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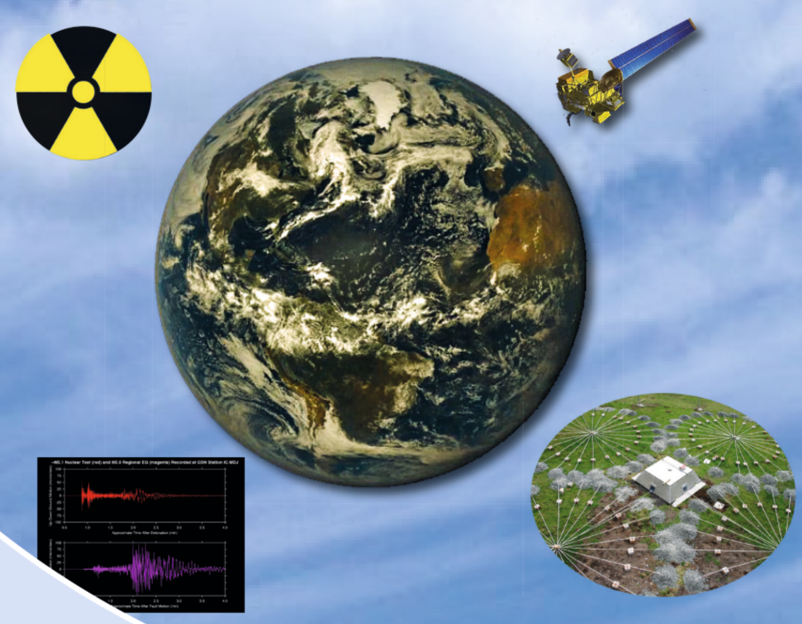

Kaveri Ashok
Arun Vishwanathan
S Chandrashekar
LV Krishnan
Lalitha Sundaresan
Rajaram Nagappa

Workshop Summary

Advanced Techniques in Environmental Monitoring

September 2016

International Strategic and Security Studies Programme
National Institute of Advanced Studies
Bengaluru, India

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Contributors:

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ABSTRACT

Our planet is witness to incidents and events of different scales-some benign, some catastrophic, some due to natural causes and some due to man-made interventions. In order to anticipate, forecast, control and manage events and their effects, information and knowledge are key. And sophisticated sensors and techniques are the key to such information and knowledge. India, with a network of seismic sensors and good remote sensing capabilities already in place, has a certain level of environmental monitoring capability. The theme of the workshop was to collate this capability, compare it with contemporary international trends and highlight measures needed for India to attain and maintain state-of-the-art capability in Advanced Environment Monitoring Techniques

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List of Abbreviations

IMS	International Monitoring System
CTBT	Comprehensive Test Ban Treaty
CTBTO	Comprehensive Test Ban Treaty Organisation
UK	United Kingdom
USSR	Union of Soviet Socialist Republics
US	United Stated
LTBT	Limited Test Ban Treaty
PTBT	Partial Test Ban Treaty
OSI	On Site Inspections
CD	Conference on Disarmament
TTBT	Threshold Test Ban Treaty
NWS	Nuclear Weapon States
NNWS	Non-Nuclear Weapon States
GSE	Group of Scientific Experts
IDC	International Data Center
GCI	Global Communications Infrastructure
DAE	Department of Atomic Energy
NGRI	National Geophysical Research Institute
NIED	National Research Institute of Earth Science and Disaster Prevention
DPRK	Democratic People's Republic of Korea
IC	Incorporated Research Institutions for Seismology (IRIS)/ United States Geological Survey (USGS)/ China Digital Seismograph Network (CDSN) Seismic Network
MDJ	Mudanjiang Seismic Station
CRS	Central Receiving Station
TNT	Trinitrotoluene
VSAT	Very Small Aperture Terminal
IRIS	Incorporated Research Institutions for Seismology
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
ISGN	Integrated Seismic and GNSS Network
ESSO	Earth System Sciences Organisation
MoES	Ministry of Earth Sciences
INCOIS	Indian National Centre for Ocean Information Services
BARC	Bhabha Atomic Reseach Centre
INSAT 3C	Indian National Satellite System series 3 - second satellite

DAQ	Data Acquisition
INGE	International Noble Gas Experiment
ARSA	Automated Radioxenon Sampler/Analyzer
SAUNA	Swedish Automatic Unit for Noble gas Acquisition
ARIX	Analyzer of Xenon Radioisotopes
SPALAX	Système de Prélèvement Automatique en Ligne avec l'Analyse du Xénon
HBRA	High Background Radiation Area
SODAR	SOnic Detection And Ranging
IERMON	Indian Environmental Radiation Moniotoring
GM Counter	Geiger Muller Counter
IGCAR	Indira Gandhi Centre for Atomic Research
UAV	Unmanned Aerial Vehicle
IRODOS	Indian Real-time Online Decision Support System
AGSS	Aerial Gamma Spectrometry System
SAR	Synthetic Aperture Radar
InSAR	Interferometric Synthetic Aperture Radar
GIS	Geographical Information System
VHRR	Very High Resolution Radiometer
GISAT	Geo Imaging Satellite
ISRO	Indian Space Research Organisation
SOSUS	US Navy SOund SUrveillance System
EEZ	Exclusive Economic Zone
SSREB	Standard Screened Radionuclide Event Bulletin
ISC	International Seismological Centre
CS	Centre of Seismology
NOFN	National Optic Fibre Network
NPTEL	National Programme on Technology Enhanced Learning
NKN	National Knowledge Network

NATIONAL INSTITUTE OF ADVANCED STUDIES
Indian Institute of Science Campus, Bengaluru- 560012, INDIA

Prof. V S Ramamurthy
Emeritus Professor

Foreword

Extreme events of any kind on the face of the earth - both natural and man-made - leave signatures of specific types on the face of the earth and in the atmosphere. Detecting and categorizing them are essential to determine their source and magnitude; assess the damage if any; and initiate relief and mitigation measures. Furthermore, in the context of national security, it is important to possess national capability to independently detect and assess any man-made event in the neighbourhood.

The International Monitoring System (IMS) of the CTBT is perhaps the only global monitoring network, comprising seismic, radionuclide, acoustic and satellite monitoring capabilities and providing data to the member countries. Although constituted to verify signatory countries' compliance to nuclear test ban, it has also served civilian causes in the process by monitoring natural phenomena like tsunami, earthquake and volcanic eruptions and providing early warning. However, countries like India, which are non-signatories to the CTBT, do not get to share the IMS data and to a large extent need to depend upon their own national capabilities. The IMS capabilities and network uses state-of-the-art techniques and thus provides a good reference yardstick to emulate. India has established its own independent monitoring capabilities in the domains of seismic monitoring, radionuclide monitoring and acoustic monitoring along with capabilities in satellite monitoring. The workshop on **"Advanced Techniques in Environmental Monitoring"** organized by the International Strategic and Security Studies Programme of the National Institute of Advanced Studies essentially took stock of the Indian capabilities in these four areas of environmental monitoring. The Workshop sessions were addressed by experts in the field. The deliberations in these sessions and the final day panel discussion highlighted areas requiring attention to stay abreast of the state of the art techniques.

Reflecting on the major take-away from the Workshop, I feel the necessity of establishing a **National Monitoring System**, which can steer an integrated programme for real-time situation awareness. There is an urgent need to increase the network capability and density capacity to the level of the IMS system. Management of big data generated needs new skills. For this our University system needs to be sensitized so that a cadre of active researchers are trained in the study, analysis and characterisation of the data.

The members of the International Strategic and Security Studies Programme have done a commendable task by putting out this Workshop Summary. It is hoped that the report will generate further discussion and pave the way for taking forward the idea of National Monitoring System.

On this occasion, I will like to recall the passion and commitment with which the Late Amb. Arundhati Ghose nucleated the idea of this Workshop and its successful conduct.

Bengaluru
19 September 2016

V S Ramamurthy
Emeritus Professor

Executive Summary

The Workshop was held at the National Institute of Advanced Studies on 25-26 September, 2014 and addressed topics in Seismic monitoring, Radionuclide monitoring, Satellite monitoring, Acoustic monitoring and data management. The workshop saw active participation from the Department of Atomic Energy (DAE), Indian Space Research Organisation (ISRO), Ministry of External Affairs (MEA), Defence Research and Development Organisation (DRDO) laboratories and the academia (IIT-Bombay, IIIT-Hyderabad, TIFR).

The thrust of the workshop was to gauge the national capabilities in advanced monitoring techniques with reference to the state-of-the-art. A panel discussion, chaired by the then Director of NIAS, Prof V S Ramamurthy, in the concluding session of the workshop took a measure of the overall presentations and made recommendations as follow-up action.[1]

Seismic Monitoring

- Current national capacities need to be augmented and digitized and the seismic network needs to be densified so as to be able to improve the detection capability of earthquakes of magnitude ≥ 2.0.
- National and regional hubs are required in order to ensure that the data is centrally acquired, standardized, processed, archived, stored and disseminated to users. The regional networks need to be integrated into national networks.
- Seismic monitoring is the workhorse for detecting both earthquakes and nuclear explosions. Synergy between IMD and BARC is desirable, since IMD gets the real time data from 200 seismological stations throughout the country. The same seismometers meet the frequency range requirements to detect the nuclear explosions. Further, some of the IMD stations in strategic locations can be equipped with microbarographs to supplement nuclear test monitoring. The data can be streamed to BARC for real time analysis as well.
- Similarly, non-sensitive data from DAE seismographs can be fed into the national network for enhancing the database and characterizing specific event signatures.
- Bureaucratic bottlenecks in the purchase procedures have caused many delays in the planned upgradation of 78 stations since 2012. It should be overcome by including it as a national security priority.
- Attention needs to be paid to the human resource requirements. The data available is voluminous and special cadre of analysts needs to be trained.

1 The other panellists in Panel Discussion were: Dr Baldev Raj, Director, NIAS; Dr. LV Krishnan, DAE (Retd); Dr. AR Sundarajan, DAE (Retd); Dr. SR Raghavan, Cabinet Sectt (Retd.); Dr. AR Reddy, DRDO (Retd.), Dr. Dekhne, Scientific Consultant to Principal Scientific Adviser and Dr. G. Suresh, Scientist, IMD.

Radionuclide Monitoring

- Although the radiation detection and monitoring is done in various modes by the DAE, its capabilities for radionuclide detection and identification needs to be improved. Radionuclide detection is referred to as the "smoking gun" evidence for a nuclear explosion; however, it remains a technology ridden with uncertainty. For the purpose of detection of an underground nuclear test, it can only be complementary to seismic, infrasound and hydroacoustic monitoring. The technology of radionuclide detection is just reaching its maturity- the first radionuclide station with noble gas detection capabilities was formally integrated into the IMS in 2010. It is important that the DAE keeps up with the global developments in this technology. Setting up of 2-3 stations with the order of sensitivity of that of the IMS radionuclide stations would suffice for the country.
- The number of detectors need to be stepped up substantially in order to effectively monitor radionuclides since it is passive, relying on air currents to move the particles or gases to the radionuclide detection site. Even for detection of radiation, given the range of a detector and possibilities of getting shielded, the density of stations should be increased.
- Data sent by the radionuclide stations to the IDC do not only include gamma radiation spectra, but also meteorological and state-of-health information. State-of-health data provide information on the station's operational status and the quality of the raw monitoring data it transmits. Kalpakkam has a meteorological division that provides data for Indira Gandhi Centre for Atomic Research (IGCAR) simulations and atmospheric transport modelling. If meteorological monitoring can be coupled with radiation monitoring stations, it will be very useful for more accurate prediction in case of an event.
- The instrumentation developed in the context of detecting underground nuclear explosions would also help to determine unequivocally the yield of nuclear warheads used in a conflict.

Satellite Monitoring

- Imaging systems complement other monitoring techniques and comes in the end, only after locating the area of testing. Imaging and detecting are hence possible only on the basis of domain knowledge. GIS and the VHRR (Very High Resolution Radiometer) of the weather satellite system with an image resolution of about 1 km, and a scanning mechanism to cover more area can be adapted for the purpose. However, it requires more satellite density for better swath. Hi-resolution imaging is more appealing for identification, but there is a constraint of it having a small footprint. Platforms like the Yaogan constellation of China have the integrated facilities for identification of coarse area within which the object of interest has been located, and the capacity to swivel hi-resolution imaging system as per requirement.
- In principle, it is possible to design a missile detection system and locate where the missile is headed. Current status of what India is planning in this regard is not known.

Acoustic Monitoring

- Some acoustic signatures corresponding to rocket launchers and supersonic aircraft are available. It would be useful to have a database of the calibrated signatures of different class of missiles, launch vehicles and aircraft. Such a database will prove valuable for detecting and identifying the noise source. Furthermore, atmospheric and shallow underground nuclear explosions can generate infrasound waves that may be detected by the infrasound network. The detection and identification possibilities of infrasound monitoring have not been explored fully. It is useful to co-locate infrasound stations with seismic stations.
- India is currently not equipped with any hydroacoustic station in order to detect underwater nuclear tests. Sensors for submarine acoustic detection are mounted on platforms such as ships, submarines, and sonarbuoys. Linear-towed array sonar has been developed in the country, but not deployed on the sea coast, as of now. Infrasound signatures of the periodic underwater launch testing need to be collected for calibration. An integrated effort between underwater acoustics and air acoustics laboratories is essential for this.

Data Management

- Individual capabilities for data collection and management exist with the operational entities engaged in this work. A national level effort aimed at trying to develop such algorithms in order to integrating these capabilities into a national data base would be very useful for deriving the maximum benefits from the existing system of data collection and event monitoring. This would raise a set of organizational and institutional issues that have to be understood and managed.
- It may be considered to release the enormous amount of data from the monitoring stations for the academic community, especially seismic and infrasonic, filtering out the sensitive strategic information. It can complement the analysis done by the assigned departments. The science spin offs of such data has the potential to contribute to studies of earthquakes and volcanoes, meteorology and oceanic topography. Organizational and institutional arrangements for facilitating such exchanges are the key to building national capabilities in this area.
- Human resources development in the area of data processing and analysis is a key area to focus on. A special cadre of trained analysts devoted to handle the data from the monitoring stations in order to detect any possible events, both natural and man-made, in the country's purview.

Advanced Techniques in Environmental Monitoring

Background

Our planet is witness to incidents and events of different scales-some benign, some catastrophic, some due to natural causes and some due to man-made interventions. Many such events like earthquakes, dam construction, conventional and nuclear explosions induce seismic activity. Activities related to chemicals release are also of interest and range from need to monitoring industrial effluents; impact of industrial accidents; emission of radioactive elements from spontaneous fission, reactor accidents and nuclear tests. Major strides have been made in satellite monitoring and today sub-metre resolution is commonly available to monitor resulting terrestrial changes. This capability provides critical advance and post event information for evaluation, loss mitigation and rehabilitation. Finally many events are discernible through acoustic signatures. Events like mine and quarry blasts, volcanic eruptions, shallow earthquakes, meteorites as well as nuclear tests and missile launches generate infrasound signals. A well-coordinated and strong monitoring capability therefore becomes important a) to log and consolidate information and build a database, b) discriminate between natural and man-made events and c) for developing tools for verifying/keeping watch on clandestine activity having bearing on national security.

The International Strategic and Security Studies Programme at NIAS organised a National Workshop from September 25-26, 2014 essentially to take stock of our monitoring capabilities; and where possible, benchmark them with the prevalent state-of-the-art international practices. In this context, the capabilities of the International Monitoring System (IMS) of the CTBTO would perhaps serve as a good reference yardstick. The workshop speakers and participants comprised experts in the techniques of monitoring, and brought valuable experience and contributions to the table. The list of participants is appended to the report.

The workshop sessions included seismic, radio-nuclide, acoustic and satellite monitoring culminating in a panel workshop on the way ahead. This report presents a summary of the deliberations under each heading.

Introduction

It would be useful to recall the events leading to the Comprehensive Test Ban Treaty (CTBT) which in turn necessitated the introduction of a verification regime. Post Hiroshima-Nagasaki, the US lost its monopoly on nuclear weapons within a short span of time. Atomic espionage helped the Soviet Union to replicate the Fat Man A-bomb within 5 years; British scientists, who were part of the Manhattan project, carried out a nuclear test successfully soon after; by 1960, France went nuclear resulting from a nuclear weapons programme initiated in early 1950s; and in 1964, with a successful test, China went nuclear.

The intense nuclear weapons race that ensued between the two emerging superpowers, the United States and the Soviet Union soon after, marked the beginning of the "Cold War." By the 1950s the United States had established a dedicated test site (on 27 January 1951, the first of over 900 nuclear tests was conducted at the Nevada Test Site) and was also using a site in the Marshall Islands (Pacific Proving Grounds) for extensive nuclear testing. The Soviet Union also began testing on a limited scale, primarily in Semipalatinsk in the Soviet Republic of Kazakhstan. Early tests were used primarily to ascertain the military effects of nuclear weapons and to test new weapon designs. During the 1950s new hydrogen bomb designs were tested in the Pacific, as were new and improved fission weapon designs.

Proposals and negotiations, bilaterally (US-USSR), trilaterally (UK-US-USSR) and multilaterally (18 nation committee on disarmament in Geneva) for cessation of nuclear weapon testing can be traced back to the beginning of nuclear age. Indian PM Jawaharlal Nehru called for "an immediate standstill" agreement on nuclear weapons testing between the US and the USSR in 1954 as the first step towards ending the arms race. In 1958, the United States, the Soviet Union, and the United Kingdom began a Conference on the Discontinuance of Nuclear Tests in Geneva, aimed at reaching agreement on an effectively controlled test ban. The Conference did not come to fruition because the sides could not reach an agreement on the issue of verification procedures. Many such attempts to negotiate a test ban failed in the subsequent years, mainly due to disagreements on verification provisions, particularly, the number of On-Site Inspections.

From 1955 to 1989, the average number of nuclear tests conducted every year was 55. Nuclear testing peaked in the late 1950s and early 1960s. The year 1962 alone saw as many as 178 tests: 96 conducted by the United States and 79 by the Soviet Union. It was in October the same year that the Cuban Missile Crisis was triggered when the United States discovered that the Soviet Union had stationed nuclear capable missiles in Cuba, placing Washington and other major cities within reach. In spite of the tense crisis situation, the year marked the maximum number of tests. Figure 1 provides the history of testing during these years as well as in subsequent years.

After the Cuban Missile Crisis, there was mounting public opinion against nuclear testing due to increased awareness of the implications for health, the environment and global security, as well as concern over the escalating nuclear arms race. On 5 August 1963, the Partial Test Ban Treaty (PTBT) — also known as the Limited Test Ban Treaty (LTBT) — was signed in Moscow by the United States, the Soviet Union, and the United Kingdom. There was no resolution over the On-Site Inspections (OSI) issue and the number of seismic stations necessary to verify compliance with PTBT. The treaty that came into force in October 10, 1963, stipulated that the signatory states could not "carry out any nuclear weapon explosion, or any other nuclear explosion…in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas." Underground testing was not aanned under the PTBT provisions, and hence onsite inspections were not required. The fundamental role of PTBT, however, was to address environmental issues rather than disarmament.

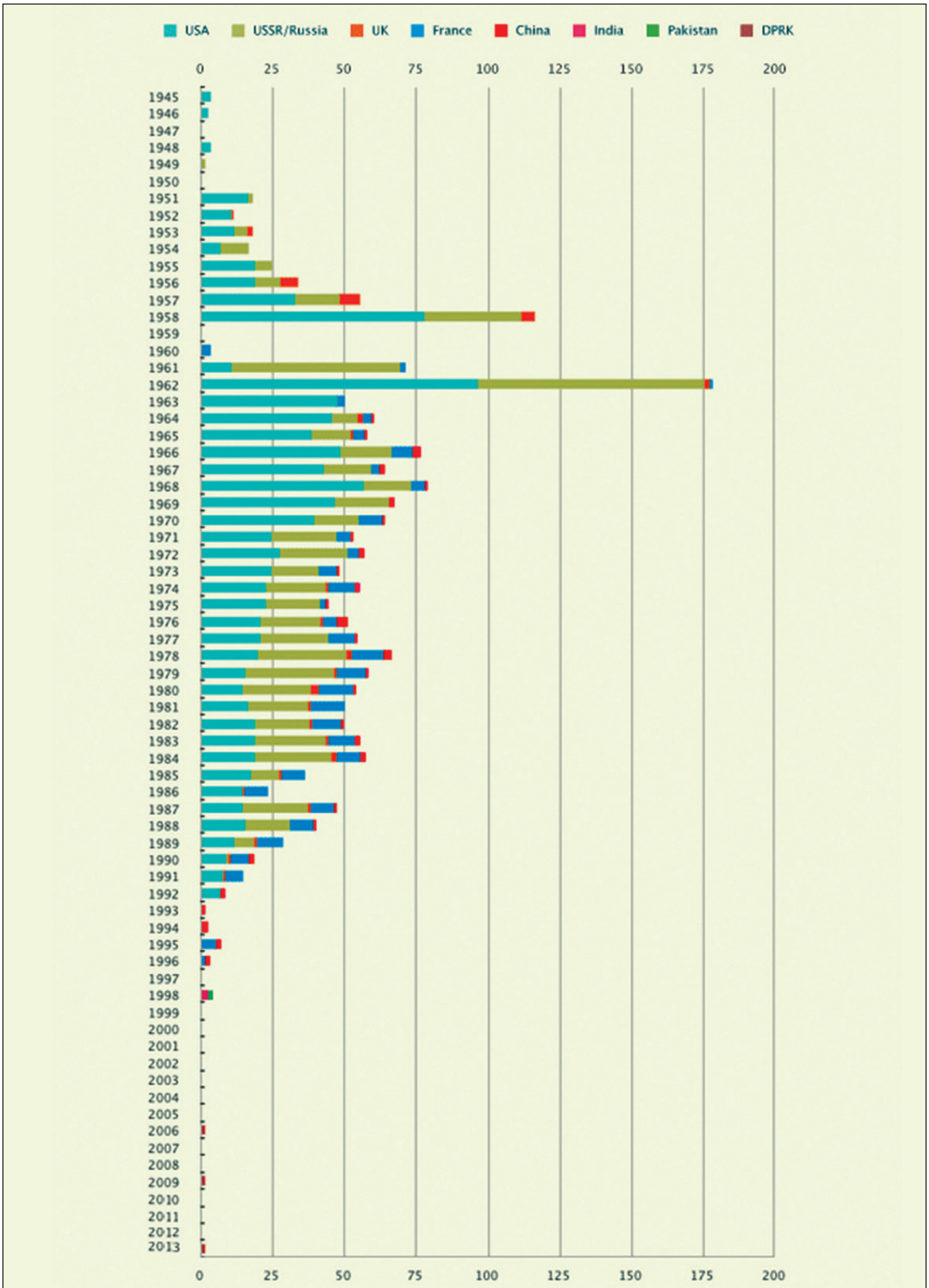

Figure 1: Worldwide Nuclear Testing 1945-2013 (Source: CTBTO)

France and China were not party to PTBT and continued atmospheric tests until 1974 and 1980 respectively. In the meanwhile, negotiations related to the Non Proliferation Treaty (NPT) continued. After a series of negotiations and with disagreements still prevailing over collective verification arrangements, the NPT was signed by the United States, the Soviet Union, the U.K. and 58 other countries on July 01, 1968. The Treaty underscored the difference between Nuclear Weapon States (NWS) and Non-Nuclear Weapon States (NNWS). Countries that had tested nuclear weapons before 1967 were categorized as NWS and all others fell in the category of NNWS.

The Treaty prohibits NWS from transferring nuclear weapons, other nuclear explosives or nuclear weapon technology to NNWS. Likewise, NNWS are obligated to refrain from acquiring nuclear weapons or other nuclear explosive devices. Nuclear disarmament was among the three pillars of NPT and its Article VI obligates States signatories to "pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament." The treaty, which laid the foundations for the international non-proliferation regime made no provisions to verify the disarmament obligations of the Nuclear Weapon States. India did not sign the treaty on account of its discriminatory nature. India, Israel and Pakistan have not signed the Non Proliferation Treaty.

In 1974, the US and the Soviet Union signed the Threshold Test Ban Treaty (TTBT), which provisioned the nuclear testing could not exceed yields of 150 kt. The Treaty also stipulates that data will be exchanged on a certain number of tests for calibration purposes. By establishing the correlation between stated yields of explosions at the specified sites and the seismic signals produced, this exchange improved assessments by both parties of the yields of explosions based primarily on the measurements derived from their seismic instruments. This signalled a significant degree of cooperation and confidence building measure between the parties, although it did little to curb nuclear testing. TTBT also undertook an obligation in its preamble and Article 1 towards the cessation of all underground nuclear weapons testing.[2]

Throughout the cold war years, consensus on cessation of underground testing proved elusive time and again. Nevertheless, research efforts on monitoring techniques and data analyses were kept live since 1976 by a group of scientists from different countries, known as the Group of Scientific Experts (GSE). It took three decades since the PTBT for the political climate to be ready for talks on a comprehensive nuclear test ban treaty. The Conference on Disarmament (CD), UN body for disarmament, started negotiations for CTBT in Geneva in 1994, which lasted until 1996.

CTBT Provisions

The fundamental provisions of the CTBT are as follows:

- Basic obligations: It prohibits States Parties from carrying out any nuclear explosion. It also prohibits any encouragement of or participation in the carrying out of any nuclear explosion.

[2] Threshold Test Ban Treaty, *Federation of American Scientists*, http://fas.org/nuke/control/ttbt/intro.htm

- Entry into force: the CTBT will enter into force after it has been signed and ratified by the 44 States listed in Annex 2 to the Treaty, i.e. the States that had nuclear power or research reactors at the time.
- The establishment of a global verification regime, including the 337-facility-strong International Monitoring System (IMS) and an on-site inspection regime.

The verification regime provisioned by the CTBT is designed to detect any nuclear explosion conducted underground, underwater or in atmosphere and is by far the most effective system. The CTBT verification regime is composed of the following:

1. International Monitoring System
2. International Data Centre
3. Global Communications Infrastructure
4. Consultation and clarification
5. On-Site Inspection
6. Confidence-building measures

International Monitoring System (IMS)

The International Monitoring System consists of 321 monitoring stations and 16 laboratories built worldwide. These 337 facilities monitor the planet for any sign of a nuclear explosion. The IMS uses four complementary verification methods based on Seismic (50 primary and 120 auxiliary seismological stations), hydroacoustic (11) and infrasound (60) stations. These stations monitor signatures emanating from underground, the large oceans and the atmosphere. Radionuclide stations (16 laboratories and 80 radionuclide stations, 40 of which have additional noble gas detection capabilities) detect radioactive debris from atmospheric explosions or vented by underground or underwater nuclear explosions.

International Data Center (IDC)

The IMS network is supported by the IDC, which is located in the CTBTO headquarters in Vienna, Austria. IDC processes and analyses data that is generated from the IMS stations and laboratories and disseminates to the member states for their evaluation.

Data is initially processed automatically and the first reports – data bulletins – are available within a span of 2 hours. One important product is the "Revised Event Bulletin," which, if compiled from seismic, hydroacoustic, and infrasound data, can be available within four to six days after an event. Radionuclide data may take up to two weeks to compile because samples must be physically collected at the monitoring site and analysed at a radionuclide lab.

The IDC has been providing monitoring system data and reports to treaty parties on a trial basis since February 2000 through secure-access accounts. The CTBT gives signatories the responsibility of drawing conclusions about IMS data regarding possible treaty violations. Hence, IDC's reports are unbiased as to the nature of any event. Extensive support is given to the users designated by the Member States by providing a standard software package, training courses and technical assistance.

Global Communications Infrastructure (GCI)

The Global Communications Infrastructure (GCI) transmits the data recorded at the IMS stations to the International Data Centre (IDC) in near-real time. It also transmits raw data and data bulletins from the IDC to the Member States. This very detailed information enables Member States to assume their rights and responsibilities under the CTBT. The GCI ensures global coverage. Data are received and distributed through a network of six geostationary satellites, based on VSAT technology. The satellites route the transmissions to three hubs on the ground, and the data are then sent to the IDC by terrestrial links.

Consultation and Clarification

If a Member State feels that certain data collected imply a nuclear explosion, a consultation and clarification process can be undertaken to resolve and clarify the matter. This process, which will be available to Member States after the Treaty's entry into force, allows a State to request clarification directly from another State or through the Executive Council. Member States can also request information from the Director-General of the CTBTO. A State that received such a request has 48 hours to clarify the event in question.

On-site inspections (OSI)

States have the right to request an on-site inspection, regardless of the results of the consultation and clarification process. Such inspections will be carried out to ascertain whether a nuclear explosion has occurred in violation of the Treaty. They will also be used to collect facts that might be of use in identifying possible violators. On-site inspections are regarded as the final verification measure under the Treaty and can only be invoked once the Treaty enters into force.

Confidence-building measures

On a voluntary basis, Member States are to notify the CTBTO Technical Secretariat in case of any chemical explosion using 300 tonnes or more of TNT-equivalent blasting material detonated on their territories. These notifications serve two purposes. First of all, they contribute to the resolution of any eventual misinterpretation of verification data so that for example a large mining explosion is not initially thought to be a nuclear explosion. Secondly, they assist in the testing and fine-tuning of the IMS network.

India and the CTBT

At the 1996 Conference on Disarmament in Geneva, India's representative, the Late Amb. Arundhati Ghose, declared that India would "never sign this unequal treaty, not now, not ever" and vetoed the draft, mainly because the treaty divides the world into nuclear "haves and have nots," and puts India permanently in the "have nots" camp.

It has been recognized that the lynchpin of a treaty such as the CTBT is the ability to "Detect and Deter." The IMS is a common resource to all the signatory parties, providing an excellent monitoring capability worldwide to detect and deter any clandestine activities. India, being a non-signatory to CTBT is deprived of access to IMS data and needs to develop and employ an independent capability to monitor and detect natural and man-made/clandestine activity – especially the possibility of clandestine testing in our neighbourhood.

Being a non-beneficiary from the CTBT and the IMS, it became necessary for India to establish its own independent monitoring capabilities, shaped according to its requirements. The Department of Atomic Energy is the premier agency tasked with the precision monitoring responsibility. DAE expertise centres around seismic monitoring and radionuclide monitoring. Besides DAE, agencies like the India Meteorological Department (IMD) and the National Geophysical Research Institute (NGRI) also operate seismic stations. India also has capabilities in acoustic and satellite monitoring. The key challenge for India, lies in defining a national strategy for monitoring and detection; this, in turn calls for interaction between scientists, technocrats and political decision-makers.

Workshop Objective

In the context of the situation described in the previous section, it was felt useful to take stock of the capabilities the country possesses for environmental monitoring. It was decided to survey the capabilities in advanced techniques employed by IMS through deliberations in a Workshop. Experts in the field were invited share their expertise and experiences, which was followed by a panel discussion. The Workshop programme can be seen at Annexure-1. The deliberations of the Workshop held from September 24-26, 2014 are presented under the broad headings of Seismic, Radionuclide, Acoustic and Satellite Monitoring, and Making sense of the Data.

Seismic Monitoring

State-of-the-Art

China

Currently, China has 1014 seismic stations as mapped in figure 5. These comprise 148 national seismic stations and 814 regional stations. In addition, China has 5 volcanic seismic networks with 33 stations and 2 seismic arrays with a total of 19 stations. The dense seismic network has given Beijing the capability to detect earthquakes as low as 0.5 on the Richter scale in certain areas and 1.5-2.0 on the Richter scale in most parts of the country (figure 6). To better integrate the functionality of this dense network of seismic stations, there are 32 regional seismic centres, in addition to the single national seismic centre.

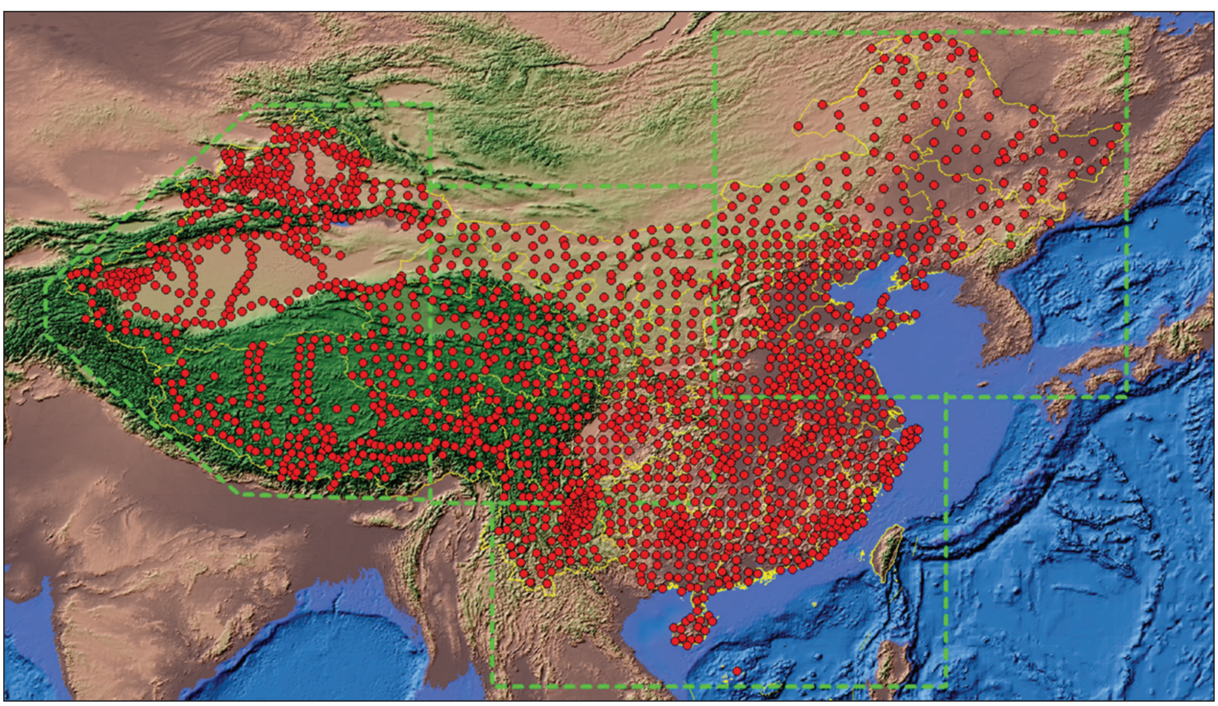

Figure 2: China's seismic network (1014 seismic stations)

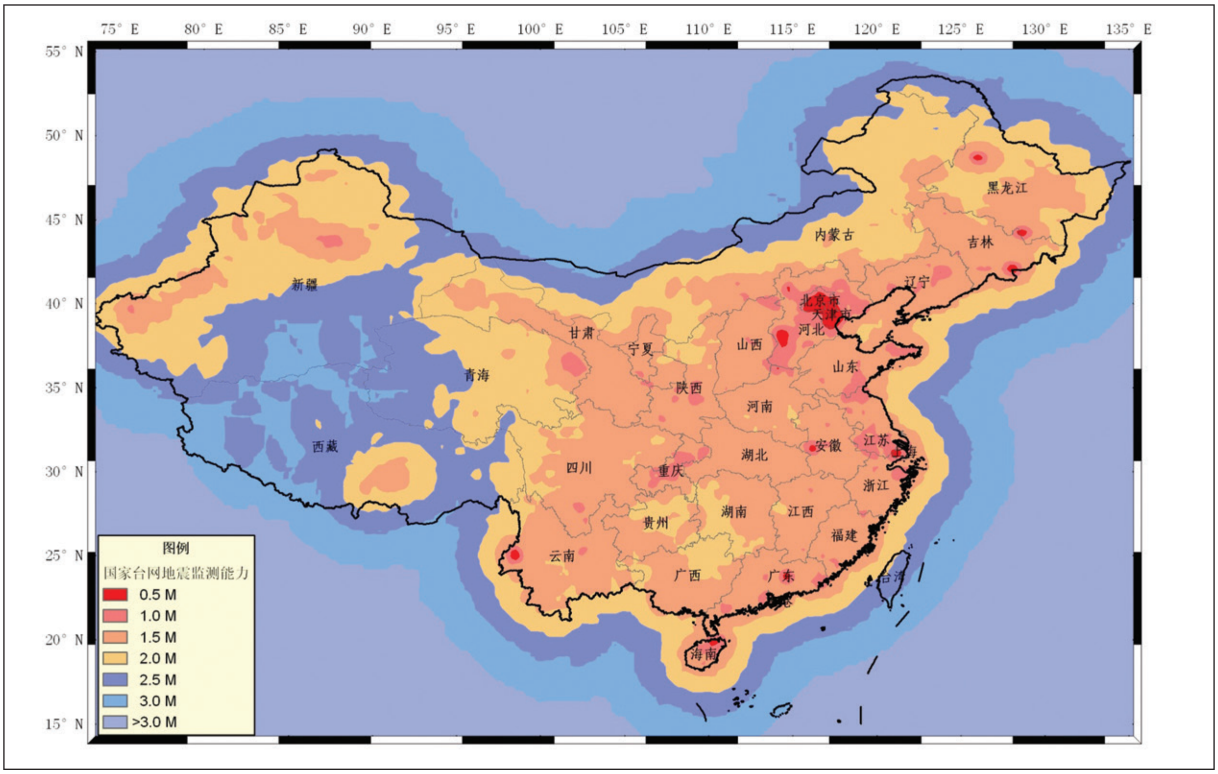

Figure 3: Monitoring capability of China's seismic network

Japan

At the time of the Kobe earthquake in 1995, Japan had nearly 550 high sensitivity seismograph stations. However, majority of these stations were concentrated in the Kanto and Tokai districts, central Japan. In the wake of the Kobe earthquake, Japanese government has established the Headquarters for Earthquake Research Promotion and started the deployment of seismic networks to evenly cover the whole of Japan. The Japanese under the auspices of National Research Institute of Earth Science and Disaster Prevention (NIED) has established three networks namely (a) High-Sensitivity Seismographic Network (Hi-net), (b) Strong Motion Seismographic network (Kyoshin in Japanese or K-Net) and (c) Full Range Broadband Seismographic Network (F-net). With these efforts Japan has achieved an observation time of less than two minutes. In 2012, NIED has started the construction of ocean bottom seismic and tsunami observation network along the Japan Trench. It is planned to layout 154 stations with an average spacing of 30 km. Each station is to be equipped with an accelerometer for seismic observation and a water pressure gauge for tsunami observation. The Japanese seismic station network is shown in figure 7.

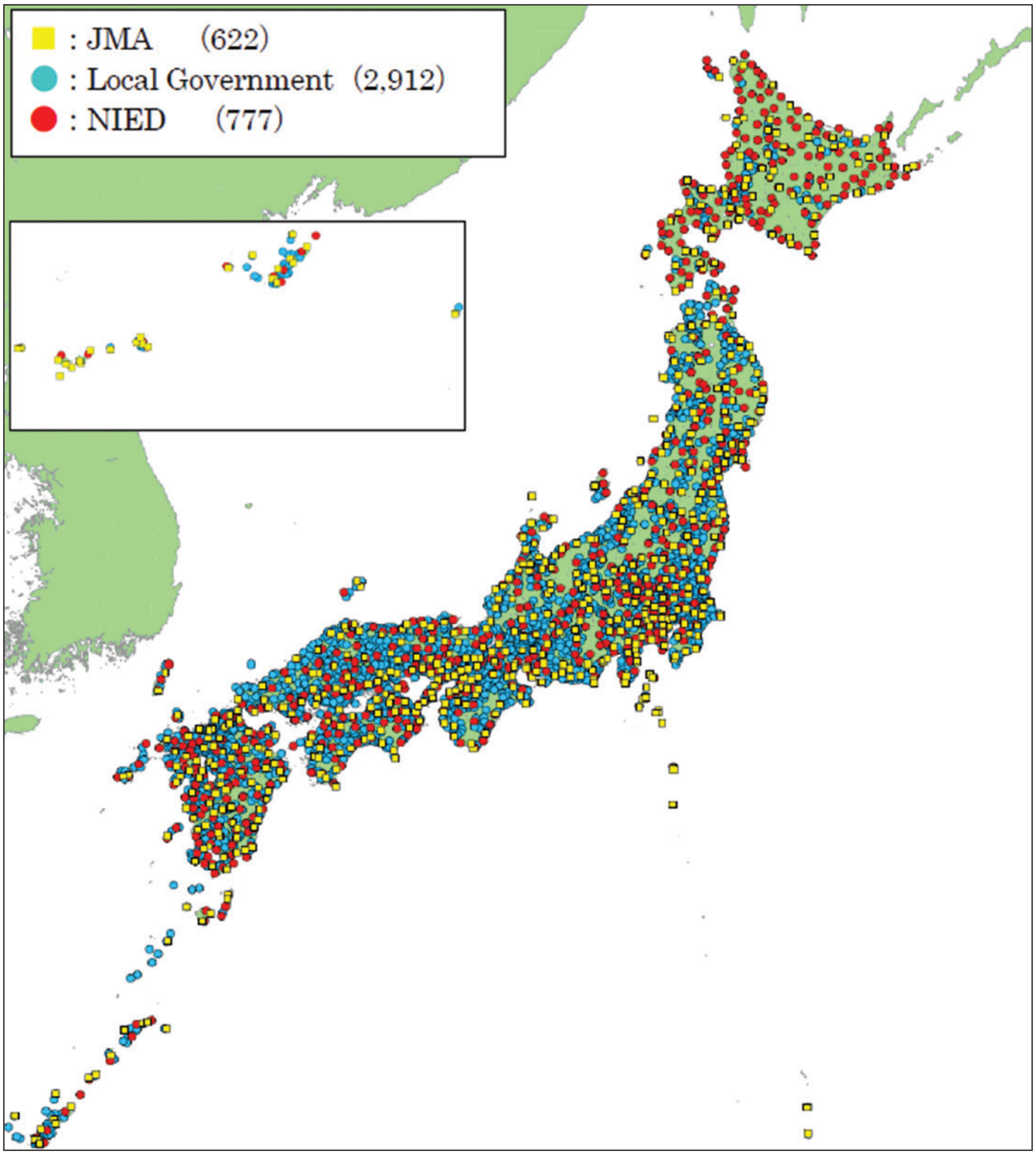

Figure 4: Japan's seismic network

Nuclear Seismology

Seismic monitoring has various civilian and national security related nuclear applications. Most recently, the value of seismic monitoring was reemphasised in the three nuclear explosions conducted by the Democratic People's Republic of Korea (DPRK) in 2006, 2009 and 2013. The seismic signals generated as a result of these explosions were recorded in Chinese monitoring stations quite accurately. This data was useful in identifying the first two tests (2006 and 2009) as sub critical tests and the third (2013) test as a critical explosion. Figure 8 shows the detection of the three DPRK tests in IC MDJ observatory situated in the Mudanjiang, Heilongjiang Province, China which is around 357 km away from the test site.

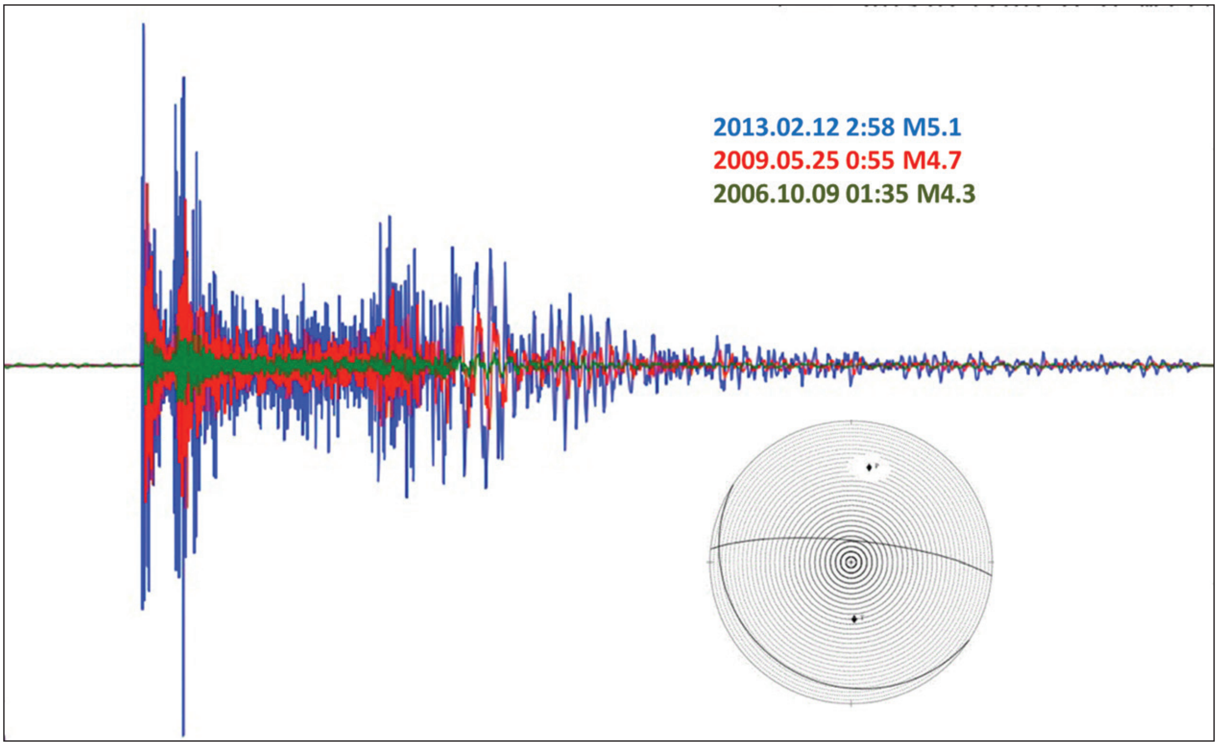

Figure 5: Waveforms as detected by the MDJ station in China, resulting from the DPRK tests

In the civilian sector, seismology has major use in siting and designing of nuclear power plants in regard to ground motion. It can also be used for tsunami warning, seismic triggering switches and other safety systems. In the strategic sector, seismic monitoring is used for detecting and characterising nuclear explosions. Nuclear explosion monitoring requires both national and global capabilities/ networks. However, one has to depend upon only national data to determine the yield of the nuclear explosion(s). Additionally, the system requires real-time data acquisition and communication system with very high reliability, complimentary supporting monitoring systems, 3-D Network, Real-time Seismic Data processing and dissemination centres, Decision and Action centres. A global seismology network should be able to locate the source, as well as estimate the magnitude of a nuclear explosion. However, Low Yield explosions are difficult to monitor and distinguish it as an explosion, especially if of clandestine nature.

As the technology has advanced it is possible to discriminate between nuclear explosions and other seismic events like earthquakes by the looking at the depth of the explosion and studying the seismic waves. In case of nuclear explosions P-waves have higher amplitudes and other waves have lower amplitudes, while an earthquake generates strong S-Waves, the seismograms of underground nuclear test lack most of these waves. So the waveforms are essentially different.

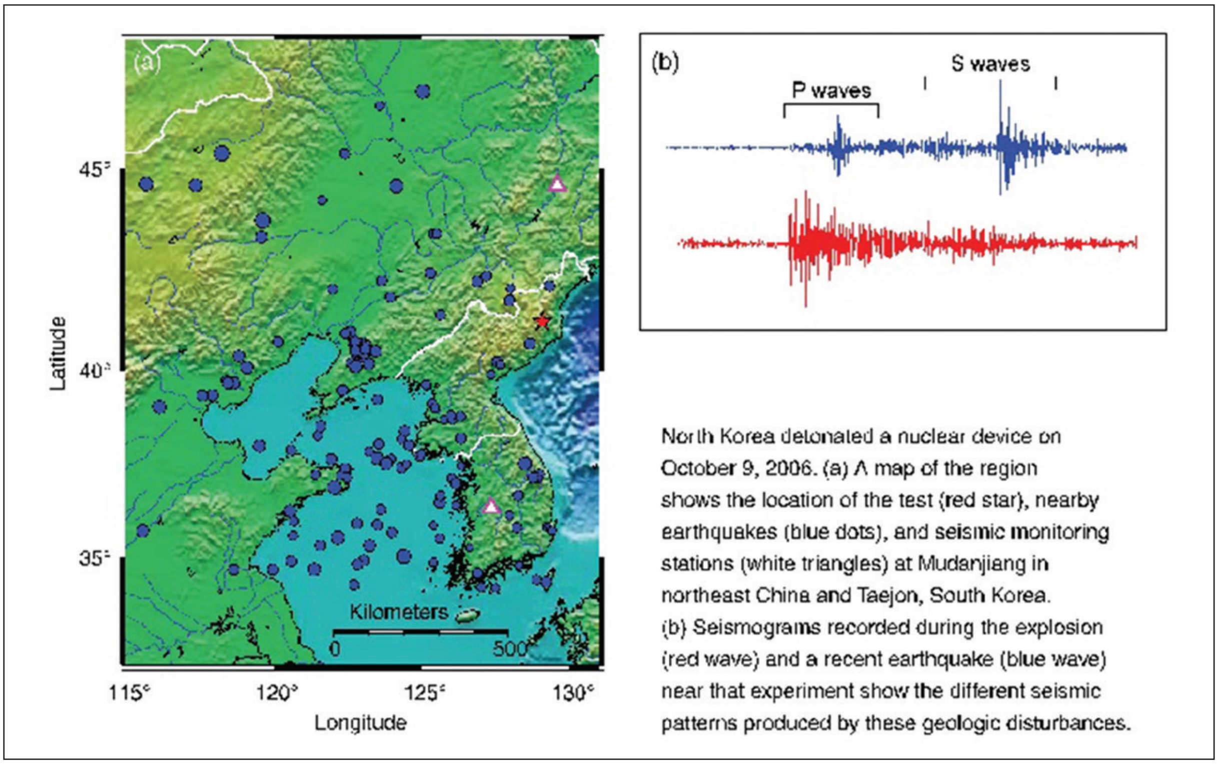

Figure 6: Earthquake generates strong S-waves, the seismograms of underground nuclear test lack most of these waves. Instead, the P- (or primary or pressure) waves dominate the seismogram from the detonation of an atomic bomb below ground

Another way to distinguish a nuclear explosion from an earthquake is by using the Body Waves and Surface Waves (Mb Ms) criteria wherein there are less surface waves as compared to body waves. Forward Modelling can also be used to determine a nuclear explosion. At the regional (<1800kms) distances, the granitic L-waves and RG waves are excited and can be a good indication of a nuclear explosion vis-a-vis an earthquake or any other seismic event. Seismic arrays are a necessity, given that they give much more data and are more efficient and precise in estimating probable locations of events.

Despite all precautions misinterpretations can occur. In 2003 the US announced that there was an ‘event’ in LopNor in China. However, this announcement was subsequently modified. This event highlights the importance of having access to data from local stations and also the fact that in certain geographical locations, it may be difficult to discriminate between explosions and natural events/ earthquakes. Uncertainty (60-90%) exists in discrimination when the event yield is low. The main issue with relying exclusively on seismic monitoring is the discrimination between explosion and earthquake. One of the ways to enhance detection capability is by monitoring the signature of surrogate explosions like those carried out in mining operations. Mining explosions are an excellent source of calibration for detection capabilities with respect to distance vs. explosive yields (80-100 km radius one can detect as much as 10T TNT equivalent yield explosions). If a set of networks are suitably planned along the border sufficient penetration to even detect yields of the order of tactical nuclear weapons (~0.1 kT) is possible.

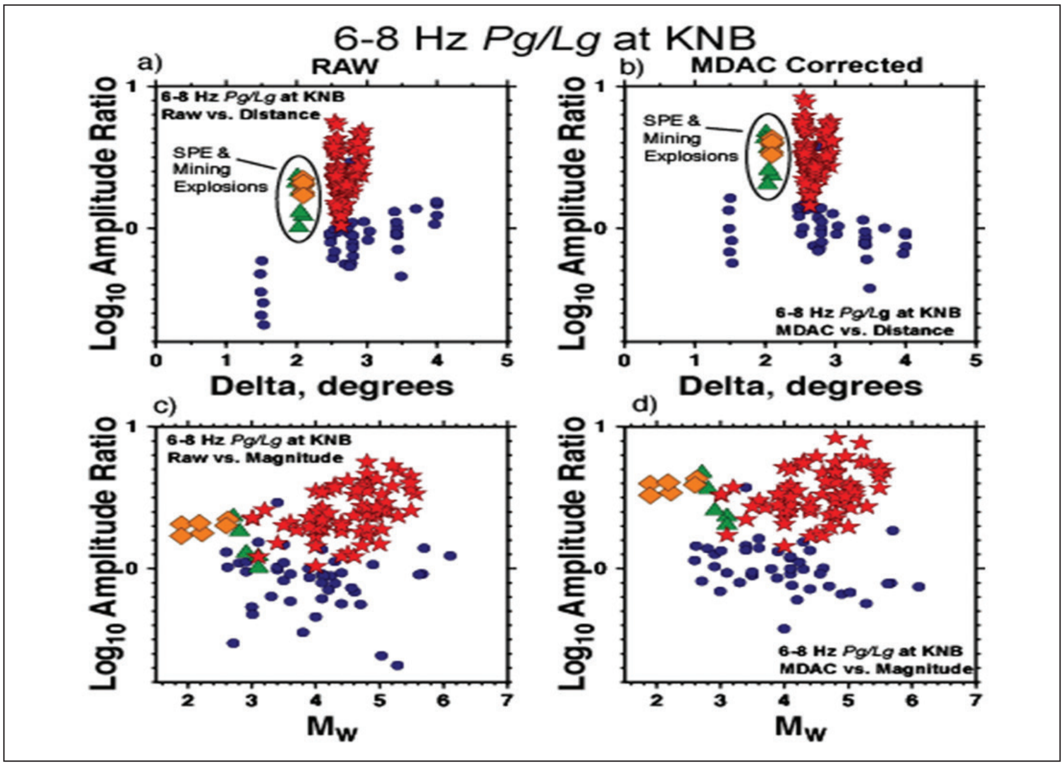

Figure 7: Mining Explosions/ Nuclear explosion surrogates

Low yield explosions are very challenging, as there are ways and means of disguising it. For instance, if a low yield test is conducted in a cavity that was produced by an earlier test, it decouples, resulting in several tens of times weaker seismic signals. Obviously, this can put off the estimate severely. Presently, even the CTBTO network is not equipped to detect yields of the order of Tactical Nuclear Weapons. China, for example, has only 11 of the IMS stations—with this kind of network, it is not possible for CTBTO to pick up any low yield signals from China.

The Indian Scene

IMD Capability

Seismological Monitoring in the country has a long history with the first monitoring station coming up at Alipur in 1898. Currently, there are 82 networks, 66 of which are broadband digital and with the remaining to be upgraded in the near future. The seismic network is shown in figure 2. The real time data from these stations is sent to the central receiving station (CRS) at New Delhi and Hyderabad, which allows for continuous waveform display and 24/7 monitoring of seismic data.

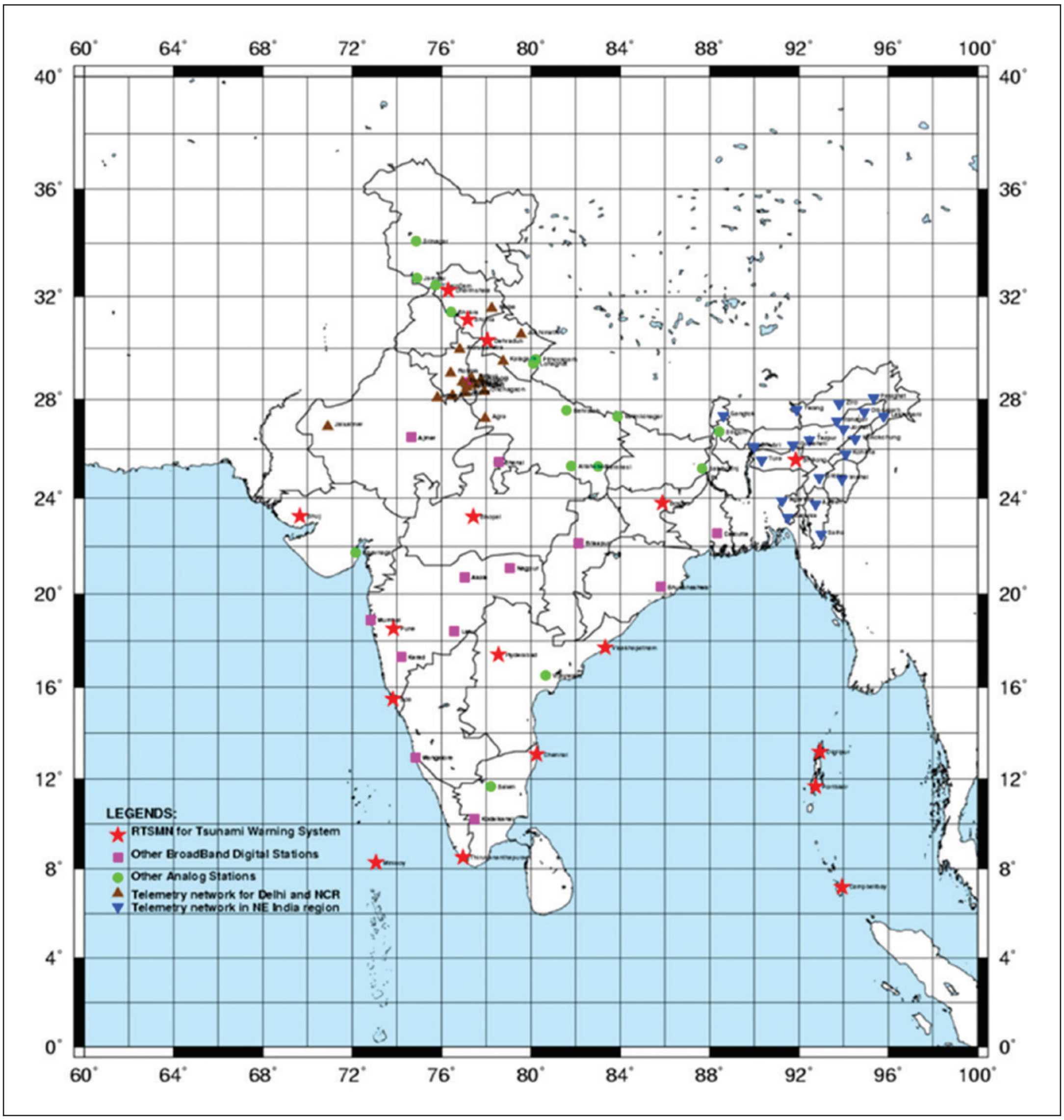

Figure 8: National seismic network (82 stations)

Continuous seismic waveform data of three seismic stations: Port Blair, Minicoy and Shillong data are transmitted to the Incorporated Research Institutions for Seismology (IRIS) network in USA, since December 2012.

The response time of the seismic monitoring has been brought down dramatically with the evolution from 1 hour with analog observatories to ~5-8 minutes with upgraded digital observatories.

Along with a terrestrial connectivity, India has a dedicated VSAT network to securely and efficiently transmit the data collected by the monitoring stations to the central stations at New Delhi and Hyderabad. Presently, 102 seismic and 26 GPS stations have been integrated with this Network.

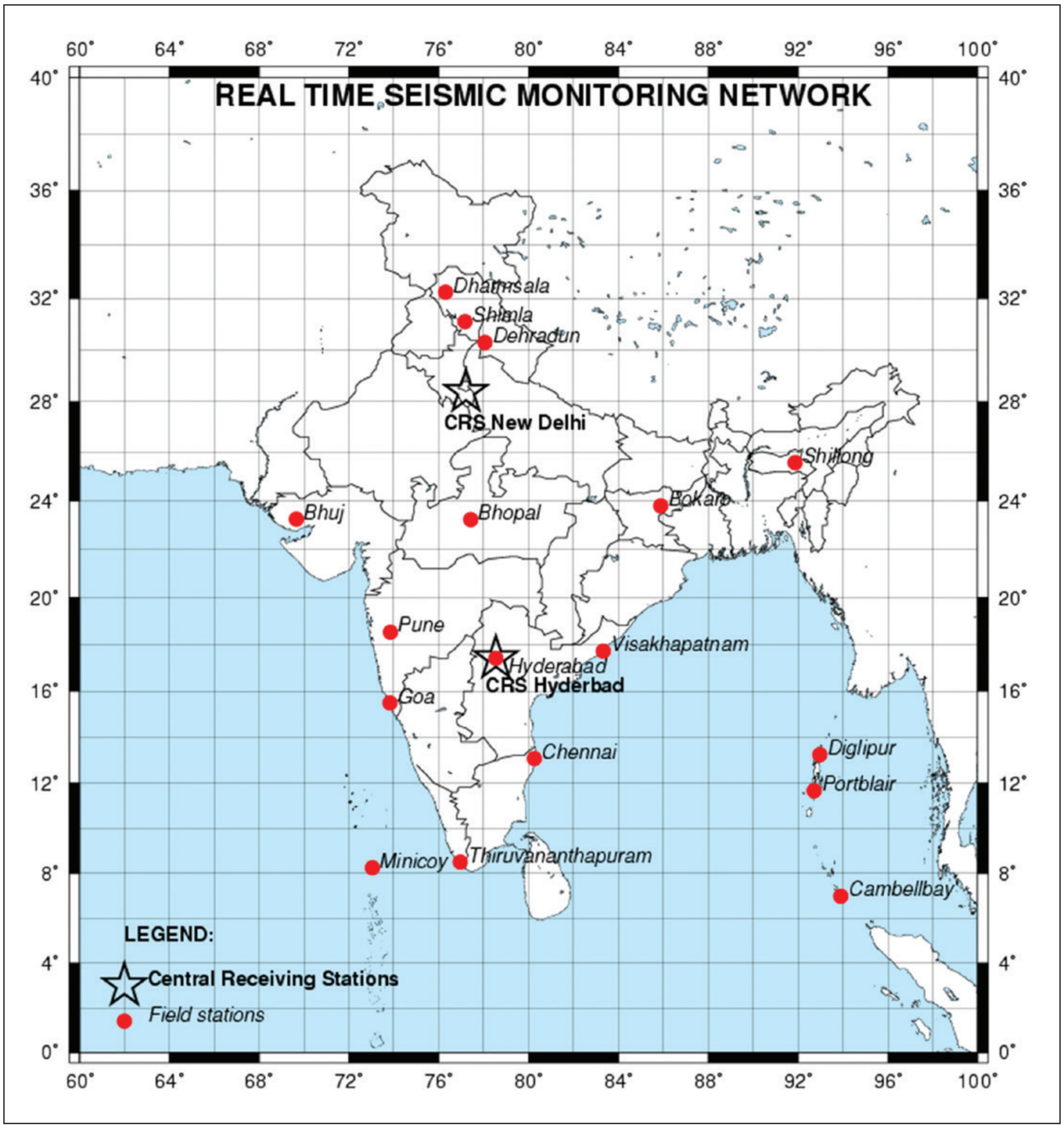

Figure 9: Real-time monitoring network (17 broadband stations)

Currently, there are17 Broadband seismic stations (figure 3) with co-located accelerometers and 24-bit digital data acquisition systems. V-SAT communication is facilitated from these field stations to two Central Receiving Stations at New Delhi and Hyderabad for real-time seismic waveform data transmission.

Establishment of Integrated Seismic and GNSS (Global Navigation Satellite System) Network (ISGN) is an initiative of Earth System Sciences Organization (ESSO), Ministry of Earth Sciences (MoES) for better integration of field stations and observatories in the country. Under this project, standalone seismic and GPS/GNSS receiver stations (provided by MoES to different National institutions through its various programmes) as well as Regional seismic data Centres of our country are integrated through satellite and terrestrial links with data centres established at Indian National Centre for Ocean Information Services (INCOIS) Hyderabad, and India Meteorological Department (IMD), New Delhi. Thus, a National central pool is created for real time acquisition of seismic and GPS data, real time processing, data sharing, storing and archival and earth quake/alert information to general public.

The current operational capabilities of the National Seismological Network of India are shown in figure 4. They comprise:

- M>3.5 - Peninsular Shield region.
- M>3.5 – Andaman & Nicobar Islands
- M>3.5 - Extra-Peninsular Shield region.
- M>4.0 - Border regions.
- M>2.5 - Delhi and surroundings.
- M>3.0 - North East India region.
- M>6.0- Earthquakes of tsunami-genic potential on Indian Coasts/ territories.

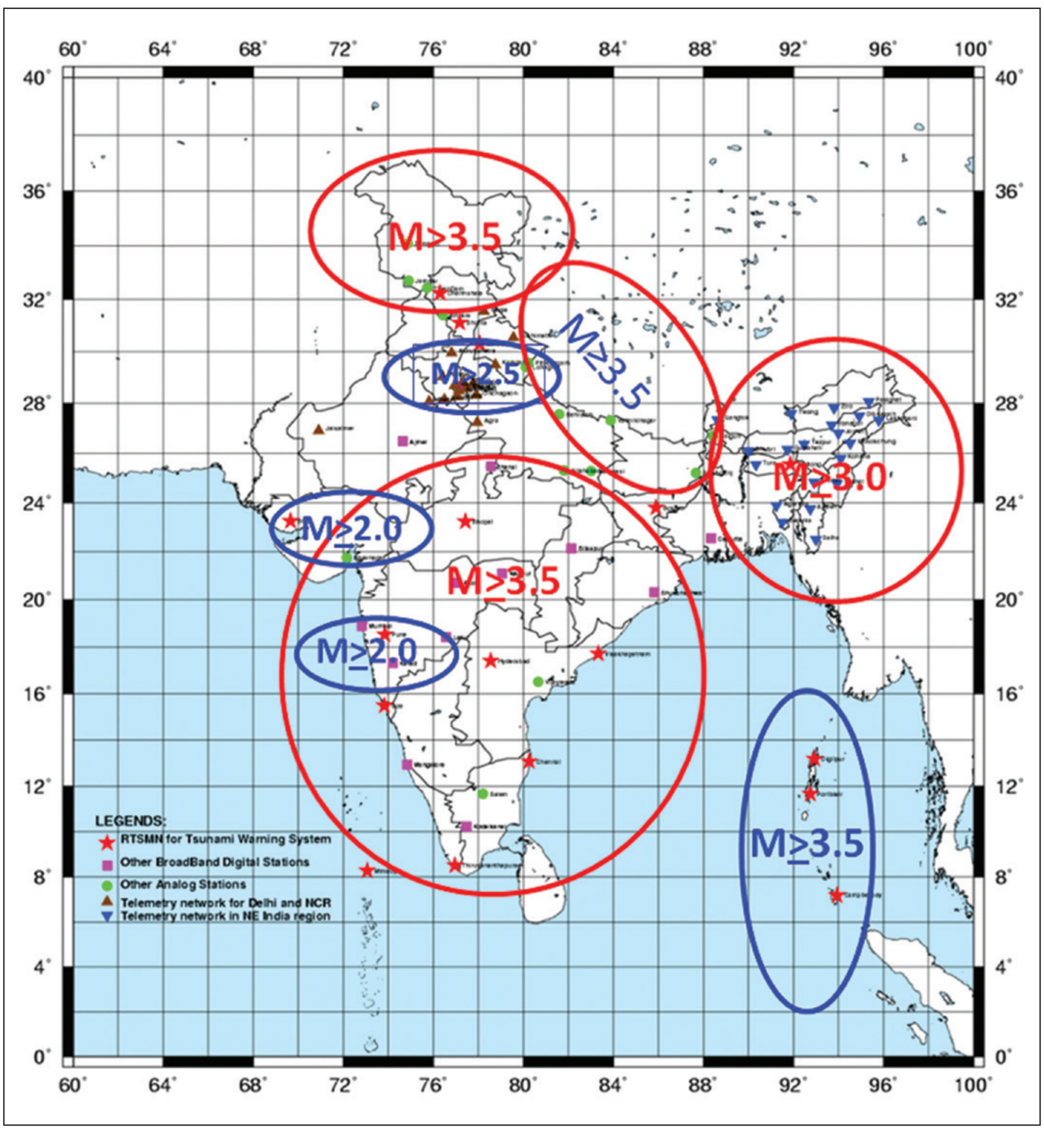

Figure 10: Operational Capabilities of existing National Seismological Network

Most of India's stations were established in the 1950s and 1960s and the magnitude detection the capability shown in figure 4 was available at the time of establishment. This has degraded over time, mainly on account of growing urbanization and related cultural and ambient noise interference with consequent degradation of signal to noise ratio significantly. The continuously deteriorating signals have rendered most of the stations with a detection capability of magnitude of 4. Research is underway to mitigate this and enhance the detection capabilities of stations. Borehole sensors are being considered to replace the detectors in areas with a lot of ambient cultural noise disrupting the signals.

DAE monitoring capability

BARC has one of the world's biggest seismic arrays at Gauribidanur, 120 km north of Bangalore. The L- shaped array - with each arm 25 km long - has 20 seismometers embedded in rock, which BARC says 'can detect events of magnitude as small as 3.3.from Sunda trench', the origin of last year's tsunami. This array has progressively undergone technology and data processing changes over the past decade and has in-house developed hardware and software needed for the real time data acquisition and processing. This array, together with a seismic station in Mumbai and another seismic array in Delhi and a link-up via India's INSAT-3C satellite to the data centre in BARC, constitute DAE's seismic monitoring capability.[3]

Since India's primary concerns are regional-based, focus must be on establishing precision seismic networks on a regional scale capable of detecting yields less than 10 T. Being non-signatory to CTBT and hence not privy to their detection technologies, it becomes critical to benchmark our capabilities against global standards. India is at par with international organisations on the instrumentation and processing side, but needs to improve on detection capabilities and network density.

To monitor such events and to estimate the yield to a certain degree of accuracy, the following capabilities are necessary:-

- Networks, Arrays, Data Acquisition
- Supporting system – Monitoring air and water
- Real-time communication - VSAT, tunnelling through Internet with proper encryption
- Real Time Data centres at the Local, Regional, National levels
- Databases and Information dissemination

In case of a nuclear strike against a country, the country will require large number arrays concentrated at key points to accurately cover the whole region. It is important to detect few tonnes/ sub-kT yield explosions because most of the weapons will either explode in the air, very near or on the surface, very few will be able to penetrate deep into the ground. Detection, interpretation and proper documentation of the data must be done fast (within 5 minutes) in order to decide and implement the response. Global multidimensional monitoring is the deterrent for Underground Nuclear Explosion of yield above 1kT.

3 BARC seismic network for tsunami alert, *Press Trust of India*, September 24, 2005, http://www.rediff.com/news/report/tsunami/20050925.htm

Our national network may need different architecture and system for seismic monitoring depending upon our security requirements

Takeaways

The key takeaways from the panel discussion are the following:

1. Current national capacities need to be augmented and digitized and the seismic network needs to be densified so as to be able to improve the detection capability of earthquakes of magnitude ≥2.0.
2. National and regional hubs are required in order to ensure that the data is centrally acquired, standardized, processed, archived, stored and disseminated to users. The regional networks need to be integrated into national networks.
3. Seismic monitoring is the workhorse for detecting both earthquakes and nuclear explosions. Synergy between IMD and BARC is desirable, since IMD gets the real time data from 200 seismological stations throughout the country. The same seismometers meet the frequency range requirements to detect the nuclear explosions. Further, some of the IMD stations in strategic locations can be equipped with microbarographs to supplement nuclear test monitoring. The data can be streamed to BARC for real time analysis as well.
4. Similarly, non-sensitive data from DAE seismographs can be fed into the national network for enhancing the database and characterizing specific event signatures.
5. Bureaucratic bottlenecks in the purchase procedures have caused many delays in the planned upgradation of 78 stations since 2012. It should be overcome by including it as a national security priority.
6. Attention needs to be paid to the human resource requirements. The data available is voluminous and special cadre of analysts needs to be trained.

Radionuclide Monitoring

Radionuclide monitoring is the only technique that can confirm whether or not the explosion detected is a nuclear explosion. Radionuclide monitoring technology measures the presence of radionuclides in the atmosphere for the purpose. Radionuclides (radioisotopes) occur in the environment either naturally or due to man-made activities. Natural radionuclides include both of terrestrial origin and cosmogenic. Manmade sources are radiopharmaceutical and reactor releases; radiological/ nuclear reactor accidents and nuclear explosions. Radionuclide monitoring also involves the detection of certain noble gases, that are produced during nuclear reactions, and do not occur naturally.

The characteristics of radionuclide release from a reactor and a nuclear weapon explosion are fundamentally different, which makes it an excellent mode of detection. In the case of a nuclear installation, both radiation and radionuclide releases are monitored, whereas in order to detect a nuclear explosion, only radionuclides and noble gasses need to be monitored. For a nuclear installation, air, water and soil samples are monitored. A nuclear explosion conducted can only be monitored by the presence of certain radionuclides in the atmosphere, so only the atmosphere needs to be monitored. Unlike atmospheric or vented explosions, well-contained underground explosions are not easy to detect. Most of the radionuclides produced remain within the cavity formed due to the explosion. The radioactivity fallout in the form of noble gases, however, reaches the surface with a good probability, as they do not react with the rock and soil within the cavity. Radionuclide monitoring for the CTBT verification regime comprises both particulate and noble gas monitoring for detection of above and underground tests respectively.

Particulate Radionuclide Monitoring

Following an atmospheric nuclear explosion, solid fission products attach to dust particles that are propagated by prevailing winds over great distances. Underwater nuclear explosion also release radioactive particles into the atmosphere. Even shallow underground nuclear explosions can be detected by their release of radioactive debris.

Lars-Erik De Geer conducted a thorough review of all possible radionuclides produced in nuclear weapon detonations and defined a list of "Relevant Radionuclides" which the Treaty State parties accepted as being the working basis of radionuclide event reports for the IDC.[4] The review considered three general groups of radionuclides classified according to their origin as: nuclear-fission products; neutron-activation products; and nuclides arising as weapon fuel residues or activation products. A subset of 92 radionuclides was identified, which are relevant from the detection point of view (4 fuel products,

4 K M Matthews, The CTBT verification significance of particulate radionuclides detected by the International Monitoring System, *National Radiation Laboratory,* 2005, http://www.moh.govt.nz/notebook/nbbooks.nsf/0/856377d65427ad6fcc257346006f47e0/$FILE/2005-1.pdf

47 fission products, and 41 neutron-activation products). A further condensation of the list is done to shortlist 'significant' radionuclides, based on the detection probability index of the radionuclide, which is a function of several factors including detector efficiency and half-life. A significant fission-product radionuclide is defined as one which appears within the group of 10 with highest DPI values at intervals of 3, 5, 10, or 20 days after production in any of six processes: ^{235}U, ^{239}Pu or ^{238}U fission; ^{235}U, ^{239}Pu or ^{238}U high-energy fission. There are thus 20 significant fission-products altogether, with a subset of 12 which have highest DPI values irrespective of weapon type: ^{99}Mo, ^{133}I, ^{143}Ce, ^{132}Te, ^{140}La, ^{131}I, ^{97}Zr, ^{141}Ce, ^{95}Nb, ^{140}Ba, ^{103}Ru and ^{95}Zr. The significant fuel products are concluded to be ^{237}U, ^{239}Np and ^{241}Am.

Particulate radionuclide detection technology is also useful to monitor the situation of radioactivity fallout and contamination after a nuclear reactor accident. The following image shows the results of radionuclide monitoring with time after the Fukushima accident as recorded by the Takasaki station from 12th March to 31st May 2011.

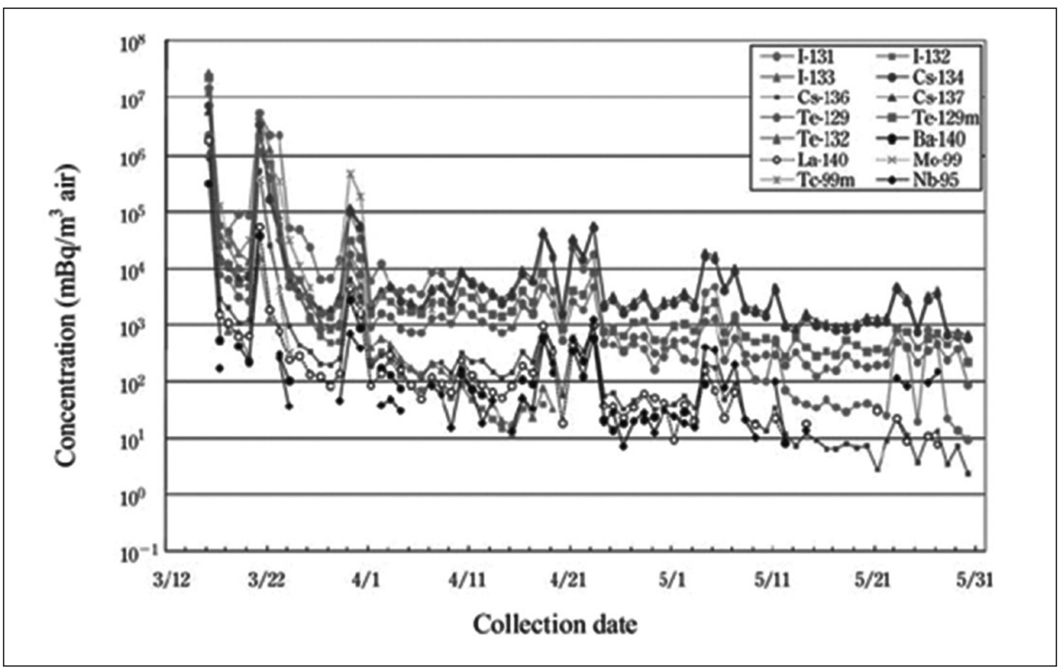

Figure 11: Radionuclide monitoring with time after the Fukushima accident as recorded by the Takasaki station from 12th March to 31st May 2011

Radioxenon and Other Noble Gas Monitoring

The detection of underground nuclear explosions with no fallout of particulate matter, require monitoring presence of specific gaseous radionuclides. In the case of atmospheric explosions and accidents in nuclear facilities, there is fallout and that enables detection of the general presence of radiation without reference to the specific radionuclides. However, if certain radionuclides are observed to be present and measured, they could provide additional information on the nature of the explosion or of the facility and its operational status.

After the testing was moved to underground, only few examples of detection of radionuclide particles have been observed over large distances from the test site. The science and technology of Xenon monitoring has been rapidly developing since the 2000s. Four isotopes of Xenon and their characteristics that are relevant for detection of underground nuclear explosion, with suitable half-lives and produced in detectable quantities are tabulated below:

Radionuclide	^{131m}**Xe**	^{133m}**Xe**	^{133}**Xe**	^{135}**Xe**
Half-life	11.93 d	2.19 d	5.25 d	9.14 h
Gamma En(keV)	163.9	233.2	81	250
Abundance (%)	1.96	10.3	37	90
X-ray (Kshell) (keV)	31	31	31	31
X-ray abundance (%)	54.1	56.3	48	5.2
Beta, Emax (keV)	-	-	346	910
Beta, abundance (%)	-	-	99	97
CE, K-shell(keV)	129	199	45	214
CE abundance (%)	60.7	63.1	54.1	5.7

Table 1: Isotopic characteristics of Xenon[5]

Xenon isotopes can also be generated by nuclear reactors, medical isotope production and other sources. The ratio of the isotopes is used to characterise release from each of the source.[6]

Source of release	**Quantity (Approx)**	**Isotopes released into atm**
Hospitals	10^6 (Bq/d)	^{133}Xe, ^{131m}Xe
Nuclear Power Plants	10^9 (Bq/d)	^{133}Xe
Radiopharmaceuticals	~ 10^{11} - ~ 10^{13} (Bq/d)	^{133}Xe, ^{133m}Xe
1 kT Nuclear explosion (Underground)	0 - ~ 10^{15} (Bq)	^{133}Xe, ^{135}Xe, ^{133m}Xe
1 kT Explosion (atm)	~ 10^{16} (Bq)	^{133}Xe, ^{135}Xe, ^{133m}Xe

Table 2: Radioxenon sources and order of magnitude of the release[7]

5 Radioxenon Detection via Beta-Gamma Coincidence Technique, *NNSA*, https://cvt.engin.umich.edu/wp-content/uploads/sites/173/2014/10/Farsoni-OSU-PPT-CVT_Kickoff_20141.pdf

6 Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios, *CTBTO*, 2009, https://www.ctbto.org/fileadmin/user_upload/ISS_2009/Poster/RN-24D%20(Germany)%20-%20Martin_Kalinowski%20Jana_Peters%20etal.pdf

7 PRJ Saey, Xenon, *Vienna University of Technology,* http://publik.tuwien.ac.at/files/PubDat_187193.pdf

Even though a large amount of xenon atoms are generated (15-20% of the fissionable atoms generate xenon at some stage), only a small fraction of it is expected to release. Furthermore it is also possible to reduce even this small amount by carefully engineering the explosion cavity. Nevertheless, uncertainties exist related to how much xenon and when and where to expect. It is hard for the tester to predict or prevent Xenon leaks, thus making it an important deterrence feature.

When the CTBT was opened for signature in 1996, noble gas detection technology hardly existed. The International Noble Gas Experiment (INGE), which brought together experts from CTBT Member States and the CTBTO, was introduced to make the noble gas measuring equipment suitable for monitoring purposes. Four prototype radioxenon monitoring systems were developed by France, Russia, Sweden and the US as part of the INGE for the IMS-

1. ARSA (Automated Radioxenon Sampler/Analyzer), developed by Pacific Northwest National Lab, USA; Minimum detectable concentration for ^{133}Xe- 0.11mBq/m^3
2. SAUNA (Swedish Automatic Unit for Noble gas Acquisition), developed by Swedish Research Agency
3. ARIX (Analyzer of Xenon Radioisotopes), developed by Russia
4. SPALAX CEA, France

Detector	Min detectable concentration of ^{133}Xe (mBq/m^3)
ARSA (Automated Radioxenon Sampler/Analyzer)	0.50
SAUNA (Swedish Automatic Unit for Noble gas Acquisition)	0.18
ARIX (Analyzer of Xenon Radioisotopes)	0.9[1]
SPALAX	0.11

Table 3: Radioxenon monitoring systems[8]

Another noble gas isotope that is useful for detecting an underground nuclear explosion is ^{37}Ar. Unlike Xenon, it is not a fission product, but is produced by neutrons (that released during fission) interacting with Calcium inside the bedrock in the cavity of explosion. Both Xenon (^{133}Xe) and Argon (^{37}Ar) are considered the "smoking guns" for detecting clandestine underground nuclear explosions.

Krypton (^{85}Kr isotope) is a fission product that gets trapped in the fuel matrix during operation and gets released during reprocessing. It is useful for validating long range Atmospheric Transport (AT) models and detecting reprocessing activities. However, the global atmospheric content of Kr-85 and release from reprocessing activity is on the rise.

8 Abdollah T. Farsoni, Real-time Radioxenon Measurement using a Compton-suppressed Well-type Phoswich Detector for Nuclear Explosion Monitoring, *Oregon State University*, https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/42388/AlemayehuBemnet2013.pdf?sequence=1

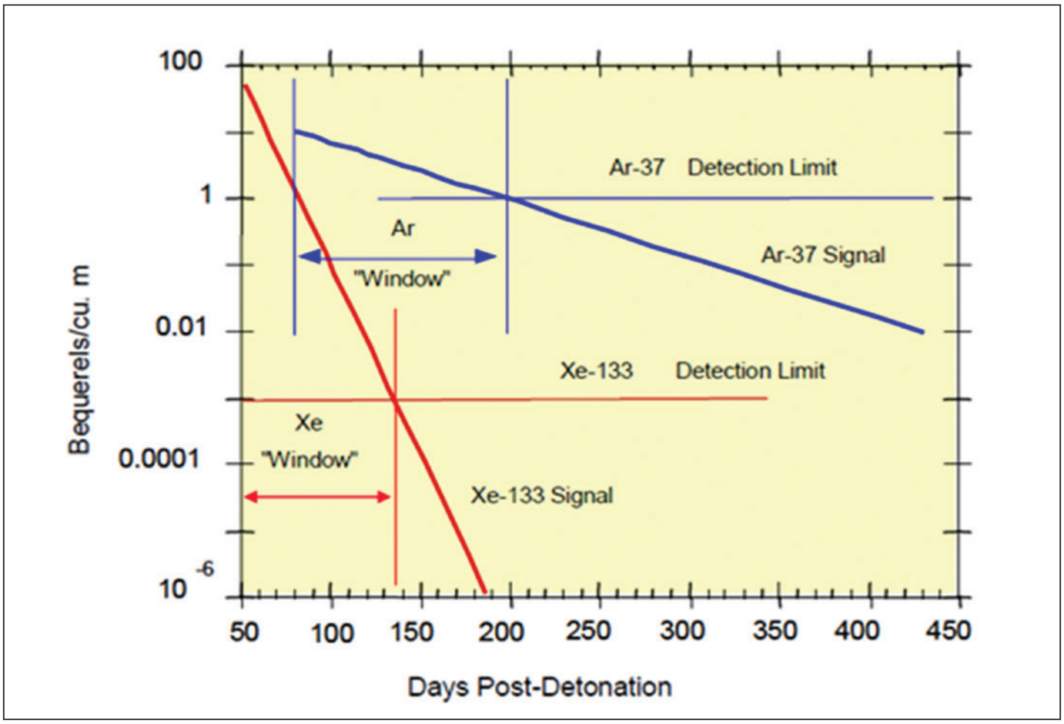

Figure 12: Detection Limit "window" for Xenon and Argon

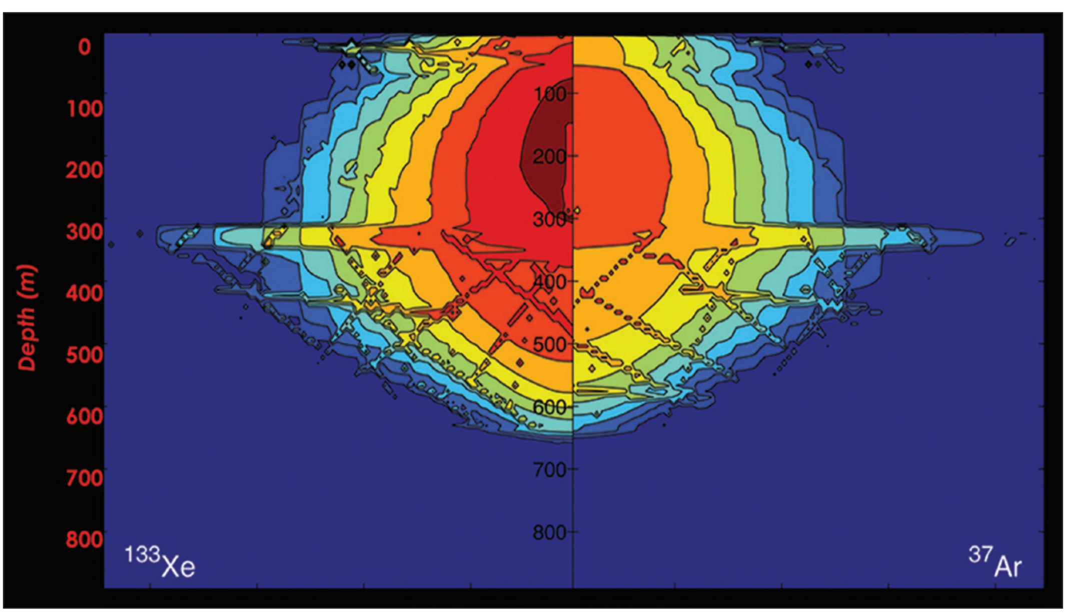

Figure 13: Gas distribution as it leaks from the chimney of a nuclear test cavity for two different gases: Xenon-133 and Argon-37

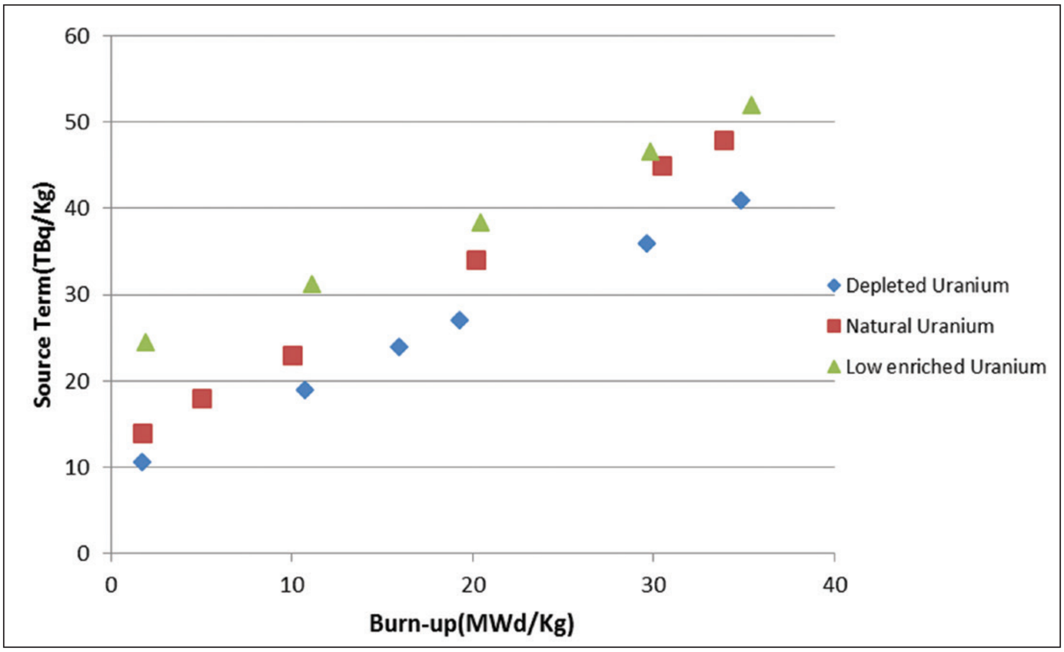

Figure 14: Krypton as an indicator of reprocessing

The Radionuclide monitoring network of the IMS transmits real time gamma ray spectra of its air filter samples to the International Data Centre (IDC). This data is analysed and results reviewed by any analyst following which the results and the raw spectral data are shared with the national data centre in member states.

Radionuclide monitoring is also carried out within nuclear facilities to ensure protection of workers and for protection of public and the environment in case of an accidental release and in High Background radiation areas (HBRA). Radionuclide Monitoring is used for the detection of smuggling of radioactive material (at ports and borders), internal dosimetry, bioassay and during radiation emergencies & transboundary emergencies (nuclear & radiological emergencies).

Uncertainties of Radionuclide detection: The Case of DPRK

The IMS detection experience of the North Korean nuclear tests illustrates the uncertainties and difficulties involved in radionuclide technique. The first nuclear test in 2006, with a seismic signature suggesting an explosion of 0.65-1.1 kT was verified two weeks later by elevated radioxenon levels at a noble gas station in Yellowknife, Canada. The readings were consistent with the established yield and location by the seismic signature. The arrival of the noble gas debris was predicted by the experts at CTBTO using their in-house developed atmospheric transport model. At the time only 10 radionuclide stations were tested and functional and there were none anywhere near North Korea.

However, the 2009 test whose seismic signatures suggested a yield of 1.5-4.5 kT, could not be verified by radioactivity release even though the Takasaki station was in operation by then. It led to the assumption that it was a well-contained nuclear test with little or no radioactive particle/gaseous release.

There is a great deal of debate around the test DPRK claimed to have conducted in 2010. Multiple radionuclide stations had picked up radionuclide signatures in correlation to the claim -- xenon isotope ratio measurements at a national radionuclide monitoring site near Geojin (South Korea) and an IMS site near Takasaki (Japan) and Barium/Lanthanum measurements at CTBTO IMS sites near Usurriysk in Russia and Okinawa in Japan. In 2015, seismic analysis was published that supported the hypothesis that nuclear tests were conducted in 2010. This was contrary to the traditional idea that if there is a seismic event, then radionuclide evidence can be used to confirm that the event was of nuclear nature.

After the 2013 test, there was a gap of 6 weeks before radioxenon fallout was detected at the Takasaki station. It is possible that the noble gases formed during the explosion were trapped inside the containment, until later when an after-shock or onsite construction led to a crack through which it could escape. There was no conclusive evidence provided by radionuclides post the claimed thermonuclear test conducted in January 2016.

Arrival at a conclusive analysis of a test with radionuclide detection is dependent on various factors such as venting, location of the monitoring stations (with a half-life of 5.5 days, Radioxenon needs to be detected before it decays off to undetectable quantities), wind distribution (dilution of the concentration, along with decay) and the growing background of radioxenon in the atmosphere due to medical isotope production facilities and nuclear reactors. While the monitoring of the noble gas isotopes would provide evidence of the nuclear nature of the event, it may still not be adequate to state with certainty whether a boosted fission or a thermonuclear device was tested. The thermonuclear nature of the device can only be established by radionuclide monitoring of Argon in the atmosphere or backed up by an OnSite Inspection.

Radiation Monitoring in India

Environmental radiation monitoring and environmental surveillance are the regular features of the environmental protection programme of the Department of Atomic Energy (DAE) and Bhabha Atomic Research Centre (BARC) continuously monitor environment, and collect site related meteorological data. Sophisticated weather monitoring SODAR systems are operational at Kaiga, Kalpakkam, Tarapur and Trombay. Environment around the nuclear sites is well monitored.

The mandate adopted by DAE in the Environmental Monitoring Programme includes:

- Analysis of pollutants in various environmental matrices & their application
- Development of continuous monitoring system for air pollutants
- Radiation Protection for the front-end of the Nuclear Fuel cycle, Environmental radioactivity monitoring in the country and instrumentation for the same
- Studies on Aerosol behaviour, environmental radiation monitoring dosimetry, site meteorology and dispersion modelling

Most significantly, BARC has established a countrywide environmental radiation monitoring network (IERMON). As on April 2014, the network has 410 monitoring systems at 80 locations (Cities/Towns) across the country. The network consists of large number of installed monitors (IERMON system) spread across the country and a data-receiving Central Station. The IERMON system monitors atmospheric gamma radiation levels of the location and sends the data to the IERMON Central Station. Under normal condition the system sends data two times in 24 hour and in case of radiation emergency it sends data every 5 minutes till radiation level comes to normal background levels.

Each station is equipped with:

- GM Counter based Radiation Monitor
- Ion Chamber based Radiation Monitor
- High Volume Air Samplers for Radionuclide Identification
- Associated Data Acquisition and Communication System

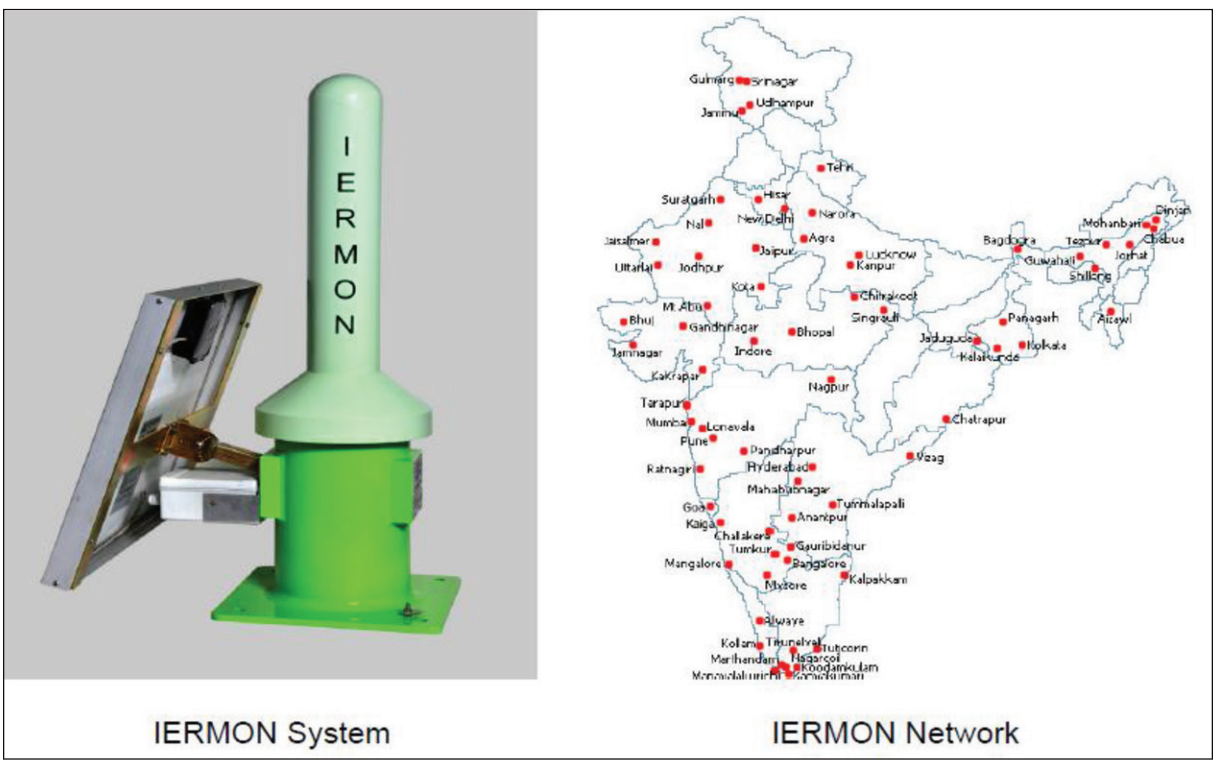

Figure 15: IERMON system and network

The DAE has state-of-the-art modelling capability and expertise. IGCAR has adopted most advanced numerical models for atmospheric dispersion (ARPS, MM5, WRF-FLEXPART, HYSPLIT, SPEEDI and locally developed sea breeze model MAM).

BARC has apparatus to detect and conduct aerial survey to detect contamination over spatial and temporal variance. UAVs are also being employed by BARC to carry out assessment. Indian Real-time

Online Decision Support System (IRODOS) has been set up for Offsite Nuclear Emergency which includes mobile systems like Aerial Gamma Spectrometry System (AGSS).

Takeaways

The key challenges and recommendations for this sector are as follows:

1. Although the radiation detection and monitoring is done in various modes by the DAE, its capabilities for radionuclide detection and identification needs to be improved. Radionuclide detection is referred to as the “smoking gun” evidence for a nuclear explosion; however, it remains a technology ridden with uncertainty. For the purpose of detection of an underground nuclear test, it can only be complementary to seismic, infrasound and hydroacoustic. The technology of radionuclide detection is just reaching its maturity- the first radionuclide station with noble gas detection capabilities was formally integrated into the IMS in 2010. It is important that the DAE keeps up with the global developments in this technology. Setting up of 2-3 stations with the order of sensitivity of that of the IMS radionuclide stations would suffice for the country.

2. The number of detectors need to be stepped up substantially in order to effectively monitor radionuclides since it is passive, relying on air currents to move the particles or gases to the radionuclide detection site. Even for detection of radiation, given the range of a detector and possibilities of getting shielded, the density of stations should be increased.

3. Data sent by the radionuclide stations to the IDC do not only include gamma radiation spectra, but also meteorological and state-of-health information. State-of-health data provide information on the station’s operational status and the quality of the raw monitoring data it transmits. Kalpakkam has a meteorological division that provides data for IGCAR simulations and atmospheric transport modelling. If meteorological monitoring can be coupled with radiation monitoring stations of IERMON, it will be very useful for more accurate prediction in case of an event.

4. The instrumentation developed in the context of detecting underground nuclear explosions would also help to determine unequivocally the yield of nuclear warheads used in a conflict.

Satellite Monitoring

Satellite observations are very useful for monitoring underground nuclear explosion as well as missile launches. Satellite based monitoring is not part of the IMS verification regime, because at the time of negotiations satellite images were difficult to acquire and expensive or classified. Today, the operational satellites are plenty in number and the data is available much more easily.

Both optical and radar observations are beneficial to monitor for underground nuclear explosions. The technology of optical satellites has developed in the last decade and a resolution of 1 m or less is possible today. Radar satellites, equipped with Synthetic Aperture Radar (SAR) operate at any time of day or night and are independent of cloud coverage, collecting both amplitude and phase data. The SAR satellites have repeating paths which, using two phase datasets for the same location at different times, allows for interferometric SAR (InSAR) showing relative ground displacements between the two datasets along the direction of the radar beam. Topographic changes as small as 0.2-0.5cm can be detected by satellite monitoring. However, InSAR analysis is fairly complex and requires large amounts of computations, limiting its applicability only as supplementary evidence to seismological and other means.

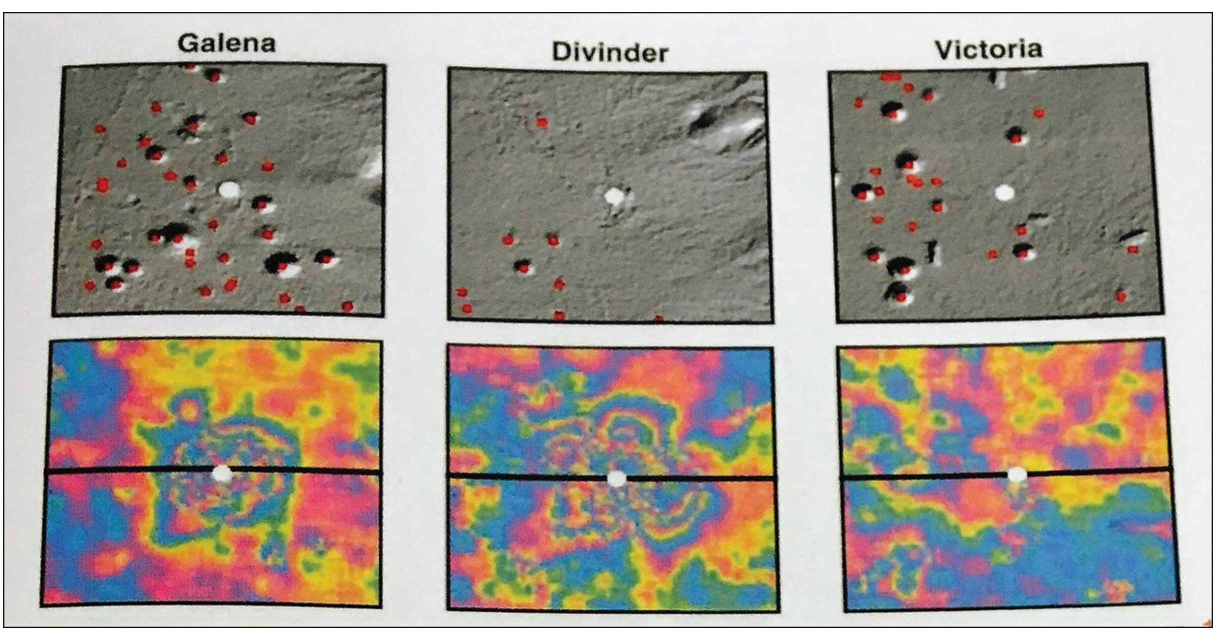

Figure 16: Coseismic surface deformation signals (white signals) from 3 underground tests conducted at the Nevada state in 1992. The top images show nearby craters (red dots) from underground tests prior to 1992. Colour interferograms in the bottom row is derived from InSAR data show surface displacement during and after explosions

On the basis of domain knowledge on what kind of equipment and preparatory work to be expected, a particular location can be monitored where a seismic event has already been detected. Similarly, continuous satellite surveillance of a specific area of interest, such as a former test site can reveal any divergence from the usual pattern of activities. Satellite surveillance forms an important component of precision monitoring.

As mentioned earlier, satellite monitoring is also useful for detecting missile launches. A geostationary satellite equipped with infrared sensors can detect missile launches at about 10-15 km altitude. Tracking the exhaust plume will enable further assessment of the missile trajectory.

Takeaways

The key challenges and recommendations for this sector are:

1. Imaging systems complement other monitoring techniques and comes in the end, only after locating the area of testing. Imaging and detecting are hence possible only on the basis of domain knowledge. GIS and the VHRR (Very High Resolution Radiometer) of the weather satellite system with an image resolution of about 1 km, and a scanning mechanism to cover more area can be adapted for the purpose. However, it requires more satellite density for better swath. Hi-resolution imaging is more appealing for identification, but there is a constraint of it having a small footprint. Platforms like the Yaogan constellation of China have the integrated facilities for identification of coarse area within which the object of interest has been located, and the capacity to swivel hi-resolution imaging system as per requirement.
2. In principle, it is possible to design a missile detection system and locate where the missile is headed. Current status of what India is planning is not known. However, the ISRO plans to launch a Geo Imaging Satellite (Gisat), carrying a GEO imager with multi-spectral (visible, near infra-red and thermal) and multi-resolution (50 m to 1.5 km) imaging instruments by 2016-17.[9]

[9] Isro designing geo imaging satellite, *Business Standard*, March 20, 2013, http://www.business-standard.com/article/current-affairs/isro-designing-geo-imaging-satellite-113032000453_1.html

Acoustic Monitoring

Infrasound Monitoring

Infrasound is acoustic waves with frequencies below 20 Hz. Infrasound waves are generated from various sources like mine blasts, chemical explosions, large surface blasts, volcanic eruptions, earthquakes, missile/satellite launches, sonic booms, space debris, atmospheric and underground nuclear explosions. This technique is mainly employed for monitoring atmospheric and shallow underground nuclear explosions. Infrasound technology has considerable potential for civil and scientific applications, including disaster prevention or mitigation. The figure below captures the normally encountered sources of infrasound.

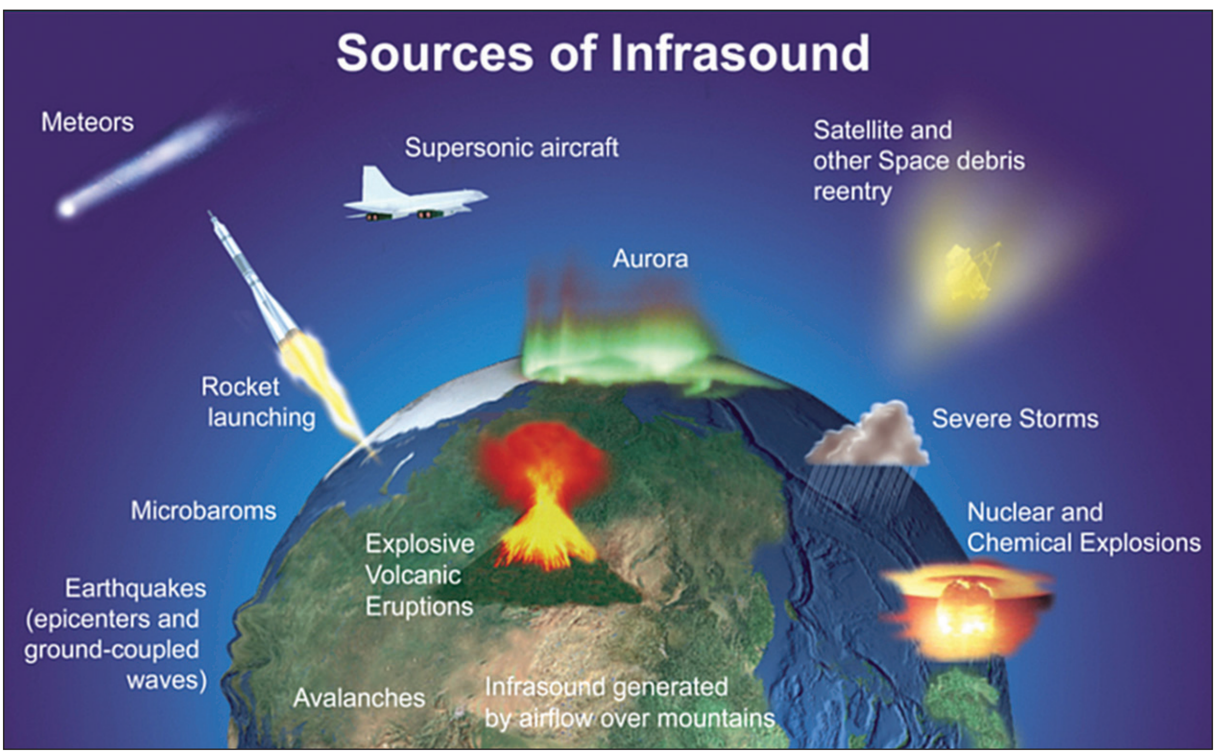

Figure 17: Sources of Infrasound

Table below lists the infrasonic observatories and potential areas for data interpretation and imaging.

Phenomena	Data interpretation and imaging
Avalanches	a) location, b) depth, c) duration
Earthquakes and seismic waves	a) ground motion – magnitude, b) source region details and c) precursors (?)
Explosions, missile launches	a) location and b) yield
Geomagnetic activity	a) location and b) particle impact zones
Meteors, space debris, supersonic aircraft	Characterized by type of entry: a) explosive, lower atmospheric and b) shock, upper atmospheric
Ocean waves	a) Wave interaction area location, b) wave magnitude and c) wave spectral content
Severe weather	a) location, b) total storm energy and c) storm processes (?)
Turbulence	a) location, b) spatial extent, c) strength (?) And d) causal mechanisms (?)
Volcanoes	a) location, b) energy release and c) potential for eruption (?)

Table 4: Infrasound data interpretation and imaging of phenomena

Infrasound Monitoring is a complimentary and not a primary system to detect nuclear explosions. Infrasound monitoring can provide corroborative evidence for an event which has been detected by Seismic and Radionuclide monitoring techniques. Infrasound propagation depends on the composition of wind and temperature structure of the atmosphere. Infrasound is able to travel great distances with little attenuation due to low atmospheric and ground absorption at infrasound frequencies and because of acoustic ceiling in the atmosphere where a positive gradient of the sound pressure with altitude causes reflections of the infrasonic rays back to the earth. This makes this technique useful for detecting atmospheric nuclear explosions. The first infrasound monitoring of a nuclear explosion was carried out in Boulder Colorado. The IMS has a much more extensive data set of infrasound records from Soviet atmospheric explosions. IDC has an archive of approximately 300 recordings from 34 Soviet atmospheric nuclear tests that were conducted in 1957 and 1961.

Infrasound data is collected through an array of micro barometers which detect atmospheric over-pressure and convert them to electrical signals. Multiple infrasound arrivals referred to as phases may be recorded at the receiving station. These phases are characterized by their apparent velocities and can be termed as stratospheric phases, thermospheric phases etc. depending on the reflecting channel. Data from number of stations can be used for localizing an event by using triangulation or cross-bearing method. A typical layout of a standard IMS array consists of three microbarometers positioned in an approximate equilateral triangle with a fourth instrument placed centrally. Concommitancy, Directionality, Characteristic Signature, and Coherence are four criteria for microphone infrasound array. The individual recordings made by the infrasound antennas are compared to each other using a variety of cross-correlation methods, searching for the tell-tale traces of coherent infrasound propagating over the array. The array technique can determine the direction from which the sound is originating. With multiple detections, from several arrays, the source of the sound can be located. There are two major techniques that characterize infrasound monitoring capabilities and these are: Wind Noise Reduction Technique by Langley Research Centre and Noise reduction technique by Australian National University. Various geometries are made use of by different countries, in array designing.

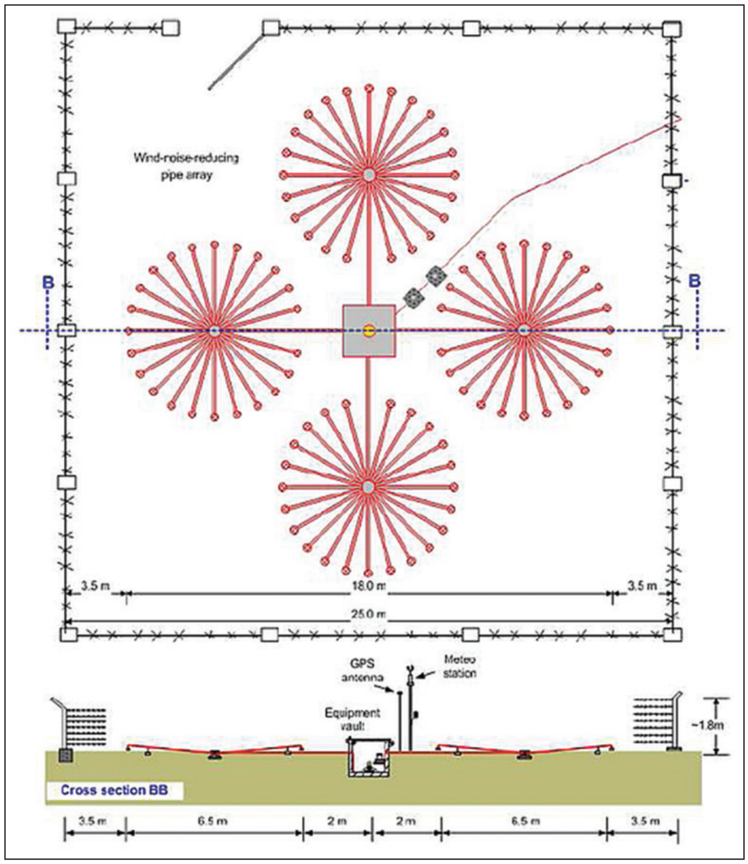

Figure 18: Configuration of array element with pipe structures to reduce wind noise

Source Discrimination is one of the most important challenges in the monitoring of infrasound wave analysis because of the unknown dynamic path function as well as the source function itself. It is important to note that signals change from time to time and event to event. Also, no two events produce the same infrasound signatures. Thus, to effectively monitor infrasound, networking and a global system become very important. The case of the International Monitoring System is a case in point. The IMS put in place by the CTBTO has 60 infrasound stations globally out of which 45 are certified.

Infrasound Monitoring is a key method to probe the atmosphere and monitor its dynamics. Co-location of infrasound and seismic monitoring arrays (IMD) is useful as both techniques need understanding of atmospheric dynamics. It is also useful for complete understanding of phenomena in the near-Earth surface especially when coupled along with seismic monitoring techniques. Infrasound Monitoring is therefore of value for early warning for volcanic eruptions and tsunami-like events.

Infrasound is a useful technique to adopt as an early warning and security tool. Calibration and characterisation of source noise is likely to be an involved exercise. Once these are done and Infrasound monitors are appropriately deployed, it is possible to effectively monitor missile launches and aircraft penetration into one's territory. Co-located with seismic monitoring units, it can corroborate nuclear explosion events as well.

Hydroacoustic Monitoring

Hydroacoustic Monitoring is a complimentary tool and is mainly used for post-event analysis to confirm that an underwater explosion has taken place. The technique can be used detect & identify underwater events having bearing on national security by employing sophisticated sensors and techniques for the task. The US has been using the Acoustic Monitoring Project of the Vents Program for continuous monitoring of ocean noise since August 1991 using the U.S. Navy SOund SUrveillance System (SOSUS) network and autonomous underwater hydrophones. Hydroacoustic monitoring can be used to detect volcanic explosions, tremors in the tectonic plates, underwater naval surveillance.

To detect explosions, a mix of Fixed Seabed Array, Moored buoys and Adhoc Underwater Sensor Networks are used. Such sensors are usually placed along the country's Exclusive Economic Zone (EEZ). A long range array at a depth of 100 m can detect an event thousands of kilometres away. This is because of the fact that underwater attenuation is low and therefore longer range detection is possible. However, profiling depends on time of the day, location of the source and ocean depth.

The limitations of the Acoustic monitoring technique are high cost, limited bandwidth, fading, and problem of monitoring over high tides. Although the technique can detect naval platforms, it cannot detect missile launches.

India has developed some capability in acoustic monitoring. It however, appears to be a stand-alone system and is not integrated or extensive enough to provide coverage of nuclear events and missile launches.

Takeaways

The key recommendations for this sector are as follows:

1. Some acoustic signatures corresponding to rocket launchers and supersonic aircraft are available. It would be useful to have a database of the calibrated signatures of different class of missiles, launch vehicles and aircraft. Such a database will prove valuable for detecting and identifying the noise source. Furthermore, atmospheric and shallow underground nuclear explosions can generate infrasound waves that may be detected by the infrasound network. The detection and identification possibilities of infrasound monitoring have not been explored fully. It is useful to co-locate infrasound stations with seismic stations.

2. India is currently not equipped with any hydroacoustic station in order to detect underwater nuclear tests. Sensors for submarine acoustic detection are mounted on platforms such as ships, submarines, and sonarbuoys. Linear-towed array sonar has been developed in the country, but not deployed on the sea coast, as of now. Infrasound signatures of the periodic underwater launch testing need to be collected for calibration. An integrated effort between underwater acoustics and air acoustics laboratories is essential for this.

Making Sense of the Data

Concept of Image reconstruction

The mathematics behind reconstruction of images is common to many fields: medical imaging, radar imaging, seismic imaging, SONAR etc. The overall principle behind reconstruction of images is that by repeatedly directing a probe (X-rays, pressure waves, Electromagnetic waves) at an object and measuring it after interaction, enough data is obtained in order to reconstruct its image.

Filtered back-projection

It is one of the most important reconstruction tools that is widely in use today. Seismic imaging, travel time tomography and detection and imaging of small radiation sources can all be done using this tool.

The following image shows the concept of X-ray transform, wherein a bunch of transmitters are probing an object with X-rays and the receivers on the other side detect the X-rays after interaction with the object.

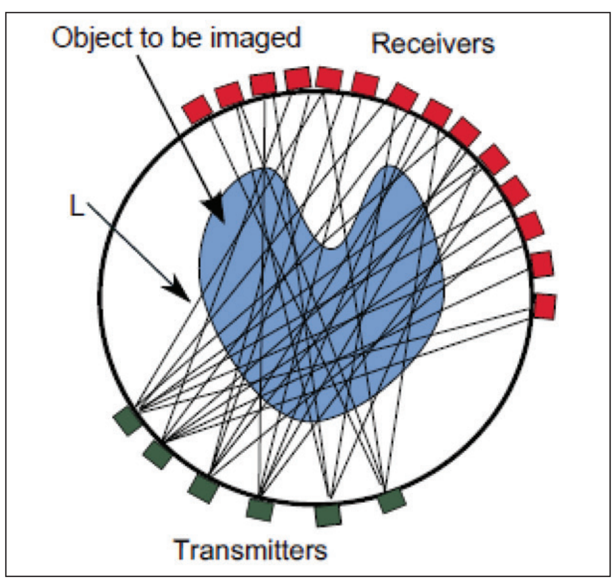

Figure 19: Back-projection

Based on the medium, the attenuation of X-ray will vary. With the knowledge of the intensity of the X-ray at its source and after interacting with the medium, the only unknown function is the attenuation integral along the line(s) (or circles, ellipses, cones etc.) of projection. Computing the unknown function can lead to recovering the image of the object.

Back-projection is when the X-ray that is being projected gets sent back with the same value, which would automatically lead to an increased intersection at where the object is, and hence renders a clearer image. The image that is thus produced gives the shape of the object, but there will be blurring. A filter can be designed to correct this and give strength to the image.

The following image shows the possibility of using filters in order to get a better image:

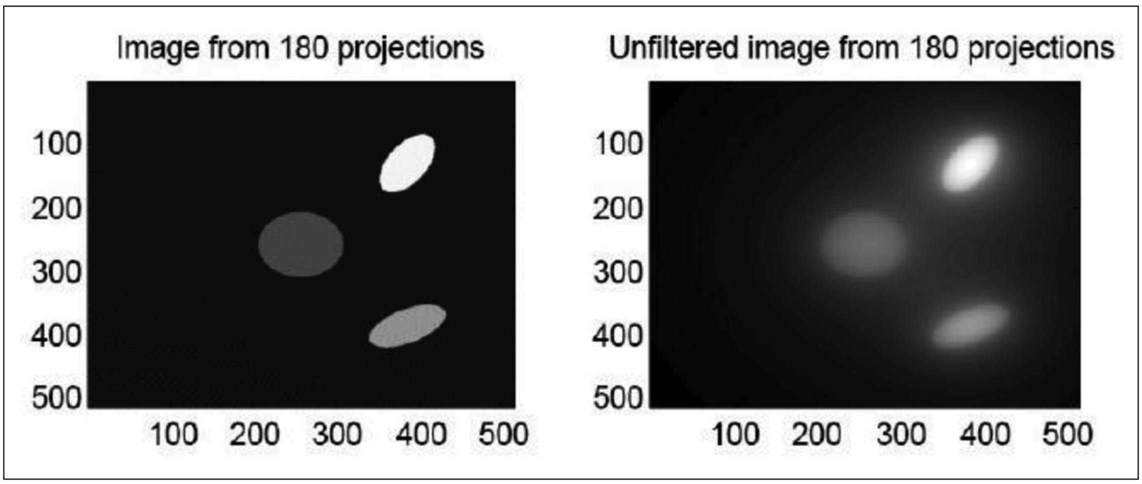

Figure 20: Filtered Back-projection

Seismic, Radar and Sonar Imaging

The imaging is done by filtered back-projection for seismic, Sonar and Radar imaging. Pressure waves generated on the surface of the earth scatter off the inhomogeneity present on the subsurface and return to the subsurface. The subsurface can be reconstructed by measuring the projections of these pressure waves. Similarly, sound waves and radio waves scattered off from objects to be reconstructed can be recovered using filtered back-projection.

Mathematically, all these problems are non-linear, which are very difficult to solve. As a thumb rule, these problems are linearised in order to gain as much information as possible by making reasonable assumptions.

Back-projection is a very powerful technique relevant to many imaging problems. The only disadvantage is that it introduces artifacts in the image. One needs to characterise those artifacts in order to get the actual image.

Travel time tomography

It is a technique used to map the inner structure of the earth based on travel times of seismic waves. It is an extremely difficult non-linear mathematical problem of our times. This also can be studied using the back-projection technique.

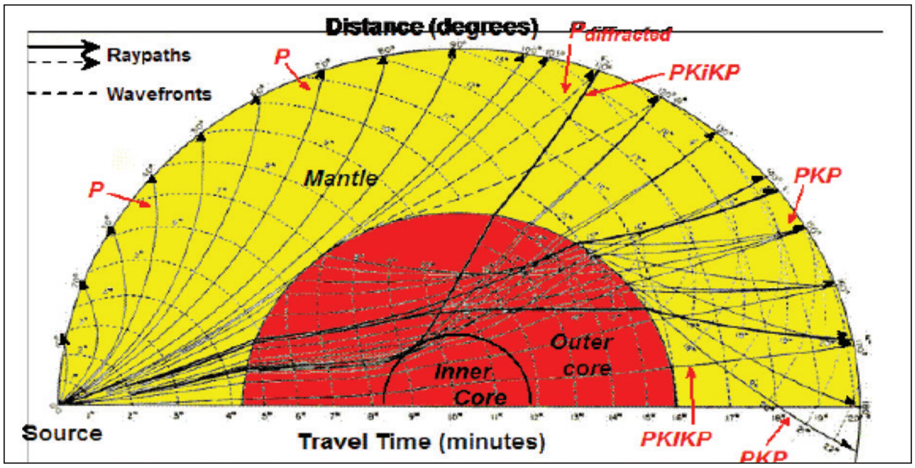

Figure 21: Travel time tomography

Detecting low emission radioactivity sources

The mathematical framework remains the same as back-projection – determining the unknown function along the cone of projection.

A Compton camera consists of two detectors one placed behind the other. A photon incident on the first detector undergoes Compton scattering which records the position at which the scattering occurs and the energy of interaction. After scattering the photon is absorbed in the second detector and position and energy are recorded. Based on this information, the scattering angle can be measured.

State of the Art: International Data Centre, CTBT

Data are at the core of the CTBT verification efforts. Their analysis at the International Data Centre (IDC) provide the information that Member States need to establish whether an ambiguous event has taken place and whether such an event may indeed have been a nuclear explosion.

The IDC is a central element of the CTBT verification mechanism. It collects, processes and analyses monitoring data originating from the 337 facilities of the International Monitoring System (IMS). Processing and analysis results are then presented as lists of events, bulletins and reports to Member States. Based on this information, States are enabled to make judgements about an ambiguous event. The IDC also archives all data and data bulletins in its computer centre.

Three of the four IMS monitoring techniques, namely, seismic, hydroacoustic and infrasound are waveform technologies. Targeted processing of monitored data is needed to give the necessary information to make decisions concerning the nature of an event. Typically, waveform data are displayed as traces moving across a computer screen with the x-axis showing time and the y-axis representing the movement of the medium that is being monitored, i.e. ground, air or water. Once the data are stored at the IDC, data from each single station undergo independent analysis to detect signals which originate from seismic or acoustic disturbances. This process is entirely automatic. If a disturbance is detected, the characteristics of the relevant signals are measured and recorded in a large database. In the case that the same event is recorded by more than one station, 'network processing' is done to sort out the signals from different stations originating from the same event.

Some monitoring stations with noble gas technology employ the same detection method as that used by radionuclide particulate stations and send gamma ray spectra of daily measured samples. Other stations use a different method of measuring the radionuclide noble gases contained in a sample by looking at the combined beta and gamma radiation. Event categorization of noble gas samples is a highly demanding task, since some civilian sources may produce radioactive xenon in concentrations close to nuclear weapons test specifics. Work is continuing to advance the event categorization of noble gas findings.

Data on radionuclide observations are sent to the International Data Centre (IDC), where they undergo an analysis process like waveform data. After the automatic analysis process, analysts refine the results during interactive review. The findings of the screening process are presented in the Standard Screened Radionuclide Event Bulletin (SSREB). This report, along with raw data and the other bulletins are made available to the Member States. It is their prerogative to make the final judgement on the findings.

Data Management in India

The available seismological data from all the network stations including those operated by other agencies is compiled, processed, analysed and archived systematically at the Database Centre of Seismology (CS) under the IMD, on a regular basis. Monthly National Seismological Bulletins containing the phase data and the processed information on source parameters of all earthquakes located by the seismological network of CS are prepared regularly. India, represented by CS/IMD, is a permanent Member of the International Seismological Centre (ISC), UK. Seismological Bulletins of CS/IMD are shared regularly with International Seismological Centre (ISC) for incorporation in the ISC's Monthly Seismological Bulletins, which contain information on earthquakes occurring all across the globe. Towards early warning of tsunamis, real-time continuous seismic waveform data of three IMD stations, viz., Port Blair, Minicoy and Shillong, is shared with global community, through IRIS (Incorporated Research Institutions of Seismology), Washington D.C., USA. The Centre of Seismology also supplies earthquake data and seismicity reports of specific regions to various user agencies such as insurance companies, industrial units, power houses, river valley projects etc. on payment basis. Seismological data and earthquake related information are supplied to agencies dealing with disaster relief and rehabilitation measures, and seismic zoning. Seismic data is shared with various scientific, academic and R&D institutions for research purposes.[10]

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[10] Centre of Seismology, *India Meteorological Department*, http://www.imd.gov.in/section/seismo/Seismology.pdf

IERMON is a countrywide network of online radiation monitoring stations, located at various parts of the country and with central monitoring station located in Mumbai. The network is designed, developed, established and managed by the Environmental Systems and Network Division of Bhabha Atomic Research Centre, Mumbai. The network employs systems developed indigenously, keeping in mind the general and strategic requirements of the country, geographical condition and available resources for power and communication. The IERMON system employs multiple radiation detectors for redundancy and extended range of measurement. The system has multichannel data communication facility.[11]

India has three nationwide projects in place including National Optic Fibre Network (NOFN), under the Department of Telecom, National Programme on Technology Enhanced Learning (NPTEL) under the Ministry of Human Resource Development and the National Knowledge Network (NKN) under the National Information Council and Department of Information Technology. A nationwide network which can collate data of CS, IERMON and INCOIS (Indian National Centre for Ocean Information Services) besides other environmental monitoring stations is essential and would prove effective for central data collection, analysis, dissemination and archiving.

Takeaways

1. Individual capabilities for data collection and management exist with the operational entities engaged in this work. A national level effort aimed at trying to develop such algorithms in order to integrating these capabilities into a national data base would be very useful for deriving the maximum benefits from the existing system of data collection and event monitoring. This would raise a set of organizational and institutional issues that have to be understood and managed.
2. It may be considered to release the enormous amount of data from the monitoring stations for the academic community, especially seismic and infrasonic, filtering out the sensitive strategic information. It can complement the analysis done by the assigned departments. The science spin offs of such data has the potential to contribute to studies of earthquakes and volcanoes, meteorology and oceanic topography. Organizational and institutional arrangements for facilitating such exchanges are the key to building national capabilities in this area.
3. Human resources development in the area of data processing and analysis is a key area to focus on. A special cadre of trained analysts devoted to handle the data from the monitoring stations in order to detect any possible events, both natural and man-made, in the country's purview.

[11] Multi-Detector Environmental Radiation Monitor with Multichannel Data Communication for Indian Environmental Radiation Monitoring Network (IERMON), *Bhabha Atomic Research Centre*, http://www.barc.gov.in/publications/nl/2011/2011050606.pdf

Acknowledgements

We extend our sincere thanks to the speakers, panellists and the session chairs for their invaluable contributions to the workshop. We are also grateful to Director, NIAS, for his constant support and encouragement.

We are deeply indebted to Late Amb Arundhati Ghose for motivating us to hold the workshop and for her thoughtful and insightful observations.

Annexure 1

Workshop Programme

Day One

Inaugural Programme with Keynote Address

Session 1: **Seismological Monitoring:**

- Overview
- Seismological Monitoring
  a. Natural and man-made non-nuclear applications
  b. Nuclear Applications
- Panel Discussion on Discrimination between man-made and natural events from Seismic point of view/ State of the Art

Session 2: Radionuclide Monitoring

- Overview
- Detection and Source Identification
- Atmospheric Modelling

Session 3: Satellite Monitoring

- Overview
- Challenges in mapping low level changes

Day Two

Session 4: Infra-sound and underwater monitoring

- Overview
- Infrasound monitoring capabilities
- Hydro-acoustic/underwater monitoring

Session 5: Data Management

- Challenges and emerging trends

Session 6: Group Discussion I

- Feedback from session chairs
- Identification of capabilities and gaps
- The way forward

Session 7: Group Discussion II

- Summary from each session on gap areas national/international capabilities
- Focus on National Priorities
- Action Plan and the Way Forward

Annexure 2

Workshop Participants

Speakers

1. **Prof Prabhakar Dhekne, BARC**

   Prof Prabhakar Dhekne is currently a Scientific Consultant to the Principle Scientific Adviser to Government of India and a Member, National Knowledge Network project. After retiring from BARC as an Associate Director, E&I Group, BARC, Mumbai, he worked as Raja Ramanna Fellow at BARC. During his tenure at ECIL, TIFR, VECC and BARC he has made invaluable contributions in the field of High Performance/Distributed/Grid Computing and information security systems spanning more than three decades. He is renowned expert, nationally as well as internationally in HPC systems & Networking. He was Apex project coordinator of DAE project "Establishment of regional Worldwide LHC Computing Grid" and Deputy Project Manager for EU-India Grid project and CHAIN project funded by European Commission during 2006-13. He is involved in the conceptualization, design & realization of National Knowledge Network (NKN), a nationwide high-speed Education & Research Network and a lead person in implementing Grid applications on NKN.

2. **Dr. V P Felix, Naval Physical and Oceanographic Lab (NPOL)**

   V P Felix, Associate Director of Naval Physical and Oceanographic Lab (NPOL), Kochi, is an alumni of IIT Kharagpur and IIT Bombay. He has vast experience in the Design, Development & Field Validation of Signal Processing systems of various underwater surveillance systems developed by NPOL. He was responsible for bringing out the technology vision document as well as in the formulation of long term technology perspective plan of DRDO for underwater surveillance systems. Indo-Singapore Collaboration on Thin Line Towed Array Sonar Technology was also steered by him.

3. **Dr. Venky Krishnan, TIFR**

   Dr Venky Krishnan is a faculty member at Tata Institute of Fundamental Research (TIFR) Centre for Applicable Mathematics (CAM) in Bangalore, India. His research interests are inverse problems, integral geometry, image reconstruction and microlocal analysis.

4. **Dr. K S Pradep Kumar, BARC**

   Dr. Pradeepkumar K.S. has been Head of the Radiation Safety Systems Division since 2013, and additionally Associate Director of the Health, Safety and Environment Group of Bhabha Atomic Research Centre in Mumbai, India, since 2015. He is currently President of the Indian Association of Radiation Protection (IARP); and member of the Indian Association of Nuclear Society. Dr. Pradeepkumar has been a member of the Indian delegation to United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) since 2014 and the representative of India for the 62nd session (2015).

5. Prof. R Pradeep Kumar, International Institute of Information Technology

Prof Pradeep Kumar is a faculty of Civil Engineering & Head Earthquake Engineering Research Centre, at the International Institute of Information Technology, Hyderabad. He started Earthquake Engineering Research Centre (EERC). He was also instrumental in initiating graduate program on Computer Aided Structural Engineering (CASE) at IIIT Hyderabad in 2002 and 5-year Dual Degree program in Building Science & Engineering in 2013.

6. Mr. Y S Mayya, IIT, Bombay

Mr. Y. S. Mayya served as the Chairman and Managing Director of Electronics Corporation of India Limited from April 30, 2009 to August 31, 2012. Mr. Mayya served as Director of Technical at Electronics Corporation Of India Ltd. since September 2007. Before this position, Mr. Mayya was heading the distributed automation and control section at the Bhabha Atomic Research Centre, Mumbai. Mr. Mayya's specialization includes antenna control systems, software analysis and design and inertia navigation. He has been an Independent Director of Antrix Corp. since January 2014. He served as a Director of Electronics Corporation Of India Ltd. until August 31, 2012.

7. Prof. Rajaram Nagappa, NIAS

Prof Rajaram Nagappa is currently Programme head of the International Strategic and Security Studies Programme and Dean of the School of Conflict and Security Studies at NIAS. He has specialised in aerospace propulsion and has worked extensively in the design and development of solid propellant rockets. His interests are in missile technology and space weaponisation. He has served in the Vikram Sarabhai Space Centre, ISRO as its Associate Director, and later was Pandalai Memorial Chair Professor at Anna University, Chennai. He has also taught at Technion-Israel Institute of Technology, Israel. He is a recipient of the Astronautical Society of India Award, Distinguished Alumnus Award of the Madras Institute of Technology, DRDO's Agni Award for Excellence in Self Reliance, Certificate of Appreciation of the International Astronautical Federation and the Honorary Fellowship of the High Energy Materials Society of India.

8. Dr. G J Nair, Amrita University

Dr Nair joined the Department of Atomic Energy, BARC from 12th batch of training school in 1968 and has ever since been involved in research and development work in the field of theoretical, experimental, computational and strategic seismology. He served as head Seismology Division, BARC, Mumbai since 1998. His major contributions are , new autoregressive deconvolution methods, real time rock-burst monitoring system, digitally communicating seismic array, participation in Pokhran I and II explosions, Vsat based national seismic network and real time Seismic Data Centre and microzonation methods. Dr Nair is a faculty in Amrita Vishwa Vidya Peetham, Kollam, Kerala, serving as a distinguished professor in the department of ECE. He is also a member of the committee for tsunami mitigation and modeling measures required for DAE installations. He was a member of International union of geodesy and geophysics, Shanti Swaroop Bhatnagar award committee, and the DST committee for earth science in addition to some state and departmental committees.

9. Dr. Sriram Raghavan, Secure Cyberspace

Dr. Sriram Raghavan is a Security and Forensic Consultant with Secure Cyber Space from where he consults on many issues the areas of Cyber Security and Digital Forensics. Dr Raghavan has been working in the area of digital forensics for over 7 years and specializes in the determination of associations among digital evidence for the purposes of evidence compositions and event reconstruction in Forensic Analysis. Sriram has also been a part of the vibrant IT industry since 2006 in various roles. He has been part of the core mobile research group at Intel Technologies, India working on Ultra mobile devices on low power Intel x86 platforms. He was the Chief Technical Architect for Nora Solutions, CA on launching their Business Intelligence solutions and the Chief Systems Architect for Linlan P&L, Brisbane for their distress signaling systems solution on mobile devices. In addition, he has been the Lead Designer and Developer for multiple projects at the Queensland University of Technology, Brisbane for automating forensic analysis on heterogeneous data sources and developing a calibration system for various types of DDoS attacks.

10. Dr. Baldev Raj, NIAS

Dr Baldev Raj is the Director of the National Institute of Advanced Studies, Bangalore, one of India's leading multi-disciplinary institutions. A distinguished scientist and former Director of the Indira Gandhi Centre for Atomic Research in Kalapakkam, Dr Raj has helped advance several challenging technologies, especially those related to the Fast Breeder Test Reactor (FBTR) and the Prototype Fast Breeder Reactor (PFBR). A recipient of the Padma Shri, Dr Baldev Raj has been recognized with several other awards, including the Life Time Achievement Award of the Indian Nuclear Society, the Homi Bhabha Gold Medal, Distinguished Materials Science Award and Materials Research Society of India. He is a distinguished alumnus of Indian Institute of Science, Bangalore.

11. Dr. R Ramachandran, Advanced Data Processing Research Institute (ADRIN)

Dr Ramchandran has been associated with the ADRIN since 1988 and is currently Associate Director, ADRIN, Secunderabad. He has established data processing facilities and infrastructure and lead the design group in development of specialized data processing systems for high resolution satellite data – DiPAMS at the ADRIN. These systems were designed to be sensor agnostic, highly suited for strategic applications and supported ISRO's satellite program. Previously, Dr Ramachandran was responsible for development of Electro Optical instruments including Drum Scanner/Imager, Additive Colour Viewer, Optical Reflecting Projector, all of which won NRDC awards during his stint at the National Remote Sensing Agency (NRSA), now National Remote Sensing Centre (NRSC). He was also the Co-investigator in DST funded project on "Hybrid Optical-digital Computing System". His major contributions are in innovative methods of Information Extraction, Digital Photogrammetry, Computer Vision algorithms.

12. Prof. V S Ramamurthy, NIAS

Prof Valangiman Subramaniam Ramamurthy, former Director of NIAS, is currently Emeritus Professor at NIAS. He was the Chairman of the IAEA Standing Advisory Group on Nuclear Applications for nearly a decade. After retirement from government service, Prof Ramamurthy, in addition to continuing research in Nuclear Physics in the Inter-University Accelerator Centre, New Delhi, has also been actively involved in human resource development in all aspects of nuclear research and applications. Prof Ramamurthy is also a Chairman, Recruitment and Assessment Board, Council of Scientific and Industrial Research and Member, National Security Advisory Board. In recognition of his services to the growth of Science and Technology in the country, Prof Ramamurthy was awarded one of the top civilian awards of the country, the Padma Bhushan, by the Government of India in 2005.

13. Dr. A R Reddy, Former Director, DRDO

Dr Reddy has an experience of more than 30 years as a research scientist, research guide and research administrator on different aspects of radiation dosimetry, radiation safety and medical and industrial applications of radiation and radioisotopes. He was Member of Committee 2 of International Commission on Radiation Protection (ICRP) from 1993-2000. He has also served as the Chairman of Safety Review Committee on Radiation Applications (SARCAR) under Atomic Energy Regulatory Board (AERB), Mumbai for about 12 years. He is also the former Chairman, Experts Appraisal Committees one for Nuclear Power Plants and another for Nuclear facilities of Strategic importance in Ministry of Environment & Forests, New Delhi. Dr Reddy was the Director of Research Labs in DRDO for nearly 7 years till end 2000.

14. Mr G Suresh, India Meteorological Department (IMD)

Mr G. Suresh joined India meteorological Department (IMD) as Meteorologist Gr.II in 1993 where he is presently working as Scientist-E. He holds M.Tech degree in Electronic Instrumentation Engineering from NIT, Warangal. He is responsible for the setting-up of seismic networks and upkeep of various seismic equipments installed in the National Seismological Network of IMD. He received National Geoscience Award in year 2010 for his outstanding contributions towards successful commissioning of Real Time Seismic Monitoring Network as part of Tsunami Warning System. He has been actively involved in the design and establishment of Integrated Seismic and GPS Network (ISGN) and instrumental in establishing VSAT Hub and Data Centre at IMD for seismological operations. He has published more than 45 research papers in National and International Journals.

15. Dr R Venkatesan, IGCAR

Dr. R.Venkatesan is a physicist with a doctoral degree from IIT Delhi in Atmospheric Sciences. He has been affiliated with Indira Gandhi Centre for Atomic Research since last 27 years. Specialised in the area of atmospheric dispersion studies with particular interest in numerical modelling of the meteorology in a high resolution spatio- temporal scale, Dr Venkatesan has developed a real-time Decision Support System for radiological emergency which is operational at IGCAR. Pooling together experts from various research institutes and universities he initiated a Round Robin Exercise to validate the site specific mesoscale meteorological model for Kalpakkam. Currently he is working on inverse modelling technique for source term estimation and dispersion modelling under extreme weather conditions.

Session Chairs

1. A.R.Sundararajan, AERB

Dr Sundararajan started his career as Health Physicist in fuel reprocessing and waste management plants in Trombay. Later he moved to Kalpakkam where, as Head, Health and Safety Division was responsible for organising surveillance for radiation protection at Indira Gandhi Centre for Atomic Research (IGCAR). He was Associate Director of Safety Research and Health Physics Group at IGCAR during 1997-98. Dr Sundararajan then joined Atomic Energy Regulatory Board (AERB) and was associated with more than 20 Safety Review Committees for various nuclear fuel cycle facilities. He was entrusted with the responsibility of setting up the Safety Research Institute (SRI) at Kalpakkam. He has participated in several IAEA Technical Committee and Advisory Group Meetings in the area of radiation protection, emergency preparedness and waste management. After his retirement in 2003 as Director, Radiological Safety Division, AERB and Director, SRI, he continues to serve in several committees of AERB and Ministry of Environment and Forest. Currently he is the Chairman of Safety Review Committee for Application of Radiation in Industry, Medicine and Research (SARCAR) of AERB.

2. L.V. Krishnan, NIAS

Dr Krishnan is currently Adjunct Faculty at National Institute of Advanced Studies. He joined the Department of Atomic Energy in 1958 after taking an Honours Degree in Physics from Madras University. Later, he graduated from the Oak Ridge School of Reactor Technology in 1964. He served in the Health Physics Division at Trombay from 1959 until 1973 and then moved to the Kalpakkam Centre to set up a Safety Research Laboratory. At Trombay, he served as Plant Health Physicist for some time. He has participated in safety evaluation of various nuclear installations including power reactors and reprocessing plants. At Kalpakkam he was Chairman of Safety Evaluation Working Group and retired in 1997 as Director, Safety Research and Health Physics Group. His current interests relates to energy and environment scene in the country. He is a Co-author with C V Sundaram and T S Iyengar the book titled 'Atomic Energy in India - Fifty Years', and also a book on 'Elements of Nuclear Power' with Raja Ramanna.

3. Prof S Chandrashekar, NIAS

Prof Chandrashekar is currently the JRD Tata Chair Professor at NIAS. He was a Professor in the Corporate Strategy and Policy Area at the Indian Institute of Management Bangalore (IIMB). Prior to his joining IIMB he spent more than 20 years working at the Indian Space Research Organisation (ISRO). His work at ISRO covered all parts of the programme - satellite, rockets as well as the applications of space technology especially remote sensing. He was also involved with activities related to international co-operation and has represented and led Indian delegations to the United Nations Committee on the Peaceful Uses of Outer Space. His research interests at IIMB include technology and competitive advantage, national technology priorities and national technology policy, studies on innovation, telecommunications in the Indian context, national innovation systems, modelling complex systems and national security issues.

4. Dr. S R Raghavan

Dr Raghavan joined the Research and Development Cell of DRDO, attached to the University Department of Geology, as a Junior Scientific Assistant. The Cell fabricated and tested an indigenous Microbarograph and a Seismograph. During a service span of close to four decades Dr Raghavan and his team surveyed suitable sites, installed and commissioned Geophysical Monitoring Stations in different parts of the country.

5. Dr R Govindarajan

Dr Govindarajan is currently professor and chairman of the Supercomputing and Education Research Centre at the Indian Institute of Sciences. His research interests include Computer Architecture, Compiler Optimizations, High-Performance Computing.