RAD_IQ User Manual

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Contents

1. Introduction

Rad_DR is a MATLAB based Graphical User Interface (GUI) for quantitative image analysis of Computed Radiography (CR) and Digital Radiography (DR) digital X-ray detectors used in General Radiography and Digital Mammography. It can be used to calculate the **Signal Transfer Property (STP)**, **Noise Component Analysis (NCA)**, **presampling Modulation Transfer Function (pMTF)**, **Normalized Noise Power Spectrum (NNPS)** and **Detective Quantum Efficiency (DQE)**. The user can insert tilted edge X-ray images for the calculation of pMTF (and DQE), and flat-field (i.e. uniform) X-ray images for the calculation of STP, NCA and NNPS / DQE. DQE requires the combination of pMTF and NNPS results. The software can **linearize** the used digital X-ray images (i.e. convert output Pixel Values (PV) to input signal (either DAK (Detector Air Kerma; in µGy) or X-ray fluence Φ (in X-rays per mm^2))) using a **Linear** or **Logarithmic response**. All results of ***Rad_IQ*** software can be saved in the ***RAD_IQ Analysis Results*** Excel file (provided with the software).

This document describes how to use ***RAD_DR*** for quantitative image analysis and save the calculated parameters (**STP**, **NCA**, **pMTF**, **NNPS** and **DQE**) to ***DR Quantitative Analysis Summary*** Excel file. The analysis algorithms are based on the **IEC 62220-1-1:2015 international standard** for General Radiography [1] and **IEC 62220-1-2:2007 standard** for Digital Mammography [2]. Users also have the option to use processing conditions described in the ***European Guidelines for Quality Assurance in breast cancer screening and diagnosis (Fourth edition – Supplements, 2013)***, also known as ***EUREF*** [3].

RAD_IQ can be used from Medical Physicists (for Quality Assurance analysis), Biomedical Engineers or researchers to analyse digital X-ray images in TIFF or DICOM format. No programming experience is required.

This document is organized into Sections corresponding to the calculation of various parameters and saving the results to Excel.

Where there is a green box this is an example of something which is helpful or good practice.

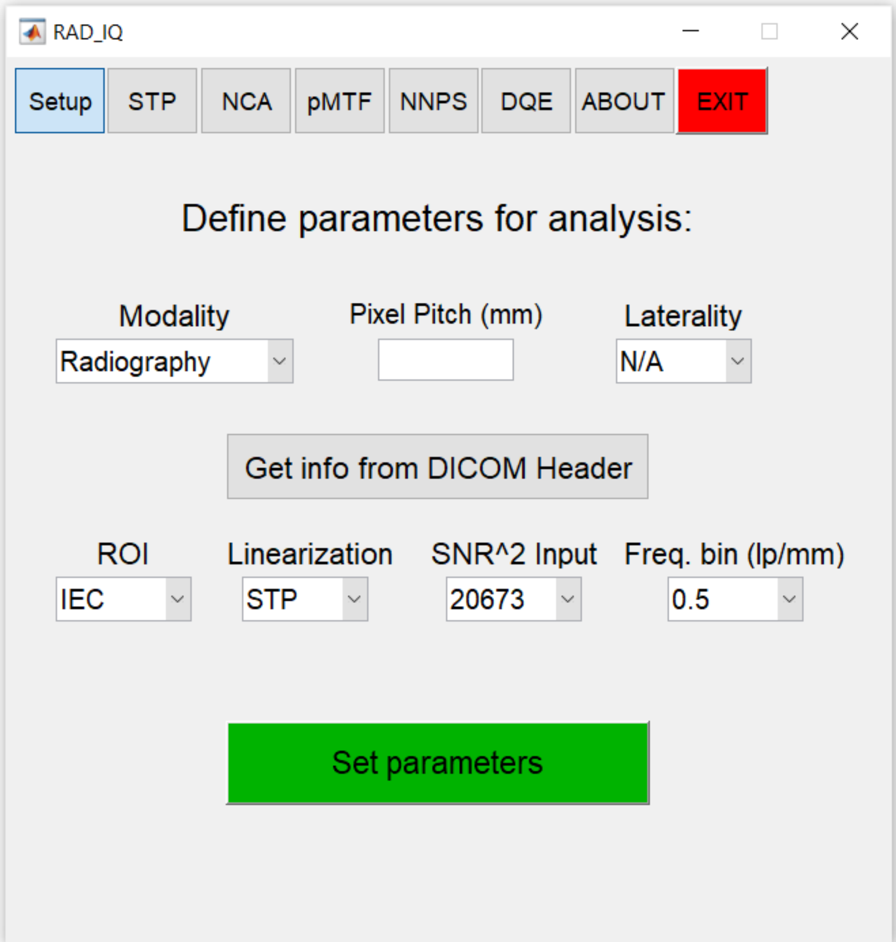
Where there is a red box this is a warning or a note of caution.

Where there is a blue box this is a note of information that can be found useful in specific conditions.

2. Setup

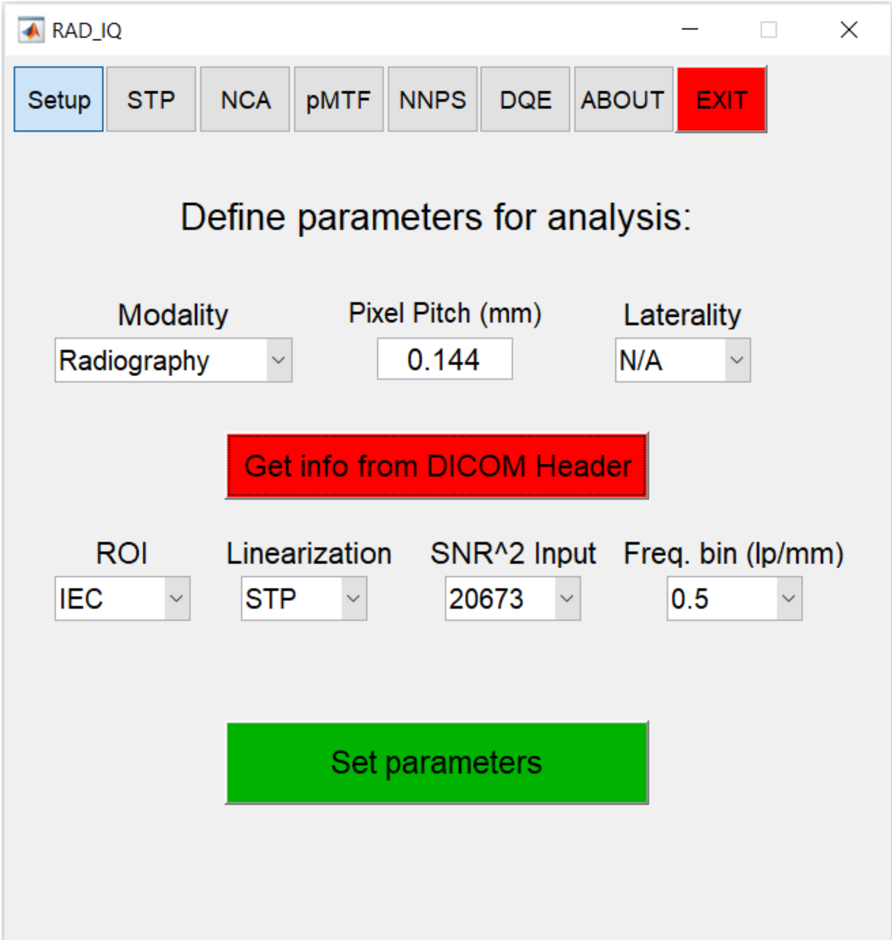
RAD_IQ software can be used to analyse tilted edge and flat-field (i.e. uniform) X-ray images in TIFF or DICOM format.

Before the analysis the user needs to define some parameters, i.e. ***Modality*** (*Radiography* or *Mammography*), ***Pixel Pitch*** (in mm), ***Laterality*** (*N/A* for Radiography, *Left* or *Right* for Mammography - to be used only when the selected ROI is *EUREF*), ***ROI*** for STP and NNPS analysis (*IEC* or *EUREF*), ***Linearization*** method (*STP* or *IEC*), ***SNR^2 Input*** (X-rays per mm^2 per µGy, depending on the used X-ray beam quality) and ***Frequency bin*** (*0,5* line pairs per mm (lp/mm) according to the IEC standards [1-2] or *0,25* lp/mm according to EUREF [3]).



The ***Modality*** affects the dimensions of the *IEC* ROIs used for the pMTF and NNPS analysis.

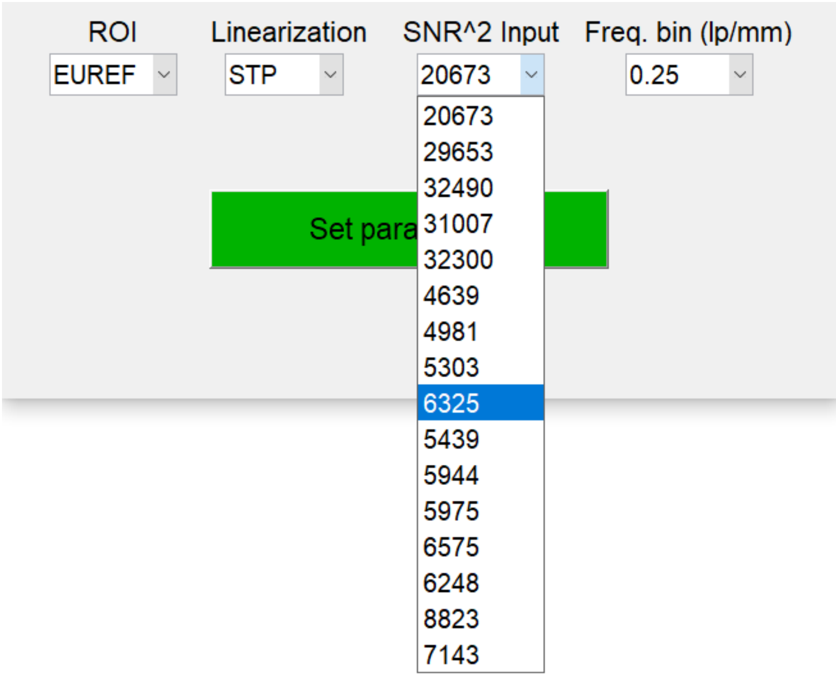
For DICOM images you can press the *Get info from DICOM Header* button to extract the *Modality*, *Pixel Pitch (mm)* and *Laterality* from the DICOM Header. In this case, you can select one of the DICOM images for analysis. The extracted values will appear in the respective cells and the *Get info from DICOM Header* button will turn red (see Figure below).



The ***IEC*** ROI corresponds to a 100 x 100 pixels square ROI in the centre of the flat images for STP calculation for both General Radiography [1] and Digital Mammography [2]. Regarding the NNPS calculation, it corresponds to a central 12,5 cm x 12,5 cm ROI for General Radiography [1] or a central 5 cm x 5 cm ROI for Digital Mammography [2]. On the other hand, the ***EUREF*** ROI (only for Digital Mammography) corresponds to a 7 mm x 7 mm ROI (positioned 6 cm from the chest wall edge and centred laterally) for the STP calculation and a central 10 cm x 10 cm ROI for the NNPS calculation [3].

The ***STP*** linearization method is using the inverse of the STP function (output mean Pixel Value (PV) as a function of input Detector's Air Kerma (DAK; in µGy)) to linearize the images [3]. The ***IEC*** linearization method is using the inverse of the conversion function (output mean PV as a function of X-ray fluence ***Φ*** (in X-rays per mm^2)) to linearize the images [1, 2].

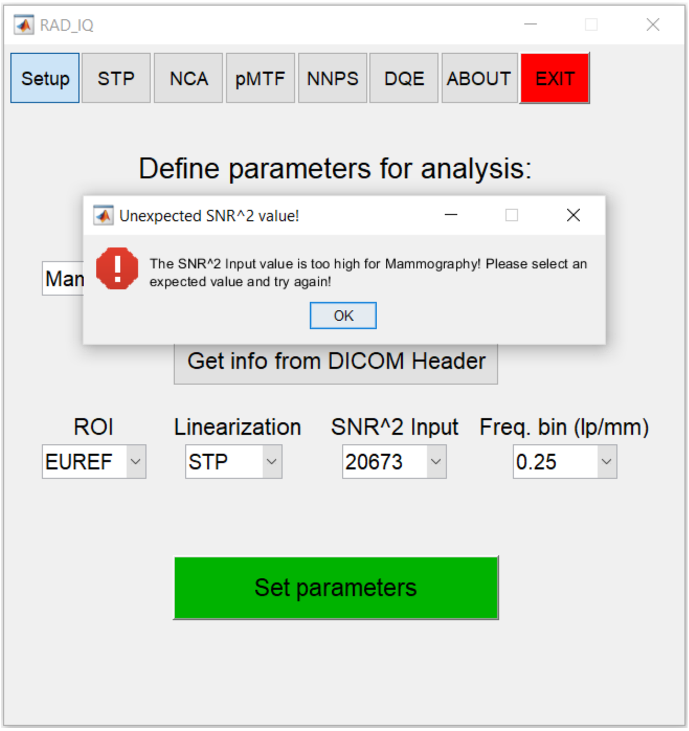
The ***SNR^2 Input*** (X-rays per mm^2 per µGy) value depends on the used X-ray beam quality, and can be used to linearize the X-ray images according to IEC [1, 2] (see *Fluence per DAK* ratio times *DAK* equals to fluence *Φ*) and calculate the DQE (see formula in Section **11. Calculate DQE**). The user can select an ***SNR^2 Input*** value over a range of Radiographic [1, 4] and Mammographic [2, 3] X-ray beam qualities (i.e. Target/Filter combinations for a given nominal Tube Voltage (in kV) and Half Value Layer (HVL)) – see following Figure and Table.

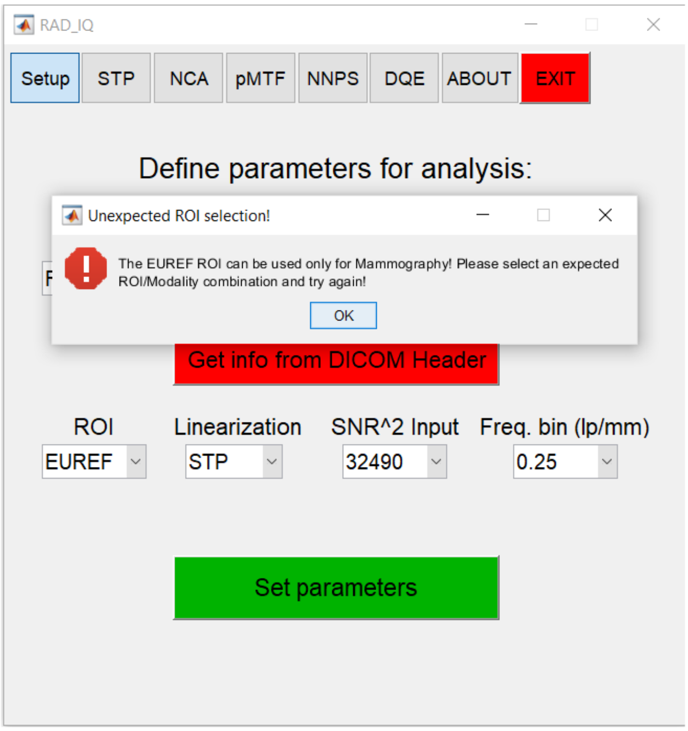


Source	Radiation Quality No.	X-ray Beam Quality*	***SNR_{in}^{2}*** (X-rays/(mm^2·µGy))
IEC 62220-1-1:2015 [1]	RQA 3	W/Al @ 50 kV, +10 mm Al, HVL=3,8 mm Al	20673
	RQA 5	W/Al @ 70 kV, +21 mm Al, HVL=6,8 mm Al	29653
	RQA 7	W/Al @ 90 kV, +30 mm Al, HVL=9,2 mm Al	32490
	RQA 9	W/Al @ 120 kV, +40 mm Al, HVL=11,6 mm Al	31007
IPEM Rep 32 Part VII [4]	IPEM 91	W/Al @ 70 kV, +1 mm Cu, HVL~7,7 mm Al	32300
IEC 62220-1-2:2007 [2]	RQA-M 1	Mo/Mo @ 25 kV, +2 mm Al, HVL=0,56 mm Al	4639
	RQA-M 2	Mo/Mo @ 28 kV, +2 mm Al, HVL=0,60 mm Al	4981
	RQA-M 3	Mo/Mo @ 30 kV, +2 mm Al, HVL=0,62 mm Al	5303
	RQA-M 4	Mo/Mo @ 35 kV, +2 mm Al, HVL=0,68 mm Al	6325
	-	Mo/Rh @ 28 kV, +2 mm Al, HVL=0,65 mm Al	5439
	-	Rh/Rh @ 28 kV, +2 mm Al, HVL=0,74 mm Al	5944
	-	W/Rh @ 28 kV, +2 mm Al, HVL=0,75 mm Al	5975
	-	W/Al @ 28 kV, +2 mm Al, HVL=0,83 mm Al	6575
EUREF [3]	-	Rh/Rh @ 29 kV, + 2 mm Al	6248
	-	W/Al @ 35 kV, + 2 mm Al	8823
	-	W/Ag @ 32 kV, + 2 mm Al	7143

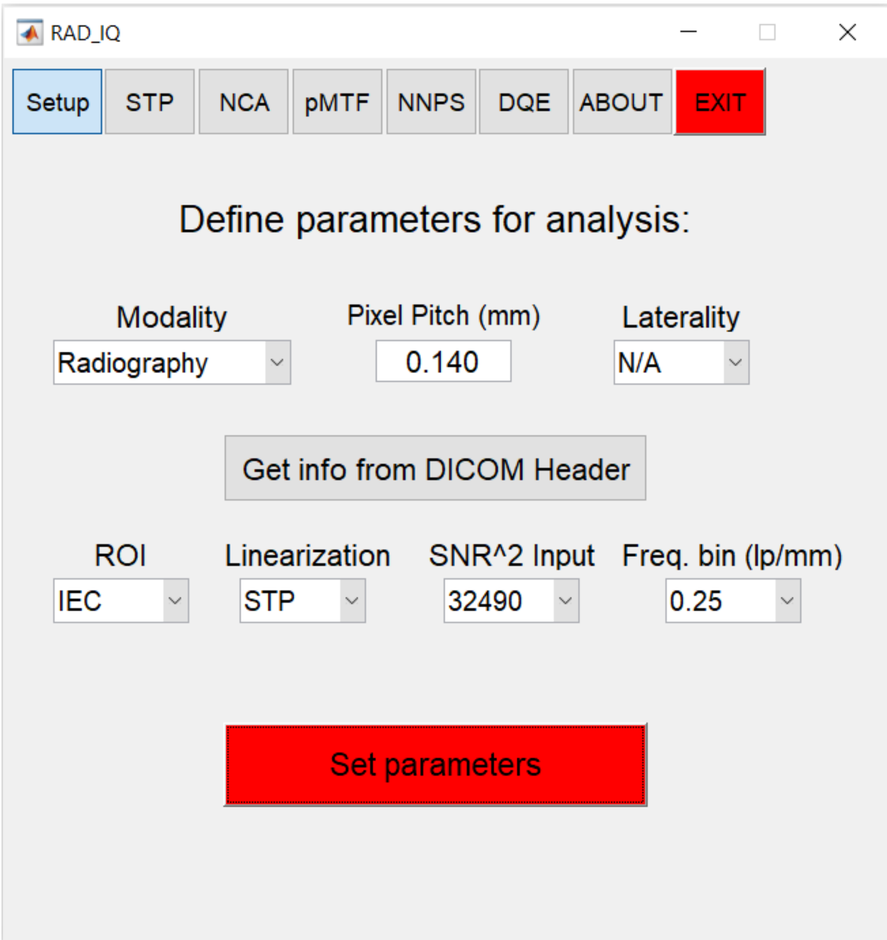
*Target/inherent Filter combination @ Tube Voltage, +additional external filtration, Half-Value Layer (HVL)

Warning messages appear for unexpected SNR^2 Input value & ROI selection (see following Figure)



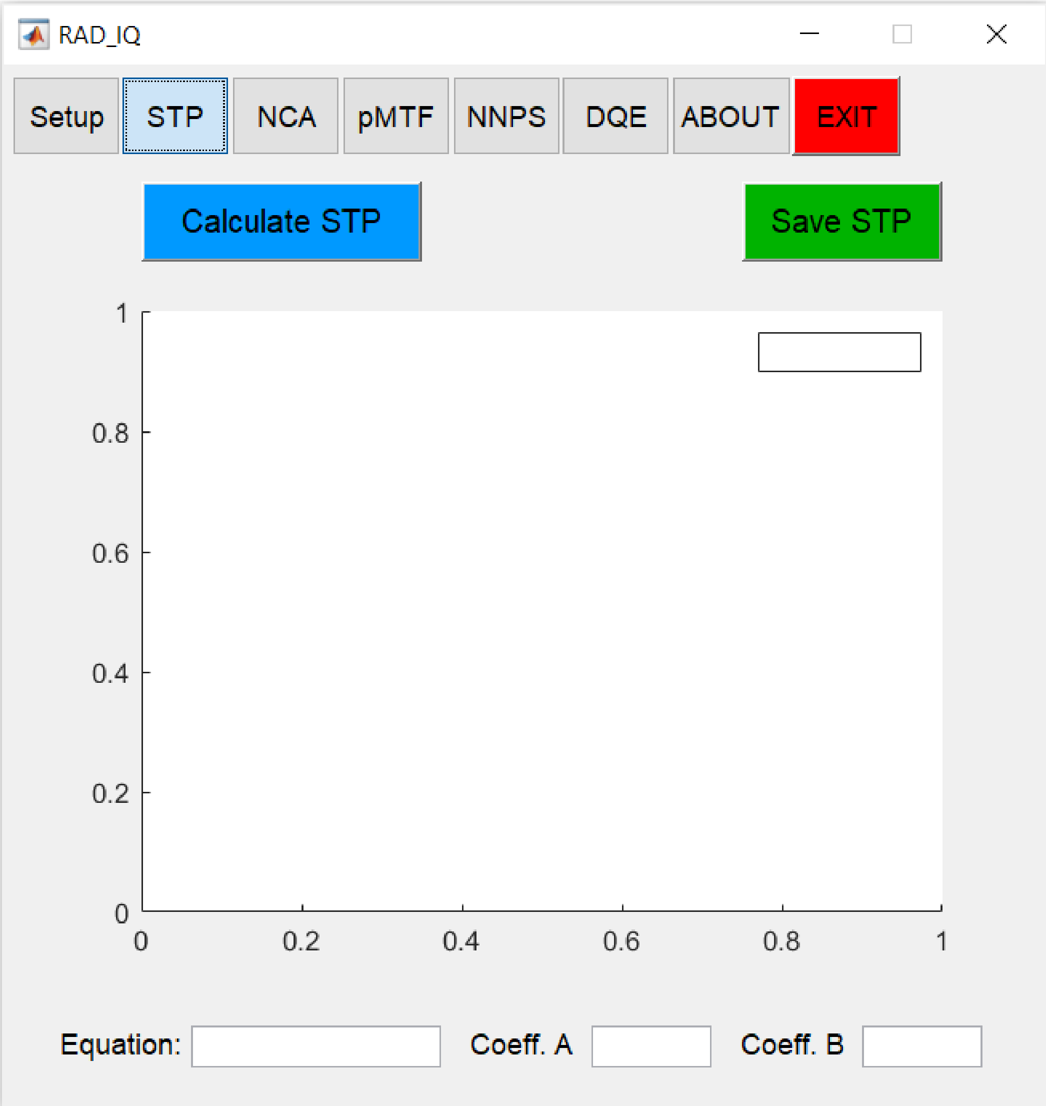


❖ Once you are happy with the defined parameters **press *Set Parameters*** to carry on with the analysis (the button turns red to indicate that all the defined parameters have been loaded).



3. Calculate STP

RAD_IQ can calculate the **Signal Transfer Property (STP)** to plot the output mean Pixel Value (PV) as a function of Detector Air Kerma (DAK; in µGy). Then it fits a Linear and Logarithmic equation, and calculates the Coefficient of Determination (R^2) for each type of equation. It plots the fit with the highest R^2 and shows the regression equation, including coefficients A and B.

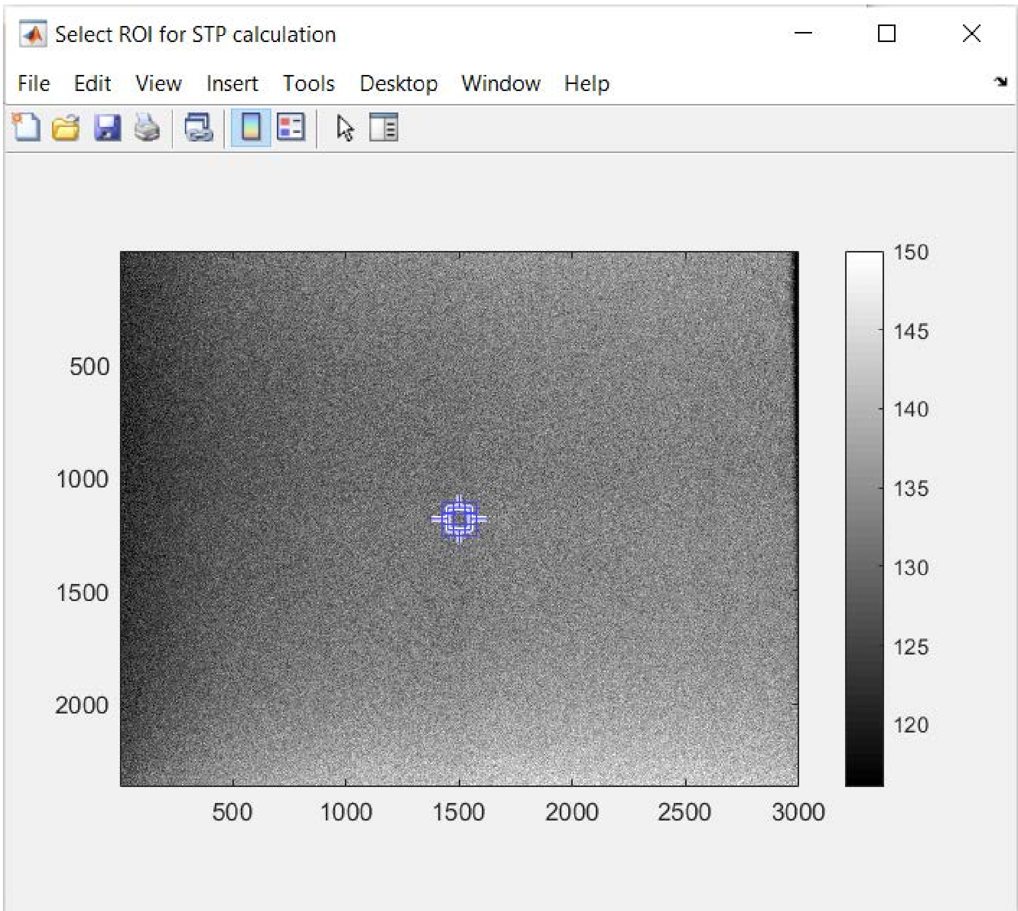


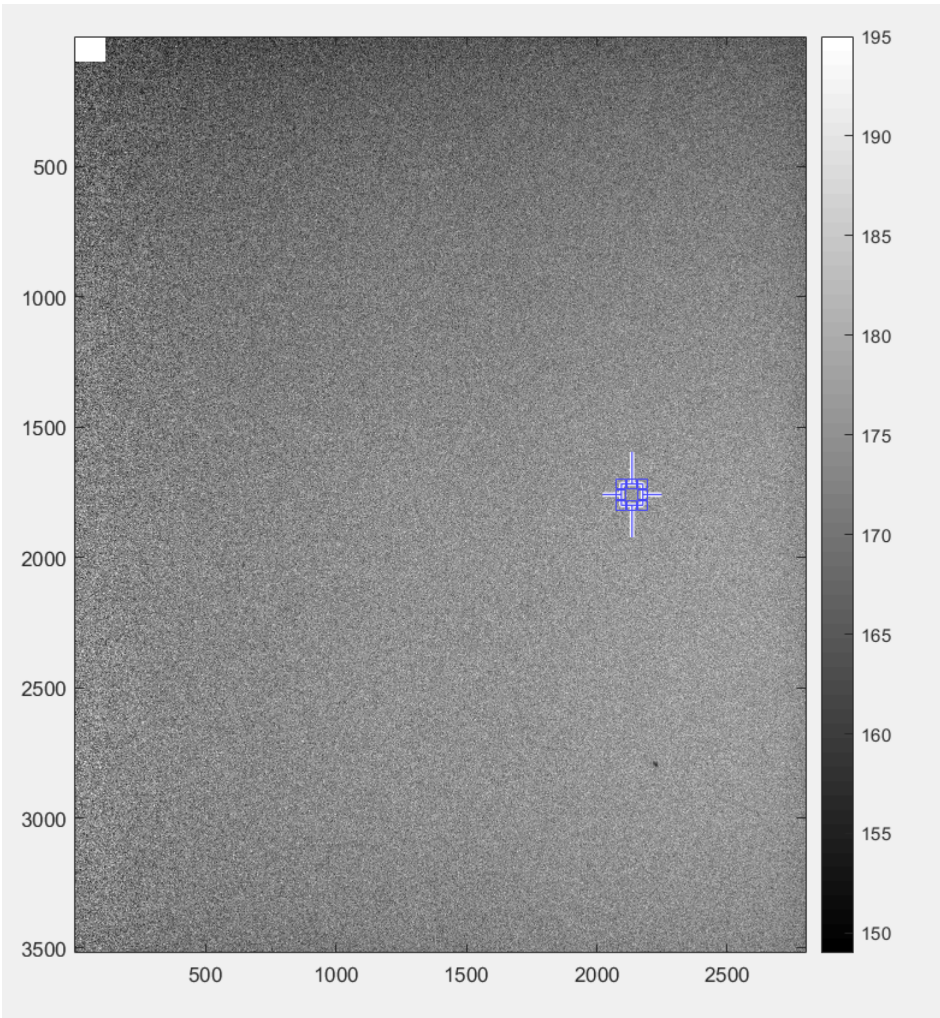
- **Select** the ***STP*** tab and **press *Calculate STP*** to select multiple flat images (for various DAK levels) in DICOM or TIFF format.

For DICOM images the software sorts the flat-field images based on the *mAs* or *acquisition time* (extracted from the DICOM header). Otherwise, for TIFF images the user should sort properly the names of the flat-field images for STP analysis.

- **Select** the **ROI** (from the first flat image) for STP calculation.

When the ***IEC*** ROI has been selected, the STP ROI covers a central area of 100 x 100 pixels (to minimize the effect of potential non-uniformities) [1, 2] – see the first figure in the following page. Otherwise, the ***EUREF*** ROI corresponds to a 7 mm x 7 mm ROI, positioned 6 cm from the chest wall edge and centred laterally [3] – see the second figure in the following page. The user can modify the ROI (position and shape), but it is not advised for consistency.


Select ROI for STP calculation
File Edit View Insert Tools Desktop Window Help
500
1000
1500
2000
500 1000 1500 2000 2500 3000
150
145
140
135
130
125
120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500 1000 1500 2000 2500
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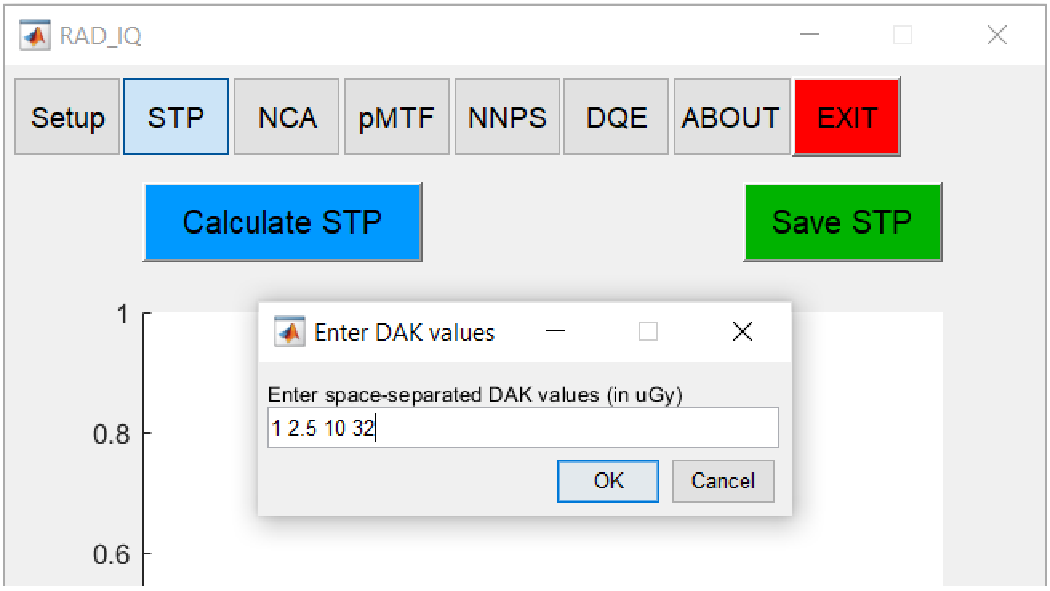
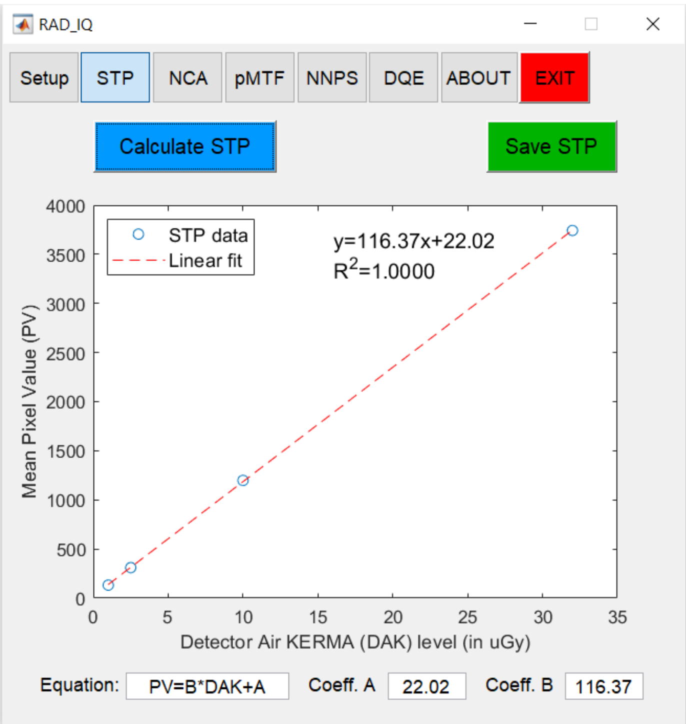
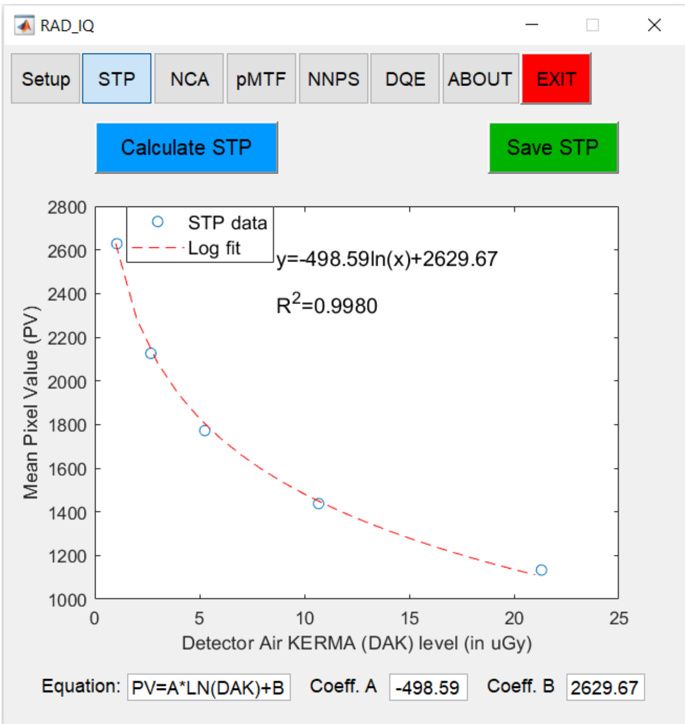
150

- **Double click** in the middle of the ROI to carry on (the cursor should have a cross shape).
- Next, **enter** space-separated DAK values (in µGy) and **press *OK***.



The software plots the STP curve, the best regression equation (Linear or Logarithmic) and presents the coefficient of determination (R^2) and the fitting coefficients A and B.





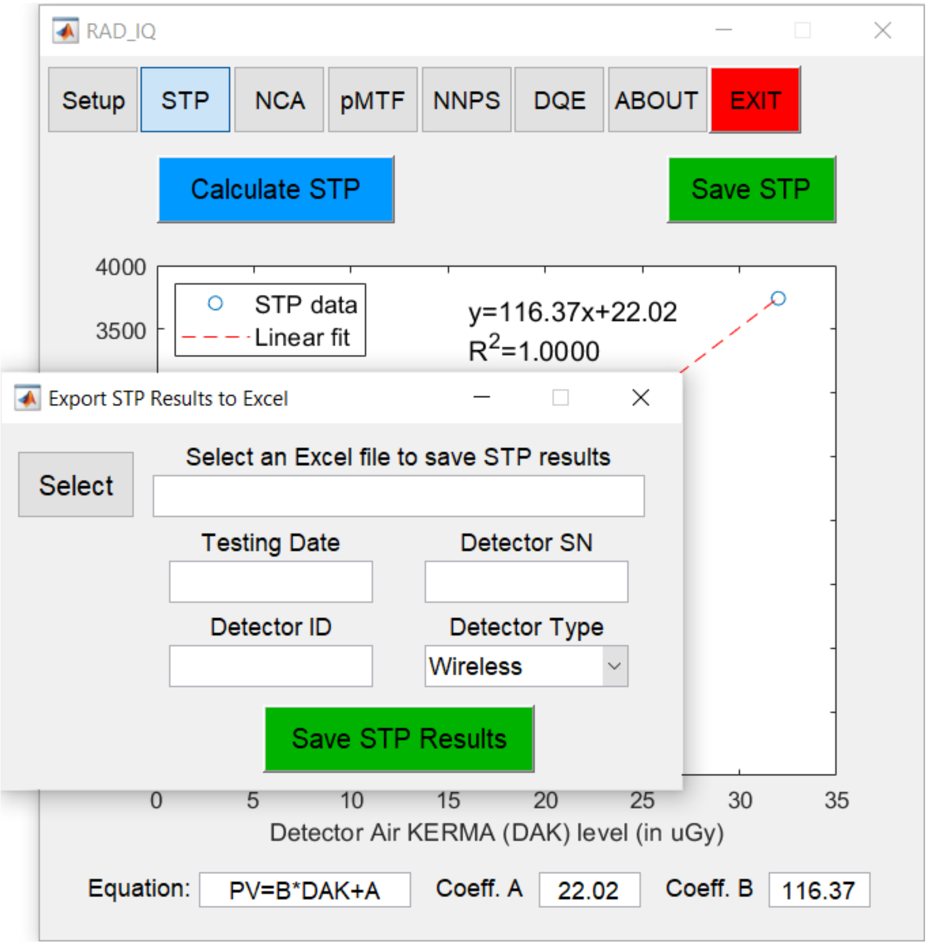
According to the ***IEC standards***, R^2 should be greater than 0,99 [1-2].

The *IEC standards* suggest 5 DAK levels for STP analysis; a maximum of 7 DAK levels can be used with *RAD_IQ* (which can be found useful particularly in Mammography).

4. Save STP

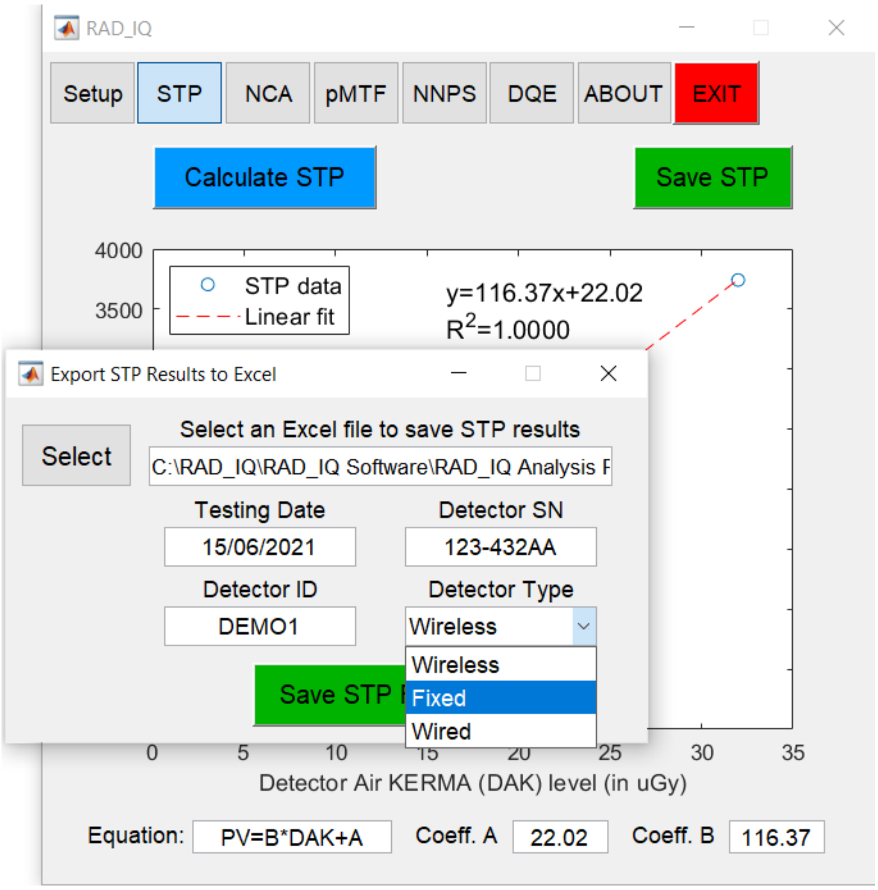
- **Press** the ***Save STP*** button to open ***Export STP Results to Excel*** window.
- **Press** ***Select*** to Select the ***RAD_IQ Analysis Results*** Excel file to save STP results

For DICOM images the software extracts automatically from the DICOM Header the *Testing Date* and *Detector S/N*. Otherwise, you can manually type this information, which can be used for reference and identification.



- You can also **define** the ***Detector ID*** (i.e. a potential name / ID of the detector) and ***Detector Type*** (***Wireless***, ***Fixed*** or ***Wired***).

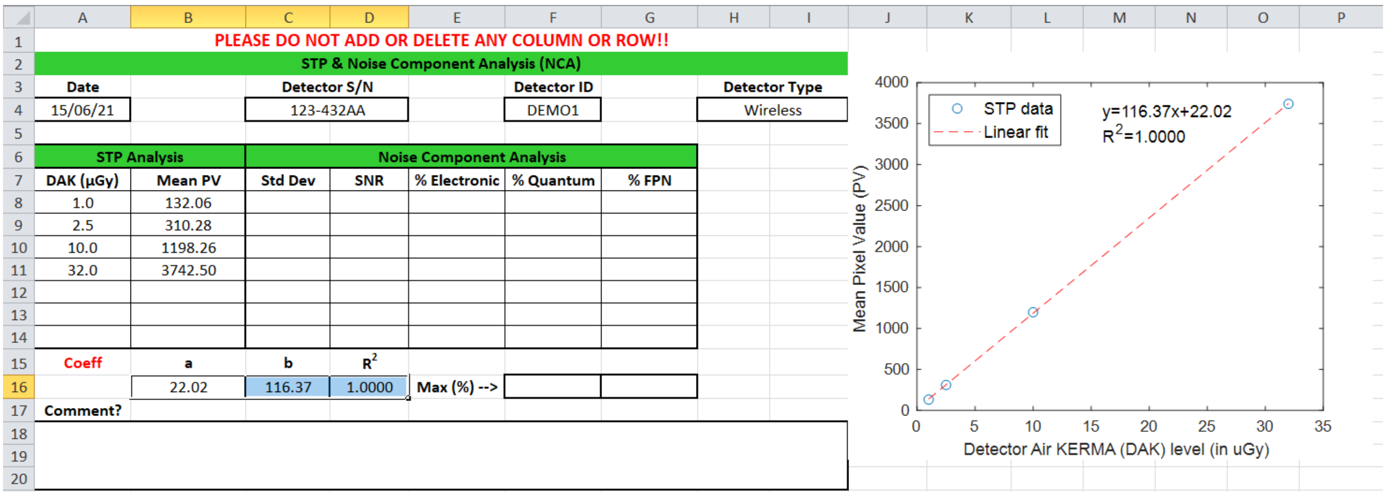
The following figure shows an example of completed information regarding the STP results to be extracted to the Excel file.



Do NOT add or remove any column/row in the Excel file with the results! Otherwise, the results will NOT be saved properly.

- **Close the Excel file** if it is open (and save it if necessary) and **press *Save STP Results***.

RAD_IQ will save the ***Testing Date***, ***Detector S/N***, ***Detector ID***, ***Detector Type***, ***DAK*** (in µGy), ***Mean PV***, fitting coefficients ***a*** & ***b***, and ***R²*** in the proper cells. It also saves the MATLAB ***STP figure*** with the best fit (i.e. with the highest R^2). The user also has the option to add a comment.

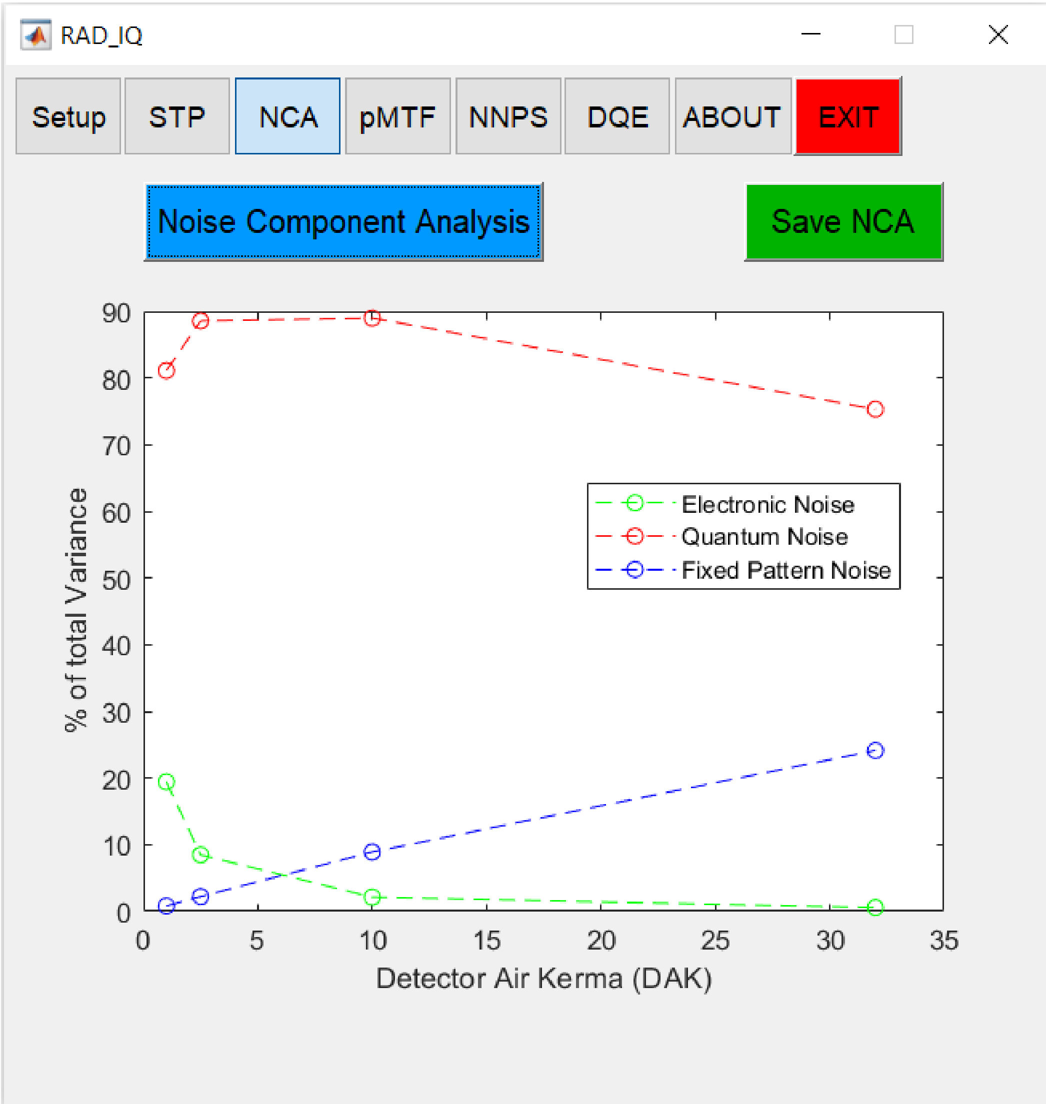


- **Close** the ***Export STP Results to Excel*** window to carry on with the quantitative image analysis.

5. Calculate NCA

Noise Component Analysis (**NCA**) can be used to analyse (in the spatial domain) the three main sources of noise: **Electronic Noise** (also known as Read Noise), **Quantum Noise** (a.k.a. Shot Noise) and **Fixed Pattern Noise** (FPN; a.k.a Structure Noise). In particular, NCA applies a second order polynomial fit to the Variance of the STP images to extract the three noise components (see ***% of total Variance***) as a function of Detector Air Kerma (DAK; in µGy). It can be used to define the DAK range where Quantum Noise is the dominant source of noise (ideally more than 80% of total variance). It can also be used to identify any remaining Fixed Pattern Noise (at low/middle DAK levels) and/or the influence of Electronic Noise (at low DAK levels).

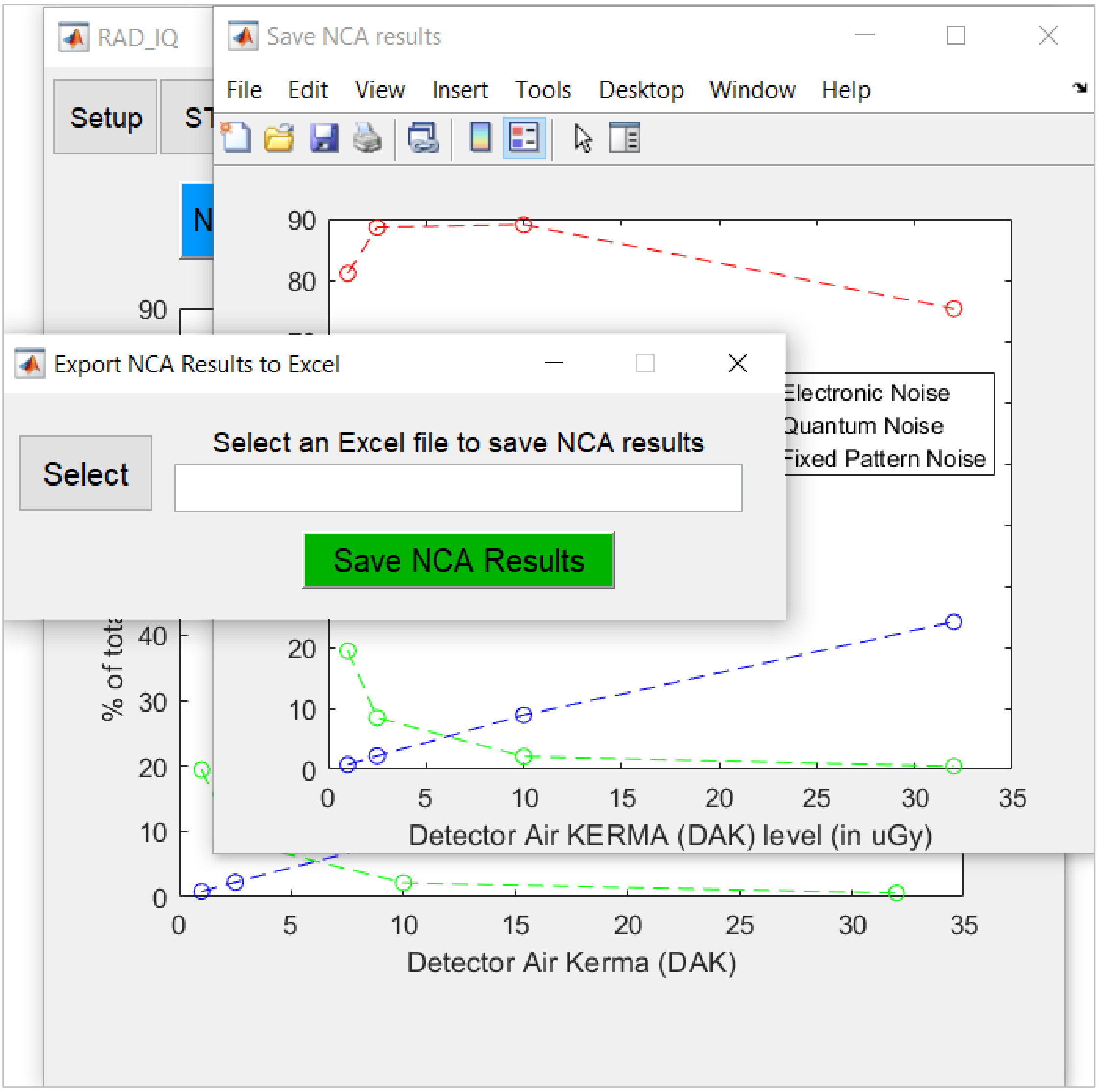
❖ **Select** the ***NCA*** tab and **press** ***Noise Component Analysis*** to perform **NCA** from the already loaded STP images.



6. Save NCA

❖ Press ***Save NCA*** to open the ***Export NCA Results to Excel*** window.

A new Figure (***Save NCA results***), which is identical to the previous one (see ***RAD_DR*** window), also appears.



Do NOT close the *Save NCA results* figure in order to save it in the Excel file.

If necessary, reposition the legend of *Save NCA results* figure (to avoid hiding the NCA curves).

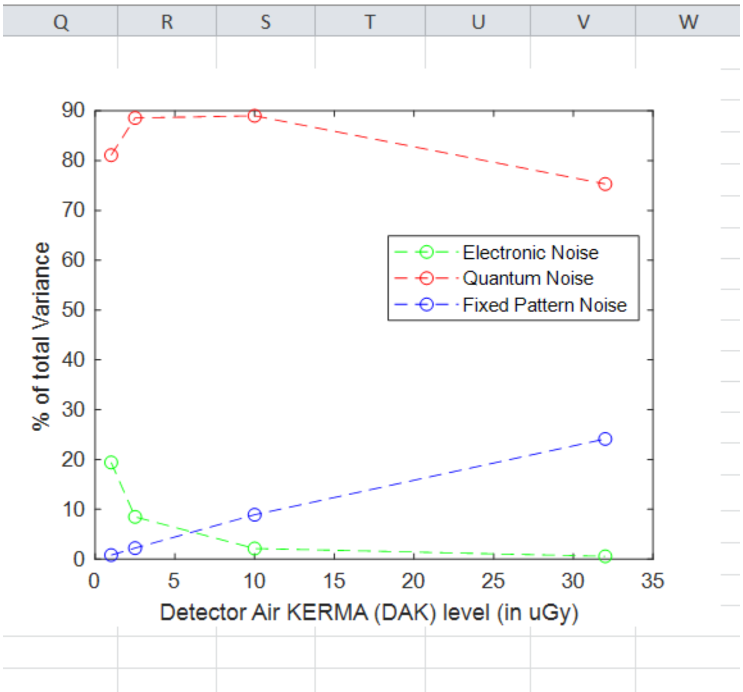
❖ In the new window (see ***Export NCA Results to Excel***) press ***Select*** to select the suggested ***RAD_IQ Analysis Results*** Excel file to save the NCA results.

❖ **Close** the **Excel file** if it is open (and save it if necessary) and **press *Save NCA Results***.

The parameters ***Std Dev***, ***SNR***, ***% Electronic*** (noise), **% Quantum** (noise) and **% FPN** (as a function of DAK) are saved next to the STP results. The maximum % Quantum and % FPN values are also indicated.

	A	B	C	D	E	F	G	H	I
1	PLEASE DO NOT ADD OR DELETE ANY COLUMN OR ROW!!								
2	STP & Noise Component Analysis (NCA)								
3	Date		Detector S/N			Detector ID		Detector Type	
4	15/06/21		123-432AA			DEMO1		Wireless	
5									
6	STP Analysis		Noise Component Analysis						
7	DAK (µGy)	Mean PV	Std Dev	SNR	% Electronic	% Quantum	% FPN		
8	1.0	132.06	2.8	46.8	19.4	81.1	0.8		
9	2.5	310.28	4.3	72.6	8.5	88.6	2.2		
10	10.0	1198.26	8.5	140.6	2.1	89.0	8.9		
11	32.0	3742.50	16.6	225.8	0.6	75.3	24.1		
12									
13									
14									
15	Coeff	a	b	R^2					
16		22.02	116.37	1.0000	Max (%) -->	89.0	24.1		
17	Comment?								
18									
19									
20									

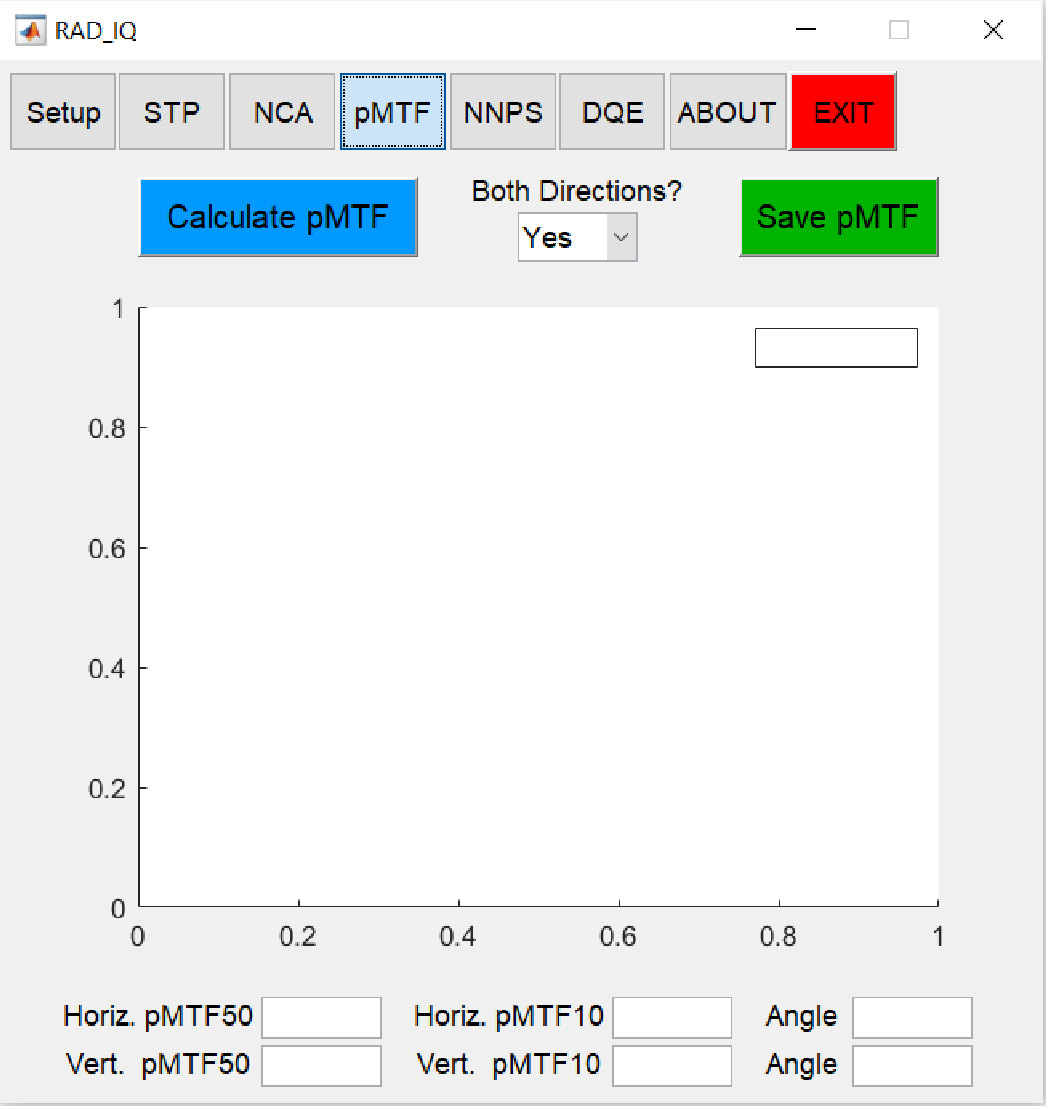
The ***Save NCA results*** MATLAB figure is also saved in Excel (next to the respective STP figure).



❖ **Close** the ***Export NCA Results to Excel*** window to carry on with the quantitative image analysis.

7. Calculate pMTF

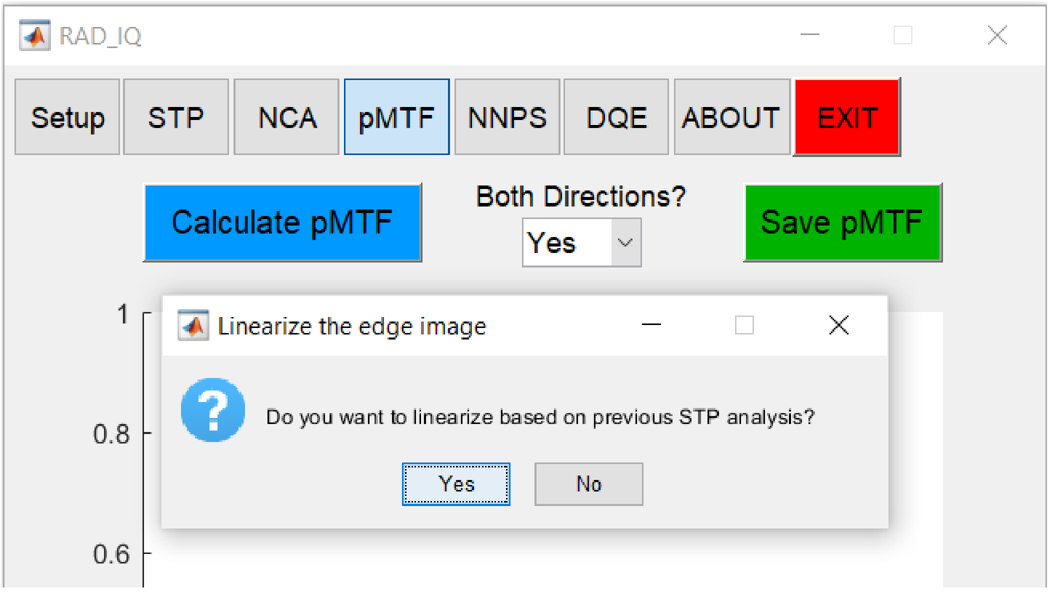
The **presampling Modulation Transfer Function (pMTF)**, which is related to spatial resolution, can be calculated for both horizontal and vertical orientations using a slightly tilted (angled between 1.5° and 5° with respect to the pixel array) edge test object (i.e. horizontal pMTF from vertical edge and vertical pMTF from horizontal edge). By default, both directions are selected (see ***Both Directions?*** pop-up menu) but the user can select to calculate only one direction (***Both Directions? → No***), i.e. either the horizontal or vertical pMTF.



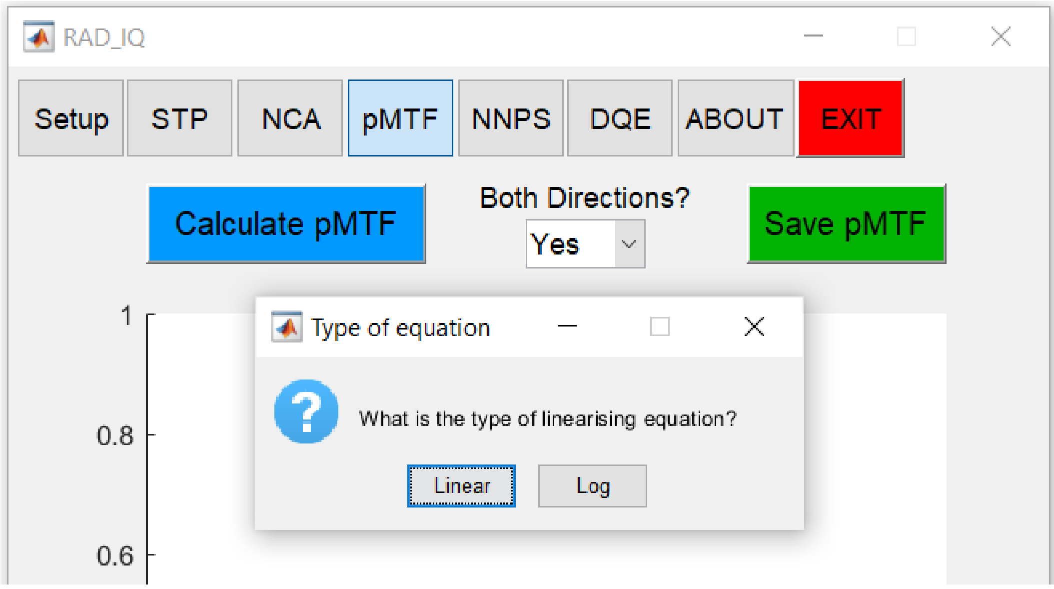
- **Select** the ***pMTF*** tab and **press *Calculate pMTF*** to select an Edge image in TIFF or DICOM format.

The software will ask if you want to ***linearize the edge image based on previous STP analysis***.

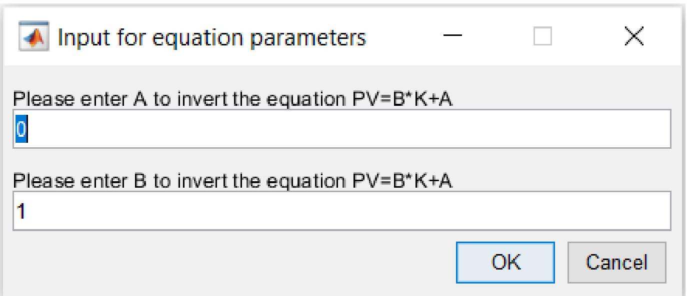
- **Press *Yes*** to get the linearized edge image (i.e. with DAK values (in µGy) instead of PV for ***STP*** linearization method, or X-ray fluence Φ (in X-rays per mm^2) for ***IEC*** linearization method) if you have already calculated the STP curve for the specific digital X-ray detector (see Section ***3. Calculate STP***).



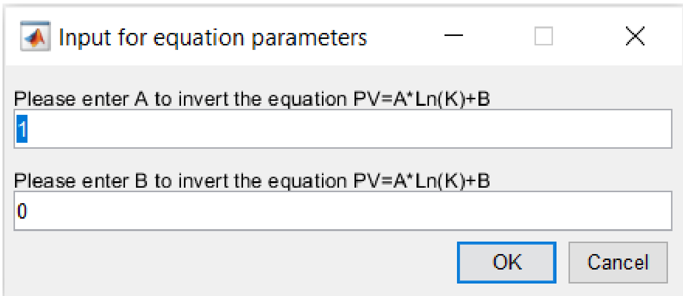
Otherwise, **select** the type of linearizing equation (i.e. ***Linear*** or ***Log***); linear is selected by default.



In this case, **type** the **coefficients *A*** and ***B*** from the STP curve to linearize the edge image.



Linear



Logarithmic

You can choose **not to linearize** the edge image if you leave the default STP coefficients for **Linear (A=0 & B=1)** equation (i.e. when the STP linearization method has been selected – see Section 2. Setup). **However, this is not advised because it will affect the pMTF (and consecutively the DQE results).**

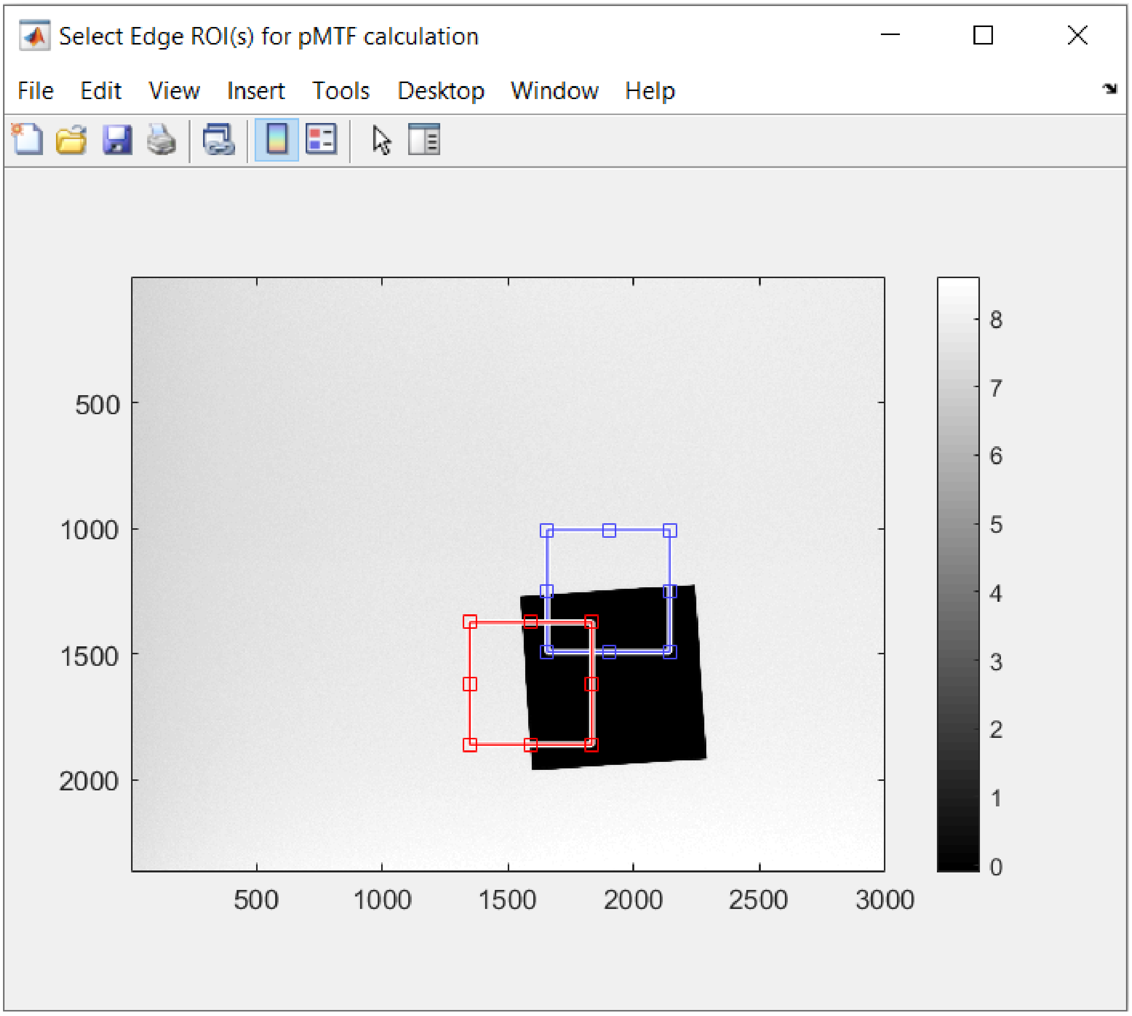
- **Move** (left click in the middle of the ROI and drag one ROI at a time) the edge ROI(s) to select the edge(s) for pMTF calculation.

Remember: Horizontal Edge → Vertical pMTF and **Vertical Edge → Vertical pMTF**.

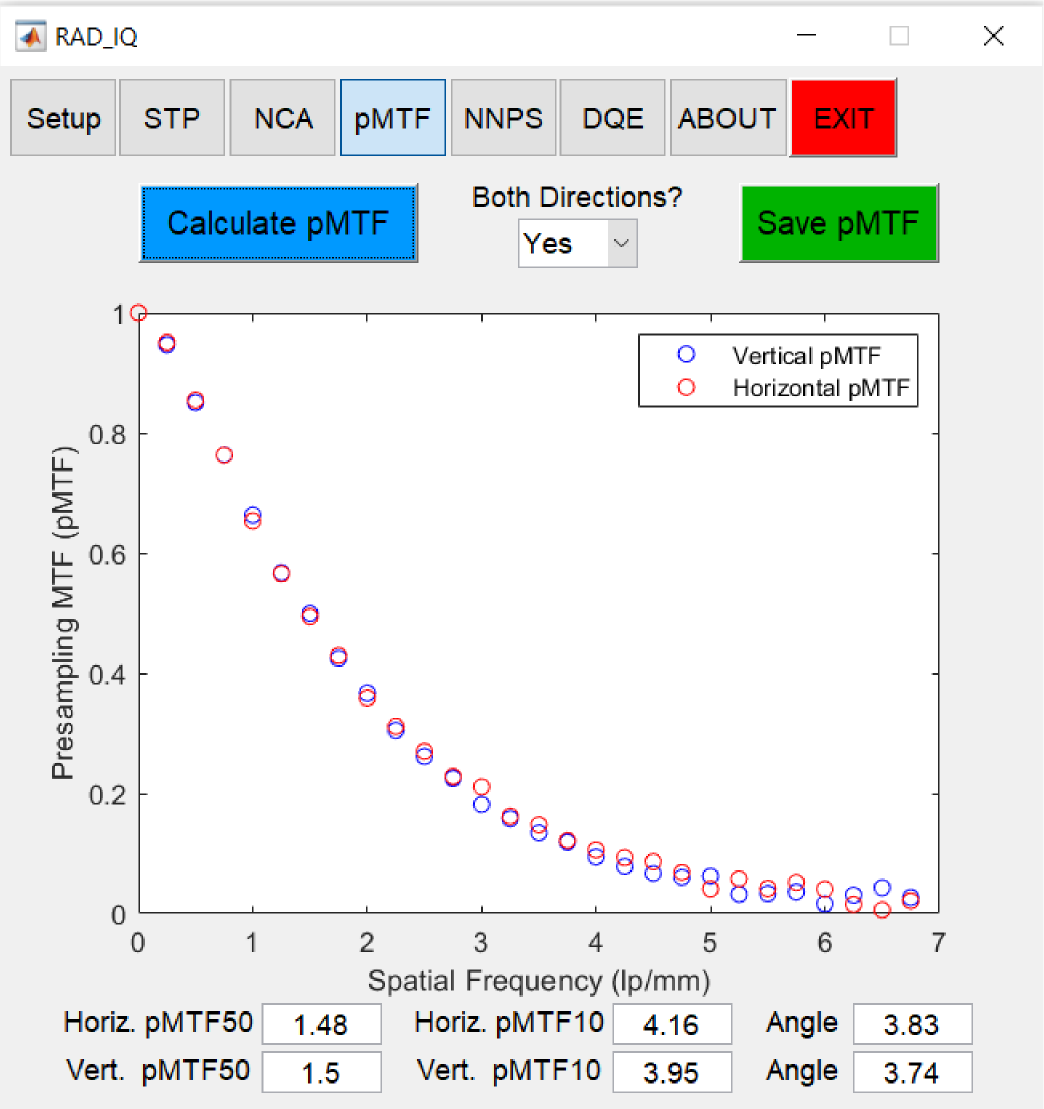
By default, the pMTF ROI is a square (70 mm x 70 mm for General Radiography or 50 mm x 50 mm for Digital Mammography). The user can change the dimensions of the ROI (click on a small box at the edge of the ROI and drag it) but this is not necessary.

- Once you are happy with the position of the ROI (i.e. in the middle of an edge) **double-click** (in the middle of the ROI) to carry on. The cursor should have a cross shape.

- If you choose both directions **press left click**, **drag** and **double-click** one ROI at a time.

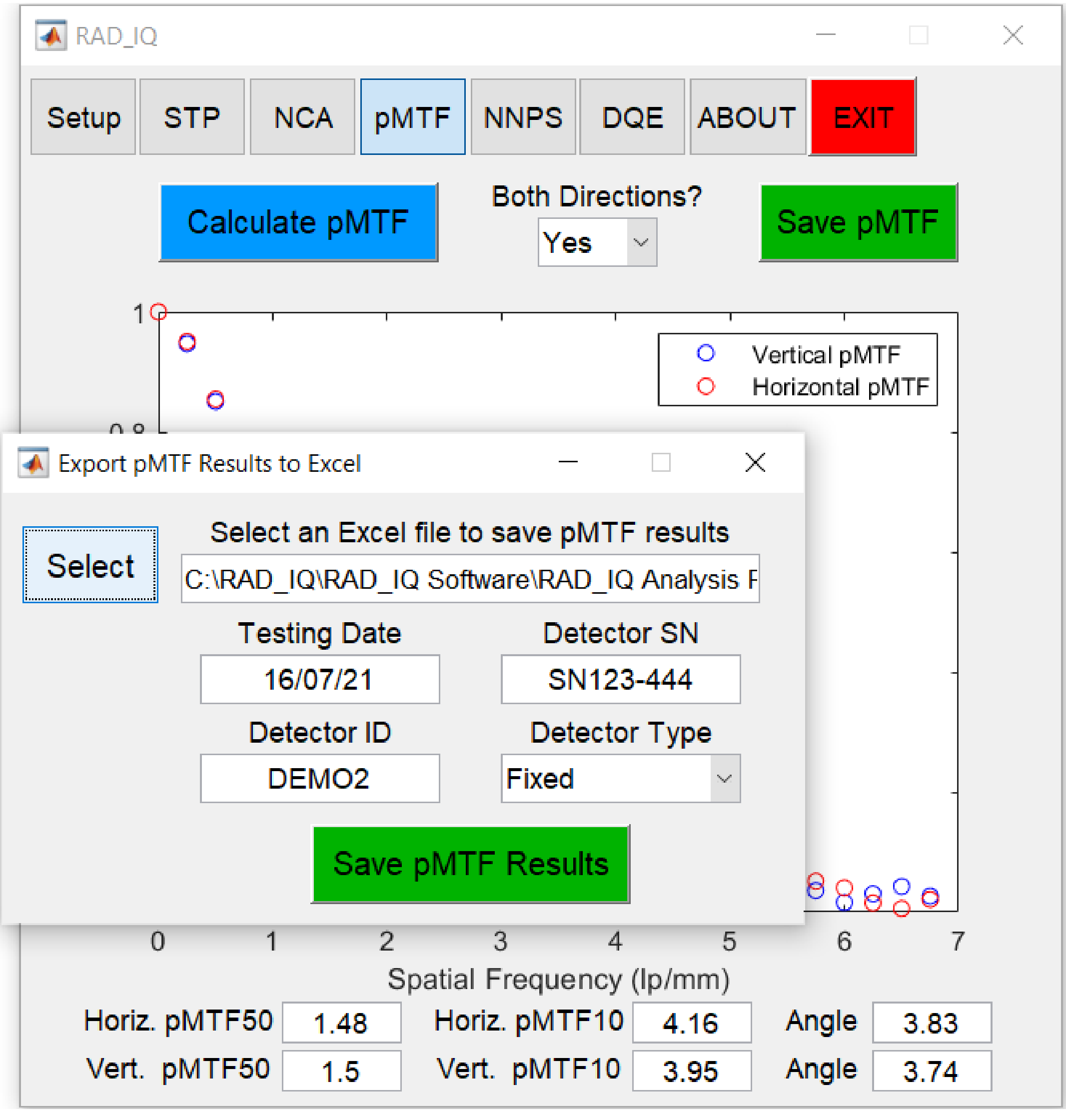


The software calculates the horizontal and/or vertical pMTF values and plots the pMTF curve(s) as a function of spatial frequency (in line pairs per millimetre; lp/mm) up to double the Nyquist Frequency. Furthermore, it extracts the horizontal and/or vertical **pMTF50** (i.e. spatial frequency the corresponds to pMTF=0,5), **pMTF10** (i.e. spatial frequency that corresponds to pMTF=0,1) and **edge angle** (ideally in the range 1,5-3 degrees according to the ***IEC standards*** [1, 2]. However, a broader range of 1,5-5 degrees is also acceptable according to ***IPEM Report 32 Part VII (2010)*** [4]) values; **pMTF50** and **pMTF10** can be used to monitor the performance of the detector over time (i.e. trend analysis).



8. Save pMTF

❖ **Press** the ***Save pMTF*** button to open the ***Export pMTF Results to Excel*** window.



❖ **Press** ***Select*** to select the ***RAD_IQ Analysis Results*** Excel file to save the pMTF results.

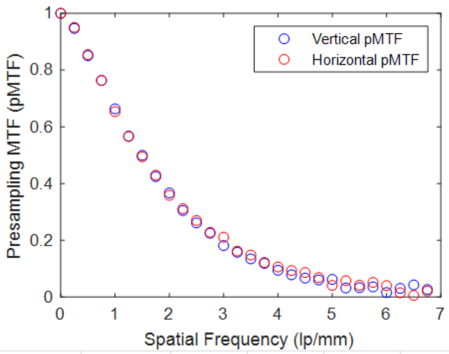
For DICOM images the software extracts automatically from the DICOM Header the *Testing Date* and *Detector S/N*. Otherwise, you can manually type this information, which can be used for reference and identification.

❖ You can also **define** the ***Detector ID*** (i.e. a potential name / ID of the detector) and ***Detector Type*** (***Wireless***, ***Fixed*** or ***Wired***).

❖ **Close** the **Excel file** if it is open (and save it if necessary) and **press *Save pMTF Results***.

The software saves the ***Date***, ***Detector S/N***, ***Detector ID***, ***Detector Type***, ***Horizontal*** and/or ***Vertical pMTF* values** (as a function of spatial frequency), ***pMTF50*** and ***pMTF10*** in the proper cells. It also saves the MATLAB **pMTF figure**.

pMTF, NNPS & DQE Analysis							
Date		Detector S/N			Detector ID		Detector Type
16/07/21		SN123-444			DEMO2		Fixed
	HORIZONTAL			VERTICAL			DAK (µGy)
Freq.	pMTF	NNPS	DQE	pMTF	NNPS	DQE	
0.25	0.95			0.95			
0.50	0.85			0.85			SNR² Input
0.75	0.76			0.76			
1.00	0.65			0.66			
1.25	0.57			0.57			
1.50	0.49			0.50			
1.75	0.43			0.42			
2.00	0.36			0.37			
2.25	0.31			0.30			
2.50	0.27			0.26			
2.75	0.23			0.22			
3.00	0.21			0.18			
3.25	0.16			0.16			



***RAD_IQ* saves the pMTF results up to the Nyquist Frequency of 50 µm pixel pitch (i.e. 10 lp/mm maximum frequency) when the selected frequency bin is 0.25 lp/mm, or up to the Nyquist Frequency of 25 µm pixel pitch (i.e. 20 lp/mm max frequency) when the selected frequency bin is 0.5 lp/mm.**

The horizontal and/or vertical ***pMTF50*** and ***pMTF10*** values are saved at the bottom (see following figure). The user also has the option to add a comment.

	pMTF50	NNPS(0.5)	DQE(0.5)	pMTF50	NNPS(0.5)	DQE(0.5)
	1.48			1.50		
	pMTF10	NNPS(2)	DQE(2)	pMTF10	NNPS(2)	DQE(2)
	4.16			3.95		
Comment?						

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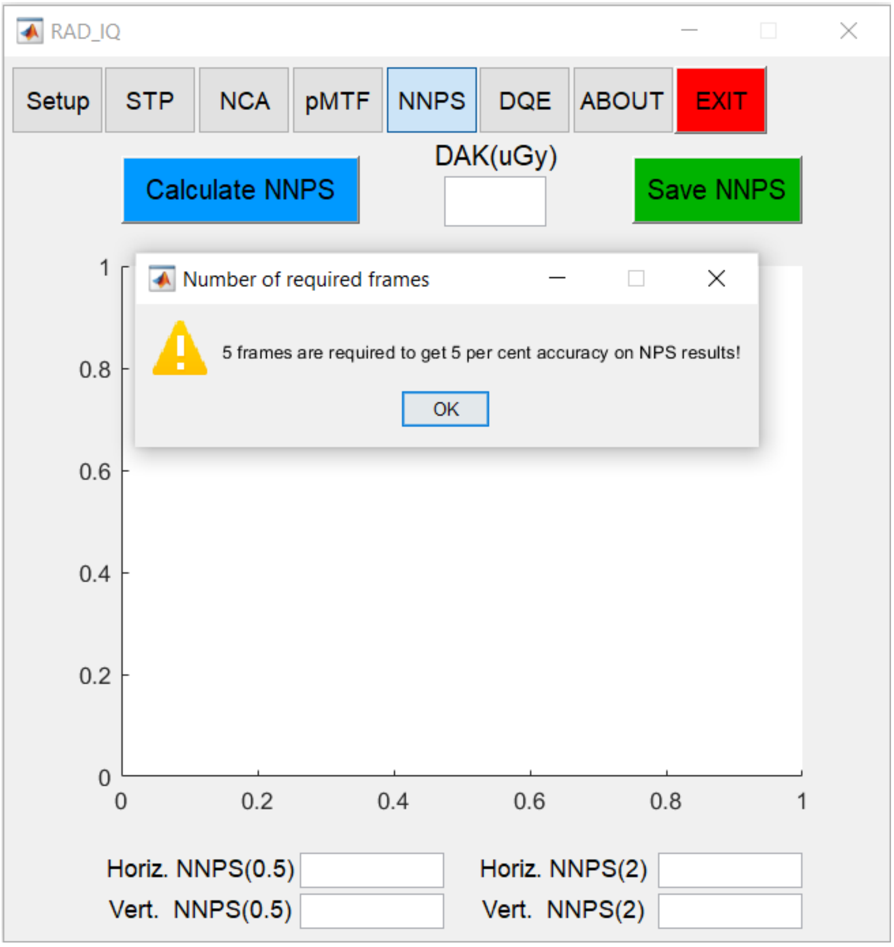
❖ **Close** the ***Export pMTF Results to Excel*** window to carry on with the quantitative image analysis.

9. Calculate NNPS

The **Normalized Noise Power Spectrum (NNPS)**, which is the normalized spectral decomposition of Variance, can be calculated from flat-field images at various DAK levels.

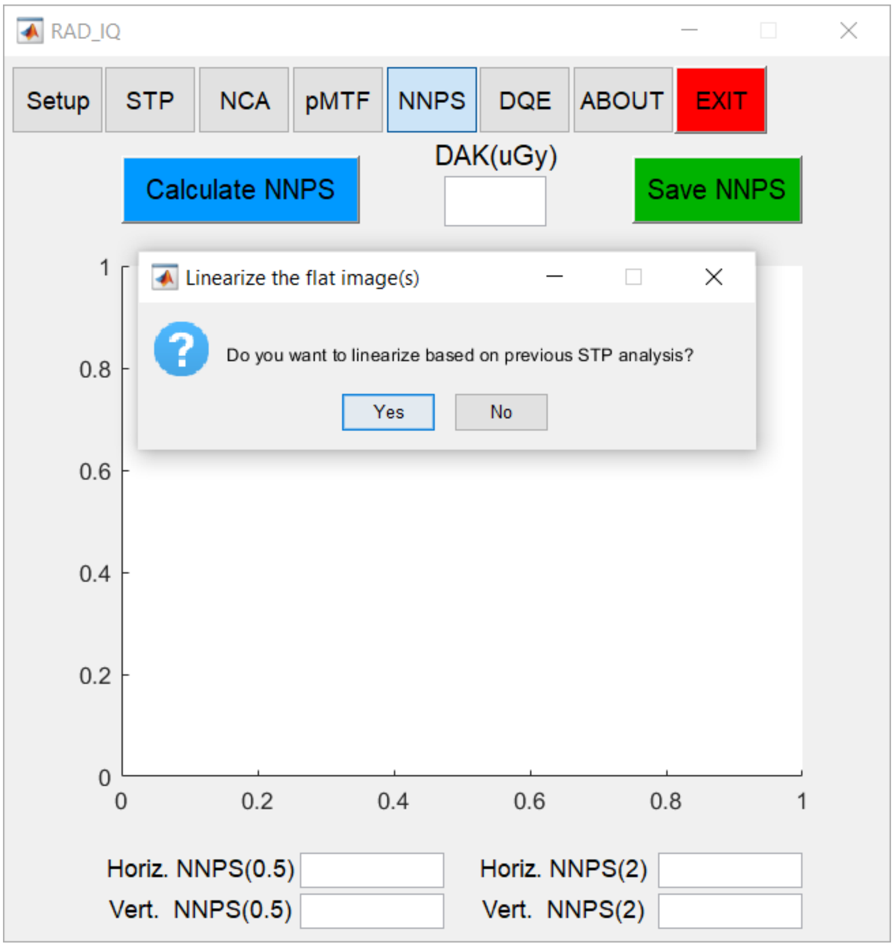
❖ **Select** the ***NNPS*** tab and **press *Calculate NNPS*** to select flat-field image(s) (in TIFF or DICOM format), usually at the standard DAK level (**~2.5 µGy** for General Radiography or **~100 µGy** for Digital Mammography).

For *IEC* ROIs the software calculates the required number of flat-field frames to get 5% accuracy on the NPS results (i.e. 4 million independent pixels according to IEC standards [1, 2]). Hence, the user can select multiple flat-field frames for a given DAK level (and X-ray beam quality) to reach the suggested accuracy. Alternatively, for Mammographic analysis you can select *EUREF* ROI for processing (because it corresponds to a larger NPS ROI – see Section 2.Setup).



The software will ask if you want to ***linearize the flat-field image based on previous STP analysis***.

❖ **Press *Yes*** to get the linearized flat-field image(s) (i.e. with DAK values (in µGy) instead of PV for ***STP*** linearization method, or X-ray fluence Φ (in X-rays per mm^2) for ***IEC*** linearization method) if you have already calculated the STP curve for the specific digital X-ray detector (see Section ***3. Calculate STP***).

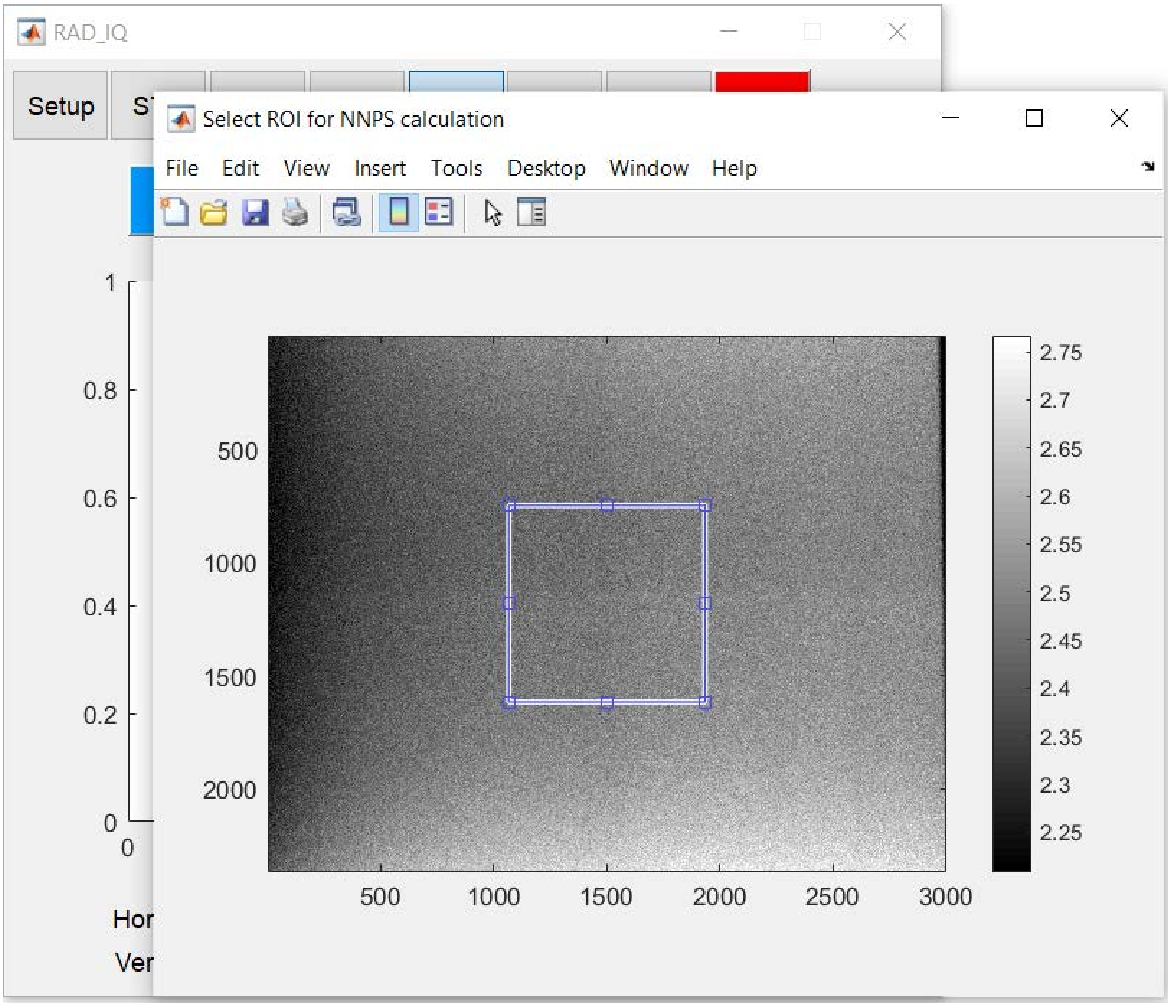


Otherwise, **select** the type of linearizing equation (i.e. ***Linear*** or ***Log***; linear is selected by default), and insert manually the **coefficients *A*** and ***B*** from the STP curve to linearize the images. See Section ***7. Calculate pMTF*** for further details.

It is strongly recommended to linearize the flat-field image for the calculation of NNPS & DQE.

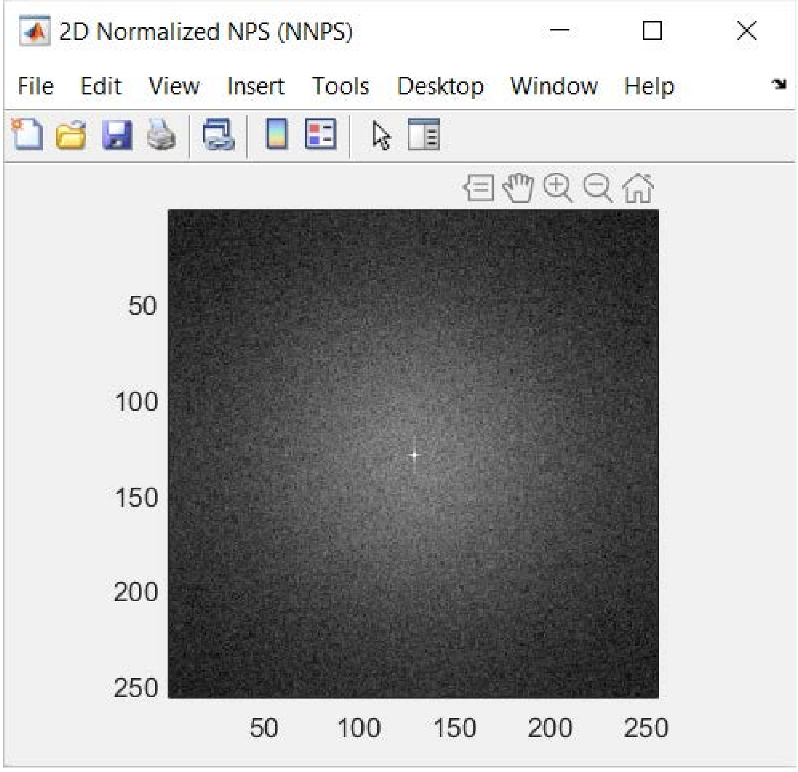
❖ **Select the ROI** for NNPS calculation.

Based on the ***IEC*** recommendation the ROI covers a central area of 12,5 cm x 12,5 cm for General Radiography [1] or a central 5 cm x 5 cm ROI for Digital Mammography [2], which requires the use of several flat-field frames (for a given DAK level and X-ray beam quality) to get sufficient accuracy on the NPS results. Alternatively, the ***EUREF*** ROI corresponds to a central 10 cm x 10 cm ROI, which means a single flat-field frame can provide sufficient accuracy for Quality Assurance (QA) purposes in Digital Mammography [3]. The user can modify the ROI (position and shape), but this is not advised.



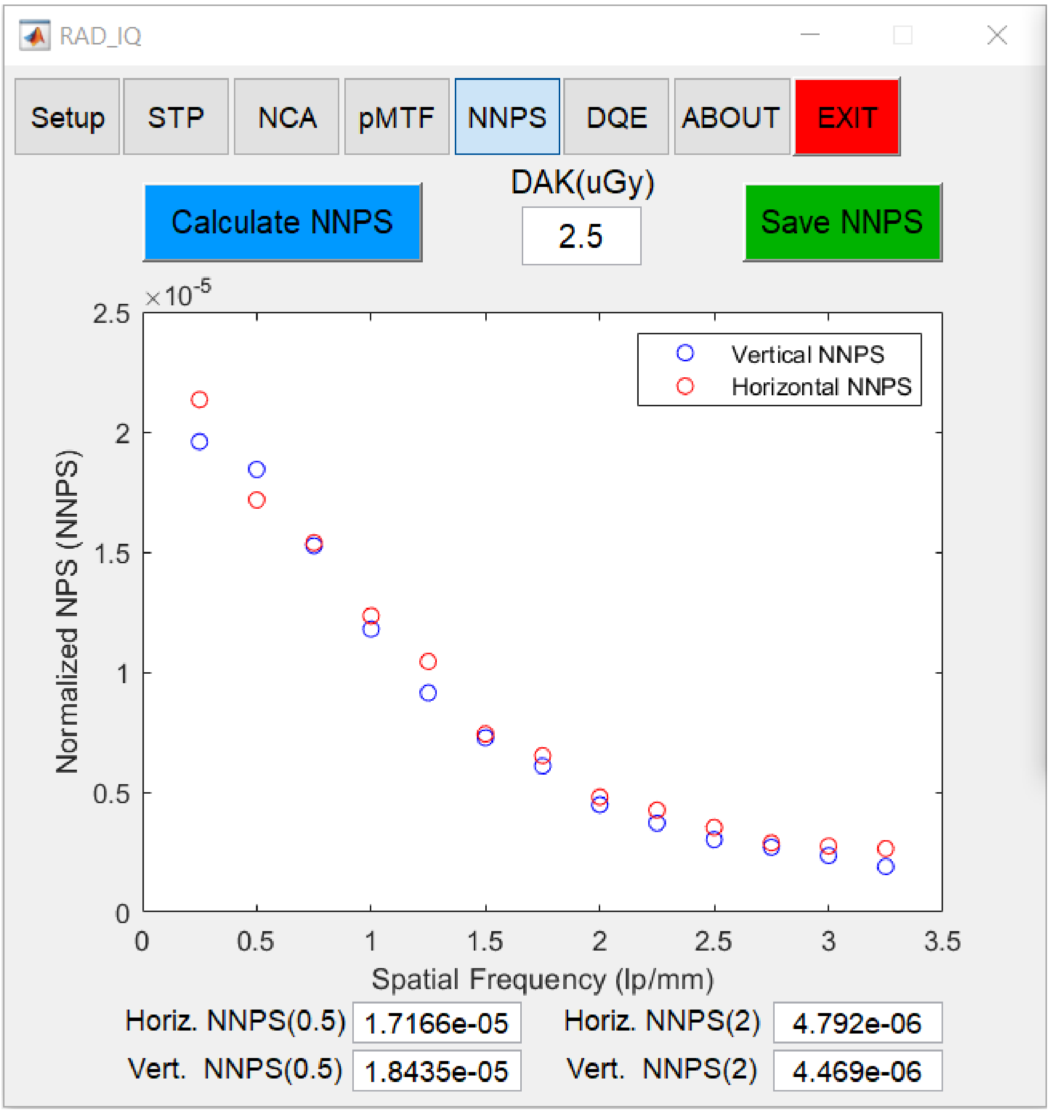
❖ **Double click** in the middle of the ROI (the cursor should have a cross-shape) to carry on.

The software calculates and plots the ***2D Normalized NPS (NNPS)***, which can be used to identify potential artefacts in the spatial frequency domain (due to a used anti-scatter grid, EMI (electro-magnetic interference) noise, horizontal / vertical artefacts, remnant Fixed Pattern Noise etc).



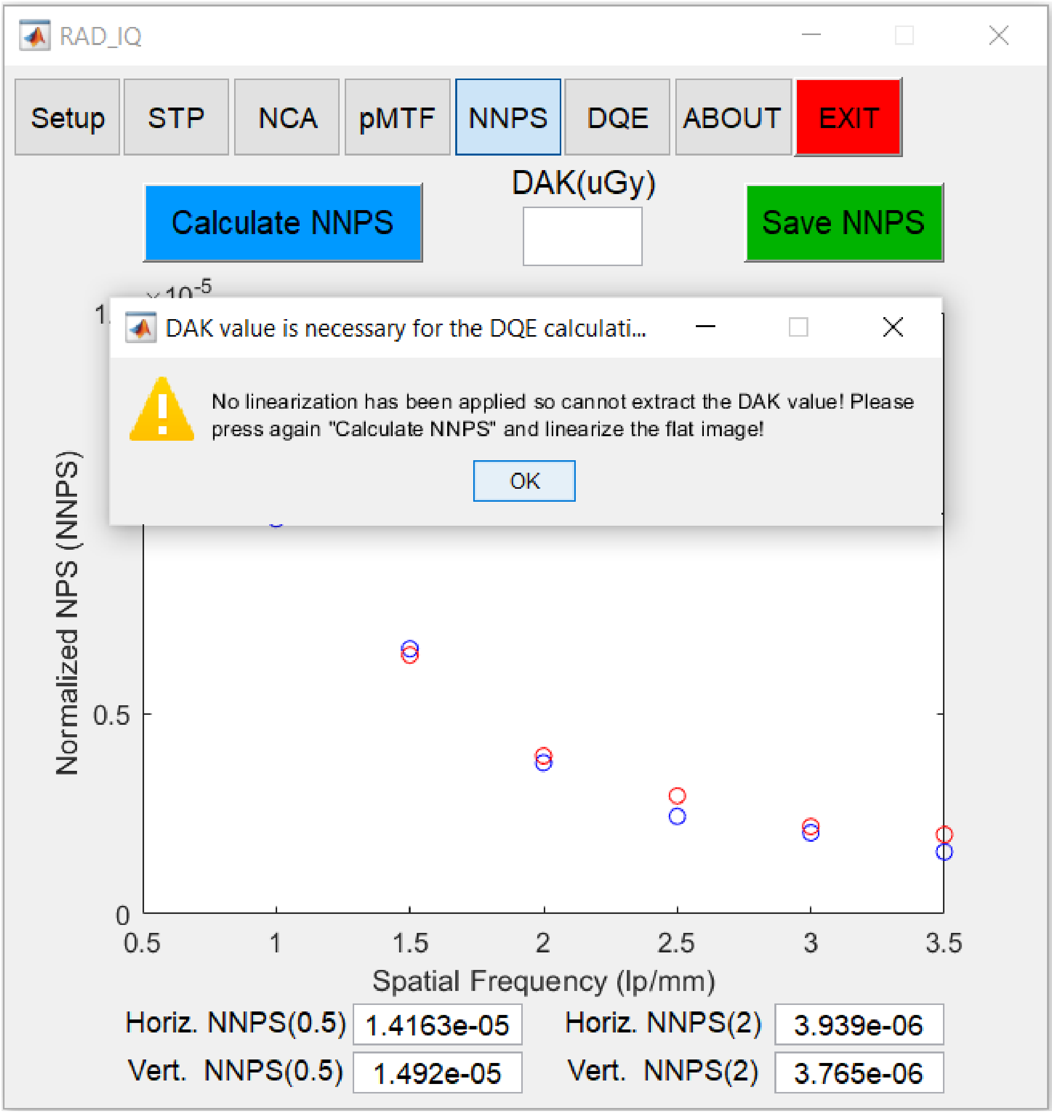
Do NOT close the *2D Normalized NPS (NNPS)* figure in order to save it in the Excel file.

The software also calculates (i.e. extracts from the 2D NNPS plot) and plots the **1D Horizontal and Vertical NNPS values** as a function of spatial frequency up to the Nyquist Frequency. It also calculates the **DAK** value (in µGy) if linearization has been applied; DAK is essential for the **DQE calculation**. Finally, it shows the Horizontal and Vertical NNPS values at 0.5 and 2 lp/mm (see **NNPS(0.5) & NNPS(2)**, respectively) that can be used to monitor the performance of the detector over time (i.e. for trend analysis).



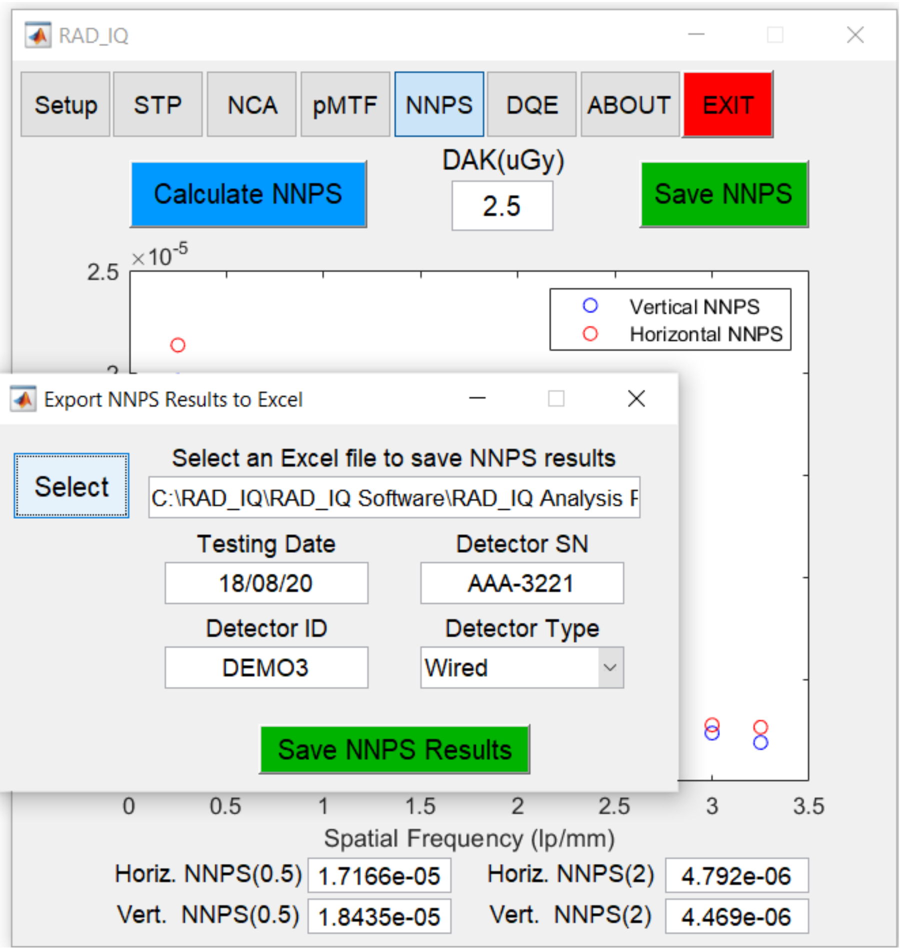
If you skip linearization the software still calculates 1D & 2D NNPS with a warning message (see figure below): *DAK value is necessary for the DQE calculation! – No linearization has been applied so cannot extract the DAK value! Please press again "Calculate NNPS" and linearize the flat image!*

In other words, in order to calculate the DQE you should always linearize the flat image(s) used for the NNPS calculation!


RAD_IQ
Setup
STP
NCA
pMTF
NNPS
DQE
ABOUT
EXIT
Calculate NNPS
DAK(uGy)
Save NNPS
DAK value is necessary for the DQE calculati...
No linearization has been applied so cannot extract the DAK value! Please press again "Calculate NNPS" and linearize the flat image!
OK
Normalized NPS (NNPS)
Spatial Frequency (lp/mm)
Horiz. NNPS(0.5)
1.4163e-05
Horiz. NNPS(2)
3.939e-06
Vert. NNPS(0.5)
1.492e-05
Vert. NNPS(2)
3.765e-06

10. Save NNPS

❖ **Press** the ***Save NNPS*** button to open ***Export NNPS Results to Excel*** window.



❖ **Press *Select*** to select the ***RAD_IQ Analysis Results*** Excel file to save the NNPS results (see Section ***8. Save pMTF*** for further details).

For DICOM images the software extracts automatically from the DICOM Header the *Testing Date* and *Detector S/N*. Otherwise, you can manually type this information, which can be used for reference and identification.

❖ You can also **define** the ***Detector ID*** (i.e. a potential name / ID of the detector) and ***Detector Type*** (***Wireless***, ***Fixed*** or ***Wired***).

You can overwrite the *Testing Date*, *Detector S/N*, *Detector ID* and *Detector Type* (previously saved from the pMTF analysis – see Section 8. Save pMTF).

❖ **Close** the **Excel file** if it is open (and save it if necessary) and **press *Save NNPS Results***.

The software saves the ***Testing Date***, ***Detector S/N***, ***Detector ID***, ***Detector Type***, ***DAK (µGy)***, ***Horizontal*** and ***Vertical 1D NNPS* values** (as a function of spatial frequency).

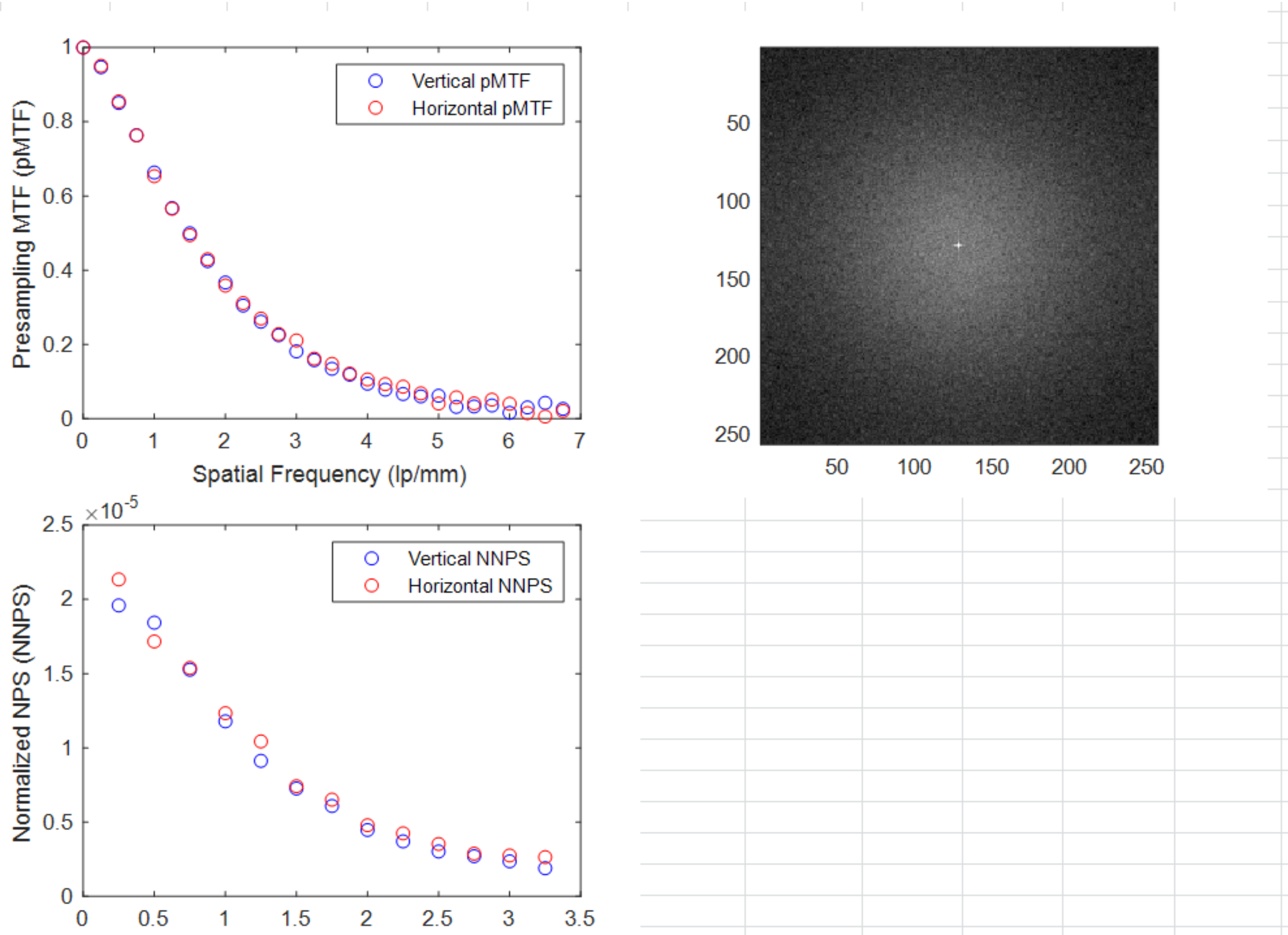
23	pMTF, NNPS & DQE Analysis							
24	**Date**		**Detector S/N**			**Detector ID**		**Detector Type**
25	18/08/20		AAA-3221			DEMO3		Wired
26								
27		**HORIZONTAL**			**VERTICAL**			**DAK (µGy)**
28	**Freq.**	**pMTF**	**NNPS**	**DQE**	**pMTF**	**NNPS**	**DQE**	2.5
29	0.25	0.95	2.13E-05		0.95	1.96E-05		
30	0.50	0.85	1.72E-05		0.85	1.84E-05		**SNR^2 Input**
31	0.75	0.76	1.54E-05		0.76	1.53E-05		
32	1.00	0.65	1.23E-05		0.66	1.18E-05		
33	1.25	0.57	1.04E-05		0.57	9.13E-06		
34	1.50	0.49	7.42E-06		0.50	7.26E-06		
35	1.75	0.43	6.51E-06		0.42	6.09E-06		
36	2.00	0.36	4.79E-06		0.37	4.47E-06		
37	2.25	0.31	4.25E-06		0.30	3.70E-06		
38	2.50	0.27	3.53E-06		0.26	3.02E-06		
39	2.75	0.23	2.88E-06		0.22	2.71E-06		
40	3.00	0.21	2.76E-06		0.18	2.36E-06		
41	3.25	0.16	2.64E-06		0.16	1.90E-06		
42								

***RAD_IQ* saves the NNPS results up to the Nyquist Frequency of 50 µm pixel pitch (i.e. 10 lp/mm maximum frequency) when the selected frequency bin is 0.25 lp/mm, or up to the Nyquist Frequency of 25 µm pixel pitch (i.e. 20 lp/mm max frequency) when the selected frequency bin is 0.5 lp/mm.**

The horizontal and vertical 1D ***NNPS(0.5)*** and ***NNPS(2)*** values are saved at the bottom (see following figure). The user also has the option to add a comment.

69							
70		**pMTF50**	**NNPS(0.5)**	**DQE(0.5)**	**pMTF50**	**NNPS(0.5)**	**DQE(0.5)**
71		1.48	1.72E-05		1.50	1.84E-05	
72		**pMTF10**	**NNPS(2)**	**DQE(2)**	**pMTF10**	**NNPS(2)**	**DQE(2)**
73		4.16	4.79E-06		3.95	4.47E-06	
74	**Comment?**						
75							
76							
77							

The software also extracts the MATLAB **2D & 1D NNPS figures**.



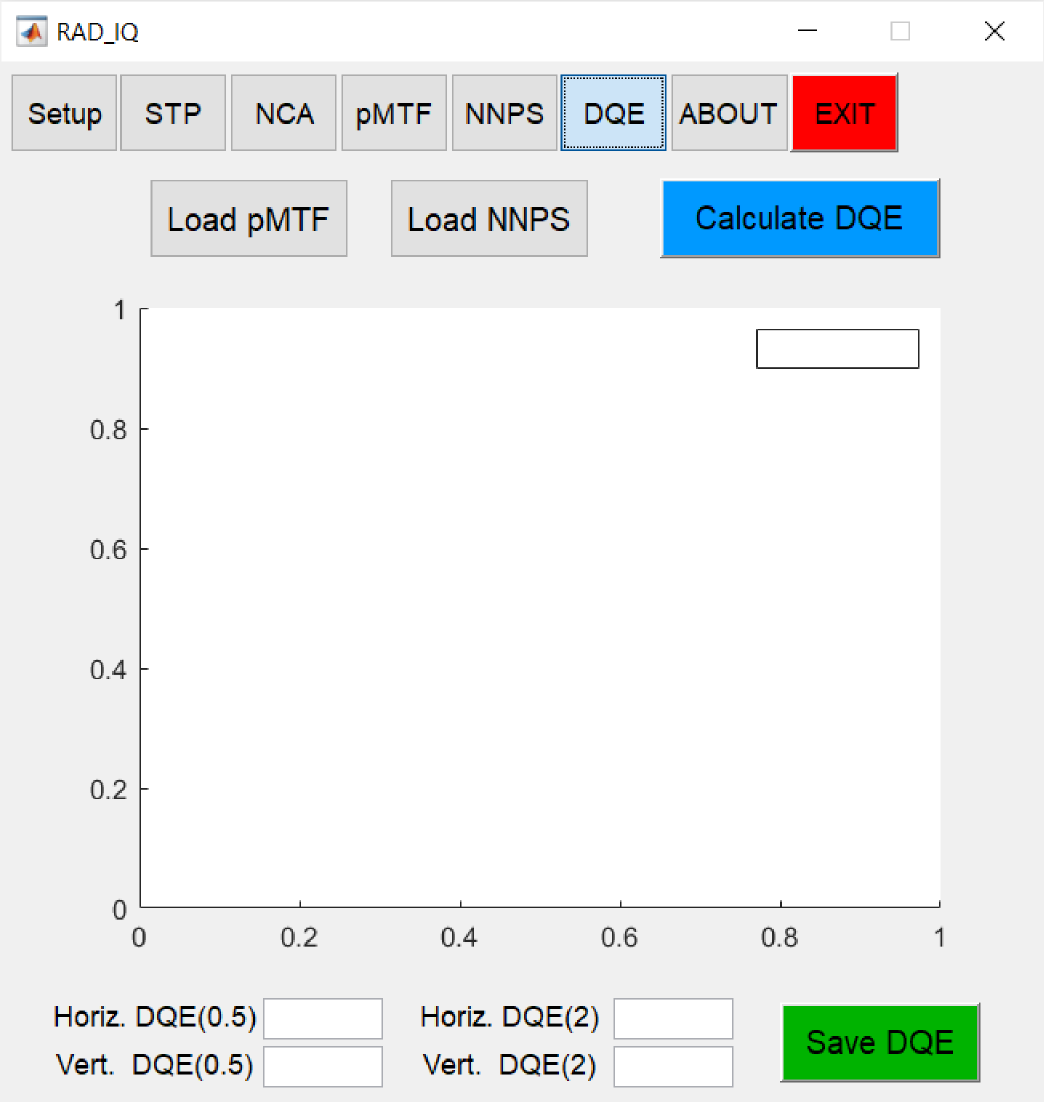
❖ **Close** the ***Export NNPS Results to Excel*** window to carry on with the quantitative image analysis.

11. Calculate DQE

The **Detective Quantum Efficiency (DQE)** takes into account spatial resolution, contrast and noise. It is calculated from the following formula:

$$DQE(f) = \frac{pMTF(f)^2}{SNR_{Input}^2 * DAK * NNPS(f)}$$

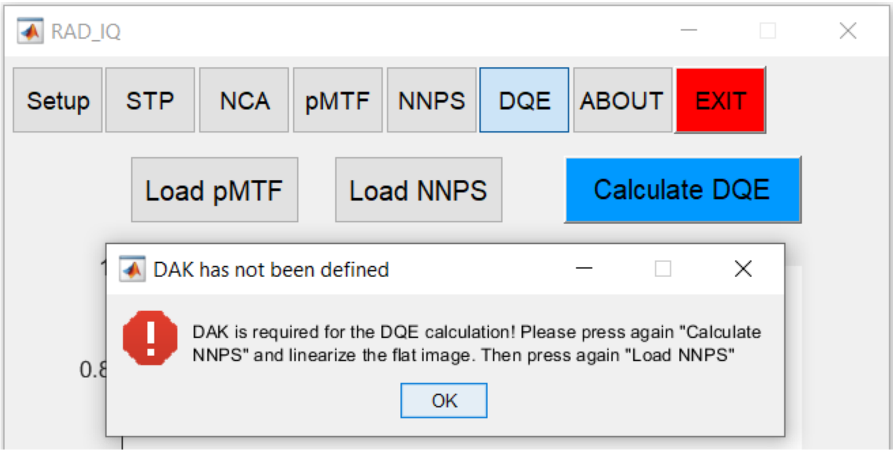
Where SNR_{Input}^2 is the *Fluence per DAK* ratio (in X-rays per µGy per mm^2) and *f* is spatial frequency (in lp/mm). Hence, all 4 parameters are necessary for the DQE calculation: ***pMTF***, $\boldsymbol{SNR_{Input}^2}$, ***DAK*** & ***NNPS***.



The $\boldsymbol{SNR_{Input}^2}$ depends on the used X-ray beam quality. It can be defined in the ***Setup*** tab (see Section [2. Setup](#)).

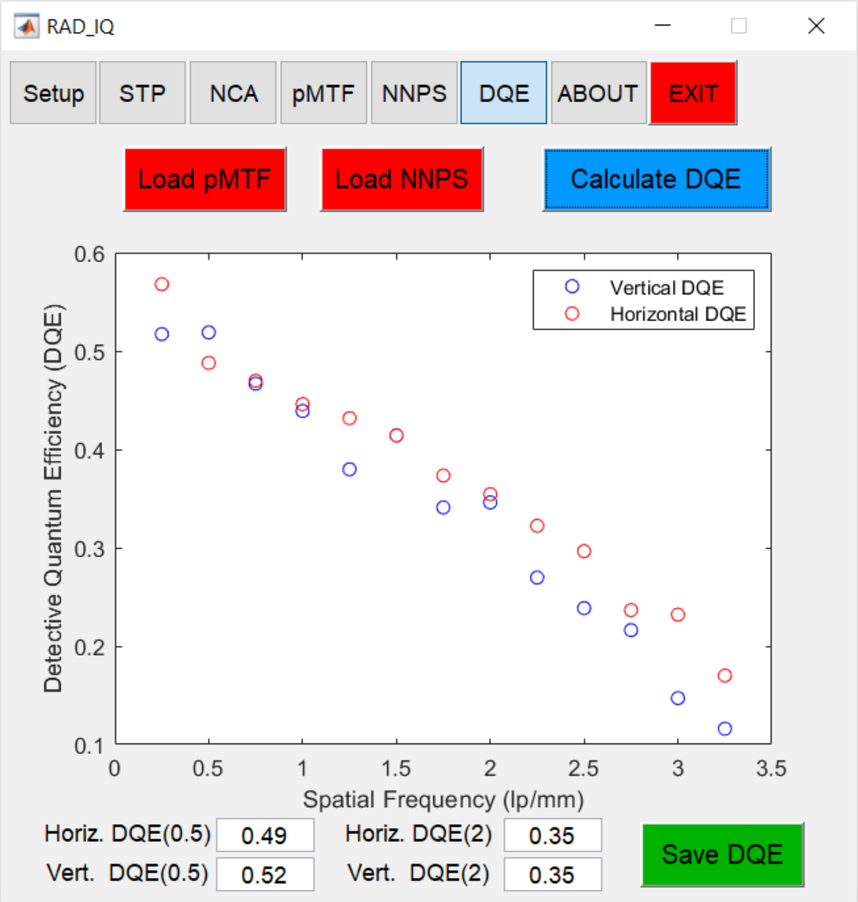
- **Select** the ***DQE*** tab and **press** ***Load pMTF*** and ***Load NNPS*** to load the calculated pMTF and NNPS.

An error message is shown if you calculated the NNPS without linearizing the flat image (see below). In this case, calculate again the NNPS values using linearization (see Section *9. Calculate NNPS*) and press again *"Load NNPS"*.



❖ When both pMTF and NNPS parameters are loaded properly (see **red *Load pMTF* & *Load NNPS*** buttons in the following figure) **press *Calc. DQE*** to calculate the horizontal and/or vertical DQE values (depending on the calculated pMTF values – see Section *7. Calculate pMTF*).

The software calculates and plots the horizontal and/or vertical DQE values as a function of spatial frequency (in lp/mm) up to the Nyquist Frequency. It also shows the DQE values at 0,5 and 2 lp/mm (see **DQE(0.5) & DQE(2)**, respectively) which can be used to monitor the detector's performance over time.

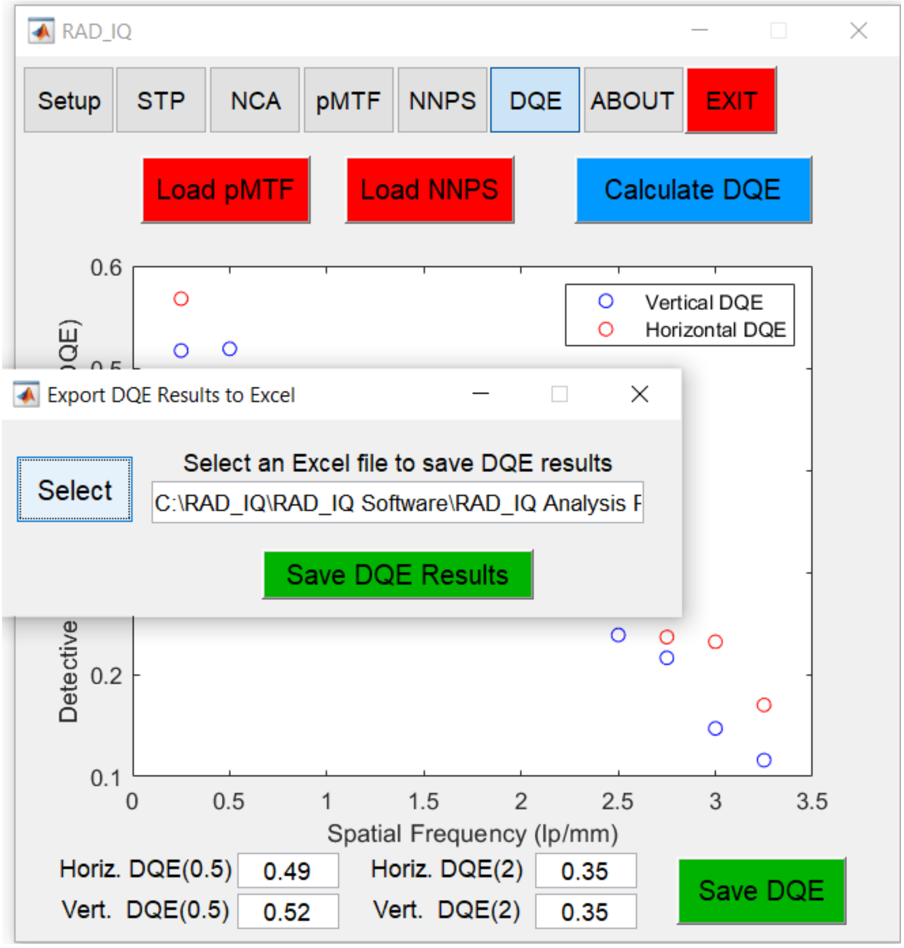


Maximum DQE values in the range 0,5-0,7 are expected for DR detectors.

12. Save DQE

❖ **Press** the ***Save DQE*** button to open ***Export DQE Results to Excel*** window.

❖ **Press *Select*** to select the ***RAD_IQ Analysis Results*** Excel file to save the DQE results (see Section ***8. Save pMTF*** for further details).



❖ **Close** the **Excel file** if it is open (and save it if necessary) and **press *Save DQE Results***.

Quant_IQ_DR saves the used ***DAK (μGy)***, ***SNR²* *Input***, ***Horizontal*** and/or ***Vertical 1D DQE*** **values** (depending on the orientation of the calculated pMTF values), ***DQE(0.5)*** and ***DQE(2)*** in the proper cells. It also saves the MATLAB **DQE figure**.

23	pMTF, NNPS & DQE Analysis							
24	**Date**		**Detector S/N**		**Detector ID**			**Detector Type**
25	18/08/20		AAA-3221		DEMO3			Wired
26								
27		**HORIZONTAL**			**VERTICAL**			**DAK (µGy)**
28	**Freq.**	**pMTF**	**NNPS**	**DQE**	**pMTF**	**NNPS**	**DQE**	2.5
29	0.25	0.95	2.13E-05	0.57	0.95	1.96E-05	0.52	
30	0.50	0.85	1.72E-05	0.49	0.85	1.84E-05	0.52	**SNR^2 Input**
31	0.75	0.76	1.54E-05	0.47	0.76	1.53E-05	0.47	32490
32	1.00	0.65	1.23E-05	0.45	0.66	1.18E-05	0.44	
33	1.25	0.57	1.04E-05	0.43	0.57	9.13E-06	0.38	
34	1.50	0.49	7.42E-06	0.41	0.50	7.26E-06	0.41	
35	1.75	0.43	6.51E-06	0.37	0.42	6.09E-06	0.34	
36	2.00	0.36	4.79E-06	0.35	0.37	4.47E-06	0.35	
37	2.25	0.31	4.25E-06	0.32	0.30	3.70E-06	0.27	
38	2.50	0.27	3.53E-06	0.30	0.26	3.02E-06	0.24	
39	2.75	0.23	2.88E-06	0.24	0.22	2.71E-06	0.22	
40	3.00	0.21	2.76E-06	0.23	0.18	2.36E-06	0.15	
41	3.25	0.16	2.64E-06	0.17	0.16	1.90E-06	0.12	
42								

69							
70		**pMTF50**	**NNPS(0.5)**	**DQE(0.5)**	**pMTF50**	**NNPS(0.5)**	**DQE(0.5)**
71		1.48	1.72E-05	0.49	1.50	1.84E-05	0.52
72		**pMTF10**	**NNPS(2)**	**DQE(2)**	**pMTF10**	**NNPS(2)**	**DQE(2)**
73		4.16	4.79E-06	0.35	3.95	4.47E-06	0.35
74	**Comment?**						
75							
76							
77							
78							

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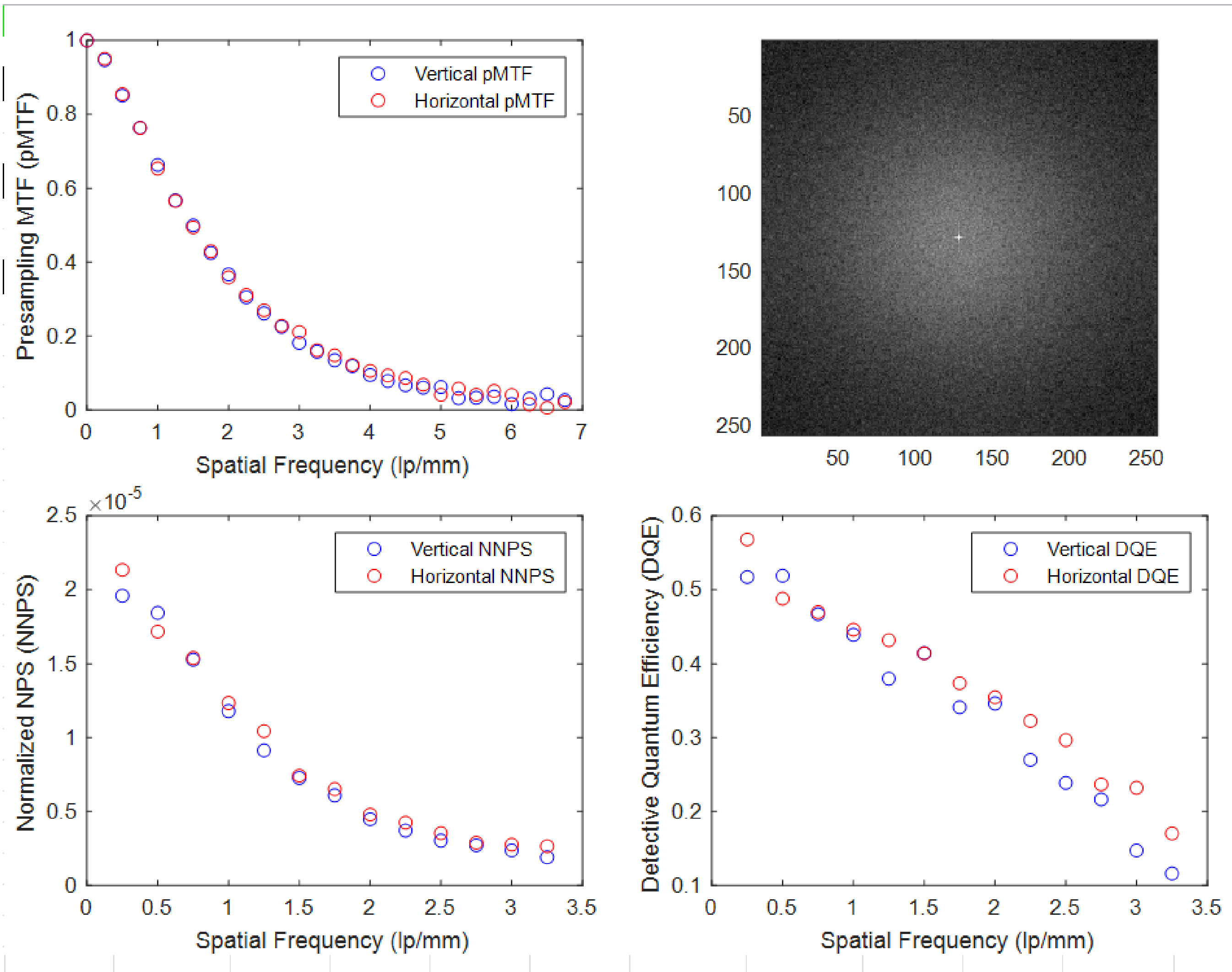
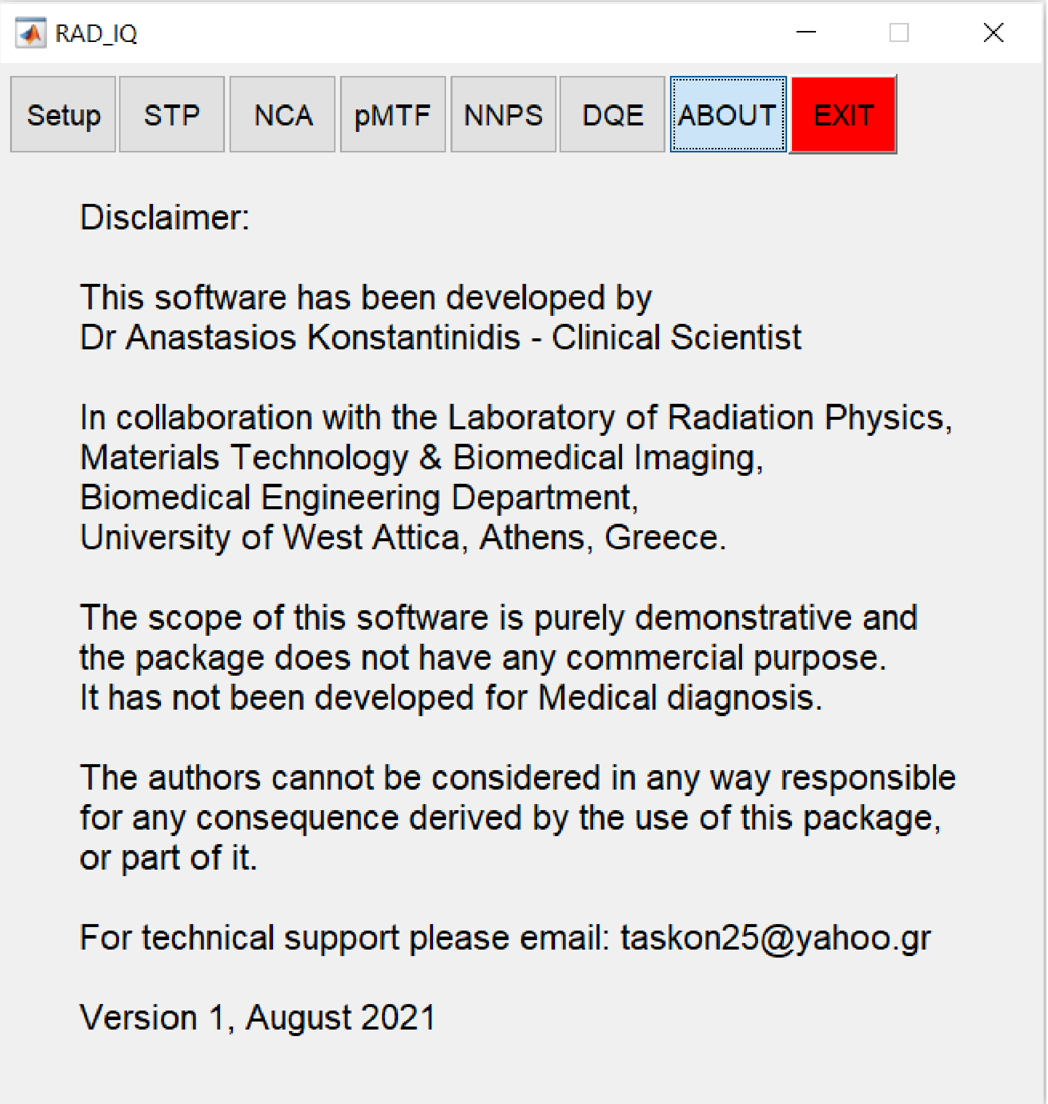


❖ **Close** the ***Export DQE Results to Excel*** window to carry on with the quantitative image analysis.

13. ABOUT

The disclaimer highlights that the software is not for commercial purpose and has not been developed for Medical diagnosis.



14. EXIT

Press the ***EXIT*** tab to close efficiently the executable GUI file.

References

[1] IEC 62220-1-1, 2015, *Medical electrical equipment - Characteristics of digital x-ray imaging devices - Part 1-1: Determination of the detective quantum efficiency - Detectors used in radiographic imaging* (Geneva: International Electrotechnical Commission)

[2] IEC 62220-1-2, 2007, *Medical electrical equipment - Characteristics of digital x-ray imaging devices - Part 1-2: Determination of the detective quantum efficiency - Detectors used in mammography* (Geneva: International Electrotechnical Commission)

[3] EUROPEAN COMMISSION, 2013, *European guidelines for quality assurance in breast cancer screening and diagnosis,* Fourth Edition – Supplements

[4] IPEM Report Number 32, Part VII, 2010, *Measurements of the Performance Characteristics of Diagnostic X-ray Systems: Digital Imaging Systems* (York: Institute of Physics and Engineering in Medicine)