8

CTBT radionuclide verification and the British Laboratory

Christine Comley and Owen Price

From the 1958 conference of scientific experts[1] onwards and the first tentative steps towards the 1996 Comprehensive Nuclear Test Ban Treaty (CTBT),[2] the use of forensic seismology[3] dominated proposals for the international co-operative verification of bilateral and multilateral nuclear test ban treaties.[4] However, during the CTBT treaty negotiations from 1994 to 1996 many technologies besides seismology were considered by the Conference on Disarmament (CD) and its expert groups.

Ultimately, four different technologies were chosen as the basis for the treaty's International Monitoring System (IMS). These technologies provide data to an International Data Centre (IDC), located at the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), currently in nascent form, in Vienna. The data are collated, processed and used to provide detailed event bulletins to states parties to enable them to verify compliance with the treaty. The technologies are intended to operate synergistically to locate and identify a nuclear test, whether it is conducted underground, under water or in the atmosphere.[5] Seismology and hydroacoustics will be used to locate underground and underwater nuclear tests, while infrasound and radionuclide monitoring will detect and locate atmospheric tests.

Of the four IMS verification technologies, radionuclide monitoring is the only one that can provide unambiguous evidence that an event is a nuclear, rather than a conventional, explosion. Hence it can provide conclusive evidence of a nuclear test. If an event were considered by the states parties to be a possible nuclear test, they could approve the conduct of an on-site inspection to locate it and establish who conducted it. During such an inspection, additional technologies, including the gathering of radioactive samples and their examination by means of radionuclide measurements, would be used to provide further evidence of a treaty violation.[6]

This chapter describes the role of radionuclide verification for the CTBT, presents the role of the United Kingdom, and reports on the progress and future plans towards certification of the UK's Radionuclide Laboratory, based at the Atomic Weapons Establishment (AWE), Aldermaston, which has been designated by the treaty as a CTBT laboratory (GBL15).[7]

Radionuclide monitoring for CTBT verification

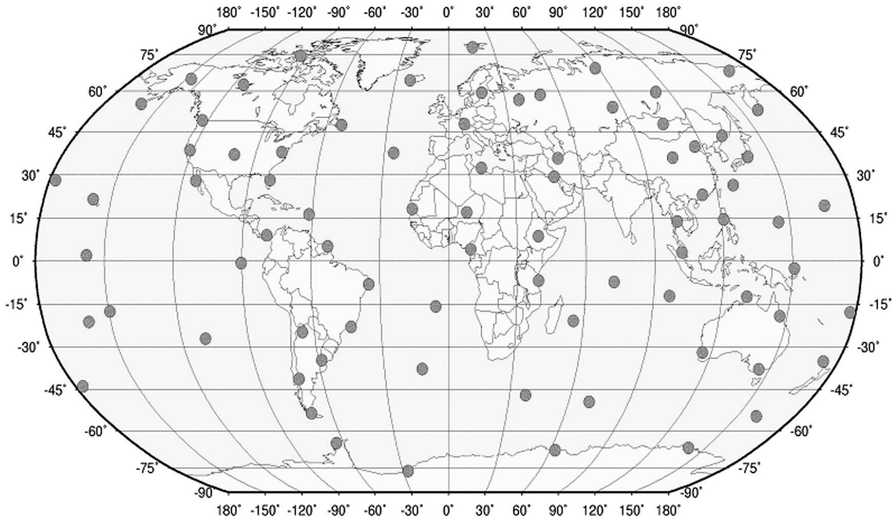
During a nuclear explosion large quantities of debris, including radioactive materials from fission products, activation products and actinides, are produced. In an atmospheric or surface test these are dispersed as plumes high into the troposphere, which can be transported many thousands of miles away. In the case of an underground test, unless the explosion is effectively contained, some of the (volatile) fission products and gaseous debris may be vented into the atmosphere.

Fission products from a nuclear explosion (1.4×10^{23} fissions per kiloton of yield) are highly radioactive and contain a mixture of radionuclides with half-lives ranging from a few seconds to many thousands of years. The radioactivity of the mixture roughly halves as the period of time doubles. Other radioactive materials present include the remains of the fissile materials that comprised the explosive core (such as uranium and plutonium), plus any materials made radioactive by the neutrons produced during the explosion. Meteorological models[8] can predict the dispersion of the debris with time, and are used to track the debris back to the detonation location. In most cases the time of the detonation can be deduced from the gamma spectrometry results from early radioactivity measurements.

As part of its International Monitoring System (IMS), the CTBT provides for the establishment worldwide of 80 stations for global radionuclide monitoring (figure 1).[9] The IMS radionuclide stations are of two types:

- particulate (aerosol) collection and analysis stations, where a high-volume air sampler (capable of collecting more than 500 cubic metres per hour (> 500 m^3/hr) collects radioactive particulate greater than 0.2 microns onto a filter for each 24 hours; and
- noble gas stations, which collect, count and analyse the short-lived radionuclides of the noble gas xenon which is released by a nuclear explosion. Half of the 80 IMS stations may eventually have this additional capability.

Figure 1 **Locations of IMS radionuclide stations**



Source Provisional Technical Secretariat (PTS), CTBTO, Vienna. Permission to reproduce granted by the PTS.

Initial analysis is usually undertaken at the station. After 24 hours' delay, to allow radioactive decay of the natural radioactivity from radon 'daughters' present in the atmosphere, the radioactive particulate collected on the filter is automatically measured using a high-purity germanium (HPGe) gamma detector. The results are categorised according the radionuclides present and their quantities. The data from the stations are sent by a satellite that is part of the CTBTO's Global Communications Infrastructure (GCI) to the IDC in Vienna, where they are merged with data obtained by the other monitoring technologies. Although some data processing will take place at the IDC, the raw data may also be made available, on request, to states parties, to enable them to do their own analysis.

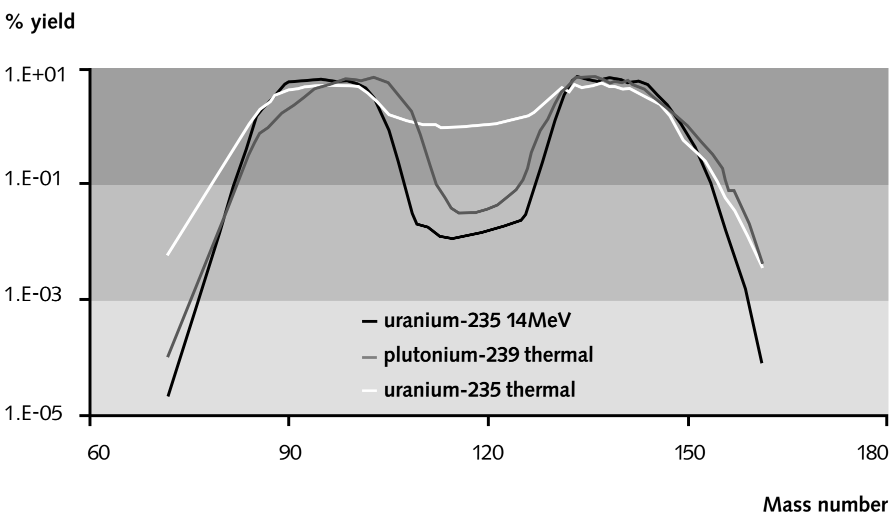
The treaty provides for 16 IMS radionuclide laboratories, located around the world, to be certified for analysing the samples collected by the IMS stations. The 16 host countries are: Argentina, Australia, Austria, Brazil, Canada, China, Finland, France, Israel, Italy, Japan, New Zealand, Russia, South Africa, the UK and the United States. The role of the laboratories includes taking additional, more sensitive measurements or confirmatory measurements of samples from any of the IMS stations. The results are transmitted to the IDC for inclusion in bulletins for states parties.

There are five alert levels for the radioactive measures taken at the IMS radionuclide stations. Alert level 5 applies when certain short half-life fission products, that may be the result of a nuclear explosion, are detected. Level 5 samples are sent to the CTBTO-certified laboratories for further analysis.

Having detected certain short-lived radioactive species, it is necessary to differentiate between a nuclear explosion and nuclear releases from nuclear power reactors, hospitals and industrial processes. The mixture of radionuclides from a nuclear test can be distinguished in several ways. Most reactors operate with neutrons in the thermal region (0.02 electron volts, ev), whereas a nuclear explosion results in fission products from fission spectrum neutrons in the MeV region. This has an effect on the shape of the fission yield curve (see figure 2); the presence of certain fission products in quantity thus becomes a diagnostic signature. Furthermore, reactor material would have been produced over a longer period than a nuclear explosion, resulting in a mixture of short-lived and decayed isotopes. High-yield fission products such as the isotopes barium-140 (140Ba) and molybdenum-99 (99Mo) are present at the peak of the curves in figure 2.

The laboratories will undertake additional measurements on selected samples from the monitoring network, participate in quality and proficiency exercises and, when required, receive and analyse samples from manual monitoring stations. The

Figure 2 **Fission yield curves**



laboratories' role in the measurement of xenon gas samples from the monitoring network is evolving as the equipment is developed to meet the technical requirements. After the CTBT enters into force some laboratories may also be required to analyse samples taken during inspections of sites where a suspected nuclear test may have occurred.

All 16 national radionuclide laboratories are required to be certified by the CTBTO before operating as a laboratory in support of the IMS. At present the Austrian Research Centre (ARC) research laboratory at Seibersdorf, Austria, and the National Radiation Laboratory, Christchurch, New Zealand, are certified. Several more are due for a certification visit by the CTBTO in 2003–2004. About two to three laboratories are expected to be certified a year. Prior to certification, the laboratories are paid a fee for the samples they measure and report on. Following certification, they are paid a monthly or annual fee, which covers activities needed to maintain a state of readiness.

To operate as a CTBTO radionuclide laboratory it is necessary to have in place adequate security and sample traceability, as well as full-spectrometer (HPGe) calibration. Owing to the forensic nature of the work, the very small size of detected samples and the need for the conclusions to be unambiguous, the processes employed need to be carefully managed to the highest standards. This is the basis of the quality system required by the CTBTO and the International Standards Organisation (ISO-17025). The CTBTO's requirements have been set out progressively by the Provisional Technical Secretariat (PTS) in CTBT documentation,[10] along with quality manuals, procedures and instructions for meeting the treaty's requirements. These documents detail requirements relating, for example, to equipment specifications, security, bonding, personnel training, environmental conditions, communications and response times. The documents are provided to states parties through the PTS's Expert Communication System (ECS), which can be accessed by registered personnel via a secure internet site. In order to connect them to the CTBTO laboratory network, two-way satellite communication links to Vienna are being established at the laboratories.

Proficiency test exercises

To ensure that the 16 laboratories operate to common standards and have similar capabilities, the PTS has organised a series of proficiency test exercises, known colloquially as 'round robin' exercises, to assess them. Each participating laboratory undertakes analysis of the same samples and reports to the organiser (in the recent exercises the UK's National Physical Laboratory has been contracted to do this for the PTS), which assesses and reports on the results. For each exercise a blank, a calibration source and a reference sample of low levels of radioactivity are provided. Sources are packed as Excepted Radioactive Material[11] and delivered by courier. This procedure tests the rapid transfer of the radioactive materials through customs in accordance with national requirements.

The exercises test the ability of the laboratories to meet the requirements of the treaty, including demonstration of the quality system, traceability and timeliness of reporting. Participation in these exercises forms part of the certification process. The PTS also tests the proficiency of the laboratories in transporting samples to or from a radionuclide station, and their ability to measure filter samples in a timely manner and to provide results of a high standard.

The IMS requires an extremely high standard of performance, which is met by careful attention to the calibration process, the measurement of a reference sample, and expert interpretation and reporting of the results, with corrections for cascade summing, parent–daughter decay and identification of all radioisotopes present. For the latest two exercises, in 2001 and 2002, short half-life fission products were provided, thus simulating real nuclear fallout. Working Group B (WGB) of the CTBT's Preparatory Commission (PrepCom), which handles verification issues, would like renowned radiochemistry laboratories that will not be part of the CTBT system to participate in some future exercises in order to compare the CTBT-designated laboratories with the best in the world.

The UK role in radionuclide monitoring

The UK will host four radionuclide stations, all on British dependent territories, as part of the IMS. These are in the British Indian Ocean Territory, on St Helena, on Tristan da Cunha and at Halley in Antarctica. In 2000 the British government nominated the radionuclide laboratory at the AWE at Aldermaston to participate as a CTBT laboratory.[12] It has been designated by the PrepCom as GBL15.[13]

The UK is fortunate in that the AWE laboratory has had many years' experience of carrying out radionuclide measurements and diagnoses. From 1952 to 1991, radionuclide analysis was a key part of the AWE's nuclear test programme.[14] The AWE Radionuclides Team collected samples from British nuclear tests to provide information vital to the interpretation of warhead performance. Samples needed to be sent from distant nuclear test sites to the AWE as quickly as possible in order to enable analysis of the fission products, activation products and residual device materials.

For many years a small group of AWE scientists has also advised the British government on technical matters relating to nuclear test ban verification. AWE staff joined the British delegation during the CTBT negotiations to provide advice on the terms of the treaty and on-site inspection procedures, as well as the design of the IMS. In addition to the role played by the Blacknest Seismology Team,[15] the AWE Radionuclides Team provided expert input to the technical negotiations leading to agreement on the radionuclide monitoring system. The team staffs GBL15 and the Environmental Monitoring Research Project (EMERGE) which is part of the AWE's Nuclear Arms Control Verification Research Programme.[16] The AWE also supported the Prototype International Data Center at the Center for Monitoring Research (CMR) in Arlington, Virginia, US before its functions were transferred to the IDC in Vienna.

GBL15: progress to date

Since the British government requested the AWE to act as the UK's CTBT radionuclide laboratory, its Radionuclides Team has been preparing for certification by the CTBTO. The team has participated in five CTBTO exercises, as well as related activities, providing valuable experience for the development of the laboratory's procedures.[17] The exercises included a sample transport exercise in 1999; a radioactive sample proficiency exercise in 2000; the ARAME[18] radioactive sample proficiency exercise in 2001; the RASA radioactive sample proficiency exercise in 2002; and a radioactive sample proficiency exercise in 2003.

To date, proficiency test exercises have demonstrated that GBL15 meets the technical performance requirements of the PTS. The demonstration of expertise in counting and analysis through participation in the exercises is a significant contribution to the certification process. GBL15's analysis has consistently ranked in the top 20 percent of the participating laboratories. The results of the first three proficiency exercises for each radionuclide tested show that the British laboratory has performed consistently well for all but three radionuclides.

The laboratory has also been recruiting and training staff, purchasing equipment and making infrastructure modifications, including the establishment of a bonded store. New HPGe gamma spectrometers have been purchased and calibrated on a rolling programme of renewal. The GCI satellite communications equipment, to provide communications between the laboratory and Vienna, has been installed and commissioned. This was not a trivial matter at a sensitive defence site such as the AWE Aldermaston, but represents further progress towards certification.

Most of the outstanding requirements of the PTS as outlined in the CTBT documentation relate to reorganisation of the laboratory's existing procedures. The procedures relate to items such as methods for the operation of the equipment, records of staff competence and work performed, and detailed descriptions of the way in which the quality assurance system meets CTBT requirements. A plan is in place and completion of the documentation is now required prior to the certification review by the PTS in 2004.

The following actions are in progress or remain outstanding in preparing GBL15 for certification review: reviewing the security and bonding infrastructure improvements, and purchasing equipment sufficient for certification of the current facility; documenting the laboratory's activities according to CTBT requirements; acquiring short half-life fission products to calibrate the HPGe gamma spectrometers for extended and close-in geometry; training staff to ensure that a sufficient number of operators are proficient in fulfilling the full duties of GBL15; reviewing formats and protocols for GBL15 participation in the IMS; demonstrating the operation of the GCI system to meet IMS requirements; continuing to participate in PTS proficiency exercises; and hosting a certification review by the CTBTO.

Peer interaction is key to the development of science in any field, and this is particularly true of the development of the IMS and the associated radionuclide laboratories. This work is fully supported by the AWE, which, for example, hosted an international workshop in 2001 for staff from the 16 designated radionuclide laboratories. More recently AWE staff have played a key role[19] in inaugurating a series of international co-operation meetings, known in the CTBTO as the London Process, which highlight the civilian and scientific benefits of the IMS technologies beyond their treaty verification role. The AWE will also host a Royal Society of Chemistry radiochemistry meeting in February 2004 on 'Radiochemistry for treaty verification'. Such events not only promote peer exchange but are also important for the development and retention of laboratory staff—a perpetual challenge for those involved in running monitoring and verification organisations or agencies. Careful choice of such events and other collaborative activities is seen as a cost-effective way to maintain skills and enhance the science of forensic radiochemistry.

Conclusion

The UK, through its AWE laboratory, is playing its part in the establishment of the IMS network of certified laboratories in preparation for entry into force of the CTBT.[20] The PTS, in setting up the verification technologies for the IMS, has in turn enabled the British laboratory to raise its standards of performance. The fact that GBL15 is at an existing laboratory, where a variety of activities are conducted for the British Ministry of Defence, has helped it develop the skills required for low-level gamma spectrometry at a high level of competence. The standard of science it reports, especially in proficiency exercises, ranks it highly among those of the other participating laboratories. The British laboratory is continuing its efforts to foster international co-operation, as peer interaction provides the only realistic performance benchmark and is fundamental in developing the science of radionuclide monitoring and its role in verification of the CTBT. The laboratory's performance and development of its infrastructure and procedures are thought likely to result in certification in 2004, a milestone in its 50-year history.

Before the CTBT enters into force, much work needs to be done both in the UK and internationally. The IMS needs to be completed and its performance demonstrated, and there is a continuing need to communicate with and educate communities, both among and beyond the CTBT states parties, on the efficacy of the CTBT.

Christine Comley is a Principal Scientist Radiochemist with the Radiochemistry group at the Atomic Weapons Establishment (AWE), Aldermaston, UK. She is a Chartered Chemist and Member of the Royal Society of Chemistry (CChem MRSC).

Owen Price is Programme Manager of the Verification Research Programme at AWE. He has a degree in Engineering from Cambridge University and a Masters in Business Administration in Engineering Management from the University of Bradford.[21]

Endnotes

[1] See United Nations, Secretariat, 'Report on the Conference of Experts to Study the Methods of Detecting Violation of a Possible Agreement on the Suspension of Nuclear Tests (July 1– August 21, 1958)', EXP/NUC/28, Vienna, 1958.
[2] See Peter Marshall, Daniela Rozgonova and Wolfgang Weiss, 'Testing times: the road to a Comprehensive Nuclear-Test-Ban Treaty', *Kerntechnik* (Munich), vol. 66, no. 3, 2001.
[3] On the term 'forensic seismology' see David Booth, 'International honours for a forensic seismologist', *Astronomy and Geophysics,* vol. 43, issue 2, 2002, pp. 2, 6. The term has long been adopted at AWE Blacknest for the application of seismology to the verification of treaties and other legal instruments.
[4] Booth, 'International honours for a forensic seismologist'.
[5] There is provision in the treaty to add further technologies to the IMS as necessary, and technical monitoring data from states parties' National Technical Means (NTM) (e.g., observation of the characteristic 'double flash' of a nuclear explosion by Global Positioning System (GPS) satellites' Bhang meters) could be considered as additional evidence, if submitted.
[6] For further information on the PTS see www.ctbto.org.
[7] Christine Comley, 'Radionuclide monitoring at AWE', *Discovery: The Science and Technology Journal of AWE,* no. 3, 2001, www.awe.co.uk. AWE is the trading name of AWE plc and AWE Management Limited, which manage and operate the United Kingdom Atomic Weapons Establishment under contract to the British Ministry of Defence. Further information on AWE plc may be found at www.awe.co.uk.
[8] Among others, the Meteorological Office at Bracknell, UK, has atmospheric models which can effectively track detected radioactivity to its source.
[9] Murray Matthews and Joachim Schultze, 'The radionuclide monitoring system of the Comprehensive Nuclear-Test-Ban Treaty Organisation: from sample to product', *Kerntechnik,* vol. 66, no. 3, 2001.
[10] Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organisation, 'Certification of radionuclide laboratories', CTBTO Documentation of Requirements, Vienna, 2002.
[11] As defined by the International Atomic Energy Agency (IAEA) International Road Transport Regulations.
[12] It is also the home of the UK National Data Centre for the CTBT, co-located with the UK's Forensic Seismology Team. Information about the team and its research may be found at www.blacknest.gov.uk.
[13] It was described erroneously in the treaty as 'AWE, Blacknest Chilton', later amended to 'AWE Aldermaston'.
[14] David Hawkings, *Keeping the Peace: The Aldermaston Story,* Pen and Sword Books/Leo Cooper, Barnsley, 2001.
[15] Alan Douglas, 'Recognising UGTS', *Discovery,* issue 1, 2000, www.awe.co.uk.
[16] Garry George and Martin Ley, 'Nuclear warhead arms control research at AWE', in Trevor Findlay and Oliver Meier (eds), *Verification Yearbook 2001,* The Verification Research, Training and Information Centre (VERTIC), London, 2001, pp. 189–206; Garry George (ed.), *Confidence, Security and Verification*, AWE plc, Aldermaston, 2000, available at www.awe.co.uk; and Owen Price and Garry George, 'Arms control verification: a summary of AWE progress', *Discovery,* issue 7, 2003, www.awe.co.uk.
[17] At WGB sessions, the PTS gives status reports on site surveys, station installations, and certification of stations, and provides a future work plan.
[18] The exercise names were based on the equipment and filter types.
[19] Peter Marshall CMG OBE, former head of the AWE Forensic Seismology Team, has chaired several such meetings, the latest being in Vienna in September 2003.
[20] The AWE is also staffing IMS survey and commissioning work, under subcontract to its strategic partner Guralp Systems Limited (GSL).
[21] The authors wish to thank Peter Marshall CMG OBE for his assistance and advice in the writing of this chapter. Permission to publish this chapter has been granted by the British Ministry of Defence, which retains Crown Copyright.