Dose Rate and Dose per Pulse Dependence of PTW Solid State and Liquid-filled Detectors

1 Introduction

In general, the response of dosimetry detectors may weakly depend on the dose rate or dose per pulse of the radiation. For air-filled chambers, several methods exist to describe this dose rate or, more precisely, dose per pulse dependence (DPPD). Less clear is the situation for solid state and liquid-filled detectors.

This document provides some background on the dose rate dependence of these detectors in the radiation of linear accelerators (linacs). We will address them commonly as “high-density detectors” in the following. To describe the dose rate dependence, we will use the following terms:

- Dose per pulse dependence: if only the dose per pulse changes but the repetition rate is fixed.
- Repetition rate dependence: if the repetition rate (i.e. frequency of the pulses) changes but the dose per pulse is fixed. For most linacs this is what happens when the MU/min setting is changed.
- Dose rate dependence: general term including both of the above dependencies.

All presented data is typical and does not include sample-to-sample fluctuations of the detector types or dependencies on linac models. The data provided shall only give an orientation about the effects that are to be expected. To correct for the DPPD of an individual high-density detector the correction factors have to be measured explicitly for the equipment, geometry, radiation quality and pulse repetition frequency used. Most of the data in this document is DPPD data.

2 Measurement method

All measurements have been performed in a PMMA phantom. The dose per pulse (DPP) was varied by changing the source-to-surface distance (SSD) of the phantom. For each SSD, the field size was adjusted to be 10x10 cm² in the depth of the detector in the phantom. This prevents effects from a possible field size dependence of the specimen. The data has been recorded at different linac models, pulse repetition frequencies and radiation qualities. Within one measurement series, the MU/min or frequency setting of the linac was not changed. The data of the specimen was normalized to DPPD-corrected data from a Semiflex 0.125 cm³ (T31010) chamber located at the same position within the phantom. The measurement uncertainty of the performed measurements was estimated to ±0.7 % (k=1).

The measurement data has been fitted to suitable functions and these fitting functions are displayed in the viewgraph (Figure 1) presented further below. The presented data corresponds to detectors which have been cross-calibrated at 0.3 mGy/pulse, which is a common dose per pulse in the depth of the dose maximum (d_{max}) for linacs with flattening filter. The data of the OCTAVIUS 1000SRS array has been calculated from the technical specifications by linearly extrapolating the 99 % saturation values. The behavior of the OCTAVIUS 1600SRS is the same as for the 1000SRS [Brodbek2021]. The data of the Semiflex 0.125 cm³ (T31010) chamber has been calculated according to the k_s-formula[1] of the German dosimetry standard DIN 6800-2 (version from 2008) and is included for comparison reasons.

3 Dose per pulse and frequency dependence

As long as the time between two consecutive linac pulses is much longer than the ion collection time of the chamber, the saturation behavior of **ionization chambers** only depends on the dose per pulse but not on the repetition frequency of the linac pulses.

For **air-filled** ionization chambers commonly used in water phantom measurements this requirement is usually fulfilled.

For **liquid-filled** ionization chambers the ion collection time is much longer than for air-filled chambers and, in addition, the recombination processes are more complicated. The saturation behavior, i.e., the dose rate dependence of liquid-filled ionization chambers usually depends on the **dose per pulse *and* on the frequency**.

For **solid state detectors** different scenarios are possible. It is possible that – within the measurement uncertainty – there is no or almost no dose rate dependence. This is, for example, the case for the microSilicon (T60023) and the microDiamond (T60019). It is also possible that a detector exhibits a dependence on the dose per pulse, on the repetition rate, on the average dose rate, or any combination of the above. This has to be deduced for each type of solid state detector individually. For some older types of silicon diode, the dose per pulse dependence is a function of the accumulated dose, see section 5 for details.

In the majority of cases, high-density detectors are used at a linac in pulsed radiation. Hence, the following data is presented on a dose per pulse axis. The linac frequency and radiation quality are given in the legend of the viewgraph.

[1] k_S is the correction factor for saturation correction. A copy of the DIN correction formula can be found in the code of practice in the PTW DETECTORS catalogue.

4 Dose per pulse diagram

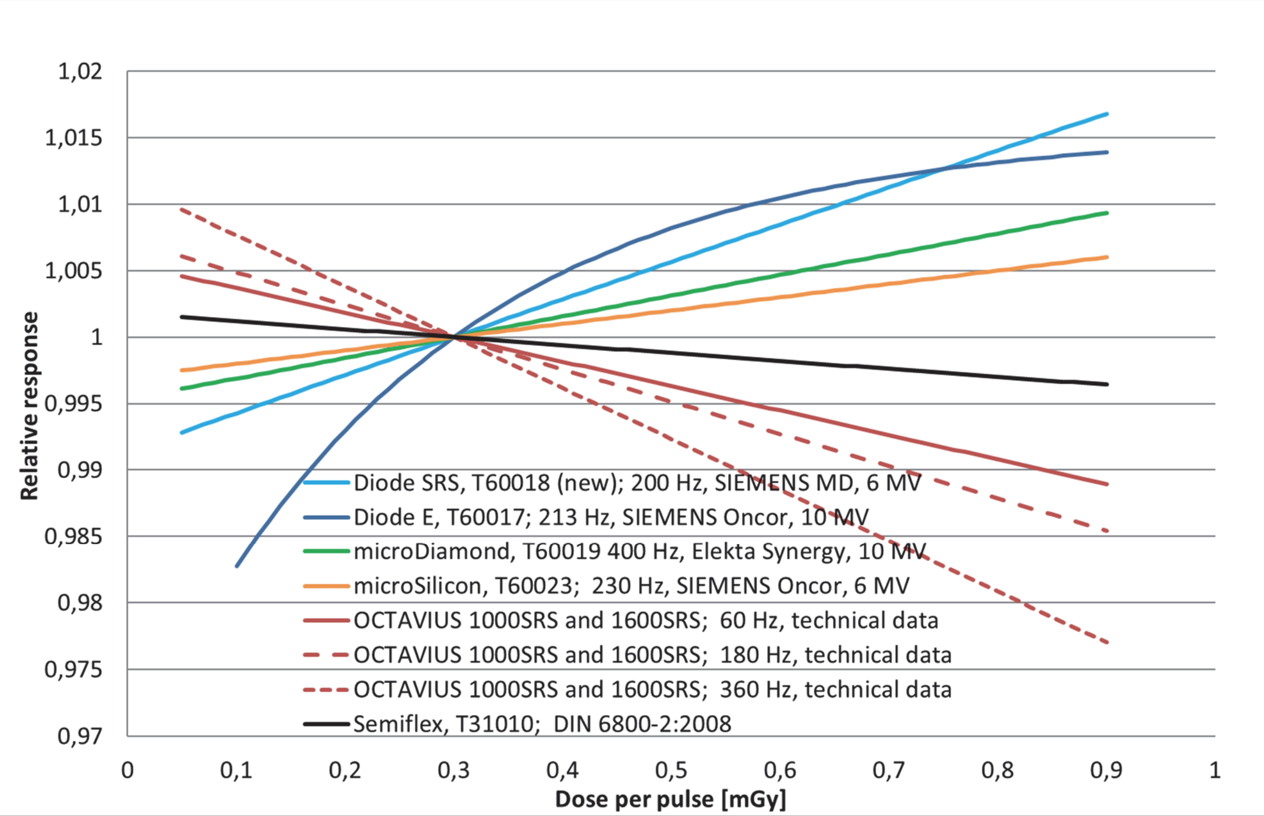

Figure 1 Relative response of PTW high-density detectors as function of the dose per pulse of a linac, including a Semiflex 0.125 cm³ (T31010) air-filled chamber for comparison. The uncertainty of the data was estimated to ±0.7 % (k=1). *Note*, the relative response is the inverse of a saturation correction.

4.1 Working with the diagram when using an OCTAVIUS 1000 SRS or 1600 SRS array

If the frequency, i.e., MU-setting of the linac, is fixed, choose the line closest to this frequency. The dose per pulse dependency will follow that line or be close to that line. In practice, this will be the case when measuring on different positions within a field (or outside of it), or if the distance between focal spot and detector changes. The dose per pulse will be proportional to the measured dose and will also vary with the field size, proportional to the output factor.

If the dose per pulse is fixed but the frequency changes you first have to estimate the dose per pulse you are currently working with. At this dose per pulse you will be moving up and down vertically between the three frequency-dependent lines in the diagram as the frequency of the linac pulses changes. In practice, this will be the case when the field size is constant but the MU/min setting changes. This can happen in a VMAT plan.

If the field size changes and also the MU/min setting – this will be the case for most VMAT plans – you have a mix of frequency change and dose per pulse change.

To keep the dose per pulse dependence low in your measurement, it is best to cross-calibrate the array in a field size and MU/min setting which will be close to the situation in the patient plan you will be testing. 4 cm x 4 cm at maximum used MU/min setting is often a good choice.

5 Dose per pulse dependence of T60008, T60012, and T60018

For some types of silicon diode, the dose per pulse dependence is a function of the accumulated dose. This is the case for the following three types of diode:

- T60008 Diode P (old type of the Diode P T60016)
- T60012 Diode E (old type of the Diode E T60017)
- T60018 Diode SRS

These three detector types may develop a relatively strong DPPD with heavy irradiation damage. “Heavy” in this respect means that the response of the detector is less than 85 % of the value when it was delivered. In case you do not keep record of the response of the detector, see section 5.1 for a DPPD-test.

For all the other types of diode (T60016 Diode P, T60017 Diode E, T60023 microSilicon, T60022 microSilicon X and T60019 microDiamond) the dose rate dependence is independent of the accumulated dose. Even after heavy irradiation damage, it does not change.

5.1 Quick DPPD test for silicon diodes

The following text describes a measurement procedure to deduce the dose per pulse dependence of a diode between two SSD values where the dose per pulse changes by a factor of approximately two.

You will need a water phantom and a medium-sized scanning chamber, such as Semiflex 0.125 cm³ or Semiflex 3D. The radiation quality should be X06 (i.e. with flattening filter). If this is not available, X06 FFF is an alternative but at slightly reduced accuracy. Place both detectors such that their effective point of measurement is in d_{max} or a few millimeters deeper than d_{max}. In the following we will assume that the detector is in 15 mm depth.
This is a high-precision measurement, detectors should be pre-irradiated as required, zeroing should have been performed well and high voltage should be set according to specifications.
You will need four single point dose measurements:

- S_{100}: 200 MU Semiflex at SSD[2] = 98.5 cm and nominal field size 10x10 cm²
- S_{70}: 200 MU Semiflex at SSD = 68.5 cm and nominal field size 14.2x14.2 cm²
  Note: The nominal field size setting makes sure that in the plain of the detector the field size is 10x10 cm² for both SSDs. This is necessary to exclude the energy response of the diode from the measurement.
- Change the detector to the diode, make sure the high voltage is set correctly to zero, wait for the signal to calm, perform zeroing and, if required, pre-irradiation.
- D_{100}: 200 MU diode at SSD = 98.5 cm and nominal field size 10x10 cm²
- D_{70}: 200 MU diode at SSD = 68.5 cm and nominal field size 14.2x14.2 cm²

You can record the signal as charge or dose; this is not important, even if the calibration factor is wrong.
Now please calculate:

- S-ratio = S_{70} / S_{100}
- D-ratio = D_{70} / D_{100}
- Final-ratio: S-ratio / D-ratio
- Result = 100 x (1 - Final-ratio)

What you have just calculated is the dose per pulse dependence of the diode in % under the approximation that the dose rate dependence of the Semiflex chamber is negligible[3].
If the absolute value of the result is **larger than 2.0 %,** we recommend to exchange the diode.

[2] The idea behind these SSD values is: put the detector in 100 cm and later in 70 cm distance from the linac focus and have 1.5 cm of water above so that the detector is approximately in d_{max}.
[3] To be precise, we have included the 0.2 % saturation correction of the semiflex chamber in the error limit of 2.0 %.

5.1.1 Possible procedure for CyberKnife users

You can use the circular collimators and follow the procedure as described above with the following settings:
Position corresponding to S_{70}: SSD = 985 mm, depth = 15 mm (i.e. SAD = 1000 mm), 35 mm collimator.
Position corresponding to S_{100}: SSD = 685 mm, depth = 15 mm (i.e. SAD 700 mm), 50 mm collimator.
Because the CyberKnife is a FFF linac with increased dose per pulse values, the saturation correction of the Semiflex chamber is slightly increased. The test-limit of the diode thus increases to 2.2 %.

5.1.2 Users with other linacs where the SSDs or field sizes cannot be set

If you cannot set the recommended SSDs or field sizes as described above, check if you have access to a classical linac where the above description is possible. If yes, use that linac.

Sometimes it is an option to put less water in the water phantom to be able to reach SSD 100 cm and SSD 70 cm.

If the above ideas do not work, choose two SSD-values where the squared ratio, i.e. (SSD_large / SSD_short)² equals 2.04. In addition, choose the nominal field sizes in a way that the field size in the plain of the detectors is as equal as possible for the two different SSDs. The more the field size is different, the more the accuracy of the test is reduced.

6 Quick DPPD test for OCTAVIUS 1600 SRS arrays

In rare cases it may happen that the dose per pulse dependence (DPPD) of an OCTAVIUS 1600SRS array is out of specification, i.e., stronger than presented in the DPPD diagram further above. If you suspect that your array is one of those, you can perform the following test:

- Place the array in an RW3 or OCTAVIUS phantom, i.e., with some build-up material to position the detector to be deeper than d_{max}.
- Perform the pre-irradiation of the array
- Choose 10 MV FFF in 4x4 cm² and the highest MU-rate of your linac. In most cases this will be 2400 (Varian) or 2200 (Elekta) MU/min
- Irradiate 100 MU at these settings. Write down the dose in the central chamber of the array: D_{high}
- Now reduce the MU-rate to 1/4, i.e., 600 or 550 MU/min. Field size and radiation quality remain the same
- Irradiate 100 MU at these settings. Write down the dose in the central chamber of the array: D_{low}
- Calculate D_{low} / D_{high}

The result has to be lower than 1.04.

7 References

[Brodbek2021] Dosimetric characterisation of liquid-filled ionisation chamber array OCTAVIUS detector 1600SRS, oral presentation at ESTRO 2021

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