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Producing tritium in North Korea

North Korea has recently been making some fairly bold statements about the sophistication of its nuclear weapon programme. The first came on 6 January 2016 in the form of a nuclear weapon test, which North Korean TV claimed to have demonstrated a 'miniaturised hydrogen bomb'. Hydrogen bombs are an advanced form of nuclear weapon that uses the energy released by a runaway fission reaction to fuse isotopes of hydrogen (deuterium and tritium), increasing the weapon's power and efficiency. Depending on how this fusion reaction is generated and how much fusion fuel is used, these weapons have a theoretically limitless yield.

The second statement came more recently, on 9 March 2016, when Kim Jong-Un paid a visit to a missile facility to have his picture taken with an object resembling a nuclear explosive device. According to *Rodong Sinmun*, he expressed gratification in seeing 'nuclear warheads with the Korean-style structure of mixed charge adequate for prompt thermo-nuclear reaction'. He then went on to note that these warheads had been miniaturised to fit onto a ballistic missile.

It is perhaps comforting to doubt the technical truth behind these announcements. While the yield extrapolated from the January test was far smaller than those produced by modern 'two-stage' hydrogen bombs, North Korea may have introduced only a small amount of fusion fuel to give a simpler fission weapon a 'boost'. In the merciful absence of a more direct and uncontained demonstration of North Korea's nuclear weapon capabilities, it is hard to determine exactly how potent or sophisticated these capabilities are. While we may not know exactly where North Korea's nuclear programme is now, we can be more certain about where it is going. North Korea's nuclear provocations are a clear statement of intent: the regime aims to develop an arsenal of sophisticated nuclear weapons that draw upon nuclear fusion to some extent. To do this, it will need a reliable supply of tritium.

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The role of tritium in hydrogen bombs

Nuclear fusion is a very different reaction to nuclear fission. While the latter involves the (sometimes spontaneous) splitting of large atomic nuclei, the former involves the fusing of light atomic nuclei. Like fission, fusion produces a large burst of energy distributed between electromagnetic radiation, subatomic particles, and product nuclei. However, unlike fission, nuclear fusion does not happen spontaneously: atomic nuclei contain positively charged protons that, like identical ends of a magnet, repel rather than attract each other. Light nuclei have to be forced into fusion by heating them to extreme temperatures, such as those found inside an exploding fission weapon.

While some light atomic nuclei can fuse in the correct conditions, only one combination of nuclei seems suitable for developing hydrogen bombs. If a deuterium nucleus (D, consisting of one proton and one neutron) can be made to fuse with a tritium nucleus (T, consisting of one proton and two neutrons), this 'DT' reaction generates a powerful burst of electromagnetic energy (y) along with a highly energetic neutron (n) and a helium-4 (He-4) nucleus.

- D + T --> He-4 + n + y

Other fusion reactions take place within a hydrogen bomb, such as those combining two deuterium nuclei (called 'DD' reactions), or those connecting a helium-3 nucleus with a deuterium nucleus. However, none of these are as easy to spark as the 'DT' reaction. Once a mixture of deuterium and tritium is brought above a certain threshold temperature, nuclei can fuse at such a rate that the energy released can keep the fuel hot enough to keep the fusion reaction burning. Importantly, this threshold temperature and density can be easily achieved in the core of a fission weapon.

The 'DD' reactions are much harder to ignite. The critical temperature at which the energy released by these reactions can substitute for the energy radiated away is far higher than the critical temperature 'DT' reaction. Helium-3 fusion can come to dominate over many other fusion reactions, but only at the extremely high temperatures associated with an active fusion burn. Sparking a fusion burn in a nuclear weapon through the 'DD' or helium-3 reactions would demand extremely high temperatures and densities, and only the 'DT' reaction seems like a feasible candidate for sparking fusion ignition in the core of a fission weapon. This makes tritium a vital component of any hydrogen bomb.

If North Korea has been able to acquire both tritium and deuterium, it is entirely possible that they successfully detonated a small 'boosted' nuclear device on 6 January 2016. According to modelling conducted by Gsponer and Hurni (2009), it is comparatively simple to develop a fission device that can spark fusion in deuterium and tritium fuel. According to the pair, 'DT' ignition is so rapid that as long as a device can compress and heat fusion fuel to the critical temperature, boosting will be relatively assured. In other words, a fission device that alone might only produce a meagre 100-tonne yield (something that could easily be considered a 'fizzle' or failure) could ignite a 'DT' reaction that would boost the yield tenfold to one kilotonne.

This is not to suggest that North Korea is pursuing this illustrative approach to fusion boosting. It is quite challenging to create a device that can reliably deliver such a marginal unboosted yield. The object pictured in Rodong Sinmun seems unnecessarily large (at approximately 60-70 centimetres in diameter) for a marginal device.

Nevertheless, North Korea does not need a hugely powerful or sophisticated implosion device to ignite a 'DT' reaction. The low yield of the January test might reinforce rather than refute North Korea's claims of successful fusion ignition. If the test were aimed solely at testing 'DT' ignition, there would be no need to waste tritium to produce a high yield detonation. If this test was successful, North Korea might soon build on this with a more spectacular demonstration of fusion boosting. If it has enough tritium and deuterium to draw on, that is.

Deuterium is relatively simple to acquire. One in every 3,200 molecules of water is in fact 'heavy water', in which two deuterium atoms have bonded with oxygen to produce D2O. It is safe to assume that North Korea can extract deuterium from seawater domestically by electrolysis or distillation. Tritium is a different matter. Contemporary boosted weapons probably consume between two and four grammes of tritium each. Natural tritium is almost impossible to come by: it is produced very rarely by spontaneous fission of uranium, or by the indirect interaction of cosmic rays and nitrogen. It is also radioactive, decaying into helium-3 at such a rate that any stockpile is reduced by approximately 5.5 percent every year. Unless North Korea can replenish any stockpiles it has, their stock would be cut in half every 12.32 years. North Korea cannot rely on any one-off acquisition of tritium: it needs a reliable and repeatable source of tritium to sustain a boosted arsenal of nuclear weapons. It has three main options to achieve this.

Importing tritium

North Korea might try to import tritium rather than generate it domestically; it is sold on international markets. However, tritium's role in nuclear weapons ensures that its trade is heavily controlled. The Nuclear Suppliers Group (NSG) have placed tritium and tritium-producing equipment or technologies on its trigger lists. Any transfers of tritium-producing equipment, or anything more than a few milligrammes of tritium, should not be authorised without credible assurance that such transfers will not contribute to nuclear proliferation. Thanks to UNSCR 1718, this restriction equates to a blanket ban on all such exports to North Korea.

This embargo is by no means bulletproof. North Korea is particularly adept at exploiting lax implementation of sanctions among UN member states to set up complex networks of officials, foreign agents, and front companies to evade sanctions. However, establishing a reliable and repeatable source of illegally imported tritium would be a challenge.

The largest commercial sources of tritium are concentrated in a few states, including Canada, Switzerland, the US, and France. These countries are unlikely to authorise any export of tritium unless there are airtight guarantees that it will not end up in the DPRK. North Korea might turn its eyes to non-commercial tritium sources in China or Pakistan, both of whom have historically turned a blind eye to misguided exports to problem states. China supplied tritium to Pakistan in the late 1980s, which itself acquired tritium and tritium handling facilities illegally from the German company NTG at around the same time. However, now that China is a member of the NSG, and seems to be cracking down on sanctioned exports to its neighbour, any exports of tritium to North Korea are probably a thing of the past. The same could be said for Pakistan, whose bid for recognition by the NSG would be ruined if any past or present tritium exports to North Korea came to light.

It is far more likely that North Korea is looking internally for a reliable source of tritium. More precisely, it will be looking internally for a strong source of neutrons - which generate tritium by interacting with materials such as lithium, helium, and deuterium. Aside from any particle accelerators (which can be used to produce isotopes) that might be operating in the country, North Korea has at least one ready source of neutrons: nuclear fission reactions.

Tritium breeding in a nuclear weapon

The most direct method for injecting tritium into a fission weapon is to breed it within the nuclear weapon itself. Lithium-6 deuteride can easily be incorporated into the fissile material core of a nuclear weapon. Upon detonation, the cascade of neutrons released by the runaway fission reaction bombard the lithium-6, which breaks down into tritium and helium-4. The tritium and deuterium can then fuse, releasing neutrons that can boost fission in the surrounding layers of fissile fuel while simultaneously breeding more tritium from the remaining pockets of lithium-6 deuteride.

This 'layer cake' approach to hydrogen bombs was explored by China, the Soviet Union, the UK, and the US in their pursuit of more sophisticated two-stage nuclear weapons. It is a relatively simple way of incorporating fusion reactions into a fission weapon, and can deliver significant improvements in yield. For example, the third Chinese nuclear weapon test used a small amount of lithium-6 deuteride to boost a 10-30kT yield by a factor of ten. Lithium-6 deuteride is also stable and solid, making it easy incorporate into a fissile pit in a permanent and robust manner. This makes lithium-6 deuteride an ideal candidate for fusion fuel.

However, no nuclear-armed state settled upon this design as a permanent solution to boosting nuclear weapons. Instead, lithium-6 is reserved only for the second reservoir of fusion fuel in two-stage nuclear weapons. This may be because each atom of tritium bred from lithium consumes a neutron which could otherwise go on to prompt fission. Speed is everything in the detonation of a nuclear weapon, and if neutron consumption by lithium-6 delays the cascading fission reaction, it may cancel out many of the benefits of boosting - such as the opportunity to shed heavy tampers and neutron reflectors from the core.

Given North Korea's claim on 6 January that it had 'proudly joined the ranks of nuclear weapon states' possessing hydrogen bombs, it seems unlikely that they would settle for an obsolete design eventually discarded by all nuclear weapons states. It is more likely that North Korea will have to turn to its nuclear reactors to generate tritium.

Tritium breeding in nuclear reactors

Tritium production in the 5MWe gas-graphite reactor

The 5MWe gas-graphite reactor at Yongbyon is the source of nearly all of North Korea's weapons-usable plutonium, and it may also be the primary source of its tritium too. The UK used a similar type of reactor (the Chapelcross MAGNOX reactor) to generate tritium for its nuclear weapon programme, and it is possible that North Korea is doing the same.

Lithium-6 again plays a central role here, and can be irradiated in a power reactor in two ways. First, the neutron-absorbing material in a reactor's control rods can be replaced with lithium-6, which consumes one neutron every time it transforms into tritium. This approach - which can simultaneously control the fission rate in a reactor while producing tritium - was explored by the US, which developed lithium-aluminium control rods coated in zirconium cladding. However, the US ultimately adopted an alternative approach to breeding tritium in a power reactor that might be more appealing to North Korea. The US currently maintains its tritium stockpile by loading lithium-filled 'Tritium Producing Burnable Absorber' (TPBAR) rods into the fuel channels of a commercial pressurised water reactor (PWR) at Watts Bar in Tennessee. TPBARs are removed after an 18-month irradiation cycle and subsequently broken down in a dedicated handling facility to extract tritium produced by the Li-6 + n -->T + He-4 reaction.

According to an article in *Science & Global Security*, a PWR could conceivably generate between one and five kilogrammes of tritium each year per gigawatt of thermal power, if it was optimised purely for tritium production. If the lithium load is reduced so that the reactor can operate normally, this generation rate will drop to between 30 and 70 grammes.

It is impossible to produce similar figures for the gas-graphite reactor at Yongbyon without knowledge of how North Korea might construct, load, irradiate, and process any tritium-producing fuel rod substitutes. Gas-graphite reactors generate a much lower energy density than PWRs, thanks to the natural (rather than enriched) uranium fuel and the bulky moderator materials required. As such, it is safe to assume that it tritium production will be slower in the former than the latter.

Nevertheless, it is reasonable to conclude that the 5MWe gas-graphite reactor (which has a thermal power of only 20 megawatts) could generate a few grammes extractable of tritium per year without interrupting normal reactor operations. In this case, the previous operating window of the reactor (assumed to be between 2003 and 2007) could have produced less than ten grammes of tritium, 38% of which would have decayed between 2007 and the present day. If North Korea relied solely on the gas graphite reactor for tritium production, it would soon be running short.

Tritium production at the IRT reactor

With this in mind, North Korea is likely to look to its pool-type research reactor to bolster its tritium stockpile. This Soviet-supplied reactor was operating on-and-off since it went critical in 1965, but it is commonly assumed that it eventually exhausted the last of its highly-enriched uranium fuel by 2011. However, the Institute for Science and International Security (ISIS) has cited two separate sources that suggest that the reactor is once again operational, fuelled by domestically enriched and fabricated uranium fuel. If this is correct, the IRT reactor will be an attractive source of tritium. After all, it is designed to irradiate material samples with moderated neutrons to generate medical isotopes.

The IAEA research reactor database suggests that if the IRT is refuelled at its former enrichment level (80 per cent enriched uranium), it can generate a maximum flux of around 8 trillion (8×10^{12}) neutrons per second, over one square centimetre. One cubic centimetre target of lithium-6 (with a density of 0.535 grammes per cubic centimetre) could generate four nanograms of tritium for each second it is exposed to this maximum flux. According to ISIS, this reactor typically operates only 60-70 percent of the year. Over an eight-month operating cycle, this cubic centimetre target of lithium-6 could, therefore, generate about 80 milligrammes of tritium. To generate three grammes of tritium (an approximate amount used in modern boosted weapons), North Korea would, therefore, have to irradiate approximately nineteen grammes of lithium-6 over an eight-month operational cycle.

It is important to note here that these estimates do not take into account a number of important factors. First, it is not clear exactly how much lithium North Korea can access, and how much it could load into its reactors. Lithium reacts strongly with water, so it would need to be alloyed with other materials before it could be exposed to water in the pool-type IRT reactor. This coating, the space requirements to keep the target cool, and the dimensions of the available fuel channels, will limit the amount of lithium that can be irradiated.

Second, the available flux of neutrons will vary along the different experimental channels, and the reactor may not always be operated at full power. While the IRT reactor is equipped with ten horizontal channels and nine vertical irradiation channels, only some will pass through the core where the neutron flux is highest. Only four of the twelve vertical experimental channels in the IRT-2000 reactor in Bulgaria (which is similar to the IRT reactor in North Korea) pass directly through the reactor core. The estimates given above might not be applicable across all experimental channels at all times.

Finally, it is not easy to extract tritium once it has been generated. The US tritium production programme had trouble tackling the permeation of tritium from TPBARs, with each tritium-producing rod losing approximately 4.2 percent of its generated tritium into the reactor. As mentioned above, 5.5 percent of generated tritium will also decay over the course of a year. Similar fractions may also be lost when targets are broken down for tritium extraction in hot cell facilities – that North Korea may or may not currently have.

Nevertheless, the IRT reactor can conceivably generate a significant amount of tritium for North Korea's nuclear programme. A single target containing nineteen grams of lithium-6 (equivalent to a slug roughly 3cm in diameter and 5cm in length) could potentially generate enough tritium for a single nuclear weapon in one yearly operational cycle. Assuming that only four of the IRT's experimental channels are located within the reactor's core, North Korea would be able to generate enough tritium for twenty 'DT' boosted nuclear weapons per year by irradiating five such slugs in each channel. While fuelling the IRT reactor for tritium production would unavoidably divert enriched uranium that could otherwise contribute directly to North Korea's arsenals, ISIS suggests that the IRT would only require 7.5 kilograms of highly-enriched uranium each year to operate such a cycle.

The future of North Korea's tritium stockpile

The evolution of North Korea's nuclear weapon stockpile depends upon its ability to acquire tritium. This isotope of hydrogen is a necessary component for boosted nuclear weapons, which are in turn an essential stepping stone towards more sophisticated two-stage thermonuclear weapons with megatonne yields. If North Korea is to integrate fusion boosting, and ultimately two-stage designs, into its nuclear arsenal it cannot rely upon a one-off acquisition. It will need a reliable supply that can keep stockpiles replenished as they decay.

The international control of tritium exports suggests that North Korea will not find such a supply abroad. While North Korea may be able to evade these restrictions on occasion, it could not reliably do so in perpetuity. Rather it will turn to either its 5MWe gas-graphite reactor or the IRT research reactor for a reliable source of tritium. While North Korea could rely on the former for tritium production (as the UK did with the Chapelcross reactor), studies of tritium production in PWRs suggest that the gas-graphite reactor would only generate a few grammes of tritium per year. At that rate, any stockpiles of tritium produced by the gas-graphite reactor to date will likely have dwindled almost to nothing.

It is far more likely that North Korea has been generating tritium in the IRT reactor and will continue to do so if (or when) it has returned to operation. The reactor is designed to irradiate materials in water-moderated neutrons, and it provides a high maximum flux of neutrons. According to ISIS, the fuel demands for the IRT reactor are 'relatively small': about 7.5 kilograms or 80 percent enriched uranium per year. While North Korea can fuel and operate the IRT reactor, it will not struggle to produce enough tritium to power a small arsenal of boosted fission weapons. With this in mind, the world might have to get used to hearing more about North Korea's 'H-bomb of justice'.

Hugh Chalmers, Senior Researcher

Monitoring space

Existing and proposed treaties governing weapons activities in outer space lack appropriate verification measures. In practice, the United States and the USSR/Russian Federation unilaterally verify the 1967 Outer Space Treaty's prohibitions on the placement, installation, and stationing of nuclear and other weapons of mass destruction through national technical means. The 2008 draft treaty on the 'Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects' (PPWT) leaves verification issues to be negotiated in a subsequent protocol. The draft treaty definition of 'space weapons' is ambiguous, creating uncertainty over what would constitute compliance. This will further impede the development of verification arrangements for the convention, in the event it is ever adopted.

The European Union has proposed an International Code of Conduct for Outer Space Activities as a transparency and confidence-building measure to help fill the void of multilateral verification of the peaceful uses of outer space. The Code, most recently revised in 2014, calls on states to refrain from the threat or use of force in space and to support the responsible and peaceful uses of outer space. It does not seek to define 'space weapons' but implicitly recognises that a wider range of space objects have weapons capabilities than those currently banned in international law. The Code's inherent purpose is confidence-building; it is not legally binding and, therefore, will not have a verification system. Its normative power will lie in States' commitment to uphold its terms, which they can demonstrate by participating in the specified 'cooperation mechanisms.' These include notification procedures, information exchanges, familiarisation and expert visits, launch observation, demonstrations of space-related technologies, dialogue, and workshops.

There is a range of tools that could be employed to monitor and ascertain the capability and behaviours of space assets as confidence-building measures under the Code. Many are land-based systems, such as optical surveillance telescopes, laser ranging stations, and radar trackers. Space-based technical means of verification are more technically and financially challenging to deploy and operate. These have been used successfully for space-to-earth observation of arms control obligations, such as the 1987 Intermediate-Range Nuclear Forces Treaty, as well as for environment and human rights agreements. The major spacefaring nations already use space-to-space technical means of monitoring on a unilateral basis (such as the US Geosynchronous Space Situational Awareness Program).

Possible multilateral space-to-space verification assets were considered in the 1980s during discussions on possible new treaties on preventing an arms race in outer space (PAROS). For example, a Canadian study of a 'peace satellite' (called PAXSAT-A) concluded that space-to-space observation could determine the role or function of a man-made space object as part of a multilateral treaty verification system. It is timely now to consider whether and how multilateral, space-to-space observation technologies could be applied to monitor non-legally binding 'rules of the road' for space, such as the EU International Code of Conduct for Outer Space Activities.

What may be required ...

Space situational awareness plays a central role in building transparency and confidence in the peaceful and responsible use of outer space. If countries cannot tell the difference between behaviours and capabilities that are consistent with non-legally binding 'rules of the road' and those that are not, they may not feel that such practices are valuable.

Modern technologies (such as micro-satellites) present new challenges to space situational awareness, but they also provide opportunity. Space-based satellite surveillance systems can monitor the capabilities and behaviours of other satellites, with greater accuracy than land-based equivalents. However, the unilateral deployment of advanced manoeuvrable surveillance satellites may degrade rather than enhance confidence in the peaceful and responsible uses of outer space. With little understanding of the technologies and operational parameters of such satellites, states may fear that monitoring could transform into espionage, disruption, or even sabotage. The unilateral deployment of increasingly sophisticated classified technologies may serve to degrade rather than build trust in the peaceful and responsible use of outer space. A multilateral system that delivers only the minimum information needed to discriminate between responsible and irresponsible behaviours could improve space situational awareness while simultaneously building trust and confidence in the peaceful and responsible uses of outer space.

It is timely for the international community to explore the desirability and feasibility of developing a multilaterally designed, constructed, and operated space-to-space surveillance and tracking system to monitor states' adherence to non-legally binding 'rules of the road' for space, such as the Code of Conduct. Key features of such a system would include the ability to identify space objects, characterise their capabilities and behaviours and compare these observations against certain criteria. It would also include processes that filter all data captured through an information barrier, and transmit notifications to participating states of behaviour and capabilities consistent or inconsistent with 'rules of the road'. Such a system would be multilaterally certified and authenticated by participating states to build confidence in its peaceful and non-intrusive nature.

Further study in this area would help to build and improve scientific and technological capabilities, for example by exploring how one could integrate existing assets into a multilateral system without revealing classified or sensitive information; either of space surveillance and tracking capabilities or of other space-based capabilities. Such studies could usefully help to build multilateral confidence in the peaceful and responsible use of outer space by identifying new ways to leverage existing technologies, rather than by developing entirely new technologies.

... with non-kinetic impacts

The European Space Agency's Space Situational Awareness program (and, in particular, its surveillance and tracking segment) has demonstrated that platforms designed and operated on a multilateral basis can be an effective means of creating and sharing information on outer space activities. This information is a powerful tool for promoting the safe and responsible uses of outer space, but the manner in which this information is collected is orientated more towards the tracking of space debris than monitoring adherence to, and thereby building confidence in, a non-legally binding 'rules of the road' in outer space.

Studies that seek to push the boundaries of current approaches to space monitoring, by exploring how a dedicated satellite system could generate information on outer space activities through state-of-the-art technologies, are desperately needed. Such technical studies could also introduce concepts developed in other areas of verification – such as information barriers and multilateral certification and authentication – into the space verification community. The former might explore how software or hardware solutions could detect and communicate indications of adherence to 'rules of the road' without releasing sensitive information on the object in question or the systems involved. The latter might explore how the collaborative development and certification of a monitoring platform can help build trust and confidence in current space surveillance and tracking operations.

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Verification Watch

Science and Diplomacy for Peace and Security

From 24 January to 5 February 2016, the Comprehensive Test-Ban Treaty Organisation (CTBTO), hosted its 'Science and Diplomacy for Peace and Security' symposium. The event was the first in a series to commemorate the twentieth anniversary of the CTBTO. Throughout the conference, many speakers reflected on the progress of the organisation and its relevance to today's world.

The symposium covered a range of issues. An entire day was devoted to the regime's international monitoring system. Another day discussed preparations for entry into force, with other events contemplating the treaty's broader legal ramifications. For the final two days, participants engaged in an Executive Council simulation that considered a theoretical on-site inspection request.

On the second day of the symposium, Ms Laura Rockwood, the director of the Vienna Centre for Disarmament and Nonproliferation (and a VERTIC trustee), moderated a panel on the treaty's implication on the future of multilateral arms verification. The panellists, James Acton, Rebecca Johnson, Zia Mian, Tibor Toth, and Victor Slipchenko, commended the treaty's ability to share information and discussed the potential application of CTBT verification measures to a fissile material cut-off treaty (FMCT). The panellists argued that the CTBT's structure of 'verifying zero', i.e., disallowing all nuclear tests, and the extensive independent international monitoring regime, provide useful insights for an FMCT.

The sixth day of the symposium covered on-site inspections. A session run by Gordon Macleod focused on the challenges of running an on-site inspection (OSI) regime without permanent inspectors. The lack of an inspectorate has widespread consequences: if an inspection is called, complex and costly international coordination for the sourcing and the arrival of the inspectorate and support staff will be required.

Furthermore, the treaty requires that all equipment is acquired, certified, functional and in-country within six days of the inspection's announcement. The coordination of these aspects has been trialled in two integrated field exercises (IFEs). The CTBTO's most recent IFE, held in 2014, provided a fruitful testing ground for many questions surrounding OSI methods and difficulties. IFE 14 took place in Jordan and aimed to provide a full-scale simulation of an on-site inspection after a supposed underground test. The exercise was the result of a four-year planning process, equipment acquisition, and the creation of a scientifically credible scenario. The exercise itself lasted 34 days and involved participants from 53 countries, playing inspectors and representatives from the inspected state party. The venture was supported by a control team, an evaluation team and technical observers.

The simulation was highly successful, Mr Macleod said. Over 150 pieces of equipment were sent to Jordan, allowing the inspectorate to test fifteen of the seventeen inspection techniques. The exercise confirmed that the verification concepts employed by the OSI regime are broadly correct and that the organisation's training procedures are sufficient.

The Jordanian Permanent Representative, Ambassador Hussam Al-Husseini, presented briefly on the challenges and successes of hosting IFE 14. Although occurring at a politically difficult moment, directly after the Arab Spring, Ambassador Al-Husseini stated that Jordan appreciated the opportunity to showcase methods to further disarmament. He emphasised that future exercises are essential for confidence building and promoting the treaty.

The symposium highlighted areas of improvement and future development in the CTBTO's OSI process. For one, OSI techniques only provide methods for detecting underground testing, as opposed to open-ocean testing, which the organisation is beginning to consider now. The organisation is also developing a technique called 'integrated team functionality', which seeks to identify interesting geological features within the inspection's 1,000 square kilometre search area.

The symposium also included a tabletop exercise exploring coordination for the 'point of entry', which involves relocating OSI equipment from a point of arrival to the site of the inspection with minimal disruption to the inspected state.

The conference showed that much has been accomplished over the last two decades since the negotiation of the CTBT. However, technical achievements alone will not bring the treaty into force. Dr Lassina Zerbo, the CTBTO's Executive Secretary, reminded participants that the major obstacles for the future of the test ban treaty are a lack of awareness and political momentum. Closing the symposium, he called on his colleagues and the next generation for support in overcoming these obstacles.

IPNDV in brief

In November 2015, VERTIC presented aspects of its work to the plenary meeting of the International Partnership for Nuclear Disarmament Verification (IPNDV). In February 2016, the initiative's three working groups met in the offices of the United State's Geneva mission to continue the work.

According to the US State Department, the initiative focuses on a simple scenario, namely 'the dismantlement of a notional nuclear weapon, the related inspection of that dismantlement by a team consisting of nuclear weapon state and non-nuclear weapon state experts, and the related technologies that could support such an inspection.' This scenario appears identical to that deployed in the so-called UK-Norway Initiative as well as the US-UK technical exchange on disarmament verification.

The IPNDV is split into three working groups. The first, chaired by Italy and the Netherlands looks at monitoring and verification objectives. The second, chaired by Australia and Poland, examines on-site inspection regimes. The final group, led by Sweden and the United States, looks at technical challenges and solutions.

Japan will host the third IPNDV plenary in June 2016.

Open skies going overcast

The 1992 Treaty on Open Skies has sometimes been called a 'silent success' of international arms control. Covering a wide geographical area, from Vancouver to Vladivostok, the treaty gives all participants an opportunity to observe activities that concern them through aerial overflight and photography. Aside from fundamental flight safety considerations, there are no restrictions as to what can be flown over and photographed. Parties are allowed to equip their aircraft with video, panoramic and framing cameras, infra-red scanners, and synthetic aperture radar. While there are limitations on the sensitivity of the sensors (as explained below), they can be used to recognise major pieces of military hardware (such as tanks, mobile artillery and missiles). A quota defines the number of overflights each party must accept in any year. The biggest parties - the United States and the Russian Federation - have agreed to permit a maximum of 42 overflights each.

The treaty has been under some stress in recent years. Disagreements over the Republic of Cyprus' application to join--unsurprisingly opposed by Turkey - has on more than one occasion threatened to become a blocking force in the work of the Open Skies Consultative Committee. Civil unrest and conflict in Ukraine led to one of their reconnaissance aircraft being shot down in June 2014, and this highlighted the treaty's limited applicability in times of asymmetric conflict (see *Trust & Verify*, no. 146, October 2014).

More recently, however, senior US defence officials have testified to Congress how the treaty could threaten national security. They appear to have two principal concerns. First, that the Russian Federation intends to deploy a second-generation digital camera on its flights over the United States and, second, that Russia has altered its flight paths to fly over critical infrastructures, such as dams and power plants.

Lt. Gen. Vincent Stewart, director of the Defense Intelligence Agency, has opined that the treaty gives the Russian Federation a 'significant advantage' due to the 'amount of data' it can collect and 'the things you can do with [image] post-processing'. Adding to that, Adm. Cecil D. Haney, the Commander of the United States Strategic Command, has written that the treaty has 'become a critical component of Russia's intelligence collection capability', cautioning that the 'vulnerabilities exposed by exploitation of this data and costs of mitigation are increasingly difficult to characterize.'

The State Department has come out defending the treaty. Undersecretary Rose Gottemoeller has written: 'Nothing in the treaty precludes shrouding these types of sensitive facilities or activities. Further, the United States receives a copy of every photo taken of flights over its territory, so we have a crystal clear idea of what countries are observing.'

US defence and intelligence agencies have clashed with its own State Department before. In 2013, a dispute over Open Skies had to be decided by the National Security Council. It ended with the United States approving the certification of Russia's second-generation digital camera (see Science and Technology Scan later in this edition).

It is unlikely that the United States would take any drastic action, such as denying a Russian flight, in coming months. Nevertheless, these statements represent a worrying trend in the relationship between the United States and the Russian Federation, one that may ultimately and fundamentally threaten the integrity of the post-Cold War security architecture.

What does the treaty allow?

According to Article IV.1 of the treaty, state parties can use four types of sensors on their overflights: optical panoramic and framing cameras; video cameras with 'real-time display'; infra-red line-scanning devices; and sideways-looking synthetic aperture radar. However, the sensors would need to conform to certain treaty requirements. In the case of optical cameras and video, the ground resolution can be no better than 30 centimetres. Infrared line-scanning devices cannot have a ground resolution better than 50 centimetres. Sideways-looking synthetic aperture radars cannot have a ground resolution better than three metres.

Before any flight takes off, the observed state has the right to conduct a pre-flight inspection. This procedure aims to confirm--among other things - that the observing state is using only certified sensors and associated equipment on the aircraft, and that there is no hidden equipment anywhere inside the airframe. If the observed state is not satisfied with the inspection, several options are on the table. It can prohibit the operation of that sensor during the observation flight, or it can prohibit the observation flight itself. Banning a flight is a measure of last resort. In those cases, the country would need to declare immediately the facts as to why it has prevented the flight. No later than seven days after that, it would need to write to all state parties to explain its reasons.

There are no restrictions to what an open skies party can fly over. However, flight plans cannot exceed the maximum flight distance detailed in Annex A of the treaty. An aeroplane that takes off from Washington-Dulles International Airport, for instance, cannot fly further than 4,900 kilometres. To take another example, flights departing from Vorkuta in northern Russia cannot travel more than 6,500 kilometres.

The end of film

As noted above, the treaty limits the ground resolution to 30 centimetres. It is possible, today, to buy imagery with that quality of resolution from commercial satellite imagery providers. GeoEye, used by Google Earth, collect images with a ground resolution of 41 centimetres while Digital Globe offers a 31-centimetre spatial resolution. If high-resolution imagery is available from elsewhere, why then, are some concerned by the introduction of digital cameras on Open Skies aircraft? The principal reason is that one cannot do extensive post-processing with wet-film, and it would so be a safer choice for continued open-skies implementation. Once the film is exposed, and the image processed into a negative, the resolution cannot be enhanced.

However, analogue film producers are discontinuing production, making it more expensive, and harder, to acquire film rolls. Therefore, many open skies parties will eventually have to face the choice of adopting digital cameras, or discontinue their participation in the treaty. Digital cameras and digital processing are likely to be here to stay. Whether this poses an unacceptable risk to national security is a sovereign decision, albeit one that would need to be made keeping in mind the overall benefits of the Open Skies regime. Transparency and openness are needed more than ever during periods of heightened tensions, and the benefits of sustaining the transparency mechanisms in the Open Skies regime may outweigh the remote chance that digital images may be altered.

GAO observations on Iran verification

In February 2016, the United States Government Accountability Office (GAO) released a set of preliminary observations on the International Atomic Energy Agency's (IAEA) role in verifying the Iran agreement. The GAO held off making any recommendations, stating instead that it will issue a final report later in 2016.

According to the report, agency officials expressed confidence that all tasks under the 2015 Joint Comprehensive Plan of Action (JCPOA) could be carried out under the organisation's existing legal authority. They were circumspect, however, as to how to conduct inspections on the so-called front-end of Iran's nuclear fuel cycle, only making cautious references to the use of surveillance systems and tamper-indicating seals. However, the agency is likely to have to implement more far-reaching measures than that if it is to verify Iran's inventory of uranium ore concentrate (also known as 'yellowcake').

The GAO highlights three challenges facing the agency when implementing the JCPOA. The first two relate to ensuring that Iran's account of its facilities and fissionable materials is complete. The second relates to internal resource management issues.

Ensuring completeness ...

Ensuring that Iran's declarations are both correct and complete will no doubt be a challenge to the agency over the coming years. However, the GAO notes - as has been highlighted by many others - that 'any uncertainties regarding the peaceful nature of Iran's nuclear program ... would have to be resolved for the agency to reach a broader conclusion that all nuclear material in Iran remains in peaceful activities.'

Moreover, agency officials told the GAO that the closing of the agenda item on the so-called Possible Military Dimensions of Iran's nuclear programme would not 'preclude future IAEA access requests to the sites that were part of the investigation, should IAEA determine that such access is warranted.' This point is important, as some observers have raised concerns that the closing of this agenda item may prevent the agency from properly investigating the country's nuclear past. The IAEA will still be able to do this through the implementation of Iran's safeguards agreements with the agency.

... at a cost

Implementing the JCPOA will cost US$10m per year for 15 years. In the first year, all of this money will be raised through voluntary contributions (so-called extra-budgetary funding). However, from 2017 the Agency plans to request approximately US$5.7m per year from the organisation's regular budget. This represents a five percent increase of safeguards expenditure. The agency intends to raise the remaining US$4.3m through voluntary donations.

The GAO report notes that some member states may respond to the regular budget adjustment by insisting that the increase is matched by a commensurate increase in the technical cooperation budget. While this is undeniably a possibility, it is by no means a certainty. What is certain, however, is that the agency's work in Iran will remain a significant expense for many years to come.

Safeguards implementation in Iran is already financed to the tune of about US$13.5m per year, making it the Department of Safeguards' second-most-costly safeguards recipient, with Japan being number one at approximately US$20m per year. The budget increase will make implementation in Iran almost as expensive as in Japan. However, the price tag is unlikely to deter states from lining up to contribute to the agency's undertaking, at least in the near term.

Staffing concerns

In the short term, the agency appears equipped to handle the increased workload. The GAO notes agency plan to transfer '18 experienced inspectors and nearly twice that number of other staff to its Iran Task Force.'

On 19 January, IAEA Director General Amano told the organisation's Board of Governors that the Task Force itself will be abolished and replaced by a dedicated office within the Department of Safeguards. Like the Task Force, this office is likely to report directly to the Deputy Director General for Safeguards, Mr Tero Varjoranta.

The GAO notes that the agency may face a potential challenge 'in meeting the need for additional experienced inspectors to work on Iran-related safeguards, while ensuring that other safeguards efforts in other countries are not understaffed.'

Lethal omissions by Syria

Recent events in Syria have cast doubt on the completeness of the country's initial declaration to the Organisation for the Prohibition of Chemical Weapons (OPCW). The declaration, reportedly 714 pages and submitted in late 2013, listed significant holdings of precursor materials. Syria declared just under 1,300 metric tonnes of chemical warfare agents, some of which are highly potent. For instance, the country wrote that it possessed 130 tonnes of Sodium-o-ethyl methyl phosphonothionate and 120 tonnes of the sarin precursor isopropanol. The process of removing these stocks from Syrian territory and then safely destroying it took more than two years.

In 2013, several observers expressed reservation that the Syrian declaration was complete. Indeed, the continued use of several types of chemical weapons in the country's bloody civil war shows that those doubts were justified. According to a BBC report last year, the OPCW found traces of undeclared sarin and VX nerve agent at a military research site in 2015. In January 2016, the BBC again reported that inspectors had found 'indications that some Syrians have been exposed to sarin or a similar nerve agent.'

Earlier this year, James Clapper, the US director of US National Intelligence, wrote in a report to Congress that the US intelligence community 'assess that Syria has not declared all the elements of its chemical-weapons program to the Chemical Weapons Convention.' He noted that despite 'the creation of a specialised team and months of work by the OPCW to address gaps and inconsistencies in Syria's declaration, numerous issues remain unresolved.'

The US State Department drew a similar conclusion in its April 2015 compliance report, noting that it could not 'certify the Syrian Arab Republic in compliance with its obligations under the [Chemical Weapons Convention].' In particular, it assessed that 'Syria has not declared all the elements of its chemical weapons program,' and could not dismiss the possibility that the country might have retained chemical weapons.

Syria's 2013 declaration formed the basis for the systematic, total and verified destruction of the country's declared chemical weapons and production facilities. Clearly, the OPCW verification regime has done a good job in verifying the correctness of Syria's chemical account. However, it is equally evident that the OPCW can only draw conclusions on completeness of any declaration with a limited degree of certainty. On the other hand, the Chemical Weapons Convention contains a challenge inspection scheme designed to deal with suspected undeclared stocks. This mechanism was not designed to be readily deployed into a war zone. Whether or not Syria's questionable compliance with the convention has wider implications for the treaty's verification regime as a whole therefore remains to be seen.

Implementation Watch

A convention on chemical terrorism

The continued use of chemical agents in Syria has prompted Russia to propose a convention aimed at suppressing acts of chemical terrorism. On 1 March 2016, its foreign minister, Sergei Lavrov, noted that the threat of chemical terrorism is 'getting extremely urgent'. He pointed to continued and repeated use of chemicals by 'the Islamic State (IS) and other terrorist groups in Syria and Iraq'. He noted that 'such activities of non-state actors in the Middle East and North Africa are becoming increasingly widespread, systemic and transboundary, and pose the risk of spilling over far beyond the region.'

Mr Lavrov chose the Conference on Disarmament in Geneva as the venue to deliver the proposal. Two days after Mr Lavrov's remarks, the Russian Federation circulated a draft proposal for a programme of work of the Conference for the duration of the 2016 session (CD/2057, dated 4 March 2016). The Russian proposal stresses the need to eliminate perceived loopholes in the international legal framework governing chemical weapons. It calls for the establishment of a working group within the Conference tasked to elaborate 'basic elements of an international convention for the suppression of acts of chemical terrorism.'

The past years' events in Syria give the Russian proposal some weight. In August 2015, the Organisation for the Prohibition of Chemical Weapons was tasked, together with the United Nations (UN) Joint Investigative Mechanism, by the UN Security Council with investigating the use of chemical weapons in Syria. It was also asked to identify those responsible for the attacks.

On 22 February 2016, the combined unit presented its first report to the Council. The report shows that efforts to halt the spread of chemical warfare are not playing out successfully in the convoluted war theatre. The joint force identified six cases of chemical weapons use from 24 September 2015 to 10 February 2016. Subsequently, a seventh case was added. Furthermore, on 15 February, a diplomat from the OPCW, speaking on condition of anonymity, affirmed that laboratory tests conducted by the international organisation prove that the Islamic State attacked Kurdish forces in Iraq last August. According to the diplomat, blood samples confirmed exposure to a blistering chemical warfare agent commonly known as mustard gas.

Worryingly, the use of chemicals as a weapon by the warring parties does not seem to have stopped. According to a report released by the Syrian American Medical Society, a US-based NGO, attacks involving chemicals in Syria have been increasing since the beginning of the civil war five years ago. Out of 161 recorded attacks, 77 percent have occurred after the September 2013 adoption of UN Security Council Resolution 2118, which created the framework for the destruction of Syria's declared chemical weapons stockpile.

Similarly in Iraq, on 26 February 2016, the Kurdistan Region Security Council announced that it had started an investigation on a further attack allegedly carried out by the Islamic State in the Sinjar area on 25 February involving the use of chlorine. More recently, on 12 March, Iraqi officials reported that the terrorist group launched two chemical attacks near Kirkuk.

States would make greater progress towards eliminating chemical weapons by enacting rigorous and efficient regulations on scheduled chemicals, and laws designed to outlaw and severely punish activities involving chemical weapons. For example, Iraqi legislation includes measures that prohibit persons and entities from engaging in activities prohibited by the CWC. Article 9, paragraph 1(e) of the 2005 Iraqi Constitution and the Law of Non-Proliferation of 2008 condemn and criminalise the development, production, acquisition, retention, transfer, stockpiling, and use of chemical weapons.

While international cooperation is crucial for work designed to stop and prevent the spread of chemical weapons, weak national legislation can hamper law enforcement efforts designed to prevent criminal use of chemical weapons; and the Aum Shinrikyo case can illustrate this. In 1995, this terrorist group launched a coordinated chemical attack in the Tokyo subway, killing twelve people and injuring more than 5,500. At the time, Japan was a Signatory to the Chemical Weapons Convention, yet legislation to implement the treaty was still pending before its national parliament. Thus, the absence of comprehensive laws that facilitates the prevention, investigation and prosecution of chemical weapons development, production and use, can have regrettable consequences.

Multilateral approaches to mitigating the threat of chemical attacks, when supported by proper domestic legislation, can help shore up international defences against the criminal use of chemical weapons, in particular for terrorist purposes. However, should the proposal from Russia be accepted, the States Parties to the new agreement would still have to enact its obligations in their national legislation. Therefore, the need for a new convention may be debatable considering that the CWC, if properly implemented, already provides for those measures necessary to prevent and prohibit the use of chemical weapons, whether by terrorists or other non-State actors.

Syria: declared stocks destroyed

On 4 January 2016, the Organisation for the Prohibition of Chemical Weapons (OPCW) announced the complete destruction of Syrian Arab Republic's declared chemical weapons stockpile. The final stage of the elimination process was carried out at the Veolia Environmental Services plant at Port Arthur in Texas in the US, where 75 cylinders of hydrogen fluoride were incinerated. These chemicals had been stored in Syria in preparation for being converted into weapons by Syrian governmental forces.

The 55-gallon drums containing the chemicals were delivered to the Veolia Environmental Service in a maritime container aboard MV Taiko, a freighter managed by the Norwegian-Swedish shipping line Wallenius Wilhelmsen Logistics, in mid-2015. According to the OPCW's news announcement on 4 January, the process for finally destroying the chemical cargo was delayed due to the 'need to devise a technical solution for treating a number of cylinders in a deteriorated and hazardous condition.'

The destruction of these chemicals concludes a process that started in September 2013 when, by the terms of the agreement negotiated by the US and Russia, Syria submitted a declaration of its stockpile of chemical weapons to the OPCW. Syria's declared stockpile contained 1,308 metric tonnes of chemicals (1,047 metric tonnes of Category 1 chemicals and 261 metric tonnes of Category 2 chemicals as defined by the Chemical Weapons Convention (CWC)). 600 metric tonnes of sulphur mustard and methylphosphonyl difluoride (DF), a precursor chemical for creating sarin gas, were neutralised at sea on the US Navy vessel, MV Cape Ray.

On 17 June 2015, the OPCW reported that the final quantities of DF effluents produced as a result of the neutralisation process aboard the Cape Ray had been disposed of at the Ekokem Riihimäki Waste Disposal Facility in Finland. This process was part of a commercial contract that included the destruction of other chemicals from Syria's chemical weapons programme.

Although Syria's declared chemical weapons stockpile has now been destroyed, questions remain over the accuracy of the original declaration. According to the Director-General of the OPCW, Ambassador Ahmet Üzümcü, efforts continue 'to clarify Syria's declaration and [to] address ongoing use of toxic chemicals as weapons in the country'.

Entry into force of CPPNM amendment

The amendment to the Convention on the Physical Protection of Nuclear Material (CPPNM) requires States Parties to protect nuclear facilities and material in peaceful domestic use, in storage, as well as in transport. The amendment – adopted by States Parties to the CPPNM in July 2005 – only enters into force once two-thirds of CPPNM States Parties deposit their instrument of ratification, acceptance or approval with the IAEA.

As of 30 March 2016, 95 States Parties to the CPPNM had adhered to the amendment. Seven more adherences were still required for it to enter into force. Two days later on 1 April, at the opening of the 2016 Nuclear Security Summit, the IAEA confirmed that 100 States Parties (and one organisation) had deposited their instrument of ratification, acceptance, or approval. By Friday 8 April, the IAEA added two more states to their list, bringing the total up to 102: enough for the agreement to enter into force.

In thirty days time, on Sunday 8 May 2016, the agreement will come into force. From this point onwards, the amendment will play a central role in defining and sustaining high standards of nuclear material security around the world. The rush of ratifications in the lead-up (and during) the nuclear security summit highlights the importance of continued high-level political attention, which the amendment will hopefully sustain into the future. The long-term goal of universal application and implementation of the amendment will not be achievable without it.

Science & Technology Scan

Monitoring Iran's Uranium Enrichment in Real-Time

Iran's uranium enrichment facilities at Natanz and Fordow have produced almost 448 kilogrammes of uranium hexafluoride (UF6) enriched to 19.75 percent uranium-235 to date. This stockpile of enriched uranium could have served as a big stepping-stone to a nuclear weapon (if Iran had chosen to pursue one). However, this stockpile has either been diluted or converted away from UF6 through the Joint Comprehensive Plan of Action (JCPOA).

Iran's stockpile of 19.75 percent UF6 now totals a meagre 600 grammes, stored under agency seal as a calibration tool for monitoring equipment. Under the JCPOA, this stock will not grow again. Iran has committed to 'keep its level of uranium enrichment at up to 3.67 per cent' for the duration of the agreement, and as of 26 February 2016, Iran is keeping to that commitment. Thanks to the JCPOA-mandated application of on-line enrichment monitors in Iran, the International Atomic Energy Agency (IAEA) will know if this changes almost immediately.

The peaceful uses of gas centrifuge enrichment plants (GCEPs) have traditionally been verified through techniques developed by the Hexapartite Safeguards Project (HSP) between 1980 and 1983. The system aims to detect the production of undeclared highly-enriched uranium through Limited Frequency Unannounced Access (LFUA) inspections within the GCEPs cascade hall, involving visual inspections, environmental sampling, seals and radiation measurements.

This tried-and-tested approach has been applied successfully in Iran for some time now, with environmental sampling techniques detecting accidental enrichment above declared levels in 2010 and 2012 (see IAEA Board of Governors documents GOV/2010/46 and GOV/2012/23). It will continue to play a central role in verifying Iran's commitment under the JCPOA, which requires Iran to accept daily IAEA inspector access to its sole operating enrichment plant if the agency so desires it. However, it takes weeks to collect samples, deliver them to a laboratory, and analyse them. A regular flow of samples from Iran would also consume valuable time and expertise within the agency's network of analytical labs, diminishing the IAEA's safeguards work elsewhere around the world.

This is where on-line enrichment monitors (OLEMs) can help. These systems monitor the characteristic radiation signatures (either spontaneous or induced) of various uranium isotopes in the gas flowing into or out of centrifuge cascades. In doing so, they can give the IAEA early warning if a GCEP operator is enriching uranium above the level declared, and detect any other undeclared enrichment activities. Importantly, these systems operate continuously and remotely, providing real-time verification without the need for a constant inspector presence.

This technology has been in development for some time and has already been deployed at URENCO enrichment plants. The system deployed in Iran builds on systems such as the Continuous Enrichment Monitor (CEMO), the Cascade Header Enrichment Monitor (CHEM), and Los Alamos National Laboratory's Advanced Enrichment Monitor (AEM). The system deployed in Iran probably uses a Sodium Iodide crystal detector to measure the characteristic low energy gamma rays generated by the decay of uranium-235. This gives the system an idea of the absolute number of uranium-235 atoms passing the detector, which can be combined with information on the total amount of UF6 passing the detector to calculate the enrichment level of the gas. The OLEM system in Iran collects information on the quantity of gas passing the detector by combining direct temperature measurements of the UF6 pipe with pressure data downloaded from the operator's sensors.

These enrichment calculations are carried out on a custom-designed computer, operating with back-ups for both data storage and electrical power. Information on the enrichment level can then be distributed from the system through a basic Ethernet cable, stripped of all commercially sensitive information--potentially giving only a notification of compliance or non-compliance. More detailed measurements are stored for some time within the OLEM's system if they need to be analysed in more detail. The OLEM system can, therefore, provide real-time monitoring, which can be integrated into facility-wide IAEA systems of data collection, without the requirement for continuous inspector presence.

Importantly, the OLEM is also protected against tampering while inspectors are not present. The data generated by the system is certified at the source and is encoded onto a Virtual Private Network (VPN) to protect it during transfer. The majority of OLEM sensors are contained within a sealable, tamper-indicating enclosure, and while the IAEA relies upon the operator's sensors for pressure information, these sensors are also sealed and regularly checked by the IAEA.

In 2012, Los Alamos National Laboratory felt that substantial work was required before OLEM prototypes could be turned into a production instrument. Four years later, the OLEM has been deployed. The verification demands presented by the JCPOA have significantly accelerated the development of the OLEM technology, and with fifteen years of JCPOA implementation ahead, it will be interesting to see what new technologies this landmark deal brings into the world.

Open Skies and the digital age

Photography has undergone a transformative change in the time since the Treaty on Open Skies entered into force in 2002. One year after the treaty became law, digital cameras started to outsell their wet film counterparts. Once oversized, with questionable image resolution and expensive storage, digital cameras have become progressively cheaper, and the quality of their imagery better. Furthermore, it has become easier and cheaper to store digital products. This imagery revolution is even starting to threaten the traditional camera industry, with digital camera sales peaking, and with compact, portable, yet highly capable smartphone cameras taking an ever-larger share of the market.

Undeniably, photography has entered the digital age, and this has led manufacturers of film to stop their production and seek profits elsewhere. In 2012, Kodak Eastman, which in the 1970s commanded 85 percent of camera sales in the United States, had to file for bankruptcy protection. So it would appear that the age of film is coming to an end, much like technologies such as compact discs and VHS cassettes before it.

Despite this, participants in the Open Skies treaty have been slow in replacing their film cameras. They need to prepare for this new reality, and adjust their thinking, or eventually find themselves without a reliable film supply. The Russian Federation has been the first major party to the treaty to introduce digital imagery, which has disgruntled others (see Open skies going overcast, above).

Like every other participant in the treaty, Russia started out with analogue cameras. The A-84ON camera can be loaded with either 130mm or 127mm film. The focal length of the lens is 300mm, supplying a 30 cm linear terrain resolution at frame centre, under the condition that the aircraft flies at 8,000 metres. The lateral coverage of photographed terrain is up to 50 kilometres on each side of the plane. The camera was designed specifically to be used with the Russian Federation's Tupolev-154/ON wide-body jet. In addition to the A-84ON, the aircraft would also be equipped with AK-111 and AK-112 framing cameras, designed to carry out both vertical and oblique photography of terrain at lower altitudes.

Russia's next generation camera, or 'electro-optical observation station' as they refer to it, is called the OSDCAM 4060. It is custom-made for open skies application. Unlike its predecessor, it contains a cluster of lenses. The camera has 34 lenses sensitive to visible light, and these will be used on high (6,500m), medium (3,200m) and low (1,050m) altitudes. Moreover, six additional lenses are used for low altitude near-infrared image capture. The camera is fitted on Russia's Antonov-30B/ON aircraft or the recently commissioned Tupolev-214/ON wide-body jet. At high altitudes, it takes images with a frame size of 56,592 x 1,696 pixels, which is finer than most aerial cameras available off the shelf. Weighing in at 52 kilogrammes, it is also lighter.

Compared to the previous generation, the camera's focal length is shorter; it varies from 16mm to 100mm. The system is capable of collecting up to 10,630 square kilometres of footage per flight-hour.

The digital risk

All digital images can be manipulated in some ways: such as image interpolation, conversion and enhancement using non-increasing operators, using debayering algorithms, and spectral shifting.

Hartvig Spitzer has detailed the procedure designed to prevent post-mission data manipulation in Trust & Verify No. 146. First, the observing state records the raw image and additional information such as navigation data on removable storage media. Inspectors from the observed state are present to supervise this operation. Second, when the flight is over, the storage media is removed and sealed. The drive is taken to a processing station, where inspectors break the seal. Inspectors from both states then observe the conversion of the raw image into the approved Open Skies digital data format (*.OSDDEF).

Third, the inspectors duplicate the OSDDEF images: the observing and the observed state both receive one dataset. Once that is done, the inspectors verify that the sets are authentic and identical. Finally, the drive containing the sensitive information is wiped in a way that does not allow for any data recovery. This process is observed, and inspectors verify that the storage media does not contain any retrievable information.

This process is not fool-proof. It is possible to enable the device to store its raw images on a hidden drive. While this cannot be discounted, the image-capture protocol, combined with rigorous pre-flight inspection, should be enough to deter the observing state from attempting clandestine image collection. In the meantime, other open-skies participants are well-advised to follow Russia's lead into the digital age.

Centre News

National Implementation

During this quarter, the NIM programme completed a set of three legislation surveys for a Caribbean State on the implementation of international instruments for nuclear security, the Biological Weapons Convention (BWC) and the Chemical Weapons Convention (CWC). Also, the programme completed three BWC legislation surveys for states in Asia, Africa and Latin America. It sent a universality package for adherence to the BWC and provided advice on ratification of the BWC to an African state.

On 26 January 2016, NIM Programme Director Scott Spence took part in a non-governmental sector Consortium Meeting on the Global Health Security Agenda in Geneva. Between 21-22 March, Researcher Alberto Muti represented the NIM Programme at a Harvard Sussex Programme/Cranfield Workshop on 'Capturing data on chemical weapons allegations and use in Syria: Project activities, opportunities and challenges for future academic research', which took place at the University of Sussex.

In January, the NIM Programme and the Stimson Center began implementing a two-phase project during 2016-17 in several states in Latin American and the Caribbean. This project is designed to: (a) raise awareness regarding national obligations under UNSCR 1540; (b) support states with a comprehensive UNSCR 1540 legislative gap analysis, and (c) provide focused and individually tailored UNSCR 1540 legal assistance. This project is funded by Global Affairs Canada's Global Partnership Program.

Finally, Mr Spence recently accepted an invitation to join the Global Fellowship Initiative at the Geneva Centre for Security Policy as (GCSP) as an Associate Fellow.

Verification and Monitoring

During this quarter, the Verification and Monitoring (VM) Programme has conducted two successful Technical Assistance Visits (TAVs) under its project on IAEA Safeguards and the Additional Protocol. VM staff members Hugh Chalmers and Alberto Muti travelled to Senegal and Zambia to discuss legal and regulatory matters concerning the implementation of IAEA Safeguards. They were joined by Mark Killinger of the US International Nuclear Safeguards Engagement Programme (INSEP) in Senegal, and by VERTIC Deputy Executive Director Angela Woodward in Zambia.

In March, VERTIC researcher Alberto Muti attended a workshop on 'Capturing Data on chemical weapons allegations and use in Syria' held by the Harvard Sussex Programme in association with Cranfield University. At the end of March, VERTIC also hosted the third and final meeting of its UK-China technical dialogue. The meeting was held at the Royal Society in London and was well-attended by a range of distinguished scholars and practitioners from the nuclear, chemical and biological fields, who discussed matters of arms control, non-proliferation and verification.

Grants and administration

This quarter, VERTIC has had to say goodbye to two members of staff. David Keir, our principal researcher, left VERTIC after five years of service. David was invaluable as programme director of the Verification and Monitoring Programme from 2010 to 2015. We wish him well in his future endeavours as a consultant at Cloverdale Ltd.

Russell Moul, Researcher, left VERTIC in April to pursue a Ph.D. in History of Science at the University of Kent. Russell's determination as a researcher and dedication as editor of this publication will be greatly missed.

VERTIC welcomes Lisa Gridley, who has joined the Office of the Executive Director as a part-time intern from March to October 2016. She is in her final year of a Bachelor of Arts majoring in Political Science at the University of Canterbury in Christchurch, New Zealand. Lisa will receive academic credit for her VERTIC internship, with the associated university course fee paid for by the New Zealand Peace and Disarmament Education Trust. Lisa is working alongside Angela Woodward, VERTIC's Deputy Executive Director, in Christchurch.

Angela Woodward was reappointed by the New Zealand Cabinet to serve on the Public Advisory Committee on Disarmament and Arms Control for another three-year term and accepted an invitation to join the Asia-Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament.

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building trust through verification

Statement

VERTIC is an independent, not-for-profit, non-governmental organisation. Our mission is to support the development, implementation and effectiveness of international agreements and related regional and national initiatives, with particular attention to issues of monitoring, review, legislation and verification. We conduct research, analysis and provide expert advice and information to governments and other stakeholders. We also provide support for capacity building, training, legislative assistance and cooperation.

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