Применение метода меченых нейтронов для определения элементного состава тела in vivo

М.Г.Сапожников

ЛФВЭ, ОИЯИ

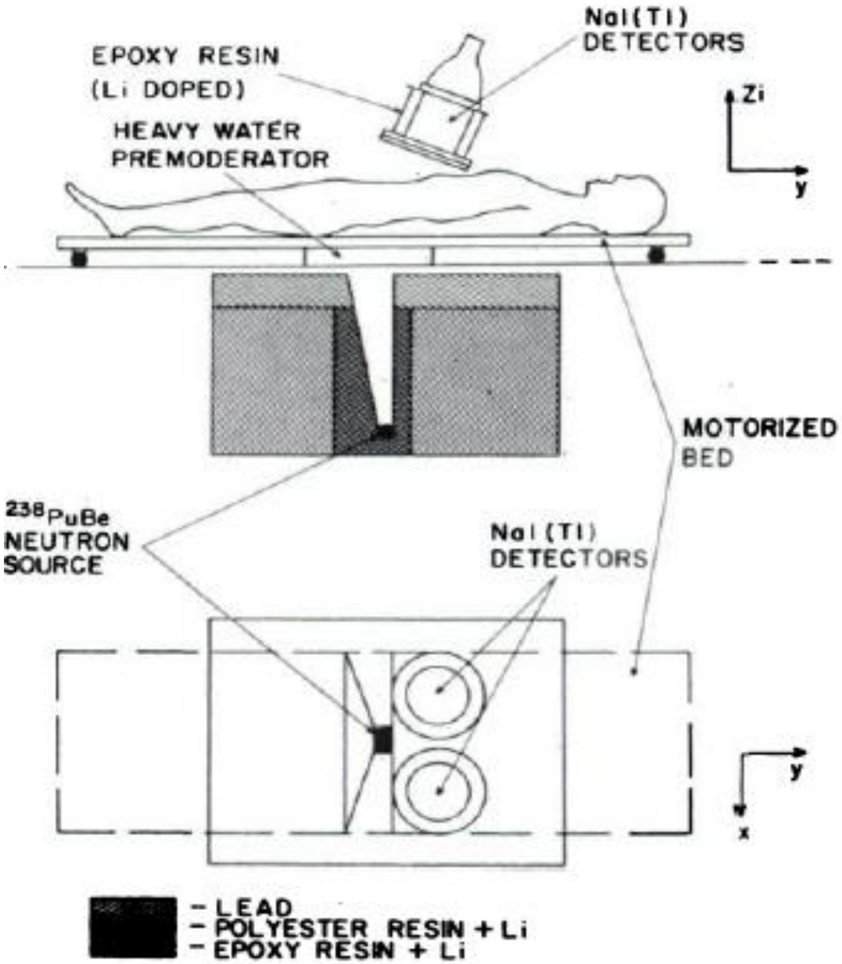
Determination of N in-vivo

- In Vivo Measurement of Body Nitrogen by Analysis of Prompt Gammas from Neutron Capture
- David Vartsky, Kenneth J. Ellis, and Stanton H. Cohn
- Brookhaven National Laboratory, Upton, New York

- A method for the in vivo determination of body nitrogen by prompt gamma photons from neutron capture is described. An 85-Ci ^{238}Pu-Be source provides the neutrons. The gamma detection system consists of two 15.24 x 15.24 cm Nal(TI) detectors placed above the patient. Absolute value of body nitrogen is determined using body hydrogen as an internal standard. The reproducibility of the method is ±3%.

J Nucl. Med. v20: 1158-1165,1979

Determination of N in-vivo-2



. 1. Irradiation-detection facility.

- Neutron energy E_{av} = 4.5 MeV
- Intensity – I= $2.3x10^8$ c^{-1}
- Distance to the source – 50 cm
- Measurements in 8 points of body
- 14 healthy men
- Irradiation time – 20 min
- Total dose – 260 μSv
- Total body N concentration

TBN= 3±0,5%

Experimental situation

J.Sutcliffe, A review of in vivo experimental methods to determine the composition of the human body, Phys.Med.Biol 41 (1996) 791

- BNL, USA
- University of Birmingham, England
- Reactor Centre, East Kilbride, Scotland
- University of Leeds, England
- Toronto General Hospital, Canada
- Auckland Hospital, Auckland, New Zealand

Measurements of 561 patients and 151 volunteers

TBN, TBC, TBO, TB (Ca, P, Mn, Mg….)

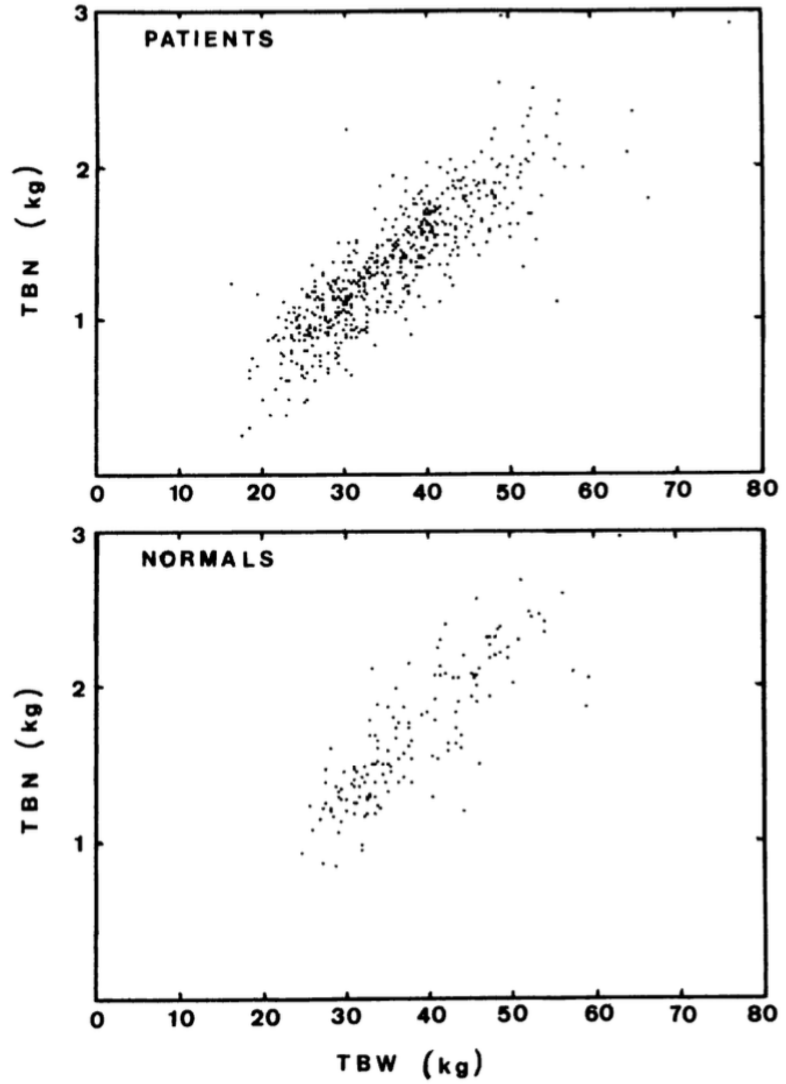


Figure 6. TBN measured by prompt-gamma IVNAA in 712 subjects (561 patients and 151 normal volunteers) plotted as a function of TBW measured by dilution of tritiated water. The data are fitted by the following equations.

patients: TBN (kg) $= -0.063(\pm 0.217) + (0.0395(\pm 0.0066))$TBW (kg) $r = 0.846$

normals: TBN (kg) $= -0.041(\pm 0.236) + (0.0449(\pm 0.0061))$TBW (kg) $r = 0.838$.

(Auckland research group 1983–88 (Mitra 1990)).

Риски при облучении

TABLE 7. *Risk associated with in vivo nitrogen measurement comparable to "every day" risks*

Activity	Type of Death
Modes of travel	
Air (150 mi.)	Accident
Air (Trans-Atlantic flight)	Cancer (cosmic rays)
Car (15 mi.)	Accident
Living conditions/location	
5,000 ft. above sea level (3 mo)	Cancer (cosmic rays)
Living in stone building (2 wk)	Cancer (radon)
Employment conditions	
Working in average United States factory (3 days)	Accident
Working in a United States coal mine (30 min)	Accident
Smoking (1 cigarette)	Cancer

K.J.Ellis, Human body composition: in vivo methods, Physiological Rev. 80 (2000) 650

Эффективная доза при облучении

Процедура	Эффективная доза облучения, мкЗв
Рентгенография грудной клетки	100
Флюорография грудной клетки	300
Компьютерная томография органов брюшной полости и таза	10 000
Компьютерная томография всего тела	10 000

Нейтроны

- Pu/Be – 300 мкЗв
- Меченые нейтроны – 30 мкЗв

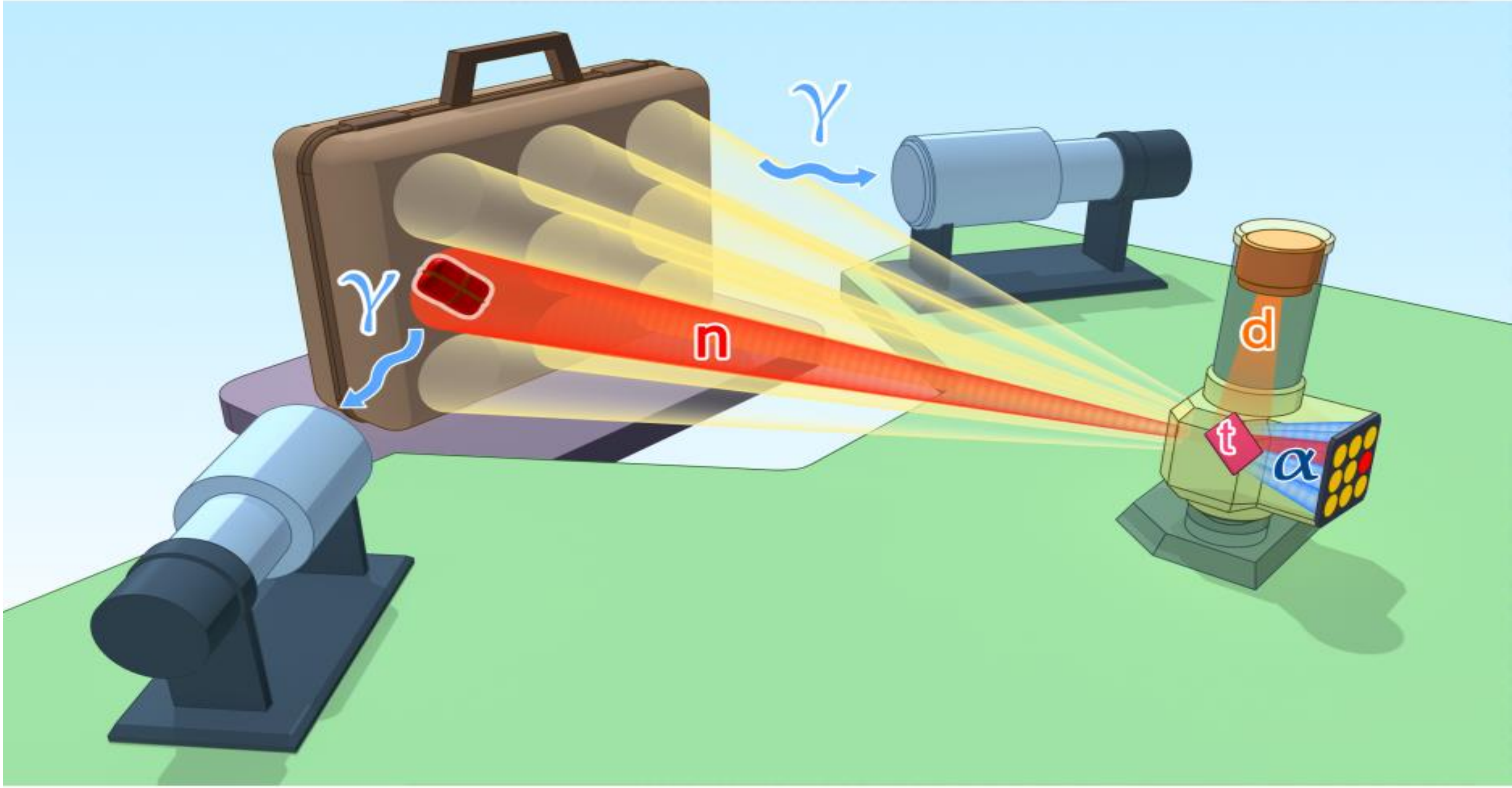
Proposal from N.V.Sklifosovsky Research Institute

Element	Tissue	Cancerous ppm	Normal ppm
K	Breast	952	224/168
P	Breast	578±79	223±33
Fe	Kidney	440±64	122±35
	Liver	1309	768
	Lung	75.1±9.7	199±101
	Prostate	1370	490
Ca	Lung	355±42	886±248
	Prostate	2240	1870
Cd	Kidney	15.6±0.9	181±44

The concentration of iron having large differences between normal and diseased tissues, ranging as large as 40% to more than 360%, which makes it a practical element of signature in medical diagnostics using APNEI

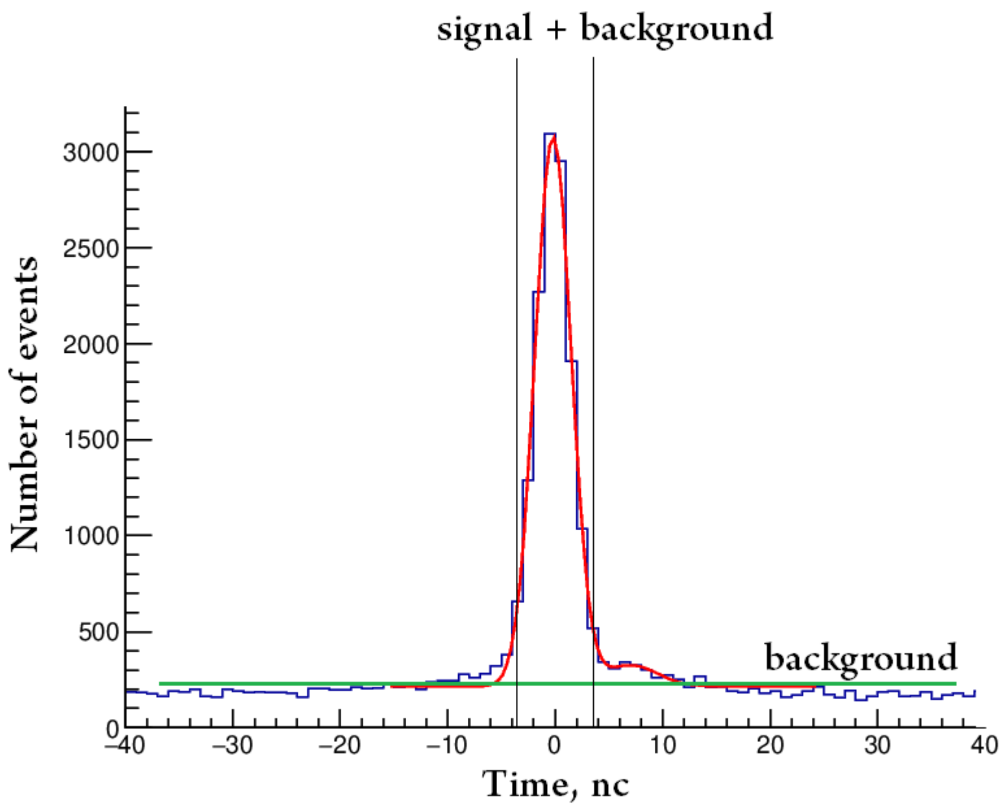
D.Koltick, L.Nie, Associated Particle Neutron Imaging for Elemental Analysis in Medical Diagnostics, IEEE Trans.Nucl. Sci. 60 (2013) 824-829.

Объект досмотра облучается пучками быстрых нейтронов



Регистрируются γ-кванты из объекта досмотра

Typical time distribution

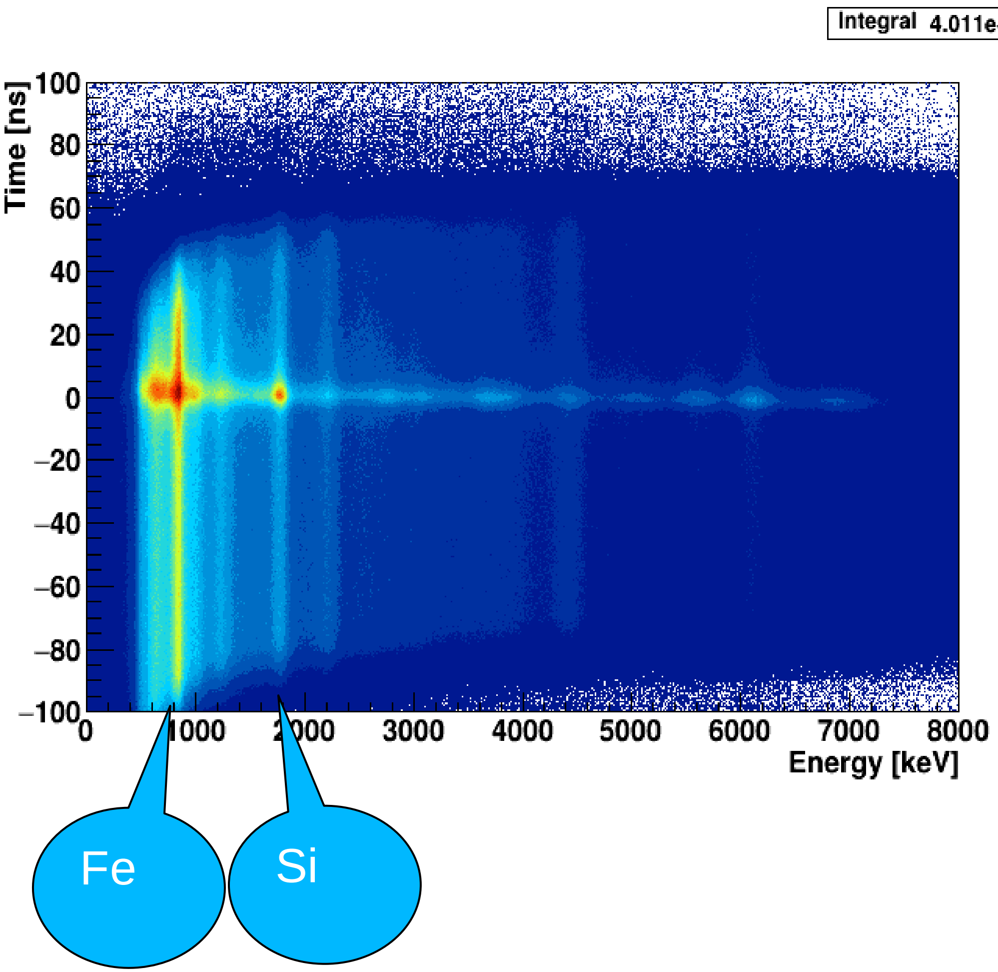


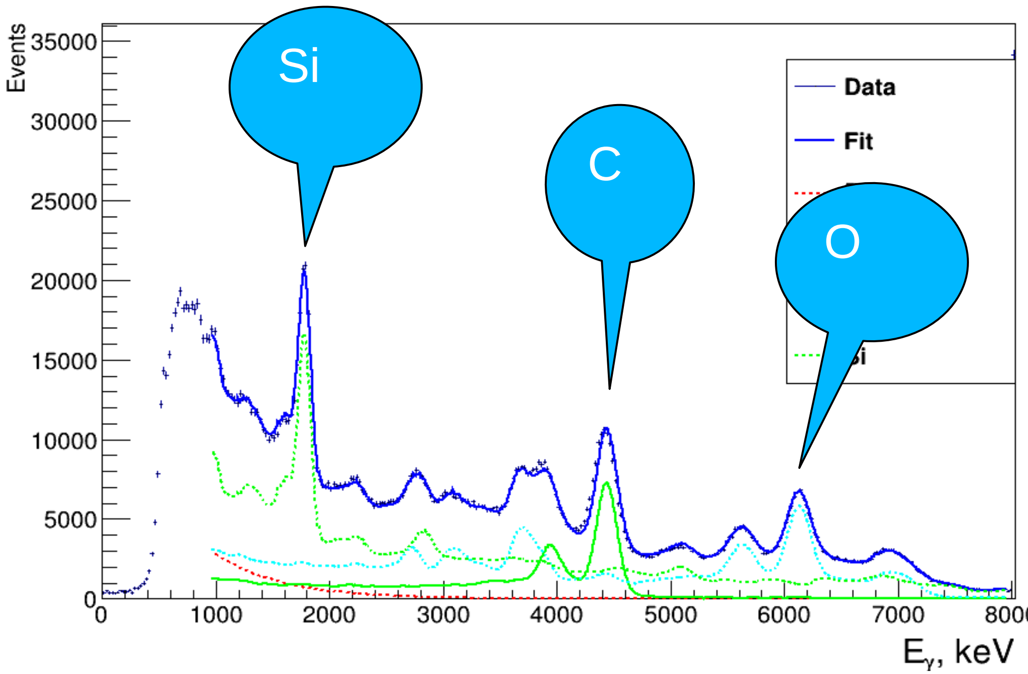
Cutting off the background of random coincidences allows you to reduce the influence of the background by 200 times.

Зачем они это делают?

Fig. 4. Mobile inelastic neutron scattering system background measurements (up to 6.7 m above the ground).

Time/Energy distribution





Нет фонового пика железа в спектре образца

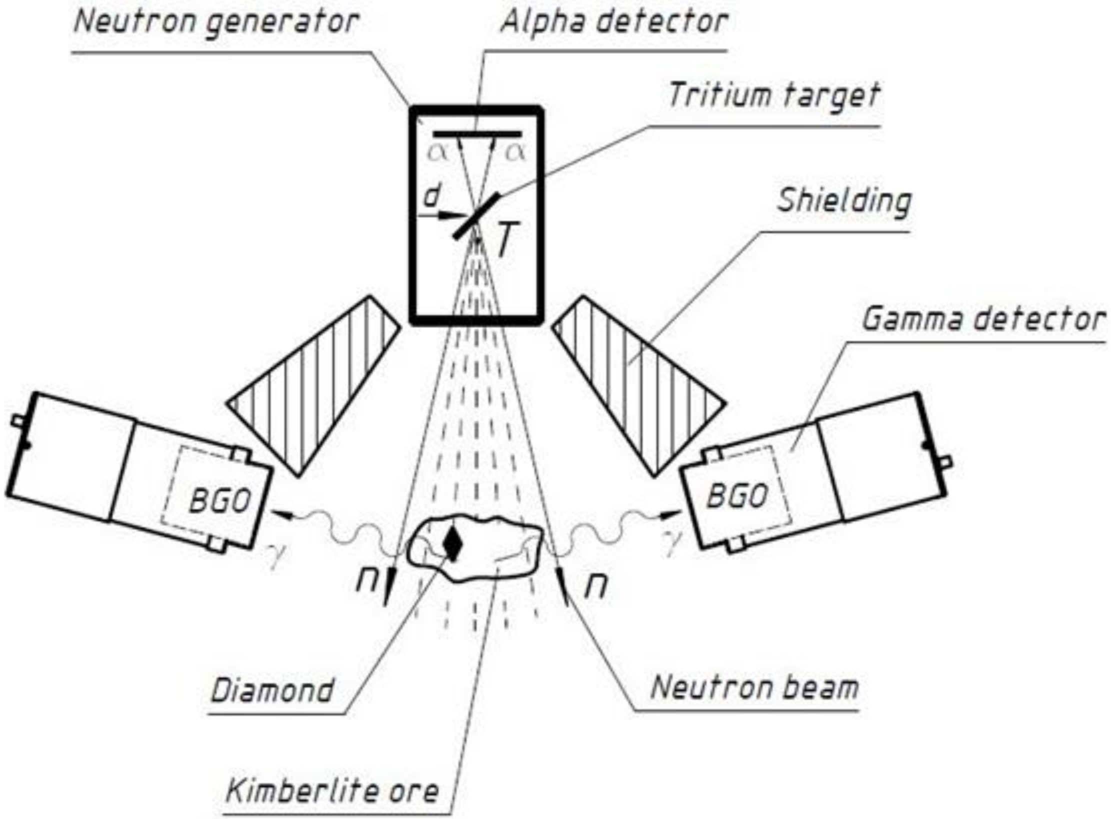
Преимущества ММН

- Большая проникающая способность – 30 см
- Отношение сигнал/шум улучшается в 200 раз
- Возможность трехмерного определения элементной концентрации
- **Нейтронная «флюорография»**

Нейтронная онкография

- ❖Объект досмотра 30х30х30 см разбивается на 256 областей (вокселей)
- ❖Определяется элементный состав каждого вокселя
- ❖Проверяется наличие избытка событий в области пиков Fe – 840 и 1240 МэВ

Tagged neutron method determines elemental concentrations in 3D

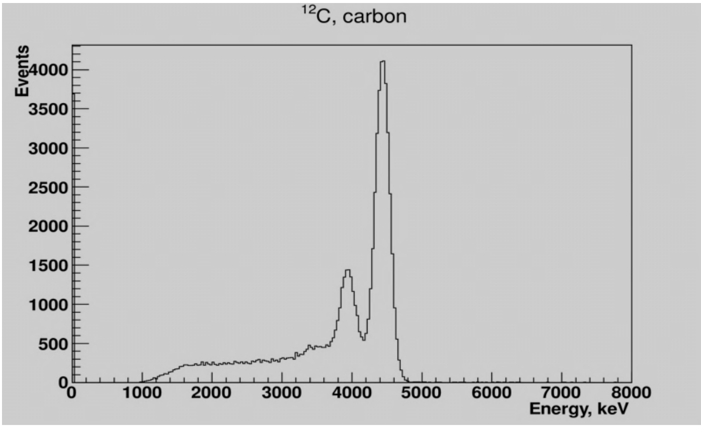


Tagged neutron method allows to find a diamond inside the kimberlite rock without its crushing.

The ore is irradiated by fast 14 MeV neutrons from reaction

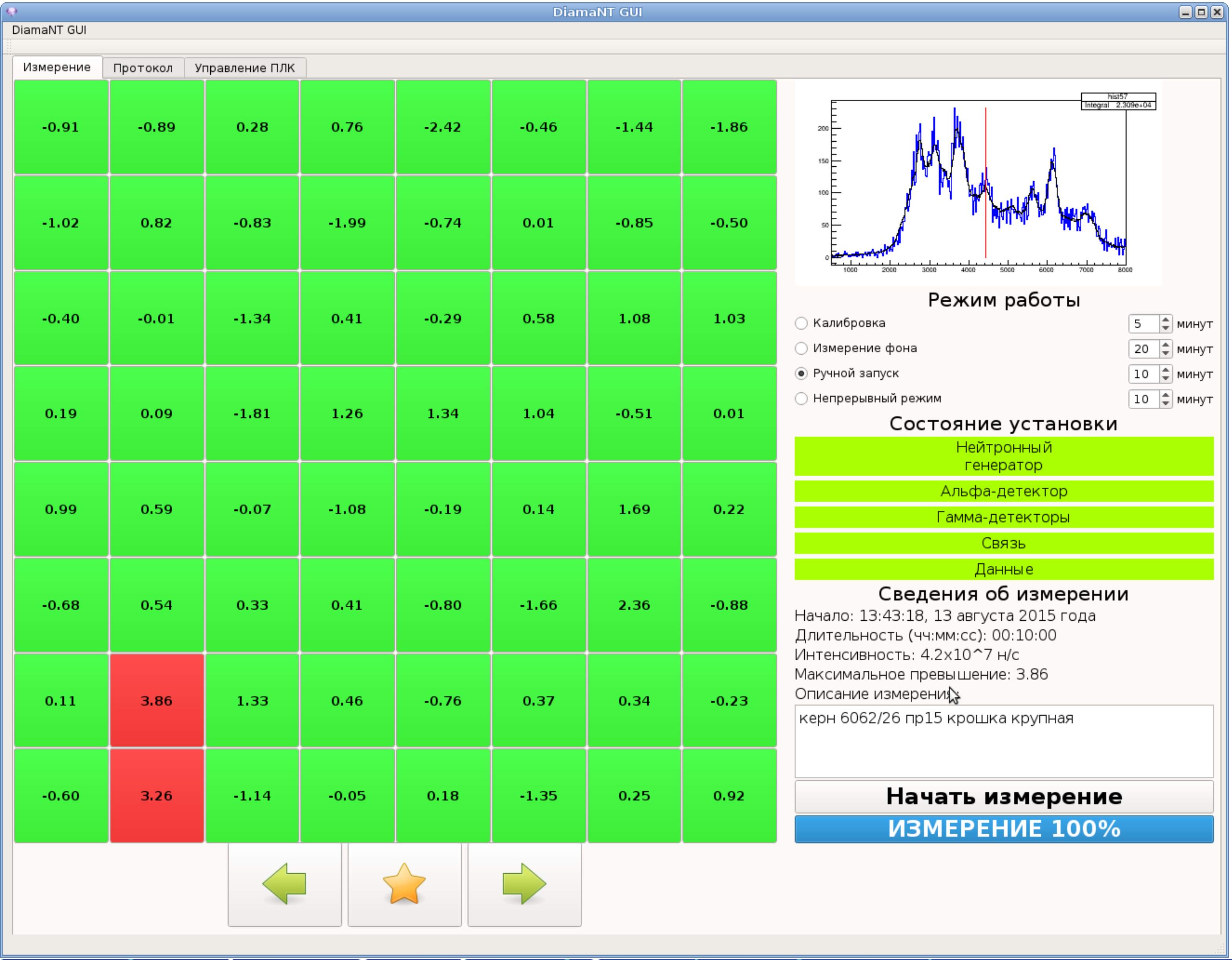
$$d + t \rightarrow \alpha + n$$

The 4.44 MeV gamma-line of carbon is used to determine carbon distribution in the ore



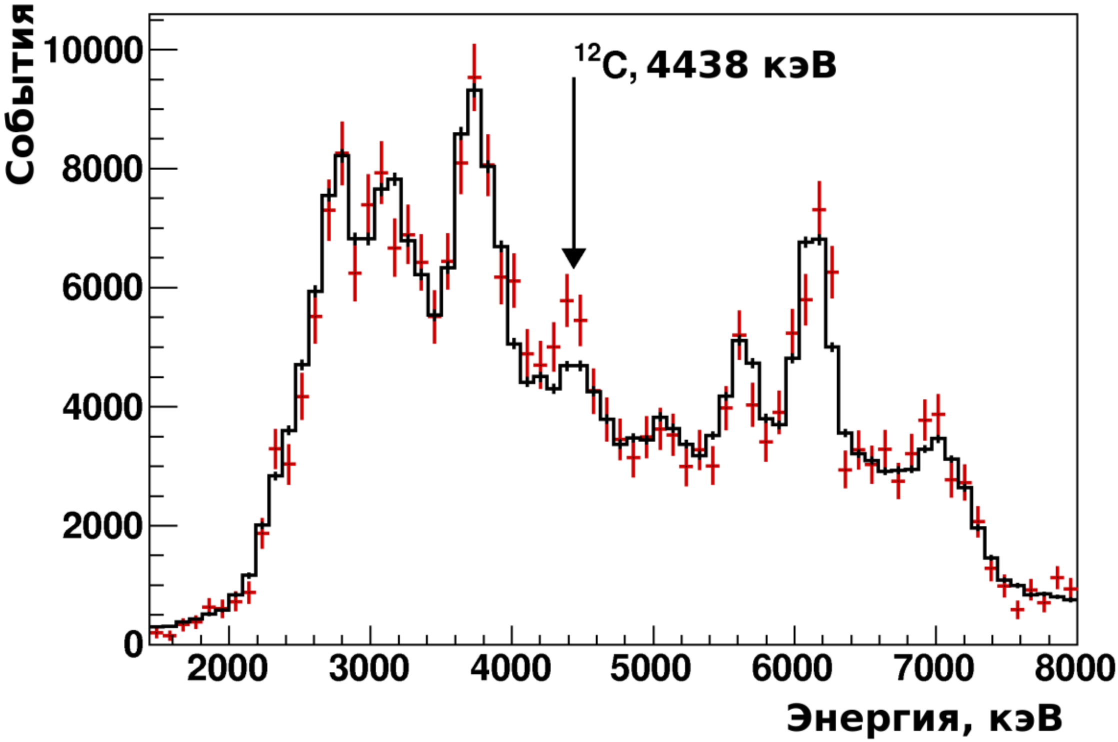
- Signature of diamond is increasing of local concentration of carbon
- The place of diamond in the kimberlite rock is determined.
- No false alarms on the rocks with carbon.

Detection procedure



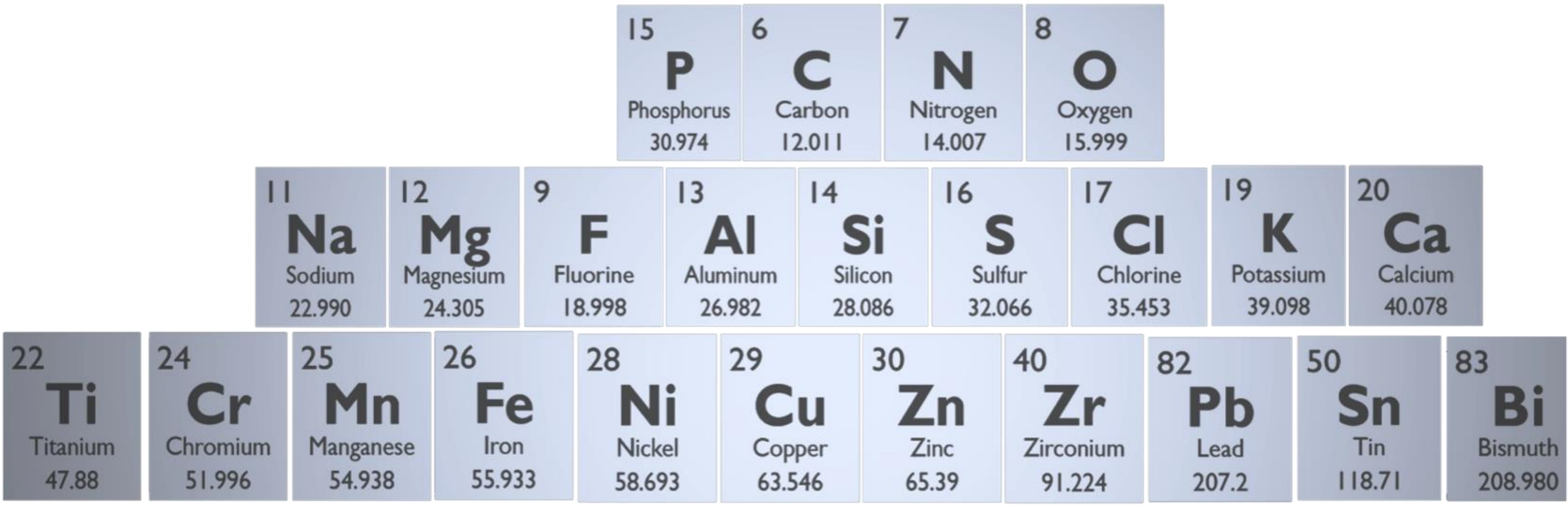
- Ore tray is divided by192 regions.
- Cell size 8x8 mm.
- In each cell a local carbon level is evaluated and compared to carbon level averaged over sample.
- Diamond signal is local carbon level excess.
- Ore sorting is carried out automatically, no human intervention required.

Possibility to work with large size ore

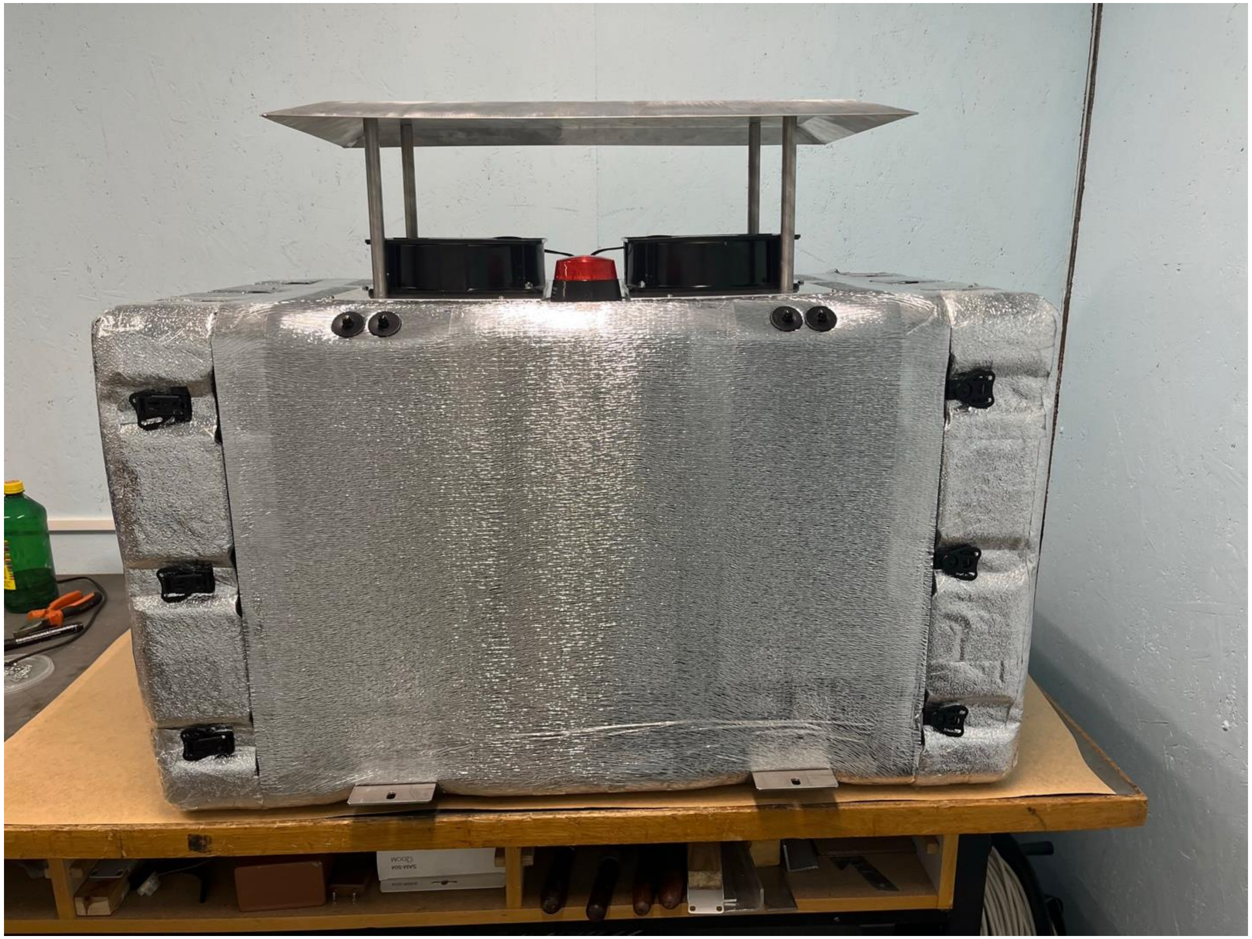


- Stone -160x90x90 mm
- Ratio of the diamond to ore size is 1:10

Определяются концентрации 24 элементов

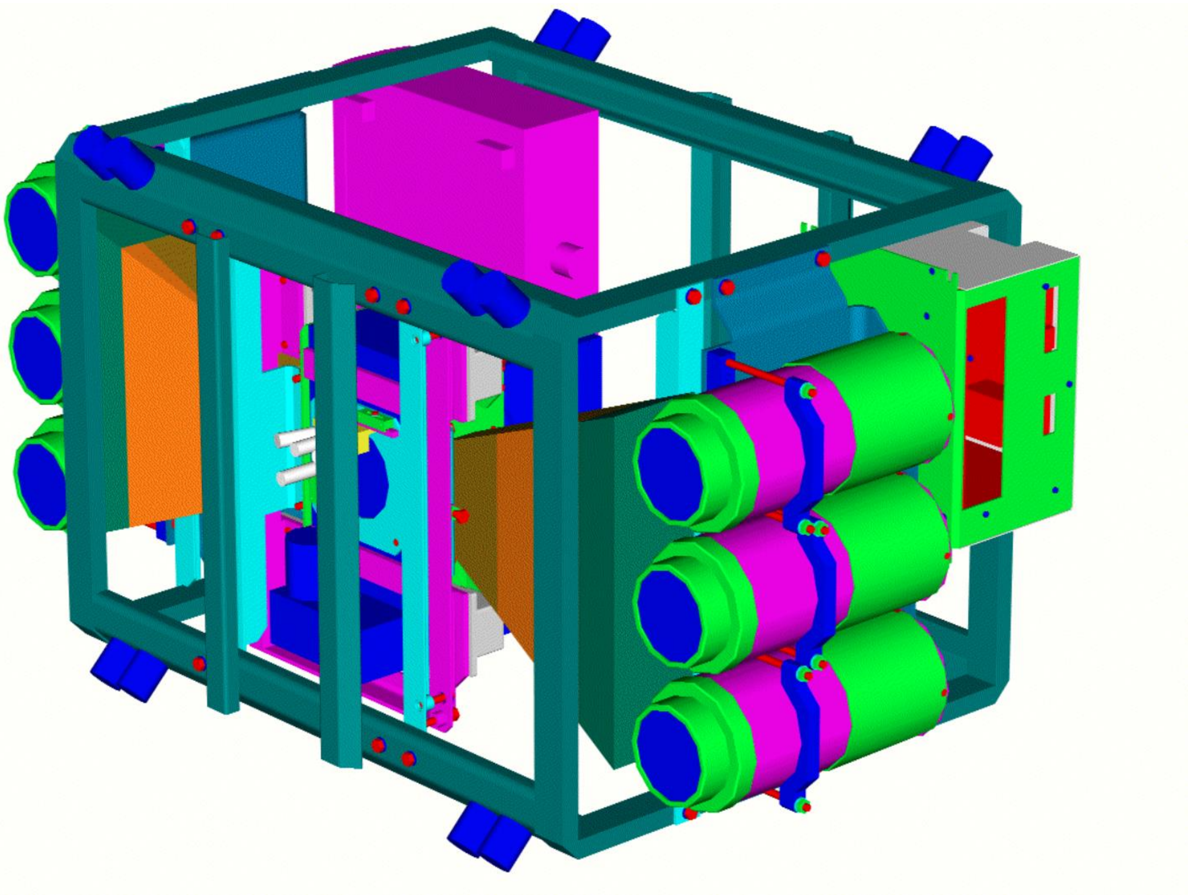


Нейтронный модуль



Сотрудничество с ЛНФ, проект TANGRA

Нейтронный модуль

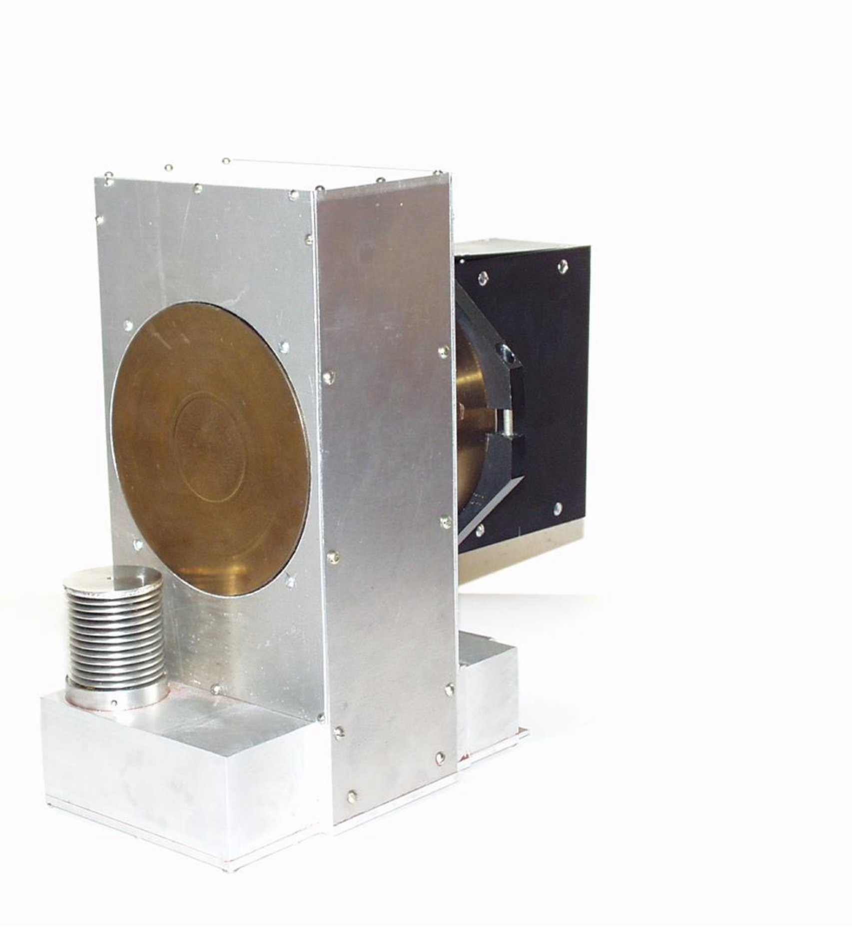


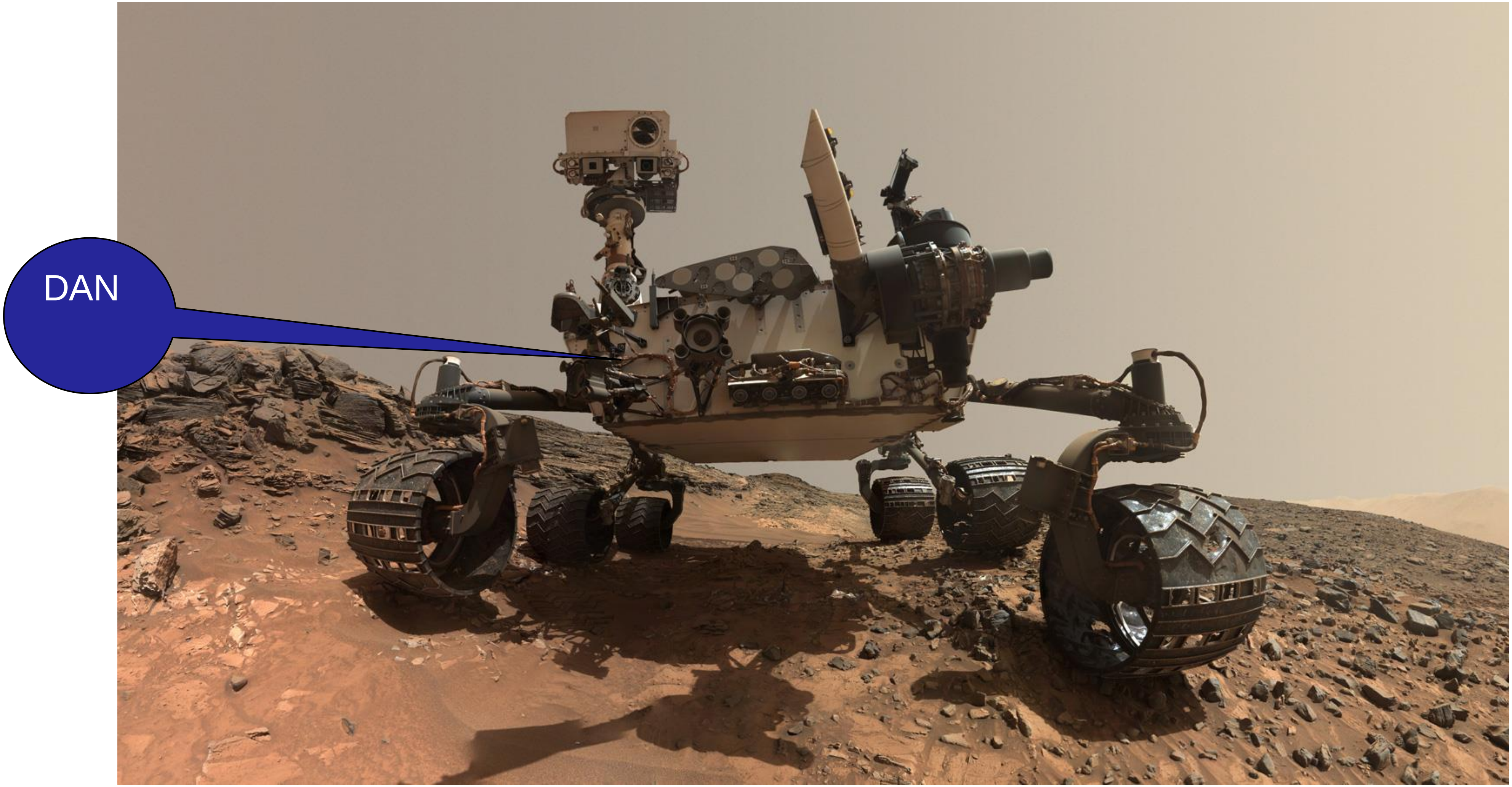
- Neutron generator ING-27 manufactured by FSUE VNIIA named after N.L.D
- I= 5 x 10^7 c^{-1}

- 6 BGO гамма-детекторов
- Silicon alpha detector - the matrix 3x3 (10x10 mm)

Neutron generator

- Neutron generator ING-27 manufactured by FSUE VNIIA named after N.L.Dukhov
- I= 5×10^{7} c^{-1}
- Weight – 8 kg
- Height – 300 mm
- Silicon alpha detector - the matrix 3x3 (10x10 mm)





The DAN neutron generator developed by VNIIA as part of the equipment for searching for water in the bowels of the planet Mars was sent on November 26, 2011 as part of the NASA Curiosity rover.

Gamma detectors

- Type of BGO scintillator
- The size of the scintillator is 76x65 mm
- Recorded energies 0.5-11 MeV
- Operating temperature range from +5 to +50oC
- Weight 3.4 kg
- Overall dimensions 89 x 265 mm
- Photoelectronic multiplierR6233 by Hamamatsu
- Γ_E = (4.42 ± 0.14) % on the 4.44 MeV line
- Γ_t = 4.82 ± 0.12 ns

- CherMK (PJSC Severstal) – 2 analyzers for sinter charge have been operating since 2021.

- NWPC JSC - an analyzer for apatite ore from the Oleniy Ruchey underground mine was delivered.

- JSC "Evraz-ZSMK" - 2 analyzers for sintering charge have been operating since 2022.

Typical precisions

Comparison with other neutron analyzers

RMS_{abs}	Al_2O_3, %	CaO, %	Fe %	MgO, %	Na_20, %	P_2O_5, %	SiO_2, %
Range ,%	**1-5**	**5-20**	**30-65**	**2-10**	**5-20**	**2-20**	**2-15**
АГП-К , %	0,13	0,32	0,29	0,12	0,20	0,25	0,10
CB OMNI, % Thermo Fisher***	0,60	0,42		0,58	0,45		0,94
NITA II**	0,5					0,5	
GEOSCAN*, %**	0,45	0,95	0,80	0,60		0,38	0,66
XENA[4],%	0,38	0,49	0,23				0,52
РАТЭК	0,3	0,4	0,4	0,3			0,5

*Д.И.Шарков, Цемент и его применения, №3, стр.90, 2015.
** Методика поверки. Анализатор элементного состава радиоизотопный NITA II, МП-33-241-2018.
***H.Kurth, D.Griffiths, Suitability of Geoscan-M elemental analyser for phosphate rock (Russian ore, 3-10% P_2O_5) ECI Symposium Series, (2015).
[4]C.S.Lim et al, An on-belt elemental analyser for the cement industry, Appl. Radiation and Isotopes 54 (2001) 11.
[5]COALSCAN 9500X, Scantech

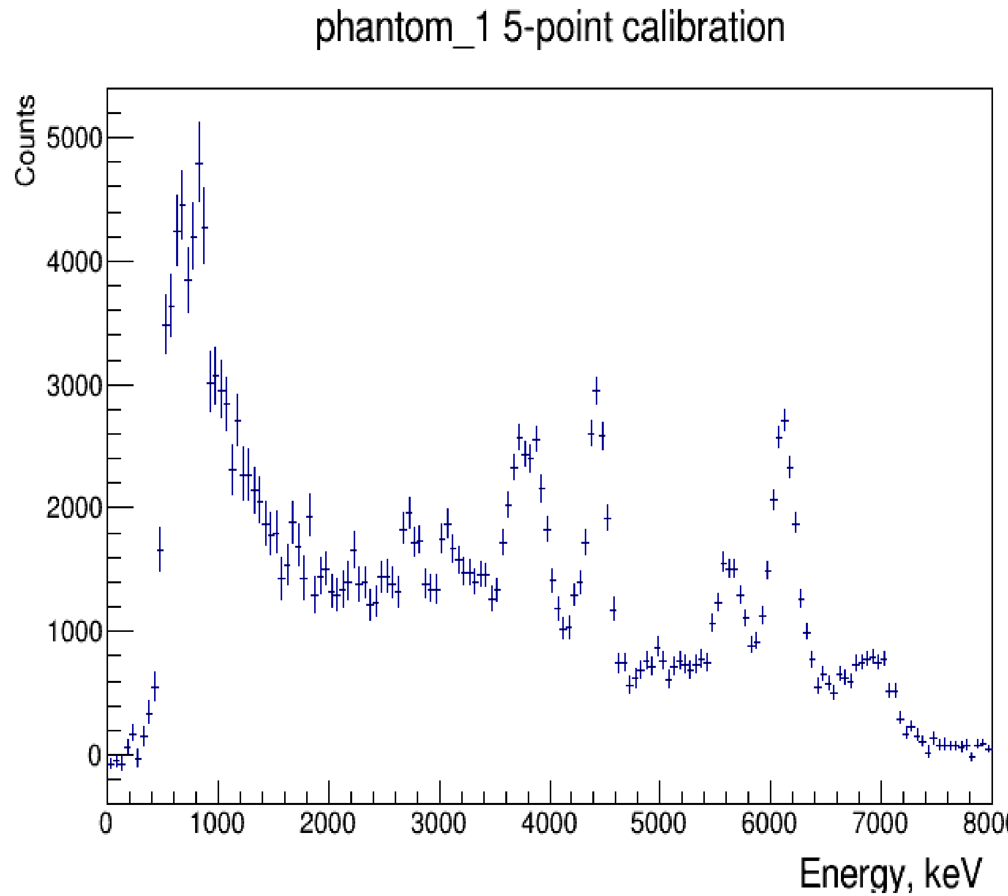
Фантомы A, B, C

- A - Нормальный хим. состав
- B – Fe= 1%
- C - Fe = 5 %

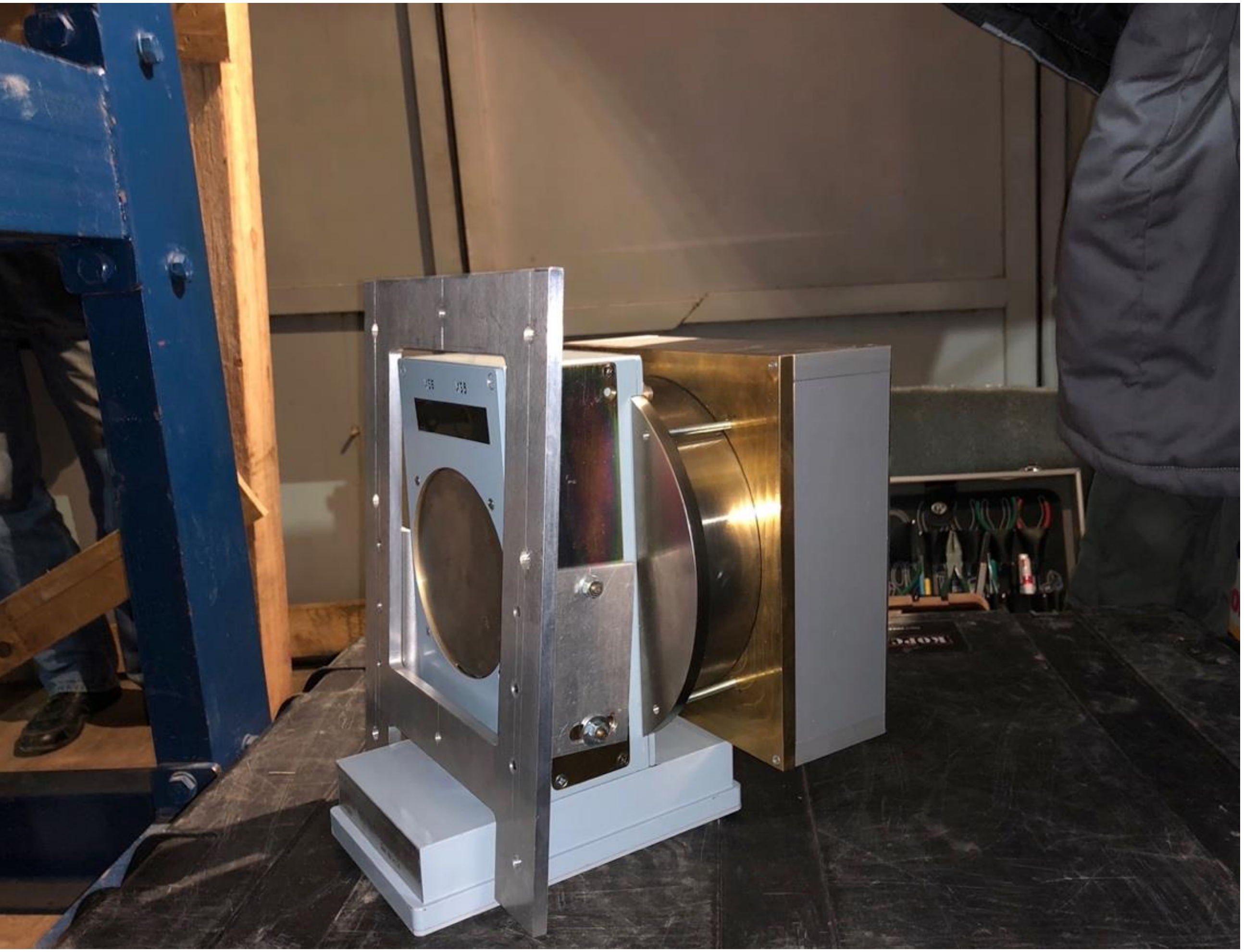
Элементный состав тела человека

O, %	70,5
C, %	18,0
H, %	8,6
N, %	3,0
Fe, %	0,0

Первые результаты



Сотрудничество с ВНИИА им. Духова



- Нейтронный генератор с 256 мечеными пучками
- Размер пикселя 2x2 mm

Цели и задачи

Задача	Цель	Сегодня	Примечание
Измерить элементный состав	Fe	Fe, C, N,O, Ca и еще 20 элементов	
Измерить содержание Fe	На уровне 0.13%	СКО = 0.29 % В большом объеме	В вокселе
Пространственное разрешение	5-10 мм	8 мм	Для 100% заполнения
Временное разрешение	0,5 – 1 нс	3- 4 нс	
Время облучения	25-30 мин	20 мин	

План работ

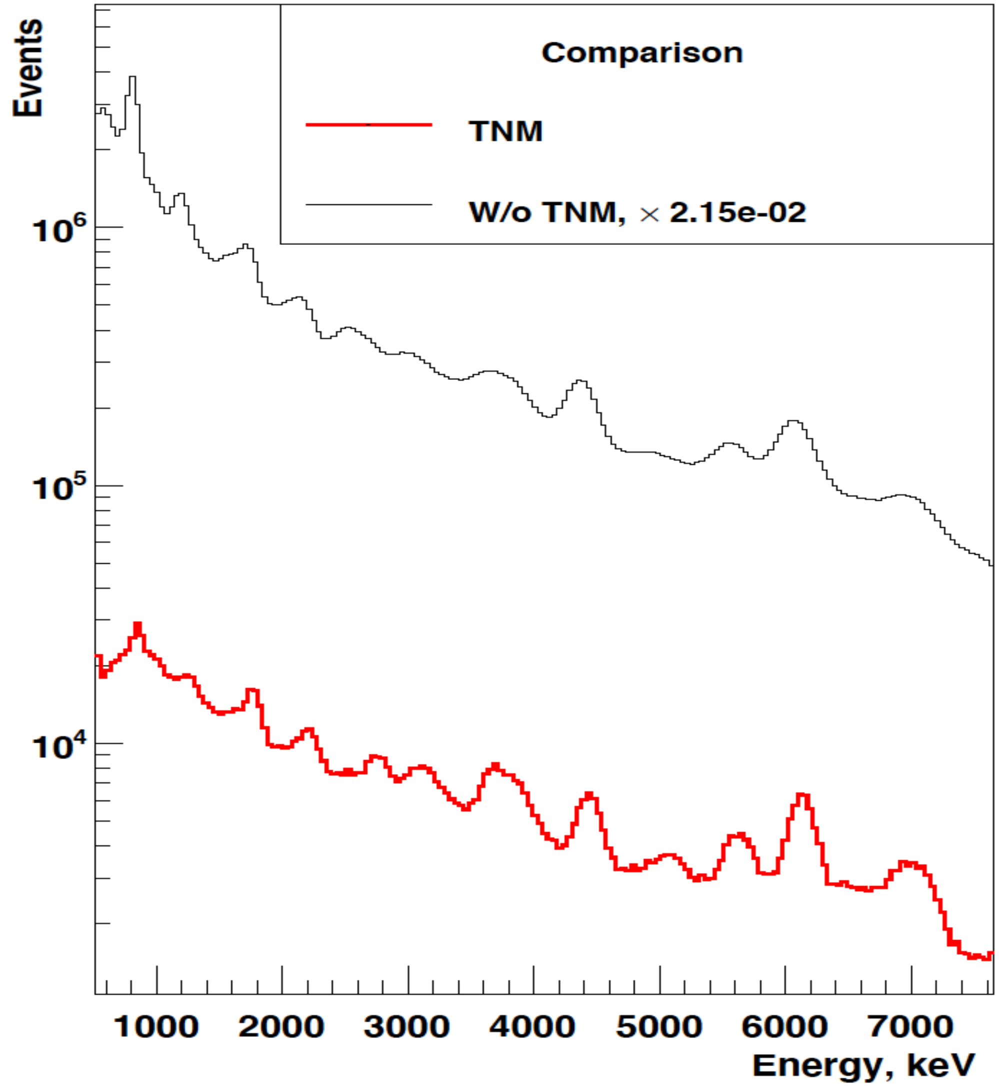
- Измерения на фантомах с помощью существующей аппаратуры (9 или 256 меченых пучков).
- Измерение злокачественных опухолей в существующей аппаратуре.
- Монте-Карло симулирование установки для диагностики.
- Разработка проекта диагностической установки.

Sample №17

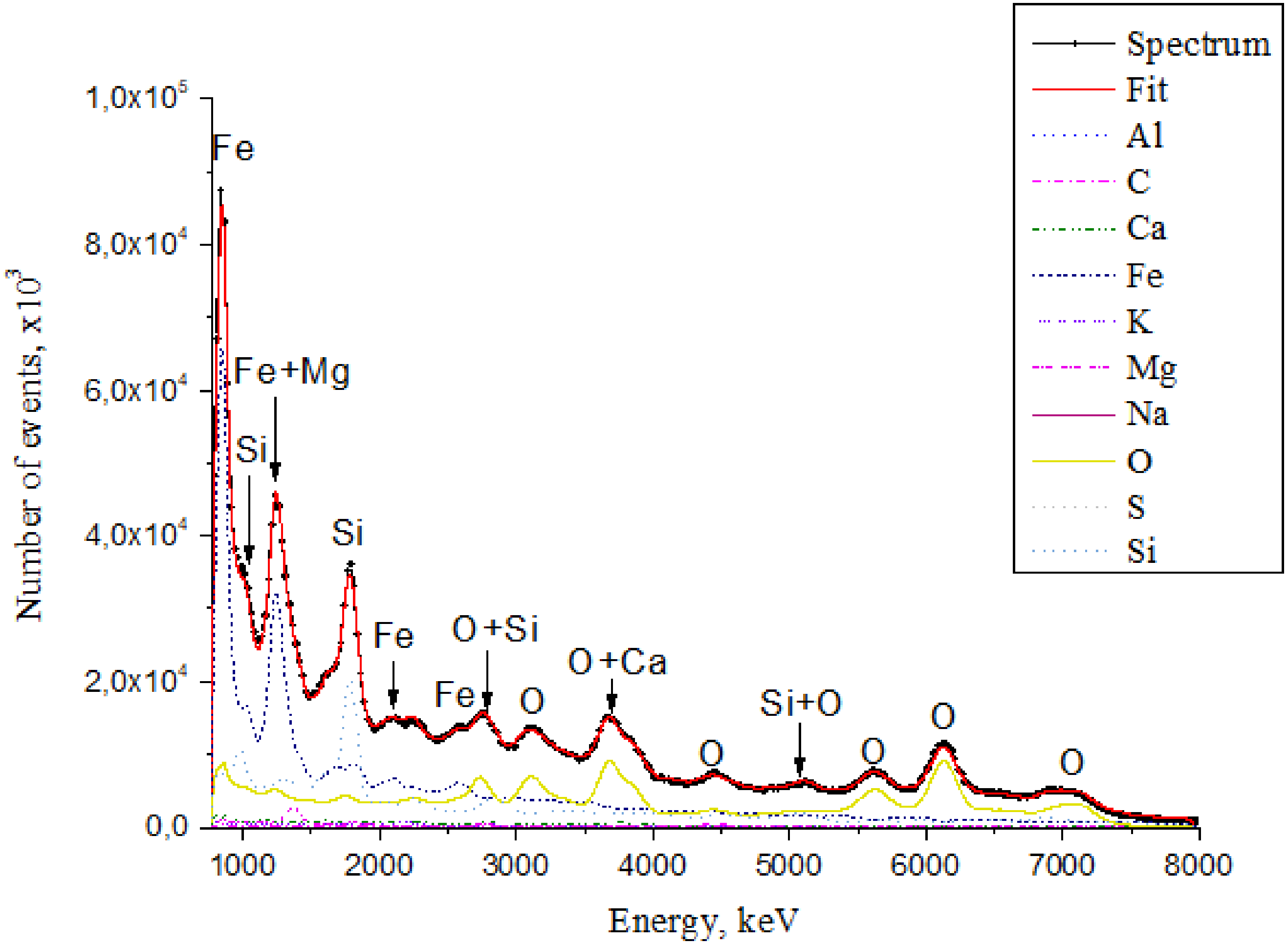
- Strong signal of carbon was found in one of 33 samples.
- Analysis of this sample reveals two regions with 7 mm diamonds.

V.Alexakhin et al., Detection of Diamonds in Kimberlite by the Tagged Neutron Method, Nuclear Instruments and Methods A785 (2015) 9 .

Energy distribution of gamma-quanta



Typical energy spectrum of gamma quanta of a sinter sample



Concentrations of Al, Ca, C, Fe, Mg, Na, O, P, Si, Ti are measured and converted to the corresponding oxides