Overview on the Radionuclide monitoring segment of the CTBTO verification regime

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CTBT - Preamble

• Constraining the development and qualitative improvement of nuclear weapons.

• Ending the development of advanced new types of nuclear weapons.

• A meaningful step in the realization of a systematic process to achieve nuclear disarmament.

CTBT - Article I. Basic Obligations

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.

2. Each State Party undertakes, furthermore, to refrain from causing, encouraging, or in any way participating in the carrying out of any nuclear weapon test explosion or any other nuclear explosion.
CTBT - Article IV. Verification

- A verification regime shall be established
  - An International Monitoring System
  - Consultation and Clarification
  - Confidence-building measures
  - On-site inspections

- At entry into force of this Treaty, the verification regime shall be capable of meeting the verification requirements of the Treaty
The Complete IMS Verification System

The CTBT Verification Regime

Acquires, analyses and disseminates IMS Data and IDC Products, to Support States’ Need for Nuclear-Test-Ban Monitoring in Multiple Environments
## Synergy between monitoring technologies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>SHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delayed response; 4 - 14 d</td>
<td>Prompt response, near real-time; &lt; 1 d</td>
</tr>
<tr>
<td>Very good detection capability</td>
<td>Good detection capability</td>
</tr>
<tr>
<td>Few events</td>
<td>Many events</td>
</tr>
<tr>
<td>Poor location ability</td>
<td>Excellent location ability</td>
</tr>
</tbody>
</table>

**Unambiguous identification**

**Impossible to identify nuclear test**

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Radionuclide monitoring supports the other technologies by providing certain forensic proof of the nature and timing of an event.

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**Introduction to CTBTO**

**Radionuclide network of the IMS**

**Radionuclide data processing at the IDC**

**Access to CTBTO data and products**

**Support to Member States after Fukushima**

**NDC-in-a-BOX software package**

**Summary**
The CTBTO Radionuclide Monitoring Network

Primary role of radionuclide monitoring: to provide an unambiguous evidence of a nuclear explosion through the detection and identification of fission products.

Design elements of the Radionuclide network: 90% capability to detect within ~14 days for a 1 kt nuclear explosion in the atmosphere or from venting by an underground or underwater detonation.

➢ 80 stations for particulate Radionuclides in aerosols
➢ among which, 40 are also equipped with capabilities to also monitor Noble Gas (4 Xenon radioisotopes: Xe-131m, Xe-133m, Xe-133 and Xe-135)

Certification of radionuclide stations

Minimum requirements:

<table>
<thead>
<tr>
<th>System</th>
<th>Manual or automated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow</td>
<td>≥100 m³/h</td>
</tr>
<tr>
<td>Collection time</td>
<td>24 h</td>
</tr>
<tr>
<td>Decay time</td>
<td>≤24 h</td>
</tr>
<tr>
<td>Measurement time</td>
<td>≥10 h</td>
</tr>
<tr>
<td>Time before reporting</td>
<td>≤72 h</td>
</tr>
<tr>
<td>Reporting frequency</td>
<td>Daily</td>
</tr>
<tr>
<td>Filter</td>
<td>Adequate composition for preparation, dissolution and analysis</td>
</tr>
</tbody>
</table>
| Particulate collection efficiency | For filters: ≥80% at Φ = 0.2μm  
Global ≥80% at Φ = 1μm |
| Measurement mode              | HPGe spectroscopy   |
| HPGe relative efficiency      | ≥40%                |
| HPGe resolution               | < 3.5 keV at 1533 keV |
| Base line sensitivity         | 33 to 50 μBq/m³ for 1μBq |
| Calibration range             | 98 to 1550 keV      |
| Data format                   | Radionuclide Monitoring System Format (RMS) |
| State of health               | Status and auxiliary data recorded every 10 minutes |
| Communication                 | Two-way             |
| Auxiliary data                | Meteorological and flow rate data recorded every 10 minutes |
| Data availability             | ≥99%                |
| Downtime                      | ≤7 consecutive days: ≤15 days annually |
Station Design :: Real Station

Radionuclide - Air Filter Spectrum

Typical Spectrum after 24 h of sampling, 24 h of decay and 24 h of counting

International Monitoring System Division, November 2002
RN20 - Beijing, China (Airsampler)

RN47 - Kaitaia, New Zealand
The CTBTO Radionuclide Monitoring Network: 80 Particulate stations

3 technologies: RASA, ARAME (cindrella), Manual
63 stations are certified

The CTBTO Radionuclide Monitoring Network: 40 with Noble Gas systems

3 technologies: SAUNA, SPALAX, ARIX
23 systems are certified
The CTBTO Radionuclide Monitoring Network: supported by 16 Laboratories

10 Laboratories certified for particulates
1st certification for NG: Dec. 2014

Laboratory Network

- Certified Lab
- Non-certified Lab
- Certified NG
Noble Gas systems

3 different technologies are operated

SPALAX

SAUNA-H

ARIX

Certification of Noble Gas systems

Minimum requirements: - technical specifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow</td>
<td>0.4 m³ h⁻¹</td>
</tr>
<tr>
<td>Total volume of sample</td>
<td>10 m³ (0.87ml of stable Xenon volume)</td>
</tr>
<tr>
<td>Collection time</td>
<td>≤ 24 h</td>
</tr>
<tr>
<td>Measurement time</td>
<td>≤ 24 h</td>
</tr>
<tr>
<td>Time before reporting</td>
<td>≤ 48 h</td>
</tr>
<tr>
<td>Reporting frequency</td>
<td>Daily</td>
</tr>
<tr>
<td>Isotopes measured</td>
<td>¹³¹mXe, ¹³³Xe, ¹³³mXe, ¹³⁵Xe</td>
</tr>
<tr>
<td>Measurement mode</td>
<td>Beta-gamma coincidence system or High resolution gamma spectrometry</td>
</tr>
<tr>
<td>Minimum Detectable Concentration</td>
<td>1 mBq m⁻³ for ¹³³Xe</td>
</tr>
<tr>
<td>State of health</td>
<td>Status data transmitted to IDC</td>
</tr>
<tr>
<td>Communication</td>
<td>Two-way</td>
</tr>
<tr>
<td>Data availability</td>
<td>95 %</td>
</tr>
<tr>
<td>Down time</td>
<td>≤ 7 consecutive days</td>
</tr>
<tr>
<td></td>
<td>≤ 15 days annually</td>
</tr>
</tbody>
</table>
22 IMS Noble Gas systems are certified and sending daily data to IDC Operations.
Spectra are reviewed in routine mode by IDC Analysts.
Automated and reviewed products (ARR/RRR) are generated and made available to NDCs, on a regular basis.

Sample category is included in ARR/RRR
Information on isotopic ratios is also provided.
IDC processing pipeline for Radionuclides

Input program

Automatic processing

*Autosaint*: Particulates and SPALAX NG

*Bg_analyze*: Beta-gamma coincidence based NG (SAUNA & ARIX)

Interactive review

Particulates and SPALAX NG: *SAINT2*

SAUNA & ARIX NG: *Norfy*

Categorization and Reviewed products

Particulates and Noble Gas with category

Types of radionuclides in the atmosphere

**Radon decay products**
- Lead-212
- Bismuth-212
- Bismuth-214
- Thallium-208

**Terrestrial radionuclides**
- Radium-226
- Actinium-228
- Uranium-235
- Potassium-40

**Cosmic-ray induced radionuclides:**
- Beryllium-7
- Sodium-22
- Germanium isotopes

**Non-relevant radionuclides:**
- not associated with nuclear weapons
- including some radio-pharmaceuticals
- and accelerator products

**CTBT Relevant radionuclides:**
- possibly from nuclear weapons
- (fission & activation products)
Fission and activation products

Fission products are produced instantly due to fission of U or Pu

- **Fission yield** is telling roughly what masses the fission is producing

- **Two figures**: yield of the isotope on its own and cumulative fission yield.

- Fission yields are slightly different for different source materials. Mass numbers around 90-100 and 130-140 are well represented in all of them

- **Activation products** are produced instantly due to activation of surrounding materials of nuclear detonation.

- Activating agent is usually neutron, typical reaction is for example Co-59 (n, gamma) Co-60

- Other particles like positrons and electrons can cause activation.

Radionuclides of interest

- **Key radionuclides**: the traces that indicate nuclear test

- Xe-135 and Xe-133 are most abundant in a 1 kt nuclear explosion, with activities increasing after a couple of days due to formation of beta-decay chain of precursors (Table 1).

- The use of several radionuclides are preferred (Table 2). These radionuclides are considered relevant as nuclear test indicators because their presence or their mutual ratios can be used to discriminate other possible sources of radioactivity.

Radionuclides of interest

- **Key radionuclides**: the traces that indicate nuclear test

- Xe-135 and Xe-133 are most abundant in a 1 kt nuclear explosion, with activities increasing after a couple of days due to formation of beta-decay chain of precursors (Table 1).

- The use of several radionuclides are preferred (Table 2). These radionuclides are considered relevant as nuclear test indicators because their presence or their mutual ratios can be used to discriminate other possible sources of radioactivity.

### Table 1. Most abundant radionuclides after a 1 kt explosion.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>1-day decay</th>
<th>3-day decay</th>
<th>10-day decay</th>
<th>30-day decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe-135</td>
<td>11.8%</td>
<td>9.6%</td>
<td>3.6%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Xe-133</td>
<td>3.4%</td>
<td>2.0%</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Zr-97</td>
<td>3.4%</td>
<td>2.0%</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Ba-105</td>
<td>4.6%</td>
<td>3.0%</td>
<td>1.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Xe-106</td>
<td>4.6%</td>
<td>3.0%</td>
<td>1.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Ce-134</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Ce-141</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Ce-143</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Ru-103</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-133m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-131m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>

### Table 2. Some radionuclides relevant as nuclear test indicators.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>1-day decay</th>
<th>3-day decay</th>
<th>10-day decay</th>
<th>30-day decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe-135</td>
<td>11.8%</td>
<td>9.6%</td>
<td>3.6%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Xe-133</td>
<td>3.4%</td>
<td>2.0%</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Zr-97</td>
<td>3.4%</td>
<td>2.0%</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
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<tr>
<td>Xe-106</td>
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<td>3.0%</td>
<td>1.1%</td>
<td>0.4%</td>
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<td>Ce-134</td>
<td>6.5%</td>
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</tr>
<tr>
<td>Ce-141</td>
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<td>0.6%</td>
</tr>
<tr>
<td>Ce-143</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Ru-103</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-133m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Xe-131m</td>
<td>6.5%</td>
<td>4.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>
Categorization scheme for particulates samples

83 CTBT relevant nuclides

AG-106N | EU-152 | IB-84 | U-237 | W-187
AG-106N | EU-152M | HB-86 | V-217
AG-108N | EU-153 | IB-892 | V-98
AG-133 | EU-164 | HB-109 | V-91
AS-74 | EU-157 | HT-180 | Y-85
AS-74 | FE-29 | HT-196 | ZN-85
AU-196 | GA-72 | SB-120 | ZN-85
AU-196 | LA-141 | SB-123 | ZR-85
AU-198 | LLa-18 | SB-124 | ZR-95
BA-133 | LLa-12 | SB-125 | ZR-97
Ba-140 | LLa-10 | SB-136 |
CB-115 | IB-790 | SB-127 |
CB-115N | IB-792 | SB-128 |
CE-141 | K-40 | YC-36 |
CE-143 | LA-60 | SC-47 |
CE-144 | SN-54 | SE-55 |
CS-57 | Mo-99 | SM-55 |
Co-58 | Na-24 | SN-155 |
Co-60 | Nb-85 | SB-91 |
Cr-51 | Nb-147 |
CS-132 | NF-130 | TF-125M |
CS-134 | Pb-203 | TF-125M |
CS-136 | Pb-212 | TF-132 |
CS-137 | PM-149 | UM-168 |

**Flag:** Concentrations Xe-133m, Xe-131m, Xe-135, Xe-133 typical?

**Flag:** Isotopic ratios Xe-133m/131m > 2? Xe-135/133 > 5? Xe-133m/Xe-133 > 0.3?

**Flag:** Quality Indicators on Sample reliability

**Flag:** Backtracking indicates known source

Noble gas categorization scheme

**Concept:**
- Three-level activity concentration based scheme
- Inter-quartile based filtering threshold, 365 days

**Flag:** Typical background

**Flag:** Typical for station

**Flag:** Anomalous for station

Scheme updated: Xe-131m can also trigger level C (even if detected alone in the sample)
IDC processing pipeline

Yearly evolution of reviewed samples (particulates stations)
Introduction to CTBTO
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Support to Member States after Fukushima
NDC-in-a-BOX software package
Summary

Workflow of IMS data and IDC products

SPHD = Sample Pulse-Height Data
ARR = Automatic Radionuclide Report
RRR = Reviewed Radionuclide Report
SSREB = Standard Screened Radionuclide Event Bulletin
RLR = Radionuclide Laboratory Report
RNPS = Radionuclide Network Product Summary
ATM = Atmospheric Transport Modeling

Met data
ECMWF

Radioluclidean and ATM processing in separate "pipelines"
Equal access to IMS data and IDC products is provided to all Member States.

Secure websites migrated to Single Sing-On system (released)
Concentration Reporting Tool extended to IDC Operations and testbed database
Concentration Reporting Tool (CRTool):
-a new window under IDC secure website

Detected isotope concentrations at JPP38, Takasaki, Japan

The station is 200 km SW from Fukushima. The radiation levels detected are low in the global scale.

Detections at CTBTO stations – after Fukushima NPP event in March 2011

Situation at the end of May, more than 40 stations have detected the event and all but closest station (Takasaki, Japan) are back to normal background radiation. More than 1600 samples contained radiation originating from Fukushima NPP.
Development timeline: Key dates

Nov. 2011:
Design elements of the project presented at INGE Workshop, Jogjakarta (Indonesia).

Oct. 2012:
Beta version was handed over to NDCs at the NDC Evaluation Workshop, Asunción (Paraguay):
- Minimal documentation
- Installation instructions (build-deployment)

Apr. 2013:
Radionuclide software tools are integrated into the same NDC-in-a-BOX Virtual Machine (along with existing Geotool, CDTool, WebGrape, SRSget):
- Bug fixing
- New functionalities
- User Guide
Development timeline: Key dates

Jun. 2013:
- Experimental training to experts from 7 NDCs.
  - Package installation
  - Tutorials /Hands-on

Jul. 2013:
- Virtual Machine made available on the IDC secure web-site
  - Documentation
  - "One click" installation

Dec. 2013:
- Five e-learning modules released on NDC-in-a-BOX
  - Radionuclide components:
    - automatic processing applications and interactive review tools
    - Particulates and Noble Gas

Development timeline: Key dates

May-June + October 2014:
- NDC-in-a-BOX customized by IDC for OSI purposes
  - RN Library configured; A/RRR customized; OSI in a line product created
  - Integrated in FIMS of OSI Field Laboratory and successfully used during IFE14, Jordan

Q4 2014:
- Training Course on NDC Capacity Building: Access and Analysis of Radionuclide IMS Data and IDC Products
  - 2 weeks per session
  - 25 NDC staff members participated

Jan. 2015:
- 2nd release
  - Efficiency calibration module
  - Processing of QC spectra from SPALAX
  - Processing of detector background spectra from SPALAX
Radionuclide software in DC-in-a-BOX package

**Automatic processing**
- Autosaint: Particulates and SPALAX NG
- Bg_analyze: Beta-gamma coincidence based NG (SAUNA & ARIX)

**Interactive review**
- openSpectra (new tool)
- SAUNA & ARIX NG: Norfy

**Categorization and Reviewed products**
- Particulates (RRR, SSREB) with category
- Noble Gas: results in Database & logfiles

Norfy GUI: review tool for SAUNA & ARIX βγ coincidence based
Noble Gas –in NDC-in-BOX
OpenSpectra GUI: review tool for particulates and SPALAX Noble Gas – newly developed tool

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Summary
Radionuclide monitoring technology is a key component of the CTBT verification regime. 

~80% of the IMS radionuclide network is installed and operated by CTBTO.

Dedicated software tools are developed and operated at the IDC for automatic processing and interactive analysis of radionuclide data from IMS network.

Both particulates and Noble Gas data are integrated into the IDC automatic processing pipeline.

Data from certified stations (63 particulates and 22 Noble Gas systems) are reviewed in routine mode in IDC Operations. Other systems are processed in IDC testbed.

CTBTO products are mission driven
underlying principles: objectivity and equal access to all Member States.

Authorised users are officially designated by CTBTO States Parties.

For the radionuclide monitoring technology (particulates and Noble Gas), the following is made available to States signatories:
- all types of raw spectral data as transmitted by IMS stations,
- IDC automatic and reviewed radionuclide reports (ARR, RRR, SSREB, …)
Access to the scientific community:
Contractual arrangements are in place within vDEC (virtual Data Exploitation Centre) agreements for accessing CTBTO data and products (all monitoring technologies).

Framework for emergency situations:
CTBTO is member of IACRNE (Inter-Agency Committee on Radiological and Nuclear Emergencies).