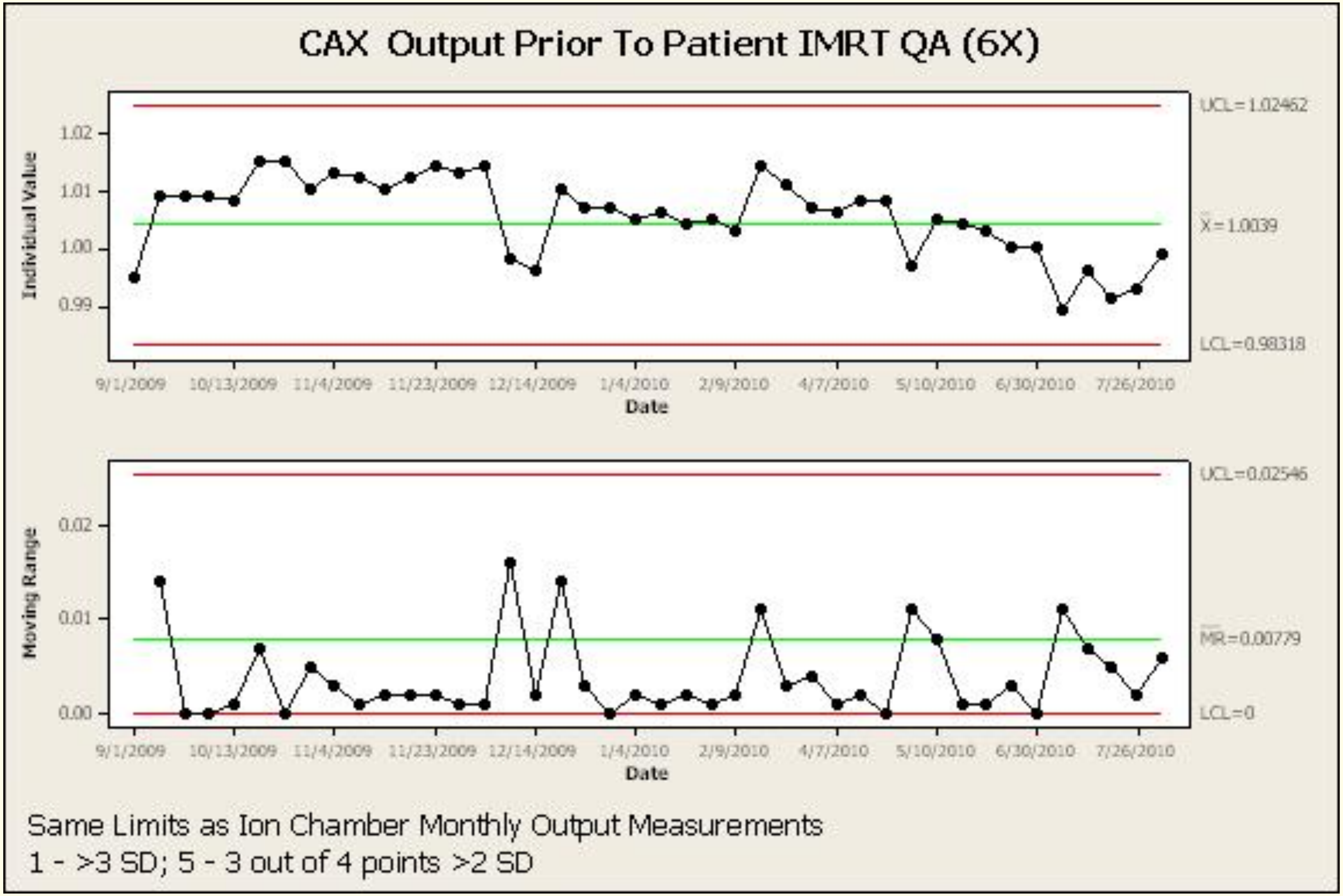
Quality Control of Absolute Dose IMRT QA



Quality Control of Absolute Dose IMRT QA



Quality Control of Absolute Dose IMRT QA

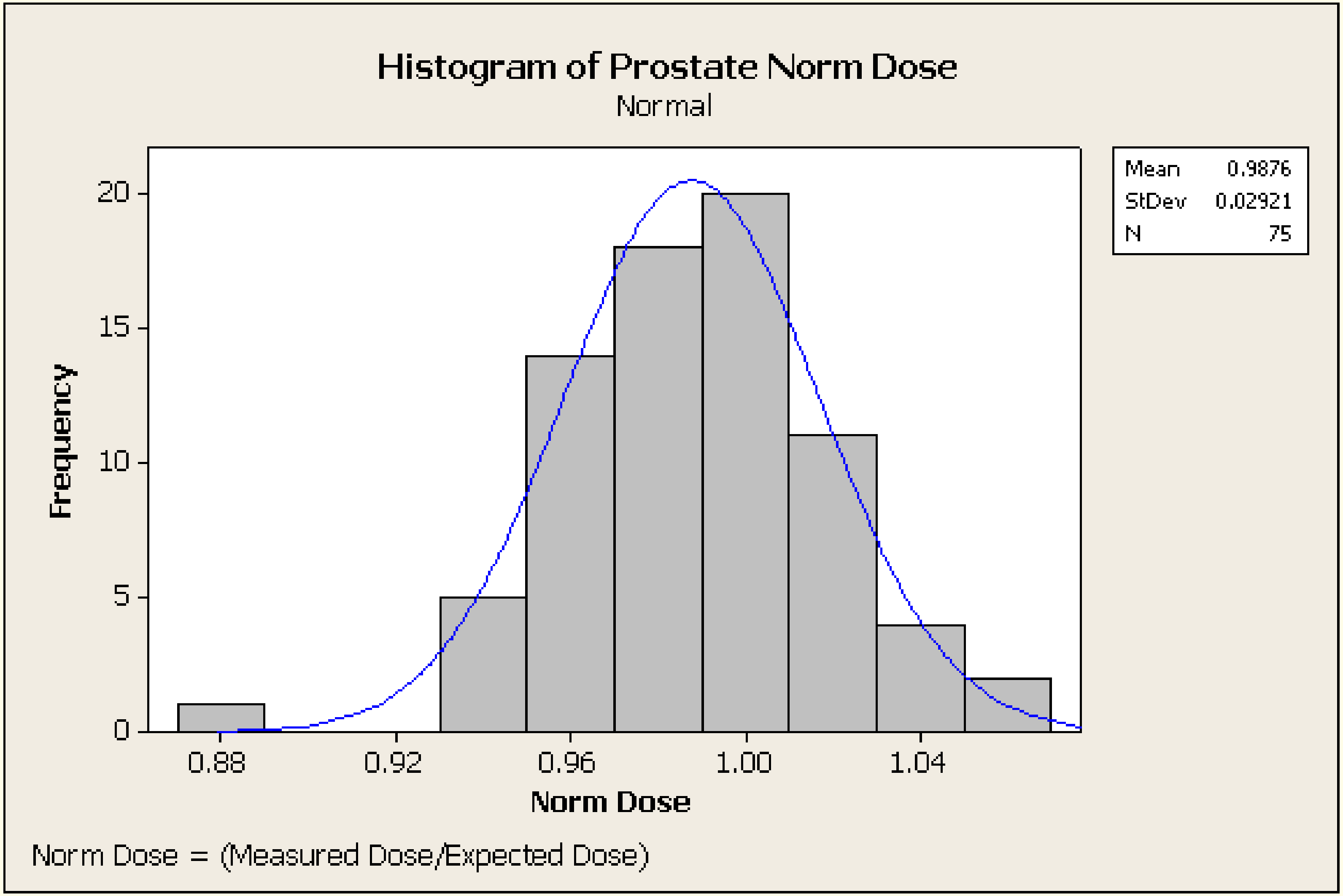


TG 119 Analysis of IMRT QA Results

TABLE XIV. Per-field measurements: Average percentage of points passing the gamma criteria of 3%/3 mm, averaged over the test plans, with associated confidence limits.

	Institution						
	A	B	C	D	E	F	H
Measurement device	Diode array	Diode array	EPID	Diode array	Diode array	Film	Diode array
Mean	98.9	93.3	99.4	99.2	98.6	99.6	96.8
Standard deviation(σ)	1.5	1.5	0.4	1.3	1.5	0.3	2.5
Local confidence limit $(100-\text{mean})+1.96\sigma$	3.9 (96.1%)	9.5 (90.5%)	1.3 (98.7%)	3.4 (96.6%)	4.3 (95.7%)	1.0 (99.0%)	8.1 (91.9%)
Number of studies	5	5	5	5	4	4	5

IMRT TG 119 Data Analysis



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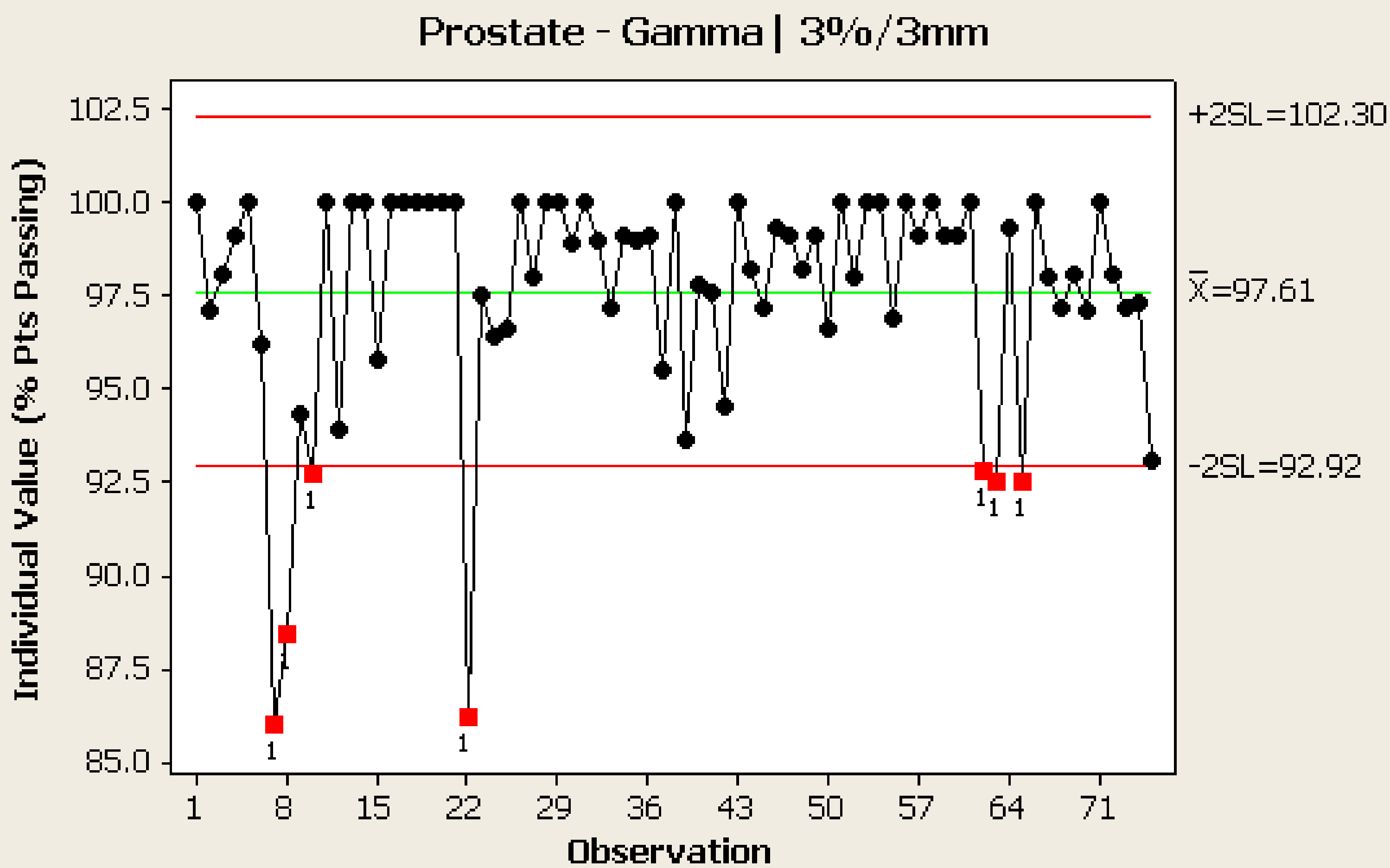
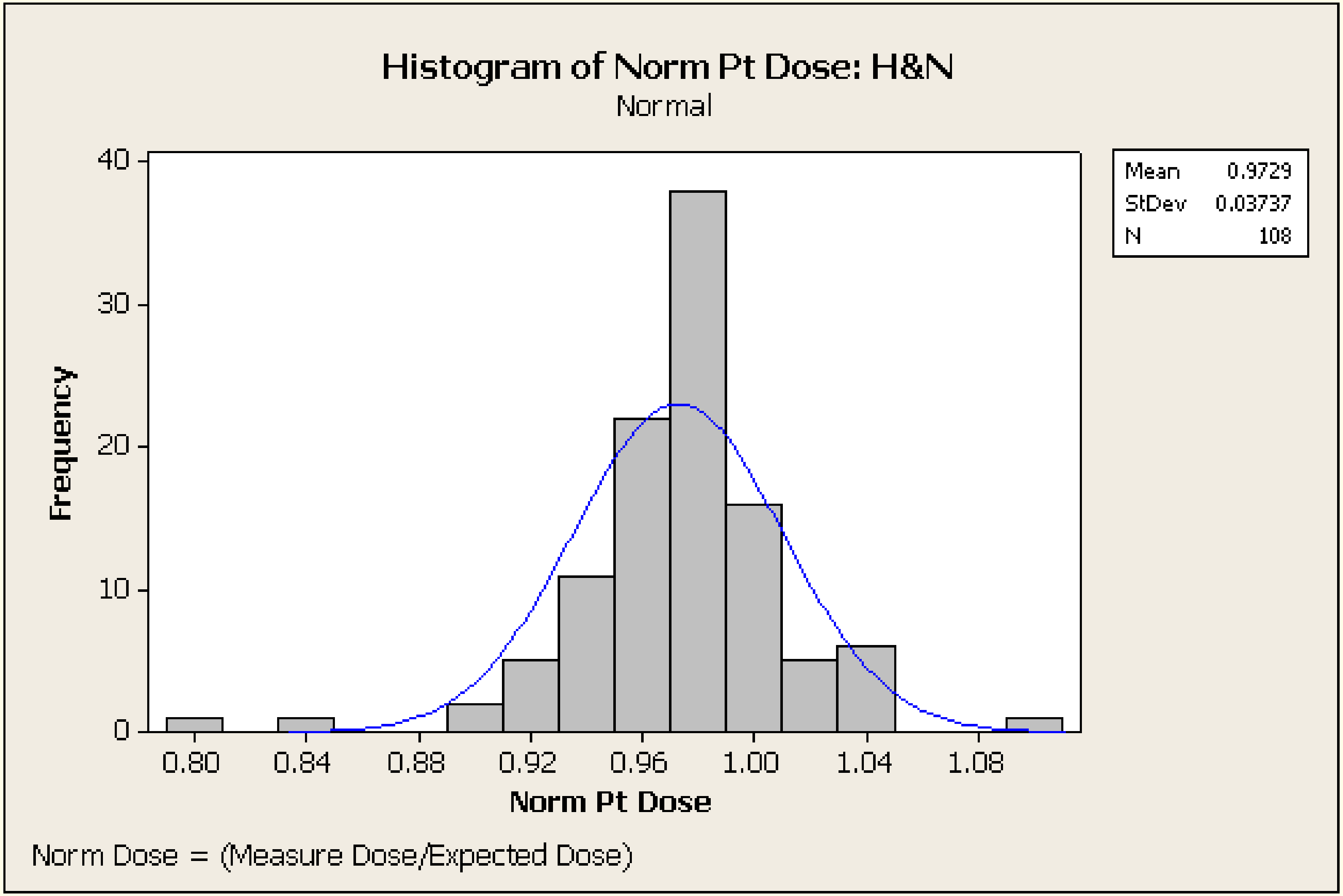
HPRHS Data Analysis



Confidence Limit = 7.1(92.9%) calculated per TG 119

HPRHS Data Analysis



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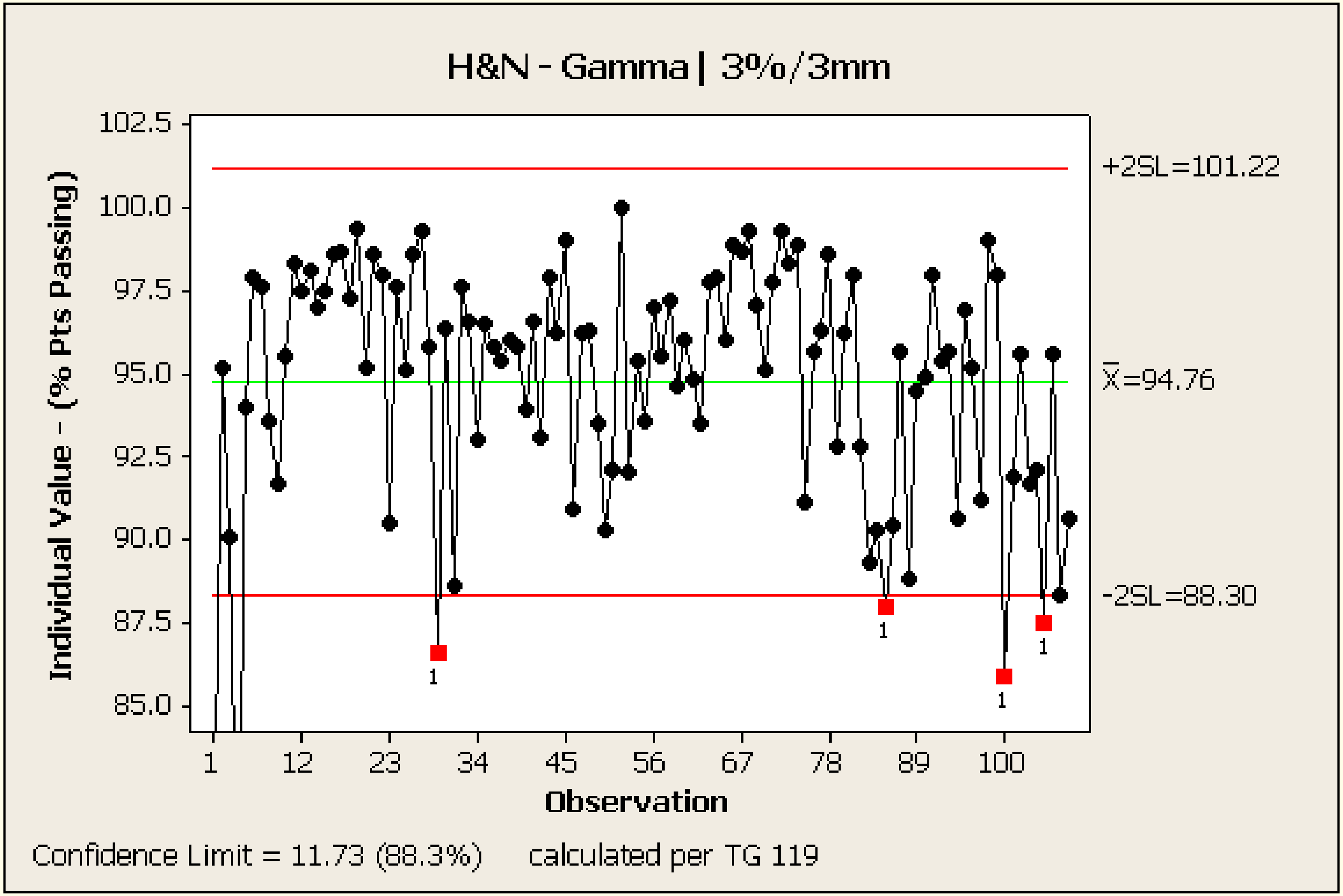
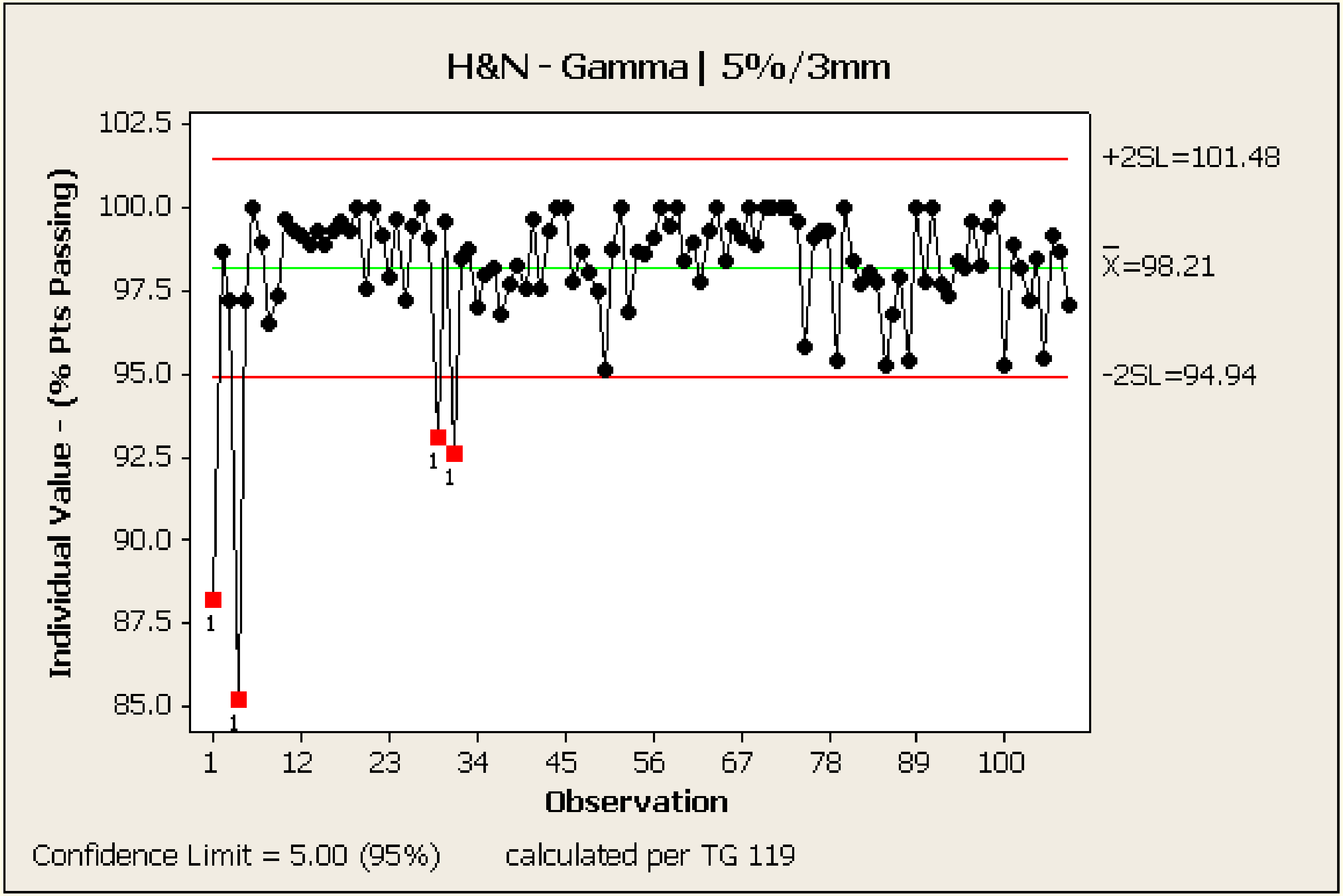


HPRHS Data Analysis



Summary of Results

TABLE XIV. Per-field measurements: Average percentage of points passing the gamma criteria of 3%/3 mm, averaged over the test plans, with associated confidence limits.

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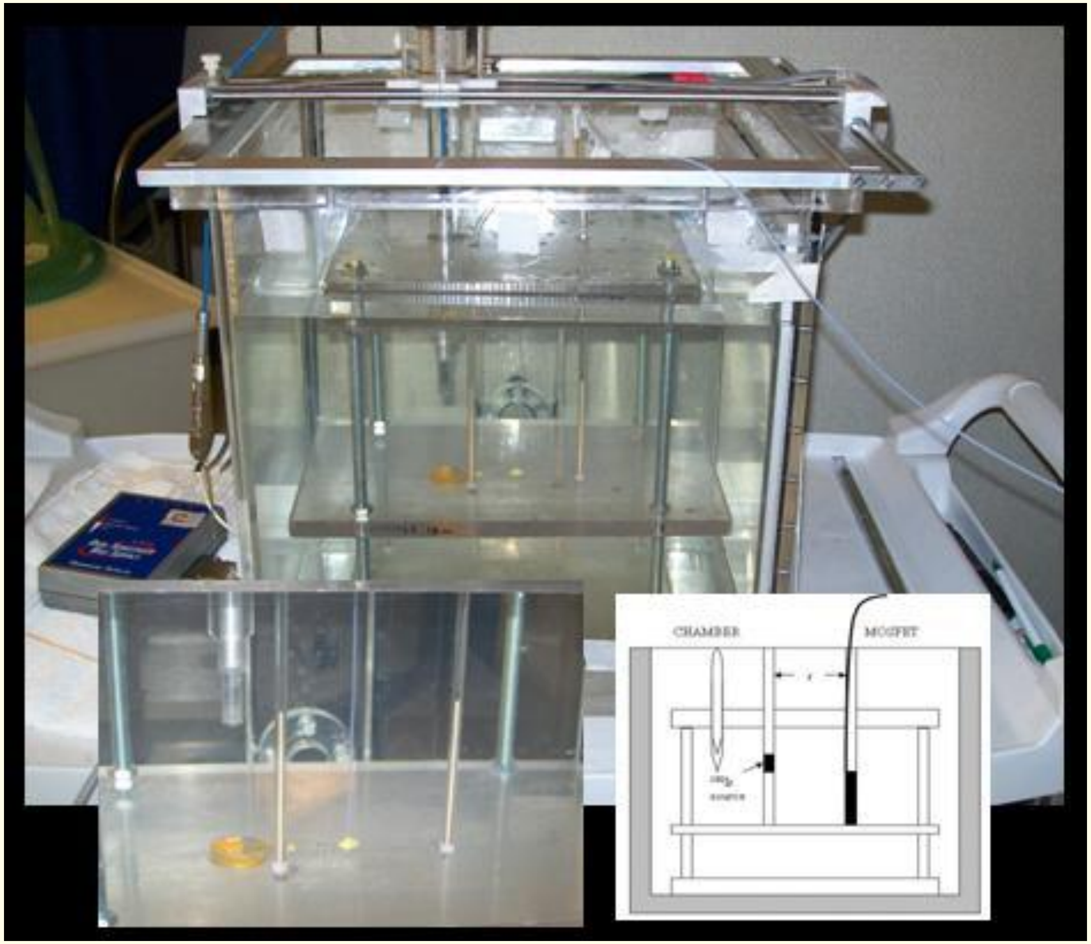
Number of studies	5	5	5	5	4	4	5

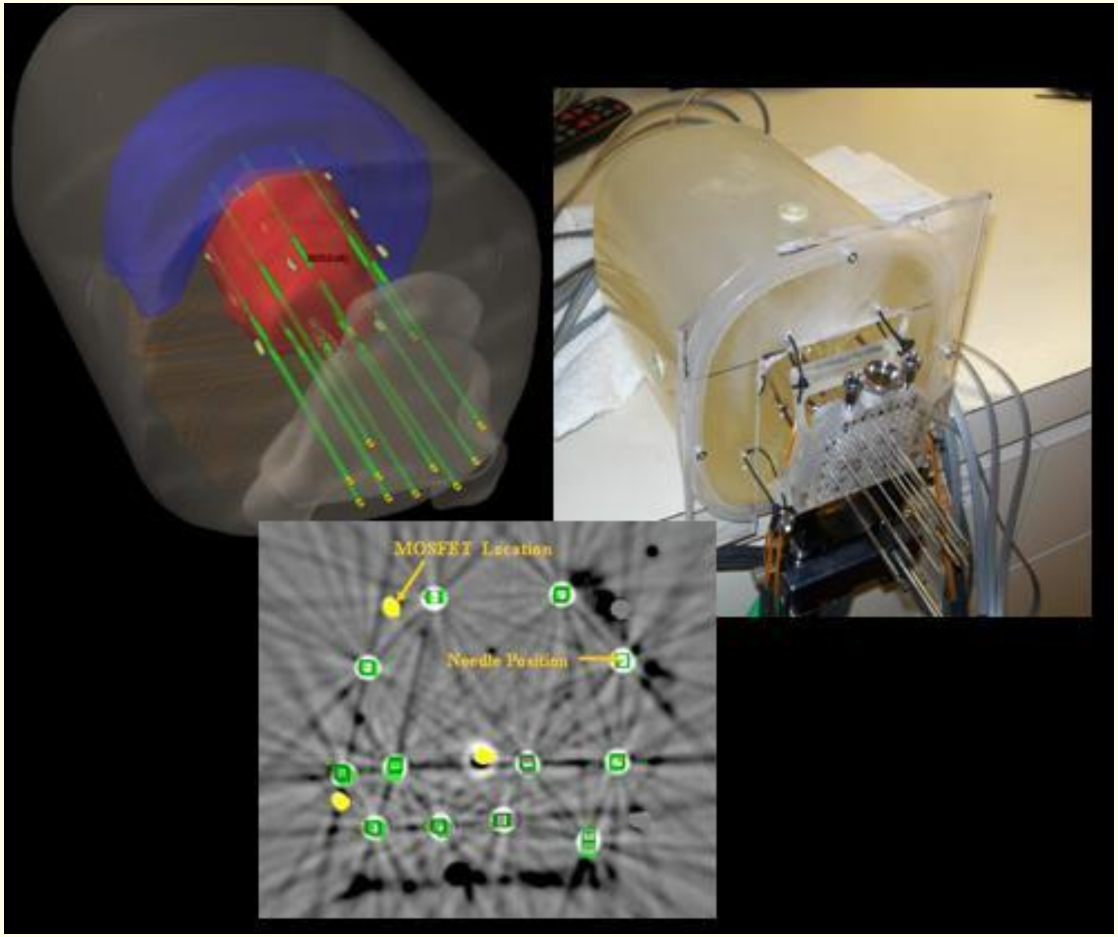
HPRHS Results
Mean = 95.9
SD = 2.9
Confidence limit = 9.8(90.2%)

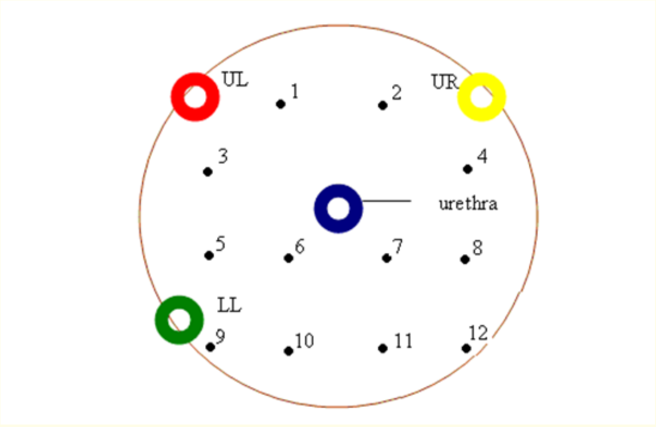
HDR Treatment Delivery Analysis Using SPC



Calibration of MOSFET detector for HDR source measurements using an ion chamber calibration.

HDR Treatment Delivery Analysis Using SPC





HDR Treatment Delivery Analysis Using SPC

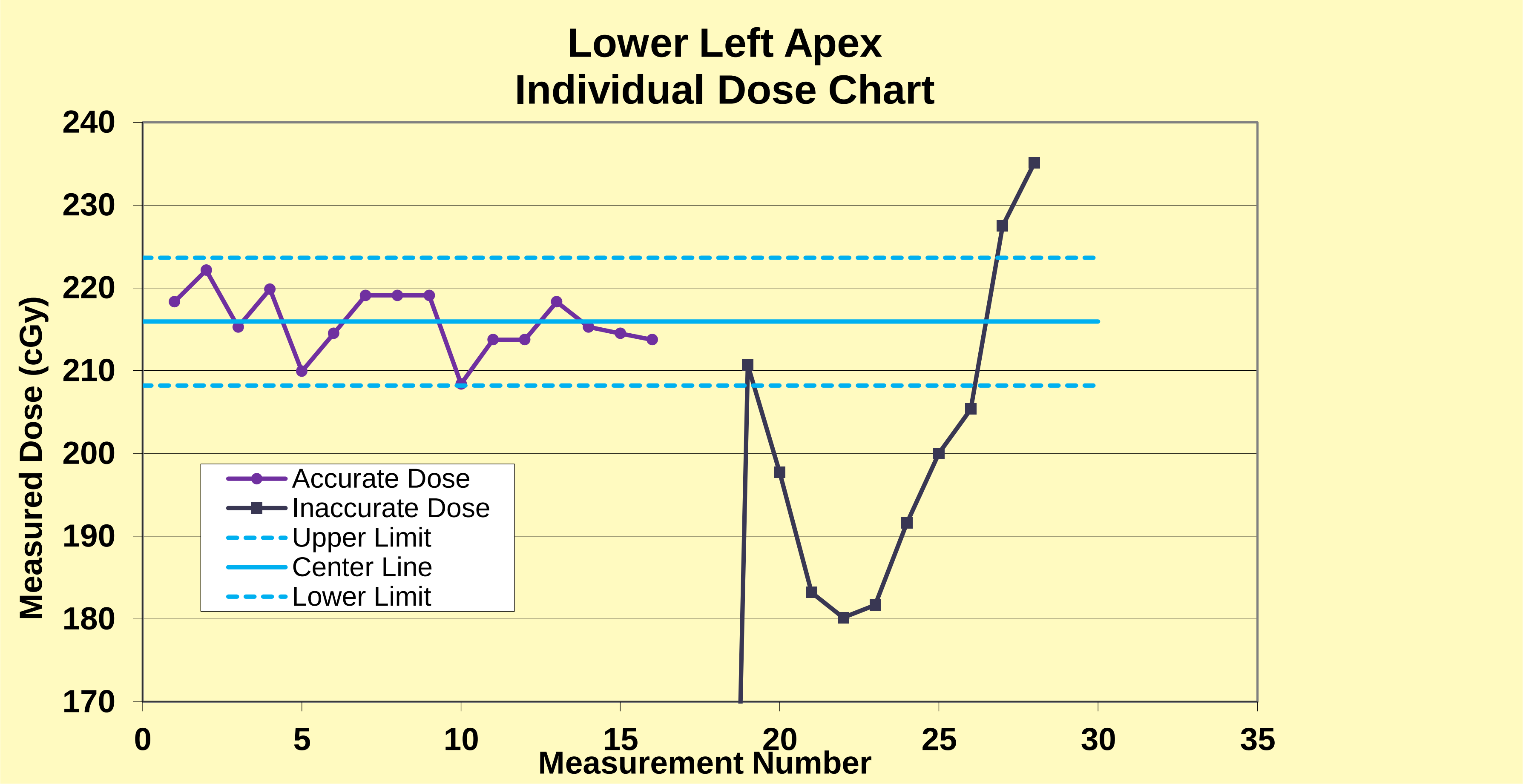
Experimental Setup

- 10 MOSFET detectors imbedded in the phantom
- 16 accurately delivered treatments used to establish SPC analysis parameters

Errors introduced

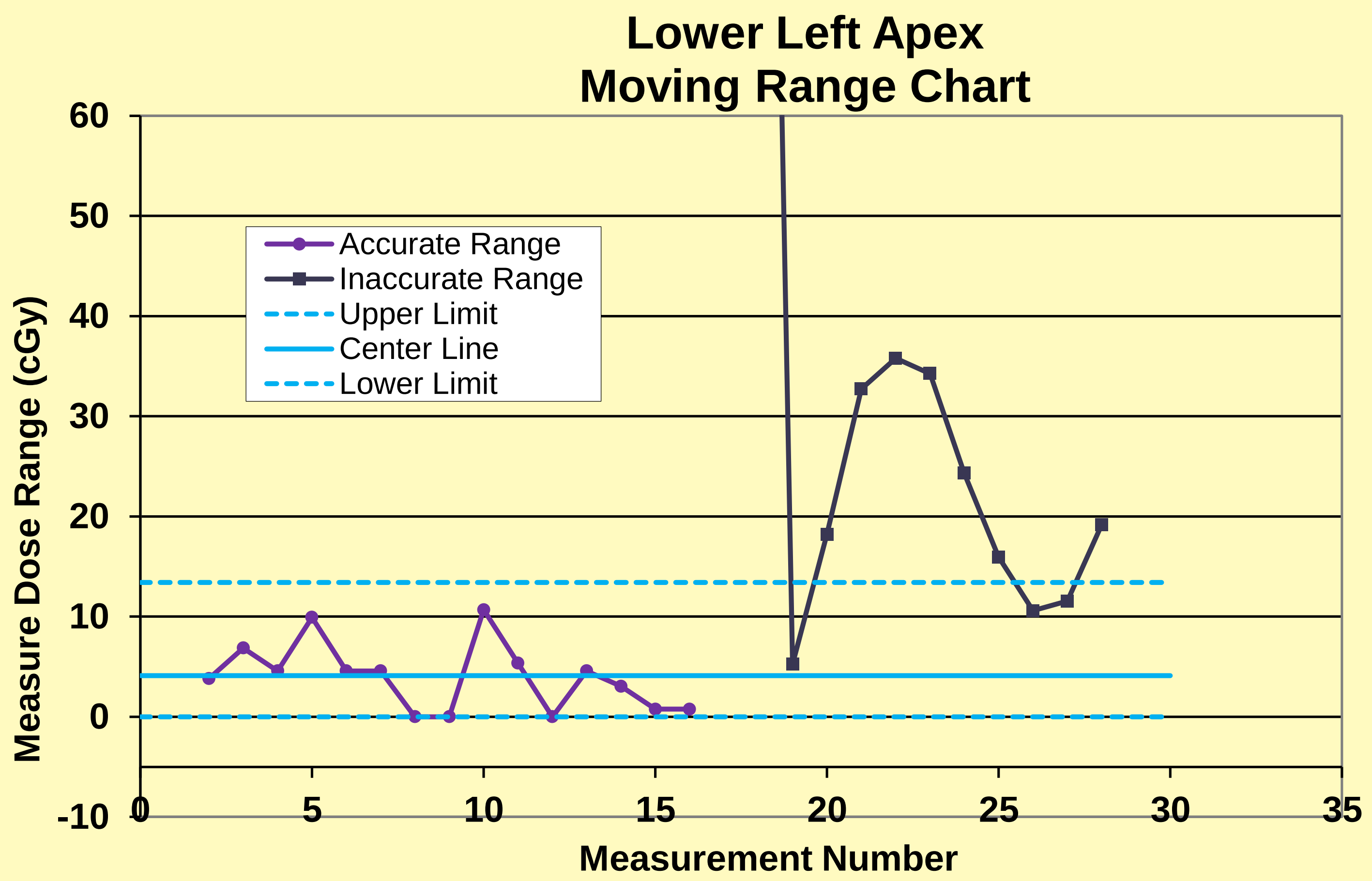
- wrong patient (one patient's plan on another patient)
- wrong source calibration (3 and 7 day source decay inaccuracy
- wrong sequence (2 needles, #6 and #10, switched in location on turret)
- single needle displaced inferiorly 5+/-1mm
- entire implant displaced inferiorly (2+/-1mm and 4+/-1mm)

HDR Treatment Delivery Analysis Using SPC



All treatment delivery errors were detected at this location with exception of 3 day source calibration error.

HDR Treatment Delivery Analysis Using SPC



Range chart results were consistent with the individual chart in detecting errors in treatment delivery.

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Summary

1. **SPC is an accessible methodology for quality control in radiation oncology.**
2. **Mean and Range chart evaluation as well as Individual and Moving Range charts are used for quality control analysis of continuous data**
3. **A wide range of applications for these tools exist in radiation oncology**

References

1. Oakland, JS. Statistical process control. Jordan Hill, Oxford, UK: Butterworth-Heinemann;2008.
2. Stapenhurst, T. Mastering statistical process control. Jordan Hill, Oxford, UK: Butterworth-Heinemann; 2005.
3. Burr, IW: The effect of non-normality on constants for Xbar and R Charts. Industrial Quality Control 1996, May: 565-569.
4. Manual on quality control of materials. American Society for Testing and Materials ;Philadelphia, PA, USA; 1951.
5. Pawlicki T, Mundt AJ. Quality in radiation oncology. *Med Phys* 2007;34:1529-1534.
6. Pawlicki T, Whitaker M. Variation and control of process behavior. *Int J Radiat Oncol Biol Phys* 2008;71 Supplement 1:S210-S214.
7. Pawlicki T, Whitaker M, Boyer A. Statistical process control for radiotherapy quality assurance. *Med Phys* 2005;32:2777-2786.
8. Ezzell GA, Burmeister JW, Dogan, N, et al. IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. *Med Phys* 2009;36:5359-5373.

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References

9. **Able, C, Bright, M. Quality control of external beam treatment delivery: mechanical parameters. *Med Phys* 2009;36:2428**
10. **Able CM, Hampton CJ, Baydush AH, Munley MT.: Initial investigation using statistical process control for quality control of accelerator beam steering. Radiation Oncology 2011 6:180**
11. **Able, C.M., Bright, M., Frizzell, B.: "Quality Control of High-Dose-Rate Brachytherapy: Treatment Delivery Analysis Using Statistical Process Control", Brachytherapy 9, S64-S65 (2010).**

Thank You!
¡Gracias!
Grazie!
Merci!
Asante!
Vielen Dank!