

Supplementary Material

S1 RCF CUTTING

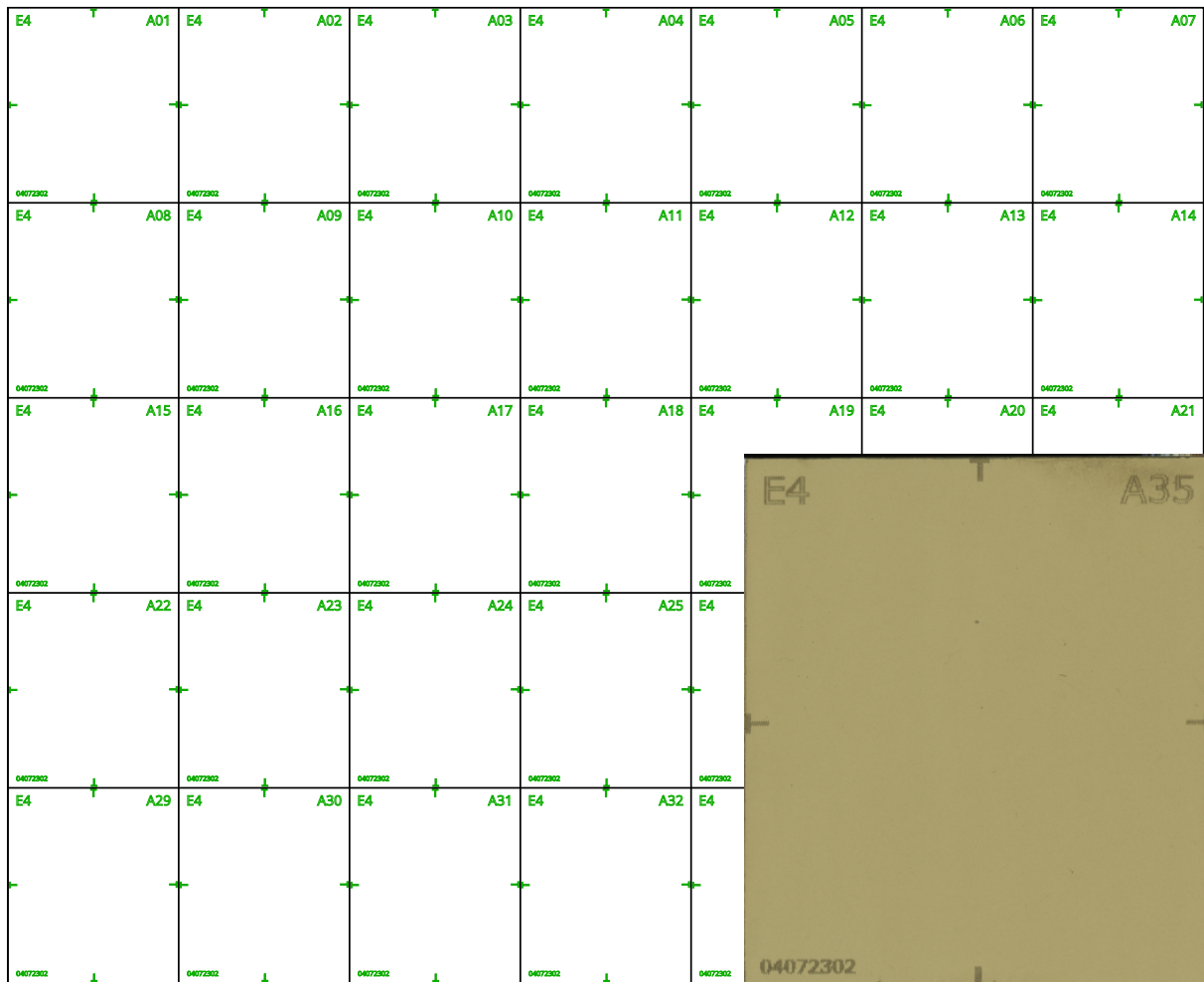


Figure S1. The SVG-template used for laser cutting and engraving along with a cut piece of RCF engraved with the RCF model, LOT number, sample number and alignment markers.

S2 RCF SCANNING

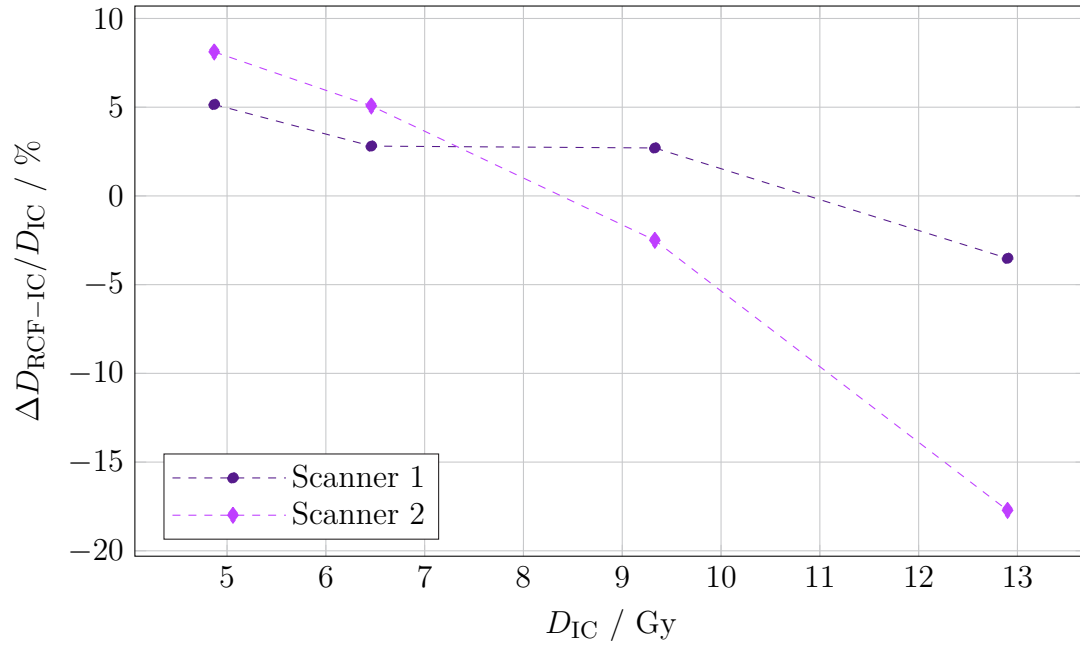


Figure S2. The dose errors of EBT3 RCFs exposed to a known dose D_{IC} at a calibration facility and scanned using two different scanners using the same software. Scanner 1 refers to the scanner which was also used for the RCF calibration, while scanner 2 is a different scanner of the same type.

S3 RCF CALIBRATION

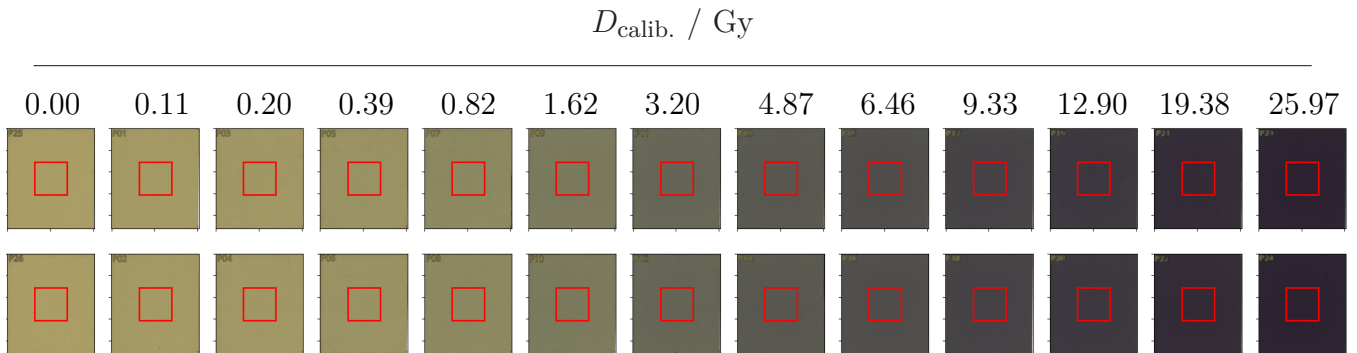


Figure S3. A scanned calibration set of EBT3 RCFs with two samples per dose point and the ROI used for response evaluation indicated.

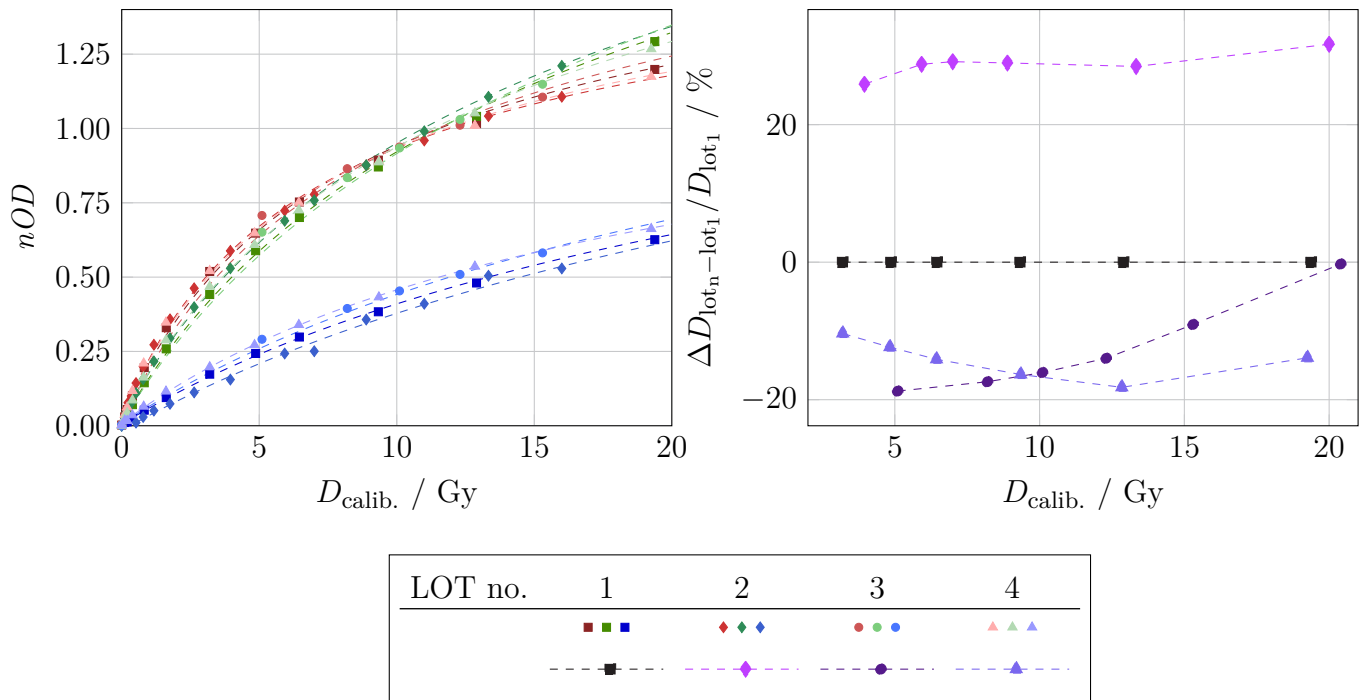


Figure S4. Left: Calibration curves for different production lots of EBT3 RCFs. **Right:** The relative errors induced by applying the calibration curve of LOT 1 to the other lots.

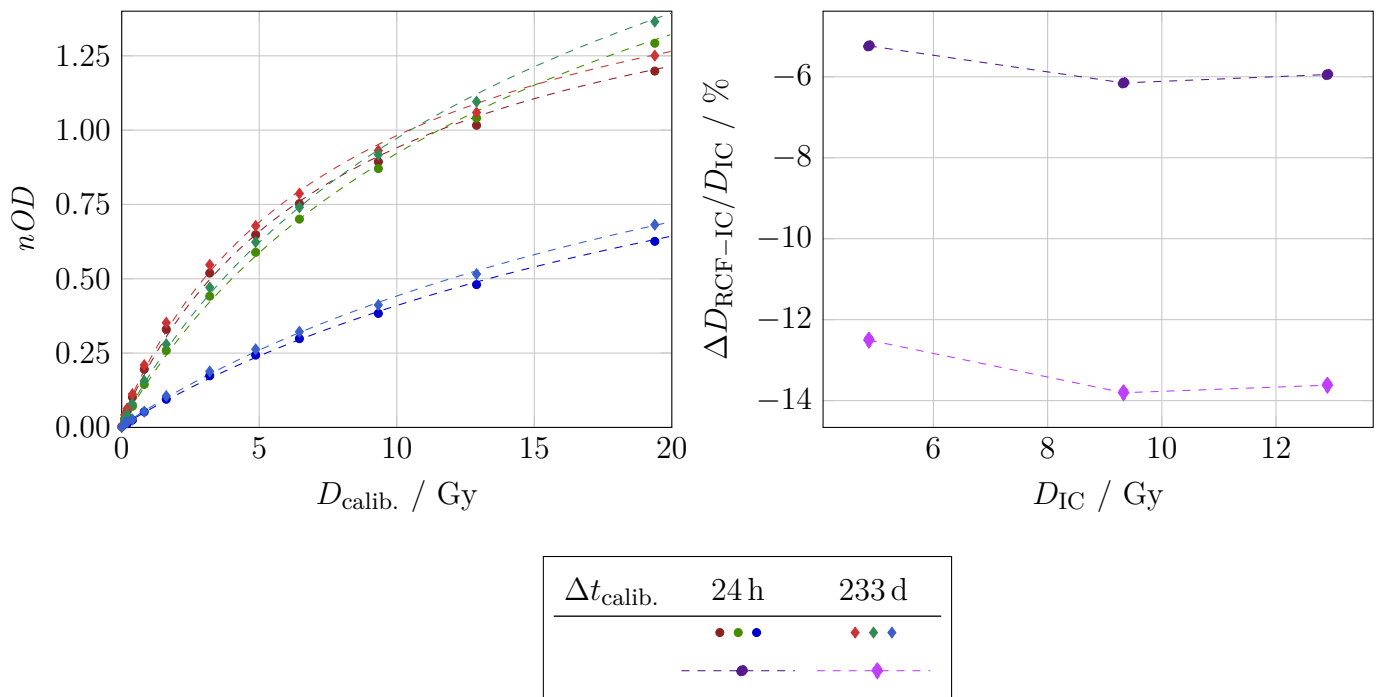


Figure S5. Left: Calibration curves for different $\Delta t_{calib.}$ for EBT3 LOT 08252101. **Right:** Reference RCFs exposed to a known dose $D_{calib.}$ and scanned after $\Delta t_{appl.} = 24$ h, analysed with two calibration curves of different $\Delta t_{calib.}$.

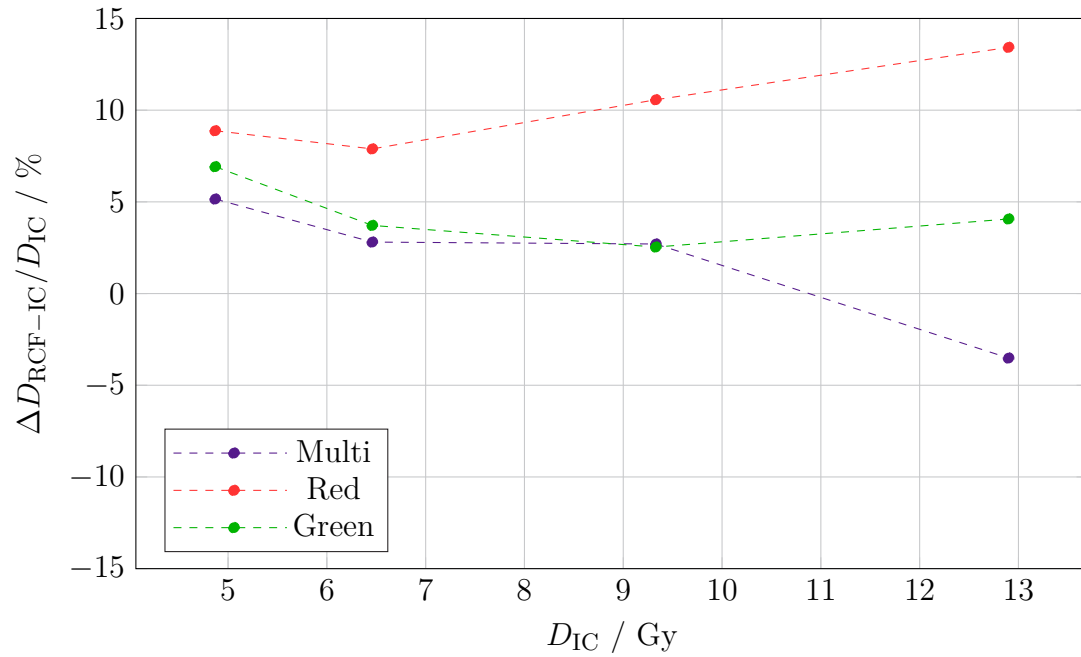


Figure S6. The dose errors of EBT3 RCFs exposed to a known dose D_{IC} at a calibration facility and processed using single-channel processing and multi-channel processing.

S4 RCF PROCESSING

In this example the relative dose error resulting from multi-channel dosimetry is within $\pm 5\%$, which is lower than the error associated with single-channel dosimetry using the green and red channels.

S5 UNCERTAINTY ESTIMATION

Converting individual PVs to OD gives an uncertainty

$$\sigma_{OD_x} = \sqrt{\left(\frac{\partial OD_x}{\partial PV_x}\right)^2 \sigma_{PV_x}^2} = \frac{\sigma_{PV_x}}{PV_x^2} . \quad (S1)$$

Propagating this further, the uncertainty of the nOD becomes

$$\sigma_{nOD_x} = \sqrt{\left(\frac{\partial nOD_x}{\partial OD_x}\right)^2 \sigma_{OD_x}^2 + \left(\frac{\partial nOD_x}{\partial \langle OD_{x,0} \rangle}\right)^2 \sigma_{\langle OD_{x,0} \rangle}^2} , \quad (S2)$$

where $\langle OD_{x,0} \rangle$ is the mean OD of the unexposed RCF piece with uncertainty

$$\sigma_{\langle OD_{x,0} \rangle} = \frac{\sigma_{OD_{x,0}}}{\sqrt{n}} , \quad (S3)$$

where n is the number of pixels used for estimating the background.

Similarly, each dose point in the calibration curve is related to a mean nOD value with uncertainty

$$\sigma_{\langle nOD_x \rangle} = \frac{\sigma_{nOD_x}}{\sqrt{n}} . \quad (S4)$$

$$\sigma_D = \sqrt{\left(\frac{\partial D}{\partial nOD}\right)^2 \sigma_{nOD}^2 + \left(\frac{\partial D}{\partial a_x}\right)^2 \sigma_{a_x}^2 + \left(\frac{\partial D}{\partial b_x}\right)^2 \sigma_{b_x}^2 + \left(\frac{\partial D}{\partial c_x}\right)^2 \sigma_{c_x}^2} , \quad (S5)$$

where σ_{nOD} is calculated from eq. (S2), and σ_{a_x} , σ_{b_x} and σ_{c_x} are the uncertainties in the fitting parameters obtained when establishing the calibration curve.

S6 TOPAS PARAMETERS

To simulate the central dose and beam size evolution of the CLEAR beam, the following key definitions were used:

1. **Physics list:** "g4em-standard_opt4"
2. **Beam type:** "Emittance"
3. **Distribution:** "twiss_gaussian"
4. **Particle fractions (X/Y):** 0.3935/0.3935
5. **Beam energy:** 200 MeV
6. **Beam energy spread:** 1%
7. **Number of simulated particles:** 100 000

The World geometry included a vacuum beam pipe with a Kapton vacuum window and the water phantom with a Kapton window. The beam was defined by the following Twiss parameters:

1. $\beta_x = 22.28$ m

2. $\beta_y = 39.64$ m
3. $\alpha_x = 0.878$
4. $\alpha_y = -1.654$
5. $\epsilon_x = 0.017834$ μm
6. $\epsilon_y = 0.010654$ μm

and propagated from the parameter's reference (measurement) point in vacuum, through the air and Kapton windows and into the water phantom. Transverse dose maps replicating the standard RCF dimensions at CLEAR were scored as "DoseToWater" using $25 \times 25 \times 1$ bins for various depths, and the beam sizes and doses were extracted from the dose maps.