

**LXXII International conference**  
**"Nucleus-2022: Fundamental problems and applications"**

DEVELOPMENT OF THE CRITERION FOR THE  
IDENTIFICATION OF CONTRAST AGENTS IN PHOTON-  
COUNTING COMPUTED TOMOGRAPHY

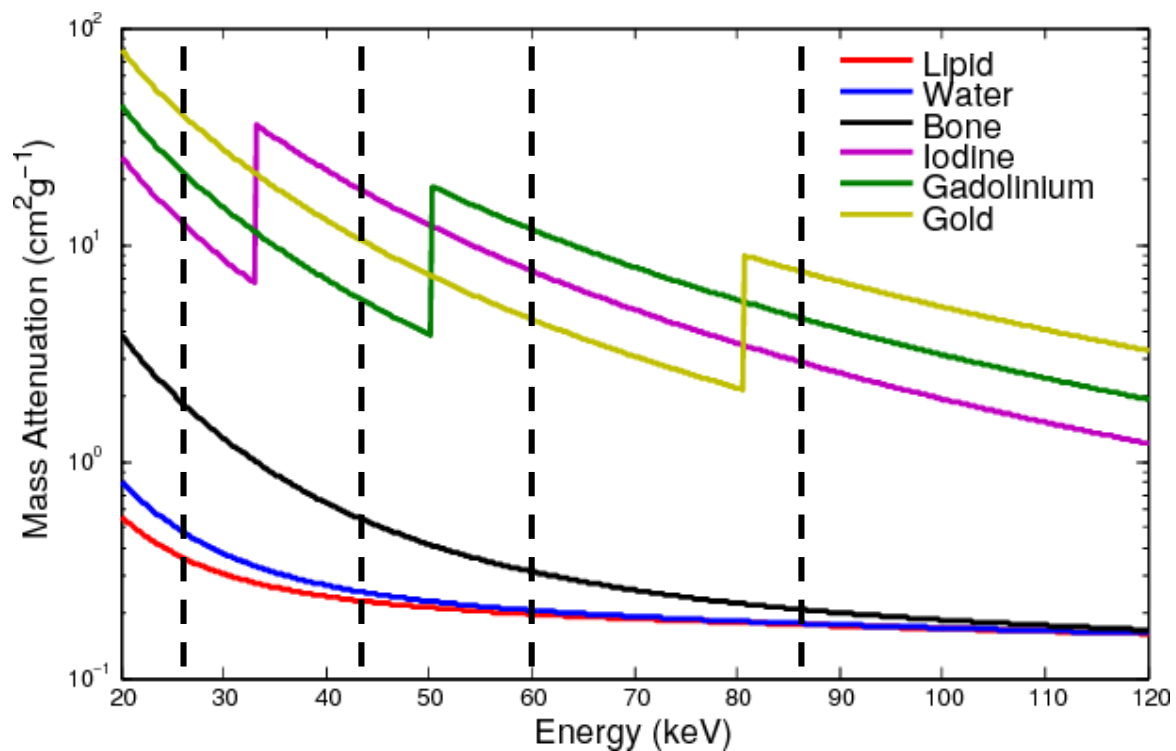
**Rostislav Sotensky**  
JINR, Dubna, Russia

13 July 2022 Moscow

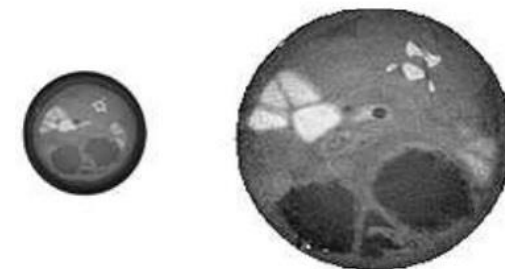
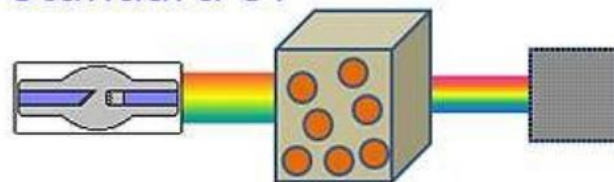
# Multi-energy tomography

$$I = I_0 \exp(-\mu \rho x),$$

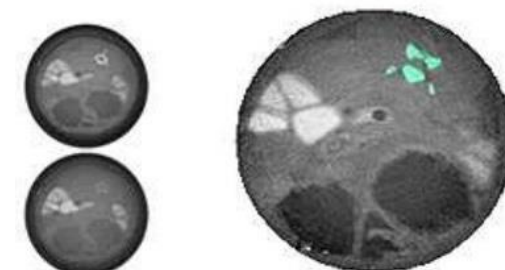
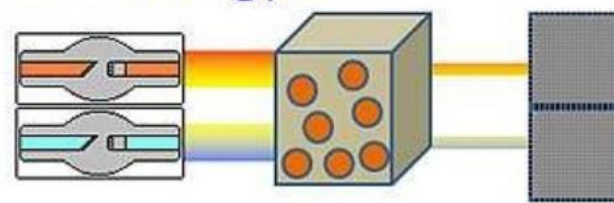
where  $\mu \sim C \frac{Z^4}{E^3}$  - mass attenuation



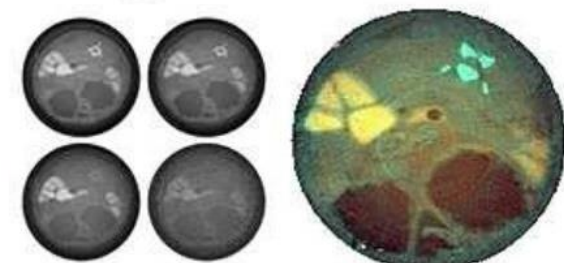
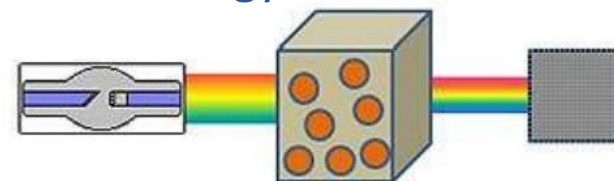
Standard CT



Dual energy CT



Multi-energy CT



Source

Subject

Detector

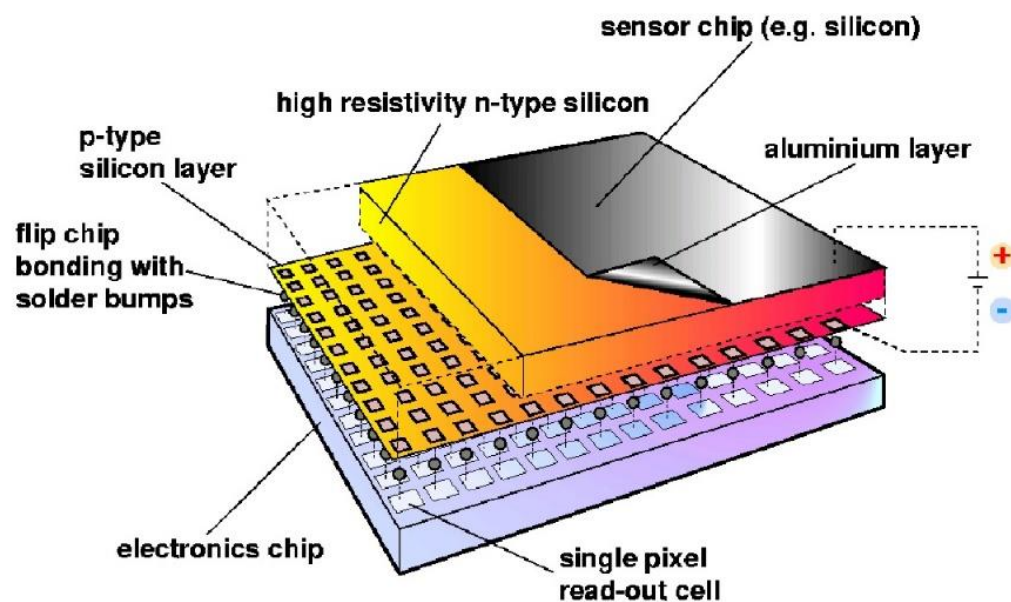
Data

Result

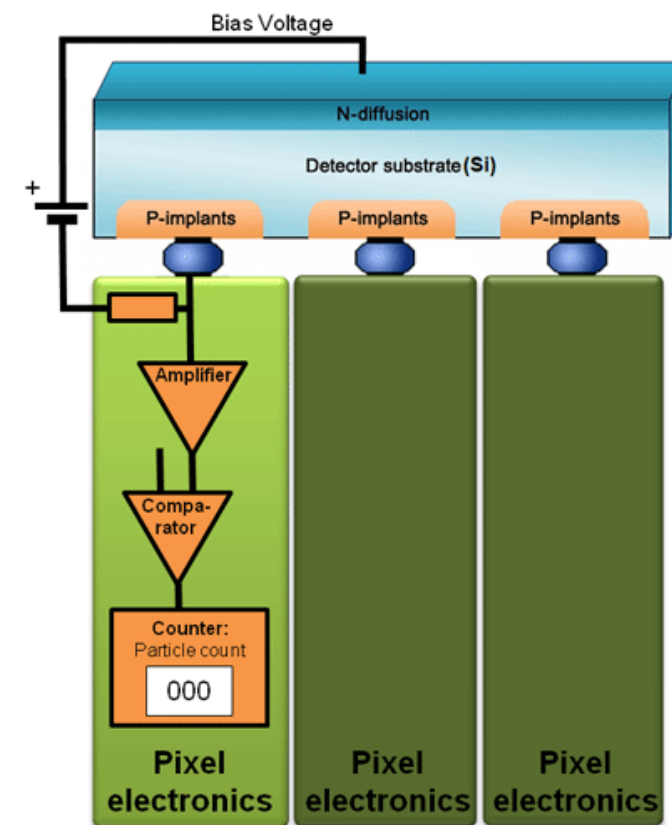
Bateman, Christopher & Rajendran, Kishore & Ruiter, Niels & Butler, Anthony & Butler, Philip & Renaud, Peter. (2015). The Hidden K-edge Signal in K-edge Imaging.

Anderson, Nigel G. et al. "Spectroscopic (multi-energy) CT distinguishes iodine and barium contrast material in MICE." *European Radiology* 20 (2010): 2126-2134.

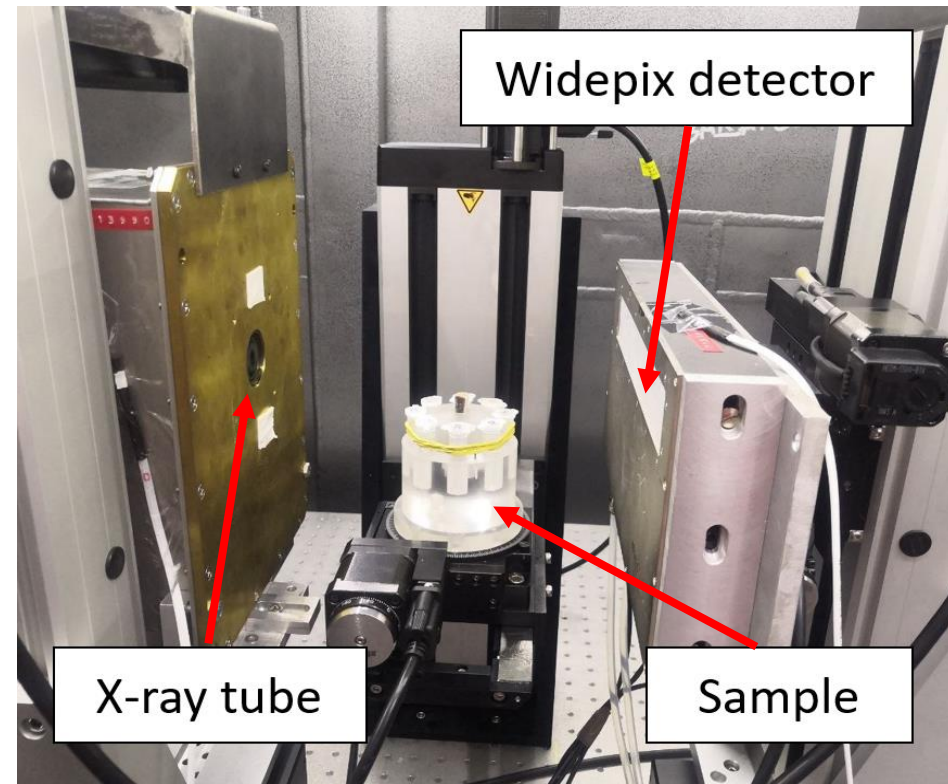
# Medipix detectors



- Medipix series detectors are hybrid semiconductor pixel detector;
- Developed by Medipix collaboration (<https://medipix.web.cern.ch/>);
- Consists of a semiconductor sensor and a readout integrated circuit;
- Photons are detected by their transferring energy to electrons. The appeared free electrons move to the pixel contact pads, causing a signal.
- The signal is digitized and compared with the threshold in a pixel. Pixels operate independent.



# Experimental Microtomograph “Kalan”



Widepix detector:

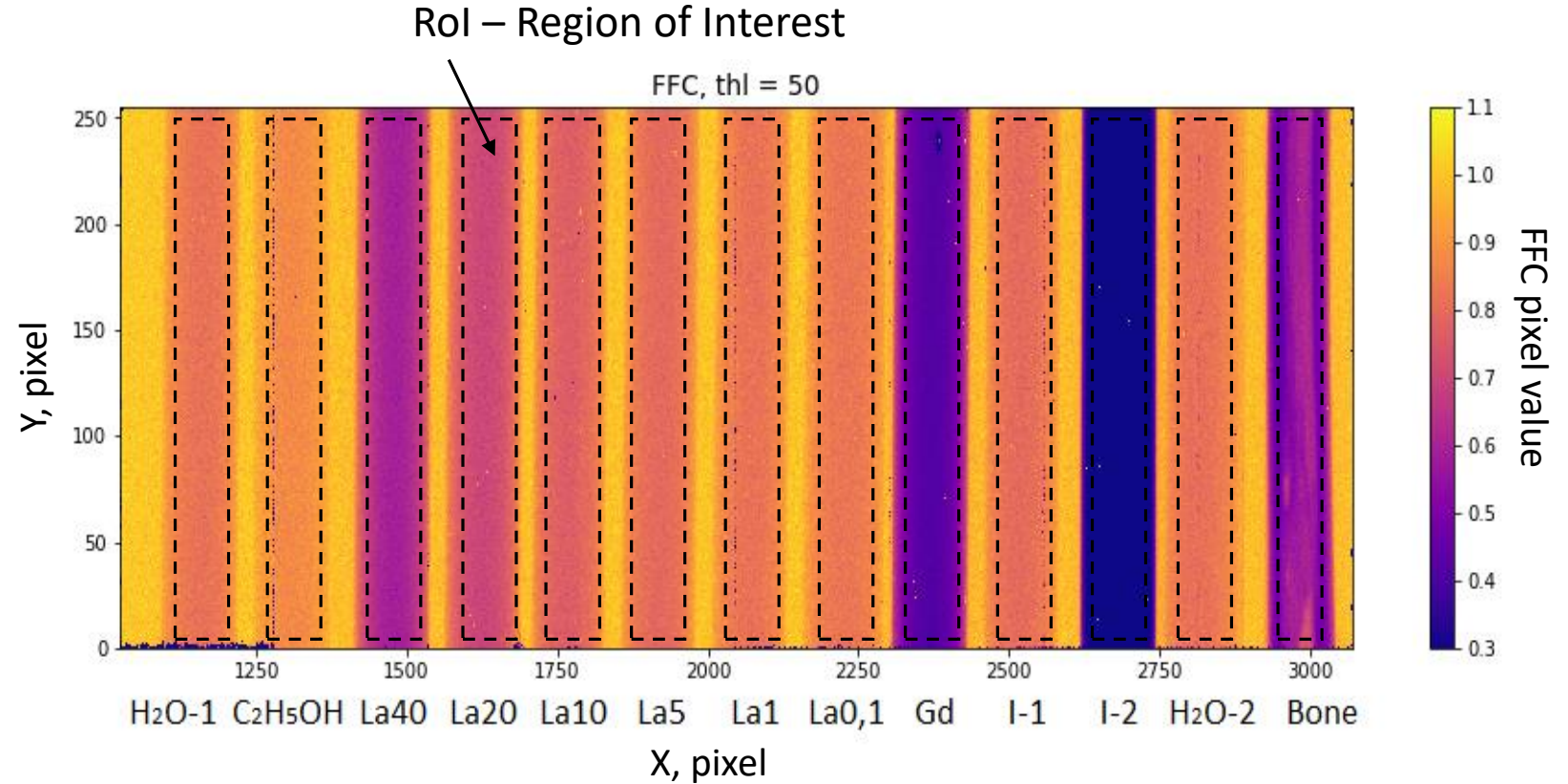
- 15 Medipix3RX in one row
- 256x3840 pixels
- Size of pixel - 55x55 mkm
- Si sensor

Goals:

- Separate materials that differ in composition. In particular, select a contrast agent that has an absorption edge in the working energy range;
- Determine the concentration of the contrast agent.

In this case, it is necessary to use as little energy as possible to reduce the scanning time.

# 2D Cocktail phantom



Frame is an image from the detector and is a 2D histogram.

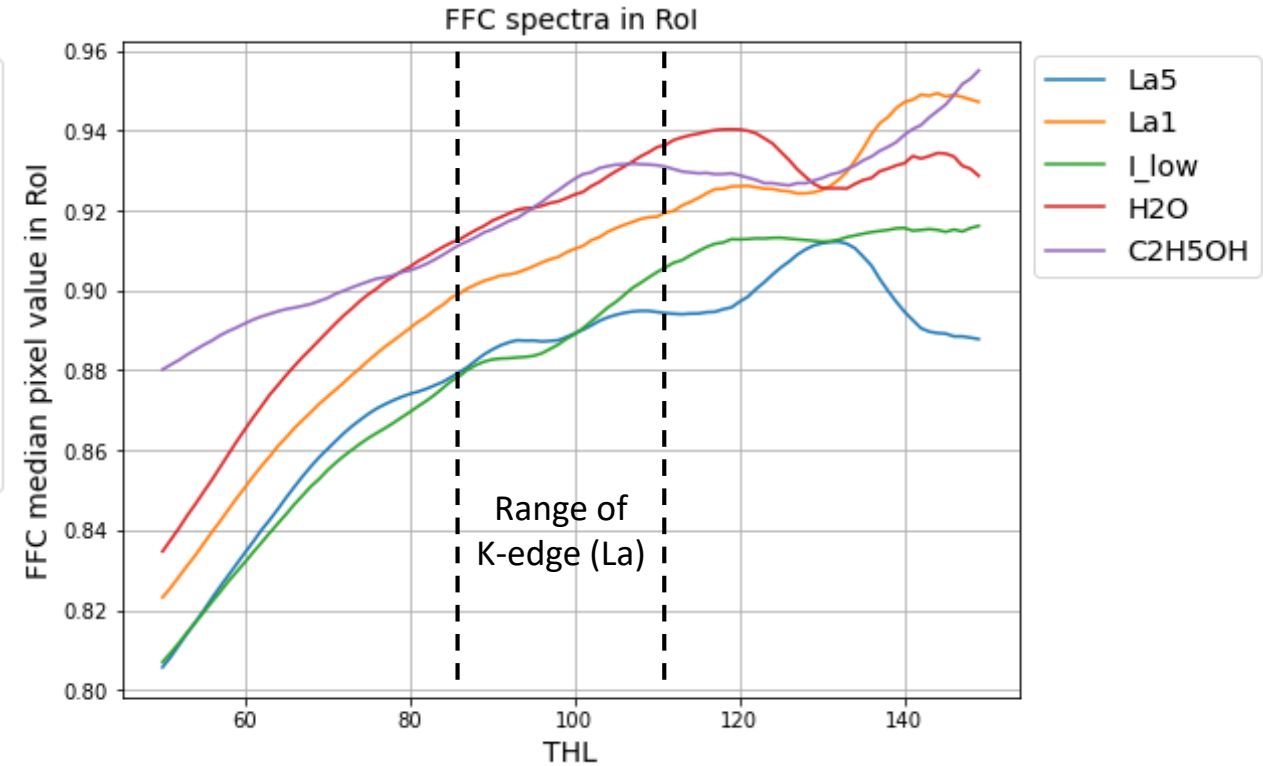
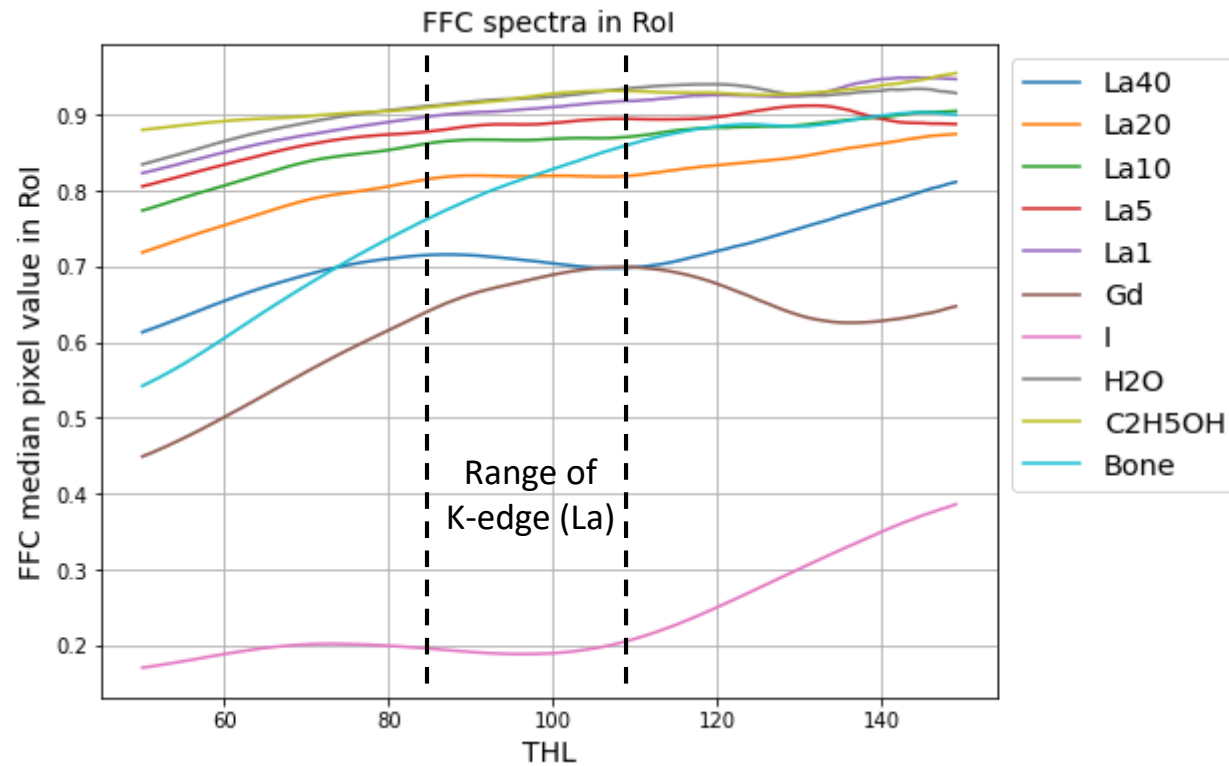
Flat Field Correction:

$$\text{FFC} = F(\text{object}) / F(\text{flat field})$$

$$\Rightarrow \text{FFC} = \exp(-\mu \rho x)$$

# Spectra received from the detector

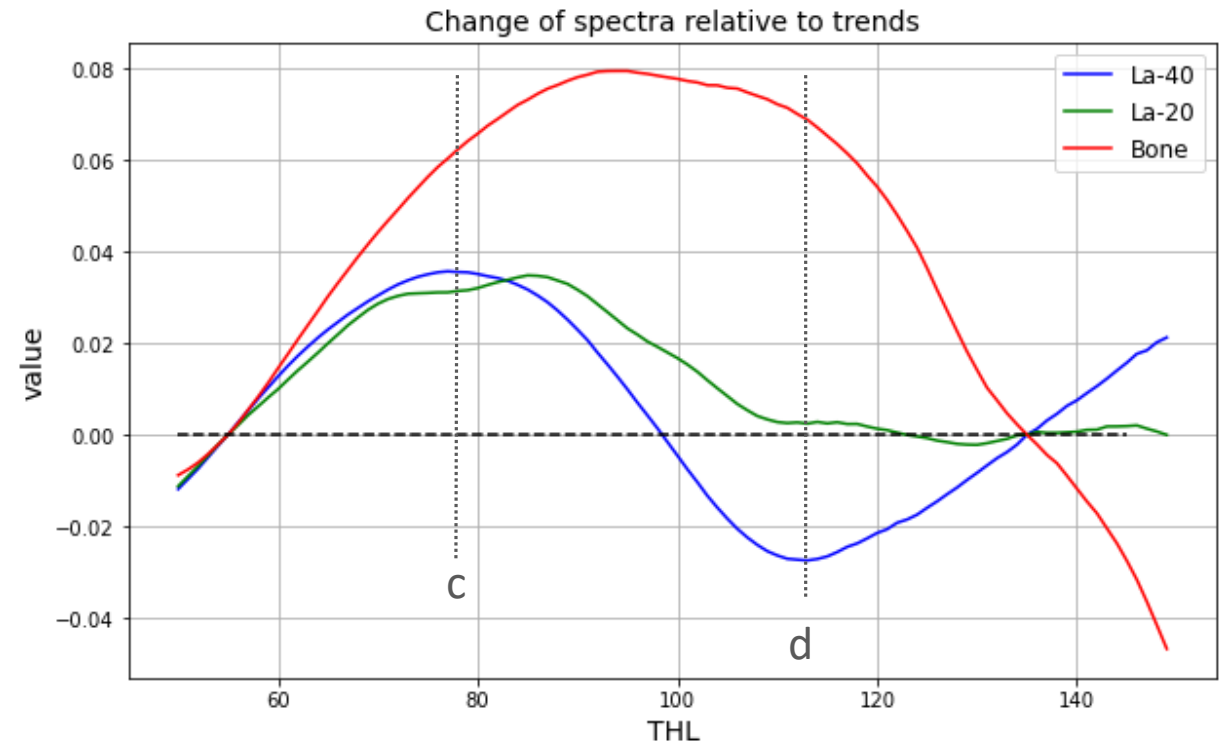
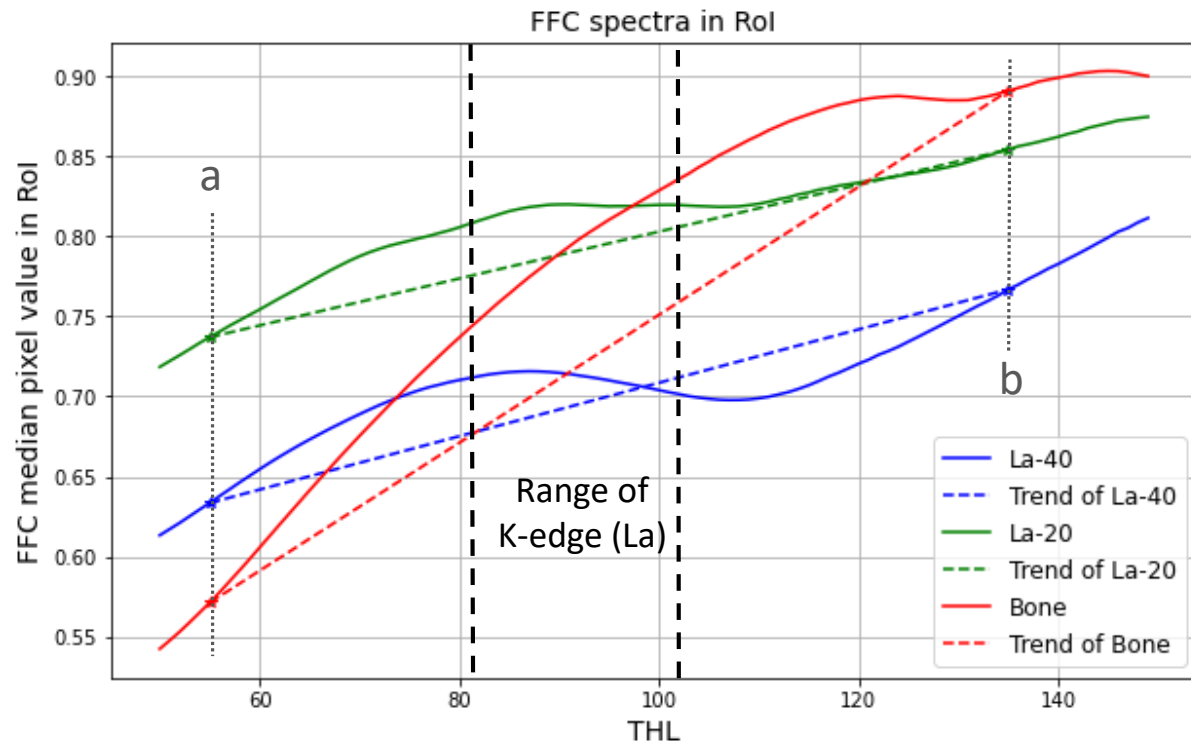
The spectrum is the average pixel values in the RoI after the FFC, depending on the threshold.



In samples with a low concentration of Lanthanum, the K-edges are almost invisible. The character of their spectra is the same as that of water, alcohol, and a weak solution of iodine. It is difficult to distinguish them.

# The criterion for the identification of contrast agents

First step: Subtraction of the linear trend of the spectrum.

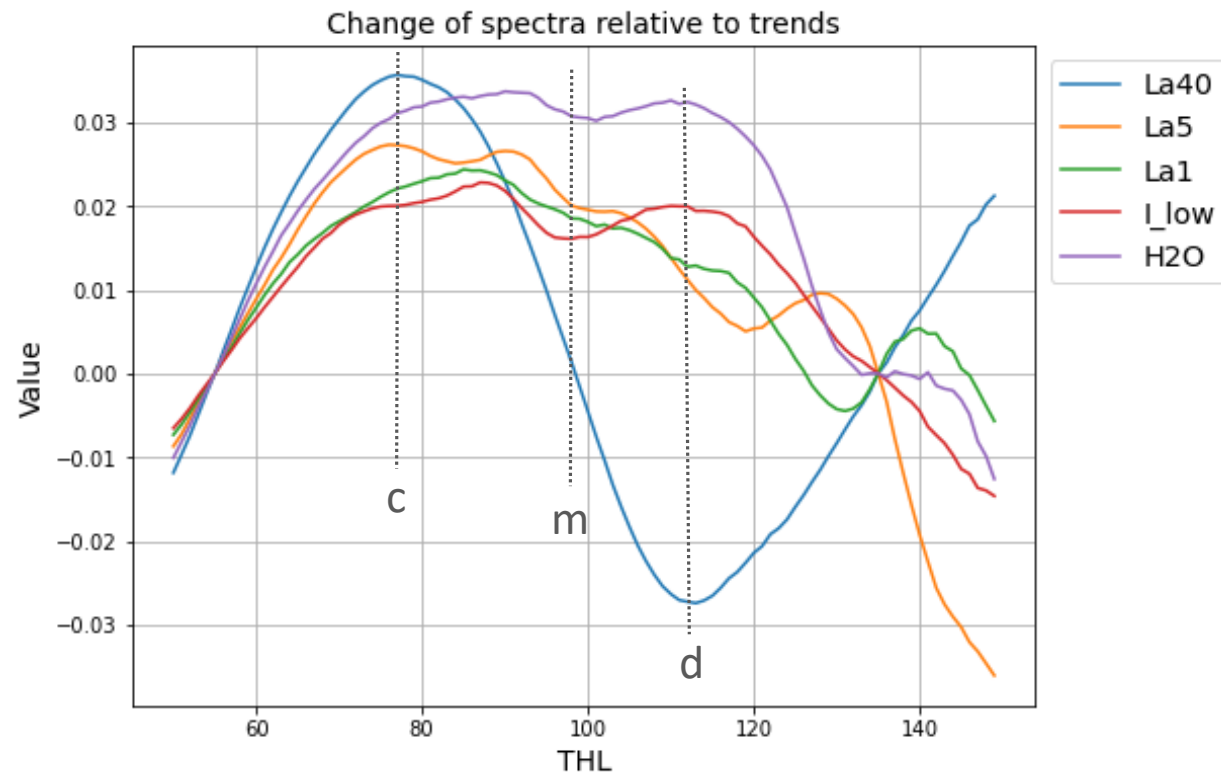
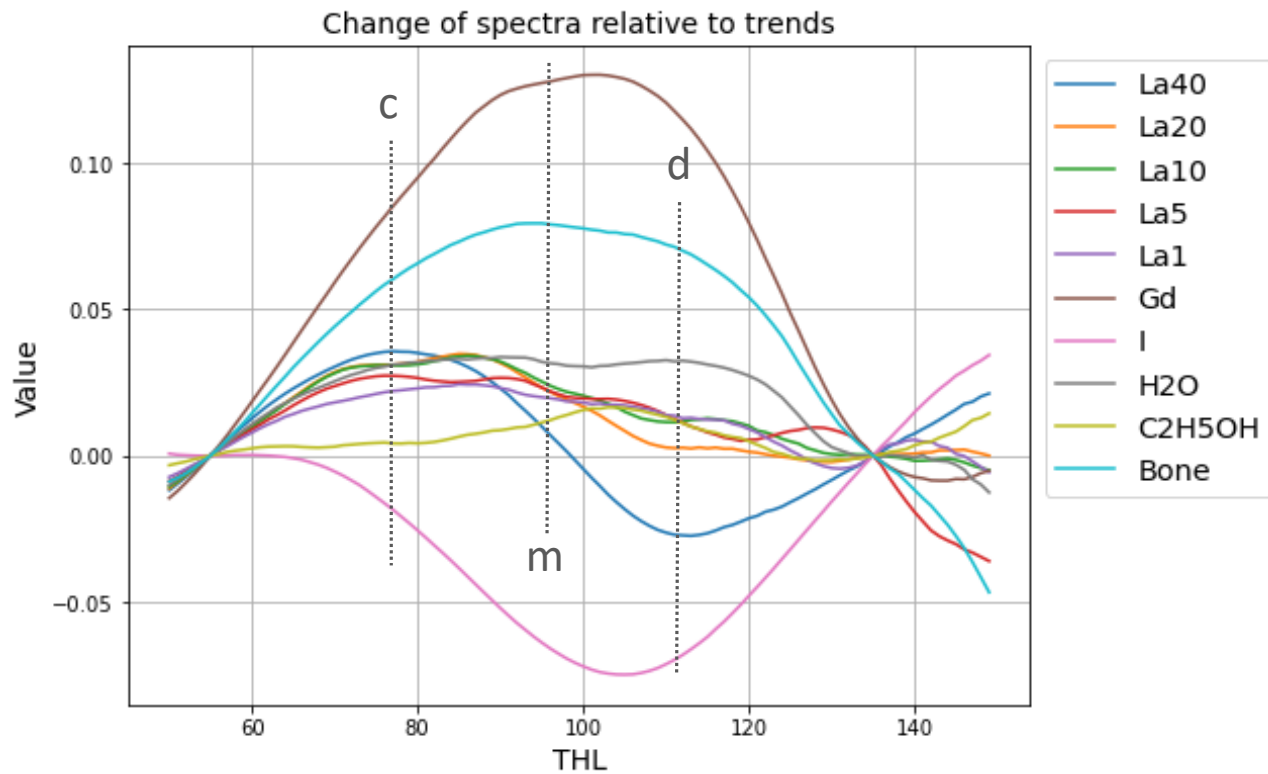


Spectrum after linear trend subtraction:

$$F_1(thl) = F_0(thl) - F_0(a) - F_0(b) \frac{thl-a}{b-a},$$

where  $F_0$  - initial spectrum

# The criterion for the identification of contrast agents



The first conditions for the fulfillment of the criterion:

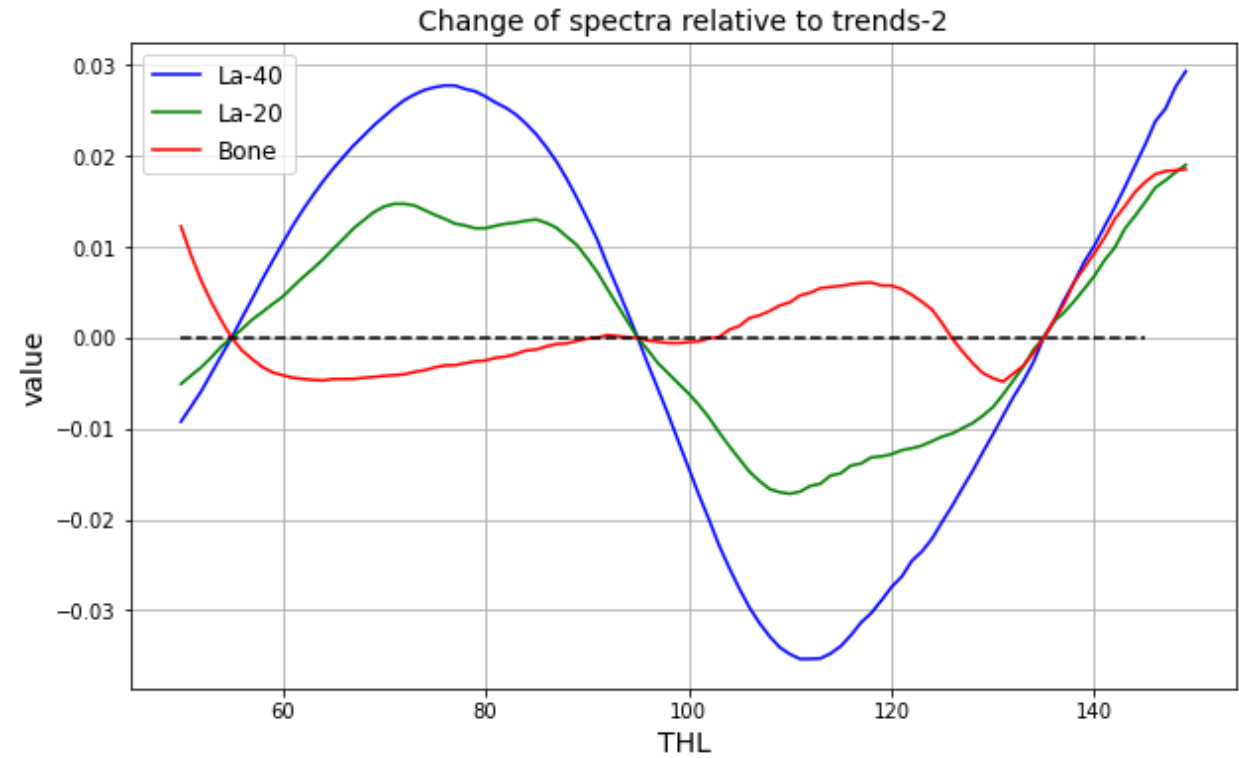
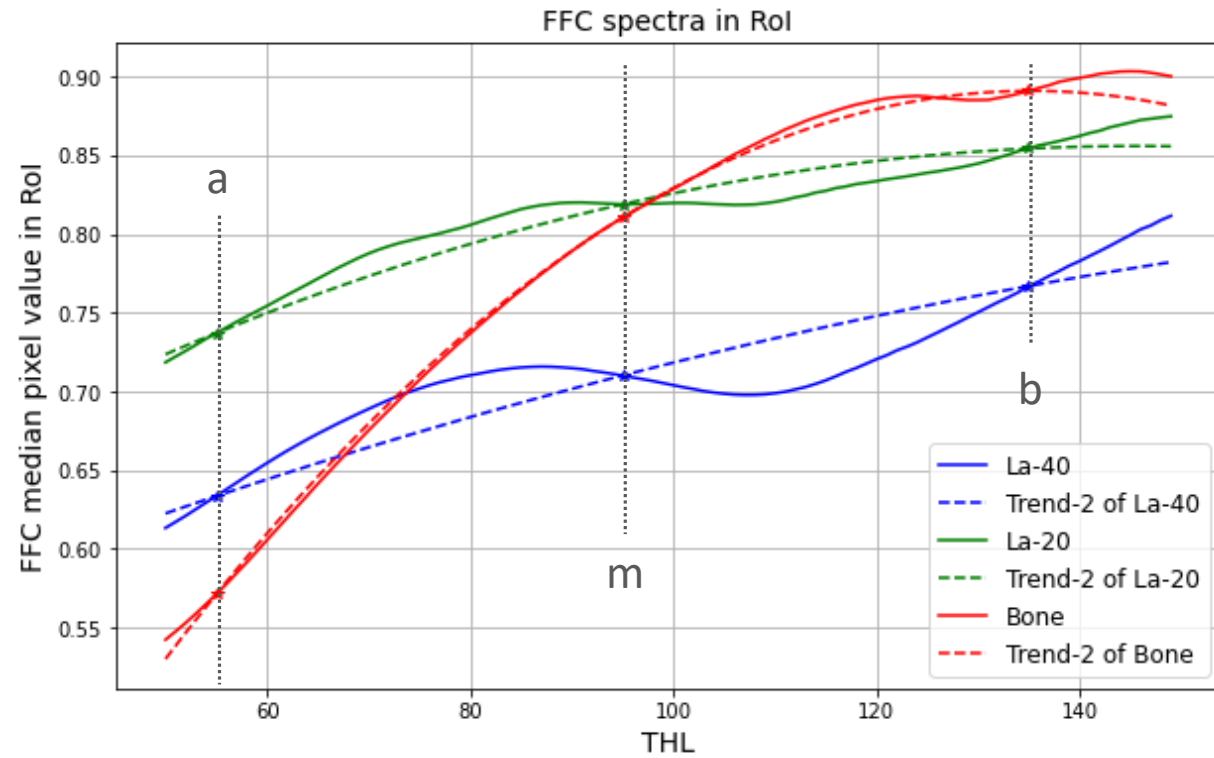
$$F_1(c) > F_1(d)$$

$$F_1(c) > 0$$

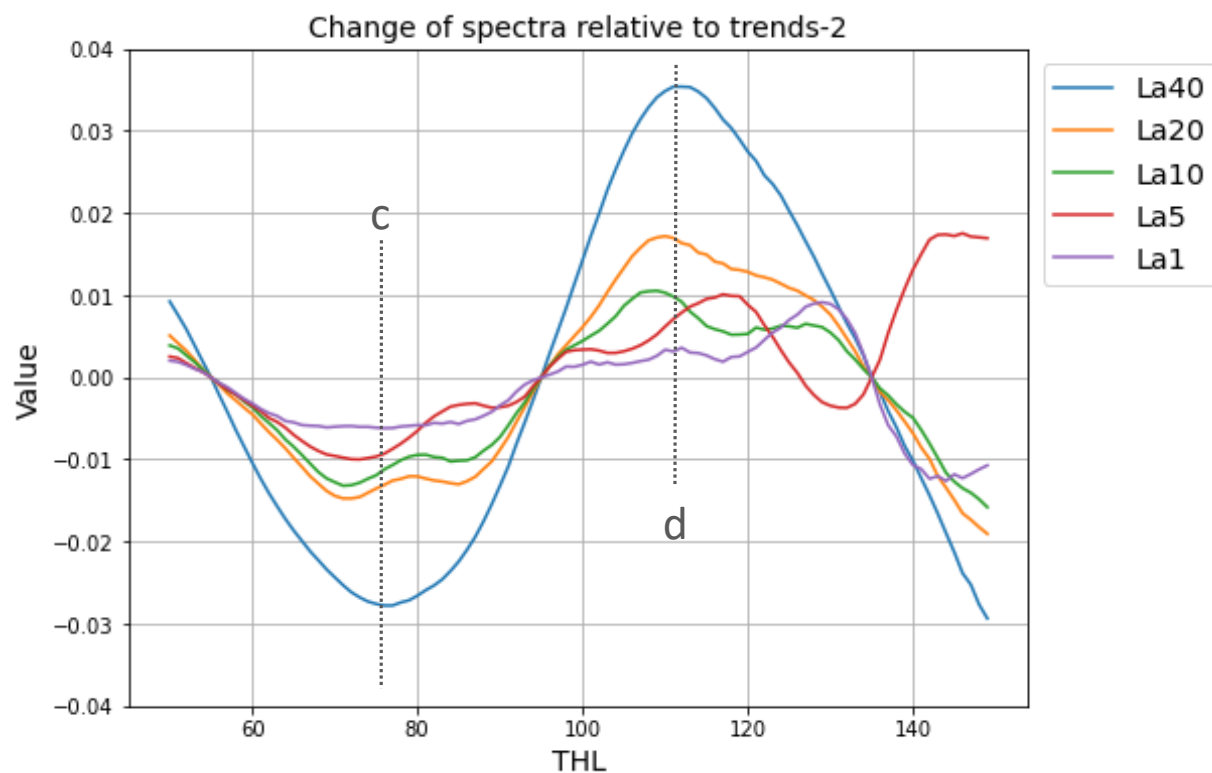


# The criterion for the identification of contrast agents

Second step: Subtraction of the Parabolic Trend of the Spectrum.



# The criterion for the identification of contrast agents



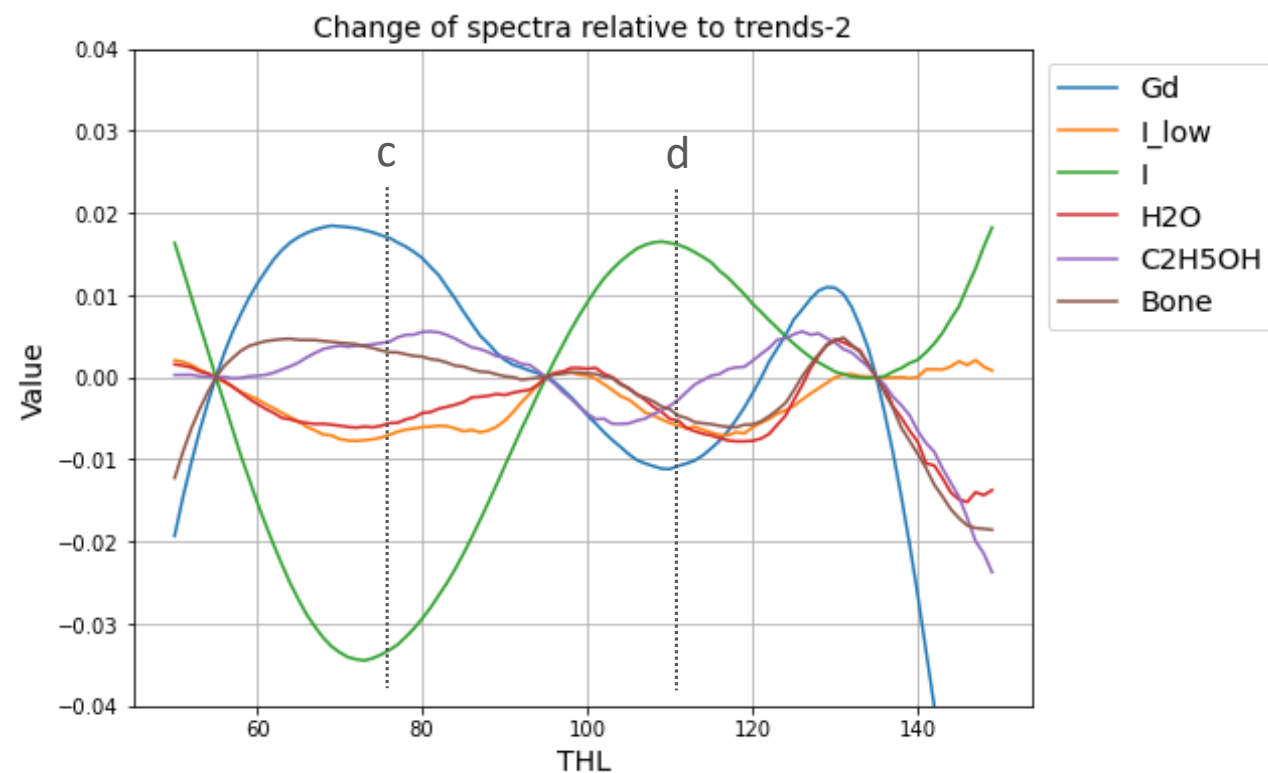
The second conditions for the fulfillment of the criterion:

$$F_2(c) < 0$$

$$F_2(d) > 0$$

Lanthanum concentration:

$$G = F_2(d) - F_2(c)$$



The sample with iodine (I) can be weeded out from the early condition (first step).

Conditions for the fulfillment of the selection criterion La:

- $F_1(c) > F_1(d)$
- $F_1(c) > 0$
- $F_2(c) < 0$
- $F_2(d) > 0$

Formula for estimating the concentration of lanthanum :

$$G = [F_2(d) - F_2(c)] \times 1000, \text{ or}$$

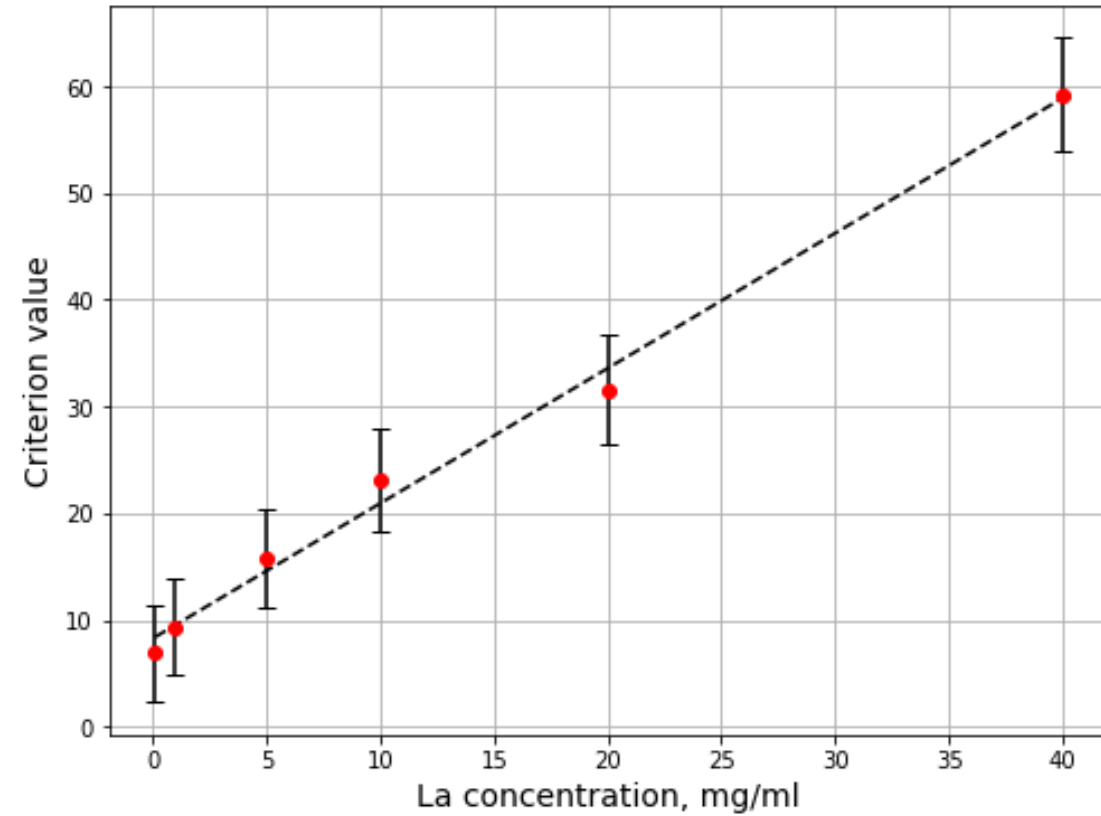
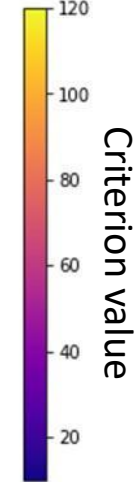
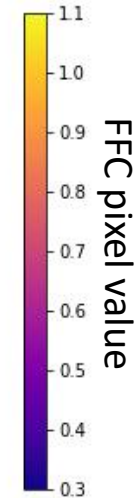
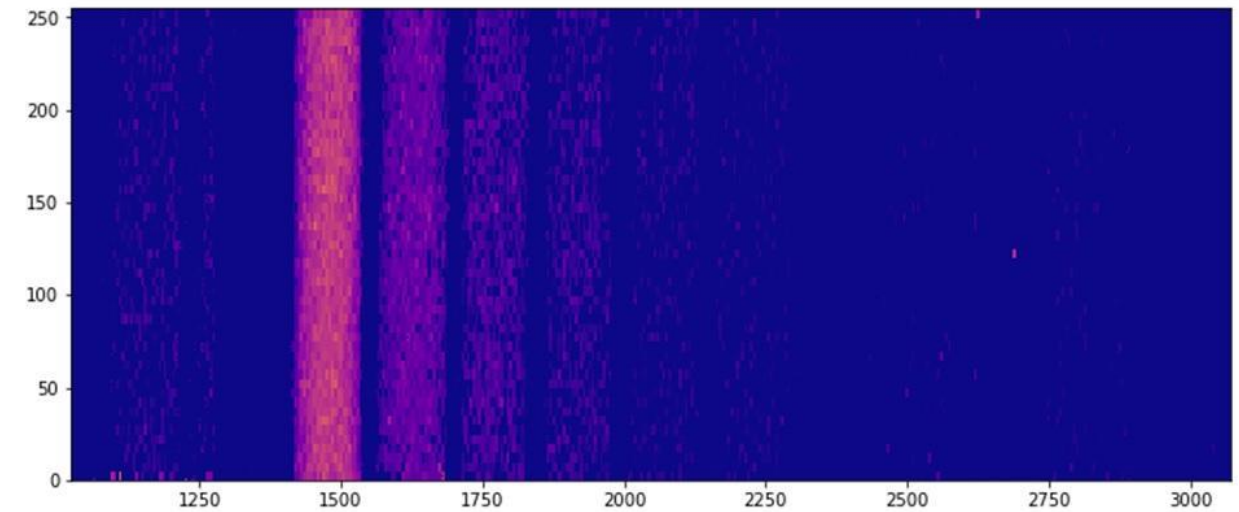
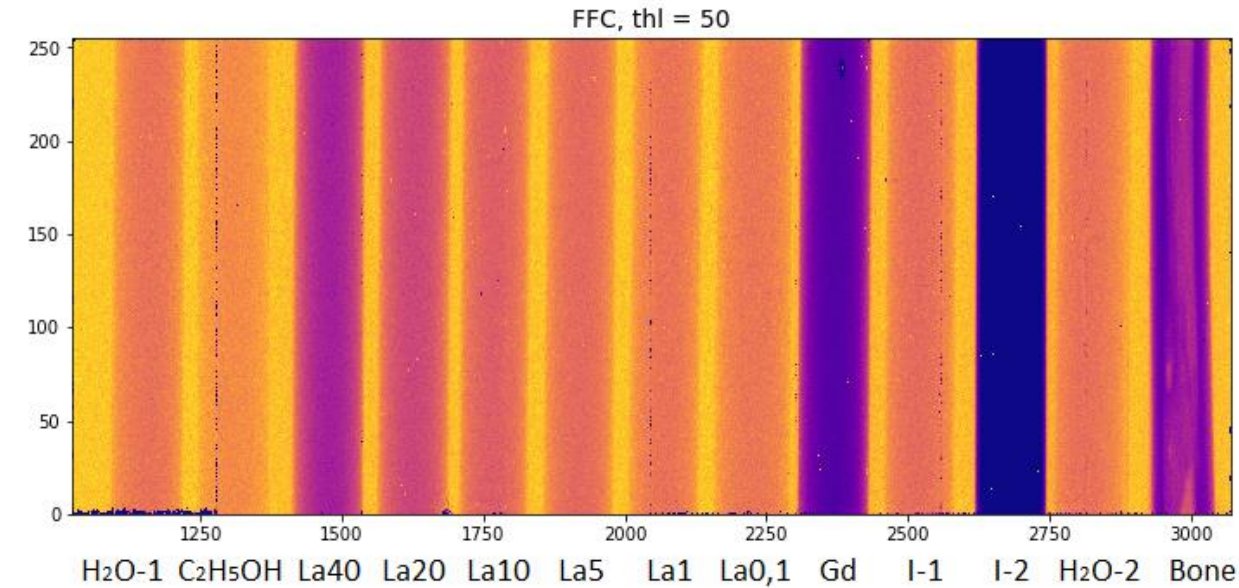
$$G = [k_1 \text{ thl}^2 + k_2 \text{ thl} + k_3 - F_0(\text{thl})] \times 1000, \quad (1)$$

where  $k_1, k_2, k_3$  - solution of a system of equations (2)

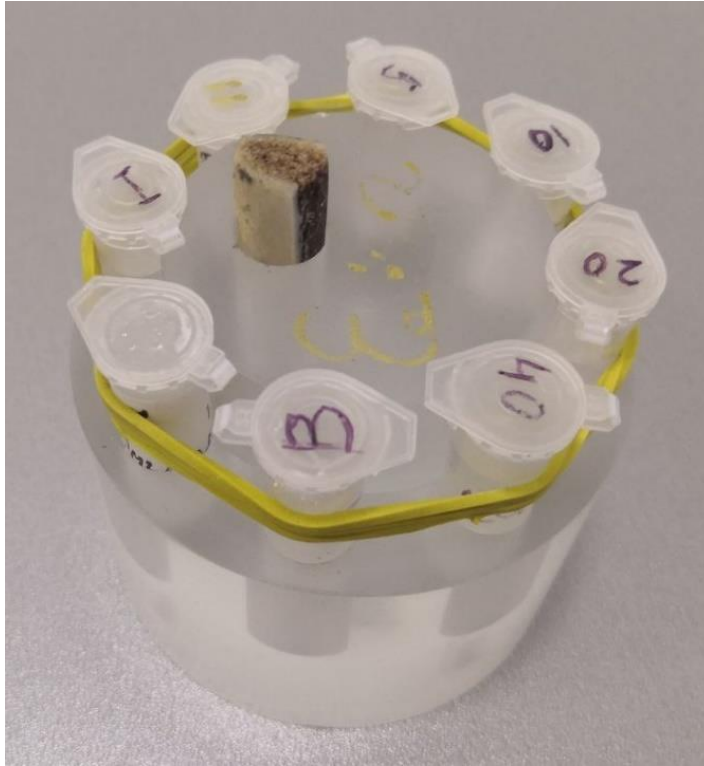
$$\left\{ \begin{array}{l} k_1 a^2 + k_2 a + k_3 = F_0(a) \\ k_1 b^2 + k_2 b + k_3 = F_0(b) \\ k_1 m^2 + k_2 m + k_3 = F_0(m) \end{array} \right. \quad (2)$$

All 5 points (a, b, c, d, m) were refined experimentally.

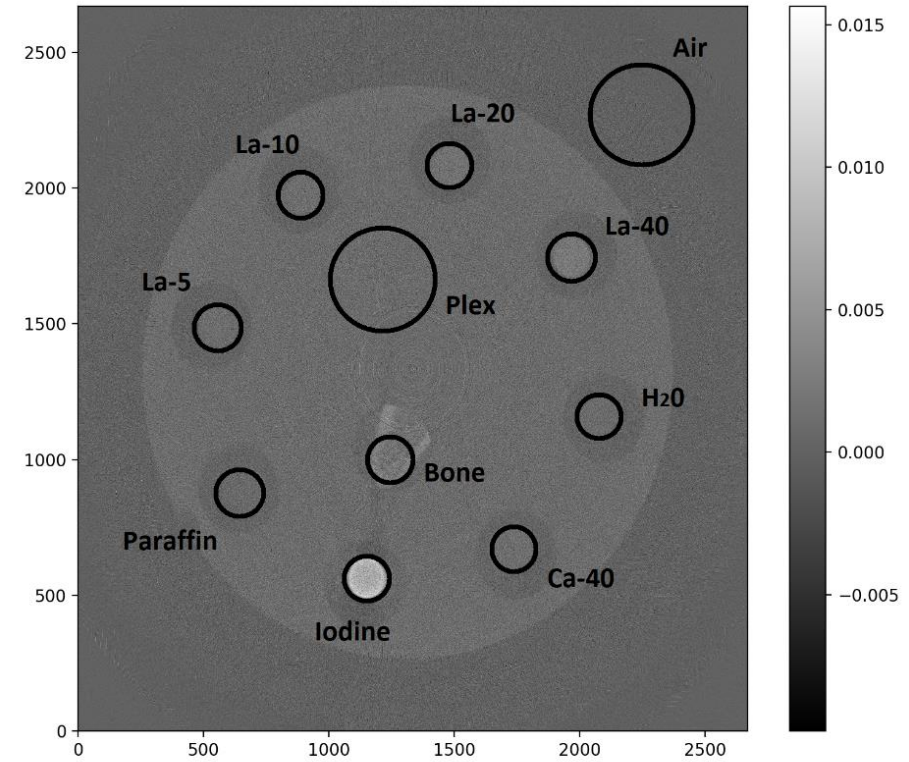
# Results of applying the criterion in 2D-CT



# Results of applying the criterion in 3D-CT

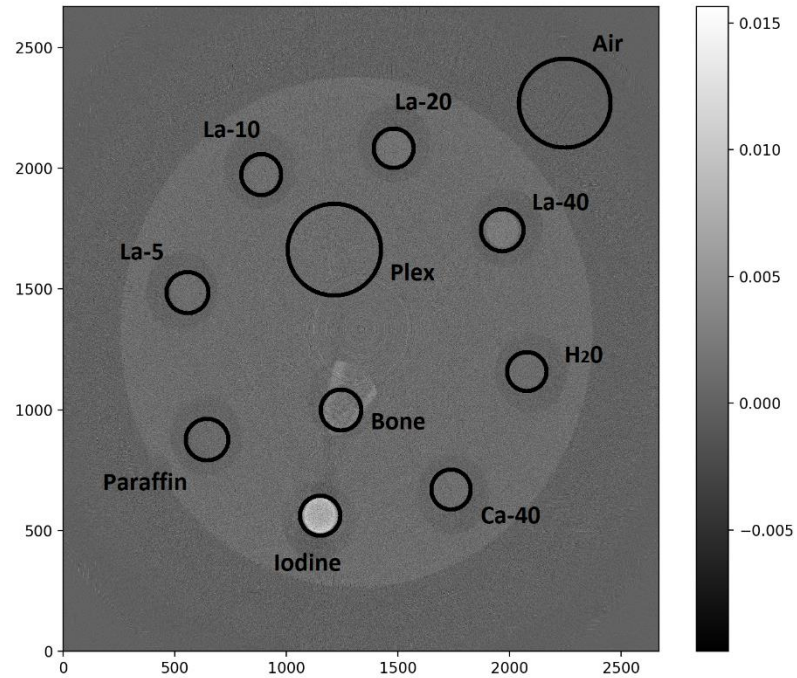


Phantom "Eva"  
Ø 70 mm

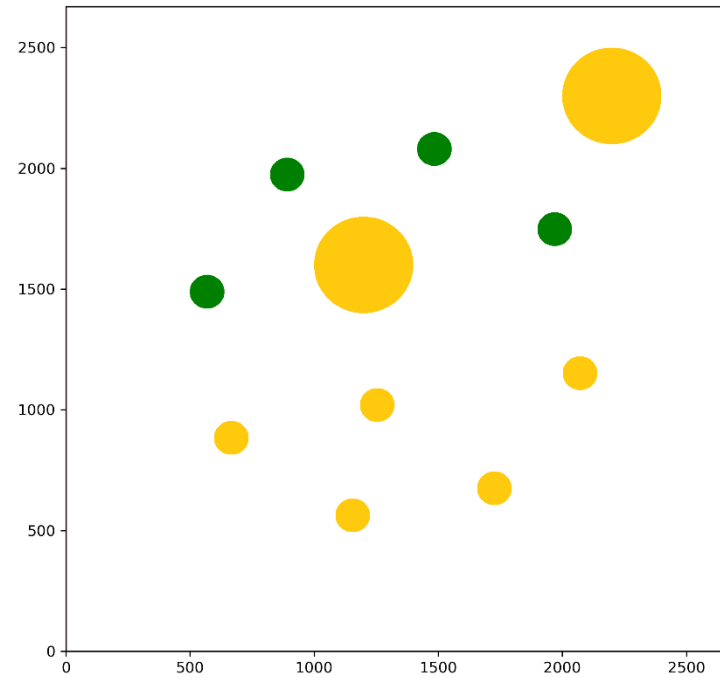


Reconstructed slice of the phantom

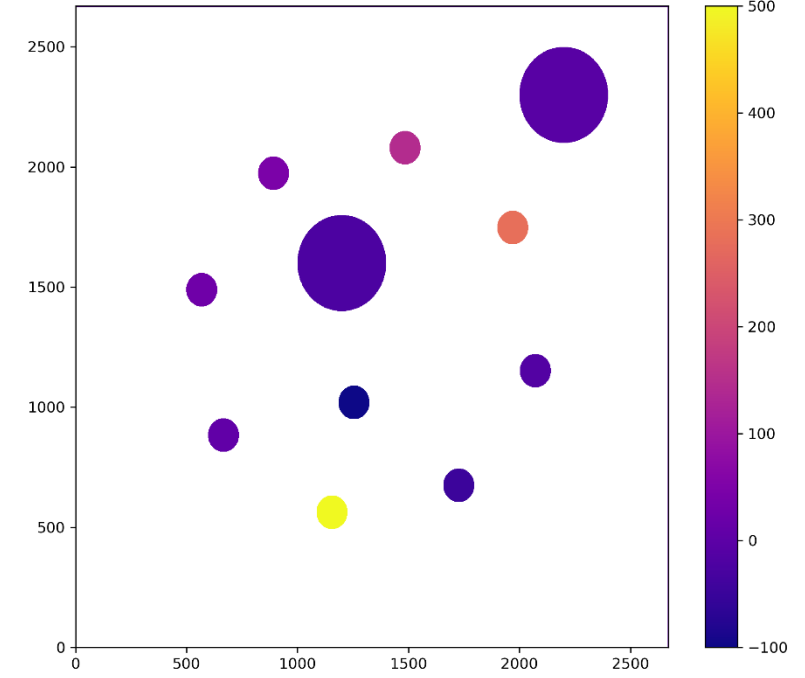
# Results of applying the criterion in 3D-CT



Slice of the phantom



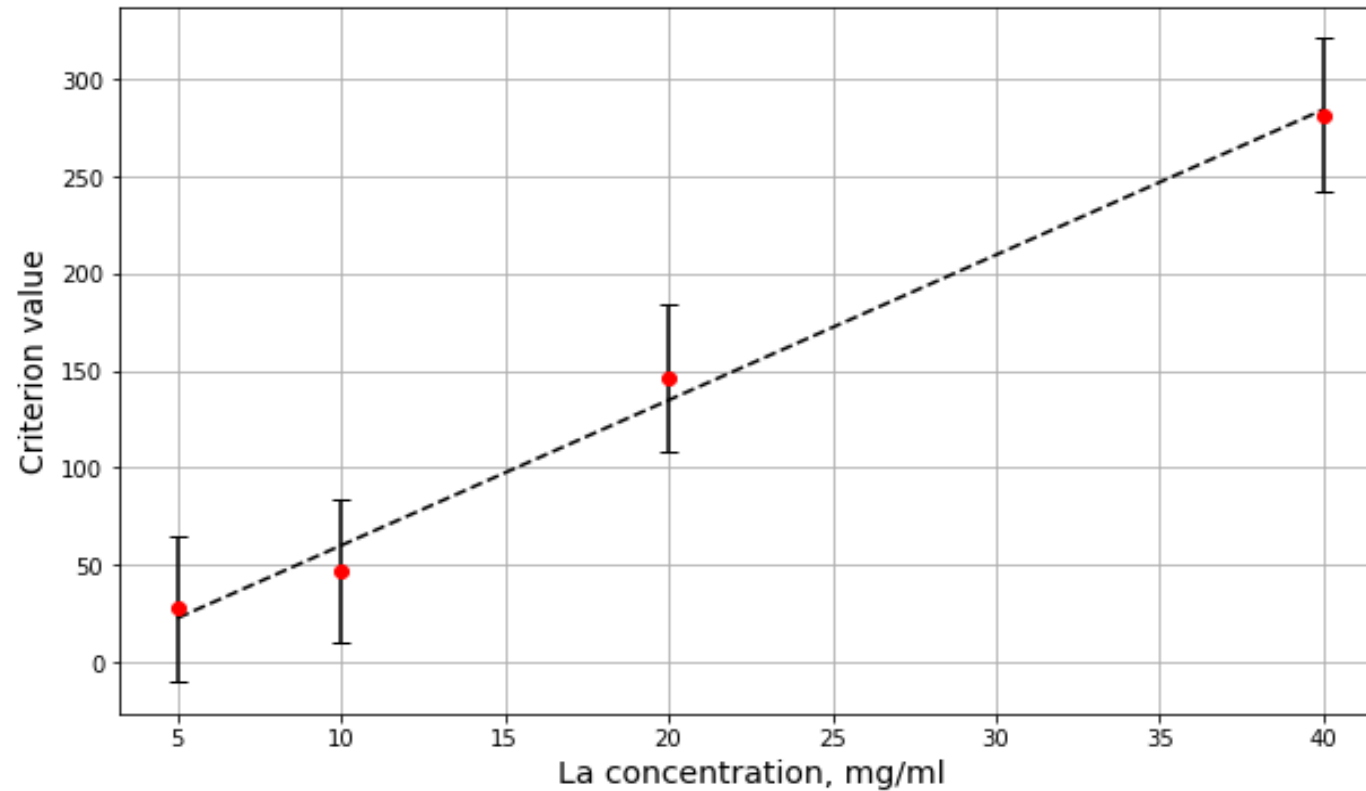
The fulfillment of the conditions for the content of lanthanum in the ROI.  
Green color - samples that meet the condition of the criterion.  
Yellow color - samples that do not meet the criterion.



The concentration of lanthanum calculated by the criterion.

# Results of applying the criterion in 3D-CT

RoI	La-40	La-20	La-10	La-5	Paraffin	Iodine	Ca-40	H2O	Bone	Plex	Air
Criterion	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Value	281.5	145.7	46.8	27.7	5.6	725.9	-48.2	-13.6	-157.8	-22.9	-7.6
Error	39.3	37.9	37.2	37.6	37.6	55.6	38.3	37.0	42.5	13.9	11.9



- The proposed method makes it possible to separate the contrast agent from other materials;
- The developed criterion can be used to assess the concentration of the contrast agent;
- There is a dependence between the actual concentration and the concentration calculated by the criterion;
- The criterion was developed for lanthanum contrast agents, but it can be used for other contrast agents;
- This criterion can be used in 2D-CT and 3D-CT;
- 5 energies are required to apply the criterion;
- By adding a few more scan energies, it is possible to separate several contrast agents at the same time

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Thank you!