Chapter 25
CTBTO Science and Technology for a Safer World

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Ladies and Gentlemen,

From the outset, I would like to express my appreciation to the organizers for the invitation to this Conference. The theme of this session "Role of science in technical and international cooperation" is very topical as most of you would agree that we are living in particularly challenging times with serious tensions among international actors which can be compounded by mistrust and misunderstanding.

Restoring trust—or more specifically—providing a justifiable basis for trust, and improving common understanding is a key objective of verification regimes. This is exactly what the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is doing!

Before I enter the main topic of my discussion I'd like to start by noting the status of the CTBTO Verification System, and its accomplishments. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) was opened for signature in 1996 and, since then, it has become one of the most adhered to arms control instruments in the world. The Treaty bans all nuclear explosions in any environment. To date, 183 countries have signed the CTBT and 166 of these have set their commitment to that principal in stone through ratification. The CTBT is underpinned by its science-based technical Verification System capable of monitoring for, detecting, and reporting nuclear explosions. The Verification System is composed of two main pillars: the International Monitoring System (IMS) and the On-Site Inspections regime (OSIs). Also the Treaty outlines a process of consultations and clarifications.

The establishment of the IMS, a system that can credibly verify compliance with a ban on nuclear testing, has been one of the CTBT's key achievements. The IMS is a global network of seismic, hydroacoustic, infrasound (atmospheric pressure wave) sensors, and atmospheric radionuclide sensors that functions as a global nervous system that can monitor for signs of testing in every part of the globe. When completed, it will comprise 337 facilities distributed all around the globe, including

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in many remote locations, meaning every country hosting a station counts and no one country can do it alone.

With monitoring stations in nearly 100 countries, the data from the IMS is transmitted to the International Data Centre (IDC) in Vienna where it is processed and analyzed by staff from all over the world. The raw data and processed results are available to Member States as fast as they are available in Vienna, they provide a level of trust and credibility that no single nation could ever accomplish. This is multilateralism at its finest—a nonproliferation and disarmament model to be proud of. Currently about 90% of the System is up and running. It has already exceeded expectations in terms of coverage and detection capabilities. The System detected all six nuclear tests announced by the Democratic People's Republic of Korea (DPRK). In doing this, the IMS and IDC demonstrated the effectiveness of the verification regime along with the democratic nature of the data collection, sharing and analysis. The international community was provided with reliable, unbiased and verifiable evidence. This transparency, openness, and international inclusiveness in the design of the verification regime is a point that I will further elaborate on in the main part of my discussion.

The OSI leg of the Verification System has also made substantial progress in the recent years. Even though the OSI process can only be launched once the Treaty enters into force, the CTBTO has already conducted two integrated field exercises (2008 and 2014), which are life-seize tests of an on-site inspection. To give you an idea, the second one which took place in Jordan, lasted for five weeks and tested crucial aspects of each phase of an on-site inspection. It entailed shipping 150 tonnes of equipment to Jordan. More than 360 experts and dignitaries from 53 States Signatories and the Secretariat participated in the event in various roles and functions. Those two exercises proved the readiness of the organization to carry out an OSI.

In short, we can state that, by all measures, we have built a deterrent that gives countries peace of mind by demonstrating that the Treaty is verifiable through a global monitoring system that is unique, reliable and efficient.

The CTBTO is an Organization which has science at its core. However one must look closely at differences in Treaty verification regimes to understand different approaches to, and implementations of technology in organizations. Earlier, the transparency, openness, and international inclusiveness of the CTBT was mentioned. The CTBT is a democratic Treaty in that all Member States are equal—having equal access to data and products, equal roles in the operation of the Technical Secretariat, and each is responsible for drawing its own conclusions from the IMS data or IDC products.

> The *International Data Centre shall* apply on a routine basis automatic processing methods and interactive human analysis to raw International Monitoring System data in order to *produce* and archive standard International Data Centre *products on behalf of all States Parties*. These

products shall be provided at no cost to States Parties and
shall be *without prejudice to final judgements with regard to*
the nature of any event, which shall remain the
responsibility of States Parties, [Protocol, Part 1, para 18]

The Technical Secretariat does not draw conclusions about Treaty violations, but rather operates a monitoring network, gathers and analyses data and makes information available to Member States who reach national positions on the nature of events detected by the IMS. Thus the verification regime is not just the sensors around the globe and the data processing in Vienna—it includes the national data centres in Member States. This nature has a profound influence on the way technology is selected, validated and employed in the monitoring system, international and national data centres. A key implication of this is that the data *and the methods to analyse the data* must be understood broadly. It's not enough that the CTBTO consists of staff from nearly 100 countries, the data and products must be understood and increasingly re-analysed in 100s of countries. So the data sources, sensor operation, calibration, analysis methods must have broad acceptance. And the analysis methods must be taught to those Member States that do not already have proficiency in these methods. This proficiency must also be evaluated so each Member State has confidence in their ability to fulfil their individual role in the multilateral collective that makes this Treaty effective. Member states want to ensure their own analyst at National Data Centres (NDCs) can produce results comparable to those produced at the IDC. This has resulted in a significant effort to build the capacity of NDCs, including assistance with computer systems to receive, store, process and display IMS information, development of standard analytical software tools (a product called NDC-in-a-Box) and scripts for analysis, and training. As new methods are incorporated into IDC analysis, efforts are also undertaken to incorporate these methods into NDC-in-a-Box and associated training. This capacity building involves hundreds of institutions and thousands of individuals. It involves documentation, videos, on-line support, e-learning in all UN languages, assistance visits, and formal class room training both regionally and in Vienna. In addition to training the analysts in Member States, the CTBTO trains the station operators who provide first-line support ensuring proper function and high availability of the more than 300 stations around the globe. These station operators typically have other functions associated with whatever parent institution is contracted for local operation and maintenance of a station. They provide invaluable and cost-effective means to ensure the monitoring network is serving the needs of all Member States. To be effective, these operators must understand how to service and troubleshoot issues related to the specific equipment at their stations including telecommunications, power and electrical issues, sensor performance, calibration, alignment, adjustment, software updates, etc.… The choice of specific equipment used for monitoring stations takes into account both standardization to achieve logistical and training efficiency, but also diversity to limit common failure or differences in environments.

Paragraph 69 of Part II to the Protocol specifically list techniques a) through h) that may be employed for on-site inspections—but in truth these 7 listed techniques include many subparts so the number of allowed methods is larger. Paragraph 16 of Article 4 of the Treaty states "The International Monitoring System shall comprise facilities for seismological monitoring, radionuclide monitoring including certified laboratories, hydroacoustic monitoring, infrasound monitoring."

These four core global monitoring technologies are what is currently implemented. The Treaty does not specify the methods to be employed in analysis of these four monitoring technologies but there has been some debate among Member States regarding the extent to which environmental background measurements or supplemental information such as meteorology and associated atmospheric transport modelling is within the scope of the Treaty. It is worth noting that what we commonly refer to as the waveform technologies (Seismic, Hydroacoustic, and Infrasound)—or SHI techniques are a minimum set for detecting explosions underground, underwater, and in the atmosphere. Although sometimes an underground explosion causes a hydroacoustic or infrasound detection, these methods could be viewed as addressing non-overlapping environments. Currently there is no redundant method or dual phenomenology built into the monitoring network such as EMP or optical flash for atmospheric tests.

> *Each State Party undertakes to cooperate* with the Organization and with other States Parties *in the improvement of the verification regime, and in the examination of the verification potential of additional monitoring technologies* such as electromagnetic pulse monitoring or satellite monitoring, with a view to developing, when appropriate, specific measures to enhance the efficient and cost-effective verification of this Treaty. *Such measures shall, when agreed, be incorporated in existing provisions in this Treaty* [Article 4, para 11]

However, Paragraph 11 of Article 4 makes it clear that new technology should be considered in the future. It is generally considered additional techniques would only be considered after Entry into Force of the Treaty. Even then several considerations would seem important; Does a proposed new technology address a shortcoming or gap in the existing network? Is it cost-effective? Is it globally equitable? As an example, it has been suggested in technical conferences that an additional technology might be observing small disturbances in GPS satellite signals as a means of measuring waves in the ionosphere which are potentially caused by interaction with explosion infrasound. This method might improve overall infrasound coverage, but perhaps only in regions of the world that are densely populated with GPS reference stations (currently North America, Western Europe, Japan). Would employment of such a technique be globally equitable or would it 'target' some Member States more than others, is it more cost-effective than a current technique or an alternate technique, does the additional coverage it provides warrant a global effort to promote more GPS reference stations everywhere, if developed as an official IMS monitoring technology what would be the support, capacity building and training cost?

Raising these questions is not an effort to discourage exploration of new techniques. In fact the CTBTO actively engages in such exploration as will be shortly discussed.

But being incorporated as an official IMS technology as mentioned in Article 4 paragraph 11 above is not the only means for new technology to be used for CTBT monitoring. The following text of the Treaty may allow for non-IMS technology to be analysed and presented to Member States;

> *The International Data Centre shall*
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> (c) *Assist*ing *individual States Parties, at their request* and at no cost for reasonable efforts, *with expert technical analysis of International Monitoring System data and other relevant data provided by the requesting State Party,* in order to help the State Party concerned to identify the source of specific events. The output of any such technical analysis shall be considered a product of the requesting State Party, but shall be available to all States Parties. [Protocol Part II, Paragraph 20 (c)]

What could the IDC reasonably do if presented with "other relevant data" by a Member State—especially if this data is of a type different than the four core technologies in which it, by necessity, maintains expertise? The IDC could comment on the pedigree of the data—does it meet modern standards for authenticity, is the data electronically signed by a recognized and verifiable system to give confidence in the integrity of the data source? The IDC could comment on the methods and algorithms applied to the data—are they broadly accepted in scientific literature relevant to the field, have they been tested and validated in relevant similar environments, is their uncertainty understood, are they repeatable? It is unclear if the IDC could implement analytical methods and reproduce results in an unfamiliar technical discipline. However, it is clear that the Treaty encourages the IDC to be broadly conversant in technologies relevant to nuclear test detection and scientifically flexible. As a proactive step, the IDC takes the opportunity to suggest to potential future data providers (such as the remote sensing industry and international standards organizations) that they consider means for data signing in next generation systems.

Sustaining the technical credibility of the monitoring regime is crucial for sustaining confidence in the regime as a deterrence against testing. Neither Member States nor the public would have confidence in a monitoring system that employs out-of-date or discredited sensors or methods. Furthermore, it will be difficult to maintain systems that are archaic—parts, commercial service, and trained personnel will be difficult to find.

Although the CTBTO is not a research organization, it must stay cognizant of technical advances in relevant scientific disciplines. To accomplish this, the CTBTO is active in international scientific societies (e.g. EGU, AGU, and domain specific forums). The CTBTO hosts its own technology workshops in the core IMS technologies, and the biennial Science and Technology Conference series.

The CTBTO engages with national and multinational research centers and other international agencies.

Planned recapitalization is necessary to replace systems prior to catastrophic failure at end-of-life. Ideally, recapitalization would occur on a schedule that best optimizes cost-effective operations and performance—which typically implies upgrading to new technology well before end-of-life when it becomes more cost effective to upgrade than maintaining old technology. The need for recapitalization applies to big hardware systems such as Hydroacoustic arrays, but also to seismometers, infrasound microbarometers, radioxenon sensors, and also to major software systems.

Currently the IDC is engaged in an effort to recapitalize the software infrastructure that supports its primary functions (receipt, archiving, automatic processing, human interactive review, and dissemination of IMS data and IDC products). The current software was designed in the 1980s using then state-of-the-practice software engineering. The software has been migrated to more modern computer hardware at great effort, but the underlying data models and flow control remain the same as the 1980s design. Many modifications, bug-fixes, patches, have been made. This has left the code 'brittle' and increasingly difficult (thus expensive) to maintain or improve further. It is time to re-design the code using modern state-of-the-practice software engineering methods while there are still scientists who understand the old code and can assist in the redesign effort. But the new code will be based on modern languages, data-models, and flow control that will be more flexible, sustainable thus able to more economically persist into the next decade.

In particular cases of recapitalization the CTBTO and the supporting communities in national research institutions must be cautious of market economic practicalities. Currently several national research institutions are developing next generation radioxenon sensors that are hoped to be more sensitive and more cost-effective to operate. However, the business case must be carefully considered —the IMS has limited potential for procurement of such systems, and there is limited market for such systems beyond the CTBTO. It's not clear how many providers can be sustained by the market.

The CTBTO does not exist in a vacuum. As we've seen with each DPRK test, public analysis by academic institutions, think-tanks, and media experts is becoming increasingly sophisticated and rapid. These sources are not constrained in their data sources, data types, or analysis methods. Their results are presented to the public quickly and form the basis for discussion and assessment long before the CTBTO can brief its Member States. Even though the CTBTO has met the timelines specified in the Treaty for issuing standard products and rapidly briefed

Member States after all six declared nuclear tests by the DPRK—it is doubtful the CTBTO will ever compete with these other sources of information in timeliness. Nor should it. The CTBTO should not compete but rather find ways to be synergistic with these public forms of analysis. We are exploring ways to issue our results in formats the Member States and public media can incorporate into their presentations and more easily reference so that they re-enforce the CTBTO data and analysis as an authenticated, credible, international baseline from which further derived results can be developed.

The countries of the world have invested considerable resources in the CTBTO monitoring regime and annually invest more in its upkeep. They also invest in their national data centres, which includes both a monetary aspect and the dedication of personnel who might otherwise provide some other service to the country. We all hope this international and national investment is never needed for its intended purpose—that is we hope there is never another nuclear test. How do we maintain Member State and public interest and investment in a system we hope will never be used as intended? How do we maintain proficiency in this system if the signal it is designed to detect is never observed? One answer to these questions is to promote civil and scientific use of the system.

Civil and scientific applications of IMS data is not just altruism—it is a means to achieve several important benefits for the nuclear test monitoring community. Particularly, civil and scientific applications provides

- a tangible return to Member States who can better justify continued investment in their NDC if those staff provide some other societal benefit such as seismic hazards analysis, tsunami warning, radiation health warnings, civil aviation safety notices, etc.…
- improved analysis methods to the nuclear test monitoring community when scientists working on a civil application develop new tools to discriminate signals of interest to them within the IMS data stream (one person's noise is another's signal)
- increased quality control on IMS data ("well exercised data is healthy data"—Paul Richards)
- an increased pool of experts familiar with IMS data who could be potential recruits into the nuclear test monitoring community
- operational tests of the monitoring network to ensure it remains functional (for example bolides test the infrasound component of the IMS)
- public exposure that reinforces awareness of the regime

In conclusion I'd like to re-emphasize several points:

The purpose of the verification regime is to promote trust and understanding. It gives confidence that parties to the Treaty are abiding by the Treaty's provisions.

The CTBT is particular in that the regime provides trusted data to the Member States that reach their own conclusions. In this, it is a democratic, non-discriminatory regime—and this has implications on technology related to the regime.

It's crucial to refresh the technology of the CTBT verification regime, and this is being done.

Both "Capacity Building" and "Civil and Scientific Applications" provide value to Member States and increase the future pool of practitioners who can be recruited to carry on the mission of the CTBTO.

The CTBTO verification regime is effective and working today.

Thank you for your attention and I welcome any questions.