Application of tagged neutrons for diamonds detection in kimberlite

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Problem

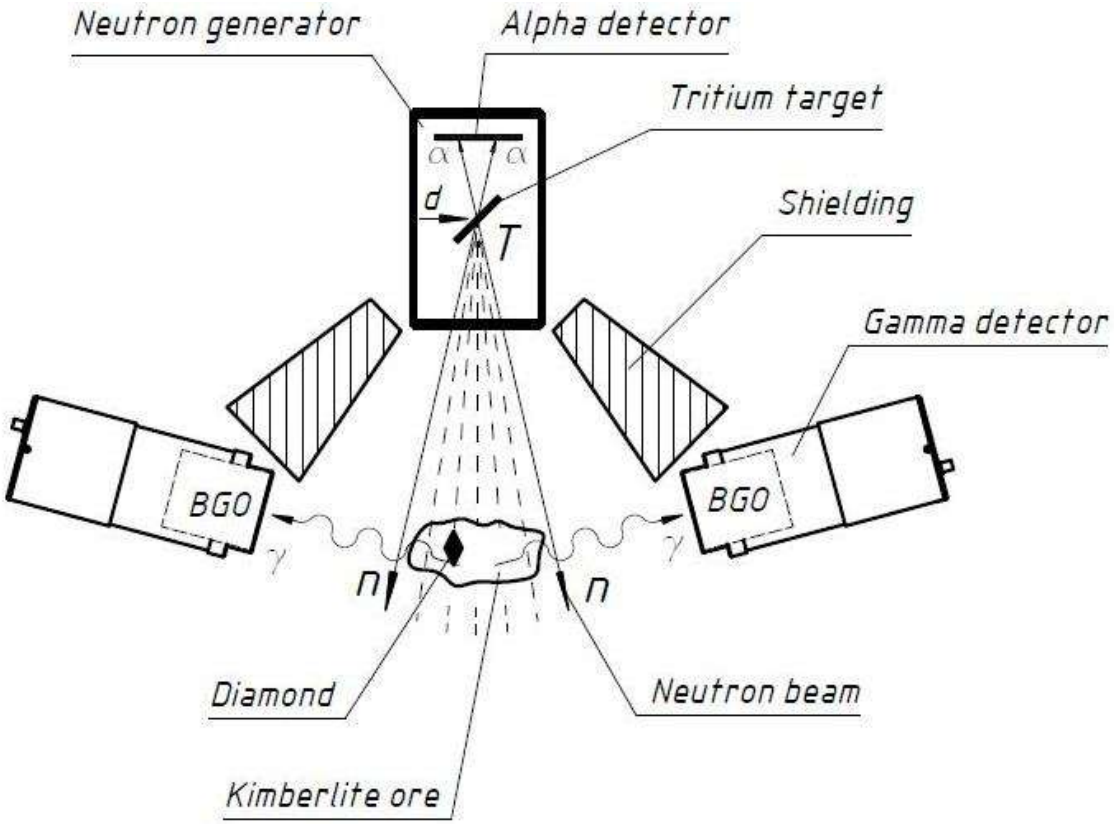
- At different stages of kimberlite ore crushing the probability for largest and most valuable diamonds to get damaged is quite high.

- Main source of diamond damage is the process of kimberlite crushing, which causes up to 29% of diamonds to loose integrity*. Damage rate for valuable crystals is from 25 to 75%, and average mass loss is up to 12%.

- Tagged neutron method allows detecting the diamond inside piece of kimberlite ore without preparatory ore crushing, which makes it possible to extract valuable crystals under preserving conditions.

* Макарский И.В., Бондаренко И.Ф., Алдонин Е.И. Оценка степени техногенного воздействия на сохранность алмазной продукции, “Обогащение руд” №3 (2012) 24

Tagged Neutron Method

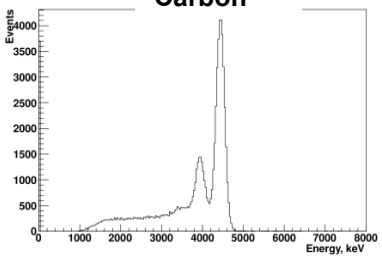


- Rock irradiated by fast 14 MeV neutrons from
  d + t –> α + n
- Irradiated by fast neutrons the substance emits gamma-rays.
- Every element has an unique gamma-spectrum.
- Carbon distribution in rock sample is analyzed by carbon 4.44 MeV line.

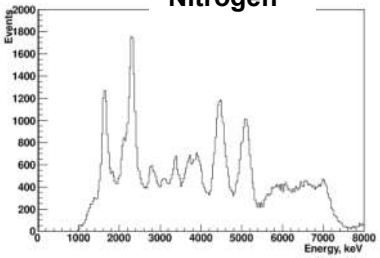
- Sign of diamond is detection of **local** carbon excess.
- Diamond location inside kimberlite sample evaluated.
- No false positives on carbon-bearing rock.

Tagged Neutron Method

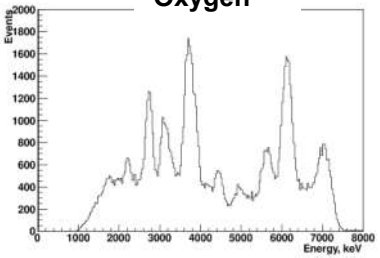
Carbon



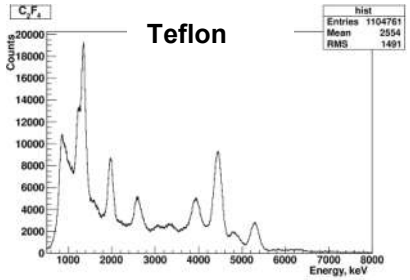
Nitrogen



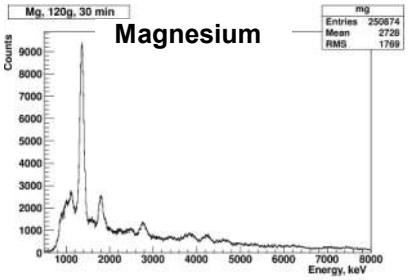
Oxygen



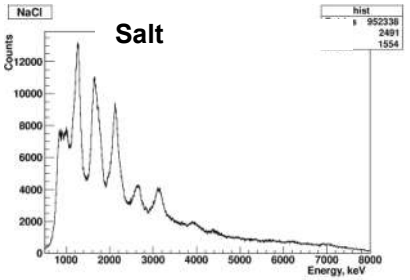
Teflon



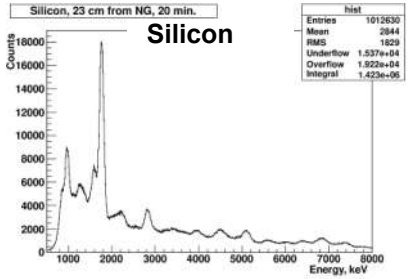
Magnesium



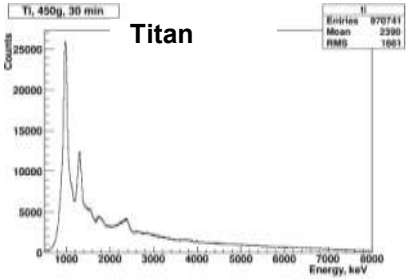
Salt



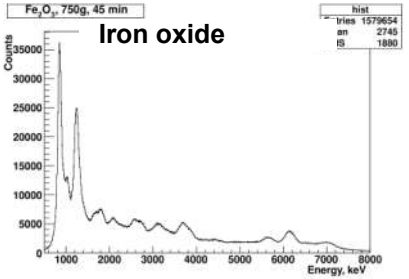
Silicon



Titan

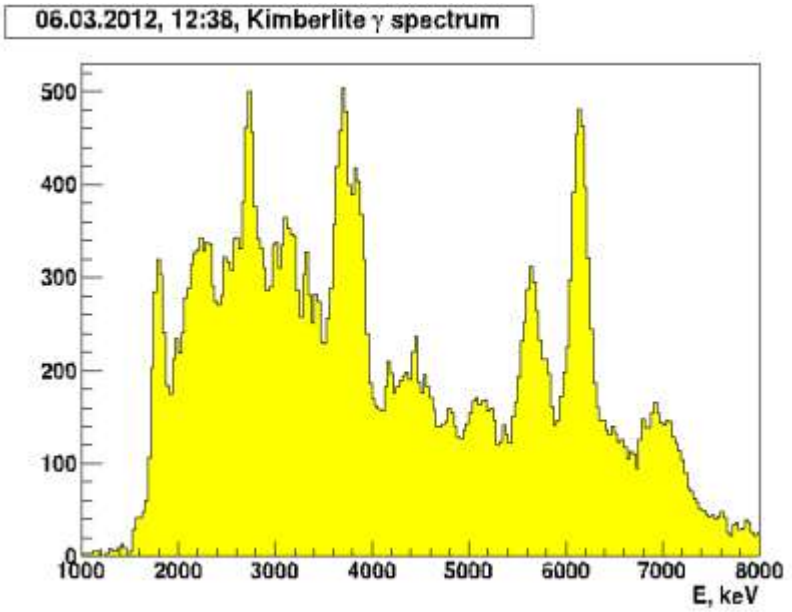


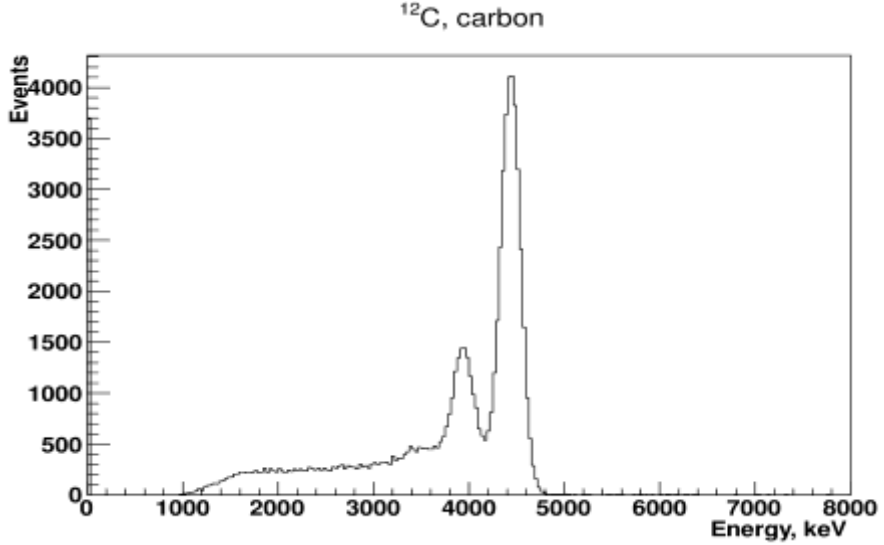
Iron oxide



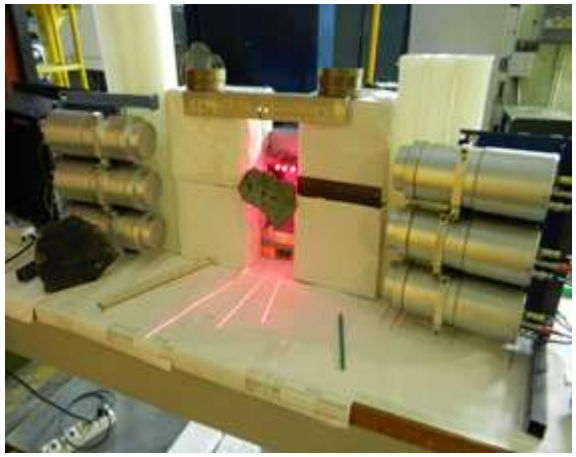
Expected result

- Diamond is a pure carbon.
- Presence of diamond leads to local carbon excess.
- Looking for signal excess around 4.44 MeV region.





What is done:



On commission from OKSC ALROSA R&D was carried out, with following results:

- ✓ A technique for diamond detection in kimberlite with TNM is developed.
- ✓ An experimental setup is created, which was used for examination of 50kg of kimberlite ore.
- ✓ **In a kimberlite sample real diamonds were detected.**

One of 33 examined samples exhibited local carbon excess.

Additional analysis of the sample in Mirny discovered two non-uniform diamond inclusions with the size up to 7 mm consisting of small particles of 1-2 mm.

Field testing on Lomonosov MPD* of PJSC Severalmaz.

Field testing of setup prototype have been done in June-September of 2015 analizying kimberlite ore of Lomonosov deposit at Enrichment Plant of Pomorskaya GRE, PJSC Severalmaz.

*MPD: Mining and Processing Division

Setup on Pomorsky Enrichment Plant

Measuring module

Measuring module

Gamma-detectors

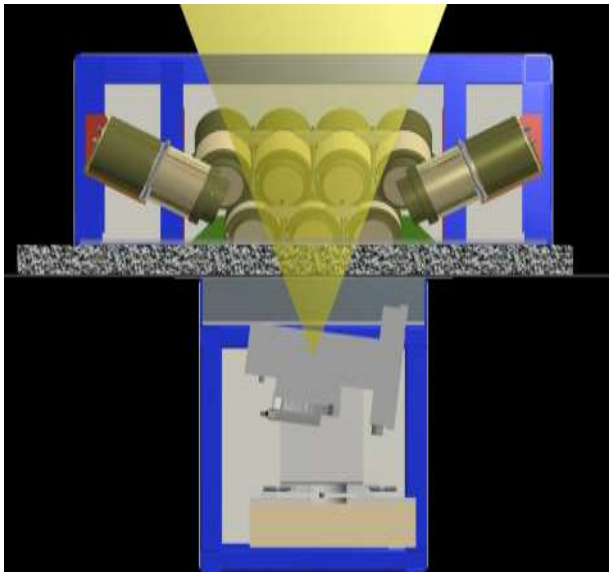
Neutron generator

Ore batcher of tray-based feed system

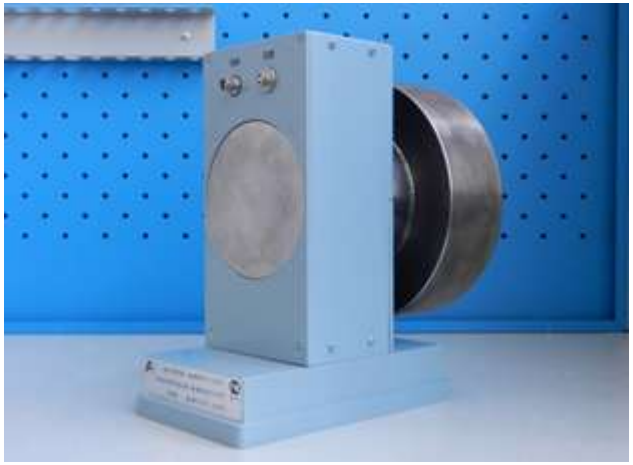
Neutron module

- An unique neutron generator irradiated an inspection zone with 192 neutron tagged beams. Specifically developed for the project by VNIIA, Moscow.
- Gamma rays are detected by gamma-detectors system
- 192-channel alpha-detector (while typical number of pixels is 9).
- Inspection zone is 3.5 times larger compared to conventional neutron generator with built-in α-detector.

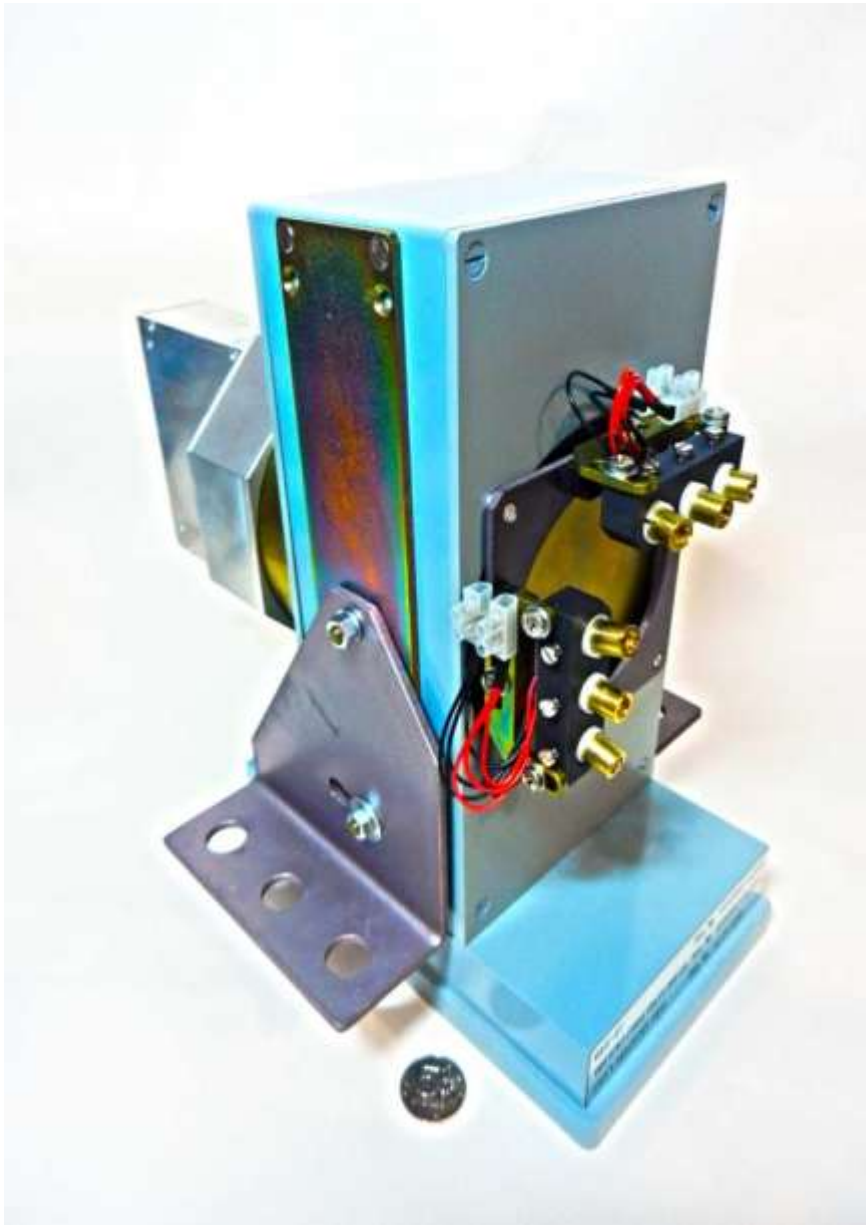
Neutron module



Neutron generator



Neutron generator LNF, JINR, 6 storey



Neutron generator by VNIIA, Moscow, 300 mm

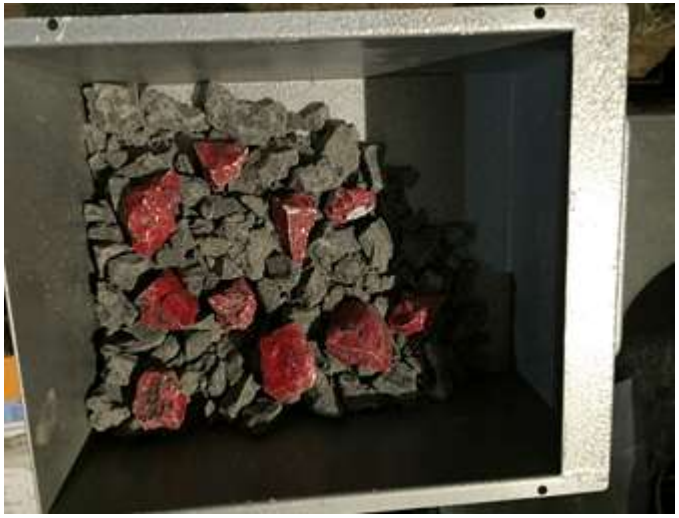
Core material

1036 kg of core material is analyzed:

- Assay К6062/26-14 from Karpinskogo tube, depth 35-41,5 m.
- Assay К6062/26-15 from Karpinskogo tube, depth 41,5-48,5 m.
- Assay Э102/-18-30 from Arkhangelskaya tube, depth124,3-130,0 m.
- Assay Э102/-18-20 from Arkhangelskaya tube, depth 66.1–74.1 m.
- Assay Э102/-18-26 from Arkhangelskaya tube, depth104,1-109,6 m.
- Assay Э116/10-24 from Arkhangelskaya tube, depth 85,0-91.0 m.

Analysis technique

Diamond imitators of 6, 8, 10, 12 mm were put inside rocks of different size (-50+20, -40+20, -30+10 mm) and mixed with ore under analysis.



Grade size analysis

Ore sample of
100x100x70 mm size with
12 mm diamond imitator

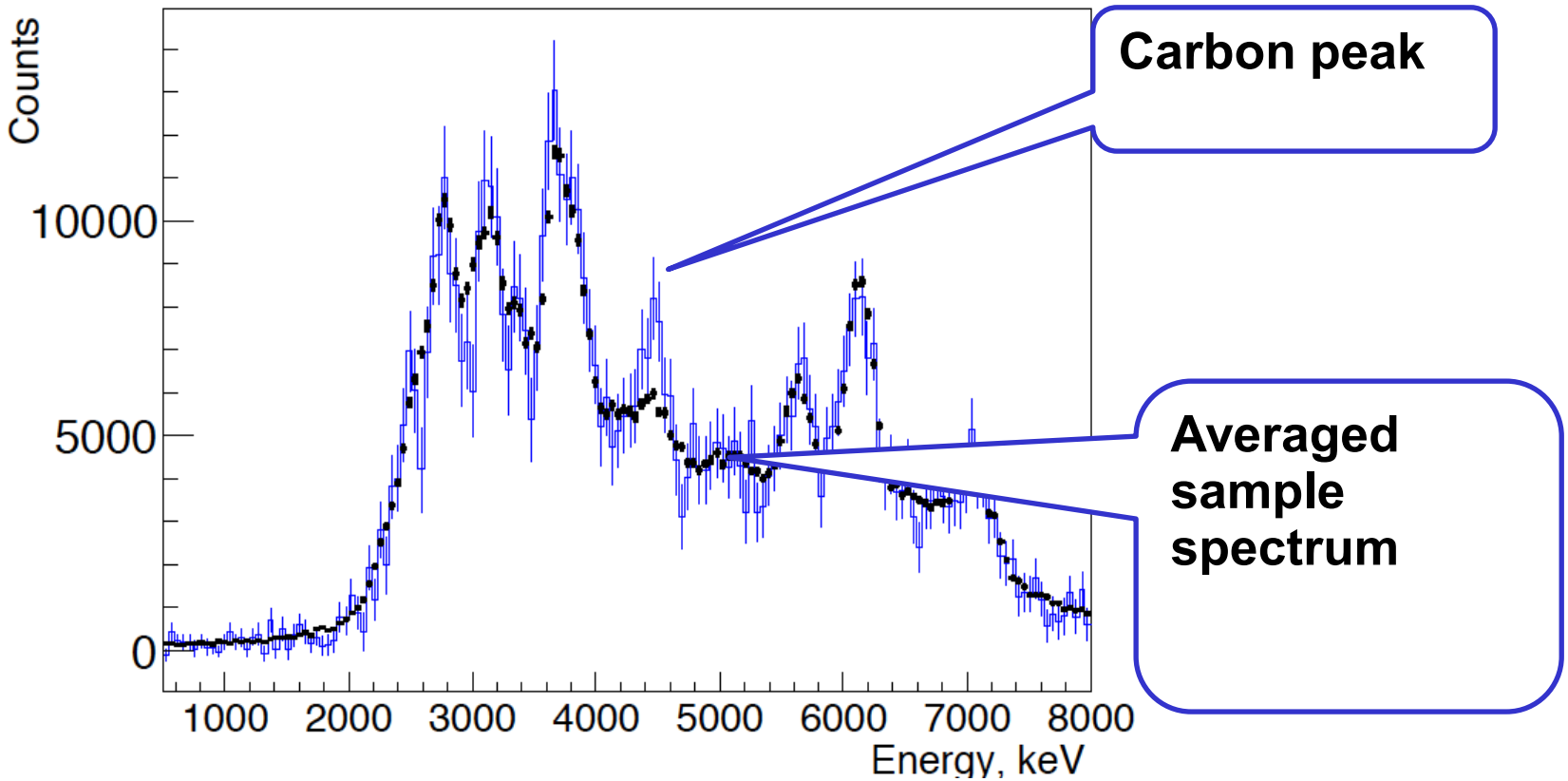
Tested diamond detection in ore of different grade size:

- **-150+100 mm**
- **-50+20 mm**
- **-40+20 mm**
- **-25+10 mm**

Detection procedure

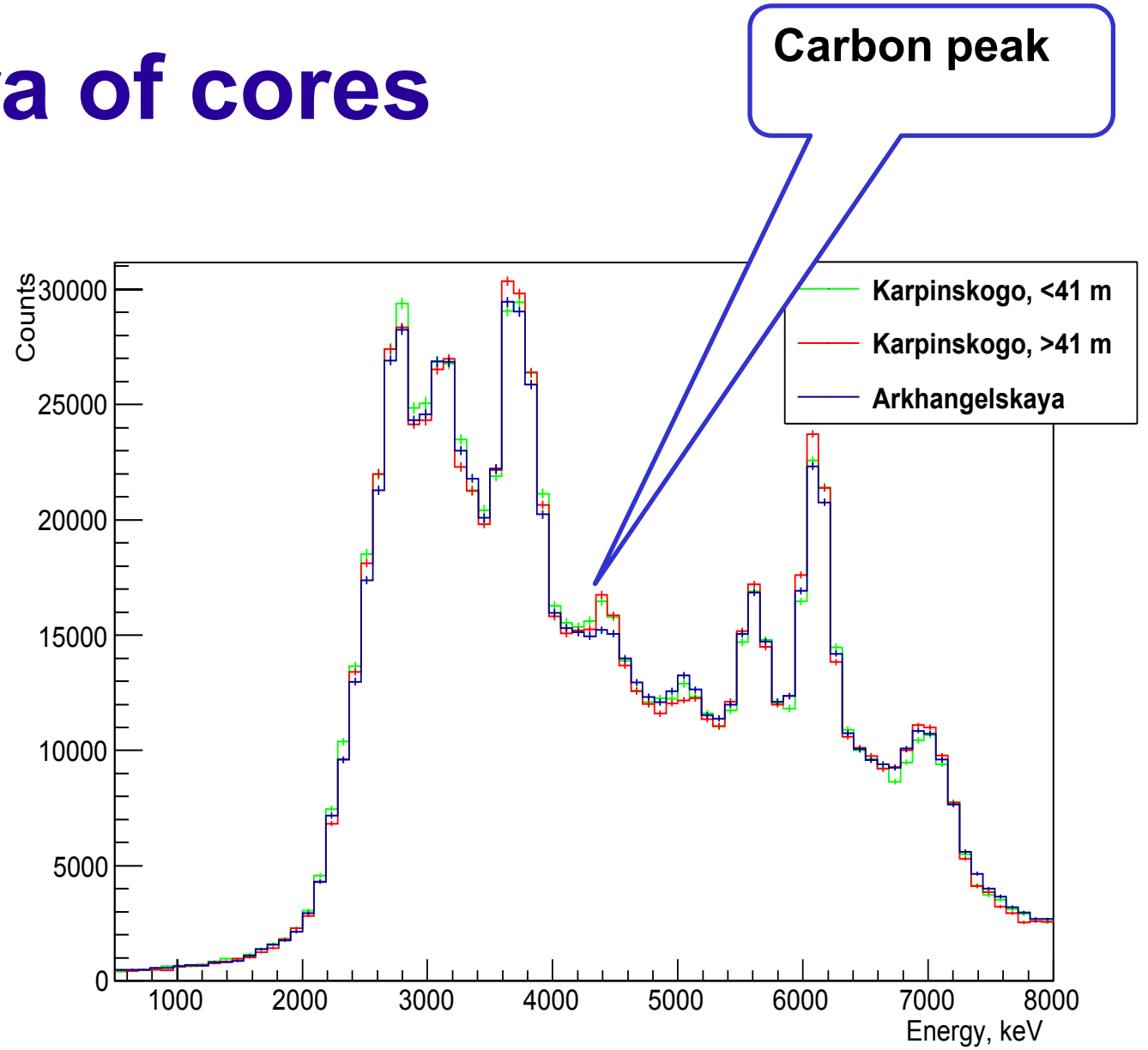
- Ore tray is divided by 192 regions.
- Cell size 8x8 mm.
- In each cell a local carbon level is evaluated and compared to carbon level averaged over sample.
- Diamond signal is local carbon level excess **σ**.
- Ore sorting is carried out automatically, no human intervention required.

Example of signal from diamond simulant



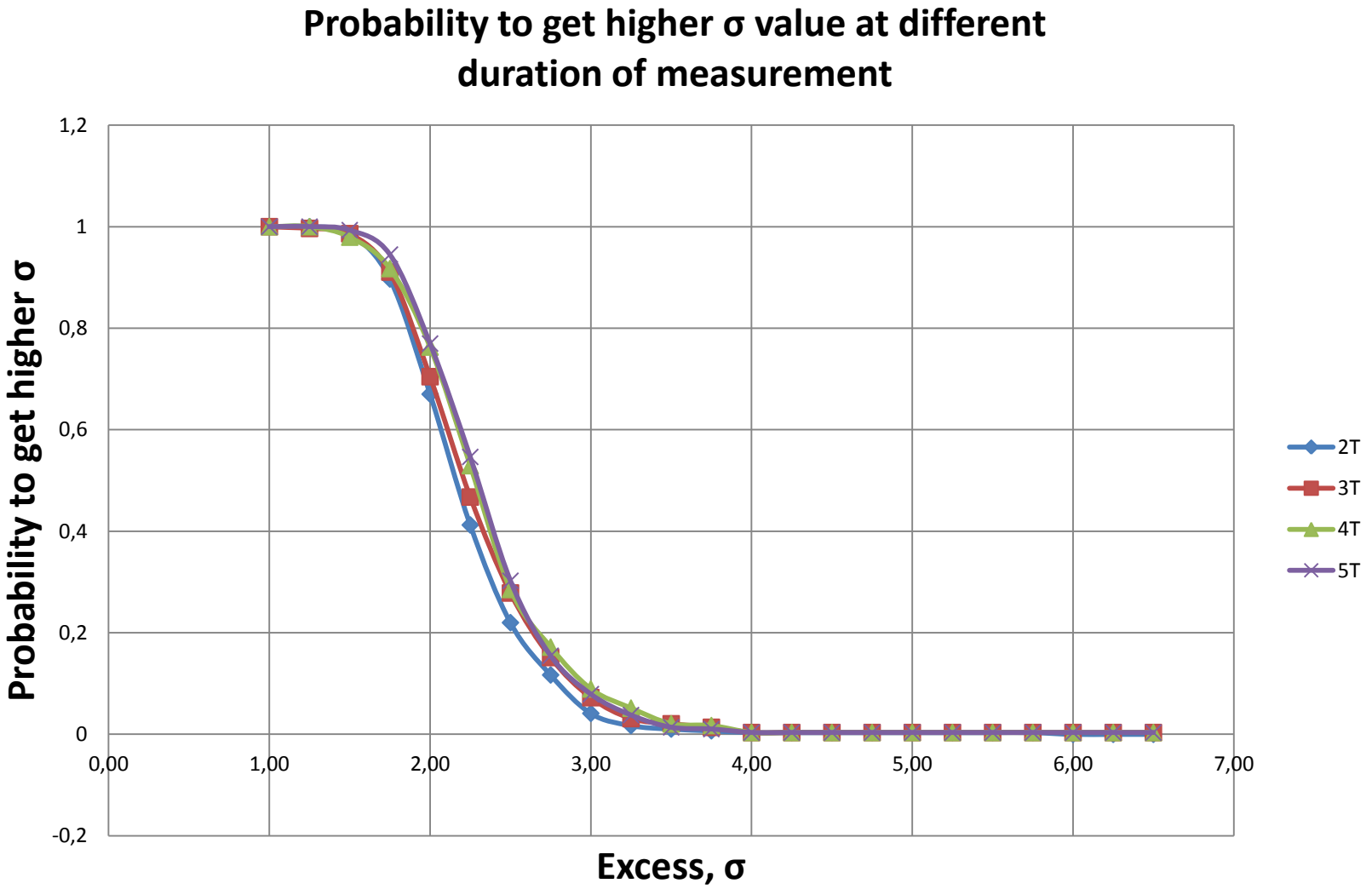
8 mm diamond imitator in -50+20 mm kimberlite ore

Spectra of cores

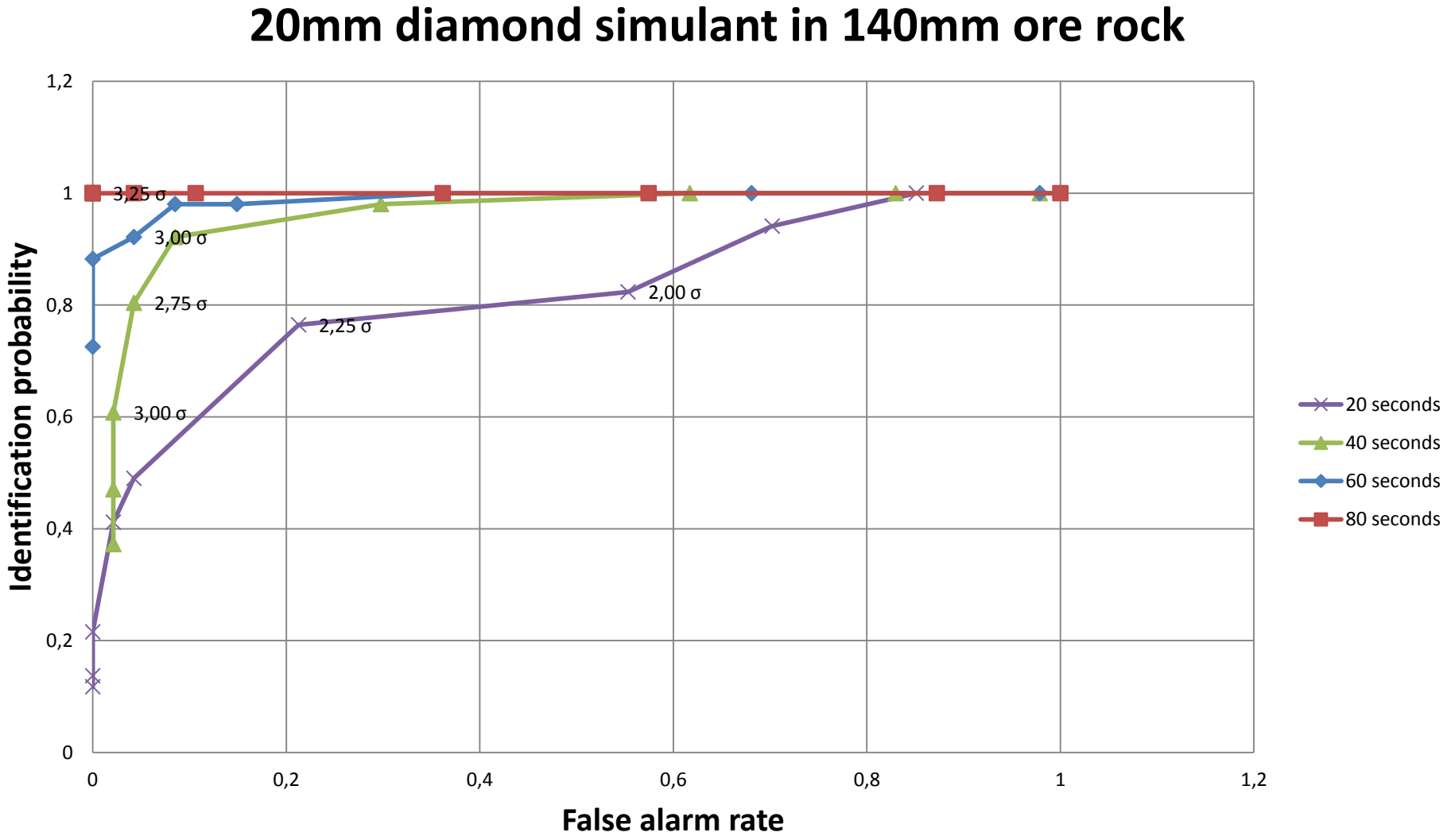


Core samples from Karpinskogo and Arhkangelskaya tubes

Optimal σ-cut



Receiver operating characteristic ROC-curve



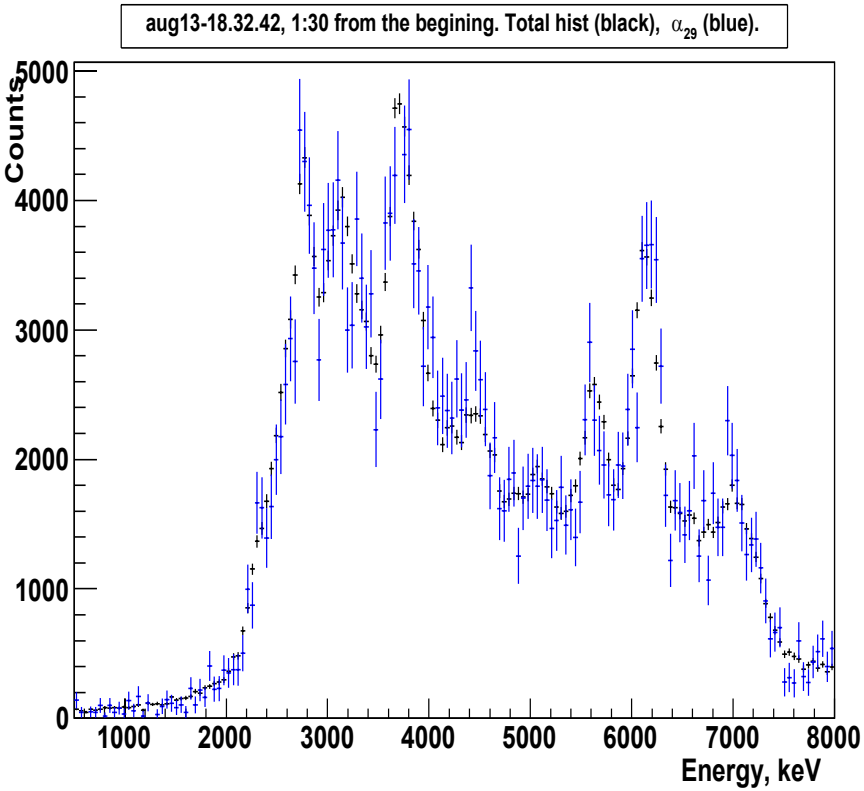
Spatial position of diamond inside the tray with ore

Two diamond simulants in one tray

Throughput estimation

- 281 measurement with different diamond imitator sizes are taken.
- Best throughput of 102 kg/hour is achieved for ore of -50+20mm size grade.
- Commercial component yield for 8mm imitators is 97%.

Large size grade ore analysis capability



Ore sample -160x90x90 mm.

Ore-to-diamond ratio is 1:8.

Concentrate properties

- Concentrate yield is 3 %.
- No -8mm diamonds detected in core samples.
- Sample processing by Pomorsky enrichment plant hasn't detected any -8+4 mm grade diamonds neither.
- There are diamond of smaller grades in concentrate.

Extraction of commercial component

Concentrate of Э116/10-24 sample:
1 pcs. -4+2 mm, 4 pcs. -2+1 mm, 10 pcs. -1+0.5 mm
Tailings: 1 pcs. -1+0.5 mm

Results and conclusions

- ☑ Prototype of experimental setup is field tested (June-September of 2015).
- ☑ All systems of neutron module were operating correctly.
  - ✓ Neutron generator worked for 218 h.
- ☑ Power consumption – 500 W.
- ☑ Radiation environment:
  - Operator location during operation – 0.11 mcSv/h
  - Core sample after irradiation – 0.17 mcSv/h
  - In transportation container when NG is off – 0.11-0.17 mcSv/h
  - Natural background of Pomorskaya GRE – 0.09-0.11 mcSv/h

Results and conclusions

☑ Main features of prototype evaluated:

- Smallest detectable diamond cluster 6 mm
- Largest ore grade size -150+100 mm
- Optimal ore grade size -50+20 mm
- Throughput for optimal ore grade is 102 kg/hour
- Concentrate yield – 3 %
- Commercial component yield – 97 %

Future plans

☑ Get Skolkovo support

☐ Experimental setup with 1 tph throughput.

- NG - 900, $I=3\times10^{8}\ s^{-1}$
- Conveyor
- New electronics
- Improved gamma-detection system
- Field tests on Severalmaz factory in 2016.
- Field tests on Mirny MPD in 2017.

☐ Full-scale setup with 20 tph throughput.

Words of gratitude

- Skolkovo Foundation for financial support.
- ALROSA for support in conducting tests and interest in our technology.