CT*ion*

Bruker microCT's xray dose calculator

Welcome to CT*ion*, the Bruker microCT xray dose calculator!

Radiation dose from xrays or any other ionizing radiation means the concentration of energy deposited in material by ionizing particle interactions. Dose is measured in units of Grays (Gy), one Gray being one joule of energy absorbed per kg of material (j/kg). One Gy is a big dose; for microCT it is convenient to use the smaller unit milliGray or mGy. Please note that dose is a concentration, not an amount, of absorbed energy from ionization.

The calculation of xray dose in CT*ion* is based on the simulations of xray photon energy spectra and dose by the program SpekCalc (http://spekcalc.weebly.com/) created by scientists from the Institute of Cancer Research (London, UK) and McGill University (Montreal, Canada). The details of the emission spectrum and dose-at-distance calculations in SpekCalc are given in the three publications referenced below. Xrays are assumed to be emitted from an xray source using a tungsten (W) target – the type most commonly used in laboratory xray sources. All SkyScan scanners (except the 2211 and 2214 nanoCT instruments in exceptional cases) use a tungsten target in their xray sources.

The input parameters: xray filter, voltage, current and distance.

Absorbed dose rate from xrays from a laboratory source is determined by the four input parameters in CT*ion*:

- Xray filter (only if it is in front of the xray source, not the camera)
- Xray source voltage
- Xray source current
- Distance from the source to the scanned object

All these parameters are reported in the log file of every scan in SkyScan microCT systems. So CT*ion* can be used for any scan. The dose rate is output in units of mGy per minute, so multiplying it by scan time in minutes gives you the total absorbed dose for a scan. Scan duration is also reported in the log file.

Filter: adding filter to the xray beam reduces absorbed dose in the sample, but only in the case that the filter is in front of the source, i.e. the xrays are filtered before they reach the object. In the following scanners the filter is always in front of the source, and therefore adding filter will reduce xray dose to the sample: all *in vivo* scanners - SkyScan1076, SkyScan1176, SkyScan1276, SkyScan 1178, SkyScan1278), and these *ex vivo* scanners - SkyScan1173, SkyScan1174, SkyScan1275. In the nanoCT scanners, SkyScan2211 and 2214, the filter can be either in front of the source in the filter "collimator", or fitted in front of the camera. You need to know which, to correctly calculate xray dose.

In the following scanners the xray filter is positioned in front of the camera, and therefore will not affect xray dose to the scanned object: SkyScan1172, SkyScan1272. In calculating dose to samples scanned in these scanners, the filter should always be set to "no filter" in CT*ion*, regardless of what filter is actually selected for the scan. (Unless you manually tape a filter in front of the source opening in these scanners – which is possible.)

Absorbed dose from filtered xrays is reduced because the lowest energy xrays in the emitted spectrum – which are the ones most likely to be absorbed in the sample and thus contribute most to dose – are preferentially removed before the xrays reach the sample. Reducing the absorption in the sample increases xray transmission; increased transmission through dense objects is the main purpose of using a filter in microCT. However reduced dose is another important effect of adding an xray filter in front of the sample. For example you give a scanned mouse a lower xray dose by using 1mm, rather than 0.5mm aluminium filter (at the same applied voltage).

Voltage: The applied voltage in an xray source is high – measured in kilovolts. The higher the applied voltage, the higher the average photon energy of the xrays. Xray photon energy spectra are complex and not discussed here in detail. The energy spectrum of xrays emitted from a lab source is stretched toward higher energies by higher applied voltage, and compressed toward lower energies by lower voltage.

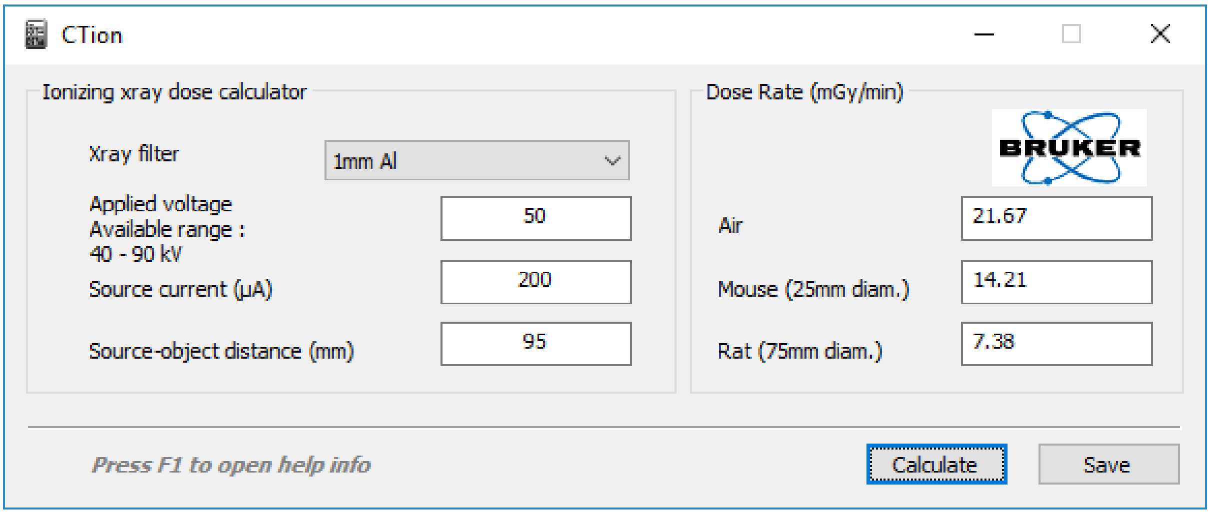
The effect of applied voltage on dose is complex, but in general higher voltage leads to higher dose. An xray photon with higher energy will, if absorbed, deposit more energy in the sample (i.e. more dose). But the same photon's higher energy also makes it less likely to be absorbed and more likely to fly through the sample without interacting (i.e. less dose). However the deciding factor is probably the increase in xray flux from a source that accompanies an increase in applied voltage. This occurs even if current is proportionally reduced so xray power in watts is the same. So even with the same power, increased voltage leads to increased flux (more xrays per second). Xray sources just emit xrays more efficiently at higher voltage.

Current: The current that runs through an xray cathode filament is low – measured in microamps. Source current determines the flux of xrays – higher current means more xrays per second and vice versa. Current does not have any effect on the energy of the emitted xrays or the shape of the xray photon energy spectrum (this is determined by the voltage). So xray absorbed dose is related in a simple linear way to source current. You can for example reduce source current to achieve a very low dose to an animal in *in vivo* scans.

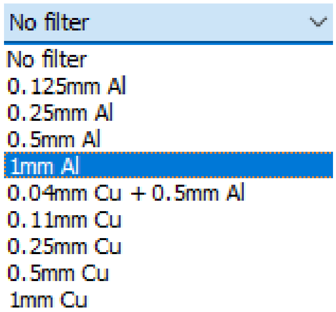
Distance: very important! The absorbed xray dose rate is related to the square of the distance from source to object. (This is because the dispersal of xrays from the source is over an area, in 2 dimensions.) So if the object moves closer to half the distance from the source, the xray dose increases by a factor of not 2 but 4. Likewise if the sample moves away to twice the distance, then dose rate is 4 times less.

The CT*ion* user interface

The CT*ion* interface is shown below:



Xray filter: A drop menu gives a choice of all the filters used in SkyScan desktop scanners and most of those used in the SkyScan nanoCT scanners using aluminium and/or copper.



Applied voltage: This is entered as an integer number (no decimal places) in units of kV. Please note that for each selected filter, the available voltage range is shown. This is the range of applied voltages appropriate to that filter. If you set a voltage outside of this range, the displayed value will jump to the closest value within the set range for the selected filter.

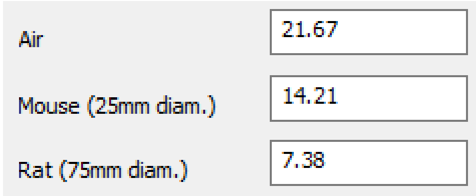
Source current: This should be entered in units of microamps (µA).

Source-object distance: This should be entered in units of mm.

Please note that all four of the above parameters can be found in the log file of a scan in a SkyScan microCT instrument.

Clicking on the F1 key on your keyboard while CT*ion* is open will open this pdf help file providing this file is in the same folder as the active executable file of CT*ion* (ction.exe).

CT*ion* calculates and displays three dose calculations: dose in air, mean dose in a mouse and in a rat (approximated as a water tubes of 25mm and 75mm diameter respectively). The dose depth corrections used to derive these doses are explained below.

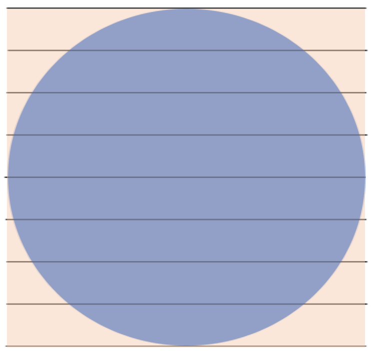


The depth correction of xray absorbed dose

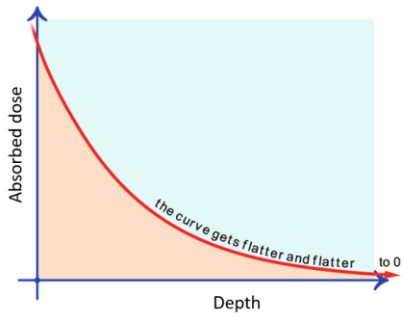
With the same scan parameters, a rat gets much less xray absorbed dose than a mouse. Why? – because of self-shielding and the attenuating effect of depth. As xrays pass through a sample they are attenuated, so the dose rate gets less with depth[1]. This means that in the same xray field, wider objects get a lower average xray dose than narrow ones due to longer paths of xrays through them. Xray attenuation is exponential – a constantly decreasing rate of attenuation with depth.

So to know the average dose to a scanned object we also need to know the average length of the path of xrays through it. This is related to its diameter – and the material it is made of. However CT*ion* takes only the examples of a mouse and a rat, which are approximated as tubes of water with diameters of 25 and 75mm respectively.

How is the average xray path through an object related to object diameter? If we assume a cylinder shape (circle in cross-section) then the ratio of the average path length to the diameter is $\pi/4$, that is, 0.785. This is the same as the ratio of areas of a circle to its bounding square.



Along the xray's path through the object the value of absorbed dose is exponentially decreasing: so how do we calculate the average dose value along that path? For this we calculate the value of absorbed dose that occurs at the fraction 1/*e* of the path length. The exponential coefficient *e* has the value (approximately) of 2.718, and 1/*e* is about 0.368. Thus the average xray absorbed dose along an xray attenuating path through an object is the



[1] In clinical xray systems with higher xray energy, dose at first increases with depth due to a phenomenon called "build-up", since interacting high energy photons release secondary ionising particles or "delta rays" that cause an avalanche of increasing dose along the beam path. This effect is only to a limited depth, after which dose decreases. This means that the highest dose is not at the surface but a little distance below it – an effect that is taken advantage of in xray beam radiotherapy in hospitals, where a cancer below the skin can by careful choice of xray energy, receive a higher xray dose than surrounding tissues. But this "build up" effect does not happen at the lower xray energies typically used in desktop microCT systems, where dose always decreases with depth.

absorption happening at a depth equal to the path length times 0.368.

Putting these two things together, the average path length through a circle being the diameter times π/4 (0.785), and the average dose along an attenuating path being 1/e (0.368) times the path length, we get a value by which we can multiply the diameter of a cylindrical object to get the depth where the absorbed dose equals the average absorbed dose for the whole object. This is called the mean effective attenuating depth, or MEAD. Its value is the path length times π/4 x 1/e; that is, the path length x ~0.29.

Thus in CT*ion* the doses to mouse and rat, which are approximated as water cylinders of 25mm and 75mm diameter respectively, are calculated by adding a depth of water of 0.29 x these diameters to the attenuation calculations in SpekCalc. This means we add water depths of 7.25mm and 21.75mm, respectively, for the mouse and rat dose calculations.

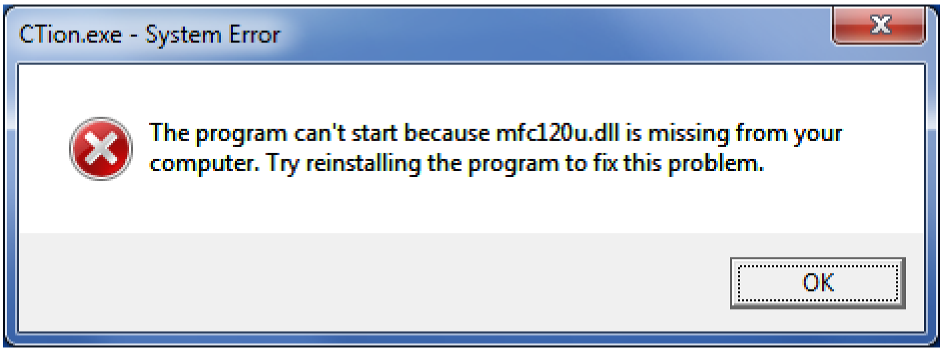
Remember finally – in a microCT scan the object or animal is irradiated from all directions over the scan orbit of 180 or 360 degrees. So while dose decreases with depth from any one direction, when averaged out over a scan, the dose distribution is more uniform, although still a little higher near surfaces than at the deepest central regions of the object or animal.

The Calculate and Save buttons

After the four xray parameters are entered, you can press the button "Calculate" to obtain the corresponding three dose rate values. With subsequent calculations the results will sometimes refresh in the output windows automatically. Calculated results can be saved in a comma delineated ASCII text file by clicking on "Save", with a file extension of .txt, or alternatively .csv which is recognised as meaning "comma separated values" and thus opens automatically in Excel or other spreadsheet programs.

DLL missing error message with (some) Windows7 pcs

In some Windows7 pcs the following error message appears when CT*ion* is run:



If this happens, then please run the file *vcredist_x86.exe* which is provided together with the CT*ion* downloaded files. This updates Windows' runtime environment. Once this is done, please restart your pc. Then CT*ion* will run.

References

Poludniowski GG, Evans PM (2007) Calculation of x-ray spectra emerging from an x-ray tube. Part I. Electron penetration characteristics in x-ray targets. Medical Physics Vol 34 Issue 6 Part 1: 2164-2174.

https://aapm.onlinelibrary.wiley.com/doi/abs/10.1118/1.2734725

Poludniowski GG (2007) Calculation of x-ray spectra emerging from an x-ray tube. Part II. X-ray production and filtration in x-ray targets. Medical Physics Vol 34 Issue 6 Part 1: 2175-2186

https://aapm.onlinelibrary.wiley.com/doi/abs/10.1118/1.2734726

Poludniowski GG, Landry G, DeBlois F, Evans PM, Verhaegen F (2009) SpekCalc: a program to calculate photon spectra from tungsten anode x-ray tubes. Physics in Medicine and Biology 54: N433.

http://iopscience.iop.org/article/10.1088/0031-9155/54/19/N01/meta