The International Monitoring System (IMS) is a global network of facilities for detecting and providing evidence of possible nuclear explosions. When completed, the IMS will consist of 321 monitoring stations and 16 radionuclide laboratories at locations around the world designated by the Treaty. Many of these locations are remote and difficult to access, posing major engineering and logistical challenges.

The IMS uses seismic, hydroacoustic and infrasound ('waveform') monitoring technologies to detect and locate energy released by an explosion – whether nuclear or non-nuclear – or a natural event that takes place underground, underwater or in the atmosphere.

The IMS uses radionuclide monitoring technologies to collect particles and noble gases from the atmosphere. The acquired samples are analysed for evidence of physical products (radionuclides) that are created by a nuclear explosion and carried through the atmosphere. This analysis can confirm whether an event recorded by the other monitoring technologies was actually a nuclear explosion.
COMPLETING THE INTERNATIONAL MONITORING SYSTEM

Establishment of a station is a general term referring to the building of a station, from its initial stages until its completion. Installation typically refers to all work performed until the station is ready to send data to the International Data Centre (IDC) in Vienna. This includes, for instance, site preparation, construction and equipment installation. A station receives certification when it meets all technical specifications, including requirements for data authentication and transmission through the Global Communications Infrastructure (GCI) link to the IDC. At this point the station is considered an operational facility of the IMS.

In 2016, following outreach to host States, the Commission made progress in the establishment of stations in a number of States where there had been no or slow progress in the past. The organization also made progress towards the completion of IMS stations in the Russian Federation.

At the end of the year, preparations were underway to certify a combined total of approximately 10 IMS stations, noble gas systems and laboratories in 2017. China recommenced transmission of data from IMS primary seismic and radionuclide stations for testing and evaluation purposes. Together, China and the Commission made concerted efforts to prepare the upgrade of these stations to IMS specifications in order to certify them as soon as possible. As a major achievement, radionuclide station RN21 was certified in December 2016.

The major installation project for hydroacoustic station HA4, Crozet Islands (France), was completed in December 2016. The planned certification of HA4 in 2017 will mark the completion of the hydroacoustic component of the IMS network.

Additional progress towards the completion of the IMS was made with the installation of radionuclide station RN24 (Ecuador), the certification of infrasound station IS60 (USA), the certification of radionuclide laboratory RL10 (Italy), the certification of the noble gas system at radionuclide station RN19 (Chile) and the certification of...
the particulate system at radionuclide station RN32 (France). Radionuclide laboratory RL16 (USA) was certified for its capability to analyse noble gas samples.

The total number of certified IMS stations and laboratories thus reached 286 (85% of the network foreseen by the Treaty), improving both the coverage and the resilience of the network.

Monitoring of radionuclide noble gases plays an essential role in the verification system of the Treaty, as was demonstrated following the announced nuclear tests by the Democratic People’s Republic of Korea in 2006 and 2013. It also proved to be invaluable following the nuclear accident at Fukushima, Japan, in 2011. In line with its priorities, the Commission continued to focus on the noble gas monitoring programme in 2016. As well as certifying the noble gas system at radionuclide station RN19, it certified the noble gas capability at laboratory RL16 (as noted above).

By the end of the year, 31 noble gas systems were installed (78% of the planned total of 40) at IMS radionuclide stations. Of these, 25 systems were certified as meeting the stringent technical requirements. The addition of these systems significantly strengthens the detection capacity of the IMS network.

The Commission continued its preparations to certify additional IMS laboratories for noble gas measurement capability. The Commission adopted certification requirements and processes for noble gas laboratories in 2012. The first certification of an IMS laboratory for noble gas measurement capability took place in 2014, and the second took place in 2016. The Commission continued to assess the analysis of noble gas data at IMS laboratories through intercomparison exercises. For the first time, these exercises were analysed according to standards used in proficiency test exercises (PTEs). The IMS laboratories demonstrated excellent performance. This new functionality is crucial for the quality assurance and quality control (QA/QC) of IMS noble gas measurements.

All of these advancements contribute to the prospect of the completion of the IMS network.
AGREEMENTS FOR MONITORING FACILITIES

The Commission has the mandate to establish procedures and a formal basis for the provisional operation of the IMS before the Treaty enters into force. This includes concluding agreements or arrangements with States that host IMS facilities to regulate activities such as site surveys, installation or upgrading work, certification and post-certification activities (PCAs).

In order to efficiently and effectively establish and sustain the IMS, the Commission needs to fully benefit from the immunities to which it is entitled as an international organization, including exemption from taxes and duties. Consequently, facility agreements or arrangements provide for the application (with changes where appropriate) of the Convention on the Privileges and Immunities of the United Nations to the activities of the Commission or explicitly list the privileges and immunities of the Commission. This may require a State that hosts one or more IMS facilities to adopt national measures to bring these privileges and immunities into effect.

In 2016, the Commission continued to address the importance of concluding facility agreements and arrangements and their subsequent national implementation. The absence of such legal mechanisms in some cases results in substantial costs (including in human resources) and major delays in sustaining certified IMS facilities. These costs and delays adversely affect the availability of data from the verification system.

Of the 89 States that host IMS facilities, 49 have signed a facility agreement or arrangement with the Commission, and 40 of these agreements and arrangements are in force. At the end of 2016, the Commission was in negotiation with 4 of the 40 host States that had not yet concluded a facility agreement or arrangement. States are showing increased interest in this subject, and it is hoped that ongoing negotiations will be concluded in the near future and that negotiations with other States may be initiated soon.

POST-CERTIFICATION ACTIVITIES

Following the certification of a station and its incorporation into the IMS, its operation focuses on the delivery of high quality data to the IDC.

PCA contracts are fixed cost contracts between the Commission and some station operators. These contracts cover station operations and various preventive maintenance activities. The total expenditure of the Commission related to PCAs in 2016 was US$17,775,324. This amount covers the costs related to PCAs for 165 facilities and noble gas systems.

Each station operator submits a monthly report on PCA performance,
which the Provisional Technical Secretariat (PTS) reviews for compliance with operation and maintenance (O&M) plans. The Commission has developed standardized criteria for the review and evaluation of the performance of station operators.

The Commission continued to standardize the services provided under PCA contracts. It requested operators of all newly certified stations and of existing stations that submitted new budget proposals to develop O&M plans in accordance with a standard template. In 2016, O&M plans for two stations were submitted in the standard format. This brought the number of stations under PCA contracts with O&M plans in the standard format to 104.

SUSTAINING PERFORMANCE

Preparing a global monitoring system of 337 facilities supplemented by 40 noble gas systems involves much more than just the building of stations. It requires a holistic approach to establishing and sustaining an intricate ‘system of systems’ that should be completed to meet the verification requirements of the Treaty while protecting the investment already made by the Commission. This can be achieved by testing, evaluating and sustaining what is in place, and then further improving on this.

The life cycle of the IMS station network proceeds from conceptual design and installation to operation, sustainment, disposal and rebuild. Sustainment covers maintenance through necessary preventive maintenance, repairs, replacement, upgrades and continuous improvements to ensure the technological relevance of the monitoring capabilities. This process also involves management, coordination and support for the full life cycle of each facility component, performed as efficiently and effectively as possible. In addition, as IMS facilities reach the end of their designed life cycle, there is the need to plan, manage and optimize the recapitalization (i.e. replacement) of all components of each facility in order to minimize downtime and optimize resources.
The support activities for IMS facilities in 2016 continued to focus on preventing interruptions to the flow of data. They also aimed at preventive and corrective maintenance and recapitalization of IMS stations and station components as they reach the end of their life cycle. The Commission enhanced its efforts to develop and implement engineering solutions to improve the robustness and resilience of IMS facilities.

Optimizing and enhancing performance also involves the continuous improvement of data quality, reliability and resilience. Hence the Commission continued to emphasize QA/QC, state of health monitoring, IMS facility calibration activities (which are essential for the reliable interpretation of detected signals) and improvement of IMS technologies. These activities contribute to maintaining a credible and technologically relevant monitoring system.

**LOGISTICS**

The support required to ensure the highest levels of data availability from a global network of facilities such as the IMS calls for an integrated approach to logistics that seeks continuous validation and optimization. In 2016, the Commission completed an in-depth assessment of its logistics requirements in three key areas (shipment of equipment and goods, warehousing and asset management) and started establishing a PTS-wide integrated logistics support structure to undertake these tasks.

The Commission also further developed its capability for logistics support analysis in order to strive for the highest possible levels of data availability at optimal cost. With over 280 certified IMS facilities around the world, often in remote sites, maintaining the highest levels of data availability requires continuous analysis, refinement and validation of IMS station life cycle costs and reliability variables. During 2016, the Commission continued its efforts to refine and validate models, with the aim of improving planning for the sustainment of the IMS network.

Effective configuration management strengthens overall confidence that IMS monitoring facilities meet IMS technical specifications and other requirements.
for certification. It ensures that changes at stations are rigorously assessed to determine their effect and, when the changes are implemented, reduces costs, effort and unforeseen drops in data availability.

In this context the Commission continued to implement and improve the internal IMS configuration management procedures that had been introduced at the end of 2013. It also worked with host States and station operators to further streamline State specific shipment procedures for IMS equipment and consumables and ensure their timely and cost free customs clearance. Nonetheless, shipping and customs clearance processes continued to be very time consuming and resource intensive. This increases the time to repair an IMS station and reduces the data availability of that station. The Commission therefore continued to analyse and optimize the availability of IMS equipment and consumables at IMS stations, at its regional depots, at supplier depots and at the depot in Vienna.
MAINTENANCE

The PTS provides maintenance support and technical assistance at IMS facilities around the globe. During 2016, numerous maintenance requests were addressed, including long running data availability problems at eight IMS facilities. The PTS also conducted preventive and corrective maintenance visits at 13 certified IMS facilities. This low figure reflects an increased reliance on station operators, contractors and other sources of support to perform such tasks, following the strategy of the PTS.

The Commission continued to establish and manage long term support contracts with manufacturers of IMS equipment and support providers. Some of these contracts were used to address support requirements for on-site inspection (OSI). In addition, the organization established and maintained a number of contracts with suppliers of equipment, material and technical services on a call-off basis. Both long term and call-off contracts ensure that necessary support can be provided to IMS monitoring stations in a timely and efficient manner.

As the entity closest to an IMS facility, the station operator is in the best position to prevent problems at stations and ensure timely resolution of any problems that occur. In 2016, the Commission continued to emphasize development of the technical capabilities of station operators. As well as technical training for operators, station visits by PTS staff included hands on training for local staff, with the aim of avoiding the need for PTS staff to travel from Vienna to resolve problems.

Up to date and reliable technical documentation for each IMS station is essential to ensure its sustainability and to maintain a high level of data availability. In 2016, the Commission made substantial progress populating the PTS Quality Management System (QMS) with station specific documentation. By the end of 2016, full sets of documentation had been developed for 26 stations, and partial information had been acquired for an additional 19 stations.

The combination of technical training for station operators, better coordination between the operators and the Commission to optimize PCA contracts, and improved station specific O&M plans and station information...
Preparation of a radionuclide sample at RN24, Isla Santa Cruz, Galápagos Islands (Ecuador).

Several recapitalization projects were completed at certified IMS facilities in 2016, involving substantial investment of human and financial resources. In three cases (PS28 (Norway), IS18 (Denmark) and IS57 (USA)), recapitalization was followed by revalidation to ensure that the stations continued to meet technical requirements. Major upgrades of noble gas systems at two certified radionuclide stations (RN11 (Brazil) and RN75 (USA)) were also completed.

ENGINEERING SOLUTIONS
The engineering and development programme for IMS facilities aims to improve the overall availability and quality of data and the cost effectiveness and performance of the IMS network by designing, validating and implementing solutions. Systems engineering is implemented throughout the life cycle of an IMS station and relies on open systems design through standardization of interfaces and modularity. It aims to improve systems and the reliability, maintainability, logistical supportability, operability and testability of equipment. Engineering and development solutions consider both end to end systems engineering of stations and optimized interaction with data processing by the IDC.

In 2016, the Commission concentrated its engineering efforts on the following:

- Signing of call-off contracts for equipment and services support

The Commission continued its work to optimize the performance of the IMS facilities and the monitoring technologies. Analysis of station failures helped identify the main causes of data loss and assisted the subsequent analysis of the subsystem failures responsible for downtime. In particular, in 2016 the Commission carried out trend analyses of the downtime of each subsystem for all waveform technologies. It also continued systematic failure analysis based on incident reports for the radionuclide particulate and noble gas systems. The outcome of these activities provided valuable input to prioritize the design, validation and implementation of improvements for IMS stations and technologies.
A project to review power requirements

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The project aims to establish specifica-

tions for power requirements and must demonstrate a ma-

jor step towards achieving traceability to a standard with

support from national metrology institutes;

• Assessment of the next genera-

tion of hydroacoustic stations and po-

tential temporary solutions;

• Continued improvement of high

purity germanium detectors, with the testing of hardened
detector design with improved vacuum.

In addition, four next generation

noble gas systems are currently under development. All systems will undergo
testing against IMS certification re-

quirements and must demonstrate operation at 95% data availability

for one year prior to deployment in the

IMS. The PTS inspected the

Russian MIKS system and reviewed data from test operation of this

system.

The PTS tested prototype software for

automated analysis of noble gas state of

health data. The software will assist in identifying system failures and in

predicting failures in order to initiate preventive maintenance.

A project to review power requirements

and standards for IMS radionuclide

stations was initiated. Poor power

quality has been identified as one of the

root causes of station downtime. The

project aims to establish specifica-

tions for power requirements and

propose solutions for power improve-

ments that are applicable to all IMS sites.

Testing of a prototype silicon PIN high

resolution beta–gamma detector for

noble gas measurements continued. A

silicon PIN detector system has been

combined with a SAUNA system for

test purposes. This technology offers

in particular improved discrimination

between metastable xenon isotopes.

These initiatives further improved the

reliability and resilience of IMS facili-
ties. They also enhanced the perform-

ance of the network and increased the

robustness of IMS stations, thus

contributing to the extension of their

life cycles and containing the risks of
data downtime. Moreover, they in-

creased the quality of data processing

and of data products.

AUXILIARY SEISMIC NETWORK

The Commission continued to monitor the

operation and sustainment of aux-

iliary seismic stations in 2016. The

data availability of auxiliary seismic

stations was maintained during the

year.

In accordance with the Treaty, the

regular O&M costs of each auxiliary

seismic station, including the cost of

physical security, are the responsibility

of the State hosting it. However, prac-
tice has shown that this constitutes a

significant challenge for auxiliary

seismic stations in developing countries

that do not belong to a parent network

with an established maintenance

programme.

The Commission has encouraged States

that host auxiliary seismic stations with

design deficiencies or with problems

related to obsolescence to review their

ability to cover the cost of upgrading

and sustaining their stations. However,

obtaining the appropriate level of
technical and financial support remains
difficult for several host States.

To address this, in 2016 the European

Union (EU) continued to support the

sustainment of auxiliary seismic sta-
nations that are hosted by developing
countries or countries in transition. This

initiative includes action to return

stations to an operational state and the

provision of transportation and funds

for additional PTS personnel to provide
technical support. The Commission

continued its discussions with other

States whose parent networks include

several auxiliary seismic stations in

order to make similar arrangements.

QUALITY ASSURANCE

In addition to improving performance at individual stations, the Commission

accords great importance to ensuring the reliability of the IMS network as a

whole. Hence, its engineering and development activities in 2016 con-
tinued to focus on measures for data

safety and calibration.

The Commission further developed

its calibration methodologies. In par-

icular, it performed its second full

frequency on-site calibration of an

infrasonic station (IS37, Norway). Also,
calibration of all hydroacoustic T-phase

stations was fully integrated into the

seismic calibration schedule. In

addition, the Commission continued the

scheduled calibration of primary and

auxiliary seismic stations and advanced

the deployment of the standard station

interface calibration module throughout

the IMS seismic network.

Calibration plays a significant role in

the verification system, as it determines and monitors parameters needed to

properly interpret signals recorded by IMS facilities. It does this either by
direct measurement or by comparison

against a standard.

The QA/QC programme for radionuclide

laboratories consisted of interlaboratory

comparison activities. The Commission

assessed the 2015 PTE and conducted

the 2016 PTE, which involved analy-
sis of test samples in the geometry of

RASA automatic systems. The Com-

mission also undertook a laboratory

surveillance visit to radionuclide labo-

ratory RL5 (Canada).

QA/QC activities for noble gas contin-

ued with the execution of three inter-

comparison exercises for the noble gas

capability of radionuclide labora-

tories.

In an ever growing but also ageing

IMS network, ensuring data availa-

bility is a daunting task. However,

through close cooperation, all stake-

holders – station operators, host States,

contractors, States Signatories and the

Commission – worked hard to ensure

the solid and effective performance of

the network.
Seismic technology is very efficient at detecting a suspected nuclear explosion, as seismic waves travel fast and can be registered within minutes of an event. Data from seismic stations of the IMS provide information on the location of a suspected underground nuclear explosion and help identify the area for an OSI.

The IMS has primary and auxiliary seismic stations. Primary seismic stations send continuous data in near real time to the IDC. Auxiliary seismic stations provide data on request from the IDC.

An IMS seismic station typically has three basic parts: a seismometer to measure ground motion, a system to record the data digitally with an accurate time stamp, and a communication system interface.

An IMS seismic station can be either a three component (3-C) station or an array station. A 3-C station records broadband ground motion in three orthogonal directions. An array station generally consists of multiple short period seismometers and 3-C broadband instruments that are separated spatially. The primary seismic network is mostly composed of arrays (30 of 50 stations), while the auxiliary seismic network is mostly composed of 3-C stations (112 of 120 stations).
Acoustic waves with very low frequencies, below the frequency band audible to the human ear, are called infrasound. Infrasound is produced by a variety of natural and anthropogenic sources. Atmospheric and shallow underground nuclear explosions can generate infrasound waves that may be detected by the infrasound monitoring network of the IMS.

Infrasound waves cause minute changes in the atmospheric pressure that are measured by microbarometers. Infrasound has the ability to cover long distances with little dissipation, which is why infrasound monitoring is a useful technique for detecting and locating atmospheric nuclear explosions. In addition, since underground nuclear explosions also generate infrasound, the combined use of the infrasound and seismic technologies enhances the ability of the IMS to identify possible underground tests.

The IMS infrasound stations exist in a wide variety of environments, ranging from equatorial rainforests to remote windswept islands and polar ice shelves. However, an ideal site for deploying an infrasound station is within a dense forest, where it is protected from prevailing winds, or at a location with the lowest possible background noise in order to improve signal detection.

An IMS infrasound station (also known as an array) typically employs several infrasound array elements arranged in different geometrical patterns, a meteorological station, a system for reducing wind noise, a central processing facility and a communication system for the transmission of data.

Example of infrasound waveform.
HYDROACOUSTIC STATIONS

Nuclear explosions underwater, in the atmosphere near the ocean surface or underground near oceanic coasts generate sound waves that can be detected by the IMS hydroacoustic monitoring network.

Hydroacoustic monitoring involves recording signals that show changes in water pressure generated by sound waves in the water. Owing to the efficient transmission of sound through water, even comparatively small signals are readily detectable at large distances. Thus 11 stations are sufficient to monitor most of the world’s oceans.

There are two types of hydroacoustic station: underwater hydrophone stations and T phase stations on islands or on the coast. The underwater hydrophone stations are among the most challenging and most costly monitoring stations to build. They must be designed to function in extremely inhospitable environments, exposed to temperatures close to freezing point, huge pressure and saline corrosiveness.

The deployment of the underwater parts of a hydrophone station (i.e. placing the hydrophones and laying the cables) is a complex undertaking. It involves the hiring of ships, extensive underwater work, and the use of specially designed material and equipment.

Example of hydroacoustic waveform.
Radionuclide monitoring technology complements the three waveform technologies employed in the Treaty verification regime. It is the only technology that is able to confirm whether an explosion detected and located by the waveform methods is indicative of a nuclear test. It provides the means to identify the ‘smoking gun’ whose existence would be evidence of a possible violation of the Treaty.

Radionuclide stations detect radionuclide particles in the air. Each station contains an air sampler, detection equipment, computers and a communication set-up. At the air sampler, air is forced through a filter, which retains most particles that reach it. The used filters are examined and the gamma radiation spectra resulting from this examination are sent to the IDC in Vienna for analysis.

The Treaty requires that, by the time it enters into force, 40 of the 80 IMS radionuclide particulate stations also have the capability to detect radioactive forms of noble gases such as xenon and argon. Special detection systems have therefore been developed and are being deployed and tested in the radionuclide monitoring network before they are integrated into routine operations.

Noble gases are inert and rarely react with other chemical elements. Like other elements, noble gases have various naturally occurring isotopes, some of which are unstable and emit radiation. There are also radioactive noble gas isotopes that do not occur naturally but which can be produced only by nuclear reactions. By virtue of their nuclear properties, four isotopes of the noble gas xenon are particularly relevant to the detection of nuclear explosions. Radioactive xenon from a well contained underground nuclear explosion can seep through layers of rock, escape into the atmosphere and be detected later, thousands of kilometres away.

All of the noble gas detection systems in the IMS work in a similar way. Air is pumped into a charcoal-containing purification device in which xenon is isolated. Contaminants of different
kinds, such as dust, water vapour and other chemical elements, are eliminated. The resulting air contains higher concentrations of xenon, in both its stable and unstable (i.e. radioactive) forms. The radioactivity of the isolated and concentrated xenon is measured and the resulting spectrum is sent to the IDC for further analysis.

RADIONUCLIDE LABORATORIES

Sixteen radionuclide laboratories, each located in a different State, support the IMS network of radionuclide monitoring stations. These laboratories have an important role in corroborating the results from an IMS station, in particular to confirm the presence of fission products or activation products that could be indicative of a nuclear test. In addition, they contribute to the quality control of station measurements and the assessment of network performance through regular analysis of routine samples from all certified IMS stations. These world class laboratories also analyse other types of sample, such as those collected during a station site survey or certification.

The radionuclide laboratories are certified under rigid requirements for analysis of gamma spectra. The certification process provides assurance that the results provided by a laboratory are accurate and valid. These laboratories also participate in the annual PTEs organized by the Commission. In addition, certification of IMS radionuclide laboratories for noble gas analysis capability started in 2014.