CTBTO PREPARATORY COMMISSION | preparatory commission for the comprehensive nuclear-test-ban treaty organization



# The International Monitoring System: Overview, Measurement Systems and Calibration

*Workshop of the Consultative Committee for Acoustics, Ultrasound and Vibration - Measurement of imperceptive matters, 20 September 2017*

Julien Marty, Seismic-Acoustic Unit Head

Comprehensive Nuclear-Test-Ban Treaty Organization
Vienna International Centre
P.O. Box 1200
1400 Vienna, Austria

# Outline

- The Treaty, The Organization
- The International Monitoring System
- Seismo-Acoustic Measurement Systems
- Calibration – Infrasound Technology
- Calibration – Seismic and Hydroacoustic Technologies

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# Article 1

1. Each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control.

- Opened for signature on 24 September 1996
- Near-universality: 183 signatures, 166 ratifications
- Entry-into-Force pending ratification of 8 States (out of 44 specific nuclear technology holder States listed in Annex 2 of the Treaty)

# CTBTO – The Organization

- The Preparatory Commission for the CTBTO is responsible for promoting the CTBT and establishing a verification regime
- Seat of the Organization in Vienna, Austria
- The Preparatory Commission consists of two main entities: a plenary body composed of all States Signatories (PrepCom) and the Provisional Technical Secretariat (PTS)
- The PTS assists the plenary body in carrying out its activities. It currently employs over 270 staff members from over 85 countries.

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# The Verification Regime

1. In order to verify compliance with this Treaty, a verification regime shall be established consisting of the following elements:

(a) An International Monitoring System;

(b) Consultation and clarification;

(c) On-site inspections; and

(d) Confidence-building measures.

At entry into force of this Treaty, the verification regime shall be capable of meeting the verification requirements of this Treaty.

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# The International Monitoring System

16. The International Monitoring System shall comprise facilities for seismological monitoring, radionuclide monitoring including certified laboratories, hydroacoustic monitoring, infrasound monitoring, and respective means of communication, and shall be supported by the International Data Centre of the Technical Secretariat.

17. The International Monitoring System shall be placed under the authority of the Technical Secretariat. All monitoring facilities of the International Monitoring System shall be owned and operated by the States hosting or otherwise taking responsibility for them in accordance with the Protocol.

# IMS Network – Overview

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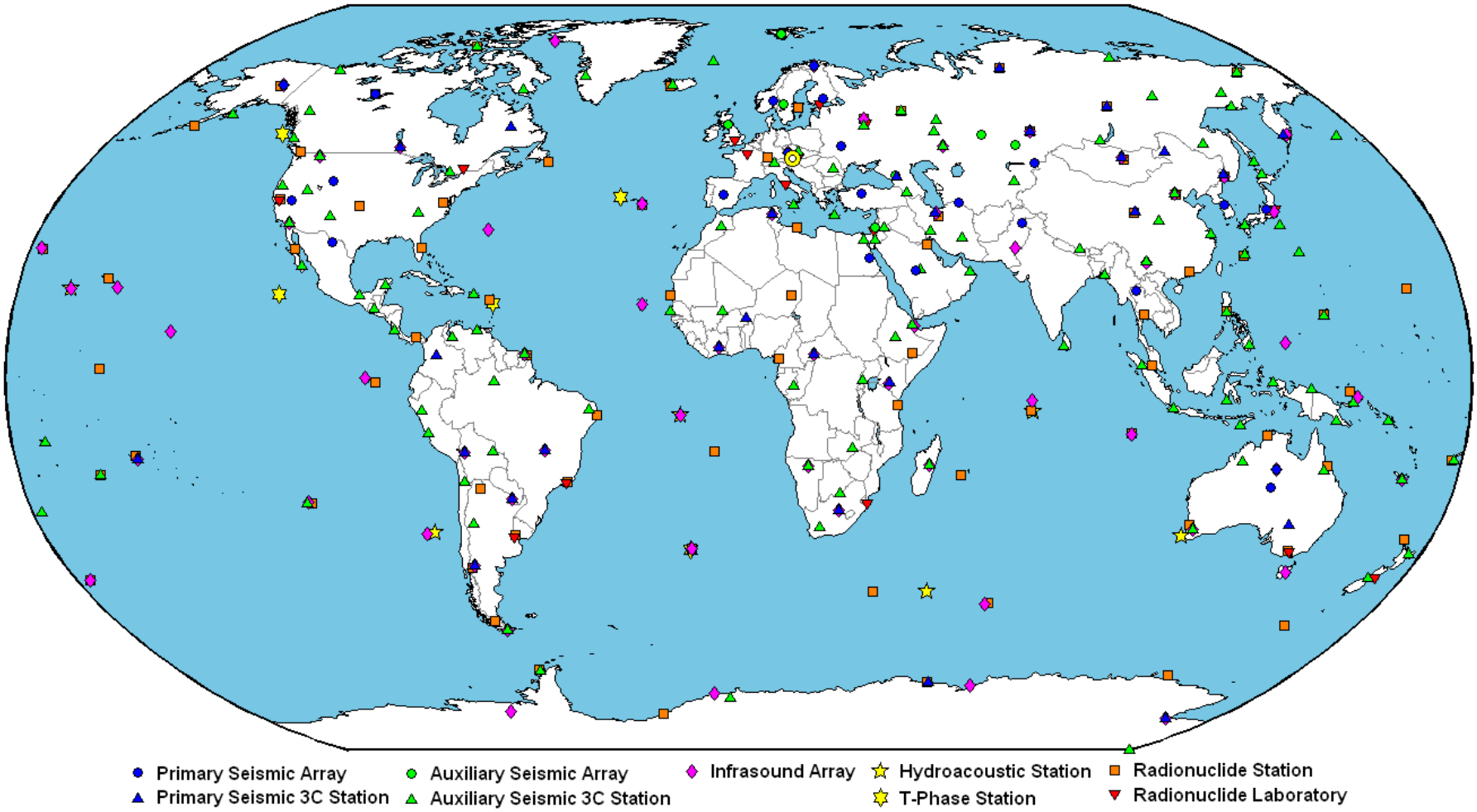

# IMS Network – Status

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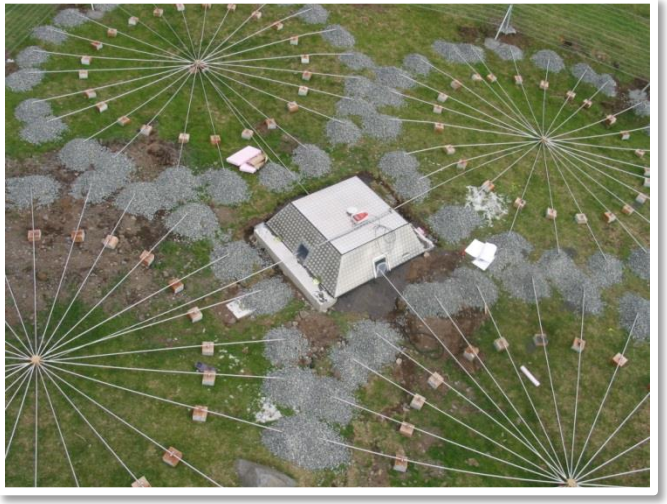
| IMS station type | Installation completed | | Under construction | Not started | Total |
|---|---|---|---|---|---|
| | Certified | Not Certified | | | |
| Primary seismic | 42 | 3 | 2 | 3 | 50 |
| Auxiliary seismic | 107 | 8 | 2 | 3 | 120 |
| Hydroacoustic | 11 | 0 | 0 | 0 | 11 |
| Infrasound | 49 | 2 | 1 | 8 | 60 |
| Radionuclide | 67 | 3 | 4 | 6 | 80 |
| Radionuclide Lab | 13 | 3 | 0 | 0 | 16 |
| Total | 289 | 19 | 9 | 20 | **337** |

Network nearing completion: 85% of stations already certified

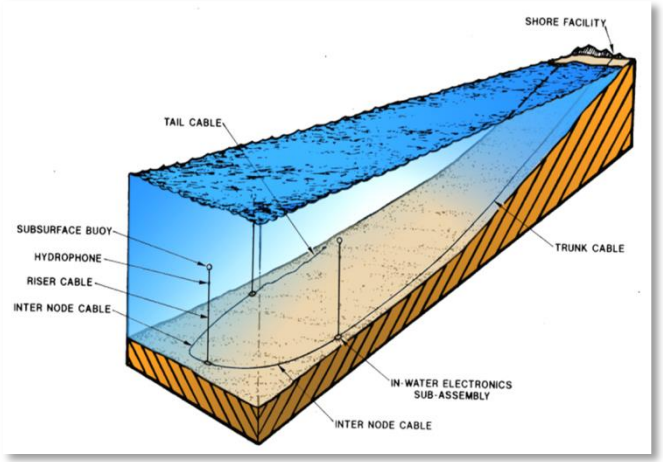
# IMS Monitoring Technologies



Infrasound

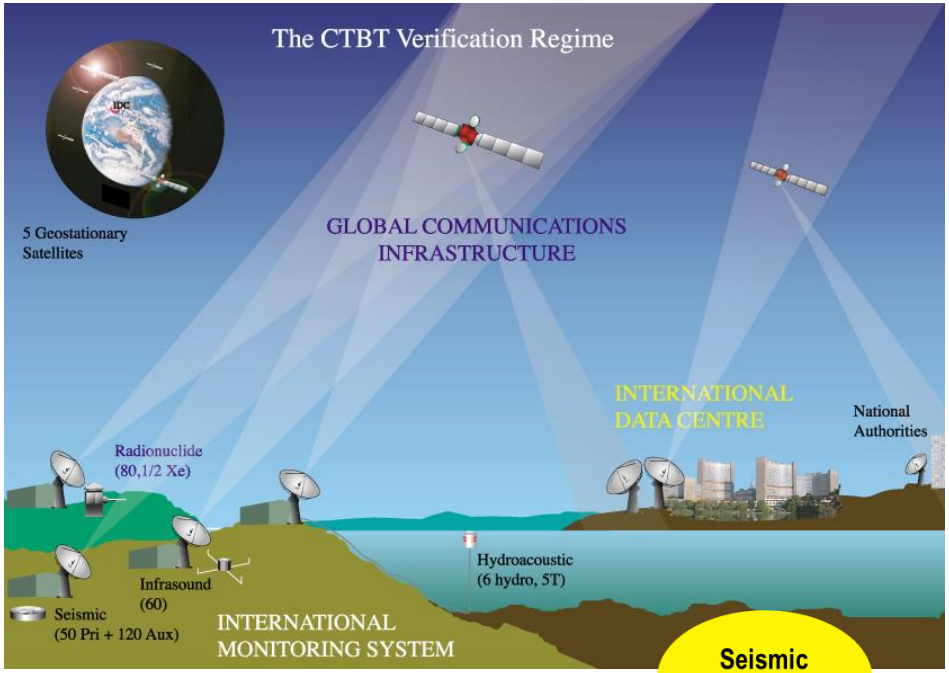
Seismic

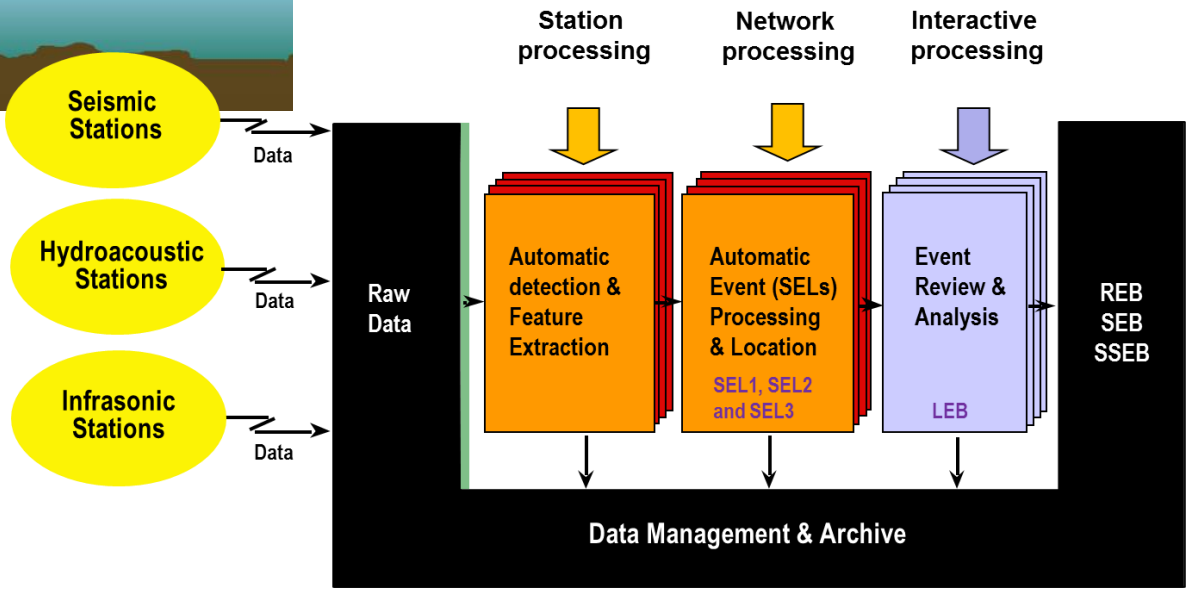
Radionuclide



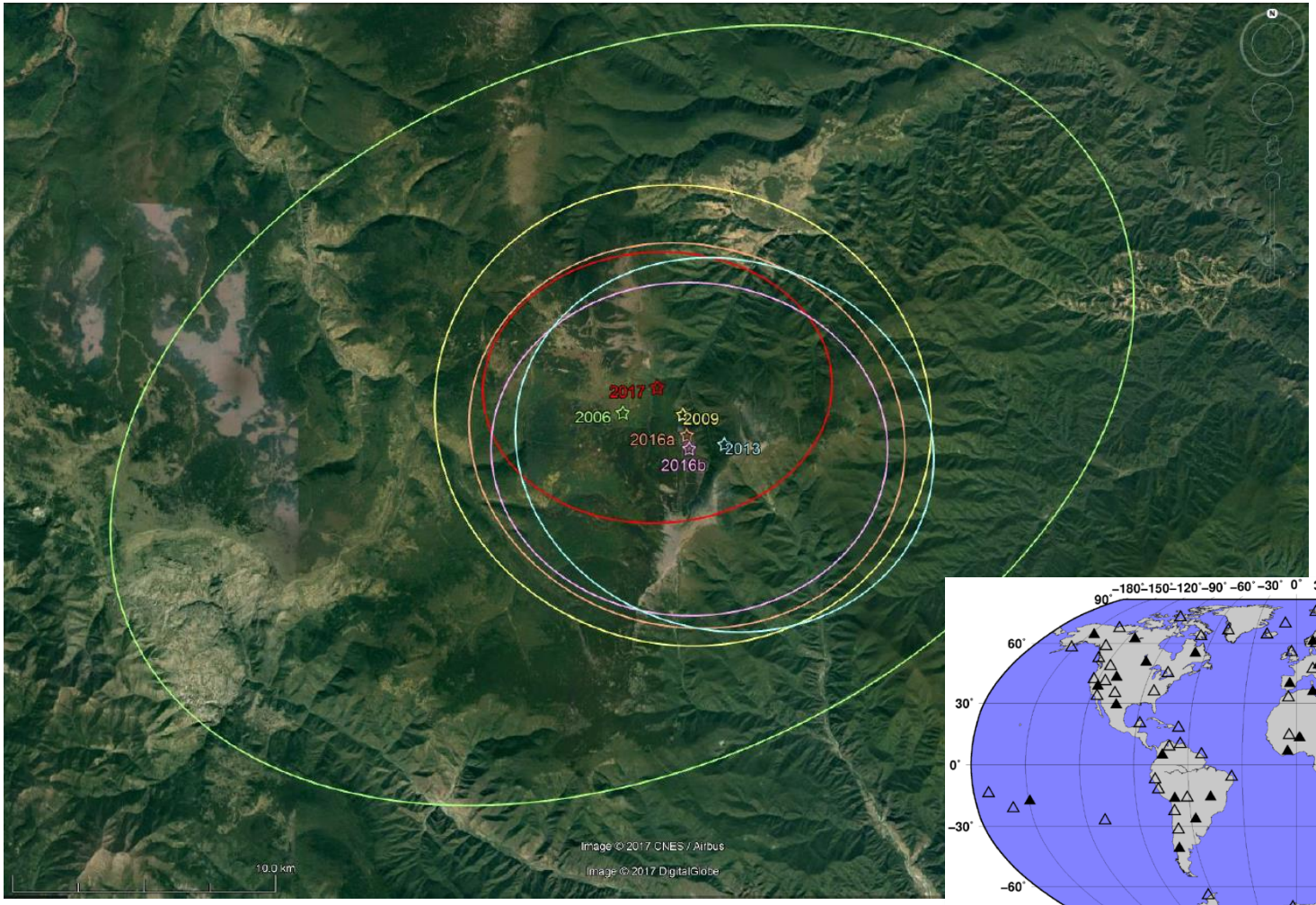

Hydroacoustic

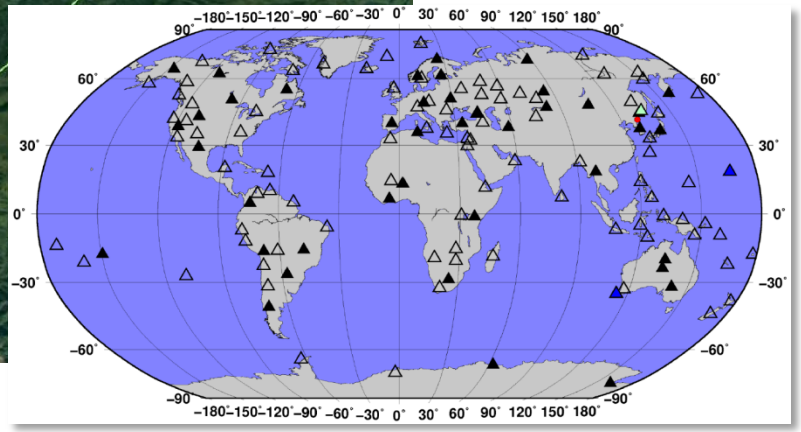
# International Data Centre



# DPRK Announced Nuclear Tests



41 PS, 90AS, 2 HA and 1 IS stations detected signals associated with DPRK event on 3 Sep 2017

# Civil and Scientific Applications

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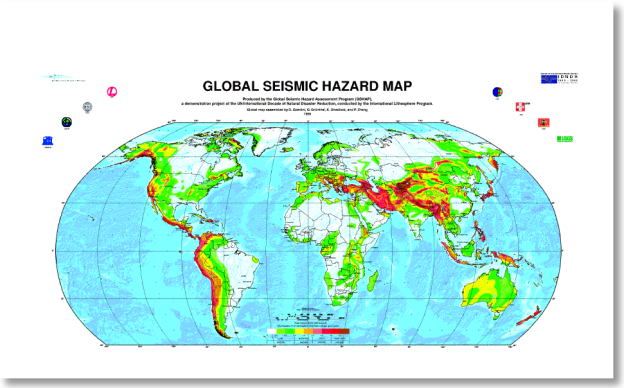
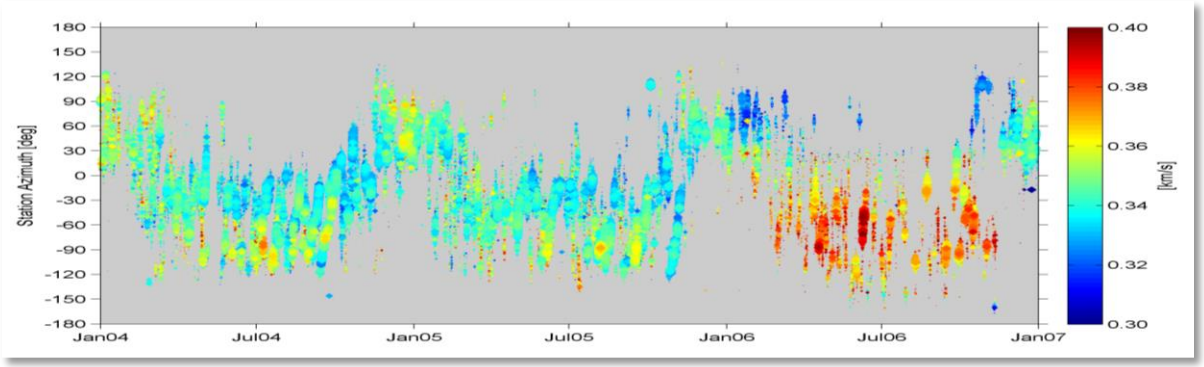



- Tsunami Agreement
- Volcano Alert System
- Earthquakes/Seismicity
- Radiation studies
- Natural and man-made sources
- Atmospheric studies




# Seismo-Acoustic Measurement Systems

# Infrasound – Minimum Requirements

| Characteristics | Minimum Requirements |
|---|---|
| Sensor type | Microbarometer |
| Number of sensors | Four element array |
| Geometry | Triangle with a component at the centre |
| Spacing | Triangle basis: 1 to 3 km |
| Measured parameter | Differential pressure |
| Passband | 0.02 to 4 Hz |
| Sensor response | Flat to pressure over the passband |
| Sensor noise | ≤18 dB below minimum acoustic noise |
| Calibration | ≤5% in absolute amplitude |
| Sampling rate | ≥10 samples per second |
| Resolution | ≥1 count per 1 mPa |
| Dynamic range | ≥108 dB |
| Timing accuracy | ≤1 ms |
| Standard temperature range | –10°C to +45°C |

*MB2005*

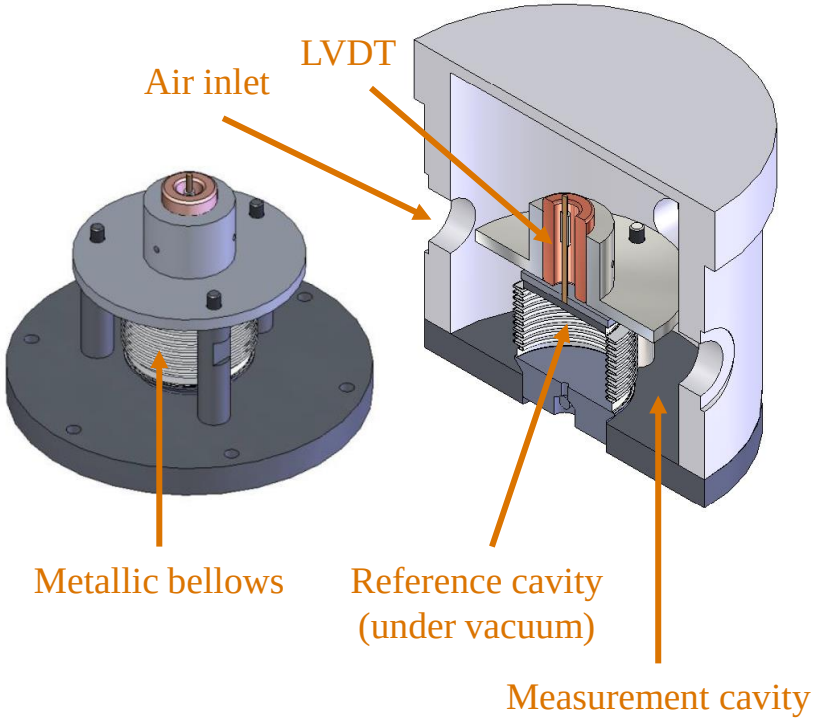
*C50A*

*MB3*

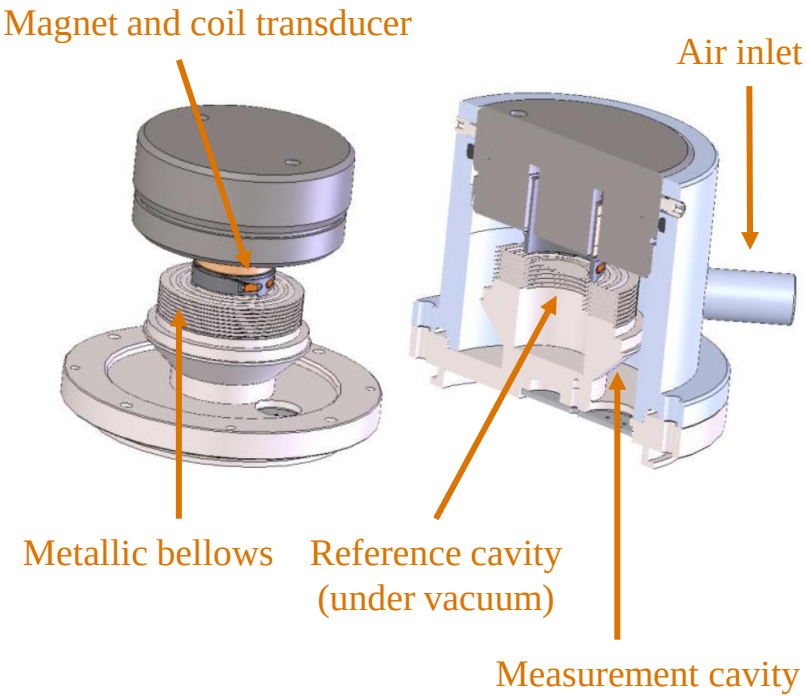
CTBT/WGB/TL-11,17/17/Rev.5

# Infrasound – Sensor Description

## MB2005




## MB3



# Seismic – Minimum Requirements

| Characteristics | Minimum Requirements |
|---|---|
| Position (with respect to ground level) | Borehole or vault |
| Three component station passband | Short period: 0.5 to 16 Hz plus long period: 0.02 to 1 Hz or broadband: 0.02 to 16 Hz |
| Array station passband | Short period: 0.5 to 16 Hz<br>Long period: 0.02 to 1 Hz |
| Sensor response | Flat to velocity or acceleration over the passband |
| Number of sensors for new arrays | 9 short period (one component) plus (1 short period (three component) plus 1 long period (three component) |
| Calibration | Within 5% in amplitude and 5° in phase over the passband |
| Sampling rate | ≥40 samples per second<br>Long period: ≥4 samples per second |
| Seismometer noise | ≤10 dB below minimum earth noise at the site over the passband |
| System noise | ≤10 dB below the noise of the seismometer over the passband |
| Resolution | 18 dB below the minimum local seismic noise |
| Dynamic range | ≥120 dB |
| Absolute timing accuracy | ≤10 ms |
| Relative timing accuracy | ≤1 ms between array elements |
| Operation temperature | –10°C to +45°C |

*CMG3TB*

*STS-2*

*GS13*

CTBT/WGB/TL-11,15/17/Rev.5

# Hydroacoustic – Minimum Requirements

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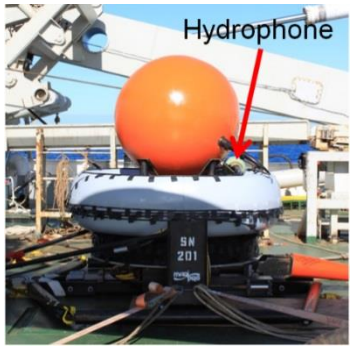
| Characteristics | Minimum Requirements |
|---|---|
| Sensor type | Seismometer |
| Position (with respect to ground level) | Borehole or vault |
| Passband | 0.5 to 20 Hz |
| Sensor response | Flat to velocity or acceleration over the passband |
| Seismometer noise | ≤10 dB below minimum earth noise at the site over the passband |
| Calibration | Within 5% in amplitude and 5° in phase over the passband |
| Sampling rate | ≥50 samples per second |
| Resolution | 18 dB below the minimum local seismic noise |
| System noise | ≤10 dB below the noise of the seismometer over the passband |
| Dynamic range | ≥120 dB |
| Absolute timing accuracy | ≤10 ms |
| Operation temperature | –10ºC to +45ºC |

T-Phase Stations

*STS-2*

Hydrophone Stations




| Characteristics | Minimum Requirements |
|---|---|
| Sensor type | Hydrophone with wet-end digitizer |
| Passband | 1 to 100 Hz |
| Sensor response | Flat to pressure over the passband |
| Number of sensors | 1 operational sensor with 2 backup sensors per cable |
| Sensors' location | In the Sound Fixing and Ranging channel |
| Location precision | ≤500 m |
| Number of cables | 2 at a site when necessary to prevent local blockage |
| System noise | ≤10 dB below Urick's deep ocean low noise curve |
| Calibration | Within 1 dB, no phase requirements |
| Sampling rate | ≥240 samples per second |
| Timing accuracy | ≤10 ms |
| Sensitivity | ≤60 dB per µPa (1 Hz band)<br>≤81 dB per µPa (wideband) |
| Dynamic range | 120 dB |

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# Calibration – Infrasound Technology

# Calibration – Goals

Demonstrate quality assurance in IMS infrasound measurement to ensure trustworthiness and credibility of IMS infrasound data

Ensure consistency in IMS infrasound measurement and equivalence in data produced across the IMS infrasound network

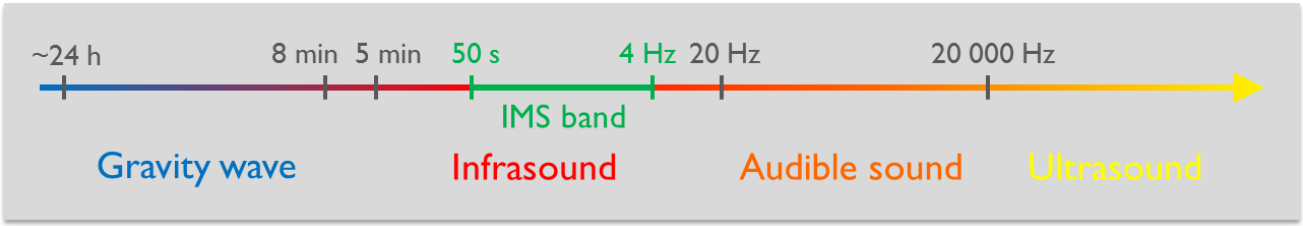
Ensure continuity and transparency of best practices independent of changes in instrumentation/service provider, or individual personnel

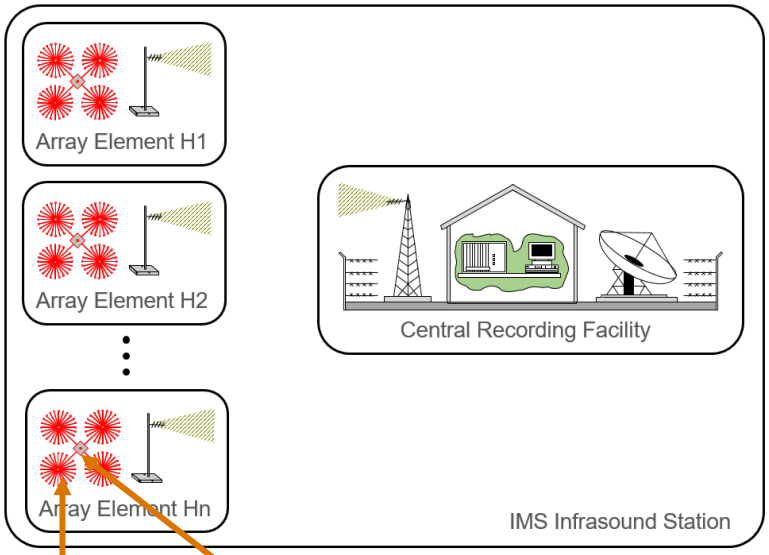
# IMS Infrasound Station

I21FR, Marquesas Islands, France

I49GB, Tristan da Cunha, UK

I60US, Wake Island, USA





Wind Noise Reduction system (WNRS)

Equipment vault

Communication equipment

# Calibration Infrastructure

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1. Type Approval

   Extensive testing of a set of a new device against IMS and manufacturer type specifications. Most of the tests are performed by a designated Expert Laboratory, which performance is regularly assessed by the PTS. If the Type Approval report is approved by the PTS, the new model is approved for use in the IMS.

2. Acceptance testing

   Testing of a individual device against manufacturer type specifications. The tests are performed by the manufacturer, whose performance is regularly assessed by the PTS. Once the data sheet is approved by the PTS, the device is declared ready for installation in the IMS.

3. Initial calibration

   Testing performed at the time of the installation in operational conditions of a new measurement system to verify that the new system performs within tolerances of the manufacturer type specifications. The tests mainly include full frequency response and self-noise measurements. The results of the initial calibration is used to establish the baseline for future calibrations.

4. On-site Calibration

   Yearly measurements of the full frequency response of a measurement system to determine is the performance of the operational device remains within the tolerance of the baseline established at the time of the Initial Calibration. When the results are not within tolerances, the required maintenance actions are initiated.

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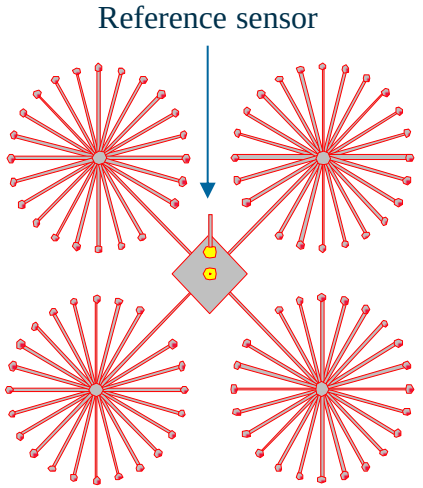
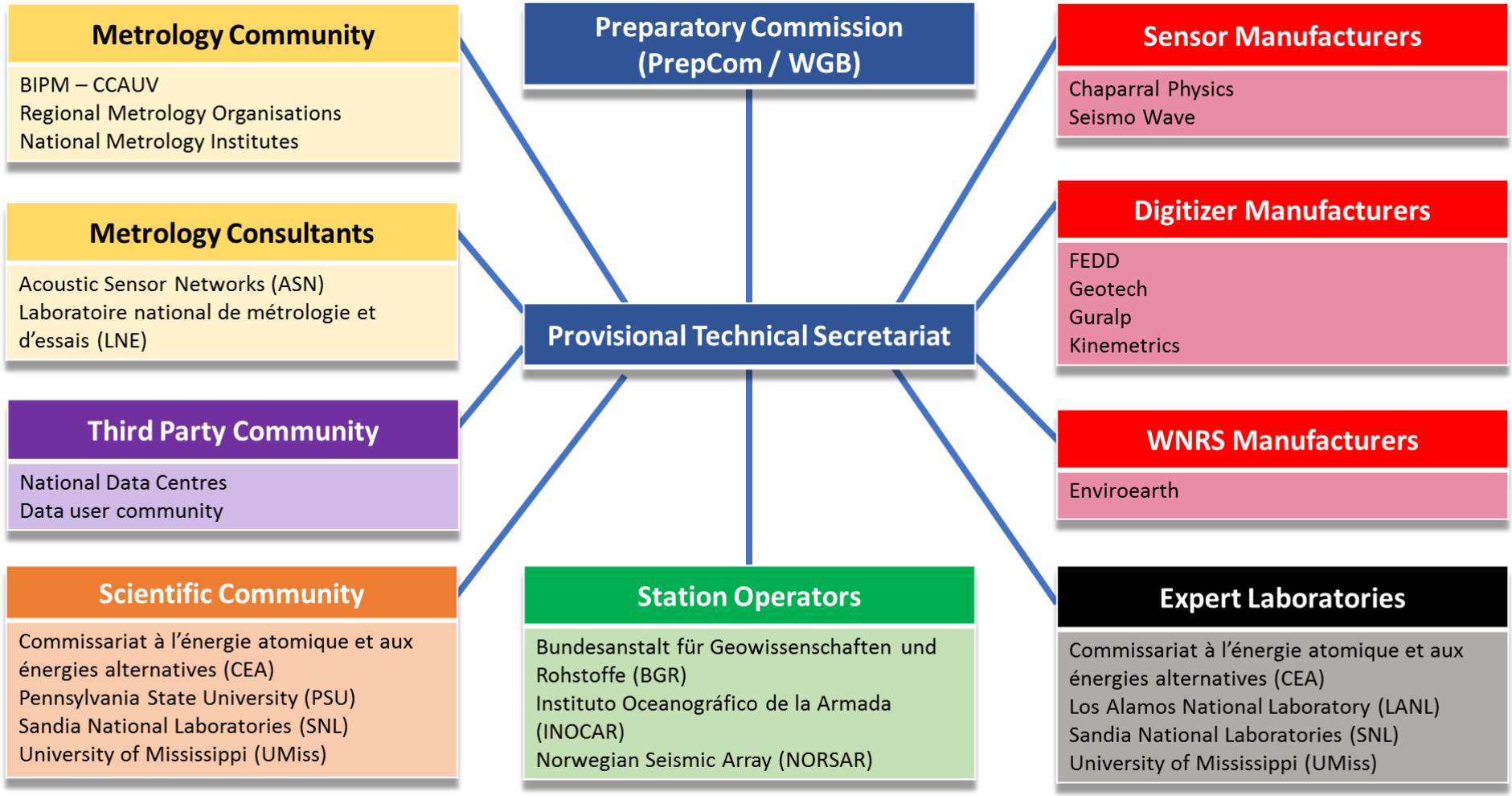
# Challenges in 2011

- Technical
  - (a) No international or national standards for infrasound technology
  - (b) No technique available for the initial and on-site calibration of infrasound measurement systems (WNRS + sensor) within IMS specifications
  - (c) No validated models for acoustic response of WNRSs
  - (d) WNRSs introducing response instabilities at some IMS infrasound stations
- Potential field calibration techniques
  - (a) Pistonphone -> does not include WNRS
  - (b) Microbarometers including calibration coil -> does not include WNRS
  - (c) Infrasound generator -> Does not cover full IMS frequency band
  - (d) Use of reference infrasound sensors -> Possible for very low background noise conditions




Side-by-side installation (Reference sensor ↔ infrasound measurement system)

# Stakeholder Map



# Achievements 2011 – 2016

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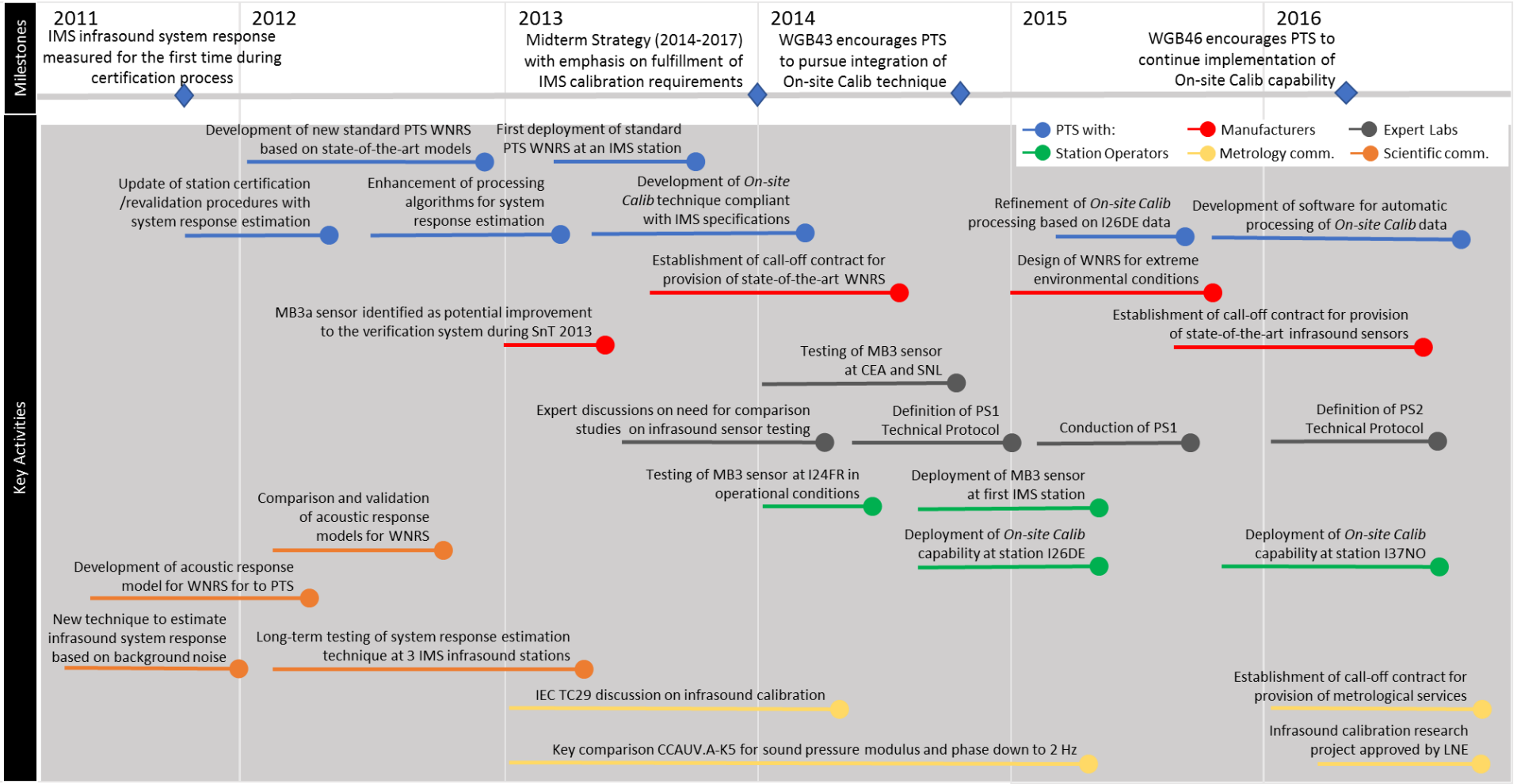

# Traceability for Infrasound Sensors

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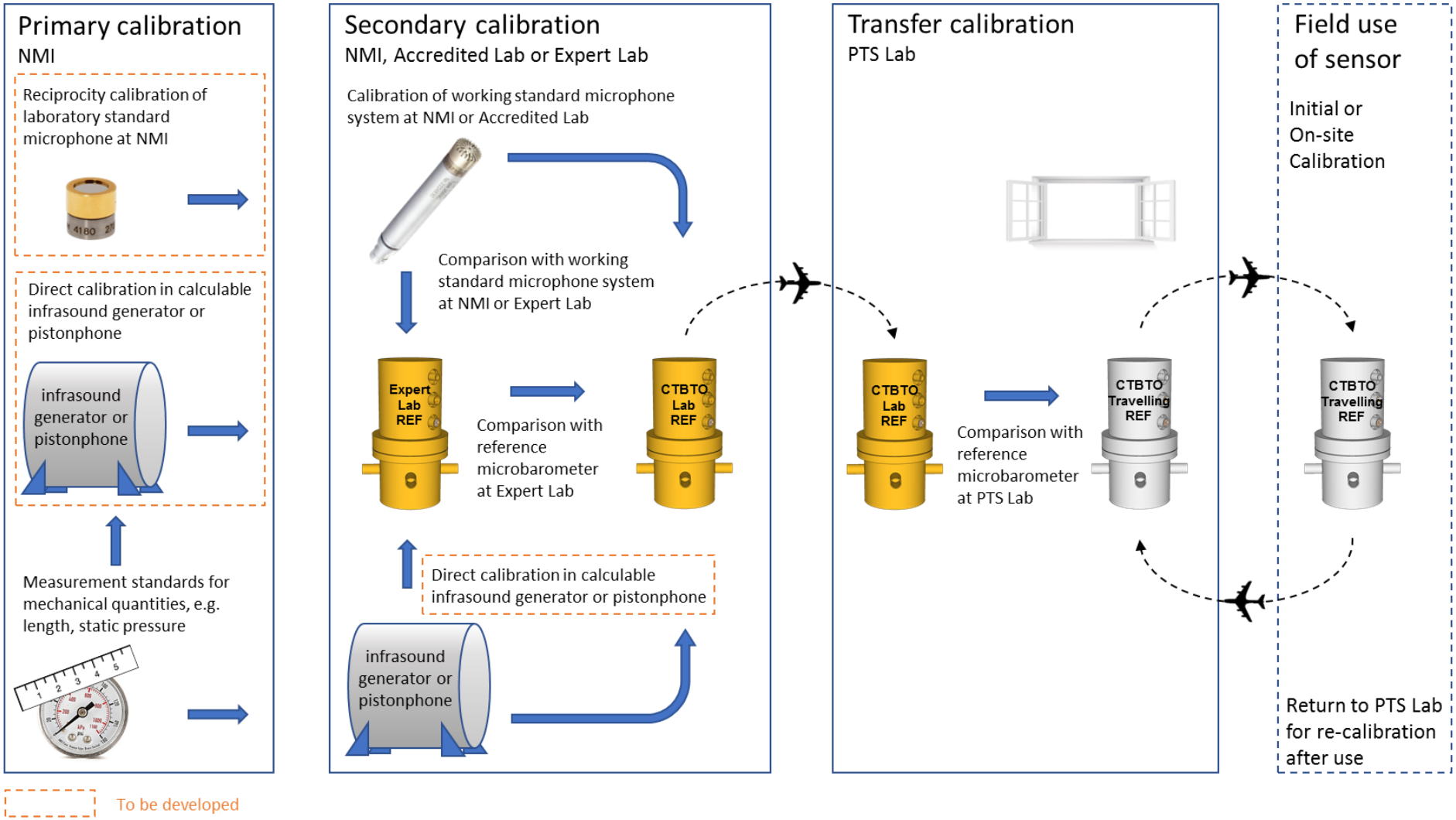

# Type Approval for Infrasound Sensors

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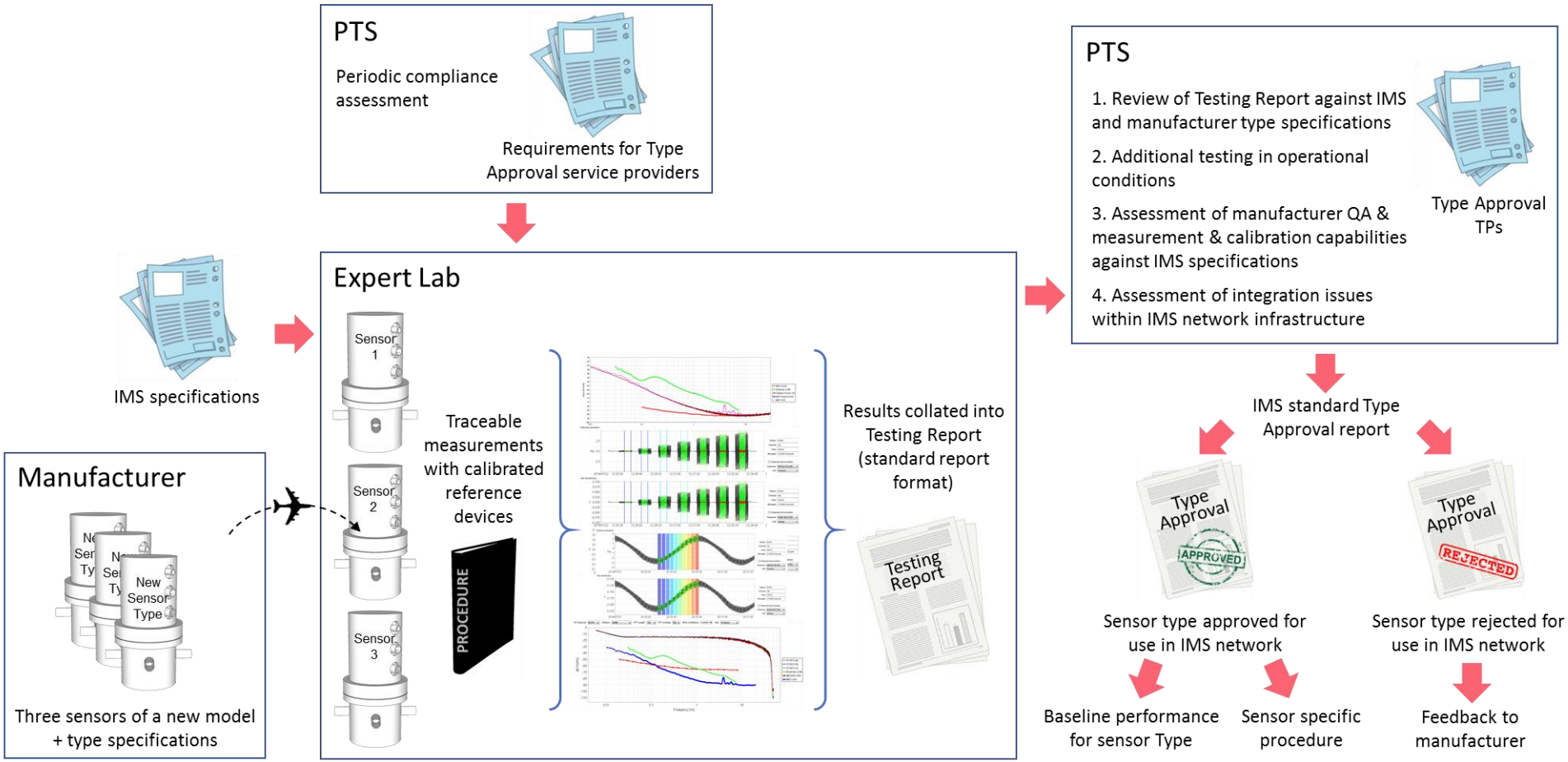


Expert Labs need traceable calibration services from metrology community

# Acceptance Testing for Infrasound Sensors

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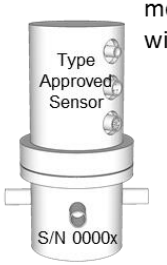
**PTS**

Periodic compliance assessment

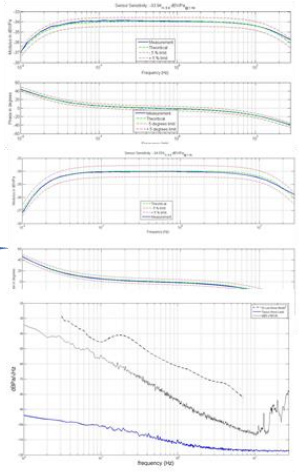
Requirements for Acceptance Testing service providers

IMS specifications

**Manufacturer**




Traceable measurements with calibrated reference devices

Manufacturer's Data Sheet for sensor S/N 0000x (standard format)


**PTS**

Review of Data Sheet against manufacturer type specifications

Acceptance Testing TPs


Sensor S/N 0000x ready to be installed in IMS network


Sensor S/N 0000x rejected for use in IMS network

Manufacturers need traceable calibration services from metrology community

# Roadmap 2017 – 2023

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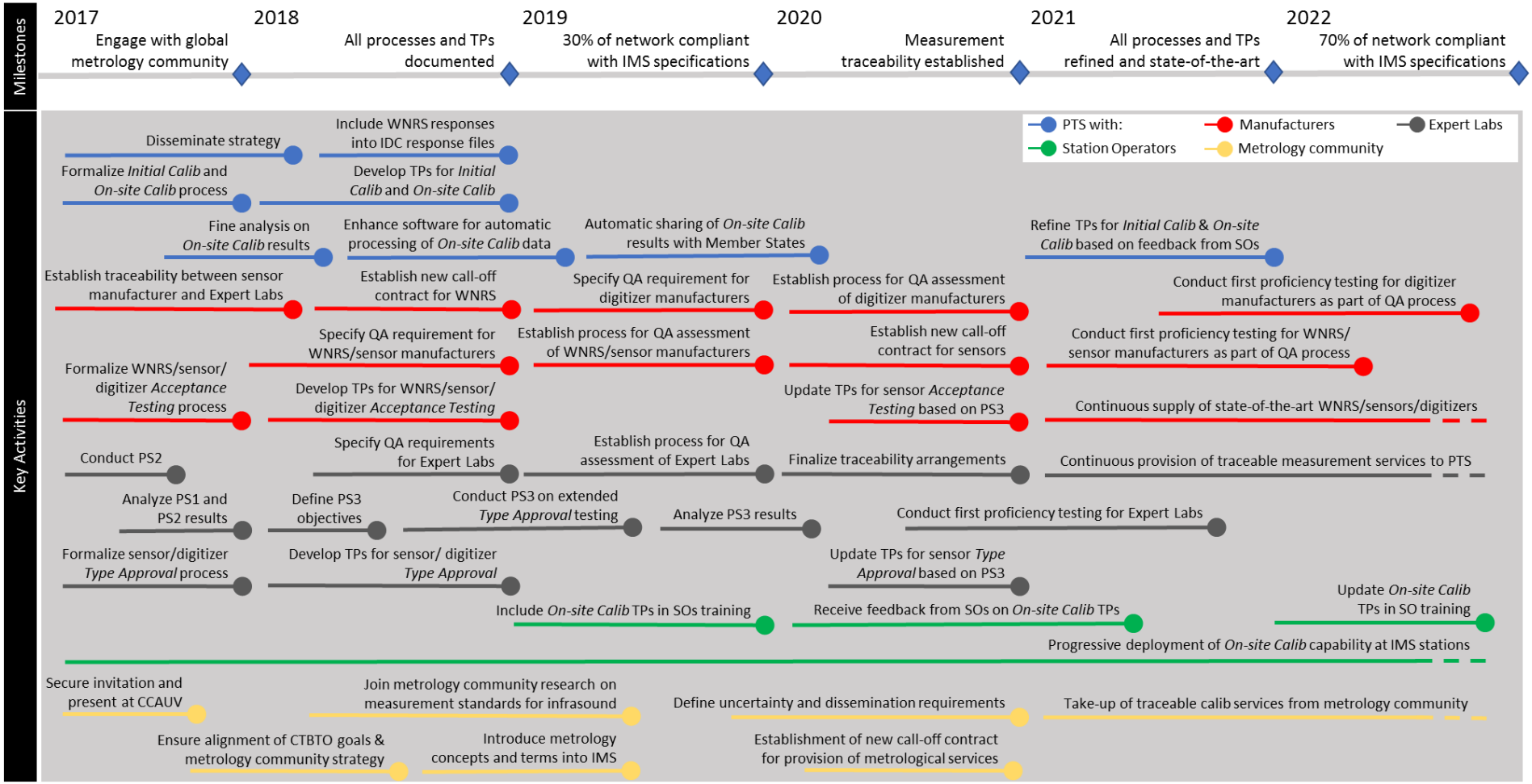


Support from metrological community required to achieve PTS objectives

# Calibration – Seismic and Hydroacoustic Technologies

# Seismic Technology

- No standard written IMS procedures for Type Approval, Acceptance Testing or Initial Calibration of IMS seismic measurement systems
- On-site Calibration implemented since 2011 through the yearly sending of electrical signals into seismometer calibration coils
- Part of seismological community moving from electrical calibration to calibration with reference sensors
- Project for definition of seismic calibration infrastructure to be initiated by the PTS in 2018
- Standard procedures for Type Approval of seismic sensors under definition with support of expert community (SNL, USGS, IRIS/IDA, etc.)
- Same set of seismic sensors sent to 2 Expert Labs (CEA, SNL) for testing in 2017 with the objective of gathering information on Expert Labs testing methodologies

# Hydroacoustic Technology

- Same processes as for seismic technology applied to T-phase stations
- Processes for hydrophone stations significantly different from those for the infrasound and seismic stations
- Acceptance testing for hydrophones currently performed in laboratory (Navy calibration facility) including calibration through the use of reference hydrophones in in pressurized tanks
- Electronic part of the hydroacoustic measurement systems calibrated on yearly basis by injecting electrical calibration signal from acquisition system
- Comparison between recording of different hydrophones within the same triplet can also be performed for periodic quality control checks

# Conclusion and Collaboration Perspectives

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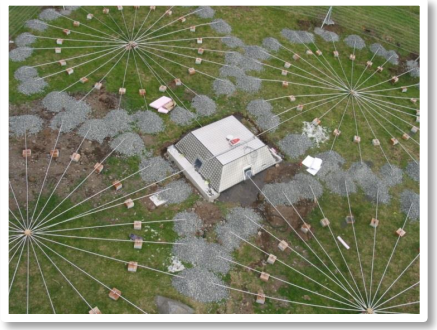
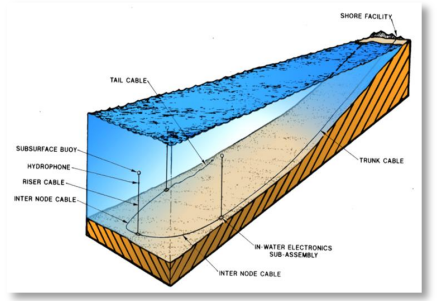
- Significant efforts made by the PTS since 2011 to define standard calibration infrastructure for infrasound technology
- Efforts to be continued to demonstrate quality assurance in IMS infrasound measurements
- Project for the definition of standard calibration infrastructure for seismic technology to be started in 2018
- Support from metrological community required for the development of primary standards in IMS frequency bands
- Target for infrasound technology: Availability of traceable calibration services by end of 2020





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