Radiation Measurements 86 (2016) 1–7

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

What can statistical process control show us about ionization chamber stability?

Juan López-Tarjuelo [a, *], Juan David Quirós-Higueras [a], Jorge Bonaque-Alandí [b], Naika Luquero-Llopis [b], Rafael García-Mollá [a], Xavier Jordi Juan-Senabre [a], Noelia de Marco-Blancas [a], Carlos Ferrer-Albiach [c, d], Agustín Santos-Serra [a]

[a] Servicio de Radiofísica y Protección Radiológica, Consorcio Hospitalario Provincial de Castellón, Avda. Dr. Clará 19, Castellón de la Plana 12002, Castellón, Spain
[b] Fundación Hospital Provincial de Castellón, Avda. Dr. Clará 19, Castellón de la Plana 12002, Castellón, Spain
[c] Servicio de Oncología Radioterápica, Consorcio Hospitalario Provincial de Castellón, Avda. Dr. Clará 19, Castellón de la Plana 12002, Castellón, Spain
[d] Facultad de Medicina, Universidad Cardenal Herrera-CEU, C/ Grecia 31, Castellón de la Plana 12006, Castellón, Spain

HIGHLIGHTS

- SPC can meaningfully report instability in the constancy of ionisation chambers.
- Surpassing the period of two years between calibrations is not recommended.
- In the interim, stability can conform to specifications of ±1.5%, according to SPC.

ARTICLE INFO

Article history:
Received 4 July 2015
Received in revised form
14 October 2015
Accepted 29 December 2015
Available online 31 December 2015

Keywords:
Statistical process control
Control charts
Radioactive stability check device
Process capability ratio
Specification band

ABSTRACT

Purpose: Statistical process control (SPC) has been shown to be a suitable tool for medical physicists to monitor quality and keep variability low and within specifications. We report our findings regarding ionisation chamber stability in our department when using a radioactive stability check device (RSCD) and we compare them with similar previously published records, including calibration results.
Methods: We retrospectively studied the stability of a PPC 40 parallel-plate chamber, and two Farmer chambers (FC65-G and FC65-P) by checking them with dedicated RSCDs. We analysed the data following SPC methodology which includes plotting I-MR control charts, monitoring out-of-control observations, calculating process capability ratios (C_p), and estimating conformance to specifications. We also estimated the C_p and adherence to specifications of previously published data.
Results: The PPC40 chamber hardly went out of the control limits over the whole six-year period assessed. However, Farmer chamber verifications drifted in opposite directions in phase II, and the deviations observed did not agree with their calibration records, which only increased by a maximum of 0.5%. In phase I the most unstable chamber was the FC65-P with a C_p equal to 0.9 at a specification level of ±1%. The PPC40 chamber was stable to within a maximum C_p of 1.3. Several sets of analysed data, including ours and those from other authors, fitted well within these limits: within ±1.9% and ±1.5% for a C_p of 1.5 and 1.33 respectively.
Conclusions: SPC with constant long-term RSCD checking gave us a meaningful plot of the instability of our ionisation chambers. Although a period of two years between calibrations should not be surpassed, in the interim this check can conform to specifications of ±1.5%.

1. Introduction

Radiotherapy departments are increasingly being studied as radiotherapy treatment producers, to which production standards can be applied. Radiotherapy requires accuracy and precision

* Corresponding author.
E-mail address: lopez_juatar@gva.es (J. López-Tarjuelo).

http://dx.doi.org/10.1016/j.radmeas.2015.12.041
1350-4487/

(Brahme, 1984; Dobbs, 1999); these departments must commit to maintaining low variability and can benefit from the quality-monitoring tools which have already been used in engineering for decades (Sutlief et al., 2013). In the modern industrial and business environment an increase in quality is defined as (and obtained with) a reduction in production variability (Montgomery, 2009c).

One powerful method for monitoring production processes, achieving stability, and reducing variability is statistical process control (SPC; Montgomery, 2009c), which was developed in the 1920s by Walter A. Shewhart and was the first productivity control application used in industrial manufacturing (Shewhart, 1931). After this W. Edwards Deming incorporated this strategy as one of the pillars of what has been called total quality management and which now has multiple applications in industrial processes, education, and services (Deming, 1986).

In recent years several groups have published work which illustrates how SPC can be applied to the different systems controlled by medical physicists in the various radiotherapy processes related to linear particle accelerator (linac) monitoring (Pawlicki et al., 2005; Able et al., 2011; de la Vega et al., 2012; Sanghangthum et al., 2013b; Létourneau et al., 2014; López-Tarjuelo et al., 2015), image guided radiation therapy (IGRT; Ung and Wee, 2011), monitor-unit verifications (Nordström et al., 2012), high-dose rate (HDR) brachytherapy treatments (Able et al., 2013), proton therapy beams (Rah et al., 2014), and different aspects of intensity-modulated treatment quality assurance (Breen et al., 2008; Pawlicki et al., 2008a, 2008b; Gérard et al., 2009; Sanghangthum et al., 2013c, 2013a; Gagneur and Ezzell, 2014).

Despite this growing trend in SPC reporting, to our knowledge, no results have so far been published using this kind of analysis to assess the stability of the ionisation chambers used in radiotherapy. Thus, our aim was to report our findings using SPC to check long-term ionisation chamber stability by means of radioactive stability check devices (RSCDs). We then compared our results with other published studies regarding long-term chamber stability and calibration (Karzmark, 1980; Barish and Lerch, 1992; de Souza et al., 1995; Sidhu et al., 2000). Finally, we discuss the consistency of the results obtained with RSCDs, and their ability to meet different stated specifications, as a result of SPC evaluation. We also provide new insights derived from SPC with regard to claims in some studies which suggest that stability checks with RSCDs can be used as a substitute for mandatory ionisation chamber calibrations (U.S.NRC, 2003) in order to ensure ionisation chamber constancy over periods longer than two years (Karzmark, 1980; Barish and Lerch, 1992). In this sense, we emphasise the results which lead us to advise against this approach.

2. Materials and methods

2.1. SPC tools

We used Shewhart control charts for individuals and their moving ranges to monitor the ionisation chamber long-term stability (Montgomery, 2009a). A control chart for individual units (I chart) is plotted by assuming that it is very unlikely that a new observation exceeds the distance 3σ (where σ is the standard deviation) from the mean of the previous sample, $\overline{x}$. This means that measurements are represented sequentially against a central line (CL) and two control limits. The CL is

$$CL = \overline{x} \tag{1}$$

and the upper and the lower control limits (UCL and LCL respectively) are evaluated using the mean of the moving ranges (MR) of two successive observations x_{i-1} and x_i:

$$MR_i = |x_i - x_{i-1}| \tag{2}$$

$$UCL = \overline{x} + 3\frac{\overline{MR}}{d_2} \tag{3}$$

$$LCL = \overline{x} - 3\frac{\overline{MR}}{d_2} \tag{4}$$

The moving ranges are also monitored with an MR chart. These are their CL and control limits:

$$CL = \overline{MR} \tag{5}$$

$$UCL = D_4\overline{MR} \tag{6}$$

$$LCL = D_3\overline{MR} \tag{7}$$

d_2, D_3 and D_4 depend on the number of samples used for the calculation, and in the case of two observations, as in this work, $d_2 = 1.128$, $D_3 = 0$, and $D_4 = 3.267$ (Montgomery, 2009a).

An observation falling outside these control limits indicates that the system has varied in a manner which is very unlikely explained by random variation. Therefore in this case a special cause may be affecting the system, which must be investigated and may require corrective action to return it to within its normal or expected operation limits. In a similar fashion, a moving range falling outside the upper control limit indicates greater-than-expected variation. There is another set of control charts also suitable for monitoring variables according to their mean and range along time ($\overline{x}$-R charts), but they are oriented to sample batches (Montgomery, 2009a).

It is important to know the detection properties of the control tool used. In the case of the Shewhart $\overline{x}$ control chart with 3σ limits (with σ representing the process standard deviation) the average run length (ARL) when the process is under control, or number of points plotted in a run until a single point falls outside the control limits (although process is still in control, i.e. a false positive) is $ARL_0 \cong 370$, and its out-of-control ARL is $ARL_1 = 2$. In other words, we would obtain an out-of-control signal for our process only two observations after a 3σ shift to an out-of-control state.

Control charts provide information about the capability or conformity to the specifications of a process; the process capability ratio C_p is used to express process capability and to tell us how much of our process variation is contained within its specification band, and is limited by the upper and the lower specification limits (USL and LSL respectively). These limits are not connected with the control limits and correspond to external demands for process outcomes (Montgomery, 2009a):

$$C_p = \frac{USL - LSL}{6\sigma} \tag{8}$$

An estimation of σ can be obtained either from the average moving range $\overline{MR}$ as

$$\widehat{\sigma}_1 = \frac{\overline{MR}}{d_2} \tag{9}$$

where, in the case of Shewart control charts, d_2 is tabulated for sample sizes of 2 as 1.128, or from the sample standard deviation as

$$\widehat{\sigma}_2 = \frac{s}{c_4} \tag{10}$$

where c_4 is also tabulated in terms of sample size.