VNIIA Works Relating to CTBT Technologies

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Abstract

VNIIA is the leading organization of Rosatom State Atomic Energy Corporation for the CTBT implementation, and currently fulfills works in the following areas:

- repair and upgrade of technological equipment of the International Monitoring System (IMS) radioactive noble gas (RNG) stations in the Russian Federation;
- scientific and methodological support of on-site inspection activities;
- collection of geophysical and radionuclide data based on the products of the International Data Center (IDC), and its further analysis to detect events evidencing possible non-observance of the CTBT by other States Parties to the Treaty;
- develops and carries out an upgrade of the e-learning system software for training of potential inspectors in the On-site Inspection (OSI) methods and procedures using the world's latest GIS technologies. Within the framework of the international cooperation with the CTBTO PrepCom, develops solutions and an interface for e-training system integration with the CTBTO PrepCom products, such as FIMS and IIMS, using a wide range of technologies: ArcGIS, WebOffice, and Cartopac management system.

Russian Segment of the CTBT International Monitoring System Stations

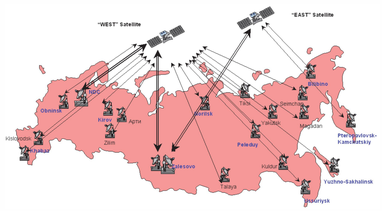


Figure 1 – Diagram of the Russian segment of the IMS and of the independent communications system

The Russian segment of the CTBT verification mechanism includes 31 IMS stations (6 seismic stations of the primary network, 13 seismic stations of auxiliary network, 8 radionuclide stations, and 4 infrasound stations), the central radionuclide control laboratory, and the National Data Center (NDC) in Dubna. The Russian segment of the Global Communications Infrastructure that links together the IMS facilities and the NDC in the territory of Russia and provides data transmission from them to the IDC and reception of the IDC data and products at the NDC should also be mentioned.

VNIIA provided the establishment and certification of 14 IMS facilities in Russia under the contracts with the CTBTO PrepCom. In addition, VNIIA provided the establishment and upgrade of 11 facilities of the independent communications system based on satellite channels.

Analysis of the IMS Stations Monitoring Data and Identification of the Sources of Radionuclides Emitted to the Atmosphere for the Purpose of Detection of Events at Nuclear Test Sites

In 2016, the Democratic People's Republic of Korea (the DPRK) conducted two nuclear tests. A nuclear explosion of Mb=4.8 magnitude was recorded by the network of the CTBTO/IMS seismic stations on January 6, and a more powerful explosion of Mb=5.3 magnitude was recorded on September 9; and then special attention was paid to the acquisition of any data on radioactive fission and decay products that conceivably entered the atmosphere.

Figure 2 shows the results of analysis of the events in North Korea as observed by the International Monitoring System of the IDC (including Russian segment of stations) and the United States Geological Survey (USGS).

Identification of North Korean explosions and determination of their yield based on Ussuriysk Station data.

Explosive yield was determined using the formula $m_b=4.45+0.75 \cdot \log(Y)$, where m_b stands for the magnitude, and Y for the explosive yield in kilotons [2].

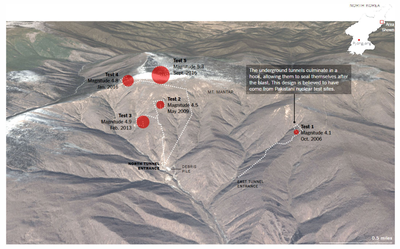
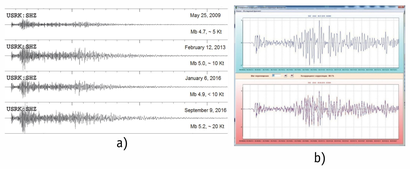


Figure 2 – Layout of nuclear explosions at the North Korean Test Site https://www.digitalglobe.com/



a) b)

Figure 3 – a) Segments of seismic records of North Korean nuclear explosions in the period from 2009 to 2016 at Ussuriysk Station, b) Correlation analysis of seismic records of events of 09.09.2016 (lower) and 06.01.2016 (upper)

Table 1 – Parameters of detected radionuclides

Data	Station	Isotope	Concentration ($\mu Bq/m^3$)	Detection error	MDC
March 12	RN22	Xe-133	206.58	25.4	155.92
March 12	RN58	Xe-133	377.54	19.7	218.56
March 13	RN58	Xe-133	2131.77	16.0	921.54
March 13	RN22	Xe-131M	174.27	23.5	95.7
March 13	RN22	Xe-135	404.13	60.1	808
March 13	RN58	Xe-135	4479.7	29.3	3950.1
March 13	RN58	Zn-65	75.77	4.9	3.88
March 13	RN58	Cs-137	426.41	5.1	2.22
March 14	RN22	Xe-133	152.98	35.2	171.61
March 14	RN58	Zn-65	7.16	13.1	4.18
March 14	RN58	Cs-137	31.44	5.6	2.44
March 15	RN22	Xe-131M	122.38	30.6	100.88
March 15	RN58	Xe-133	1446.1	9.8	384.88
March 16	RN22	Xe-131M	205.62	25,6	144.45
March 16	RN58	Xe-131M	238.27	35.9	258.11
March 16	RN58	Xe-133M	126.38	63.1	263.47
March 16	RN58	Xe-135	1169.7	36.1	1301.21

Monitoring and Localization of Technogeneous Accidents in the Territory of Russia and Neighboring Areas

The results are exemplified by the event in the area of Japan on March 11, 2017. RN38 Radionuclide Station (Takasaki, Japan) recorded radionuclide emission on March 13 (Figure 5 and Table 2).

It should be noted that radionuclide emission was detected after a new large earthquake that occurred on March 11, 2017 (Mb=5.0) (Figure 6a) at the same place, where the earthquake on March 11, 2011 accompanied by tsunami occurred and led to environmental disaster at Fukushima NPP. Figure 6b shows cartographic image of back atmospheric transfer to Takasaki Radionuclide Station that recorded increased concentration of aerosols and noble gases during March 13, 2017.

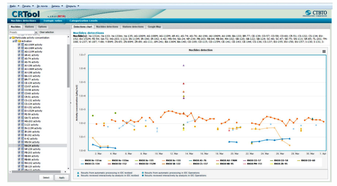


Figure 5 – Radionuclides detected at Takasaki Station (RN38) in March, 2017



Figure 6 – Data on the earthquake of March 11, 2017 based on the IDC data (a), and results of back atmospheric transfer to Takasaki Radionuclide Station that recorded increased concentration of aerosols and noble gases on March 13, 2017

Table 2 – Radionuclides detected at RN38 Station (Takasaki, Japan) on March 13, 2017

Date	Station	Isotope	Concentration ($\mu Bq/m^3$)	Detection error ($\mu Bq/m^3$)
March 13	RN38	Xe-131M	120.16	56.23
March 13	RN38	Xe-133	496.46	62.87
March 13	RN38	Xe-133	331.55	70.26
March 13	RN38	Xe-131M	174.27	23.5
March 13	RN38	Au-196M	81868.61	24546.28
March 13	RN38	Co-57	7083.09	145.72
March 13	RN38	Co-58	81.24	3.52
March 13	RN38	Co-60	9887.97	172.89
March 13	RN38	Eu-152	21164.8	435.45
March 13	RN38	Eu-152M	1733943.0	145650.4
March 13	RN38	Sb-122	577.04	18.5
March 13	RN38	Cs-137	22721.5	428.09
March 13	RN38	Nb-95	46.07	3.27
March 13	RN38	Zr-95	34.9	5.41

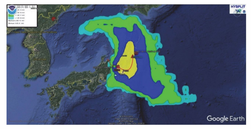


Figure 7 – Calculation of the direct atmospheric transfer from the territory of Fukushima NPP on March 12-13, 2017

E-learning System for Training Potential Inspectors in OSI Methods and Procedures

The model and software of the e-learning system are developed at VNIIA for the tryout of the OSI procedures. The system is designed for training inspectors in procedures and methods of conducting on-site inspections within the framework of the CTBT. Functional capabilities of the system enable to model real situations that can take place in the course of an OSI, play through the actions of the inspection team members during the preparation and conduction of an OSI, implement the simulation of inspection activities at the stage of data collection and processing, and visualize the simulation results on monitor screens.

The system was tested within the framework of the international Tabletop Exercise TTE08 conducted by the PTS in Baden in 2008 and a number of arrangements organized by the CTBTO PrepCom in the course of preparation for the Integrated Field Exercise 2014.



Figure 8 – Interfaces of e-training system individual blocks



Figure 9 – Software tools that provide e-training system operability for ArcGis 9.3 and ArcGis10.X products

E-training System Evolution: OSI_E-Training_3D Program Design

Within the framework of the e-training system upgrade a training program 3D module OSI_E-Training_3D for potential inspectors is also being developed. The aim of this work is to design an interactive three-dimensional space with the actual landscape of the inspected region, create the landscape texture, including rivers, lakes, roads, houses, forests and so on, and design 3D models of personages, inspection equipment, and OSI scripts.

OSI_E-Training_3D program is an application operating on Windows, Linux, and OS operation systems. The application is a 3D game that consists of several scenes containing their own virtual three-dimensional spaces. Every scene contains a terrain (game location) and game objects, including personages.

The e-training system update concerning the development of OSI_E-Training_3D module for inspectors training, is focused on the following:

- modeling of the three-dimensional interactive space of the inspected region based on the actual landscape, including simulation of infrastructure objects, forest cover, water bodies, roads, and so on;
- design of network interaction using Authoritative Server. Design of multiuser connection to the program;
- spatial 3D modeling of complex-shape objects. Development of assets – geometrical models, textures, and etc;
- creation of high-polygonal 3D personages and their character controllers;
- writing scripts for components interaction in the program;
- user interface (UI) elements development;
- development of OSI scenario in OSI_E-Training_3D program.

OSI_E-Training_3D program is designed for training experts in implementation of OSI activities. The program will be placed in special cluster of the training server.

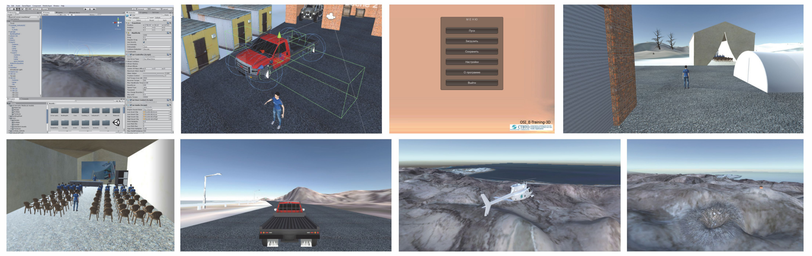


Figure 10 – OSI_E-Training_3D program

Development of New Xe Isotopes Monitoring Equipment and Its Installation at RN58 IMS Station

A commercial prototype automated system named MIKS for monitoring radioactive noble gases content in the surface atmospheric layer was designed and manufactured at VNIIA within the period from December, 2013 to June, 2016.

The prototype system was demonstrated to the Executive Secretary of the CTBTO during his official visit to Russia in April, 2016.

Initially, it was planned to install the MIKS system at RN61 Dubna Radionuclide Station in order to enhance its characteristics to the values required for the station certification, however, after the test carried out at the DPRK on 09.09.2016 there appeared the necessity to install Xe isotopes monitoring equipment at the Ussuriysk Radionuclide Station.



Figure 11 – MIKS system demonstration to Lassina Zerbo, the Executive Secretary of the CTBTO, and to Yu.G. Sych, Head of 12th GU MO of the RF



Figure 12 – MIKS system is deployed at RN 58 Ussuriysk Radionuclide Station

Pursuant to the joint Rosatom and MoD RF resolution the MIKS system was promptly delivered to Ussuriysk (on September 19, 2016) and installed. On October 16, 2016 measurements were started.

Since November 16, 2016 data from MIKS system has started to come to the International Data Center.

Currently, the system operates in automatic mode and monitors continuously RNG at the IMS Station at Ussuriysk.

At the same time works are carried out to prepare the system for certification.

Investigations of Trend in the Results of Xe Isotopes Specific Activity Measurements at the IMS Stations

Data on measurement results of Xe isotopes content in the air are provided on ctbto.org website of the International Data Center in graphic and digital form separately for each of the four radionuclides (^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe) that are a subject of research of the International Monitoring System established by the CTBT Organization in compliance with the Comprehensive Nuclear-Test-Ban Treaty.

Radioxenon sources include nuclear power plants, nuclear engines, enterprises that manufacture isotope medical products, and explosions of weapon nuclear devices.

We have carried out the analysis of data given on page https://crtool.ctbto.org/preport/crtool/viewDetectionNuclides.do in order to determine whether there are any trends in Xe radioactive isotope measurement results.

The period of increased radioxenon concentration in atmosphere in 2011 related to the accident at Fucushima Nuclear Power Plant (Japan) was excluded from the analysis.

Figure 13 shows measurement results of the respective Xe isotopes with the superposed trend lines.

In order to form a time trend line the linear single-factor regression Y=a·X+b and least square procedure were applied. Only representative data samples of N>30 size were analyzed.

Calculated coefficients of determination and validity coefficients of approximation are given in Table 3.

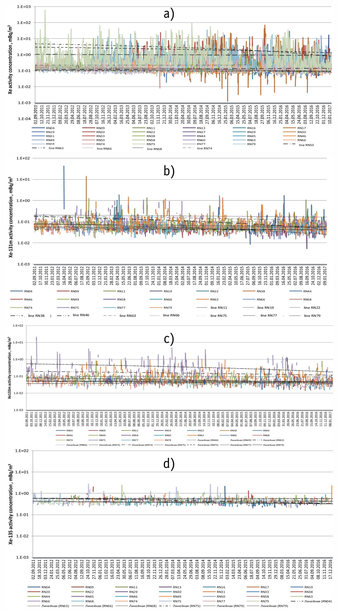


Figure 13 – a) through d)
Measurement results of ^{133}Xe, ^{133m}Xe, ^{135m}Xe, ^{135}Xe concentration having been acquired by the CTBT IMS since September, 2011 and lines of the appropriate trends

Table 3 – Summary table of trend line coefficients

RN #	a				b				R^2			
	133	133m	131m	135	133	133m	131m	135	133	133m	131m	135
4	-0.422	-0.435	-0.121	-1.023	1102.3	115.35	90.523	416.35	7.00E-05	0.0118	0.0027	0.0103
9	-0.18	0.021	-0.002	-0.923	193.61	48.88	50.502	519.01	0.0123	0.0059	0.0002	0.1344
11	-0.042	-0.053	-0.022	-0.432	137.91	61.357	75.387	469.19	0.0066	0.0503	0.0039	0.0228
13	-17.74	-	-	-	352.75	-	-		0.2685	-	-	-
16	-1.26	-	-	-	178.7	-	-		0.0394	-	-	-
17	-1.65	-	-	-112.6	2145.2	-	-	949.35	0.0028	-	-	0.2329
19	0.0215	0.004	-0.11	0.5889	66.638	29.154	42.242	269.55	0.0019	0.0001	0.0299	0.0673
20	-0.253	-	-	-42.33	233.81	-	-	275.65	0.0018	-	-	0.5699
22	-1.745	-1.926	-0.047	-42.33	295.17	102.38	188.29	275.65	0.0238	0.263	2.00E-05	0.5699
27	-44.93	-	-	-	386.4	-	-		0.6768	-	-	-
29	10.489	-	-	-	328.81	-	-		0.0415	-	-	-
30	-0.905	-	-	-	1425.8	-	-		0.2624	-	-	-
31	-8.94	-	-	-	177.92	-	-		0.1971	-	-	-
33	-0.091	-	-	162	1172.2	-	-	326.5	1.00E-04	-	-	0.3645
38	-0.104	-0.496	-0.217	-14.94	303.02	249.23	182.63	3078	0.0053	0.0043	0.0039	0.0256
44	-1.421	-0.05	-0.358	-0.688	513.27	68.682	467.18	613.89	0.0095	0.0766	0.0077	0.0977
45	0.5909	-	-	41.844	307.74	-	-	510.63	0.0467	-	-	0.2713
46	0.0627	0.0187	-0.001	0.2741	151.7	38.376	41.801	330.89	0.0016	0.0073	3.00E-05	0.0937
49	0.1929	-0.026	-0.085	0.2365	307.15	98.061	115.55	543.7	0.0022	0.0018	0.0122	0.004
50	-0.91	-	-	-31.7	138.26	-	-	186.97	0.0026	-	-	0.1151
58	0.402	-1.037	-0.802	-41.69	129	74.542	76.858	812.68	0.0179	0.4028	0.114	0.6649
60	9.619	-2.84	-11	-	104.4	67.417	87.09	-	0.3824	0.2787	0.4133	-
63	-0.087	-0.118	-0.129	-0.508	1012	180.65	178.74	559.82	0.0003	0.0195	0.0169	0.0206
66	-0.17	-0.08	-0.029	-0.716	188.32	64.855	55.678	443.4	0.1334	0.1647	0.0407	0.0782
68	-0.046	-0.052	-0.058	-0.4	113.84	48.483	53.986	416.35	0.0173	0.1221	0.1324	0.0748
74	0.0016	-0.079	-0.045	-0.198	221.26	83.054	75.093	448.8	9.00E-07	0.1528	0.0965	0.0183
75	-2.851	-0.662	-0.083	0.0302	5041	563.42	181.28	574.09	0.0037	0.0082	0.0036	3.00E-05
77	-0.011	-0.034	-0.016	0.1058	97.139	48.53	48.782	399.07	0.0012	0.0486	0.0138	0.0019
79	0.0079	-0.004	-0.004	0.0715	105.32	51.121	56.907	390.37	0.0008	0.0011	0.001	0.0066

Trends importance estimation was carried out, i.e. the degree of importance of their contribution to data variability. Student's t-test was applied for this purpose. The analysis has shown that data on 135Xe isotope concentration is of essentially changeable nature, while ^{135}Xe, ^{131m}Xe, and ^{133m}Xe concentration data are quite stable; at significance level p=0.05 inclination factor **a** is indistinguishable from 0, i.e. no long-term trends could be revealed, which is clearly shown in Figure 14.

It should be noted that data for the stations is of different volume and has considerable time gaps, which makes it difficult to perform their analysis and comparison.

Only 3 of 87 investigated trends have significant positive angle of inclination according to Student's t-test (p=0.05) (RN19 Xe-135, RN45 Xe-133, RN46 Xe-135). However at the same time these trends have low validity coefficients of approximation. This data can be neglected relative to the general background.

Wide range of investigated data allows trends obtained, and, first of all, lack of positive trends in the results of measurements of radioactive xenon isotopes to be considered as representative.

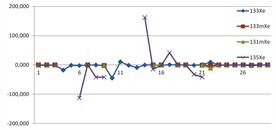


Figure 14– Inclination factors a of assumed trends of radioxenon measurement results

It is possible to state:

1. Data on 133Xe, 131mXe, 133mXe isotope concentrations is of essentially variable nature;
2. There is no tendency of radioactive xenon isotopes content rise in atmosphere.

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