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How Can Science Support a Process Towards a World Free of Nuclear Weapons?

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Scientists have, within the frame of the Conference on Disarmament, been successfully engaged in support of the Comprehensive Nuclear Test Ban Treaty (CTBT) for many decades, starting long before negotiations began. This article proposes an International Scientific Network (ISN) to engage the global scientific community to explore how scientific and technological developments can support nuclear disarmament and non-proliferation. It reviews the experience gained from scientific work on the CTBT and identifies a broad range of science and technologies that might be the focus of an ISN. A key question is how such an international scientific cooperation can be created in the absence of an existing established political or managerial framework.

INTRODUCTION

At their Summit meeting in Reykjavik in 1986, President Reagan and Secretary-General Gorbachev shared a vision "to abolish all nuclear weapons."[1] Over the last few years there have been a number of political initiatives to initiate processes to reduce and ultimately eliminate nuclear weapons and to strengthen nuclear non-proliferation and in particular to prevent terror organizations from acquiring a nuclear capability.[2] An international movement, Global Zero, was launched in 2008 for the elimination of all nuclear weapons.[3]

The process of creating a world free of nuclear weapons will be one of the most challenging global efforts and achievements in history. The world has to change for this process to move forward and the process itself will change the world. Such a process must have a global reach and encompass two mutually re-enforcing elements: to reduce and eventually eliminate nuclear weapons and to strengthen nuclear non-proliferation.[4]

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Science and scientists have been driving forces in developing the military components of security systems around the globe and have also supported the negotiation and implementation of existing disarmament treaties. The U.K. Royal Society, in a policy document, argues that it is "timely to highlight how the scientific community can support nuclear arms control and multilateral disarmament. This cooperation could catalyze the political conditions necessary for multilateral disarmament by helping to build much needed trust between states." The document further suggests "scientific cooperation to prepare the foundations for future negotiations."[5] The paper notes that "no international group focuses specifically on the scientific and technical challenges of nuclear disarmament."

Similar ideas on how international scientific cooperation is essential to support nuclear disarmament were presented by three experts from the Royal Society in 2010. They argue that "the scientific community must now help to develop the technology to support the process of disarmament, so that the technical groundwork is done when multilateral negotiations require it." They further note that "the scientific community's well-established international networks can reach into countries where political links are tense or weak."[6]

A sustained international scientific cooperation program could support a process towards a nuclear free world in a number of ways. A global dialog among scientific experts, hopefully including experts from states that until now have been reluctant to engage, would help to build mutual trust and confidence. Global scientific cooperation would also identify scientific and technological developments that might support nuclear disarmament and non-proliferation.

Verification plays a central role in the steps towards a nuclear weapon free world. The development of verification systems will benefit from dramatic progress in a number of sciences and technologies, including sensors, communications, and information analysis. Sensors are getting smaller, more advanced, cheaper, and can be deployed in large numbers for close-in and remote monitoring. Communication systems provide high volume global data transfer at high speeds and low cost. An increasing amount of information is available in the public domain and the dramatic global expansion of advanced mobile phone technology has dramatically increased information exchange and availability. Managing, analyzing, and interpreting this rapidly increasing flow of data for verification purposes is likely our greatest challenge in the years to come. Luckily the scientific developments in data mining, a catchword for recent developments in the analysis and interpretation of data, are also most dramatic and our challenge is to harvest and apply those developments.

Based on the positive experience from scientific support of the nuclear test ban treaty, this article is a call to the international scientific community to come together to make critical contributions to the challenging process leading towards a world without nuclear weapons.

SCIENCE AND THE NUCLEAR TEST BAN TREATY

The Comprehensive Nuclear Test Ban Treaty (CTBT) is, more than any other international treaty, dependent on science and technology (S&T) for its verification regime.[7] In July 1976, before the political CTBT negotiations started, the Conference of the Committee on Disarmament created the Group of Scientific Experts (GSE) to "specify the characteristics of an international monitoring system." The GSE worked for 20 years, until the nuclear test ban treaty negotiations were concluded in 1996, in a formal process to provide the groundwork on verification for a CTBT.[8] For political reasons the Group's work was limited to seismic verification. The GSE met for four weeks every year, with participation of experts from around the globe. These meetings were only the tip of an iceberg. Hundreds of people in many states were engaged in establishing modern stations and data analysis facilities to test the systems proposed by the group.

Early on the GSE decided on a design in principle of a global seismological system for monitoring a test ban treaty, consisting of three main elements:[9]

- A network of more than 50 seismological stations around the world.
- An international data exchange system.
- International Data Centers for the routine processing of data.

It is interesting to note that the principal design presented by the GSE as early as 1978 is the basis for the International Monitoring System (IMS) in the CTBT.

The technologies available in the late 1970s put severe restraints on what could be practically implemented. An essential part of the GSE was conducting a large number of systems tests, and new technologies were gradually implemented when they became available. Most of these tests were small-scale activities among a few participating institutions. The group also conducted three experiments with the participation of institutions around the globe, labeled large-scale tests. The first such large-scale test was conducted in late 1984. Data extracted from seismological recordings were reported from 75 stations in 37 countries. Data from observed events, primarily naturally occurring earthquakes, were analyzed at three experimental international data centers (EIDC) established in Moscow, Stockholm, and Washington. A second test conducted in 1991 had a similar participation and digital data was used on an experimental basis. This involved a fourth experimental international data center in Canberra and dedicated computer-to-computer communication links established between the centers.

Based on the results of the second test and benefiting from the rapid development in communications and computer hardware and software, the system developed further. There were two main developments: to have a two-tiered station network of some 50 primary stations, reporting digital data continuously on-line, and about 100 auxiliary stations from which data could be obtained upon request. The second development was to have just one EIDC, located in Washington.

The third and last large-scale test started in 1995 and continued through the initial build-up of the facilities at the Provisional Technical Secretariat (PTS) of the Comprehensive Test Ban Treaty Organization (CTBTO) Preparatory Commission in Vienna. The EIDC in Washington was not closed until March 2000. Sixty countries participated in this test, and included 43 primary and 90 auxiliary seismological stations. This test was conducted in the startup phase of the seismological component of the IMS system which is now, by and large, implemented.

GSE not only provided a proposal for the seismological element of a CTBT verification system, it also served as a template for other verification technologies. It proved that such a system could be implemented and demonstrated its monitoring capability. As part of GSE, a number of modern seismological stations were established around the world. The analysis procedures and the necessary data analysis software at IDC were developed, tested, and eventually transferred to the PTS in Vienna.

What lessons can be learned from 20 years of GSE work? GSE proved that it was possible, and indeed most useful, to conduct preparatory scientific and technical analysis prior to political negotiations. The work of the GSE was not seen as a substitute for political negotiations, nor a commitment to commence such negotiations. It was a thorough scientific and technical effort to develop and test the concept of a verification system. The formal framework of GSE provided by the Conference on Disarmament was important in several ways. It not only facilitated the Group's meetings, it provided a link to a political body. The formal framework engaged the states, making it easier for them to not only commit experts to participate in the meetings, but also make considerable investments in tests, monitoring stations, and other facilities. The GSE was granted a unique long-term mandate and self-determination of management and leadership—as it is normal in international organizations for the chair to rotate. GSE had only two chairmen in 20 years. This resulted in a sustained, consistent, and focused effort over a long period of time. The GSE's activities also provided mutual learning among the global participants and many of the experts have since contributed to the implementation of the verification regime.

Another CTBT related activity is the International Scientific Studies (ISS) project launched in March 2008 by the Provisional Technical Secretariat (PTS) of the CTBTO in Vienna. ISS had a dual purpose; to assess the readiness and the capability of the CTBT verification regime and to identify areas where states and the CTBTO could "harvest the fruits" of scientific and technical developments to improve the activities and capabilities of the verification system.

ISS was organized in a network structure covering eight selected S&T areas of key importance to the CTBT. Four of these areas involved monitoring technologies; seismology, infrasound, hydroacoustics, and radionuclide. The four additional areas related to on-site inspections, system analysis, data mining, and atmospheric transport modeling, to support the interpretation of radionuclide observations.

The scientific work of the ISS was carried out by national scientific and academic institutions, both governmental and private. A number of seminars and workshops were held, mainly in the different S&T areas. The results of more than 200 studies were presented at the ISS 09 conference in Vienna in June 2009 with more than 600 participants from 100 countries.[10]

Most of the contributions were scientific studies within each discipline. Only a few of the studies were conducted for the sole purpose of addressing the CTBT and related issues. They, however, proved most relevant to underpinning the assessments and improvements to CTBT verification. In general, the studies revealed that in many areas, science and the scientific infrastructure has advanced significantly since the treaty was negotiated in the late 1990s. Developments in infrasound and noble gas detection were most prominent. Both were in their infancy when the treaty was negotiated and they have advanced considerably. Noble gas detection is now an important tool for monitoring underground nuclear tests whereas infrasound is likely to find its most important applications not in CTBT monitoring but in studies of the atmosphere. ISN, for the first time, also presented studies of how different geophysical techniques can be used during on-site inspections of suspicious events.

In some areas, particularly seismology, the scientific community has established a large number of new stations with the same quality and capability as those in the IMS. Taken together, those stations monitor a given area with a capability that goes far beyond what the IMS can achieve alone. Similar developments are under way in other technologies. This illustrates that existing scientific infrastructure can provide useful data for verification purposes. As scientific systems develop and improve over time, they may provide greater capabilities than treaty-defined verification systems that run the risk of being obsolete.

An important element during the ISS process was to explore how data mining could facilitate the analysis and interpretation of different kinds of verification data. It took a substantial effort and several meetings and seminars among data mining, seismological, and other verification technology experts to bridge the gap between the sciences and to identify how data mining could prove useful. It was found that traditional methods of analyzing data, e.g., seismological, can be significantly improved and that new paradigms may be developed. Data mining might also improve the integrated interpretation of different kinds of data. The application of modern data mining methods to verification is still in its infancy but it is likely that its contribution will be dramatic.

PTS arranged a follow-up conference in 2011 and a new Science and Technology conference is planned for June 2013.[11] The experiences from these unique methods for engaging the scientific community revealed that:

- When challenged, scientists are eager to engage and contribute to the resolution of important global issues.
- A large body of knowledge and infrastructure in the scientific community is available and can be applied to nuclear disarmament and other global security issues.
- To address complex technical issues, such as verification of disarmament, a long-term engagement is needed. This will require a framework and a coordinating mechanism; ad-hoc meetings and publications alone cannot achieve substantial progress.
- It is important to find new ways to promote dialogue between the political and the scientific processes.

WHAT CAN SCIENCE CONTRIBUTE?

A multitude of issues are likely to surface as we move toward a world without nuclear weapons.[12] One key challenge would be to prevent the proliferation of nuclear material. This includes a broad spectrum of issues including FMCT,[13] detection of illicit nuclear material transfer and development of proliferation resistant nuclear fuel cycles. Another key challenge is "proliferation resistant transparency," to ensure that nuclear disarmament is transparent to all states without proliferating sensitive information restricted by the NPT. A number of concrete tasks have been identified including verification of nuclear weapon declarations, storage and dismantling.[14] To address these and other issues there will be a need to understand, integrate, and apply scientific developments in a number of areas, some examples are given below.

Recent micro- and nanotechnology advances are enabling revolutionary new microscale, solid-state sensor systems. A key application for these systems is to prevent illicit international transfer of nuclear material on the world's borders.[15] There is an immediate and urgent need for tamper proof tags and seals to ensure the integrity of containers, and for robust and highly sensitive sensors and sensor systems to scan containers at high speed, as large ports have a throughput of the order of 10–20,000 containers a day.[16] In 2003 the U.S. National Nuclear Security Administration (NNSA) initiated the Megaports Initiative with the goal of equipping 100 large seaports in 31 countries with radiation detection equipment. As of August 2012 only 42 ports had been completed.[17]

Sensor systems can also, together with seals and tags, monitor weapons or weapon components in storage or during the dismantling process.[18,19] It is critical to have the capacity to confirm the integrity of the chain of custody of weapons grade nuclear materials. Monitoring the dismantling process in an international context presents special challenges; it should be transparent to the extent that it shows that weapons have been dismantled as agreed, but it should, on the other hand, not reveal certain weapon technology related information. This difficult balance is addressed in a multi-year United Kingdom–Norway cooperative effort on the verification of nuclear warhead dismantlement.[20] Information barriers and procedures for managed access addressed in this project have a number of applications in nuclear disarmament and arms control.

Satellite observations have been important for monitoring nuclear and other disarmament and arms control agreements and have also greatly reduced uncertainty and increased confidence among states. Such observations have improved significantly in the last decades. The ground and spectral resolutions of optical satellites have increased and radar sensors make it possible to observe at night and in cloudy conditions. Today, optical satellites have a spatial resolution near one meter. The corresponding resolution of radar satellites depends on the frequency band used and can be as high as one meter for X-band and 10–30 meters for C-band. An increased number of satellites and improvements in satellite technology have improved coverage and provided the capability of more frequent and higher resolution observations. Satellite data and computer programs' more sophisticated analysis of satellite data are more generally available. Satellite observations are likely to continue supporting confidence building and verification.[21]

Unmanned drones have been developed and used for military purposes over the last two decades. They are increasingly sophisticated, carry multiple types of sensors, and operate over long distances. Drones are also used for non-military purposes such as observing hurricanes.[22] In the future, drones might be applied to arms control and disarmament as a platform for different kinds of sensors, such as optical, infrared, and radionuclide.

Unattended ground sensor systems have been developed for military applications.[23,24] Similar systems might be used to monitor the movement of people and vehicles and the transfer of larger objects in and out of specified facilities and areas.

The amount of generally available information (open source data) has increased dramatically over the last decade as we move towards increased globalization. Today more than 50 percent of the global population has access to cell phones, the internet, or both. Social networks facilitate dissemination of information and the web provides a convenient tool to search for information from all over the world. How can this abundance of information be used to support nuclear disarmament and enhance confidence among states and for improving verification?[25]

The dramatic increase of data has been matched by a similar increase in our ability to communicate, store, analyze, and interpret large volumes of data. Progress in the field of artificial intelligence shows great potential for developing increasingly more sophisticated tools, not only to automatically analyze large volumes of data, but also to help integrate and interpret different kinds of information.[26] As discussed previously, the very first applications to CTBT verification proved most interesting and promising.[27,28]

In addition to progress in individual verification technologies and data analysis, science can provide support at a broader system level. System analysis is essential to explore how different components can be combined to predict outcomes. It is also an important tool to identify critical components in a verification system and to explore how overall system performance may be improved.[29,30]

Operational analysis takes an even broader approach by analyzing systems in relation to the tasks and the environments in which they operate, a methodology that originated in the late 1930s and came to fruition during the Second World War.[31] It has since been used extensively within the global military community and has gradually migrated into a broad range of civilian applications.[32] Operational analysis could address different issues related to nuclear disarmament and non-proliferation, in particular how verification systems might meet political and operational requirements.

THE WAY FORWARD?

There is no established political forum for negotiating or considering how to promote and achieve a world without nuclear weapons, and this goal may never be accomplished by one forum alone. Different issues might be dealt with by different forums. This means that presently there is no natural political framework to promote global cooperation among scientific experts on nuclear disarmament and non-proliferation verification.

An ISN could serve as a means for engaging and organizing the global scientific community to explore how scientific and technological developments can support and underpin nuclear disarmament and non-proliferation. The focus of an ISN would be to bring together S&T developments in different areas and to integrate and apply them to nuclear disarmament and non-proliferation. The intention is to not prejudge political developments or possible agreements that might emerge, but rather to identify what tools science can contribute in support of future political processes. Such a scientific cooperation would contribute to building a global knowledge base in the scientific areas relevant to nuclear disarmament and non-proliferation.

An ISN should bring together the scientific community and be open to scientists and scientific institutions in all countries. National scientific societies might provide important contributions and conduct joint studies, building on the model of the U.S. National Academies and Russian Academy of Sciences joint project on what the international nuclear security environment will look like in 2015.[33] ISN would be a global learning exercise and would create a dialogue with those that are normally not engaged in discussions related to nuclear disarmament and non-proliferation. Global scientific cooperation on issues related to nuclear disarmament and non-proliferation would also build confidence and thereby contribute to a sustained and resilient process towards a world free of nuclear weapons.

An ISN might be organized as an open network with a non-hierarchical project management structure to facilitate and encourage the open exchange of information and opinions. The network could have a number of nodes, each focusing on a specific scientific area or a particular application. One or two experts could be responsible for each node, coordinating the dialog and cooperation within the expert community or on a particular application. An initial step to establish an ISN would include identifying these experts and bringing them together to establish an initial work plan. The nodes should be located at institutions around the world to encourage global engagement. The network might be served by a small secretariat to facilitate coordination and integration and to maintain a joint ISN homepage.

An ISN should arrange and encourage a number of activities including workshops, seminars, special sessions at scientific conferences, studies of special applications, political outreach and, from time to time, large scale conferences. ISN might also work with organizations and institutions to create joint activities and initiatives. The annual IAEA safeguards conferences and the Institute of Nuclear Materials Management (INMM) conferences might provide good opportunities to cover areas of interest to the ISN. The same might be true for the Science and Technology conferences of the CTBTO.

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