2. UNDERSTANDING THE NUCLEAR EXPLOSION SOURCE

Conveners:

MIKA NIKKINEN
International Data Centre
CTBTO

MATJAZ PRAH
On-Site Inspection Division
CTBTO

MARTIN KALINOWSKI
Centre for Science and Peace Research,
University of Hamburg
Germany

Invited Speakers:

HARRY MILEY
Pacific NW National Laboratory
United States of America

ANDERS RINGBOM
Swedish Defence Research Agency (FOI),
Sweden

HARRI TOIVONEN
Security Technology Radiation and Nuclear
Safety Authority (STUK)
Finland

ORAL PRESENTATIONS:

T2-O1. Understanding the radionuclide source term for underground nuclear explosions

Harry Miley
Pacific Northwest National Laboratory, United States of America
Contact: *harry.miley@pnl.gov*

The design of the International Monitoring System (IMS) radionuclide network and the design of an On Site Inspection depend critically on the radionuclides emitted from an underground test. The largest uncertainties in understanding the detectability of radionuclides in the IMS and OSI originate from the relatively unstudied processes that govern the transport of radioactive material from the site of an explosion to the accessible environment, i.e. the atmosphere, surface waters, and the surface soil, including the top few meters of soil. A surprising recent result is that Xe-131m may be the most important xenon isotope available for OSI, and backgrounds arising from natural and anthropogenic sources should be very low. A new idea about the collection of radioactive material at depth will be presented. The results of several recent investigations into transport and natural backgrounds will be reviewed, especially concerning noble gas, and suggestions for future research directions in radionuclide source terms will be presented.

T2-O2. The global atmospheric noble gas background

Anders Ringbom
Swedish Defence Research Agency (FOI), Sweden
Contact: *anders.ringbom@foi.se*

The 40 station noble gas network in the International Monitoring System (IMS) is well underway to be finalized. Presently, more than 1000 air samples per month are measured with respect to the four isotopes 133Xe, 133mXe, 131mXe, and 135Xe, and the resulting spectra are transmitted to the International Data Center (IDC), and to the National Data Centers around the world. In addition, several measurement campaigns have been performed at key locations in order to further increase the global radioxenon data set.
Studies of the observed atmospheric activity concentrations and isotopic ratios and the use of atmospheric transport modeling has gained new knowledge of the anthropogenic radioxenon background as well as new insights in the possibilities to detect nuclear explosions using radioxenon detection.
Among the most important result from the collected data is the conclusion that the global background is dominated by releases from facilities producing medical isotopes.
An updated analysis of the global radioxenon background will be presented, as well as an assessment of the global coverage of the radioxenon network, including possible improvements of the network with respect to the number of installed noble gas stations and station locations.

T2-O3. New and novel technologies for CTBT radionuclide measurement and analysis

Harri Toivonen
Finnish Radiation and Nuclear Safety Authority, Finland
Contact: *harri.toivonen@stuk.fi*

Many of recent advances in radiation detection technology have their origin in nuclear security and safeguards. These R&D efforts are promising also from the point of view of the CTBT verification. The present paper reviews the radionuclide detection technologies and seeks for scientific and technical improvements, also from the point of view of other disciplines, such as optics. The radionuclide particle detection system of the CTBTO is state-of-the-art technology from 1990's. The major drawback is the filter itself which is large and provides bad geometry for the data acquisition. The detection limits could be essentially improved through better sampling technology facilitating the use of novel non-destructive measurement technologies – in addition to gamma spectroscopy. The noble gases – krypton, xenon and argon – produced in an underground nuclear test may leak to the surface. The CTBT verification technology has thus far been focused on xenon. However, the gas sampling, measurement and analysis are not yet fully optimized. The quality of the monitoring results is based on the reliability of the isotope ratios. This target can be improved by high-purity standards. In addition, the nuclear decay data must be known much better than today. Of particular importance are the direct fission yields. Advanced argon measurement technology could reveal an underground nuclear test months after the detonation. However, the low-energy photons and electrons are a major challenge for the detection system.

T2-O4. Numerical experiments on explosions triggering earthquakes

Luis Angel Dalguer, Florian Haslinger, Seok Goo Song, Tarje Nissen-Meyer, Domenico Giardini
Swiss Seismological Service, ETH-Zurich, Switzerland
Contact: *dalguer@sed.ethz.ch*

Seismic triggering from underground nuclear explosions are of considerable interest in the context of verification and test limitation treaties. Whether and how underground nuclear explosions (UNEs) can trigger earthquakes is still not fully understood. To date exists no strong evidence of a causal connection between UNEs and large earthquakes. Analysis of local seismic recordings of UNEs at the Nevada Test Site show, however, that some tectonic stress is released simultaneously with the explosion (USGS website), suggesting that the explosions release elastic strain energy stored in the rock, and consequently inhibit the activation of earthquake. We develop 3D numerical models of UNEs near potential active faults to evaluate the possibility of earthquake faulting activation or inhibition. The explosion source is modeled as an equivalent point source in an elastic medium. Modeling is performed for wavelengths long compared to the characteristic source dimensions and for explosion from kiloton to megaton TNT-equivalent. The earthquake is modeled as a dynamically running shear crack on a frictional interface embedded in a linearly elastic continuum. The state of stress and frictional properties on the active faults are hypothetically set to represent a fault in the hypocentral area close to rupture initiation. Stress distribution on the fault is stochastically represented so that average stress drop is around 3MPa, as statistically derived from seismological observations of past earthquakes. Fault rupture, if activated, is triggered when the stress overcome the strength of the fault. The level of the dynamic stress perturbation on the fault after the explosion is evaluated.

T2-O5. Unstructured grid simulation of the atmospheric pressure-driven subsurface xenon-tracer transport

Robert Annewandter, Karen Schmid
Institute of Petroleum Engineering, Heriot-Watt University, United Kingdom
Contact: *robert.annewandter@pet.hw.ac.uk*

Source discrimination for underground nuclear explosions can be affected by differences in the diffusivities of the four CTBT-relevant radioxenon isotopes during migration through geologic media caused by atmospheric pumping. Calculations on arrival times of these isotopes and their surface concentration levels, depending on weather patterns, are critical in narrowing down the on-site inspection activities such as soil gas sampling according to the CTBT provisions. A better understanding of the surface concentration level distributions can support optimised soil gas sampling schemes. A prior numerical test-site model for the Nonproliferation Experiment was realized through a uniform porous medium traversed by a narrow, millimeter-width fracture. We revisit the experiment by simulating the experimental data using a higher-order accurate finite volume - finite element method, which is implemented into the Complex System Modeling Platform (CSMP). This enables us to predict the arrival times and concentrations with greater accuracy. Additionally, the combination of finite volumes and finite elements allows for better geometric flexibility. We can therefore study tracer transport in more complex, but geologically more realistic, fracture models and evaluate how the predictions change compared to the prior model. This study presents results on time of arrival of the four CTBT-relevant xenon isotopes as well as their surface concentration levels and isotopic activity ratios.

T2-O6. Analysis of fission products in air samples due to nuclear explosion source

Abdus Sattar Mollah
Bangladesh Atomic Energy Commission
Contact: *mollahas@gmail.com*

The most important source of artificially created radionuclides is neutron-induced nuclear fission. The chemical and physical forms of the active species determine deposition, migration and uptake are radioactivity by living organisms. A variety of systems and processes may introduce radioactivity into the environment. Human activities involving nuclear weapons and the nuclear fuel cycle (including mining, milling, fuel enrichment and fabrication, reactor operation, spent fuel storage and reprocessing and waste storage), leading to significant creation and release of radioactivity. The physical and chemical form of radionuclides may vary depending on the release and transport conditions in addition to the element properties. After a peer review of literature data about nuclear fission products, it is observed that no clear chemical species, chemical compounds, or chemical processes were available after actual releases of nuclear fission products during planned releases, accidents, or in nuclear detonations. Detection and measurements of fission products are necessary in the field of nuclear safety and radiation protection, as well as reducing the expected potential risk associated with the radionuclides of interest. A programme has been undertaken to develop a simple analytical technique for easy detection of fission products in air samples. The objective of this study is to provide a simple analytical technique for detection and analysis of radionuclides due to fission products in air samples. This technique will be utilized for rapid detection and analysis of fission products in air samples due to nuclear explosion source. Observed radionuclide

concentrations are reported and isotope ratios and meteorological air parcel trajectories are used to characterize the source.

T2-O7. Modelling of elastic waves generated by a point explosion

Zurab Kereselidze, Nino Tsereeli
Alexidze st.1. 0171 Tbilisi, Georgia
Contact: *z_kereselidze@yahoo.com*

During the explosion the avalanche emission of energy take place. A shock wave is arisen. It causes plastic deformation. In case of homogeneity medium in the souse area the plastic wave front must be redial. It is evidence that the elastic deformation became effective when density of the released energy became proportional to the density of energy of elastic deformations. It takes place on surface of earthquake source. Spherical symmetry is true only near the hypocenter. On the surface of source this symmetry can be failed, but not as much that approximation form of source became irregular. To the full sufficiency can consider the approximation form of source as a rotational ellipsoid. So Generated waves caused due to the elastic deformation of rocks appear only on the surface of source and then propagate trough the medium. As per our model the tension – compression deformation (comprehensively tension) will be considered. This deformations produce body waves on the surface of source.
Conditions of equilibrium of the ellipsoid boundary can be obtained by the analogue equation of Laplacian one. In this equation instead of capillary tension coefficient (elastic module) will be taken incompressibility or bulk modules K multiplied on the characteristic size of ellipsoid c.
The free oscillations frequency spectra of elongated rotational ellipsoid (source of xplosion) is calculated.
This model give us possibility to solve inverse task by analyze discrete spectra of source self oscillation. So it is possible to determine linear parameters of source. After this It is possible to calculate the release energy of explosion. From theoretical point of view very interesting is to calculate synthetic seismograms by spectra of explosion.

T2-O8. The source time function of an explosive source

Anton Ziolkowski
University of Edinburgh, United Kingdom
Contact: *Anton.Ziolkowski@ed.ac.uk*

The purpose of this paper is to draw the attention of the seismological community to a published method for determining the source time function of an explosive source, where there is more than one explosion at the same site. It is normally impossible to measure the source signature of an explosive source, because the incident and scattered fields overlap in time. The problem can be solved when a second explosion occurs at the same site: the source signatures are related by a scaling law, which follows from the invariance of the medium parameters with the size of the charge. The volume injection function of the larger shot is an amplified and stretched version of that of the smaller shot, the amplification factor being equal to the ratio of the source energies and the time stretch factor being equal to the cube-root of this ratio. At a given receiver, the response to one shot is a convolution of the source signature with the impulse response of the earth, plus noise. The two shots and the scaling law give three independent equations relating the three unknowns: the two source signatures and the impulse response of the earth (plus noise). We present a test of this idea using published dynamite data and a third shot which puts the theory at risk.

T2-O9. Effects of non-isotropic explosion sources upon the utility of the Ms-mb discriminant

Paul G. Richards
Columbia University, United States of America
Contact: *richards@LDEO.columbia.edu*

The Ms--mb discriminant was discovered nearly fifty years ago, and was effective for distinguishing between earthquakes and explosions in the era of teleseismic monitoring. It is still useful, though now it competes with methods based upon regional signals. In that competition, it will be of interest to see how small a seismic event can be, and still have a reliably-measured surface-wave magnitude---assigned, perhaps, on the basis of a stack of recordings from numerous broadband stations. The discriminant works well for sources large enough that body waves (from earthquakes) are radiated incoherently. But why does it also work well when source dimensions are small enough for the resulting body waves to be coherent? Patton and Taylor (Geophysical Research Letters, 2008) took a new look at plausible non-isotropic terms in the moment tensor representation of an underground nuclear explosion. In the context of tectonic release via a strike-slip fault mechanism, Patton and Taylor demonstrated the merits of including also the possibility of a type of horizontal tension crack. Such a phenomenon leads to spall, and suppression of surface waves, and hence to a reduced Ms. In this paper their method is extended in two ways: (1) by allowing for a more general type of shear faulting; and (2) by discussing

effects on body waves as well as surface waves---finding cases where the non-isotropic terms proposed by Patton and Taylor can enhance mb.

T2-O10. Temporal evolution of the radioxenon signature from underground nuclear explosions

Martin Kalinowski
University of Hamburg, Germany
Contact: *martin.kalinowski@uni-hamburg.de*

This paper reviews radioxenon signatures from underground nuclear explosions. A typology of radionuclide releases from underground nuclear explosions distinguishes five different modes. The uncontained distribution, a containment failure and an operational release could possibly be detected by the International Monitoring System. The barometrically driven seepage and the migration into soil gas are modes that offer detection opportunities during on-site inspections. Each of these modes produces a typical signature and has its own challenges for detection. The main difference is the temporal evolution of the releases.
Data from underground nuclear tests at Nevada offer a comprehensive information base for understanding the radionuclide signature. About 500 cases of atmospheric radioactivity releases from underground nuclear tests are analyzed. The reported data compare well with theoretically derived xenon activities. Conclusions are drawn on the main features of releases that can be expected as a function of release time.
These findings are relevant for developing and validating methods to be applied in global monitoring of atmospheric radioactivity with respect to indications of an underground nuclear explosion. In particular, it is important for fusing radionuclide and seismic events to have an understanding of the possible delay time between the explosion and the radioactive release. For uncontrolled test releases, the release occurs within a few minutes up to several hours. This is smaller than or similar to the time resolution of state-of-the-art atmospheric transport simulations for source location (3 hours). However, operational releases can have a significant delay, typically between one day and one week.

T2-O11. Seismo-acoustic energy partitioning from shallow and surface explosions

Jessie Bonner[1], Mark Leidig[1], Yefim Gitterman[2], Todd Ewy[3], Phillip Cole[4], Aaron Ferris[1], Robert Reinke[3], Roger Waxler[5]
[1]Weston Geophysical Corp., United States of America
[2]Geophysical Institute of Israel
[3]Defense Threat Reduction Agency, United States of America
[4]TASC Engineering, United States of America
[5]University of Mississippi
Contact: *bonner@westongeophysical.com*

Estimation of the yield of shallow or surface nuclear and chemical explosions will require multiple signal technologies and improved understanding of the relative partitioning of seismic and acoustic energy. The 2007 and 2009 HUMBLE REDWOOD experiments (Albuquerque, New Mexico, USA; Foxall et al., 2008; 2010) and the 2009 and 2011 Sayarim explosions (Negev Desert, Israel; Gitterman, 2009) provide unique datasets to study the seismo-acoustic energy partitioning for shallow sources at near-source and local distances. In this paper, we present an analysis of the seismic and acoustic signals generated from three explosions conducted as part of the 2011 Sayarim calibration experiment. The explosions ranged from 10 kg to 102,140 kg of ANFO detonated on the surface. A seismo-acoustic network was deployed at distances between 1 and 37 km from the explosions. The data confirm that the largest of the calibration explosions produced near-source (< 6 km) overpressure signals consistent with a complete and simultaneous surface detonation of 102 tons of ANFO (~80 tons TNT). For this shot, we observe acoustic amplification at local distances (20-40 km) that can be explained by the atmospheric wind velocity profiles at the time of the explosion. For the smaller calibration shots, we note amplification of the overpressure signals at near-source distances (< 5 km), possibly due to site effects or local wind velocity profiles. Conversely, the seismic ground motion is much less than would be expected for fully coupled explosions, and can be modeled by using an amplitude suppression factor of ~3 with intermediate-strength rock coupling.

T2-O12. Medical isotopes studies

Judah Friese, Rosara Payne
Pacific Northwest National Laboratory, United States of America
Contact: *judah.friese@pnl.gov*

The use of medical isotopes in diagnostic procedures, specifically 99Mo for vascular blockage studies, is increasing worldwide at a high rate. Today, four major producers dominate the production of 99Mo, but closures and spreading of demand for the short-lived isotopes have prompted announcement of several new facilities in the planning stages. Preliminary studies of emissions from the major existing facilities suggest that screening IMS detection of these emissions is possible, but challenging, based on isotopic ratios. There are several ways to reduce this challenge that will be discussed: reduced emissions via improved practice, stack-monitored emission data flowing to the International Data Center, and tagging the emission with a tracing agent like SF6. Worldwide cooperation on the sharing of information about these approaches is underway, and will be reported.

T2-O13. The IAEA Department of Safeguards: Crossover novel technologies

Andrew Monteith, Julian Whichello
Novel Technologies Unit, SGTS, IAEA
Contact: *a.monteith@iaea.org*

The International Atomic Energy Agency (IAEA) Novel Technologies Project examines the emerging and future verification requirements of the safeguards inspectorate, especially in relation to the detection of undeclared nuclear activities, materials and facilities. The Project is providing access to a wider range of methods and instruments that can be applied to enhance safeguards, as well as establishing a systematic mechanism through which the inspectorate can identify and analyse gaps in its technical support capabilities. This paper discusses possible crossover technologies currently under consideration that may also be of relevance to test ban verification, such as on-site and location specific noble gas sampling or the microseismic monitoring of underground facilities and activities.

POSTER PRESENTATIONS:

T2-P1. Application of geophysical methods while revealing UNE signatures at Semipalatinsk Test Site (for OSI purposes)

Andrey Belyashov, Victor Shaitorov, Mikhail Yefremov
National Nuclear Center, Institute of Geophysical Research, Kazakhstan
Contact: *abelyashov@gmail.com*

For effective OSI tasks solution it is necessary to understand how UNE signatures are visualized in geophysical fields, in particular, to reveal consequences of UNEs and their discrimination within the inspected area. Various geology-geophysical technologies such as seismometry, electromagnetometry, thermometry and atmogeochemical surveys are applied at Semipalatinsk Test Site within borehole UNEs sites. The main purpose of these investigations is to determine UNE phenomenology and monitor geodynamic processes that occur at near-the-focal areas of UNEs. The presentation gives basic results of complex geology-geophysical observations within one of the borehole at Semipalatinsk Test Site. The paper also highlights methodical and technical aspects of application of geophysical methods to solve OSI tasks, such as determination of observational system configuration, equipment parameters setting etc.

T2-P2. A near-regional verification analysis of North Korean nuclear tests

Kin-Yip Chun
Shanghai Normal University, China
Contact: *seismochun@gmail.com*

A 16-station seismic network, operating since 2004 at the Sino-Korean border, was at the right time and right place to capture two recent North Korean nuclear tests. Featuring textbook examples of near-regional phases Pn, Pg, Lg and Rg ($150 \leq \Delta \leq 346$ km) — recorded along pure-continental paths — the data offer the only opportunity to date for evaluating the capability of an out-country network to monitor at close proximity North Korea's compliance with a future Comprehensive Nuclear Test Ban Treaty. I demonstrate, using newly derived Q models, that the mb(Lg) for the October 9, 2006 and May 25, 2009 tests are 4.32±0.13 and 4.86±0.13, respectively. Assuming that the magnitude-yield relations used in published studies hold, mb(Lg) of 4.32 and 4.86 would imply yields of 1.2 and 6.5 kt, respectively, or 2–3 times the reported values. The North Korean nuclear tests are said to distinguish themselves from others in their near-complete suppression of tectonic stress release and tensile failure, thus preventing destructive interference of Rayleigh waves between explosive monopole and extensional CLVD sources (Patton and Taylor, GRL, 35, L14301, doi: 10.1029/2008GL034211).

This presumably explains the reported failures of Ms–mb plot to separate the North Korean explosions from Eurasian earthquakes. I show that the North Korean events are correctly identified by Ms–mb(Lg), a largely untested discriminant, and by Pg/Lg amplitude ratio (3–11 Hz). I also find Ms–mb does work but it is not robust since teleseismic P waves from lowmagnitude events are not only feeble but also sensitive to source radiation pattern and station geology.

T2-P3. Contribution of isotopes production facilities and nuclear power plants to Xe-133 worldwide atmospheric background

Pascal Achim, Gilbert Le Petit
CEA DAM, France
Contact: *pascal.achim@cea.fr*

Monitoring atmospheric activity concentration of radioxenon is relevant to provide evidence of atmospheric or underground nuclear weapon tests. However, the interpretation of measurements is impacted by the fact that many nuclear facilities emit these isotopes in the atmosphere leading to a significant worldwide background in radioxenon. The average value on the globe depends on the considered area, because directly connected to the regional density of facilities and the frequency and amplitude of their releases. The characterization of the background levels in radioxenon around the world can be carried out by the analysis over a long period, of measurements resulting from International Monitoring System (IMS) noble gas stations. An additional way is to simulate the worldwide background in radioxenon using global Atmospheric Transport Models (ATM). In the present study, Xe 133 global atmospheric dispersion is simulated over a period of 3 years. The atmospheric releases of radioxenon of the main contributors of which annual source terms are known have been considered: the Nuclear Power Plants (NPPs) and medical Isotopes Production Facilities (IPFs). Simulation results are compared to measurements issued from relevant IMS noble gas stations. It is highlighted that the background can be locally complex, and especially, it is shown that some large peaks may be due to the equal contribution of local and distant sources. Without knowledge of the local background level, such peaks, if observed, could be wrongly analyzed as being due to a major contributor. These results demonstrate that the analysis by atmospheric transport modeling of real peaks must take account of an as accurate as possible estimate of the local background noise.

T2-P4. Study on underground vacancy detection based on vertical gravity gradient measurements

Qingbin Wang, Dong Jiang, Yin Chen, Dongming Zhao
Institute of Surveying and Mapping, Zhengzhou, China
Contact: *gravity98@hotmail.com*

Vertical gravity gradient measurement is a technique that can be used for detecting geologic structure and small anomaly mass. However, it is rather difficult to carry out the vertical gravity gradient measurement, and not enough measurements are obtained, and therefore researchers make less progress on its application. Based on the requirements of On-Site-Investigation(OSI), the gravity anomaly and vertical gradient are calculated at different places with the given position and size of underground vacancy with the method of direct calculation of gravity anomaly; and the detecting ability using vertical gradient is studied with the calculation results; and the influence of underground vacancy's position and size on gravity anomaly and vertical gradient is analyzed, and an experiment has been carried out with the CG-5 gravimeter in this article. The results show that if the precision of gravity gradiometers is 10-6E, the detection depth of vertical gravity gradient measurement can reach the level of 1km; at the same time, it shows a great advantage over that based on gravity anomaly measurements.

T2-P5. Spectral ratios of regional phases recorded at the Dongbei Seismic Network for the North Korean explosions in 2006 and 2009

Hans Israelsson[1], Kin-Yip Chun[2]
[1]SeismicInfra Research, United States of America
[2]Shanghai National Unviersity, China
Contact: *hisraelsson@earthlink.net*

We analyze regional phases recorded at stations of the Dongbei seismic network from the North Korean explosions in 2006 and 2009. The stations are located between about 160-350 km from the North Korean test site and are equipped with broad-band high-fidelity instruments. The analysis focuses on the frequency dependence of spectral ratios 2009(phase)/2006(phase) for the phases Pn, Pg, Lg, and Rg. Spectral estimates of the initial Pn phase are corrected for preceding ambient noise while secondary phases are corrected for the coda of preceding phases so that Pg is corrected for the coda of Pn and so on. This affords more conservative estimates of the spectra of secondary phases than the commonly used correction for ambient noise preceding the initial phase. Spectral ratios for a given phase are averaged over stations and instrument components. Spectral ratios for both the initial Pn phase and the following Pg phase show similar scalloping between 5-30 Hz suggesting differences

in emplacement depths between the two explosions. A model based on surface-reflected P fitted to the the scalloping resulted in depths of 140 and 260 m for the 2006 and 2009 explosions respectively. The Lg spectral ratio between 0.5-12 Hz has pronounced minima at about 2 and 10 Hz, possibly due to Rg- and P-imprinting respectively. Relative amplitudes of the Lg phase based on the maximum trace amplitude at the dominant period (about 0.5 sec) would lead to smaller relative magnitudes for the two explosions than would other regional phases.

T2-P6. CTBT related activities of Turkish National Data Center

Nurcan Meral Ozel, Ocal Necmioglu, Korhan Umut Semin, Serdar Kocak, Tahir Cem Destici, Ugur Teoman
B.U.Kandilli Observatory&ERI, Turkey
Contact: *ozeln@boun.edu.tr*

Bogazici University - Kandilli Observatory and Earthquake Research Institute (KOERI) is acting as the Turkish National Data Center (NDC) and responsible for the operation of the International Monitoring System (IMS) Primary Seismic Station (PS-43) under Belbasi Nuclear Tests Monitoring Center for the verification of compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). PS-43 is composed of two sub-arrays (Ankara and Keskin): the medium-period array with a ~40 km radius located in Ankara and the short-period array with a ~3 km radius located in Keskin. Each array has a broadband element located at the middle of the circular geometry.
On 25 May 2009, The Democratic People's Republic of Korea (DPRK) conducted a nuclear test. Corresponding seismic event was recorded by IMS and IDC released first automatic estimation of time (00:54:43 GMT), location (41.2896°N and 129.0480°E) and the magnitude (4.52 mb) of the event in less than two hours time (USGS: 00:54:43 GMT; 41.306°N, 129.029°E; 4.7 mb). During our preliminary analysis of this event, a clear P-arrival at 01:05:47 (GMT) at BRTR SP array was observed, which was not associated to the event in SEL3. The result of the f-k analysis performed in Geotool software, provided by CTBTO and installed at NDC facilities in 2008, was also indicating that the arrival belongs to the DPRK event. The arrival was included in REB, however when comparing our f-k results with IDC-REB, however, it was noticed that our calculation and therefore corresponding residuals with reference to REB residuals are much better. The outcome of this analysis was communicated to CTBTO and the case story represents an example of cooperation

T2-P7. Features of geomagnetic anomalies

Dmitry A. Sagaradze, Natalia V. Rachkova
Russian Federal Nuclear Centre – VNIITF, Russian Federation
Contact: *sagaradze@mail.ru*

These studies experimentally demonstrated that there is an anomaly of the Earth geomagnetic field in the ground zero zone both prior to and after the underground nuclear explosion (UNE).

T2-P8. Discrimination of natural earthquakes and artificial explosions in 2010, North Korea

Yun Kyung Park, Sung Tae Nam, Young Woong Kim
KIGAM(Korea Institute of Geoscience and Mineral Resources), Republic of Korea
Contact: *yun@kigam.re.kr*

Seismo-acoustic analysis was conducted to discriminate surface explosions from natural earthquakes in North Korea for 2010. Seismic events were analyzed from Korea Institute of Geoscience and Mineral Resources(KIGAM)'s seismic station network and 7 seismo-acoustic array in the Republic of Korea and 5 Korea-China joint seismic stations in China. 119 seismo-acoustic events corresponding to 29.9 percent of total seismic events were analyzed and magnitude(ML) was in range of 0.8 to 2.7. More than 98 percent of seismo-acoustic events were concentrated in day time and occurred around the Joongkang, Pyeongyang and Wonsan regions. In Joongkang, the magnitude from 2.6 to 2.7 as a relatively large-scale were observed and Pyeongyang region accounted for approximately 34 percent of the total seismo-acoustic events.

T2-P9. Tritium in the air as an indicator of nuclear testing venues

Sergey Lukashenko[1], Oxana Lyakhova[2]
[1]National Nuclear Centre of Republic of Kazakhstan
[2]Institute of Radiation Safety and Ecolodgy of National Nuclear Centre of Republic of Kazahstan
Contact: *Lukashenko@nnc.kz*

Nuclear explosions cause large amount of tritium, which has very long half-life and its natural content in the atmosphere is only a small fraction of the total. On a par with the chemical inert RNG, tritium, as an isotope of hydrogen, effectively incorporates into the air and when creating certain conditions for sampling, can be found even in quite small amounts, about 1 Bq/m3.
Inspecting the possibility of using tritium as an indicator was conducted at two test sites "Degelen" and "Balapan" located at the former Semipalatinsk test site.
In the territory of 'Degelen" mountain massif nuclear weapons tests were conducted in a horizontal mine workings - the tunnels, located inside the rock, with a cross section of from 9 m2 to 25 m2 and a depth of 1500 m. The nuclear charge was placed at the end of the tunnel in a specially designed box.
At "Balapan" site nuclear tests were conducted in vertical workings - boreholes, partly with casing pipes of various diameters and below the open hole with a diameter of 900 mm. Borehole depth was 500-600 m.
After the nuclear testing, both the boreholes and tunnels have been partially "conserved" – being constructed special sealing complex, a combination of cement plugs and gravel backfill, the entrance to the tunnel was carefully poured with the rock and ground, and razed, borehole head was poured with soil.
When studying the tritium content in the atmosphere of "Degelen" site there was recorded the presence of tritium in air, not only within the tunnels, but also outside, at the tunnel portal and their estuarine areas, even when the tunnels were completely "conserved." The content of tritium in the air at the outlet of the tunnels ranged from 1 to 300 Bq/m3 at the "conserved" tunnels and hundreds of Bq/m3, and in some cases, thousands of Bq/m3 of tritium at the area of an open tunnel.
In the territory of "Balapan" site when investigating the level and distribution of tritium in the vicinity of the warfare boreholes there was found that the content of tritium in the atmosphere even at a distance from the immediate scene of the explosion, is a few and tens of Bq/m3. In particular, the content of tritium in the atmosphere near the mouth of one of the warfare boreholes was 70 Bq/m3.
Studies have shown the fundamental possibility of determining the tritium in the air in small amounts, as well as, most importantly - the fact of tritium appearance on the surface of the nuclear testing ground.
All of this confirms the possibility of using radionuclide tritium as an indicator of underground nuclear explosion venues, even after dozens of years after the event.

T2-P10. Design based approach to OSI sampling strategy

Antonietta Rizzo, Paolo Bartolomei
ENEA, Italy
Contact: *antonietta.rizzo@enea.it*

We propose the use of designed based approach for assessing the sampling strategy in an On-site Inspection in the frame work of the verification of the Comprehensive Test Ban Treaty.
The dispersion of radioactive products from an underground nuclear test will follow the migration paths of the geophysical environmental in which the test has been conducted. The identification of the transport mechanism through the geosphere and the biosphere can be combined with the modeling of the migration paths, in order to identify the accumulation points to be surveyed.
As the OSI has to be conducted in a relative short time it’s important to dedicate a big effort to design an effective and reliable sampling/survey strategy in order to collect the right number of information for the OSI purpose. In this framework the grid base sampling strategy may be not as effective as in other environmental survey sampling because of the nature of the source event and the different physical features of the analytes.
In this work we present the application of AMBER, a compartment model based software that depict and give numerical quantification of the migration paths of radioactive particles in soils, rocks and water tablet, for the design of OSI sampling strategy. This software was commercially available and it was originally designed for the assessment of a radioactive waste disposal. We demonstrated its effectiveness in a different application and its possible customization for the OSI purpose.

T2-P11. Nuclear test fall-out determination by plutonium isotopic composition

Dalis Baltrunas, Andrius Puzas, Ruta Druteikiene, Vidmantas Remeikis
Center for Physical Sciences and Technology, Lithuania
Contact: *dalis@ar.fi.lt*

The assessment of plutonium isotopic composition is important for determination of the artificial radionuclide source. During the last century the Northern hemisphere was influenced by fall-out of nuclear weapon tests and Chernobyl accident releases. As 238Pu/239+240Pu and 240Pu/239Pu isotopic ratios are equal to 0.04 and 0.180

in fall-out dominated regions, respectively, and are as high as 0.51 and 0.408 in the emission from the Chernobyl fourth reactor thus there is a possibility to determine the radionuclide contamination source by plutonium isotopic composition. For this purpose, samples of undisturbed grassland soils were taken from ten locations which reflect the whole geographical area of Lithuania. 238Pu/239+240Pu activity ratio was measured by the alpha spectrometric technique and interpreted along with 240Pu/239Pu isotopic ratio measured by the inductively coupled plasma high resolution mass spectrometry. 238Pu/239+240Pu activity and 240Pu/239Pu isotopic ratios varied within 0.02 – 0.25 and 0.173 – 0.196, respectively. Based on linear interpolation, it has been evaluated that fall-out from nuclear weapon tests is predominant. It is shown that mass spectrometric results complement alpha spectrometric ones, as well. Thus, the possibility to determine the origin of artificial plutonium by assessing its isotopic composition is clearly demonstrated.

T2-P12. Finding and identifying radioactive material by carborne search for OSI deployment

Theo Köble, Wolfram Berky, Sebastian Chmel, Hermann Friedrich, Monika Risse, Wolfgang Rosenstock, Olaf Schumann
Fraunhofer-INT, Germany
Contact: *theo.koeble@int.fraunhofer.de*

The CTBTO verification system comprises an On-Site Inspection (OSI) to verify the suspicion of a banned nuclear test. An OSI comprises different methods of verification, one of them being the radiological survey of the inspection area.
The radiological survey is done by airborne survey, carborne survey and environmental sampling, thereby narrowing the inspected area with each step. Our institute operates a measurement car with highly sensitive neutron and gamma detection systems. We investigated search strategies with the gamma detectors of this system. Of course large area surveys should be done by gross gamma counting. One problem with gamma survey are variations in background which may lead to incorrect identification of relevant spots or, even worse, to a miss of relevant spots due to high background. Therefore, our gamma detectors are equipped with special software, called NBR (natural background reduction). This is a proprietary technique which allows discriminating artificial from natural gamma radiation in a simple way without qualified spectral information and is therefore suitable, e. g., for plastic scintillators. This technique has proved to be valuable for the detection of artificial radiation for example at border crossing stations. This procedure was investigated for OSI operations where different nuclides are involved (see e.g. the list of relevant nuclides in the On Site Inspection Test Manual). After locating a refined search with hand-held devices can only be done with blinded instruments according to the treaty.

T2-P13. The use of explosion aftershock probabilities for on-site inspection planning, deployment, and reporting

Sean Ford[1], Peter Labak[2], Gideon Leonard, Albert Smith, Jerry Sweeney[2]
[1]Lawrence Livermore National Laboratory, United States of America
[2]CTBTO
[3]Israel Atomic Energy Commission
Contact: *sean@llnl.gov*

An estimate of aftershock activity due to a theoretical underground nuclear explosion is produced using a simple aftershock rate model (Ford and Walter, 2010). The model is developed with data from the Nevada Test Site and Semipalatinsk Test Site, which we take to represent soft- and hardrock testing environments, respectively. Estimates of expected magnitude and number of aftershocks are calculated using the models for different testing and inspection scenarios. These estimates can help inform the Seismic Aftershock Monitoring System (SAMS) deployment in a potential On-Site Inspection (OSI) by giving the OSI team a probabilistic assessment of potential aftershocks in the Inspection Area (IA). The aftershock assessment combined with an estimate of the background seismicity in the IA and an empirically-derived map of threshold magnitude for the SAMS network could aid the OSI team in reporting. We apply the hard-rock model to a scenario similar to the 2009 DPRK explosion and produce an estimate of aftershock activity.

T2-P14. Analysis and modeling of shear waves generated by explosions at the San Andreas Fault Observatory at depth

Justin L. Rubinstein, Fred Pollitz, William L. Ellsworth
USGS, United States of America
Contact: *jrubinstein@usgs.gov*

Using multiple deployments of an 80-element, 3-component seismic array stretching from the surface to 2.3km depth we examine recordings of chemical explosions to better understand the generation of shear waves by explosive sources. The well is near-vertical in the upper 1.5km and gradually transitions to a dip of 38 degrees at the deepest recording location. The chemical shots are high velocity boosters buried 3-4 m and fired electrically, ranging in size from 5-10lbs. The shotpoints are offset from the wellhead by approximately 40m. The recordings have a strong, impulsive P arrival on the vertical channels. Additional, coherent phases arrive later on the vertical channel propagating at the P velocity. We have preliminary evidence for a weak S arrival on the horizontal channels. The predicted theoretical response for observations directly below a shallow source, agrees with our observations, indicating that the S should be weak at vertical incidence, strengthening as the incidence angle decreases. We have also examined attenuation in the near surface. The upper 450 meters are highly attenuating; Q(P) ranges between 20 and 50.We compare our observations with synthetic waveforms on a suitable 1D structure using the Direct Radial Integration method of Friederich and Dalkolmo (1995), which handles a layered transversely isotropic medium with anelasticity. For a zero-offset, shallow-burial source the synthetics yield a highly impulsive P in addition to a small S. Given this result, we are exploring f-k filtering methods to mute the P in our data so that we can better accentuate the S arrival.

T2-P15. Emerging science for nuclear test monitoring

Joanna Ingraham, Justin McIntyre
Defense Threat Reduction Agency, United States of America
Contact: *joanna.ingraham@dtra.mil*

Ongoing research and development efforts enable future capabilities to better counter threats posed by weapons of mass destruction. Cooperative research with global partners improves international collaboration to detect and characterize weapons of mass destruction, and enhances a host nation's sustainment of scientific programs. Recent topics that are relevant to the CTBTO identify science focus areas to address challenges of an on-site inspection. Recent topics have included research for a number of basic science areas. For example radiation sensitive materials that change their optical properties and novel sensing materials used as indicators of container or seal integrity between inspections will be explored. These novel sensing materials can help provide unique assurance against tampering to assist verification. In addition integration of multiple sensor technologies and techniques using advanced mathematical methods to improve seismic location algorithms and modeling of explosions. More general topics that are planned for the future and that are relevant to the International Monitoring System and International Data Center include: alternative remote sensing materials and methods; new methods and modeling for radiochemical analysis, sample collection, concentration and selectivity; and novel long-range methods for example environmental changes.

T2-P16. On-site inspection strategy for subsurface detection of noble gases from an underground nuclear test

Charles R. Carrigan, Yunwei Sun, Gardar Johannesson
Lawrence Livermore National Laboratory, United States of America
Contact: *carrigan1@LLNL.gov*

Detection of significant levels of short-lived Xe-133 and Ar-37 isotopes in soil gas at the site of a suspected nuclear explosion is an excellent indicator that the event was nuclear in origin. Using computer simulations and field tests, we have developed a strategy for sampling subsurface gases in the context of an on-site inspection. This strategy takes into account a variety of challenges that must be addressed by the inspection team during its search-area-reduction and noble gas sampling activities. These challenges include (1) integration of different lines of evidence and expert opinion in the search area reduction phase, (2) sampling buried fractures that transport gases from depth, (3) avoiding dilution and contamination of subsurface samples by atmospheric gases, (4) implementing sample quality control indicators in the subsurface sampling procedure and (5) computer-controlled operation of sampling stations to optimize the sample-acquisition process and minimize manpower requirements. Most of the capability required is “off the shelf”. We describe the theoretical basis for this strategy and offer suggestions for its implementation.

T2-P17. Analysis into the evolution of radionuclide inventory with time for some scenarios of nuclide migration into the atmosphere after a nuclear test

Andrey Ustselemov

RFNC-VNIITF, Russian Federation
Contact: *ustselemov@mail.ru*

An underground nuclear test first produces a cavity filled with a hot gas of radioactive fission products. High pressure and temperature may cause them to move to the surface and then into the atmosphere. Gas cooling and condensation with time is accompanied with the radioactive decay of fission fragments which become more or less mobile depending on physicochemical properties –condensation temperature and ability to form volatiles. The main scenarios of radionuclide migration into the atmosphere are as follows: 1) The cavity remains leaktight as long as to allow radionuclides to condensate. In this case only radioactive noble gases (RNG) and volatiles move to the atmosphere; 2) Fast (within several hours after the explosion) migration of most volatile radionuclides and RNG to the surface and slow migration in the explosion region; 3) Fast (without cooling) migration of most radionuclides to the surface and into the atmosphere, and further movement through the environment in the form a hot gas cloud. Some of the radionuclides which reach the atmosphere condensate during cooling and deposit onto the surface forming a radioactive plume. The others (RNG and volatiles) move through the atmosphere till become non-volatile due to decays and deposit onto the surface. The further decay of deposited nuclides and their compounds may make them volatile again and allow their further transport in the atmosphere. The paper aims to analyze radionuclide inventory on the surface and in the atmosphere for some times in the specific scenarios of radionuclide migration into the atmosphere and further transport.

T2-P18. Proficiency test program for CTBT radionuclide laboratories: An update

Emerenciana Duran, Kirill Khrustalev, Matthias Auer
CTBTO Preparatory Commission
Contact: *emerenciana.duran@ctbto.org*

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) Protocol provides for 16 radionuclide laboratories to support the network of radionuclide monitoring stations being established as part of its verification regime. These laboratories support radionuclide stations by: (i) corroborating the results of routine analysis of a sample from an IMS station, in particular to confirm the presence of fission products and/or activation products, (ii) providing more accurate and precise measurements and (iii) clarifying the presence or absence of fission products and/or activation products in the case of a suspect or irregular analytical result from a particular station (CTBT/WGB/TL-11/5/Rev. 10). The expert services provided by these laboratories are utilized in the QA/QC program of the IMS radionuclide network. In turn, the Proficiency Test Exercise (PTE) is a means of assessing the level of accuracy of nuclide identification and measurement by laboratories and of triggering corrective actions when there are discrepant results. Since 2000, the Provisional Technical Secretariat (PTS) has organized annual PTEs, the results of which were presented during the International Scientific Symposium in 2009. The poster presents a snapshot of the IMS laboratory network and an update on the scope of the PTEs and the grading scheme that has been applied to PTE results since 2009.

T2-P19. Proposal for an information-led search logic during an on-site inspection

George W. Tuckwell, Luis R. Gaya-Piqué
OSI, CTBTO
Contact: *gtuckwell@rsk.co.uk*

The provisions under which an on-site inspection (OSI) can be conducted constrain the timelines (before and during the inspection), the size of the area to be inspected, the number of inspectors, the techniques authorized by the Treaty, and also the way these techniques can be applied. The inspection team functionality and the search logic applied must operate within these constraints. In this paper we present a new search logic specifically designed to accommodate the constraints of an OSI. The concept of reconnaissance and hypothesis testing missions are introduced as the building blocks of an inspection's technical activity. The key requirements of an effective search logic methodology are defined, including inter alia robustness, and development of new missions based on the site specific information available. The advantages of the information led search logic to the unique problems of an OSI are discussed in the context of alternative heuristic and probabilistic approaches. A detailed methodology has been developed to implement the information led search logic and it is hereby presented. The successful application of the methodology to an OSI is demonstrated by applying it to case studies based on previous OSI field exercises.

T2-P20. Barkhan (Baluchistan) earthquakes of June 26 and July 12, 1999: Source process from teleseismic body waves

Mohammad Tahir, Tariq Mahmood Taiq
MSSP, Islamabad Pakistan
Contact: *mtyousafzai@yahoo.com*

Source process of the June 26 and July 12, 1999 earthquakes, which occurred in the eastern part of Kirthar Sulaiman shear zone near Barkhan in the province of Baluchistan, were studied using the teleseismic body waves recorded at the IRIS Global Seismographic Network. The P and SH waveforms of these events were inverted to double couple source using the method of Kikuchi and Kanamori. The azimuthal coverage of seismograph stations is good enough to resolve some details of heterogeneous moment tensor. Aftershocks of the earthquakes were plotted to have information about the orientation and length of the fault involved. It was found that the movement on the eastern section of the Karmari thrust was responsible for these earthquakes. The focal mechanism solutions show thrust faulting. The strike, dip and slip of the causative fault of the June 26 earthquake are respectively 243o, 39o and 92o and that of July 12, earthquake are 237o, of 32o, and 111o. The seismic moment is estimated as Mo = 2.3 x 1017 Nm for June 26 and Mo = 3.3 x1017 Nm for July 12, 1999. The solution of the event is compared with fault plane solution derived from first motion polarity data recorded by local seismic network, USGS and also with the Harvard CMT solution. The moment tensor solution is in agreement with those obtained from first motion polarity, USGS and CMT solution.

T2-P21. Exploitation of the IMS and other data for a comprehensive, advanced analysis of the North Korean nuclear tests

Benjamin Kohl, John R. Murphy, Jeffry Stevens, Theron J. Bennett
Science Applications International Corporation, United States of America
Contact: *kohlb@saic.com*

The October 9, 2006 and May 25, 2009 underground nuclear tests in North Korea provide a unique data set to demonstrate advanced techniques in the processing and analysis of IMS data for verification purposes. We analyzed the available short-period seismic data in an attempt to define accurate locations, depths and yields for these two events. The location of the 2009 explosion relative to the position of the 2006 event was estimated using the Joint Hypocenter Determination (JHD), Double Difference (DD) and Differential Waveform Interferometry (DWIF) location algorithms. All of these relative location techniques yielded similar results, indicating that the 2009 test was conducted about 2.5 km west-northwest of the 2006 test. These locations were subsequently integrated with the local topographic data and satellite imagery to define accurate absolute locations for these two explosions. The corresponding source depths could not be reliably determined using the currently available arrival time data. Consequently, we implemented a new approach using broadband P wave spectral ratios of the two explosions at common regional stations to obtain estimates of the corresponding broadband source spectral ratios. The resulting network-averaged source spectral ratio was then compared with theoretical Mueller/Murphy based source spectral ratios to estimate best-fitting source depths and associated yields. The results indicated that the two explosions were not detonated at any common depth in the 100 to 800 m depth range; rather the observations are best fit by source depths of about 200 m for the 2006 test and 550 m for the 2009 test.

T2-P22. Stable coda estimates from P and S codas at regional and near-teleseismic distances

Kevin Mayeda
Weston Geophysical Corporation, United States of America
Contact: *kmayeda@yahoo.com*

For nearly the past 2 decades, regional shear wave coda has been shown to provide the most stable estimates of the explosion and earthquake source, making its use ideal when station coverage is sparse. As a result, moment-magnitude is determined with unprecedented stability from as few as one station and is being used in a number of explosion monitoring applications. In spite of its success, a significant magnitude bias exists for S-based regional magnitudes such as mb(Lg) and mb (Lg-coda) between explosions and earthquakes when compared to their teleseismic mb(P) counterpart. In this study, we first show preliminary results for regional and near-teleseismc P-coda for both earthquakes and explosions to see if a bias still exists with the teleseismic mb. In addition, there is a point of debate on whether the regional P-coda calibration will remove the effects of the path and upper mantle effects which bias teleseismic mb(P) estimates for some test sites. We find that the P-coda does not exhibit a magnitude bias between earthquakes and explosions, in sharp contrast to S-based magnitudes such as mb(Lg) when compared to the teleseismic mb(P). We plan to give a summary of regional coda research and specifically address our recent P-coda findings.