



### Abstract

VNIIA is the leading organization of Rosatom State Corporation for Atomic Energy for implementation of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Currently, it carries out the complex of research works in the following fields:

- develops scientific and methodical support as well as hardware and software for provision of the CTBT on-site inspection activity;
- develops and upgrades software for OSI E-training and Simulation System (OSI\_E\_Training) for training surrogate inspectors in on-site inspection (OSI) methods and procedures;
- takes part in the analysis of events testifying to probable non-observance of the CTBT by other states parties of the CTBT; carries out collection of geophysical and radionuclide information using the International Data Center (IDC) products;
- studies and improves processes of weak seismoacoustic event detection and location at regional distances (by the example of the Democratic People's Republic of Korea territory);
- VNIIA jointly with the Special Monitoring Service of the Ministry of Defense of the Russian Federation (RF MoD) and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO PrepCom) carry out work on preparation for certification of domestic RNG monitoring equipment – Xenon Isotopes Monitoring System (MIKS).

### Development of Scientific and Methodical Support As Well As Hardware and Software for Provision of the CTBT On-site Inspection Activity

VNIIA executes complex of works to ensure the development of methodical support for the inspection activity and for the negotiation process of the Russian Federation in the field of the CTBT. Within the frames of these works the Information and Analytical System (IAS) is upgraded for it to be used in applied research to ensure implementation by Rosatom State Corporation of its assigned functions. The Information and Analytical System is used to study technical capabilities of the CTBT verification regime. The IAS is used to collect data on scientific, methodical, and technical state of OSI regime, as well as to collect, analyze, and accumulate geophysical and radionuclide information based on the IDC products. The structure of the information & reference database used while operation of the information and analytical system includes several independent information sections (Figure 1):

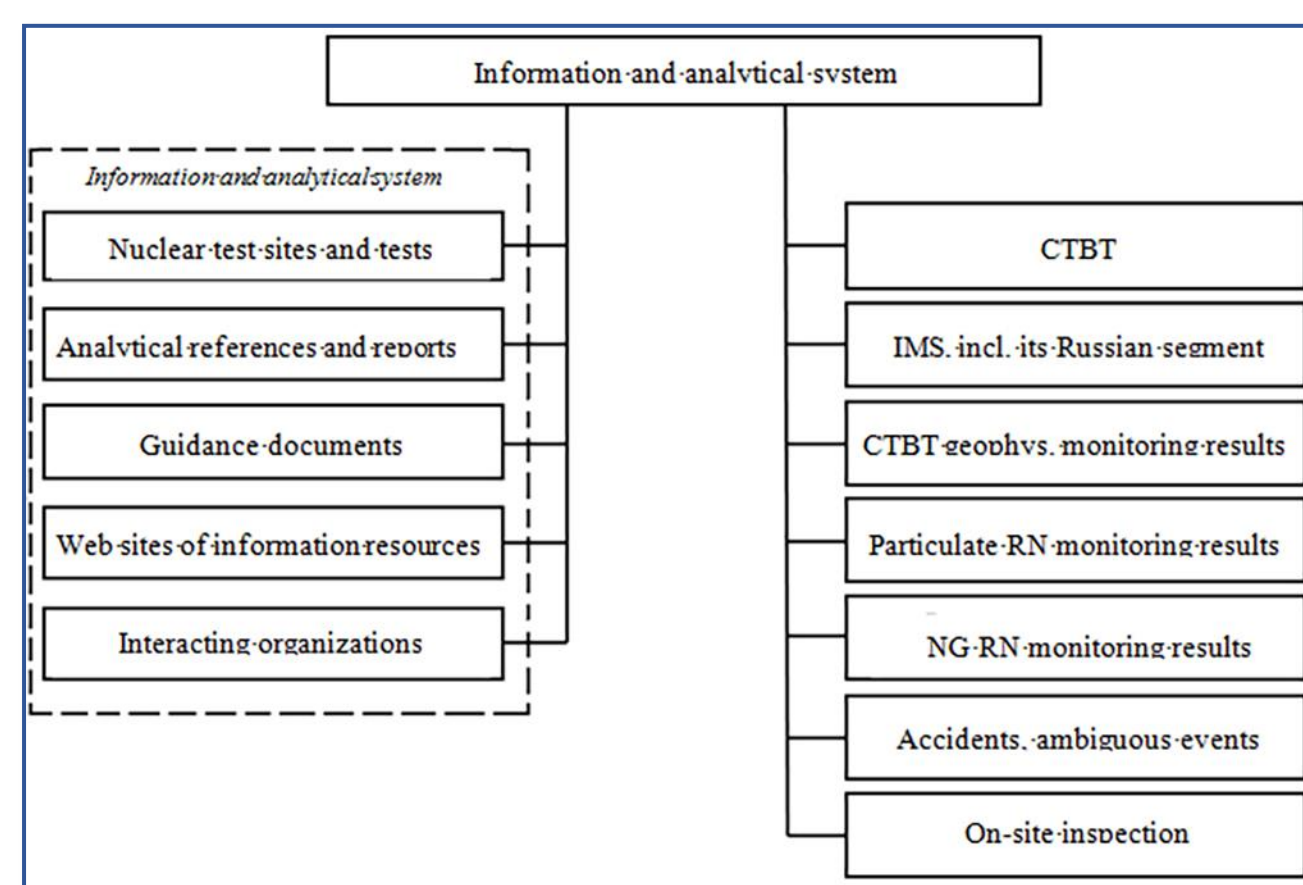


Figure 1 – IAS database block diagram

### E-training System for training surrogate inspectors in OSI Methods and Procedures

VNIIA has developed e-training system (OSI\_E\_Training) that allows training surrogate on-site inspectors in inspection procedures in the modes close to real situations. Currently, the task of OSI\_E\_Training upgrade as regards visualization and 3D-modeling is being solved. Works have been successfully completed on the development of a new program module OSI\_E\_Training\_3D that allows creating a three-dimensional space of OSI inspection area and inspection equipment models, as well as simulating OSI processes. OSI\_E\_Training-3D is being designed in such a way that to reflect most fully real equipment operation logic and logic of real inspection processes.

### OSI\_E\_Training Development: OSI\_E\_Training\_3D Program Module Designing

OSI\_E\_Training\_3D is designed using Unity3D and Visual Studio2007 programs for interactive training of OSI inspectors. The system includes work with graphical user interface (execution of documentation, menu, and so on). Functional capabilities of the system enable to do the following:

- Create 3D-models of really existing relief using a height map;
- Place any models of 3D-objects on the map (including equipment, infrastructure facilities, artifacts, and etc.);
- Specify any dependences between objects, including abstract ones (models of magnetic and gravitational fields);
- Implement first/third-person control (movement over the map, interaction with objects ...).

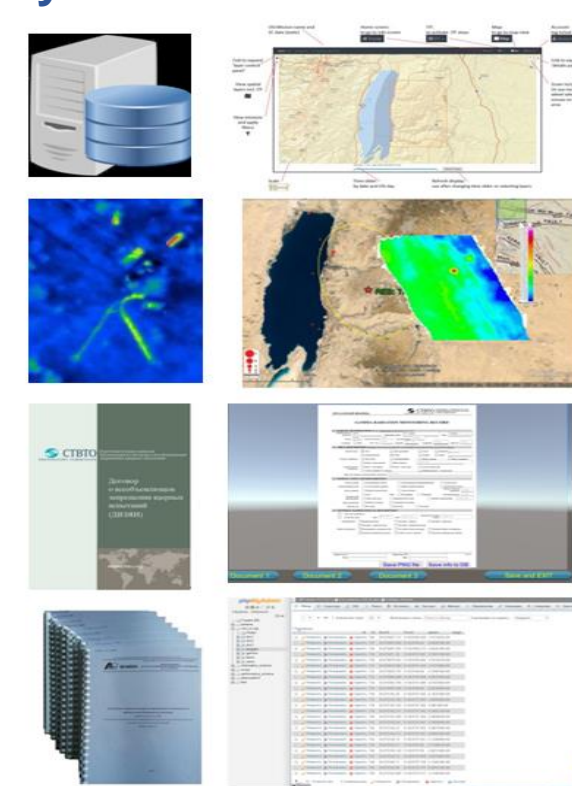
### Main Aims of OSI\_E\_Training\_3D Development

- Development of interactive 3D simulator for remote training of inspectors in OSI basic principles and methods;
- Development of the database of 3D-models of equipment that CTBTO PrepCom possesses for OSI conduction, including capability to use the equipment models while virtual learning;
- Development of OSI conduction scenarios for single/multi-user modes of program usage;
- Development of a database for OSI\_E\_Training\_3D and its integration with the existing database of on-site inspection Methods and tools;
- 3D-visualization of inspection process.
- Efficient training of surrogate inspectors in team and individual skills to work in inspection team.



### Basic Tasks Applied in the OSI\_E-training\_3D system

- Development of OSI\_E\_Training\_3D database for storing scenarios, documents, files, and for saving/downloading work scenarios;
- Development of scenarios for OSI\_E\_Training\_3D, development of character control functionality (work with equipment, motion functions, ...);
- Creation in the program of geophysical field models (gravitational and magnetic fields);
- Development of graphical editor to work with documentation (filling of typical document forms (Sampling Log/chain of custody, Gamma radiation monitoring record), their saving in document database);
- Optimization of system operation speed on different devices.



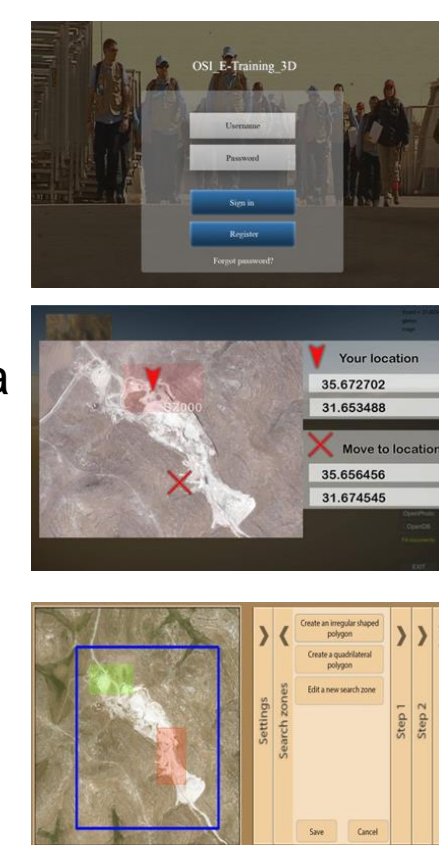
### Inspection Methods and Equipment Models Applied in OSI\_E\_Training\_3D



Figure 2 – 3D-modeling of irregular-shape objects for OSI\_E\_Training\_3D program module

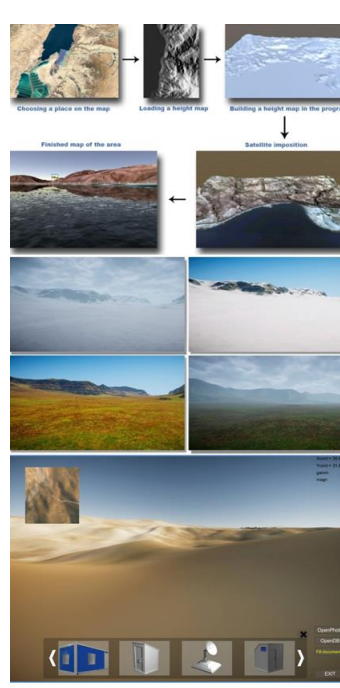
### OSI\_E\_Training\_3D Advantages

- Friendly interface and intuitively clear control;
- Multiplatform – capable of operating on different operation systems;
- User online interaction with studied OSI materials and processes;
- Capability to work in groups via local network or internet;
- Conciseness of material presentation;
- Wide application of state-of-the-art computer design tools and multimedia technologies;
- Work with the world's best technologies in the field of three-dimensional simulation (Unity and CAD systems)
- Import of 3D-models in different formats;
- Import of images in different formats;
- Import of sound;
- Import of video;
- Creation and import of animation.



### Creation of OSI Scenarios in OSI\_E\_Training\_3D

- Download of any relief from SAS Planet and Google Map;
- Fast setting of textures;
- Setting of weather conditions;
- Time setting;
- Placing of objects on a map (base of operations, artifacts, buildings);
- Setting of inspection teams;
- Selection of character external appearance;
- Audio/video presentation;
- User interface setting;
- Selection of equipment for OSI methods implemented in OSI\_E\_Training\_3D.



### Development prospects of the next version of the OSI\_E-Training\_3D system

To date OSI\_E\_Training\_3D is a program simulator for interactive training of OSI inspectors developed using the world's best technologies in the field of three-dimensional modeling, with friendly interface, ease of use and control. It provides a wide range of capabilities to import 3D models in different formats, sound, video, graphics, and animation. OSI\_E\_Training\_3D further development can take place in the following fields:

1. Development of extended menu of user settings for work with the program;
2. Development of an editor for work with documentation and for communication between users. Extension of available document templates in OSI\_E\_Training\_3D database (PIR, PFD);
3. Integration of additional geophysical field models into the OSI\_E-training\_3D system: based on the gravitational field mapping method:
  - model of the collapse sink anomaly
  - model of the fracture zone anomaly
 based on the passive seismic method:
  - simulation model of aftershocks seismic sources area
4. Development of integrated three-dimensional earth surface generator, generation of objects on the earth's surface, time scale, generator of weather conditions, change of day and night time, and etc.;
5. Extension of the database of 3D models of inspection equipment;
6. Development of multiplatform version of the program operating on the most of well-known Operation Systems and devices.

### IMS Stations Monitoring Data Analysis

VNIIA carries out the analysis of the International Monitoring System (IMS) data in order to detect seismic and infrasound events of interest as well as to reveal radiation situation over the terrestrial globe.

### Recording of Chemical Explosions in the North Korea by Ussuriysk Station

For 10 years of operation, the IMS seismic (PS37) and acoustic (IS45) arrays located at Ussuriysk region have detected about one hundred chemical explosions in the north part of the DPRK territory. Basically, the explosions were conducted out at two sites. The location of the sites and the epicenters of the explosions are shown in Figure 3.

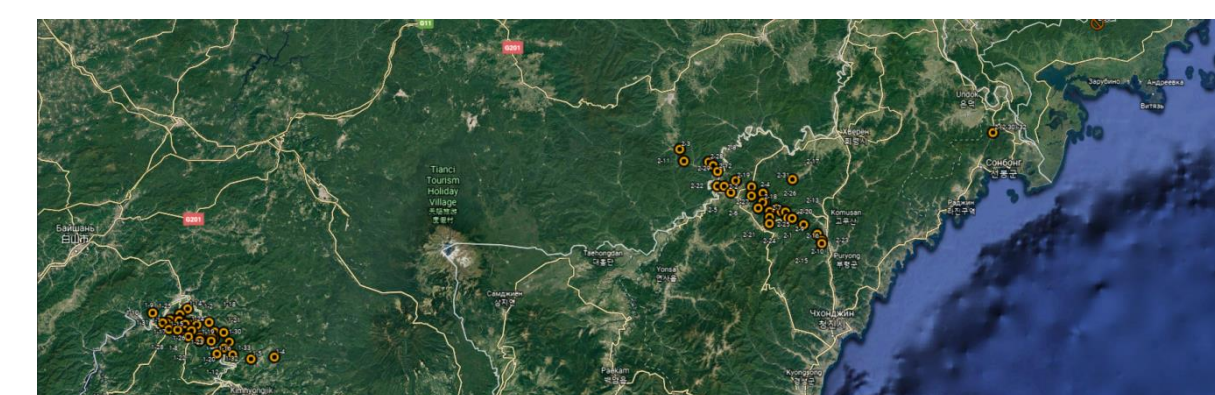


Figure 3 – Location of epicenters of chemical explosions in the north part of the DPRK territory

Seismic records of explosions for each site well correlate between each other, and are accompanied by acoustic signal. In the most of cases seismic signals from explosions were recorded by Ussuriysk station (PS37) and by the South Korean array (PS31); in some cases auxiliary station Kuldur (AS089) participated in processing. Acoustic signals were recorded practically by acoustic array at Ussuriysk (IS45) only, and in single cases by Japanese station IS30. The first site includes the territory of the missile base at Yeongjeo-Dong (North Korean Missile Base at Yeongjeo-Dong, Dave Schmerler, December 6, 2018). In 2014, the construction of a new facility was started near Hojung-ni (41.369776, 126.913196) [1]. Table 1 shows the list of explosions that have been recorded in this region since 2010 till now. The second site is located in the area of Tumangan and covers several square kilometers. There is also the largest railway junction connecting North Korea with Russia and China (2). Explosions start in the territory of China and cross the DPRK from north-east to south-west. Table 2 shows the data of explosions that have been detected in this region since 2010 till now.

Table 1. Explosions detected on the first site

NN	Date	Time h m s	Location	Depth, km	Magnitude, ML
1.	15.01.2010	06:18:01.4	41° 44' 126° 54'	0.0	2.1
2.	05.01.2011	05:46:05.7	41° 43' 126° 58'	0.0	2.0
3.	18.02.2011	15:25:58.2	41° 44' 126° 53'	0.0	2.5
4.	11.05.2011	05:30:07.7	41° 38' 127° 21'	0.0	1.9
5.	19.09.2011	03:30:25.2	41° 37' 127° 15'	0.0	1.5
6.	18.12.2011	05:18:05.1	41° 42' 127° 05'	0.0	2.1
7.	21.01.2012	04:51:58.4	41° 43' 126° 58'	0.0	2.1
8.	21.01.2012	06:19:31.9	41° 42' 126° 59'	0.0	2.4
9.	07.09.2012	04:50:50.8	41° 43' 126° 52'	0.0	2.1
10.	07.09.2012	04:53:30.5	41° 45' 126° 48'	0.0	1.9
11.	24.10.2012	04:37:14.9	41° 44' 126° 56'	0.0	2.6
12.	31.01.2013	05:22:07.7	41° 38' 127° 10'	0.0	1.4
13.	31.01.2013	07:39:50.2	41° 41' 126° 55'	0.0	2.3
14.	23.02.2013	04:40:51.6	41° 46' 126° 57'	0.0	2.5
15.	02.03.2013	09:43:10.7	41° 42' 126° 53'	0.0	2.1
16.	20.01.2015	04:12:56.5	41° 38' 127° 06'	0.0	1.9
17.	09.10.2015	03:37:49.4	41° 45' 126° 55'	0.0	2.2
18.	09.10.2015	04:41:17.9	41° 44' 127° 03'	0.0	1.3
19.	18.12.2015	05:53:07.2	41° 41' 127° 01'	0.0	2.2
20.	31.01.2016	08:44:42.8	41° 40' 127° 09'	0.0	2.4
21.	01.03.2016	04:06:41.7	41° 41' 127° 05'	0.0	1.6
22.	15.12.2016	05:25:59.2	41° 40' 127° 01'	0.0	2.9
23.	15.12.2016	09:23:48.0	41° 43' 127° 00'	0.0	2.7
24.	17.01.2017	06:08:52.0	41° 43' 126° 58'	0.0	2.9
25.	30.04.2017	05:05:54.4	41° 43' 126° 57'	0.0	2.7
26.	30.09.2017	06:47:29.7	41° 44' 126° 55'	0.0	2.5
27.	30.09.2017	07:43:58.1	41° 42' 126° 57'	0.0	2.6
28.	25.12.2017	04:03:15.1	41° 42' 126° 55'	0.0	2.6
29.	18.02.2018	04:45:36.9	41° 41' 127° 04'	0.0	2.5
30.	16.03.2018	06:21:40.6	41° 42' 127° 05'	0.0	2.8
31.	29.10.2018	04:04:03.7	41° 43' 126° 51'	0.0	2.7
32.	25.11.2018	04:56:16.3	41° 40' 127° 04'	0.0	2.4
33.	25.11.2018	05:00:03.4	41° 39' 127° 08'	0.0	2.7
34.	12.01.2019	06:14:07.1	41° 40' 127° 01'	0.0	2.5

Table 2. Explosions at Tumangan

NN	Date	Time h m s	Location	Depth, km	Magnitude, ML
1.	06.03.2011	08:58:14.5	42° 09' 129° 32'	0.0	1.7
2.	19.05.2011	09:38:21.6	42° 15' 129° 22'	0.0	1.8
3.	07.06.2011	09:50:34.7	42° 22' 129° 03'	0.0	1.8
4.	29.10.2011	07:27:49.6	42° 12' 129° 26'	0.0	1.9
5.	01.01.2012	01:12:57.7	42° 14' 129° 17'	0.0	1.6
6.	21.01.2012	07:54:45.6	42° 13' 129° 22'	0.0	1.8
7.	06.06.2012	07:04:16.7	42° 11' 129° 24'	0.0	1.8
8.	07.08.2012	10:11:02.3	42° 19' 129° 12'	0.0	1.7
9.	12.12.2012	08:31:27.4	42° 10' 129° 30'	0.0	1.6
10.	13.12.2012	08:25:52.3	42° 06' 129° 40'	0.0	2.0
11.	09.07.2013	07:33:41.4	42° 20' 129° 04'	0.0	1.7
12.	12.08.2013	05:53:45.5	42° 18' 129° 13'	0.0	2.6
13.	19.02.2016	10:55:09.1	42° 09' 129° 33'	0.0	1.8
14.	06.03.2016	11:05:03.8	42° 11' 129° 29'	0.0	1.7
15.	03.04.2016	09:15:27.5	42° 04' 129° 41'	0.0	1.9
16.	28.04.2016	08:17:48.9	42° 09' 129° 33'	0.0	2.0
17.	07.06.2016	10:29:18.3	42° 17' 129° 15'	0.0	1.9
18.	13.08.2016	09:42:01.4	42° 12' 129° 25'	0.0	1.8
19.	01.11.2016	10:24:16.4	42° 16' 129° 18'	0.0	1.9
20.	18.11.2016	10:40:49.0	42° 10' 129° 31'	0.0	2.3
21.	07.12.2016	09:58:20.2	42° 09' 129° 27'	0.0	2.4
22.	07.01.2017	08:15:57.8	42° 15' 129° 13'	0.0	2.3
23.	09.01.2017	10:14:08.1	42° 05' 129° 41'	0.0	2.1
24.	21.01.2017	12:30:11.0	42° 08' 129° 27'	0.0	2.2
25.	22.02.2017	09:55:27.7	42° 08' 129° 36'	0.0	2.0
26.	11.03.2017	10:23:23.3	42° 10' 129° 27'	0.0	2.0
27.	18.04.2017	17:54:00.4	42° 12' 129° 25'	0.0	2.1
28.	30.04.2017	09:38:58.6	42° 20' 129° 11'	0.0	2.4
29.	18.08.2017	09:46:14.3	42° 15' 129° 15'	0.0	2.3
30.	18.08.2017	09:46:14.3	42° 15' 129° 15'	0.0	2.3
31.	05.12.2018	07:21:32.8	42° 15' 130° 57'	0.0	-
32.	11.01.2019	09:21:51.1	42° 14' 129° 25'	0.0	2.9

Investigations have been carried out to locate more accurately North Korean chemical explosions by means of joint processing of seismic and acoustic signals acquired by regional stations. Data of the strongest events that took place on these sites recorded by at least two stations were used to make more accurate estimations of seismic and acoustic wave velocity and azimuth values for this region. The results obtained allow determining weak event epicenter location by regional arrays with less uncertainty. It is interesting to note the change of location of the infrasound source that took place on December 5, 2018 (0=07:21:32.8, REB) at Russian-Chinese boundary region according to the REB data after the processing of the event based on Ussuriysk seismic and infrasound array data. Application of the method of multichannel processing of seismic arrays records for identification of a weak signal based on the array of sensors, and forming of a phase beam [2] made it possible to reveal a weak seismic signal at Ussuriysk station (Figure 4).

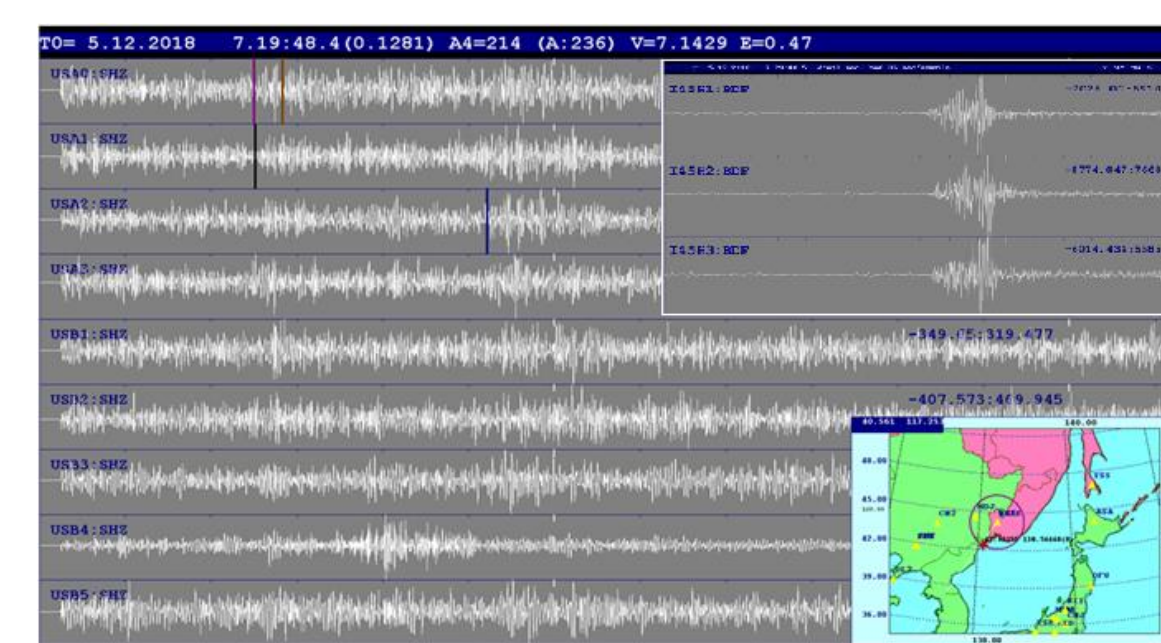


Figure 4 – Records of seismic and infrasound signals from explosion on 5.12.2018 by seismic and infrasound arrays at Ussuriysk

Joint processing of infrasound and seismic signals changed epicenter location on 60 km, and the source shifted to the territory of the largest DPRK railway junction Tumangan (42.417, 130.618) that connects the DPRK with Russia and China [3]. Currently, Russia and the DPRK are going to build a road bridge crossing the Tumen river. Figure 5 shows location results.

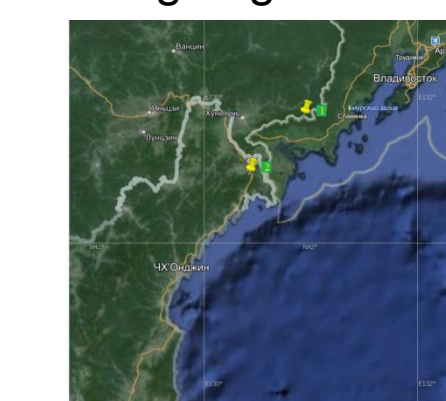


Figure 5 – Seismoacoustic source detected on December 5, 2018, 1 – epicenter location based on the REB, 2 – epicenter location estimated considering seismic data of Ussuriysk stations.

Application of the cross-correlation method for determining weak signals will make it possible to detect a lot of weak explosions and determine the level of economic and military activity in this region [4].

### Development and Installation at the IMS RN58 Station of the New Equipment for Monitoring Xe Isotopes

Production prototype of the automated equipment system for monitoring of radioactive noble gases contained in the atmosphere surface layer named MIKS had been developed and produced at VNIIA during the period from December, 2013 till June, 2016. The system prototype was demonstrated to the Executive Secretary of the CTBTO PrepCom during his official visit to Russia in April, 2016. Initially it was planned to install MIKS system at radionuclide station RN61 for updating its characteristics to the required level for certification of the station. However, after conduction of tests on 09.09.2016 in the DPRK there appeared the necessity to install xenon isotopes monitoring equipment at Ussuriysk radionuclide station. Following Rosatom SC and the RF MoD mutual decision MIKS system was promptly delivered to Ussuriysk (September 19, 2016) and mounted. Measurements were started on October 16, 2016. Since November, 2016 data of MIKS system has started to arrive in the International Data Center.



Figure 6 – MIKS system is deployed at RN58 Ussuriysk Station

Currently, the system operates in automatic mode and implements continuous monitoring of radioactive noble gases (RNG) at the IMS station Ussuriysk. In the course of trial operation of the system, by the end of the year 2018, there had been carried out updates of the detecting and gas-processing units of the system aimed to meet the certification requirements as to their characteristics (Figure 7).

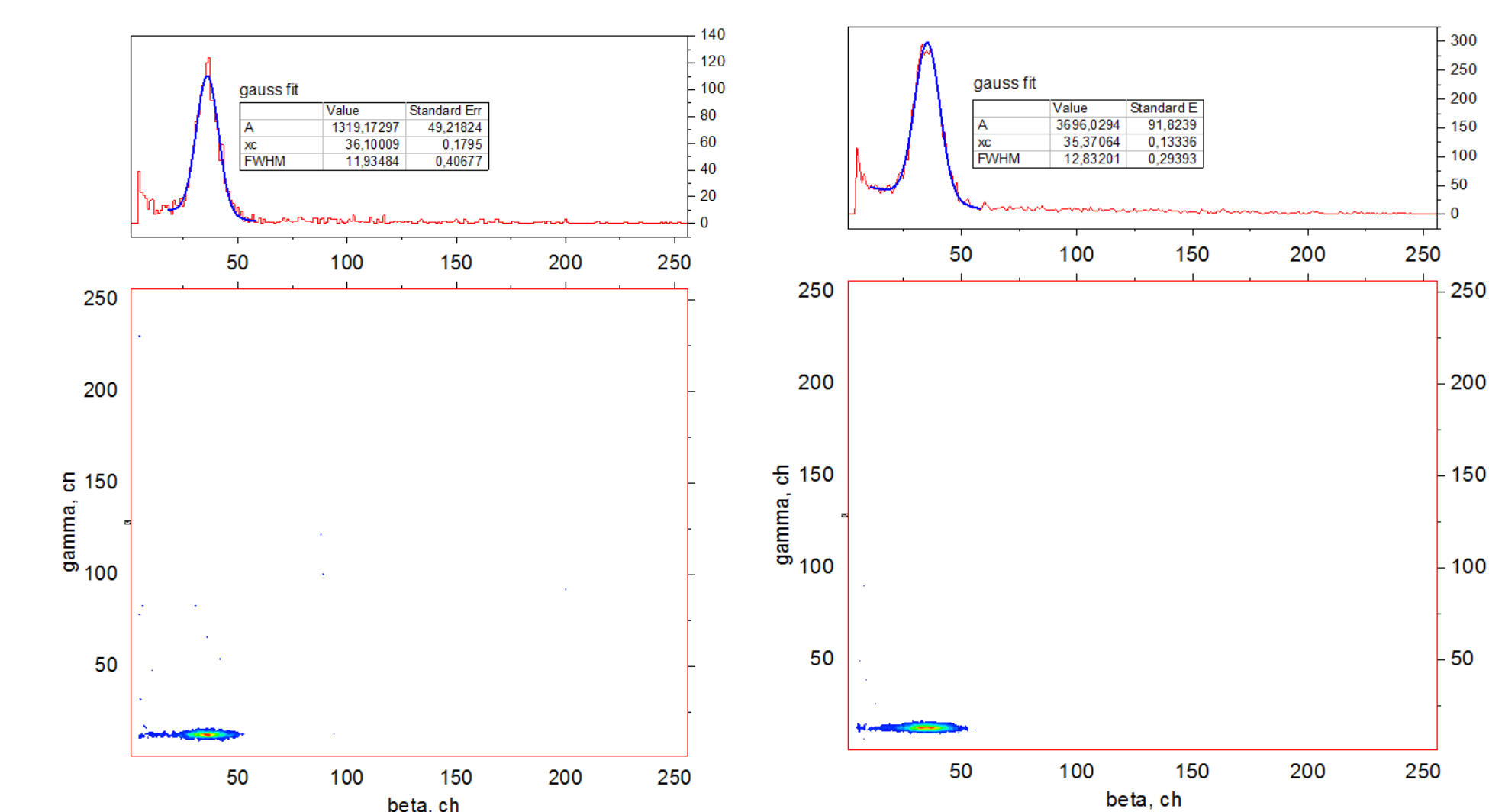


Figure 7 – Bar charts of <sup>131</sup>Xe emission distribution recorded by the detectors of the first (on the left), and the second (on the right) sides of the system. Energy resolution of the detectors at 129 keV beta energy is 36 and 38 keV, respectively

In January, 2019, ATLO3 confirmed that archive bottles of MIKS system submitted for analysis contain stable xenon, and the results satisfactorily agree with the volume measured by the system. The system extracts at least 0.87 ml of stable xenon a day from the air (Figure 8).

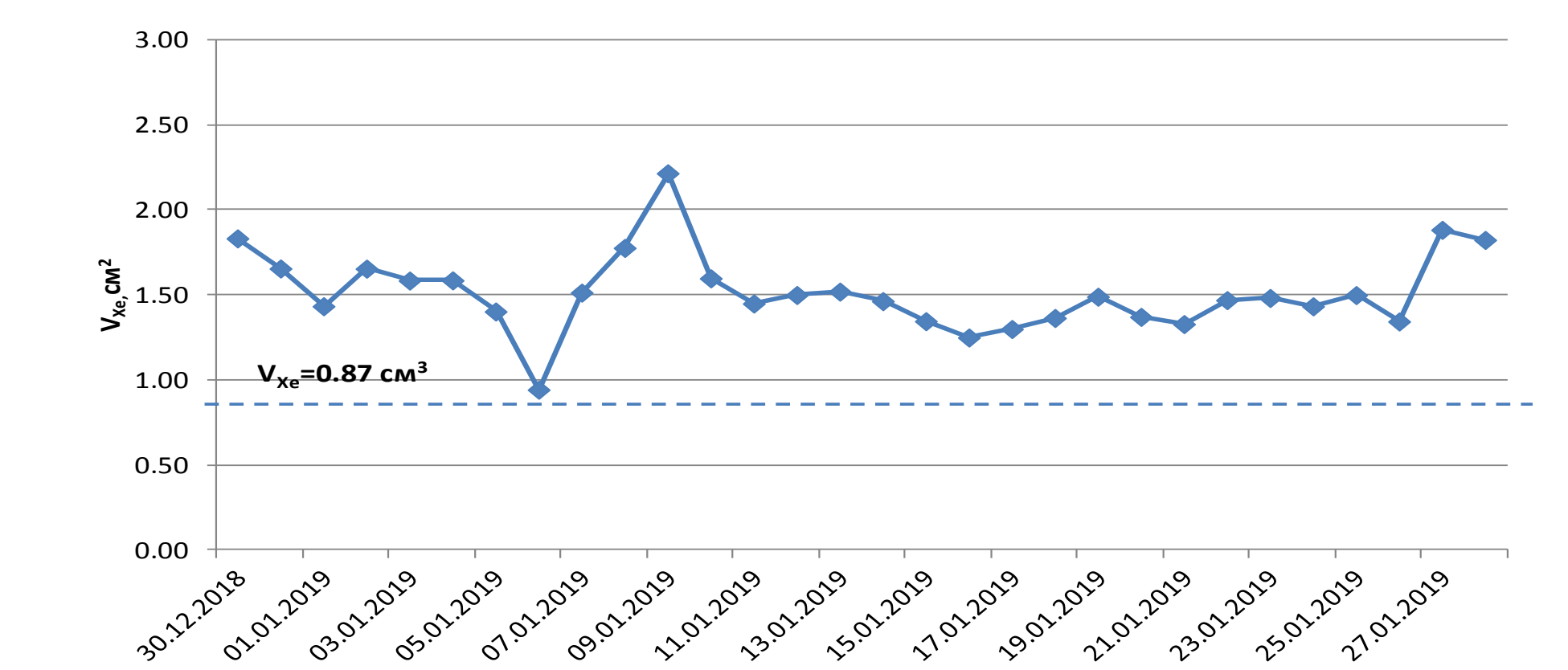


Figure 8 – Xe volume for 24 hours over 0.87 ml

Based on the results of on-site pre-acceptance procedure planned to be conducted at RN58 station in June, 2019 there will be prepared a report to the PTS on the system compliance with the PTS tasks.

### References:

1. <https://www.armscontrolwonk.com/archive/1206442/north-korean-missile-base-at-yeongjeo-dong/>
2. Ringdal, F. and T. Kværna (1989): A multichannel processing approach to real time network detection, phase association and threshold monitoring, Bull. Seism. Soc. Am., 79, pp. 1927-1940.
3. <https://beyondparallel.csis.org/making-solid-tracks-north-korea-railway-connections-china-russia/>
4. Finding aftershocks with waveform cross correlation. D. Bobrov, I. Kitov, M. Rozhkov. IDC. CTBTO, SnT2017, T3.5-P19.